Human Behaviour Outdoors and the Environmental Factors

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Abstract

The study of human behaviour outdoors has been an area of interest examined from different perspectives. Even so, the study of human behaviour in outdoor public spaces still requires further input from the perspective of human factors.

This thesis presents a literature review of behaviour in public spaces where the author evaluated the attendance to public squares, the activities performed by users, the time of permanence, the sitting preferences of users and people's characteristics among other behaviours. Previous studies have reported a relationship between thermal comfort and human behaviour; however, there is a lack of studies approaching the study of human behaviour using observational methods which allows assessing human behaviours such as number of people, number of groups, time of permanence among others, taking into account environmental factors such as: air temperature, globe temperature, mean radiant temperature, relative humidity, wind speed, sun and shadow presence and illuminance.

As part of this research, three studies were conducted in the city centre of Nottingham during summer and autumn of 2015 and winter of 2016 in order to collect data of human behaviour and find its relationship with the air and globe temperature, calculated mean radiant temperature, wind speed, relative humidity and illuminance. These studies were conducted using observational methods by creating a coding scheme after conducting video analysis of social and individual behaviours. A methodology was created to incorporate processes that allow gathering data for observational analysis, which was subsequently processed using multiple regression models and survival analyses.

The overall analysis led to the identification of the main environmental factors influencing human behaviour across different environmental conditions. The studies and analyses conducted showed that various environmental factors work together to influence the decisions of the users of a public space. Accordingly, the models used to predict human behaviour should include the environmental variables that explain better its variability, based on the environmental data of the place. Moreover, this study showed that individual analysis should be performed on a seasonal basis using the environmental and human behaviour data of each season in addition to the analysis performed to the whole data set. The reason for this is that the seasonal data is better at explaining some human behaviours than the model built with the whole data set collected in various seasons. For instance, the relationship between wind speed and number of people is positive during summer and negative during autumn and winter; however, when the three seasons are analysed together, the relationship is negative, which does not explain accurately the phenomena in summer. Conversely, illuminance was found to be an important factor influencing behaviour across the seasons and also contributed to the prediction of behaviour in the all season's analysis.

Finally, this thesis presents an application of the results by presenting general recommendations of urban design based on the findings of analysing human behaviour in accordance with the thermal environment.

The studies conducted during the three seasons presented a cross-internal validation of the multiple regression models. In addition, a final study which consisted in a mock scenario was conducted to perform an external validation of the previous results. A number of conclusions were drawn about the conditions required to perform further external validations, following the parameters identified that may affect the results of the validation.

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Publications

The following publications were produced during the time of this research;

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1. Introduction

1.1. Chapter Overview

This chapter will introduce the study of human behaviour outdoors and previous developments in the area to include the analysis of the environmental factors. Subsequently, the chapter will present the aim of the research, the studies conducted in accordance with the objectives and the novel contribution this thesis provides to the field. Finally, the content of each chapter is summarised as an overview of the thesis.

1.2. Background

The study of human behaviour outdoors is an important source of information to understand "how well the physical design and urban policy of cities suit the needs and desire of residents" (Gehl Institute, 2017, p. 4). Early studies come from the 1970s when the urbanist William Whyte conducted a series of analyses to generate metrics that helped establish the premises of design for the planning of New York City (Whyte, 2009). The author suggested that well designed spaces have characteristics such as: allowing users to socialise since the presence of couples and big groups are signs of "well-used" spaces, and having seating availability to generate permanence of users, as "people tend to sit most where there are places to sit" (p. 110).

In the same way, Carmona (2001) suggested that good urban design responds to the occupiers' demands, promotes higher densities of people and supports the mixed use of spaces.

Whyte suggests that "Good places are largely self-policing" (Whyte, 2009, p. 158). This means that the design of a place can induce the bad or good behaviour of the users. For instance, the construction of fences to keep parks safer could affect the attendance and generate a contrary effect due to the lack of occupancy of the place.

Previous studies aimed to increase the attendance, modify the use of public spaces, improve the comfort of the users or support the urban design of cities. Significant improvements have been reported about the users' attendance and comfort when the environmental conditions were considered in the retrofit of outdoor spaces. For instance Huang et al. (2016) performed a series of environmental and behavioural analysis before renovating a park in Wuhan, China. It was found in this study that the retrofit of the space considering the thermal conditions increased the use of the park by approximately 80%. The strategies used consisted of generating places with shade and seating areas, planting vegetation, and creating barriers to enhance the microclimatic conditions of the place to fit the end user's needs. Other interventions have reported a similar success. For instance, Gehl & Svarre (2013) conducted several studies to retrofit urban spaces in the UK, Australia and Denmark using behavioural analyses from data collected before and after the renovation. In these interventions, the authors counted pedestrians traffic, observed the users' activities and recorded attendance considering demographical data. As a result, these studies applied a user-centred design which effectively increased the use of the places.

The success of the mentioned interventions were measured by evaluating the amount of people occupying the spaces before and after the retrofit, analysing the variety of activities and classifying the type of users. This was done by observing, mapping, photographing and filming the behaviour of people (Gehl & Svarre, 2013; Whyte, 2009). Accordingly, the rate of success of studies in the field of human behaviour in outdoor public spaces is related to the amount of use given to a space by the citizens, and the variety of activities conducted which benefit most of the people.

Studies in behavioural activities outdoors such as the ones conducted by Whyte (2009), Gehl & Svarre (2013), Nasar & Yurdakul (1990) and Hillier & Hanson Julienne (1970) were focused on the social patterns of the behaviour rather than measuring the influence of the environment on human behaviour. This may be because of the absence of the technological aids, available today to conduct environmental measurements, causing a relegation of the microclimatic variables (Chen & Ng, 2011). In some of the studies, general environmental conditions were recorded, such as the presence of sun and shadows, air temperature, or qualitative perceptions of the weather.

On the other hand, studies related to the thermal environment have been focused primarily on reporting the perceived thermal comfort of the users and are limited to, at best, analysing high-level categories of behaviour. Some of the most comprehensive works have been made using subjective and observational methods to measure the perceived comfort outdoors compared with indoor comfort models and the behaviour of users such as: attendance and sitting preference (Nikolopoulou et al., 2001; Nikolopoulou et al., 2004; Nikolopoulou & Lykoudis, 2006, 2007; Nikolopoulou & Steemers, 2003). However, these studies also addressed the complexity of defining the thermal comfort outdoors by considering multiple factors that influence the user's comfort, such as expectations, thermal history or enjoyment of the user under extreme conditions, for example being exposed to temperatures over 40ºC on a beach (Höppe, 2002). As mentioned by Robinson (2011), there are multiple factors affecting people's perception of outdoors, and thus their satisfaction. Accordingly, the assessment of the user's satisfaction would also require consideration of sociological aspects that should be included in dynamic models (Robinson, 2011).

According to Li (1994), cities are constantly found to be coping with seasonal changes in two ways: problem-focused or emotional-focus initiatives. The former strategy refers to the direct intervention to the source of the stress by creating artificial indoor environments that isolate the users from the external conditions. The latter strategy aims to promote urban spaces by encouraging people to endure the environmental conditions. According to the author, there should be a third option in between these two, focused on balancing the environmental conditions of the outdoor thermal environment by creating spaces adjusted to the specific environmental characteristics of different seasons in order to improve the users' experience.

Agreeing with previous studies on the subject of thermal comfort outdoors, Zacharias, et al. (2001) confirmed the existence of shared perceptions between the users regarding the thermal environment. However, it is still not clear how the environment has influenced their perception and behaviour and this is what urban planners and policy makers need to find out in order to control the microclimatic conditions of urban spaces. Some of the most relevant studies regarding behaviour of people and environmental factors were conducted in Montreal and San Francisco, during which the authors evaluated the microclimatic conditions and behaviour such as: attendance, presence in the sun and shadow and posture (sitting, standing or smoking) (Zacharias, 2004; Zacharias et al., 2001). Both studies were conducted through the evaluation of seven different public spaces areas (e.g. squares) for each city. The authors reported a significant influence of the microclimatic conditions over the variance in the use of the squares. Moreover, it was found that the air temperature and sunlight affected the presence of users. Similarly, Eliasson et al. (2007) conducted a study comparing different public spaces in Gothenburg and found that the clearness index, air temperature and wind speed affected attendance and perception of aesthetic of the users. The authors remarked upon the difficulty of applying one general rule for all types of outdoor public spaces; however, they highlighted the importance of performing climate-sensitive analysis before proposing a new development or retrofitting an urban space.

Chen & Ng (2011) made a review of the literature about comfort outdoors in the past decade and stated that although the relationship between behaviour and thermal environment has only been addressed in the last 10 years due to recent technological developments enabling researchers to record environmental data, there is still a lack of agreement on the best methods to collect and analyse the environmental data and human behaviour. Based on this study, various methods found in the literature review were identified, classified and combined, in order to design a methodology to study the human behaviour capable of integrating human and environmental data, as a preliminary step required to accomplish the aims of this research.

1.3. Aim and Objectives

The overall aim of this research was to study human behaviour when people are exposed to different environmental conditions in outdoors. Throughout the research, the methods to study behaviour and environmental factors were assessed, a representative dataset was collected, and a statistical analysis to predict the occurrence of the behaviours was conducted. The following objectives addressed the overall purpose of this research:

Objective 1: To identify methods to assess human behaviour and environmental factors from a Human Factors perspective and select or create an appropriate method for this research.

The methods selected to evaluate human behaviour and the thermal environment were taken from the Literature Review (Chapter 2) and defined in the General Methodology (Chapter 3). The filtered methods were tested in the Pilot Study (Chapter 4) and adjusted according to the results obtained.

Objective 2: To collect a representative dataset of the environmental conditions throughout the year, which includes human behaviour and environmental variables.

The studies conducted to achieve this objective were included in Chapter 5, Chapter 6 and Chapter 7. A dataset of human behaviour and environmental factors during summer, autumn and winter was collected. The data set contains 3780 environmental measurements (air temperature, relative humidity, globe temperature (sun and shadow), wind speed and light). A total sample of 5330 users were analysed.

Objective 3: To observe, codify, analyse and predict human behaviour in terms of: occupancy, group size, time of permanence, body postures, activities and adaptive behaviour.

The studies conducted to achieve this aim were included in Chapters 5, 6, 7 and 8. The data set collected was processed by conducting observational analysis of the video and classifying Social Behaviour per minute (occupancy and grouping), and Individual Behaviour per person (Time of Permanence, Body Postures, Activities and Adaptive Actions).

Objective 4: To compare the data gathered in the different seasons selected (summer and autumn 2015 and winter 2016), in order to

identify whether there is a relationship between the environmental variables and human behaviour.

The analysis per season (Chapter 5, Chapter 6 and Chapter 7) enabled evaluation of the relationship between different variables and behaviour. The methods used (correlation, multiple regression and survival analysis) permitted identification and quantification of the relationship of each behaviour with the environmental variables. Chapter 08 presents the analysis of the all-seasons data set.

Objective 5: **To conduct internal and external validations of the results of the studies, in order to achieve comparable, generalisable and replicable results.**

The scope of this objective was to validate the outcomes obtained in each experiment. Therefore, the multiple regression models on Chapter 5, Chapter 6, Chapter 7 and Chapter 8 included a section of internal cross-validation where the data set was split in order to generate the equations with one part of the data and to test the results with the remaining data. Chapter 9 presents the results of an experiment conducted in a different environment which aimed to compare the conclusions of the seasonal studies with a different sample.

Objective 6: **To generate recommendations in urban design based on the results obtained from the data gathered.**

This objective is aimed to show one of the possible applications of the results obtained in this research by producing design recommendations from the urban design perspective.

Therefore, Chapter 10 presents recommendations to improve the urban design of Trinity Square according with the outcomes of the studies conducted throughout this research.

The relationships between the objectives of this research are presented in **Error! Reference source not found.** The scope of objective 1 was to achieve a reliable method. Objectives 2, 3 and 4 are directly connected to objective 1, as they require gathering and analysis of a robust dataset to study human behaviour under different environmental conditions. Objective 5 is intended to measure the reproducibility and generalisability of the results. Finally, objective 6 shows one of the possible uses of the data collected and analyses produced.

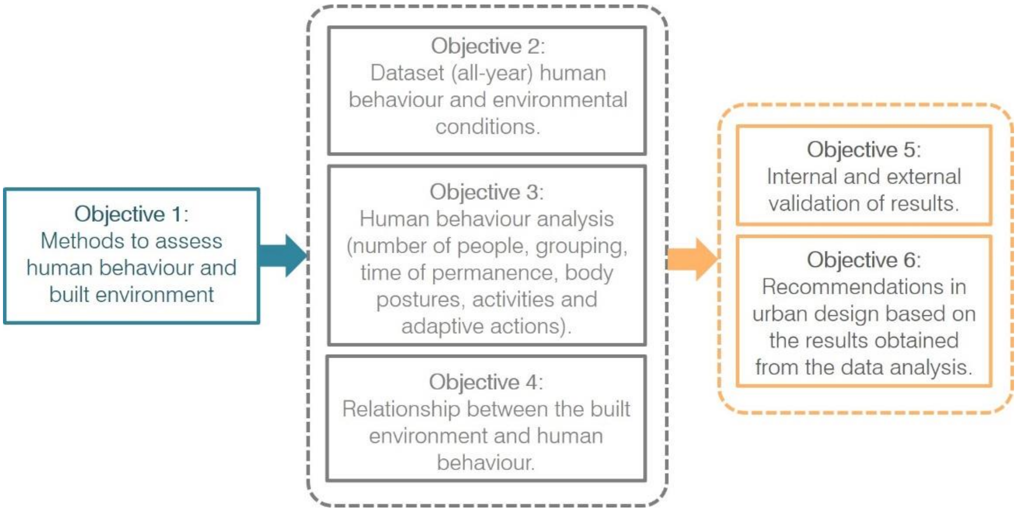


Figure 1 - Relationship between the objectives of this research

1.4. Contribution

The Literature Review (Chapter 2) identified different ways to study human behaviour and the thermal environment. This research created a new methodology based in a mixture of methods found in the literature review. It consists of observational methods to analyse behaviours according to the environment which include several variables from the environment, and behavioural perspectives that had not been analysed together before. The data set collected that included over 5,330 people observed and one week of analysis per season (excluding spring due to its similarities with autumn) can be identified as one of the most detailed in terms of behavioural analysis and sample size.

The studies conducted per season (Chapters 5, 6 and 7) generated prediction and probability models of behaviour in relationship to the thermal environment per season. These models used multiple environmental variables at the same time in order to increase the power of the model. Finally, the models were internally cross-validated and the percentage of variability of each behaviour was defined.

The analysis of the dataset collected during the three seasons (Chapter 8) allowed generating models to predict the variability of the human behaviour in a wide range of environmental conditions. One of the main outcomes of this study was showing that the influence of the environmental factors over the human behaviour varies significantly depending on the particular season. Therefore, the models constructed from the three-season's dataset do not explain the variance of the behaviours observed in the seasons considered independently.

The validation of the data (Chapters 5, 6, 7, 8 and 9) contributed to determine the reliability of the results and generalisability of the data. None of the previous studies reported in the literature (Chapter 2) conducted reliability analysis of the observations, internal cross-validation or external validation.

1.5. Thesis Overview

This section presents an overview of the research with the summary of each chapter.

Chapter 2. Literature Review

This chapter presents a summary of the literature in the field. It starts by describing behaviour in public spaces and the importance of these to user quality of life. This section describes the evolution, methods and contribution of social science studies to behavioural analysis, followed by studies addressing the issue from the perspective of comfort and the methods they used to evaluate the thermal sensation of the users. Subsequently, the lack of behavioural analysis from this type of studies is highlighted and an overview of the most comprehensive studies regarding behaviour and thermal environment is presented.

Chapter 3. General Methodology

Chapter 3 introduces the methodology of this research by presenting fundamental concepts regarding the evaluation of human behaviour. In this section, a critical review of the behavioural methods, subjective methods, objective methods and modelling methods is made. Subsequently the concepts of validity, reliability and generalisability are discussed. At the end, the research methodology to be used in this research is proposed, using as reference the methods that best support the aims of this study.

Chapter 4. Pilot Study

This chapter presents the first study conducted which was to test the subjective and the behavioural methods observed in the literature review. The study included questionnaires in the place of study, observations made via a video recording camera, and environmental measurements. The results were used to contrast the data with the literature and plan the studies of human behaviour during summer, autumn and winter.

Chapter 5. Human Behaviour in Summer

Chapter 5 presents a study conducted to analyse human behaviour and thermal environment during summer. The method of data collection was adjusted according to the results obtained in the Pilot Study. The data analysed consisted of three hours of video recording per day during one week in summer. The results included multiple regression models of the number of people and the number of groups of different sizes present in Trinity Square, as well as survival analysis models of the time of permanence of 2330 users. In the discussion, the influence of each environmental factor on the behaviour is analysed.

Chapter 6. Human Behaviour in Autumn

This chapter presents the results of a study conducted to evaluate human behaviour and thermal environment during autumn. The data collection and analysis followed the same procedures of the study conducted during summer. The results included multiple regression models of the number of people and number of groups of different sizes, as well as survival analysis of the Time of Permanence of 1873 users. The influence of the environmental conditions on the behaviour of people is discussed.

Chapter 7. Human Behaviour in Winter

This chapter presents the study to evaluate human behaviour and environmental conditions during winter. The methods and analysis conducted are the same as the ones used in the previous two chapters. The results include the multiple regression models and survival analysis of the behaviours according to the thermal environment during winter. The influence of each environmental factor on the behaviour of users is analysed in the discussion.

Chapter 8. Human Behaviour in All-Seasons

This chapter presents a statistical analysis of the dataset of the three seasons evaluated: summer, autumn and winter. The outcomes are models to predict the variance of the number of people, group sizes, time of permanence, body postures, activities and adaptive actions. The discussion integrates the findings of the individual seasons and the all-seasons data set.

Chapter 9. Human behaviour in a Mock Scenario

Chapter 9 presents a study of human behaviour in a fabricated space designed to validate the results obtained in the previous studies. The installation consisted of four types of scenarios: a) seating furniture, b) seating furniture and shading devices, c) seating furniture and wind barriers, and d) seating furniture, shading devices and wind barriers. The results compared the behaviour of users under different sets and also compares it with the results obtained in the previous studies of this research.

Chapter 10. General Discussion and Conclusion

This chapter presents the outcomes of this research. The results are discussed in comparison with the literature in the field. A set of recommendations is made for proposed urban interventions to Trinity Square in Nottingham City centre. The novel contribution of this work is discussed and the general conclusions observed about the evaluation of human behaviour and thermal environment in outdoors are highlighted, as well as, the recommendations for future works.

1.6. Chapter Summary

This chapter introduced the research motivation and scope. The description of some of the main studies in the field and the evolution of evaluating human behaviour in outdoors are presented. It also presents the research aims and the studies conducted to achieve in this research to achieve them. Subsequently, the chapter presents a summary of the novel contribution of this research to the field. At the end, the content of each chapter is summarised.

2. Literature Review

2.1. Chapter Overview

This chapter presents a review of the literature in human behaviour, outdoors and thermal environment.

Figure 2 presents the structure and contents of the review conducted. The first section describes the history of the study of human behaviour in public spaces, and is followed by the initiation of behavioural studies to improve urban design referring to the main contributors in the field. The second section contains the studies regarding studies in comfort and lighting outdoors. This section specifies the type of data generated and highlights the gap in the studies of microclimatic conditions with regards to the behaviour of people in public spaces. Finally, the last section concentrates on studies that have integrated the microclimatic conditions and human behaviour.

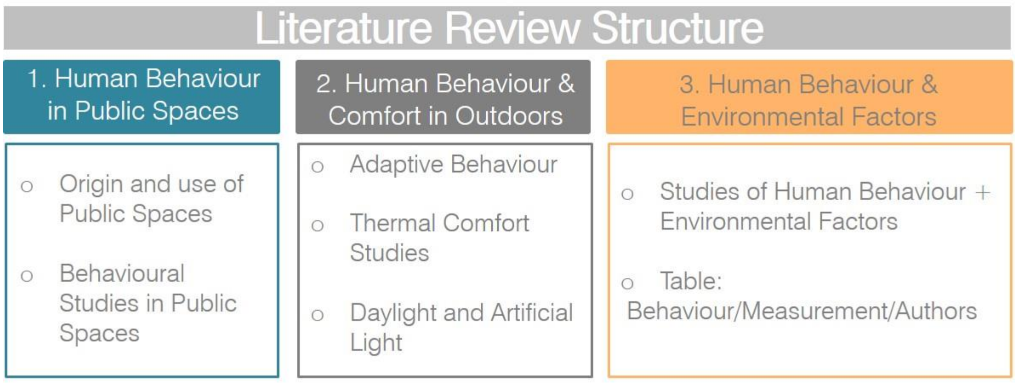


Figure 2 - Literature review structure and content

2.2. Human Behaviour in Public Spaces

According to Dovey (2016) the root of the word 'urban' comes from the Latin 'urbanus' which means 'courteous' and refers to the act of showing courtesy and respect for others. The origin of urban spaces date from the beginning of the democracy in Greece, where places like the agora or the market determined the involvement of the citizens in public activities (Dovey, 2016). The public use of the urban spaces involved certain behaviours and disposition of citizens to take part of different activities, for instance: "... political, military, sporting and religious functions" (Dovey, 2016, p. 10). These activities have been constantly changing and are determined by the social, cultural and environmental characteristics of the places.

As described by Gehl & Svarre (2013) squares were first used as markets, limiting this type of outdoor urban space for trading services and products. With the evolution of the cities, they started to be used as places of gathering for social activities such as protests, political speeches or marches. However, just a few decades ago outdoor urban squares started to exist mainly for leisure, health and well-being of populations (Gehl & Svarre, 2013). The evolution of these spaces is followed by the evolution of the human activities, preferences, routines and use of outdoors spaces, which started to be determined by the social conditions and "the leisure society" (Gehl & Svarre, 2013). One determinant factor of "the leisure society" was the increment of leisure time and the evolution of working patterns. A milestone of this change in human habits was Article 24 of the Universal Declaration of Human Rights (UN General Assembly, 1948), which stated that: "Everyone has the right to rest and leisure, including reasonable limitation of working hours and periodic holidays with pay".

As mentioned by Carmona & Wunderlich (2012), the 'public' in a 'public space' is fragmented by the socio-economic and physiological differences of people. Each person perceives the space in a different and complex way and may even pursue incompatible goals in the activities in comparison to others' activities; e.g. someone reading versus a group of people protesting. This uniqueness of the human condition makes the process of urban design complex. As defined by Carmona (2014), research in urban design is important since it is focused on "...the vagaries of human actions and are therefore subjects to continual change and varied interpretation as, in essence, they are unpredictable and poorly understood" (p. 5), unlike the laws of physical science.

As a result of the complexities involved in understanding the characteristics required for urban spaces, the public and private actors involved in the development of cities have been criticised for their lack of inclusive view of public spaces, which has led to neglected, invaded, exclusionary, segregated or privatised public spaces (Carmona & Wunderlich, 2012). According to Felce & Perry (1995) quality of life is a combination of a person's life conditions and personal satisfaction. There are five main domains to assess the quality of life: Physical Wellbeing, Material Wellbeing, Social Wellbeing, Development and Activity, and Emotional Wellbeing (Felce & Perry, 1995). Public space can be considered as an essential part of the development of individual and social activities that permit achievement of quality of life of individuals. Nevertheless, investing in urban design studies has been perceived as something luxurious more than a necessity of cities (Carmona, 2014).

The use and appropriation of public spaces is determined by several factors. As mentioned by Salazar (2010), in the process of designing an urban space the architect does not know for sure how the new space will influence the behavioural patterns. This is because a new place is proposed and not only social characteristics determine its use, but also the microclimatic condition proposed by the built environment will suggest new behaviour of users.

Studies of human behaviour in outdoor urban spaces date from the 1970's. According to Nasar & Yurdakul (1990) these studies were conducted by registering user activities by hand on paper, time lapse photography, motion pictures and video tapes. One of the pioneers in observing and mapping people's preferences, activities and interactions was William Whyte. In the book 'Rediscovering the city center' (2009), Whyte presented different studies conducted in New York, some of these aimed to evaluate the density of public squares; since he considered the public space fundamental for the health and wellbeing of societies. His concern on density was inspired by the works of the ethologist Dr Calhoun (1962), where in his experiments with rats and mice it was discovered that the variation of crowdedness of the animals resulted in abnormal patterns of behaviour and led to the extinction of the population due to neurotic and suicidal behaviour.

The work conducted by Whyte (2009) was mainly focused on the streets of New York. He reported that the highest traffic places and specially the corners of the blocks tended to concentrate the majority of the conversations. From 133 conversations mapped, 57 were recorded in the busiest areas evaluated. It was observed that the crowdedness of the places was not related to the size of the place, since some of the smallest places he evaluated presented the highest occupancy. However, he found that seating availability highly influenced the presence of users since "People tend to sit most where there are places to sit" (Whyte, 2009, p. 115). Whyte also presented some studies about installations of movable chairs, where people were entitled to adjust them according to their needs. He observed that users tended to move the chair even just a few inches, like a declaration of their freewill and the available option to adapt the seat to them.

The methods used in the 1970's by Whyte (2009) included filming with time-lapse cameras and analysing frame by frame, counting the number of individuals, position of the people and the exact moment of occurrence of an event, among other behaviour. In some cases, the cameras were observable by the occupants of the public space, and in other occasions, he found the way to hide the cameras by positioning them in higher spots overlooking the places evaluated. Figure 3 is a handmade diagram of one of the observations reported. Each line corresponds to the permanence of one individual in the seating area. A short line means a short permanence in the place, while a long line represented a long permanence. It is possible to determine the time of arrival of a group, or the moment of the day with more occupancy.

Figure 3 permitted the observation of patterns of behaviour in the 70's, before observational software or computational methods were available.

This diagram presents a seating area with 11 sections. From left to right it is possible to know when someone decided to sit and the duration of the sitting. On the right side is totalised the number of people per section, while in the bottom of the diagram is presented the total people using the seating area every 5 minutes. The author also reported comparing the results with local weather records, he stated "... sun and warmth bring people out; rain and cold keep them away. It is the marginal days that are most interesting. They indicate that the difference between use and non-use can rest in minor design features" (Whyte, 2009, p. 136). This research aided with the urban design of New York City and had a high impact in the work of other urbanists.

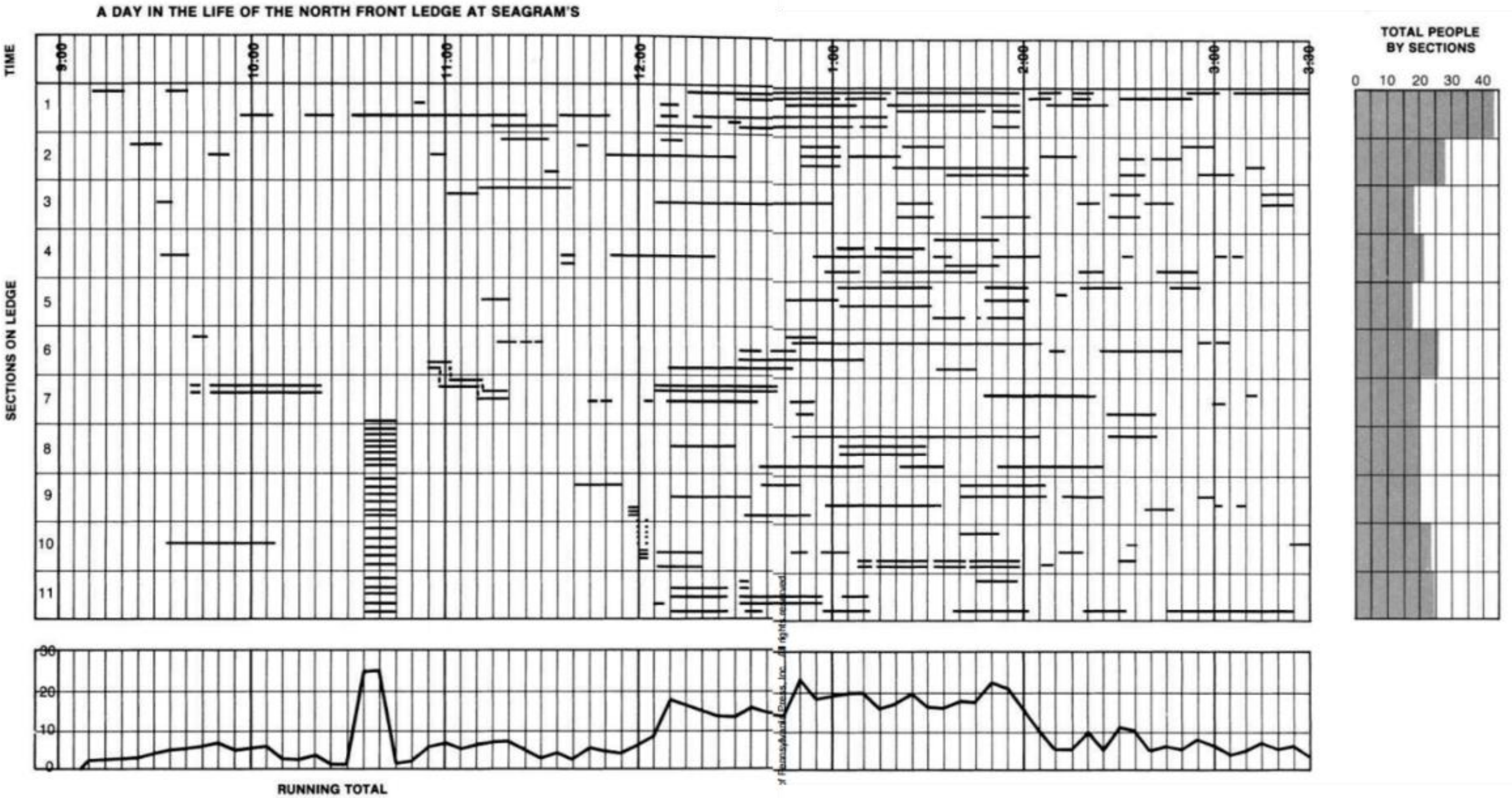


Figure 3 - Mapping presence of sitters (Whyte, 2009). Copyright © Estate of William H., reprinted by permission of The Albert LaFarge Literary Agency.

Other pioneers on the field of human behaviour outdoors are Gehl Architects from Denmark. In the book 'How to study public life' (Gehl & Svarre, 2013), they summarised some of their findings. They compare studying people's behaviour to: "... studying and structuring other forms of living organisms. They could be animals or cells: counting how many there are in total, how quickly they move under various conditions, and generally describing how they behave on the basis of systematic observation" (p. 5). They conducted urban observations to analyse factors such as: pedestrian pathways, gait speed and pedestrian's perceptions of spaces in cities like New York, Melbourne, Brighton and Copenhagen.

According to Gehl et al. (2006), the human sensory apparatus is designed to perceive the space at 5 km/h of gait speed. Some studies have evaluated the appearance in places and materials such as: ground floor interactive façades, diverse information exposed to the human eye level, variety of activities and multiple functions inside the building can enrich the pedestrian experience. In their study they selected two façades with different characteristics: A) a façade with several doors, visual contact between outdoors and indoors and different activities occurring inside the building; and B) a uniform façade with a few doors and non-contact between outdoors and indoors. They found that the traffic speed was 13% slower with façade A, 75% of people turned their heads towards the façade A compared to 21% of people passing in front of façade B. 25% of the pedestrians stopped in front of façade A and only 1% stopped in front of façade B.

Nasar & Yurdakul (1990) conducted a comprehensive study of patterns of behaviour in outdoor urban spaces in Ohio. In their research four public squares were evaluated mapping frequencies of behaviour, and the characteristics of users, activities, time, space and environmental features.

The method used to record behaviour was a video camera located inside a car that was passing around the evaluated area to avoid disturbing the natural behaviour of users. The observations were conducted during two weeks of May, using time intervals of 8:15 to 9:30, 13:30 to 14:00 and 16:00 to 18:30 hrs, for a total of 21 recordings. The researchers were aware of the air temperature during the recorded periods but they did not record microclimatic conditions. Figure 4 is reprinted with permission of the authors, this handmade analysis contains the location of people, their gender, age and activity at the moment of the registration. The mapping was done in a specific hour and the mean air temperature and solar conditions were recorded (Nasar & Yurdakul, 1990).

In the study conducted by Nasar & Yurdakul (1990), 6,618 people were counted. The authors reported that the favourite posture of pedestrians was standing with exemption of the bus stops. However, the availability of sitting was limited and they tended to be occupied most of the time. They also reported differences with the findings reported by Whyte (2009); for instance they did not find support to the statements that users stopped to converse more frequently in the corners, or that the presence of females and groups were indices of desirability of plazas because conversations occurred along the block analysed and the number of people was not related to the proportion of the mentioned indices.

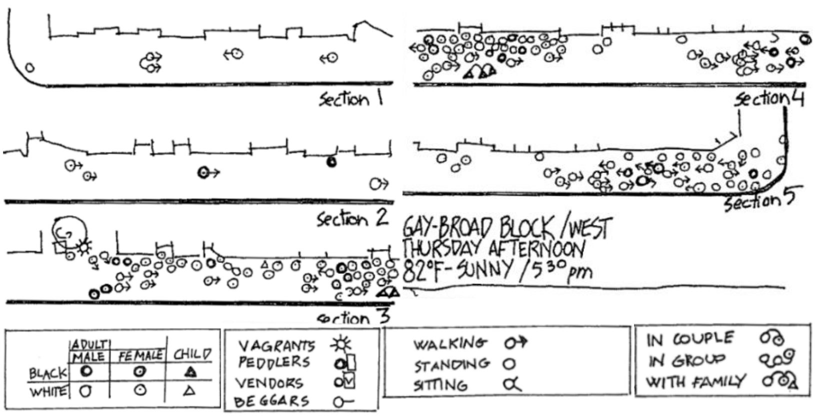


Figure 4 – Mapping social interaction (Nasar & Yurdakul, 1990).

The study conducted by Maruši (2011) regarding the analysis of occupancy in two different cities, Edinburgh and Ljubljana aimed to map different urban activities at different times to create behavioural maps using geographic information system. The data gathered included body postures and activities. In the findings, the author presented a technique that allowed them to visualise urban maps by occupation and activities according to different times. Previous research from the same data sample (Goličnik & Ward Thompson, 2010), presented analysis of the distances adopted according to the personal spaces of users. They confirmed the dimension of the social distance defined by Hall (1969) of 3.7 m, since they observed tendency of keeping around 4 m of distance between persons or small groups of people sitting along an edge.

The perception of users with regards their urban space has also been reported by other authors. For instance, Abdulkarim & Nasar (2014) conducted a qualitative study in order to see whether the presence of food, vendors and furniture as an attraction for users to stop and meet would increase the use of public spaces. In this study they recruited 60 participants and presented to them 12 different scenarios in virtual reality where the presence of food, vendors and furniture was modified. It was found that the availability of a seating area was the characteristic that increased most the use of the space and these results were even improved by combining the seating area with the presence of sculptures. The results also indicated no difference in the perception of the places between men and women.

From the policy perspective point of view, and the urban intervention to improve public life, Donald (2011) presented analysis of some policy initiatives in Sydney. In this report the author describes the strategies discussed in the planning of the city to improve pedestrians' experience by increasing commerce, creating connections and integrating the private and public parts in the dynamics of the urban life proposed by Jan Gehl. The proposed buildings included recovering under used areas, increasing the use of commerce on the ground floor, promoting the walkability and adapting some buildings for public use. This paper reports the generation of policies after generating metrics of the use of public spaces according to the pedestrians' perception.

In connection with the previous urban design policy strategies, the punctual interventions designed need to be informed by measurements capable of integrating the urban layout with the human use. A good example is the work developed by Hillier et al. (1987), described here. With the aim of identifying whether the spatial layout of an urban area would influence the pattern of use, the researchers conducted a study using the *space syntax tool* and conducted fieldwork to evaluate the movement patterns of people in real life. Space syntax (Hillier & Hanson, 1970) is a human-focused simulation tool that allows study of the relationship between the layout and social, economic and environmental phenomena. In the analysis, the researchers evaluated 75 towns to determine an index per route according to: its integration with other routes, the control that the pedestrian had of the space by the options to move around different routes, and the degree of choice to select the routes. In parallel, they selected some routes to evaluate the dynamics of pedestrians in real life, by registering people moving through these routes. At the end, the data from the characteristics of the routes and the pedestrians recorded per route were compared using Pearson correlation analysis. The researchers reported the correlation between the number of people recorded and the integration index (which is the availability of connection between routes) at different places ($r = .80$ and $r = .73$), meaning that the connectivity of the cities increase the probability of people socialising and generating encounters. With this study they presented the relationship between the spatial layout and the human activity generated by this.

The literature described so far presents the complexity of evaluating human conduct and the ‘wildness’ of public space. The authors mentioned are the most important contributors to the field. However, studies of human behaviour in public spaces that are purely focused on understanding the behaviour, activities, movement and motivation of users do not take into account the influence of the environmental conditions. The built environment outdoors by itself is a modification of the environmental conditions of a place which can increase or decrease the wind speed, allow or restrict the solar radiation and increase or decrease the light intensity by generating its own microclimatic conditions; for example, the construction of walls, columns or other architectural devices may change the flow of air circulating through a space, increasing or decreasing the wind speed.

2.3. Human Behaviour and Comfort in Outdoor Environments

In the literature it is widely recognised that the built environment and environmental conditions can affect human conduct. It is referred to as the ‘Adaptive Principle’, which means that “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Fergus et al., 2013, p. 8), the search of thermal comfort, for example, comes from the natural need to regulate the body’s temperature. This adaptive principle is described for indoor environments; however, some of its parameters are transferable to conditions outdoors. Fergus et al., (2013) proposed a list of actions initiated from the physiological, psychological, social and behavioural perspective in response to cold or hot environments. Table 1 collects some of the actions proposed by Fergus et al. (2013) but defined in a way compatible with outdoors, and also includes some other actions reported in other studies.

Table 1 – Conceivable actions in response to hot and cold environment

Actions in response to			
Authors	Cold Environments	Authors	Hot Environments
(Fergus et al., 2013)	Vasoconstriction (reduces blood flow to the surface tissues)	(Fergus et al., 2013)	Vasodilation (increases blood flow to surface tissues)
	Increasing muscle tension and shivering (generates more heat in the muscles)		Sweating (evaporative cooling)
	Curling up or cuddling up (reducing the surface area available for heat loss)		Adopting an open posture (increases the area available for heat loss).
	Increasing the level of activity (generates body heat)		Reducing the level of activity (reduces bodily heat production). Adopting the siesta routine (matches the activity to the thermal environment)
	Adding clothing (reduces the rate of heat loss per unit area)	(Lin et al., 2013)	Adjusting clothing level. Wearing hats, parasols (protection from direct solar radiation)
	Finding a warmer spot (select a warmer environment)		Finding a cool spot (hoping for a cooler temperature)
	Emigrating (seeking a warmer place long term)		Emigrating (long-term way of finding a cooler place)
	Acclimatising (letting body and mind become more resistant to cold stress)		Acclimatising (letting body and mind adjust so that heat is less stressful)
	Visiting a warmer environment	(Whyte, 2009)	Visiting a cooler environment (e.g. places with shadow availability or water fountains)
(Lin et al., 2013)	Consuming hot beverages (pleasant stimuli)		Having a cold drink (pleasant stimuli). Having a beer (induces sweating and increases heat loss). Drinking a cup of tea (induces sweating, more than compensating for its heat). Eating less (reduces body heat production)
(Li, 1994)	Adopting upright postures to minimise contact with cold furniture (reduces the area available for heat loss)		Adopting an open posture (increases the area available for heat loss)

Adaptive actions and thermal comfort have been widely studied with an exponential trend over the last decade (Rupp et al., 2015). Nevertheless, the studies for outdoors have been more limited with a slower increase of publications in comparison to indoor studies. In a refinement of the data published by (Rupp et al., 2015), Figure 5 presents the number of papers published in each environment, this figure is printed in this work with the permission of the authors. It is observed that, despite the increment in the number of works over the last years, the amount of findings published for outdoors is very narrow in comparison to the studies conducted indoors, which suggests the existence of a gap in this field of study.

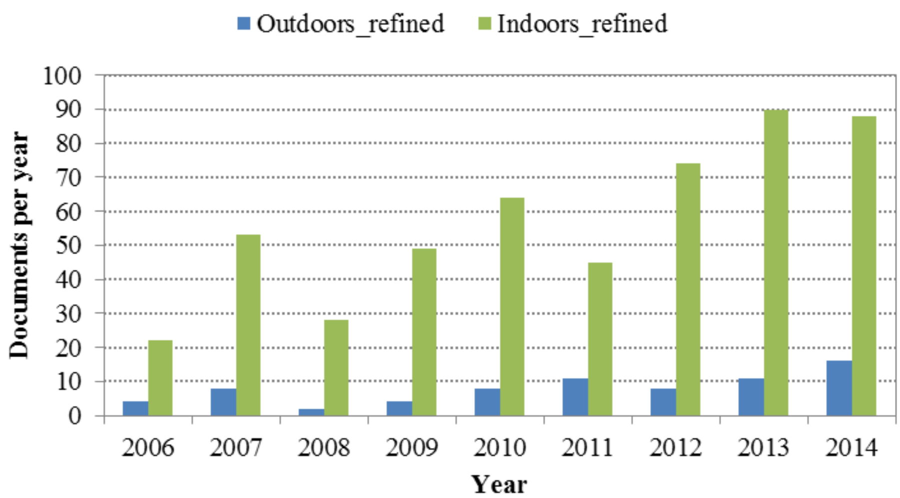


Figure 5 – Number of articles published per year for indoors and outdoors comfort (Rupp, Vásquez, & Lamberts, 2015)

Some authors have used the methodology previously used in indoors to measure the comfort outdoors. An example of this is the study conducted by Nikolopoulou et al. (2001) where she compared the percentage of people thermally dissatisfied (predicted mean vote PMV) (Fanger, 1970) with the actual sensation vote without finding similarities between the prediction and the people’s perception. According to Robinson (2011) the models applied to measure thermal comfort indoors are not applicable to be used outdoors. The use of this indoors model is commonly observed in the literature for outdoor comfort studies, indicating the existence of a gap in terms of methodology for outdoor comfort studies.

One of the most comprehensive studies regarding thermal comfort outdoors was conducted by Nikolopoulou et al. (2004) with the project RUROS. This study was conducted in seven European cities (Athens, Thessaloniki, Milan, Fribourg, Cambridge, Sheffield and Kassel), collecting more than 10,000 interviews and measuring environmental conditions in the different seasons. The thermal sensation was assessed by measuring the Actual Sensation Vote (ASV) which is the perceived thermal sensation of users on a 5-point scale from very cold to very hot. The results were compared with the predicted Mean Vote (PMV). The study also integrated different tools of analysis regarding the wind speed, mean radiant temperature, urban morphology, visual comfort and acoustics. At the end the authors presented a set of principles of design based on bioclimatic parameters for the evaluated cities.

From the same data set collected during RUROS, the authors published more extensive analysis in other papers. For instance, the data collected in Greece was evaluated to determine the use of spaces in Mediterranean environments (Nikolopoulou & Lykoudis, 2007). This study covered the four seasons, collecting the data during a week in each season. A total sample of 1503 interviews were collected and microclimatic conditions were measured in parallel. The researchers also recorded the number of people in different places. The results indicated a negative correlation between the air temperature in the presence of people in the sun ($r = -.23$) indicating that as the air temperature increased, the number of people remaining in areas with sun decreased.

The results from the 10,000 interviews collected in project RUROS were published by Nikolopoulou & Lykoudis (2006). The data collection was conducted during a week in each of the four seasons, in parallel the researchers measured the microclimatic conditions. According to the authors, the Actual Sensation Vote correlated better with the globe temperature ($r = .53$, $p < .01$) than with air temperature ($r = .43$, $p < .01$) indicating an influence of the radiant effect of the sun. In order to analyse the source of discomfort, it was found that strong wind speed was associated with discomfort in low air temperatures, while calm conditions were related to discomfort in places with high at temperatures. Regarding the relative humidity, the authors report that people are not good at judging the relative humidity levels unless they are exposed to too high or low levels. The authors concluded that air temperature and solar radiation were determinants element for comfort, nevertheless one parameter alone was not sufficient to assess the thermal comfort conditions.

Work conducted by Nikolopoulou et al. (2001) in four public squares of Cambridge aimed to identify the conditions that influenced people's behaviour and use of outdoor spaces. This research was conducted during spring, summer and winter at lunch time during 5 days of a week in each season. The researcher collected 1431 interviews and measured the microclimatic conditions simultaneously. A correlation was reported between the attendance to the squares and the globe temperature ($r = .56$). In this work, the authors reported the comparison big differences found between the ASV and the PMV. They concluded that the 'environmental stimulation' plays an important role, since people attend to public spaces by their own choice "to 'charge up' with the heat and fresh air" (p. 234).

After conducting the study in Cambridge, Nikolopoulou & Steemers (2003) published an interesting analysis about the psychological adaptation to the thermal environment. The starting point of the discussion was the big difference found between the predicted mean vote (PMV) which is to predict the percentage of people thermally dissatisfied and the actual sensation vote (ASV) which evaluates the perception of people regarding the current thermal environment. The authors suggested that the discrepancy between these two models can be explained by the adaptation of users to the outdoor environment. They explained different categories of adaptive opportunities that user could have to improve their thermal experience. The physical adaptation refers to alterations on the clothing level, body posture or consumption of hot or cold beverages. The physiological adaptation refers to the acclimatisation of the body by exposure to the same environment. Naturalness, refers to the tolerance to the thermal changes because they are naturally produced. Expectations refers to the perceived condition vs. the expected conditions. Experience refers to the memory of the user and their expectations. The time of exposure is related to the period users are exposed to the thermal environment. The perceived control refers to the flexibility of the place to modify the thermal conditions. These adaptation opportunities defined by Nikolopoulou & Steemers (2003), reinforced the adaptive actions presented by Fergus et al. (2013) at the beginning of this section. However, Robinson (2011) argued that the adaptations suggested by Nikolopoulou & Steemers (2003) are not the reasons to explain the difference between PMV and ASV, and moreover, the thermal history of the users is ignored when using a stationary model, since the outdoor thermal environment requires a dynamic model that allows the integration of elements such as the thermal history of the user.

The Universal Thermal Climate Index (UTCI) (Bröde et al., 2012) presents a model to predict the physiological reaction of people to a multidimensional outdoor thermal environment. This prediction integrates wind speed, radiation, humidity and air temperature. This index calculates physiological values such as: rectal temperature, mean skin temperature, facial skin temperature, skin blood flow, sweat rate, skin wittedness and heart rate by shivering. The reference condition was a person walking at 4 km/h, 50% of relative humidity and a wind speed of 0.5 m/s. This model presented good results in terms of the physiological response; nevertheless, the authors suggest that the thermoregulation and adaptation is not considered as well as different activities affecting the metabolic rate.

Lighting

According to Parsons (2000), "there is a continuous and dynamic interaction between people and their surroundings that produces physiological and psychological adaptation" (p. 582). From the environmental ergonomics perspective, comfort is evaluated by considering the interaction between the thermal, acoustic, vibration, lighting and air quality environment as these factors can affect performance, productivity, health and safety of people and has therefore influence over their behavioural response (Parsons, 2015). However, the intention to evaluate the environmental factors are commonly concerned with human responses to cold and hot conditions, rather than assessing the environment as a whole (Parsons, 2015).

However, there are some authors that also included other environmental factors, such as light. For instance, Nikolopoulou et al. (2004) conducted thermal, visual and audible comfort analysis in seven countries. In the visual comfort analysis, the authors measured the daylight illuminance in the shade and the sun and conducted surveys, observations and simulations. The Luminous Sensation Vote (LSV), which is a 5-point scale varying from "very dark" to "very bright", was registered. The observations included the registration of behaviours such as: wearing sunglasses, moving hands above the eyes, rotating or bending the head, blinking, reading/writing or other adaptation taken. In their conclusions, the authors suggest that with exception of very narrow urban canyons or similar urban shapes, the daylight illuminance levels should be sufficient for the use of public spaces during the day. It is also suggested that the sites should allow sunlight access to 20-80% of the area. However, the visual environment conclusions are not interrelated to the thermal comfort evaluations as they are presented as independent analyses. As stated by Nicol et al. (2014): "About half of the radiant energy from the sun is emitted in the visible range"…"This means that solar radiation is relatively efficient as a light source" (p.14). Moreover, the presence of sunlight outdoors is affected by the regular variation of the time, seasons and also the irregular changes of the meteorological conditions (Walsh, 1961). In outdoor environments, the main source of daylight comes from the sun. "The sun radiates a wide range of the electromagnetic spectrum, some of which passes through the atmosphere and some of which is filtered out by it" (Howarth, 2015, p. 679). The amount of light is measured by the *illuminance*, which correspond to the amount of light going to the eye; and the *luminance,* which is the amount of light emitted by a point source (Howarth, 2015). The illuminance is measured in 'lux' (lx) and the luminance is measured in candela per square meter (cd m^{-2}) (Howarth, 2015).

According to (Hodder & Parsons, 2007), "the environmental parameter most significantly affected by solar radiation is the mean radiant temperature" (p. 234). For instance, Nasar & Yurdakul (1990) referred to the light as the sunlight presence in the public space. In their work, the authors reported that more people decided to sit or stand in shaded areas: "where there was a choice between sunny and shaded wall-side location, the shaded ones were selected" (p. 81)

The relationship between use of space and artificial lighting has been also evaluated in order to enhance the urban quality. Choi et al. (2006), applied an urban analysis in Seoul, Korea using the theories of Space Syntax regarding pedestrian movement, to define the lighting system of the city. This strategy aimed to improve the safety of streets. Similarly, Nasar & Bokharaei (2017) conducted an evaluation of different types of artificial lighting in simulated plazas. The sample was 363 adults who were asked about their preference in different types of scenarios. Their findings suggest that "bright, uniform and overhead lighting can make public squares more appealing" (Nasar & Bokharaei, 2017, p. 104).

2.4. Human Behaviour and Environmental Factors

As presented before, the influence of the environmental factors on the behaviour of people in outdoors is recognised in the literature. A review of the literature was conducted by classifying and separating the studies that included terms relevant to this study, such as, number of people, thermal environment, and time of permanence among others. This section will introduce some of the most relevant studies to the area of study of this research regarding the understanding of human behaviour in response to different environmental conditions.

Zacharias et al. (2001) investigated the relationship between microclimatic conditions and attendance and activity in seven corporate plazas in Montreal. The authors defined the independent variables as: time of day, air temperature, presence of sunlight, proportion of surface in sunlight and wind speed. The dependent variables of the study were: attendance, number of people standing, sitting and smoking, and with these categories number of people in the sun and shade. The study was conducted over four hours at lunch time per day during April, May, June, September and October. Rainy days were excluded. The data collection was made by plotting in maps the position and activity of each user rotating the observation between the seven squares between 11 am and 3 pm. At the end the sample observed consisted of 9,030 individuals mapped and 495 censuses. The findings reported an increment of the presence of people with the sunlight presence despite the air temperature level. The results suggested that above 20ºC, the preference for users to stay in places with sunlight was reduced. The authors used multiple regression models where the presence of people was evaluated according to the microclimatic conditions (sun, temperature and wind), the type of spaces and the time of recording (30 minutes intervals between 11 am and 3 pm). The microclimatic variables accounted for 12% of the variance, the type of square 38% and the period of time 7%. This study presented a comprehensive method of comparison between different spaces, however it ignored important variables such as relative humidity and globe temperature, in addition the measurement of the wind speed was conducted in a qualitative scale that did not permit examination of the influence of this parameter on the behaviour of people. This study was however used as referent to compare the results and improve the methodology used by the authors to assess the human behaviour in outdoor public spaces. Additionally, other variables such as wind speed, relative humidity and globe temperature were added to this research.

The same methodology of the previous study was used to study seven plazas located in a corporate area of San Francisco (Zacharias, 2004). In this study it was found that 11% of the variance was explained by the microclimatic variables, 7% by the places and 11% by the time. It was reported that the time of permanence of 100 people was evaluated against the air temperature, however non-significant correlations were found. The study also found a logarithmic relationship between the proportion of users and the proportion of the plaza with sunlight (R^2= .75), which means that as the sunlight area available increased, the number of people also increased. Similar trends in the results of the air temperature, sunlight and attendance were observed in the study conducted in Montreal. This study expanded the results obtained by the author regarding the location, for instance, it was observed that the microclimatic conditions in Montreal and San Francisco explained around 12% of the variability of the attendance, which suggest a pattern of this behaviour when the environmental conditions are similar.

Li (1994) conducted a study regarding behaviour of people during spring, autumn and winter. The author described that cities are generally coping with the environmental stress of cold seasons by motivating users to remain in indoors and create warm artificial environments such as “indoor cities”, another option is to try not to overprotect people by encouraging them embrace the natural condition and enjoy the cold weather. The author collected observational samples in fifteen squares of New York, the data was recorded by hand during seven days, between January and March, October and December 1989 and February and April 1993, at lunch time. The demographics, time of stay, grouping (alone or in groups) and air temperature were recorded. In the findings the author reported a relationship between the presence of people and temperature, however, the attendance of people during winter did not show a relationship with this variable (r =. 09). The author also evaluated other qualitative variables such as occurrence of recreational and commercial activities, and visual diversity which is the variety of building surrounding the place. This study presents valuable results regarding the local behaviour and qualitative characteristics of the evaluated squares, nevertheless the lack of detailed microclimatic conditions make it difficult to assess the generalisability of the results.

Eliasson et al. (2007) conducted research evaluating the relationship between microclimatic conditions and human perception in Gothenburg, Sweden. The study included as independent variables the clearness index (cloudiness), which refers to "the ratio between a measured and a theoretical maximum incoming solar radiation for a specific time and location on the earth's surface" (p. 74), air temperature and wind; and recorded the participants' perception on the weather conditions and behaviour, aesthetics and emotions regarding four public spaces. The data collection was done during five days over two weeks in each season, between 11am and 3pm. Rainy days were excluded. The observations were made every 20 minutes, by registering: the number of people in each posture (lying, sitting, standing and walking) and activities (eating, talking and reading). The interviews collected demographics data, clothing and questions regarding the perceived weather. In total the authors collected 1379 interviews. The data was analysed using multiple regression analysis to evaluate the influence of the environmental variables over the behaviour and perception. The findings showed a relationship between the attendance and different environmental factors according to the place. For instance, in one of the places the clearness index and air temperature affected the attendance by 33%, in other space wind speed, solar radiation and air temperature influence 49% of attendance. The authors also reported a relationship between aesthetics and wind speed, as positive in a waterfront area and negative in a public square.

Due to the multiple analysis regarding environmental factors and human behaviour found in the literature, Table 2 presents a list summarising some of the behaviour studied, the measurements associated with them and the authors.

Table 2 – List of behaviour, measurements and authors

Literature Review of Behaviours in Outdoor Environments	
Behaviours	**Measurements / Authors**
Number of People (total and per zone)	*Measurements* Globe Temperature, Type of space, Companions, Mean Radiant Temperature, Air Temperature, Wind Speed, Sun, Solar Radiation, Season and Time, Thermal Preference, Activities, Comparison in two cities, Thermal History, Physiological Equivalent Temperature. *Authors* (Aljawabra & Nikolopoulou, 2010; De Castro Fontes et al., 2008; Eliasson et al., 2007; Lin et al., 2013; Nikolopoulou et al., 2001; Nikolopoulou & Lykoudis, 2006; Stathopoulos, Wu, & Zacharias, 2004; Thorsson et al., 2004; Whyte, 2009; Zacharias et al., 2001; Abdulkarim, D., & Nasar, J. L., 2014)
Sun and Shadow (preference to stay)	*Measurements* Globe Temperature, Mean Radiant Temperature, Air Temperature, observed sun and shadow *Authors* (Arens & Bosselmannt, 1989; Martinelli et al., 2015; Nikolopoulou et al., 2001, 2004; Spagnolo & de Dear, 2003; Stathopoulos et al., 2004; Thorsson et al., 2004; Watanabe et al., 2014; Zacharias et al., 2001)
Clothing Level	*Measurements* Air Temperature, Wind Speed, Relative Humidity, Globe Temperature, Mean Radiant Temperature, and Comparison in two cities. *Authors* (Aljawabra & Nikolopoulou, 2010; Humphreys, 1977; Nikolopoulou et al., 2001; Nikolopoulou et al., 2004; Nikolopoulou & Lykoudis, 2006; Thorsson et al., 2004)
"Reasons to be there"	*Measurements* Comfort State, Number of People. *Authors* (Nikolopoulou & Lykoudis, 2006; Thorsson et al., 2007)
Pedestrian Movement, Pedestrian Flow	*Measurements* Simulation, Mean daily Movement, Time of the day, proximity to road, quality of pathway, ground level activity, accessibility, walkability. *Authors* (Helbing & Molnár, 1995; Stonor et al., 2001)
Activities	*Measurements* Different Spaces, Solar Radiation, Comparison in two cities, Number of People. *Authors* (Aljawabra & Nikolopoulou, 2010; Eliasson et al., 2007; Huang et al., 2016; Lee et al., 2012; Maruši, 2011)
Walkability	*Measurements* Linear Regression with perception of people. *Authors* (Oreskovic et al., 2014; Stonor et al., 2001)
Time of Permanence	*Measurements* Time per zone, Thermal Perception, Predicted Mean Vote, Weather Expectations, time usually spent, socio-economical group, Solar Radiation, Comparison in two *Authors* (Aljawabra & Nikolopoulou, 2010; Thorsson et al., 2004; Whyte, 2009; Zacharias, 2004)
Crossing Street	*Measurements*

	Time of waiting to cross with red and green light. *Authors* (Stonor et al., 2001)
Preferences to remain (by age)	*Measurements* Season, Location. *Authors* (Maruši, 2011; Nikolopoulou & Lykoudis, 2007)
Occupation of Space	*Measurements* Area, Time of day, Intensity. *Authors* (Maruši, 2011)
Thermal Sensation (PMV - ASV)	*Measurements* Air Temperature, Relative Humidity, Wind, Clothing, Metabolic Rate. *Authors* (Aljawabra & Nikolopoulou, 2010; De Castro Fontes et al., 2008; Nagara et al., 1996; Nikolopoulou et al., 2001; Nikolopoulou et al., 2011; Ruiz & Correa, 2015; Spagnolo & de Dear, 2003; Thorsson et al., 2004)
Comfort and Discomfort	*Measurements* Actual Sensation Vote, Wind, Humidity, Thermal, Air Temperature, Activity, Clothing, Solar Radiation, Metabolic Rate, time of exposure, posture sitting-standing-walking, simulations, Acceptance by Activity, Shade. *Authors* (Arens & Bosselmannt, 1989; Bröde et al., 2012; De Looze et al., 2003; Lai et al., 2014; Maruši, 2011; Nikolopoulou & Lykoudis, 2006; Nikolopoulou et al., 2004; Soligo et al., 1998; Stathopoulos et al., 2004)
Air Cleanness & Quality	*Measurements* Perception and Particulate Matter Measurement. *Authors* (De Castro Fontes et al., 2008; Nikolopoulou et al., 2011)
Air Temperature (Perception)	*Measurements* Perception. *Authors* (Spagnolo & de Dear, 2003; Thorsson, et al., 2004)
Air Movement (Preference)	*Measurements* Perception. *Authors* (Spagnolo & de Dear, 2003)
Thermal Neutrality (Perceived)	*Measurements* Perception and Meteorological Measurements. *Authors* (Nikolopoulou et al., 2004)
Acoustic Comfort	*Measurements* Age Preference / Sound Pressure. *Authors* (Nikolopoulou et al., 2004)
Health Condition (Perceived)	*Measurements* Perception. *Authors* (Thorsson et al., 2004)
Accessibility (Perceived)	*Measurements* Distance from the user´s house. *Authors* (Thorsson et al., 2004)

After conducting the review of the behavioural studies in outdoor urban spaces, it was observed that this type of analyses have supported the planning of cities by focusing the design on the users' preferences (e.g. the works conducted by Gehl (2011), Huang, et al. (2016) and Whyte (2009)).

In addition, the review of the literature showed that most of the research related to human behaviour did not include quantitative measurements of the environmental conditions. In the same way, the studies regarding the environmental conditions are focused on the adaptive behaviour and perception of users.

It was found also that studies related to thermal comfort outdoors are a common concern in the literature. These studies were based on subjective methods to assess the users' perception of the environmental conditions (e.g. ASV and PMV). These studies considered some behavioural patterns, such as: number of people, type of activities and clothing. A high correlation was found between some of the behaviours analysed and the environmental variables; however, these studies have not used behavioural methods to conduct the evaluation.

The studies of thermal comfort showed that there is a relationship between: air temperature and the presence of people in the sun, the actual sensation vote and the globe temperature and attendance and globe temperature, among others. Parsons (2015) also suggested that comfort is affected by multiple factors (e.g. light and noise) and not only by the thermal environment, as suggested frequently in the literature. On the other hand, Nicol, et al. (2014) highlights that there is an important amount of radiant energy coming from the sun that is light, which suggests a relationship between mean radiant temperature and globe temperature with the illuminance outdoors. Therefore, it is concluded that the thermal variables may also include the illuminance level as a parameter to understand behavioural patterns outdoors.

The methods to study human behaviour observed in the literature included: observation (photography and video), mapping, counting and registering the duration of activities and taking notes on place, among others. The methods to evaluate the comfort outdoors were: surveys based on a 5-point or 7-point scale to rate the perception of users regarding their thermal environment (e.g. ASV). The environmental measurements included: air temperature, globe temperature, mean radiant temperature, wind speed and relative humidity. Other studies also included the perceived light level (Luminous Sensation Vote), the preference to stay in the sun or shade and adaptive behaviours regarding light.

Finally, a lack of standardisation and validation was found on the type of data gathered and the methodology selected. In addition, there was no basis to explain why those variables were selected to evaluate human behaviour and environmental factors. However, the studies found presented an agreement in the use of variables related to sun presence, such as globe temperature and mean radiant temperature. Therefore, the Pilot Study was conducted using a mixed methodology consisting of: 1. On-site observations, recording and video analysis; 2. Surveys assessing users' perception; and 3. Environmental measurements.

2.5. Chapter Summary

This chapter presented an overview of human behaviour and the built environment. The evolution of public urban spaces, activities and their influence on people's quality life was addressed in the first section. Subsequently the evolution of studies in public spaces and methods used to register human behaviour were detailed. The studies in comfort outdoors were explored and the types of evaluations and behaviour commonly evaluated were presented. Finally, a compilation of the main behaviours, authors and methods of human behaviour and built environment were exposed.

3. General Methodology

3.1. Chapter Overview

This chapter presents the general methodology of this research and refers to the foundations behind the methods used to study human behaviour in public outdoor spaces, in accordance with the thermal environment. Various methodologies were identified and tested in a pilot study before selecting the appropriate methodology to address the aims of the research.

The methodology chosen can be classified under the heading of *Behavioural Methods*, comprising techniques for observation and classification of human behaviour in combination with other factors (such as microclimatic conditions or physiological measurements), and keeping records of the data collected for further analysis and processing. This methodological approach allows measuring and standardising the human behaviour for subsequent statistical analysis recurring exclusively to observational data such as the count of people or the time of permanence, as opposed to collecting individual perceptions of the participants, which affects the spontaneity of people and is the interest of studies focused specifically on the psychological or physiological characteristics of the participants.

The method also considered the use of validity, reliability, generalisability, and ethics to assess the quality of the results. This aimed to permit replicability of the results in other environments.

3.2. Introduction

The literature review revealed the lack of standardisation and validation of methods and results when studying human behaviour outdoors (Chapter 2). Therefore, the foundations for the development of the general methodology was based on contrasting different approaches found in the literature to study human behaviour in relation to the thermal environment. Further, the methods to assess validity, reliability, generalisability, acceptability and ethics of the results are presented due to the relevance of these factors when performing analysis aimed at behavioural predictions.

The PhD methodology aimed to identify the methods that would be suitable to achieve the research objectives:

1. To identify methods to assess human behaviour and environmental factors from a Human Factors perspective and select or create an appropriate method for this research.
2. To collect a representative dataset of the environmental conditions throughout the year, which includes human behaviour and environmental variables.
3. To observe, codify, analyse and predict human behaviour in terms of: occupancy, group size, time of permanence, body postures, activities and adaptive behaviour.
4. To compare the data gathered in the different seasons selected (summer and autumn 2015 and winter 2016), in order to identify whether there is a relationship between the environmental variables and human behaviour.
5. To conduct internal and external validations of the results of the studies, in order to achieve comparable, generalisable and replicable results.
6. To generate recommendations in urban design based on the results obtained from the data gathered.

With these objectives in mind, the following sections present a review of alternative methods and discussion of considerations applied in the selection of methods used in this research.

3.3. Methods to assess Human Behaviour and Environmental Conditions

According to the literature review, previous studies have approached the assessment of human behaviour from different perspectives. Some authors approached the study from the subjective perspective by applying questionnaires to find users' thermal perception and comfort (e.g. Nikolopoulou & Lykoudis, (2006); Thorsson et al., (2007)). Opposed to those are the objective methods, which aim to capture direct quantitative data (i.e. heartbeat of a person). Other authors have based their research on Behavioural methods based on observational analyses and mapping user behaviour (e.g. Gehl et al. (2006) and Maruši (2011)). Finally, the Modelling methods aim to generate models to predict simulated conditions of the human behaviour. Below is a description of this four commonly-used methodologies to evaluate human response to the environmental conditions:

Subjective Methods: these methods are focused on the user response. Subjective methods are commonly used to assess the thermal comfort of the users and have been widely applied by several authors evaluating thermal comfort in outdoor public spaces. To mention a few, Nikolopoulou & Lykoudis (2006) measured the Actual Sensation Vote (ASV) using a 5-point scale; Thorsson et al. (2004) also used the ASV but with a 7-point scale; Lin et al. (2013) used the ASHRAE 7-level thermal sensation vote; and Stathopoulos et al., (2004) established a 5-point scale of agreement and disagreement. Other authors also included open-ended questionnaires regarding the thermal perception of users.

The positive side of subjective methods is that they are relatively easy to carry out and are useful for assessing the psychological response (Parsons, 2015). This studies take into account the input from the participants which can aid with the improvement of public spaces from the perspective of comfort. However, these methods can be limited in the type of population to evaluate because they may not be appropriate to be used with children and people with cognitive impairment (Parsons, 2015). Subjective methods can also have methodological biases; the results may be affected by the participant's fatigue, the duration of the questionnaire, and other factors that may change the response of the person such as being observed or knowing the purpose of the experiment (Sharples & Cobb, 2015). Other type of bias may come from the investigator; for instance, the type of hypothesis or expected results, the design of the questions with a positive influence in the expected outcome or event, and comments during the interview with the participants, may all affect the result (Sharples & Cobb, 2015).

Objective Methods: these methods are focused on measuring the human body's response to the thermal environment. For instance, Voorhees et al., (2013) used accelerometer sensors to measure the physical activity of teenagers according to the weather. This method obtains direct quantitative data which can be analysed in order to identify predictive results. However, some important disadvantages of objective methods are that the equipment used can interfere with the normal development of the activity measured and the results are not related to the status or experience of the subjects, for example comfort (Parsons, 2015). Another constraint of these methods is that the participants need to be exposed to the evaluated environment which implies that considerable planning is required to set the scenarios.

Behavioural Methods: these methods are focused on observing the behaviour of a person or a group in relation to the environment. For instance, Thorsson et al., (2007) collected observational data of number of people and type of activities, in conjunction with environmental measurements, in public spaces in Tokyo. Similarly, Aljawabra & Nikolopoulou (2010) conducted simultaneous environmental measurements and human monitoring in two different countries, comparing the results obtained. Behavioural methods "…can have the unique advantage of not interfering with what they are attempting to measure" (Parsons, 2015). These observational methods are suitable to evaluate special populations, such as children or people with disabilities (Parsons, 2015). The main disadvantage of behavioural methods is the difficulty of ascertaining cause and effect, since the outcome could be related to other variables not included in the research (Parsons, 2015).

Modelling methods: these methods correspond to models generated from data collected in previous studies that are used to form predictions about human response to proposed thermal conditions. For instance, Höppe (1999) created the physiological equivalent temperature index (PET), which was based on energy balance equations of the human body in order to predict and assess the conditions of the thermal environment. Arens & Bosselmannt (1989) predicted thermal comfort of people in outdoor spaces, based on a mathematical model of the human body's thermoregulatory system. Bröde et al. (2012) built the Universal Thermal Comfort Index (UTCI) to predict the physiological thermal response using wind speed radiation relative humidity and air temperature as the predictor variables. The advantage of modelling methods is that the responses are consistent throughout different scenarios and can be used as a tool during the process of design to evaluate different options, or to assess an existent condition (Parsons, 2015). However, they exclude individual characteristics or omit specific conditions of the real environment (Parsons, 2015).

From these four different types of approaches to the study of human behaviour, the objective methods were excluded as they require the use of devices which may affect the human behaviour. In addition, the modelling methods were excluded because the software that currently support the urban design are based in models of thermal comfort or fluids simulation. Subjective and behavioural methods were tested in a pilot study (Chapter 4) using both questionnaires and observations, while environmental measurements were being recorded. The data analysis evaluated the type of results obtained from each method. At the end, two characteristics of the subjective methods determined their exclusion from the seasonal studies:

1. Most of the data available in the field has been collected using subjective methods, such as questionnaires to predict thermal comfort simultaneously with observational techniques. This approach created a robust data regarding actual sensation vote, predicted mean vote, thermal sensation and other models, the most comprehensive study in this field is a large data set that covered up to seven European cities (Nikolopoulou & Lykoudis, 2006). Conversely, there are not enough studies collecting observational data which has caused a gap in studies of human behaviour outdoors using behavioural methods.
2. While running the observational data collection simultaneously with the questionnaires, it was found that the behaviour of users was highly affected by the presence of a researcher.

In concordance with the aim of this research of “studying the human behaviour when people were exposed to different environmental conditions in outdoors” it was decided to prioritise studying the natural behaviour of users and perform a deeper investigation using behavioural methods.

Regarding the modelling methods, one of the most interesting approaches to simulate behaviour of people according to the thermal environment is the software BOTworld (Bruse, 2005), which assesses the thermal comfort of people in an urban space using multi-agents. This simulation technique is based on equations of the thermoregulatory system of the human body. This valuable approach, although allowing assessment of the thermal satisfaction, does not explain non-physiological factors that modify the conduct of people in urban spaces, or the movement of agents in a simulated environment. As mentioned before, a robust data set of thermal sensation has been built, nevertheless the data related to behaviour of people is more reduced and lacks uniformity (e.g. units used to measure people). As a call for standardising the data collection regarding human behaviour in outdoor public spaces, (Gehl Institute, 2017) released a public life data protocol aiming to invite other researchers and urban planners to build robust data sets with the same coding scheme to allow comparison and generalisability of results. This call highlights the lack in the field of unified data regarding behaviour and built environment.

Furthermore, the literature review and the exploration of the available tools revealed the lack of data to perform studies using modelling methods. This research therefore aimed to provide data which could be used in the future to support modelling methods.

3.4. Implementing the Behavioural Method

Following from above, behavioural methods are one of the main approaches to study human behaviour. For example, "…the behaviour of a person or group is observed and related to responses to the environment (e.g. change posture, move away)" (Parsons, 2015, p. 644).

Observational studies can be done through indirect or direct methods. Indirect observation refers to the evaluation of archived data observed at a different time from when it was collected (Sharples & Cobb, 2015), an example of which is a study by Hampton et al. (2010) comparing human behaviour in public spaces of New York in 1980 and 2010. This type of study allows comparison of different contexts. However, indirect observation brings limitations regarding the interpretation of the data observed, since it is difficult to know the context of the data collected.

It should be noted that direct observation is far more commonly-reported in the academic literature. In this method, the researcher takes notes, draws maps, takes photos and records videos on site. The pioneering studies using observational methods of human behaviour in urban spaces were conducted between 1960 and 1980 (Gehl, 2011; Gehl & Svarre, 2013).Much of this work was conducted by the architecture office Gehl Architects in different cities such as: Copenhagen, Melbourne, Sydney and Brighton, and the urbanist William Whyte, who conducted direct observations in New York (Whyte, 2009).

The methods used in direct observation can range from use of very low-tech instruments such as “a pen, piece of paper, and perhaps a counter and stopwatch” (Gehl & Svarre, 2013), to equipment for video and audio recording. Some researchers have also reported the use of other parallel sources of data in combination with the observations in order to capture a richer data set (Bisantz et al., 2015). Video, photographs and audio recordings are tools used to capture data for later analysis. This technique presents the unique advantage of allowing reviewing the scene multiple times. For the evaluation of human behaviour outdoors this is an important factor, since it is difficult for the observer to register behaviours occurring simultaneously by different users. However, the disadvantage of these methods is the time required to analyse the data. It is reported that it can reach levels as high as 100 hours of analysis per 1 hour of video. This depends in the granularity of the behavioural study (Bisantz et al., 2015).

Nowadays, video analysis is aided by different "hardware and software systems which facilitate analysis of real-time of videotaped data (e.g. Noldus, NVivo, Morae)" (Bisantz et al., 2015, p. 65). These tools support the coding of behaviour by classifying the data by occurrence, timing of events, sequences, behaviour, interaction and individual characteristics of users, which is later used for statistical analysis. These data can be also contrasted with a parallel source of data, such as environmental measurements and field notes in order to create a richer data set (Bisantz et al., 2015).

In observational methods, the researcher can code behaviours on site, but the information collected can be superficial and biased by the researcher's perception since it does not allow verification of the collected data. Therefore, the use of technology is required to register multiple behaviours at the same time and review the material as many times as required. It is also possible to collect the data by hand and map the results, however the transcription of the data to computational maps to be analysed can be a complex task (e.g. the work conducted by Goličnik & Ward Thompson, (2010) and Maruši, (2011)). In order to analyse behaviours with more granularity, specialised software is required to process the information. Finally, the materials obtained from the observations, (such as videos, coding schemes and data sets), can also be considered an outcome in itself, as they are part of complex processes of data collection and analysis about the people and the dynamics that are taking place in that particular circumstance.

3.5. Validity, Reliability and Generalisability

Despite the significant amount of studies reporting analysis of human behaviour in outdoor public spaces, most did not undertake validation and reliability tests of the data collected. Assessing human behaviour is a difficult task which requires technological aids and long periods of data analysis. This may cause inaccuracies or errors due to the interpretation of the behaviour by the observer, which could affect the outcome.

One of the objectives of this research was to validate the study conducted in order to achieve generalisable and replicable results. This means that the data collected should "measures what it claims to measure" (Wilson & Sharples, 2015, p.26) and the results obtained are replicable in the same scenarios.

In the methods to study human behaviour, various factors have been identified as tools to assess the adequacy and quality of the methods used: Validity, Reliability, Generalisability, Interference, Sensitivity, Feasibility, Acceptability and Ethics, and Resources (Wilson & Sharples, 2015b). As reported by Wilson & Sharples (2015b, p.25): "we rarely, if ever, be able to satisfy all of these criteria". In this research, the criterion Sensitivity and Feasibility were not reviewed to measure the quality of the methods, as they relate the accuracy and simplicity of the methods which were not part of the objectives of this research. The criterion that helped to assess the reliability of the outcomes are described below:

Validity: is defined as "…whether something measures what it claims to measure" (Wilson & Sharples, 2015b, p. 26). According to the authors the main types of validity are: Construct Validity, Content Validity, Convergent Validity, Divergent Validity, Face Validity, Internal Validity, External Validity, Criterion Validity, Concurrent Validity and Predicted Validity. Due to the nature of the studies to be conducted which are aimed to build a data base and create models to predict the human behaviour, the Predictive and External Validity were considered. Predictive Validity refers to the capability of a method to predict future events and whether the outcomes obtained can be extended to other scenarios. In this research, the Predicted Validity was applied in Chapter 5, Chapter 6, Chapter 7 and Chapter 8, where the models to predict human behaviour were validated by splitting the data in 60% and 40%. Multiple regression analysis models were created from 60% of the sample and the other 40% was retained to test how well the model predicted the behaviour, following the procedure suggested by Stevens (2009). External validity, also known as generalisability, is explained below.

Reliability: asks "… whether we would get the same results and interpretations if we repeatedly use a method or measure" (Wilson & Sharples, 2015b, p. 26). This helps to identify whether it is possible to obtain the same results in different samples or scenarios. There are different methods to assess reliability. One of them is the Inter-reliability, which is the option offered by observer XT and refers to the consistency between results in subjective experiments (Lawson, 2011). This type of assessment was used to test the coding scheme designed for the analysis during the pilot study, which will be described in Chapter 5.

Interference: It refers to the influence of the measurement on the performance of people (Wilson & Sharples, 2015b). This criterion was considered during the data collection by locating video camera and environmental station in a discreet position.

Generalisability: or external validity refers to "… how well a method, measure or measurement, and data from that method, will generalise into other domains, situations, settings or populations" (Wilson & Sharples, 2015b, p.27). This assessment was used to test the results of the main studies in a different scenario, here referred to as Mock Scenario, as described in Chapter 10.

In summary, the validity refers to the credibility of the research, the external validity aims to generalise the results and methods, and the reliability represents the auditability and connection of the results with the theory (Hignett & McDermott, 2015).

Another two important criteria to assess the quality of the methods and outcomes are Acceptability and Ethics (Wilson & Sharples, 2015b). Therefore, the strategy used to guarantee the quality of the methods regarding this criteria is presented.

Acceptability and Ethics: Observational studies of human behaviour must comply with the principles of good practice in conducting research and follow the standards and regulations of other relevant bodies (Wilson & Sharples, 2015b). In this research, the relevant bodies contacted and consulted by the researcher about the field studies, were as follows:

1. Ethics Committee from the Faculty of Engineering from the University of Nottingham.
2. Nottinghamshire Police.
3. Nottingham City Council.

From the legal perspective it is worth mentioning that "UK law enables individuals to film or take photos of places or individuals from or in a public place" (Wiles et al., 2008, p. 11). However, the law also recognises the right to have privacy when it is expected. Therefore, recoding or taking photographs of public places is a lawful activity as long as it does not invade the right of privacy where privacy is expected, such as in indoor spaces (Wiles et al., 2008). In order to comply with the right of privacy, the video camera was located in a place which prevented recording private places.

Following the requirements of the ethics application, a set of guides were adopted while conducting the studies such as: placing posters advertising the studies, anonymization of the data collected and opt out mechanisms. This to guarantee that vulnerable population (e.g. children) were not affected by the data collection.

3.6. Research Methodology

As explained in section 4, behavioural methods were selected as they adapt better to the objectives of the present research in compliance with the principles of validity, reliability and generalisability, as described in section 5.

Figure 6 presents an overview of the research methodology, split in three stages: 1. Literature Review and Pilot Study; 2. Human Behaviour in summer autumn and winter (spring was excluded as it presents similar conditions to autumn); and 3. Mock Scenario. Each stage made a contribution to the different objectives of the research.

The literature review conducted as the first activity evidenced gaps in different fields regarding the study of the human behaviour and the environmental conditions. In addition, the studies regarding human behaviour did not apply the relevant factors from a Human Factors perspective, to guarantee the quality of the methods to generate standardised and validated data. The second block of activities developed during the PhD corresponded to the field studies conducted in summer, autumn and winter, and the analysis of the data collected. These studies allowed gathering of human behaviour data in the conditions required, which were then analysed with the purpose of identifying the influence of the environmental variables and the predictability of each behaviour in different environmental conditions. Finally, a study was conducted in a mock scenario with the aim of testing the generalisability or external validity of the data obtained during the previous stages in an alternative scenario custom-made for this purpose.

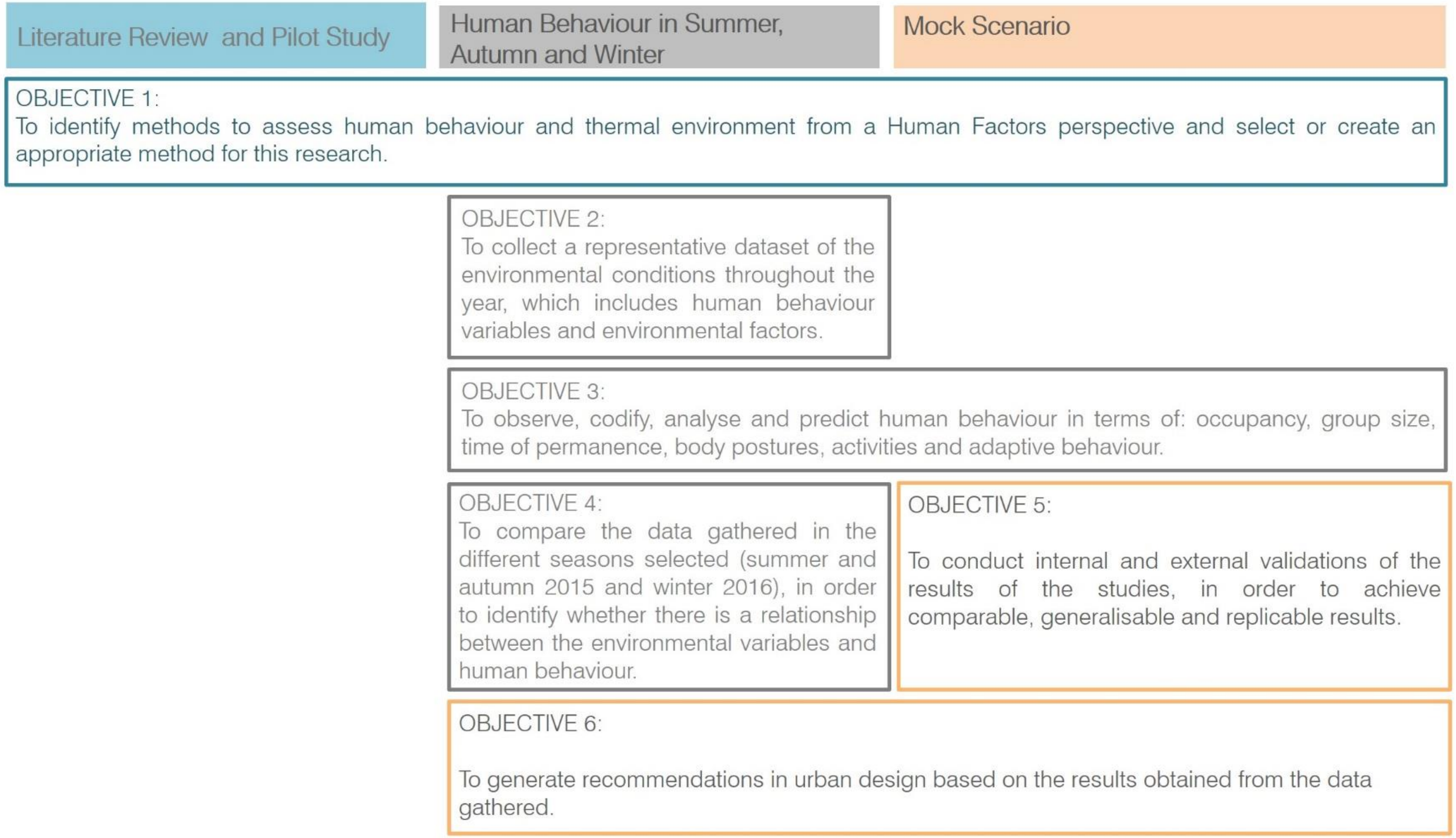


Figure 6 - Activities conducted to achieve the research aims

The research consisted of five field studies: one pilot study, three seasonal data collection studies and one validation study or mock scenario.

The Pilot study was conducted in autumn 2014 using various methods identified in the literature, including subjective and behavioural methods. The study included questionnaires, environmental measurements, video recordings and direct observation by the researcher, aided by a field diary. This study allowed the creation of a coding scheme to assign parameters to interpret the behaviours observed in the videos. The coding scheme was validated with an inter-reliability test, as this scheme needed to be used for the analysis of the seasonal studies and mock scenario.

The seasonal data collection studies were conducted in summer and autumn 2015 and winter 2016. The methodology applied was behavioural methods, including environmental measurements, video recordings and direct observation by the researcher, aided by a field diary. The data collected was analysed using correlations between environmental factors and human behaviour, and then, the higher correlations were selected for further analysis. These correlations were then used in multiple regression models and survival analysis in order to predict human behaviour according to the environment. The results were validated by splitting the dataset and running a second analysis with the retained sample.

Finally, the validation study or mock scenario consisted of constructing an outdoor seating area, which was available for public use during three weeks in summer 2016. The set was made of different types of benches and stools equipped with pressure sensors, along with wind barriers and a parasol which could be modified during the study in order to produce different microclimatic conditions. During the study, video recording was taken along with environmental measurements and direct observation of the researcher, aided with a field diary. The data analysis consisted in the validation of the equations made with the data gathered in the main studies conducted in summer, autumn and winter.

The general methodology was based on behavioural methods which aimed to derive predictions of human behaviour and their relationship with the thermal environment. The reason for this is that previous studies presented lack of detail, standardisation and reliability in the research field regarding observational studies of users in outdoor public spaces. Therefore, this research aimed to contribute to the field of study of human behaviour in outdoor public spaces according to the thermal environment by using Ergonomics and Human Factors methods.

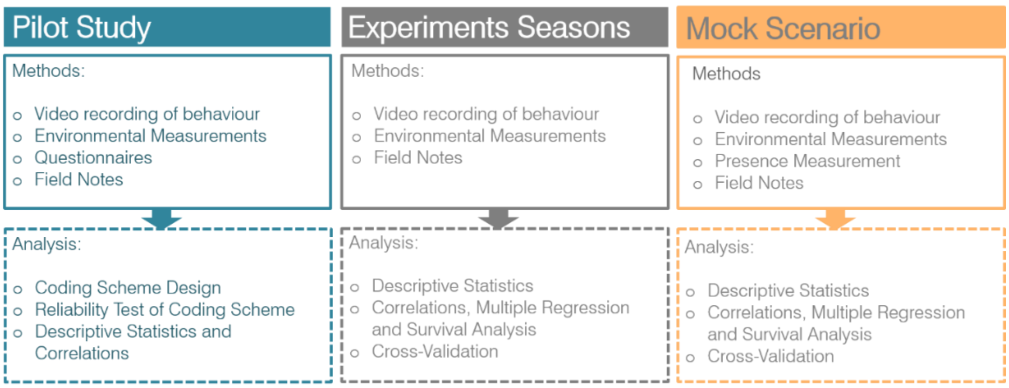


Figure 7 - Methods and analysis used during the PhD

3.7. Methodology for Seasonal Studies

This section describes the general aspects of the methodology used in the seasonal studies of autumn, summer and winter at Trinity Square (Chapters 5, 6, 7 and 8). The general methodology was created upon the findings in the Pilot Study (Chapter 4). The All-seasons study (Chapter 8) has an additional methodology to analyse additional behaviours across the seasons.

Population and Time Sample

This research aimed to observe social and individual behaviours of people while using an outdoor public square, in order to determine the influence of the thermal environment and whether a pattern could be observed which could lead to the prediction of these behaviours in similar circumstances. Therefore, the analysis conducted included two ways of evaluating the data: by 'Aggregates' and by 'Individual Counts'. This means that the data was collected by volume in the space and by person (Gehl Institute, 2017). These two types of analysis were called Individual Behaviour and Social Behaviour.

Only people remaining in Trinity Square were recorded, in Figure 8 are marked in orange the users selected for the Individual Analysis. The criteria to include users in the analysis were: they remained in the evaluated area, the video captured their permanence from the beginning to the end, they were not just passing through the square, and they were not at the restaurants surrounding the square. These criteria were defined to identify the users that attended to the square with the aim of using this open public space.

Figure 8 - People passing and remaining - Social and individual analysis

Location

The place selected for this study was Trinity Square, located in Nottingham city centre. This was selected because it has the required characteristics for an outdoor public space and can be considered similar to other squares of many European cities. The literature defines that the places to conduct these kind of studies must have 'Routes' and 'Resting' areas (Gehl & Svarre, 2013; Nikolopoulou et al., 2001) or places to sit and walk in order to have a wide range of activities.

Figure 9 - Top view of Trinity Square, Nottingham

Another important characteristic of Trinity Square is that it is not the main square of the city but is still located in the city centre. This contributes with the generalisability of the results, as there are fewer chances of space-specific activities occurring in the place, as there would be in the main square of the city. Trinity square is located in a pedestrian zone surrounded by commercial buildings, which is a common characteristic from medium to small size squares of European countries. The square has different types of furniture allowing diverse body postures from laying down to leaning or standing, which permitted the evaluation of a wide range of body positions and activities. The size of the square also permitted the collection of data using one camera from an angle which could register all the public area (Figure 10). This characteristic was important because the researcher had to pay attention to the equipment installed as well as taking notes in the field diary. In addition, more cameras would significantly increase the time of video analysis.

Figure 10 - 3D View of Trinity Square and Location of Equipment

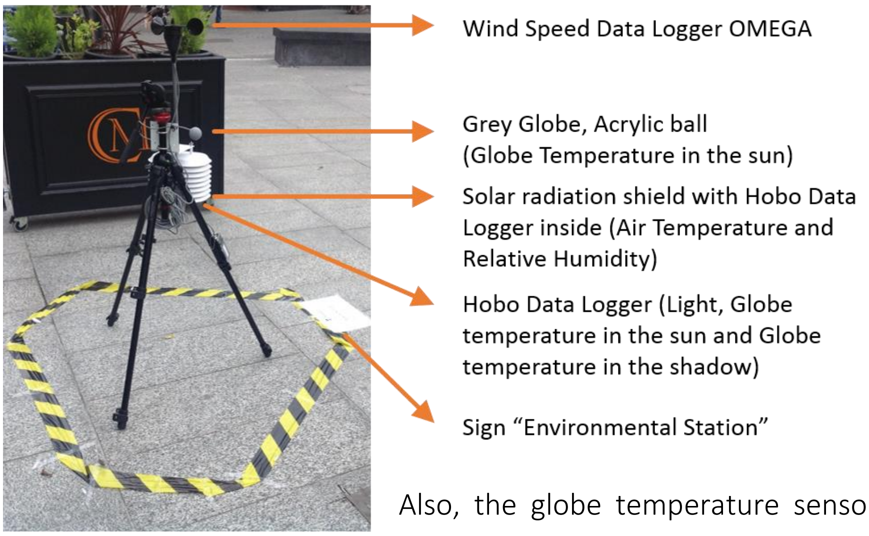
Equipment

Video Camera: HD Samsung. The video camera quality was improved after the pilot study as this study showed that low quality of video affected the accuracy and speed of the video analysis and coding.

Figure 11 - Left: Camera view of Trinity Square. Right: Researcher setting the camera position

Environmental Station: A portable microclimatic environmental station similar to the one described in the *Pilot Study* was used for the studies during three seasons (Figure 12).

The environmental station consisted of a *Wind Speed Data Logger OMEGA* to record the air velocity (m/s) and two *Hobo Data Logger*: one of them was protected by a shield and recorded the air temperature (ºC) and relative humidity (%), the second sensor was protected from direct solar radiation but it was facing to the square to measure the illuminance level variations (lx), simultaneously it measured the globe temperature using grey globes (one exposed to the sun and the other one protected from the solar radiation).



Also, the globe temperature sensor was

Figure 12 – Portable Environmental Station

modified using a 38 mm acrylic table tennis ball painted in grey instead of the Vernon Copper ball, following the successful explorations made by Nikolopoulou et al. (1999) and Thorsson et al. (2007) which suggested this globe thermometer as a more efficient way of measuring the globe temperature with a low cost. For the studies during summer, autumn and winter, two grey acrylic balls were placed in the environmental station to measure the globe temperature in the sun and shadow. According to Nikolopoulou et al. (1999), the acrylic table tennis ball improves the time of response of the measurements in comparison to the Vernon globe, from 20 minutes to 4 minutes of response. The measurements were conducted in compliance with the ISO Standard 7726 (2001). The sensor and wind speed meters were programmed to record data every minute and all the devices were attached to a tripod as showed in Figure 12.

The environmental station was placed in a spot which allowed measuring environmental data at head height of the users, without interfering with the behaviour of the users.

Field Diary: The researcher carried a diary to register hours of installation and the time of start and finish. Special events were also recorded: noises, crowds, incidents, or any atypical circumstance that could affect the behaviour of people. Additionally, observable characteristics of the behaviours were recorded in order to support the data analysis. Figure 13 illustrates some of the notes taken during the observation.

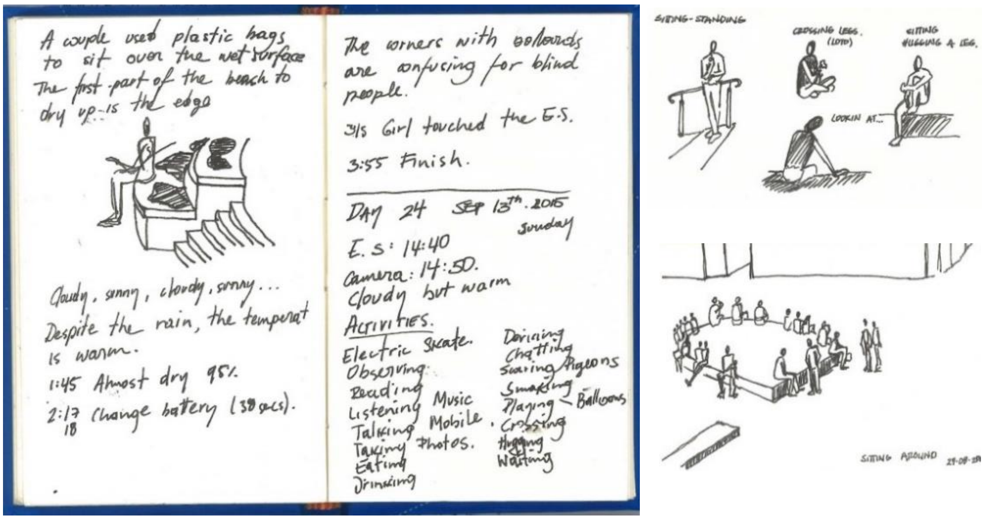


Figure 13 – Fieldwork diary notes

Environmental Measurements

The environmental station placed in the public square was set to measure every minute. A total data set of 1260 minutes obtained during each season was classified for analysis. The sample corresponds to three hours of video recording every day between 10:30 am and 6:30 pm for seven days. The environmental variables measured were: air temperature (Ta, ^{o}C), relative humidity (rH, %), globe temperature in the sun (Tg_sun, ^{o}C), globe temperature in the shadow (Tg_shad, ^{o}C), wind speed (Va, m/s) and illuminance (lx). The mean radiant temperature (Tr_sun and Tr_shadow, ^{o}C) was calculated following the method specified by the ISO Standard 7726 (2001) with the equation:

$$Tr = \left[(Tg + 273)^4 + \frac{1.1 * 10^8 * Va^{0.6}}{\varepsilon g * D^4}(Tg - Ta)\right]^{1/4} - 273$$

where,

- *Tr* is the mean radiant temperature, ^{o}C
- Tg is the globe temperature, ^{o}C

- Va is the air velocity, m/s
- εg is the emissivity of the globe (grey colour 0.95) (Nikolopoulou et al., 1999)
- D is the diameter of the globe (38 mm)

Environmental Conditions at Trinity Square

In order to measure the differences between the microclimatic conditions at different spots of the square, independent measurements were conducted placing the sensors in five points of Trinity square (Figure 14). This measurement aimed to identify the variability and uniformity of the variables measured at Trinity Square. The measurements were conducted on April 19th of 2018 between 2:00 pm and 3:00 pm. A sunny day with no clouds was selected in order to have uniformity regarding solar radiation.

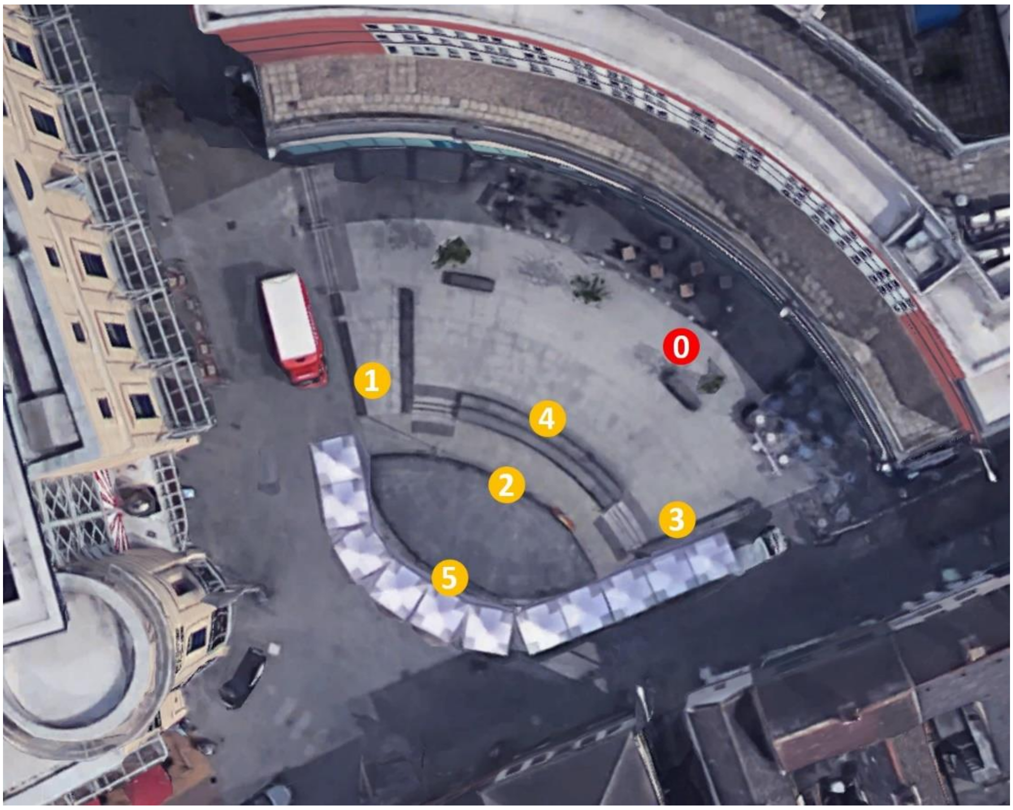


Figure 14 – Plan view of location of Environmental Station at different points

The data was collected by placing the environmental station in five different points of Trinity Square in addition to the original location. The station measured for five minutes to stabilise the measurements and then record the following five minutes. After that period the station was moved to the next location.

Table 3 presents the mean of the five minutes recorded. It is observed that air temperature, relative humidity, globe temperature in the sun and globe temperature in the shadow presented very small variations, while wind speed and light were more variable.

Air temperature presented the highest variation, but it only reached a maximum difference of +1ºC with respect of the original location. Relative humidity presented +/- 2%, the globe temperature in the sun +0.3ºC, -1.6ºC, the globe temperature in the sun +/- 0.7ºC, the wind speed + 0.437 m/s and the illuminance – 6244 lx.

Table 3 – Average Environmental Measurements per Point

	Ta, °C	*rH, %*	*Tg_sun, °C*	*Tg_shadow, °C*	*Va, m/s*	*Light, lx*
0	26.8	42	35.8	29.6	0.239	15544
1	27.8	40	35.5	30.3	0.451	10831
2	26.8	42	34.2	28.9	0.676	11445
3	26.6	44	34.7	28.9	0.302	9911
4	26.8	43	36.1	30.1	0.281	11643
5	26.8	43	36.1	29.0	0.643	9300

Acronyms: air temperature (Ta), relative humidity (rH), globe temperature_sun (Tg_sun), globe temperature_shadow (Tg_shadow), wind speed (Va), illuminance (Light)

The variation of the illuminance can be explained by the fact that this phenomena depends on the light reflected from the surfaces and the visual field captured by the sensor. In the case of Trinity Square, the seating area and some areas of the floor are dark grey, while others are light grey. Therefore, after varying the position of the environmental station, the light measurements can be reduced when placing the environmental station close to dark surfaces or increased when placed in light-coloured surfaces. The lowest illuminance was captured in point 5 where the surface is dark grey and the highest illuminance was capture in the original location where the surface is light grey. Similarly, the wind speed presented some variation, with points 2 and 5 having the higher means. This variations could obey to the fact that this area has a wind stream coming from in-between buildings and is therefore affected by them.

Exclusion Criteria

The main exclusion criteria were rainy days. According to Gehl & Svarre (2013), people avoid sitting in a wet bench and refuse to remain in a place during rain. This studies followed the exclusion used by Thorsson et al. (2004): “days on which precipitation occurred were excluded from the analysis” (p. 150).

Days with public events were also excluded. During the study some unusual activities affected the normal use of the square, for example: a charity event with a chorus singing in the middle of the square, a giant Christmas deer installation in winter, food festival tents, and square closures with fences. These days were recorded but excluded from the analysis because they affected the patterns of use of the square by modifying the normal attendance and the permanence and use of the furniture and the space.

Technical problems are part of the data gathering in outdoors. Therefore, when the data collected was incomplete due to, for example, sensors or video camera malfunction, the day was also excluded from the study. To mention a few examples, in a couple of sessions the anemometer did not start recording and did not measure the environmental conditions. On other occasions, the batteries of the camera did not last long enough to record the complete session.

Duration and Season

The data collection was conducted for four weeks in summer, from the 21st of August to the 21st of September 2015; autumn, from the 24th of October to the 21st of November 2015; and winter, from the 26th of January to the 2nd of March 2016. The weeks were selected according to the historic data of the temperature variation in Nottingham. Figure 15 highlights the periods selected for the studies in summer, autumn and winter (Met Office). The aim was to capture a wide range of environmental variation for each season.

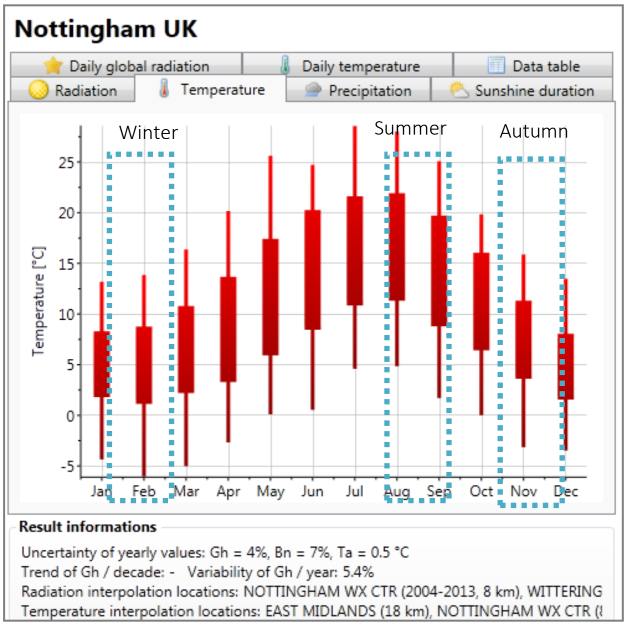


Figure 15 – Box plot annual temperatures in Nottingham and seasons evaluated. Source: Meteonorm 7

Announcing the study

Posters were placed next to the video camera and the environmental station announcing to the people that a study was taking place in that square and that video recordings were being taken. The posters contained the researcher's contact details, in case any participant wanted their data to be removed from the analysis.

The researcher contacted the authorities of Nottingham City Council, who confirmed that the study, including video recording, could be done in the public spaces of the city. The researcher also contacted the Nottinghamshire Police to inform them about the study.

Ethics Approval

This study was approved by the Ethics Committee from the Faculty of Engineering from the University of Nottingham. During the application, the researcher confirmed that all the information gathered would be anonymised by blanking the faces out. Additionally, the experiment did not commenced until the local authorities were aware of the data collection.

Procedure

The procedure to collect the data was the same every day:

1. Configure and position the environmental station 10 minutes before the starting time of the study. This allowed the sensors to stabilise their measurements according to the real conditions of the environment. The environmental station was located at head height of a sitting person in an area where the environmental conditions were representative of a person sitting in the square, but without obstructing the normal use of the space. It was located in the same place for all the recording periods.
2. The video camera was placed in a hidden discrete position. Its location was the same for every day of the study.
3. The recording sessions had a minimum duration of three hours. The exact moment when the camera started and stopped was recorded in

the Field Diary in order to synchronise the video files with the data loggers.

4. During the recording period the researcher was located in a place outside the evaluated area, supervising the study and taking notes in the Field Diary.
5. Once the session finished, the researcher removed the environmental station and camera from the area of study.
6. As soon as the data collection was completed, the researcher uploaded the videos into Observer XT 10 to be coded. The videos were codified with the coding scheme of behaviours designed and tested during the Pilot Study.

Coding Scheme

The video analysis was conducted using Observer XT 10 which is software that allows registering and classifying the human behaviour and comparing it with external data, such as environmental measurements. This software permitted coding the information per individual. This methodology was developed during the Pilot Study and will be explained in Chapter 4.

Multiple Regression

In order to analyse the social behaviour in conjunction with the environmental measurements, a multiple regression analysis was performed. This analysis aimed to identify the environmental variables that were the best predictors of the variation in each of the identified behaviour. "The multiple regression is a statistical technique that allows us to predict someone's score on one variable on the basis of their score on several other variables" (Brace et al., 2000, p. 206). Using this technique, various factors called independent variables, are analysed in order to determine their influence over the dependant variables. In this research the independent variables are the environmental factors and the behaviours are the dependant variables.

The process to analyse the data had different steps. The first step consisted of preparing the data to perform a cross-validation at the end of the analysis. This included a data split where the bigger percentage of the data was used to generate the equations and the rest of the data was reserved to test the results obtained. Secondly, a Spearman's rho correlation analysis was performed to identify the independent variables presenting correlation with the behaviours. The third step consisted of selecting the best correlated independent variables to predict each behaviour. These variables were used to perform the multiple regression analysis. Finally, the predictions obtained for each behaviour were tested against the data that was reserved for the cross-validation.

Survival Analysis

Survival analysis "…has not yet been used in our context, but has long-since been applied in reliability studies and biomedical research"(Frederic Haldi & Robinson, 2009, p. 2381). This method is currently used to prove or disprove the efficiency of a medical treatment, to understand risk factors, to evaluate the reliability of an equipment, or monitoring social phenomena (Aalen et al., 2008). Survival analysis is made by modelling the time until a failure or event occurs. By event it is understood death, divorce, cancer diagnosis or any other event under research (Aalen et al., 2008). Consequently, in this research it was used to evaluate the duration of the behaviour by defining the failure event as the moment when the person ended the activity. For instance, the time a person spent in the square under certain conditions and decided to leave.

3.8. Chapter Summary

This chapter introduced the methods used to study human behaviour in outdoor urban spaces. The reasons for choosing the corresponding methodology are explained, based on the literature review conducted. The chapter also presented the contribution to the field in terms of guaranteeing the quality of the data and results by implementing methods to assess the validity reliability, generalisability and ethics. Finally, the methodology applied in the seasonal studies conducted in Trinity Square is presented.

4. Pilot Study

4.1. Chapter Overview

This chapter presents the results obtained in the Pilot Study conducted in summer 2014. This experiment aimed to test different methods, adapted from the literature review that could be used to evaluate human behaviour and environmental factors. The study was conducted in an outdoor seating area of the University of Nottingham over four weeks. Three random days per week were selected, and recording took place for approximately two hours during lunch time. The experiment included environmental measurements, video recordings and surveys of the users of the seating area. In total 189 people were observed and 27 completed surveys were gathered. The results and discussions are presented in three sections: environmental measurements, observations and surveys. The discussion section highlights the required improvements for the tools and methods to be used in the following studies.

4.2. Introduction

The literature review (Chapter 2) showed that a diversity of methods have been used to evaluate human behaviour in the outdoors. As reported in the General Methodology (Chapter 3), previous studies have approached the study of human behaviour in outdoor urban spaces using different methodologies. Four methodologies were identified: Behavioural methods, Subjective methods, Objective methods, and Modelling methods. The Pilot Study tested the two methodologies which were better suited to the aim of the present research considering the challenges of measuring human behaviour which cannot be completely quantified, along with environmental data, which can be accurately measured.

This chapter will present the findings of the Pilot Study conducted in summer 2014, as a preliminary study to test the methodology and refine the structure for the main studies to be conducted in autumn, spring 2015 and winter 2016. Previous studies regarding human behaviour in outdoor spaces had demonstrated a strong relationship between the weather and people's behaviour. As mentioned by Parsons (2015a) the body responds in a dynamic way to environmental stimuli. For instance, Nikolopoulou et al. (2001) identified the 'adaptive actions' taken by users in outdoor spaces according to the increase or decrease of the globe temperature. These actions include: modification of clothing, position, posture or consumption of cool or hot drinks. Likewise, the studies conducted by Jan Gehl in Copenhagen indicate that gait speed is higher in winter than in summer, and additionally, that pathway taken by the pedestrian is more 'goal-oriented' in the coldest season (Gehl & Svarre, 2013).

The two methods chosen for the Pilot Study were therefore Subjective and Behavioural as explained in the General Methodology (Chapter 3). The first is based on the user's perception, whilst the second focuses on observational techniques where the researcher observes the behaviour of people rather than asking the participants their input. As noted by Wilson & Sharples (2015), the study of Human Factors can be allocated in-between a qualitative and quantitative continuum, which means a mixed methods approach. However, there is a gap in the study of human behaviour in outdoor urban spaces using reliable methods that can be used to understand and measure the influence of the environmental variables in human behaviour.

The aim of this research was to assess the methods to study patterns of human behaviour when people are exposed to different environmental conditions in an outdoor seating area. The specific objectives of this experiment were: 1. to explore different methods previously used in observational and subjective studies of human behaviour in outdoor spaces; 2. to test the methodology designed to collect subjective data, video recording and environmental measurements; 3. to gather data of human behaviour; 4. to evaluate the process of data analysis; and 5. to adjust the methodology to be used in the next experiments.

4.3. Method

The methodology chosen includes three different methods: 1. Observation: the experiment was recorded and the videos were analysed after the data collection, 2. Environmental Measurements: the study included readings from a portable weather station to register the environmental conditions of the location every minute (air temperature (ºC), relative humidity (%), light level variations (lx), globe temperature and wind speed (m/s)) and 3. Surveys: the researcher implemented surveys to the attendants of the observed location after the recorded periods.

Location

The experiment was conducted in an outdoor seating area at the University of Nottingham – Park Campus. This was outside of the canteen of Coates Building in the Faculty of Engineering, Figure 16. It was selected because of its accessibility and the availability of places to safely install the equipment: a camera and an environmental station. The seating area selected had the required characteristics of similar spaces from the literature: spaces to circulate or 'Routes' and spaces to remain or 'Resting areas' (Gehl & Svarre, 2013; Nikolopoulou et al., 2001). These characteristics were included during the Pilot Study to determine what conditions the choice of location should meet for the further seasonal studies.

Figure 16 - Outdoors seating area Coates Building, University of Nottingham

Dates and Time

The experiment was conducted over four weeks of August and September 2014 which is out of term time in the University. Three random days per week were selected and an extra day was added to the last week as a backup date.

Prior to the start of the experiment, the researcher visited the location of the study, and identified that lunchtime was the peak hour of use of the seating area. This aided choosing the times and length of the recordings. The sessions every day consisted of a minimum of one and a half hours of video recording between 12:00 and 15:00 hrs, this time was extended until the last person entering during that time lapse left the place. This means that the duration of the study varied each day according to the length of the presence of people in the location.

The exclusion criteria for the data collection were weekends and bank holidays since the use of the space was conditioned by the operation of the university buildings. Rainy days were also excluded because there is evidence that people avoid sitting in a wet surface and generally refuse to remain in a place during rain (Gehl & Svarre, 2013). Table 4 presents the dates selected for the recordings, excluding weekends and bank holidays.

Table 4 - Dates of data collection

AUGUST 2014							*SEPTEMBER 2014*						
Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
				1	2	3	1	2	3	4	5	6	7
4	5	6	7	8	9	10	8	9	10	11	12	13	14
11	12	13	14	15	16	17	15	16	17	18	19	20	21
18	19	20	21	22	23	24	22	23	24	25	26	27	28
25	26	27	28	29	30	31	29	30					

Equipment

The equipment used included a video camera, an environmental station and stationary. These are detailed below.

Video Camera: A basic video camera (Samsung Handycam) was used. It was placed in a manner that it did not represent a disturbance for the users of the seating area (Salazar, 2010; Whyte, 2009). At the same time, the camera was located in a position that allowed registering the arrival, stay and departure of the users (Figure 17).

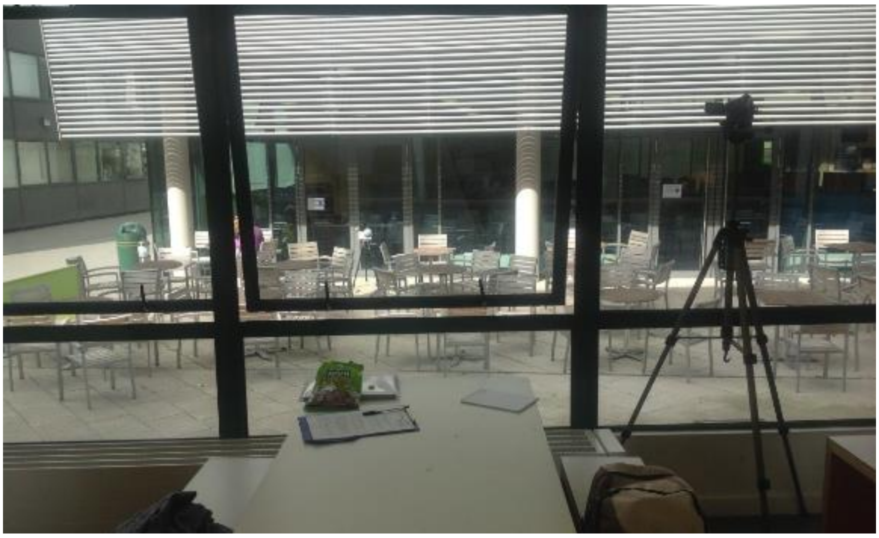


Figure 17 - Video camera and researcher's location

Environmental station: A portable microclimatic environmental station was assembled in accordance with the British Standard Ergonomics of the thermal environment – Instruments for measuring physical quantities ISO 7726 (2001). The station was placed in the evaluated space in a zone where the environmental conditions were representative of a person sitting, but without obstructing the normal use of the area (Figure 18). In order to capture the conditions perceived by the users, the environmental station was placed at head height of a person sitting.

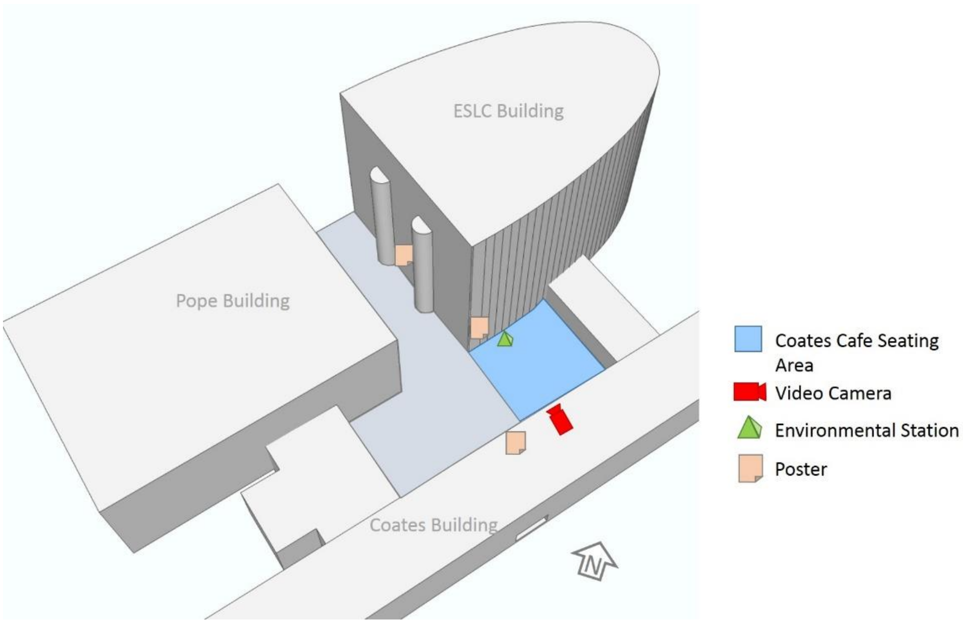


Figure 18 - 3D view equipment location and recording area

The globe temperature sensor was exposed to direct solar radiation. Therefore, the environmental station was placed in a sunny spot of the seating area. It was also intentionally placed on the border of the studied area in order to minimise the impact on the behaviour of people.

The environmental station was made of a Wind Speed Data Logger OMEGA to record the air velocity (m/s) and a Hobo Data Logger which measured and recorded the air temperature (°C), relative humidity (%) and globe temperature (°C). The latter was measured through a grey globe with an air temperature sensor inside.

The measurements were conducted in compliance with ISO 7726 (2001). The sensor and wind speed meters were programmed to record data every minute. The data loggers were attached to a tripod as showed in Figure 19.

Figure 19 - Environmental Station

Survey to assess subjective perception: In Environmental Ergonomics, the use of surveys is classified as a subjective method (Parsons, 2015b) where the person reports their experience according to the environmental conditions. This method is "… particularly suited to assessing psychological responses such as comfort and annoyance" (Parsons, 2015b, p.644).

The survey used in this study included questions related to past (Figure 20), current (Figure 21) and future (Figure 22) conditions and perception of the users regarding the environmental conditions. The survey was designed based on the most relevant works regarding comfort and behaviour found in the literature review.

Outdoors Survey

The aim of this research is to identify and classify patterns of the human behaviour in the outdoors.

All information provided will be treated as confidential and individual identities won't be revealed.

Participation is voluntary. **You do not have to answer any question you do not wish to**, and you can withdraw at any point without giving a reason why.

If you have any question or concerns about the study, please contact:
Julie Waldron
julie.waldron@nottingham.ac.uk

Participant Information

1. What is your country of origin? ____________
2. What is your age? ____________
3. … and your sex? O Male O Female
4. What is your occupation? ____________

Remember that all information is optional

Height ______ *(units)* ______

Weight ______ *(units)* ______

This will be used to investigate the influence of the body-size on human behaviour

Prior Activities Information

5. Where were you 20 minutes before you came here? *Please Tick and Describe*

☐	Outdoors: *Please Describe*
☐	Indoors: *Please Describe*

6. Which was your main activity 20 minutes prior to staying in Coates (excluding walking to destination)? *Please Tick*

☐	Running/Cycling
☐	Cycling
☐	Walking Fast
☐	Walking Normal
☐	Walking Slow
☐	Standing, medium activity (shop assistant, domestic work)
☐	Standing, light activity (shopping, laboratory, light industry)
☐	Sedentary activity (office, dwelling, school, laboratory)
☐	Seated Relax
☐	Sleeping
☐	Other: *Please Describe*

7. How long did it take you to walk to Coates?

________ *(Time in minutes)*

8. How would you describe the conditions in your activity prior to sitting in Coates? *Please circle each scale*

Air Quality:

Dry	1	2	3	4	5	6	7	Humid
Fresh	1	2	3	4	5	6	7	Stuffy
Odourless	1	2	3	4	5	6	7	Smelly

Temperature:

Hot	1	2	3	4	5	6	7	Cold
Comfortable	1	2	3	4	5	6	7	Uncomfortable

Figure 20 - 'Prior activities' section. Survey to assess subjective perception

Current Environmental Conditions

8. How would you describe the conditions <u>when sitting</u> in Coates? *Please circle each scale*

Temperature:

Hot	1	2	3	4	5	6	7	Cold
Comfortable	1	2	3	4	5	6	7	Uncomfortable

Sun:

Sunny	1	2	3	4	5	6	7	Overcast

Air:

Still	1	2	3	4	5	6	7	Draughty
Dry	1	2	3	4	5	6	7	Humid
Fresh	1	2	3	4	5	6	7	Stuffy
Odourless	1	2	3	4	5	6	7	Smelly

Natural Light:

Light	1	2	3	4	5	6	7	Dark

Noise:

Noisy	1	2	3	4	5	6	7	Quiet

Cleanness:

Clean	1	2	3	4	5	6	7	Dirty

Safety:

Safe	1	2	3	4	5	6	7	Unsafe

Accessibility:

Accessible	1	2	3	4	5	6	7	Inaccessible

Aesthetic:

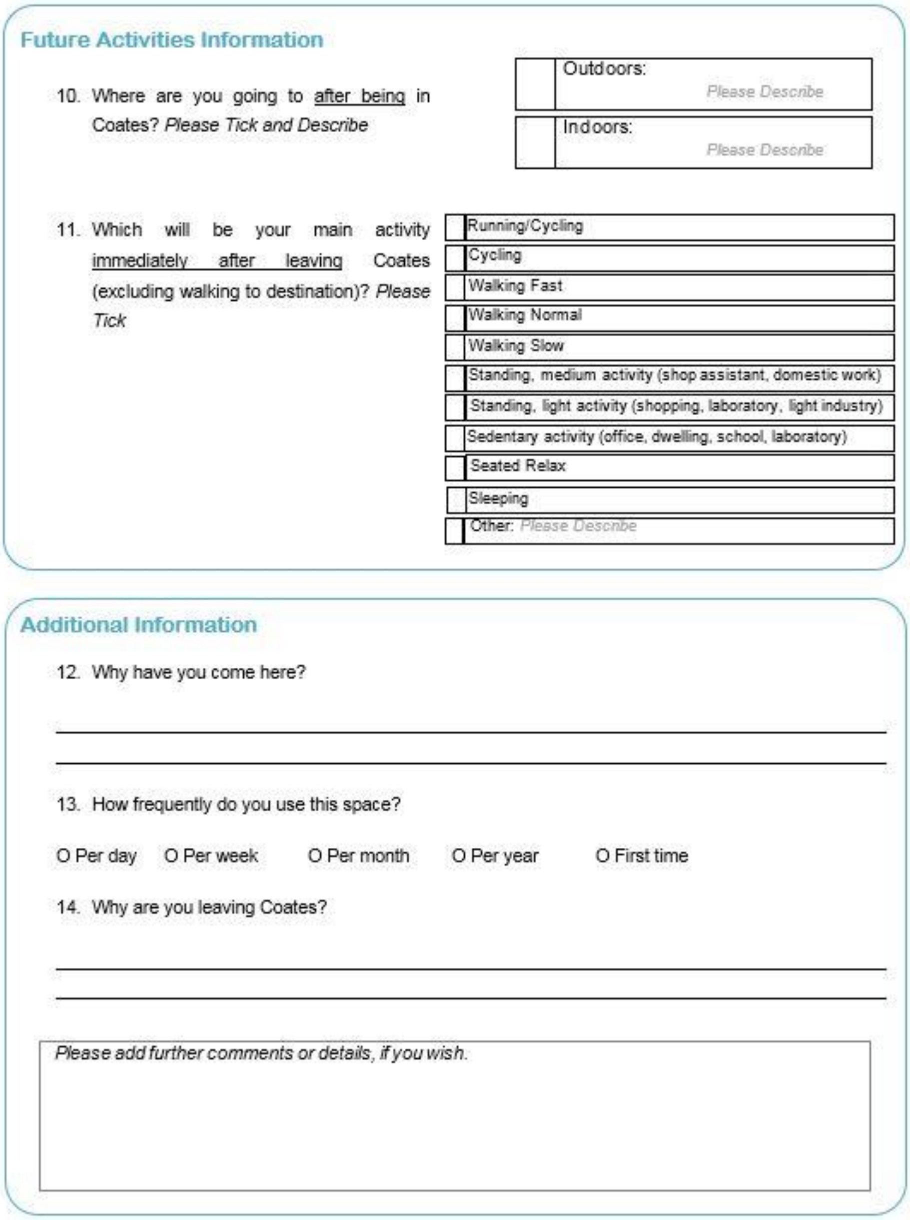
Attractive	1	2	3	4	5	6	7	Unattractive

9. <u>When staying</u> in Coates, how did you feel? *Please circle*

Comfortable overall	1	2	3	4	5	6	7	Uncomfortable overall

Please provide comments to help us understand particularly high or low rates

Figure 21 - 'Current Conditions' survey to assess subjective perception



Future Activities Information

10. Where are you going to <u>after being</u> in Coates? *Please Tick and Describe*

- [ ] Outdoors: *Please Describe*
- [ ] Indoors: *Please Describe*

11. Which will be your main activity <u>immediately after leaving</u> Coates (excluding walking to destination)? *Please Tick*

- [ ] Running/Cycling
- [ ] Cycling
- [ ] Walking Fast
- [ ] Walking Normal
- [ ] Walking Slow
- [ ] Standing, medium activity (shop assistant, domestic work)
- [ ] Standing, light activity (shopping, laboratory, light industry)
- [ ] Sedentary activity (office, dwelling, school, laboratory)
- [ ] Seated Relax
- [ ] Sleeping
- [ ] Other: *Please Describe*

Additional Information

12. Why have you come here?

13. How frequently do you use this space?

O Per day O Per week O Per month O Per year O First time

14. Why are you leaving Coates?

Please add further comments or details, if you wish.

Figure 22 - 'Future Conditions' survey to assess subjective perception

The studies developed for RUROS project about thermal comfort in outdoors (Nikolopoulou et al., 2004) and the surveys designed for the research of human comfort in indoors conducted by (Levermore & Meyers, 1996), helped to structure the type of questions. In addition, the importance of understanding the thermal history of people and their influence on current behaviour, was based on other authors (e.g. Höppe, 2002; Nikolopoulou & Steemers, 2003; Robinson, 2011).

Ethical Considerations

This study was approved by the Ethics Committee of the Faculty of Engineering from the University of Nottingham. Additionally, the researcher obtained permission from the Faculty of Engineering Research Manager to use the Coates canteen outdoors seating area for the study.

Procedure

The ethical approval and consents from the University of Nottingham were obtained prior the commencement of the experiment. The researcher placed the poster at the spot marked in Figure 10 announcing that video recording was taking place in that area.

The environmental station was placed at head height of a sitting person in the area defined where the environmental conditions were representative of a person sitting, but without obstructing the normal use of the space. The location of the environmental station was the same for the rest of the experiment. A warning sign was attached to the environmental station, indicating that a study was taking place and that environmental measurements were being recorded. The environmental station was placed at least 15 minutes before starting the recording, to allow the data loggers stabilise with the microclimatic conditions.

The video camera was placed in an area which did not disturb the users. Its location was the same for all the days of the study. When the video recording started, the starting time was recorded in the fieldwork diary.

According to ethical considerations, a visible poster was placed beside the recording area to inform the users of the place that a study was being conducted there and that video recording was taking place as part of it. The poster explained the purpose of the study and contained the contact details of the researcher in case someone wanted to be excluded from the recordings made.

During the recording period, the researcher sat near the camera. The researcher took notes of particular events which could explain abrupt changes in the behaviour or the environmental data (e.g. when a curious person touched the data loggers). The researcher did not intervene in the area of study, unless it was necessary to rearrange the direction of the environmental station or to prevent users affecting the measurements by touching the sensors.

The researcher approached users that were leaving the place to ask them to fill in the surveys. Since all users that remained were apt to be considered, the selection criteria depended on the availability of the researcher to collect one survey at the time. Most of the users declined from filling the survey due to after-lunch commitments. Users were only asked to complete the survey once; they were not considered for surveys when revisiting the area on subsequent days.

According to ethical considerations, the participants who agreed to fill in the surveys had the opportunity to first read the ‘Participant’s Information Sheet’ which contained detailed information about the experiment. They then signed a ‘Consent Form’. These documents explained the purpose of the experiment, data management and stated that they were able to withdraw the study at any time (Sharples & Cobb, 2015).

When the user who last entered into the evaluated are within the evaluated period had left the area of study, the camera was stopped and the time was recorded in the fieldwork diary. Once the session ended, the researcher removed the environmental station, the camera and posters from the area of study. The researcher made a mark of the position of the equipment’s to position them in a similar location in the following session.

The environmental data and video recordings were uploaded into Observer XT 10 for analysis.

Sample Size

The data sample consisted of two sets: the sample from the video recordings and the sample from the surveys.

Observation: 165 people, 99 male and 66 female, were video recorded. Only those whose permanence in the place was entirely captured in the video were considered for the purposes of this study. Since the seating area is a central place of the university campus, it can be visited by different users, many of whom return to this place on various occasions every week. Nevertheless, for the purposes of the observation, frequent users were analysed in the same manner as new users. In addition, people passing through the seating area were excluded.

Surveys: 27 people, 12 male and 15 female, completed the survey. They had a mean age of 31 years (SD = 10.6). The procedure to select the sample was randomly inviting people that were recorded from the beginning to the end of their permanence. The sample size is the product of asking as many participants as possible from the attendants during the 13 sessions. Contrary to the video recording sample, in this gathering the frequent users were only included once. The survey took approximately 10 minutes per participant.

4.4. Results

4.4.1. Environmental Measurements

This section presents the microclimatic conditions measured during the Pilot Study. Table 5 presents the descriptive statistics of the environmental data collected during the four weeks.

Table 5 – Descriptive statistics environmental measurements

Environmental Station (N = 1336)

	Minimum	Maximum	Mean	Std. Deviation
Air Temperature, Ta, ºC	17.2	25.7	20.5	2.1
Relative Humidity, rH, %	35	85	61	12
Globe Temperature, Tg, ºC	17.3	34.8	23.7	4.5
Air Velocity, Va, m/s	0	0.232	0.011	0.027
Calculated Mean Radiant Temperature, Tr, ºC	17.3	51.8	25.8	6.4

As can be observed in Table 5, the measurements of air temperature (Ta), relative humidity (rH), globe temperature (Tg) and radiant temperature (Tr) were diverse, covering a wide range of microclimatic conditions. For instance, the air temperature oscillated between 17ºC and 25ºC and the humidity recorded varied within 35% and 85%. Conversely, the air velocity only varied between 0.01 and 0.23 m/s and almost 60% of the data collected was 0.000 m/s. This measurement corresponds to the conditions of the seating area, which was an enclosed area protected from the wind by surrounding buildings.

Figure 23 and Figure 24 present the bar charts of the binned distribution of the air temperature, relative humidity, globe temperature, mean radiant temperature and air velocity.

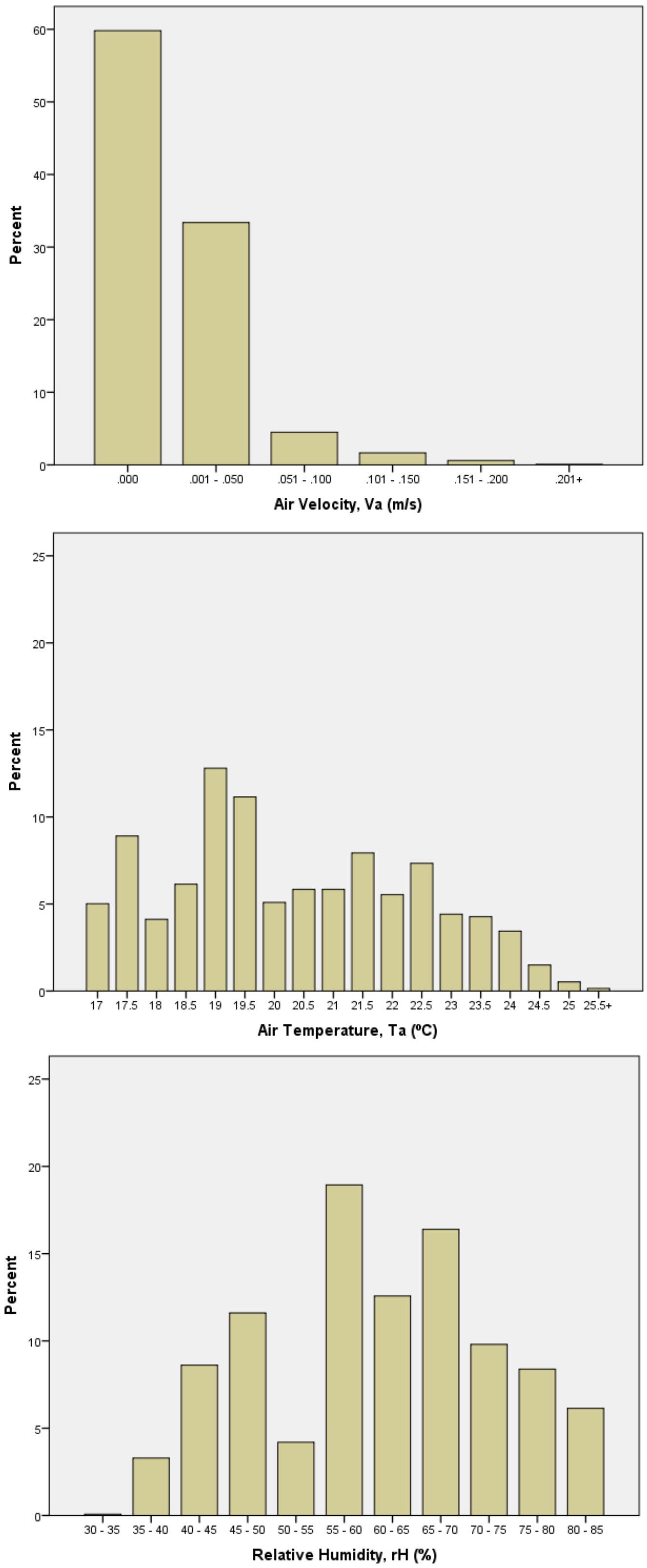


Figure 23 – Percentage distribution air velocity, air temperature and relative humidity.

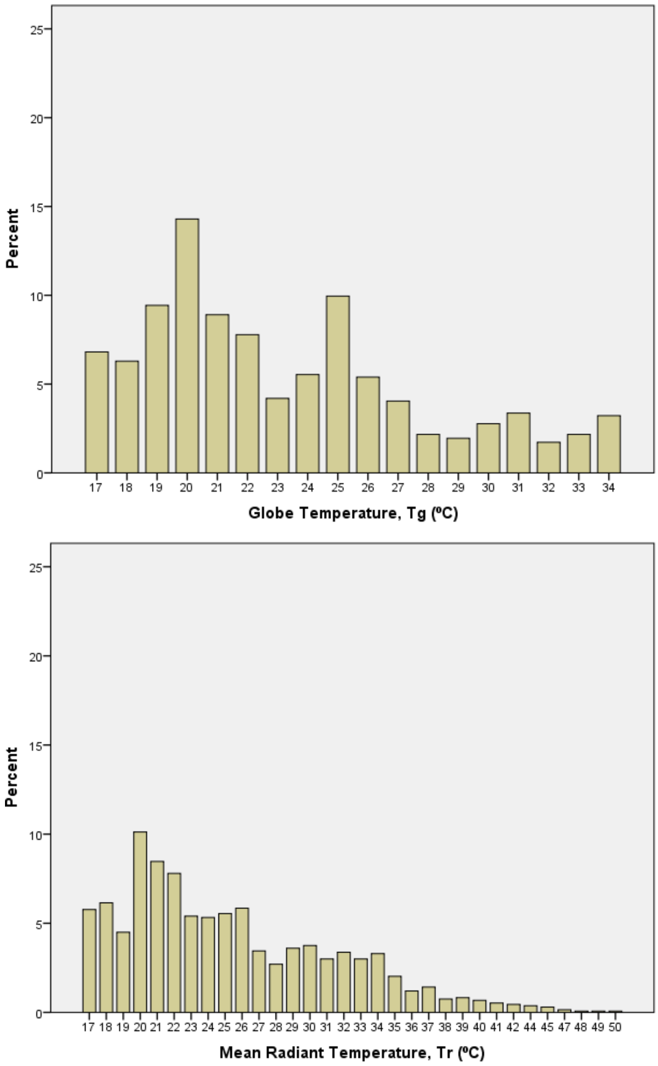


Figure 24 – Percentage distribution globe temperature and mean radiant temperature

Table 6 presents the correlation analysis performed between the environmental variables. The analysis was conducted by using the data recorded per minute during the recorded periods. The highest correlations found were Globe Temperature (Tg) and Air Temperature (Ta) ($r = .918$, $p<.001$), and Globe Temperature and Mean Radiant Temperature (Tr) ($r = .854$, $p<.001$). It was interesting to find a negative correlation between Globe Temperature and Relative Humidity (rH) ($r = -.812$, $p<.001$) showing that when the Globe Temperature increases the Relative Humidity decreases. Similarly, a relationship was found between the air velocity (Va) and the relative humidity (r = -.367, p<.001).

The few weak relationships found were between air velocity and air temperature (r = .097, p<.001), and air velocity with globe temperature (r = .168, p<.001).

Table 6 - Correlation between environmental factors

Spearman's rho Correlations

		Air Temp.	Relative Humidity	Globe Temp.	Air Velocity	Mean Radiant Temp.
Air Temperature (Ta)	Correlation Coefficient	1.00				
	Sig. (2-tailed)					
Relative Humidity (rH)	Correlation Coefficient	**-.782****	1.00			
	Sig. (2-tailed)	0.00				
Globe Temperature (Tg)	Correlation Coefficient	**.918****	**-.812****	1.00		
	Sig. (2-tailed)	0.00	0.00			
Air Velocity (Va)	Correlation Coefficient	.097**	**-.367****	.168**	1.00	
	Sig. (2-tailed)	0.00	0.00	0.00		
Mean Radiant Temperature (Tr)	Correlation Coefficient	**.762****	**-.843****	**.854****	**.595****	1.00
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	

4.4.2. Behavioural Analysis

The researcher created a coding scheme to codify the behaviour per individual. The method for this consisted in enumerating the participants, the behaviour and the modifiers. There were 165 participants. They were identified by a number in the coding scheme, according to the moment of entrance in the video.

The behaviour coding scheme was designed according to the behaviours found in the literature and also the observation of the behaviour adopted by the subjects in the seating area during the Pilot Study. The groups of behaviour and modifiers were defined as follows (Table 7):

Table 7 - Description types of behaviour

Group of Behaviour	*Explanation*
Time of Permanence	Arrival and Departure of subjects
Garment Level	From 0.3 to 1.1 clo. According to ISO 9920 (2009)
Body Postures	According to the common postures observed in the place
Interactions	Communication activities with other people or devices
Consuming	Food, drinks or cigarettes
Grouping	Number of companions
Reaction to sun/shadow	Decision to sit or relocated based on sun or shadow
Adaptive actions	Adaptive behaviour to temperature or light

Figure 25 presents the coding scheme created in Observer XT. The left column contain the participants, the column in the middle contains the behaviour group, each behaviour type is classified as a state, point or connected to a modifier. The column on the right contains the modifiers which are additional categories given to the behaviours. For example, the garment level is to classify according to ISO 9920 (2009) the CLO level of the participants.

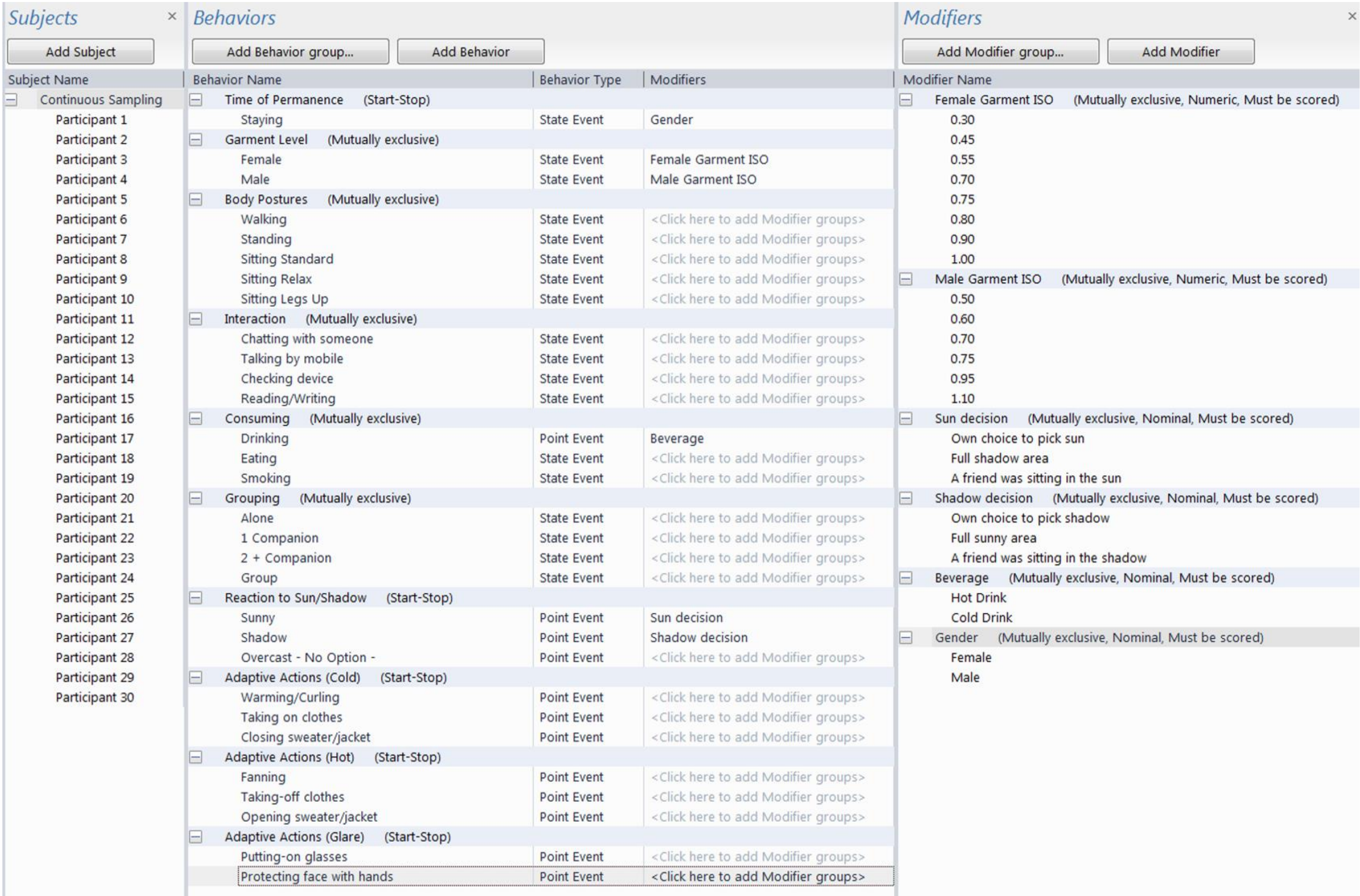


Figure 25 - Coding scheme Observer XT

Figure 26 is an example of the structure of the coding scheme, showing the observed behaviour of Participant #134 in the blue highlighted text. This participant is walking and drinking a hot drink. One participant could be conducting multiple activities at the same if they were not mutually exclusive for example walking and drinking.

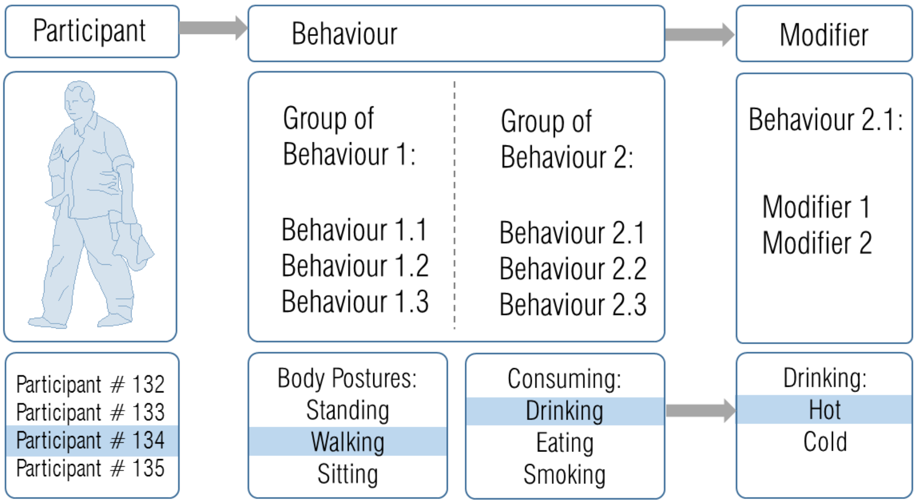


Figure 26 - Example of the coding scheme structure

The behaviours were divided into groups of behaviour according to their attributes. Mutually exclusive behaviours or behaviours of the same family were grouped together. For example, all the 'Body Postures' were grouped as all the activities in this category and were mutually exclusive (a participant could be standing or sitting, but not both at the same time). On certain occasions some behaviours were grouped together despite not being mutually exclusive. For instance, the behaviour drinking, eating and smoking were grouped within 'Consuming' despite not being mutually exclusive, as including these behaviours in the same category helped with processing the data. Finally, the modifiers are additional information of the behaviour. Figure 26 illustrated the modifiers of 'drinking', which are 'hot' or 'cold'.

The coding also classified whether the behaviour type was a state or a point event. Figure 27 shows the difference between a state and point behaviour. A state behaviour means that the duration of the activity was evaluated. The point events refer to the moment when the behaviour occurred, or, the frequency of occurrence. For instance, the 'time of permanence' was classified as a state event as the purpose of this behaviour is to register the length of time a person remained in the place. However, the behaviour 'sunglasses-on' is a point event as the length of the event is not as important as the register of the occurrence of the event.

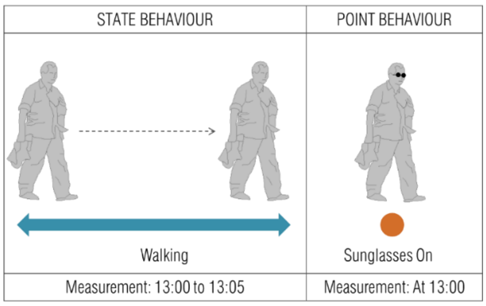


Figure 27 - Example of 'state' and 'point' behaviour

Some of the state event were mutually exclusive, which means that each one of them can only occur one at a time and not simultaneously. Figure 28 is an example of the visualisation of mutually exclusive data, where each body posture was successive to another and had a start and an end point.

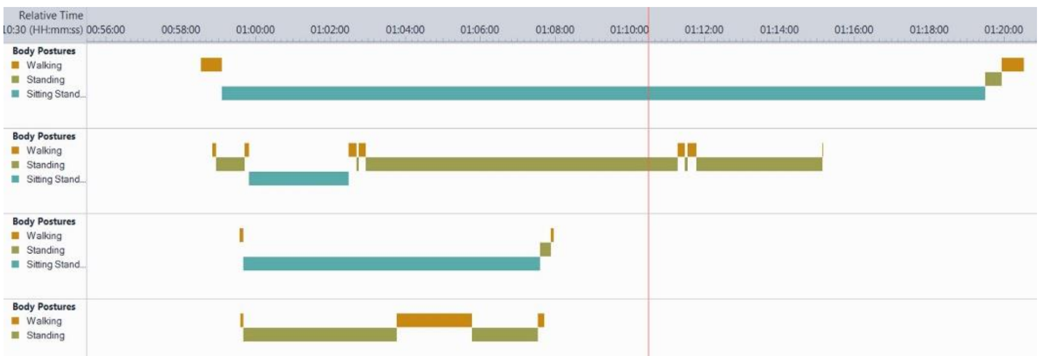


Figure 28 - Example of Body Posture registration per user.

Figure 29 presents a screen shot of the process of video analysis conducted. The left column contains the video files. The video was reproduced while the researcher recorded a behaviour as it was occurring. The behaviour list was located below the video screen and it can be observed that the exact time of occurrence and the modifiers are also recorded there. The right column permitted to track the behaviour that was active in order to avoid errors.

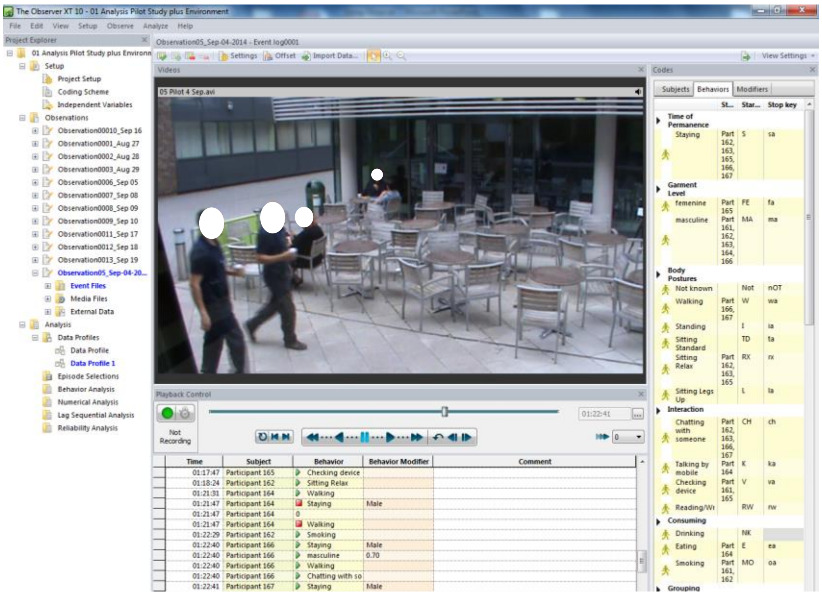


Figure 29 - Capture screen process of video analysis with Observer XT

In order to assess the validity of this coding scheme, an inter-reliability test was conducted. As reported in other studies, the reliability of coding video data can be affected by factors such as: practise of the person coding, experience, training, the rapidity of behaviour, the energy level of the observer and/or the clarity of a specific behaviour's definition (Kaufman & Rosenthal, 2009).

A researcher with Human Factors background was invited for the inter-observer test. The process of validation consisted of: 1. A training session to teach them how to use the coding scheme; 2. A mock test to check the agreements and disagreements between both researchers and clarify the interpretation of each behaviour, as it was found in the literature that "a single observer can be extremely consistent at measuring the wrong behaviour" (Kaufman & Rosenthal, 2009) (p. 1488); and 3. The invited researcher randomly selected one of the videos to perform the coding, excluding the ones used for training.

The results obtained from both observers were compared using the Reliability Analysis available in Observer XT. A total of six people, with 286 recorded behaviour entries, were used to check the inter-reliability test. The total number of agreement was 250; and there were 36 disagreements. The inter-observer reliability test (Kappa of 0.87, $p < 0.001$) showed a substantial strength of agreement between both observers (Landis & Koch, 1977).

4.4.3. Environmental Factors and Human Behaviour Analysis

To determine the type of analysis required for the correlations between environmental factors and behaviours, a Kolmogorov – Smirnov test was conducted. The results obtained for all the variables were $p < .05$ which indicated a non-normal distribution. Therefore, a non–parametric statistic correlation evaluation with Spearman's rho was calculated for each analysis.

Number of People

Number of People or Occupancy refers to the 'Use of outdoor space' (Nikolopoulou et al., 2001). It is the number of people in the space compared to the environmental factors. The methodology used in previous studies for measuring this factor was "counting the number of people using the spaces at various intervals" (Nikolopoulou et al., 2001, p. 228). In this Pilot Study the time intervals used to calculate the occupancy were 12:30, 12:40, 12:50, 13:00, 13:10, 13:20 and 13:30 during the 12 days evaluated.

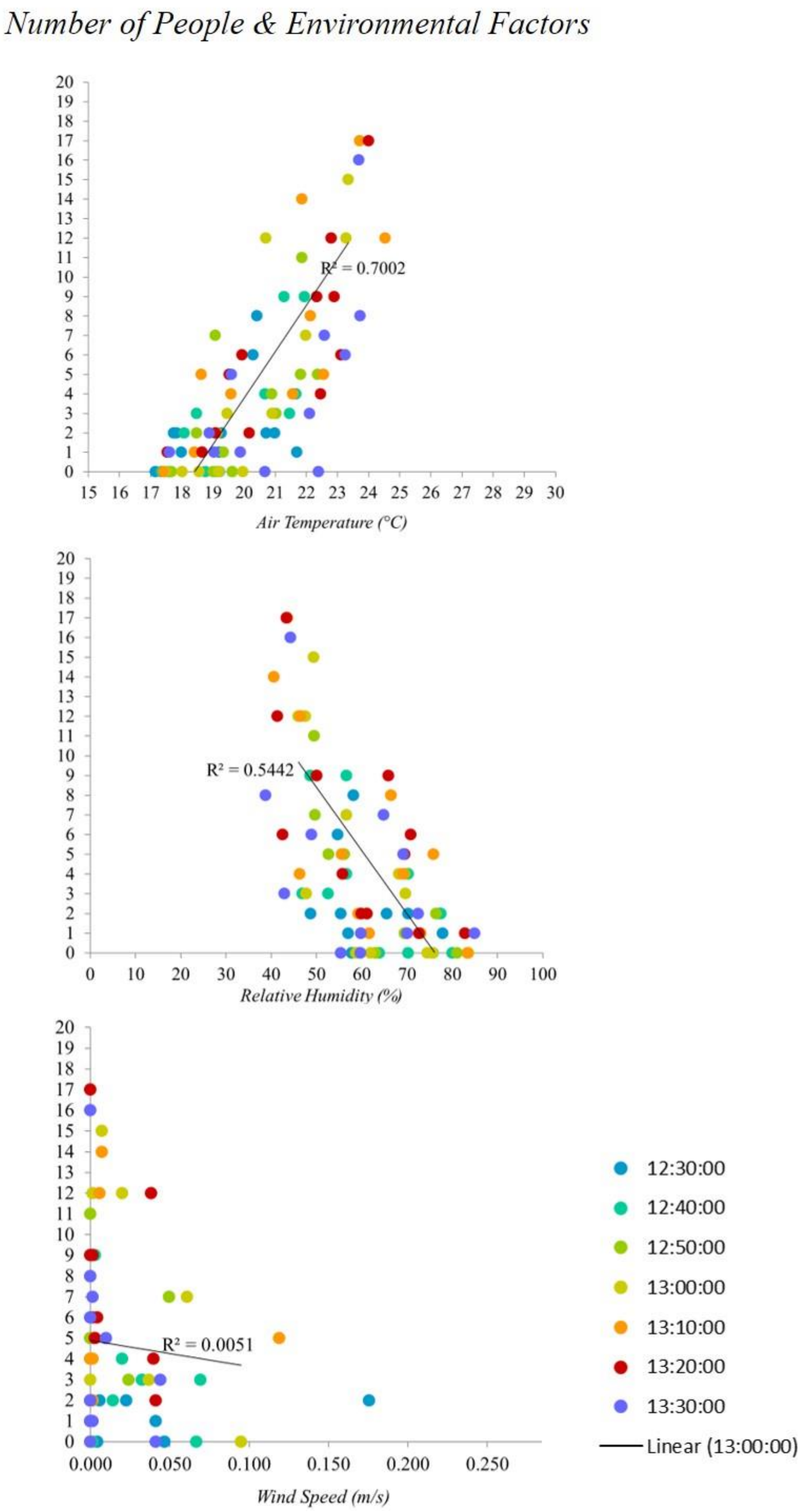


Figure 30 - Scatter plots Number of People and air temperature, relative humidity and wind speed

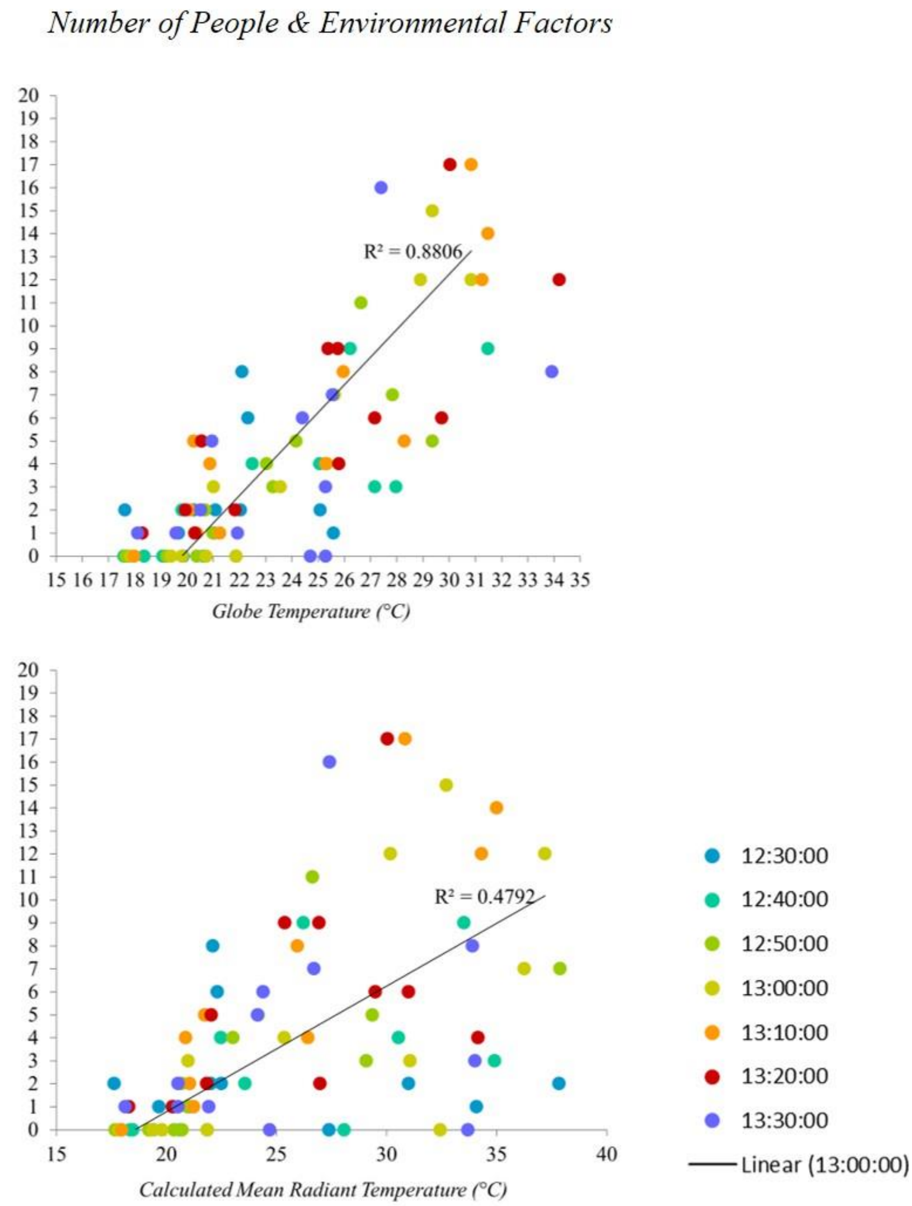


Figure 31 -- Scatter plots Number of People and globe temperature and calculated mean radiant temperature

Figure 30 and Figure 31 present the scatter plots between the Number of People and the environmental conditions. A positive relationship was observed between Number of People and air temperature, globe temperature and radiant temperature; a negative relationship was observed with relative humidity; and no relationship was found between Number of People and air velocity.

Table 8 presents the correlation analysis between Number of People and different environmental variables. The number of people was significantly correlated with air temperature, r = .73, relative humidity, r = -.62, globe temperature, r = .79, and mean radiant temperature, r = .61 (all ps < .001).

Table 8 – Correlation Number of People and Environmental Factors

Spearman's rho - Number of People

Air Temperature	Correlation Coefficient	**.738****
	Sig. (2-tailed)	.000
Relative Humidity	Correlation Coefficient	**-.62****
	Sig. (2-tailed)	.000
Globe Temperature	Correlation Coefficient	**.79****
	Sig. (2-tailed)	.000
M.Radiant Temperature	Correlation Coefficient	**.61****
	Sig. (2-tailed)	.000
Air velocity	Correlation Coefficient	.14
	Sig. (2-tailed)	.207

**Correlation is significant at the 0.01 level (2-tailed).

The Number of People was also evaluated according to the users' decision to sit in the sun or shadow. To do this, a calculation was made of the number of people who decided to sit in the sun, shadow or if at the moment of their arrival the sky was overcast (Figure 32). It was observed that the preference to sit in the sun (42%) was double the decision to sit in the shadow (20%). The overcast corresponded to the moments where the users did not have option to select a condition, which was around 40% of the times.

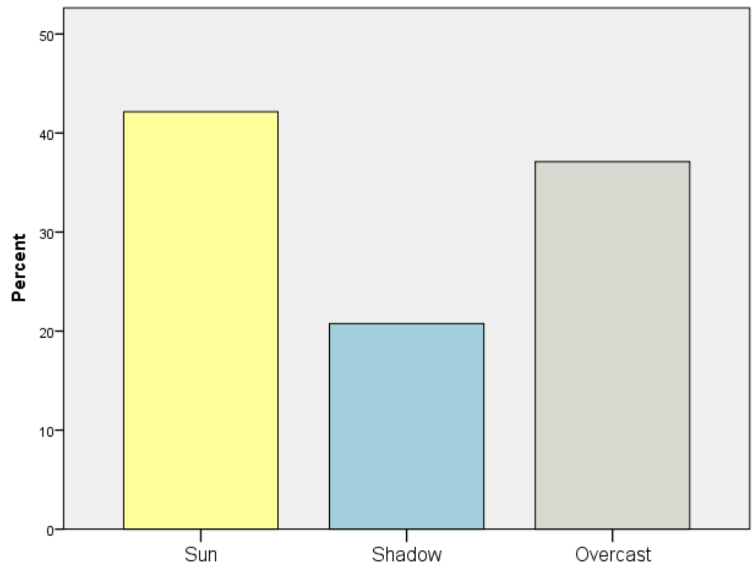


Figure 32 - Percentage of people sitting in the sun or shade, at air temperature from 17°C to 25°C

Time of Permanence

Time of Permanence is the period of time a person remains in the evaluated place. It was measured in minutes per person. This calculation was done by registering in Observer XT the time of arrival and departure of each participant.

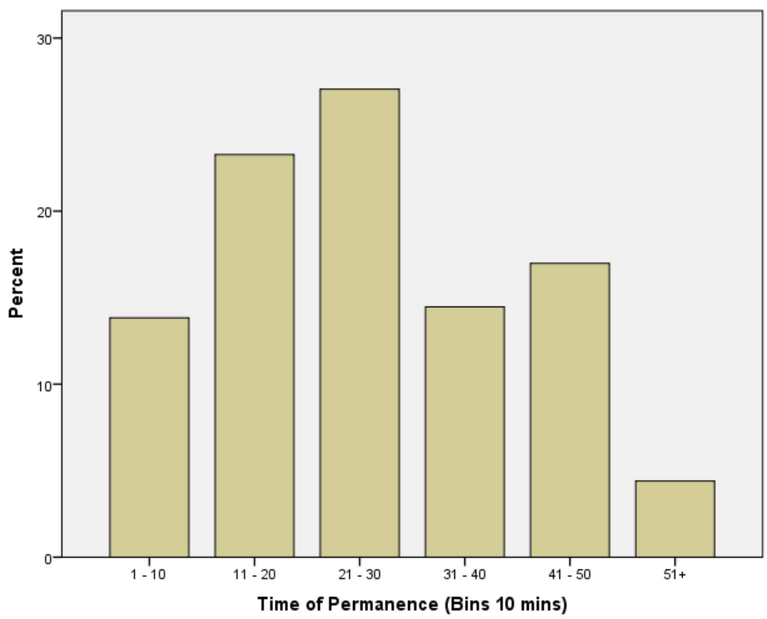


Figure 33 - Distribution of the Time of Permanence

Figure 33 presented the data distribution of the time of permanence. The data was classified in bins of 10 minutes, in order to compare different ranges of time. As can be observed in there, around 28% of the attendants stayed between 21 and 30 minutes. The lowest attendance was for users remaining more than 51 minutes.

Table 9 presents the correlations between Time of Permanence and the environmental variables. Air velocity was the only factor significantly correlated to the time of permanence, $r = .22$, $p < .01$**.

Table 9 - Correlations Time of Permanence and environmental variables

Spearman's rho		Time of Permanence (N = 189)
Time of Permanence	Correlation Coefficient	1.000
	Sig. (2-tailed)	
Air Temperature	Correlation Coefficient	.09
	Sig. (2-tailed)	.240
Relative Humidity	Correlation Coefficient	-.10
	Sig. (2-tailed)	.217
Radiant Temperature	Correlation Coefficient	.01
	Sig. (2-tailed)	.867
Air Velocity	Correlation Coefficient	**.22****
	Sig. (2-tailed)	.005
Globe Temperature	Correlation Coefficient	.12
	Sig. (2-tailed)	.135

**. Correlation is significant at the 0.01 level (2-tailed).

A low correlation was observed between the environmental factors and the Time of Permanence, therefore it was decided to run a further analysis. The lack of correlation may be explained by the fact that the time of permanence can be of any duration at any condition, since users are always attending spaces for compulsory activities. However, it was decided that further analysis was required to determine whether remaining in the place was in any way related with any of the evaluated environmental variables (which is evaluated using survival analysis in the following studies).

Figure 34 presents boxplots indicating a pattern when comparing the Time of Permanence with the environmental conditions. The top chart presents the box plots of the time of permanence according to the air temperature, from 17ºC to 25ºC. As can be observed, the median of Time of Permanence increases with the rise of the temperature, with some exemptions: 22ºC, 24ºC and 25ºC. The most extended whiskers occurred between 19ºC and 23ºC. Finally, as can be seen, the boxes in 24ºC and 25ºC are small, but this may be could be related to the sample size since the data gathered in this range of temperature was less than 5% of the sample.

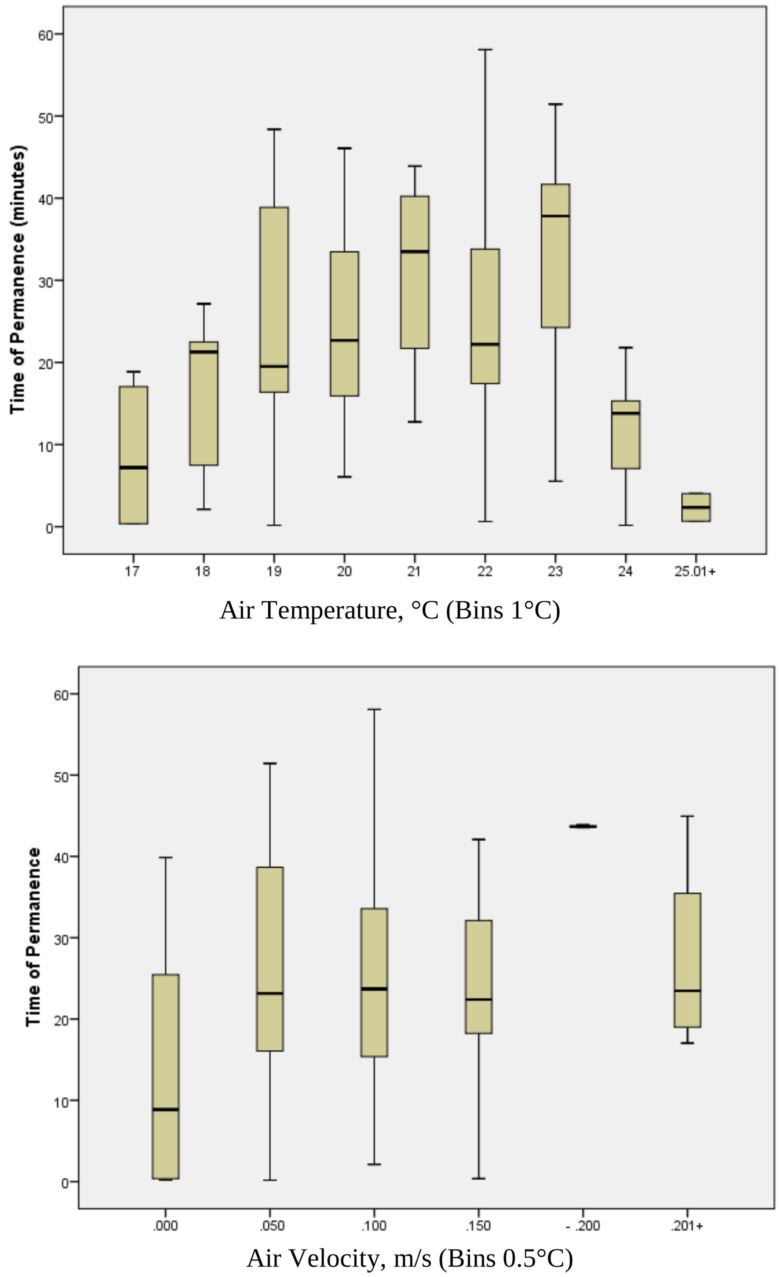


Figure 34 - Box plots air temperature and air velocity

In Figure 34 bottom, containing the time of permanence per Air Velocity, an opposite effect is evidenced. The bigger bins occurred at 0.00 m/s and started decreasing from 0.20 m/s and above. The data was binned at 1ºC for Air Temperature and at 0.5ºC for Air Velocity, for illustrative purposes.

Body Postures

The Body Postures are the body positions adopted by the people during the study. Waldron & Salazar (2013) defined groups of standard postures adopted in public spaces, which are illustrated in Figure 35 below. From left to right, the postures are: Laying, Sitting Legs Extended, Lotus, Sitting Standard, Leaning / Ischiatic Support, Standing, Walking, Running.

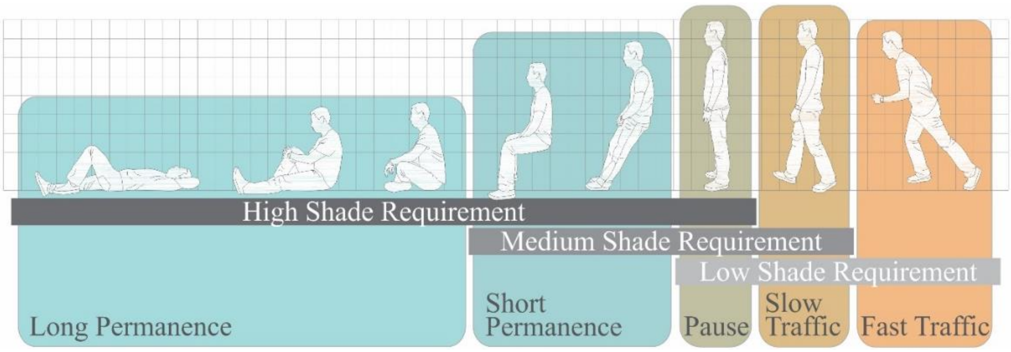


Figure 35 - Standard Postures adopted in public spaces (Waldron & Salazar, 2013)

From the group of postures described, the following were identified during the Pilot Study: Walking, Standing and Sitting Standard. Additionally, two variations of the Sitting Standard were observed: Sitting Relaxed and Sitting Legs Up. Sitting Relaxed refers to the sitting posture with the back supported in a backrest. Sitting Legs Up refers to the sitting posture extending the legs on another chair.

The body postures were evaluated by registering the postural changes per individual. At the end, the duration in every posture per person was calculated and compared with the mean of air temperature, relative humidity, mean radiant temperature, air velocity and globe temperature during the time the person remained in the square. Table 10 presents the Spearman's rho correlation analysis between the Body Postures and the environmental conditions.

Table 10 - Correlation between Body Postures and Environmental Factors

			Standing	*Sitting*	*Sitting*	*Sitting*
Spearman's rho	Air Temperature	Correlation	.24**	.20*	.02	-.07
		Sig. (2-tailed)	.002	.01	.801	.373
	Relative Humidity	Correlation	-.27**	-.18*	-.01	-.02
		Sig. (2-tailed)	.001	.02	.953	.772
	Mean Radiant Temperature	Correlation	.15	.06	.02	.07
		Sig. (2-tailed)	.066	.492	.798	.384
	Air Velocity	Correlation	.01	.05	.22**	.12
		Sig. (2-tailed)	.945	.552	.005	.150
	Globe Temperature	Correlation	.24**	.18*	.05	.03
		Sig. (2-tailed)	.003	.023	.566	.679

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The posture Standing presented a significant correlation with air temperature, r = .24, relative humidity, r = -.27 and globe temperature, r = .24 (all ps <.005).

The posture Sitting Standard presented significant correlation with air temperature, r = .20, relative humidity, r = -.18, and globe temperature, r = .18 (all ps <.05).

The posture Sitting Relaxed presented a significant correlation with air velocity, r = .22 (p < .01).

Clothing

The clo is the unit of thermal insulation of clothing. According to the Ergonomics of the thermal environment (ISO, 2001), estimation of thermal insulation and water vapour resistance in clothing ensemble: 1 clo = 0.155 (m2*K*W-1).

The measurement of the clo per person was made by observing and classifying the user's outfit, according to the 'Thermal insulation for typical combinations of garment' (ISO, 2005).This data was compared with the environmental factors and the results are presented in Table 11.

Table 11 - Correlation between clo and Environmental Factors

		Clothing (N = 159)	
Spearman's rho	Clo	Correlation Coefficient	1.000
		Sig. (2-tailed)	
	Air Temperature	Correlation Coefficient	**-.17***
		Sig. (2-tailed)	.034
	Relative Humidity	Correlation Coefficient	.15
		Sig. (2-tailed)	.053
	Mean Radiant Temperature	Correlation Coefficient	-.10
		Sig. (2-tailed)	.216
	Air Velocity	Correlation Coefficient	-.09
		Sig. (2-tailed)	.253
	Globe Temperature	Correlation Coefficient	-.12
		Sig. (2-tailed)	.134

*. Correlation is significant at the 0.05 level (2-tailed).

As can be seen in Table 11, the only environmental condition that presented significant correlation with the garment was air temperature, $r = -.17$ ($p < .05$).

Companions

Companions refer to the number of people accompanying each person. The number of companions was recorded with Observer XT at the moment of arrival to the evaluated space. Table 12 presents the correlations between the numbers of companions with the environmental conditions. The only significant correlation found of Companions, was with air temperature, r = .22 ($p < .005$) **.

Table 12 - Correlations numbers of companions and environmental factors

Spearman's rho Companions		
Companions	Correlation Coefficient	1.000
	Sig. (2-tailed)	
Air Temp	Correlation Coefficient	**.22****
	Sig. (2-tailed)	.004
R Humidity	Correlation Coefficient	-.10
	Sig. (2-tailed)	.223
Rad Temp	Correlation Coefficient	.04
	Sig. (2-tailed)	.588
Wind	Correlation Coefficient	.03
	Sig. (2-tailed)	.727
Light	Correlation Coefficient	.11
	Sig. (2-tailed)	.223
Globe Temp	Correlation Coefficient	.15
	Sig. (2-tailed)	.067

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Surveys

The participants were asked to report their previous activities and to rate, on a 7 point scale, their perception of the environment in their previous and present locations. The results are presented in two sections: 'Previous vs. Current Environmental Conditions', and 'Perception vs. Measured environmental conditions at the seating area'.

The participants were asked to report their previous environment, activity and their perception of the air quality and temperature. This section presents the results obtained.

From the sample of 27 people, 21 reported to be in an indoor space before coming to the studied area, and the remaining 6 were in an outdoor space prior to the observation. The activities list of the survey was taken from the type of activities of ISO 7730 (2005). This list also contain the classification of metabolic rate by category as presented in Table 13.

Table 13 – Metabolic Rate according to Activities ISO 7730

Activities (adapted from ISO 7730:2005)	*Metabolic Rate*
Running/Cycling (Walking 5 km/h)	200 W/m^2
Walking Fast	165 W/m^2
Walking Normal	140 W/m^2
Walking Slow	110 W/m^2
Standing, medium activity (shop assistant, domestic work)	116 W/m^2
Standing, light activity (shopping, laboratory, light industry)	93 W/m^2
Sedentary activity (office, dwelling, school, laboratory)	70 W/m^2
Seated Relax	58 W/m^2

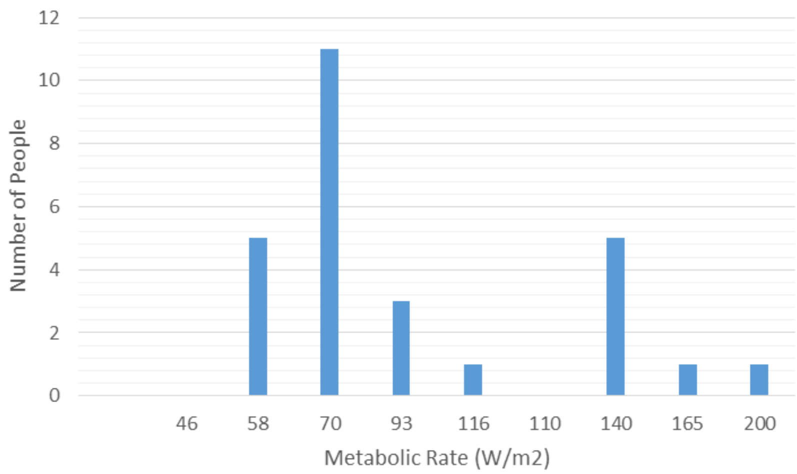


Figure 36 - Number of People and Metabolic Rate

Figure 36 display the results of Number of people per Metabolic Rate level. It is observed that most of the participants were previously performing activities between 58 and 93 W/m2, 7 participants were doing activities with a Moderate Metabolic Rate (130 to 200 W/m2), 15 participants were performing a Low Metabolic Rate activity (70 to 130 W/m2) and 5 participants were Resting (55 to 70 W/m2). This means that the majority of the sample were not exposed to high metabolic rate activities which could have affected their perceived thermal sensation.

Air Quality was the first variable studied. The participants were asked to rate on a 7 point scale their perception of the quality of the air in terms of: dry – humid, fresh – stuffy, and odourless – smelly. This was also asked about the participant's previous environment.

Figure 37 presents the results of comparing their previous and current perception of the Air Quality. The first variable Dry-Humid, where 1 is Dry and 7 is Humid, presented a median of 4 in the previous and current environment which agrees with previous studies where it is said that "people are not very good at judging changes in humidity levels, unless relative humidity is very high or very low" (Nikolopoulou & Lykoudis, 2006). It is also observed that the capacity to agree in the humidity levels was higher for previous (indoors) than for outdoors.

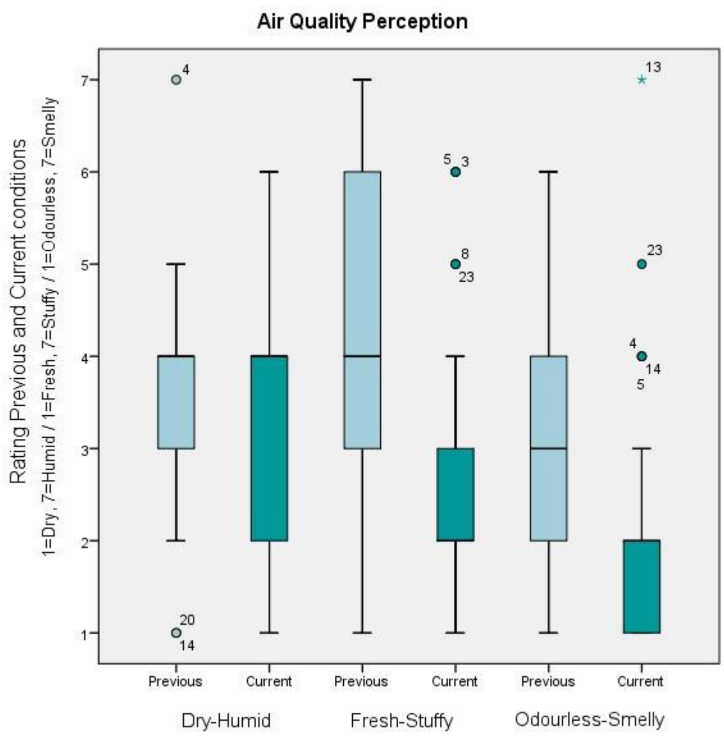


Figure 37 - Air quality perception

The second factor evaluated was the perception of air Freshness-Stuffiness, where 1 was Fresh and 7 Stuffy. It is observed that the previous location (indoors) seemed to be stuffier in comparison to the current condition. This can be explained by the fact that most of the participants were in an indoor environment before.

The last factor regarding air quality was the perception about it being odourless-smelly, where 1 was odourless and 7 smelly. In this condition, half of the participants rated the previous place between 2 and 4. Additionally, the top whisker extended up to 6 suggesting a low quality of the previous environment regarding the smell. Conversely, the seating area was rated between 1 and 2 and the box is comparatively shorter, which means a high level of agreement between users about their perception of ‘odourless’.

The temperature and comfort were also studied in comparison with the environment in the users’ previous location. Figure 38 presents the results of the rating made by the users. The temperature was rated between 1 and 7, where 1 was hot and 7 cold. It is observed in the Temperature that the result for the previous environment suggest a high level of agreement with half of the rates between 3 and 4. This result is interesting because all the users arrived from different environments. In contrast, the rating for the current seating area in terms of Temperature varied between 3 and 5, which may be explained by the steadier conditions existing in indoor spaces (Höppe, 2002) in comparison with the variability of outdoors.

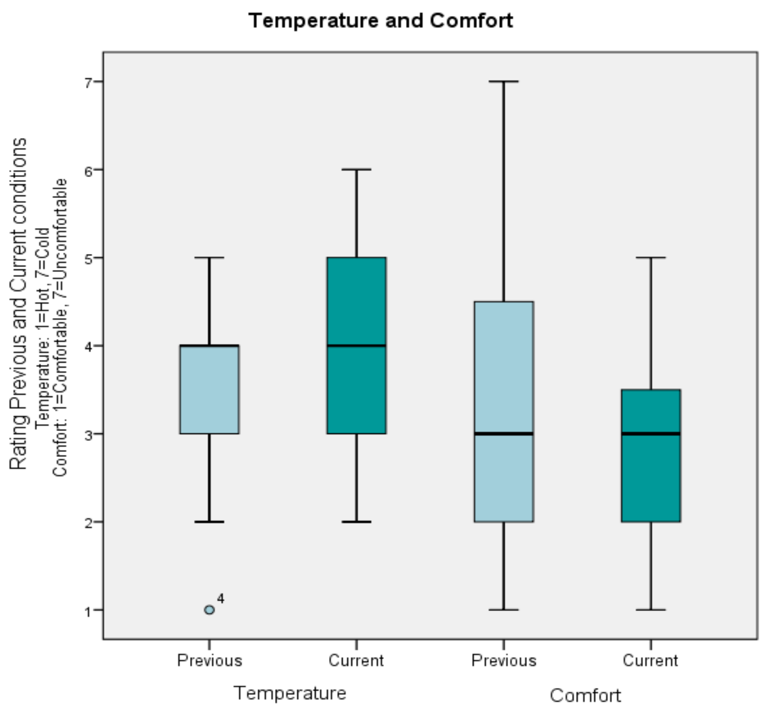


Figure 38 - Perceived temperature and comfort

Comfort was also evaluated with a 7 point scale, where 1 means Comfortable and 7 Uncomfortable. As can be observed in Figure 38, the study showed that the perceived comfort was different between users, since the whiskers are extended over the 7 point scale and 50% of the sample rated it between 2 and 5. This result is very interesting when compared with the temperature results, because half of the users agreed in a medium perception of the temperature in their previous environment, but when they were asked about comfort, the agreement between them was null. The comfort in the users' current location had more agreement as around 75% of the sample rated the space below 4.

Perception vs Measured environmental conditions at the seating area

In order to analyse the perceived current environmental conditions (7 point scale) against the measured conditions, a correlation analysis was conducted. The mean of the air temperature, relative humidity, globe temperature, air velocity and mean radiant temperature were calculated, during the period of time each user stayed in the seating area.

From the sample of 27 surveys 2 were excluded because the environmental data of the 2nd of September was incomplete.

The Spearman's Rho correlation analysis is presented in Table 14. It is interesting to see that the overall comfort and the temperature comfort are correlated to the globe temperature ($r = -.451$ and $r = -.408$, $ps < .05$). This result agrees with other studies where the attendance to a place is correlated to the globe temperature (Nikolopoulou et al., 2001).

Some of the expected correlations between perceived and measured conditions are: wind speed and still-draughty ($r = .406$, $p < .05$), globe temperature and sunny-overcast ($r = -.399$, $p < .05$) and mean radiant temperature and sunny-overcast ($r = -.438$, $p < .05$).

The Number of People present at the moment of conducting each interview was also evaluated. It was observed that this variable did not present correlation with the environmental factors; however, the number of people presented a negative relationship with the rating of the people in the questionnaires about the relationship sunny/overcast ($r = -.50$, $p <.05$), which means that the number of people decreased as the space was perceived as 'overcast'. A correlation was also observed between number of people and the perception, according to the questionnaires, about the odourless/smelly condition of place ($r = .40$, $p < .05$). This means that the number of people decreased as it was perceived as 'smelly'.

Table 14 - Spearman's correlation analysis between measured and perceived factors

Spearman's Rho Correlations (N = 27)

		Number of People	Air Temperature	Relative Humidity	Globe Temperature	Wind Speed	Calculated Mean Radiant Temperature
Time Permanence	Correlation Coefficient	.188	-.217	.162	-.075	-.071	-.071
	Sig. (2-tailed)	.347	.298	.439	.722	.737	.734
Number of People	Correlation Coefficient	1.0	.20	-0.37	0.33	0.15	0.28
	Sig. (2-tailed)	.	.348	.066	.111	.477	.182
Overall Comfort / Uncomfortable	Correlation Coefficient	-.107	-.297	.327	**-.451***	.009	-.372
	Sig. (2-tailed)	.597	.149	.110	.024	.966	.067
Temperature Hot / Cold	Correlation Coefficient	-.127	-.184	**.497***	-.255	-.312	-.374
	Sig. (2-tailed)	.529	.380	.011	.218	.129	.066
Temperature Comfortable / Uncomfortable	Correlation Coefficient	-.216	-.283	.298	**-.408***	-.137	-.392
	Sig. (2-tailed)	.279	.171	.148	.043	.512	.053
Sunny / Overcast	Correlation Coefficient	**-.503****	-.284	**.552****	**-.399***	-.165	**-.438***
	Sig. (2-tailed)	.008	.168	.004	.048	.430	.028
Air Still / Draughty	Correlation Coefficient	-.122	.183	-.195	.168	**.406***	.234
	Sig. (2-tailed)	.545	.380	.349	.422	.044	.260
Dry / Humid	Correlation Coefficient	-.110	.171	-.011	.048	.288	.178
	Sig. (2-tailed)	.587	.415	.960	.819	.162	.396
Fresh / Stuffy	Correlation Coefficient	-.038	-.231	.122	-.198	.176	-.004

	Sig. (2-tailed)	.849	.267	.560	.343	.400	.985
Odourless / Smelly	Correlation Coefficient	**.396***	-.099	.028	.022	-.076	.038
	Sig. (2-tailed)	.041	.636	.892	.917	.718	.858
Light / Dark	Correlation Coefficient	-.309	**-.404***	.301	-.375	.089	-.286
	Sig. (2-tailed)	.117	.045	.144	.065	.671	.165
Noisy / Quiet	Correlation Coefficient	-.243	**-.468***	.346	**-.458***	-.322	**-.421***
	Sig. (2-tailed)	.222	.018	.090	.021	.116	.036
Clean / Dirty	Correlation Coefficient	-.133	-.380	.124	-.253	.098	-.148
	Sig. (2-tailed)	.509	.061	.556	.222	.642	.480
Safe / Unsafe	Correlation Coefficient	-.097	-.016	.208	-.095	.056	-.084
	Sig. (2-tailed)	.632	.938	.319	.651	.790	.689
Accessible / Inaccessible	Correlation Coefficient	-.025	-.344	.319	-.370	-.054	-.287
	Sig. (2-tailed)	.901	.093	.121	.068	.796	.164
Attractive / Unattractive	Correlation Coefficient	-.081	-.302	.225	-.331	-.038	-.321
	Sig. (2-tailed)	.687	.142	.279	.106	.857	.117

*. Correlation is significant at the 0.05 level (2-tailed).

4.5. Discussion

This chapter presented a Pilot Study which aimed to evaluate the methods to be used in the following experiments of this research, regarding Human Behaviour in outdoor public spaces according to environmental conditions. The data gathered showed a number of significant correlations between the environmental factors and human behaviour.

This study presented results from three sources: environmental measurements, surveys and observations and are discussed in turn in the following sections.

4.5.1. Environmental Measurements

The study measured the microclimatic conditions of the space, in order to evaluate accurately the human response to the environment. The sensors showed results consistent with previous studies (e.g. Nikolopoulou et al. (1999) and Spagnolo & de Dear (2003)). The air temperature showed a negative correlation with humidity and the globe temperature increased with the solar radiation. However, some improvements for the following measurements were considered and explained in Chapter 5.

The air temperature can be highly influenced by the radiant temperature coming from many sources, such as the sun or near surfaces. Therefore, these heat sources must be controlled in further studies to avoid affecting the results.

The globe temperature was measured with a copper ball with a diameter of 150mm as per ISO 7726 (2001). According to Nikolopoulou et al. (1999), this globe presents an offset delay in the measurements of around 20 minutes which is the time that takes the air temperature inside the ball to adjust to the outside conditions. This means that the occurrence of the environmental factor is not synchronised with the human behaviour unless the sensor has been measuring for 20 minutes. In order to calculate the influence of the environmental factors with the behaviour, the mean temperature perceived by the person was calculated, therefore, a delay led to inaccuracies of the occurrence of the behaviour with the perceived environment. To correct this, Nikolopoulou et al. (1999) tested other types of globes and found that an acrylic ball of 35mm diameter, has only four minutes delay. The 150mm ball was used for the Pilot Study; however, due to the issues reported by the literature, the 35mm acrylic ball was the chosen device to improve the measurements in the following studies (Chapters 5 to 8).

The measurements of the Globe Temperature were taken only in the sun and not in the shadow. The data of the Globe Temperature of the shadow would have been interesting to explain some of the behaviours captured by observation, such as the one in Figure 32, where it can be seen that around 20% of the users preferred to sit in the shadow.

It is important to note that around 60% of the measurements of the air velocity were 0 m/s. As explained before, this may have been due to the geometry of the buildings surrounding the evaluated area. In order to collect a bigger range of wind conditions a place with a better wind flow would be selected.

Finally, this Pilot Study intended to include the illuminance level. However, the lux meter used was a manual device and the researcher needed to record the measurements manually every five minutes. These measurements were not taken into account as the data presented big gaps, due to the fact that the researcher was constantly occupied doing the surveys. Nevertheless, a relationship was found between the air temperature and the perceived light from the questionnaires, because people reported perceiving more light when the air temperature increased. In order to study this phenomena more accurately, the following studies required from a data logger to measure the illuminance levels (lx) in order to collect synchronized data of environmental factor and human behaviour for further analysis.

4.5.2. Behavioural Analysis

In the observational analysis, the Number of People presented correlation with multiple factors: Air Temperature ($r = .73$), relative humidity ($r = -.62$), globe temperature ($r = .79$) and calculated mean radiant temperature ($r = .61$). This result agrees with the findings presented by Thorsson et al. (2004), who reported the relationship of this factor with the mean radiant temperature in a park in Goteborg, Sweden. Nikolopoulou et al., (2001) reported the relationship of this factor with Globe Temperature after a study conducted in Cambridge, UK. From the many factors correlated, one that is particularly interesting is Globe Temperature, since it is the strongest correlation and it is also related to the solar radiation. This means that the sun is an important variable for the attendance of people in an outdoor space. Similarly, Figure 32 shows how more than 40% of the people chose to sit in the sun whilst only 20% chose to sit in the shadow. The rest of the sample corresponded to people seating while the environment was overcast.

The Pilot Study had an interval for counting the people of 10 minutes. Due to the strong correlation existing between Number of People and the environmental conditions, the frequency of evaluation ought to be increased in the following studies, as this may aid the accuracy and strength of the results. Also, the correlation between Number of People with various factors had been consistent in other locations as explained before.

The Time of Permanence presented a correlation with the air velocity, but this environmental factor did not show a relationship with Number of People. This suggests that the air velocity has no influence over the occupancy of the place but it does affect the amount of time they will remain there. (Zacharias, 2004) concluded that there is no significant correlation between the time of permanence and temperature. In their findings they reported a mean stay of 20 minutes and a standard deviation of 40 minutes. However, this study showed a standard deviation of 14 minutes, which means that the data gathered is scattered and a lineal pattern was not observed. In the Pilot Study, the data presented a similar distribution; however, when using box plots, a pattern in the ranges of the time of permanence was identified. For instance, for an air temperature of 17°C, a box between 0 and 20 minutes was obtained. This means that an activity on that temperature will have duration within this range. The boxes increased their range as the air temperature increased (Figure 34). The opposite phenomenon was observed between Time of Permanence and air velocity. This finding suggested that the time related factors should be analysed differently. This led to consideration of the survival analysis for the following studies, where the relationship between variables is evaluated in terms of time (e.g. the survival analysis conducted in the work of Haldi & Robinson (2009)).

The main body postures evaluated were sitting standard and sitting relaxed as they had been the ones which people assumed most. Sitting standard presented a correlation with air temperature, relative humidity and globe temperature, while sitting relaxed presented a correlation with air velocity. According to Fergus et al. (2013), the body postures may be classified as adaptive behaviours. For instance, in order to keep the body temperature, people tend to assume curled postures with arms and legs close to the trunk or to each other; while in hot environments, the postures tend to be more open in order to expose body surface which allows releasing the heat of the body. In the Pilot Study, the posture seating relaxed had a positive correlation with the air velocity: the higher the velocity of the air the longer the time people remained sitting relaxed. This can be explained by the fact that the data was gathered in summer time when the increase in the wind speed can be perceived positively to help release an excess of heat from the body, helping with thermoregulation.

Several behaviours were studied, but some of them were only partially coded as video analysis proved to be too time consuming to analyse these in detail (e.g. duration of activities and clothing). Some authors report a rate of ten hours of analysis per one hour of video (Brace et al., 2000). Therefore, for the next experiments, the video analysis was refined to include the parameters that affect most the relationship between human behaviour and the built environment: Number of People, Time of Permanence, Body Postures and Activities.

The literature review showed a considerable number of studies about the relationship between 'number of people' and environment (Table 2). This research will generate a deeper analysis of this behaviour as it relates to the use of outdoor spaces. The number of groups and groups' sizes will be also analysed as they can be identified as a measurement of best-used or least-used spaces (Whyte, 2009). Similarly, the activities will be part of the next studies, as previous studies have shown that spaces with a variety of activities conducted in them are good quality areas (Gehl, 2011). In the study conducted by Gehl (2011) the activities were classified as: necessary, optional and social. In spaces with poor quality only necessary activities occur; while, in places with good quality more optional and social activities occur (Gehl, 2011).

The time of permanence will be also considered as a variable that may serve to measure the success of urban spaces. According to Gehl (2011), the more time people spend outdoors, the more frequently they meet and talk. The time of permanence can be an indicator of the quality of outdoor spaces as they provide the required conditions to remain in the place. The body postures were also reviewed by other authors as it relates to the thermal comfort. Fergus et al. (2013), described that a postural change may occur to improve the thermos-physiological response to the environment. Accordingly, this study will also evaluate the adaptive behaviours as a response to the environmental conditions.

4.5.3. Subjective Analysis

From the sample of people who completed the surveys, 21 of 27 reported to have been indoors before attending the evaluated space. Despite this, there was a high disagreement between all the participants regarding their perception of comfort in their previous environment, even though, there is agreement in their perception about the temperature in the previous environment (50% of the participants rated the previous temperature between 3 and 4 in a scale of 7). This result agrees with Peter Höppe (2002) who found that the thermal history of a subject is important, but it is hard to standardise.

Interesting results were found regarding the perceived environment and the measured environment. For instance, the globe temperature and air temperature were correlated with comfort, and wind speed was correlated with the perception of the movement of the airflow (still – draughty). It was also found that the number of people correlated with the perception of a sunny or overcast day, which agrees with previous studies regarding the relationship between the use of outdoor spaces and the presence of sun. It was also found that the space was also perceived as smellier when more people were present. This could be explained by two factors:

1) In two of the questionnaires (Appendix 1), the participants reported in the comments section of 'current environmental conditions' the following: Participant 7: "Fresh air, feel relaxed, can smoke" and Participant 13: "Someone smoking next to me". Therefore, as the number of people increased, more are the chances of people smoking in the place which reduces the positive perception of the air quality.
2) The study was conducted during lunchtime, so there can be smells of food in the air. However, none of the participant reported this as a source of smells.

To summarize, the finding of the interviews allowed understanding some perceptions of the users; however, the outcomes obtained and the difficulties observed by this subjective method in terms of spontaneity of the users, had the consequence that no further questionnaires were made in the further studies as theses were focused in observational methods. Several studies reported the comfort of people in outdoor urban spaces through subjective methods, one of the most exhaustive research studies was the RUROS project which reported over 10,000 interviews and environmental data of seven cities in Europe Nikolopoulou et al. (2011). Therefore, it was found difficult to offer new contributions to the field using subjective methods. Contrariwise, observational methods presented interesting patterns which suggest possibilities for further studies, such as the existence of correlation between Time of Permanence or Body Postures and the thermal conditions.

4.6. Conclusions

The Pilot Study was intended to test the different methodologies found in the literature, in order to establish those most appropriate for the study of human behaviour in the present study. The difficulties found through the data collection, processing and analysis, allowed customising a methodology which adapts to the current needs and expectations of the researchers.

From the methods used, the one that provided new findings to the field was the observation method, as it allowed discovering new perspectives to understand and measure human behaviour. The environmental measurements and observation methods were refined from the findings in the Pilot Study and the methodology for the following studies was designed according to this. The surveys permitted understanding the perception of some users; however, the existence of previous studies approaching thermal comfort in a more comprehensive manner, made it redundant to continue this path of subjective methods. In addition, the use of subjective methods may affect the behaviour of the users whilst recording data using observational methods. Accordingly subjective methods were discarded in the following studies.

5. Human Behaviour in Summer

5.1. Chapter Overview

This chapter presents the results of a study conducted during the summer about human behaviour in response to the thermal environment of an outdoor public spaces according to the thermal environment. The observations were conducted in Trinity Square at Nottingham city centre during August and September 2015. The methodology was based on observing the behaviour of people and comparing this to the environmental conditions of the place. The behaviour was classified into two groups for the analysis: social behaviour and individual behaviour. The social behaviour consisted of observing the number of people and the size of the groups present in the square. Individual behaviour comprised of observing the conduct performed per individual. In the social behaviour the sample consisted of selecting three random hours of observations per day during one week, after which the data was analysed per minute using multiple regression models. In the individual behaviour, the time of permanence per user was analysed. The sample consisted of 2330 users and the data was analysed using survival analysis. The results were used to derive models to predict the behaviour based on the main predictors.

5.2. Introduction

According to Höppe (2002), adaptation of the human body to the environment occurs faster in hot rather than cold temperatures. This is because the blood flow is increased by the vasodilatation (Höppe, 2002). However, the heat exchange between the body and the environment occurs in a complex way, as sources of heat are diverse and may vary in time and location. When a person is outdoors, the air temperature, relative humidity, and radiant temperature from nearby surfaces, as well as other environmental factors, may vary according to the time of the day and the properties of the construction (Robinson, 2011). In the same way, the effectiveness of the thermoregulatory body system to adapt to the thermal environment may vary according to "personal expectations, opportunities available to us to adapt our environment and possibly also age and gender" (Robinson, 2011, p. 96).

Other studies have reported that summer is a season attracting more users outdoors, as the attendance increases when the globe temperature increases (Nikolopoulou et al., 2001). However, it has been also stated that conditions of thermal comfort do not necessarily mean an optimum state in terms of health (Höppe, 2002). According to Huang et al. (2016), depending on the environmental conditions, the thermal environment during summer can reduce the attendance to a public space, increase the thermal stress of users, or, disincentive social activities. The authors reported in this study that renovating a playground in Wuhan – China by installing shading shelters and new vegetation increased the attendance to the place in around 80%, reduced the thermal stress of the users and promoted more social activities.

However, it has been found that, despite a multiplicity of environmental factors influencing the human behaviour in the outdoors, there are not enough studies about the specific participation of every environmental factor over human behaviour.

This study aims to assess the influence of the air temperature, relative humidity, globe temperature in the sun and in the shade, mean radiant temperature in the sun and in the shade, wind speed and light, over the human behaviour. This is the first study where three samples gathered in different seasons (summer, autumn and winter).

5.3. Method

The methods and tools used for this study were similar to the ones tested during the Pilot Study (Chapter 04), however some improvements to the equipment and analysis were made to increase the quality of the outcome. The aim of the methodology was to collect observational data of human behaviour in outdoor urban spaces in simultaneity with the measurement of the environmental conditions. The data collection, tools and video analysis were refined according to the experience gained during the Pilot Study. The improvements made will be mentioned in each relevant section of the method.

Population and Time Sample

The sample of the Social Behaviour were all the people passing and remaining in the square during the recording period, however their individual characteristics were not considered. The time sample of the Social Behaviour was 3 hours per day, during seven days (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday). A total of 1260 minutes during summer were analysed.

For the Individual Behaviour a total of 2330 individuals were evaluated. They were the people who attended to the square where the study was taking place (Trinity Square, Nottingham).

The individuals were classified during the analysis in age groups, by observing their characteristics: baby, child, teenager, adult and mobility reduced. The last group was defined as people with difficulties to move or aided by elements such as: wheelchair, crutch or other. According to the data presented in Table 15 most of the people were adults, 87.3%.

Table 15 – Frequency distribution of the age group

Age (N = 2330)

		Frequency	Percent	Valid Percent	Cumulative
Valid	adult	2035	87.3	87.3	87.3
	teenager	92	3.9	3.9	91.3
	child	133	5.7	5.7	97.0
	baby	25	1.1	1.1	98.1
	mobility reduced	45	1.9	1.9	100.0
	Total	2330	100.0	100.0	

The sample was also classified by gender: male, female and none of these. Table 16 presents the data percentage observed per gender, a higher percentage of men 52.1% in comparison to 47.9% of woman attendance were recorded.

Table 16 - Frequency table of Gender

Gender (N = 2330)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	1214	52.1	52.1	52.1
	Female	1116	47.9	47.9	100.0
	Total	2330	100.0	100.0	

Duration and Season

The data collection was conducted for four weeks in summer, from the 21st of August to the 21st of September 2015. The weeks were selected according to the historic data of the temperature variation in Nottingham.

From the data gathered one week was selected to be analysed; however, in the cases where a day was excluded by any of the exclusion criteria, then that day was compensated with another day of the following week (Table 17).

Table 17 - Calendar of data collection and days selected for analysis

Aug-15						
Mo	Tu	We	Th	Fr	Sa	Su
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Sep-15						
Mo	Tu	We	Th	Fr	Sa	Su
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Selected Days for Analysis
Recorded Period
Excluded from the analysis(Exclusion Criteria)

The data was collected for three hours randomly selected for each day between 10:30 and 17:00 hrs. This period was selected because this is the time when most of the city services are open. Table 18 presents the hours recorded each of the selected days.

Table 18 - Time randomly selected to collect data each day

Summer 2015							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
10:30							
11:00							
11:30							
12:00							
12:30							
13:00							
13:30							
14:00							
14:30							
15:00							
15:30							
16:00							
16:30							
17:00							
17:30							
18:00							

5.4. Results

As mentioned before, this study evaluated the human behaviour in two ways Social Behaviour and Individual Behaviour.

According to Barker (1975), the environment or place of evaluation is a setting mediating the social and dynamic behaviour of people. He defines some of the attributes to consider in a behavioural setting:

- Occurrence and Duration of behaviours: The occurrence is the moment when the behaviour happened. It can occur once or several times. The duration refers to the length of the occurrence.
- Population is the number of people at each occurrence.
- Occupancy time refers to the number of people per hour, or it can be the mean population per occurrence and the duration of all occurrences.

These interactions will be referred to as Social Behaviours, which will be measured by counting the Number of People and also the Number of Groups (2 or more people) per minute in relation to the place evaluated.

The second type of evaluation is the Individual Behaviour, also called in the literature as "body idiom" (Goffman, 1963). This is the non-spoken communication that the individual is making to engage in a situation. The Individual Behaviour was analysed by registering the specific conduct of people. This study focused on analysing the following individual behaviours: time of permanence, body postures, activities and adaptive actions performed by each individual evaluated. The age group and gender of the individuals were also recorded in order to evaluate the characteristics of the sample observed.

The Social Behaviour and Individual Behaviour analysis were also referred as “Aggregates” and “Individual Counts” respectively by the Gehl Institute (2017) in their project to collect a Public Life Data Protocol. The aggregates help to understand the conditions of the environment, while the individual counts describe the behaviour per person. This section contains the results obtained by measuring the environmental conditions of the square and contrasting them with the Social and Individual Behaviour.

5.4.1. Environmental Measurements

A total data set of 1260 minutes obtained during the summer study was classified for analysis. The sample corresponds to three hours of video recording every day between 10:30 am and 6:30 pm for seven days. Table 19 presents the descriptive statistics of the environmental data collected. The variables measured were: air temperature (Ta, ^{o}C), relative humidity (rH, %), globe temperature in the sun (Tg_sun, ^{o}C), globe temperature in the shadow (Tg_shad, ^{o}C), wind speed (Va, m/s) and light (lx).

Table 19 - Descriptive statistics of the environmental variables

Statistics (N = 1260)

	Ta	rH	Tg_Sun	Tg_Sha	Tr_Sun	Tr_Sha	Va	Light
Mean	18.9	57	22.0	20.3	32.6	25.1	.844	7127
Median	19.1	53	21.8	20.2	31.3	24.3	.674	6019
Std.	3.8	12	5.0	4.2	13.1	7.8	.698	4557
Minimum	12.4	37	13.1	12.7	13.8	12.8	.000	1005
Maximum	27.1	80	34.9	29.5	83.6	55.5	3.344	24325

a. Multiple modes exist. The smallest value is shown

Acronyms: Air temperature (**Ta**), relative humidity (**rH**), globe temperature in the sun (**Tg_sun**), globe temperature in the shadow (**Tg_sha**), mean radiant temperature in the sun (**Tr_sun**), mean radiant temperature in the shadow (**Tr_sha**), wind speed (**Va**)

Table 20 - Correlations between environmental variables in summer

Spearman's rho Correlations (N = 1260)

		Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sh	Va	Ligh
Ta	Correlation	1.00							
	Sig. (2-tailed)	.							
rH	Correlation	**-**	1.000						
	Sig. (2-tailed)	.000	.						
Tg_sun	Correlation	**.94***	**-.74****	1.000					
	Sig. (2-tailed)	.000	.000	.					
Tg_sha	Correlation	**.98***	**-.78****	**.97****	1.000				
	Sig. (2-tailed)	.000	.000	.000	.				
Tr_sun	Correlation	**.81***	**-.56****	**.88****	**.84****	1.000			
	Sig. (2-tailed)	.000	.000	.000	.000	.			
Tr_sha	Correlation	**.90***	**-.66****	**.93****	**.93****	**.96****	1.000		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.		
Va	Correlation	**.62***	**-.41****	**.57****	**.59****	**.77****	**.75****	1.000	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.	
Light	Correlation	**.56***	**-.29****	**.68****	**.61****	**.80****	**.72****	**.47****	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

Acronyms: Air temperature (**Ta**), relative humidity (**rH**), globe temperature in the sun (**Tg_sun**), globe temperature in the shadow (**Tg_sha**), mean radiant temperature in the sun (**Tr_sun**), mean radiant temperature in the shadow (**Tr_sha**), wind speed (**Va**)

Table 20 presents the Spearman's rho correlation analysis between the environmental variables. This procedure was conducted to evaluate the environmental characteristics recorded during summer and the relationship between these variables.

According to Table 20, all the variables presented significant correlation to each other. Various environmental variables had very high correlations with other variables, which could cause multicollinearity in the regression models. The highest correlation found were: air temperature and globe temperature in the shadow ($r = .98$, $p < .001$), air temperature and globe temperature in the sun ($r = .94$, $p < .001$), and globe temperature in the sun and globe temperature in the shadow ($r = .97$, $p < .001$).

The lowest correlations found were light and relative humidity ($r = -.29$, $p < .001$), light and wind speed ($r = .47$, $p <.001$) and wind speed and relative humidity ($r = -.41$, $p < .001$). These results suggest that most of the environmental variables in summer presented strong relationship to each other and a few presented moderate and weak relationships.

The following figures will present the percentage distribution of the environmental measurements. For illustrative purposes (Frédéric Haldi & Robinson, 2008), the data was binned as follows: air and globe temperature were binned at 1^{o}C, relative humidity at 5%, mean radiant temperature at 5^{o}C, wind speed at 0.5 m/s and light at 1,000 lx. The bin sizes were determined according to the density of the data. This binning was also required for processing the data during the survival analysis.

Figure 39 presents the percentage of distribution of the air temperature data. The temperatures recorded varied between 12°C and 27°C. It was observed that the most common measurements were between 18°C and 20°C.

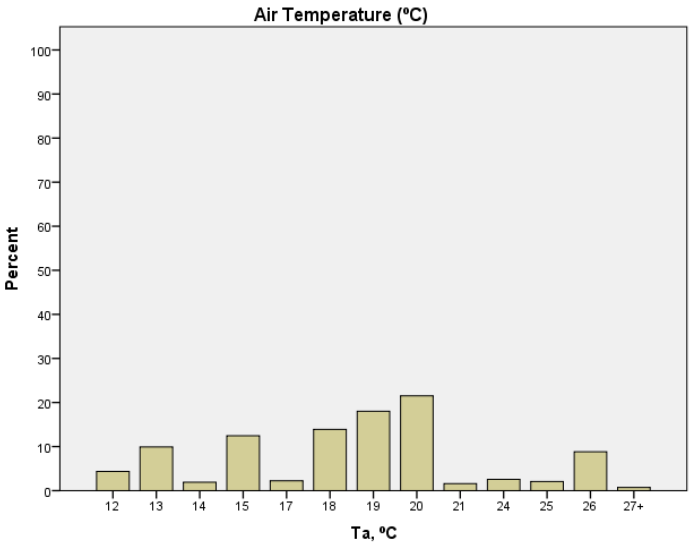


Figure 39 - Air Temperature (ºC) percentage distribution summer

Figure 40 presents the percentage distribution of the relative humidity. The data was distributed irregularly between 36% and 80%.

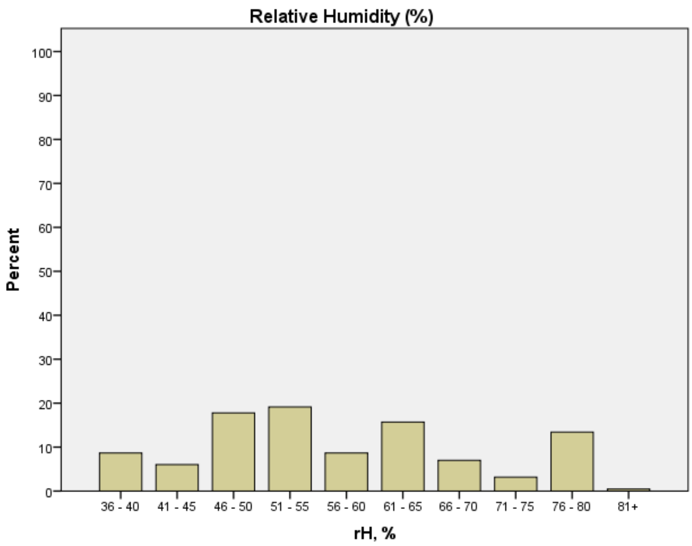


Figure 40– Relative Humidity (%) percentage distribution summer

The globe temperature in the sun oscillated between 13ºC and 34ºC (Figure 41). However, 20% of the data was recorded at 21ºC and the rest of values did not exceed 10% of the total data.

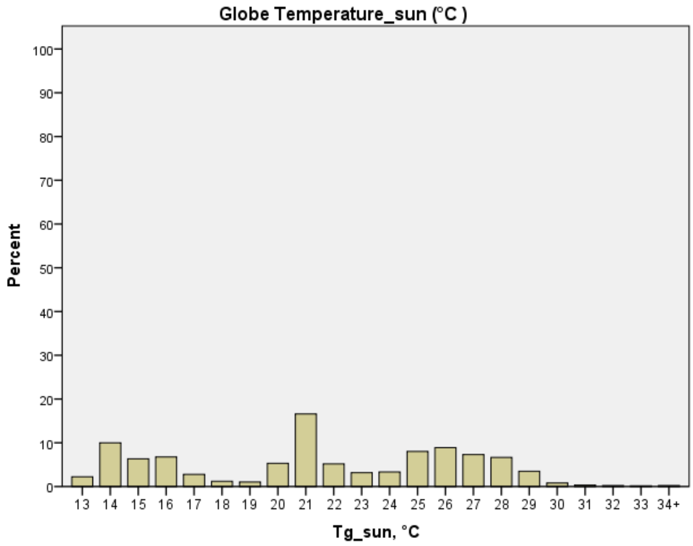


Figure 41 - Globe temperature in the sun (ºC) percentage distribution summer

Figure 42 presents the percentage distribution of the globe temperature in the shadow data. The data was recorded mainly between 12ºC and 29ºC. The most frequent conditions for globe temperature in the shadow in summer were 19ºC and 20ºC.

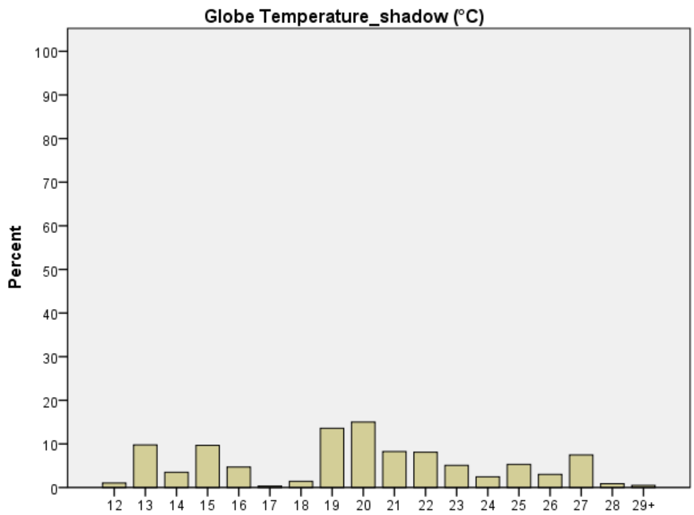


Figure 42 - Globe temperature in the shadow (ºC) percentage distribution summer

Figure 44 is the percentage distribution of the calculated mean radiant temperature in the sun, binned at 5°C. The temperatures oscillated between 10°C and 70°C. 20% of the data was recorded between 15°C and 20°C. The conditions between 20°C and 45°C were distributed evenly.

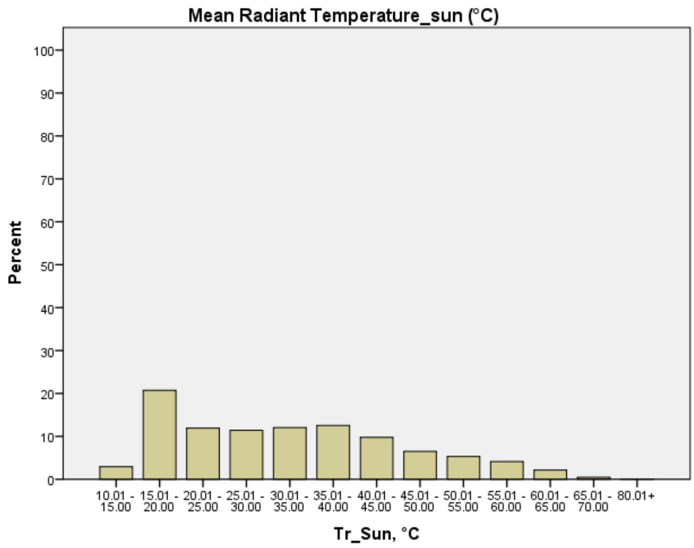


Figure 44 - Calculated Mean radiant temperature in the sun (°C) percentage distribution summer

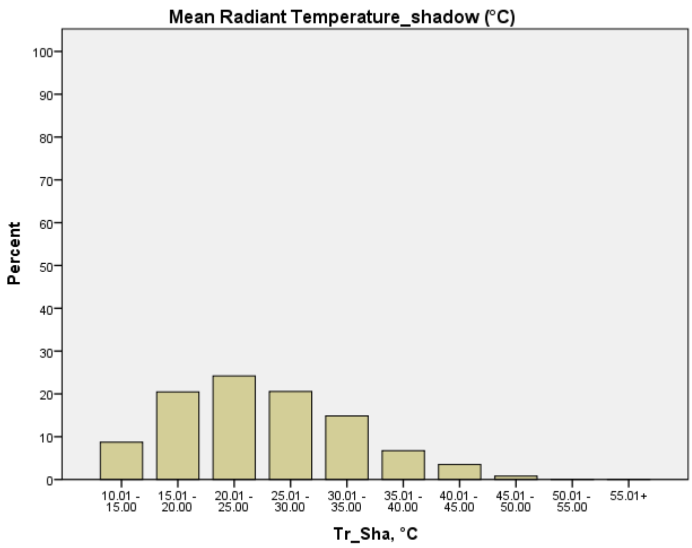


Figure 43- Mean radiant temperature in the shadow (ºC) percentage distribution summer

Figure 43 presents the percentage distribution of the mean radiant temperature in the shadow. The values recorded oscillated between 10ºC and 50ºC. It is observed that approximately 65% of the data was recorded within 15ºC and 30ºC.

The wind speed recorded velocities between 0 m/s and 3 m/s (Figure 45). The most frequent condition observed was within the range of 0.001 m/s and 0.5 m/s. The lowest percentages were observed at 0 m/s and between 2.5 and 3 m/s.

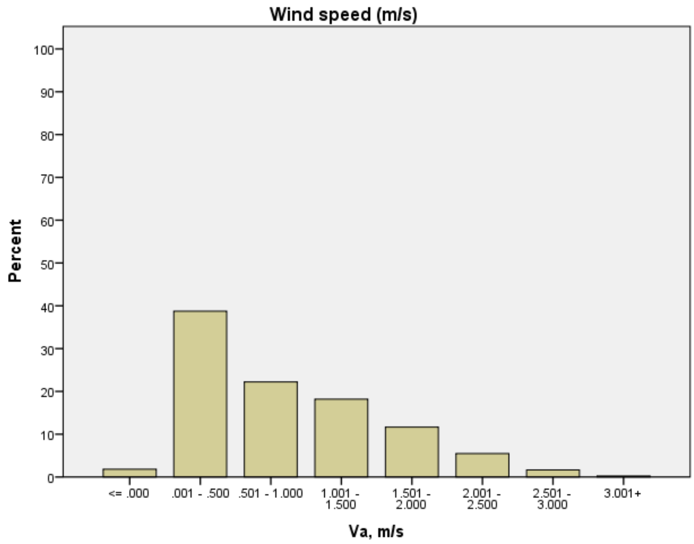


Figure 45 - Wind speed (m/s) percentage distribution summer

Figure 45 presents the percentage of distribution of the illuminance data. The data ranged from 1,001 lx and 24,000 lx. Most of the data was recorded between 2,000 lx and 7,000 lx. 5% of the data presented light conditions below 2,000 lx.

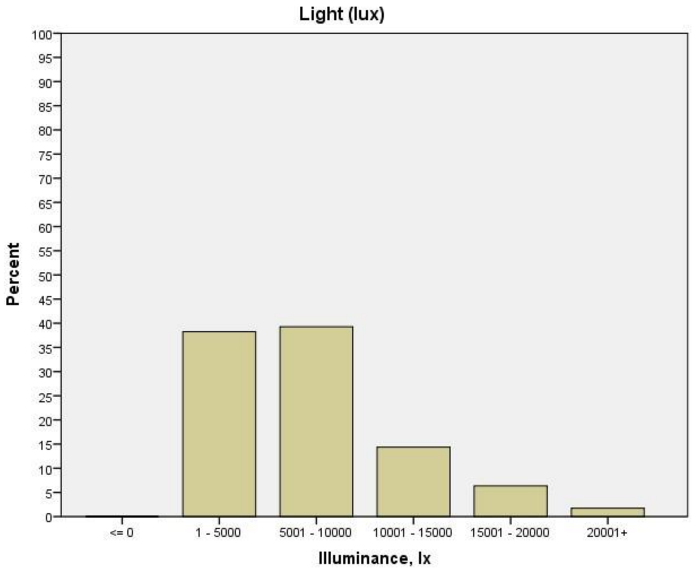


Figure 46 - Illuminance (lx) percentage distribution summer

The environmental data recorded showed a wide variety of conditions in the study conducted in summer. Since the following sections are based on these thermal conditions, the generalisability of the conclusions will be limited to places with similar environmental characteristics.

5.4.2. Social Behaviour

This analysis was focused on the presence of people in the areas of study, and whether they were part of a group or an individual. As mentioned before, previous studies have analysed spaces by evaluating the amount of people and the variety of activities after conducting a retrofit of a public square (Gehl & Svarre, 2013; Whyte, 2009). The occupancy is therefore a standard of success of a public space (Huang et al., 2016), and the variety of grouping is a rate of well used spaces (Whyte, 2009).

Table 21 presents the descriptive statistics of the *Number of People* and *Number of Groups* observed per minute in the area of study. The mean corresponds to the total *Number of People* observed per minute divided by the number of minutes. The mean *Number of People* was 26 and the standard deviation was 11, which indicates a high variability of the total of people per minute in the square.

Table 21 - Descriptive statistics of the Number of People and Number of Groups

Statistics (N = 1260)

	Number of People	G1	G2	G3	G4more
Mean	26	8	5	1	1
Median	24	8	4	1	1
Std.	11	4	3	1	1
Minimum	4	0	0	0	0
Maximum	63	23	17	7	6

Acronyms: G1: Groups of 1, G2: Groups of 2, G3: Groups of 3, G4more: Groups of 4 or more

The evaluation of the groups was conducted by creating four categories depending on the number of people per group. These categories were: 1 person (G1), 2 persons (G2), 3 persons (G3) and 4 or more people (G4more). The category G4more contained groups of 4 and up to 16 people which was the maximum observed. This category included all the big groups, because of the infrequent nature of these sizes, compared to the frequency of smaller groups. The sum of observations of G4more totalled 1052, which corresponds to 5.7% of the total of observations.

According to Table 21, the highest Number of Groups per minute was 23 groups of one person (G1), followed by 17 couples (G2), 7 trios (G3), and finally, 6 groups of four or more people (G4more). The most frequent observation was people alone, since a mean of 8 groups of one person (G1) per minute was observed. The mean corresponds to the total Number of Groups of G1 observed per minute divided by the number of minutes.

Figure 47 presents the frequency distribution of the number of people per minute in the study in summer. It is observed that the highest frequency of *Number of People* observed was between 13 and 32 people per minute. The maximum occupancy was 62 people and the lowest was 4 people.

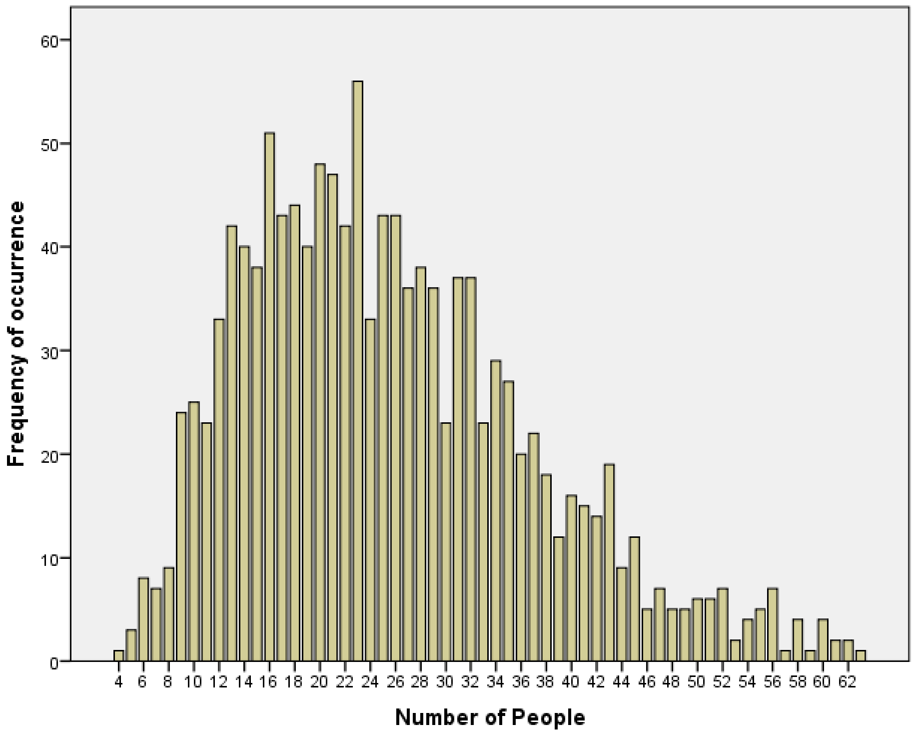


Figure 47 – Frequency distribution Number of People per minute summer

Figure 48 contains the frequency distribution of the groups of one person *G1*. The most frequent *Number of Groups of G1* per minute was 5, but this did not exceed 5% of the data. The data is distributed evenly between 4 and 10 groups of one person recorded per minute, being 23 the highest *Number of Groups of G1*, but this had a low frequency.

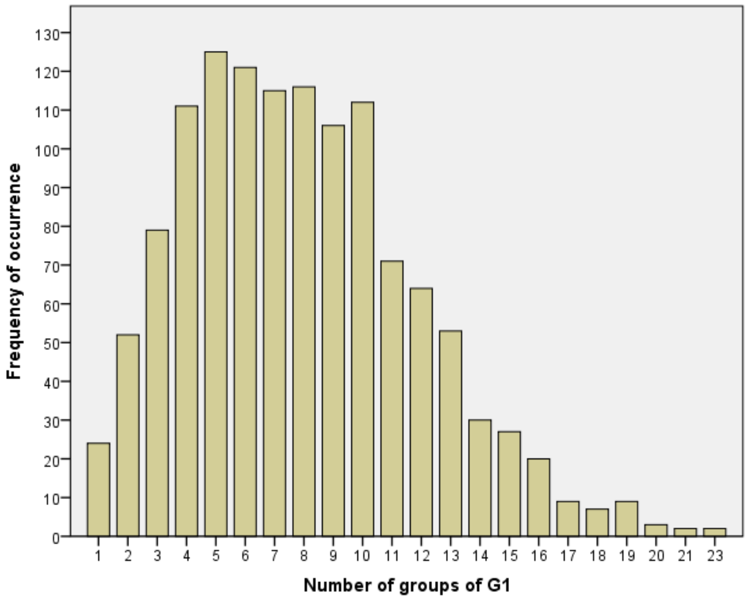


Figure 48 – Frequency distribution Number of groups of G1 per minute

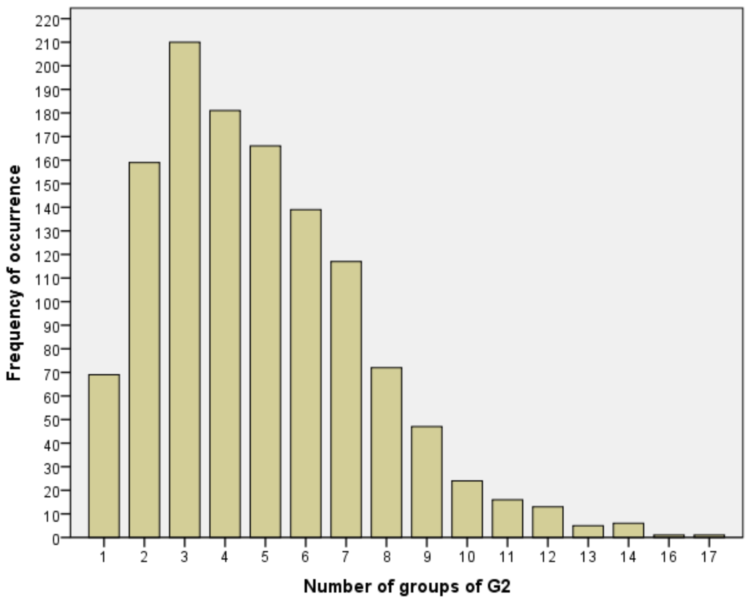


Figure 49 – Frequency distribution Number of Groups of G2 per minute

Figure 49 corresponds to the frequency distribution of the data of couples observed (*G2*). The highest frequency corresponded to 3 couples per minute, which is the most common observation in this category. The largest number of groups of 2 observed in the area of study at one time was 17, but this observation constitutes less than 1% of the total data and was therefore rare.

In Figure 50 is observed a high frequency of one group of G3 per minute. The second most common observation was two groups of G3 per minute. The participation in the data of three and four groups of G3 is further reduced. The highest number of groups of G3 recorded was seven, but this had a low frequency.

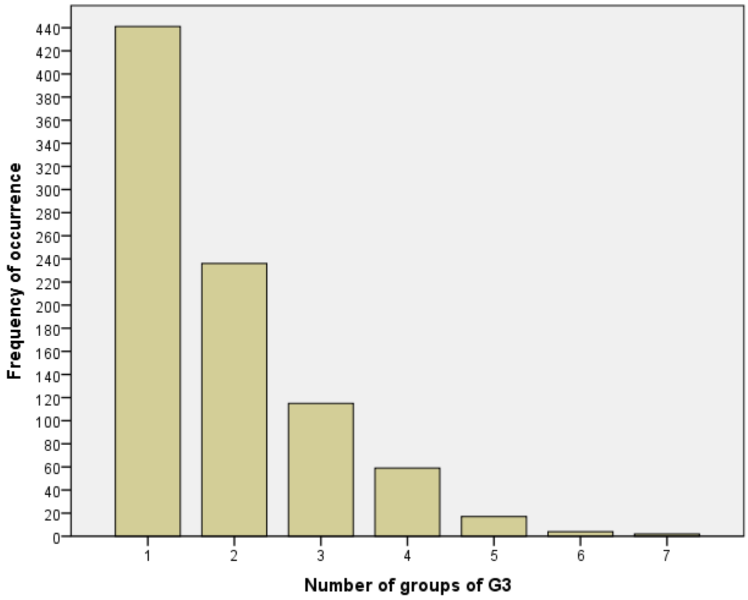


Figure 50 - Frequency distribution Number of Groups of G3 per minute

Similarly, Figure 51 presents the frequency distribution of the *Number of Groups of 4 or more* (*G4more*). It is observed that 1 group of G4more was the most frequent observation of attendance to the square of big groups per minute. Two groups of at least 4 people was the second most frequent observation, while observations of 3 or more groups of G4more were observed although not as frequent as 1 or 2 Groups of G4more.

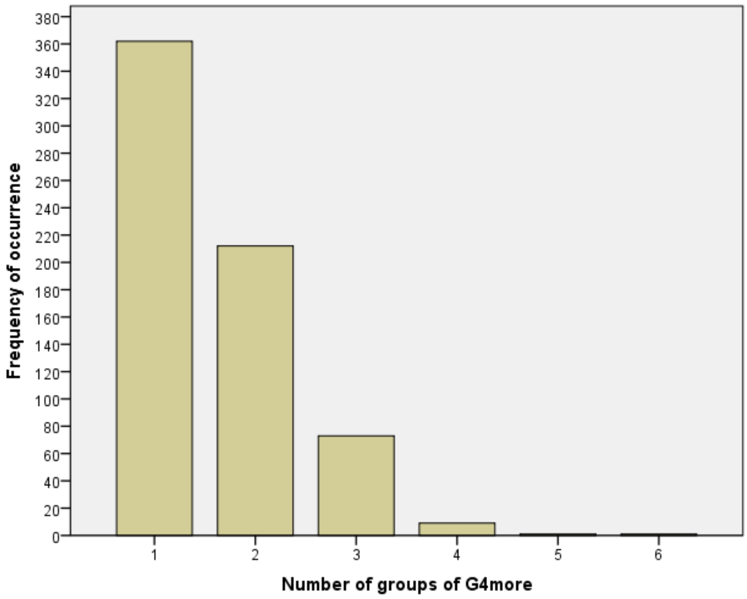


Figure 51 - Frequency distribution Number of Groups of G4more per minute

5.4.2.1. Correlations

The process to analyse the data had different steps. The first step consisted of preparing the data to perform a cross-validation at the end of the analysis. This included a 60% 40% data split where the bigger percentage of the data was used to generate the equations and the rest of the data was reserved to test the results obtained (Training N = 737 and Validation N = 523). Secondly, a *Spearman's rho* correlation analysis was performed to identify the independent variables presenting correlation with the behaviours. The third step consisted of selecting the best correlated independent variables to predict each behaviour. These variables were used to perform the multiple regression analysis. Finally, the predictions obtained for each behaviour were tested against the data that was reserved for the cross-validation.

The first analysis consisted of evaluating the correlation between most of the variables. This had the purpose of finding the relationship between human behaviour and the environmental variables, and determining which of the environmental factors influenced what behaviour. Before running the correlation analysis, it was necessary to test whether the distribution of the data was normal in all variables in order to select the type of correlation analysis to use. For this, a Kolmogorov Smirnov test was applied to the data set.

The results of the test of normality (Appendix 2) presented that all the variables were significantly non-normal, since all of them obtained D (771) < .001. According to this, the type of correlation analysis required to study the relationship between variables is a Spearman's rho correlation test.

Table 22 presents the outcome of the correlation analysis conducted between the Social Behaviour and the environmental variables. Two types of correlations are presented: the correlations between the social behaviours and the environmental variables, which are shown in blue and the correlations between environmental variables with each other, which are shown in black.

Table 22 - Spearman's rho Correlation - Summer

		N_People	G1	G2	G3	G4mor	Ta	rH	Tg_Sun	Tg_Sh	Tr_Sun	Tr_Sha	Va	Light
Ta	Correlation Coefficient	.25**	.00	.25**	.17**	.14**	1.000							
	Sig. (2-tailed)	.000	.909	.000	.000	.000	.							
rH	Correlation Coefficient	.00	.18**	-.16**	-.06	.11**	-.79**	1.000						
	Sig. (2-tailed)	.978	.000	.000	.075	.002	.000	.						
Tg_Sun	Correlation Coefficient	.24**	.00	.24**	.15**	.11**	.94**	-.75**	1.000					
	Sig. (2-tailed)	.000	.904	.000	.000	.003	.000	.000	.					
Tg_Sha	Correlation Coefficient	.26**	-.01	.26**	.14**	.13**	.98**	-.79**	.98**	1.000				
	Sig. (2-tailed)	.000	.870	.000	.000	.000	.000	.000	.000	.				
Tr_Sun	Correlation Coefficient	.38**	.20**	.33**	.19**	.11**	.79**	-.55**	.87**	.83**	1.000			
	Sig. (2-tailed)	.000	.000	.000	.000	.003	.000	.000	.000	.000	.			
Tr_Sha	Correlation Coefficient	.35**	.12**	.33**	.16**	.14**	.90**	-.67**	.93**	.93**	.95**	1.000		
	Sig. (2-tailed)	.000	.001	.000	.000	.000	.000	.000	.000	.000	.000	.		
Va	Correlation Coefficient	.27**	.17**	.27**	.14**	.07	.62**	-.41**	.57**	.59**	.77**	.75**	1.000	
	Sig. (2-tailed)	.000	.000	.000	.000	.064	.000	.000	.000	.000	.000	.000	.	
Light	Correlation Coefficient	.46**	.33**	.27**	.23**	.19**	.55**	-.27**	.67**	.60**	.79**	.71**	.46**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.

. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). Acronyms: Air temperature (Ta**), relative humidity (**rH**), globe temperature_sun (**Tg_sun**), globe temperature_shadow (**Tg_sha**), calc. mean radiant temperature_sun (**Tr_sun**), calc. mean radiant temperature_shadow (**Tr_sha**), wind speed (**Va**), N. of People (**N_People**), N. of Groups of one (**G1**), N. of Groups of two (**G2**), N. of Groups of three (**G3**), N. of Groups of four or more (**G4**). Blue: Social Behaviour + Environmental variables. Black: Environmental variables + Environmental variables.

Number of People presented the strongest correlations with light ($r = .46$, $p < .001$), mean radiant temperature in the sun ($r = .38$, $p < .001$) and mean radiant temperature in the shadow ($r = .35$, $p < .001$). Other environmental variables presented weak correlations with the number of people.

The highest influencer of Number of Groups of G1 was also light ($r = .33$, $p < .001$). The other environmental variables presented weak correlation to groups of one (G1) with exception of the air temperature and globe temperature in the sun which did not present relationship with the presence of people alone in the evaluated area.

Number of Groups of G2 presented a moderate relationship with the mean radiant temperature in the sun and shadow (both $r = .33$, $p < .001$). G2 also presented a weak correlation with the rest of the environmental variables.

Number of Groups of G3 presented correlation with light, it also presented a weak relationship with all the environmental variables and a null correlation with relative humidity. Similarly, Number of Groups of G4more presented correlation with light and a weak relationships with the other environmental variables, except wind speed with which the relationship is null.

Correlation Analysis Environment and Behaviour in Summer: Key Findings

Regarding the relationship between environmental variables:

- All the environmental variables presented relationships to each other.
- The variables related to the temperature presented strong correlations: **air temperature**, **globe temperature sun and shadow** and **mean radiant temperature sun and shadow**.

Regarding the relationship between environmental and social variables:

- *Number of People* was mainly influenced by **light**.
- *Number of Groups of G1* presented moderate correlation with **light**.
- *Number of Groups of G2* were equally influenced by the **mean radiant temperature in the sun** and the **mean radiant temperature in the shadow**.
- *Number of Groups of G3* and *G4more* were correlated to **light**.

5.4.2.2. Multiple regression analysis

During this analysis, the environmental factors were treated as independent variables or predictors. The environmental variables analysed were: air temperature, relative humidity, globe temperature sun and shadow, calculated mean radiant temperature sun and shadow, wind speed and illuminance. On the other hand, the dependant or predicted variables were the social behaviours: Number of People, Number of Groups of G1, Number of Groups of G2, Number of Groups of G3 and Number of Groups of G4more.

The aim of this analysis was to build a model to predict Number of People and Number of Groups, based on their relationship with the environmental variables. In order to do this, 60% data sample was selected to perform the analysis. Subsequently, the outcome was tested with 40% of the data, which had been retained for the purpose of validating the results.

The analysis to choose which environmental variables explain better a behaviour, was made through an adaptation of a waterfall model, in which every step leaded naturally to the next step (Houghton et al., 2015, p. 225). Figure 52 illustrates the sequence of steps conducted to filter the data to obtain the final models. The waterfall consists of three steps and a validation, these are:

Correlation: It aimed to find the relationship between variables. From the results, only the variables which had correlation with the predicted variable were chosen. The highest correlation was selected as the best predictor.

Multicollinearity: This process was made to discard variables which are highly linearly related. The process consisted of correlating the best predictor to the rest of environmental variables and discarding those in which there is a strong relationship with the best predictor. Correlations smaller than $r = .80$ were safe to be used in the same model according to the procedure described by Field (2009). However, opting for a more conservative approach, all the correlations higher than $r = .75$ were discarded. This procedure was done to prevent biases of the model. If a regression model has two or more independent variables highly correlated to each other, it is not possible to identify the contribution that each of them is making to the prediction.

Waterfall scheme to select the best predictors of the behaviour

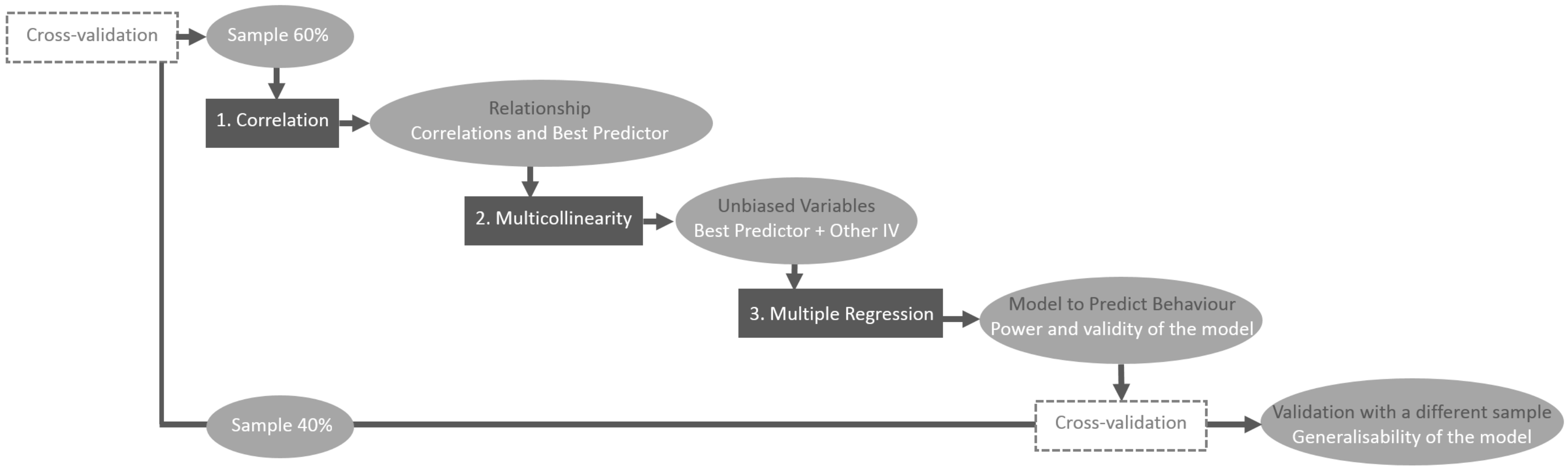


Figure 52 - Waterfall analysis to filter the variables per each model. Adaptation from the "waterfall model of the software life-cycle".

The Multiple Regression Model was conducted with the variables selected. The aim was to find the best model to predict the behaviour. The regression method selected was Forward. In this method all the variables are entered and the computer selected the best predictor by choosing the highest simple correlation. Subsequently, the computer selected the second criterion by choosing the highest semi-partial correlation in order to see additional contribution to the prediction. If the predictor made a significant contribution it was retained; otherwise, it was discarded (Field, 2009).

The equation obtained from the multiple regression model is made of a coefficient per predictor and the environmental variable. The models were tested by replacing the b-values in the regression equation according to the procedure described by Field (2009):

$$\boldsymbol{Y_i = (b_0 + b_1X_{i1} + b_2X_{i2} \ldots + b_nX_n) + \mathcal{E}_i}$$

Y = Outcome Variable

b_0 = Intercept with the Y axis

b_1 = Coefficient first predictor (X_1)

b_2 = Coefficient second predictor (X_2)

b_n = Coefficient n predictor (X_n)

$\mathcal{E}_i$ = Difference between the predicted and the observed value of Y

Model to Predict Number of People

Figure 53 presents the process to filter the variables for the model to predict *Number of People* (occupancy). The second column is the list of correlations found between Number of People and environmental factors. The correlations were listed from the highest to the lowest and only significant correlations were included. In the top is the variable light, which was identified as the best predictor, r = .46, p < .001. The other columns correspond to the process of identifying and discarding high correlations between independent variables.

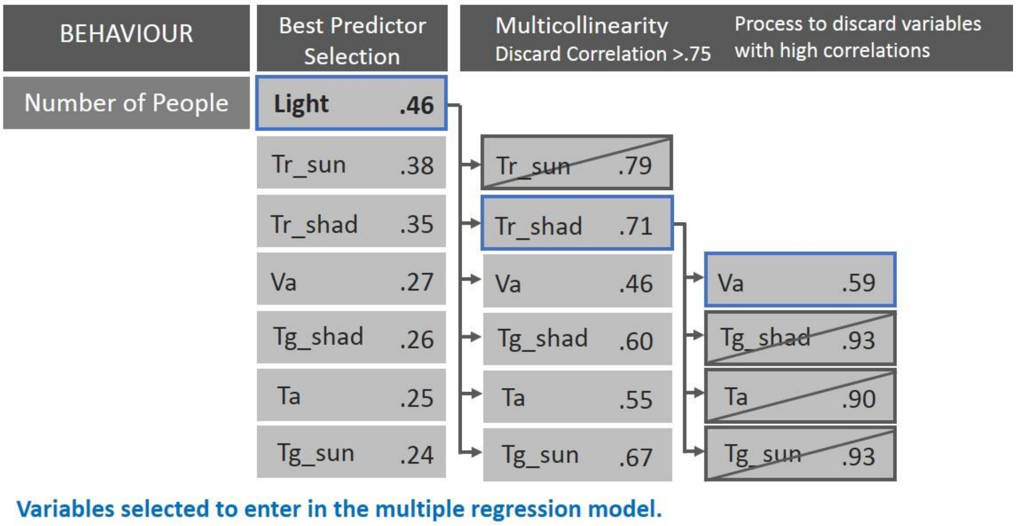


Figure 53 - Diagram variables filtered model to predict Number of People.

Acronyms: Tr: Mean Radiant Temperature (sun and shadow), Va: Wind Speed, Tg: Globe Temperature (sun and shadow) and Ta: Air Temperature.

The process of discarding consisted of checking the correlation between the best predictor with the other environmental variables. As an example, the third column in Figure 53 corresponds to the relationship between light with the other variables. After this filter it was found that there is multicollinearity between light and radiant temperature in the sun, so it was discarded. From the rest of the variables, radiant temperature in the shadow was the variable with the highest correlation with light, therefore, this variable was then selected to perform further correlations with the remaining variables, after which, those highly correlated with it were also discarded. This process was repeated until the variables were discarded because of high correlations (variables crossed) or selected to be part of the model (variables in blue).

The variables selected for the model to predict *Number of People* were: light, mean radiant temperature in the shadow (Tr_shad) and wind speed (Va). Table 23 presents the descriptive statistics of the model.

Table 23 - Variables included in the regression model

Descriptive Statistics

	Mean	Std. Deviation
N_People	25	12
Light	6880	4338
Tr_Sha	24.9	7.7
Va	.832	.689

Table 24 presents the variables entered during the different iterations made by the software SPSS. As mentioned before, the Forward method was used to evaluate the contribution of each independent variable generating different models to predict the dependant variable. All the variables from Table 23 were introduced in the order presented; however, SPSS selected only the ones that added power to the model. It is observed that the light and wind speed were considered as contributors, while the mean radiant temperature in the shadow was discarded.

Table 24 - List of variables added in every iteration

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: N_People

Table 25 contains the regression model summary. The first column indicates the number of models or iterations run according to the variables added. It is observed that when wind speed was added, it increased the simple correlation of the first model from r = .33 to r = .35. The adjusted R^2 of the models increased from .11 to .12. The *adjusted R^2* can be interpreted as the percentage of variation in the predicted variable which is accounted by the model (Field, 2009). This means that 11% of the variability of the *Number of People* was explained by light and 1% by the wind speed. Despite the small amount of contribution of the wind speed, the analysis was focused on the second model that seemed to be slightly higher predicting the *Number of People* during summer.

Table 25 - Regression model summary to predict Number of People in Summer

Model Summary[c]

Mode l	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.33[a]	.11	.11	10.93	.11	96.0	1	769	.000
2	.35[b]	.12	.12	10.88	.01	7.9	1	768	.005

a. Predictors: (Constant), Light

b. Predictors: (Constant), Light, Va

c. Dependent Variable: N_People

It is observed that the value of the R^2 and the adjusted-R^2 in the second model were the same (r = .12), meaning this that there is a good generalisability. According to Field (2009), this indicates that if the model resulted from the real population, then the variance of the outcomes would be minimum.

According to Field (2009), the ANOVA "tests whether the model is significantly better at predicting the outcome than using the mean as a 'best guess'" (p. 236). The result obtained in Table 26 was significant $p < .001$. The F-ration was greater than 1, meaning that the model is significantly better predicting the Number of People than using the mean Number of People.

Table 26 - ANOVA test Number of People - Summer

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	12407	2	6203	52	.000[c]
	Residual	90947	768	118		
	Total	103353	770			

a. Dependent Variable: N_People

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, Va

Table 27 presents the coefficients of the model to predict *Number of People* during summer. The third column (B) corresponds to the b-values of the model, these fractions are the individual contribution of the variables. The b-values were used in the regression equation to predict *Number of People* based on the light and wind speed.

Table 27 – Coefficients model to predict Number of People - Summer

Coefficients[a]

Model		Unstandardized		Standardiz	t	Sig.	95.0% Confidence	
		B	Std. Error	Beta			Lower	Upper
2	(Constan	18.391	.77		23.82	.000	16.876	19.907
	Light	.001	.00	.29	7.76	.000	.001	.001
	Va	1.763	.63	.10	2.81	.005	.533	2.994

a. Dependent Variable: N_People

Equation 1 - Model to predict Number of People - Summer

$$N\_People = b_0 + b_1 Light + b_2 Va$$

$$N\_People = 18.391 + (0.001 * Light) + (1.763 * Va)$$

It is observed that the light (b = .001) and wind speed (b = 1.763) had a positive relationship with the *Number of People*. The t-test (t) showed that the predictors made significant contributions to the model (light: p < .001, and wind speed p = .005). The Standardized Beta indicated that the greater contributor to the model was light (t(768) = .29, p < .001). The 95% Confidence Interval indicated the boundaries of the b-value. It is observed that none of the values obtained was below zero, this means that the model is representative of the true population.

Validation of the model to predict Number of People

The validation of the results was done using the 40% of the data retained (N = 489). To validate the equation, a new variable was created in SPSS called *PREDICTED_Number of People*. This variable used the *Equation 1 - Model to predict Number of People - Summer* and replacing the values of light and wind speed with the data collected in Trinity Square:

$$N\_People = 18.391 + (0.001 * Light) + (1.763 * Va)$$

As an example, the data of one of the minutes of the data set will be used. With a light level of 9181 lx and wind speed of 0.114 m/s, the model to predict number of people is:

$$Predicted\_N\_People = 18.391 + (0.001 * 9181) + (1763 * 0.114)$$

$$Predicted\_N\_People = 27.772$$

This result means that the *Number of People* under the environmental parameter introduced would be approximately 28. The result from the real data obtained from counting the number of people in the video for the minute selected was 23 people. However, this is just an example of several minutes measured under many different conditions tested.

In order to compare the real data against the predicted data, the results obtained of Predicted Number of People were correlated with the observed *Number of People* in Figure 54. It was observed that the model is limited as it calculates the *Number of People* within a range of 20 and 50 persons per minute in the square, whilst in reality the Number of People observed covered a range between 5 and 65 people.

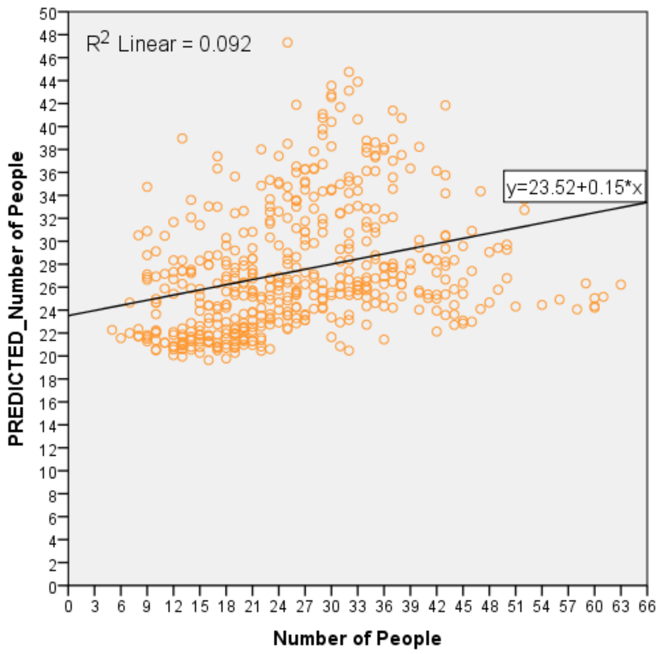


Figure 54 - Scatter plot Predicted Number of People and Number of People - Summer

Table 28 presents the simple correlation between the *PREDICTED_Number of People* and the real *Number of People* from the 40% of the data. The variables presented a moderate correlation $r = .30$, $p < .001$.

Table 28 - Correlation between the Predicted Number of People and the real Number of People

Correlations

		PRED_N_People	Number of People
PREDICTED Number of People	Pearson	1	.303**
	Sig. (2-tailed)		.000
Number of People	Pearson	.303**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

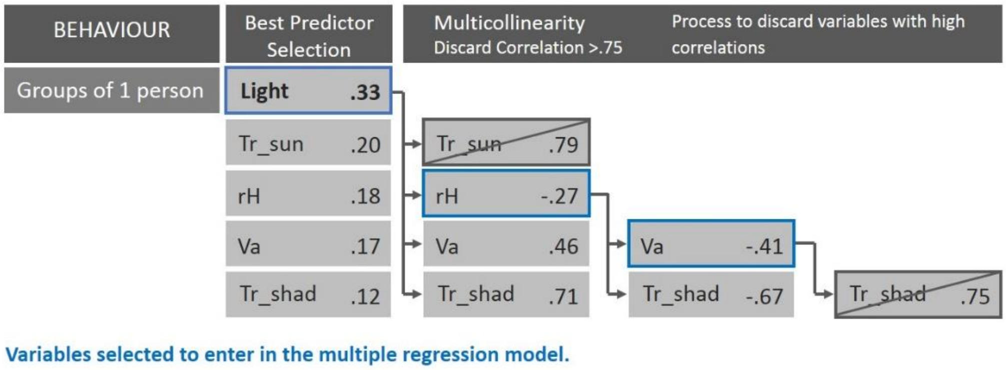
In conclusion, the *Number of People* was mainly influenced by the light and wind speed. The model built with these variables accounted for the 12% of the *Number of People* during summer, as can be seen in Table 25. The results were internally cross-validated obtaining a correlation of r = .30 (Table 28) which is a similar result to the simple correlation estimated by the model presented on Table 25, r = .35, p = .005.

Analysis of Number of Groups

The same procedure used to evaluate the *Number of People* was applied to analyse the group size. This section presents the summarised results of the models to predict *Number of groups of G1, G2, G3* and *G4more*.

With the aim of filtering the variables for each model, the best predictor was identified and the environmental variables that presented strong correlation between them were discarded for each type of group (Figure 55, Figure 56, Figure 57 and Figure 58).

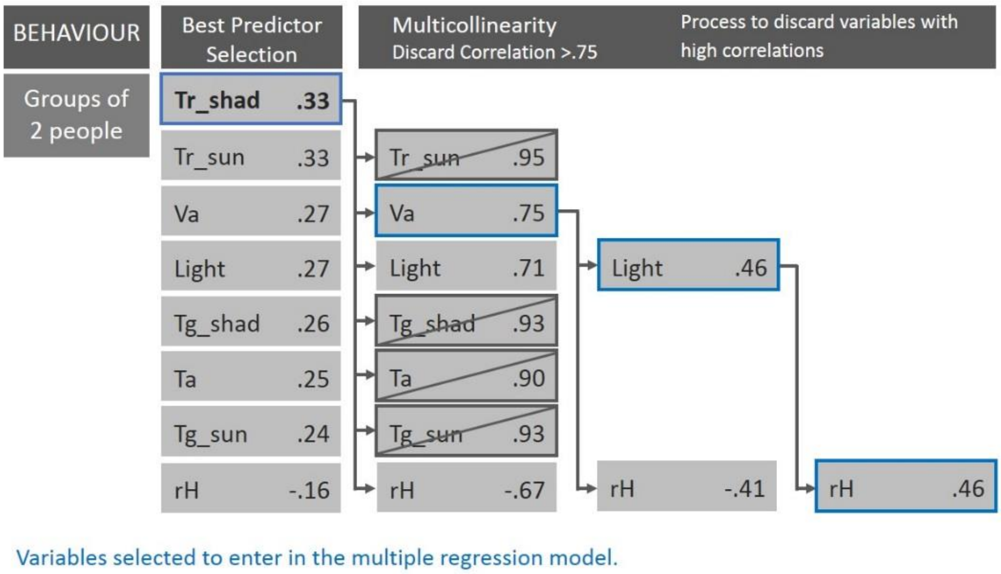
The variables selected for the model to predict *Number of Groups of G1* were: light, relative humidity (rH) and wind speed (Va). Some of the variables were not included in the analysis because they did not present correlation with *G1*. At the end, Tr_sun and Tr_shad were discarded because the presented high correlation with other environmental factors (Figure 55).



Acronyms: Illuminance (Light), Globe temperature in the sun (Tg_sun), relative humidity (rH), wind speed (Va), Mean radiant temperature in the shadow (Tr_shad).

Figure 55 - Diagram variables selected to predict Number of Groups of G1 - Summer.

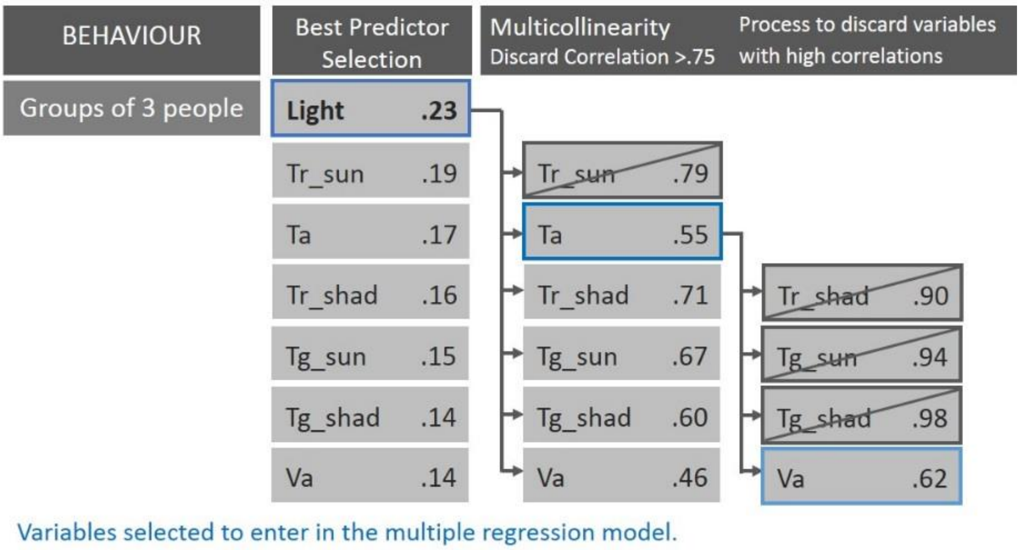
The variables selected to predict *Number of Groups of G2* were: mean radiant temperature in the shadow (Tr_shad), wind speed (Va), Light and relative humidity (rH). *G2* presented correlation with all the environmental variables, at the end Tr_sun, Tg_shad, Ta and Tg_shad were discarded because they had strong correlation with the main predictor (Figure 56).



Acronyms: Mean radiant temperature sun and shadow (Tr), wind speed (Va), globe temperature sun and shadow (Tg), air temperature (Ta), relative humidity (rH).

Figure 56 - Diagram variables selected to predict Number of Groups of G2 - Summer.

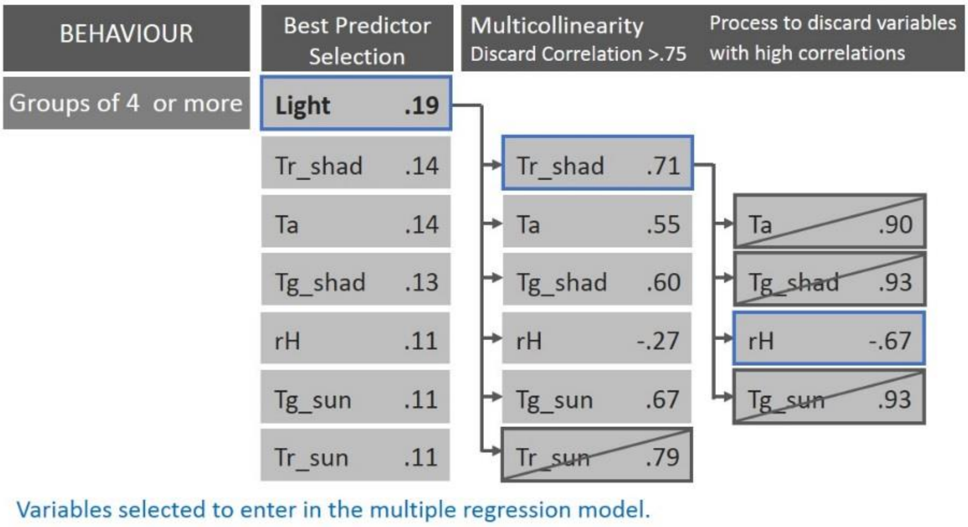
The variables selected to predict *Number of Groups of G3* were: light, air temperature and wind speed. Relative humidity did not present correlation with *G3*, therefore it was not included. Subsequently, Tr_sun, Tr_shad, Tg_sun and Tg_shad were discarded to prevent multicollinearity (Figure 57).



Acronyms: Illuminance (Light), Mean radiant temperature sun and shadow (Tr), Air Temperature (Ta), globe temperature sun and shadow (Tg), wind speed (Va).humidity (rH).

Figure 57 –Diagram variables selected to predict Number of Groups of G3 - Summer.

Finally, the variables selected to predict *Number of Groups of G4 or more* were: light, mean radiant temperature in the shadow and relative humidity. Wind speed was excluded from the beginning because did not present correlation with *G4more*. At the end, Tr_sun, Ta, Tg_shad and Tg_sun were discarded to prevent multicollinearity (Figure 58).



Acronyms: Illuminance (Light), Mean radiant temperature sun and shadow (Tr), air temperature (Ta), globe temperature sun and shadow (Tg), relative humidity (rH).

Figure 58 - Diagram variables selected to predict Groups of 4 or more.

Model to Predict Number of Groups of one person (G1)

Table 29 presents the summary of the regression models. It is observed that the first model is able to explain 9% of the occurrence of the number of people staying alone, while the third model increased this prediction up to 15% by adding two variables.

Table 29 - Regression model summary Number of Groups of G1 - Summer

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.31[a]	.09	.09	3.76	.09	79.6	1	769	.000
2	.37[b]	.14	.14	3.67	.05	41.5	1	768	.000
3	.39[c]	.16	.15	3.64	.02	14.1	1	767	.000

a. Predictors: (Constant), Light

b. Predictors: (Constant), Light, rH

c. Predictors: (Constant), Light, rH, Va

d. Dependent Variable: G1

However, when analysing the coefficients of each model. It is observed that the t-test of the constant values in model 2 and model 3 were not significant (p = .059 and p = .693 respectively, highlighted in red) (Table 30). Therefore, the model selected to predict *Number of Groups of G1* only considered the variable light.

Table 30 – Regression models coefficients - Summer

Coefficients[a]

Model		Unstandardized B	Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	Upper
1	(Constan	5.905	.25		23.24	.000	5.407	6.404
	Light	.0003	.00	.31	8.92	.000	.000	.000
2	(Constan	1.403	.74		1.89	.059	-.052	2.858
	Light	.000	.00	.37	10.57	.000	.000	.000
	rH	.073	.01	.22	6.44	.000	.051	.095
3	(Constan	.312	.79		.39	.693	-1.240	1.864
	Light	.000	.00	.32	8.63	.000	.000	.000
	rH	.085	.01	.26	7.30	.000	.062	.108
	Va	.820	.22	.14	3.75	.000	.391	1.250

a. Dependent Variable: G1

The b-values were used in the regression to predict *G1* (Equation 2):

Equation 2 - Model to predict G1 - Summer

$$Groups\ of\ G1 = b_0 + b_1 Light$$

$$Groups\ of\ G1 = 5.905 + (0.003 * Light)$$

This interpretation is true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G1

The validation of the model was done using the 40% of data retained for this purpose. A new variable called *PREDICTED_G1* was created in SPSS and the

Equation 2 was used for the calculation. Figure 59 presents the scatter plot between the *PREDICTED_G1* and the real *G1*. The y-axis correspond to the results of the prediction and the x-axis is the number of *G1* recorded in the data set.

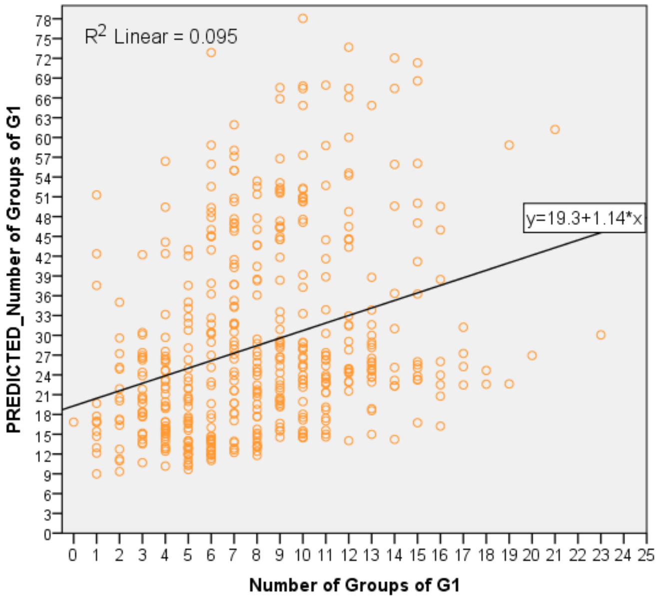


Figure 59 - Scatter plot Predicted G1 and G1 - Summer

Table 31 presents the simple correlation between *PREDICTED_G1* and the *Number of Groups of G1*. The result r = .30, p < .001 is similar to the simple correlation estimated for the model on Table 29, r = .31, p < .001.

Table 31 - Correlation between Predicted G1 and observed G1 - Summer

Correlations

		PREDICTED_G1	G1
PREDICTED_G1	Pearson Correlation	1	.309**
	Sig. (2-tailed)		.000
G1	Pearson Correlation	.309**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the number of groups of one person were influenced by the light. The selected model explained 9% of the presence of people alone. In Figure 59 is observed that the calculation is overestimating the presence of people alone.

Model to Predict Number of Groups of two persons (G2)

Table 32 presents the summary of the regression models to predict *Number of Groups of G2*. The first model is compound by the mean radiant temperature in the shadow and it is able to explain the presence of couples in 11%, $p < .001$. For the second model the relative humidity was added, the model improved 1% and the significant change was $p = .005$. The first model was selected based on the results obtained in Table 33 and described below.

Table 32 - Regression model to predict Number of Groups of G2 - Summer

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.34	.11	.11	2.59	.11	98.6	1	769	.000
2	.35	.12	.12	2.57	.01	8.0	1	768	.005

a. Predictors: (Constant), Tr_Sha

b. Predictors: (Constant), Tr_Sha, rH

c. Dependent Variable: G2

As described before, model 1 highlighted in blue was selected since the results of the t-test (t) of model 2 in Table 33 were not significant (Constant t (768) = -.63, p = .529) (highlighted in red).

Table 33 - Coefficients regression models to predict Number of Groups of G2 - Summer

Coefficients[a]

Model		Unstandardized		Standardize	t	Sig.	95.0% Confidence Interval	
		B	Std. Error	Beta			Lower	Upper
1	(Constant	1.673	.32		5.27	.000	1.050	2.296
	Tr_Sha	.121	.01	.34	9.93	.000	.097	.145
2	(Constant	-.529	.84		-.63	.529	-2.179	1.121
	Tr_Sha	.147	.02	.41	9.62	.000	.117	.177
	rH	.027	.01	.12	2.83	.005	.008	.046

a. Dependent Variable: G2

The model to predict *Number of Groups of G2* was built with the b-values of the constant and the mean radiant temperature in the shadow (Equation 3):

Equation 3 - Model to predict Number of Groups of G2 - Summer

$$Groups\ of\ G2 = b_0 + b_1 Tr\_shad$$

$$Grous\ of\ G2 = 1.673 + (0.121 * Tr\_shad)$$

This interpretation is true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G2

The validation of the model was done using the 40% of data retained. The results obtained with the *PREDICTED_G2* were compared with the observed *G2* (Figure 60). It is observed that the real data covers a wider range of number of couples up to 16, while the prediction (y-axis) reached up to 8 couples.

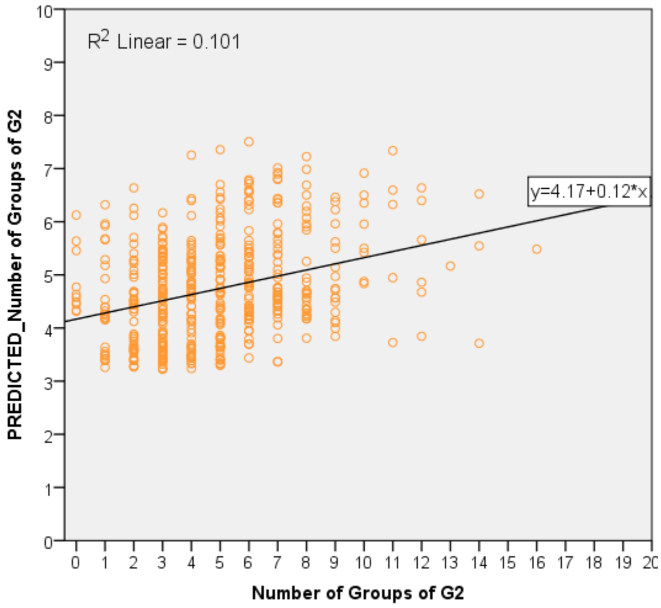


Figure 60 - Scatter plot Predicted Number of G2 and G2

Table 34 is the correlation between the *PREDICTED_G2* and *G2*. The result r = .31, p < .001 is similar to the simple correlation of the model r =.34 (Table 32).

Table 34 - Correlation between the Predicted Number of G2 and G2 - Summer

Correlations

		PREDICTED_G2	G2
PREDICTED_G2	Pearson Correlation	1	.317**
	Sig. (2-tailed)		.000
G2	Pearson Correlation	.317**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the multiple regression model to predict *Number of Groups of G2* based on the mean radiant temperature in the shadow explains 11% of the presence of couples. The other variables did not contribute to improve the model, therefore they were discarded.

Model to Predict Number of Groups of three people (G3)

Table 35 contains the summary of the regression model to predict *Number of Groups of G3*. It is observed that only the variable light was included as a contributor during the analysis. However, the results obtained are weak because the model presented a low adjusted R^2 = .05, which means that the model explains 5% of the presence of groups of three people.

Table 35 - Regression model summary to predict Number of Groups of G3 - summer

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.22[a]	.05	.05	1.20	.05	38.8	1	769	.000

a. Predictors: (Constant), Light

b. Dependent Variable: G3

According to the coefficients of the model presented on Table 36, the equation to predict G3 can be defined as:

Equation 4 - Model to predict Number of Groups of G3 - Summer

$$Groups\ of\ G3 = b_0 + b_1 Light$$

$$Groups\ of\ G3 = .821 + 0.00006 Light$$

Table 36 - Coefficients regression model to predict Number of Groups of G3 - Summer

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
1	(Constan	.821	.08		10.10	.000	.661	.980
	Light	6.223E-5	.00	.22	6.23	.000	.000	.000

a. Dependent Variable: G3

Validation of the Model to Predict Number of G3

The results of the model were tested in the 40% of data retained for this purpose. Equation 4 was introduce as a new variable and the values of light were replaced. The resultant variable of this process was called *PREDICTED_G3* and the data was compared against the real number of groups of three people observed per minute.

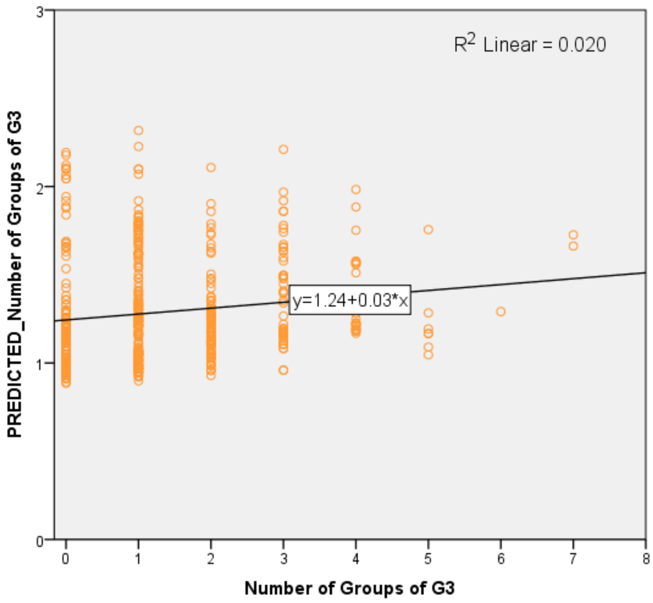


Figure 61 - Scatter plot of Predicted G3 and G3

Table 37 - Correlation between Predicted G3 and G3

Correlations

		PREDICTED_G3	G3
PREDICTED_G3	Pearson Correlation	1	.140**
	Sig. (2-tailed)		.002
G3	Pearson Correlation	.140**	1
	Sig. (2-tailed)	.002	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 37 contains the correlation between *PREDICTED_G3* and observed *G3*. The results r = .14 indicate a low correlation between the prediction and the data gathered. This correlation differs from the simple correlation of the model r = .22 (Table 35).

In conclusion, the multiple regression model presented weak results to predict the number of groups of three. It is observed by the analysis that the light had some influence in this type of groups, however the strength of their relationship is not enough to stablish a model able to predict more than 5% of the presence of *G3*.

Model to Predict Number of Groups of four or more people (G4more)

In Table 38 is observed that the first model was built with relative humidity with very low percentage of predictability (1%). The second model with the mean radiant temperature in the shadow increased the Adjusted R^2 to .05.

Table 38 - Regression model summary G4more - Summer

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.1	.01	.01	.98	.01	10.8	1	769	.001
2	.2	.06	.05	.96	.04	33.6	1	768	.000

a. Predictors: (Constant), rH

b. Predictors: (Constant), rH, Tr_Sha

c. Dependent Variable: G4more

Table 39 presents the coefficients of the regression model to predict *G4more*. The t-test of the model presented significant results ($p < .001$) and the

Standardized Coefficient (Beta) suggested that the relative humidity and the mean radiant temperature in the shadow had the same importance in the model (rH β = .27 and Tr_shad β = .26). The b-values (B) were used for the regression Equation 5:

Table 39 - Coefficients regression model to predict Number of Groups of G4more - Summer

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardize Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
2	(Constant)	-1.292	.31		-	.000	-1.909	-.675
	rH	.022	.00	.27	6.20	.000	.015	.029
	Tr_Sha	.033	.01	.26	5.80	.000	.022	.044

a. Dependent Variable: G4more

Equation 5 – Model to predict Number of Groups of G4 or more - Summer

$$Groups\ of\ G4more = b_0 + b_1 rH + b_2 Tr\_shad$$

$$Groups\ of\ G4more = -1.292 + (0.022 * rH) + (0.33 * Tr\_shad)$$

Validation of the Model to Predict Number of Groups of G4more

The results of the model were tested with the 40% of data retained for this purpose. Equation 5 was calculated using the data set of relative humidity and mean radiant temperature in the shadow. Figure 62 is the scatter plot of the prediction against the real data. It is observed a lack of a pattern between both variables. The *Predicted_G4more* on the y-axis had a range between 4 and 16 groups of four or more people at the same time, while the real observation was limited between 0 and 4 groups.

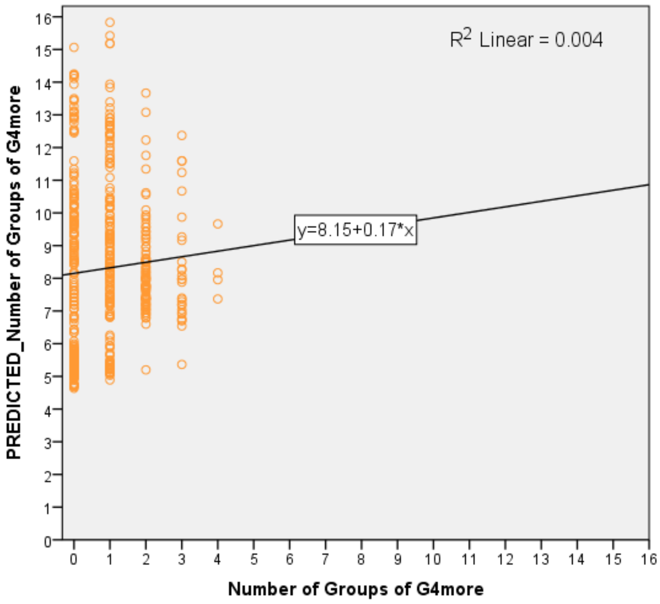


Figure 62 - Scatter plot of Predicted G4more and G4

Table 40 presents the simple correlation between both variables. The result r = .06, p = .152 indicate a poor prediction and non-significant results of the model.

Table 40 - Correlation between Predicted G4more and G4more

Correlations

		PREDICTED_G4more	G4mor
PREDICTED_G4more	Pearson Correlation	1	.065
	Sig. (2-tailed)		.152
G4more	Pearson Correlation	.065	1
	Sig. (2-tailed)	.152	

In conclusion, the presence of groups of four or more people presented very weak correlations with the thermal environment during summer. The multiple regression model was not able to explain or predict the *Number of Groups of G4more*.

Multiple Regressions - Number of People and Groups: Key Findings

- *Number of People* 12% of the variance is explained by light and wind speed.

$$N\_People = 18.391 + (0.001 * Light) + (1.763 * Va)$$

- *Number of Groups of G1* were influenced by the light. This model was able to explain 9% of the presence of people alone.

$$Groups\ of\ G1 = 5.905 + (0.003 * Light)$$

- *Number of Groups of G2* were influenced by the calculated mean radiant temperature in the shadow (Table 33). This variable was able to explain 11% of the presence of couples as can be observed in Table 32.

$$Groups\ of\ G2 = 1.673 + (0.121 * Tr\_shad)$$

- *Number of Groups of G3* and *G4 or more* presented weak relationship with the thermal environment, which can be explained be the small sample collected of this two groups. The model for ***G3*** was able to predict up to 5% of the presence of trios. On the other hand, ***G4more*** was not able to be predicted because of the lack of significance in the results to explain the variance of the presence of these types of groups.

5.4.2.3. Cluster analysis

As mentioned in the General Methodology (Chapter 3), the cluster analysis is used to obtain objective and stable data by classifying the objects of a group using the same numerical methods (Everitt et al., 2011). A two-step cluster analysis was performed using SPSS. The continuous variables selected were: number of groups of 'G1', 'G2', 'G3' and 'G4 or more'. The evaluation field was the Number of People. Figure 63, presents the importance of each variable to create the clusters and Figure 64 presents the cluster quality rate. The variables used presented a 'fair' quality for clustering the data. It is observed that G4more made the highest contribution to the classification. This must be due to the fact that each group of this type contains a higher number of people.

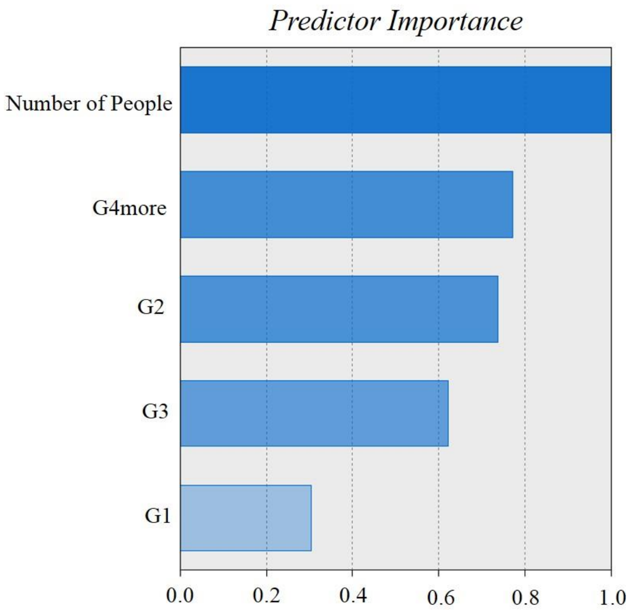


Figure 63 – Predictor Importance of variables for cluster analysis

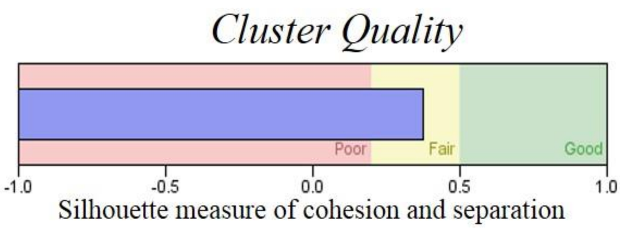


Figure 64 – Cluster Quality Rate

Figure 65 presents the relationship between the Number of People, Number of Groups and Clusters (R^2 = 0.85). It is observed that cluster 1 presented more spread data than the other clusters. Cluster 2 presents a similar slope to the fit line with a possible different intercept as the data is over the line. Conversely, cluster 3 is located below the fit line and may have a higher slop and lower intercept. Finally, cluster 4 seems to have a similar fit line to the whole dataset.

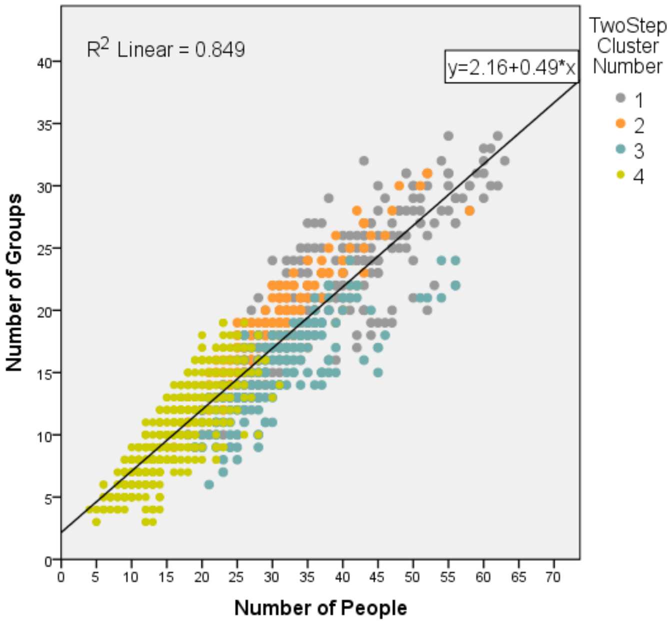


Figure 65 - Relationship between Number of People, Number of Groups and Clusters – Summer

Cluster Analysis: Key Findings

- Number of People and Number of Groups presented a strong relationship (R^2 = 0.85).
- The number of G4more and G2 were the main predictors to generate the clusters.

5.4.3. Individual Behaviour

As mentioned before, the analysis of the behaviour was divided in Social and Individual Behaviour. The sample of the Individual Behaviour were the users that remained in the square, a total of 2330 people were observed 52.1% men and 47.9% women. The sample consisted of 87.3% adults, 3.9% teenagers, 5.7% children, 1.1% babies and 1.9% mobility reduced users.

The behaviour analysed per person were: Time of Permanence, Body Postures (time and postural changes), Adaptive Behaviours and Activities. The behaviour was classified in time dependant or point events, depending on their duration. In this section the results of Time of Permanence will be presented, and in Chapter 08 – Human Behaviour in all-seasons, will be presented the results of the Body Postures, Adaptive Behaviours and Activities.

The observational analysis of the behaviour was made by registering the duration of the event, for the time dependant behaviour, or by registering its frequency and/or the moment of occurrence, for the instantaneous behaviour or point events. For the time dependant behaviour, a survival analysis was conducted. This is a statistical technique to evaluate the duration of the behaviour.

5.4.3.1. Survival Analysis

With the aim of analysing the influence of different factors on the Time of Permanence (period of time users remained in the square), a survival analysis was performed using the non-parametric Kaplan-Meier estimator. This test displayed a cumulative survival probability per variable. .

The results of the Kaplan-Meier presented the means and medians of the survival time, however the results of the cumulative survival curved were generated by time points. Therefore, in the cases with significant results it is displayed a table with the summary of the cumulative survival analysis at different times.

Time of Permanence and Gender

The survival analysis was also applied to determine whether there is any difference on the Time of Permanence according to the Gender of the users. Table 41 contains the means and medians of the survival time obtained. It is observed that the estimated median Time of Permanence for men was 7.00 minutes and 6.70 minutes for women. The median corresponds to the time when 50% of the users left the square.

Table 41 - Mean and medians of Survival Time according to Gender

Means and Medians for Survival Time

	Mean[a]				Median			
Gender	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper	Estimate	Std. Erro	95% Confidence Interval Lower	95% Confidence Interval Upper
Male	9.95	.29	9.39	10.52	7.00	.22	6.57	7.43
Female	9.14	.24	8.66	9.62	6.70	.25	6.21	7.19
Overall	9.56	.19	9.19	9.94	6.80	.17	6.47	7.13

a. Estimation is limited to the largest survival time if it is censored.

Figure 70 presents the survival curve of *Time of Permanence* according to the *Gender*. The y-axis of the chart represents the cumulative survival, where 1 is the survival in 100% of the cases and the x-axis is the time in minutes. This means that at the beginning, or 0 minutes, the cumulative survival is 1, or 100% of the sample and it starts to decrease as the users leave the place.

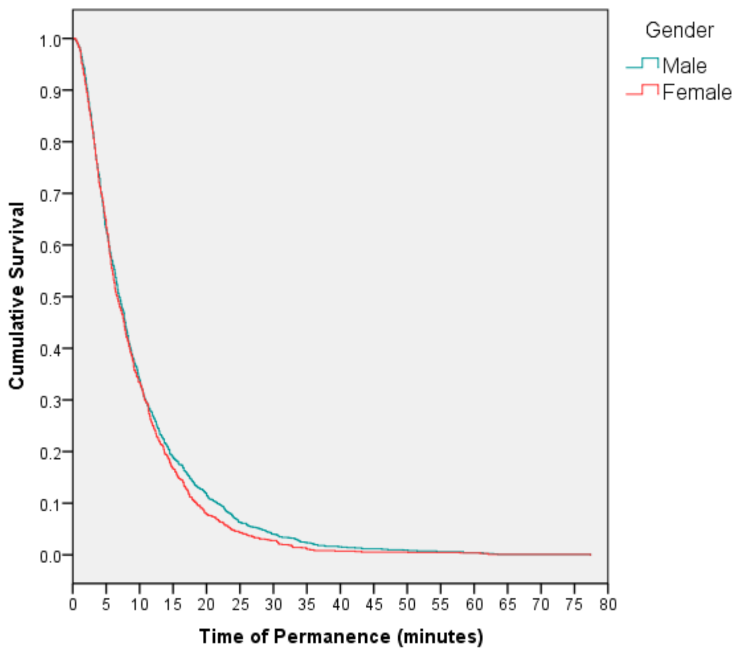


Figure 66 - Survival Function Time of Permanence according to Gender - Summer

It was observed that the red line (women) was delayed for a few minutes between 0% and 20% of the population. This indicates a shorter permanence of women in comparison to men. However, since both curves are very similar, a Log-rank test was performed to determine whether there is a significant difference. This analysis is used to test the null hypothesis of no difference in survival times between the curves. Table 42 presents the results of the Log-Rank, p = 0.05. This indicated that the Gender curves did not present a significant difference in the Time of Permanence.

Table 42 - Log Rank test results

Overall Comparisons

	Chi-Square	df	Sig.
Log Rank (Mantel-Cox)	3.909	1	.048

Test of equality of survival distributions for the different levels of Gender.

In conclusion, the *Gender* did not affect significantly the *Time of Permanence*.

Time of Permanence and Environmental Factors

In order to analyse the influence of the environmental factors in the Time of Permanence of the people in the square, a survival analysis per variable was performed. To conduct the analysis, pre-processing of the data was necessary to bin the results so they could be visualised by ranges (e.g. air temperature was binned every 1°C, so the survival curves are plotted at 8.1 - 9.0°C, 9.1 - 10.0°C, 10.1 – 11.0°C, etc.), this was conducted in accordance to the procedure done by Haldi & Robinson (2009). The most relevant results will be presented next.

Figure 67 correspond to the survival curve of the *Time of Permanence* according to the relative humidity. It is observed that the longest *Times of Permanence* occurred at lowest ranges of humidity 36% to 45% and the shortest at the highest levels of humidity (red lines).

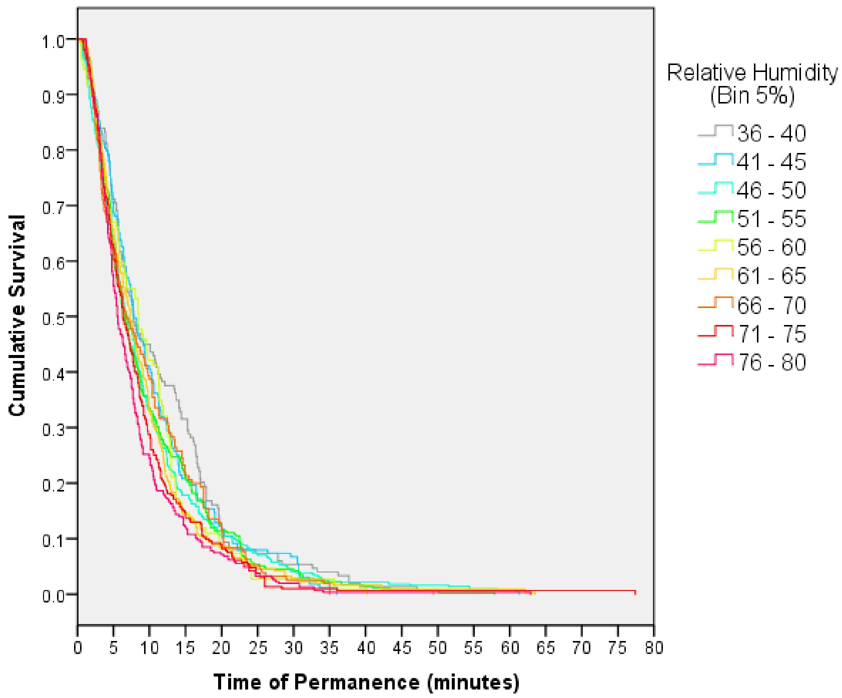


Figure 67 - Survival function curves Time of Permanence and relative humidity - Summer

The general result of the means and medians values of the survival time are presented on Table 43. It is observed that the estimated mean is 12.2 min at 36% – 40% of relative humidity and this value decreased up to 8 min over 76% of humidity.

Table 43 - Means and Medians of the survival time according to the relative humidity

Means and Medians for Survival Time

rH (Bin 5%)	Mean[a]				Median			
	Estimate	Std. Error	95% Confidence		Estimate	Std. Error	95% Confidence	
			Lower	Upper			Lower	Upper
36 - 40	12.2	1.2	9.9	14.5	7.8	.9	6.0	9.6
41 - 45	10.4	.6	9.2	11.7	7.8	.7	6.4	9.2
46 - 50	9.8	.4	8.9	10.6	6.8	.4	6.1	7.5
51 - 55	9.9	.5	8.9	10.8	6.6	.3	5.9	7.3
56 - 60	9.6	.7	8.2	11.0	8.5	1.2	6.1	10.9
61 - 65	9.4	.5	8.5	10.4	7.3	.4	6.4	8.2
66 - 70	9.7	.6	8.4	10.9	6.8	.9	5.1	8.5
71 - 75	8.7	.5	7.8	9.7	6.3	.4	5.5	7.1
76+	8.0	.4	7.2	8.8	5.5	.4	4.8	6.2
Overall	9.6	.2	9.2	9.9	6.8	.2	6.5	7.1

a. Estimation is limited to the largest survival time if it is censored.

Table 44 is the summary of the cumulative proportion of people. The analysis was conducted to identify the percentage of people that stayed in the square certain time under certain conditions of relative humidity. For example, the analysis showed that 45% of the people stayed for more than 10 minutes when the relative humidity oscillated between 36% and 40%, while only 25% decided to stay when the relative humidity was over 76%. The cumulative summary presents results up to 40 minutes of permanence.

Table 44 - Summary cumulative proportion of people and relative humidity indicated

Time (min)	*Relative Humidity (rH, %)* 36 - 40	41 - 45	46 - 50	51 - 55	56 - 60	61 - 65	66 - 70	71 - 75	76+
1	97%	95%	97%	100%	95%	99%	98%	98%	100%
5	70%	70%	65%	60%	67%	66%	61%	63%	56%
10	45%	40%	33%	34%	42%	33%	39%	29%	25%
15	32%	20%	18%	22%	15%	14%	21%	14%	12%
20	12%	10%	10%	12%	7%	9%	12%	9%	7%
25	8%	8%	7%	6%	3%	5%	5%	4%	3%
30	5%	7%	4%	4%	3%	3%	3%	1%	1%
35	4%	1%	2%	3%	2%	2%	0%	1%	0%
40	1%	0%	2%	1%	0%	2%	0%	0%	0%

Figure 68 contains the survival curves of the *Time of Permanence* according to the calculated mean radiant temperature in the sun. It is observed that high and low mean radiant temperatures (red and blue) presented the shortest time of permanence.

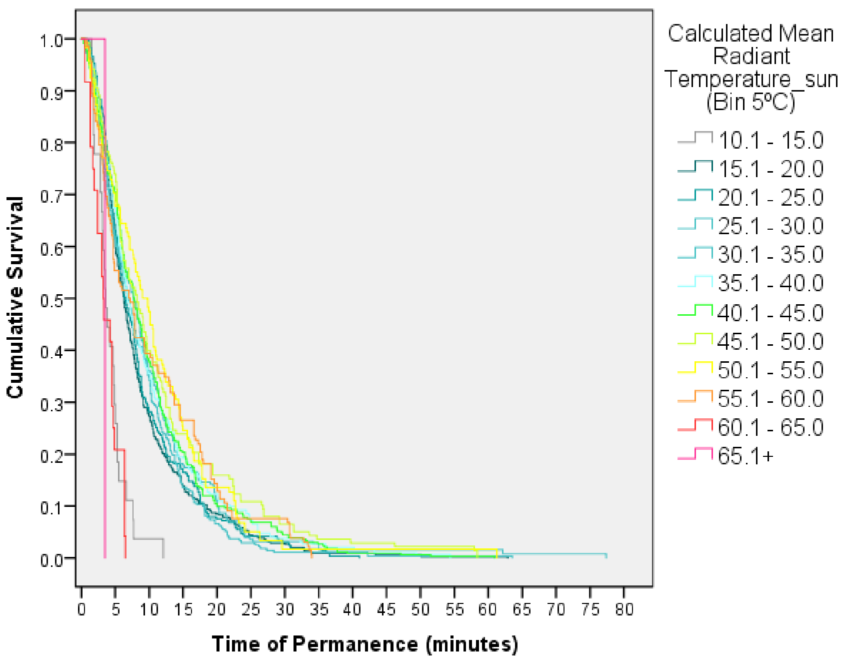


Figure 68 - Survival function Time of Permanence and calculated mean radiant temperature_sun

In Figure 68, the yellow and green lines which correspond to the median measurements calculated of the Mean Radiant Temperature in the sun (between 35°C to 50°C) presented the longest times of permanence.

Table 45 - Means and Medians survival time according to the calculated mean radiant temperature_sun

Means and Medians for Survival Time

Tr_sun (Bin 5°C)	Mean[a]				Median			
	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper
<= 15.0	4.2	.5	3.3	5.1	3.6	.3	2.9	4.3
15.1 - 20.0	8.8	.4	8.0	9.5	6.3	.3	5.7	6.9
20.1 - 25.0	8.9	.4	8.1	9.7	6.5	.5	5.6	7.4
25.1 - 30.0	8.9	.4	8.0	9.8	7.7	.5	6.6	8.8
30.1 - 35.0	9.8	.7	8.5	11.1	6.8	.5	5.9	7.7
35.1 - 40.0	**10.0**	.5	8.9	11.0	6.8	.4	6.1	7.5
40.1 - 45.0	**10.5**	.6	9.3	11.8	7.7	.6	6.5	8.9
45.1 - 50.0	**11.6**	1.0	9.7	13.5	8.2	1.0	6.2	10.2
50.1 - 55.0	**11.1**	.9	9.3	12.8	9.0	1.0	7.1	10.9
55.1 - 60.0	**10.2**	.8	8.7	11.7	7.0	1.0	5.0	9.0
60.1 - 65.0	3.6	.4	2.8	4.3	3.2	.9	1.5	4.9
65.1+	3.5	.0	3.5	3.5	3.5	.	.	.
Overall	9.6	.2	9.2	9.9	6.8	.2	6.5	7.1

a. Estimation is limited to the largest survival time if it is censored.

The general results of the survival analysis are presented on Table 45. It is observed that the estimate median *Time of Permanence* is higher in the bins between 35.1°C and 60.0°C of calculated Mean Radiant Temperature in the Sun (equal or higher than 10 minutes).

The proportion of people remaining in the square under certain conditions of mean radiant temperature are summarised in Table 46. It is worth mentioning that the survival probabilities depend on the time of occurrence of the events, therefore, they are reported at certain time/temperature points. The percentage correspond to the amount of people that remained in the square. For instance, it is observed that as reported before the middle values (30°C to 55°C) presented longer permanencies, since more than 10% of the users decided to stay in the square after 20 minutes.

Table 46 - Summary proportion of people remaining according to the mean radiant temperature_sun

	Mean Radiant Temperature_sun (Tr_sun, °C)										
Time (min)	<= 15.0	15.1 - 20.0	20.1 - 25.0	25.1 - 30.0	30.1 - 35.0	35.1 - 40.0	40.1 - 45.0	45.1 - 50.0	50.1 - 55.0	55.1 - 60.0	60.1 - 65.0
1	93%	100 %	100%	99%	97%	98%	96%	99%	98%	98%	92%
5	26%	62%	64%	61%	62%	68%	70%	74%	70%	96%	21%
10	4%	28%	28%	35%	36%	36%	38%	40%	48%	39%	0%
15	0%	14%	17%	14%	18%	20%	20%	24%	25%	27%	0%
20	0%	9%	8%	7%	10%	12%	11%	16%	14%	14%	0%
25	0%	5%	4%	3%	4%	7%	8%	11%	5%	8%	0%
30	0%	3%	3%	1%	3%	4%	5%	7%	2%	8%	0%
35	0%	1%	2%	0%	3%	3%	3%	4%	0%	0%	0%
40	0%	0%	0%	0%	0%	2%	1%	3%	0%	0%	0%

The cumulative curves of the *Time of Permanence* according to the other variables (air temperature, globe temperature in the sun and shadow, mean radiant temperature in the shadow, wind speed and light) are presented in the Appendix 2.

Survival Analysis – Time of Permanence during winter: Key Findings

- ***Gender*** did not influence the ***Time of Permanence*** during summer.
- The ***Time of Permanence*** was influenced by the ***relative humidity***. The shortest permanencies occurred during the highest levels of humidity and vice versa.
- The ***Time of Permanence*** was influenced by ***the mean radiant temperature in the sun***. The longest and shortest permanencies occurred at the low and high temperatures, indicating a preference for the median mean radiant temperature.

5.5. Discussion

This chapter presents a study which aimed to analyse the influence of the built environment over the behaviour of people during summer. Various environmental factors were evaluated in order to determine whether there is a relationship between these variables and human behaviour to generate data that can predict future behaviour in outdoor public spaces.

According to the study conducted, the environmental factors that influence the *Number of People* and *Groups* in the outdoor public space in summer are: illuminance, wind speed and calculated mean radiant temperature in the shadow. On the other hand, the factors that affected the *Time of Permanence* of the people in the outdoor public space were: relative humidity and mean radiant temperature in the sun.

An interesting finding was the relationship observed between the light and the presence of people (*Number of People* and Number of Groups of G1) in the evaluated area. This means that the presence of high natural ligh influenced the decision of people to stay in a given place. Several studies associated the attendance of people to outdoor public spaces mainly with temperature-related environmental variables. For instance, Zacharias et al. (2001) studied the effect of the air temperature and the sunlight over the attendance of people to an outdoor space during spring, summer and autumn; Thorsson et al. (2004) reported the number of people in a park as a function of the mean radiant temperature during July and October in Gothenburg; Nikolopoulou et al. (2001) found a relationship between the average globe temperature and the number of people during spring, summer and winter.

However, the results of this study have suggested that the visual environment plays an important role in the attendance of people to an outdoor public space during summer. According to Eliasson et al. (2007) the clearness (sky) index presented a correlation with the attendance in a study conducted in Gothenburg. In their regression model they concluded that this factor and the air temperature and wind speed influenced the attendance of people.

It is worth mentioning that light has not usually been included in previous studies about the human behaviour in outdoor public spaces, since these studies commonly focus on determining the thermal comfort of users and the thermoregulation of the human body. Nevertheless, some authors have included measurements of daylight in the shade and the sun by conducting surveys, observations and simulations, in addition to the thermal comfort evaluations (e.g. Nikolopoulou et al. (2004)). Nasar & Yurdakul (1990) also studied the presence of sunlight in the public space, reporting that more people decided to sit or stand in shaded areas: "where there was a choice between sunny and shaded wall-side location, the shaded ones were selected" (p. 81). The present study has corroborated the importance of studying illuminance along with the thermal environment as a correlation has been found between light and the air temperature and globe and radiant temperatures. Moreover, light was found to be the best predictor of *Number of People* and *Number of Groups* of one person during summer. This also shows the importance of conducting separate analysis of the environmental conditions on each season, in addition to the overall analysis of the dataset.

The equation to Predict Number of People was also improved by adding the wind speed coefficient: *N_People = 18.391 + (0.001*Light)+(1.763*Va)* (R^2= .12). According to the outcome of this study, during summer, as the air velocity increased the *Number of People* also increased. However, this positive reaction by people to increasing wind speeds has not been found to occur in other seasons. For instance, Givoni et al. (2003) conducted a study to determine the thermal satisfaction in different seasons in Japan. In their model which included all the seasons together, the wind speed presented a negative contribution, meaning that people's thermal satisfaction was reduced as the wind speed increased: *TS = 1.2 + (0.1115*Air Temperature) + (0.0019*Solar Radiation) + (-0.3185*Wind Speed)* (R^2 = .87).

According to Kroemer et al. (2001), the thermoregulation system of the body works in a way that the heat produced must be dissipated by losing it through convection, conduction or radiation. However, if that dissipation is not sufficient the sweat glands are activated and the evaporation helps to cool down the body skin. Therefore, the movement of the air helps dissipating the heat of the body by convection and evaporation, which is why air is an important factor to determine the thermal satisfaction during summer and not during cold seasons. This physiological response to the thermal environment may explain the increase of number of people in outdoor spaces during summer when the wind speed is also increasing. However, it was observed that the time of permanence was affected with velocities over 2m/s.

Regarding *Number of Groups of G2*, the main influencer was the mean radiant temperature in the shadow, since these kind of groupings increased as this environmental factor increased. This results agrees with Lin et al. (2013) which suggests that the attendance of people to outdoor public spaces increases with the shade availability. This result suggests that couples prefer to remain in places without direct solar radiation.

The attendance of groups of three, four or more people did not present significant relationship with the environmental factors. This may be explained by the fact that interacting in bigger groups is more influenced by other social variables. However, the cluster analysis suggests that groups of G4more and groups of G2 could generate good predictions of the Number of People (Figure 63).

In order to analyse the influence of the groups' size, this research proposes the 'Group Diversity Index' (GDI) as a test to measure the quality of spaces based on the variety of groups present in simultaneity in a built environment outdoors (Table 47). The index consists of a scale between 0 and 1, being 0 the situation where no groups are present in the place and 1 where all the types of groups are present there. The middle ranges of this index are: a rate of 0.25 when the space had only 1 type of group, 0.5 when the place had at least 2 types of groups, and 0.75 when at least three types of groups were present at the same time.

Figure 69 presents the relationship between Number of Groups, Number of People and the 'Groups' Diversity Index' (GDI). It is observed that the variety of groups is higher (1.00) when the number of people and groups are higher.

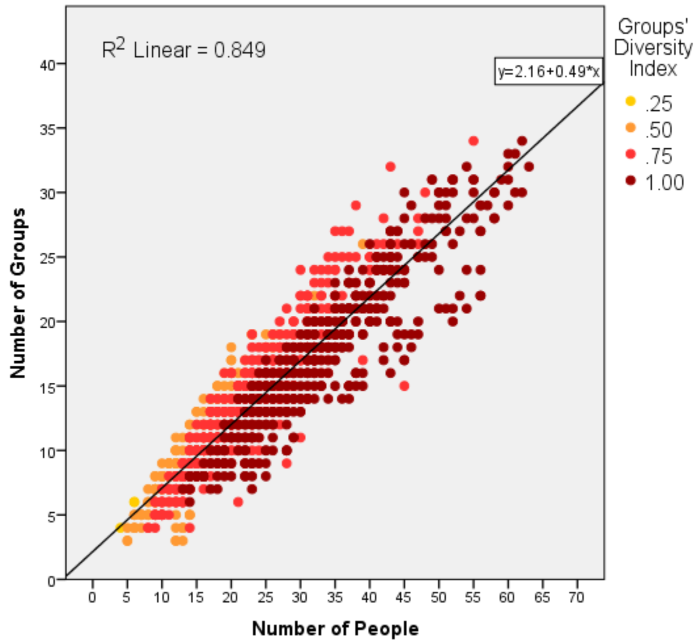


Figure 69 – Scatter Plot Number of Groups, Number of People and GDI - Summer

Table 47 presents the Group Diversity Index in summer. As can be seen in the Index, summer presents a very high rate of groups' diversity, between 0.75 and 1.00. This is because 83% of the time, the square was occupied by at least three types of groups (e.g. people alone, couples, groups of three and big groups of four or more).

Table 47 - Groups Diversity Index (GDI) - Summer

Groups Diversity Index			
		Frequency	Percent
Valid	0	0	0
	.25	3	.2
	.50	209	16.6
	.75	597	47.4
	1.00	451	35.8
	Total	1260	100.0

As observed in Table 47 - Groups Diversity Index (GDI) - Summer, most of the time, there were three types of groups, corresponding to 47.4% of the time, followed by the rate of four types of groups, which occurred simultaneously during 35.8% of the time. According to this, Trinity square is a successful space in terms of quality in summer as it is used by a variety of groups simultaneously most of the time. As described by Whyte (2009): "the best-used plazas are sociable places, with a higher proportion of couples and groups than you will find in less used places" (p. 111). Accordingly, the 'Groups' Diversity Index' (GDI) allows measuring the diversity of use of the space, which can be also considered as a rate of success of public spaces.

Zacharias (2004) evaluated the effects of microclimatic conditions in different plazas of San Francisco. In this study the researcher evaluated different behaviours of 12,378 individual but took a sample of only 100 individuals to evaluate the time of permanence and the relationship with the thermal environment. He reported that no significant correlation was found between the duration of the stay and the temperature, but suggested that a much larger sample would be needed "to determine whether a relationship exists between stay duration and microclimate" (p. 647). The researcher also suggested that "other factors such as an ongoing conversation, lunch with another person, or reading material, lead to longer stays" (p.647).

Contrary to the findings reported by Zacharias (2004), this study found a pattern in the cumulative survival curves between the time of permanence, the relative humidity and the mean radiant temperature in the sun. According to the analysis conducted in the present study, at low levels of relative humidity the time of permanence of the people in the square increased. This may be explained by the fact that lower levels of humidity in the air allow a more efficient evaporation of the sweat and therefore a better cooling of the body. The heat loss of the body depends on the wet body surface and the humidity of the air, with higher humidity the evaporative heat loss is more difficult than with dryer air (Kroemer, Kroemer, & Kroemer-Elbert, 2001). This result has also an interesting link with the equation of the number of people, since one of the variables of that equation was the wind speed which is a factor that helps to reduce the body heat by convection and evaporation as reported before, taking into account that the time of permanence was affected with velocities over 2m/s.

In the case of the calculated mean radian temperature in the sun, the days in the mid-range of temperature, between 30ºC and 50ºC, motivated the longest times of permanencies. This means that the days that were neither hot nor cold presented the optimum conditions to remain for longer periods of time.

The overall results suggest that the illuminance played an important role during summer, since the light was one of the main predictors of the social behaviours. Other studies such as the subjective measurements and climatic conditions conducted by Eliasson et al. (2007), suggested that the clearness (sky) index presented a correlation with the positive perception of the users about the place to conduct outdoor activities. The natural light levels in the built environment are affected by the solar access, which is sometime obstructed by tall buildings and the reflectance of the materials. The results of this study pointed to this aspects as factors to take into account to improve the attendance of people to outdoor spaces in summer.

Similarly, the efficiency of the thermoregulation of the body seemed to play an important role in the attendance and permanence in outdoor public spaces in summer. Therefore, strategies such as allowing wind flow in the seating areas and controlling the solar radiation through shading devices, to allow the option of remain in the sun or in the shadow, could motivate the attendance and permanence of users in the public space during summer.

The results of this study are limited by the location of the sample and the characteristics of Trinity Square. Nevertheless, the place selected for this study presents similar characteristics to other public squares in the United Kingdom and even other countries in Europe.

5.6. Conclusions

This study evaluated the influence of the environment in social and individual behaviours during summer. It showed that illuminance, wind speed and mean radiant temperature in the shadow influenced the social behaviour of the people in outdoors, while the relative humidity and the mean radiant temperature in the sun affected the individual behaviours. The models were compared with studies of thermal satisfaction and attendance to public spaces. The results obtained and the analysis of the three seasons conducted (Chapter 8) indicate that it is necessary to undertake an evaluation of the environmental factors in each season independently in addition to the overall analysis, as the way the environment influences the human behaviour varies with each season.

This chapter presented the models to predict *Number of People*, *Number of Groups of G1, G2, G3 and G4more* and *Time of Permanence* according to the environmental characteristics of summer. The cross-validation of the models and the prediction power were presented.

It was reported that the results are limited to the characteristics of Trinity Square and Nottingham. However, the tendency of the behaviour and the general understanding of the influence of the thermal conditions presented comparable results with other studies conducted in different locations, which shows the generalisability of the results and is a further step in the development of the understanding of the use of public spaces. Some general ideas of how these results may affect the characteristics of the built environment were presented in the discussion.

6. Human Behaviour in Autumn

6.1. Chapter Overview

This chapter presents the analysis of behaviour of people during autumn 2015 according to environmental conditions. The methods applied for the data collection and analysis were the same as in the former summer study (Chapter 5). The sample size for the *Social Behaviour* analysis was 180 minutes, which corresponded to three hours of recording per day over seven days. For the *Individual Behaviour* analysis, a sample of 1873 people was evaluated. The data analysis consisted officially in the analysis between all the variables, then when a correlation was found, a multiple regression analysis or survival analysis was conducted. At the end, equations based on the relationship between environmental factors and human behaviours were generated.

6.2. Introduction

Previous literature has reported that autumn and spring are seasons with good conditions for outdoor activities (Goličnik & Ward Thompson, 2010; Nasar & Yurdakul, 1990; Zacharias, 2004). Some researchers have evaluated behaviour such as: the opportunity to sit in the sun or the shadow (Eliasson et al., 2007; Lin et al., 2013; Stathopoulos et al.,2004; Zacharias, 2004), attendance (Eliasson et al., 2007; Nikolopoulou et al., 2001; Zacharias, 2004), the thermal sensation experienced by people (Eliasson et al., 2007; Nikolopoulou et al., 2001) and the activities and body postures adopted by the occupants according to the space (Goličnik & Ward Thompson, 2010; Nasar & Yurdakul, 1990).

Studies conducted in autumn and spring are generally part of a whole year seasonal study. However, some studies have focused on these seasons independently. For instance, (Zacharias et al., 2001) recorded the number of people standing, sitting or smoking in the sun or shadow at different public spaces of Montreal during spring and autumn. Stathopoulos et al., (2004) reported that the decision to study the behaviour during these seasons was to conduct the study in moderate air temperature conditions in order to evidence the effects of the other parameters. In the same way, another study conducted in Hungary evaluated the comfort of people during spring, summer and autumn, providing the following rationale: "…transient seasons and summer months are of particular importance in Hungary, while the issue of outdoor thermal comfort in winter does not concern a central European city" (Kántor et al., 2016, p. 1618).

The present study aimed to obtain comprehensive data of human behaviour in public spaces, which included all the ranges of environmental conditions. However, for this study autumn was selected as the sample of the transient seasons (i.e. autumn and spring), since the environmental conditions recorded during autumn are similar to those in spring. In order to verify this premise, the historic weather data of Nottingham City, not finding significant differences between these two seasons over the past ten years Figure 70 (Met Office).

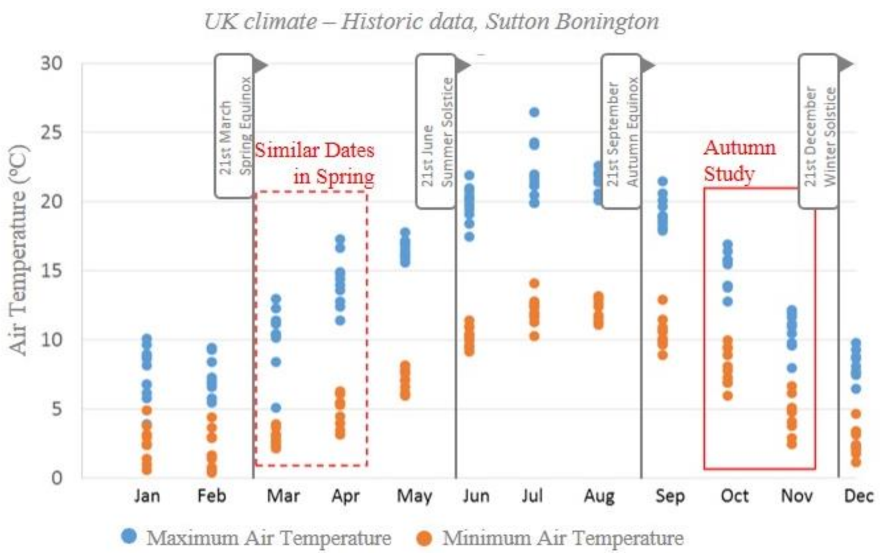


Figure 70 - Air Temperature Nottingham. Sutton Bonington. Met Office

Most of the cross-seasonal studies have evaluated the data collected as a whole year data set. However, in this research each season has been evaluated independently in order to detail the human behaviour in each season, before examining the entire data set as a whole (Chapter 8).

As the concern of this research refers to the variability of the human behaviour according to different environmental conditions, this chapter will be focused on the behaviour of people during autumn. The aim of this study was to assess the influence of the *air temperature*, *wind speed*, *globe temperature*, *radiant temperature*, *light* and *relative humidity* on the human behaviour during autumn.

6.3. Method

These studies used the methodology tested and refined during the pilot study (Chapter 4). The aim of the methodology was to collect observational data of human behaviour in outdoor urban spaces in simultaneity with the measurement of the environmental conditions. The data collection followed the methodology reported in Chapters 3 and 5. The location, equipment, exclusion criteria, announcing the study and the ethics approval were the same as the procedure used during the summer study. Therefore only Population Sample and Duration of the study are presented in this section.

Population and Time Sample

A total of 1873 individuals were evaluated. They were the people who attended the square where the study was taking place (Trinity Square, Nottingham). The people who remained in this square were recorded since their arrival and until their departure.

The criteria to include users in the analysis were: they remained in the evaluated area, the video captured their permanence from the beginning to the end; they were not just passing through the square, and they were not sitting or being part of the restaurants' activities next to the square (Figure 71). These criteria were defined to identify the users that attended to the square with the aim of using this open public space.

Figure 71 - View of the users during autumn. Trinity Square, October 2015.

The individuals were classified by observation in age groups: baby, child, teenager, adult and mobility reduced. The last group was defined as people with difficulties to move or aided by elements such as: wheelchair, crutch or other. According to the data presented in Table 48 most of the people were adults, 89.6%.

The sample was also classified by gender: male, female and not known. The last group was selected when the observer wasn't able to identify the gender of the individual. Gender Table presents the data percentage observed, a higher percentage of men 57.6% in comparison to 42.2% of woman attendance was recorded (Table 48).

Table 48 - Age and Gender during autumn

Age Frequency

	Frequency	Percent
baby	21	1.1
child	65	3.5
teenager	68	3.6
adult	1679	89.6
mobility	40	2.1
Total	1873	100.0

Gender Frequency

	Frequency	Percent
Male	1078	57.6
Female	791	42.2
Not Known	4	.2
Total	1873	100.0

Duration and Season

The data collection was conducted for four weeks in autumn, from the 24th of October to the 21st of November 2015 (Table 49). The weeks were selected according to the historic data of the temperature variation (Figure 70).

Table 49 – Calendar of data collection - Autumn

October

Mo	Tu	We	Th	Fr	Sa	Su
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

November

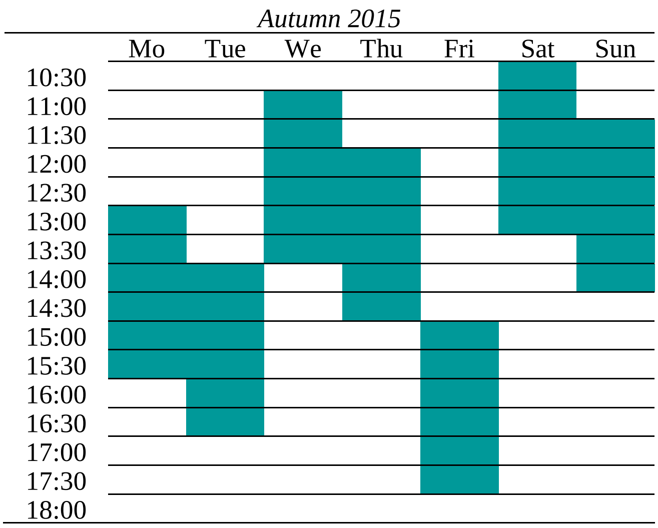
Mo	Tu	We	Th	Fr	Sa	Su
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

Selected Days for Analysis
Recorded Period

The aim was to capture a high environmental variation for each season. From the data gathered, each day of the week was selected to be analysed, for example, one Monday, one Tuesday and so on. This strategy allowed obtaining a sample which was not affected by several factors often present when collecting data from a natural environment: rain, technical problems, public activities, security, among others. Therefore, if the first day of the week recorded presented any of the exclusion criteria, then the next day of the following week was selected for the evaluation.

The data was collected for three hours randomly selected for each day between 10:30 am and 6:30 pm. This period was selected because this is the time when most of the city services are open. Table 50 presents the hours recorded each of the selected days.

Table 50 - Time randomly selected to collect data



6.4. Results

6.4.1. Environmental Measurements

The environmental data was gathered per minute. A total data set of 1260 minutes was collected during autumn 2015, which corresponds to three hours per day during seven days, between 10:30 am and 6:30 pm (Table 51).

Table 51 - Environmental data - Autumn

Statistics (N = 1260)

	Ta	rH	Tg_sun	Tg_shad	Tr_sun	Tr_shad	Va	Light
Mean	14.1	76	16.2	15.1	18.5	15.8	.703	1917
Median	14.9	78	15.6	15.2	17.1	15.6	.513	927
Mode	14.6	79	14.7	15.3	17.0	15.4[a]	0.000	12
Std.	2.7	9	4.4	3.4	7.6	4.5	.664	2147
Minimum	8.1	55	7.5	8.0	2.9	7.0	0.000	12
Maximum	17.8	91	26.7	24.6	47.9	37.0	3.262	8936

a. Multiple modes exist. The smallest value is shown

Acronyms: Air Temperature (Ta), Relative Humidity (rH), Globe Temperature (Tg), Calculated Mean Radiant Temperature (Tr), Wind Speed (Va) and Illuminance (Light).

Figure 72 shows the frequency distribution of the air temperature data recorded by the sensors, binned at 1°C. As can be observed, there is no data collected at 10.1 - 11.0 °C. This was simply because none of the data were captured at this temperature. The most frequent condition captured for Air Temperature was 14.1 – 15.0 °C followed by 16.1 – 17.0 °C.

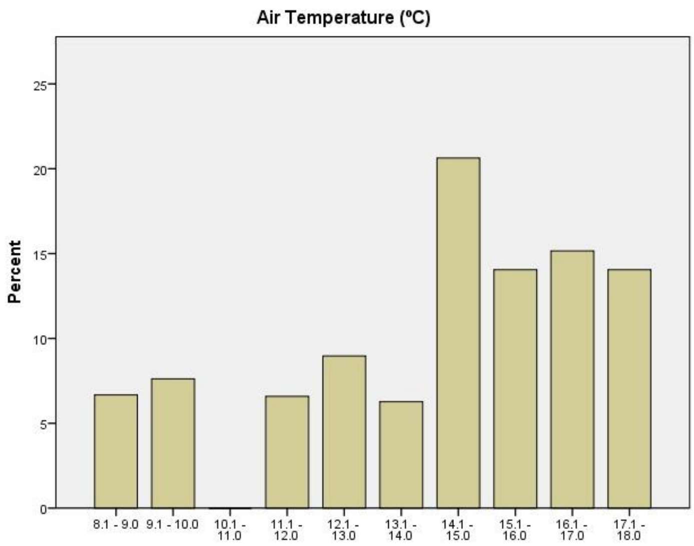


Figure 72 - Percentage distribution Air Temperature (°C) – Autumn

Figure 73 presents the results of the Relative Humidity binned at 5%. The highest frequency captured was 76 – 80% followed by 61 - 65%. The lowest Relative Humidity frequency recorded was below 60% and over 90%.

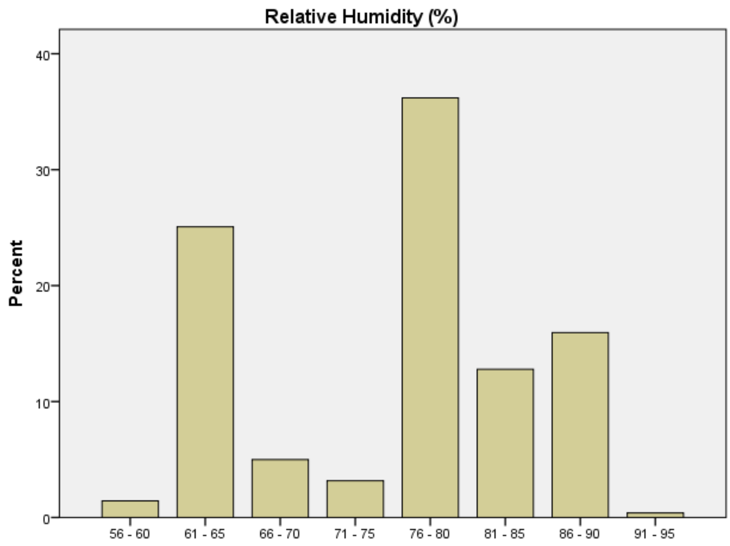


Figure 73 - Percentage distribution Relative Humidity (%) – Autumn

The Globe Temperature was binned at 2°C (Figure 74 and Figure 75). The results in the sun also presented a gap between 10.01°C and 12°C. The most frequent measurement of the Globe Temperature in the Sun was 14.01 – 16°C, followed by 16.01 - 18°C. Similarly, the most frequent Globe Temperature recorded in the Shadow was 14.01 – 16°C followed by 16.01-18°C. A similar measurement between sun and shadow was observed, which suggests a low presence of solar radiation.

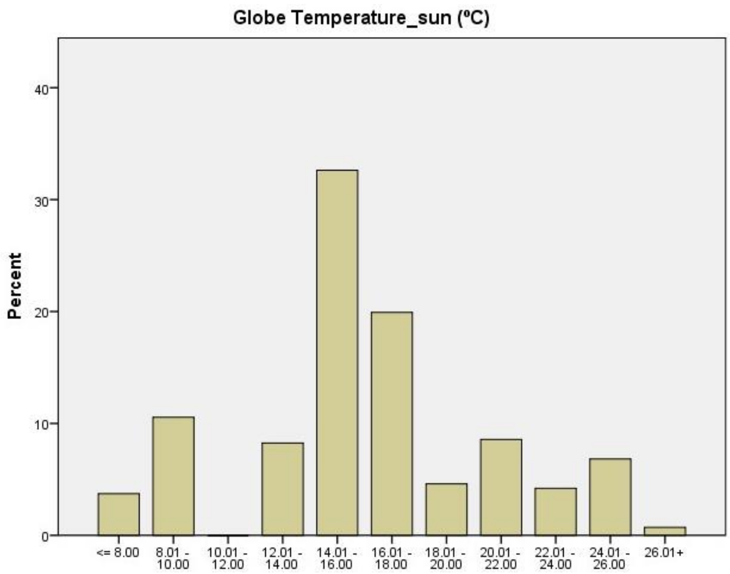


Figure 74 – Percentage Globe Temperature sun - Autumn

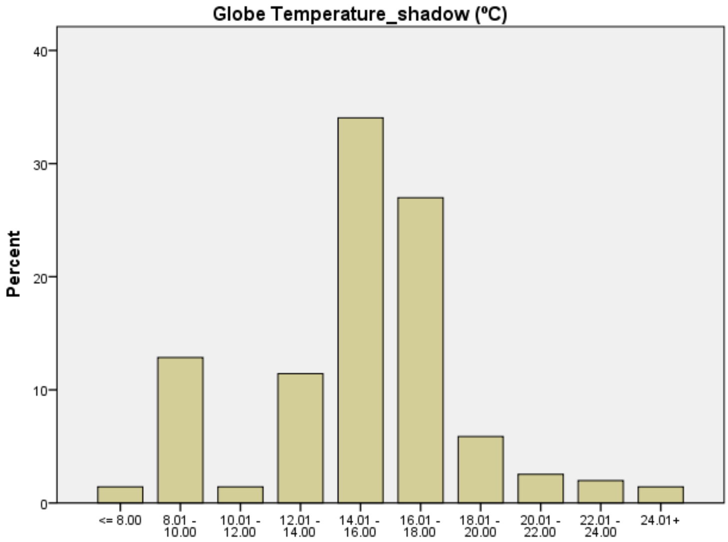


Figure 75 -Percentage Globe Temperature sun shadow - Autumn

Figure 76 corresponds to the results of the calculated Mean Radiant Temperature in the Sun and Shadow. It was observed that almost 50% of the data was gathered from 15.01 to 20ºC. Higher measurements were recorded in the sun between 20 and 45ºC. Interestingly, the lowest values below 5ºC were recorded in the sun, while in the shadow the lowest measurement was 7ºC. This could be due to the fact that Radiant Temperature is calculated through an equation which includes Air Temperature, Globe Temperature, and Wind Velocity. This means that the sensor that is usually exposed to direct solar radiation is also affected by the wind, which increases the rate at which it loses heat, compared to the sensor in the shadow, which is more protected.

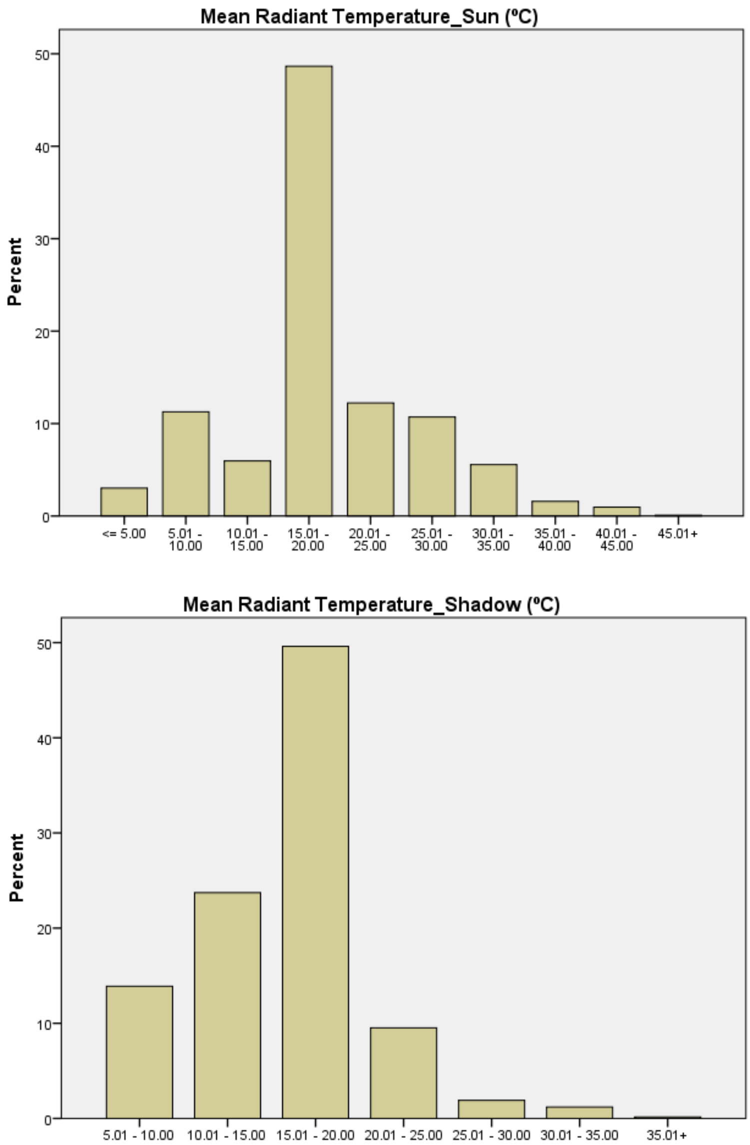


Figure 76 – Percentage distribution Calculated Mean Radiant Temperature sun and shadow - Autumn

The graph of the wind speed shows that the most frequent condition was 0.001 to 0.500m/s (Figure 77). This condition increases up to over 3 m/s. In a similar pattern, the graph of Light Level indicates that the minimum recorded was between 1 – 500 lx which was also the most frequent condition. This is because, after 2:00 pm the square didn't have direct solar radiation and therefore the surfaces didn't reflect much light.

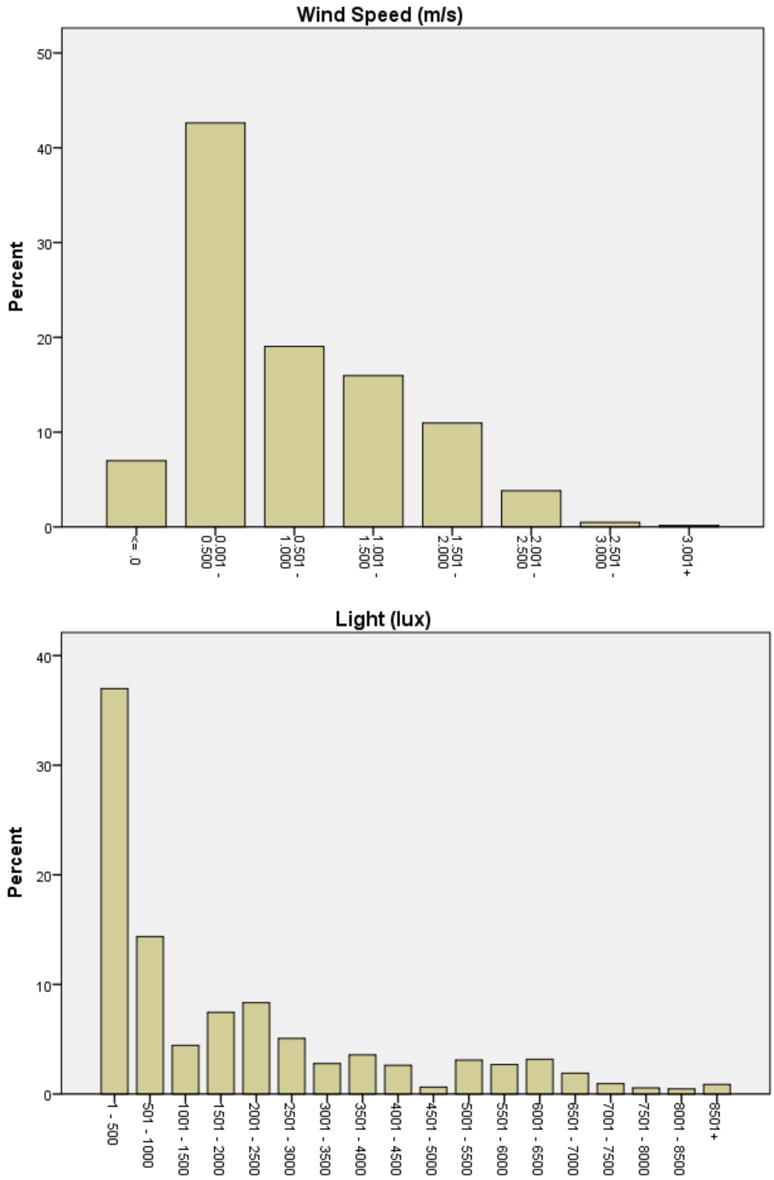


Figure 77 – Percentage distribution Wind Speed and Light - Autumn

The data presented describes the environmental characteristics of Trinity Square in Nottingham during autumn. It is expected that the results of this study can be applicable to similar squares presenting the environmental ranges described in this section.

6.4.2. Social Behaviour

As described in Chapter 5, the social behaviour aims to capture the occurrence of events in relation to the place by counting the aggregates of social behaviours. This analysis was focused on the presence of people in the areas of study, and whether they were part of a group or an individual.

Table 52 presents the descriptive statistics of the number of people and groups observed per minute in the area of study. The mean corresponds to the total number of people observed per minute divided by the number of minutes. The mean number of people was 17 and the standard deviation was 10, which indicates a high variability of the total of people per minute in the square.

Table 52 - Descriptive statistics number of people and number of groups (sizes) during autumn per minute

Statistics

	Number of People	G1	G2	G3	G4more
Mean	17	6	3	1	
Median	16	6	3	1	0
Mode	16	5	1[a]	0	0
Std.Deviation	10	3	3	1	1
Minimum	0	0	0	0	0
Maximum	54	21	15	8	5

a. Multiple modes exist. The smallest value is shown

The evaluation of groups was also conducted by creating four categories depending on the number of people per group (Chapter 05). These categories were: 1 person (G1), 2 persons (G2), 3 persons (G3) and 4 or more people (G4more). The category G4more contains groups of 4 and up to 16 people which was the maximum observed. The sum of observations of G4more totalled 446, which is a 3.7% of the total of observations.

The highest number of groups per minute was 21 groups of one person (G1), followed by 15 couples (G2), 8 trios (G3), and finally, 5 groups of 4 or more people (G4more). The most frequent observation was people alone, a mean of 6 groups of one person (G1) per minute was observed (Table 52). The mean corresponds to the total number of G1 observed per minute divided by the number of minutes.

Figure 78 presents the frequency distributions of the data of number of people. A positive skew is observed in most of cases between 1 and 22 people and a smaller amount of observations between 23 and 54 of number of people.

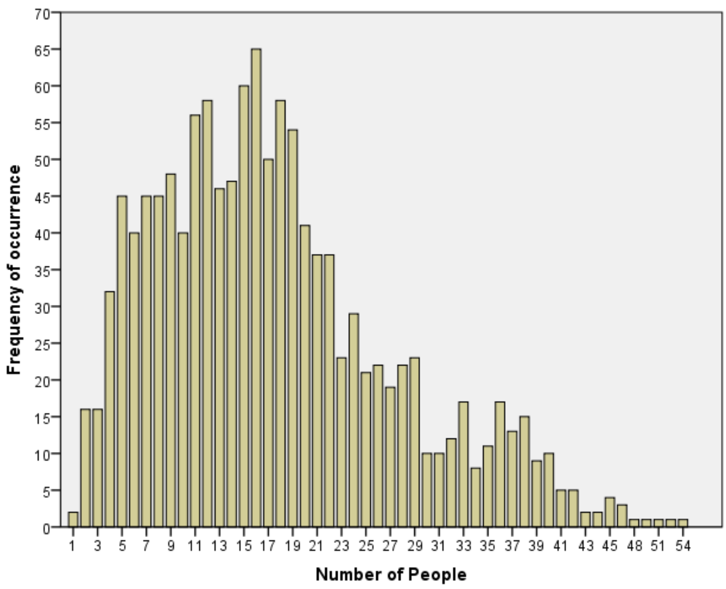


Figure 78 – Frequency Number of People

The most frequent number of people observed was between 15 and 19 people. The lowest percentage recorded was from 43 to 54 people, which represents the moments of bigger crowds using the square.

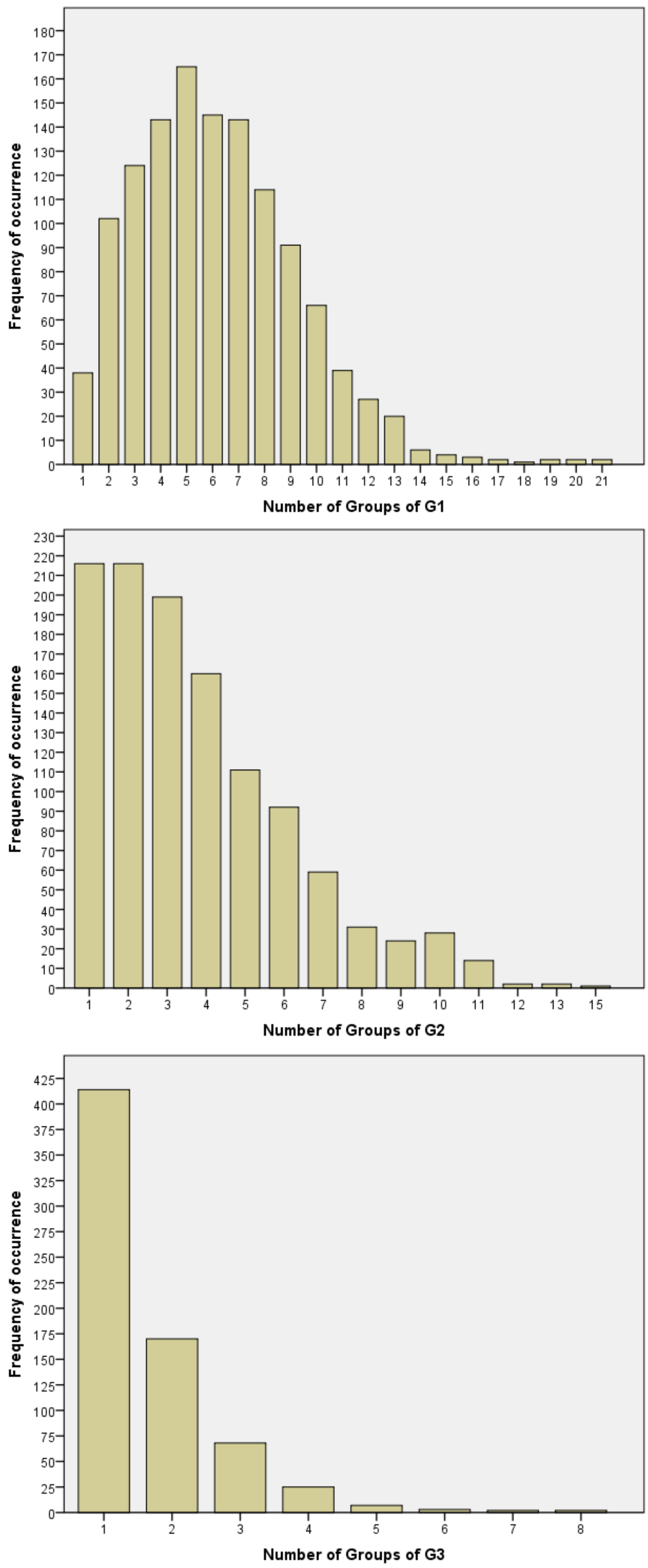


Figure 79 – Frequency distribution Number of Groups of G1, G2 and G3

Figure 79 presents the data frequency of G1, G2 and G3. The highest percentages of G1 were observed between 3 and 8 groups of people. Conversely, the distribution of G2 indicates that it is more frequent to have small number of couples since the peak of the data is reached in 1, 2 and 3 groups of two people.

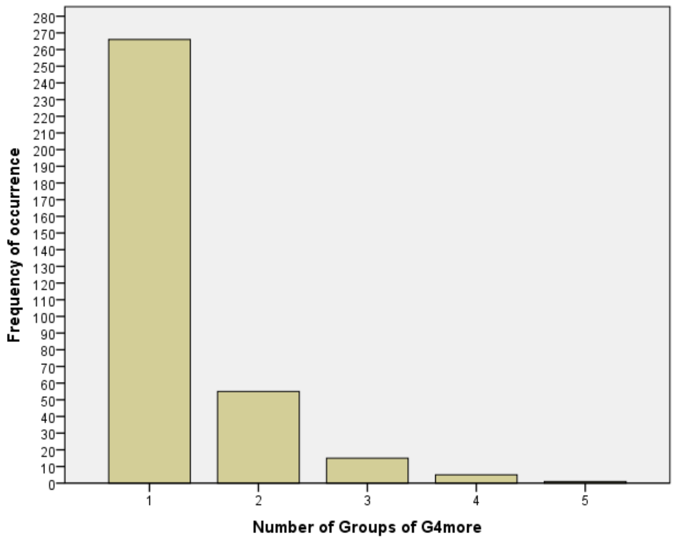


Figure 80 – Frequency distribution Number of Groups of G4more

In Figure 80 is observed that big groups of 3 and 4 or more people were mainly observed once at a time. This means that as the groups size increases, the probability of seeing several big groups at the same time in the square decreases.

6.4.2.1. Correlation

In order to analyse the social behaviour in conjunction with the environmental measurements, a multiple regression analysis was performed. This analysis aimed to identify the environmental variables that were the best predictors of the variation in each behaviour. “The multiple regression is a statistical technique that allows us to predict someone’s score on one variable on the basis of their score on several other variables" (Brace et al., 2000, p . 206). This means that the independent variables, in this research the environmental factors, were analysed to see their influence on the dependant variable, or behaviour.

The process to analyse the data had the same cross-validation procedure described in the study conducted in summer (Chapter 5). The Training data set had a sample size of 737 cases, and the Validation data 523. Before running the correlation analysis, it was checked whether the distribution of the data was normal in all variables in order to select the type of correlation analysis. For this, a Kolmogorov Smirnov test was applied to the data set (Appendix 3). All the variables were significantly non-normal, $D(737) < .001$. According to this, the type of correlation analysis required to study the relationship between variables was a Spearman's rank correlation.

The analysis in Table 53 corresponds to the correlation between the social and the environmental variables. The correlations between the social behaviour and environmental variables are shown in blue; the correlations between variables of the same group are shown in black.

Table 53 – Spearman's rho Correlation - Autumn

		N_Peop	G1	G2	G3	G4+	Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sha	Va
Number of People	Correlation	1.00											
	Sig. (2-tailed)	.											
Groups of G1	Correlation	.54**	1.00										
	Sig. (2-tailed)	.000	.										
Groups of G2	Correlation	.82**	.31**	1.00									
	Sig. (2-tailed)	.000	.000	.									
Groups of G3	Correlation	.67**	.21**	.42**	1.00								
	Sig. (2-tailed)	.000	.000	.000	.								
Groups of G4more	Correlation	.49**	-.01	.26**	.26**	1.00							
	Sig. (2-tailed)	.000	.691	.000	.000	.							
Air Temperature	Correlation	.39**	.26**	.34**	.20**	.13**	1.00						
	Sig. (2-tailed)	.000	.000	.000	.000	.001	.						
Relative Humidity	Correlation	.01	-.09*	.05	.06	.03	-.01	1.00					
	Sig. (2-tailed)	.705	.010	.171	.088	.385	.706	.					
Globe Temperature sun	Correlation	.46**	.15**	.42**	.31**	.23**	.77**	.04	1.00				
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.310	.				
Globe Temperature shadow	Correlation	.40**	.12**	.37**	.26**	.20**	.84**	.09*	.96**	1.00			
	Sig. (2-tailed)	.000	.001	.000	.000	.000	.000	.017	.000	.			

Mean Radiant Temperature	Correlation	.51**	.19**	.45**	.33**	.28**	.52**	.06	.86**	.75**	1.00		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.107	.000	.000	.		
Mean Radiant Temperature	Correlation	.48**	.15**	.44**	.32**	.25**	.69**	.06	.96**	.92**	.92**	1.00	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.078	.000	.000	.000	.	
Wind Speed	Correlation	-.34**	.07	-.29**	-.38**	-.26**	-.07*	-.31**	-.39**	-.32**	-.33**	-.37**	1.00
	Sig. (2-tailed)	.000	.064	.000	.000	.000	.043	.000	.000	.000	.000	.000	.
Illuminance	Correlation	.38**	-.04	.35**	.35**	.32**	.06	.32**	.53**	.41**	.71**	.59**	-.66**
	Sig. (2-tailed)	.000	.249	.000	.000	.000	.090	.000	.000	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).
**. Correlation is significant at the 0.05 level (2-tailed).

The variables associated with temperature were highly correlated between each other. Among these, Globe Temperature and Radiant Temperature presented the highest values, which could be explained by the fact that the Globe Temperature is used in the equation to calculate the Radiant Temperature.

The negative relationship obtained between Light and Wind ($r = -.66$) is an interesting result, since these are two independent phenomena. Conversely, the Air Temperature and Light did not present a correlation. Light was also correlated to Radiant Temperature_sun ($r = .71$, $p < .001$) and Globe Temperature_sun ($r = .52$, $p < .001$). This is also explained by the fact that direct solar radiation over the surfaces increases the light reflection over the surfaces.

The highest significant relationship between environment and behaviour was between Number of People and Radiant Temperature_sun, $r = .51$, $p < .001$. The Number of People also presented a correlation with the other variables, but not with the Relative Humidity.

There was no correlation between Wind Speed and Relative Humidity with almost all the social variables. The exception was between Wind Speed and Number of People, $r = .34$, $p < .001$. Some correlations were also found between groups of people and the environmental variables.

Correlation Analysis Environment and Behaviour: Key Findings

- The social variables presented high correlations; however, it was interesting how **G1**, **G3** and **G4more** had completely independent behaviours in terms of frequency of the observations, since the highest frequency for G1 was 5 whilst for **G3** and **G4more**, it was 1.
- A strong relationship was found between Globe and Calculated Mean Radiant Temperature in sun and shadow, as expected.
- The Illuminance was correlated to other variables affected by the solar radiation, such as Radiant Temperature and Globe Temperature.
- **Number of People** and Calculated Mean Radiant Temperature_sun presented the highest correlation between environmental and social variables.
- **Number of People** presented significant correlation with all the environmental variables, with the exception of Relative Humidity.
- With exception of Wind Speed and Relative Humidity, the environmental variables presented significant correlation with the groups' sizes.

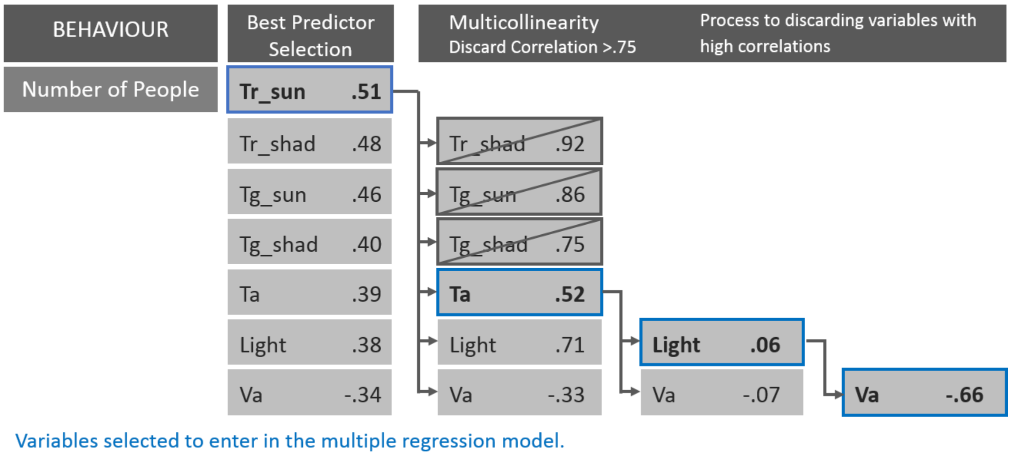
6.4.2.2. Multiple Regression Analysis

This analysis was carried out by identifying the social variables as the dependant or predicted variables, and the environmental data as the independent or predictor variables, following the same procedure described in Chapter 5.

Model to Predict Number of People

This model was designed by choosing the best correlated variable with Number of People, which was Calculated Mean Radiant Temperature_sun. In order to prevent multicollinearity which is the linear relationship between predictors, the correlation between the environmental variables were examined and the predictors with correlations over r = .75, p < .001 were excluded from the analysis (Field, 2009).

Figure 81 shows the variables filtered for this model. The calculated mean radiant temperature in the sun was selected as the best predictor and the air temperature, light and wind speed were the other variables contributing to the model.



Acronyms: Tr: Calculated Mean Radiant Temperature (sun and shadow), Tg: Globe Temperature (sun and shadow), Ta: Air Temperature, Va: Wind Speed and Light: Illuminance.

Figure 81 - Diagram of the process to select the variables to predict Number of People.

The variables selected for the model were calculated Radiant Temperature in the sun, Air Temperature, Light and Wind.

Table 54 presents the Model Summary. The first model obtained the same simple correlation of the Tr_sun, r = .51. This correlation increased in the second and third model by adding Wind, r = .55 and Light, r = .58. The R^2 of the Radiant Temperature_sun accounts for the 26% of the Number of People. By adding Wind and Light the value increases up to 33%. It was observed that the value of the R^2 and the adjusted-R^2 in the third model is close, .331 - .328 = .003. This means that the model has a good generalisability.

Table 54 - Regression Model Summary Number of People - Autumn

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.51[a]	.26	.26	8.55	.26	264.62	1	735	.000
2	.55[b]	.30	.30	8.34	.04	38.51	1	734	.000
3	.58[c]	.33	.33	8.17	.03	32.08	1	733	.000

a. Predictors: (Constant), Tr_sun
b. Predictors: (Constant), Tr_sun, Va
c. Predictors: (Constant), Tr_sun, Va, Light
d. Dependent Variable: N_People

Table 55 presents the coefficients table with the results of the three models. According to the previous analysis, model 3 is the best predicting the Number of People because it presents the highest R^2. Therefore, the following analysis was focused only on this model.

Table 55 – Coefficients of the regression models to predict Number of People - Autumn

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.	95.0% Confidence Interval for B: Lower Bound	Upper Bound
1	(Constant)	5.2	.83		6.2	.000	3.53	6.80
	Tr_sun	.7	.04	.51	16.3	.000	.59	.76
2	(Constant)	9.4	1.06		8.9	.000	7.31	11.48
	Tr_sun	.6	.04	.43	12.9	.000	.48	.66
	Va	-3.2	.51	-.21	-6.2	.000	-4.17	-2.17
3	(Constant)	9.6	1.04		9.2	.000	7.56	11.64
	Tr_sun	.7	.05	.55	14.2	.000	.62	.83
	Va	-4.5	.55	-.30	-8.2	.000	-5.62	-3.44
	Light	.0	.00	-.24	-5.7	.000	.00	.00

a. Dependent Variable: N_People

The b-values (B) corresponded to the individual contribution of each predictor to the model. Therefore, they were used for the regression equation that predicts the Number of People according to the Calculated Mean Radiant Temperature in the sun, Wind Speed and Light:

Equation 6 - Model to predict Number of People

$$N\_People = b_0 + b_1 Tr\_sun + b_2 Va + b_3 Light$$

$$N\_People = 9.59 + (0.72 * Tr\_sun) + (-4.53 * Va) + (0.001 * Light)$$

The t-test (t) shows that the predictors are making a significant contribution to the model, $p < .001$.

It is important to highlight that these interpretations are true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of People

As mentioned before, the data set was split in two samples. The first 60% (n = 737) was used to design the equation to predict Number of People, and the remaining 40% (n = 576) was retained to calculate the outcome of the equation designed and compare it with the real results.

The validation procedure consisted of taking the 40% of the data remaining and creating a new variable called PREDICTION. In this way there were two columns of data: the real Number of People and the PREDICTED number of people. The PREDICTED Number of People was built using the regression equation created before *Model to predict Number of People:*

$$N\_People = 9.59 + (0.72 * Tr\_sun) + (-4.53 * Va) + (0.001 * Light)$$

The values of Radiant Temperature in the sun, Wind Speed and Light were forced to enter in the equation. In this way, a prediction based on the Radiant

Temperature in the sun (Tr_sun), Wind Speed (Va) and Light (Light) was created.

Subsequently, the results obtained for the PREDICTED number of people and the measured Number of People was compared in a correlation (Figure 82).

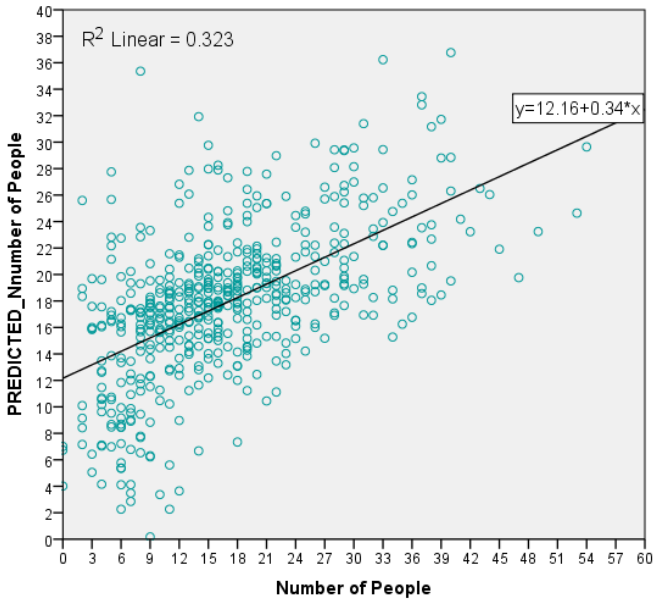


Figure 82 Scatter plot Number of People and Predicted Number of People - Autumn

Table 56 - Correlation Number of People and Predicted Number of People - Autumn

Correlations

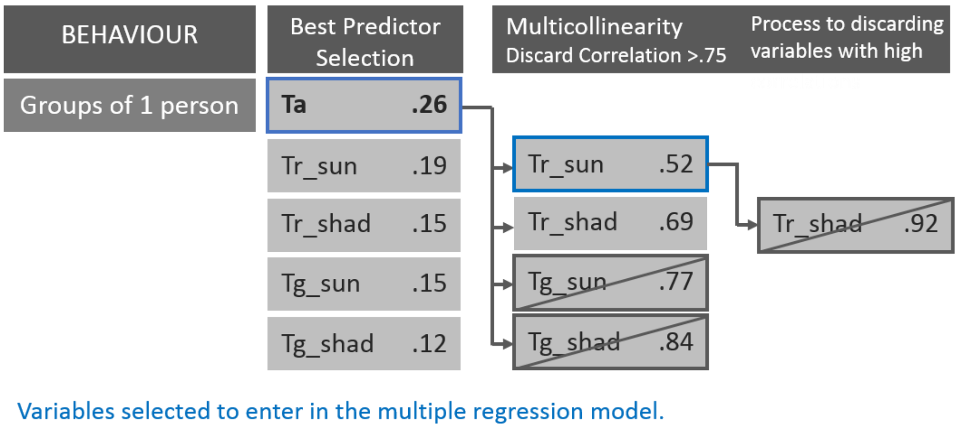
			PREDICTION	N_People
Spearman's rho	PREDICTION	Correlation Coefficient	1.000	.576**
		Sig. (2-tailed)	.	.000
		N	523	523
	N_People	Correlation Coefficient	.576**	1.000
		Sig. (2-tailed)	.000	.
		N	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the multiple regression model built using the Radiant Temperature in the sun, Wind Speed and Light is accounting for the 33% of the Number of People in the square. These results were internally cross-validated and the correlation obtained between the Number of People and the Predicted number of people was 0.58, $p < .001$ which is the same correlation obtained in Table 54 - Model 3 (.58, $p < 001$). This result indicates a good generalisability of the model selected to predict Number of People.

Model to Predict Groups of one person (G1)

This analysis was conducted to evaluate the variability of number of Groups of one person (G1) and its relationship with the environmental conditions. Similarly to the Number of People, the number of users remaining alone in the square were counted per minute. Figure 83 presents the variables selected as best predictors: air temperature and mean radiant temperature in the sun.



Acronyms: Air Temperature (Ta), Radiant Temperature (Tr - sun and shadow), Globe Temperature (Tg: sun and shadow)

Figure 83 - Diagram variables selected to predict G1.

Table 57 presents the model summary. The calculated mean radiant temperature in the sun made a significant contribution to the model as its correlation was not high enough to cause multicollinearity.

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.31[a]	.095	.09	3.12	.09	77.1	1	735	.000
2	.32[b]	.101	.10	3.11	.01	4.9	1	734	.026

a. Predictors: (Constant), Ta
b. Predictors: (Constant), Ta, Tr_sun
c. Dependent Variable: G1

Table 57 - Model summary to predict Groups of 1 person

In Table 58 the coefficients of the models to predict G1 are presented. In model 2 where the Radiant Temperature in the sun is added, it is observed that its contribution still significant at $p < .05$. According to the results, it was observed that the *Tr_sun* did not add power to the model and affected its significance. Therefore, model 1 was selected to predict G1.

Table 58 - Coefficients of the regression model to predict Groups of 1 person - Autumn

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.	95.0% Confidence Interval for B: Lower Bound	Upper Bound
1	(Constant)	.89	.61		1.5	.144	-.31	2.09
	Ta	.37	.04	.31	8.8	.000	.29	.46
2	(Constant)	1.10	.62		1.8	.074	-.11	2.31
	Ta	.30	.05	.25	5.7	.000	.20	.41
	Tr_sun	.04	.02	.10	2.2	.026	.00	.08

a. Dependent Variable: G1

The b-values (B) correspond to the individual contribution of each predictor to the model. They were used to build the regression equation to predict G1:

Equation 7. Model to predict Groups of 1 person (G1)

$$G1 = b_0 + b_1 Ta$$

$$G1 = 0.89 + (0.37 * Ta)$$

This interpretation is true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G1

The values of Air Temperature were forced into the equation. This way, a prediction with the 40% of the remaining data was created. Subsequently, a correlation analysis was conducted between G1 and PREDICTED_G1 from the reserved sample (Figure 84 and Table 59).

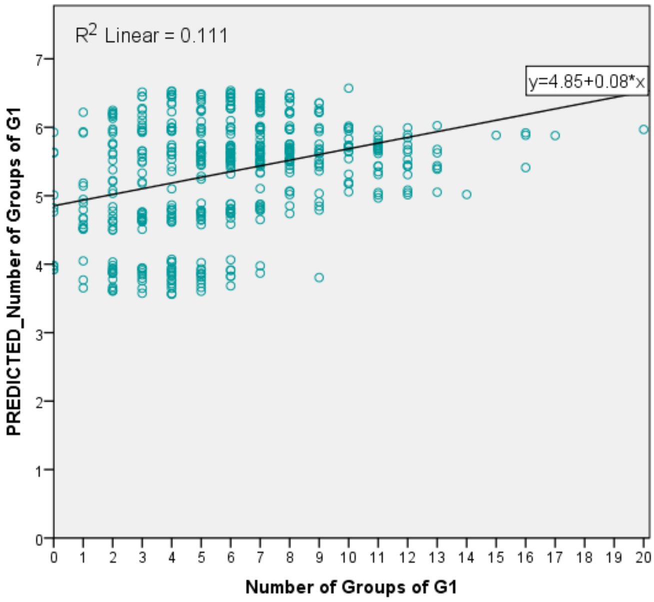


Figure 84 – Scatter plot of the Predicted G1, against G1 (Groups of 1 person).

Table 59 - Spearman' rho correlation for the Predicted G1 and G1.

Correlations

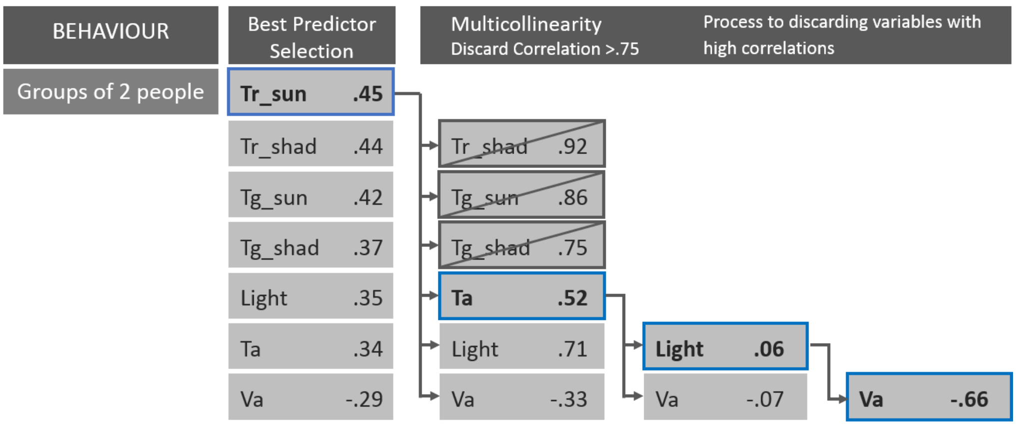
			PREDICTED_G1	G1
Spearman's rho	PREDICTED_G1	Correlation Coefficient	1.00	.31**
		Sig. (2-tailed)	.	.000
		N	523	523
	G1	Correlation Coefficient	.31**	1.00
		Sig. (2-tailed)	.000	.
		N	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the regression model is accounting for the 10% of the number of groups of one person in the public square. These results were internally cross-validated and the correlation obtained between G1 and the Predicted G1 was 0.31, p < .001 which is similar to the simple correlation obtained in model 1 r = .31, p < 001, indicating a good generalisability of the model. Nevertheless, this is a weak model since it can only explain the 10% of the variation of the behaviour, which means that the remaining 90% of the decisions of single users respond to unknown variables affecting the behaviour, besides those accounted for in this study.

Model to Predict Groups of two persons (G2)

This analysis was conducted to study the variability of the behaviour of groups of two people and the influence of the thermal environment on this type of grouping. The variables selected for the model were Radiant Temperature in the sun, Air Temperature, Light and Wind Speed (Figure 85).



Variables selected to enter in the multiple regression model.

Acronyms: Radiant Temperature (Tr), Globe Temperature (Tg), Light, Air Temperature (Ta) and Wind Speed (Va).

Figure 85 - Diagram of the variables selected to predict Groups of 2 people – Autumn

In Table 60 the R value of model 1 corresponds to the simple correlation of the Radiant Temperature in the sun, *r* = .50, *p* < .001. The first model accounts for the 25% of the number of G2. This percentage is increased up to 29% in the third model by adding Light and Wind Speed, with a significant contribution, $p < .001$. The R^2 and the adjusted-R^2 of the models are the same. This means that if the model had been derived from the original population rather than a sample, the variance in the outcome would be small (Field, 2009).

Table 60 - Model summary to predict Groups of 2 people.

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.50[a]	.25	.25	2.24	.25	249.94	1	735	.000
2	.52[b]	.27	.27	2.22	.02	15.22	1	734	.000
3	.54[c]	.29	.29	2.19	.02	22.75	1	733	.000

a. Predictors: (Constant), Tr_sun
b. Predictors: (Constant), Tr_Sun, Va
c. Predictors: (Constant), Tr_Sun, Va, Light
d. Dependent Variable: G2

Table 61 contains the coefficients results of the three models. The model that presented the highest power of prediction was the third one, $R^2 = .29$, $p < .001$. However, after analysing the individual contribution of the variables it is observed that the b-value (B) of Light was .00, which indicates a null contribution. Therefore, the model selected to predict G2 was the second one, $R^2 = .27$, $p < .001$. The t-test (t) helped to determine if the contribution of each variable is significantly different from zero, all were $p < .001$.

Table 61 - Coefficients of the regression model to predict Groups of 2 people - Autumn

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
1	(Constant)	.32	.22		1.5	.145	-.11	.75
	Tr_sun	.17	.01	.50	15.8	.000	.15	.19
2	(Constant)	1.03	.28		3.6	.000	.47	1.58
	Tr_sun	.15	.01	.45	13.2	.000	.13	.18
	Va	-.53	.14	-.13	-3.9	.000	-.80	-.26
3	(Constant)	1.07	.28		3.9	.000	.53	1.62
	Tr_sun	.19	.01	.55	13.8	.000	.16	.22
	Va	-.84	.15	-.21	-5.6	.000	-1.13	-.55
	Light	.00	.00	-.21	-4.8	.000	.00	.00

a. Dependent Variable: G2

The b-values correspond to the individual contribution of each predictor to the model. They were used for the regression equation to predict G2:

Equation 8. Model to predict Groups of 2 people (G2)

$$G2 = b_0 + b_1 Tr\_sun + b_2 Va$$

$$G2 = 1.03 + (0.15 * Tr\_sun) + (-0.53 * Va)$$

These interpretations are true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G2

The values of Radiant Temperature in the sun and Wind Speed were forced into the equation to predicted Number of Groups of G2 and compare them with the real values. The comparison of the data is presented in Figure 86.

$$G2 = 1.03 + (0.15 * Tr\_sun) + (-0.53 * Va)$$

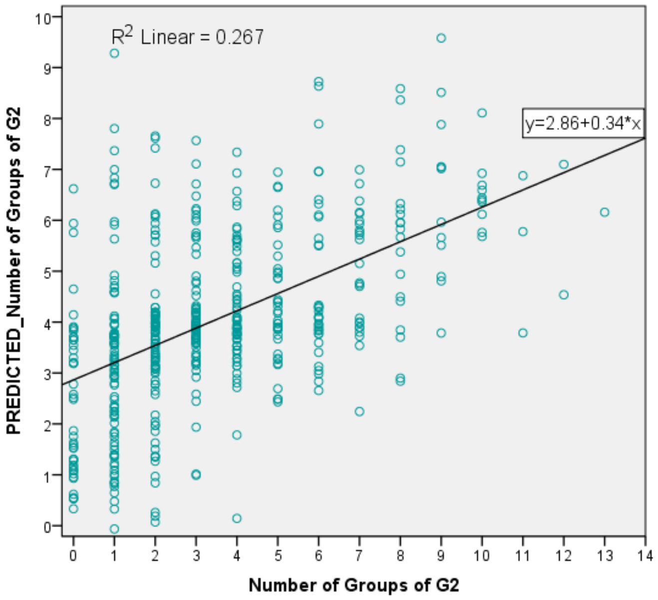


Figure 86 - Scatterplot of the G2 and the Prediction of G2.

Table 62 - Correlation between G2 and Predicted G2.

Correlations

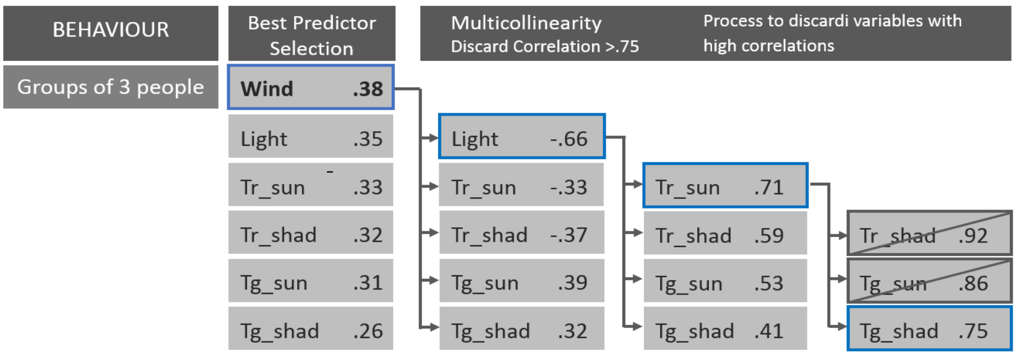
			PREDICTED_G2	G2
Spearman's rho	PREDICTED_G2	Correlation Coefficient	1.000	.52**
		Sig. (2-tailed)	.	.000
		N	523	523
	G2	Correlation Coefficient	.52**	1.000
		Sig. (2-tailed)	.000	.
		N	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the multiple regression model built with Radiant Temperature in the sun and Wind Speed accounted for 27% of the groups of two in the square. These results were internally cross-validated and the correlation obtained between the real data and the predicted data was 0.52, $p < .001$ which is the same simple correlation that was obtained in the model 2 ($R^2 = .27$, $p < 001$), indicating a good generalisability of the model.

Model to Predict Groups of three people (G3)

This analysis was carried out to evaluate the variability of the Groups of 3 people according to the thermal environment. According to Figure 87, the variables selectee were: wind speed, light, calculated mean radiant temperature in the sun and globe temperature in the shadow.



Variables selected to enter in the multiple regression model.

Figure 87 - Diagram selected variables to predict Groups of G3.

The best predictor of G3 was wind speed. This variable was combined with Light, Radiant Temperature in the sun and Globe Temperature in the shadow. The method used for the regression was Forward, the Light and Radiant Temperature in the shadow were discarded in the process.

According to the model summary on Table 63, G3 is explained in 13% by the Wind Speed and 3% by the Radiant Temperature in the sun.

Table 63 - Model summary to predict Groups of G3 - Autumn

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.37[a]	.13	.13	1.05	.13	113.1	1	735	.000
2	.40[b]	.16	.15	1.04	.02	19.9	1	734	.000

a. Predictors: (Constant), Va

b. Predictors: (Constant), Va, Tr_sun

c. Dependent Variable: G3

Table 64 - Coefficients to predict Groups of G3 people - Autumn

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
1	(Constant)	1.40	.06		24.46	.000	1.28	1.51
	Va	-.63	.06	-.37	-10.64	.000	-.75	-.51
2	(Constant)	.86	.13		6.53	.000	.60	1.12
	Va	-.52	.06	-.30	-8.16	.000	-.64	-.39
	Tr_sun	.02	.01	.16	4.47	.000	.01	.04

a. Dependent Variable: G3

It is observed that the difference between R^2 and adjusted-R^2 in both models is very similar. For instance, in the second model is 0.16-0.15 = 0.01, which means that in a real population it would have approximately 1% of variance in the outcome (Field, 2009).

In Table 64 are presented the coefficients of the models to predict Groups of 3. Based on the R^2 and the significance of the contribution made per variable, the model selected to predict G3 is the second one: Wind Speed and Radiant Temperature in the sun ($R^2 = .16$, $p < .001$).

The b-values (B) of the individual contribution of each predictor to the model. They were used to build the regression equation:

Equation 9 - Model to predict Groups of G3 people (G3)

$$G3 = b_0 + b_1 Va + b_2 Tr\_sun$$

$$G3 = 0.86 + (-0.52 * Va) + (0.02 * Tr\_sun)$$

The t-test (t) shows that the Wind Speed is doing a bigger contribution to the model (-8.16) than the other predictors. However, all the predictors included in the model are making a significant contribution to the model, ps < .001.

The interpretations presented before are true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G3

The validation procedure consisted of creating in the SPSS file a new variable called PREDICTED_G3. This variable was built with the regression equation:

$$G3 = 0.86 + (-0.52 * Va) + (0.02 * Tr\_sun)$$

The values of Wind Speed and Radiant Temperature in the sun were forced into the equation. In this way, a prediction based on the environmental data was created. Subsequently, the real quantity of G3 obtained in the 40% of the sample retained and the PREDICTED_G3 were correlated.

The model to predict the presence of Groups of 3 people was built with the Wind Speed and the Radiant Temperature in the sun. The adjusted-R^2 for this model was .15, $p < .001$. These results were internally cross-validated and the correlation obtained between the real and the PREDICTED_G3 was 0.52, $p < .001$ Table 65. This correlation differs from the result of the model $R = .40$, $p < .001$.

Table 65 - Correlation between G3 and Predicted G3.

Correlations

			PREDICTED_G3	G3
Spearman's rho	PREDICTED_G3	Correlation Coefficient	1.000	.39**
		Sig. (2-tailed)	.	.000
		N	523	523
	G3	Correlation Coefficient	.39**	1.000
		Sig. (2-tailed)	.000	.
		N	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

Despite the fact that the model is able to explain 16% of the variance of Groups of 3 people, it is observed in the scatter plot (Figure 88) that the PREDICTION_G3 is not reaching values over 2, while in the original data the values go up to 8.

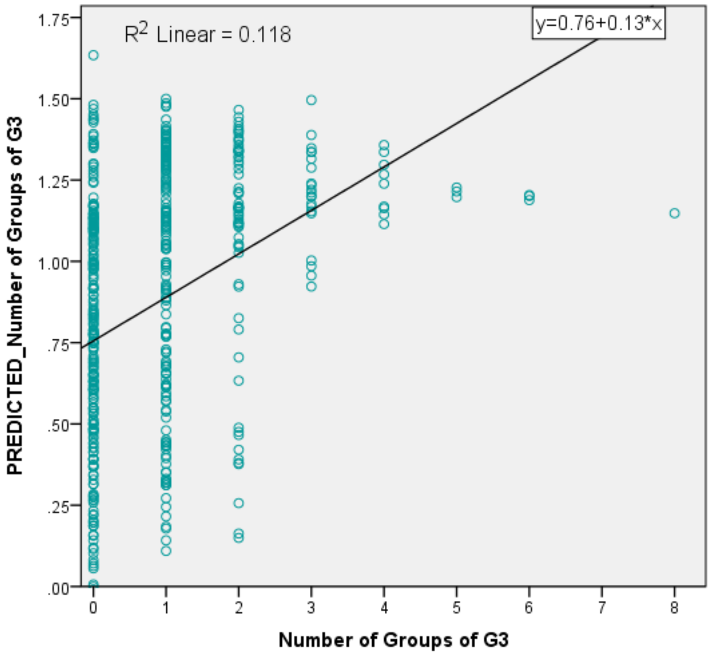


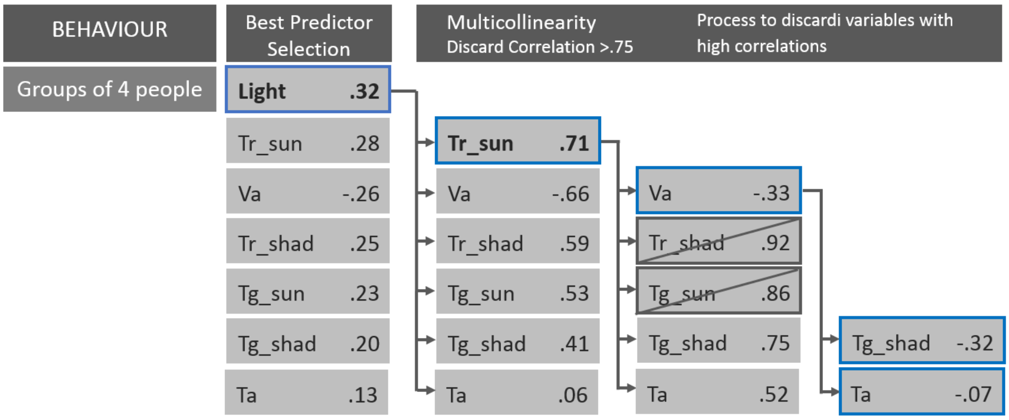
Figure 88 - Scatterplot of the G3 and Prediction of G3.

It was also observed that most of the data gathered lays between 0 and 2. Therefore, the sample of the model was not big enough to calculate higher results.

In conclusion, the model to predict Groups of 3 obtained significant results in the design of the equation. However, the results from the cross-validation and scatter plot suggest that the generalisability of the results were affected as they can predict a small attendance but not changes in larger numbers of G3.

Model to Predict of Groups of four or more people (G4more)

This analysis was carried out to evaluate the variability of Groups of 4 people or more and the influence of the thermal environment The Light was the best predictor of G4more. The Radiant Temperature in the sun, Wind Speed, Globe Temperature in the shadow and Air Temperature, were also selected as predictor variables.



Variables selected to enter in the multiple regression model.

Acronyms: Illuminance (Light), Calculated Mean Radiant Temperature (Tr, sun and shadow), Wind Speed (Va), Globe Temperature (Tg, sun and shadow), Air Temperature (Ta).

Table 66 – Variables selected to predict G4more - Autumn

The method used for the regression was *Forward*, where the computer selected the best predictor and later added other variables. At the end, Tr_sun, Tg_shadow and Ta were discarded as they did not contribute to the model.

Table 67 - Model summary to predict G4more - Autumn

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.32[a]	.10	.10	.63	.10	81.12	1	735	.000
2	.32[b]	.10	.10	.63	.01	4.46	1	734	.035

a. Predictors: (Constant), Light

b. Predictors: (Constant), Light, Va

c. Dependent Variable: G4more

In the Model Summary, the R of the first model corresponds to the simple correlation of the Light, R= .32, $p < .001$. This R value was the same in the second model and the significance was affected, $p < .05$.

The coefficients table contains the results of both models. According to the previous analysis, model 1 is the best predicting G4more, since the Wind Speed did not add power to the equation and instead, it affected the significance of the model. Therefore, the next analysis was focused on this model.

Table 68 - Coefficients model to predict G4more - Autumn

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	.16	.031		5.234	.000	.10	.22
	Light	9.78E-5	.000	.315	9.007	.000	.00	.00
2	(Constant)	.25	.054		4.746	.000	.15	.36
	Light	8.25E-5	.000	.266	6.323	.000	.00	.00
	Va	-.09	.043	-.089	-2.112	.035	-.17	-.01

a. Dependent Variable: G4more

The b-values (B) in Table 68 correspond to the individual contribution of each predictor to the model. Therefore, they were used for the regression equation:

Equation 10. Model to predict Groups of 4 people or more (G4more)

$$G4more = b_0 + b_1 Light$$

$$G4more = 0.16 + (9.78E - 5 * Light)$$

These interpretations are true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of Groups of G4more

The values of light from the validation data set were forced into the equation.

$$G4more = 0.16 + (9.78E - 5 * Light)$$

The real number of G4more from the validation data set were compared with the PREDICTED G4more. Figure 89 presents the scatter plot of both variables.

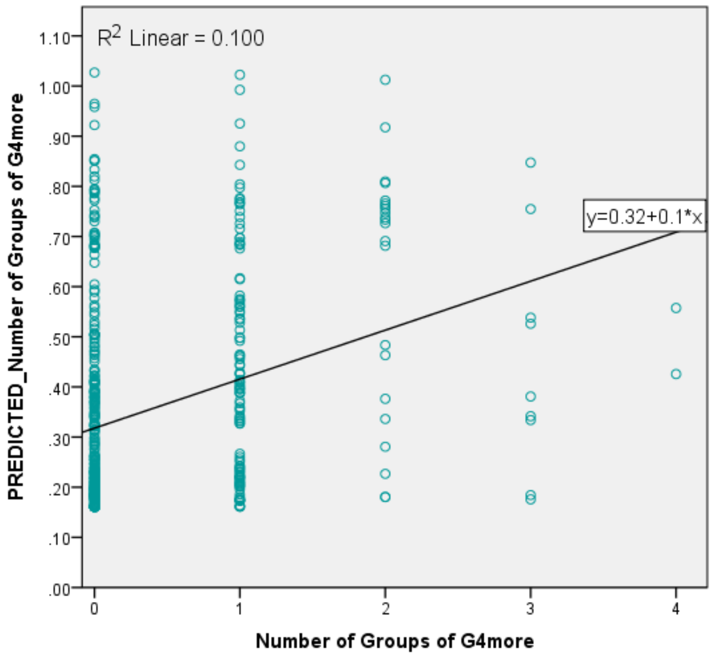


Figure 89 - Scatterplot of the G4more and Prediction of G4 - Autumn

Table 69 - Correlation between G4more and Predicted G4more.

Correlations

			G4more	PRED_G4more
Spearman's rho	G4more	Correlation Coefficient	1.000	.33**
		Sig. (2-tailed)	.	.000
		N	523	523
	PRED_G4more	Correlation Coefficient	.33**	1.000
		Sig. (2-tailed)	.000	.
		N	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

The result of the correlation between G4more and PREDICTED_G4more was 0.33, $p < .001$ (Table 69). This value is similar to the simple correlation obtained in Table 67 for the model, $r = .32$ which means that the generalisability of the equation is good. However, in the scatter plot is observed that the predicted results are not reaching values higher than 1. As happened in the previous model to predict G3, this could be explained by the fact that the sample of bigger groups is smaller than the sample of groups of 1 or 2 people. Moreover, the majority of the data corresponds to observations of 1 or 2 big groups at the same time.

In conclusion, the model to predict Groups of 4 or more people obtained significant results of the equation. However, the plots from the cross-validation suggest that the calculation of the number of groups could be underestimated.

Multiple Regressions - Number of People and Groups: Key Findings

- The **Number of People** model explained up to 33% of the variability based on the Calculated Mean Radiant Temperature in the sun, Wind Speed and Illuminance (Figure 81 and Table 54).

$$\boldsymbol{N\_People} = 9.59 + (0.72 * Tr\_sun) + (-4.53 * Va) + (-0.001 * Light)$$

- **Groups of 1 person** were only influenced by the Air Temperature which explained 10% of its variability. The remaining 90% was affected by other external factors.

$$\boldsymbol{G1} = 0.89 + (0.37 * Ta)$$

- **Groups of 2 people (G2)** was affected by the Radiant Temperature in the sun and the Wind Speed. 27% of the variance of this variable was explained by this model:

$$\boldsymbol{G2} = 1.03 + (0.15 * Tr\_sun) + (-0.53 * Va)$$

- **Groups of 3 people (G3)** were influenced by the thermal environment. The Radiant Temperature in the sun and Wind Speed explained 16% of the variability of this behaviour.

$$\boldsymbol{G3} = 0.86 + (-0.52 * Va) + (0.02 * Tr_{sun})$$

- **Groups of 4 or more people (G4more)** were influence by the Light. This model accounts for the 10% of the variability of the big groups.

$$\boldsymbol{G4more} = 0.16 + (9.78E - 5 * Light)$$

The generalisability of the results for **G3** and **G4** were weaker than the predictability of **Number of People**, **G1** and **G2**.

6.4.2.3. Cluster Analysis

The cluster analysis of autumn was conducted using the same procedure described in the General Methodology and Summer Chapters (Chapters3 and 5). The continuous variables selected were: number of groups of 'G1', 'G2', 'G3' and 'G4 or more'. The variable evaluated was the Number of People. Figure 90 presents the cluster quality rate. It is observed that the four variables used presented a 'fair' quality for clustering the data. The Predictor also plotted the Importance of each variable to create the clusters. It is observed that G4more and G2 made the highest contribution to the classification. However, it was also observed that the variables containing higher numbers of people could potentially perform better at predicting the total occupancy.

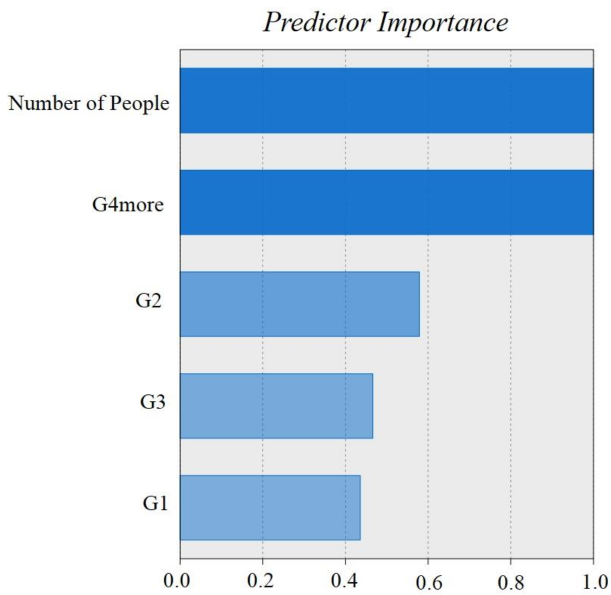


Figure 90 – Predictor Importance of variables for cluster analysis – Autumn

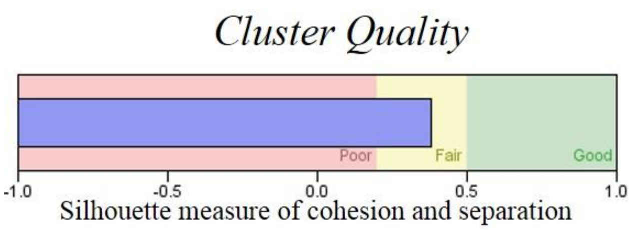


Figure 91 – Cluster Quality Rate

Figure 92 presents the relationship between Number of People, Number of Groups and Clusters (R2 = 0.86). The clusters present a similar distribution to the clusters generated for summer. Cluster 1 presents more distance between the points, cluster 2 is located over the fit line, cluster 3 is located below the fit line and cluster 4 corresponds to the lowest number of groups and people.

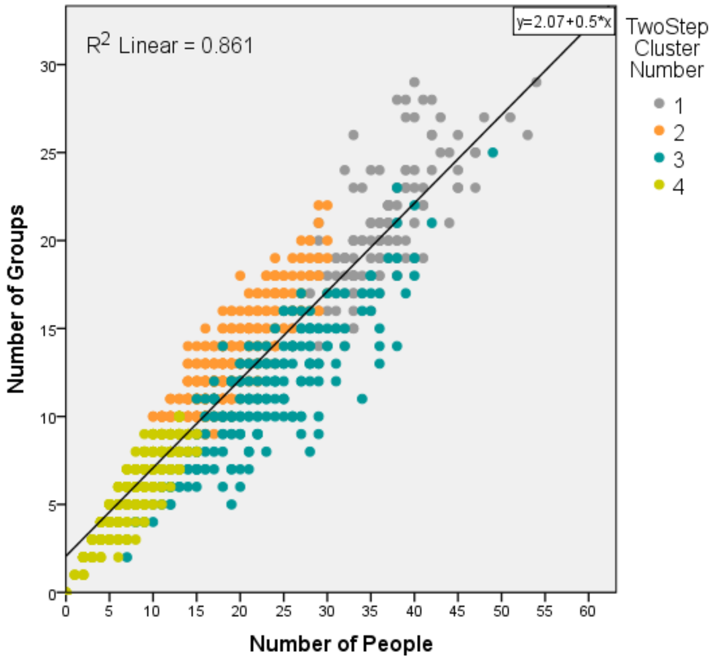


Figure 92 - Relationship between Number of People, Number of Groups and Clusters – Autumn

Cluster Analysis: Key Findings

- Number of People and Number of Groups presented a strong relationship (R^2 = 0.86).
- The number of G4more and G2 were the main predictors to generate the clusters.

6.4.3. Individual Behaviour

As mentioned at the beginning of this section, some of the individual behaviours of the users were recorded and analysed. The sample size was 1873 of people, 57.6% men and 42.2% women. The sample consisted of 89.6% adults, 3.65 teenagers, 3.5% children, 2.1% reduced mobility and 1.1% babies (Table 48).

6.4.3.1. Survival Analysis

This analysis was conducted using the same statistical methods presented in Chapters 3 and 5. A Kaplan-Meier estimator was used to generate the cumulative survival curves of the Time of Permanence of people according to their gender and the environmental conditions during their permanence in the public square. The results will include the means and medians of the survival time. Additionally, a summary of the cumulative survival analysis at different times. Is presented.

Time of Permanence and Gender

For this study, the complete sample was evaluated, this consisted of 1078 male, 791 female and 4 not known. Table 70 shows the means and medians of the survival time. It is observed that the estimated median of Time of Permanence for men was 5.6 minutes and 6.6 minutes for women. The median corresponds to the time when 50% of the users left the square.

Table 70 - Means and Medians for Survival Time

	Mean[a]				Median			
Gender	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper
Male	7.84	.22	7.42	8.26	5.60	.21	5.20	6.01
Female	8.59	.27	8.06	9.11	6.60	.20	6.20	7.00
Not	6.85	2.14	2.65	11.05	4.65	1.97	.80	8.50
Overall	8.15	.17	7.82	8.48	6.05	.17	5.71	6.39

a. Estimation is limited to the largest survival time if it is censored.

Figure 93 presents the survival curve of Time of Permanence according to the Gender. The y-axis of the chart represents the cumulative survival, where 1 is the survival in 100% of the cases and the x-axis is the time in minutes. This means that at the beginning, or zero minutes, the cumulative survival is 1, or 100% of the sample and it starts to decrease as the users leave the place.

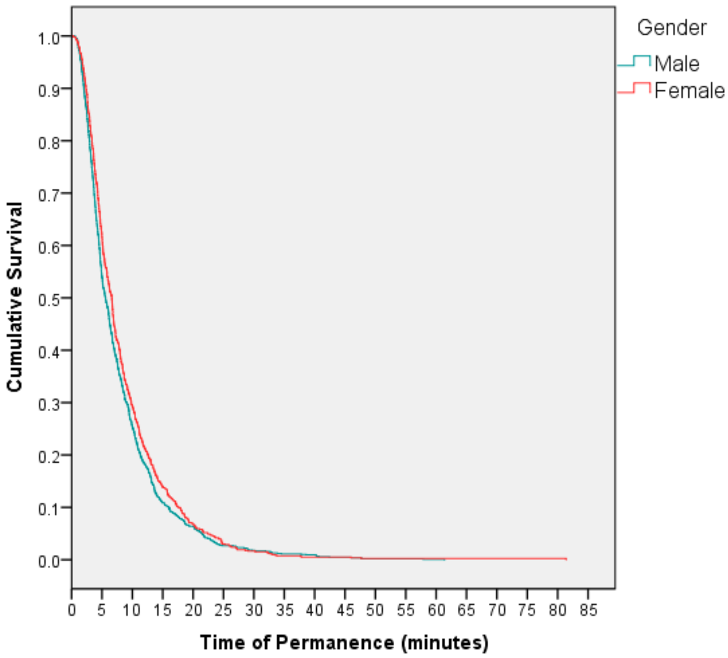


Figure 93 - Survival Function of Time of Permanence according to the Gender of users

It was observed that the blue line (men) was delayed for a few minutes between 5% and 50% of the population. This indicates a shorter permanence of men in comparison to women. However, since the curves of men and women are very similar, a Log-rank test was performed to determine if there is a significant difference. This analysis is used to test the null hypothesis of no difference in survival times between the curves. In Table 71 is observed a Log-rank $p > 0.05$, this indicated that the Gender curves did not present a significant difference in the Time of Permanence.

Table 71 - Log-rank test results

Overall Comparisons

	Chi-Square	df	Sig.
Log Rank (Mantel-Cox)	5.528	2	.063

Test of equality of survival distributions for the different levels of Gender.

In conclusion, the Gender did not affect significantly the Time of Permanence, although it showed a significance of $p = .063$ (Table 71). Nevertheless, it was found that almost half of the women stayed for a few minutes longer than men in times of permanence between 10 and 20 minutes.

Time of Permanence and Environmental Factors

In order to analyse the influence of the environmental factors in the Time of Permanence of the people in the square, a survival analysis per variable was performed. To conduct the analysis, pre-processing of the data was necessary to bin the results so they could be, visualised by ranges. In this section we are going to highlight and expand the main results of the survival analysis.

Figure 94 presents the survival curves of Time of Permanence according to the Air Temperature. It is observed that the longest permanencies were achieved when the Air Temperature was higher and the second lowest temperature presented the shortest Time of Permanence.

The general results of the survival analysis are presented on Table 72. It is observed that the estimated median for the shortest Time of Permanence occurred at 9^{o}C. This means that 50% of the users left the square at or before 3.12 minutes. Conversely, the highest estimated mean Time of Permanence occurred between 12^{o}C and 14^{o}C.

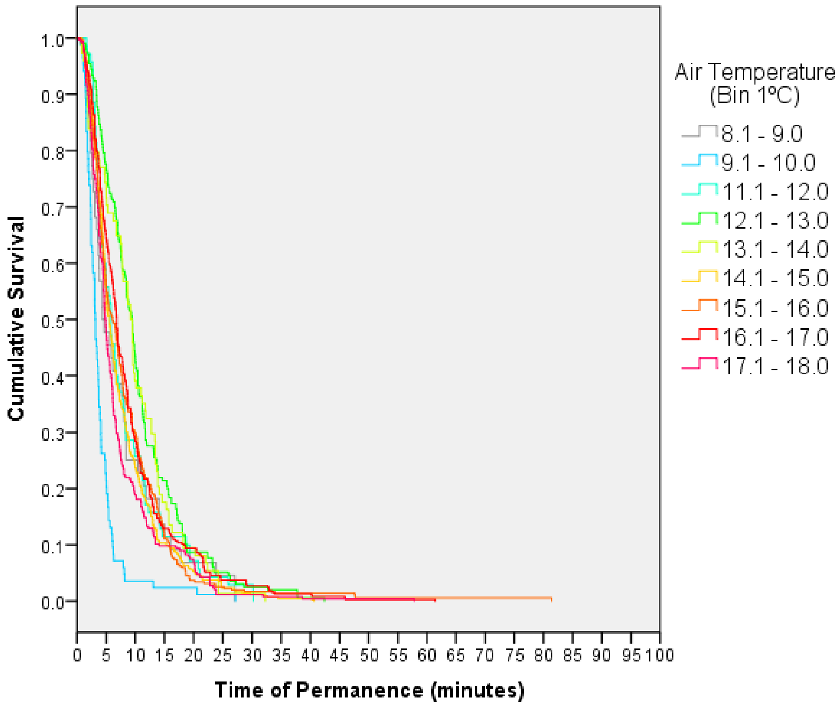


Figure 94 - Survival function of Time of Permanence and Air Temperature

Table 72 - Means and Medians for Survival Time

Air Temp. (Bin 1	Mean				Median			
	Estimate	Std. Error	95% Confidence Lower	Upper	Estimate	Std. Error	95% Confidence Lower	Upper
8.1 -	7.46	1.01	5.49	9.44	4.35	1.13	2.13	6.57
9.1 -	3.96	.41	3.16	4.76	3.12	.19	2.75	3.48
11.1 -	8.06	.78	6.53	9.59	5.82	.79	4.26	7.37
12.1 -	10.60	.52	9.57	11.62	9.38	.46	8.49	10.28
13.1 -	9.80	.77	8.28	11.32	9.15	.66	7.86	10.44
14.1 -	7.60	.30	7.01	8.20	5.47	.26	4.95	5.98
15.1 -	8.34	.46	7.44	9.24	6.10	.51	5.10	7.10
16.1 -	8.84	.40	8.05	9.63	6.78	.25	6.30	7.26
17.1+	6.97	.42	6.14	7.79	4.88	.18	4.54	5.23
Overall	8.15	.17	7.82	8.48	6.05	.17	5.71	6.39

With the aim of defining the amount of people remaining in the square in the different conditions of air temperature, the results of the survival curve were analysed and summarized. It is worth mentioning that the survival probabilities depend on the time of occurrence of the events, therefore, they are reported at certain time points. Accordingly, Table 73 contains the Air Temperature every 1ºC, Time of Permanence every five minutes and the estimated percentage of people remaining in the square under those conditions of time and air temperature.

Table 73 - Summary cumulative proportion of people remaining at the time

	Air Temperature								
Time	8°C	9°C	11°C	12°C	13°C	14°C	15°C	16°C	17°C +
1	100%	95%	100%	99%	97%	99%	99%	99%	99%
5	48%	20%	55%	78%	71%	55%	56%	64%	48%
10	25%	4%	26%	44%	39%	24%	30%	28%	19%
15	11%	2%	11%	21%	18%	10%	11%	13%	10%
20	7%	0%	7%	9%	10%	5%	3%	9%	7%
25	5%	0%	4%	5%	1%	2%	3%	5%	1%
30	0%	0%	0%	3%	1%	1%	1%	3%	0%

The survival curves presented differences according to the Air Temperature. The shortest time of permanence occurred at 9°C to 10°C, and the longest (exceeding one hour) occurred when the temperature was over 16°C.

Table 74 - Means and Medians for Survival Time Globe Temperature_sun

Tg_sun (Bin 2°C)	Mean				Median			
	Estimate	Std. Error	95% Confidence		Estimate	Std. Error	95% Confidence	
			Lower	Upper			Lower	Upper
<= 8.0	9.4	1.4	6.6	12.1	8.1	1.7	4.8	11.4
8.1 - 10.0	4.0	.4	3.3	4.8	3.1	.2	2.8	3.5
12.1 - 14.0	7.7	.6	6.5	8.9	5.9	.5	4.9	6.8
14.1 - 16.0	8.0	.2	7.6	8.5	6.3	.2	5.9	6.8
16.1 - 18.0	8.6	.4	7.7	9.5	5.3	.3	4.7	5.9
18.1 - 20.0	7.4	.7	6.1	8.8	5.0	.3	4.5	5.5
20.1 - 22.0	8.7	.5	7.8	9.6	6.9	.5	6.0	7.8
22.1 - 24.0	9.8	.9	8.1	11.6	7.7	.7	6.3	9.1
24.1+	9.1	.7	7.7	10.5	7.3	.4	6.5	8.0
Overall	8.2	.2	7.8	8.5	6.1	.2	5.8	6.4

Table 74 shows the results of the survival analysis for the Globe Temperature in the sun. It is observed that the Estimate Median for the shortest time of permanence occurs at 8 - 9°C. This means that 50% of the users left the square at or before 3.1 minutes with this condition. The second highest medians were observed over 22°C.

The clearest pattern on the survival analysis was found between the Time of Permanence and the Wind Speed. Table 75 corresponds to the means and medians of Time of Permanence according to different wind speeds. As can be observed, the time values descend when the air velocity increases. For instance, when the air velocity was 0.5 m/s or less, the mean Time of Permanence was 9.2 minutes, and when the air velocity increased over 2 m/s, the mean Time of Permanence was reduced to 2.2 minutes.

Table 75 - Means and Medians for Survival Time

Wind Speed	Mean				Median			
		Std.	95% Confidence Interval			Std.	95% Confidence	
(Bin 0.5 m/s)	Estimate	Error	Lower	Upper	Estimate	Error	Lower	Upper
<= .500	9.2	.3	8.7	9.7	7.0	.2	6.6	7.4
.501 - 1.0	7.7	.3	7.0	8.3	5.8	.3	5.1	6.4
1.001 - 1.5	7.6	.3	7.0	8.2	5.6	.3	5.0	6.2
1.501 - 2.0	4.0	.2	3.5	4.5	3.6	.3	2.9	4.2
2.001+	2.2	.2	1.8	2.6	2.0	.6	.8	3.1
Overall	8.2	.2	7.8	8.5	6.1	.2	5.7	6.4

The survival curves (Figure 95) proved the tendency observed before with the medians. In addition, the permanencies are consistently affected from the beginning to the end by the Wind Speed. As can be seen the green and cyan line, representing wind speeds between 0.5 - 1.0 m/s and 1.0 - 1.5 m/s, are very close. This indicates that people do not perceive strong differences between 0 and 1.5 m/s, regarding their decision to leave the square. Nevertheless, it is also observed that the length of the cyan line is extended up to 80 minutes.

In Table 76 are summarised the survival curves. It contains the total percentage of people remaining in the square according to the time and air velocity. For instance, with a Wind Speed of 1.0 - 1.5 m/s, 56% of the population remained in the square for at least 5 minutes, but only 5% decided to stay after 20 minutes.

In conclusion, the Wind Speed is a variable that highly influenced the Time of Permanence of the users in Trinity Square during autumn.

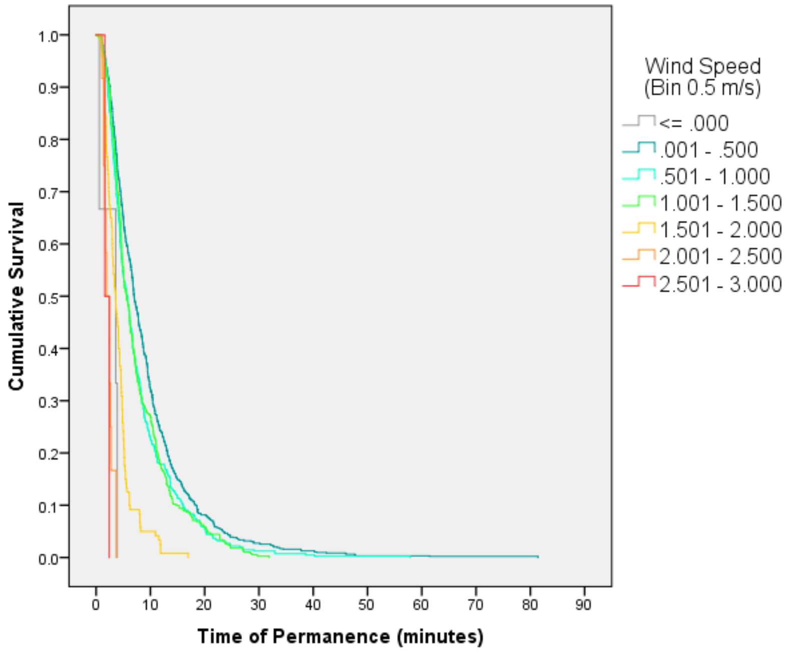


Figure 95 - Survival curves Time of Permanence according to Wind Speed

Table 76 - Summary proportion of people remaining at the time

	Wind Speed				
Time (min)	<=0.5 m/s	0.5 - 1.0 m/s	1.0 - 1.5 m/s	1.5 - 2.0 m/s	2.0 +
1	99%	99%	99%	98%	93%
5	65%	54%	56%	24%	0%
10	32%	23%	27%	5%	0%
15	15%	11%	10%	0%	0%
20	8%	5%	5%	0%	0%
25	4%	2%	2%	0%	0%
30	3%	1%	0%	0%	0%
35	2%	0%	0%	0%	0%

Survival Analysis – Time of Permanence: Key Findings

- **Gender** did not affect significantly the **Time of Permanence** during autumn. However, within the range of 10 to 20 minutes women presented a higher **Time of Permanence** than men.
- **Air Temperature** influenced the **Time of permanence**. The longest permanencies of more than an hour occurred during the highest temperatures (16°C or more) during autumn.
- The users remained for longer periods of time when the Calculated Mean Radiant Temperature presented average autumn conditions (14 to 20°C Tr_shadow). The shortest permanencies occurred during the lowest or highest Calculated Mean Radiant Temperatures.
- The most important finding was the pattern generated by the Wind Speed. It was observed that this variable clearly influenced the Time of Permanence of the users. As the Wind Speed increased,

6.5. Discussion

This study aimed to evaluate the influence of the thermal environment on social and individual behaviours during autumn and identify the environmental factors with the strongest relationship with the behaviour, in order to generate models to predict human behaviour.

According to the results, Number of People was significantly correlated to the thermal environment variables, with the exception of Relative Humidity. Almost all the correlations were positive indicating that as the environmental factors increased or decreased, so did the Number of People. The wind speed, as expected, is the only negative relationship. According to Nikolopoulou & Steemers (2003), the strongest correlation found to explain the occupancy was Globe Temperature. However, this study showed that the highest correlation existing between environmental factors and human behaviours in autumn, was between Number of People and calculated Mean Radiant Temperature in the Sun ($r = .51$, $p < .001$).

The strong correlation between the calculated Mean Radiant Temperature and the Number of People may be explained by the fact that “The net amount of radiant heat lost or received by the human body is the algebraic sum of all radiant fluxes exchanged by its exposed parts with the various surrounding heat source” (ISO, 2001, p. 14). Moreover, Nikolopoulou & Steemers (2003) did not report relationship between wind speed and occupancy, whilst this research showed that the air velocity contributed with the strength of the model and is present with a negative figure in the equation to predict number of people in autumn, according to which the number of people decreases when the wind speed increase. Conversely, the calculated Mean Radiant Temperature and the illuminance were positive figures in the equation, according to which, this factors influenced positively the attendance of people to the place in autumn. About this, Stathopoulos et al., (2004), who conducted a study of comfort in spring and autumn, stated: “highest preference for solar radiation occurred when the actual solar radiation is at the lowest” (p. 303). Therefore, a variable that considers multiple factors like wind speed, solar radiation and calculated mean radiant temperature, is more likely to be perceived by the users, and can therefore influence better their attendance to a public space.

After running the correlations and the multiple regression models, it was found that the use of various environmental factors together help increasing the models’ predictive power using the forward method. For example, the equation to predict the Number of People in autumn, which accounts for the

33% of the variance of the behaviour, includes the influence of the Radiant Temperature in the Sun, the Wind Speed and Light.

In consequence, the main finding of this study was showing agreement with the findings of the literature review where it has been said that the attendance of people is better predicted by taking into consideration various factors rather than a unique factor or a main predictor. The human body is a multi-sensory receptor, according to which the integration of conditions make a space more or less attractive for the permanence of people.

Regarding Number of Groups of G1 it was found that, in general, this Social Behaviour presented weak correlations with the thermal environment during autumn. The highest correlation found was Air Temperature ($r = .26$, $p < .001$) and is the only factor contributing with the model to predict the variance of Number of Groups of G1, which makes it a weak model as it only accounts for 10% of the variance of the behaviour.

Wind Speed is a common factor influencing Number of Groups of G2 and Number of Groups of G3. However it must be noted that this factor presented a weak correlation with the Social Behaviours in General. The best predictor for Number of Groups of G2 was Mean Radiant Temperature_sun ($r = .45$, $p < .001$), and the model produced accounted for 27% of the variance of this behaviour. As has been stated before, the human behaviour responds to several variables and the models built only accounts for the response of the human body to environmental stimuli.

Finally, it was observed that the model produced to predict Groups of G4 or more during autumn presents a $R^2 = 0.1$ and a poor generalisability, due to the low correlations observed between this behaviour and the environmental factors. Accordingly, this model has a low performance predicting the variance of this Social Behaviour during autumn. However, as it occurred in summer, the cluster analysis suggests that bigger groups could be better predictors of the total occupancy than the smaller groups.

In consequence, a 'Group Diversity Index' (GDI) was conducted for Autumn following the same parameters as Summer: 0 is the situation where no groups were present at the square, 0.25 correspond to at least one type of group present, 0.5 when two types of groups are present, 0.75 for three types of groups present simultaneously, and 1 when all the types of groups were present in the square.

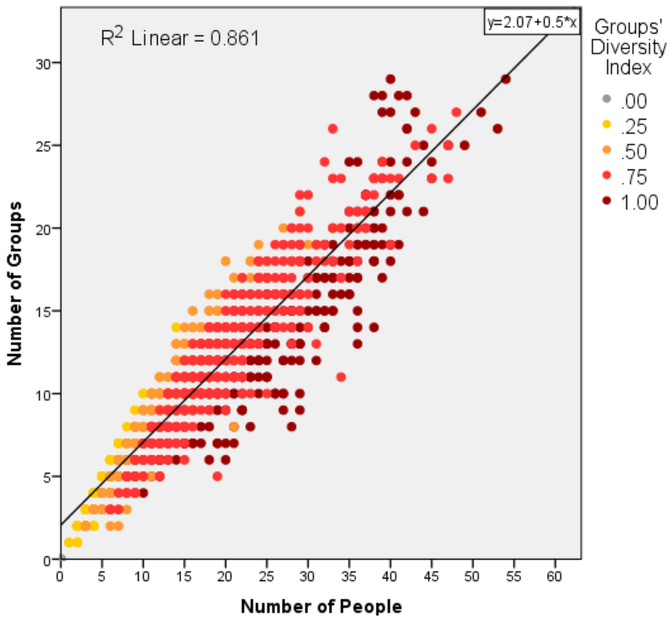


Figure 96 – Scatter Plot Number of Groups, Number of People and GDI - Autumn

Table 77, presents the percentage of data in each cluster. It is observed that most of the time the GDI is 0.75 (41.2%), which means that 41% of the time there was presence in the square of a variety of three groups which is a similar result to Summer, when there were three varieties of groups 47% of the time. However, it is worth mentioning that Summer presented a higher percentage of time with four types of groups cohabitating the space (35.8% of the time corresponding to a rate of 1.00); whilst in autumn, only 18.4% of the time 4 or more types of groups were present in the square at the same time (GDI: 1.00 = 18.7%).

Table 77 - Groups Diversity Index (GDI) - Autumn

Groups' Diversity Index (GDI)			
		Frequency	Percent
	.00	5	.4
	.25	74	5.9
	.50	426	33.8
	.75	519	41.2
	1.00	236	18.7
Valid	Total	1260	100.0

Regarding Individual behaviours in autumn, it should be said that no difference is reported between the behaviours of people in the square by gender, as has been previously reported by Fanger (1970), although the analysis here conducted was close to significant $p = .063$ (Table 71). Wind Speed was the environmental factor that presented the highest influence on Individual Behaviours. The survival analysis conducted showed that the Time of Permanence was lower as of Wind Speed increased. 60% of the users remained in the square at least 10 minutes with Wind Speeds between 0.5 – 1.0 m/s and 1.0 – 1.5 m/s. However the survival curves for Wind Speeds of more than 1.5 m/s drops dramatically as almost all the users decided to depart from the square after 10 minutes of permanence with Wind Speeds of 1.5 – 2.0 m/s and only 5 minutes for Wind Speeds above 2.0 m/s.

Regarding Air temperature, only temperatures between the ranges of 9.1^{o}C – 10.0^{o}C presented considerable difference in the Time of Permanence of Users. At this temperature most of the users decided to leave the square just after 5 minutes of permanence, while in the other temperatures registered, most of the users remained 10 minutes or more in the square.

These results highlight the importance of Wind Speed and Air temperature to the use of urban spaces in autumn in terms of individual behaviours.

6.6. Conclusions

This study presented an insight of the human behaviour in a public space during autumn, according to the thermal environment. The chapter presented equations to predict the variance of Social Behaviours of Number of People, Number of Groups of G1, Number of Groups of G2, Number of Groups of G3 and Number of Groups of G4; although, due to the low relationships found for Number of Groups of G4 and the environmental factors, the power to predict of this model is low. The model with the highest prediction power was the Number of People which accounts for the 33% of the variance of the behaviour. The factors contributing to this model were Calculated Mean Radiant Temperature in the Sun, Wind Speed and Light.

Environmental factors such as Wind Speed and Air Temperature proved to have influence on the individual behaviours as they affected the Time of Permanence of the users of the public square in autumn.

This chapter showed that human behaviour is affected by a different set of environmental factors, which have to be considered together when assessing their predictability in an outdoor public space. This principle aligns closely with the statement of Arens & Bosselmann (1989) “In reality, comfort is affected by the combined influences of sun, radiation, temperature, humidity and rain” (p. 315). Therefore, there must be an understanding of the correct combination of the environmental influencers affecting the behaviours, in order to design better urban spaces.

7. Human Behaviour in Winter

7.1. Chapter Overview

This chapter presents the results of a further study of human behaviour according to the thermal environment. For this instance, data were collected in winter 2016. The methodology used was the same as in the summer and autumn studies. The sample size of the study in winter was 1260 minutes for Social Behaviour and 1127 people for the individual behaviour analysis. The data analysis consisted of correlating all the variables and filtering the most significant correlations to be used in a subsequent multiple regression analysis and survival analysis with the aim of producing equations to predict the human behaviour according to the thermal environment. It was found that light, wind speed and relative humidity explained up to 46% of the number of people. Additionally, it was found that the wind speed influenced the time of permanence: as the wind speed increased the time of permanence decreased.

7.2. Introduction

Johansson et al. (2014) and Chen & Ng (2011) made a review of the publications in comfort over the last decade and none of the studies listed was focused exclusively in winter, as the studies also included data in summer, autumn or spring. This lack of interest of evaluating human behaviour in outdoor urban spaces during winter may follow to the lack of use of outdoor public spaces over the coldest season. As reported by Nikolopoulou et al., (2001), the number of people in four different outdoor public spaces in Cambridge was correlated to the globe temperature; the attendance over the seasons was very low when the mean globe temperature went below 10^{o}C, which were measurements recorded during winter.

Höppe, P. (2002) reported that the main difference between indoors and outdoors is the time spent in these places: indoor spaces are commonly used for hours whereas outdoor spaces are used for minutes. In one of his studies, the thermo-physiological response of the body was simulated while a person moved from comfortable indoor conditions to an outdoor space in a cold winter day. It was found that the body response to the cold environment is higher during winter than summer due to the vasoconstriction which helps reduce body heat loss (Parsons, K. 2003) The main issue in outdoor urban spaces is however not to determine the limit of resistance of the human body to low temperatures, but the lack of use of this spaces in this season, since the main adaptive behaviour people take under winter conditions is to remain in indoors. Accordingly, the concern should be what makes the space suitable to be occupied for the longest period of time, or used with greater frequency.

The present study is part of a three seasons' data set, where the behaviour of users was studied according to different thermal conditions. The aim of the study during winter was to assess the influence of air temperature, wind speed, globe temperature, radiant temperature, light and relative humidity on human behaviour.

7.3. Method

The methodology used in winter is the same used during summer and autumn (Chapters 5 and 6), with the minor differences reported below. The sections: equipment, exclusion criteria, announcing the study, ethics approval and procedure are the same as defined in Chapter3, and are therefore not reported here. The aim of this study was to assist the collection of data of human behaviour in public spaces, whilst measuring the environmental conditions during winter.

Population and Time Sample

There were two types of observations performed in summer, autumn and winter, social behaviour and individual behaviour, as explained in Chapters 395. The sample of Social Behaviour analysis was the total minutes recorded. During the period recorded, all the people remaining in the square or passing through it were recorded, but no individual characteristics were analysed at this stage as this was made later in the Individual Behaviour analysis. The time sample of this study was 180 minutes per day, during each of the seven days of the week. A total of 1260 minutes of the winter study were evaluated.

In the individual behaviour analysis, a total of 1127 occupants were evaluated. These were the people who entered into the square and remained there, as opposed to people just transiting to another destination. The criteria to include users in the analysis were: people remaining in the evaluated area, people whose permanence in the square was recorded from beginning (i.e. entry to the square) to the end (exit of the square), people not transiting to the shops next to the square, and people not sitting or being part of the restaurants' activities next to the square.

Individuals were classified by observation in age groups: baby, child, teenager, adult and mobility reduced. The people in the last group included those who mobilised using assisting devises such as: wheelchairs, crutches, canes and others. According to the data presented in Table 78 most of the people were adults, 90.7%.

Table 78 – Age Frequency

Age Frequency

		Frequency	Percent
Valid	adult	1022	90.7
	teenager	50	4.4
	child	33	2.9
	baby	7	.6
	mobility reduced	15	1.3
	Total	1127	100.0

The sample was also classified by gender: male, female and not known. The last group was selected when the observer was not able to identify the gender of the individual with the video analysis. Table 79 presents the gender frequency observed, a higher percentage of attendance of men (60.6%) in comparison to women (39%), was recorded.

Table 79 - Gender Frequency

Gender Frequency

		Frequency	Percent
Valid	Male	683	60.6
	Female	439	39.0
	Not Known	5	.4
	Total	1127	100.0

Duration and Season

The data collection was conducted for five weeks in winter, from the 26^{th} of January to the 2^{nd} of March 2016, of which seven days were randomly selected for analysis (Table 80). Studies of the previous seasons were conducted during four weeks; however, in winter some of the days were excluded because of heavy rain, square closures or fairs. Therefore the study in winter was extended. The weeks of the study were selected according to the historic data of the temperature variation of Nottingham. The aim was to capture a high environmental variation from the lowest temperatures historically recorded and the moment when the temperature started to increase.

From the data gathered seven days were selected to be analysed: one of each day of the week (Table 80). This strategy allowed obtaining a sample which was not affected by several factors often present when collecting data from a natural environment: rain, technical problems, social events, security, among others. Therefore, if the first day of the week recorded presented any of the exclusion criteria, then the next day of the following week was selected to be analysed.

Table 80 - Calendar of data collection and days selected for analysis

January 2016						
Mo	Tu	We	Th	Fr	Sa	Su
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

February 2016						
Mo	Tu	We	Th	Fr	Sa	Su
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	1	2				

Selected Days for Analysis

Recorded Period

Excluded (Fairs or Heavy Rain)

The data was collected for three hours randomly selected for each day between 10:30 am and 6:30 pm. This period was selected because this is the time when most of the city services are open. Table 81 presents the hours recorded for each of the selected days.

Table 81 - Time randomly selected to collect data each day

Winter 2016

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
10:30		■	■				
11:00		■	■				
11:30		■	■				
12:00		■	■				
12:30		■	■				
13:00		■	■				
13:30	■					■	
14:00	■			■		■	
14:30	■			■		■	■
15:00	■			■	■	■	■
15:30	■			■	■	■	■
16:00	■			■	■	■	■
16:30				■	■		■
17:00					■		■
17:30					■		
18:00					■		

7.4. Results

The results, as in the previous seasons, were divided in three sections: 1. Environmental Data, which describes the environmental conditions recorded during the study; 2. Social Behaviour analysis, which contains the occurrence of events in relation to the place by counting the aggregates of general behaviours (number of people and grouping); and 3. Individual Behaviour analysis, referring to the specific conduct of users. This section will show the analysis of the time of permanence of users according to the environmental variables.

7.4.1. Environmental Measurements

Environmental sensors were placed in the public square, set to measure every minute. A total data set of 1260 minutes was filtered to analyse during winter, which corresponds to 3 hours between 10:30 a.m. and 6:30 p.m. during seven days (Table 80 and Table 81).

Table 82 presents the descriptive statistics of the environmental data collected. The variables measured were: air temperature, Ta (ºC); relative humidity, rH (%); globe temperature in the sun, Tg_sun (ºC); globe temperature in the shadow, Tg_shad (ºC); mean radiant temperature in the sun, Tr_sun (ºC); mean radiant temperature in the shadow, Tr_shad (ºC); wind speed, Va (m/s) and light, Light (lx).

Table 82 - Descriptive statistics of the environmental variables

Statistics (N = 1260)

	Ta (ºC)	rH	Tg_sun	Tg_shad	Tr_sun	Tr_sha	Va	Light
Mean	9.3	58	11.4	9.9	16.4	11.3	1.421	2541
Std.	2.3	9	3.9	2.3	12.5	4.4	.982	3402
Minimum	5.1	39	6.1	5.9	2.6	6.0	.000	12
Maximum	14.7	76	28.0	15.6	69.3	35.7	4.959	14534

Acronyms: Air temperature (Ta), relative humidity (rH), globe temperature (Tg), calculated mean radiant temperature (Tr), wind speed (Va) and illuminance (Light).

Table 83 contains the correlation analysis of some environmental variables with each other. This procedure was conducted to determine the relationship of the independent variables with each other and the variation of the environment during winter.

According to Table 83, the air temperature presented significant correlation with almost all the variables, except light. As expected, this was negatively correlated with relative humidity ($r = -.41$, $p < .001$). The highest correlation found was with globe temperature in the shadow ($r = .92$, $p < .001$), this may be explained by the fact that during winter the grey globe is not highly exposed to high radiation due to the heat loss of the surfaces, therefore the results are similar to measuring the air temperature.

Table 83 - Correlations between environmental variables in winter

Spearman's rho Correlations (N = 1260)

		Ta	rH	Tg_Sun	Tg_Shad	Tr_Su	Tr_Sh	Va	Light
Ta	Correlation	1.00							
	Sig. (2-tailed)	.							
rH	Correlation	-	1.00						
	Sig. (2-tailed)	.000	.						
Tg_Sun	Correlation	**.58****	**-.71****	1.00					
	Sig. (2-tailed)	.000	.000	.					
Tg_Shad	Correlation	**.92****	**-.59****	**.81****	1.00				
	Sig. (2-tailed)	.000	.000	.000	.				
Tr_Sun	Correlation	**.25****	**-.62****	**.79****	**.47****	1.00			
	Sig. (2-tailed)	.000	.000	.000	.000	.			
Tr_Sha	Correlation	**.62****	**-.73****	**.87****	**.79****	**.85****	1.00		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.		
Va	Correlation	**.43****	.04	-.08**	**.24****	-.09**	**.13****	1.00	
	Sig. (2-tailed)	.000	.142	.007	.000	.001	.000	.	
Light	Correlation	-.04	**-.54****	**.63****	**.23****	**.79****	**.58****	**-.34****	1.00
	Sig. (2-tailed)	.167	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).+

Acronyms: Air temperature (**Ta**), relative humidity (**rH**), globe temperature in the sun (**Tg_sun**), globe temperature in the shadow (**Tg_shad**), mean radiant temperature in the sun (**Tr_sun**), mean radiant temperature in tha shadow (**Tr_shadow**), wind speed (**Va**).

A strong negative relationship was also found between relative humidity and the globe and radiant temperatures (e.g. Tr_shadow $r = -.73$, $p < .001$). This means that as the relative humidity increased, the globe and mean radiant temperatures decreased. As expected, the globe and radiant temperatures in the sun and shadow were highly correlated to each other.

The wind speed presented a significant relationship with the air temperature ($r = .43$, $p < .001$), and negative correlation with light ($r = -.34$, $p < .001$). Light presented significant correlation with almost all the variables, except air temperature. The higher correlation of Light was with the variables related to the direct solar radiation: globe temperature in the sun, $r = .63$ and mean radiant temperature in the sun, $r = .79$, both $p < .001$.

Figure 97 presents the percentage distribution of the air temperature during the sample recorded. For illustrative purposes the data was binned at 1°C (Haldi & Robinson, 2009). As can be seen, the majority of the air temperature was measured between 8.1 – 9.0 °C. Almost 40% of the environmental data gathered was between this ranges, which was therefore the most common condition during the study in winter. The highest air temperature recorded exceeded 14.1 °C and the lowest was 5.1 – 6.0. °C.

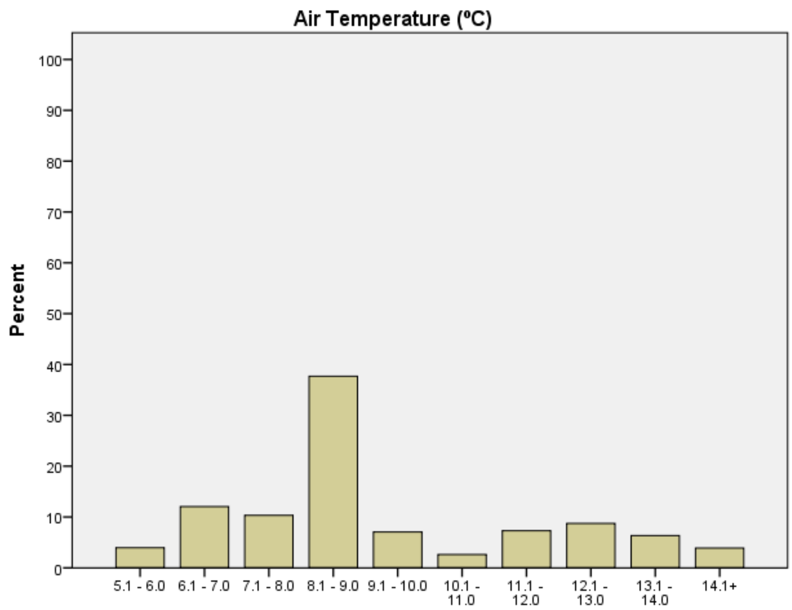


Figure 97 - Air temperature (ºC) percentage distribution - winter

Figure 98 presents the relative humidity percentage distribution, which was binned at 5%. The most frequent condition was 51 – 55%, followed by 46 – 50%. Most of the data was collected within 46 – 75% of relative humidity, being the most frequent condition 51 – 55%.

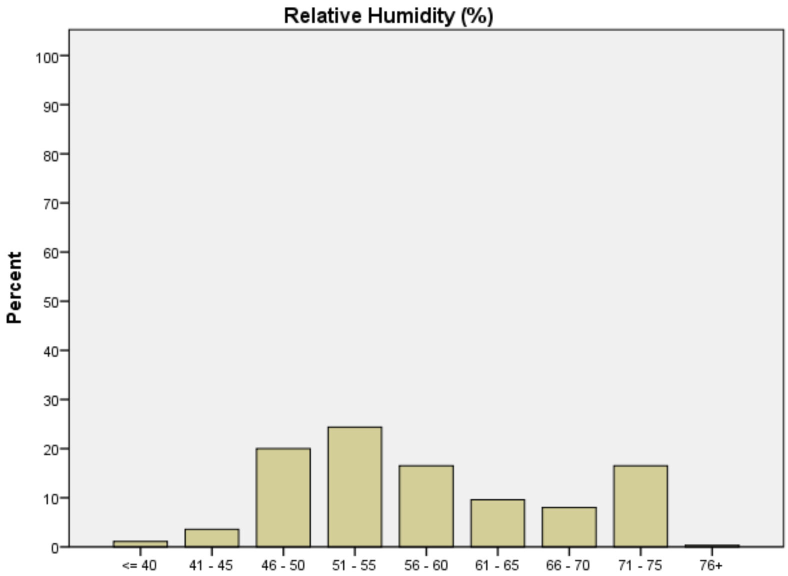


Figure 98 - Relative Humidity (%) percentage distribution - winter

Figure 99 presents the globe temperature in the sun distribution binned at 2°C. The most common condition was 8.01 – 10.0°C. In addition, the majority of the data collected was between 6.01 – 14.0°C.

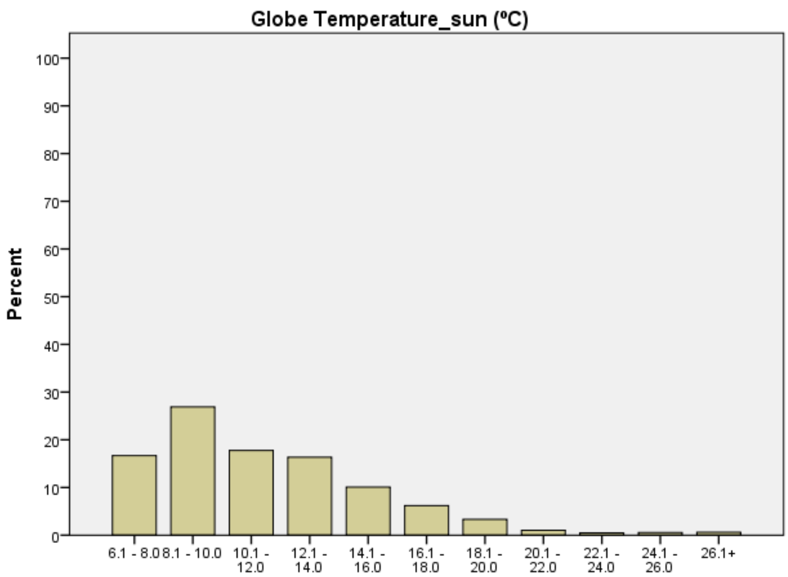


Figure 99 - Globe temperature in the sun (ºC) percentage distribution - winter

The globe temperature in the shadow (Figure 101) recorded a lower percentage of temperatures above 14.01°C than globe temperature in the sun. It is however observed that, in general, sun and shadow presented similar measurements, which suggests an overall low presence of solar radiation.

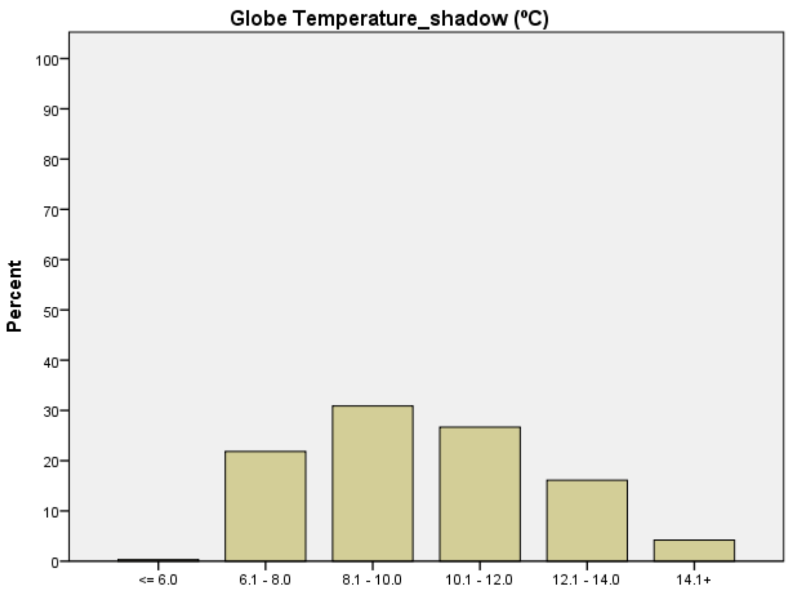


Figure 101 - Globe temperature in the shadow (ºC) percentage distribution - winter

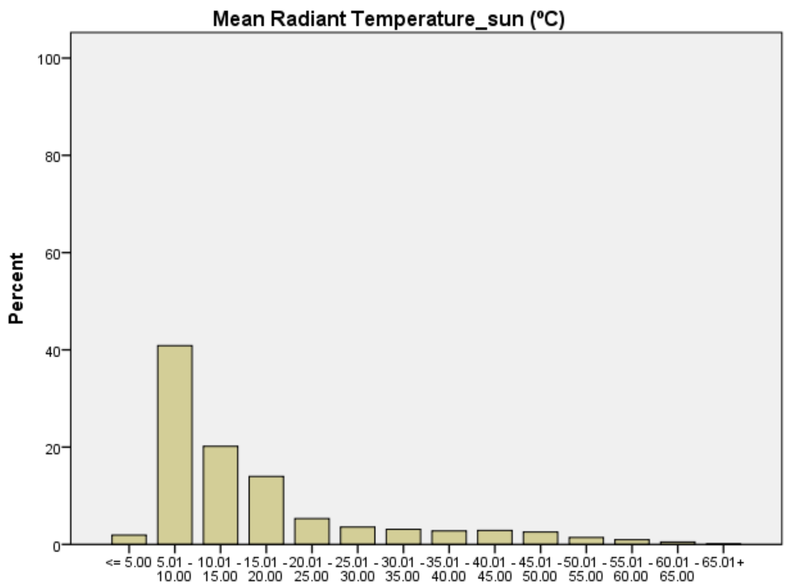


Figure 100 - Mean radiant temperature in the sun (ºC) percentage distribution - winter

Figure 100 shows the frequency of the calculated mean radiant temperature in the sun during the winter study. The most frequent condition, with 40% of the data, occurred at 5.01 – 10.0°C. The majority of the data was gathered between 5.01 and 20.0°C.

Interestingly, the majority of the data of mean radiant temperature in the shadow was between 5.01°C and 15.0°C, as there was less data gathered above 15.01°C in the shadow than in the sun (Figure 102).

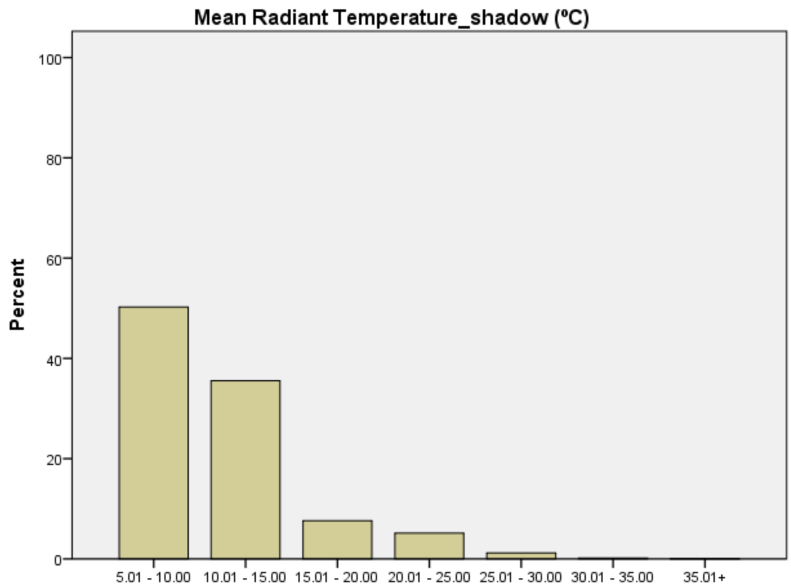


Figure 102 - Mean radiant temperature in the shadow (ºC) percentage distribution - winter

Regarding wind speed measurements, most of the data was collected between .001m/s and 2.50m/s (Figure 103). The most common measurement occurred at 1.00 m/s - 1.50 m/s followed closely by measurements between 0.001 - 0.50 m/s. The sensor reached a few lectures of wind speed of up to 4.5 m/s and above.

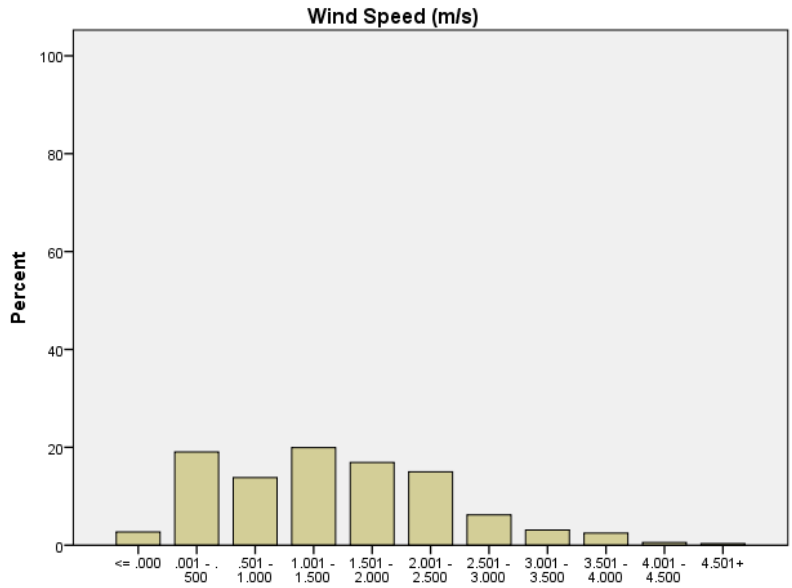


Figure 103 - Wind speed (m/s) percentage distribution - winter

Finally, the illuminance levels measured were mainly obtained within the range of 0 – 1,500 lx (Figure 104). This can be explained by the early sunset time during winter and cloudiness in most of the days analysed. The rest of the measurements between 1,501 lx and 14,001 lx plus, presented a low frequency.

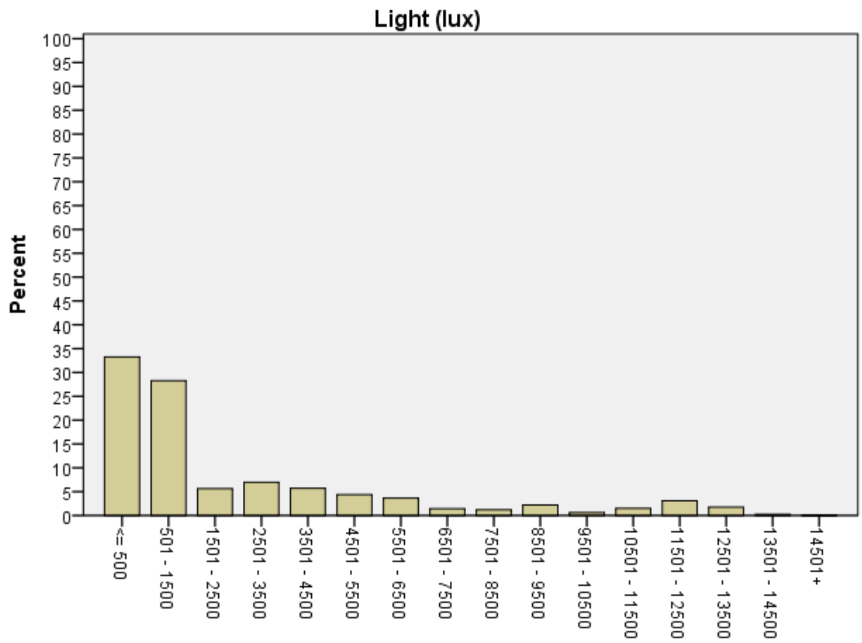


Figure 104 - Illuminance (lx) percentage distribution - winter

The data presented describes the environmental characteristics of Trinity square in Nottingham during winter.

7.4.2. Social Behaviour

The methodology used for winter was the same as in summer and autumn, which consisted of counting the Number of People and the Number of Groups present in the square per minute. Table 84 presents the descriptive statistics of the Number of People, Number of Groups of one (G1), two (G2), three (G3) and four or more (G4more).

Table 84 - Descriptive statistics of the Number of People and number of group types

Statistics

	Number of People	G1	G2	G3	G4more
Mean	10	3	2	0	0
Median	8	3	1	0	0
Std. Deviation	7	3	2	1	1
Minimum	0	0	0	0	0
Maximum	36	15	11	4	3

Acronyms: Groups of 1 (G1), Groups of 2 (G2), Groups of 3 (G3),

The category G4more contains groups of 4 and up to 14 people which was the biggest group size observed. This category included all the other big groups, because of the infrequent nature of these sizes, compared to the frequency of the other groups. The sum of observations of G4more totalled 355, which is 4.7% of the total of observations.

In Table 84, the mean is the total Number of People or Number of Groups observed per minute, divided by the number of minutes. The mean Number of People per minute was 10, with a standard deviation of 7. The median of G3 and G4more was 0 which means that most of the time there were no groups with this quantity of people in the square.

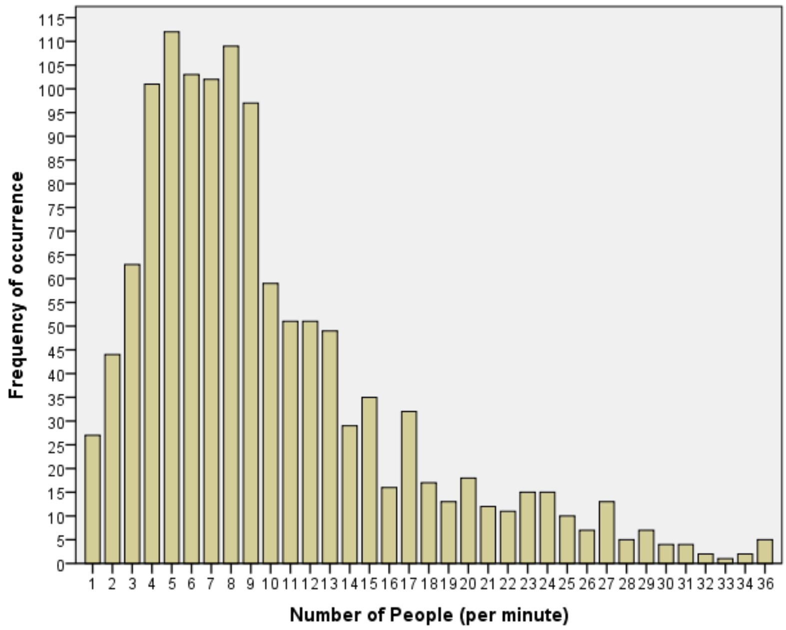


Figure 105 - Number of People frequency distribution - winter

Figure 105 presents the frequency distribution of the Number of People per minute in the square during winter. The most frequent occupancy per minute was 5 people; while the highest occupancy observed was 36 people. It must be however observed that the percentage of frequency of 5 people per minute is below 10% which was close to the data of 4 to 9 number of people per minute in the square.

Figure 106 and Figure 107 present the percentage distribution of G1 and G2. As can be seen in G1, the most frequent observation per minute was 2, followed by 3 and 1 groups of one person per minute. Although more than 8 groups of one person were observed, their frequency was low. In Figure 107 it can be observed that the peak is at 1 couple per minute as the most frequent Number of Groups of 2 present in the square in winter.

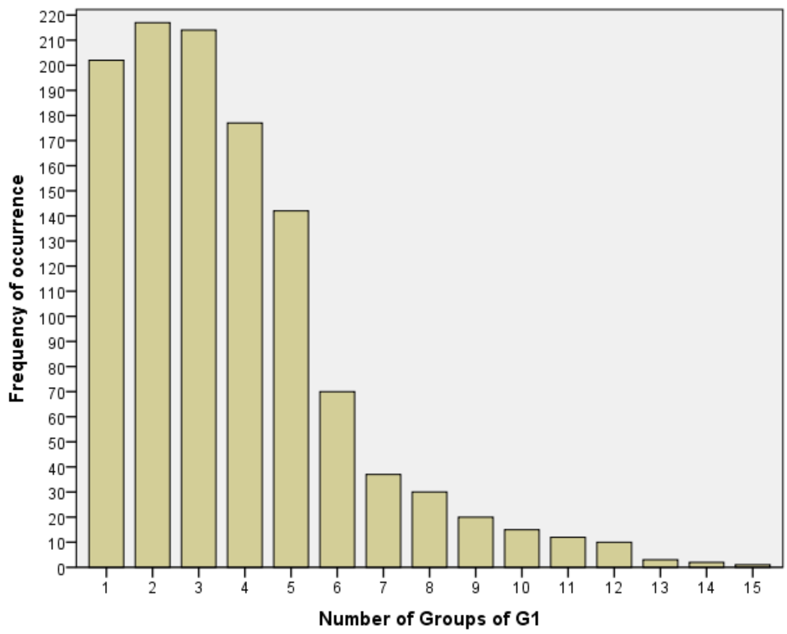


Figure 106 - Groups of 1 frequency distribution

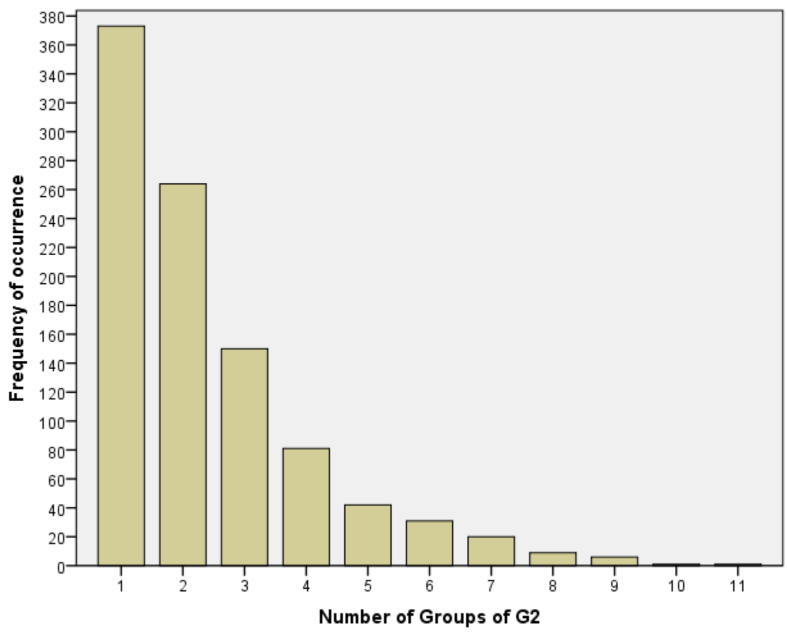


Figure 107 - Groups 2 frequency distribution

Figure 108 and Figure 109 present the distribution of the data of groups of 3 and groups of 4 or more per minute. As can be observed, in the case of G3 at least one group was present in 25% of the observations. Similarly, one group of four or more people was present in the square in approximately 18% of the times. The presence of more than one big group at the same time was infrequent; it is observed that less than 5% of the time recorded presented two big groups in simultaneity. Even the condition of three or more groups at the same time was very rare.

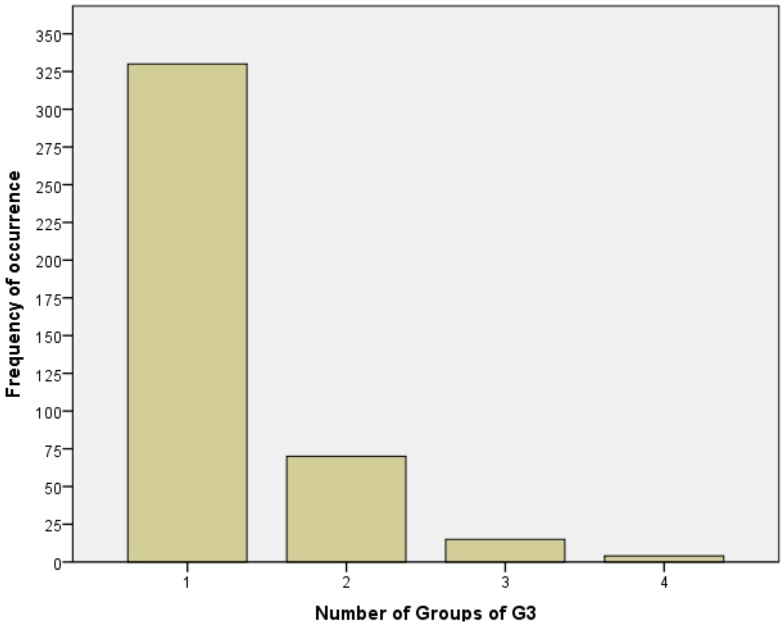


Figure 108 - Groups 3 frequency distribution

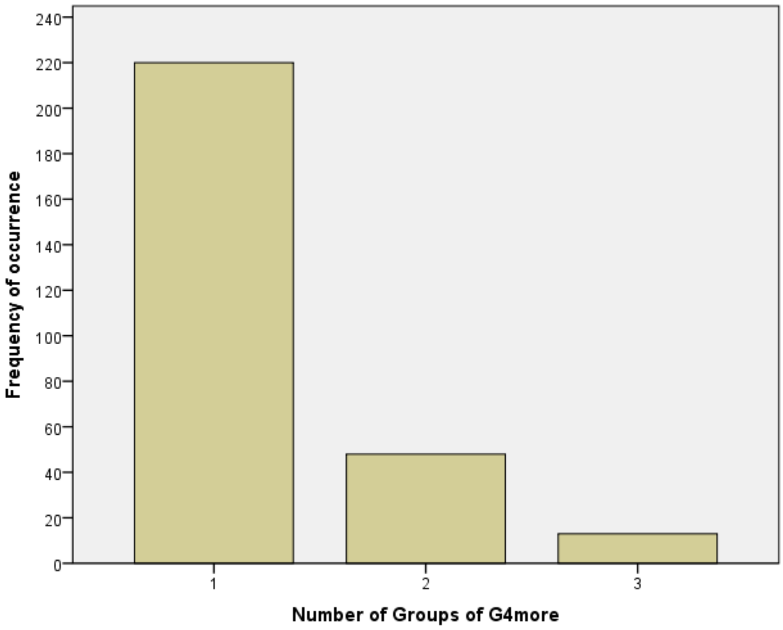


Figure 109 - Groups 4 or more frequency distribution

7.4.2.1. Correlation

This analysis consisted of evaluating the correlation between environmental variables, Number of People and Number of Groups. This had the purpose of identifying the influence of the environmental factors over the behaviours. Before conducting the correlations, a Kolmogorov Smirnov test was performed to verify whether the distribution of the data was normal in all variables in order to select the type of correlation analysis (Appendix 4). All the variables were significantly non-normal, since all of them obtained $D(771) < .001$. According to this, the type of correlation analysis required to study the relationship between variables is a Spearman's rho correlation.

Table 85 corresponds to the correlation between the social and the environmental variables (blue highlight). It is worth mentioning that the correlation of the environmental variables in Table 85 will differ slightly from the results in Table 83 because the sample was split for this analysis. However, as can be evidenced in both tables, the correlations found presented very similar values.

Table 85 - Correlations between social and environmental variables

Spearman's rho Correlations (N = 771)

		N_People	G1	G2	G3	G4more	Ta	rH	Tg_Su	Tg_Sh	Tr_Sun	Tr_Sh	Va	Ligh
Ta	Correlation Coefficient	-.11**	.14**	-.06	-.11**	-.24**	1.00							
	Sig. (2-tailed)	.001	.000	.097	.003	.000	.							
rH	Correlation Coefficient	-.40**	-.44**	-.32**	-.08*	-.09*	-.41**	1.00						
	Sig. (2-tailed)	.000	.000	.000	.019	.014	.000	.						
Tg_Sun	Correlation Coefficient	.25**	.47**	.23**	.03	-.12**	.61**	-.69**	1.00					
	Sig. (2-tailed)	.000	.000	.000	.367	.001	.000	.000	.					
Tg_Shad	Correlation Coefficient	.07*	.29**	.10**	-.02	-.18**	.93**	-.58**	.82**	1.00				
	Sig. (2-tailed)	.048	.000	.007	.576	.000	.000	.000	.000	.				
Tr_Sun	Correlation Coefficient	.29**	.35**	.19**	.12**	.01	.29**	-.62**	.80**	.49**	1.00			
	Sig. (2-tailed)	.000	.000	.000	.001	.740	.000	.000	.000	.000	.			
Tr_Sha	Correlation Coefficient	.22**	.32**	.18**	.07	-.06	.65**	-.73**	.88**	.81**	.85**	1.00		
	Sig. (2-tailed)	.000	.000	.000	.052	.098	.000	.000	.000	.000	.000	.		
Va	Correlation Coefficient	-.41**	-.22**	-.37**	-.15**	-.16**	.43**	.05	-.05	.26**	-.10**	.13**	1.00	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.156	.169	.000	.008	.000	.	
Light	Correlation Coefficient	.41**	.34**	.26**	.25**	.14**	-.02	-.54**	.61**	.23**	.79**	.57**	-.34**	1.00
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.492	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed). / *. Correlation is significant at the 0.05 level (2-tailed).

Acronyms: Air Temperature (**Ta**), Relative humidity (**rH**), Globe temperature in the sun (**Tg_sun**), Globe temperature in the shadow (**Tg_shad**), Mean radiant temperature in the sun (**Tr_sun**), Mean radiant temperature in the shadow (**Tr_shad**) and Wind speed (**Va**)

The Number of People presented correlation with all the variables, however, some of them like air temperature and globe temperature in the shadow were weak. The strongest relationships found were with wind speed ($r = -.41$, $p < .001$), light ($r = .41$, $p < .001$) and relative humidity ($r = -.40$, $p < .001$).

The highest influencer of Groups of one (G1) was the globe temperature in the sun ($r = .47$, $p < .001$), followed by the negative influence of the relative humidity ($r = -.44$, $p < .001$).

The wind speed had a negative relationship with the couples ($r = -.37$, $p < .001$). This means that as the wind speed decreased, G2 increased. Similarly, the relative humidity also influenced negatively the groups of two people ($r = -.32$, $p < .001$).

The groups of three (G3) didn’t present strong correlations with the environmental variables. The highest relationship found was with light ($r = .25$, $p < .001$).

Finally, the groups of four or more (G4more) presented negative relationship with the air temperature ($r = -.24$, $p < .001$), globe temperature in the shadow ($r = -.18$, $p < .001$) and wind speed ($r = -.16$, $p < .001$).

Correlation Analysis Environment and Behaviour: Key Findings

Regarding the relationship between environmental variables:

- A strong relationship was found between **Globe** and **Radiant Temperature** in sun and shadow, as expected.
- **Light** was strongly correlated to the variables affected by the solar radiation, such as Calculated Mean **Radiant Temperature** and **Globe Temperature**.

Regarding the relationship between environmental and social variables:

- **Number of people** was influenced by **relative humidity**, **wind speed** and **light**, in the same proportion.
- **Groups of one** presented strong correlation with **globe temperature in the sun**. It was also negatively related to the **relative humidity**.
- **Groups of two** were negatively influenced by the **wind speed** and the **relative humidity**.
- **G3** and **G4more** didn't present strong relationships with the environmental variables.

7.4.2.2. Multiple Regression Analysis

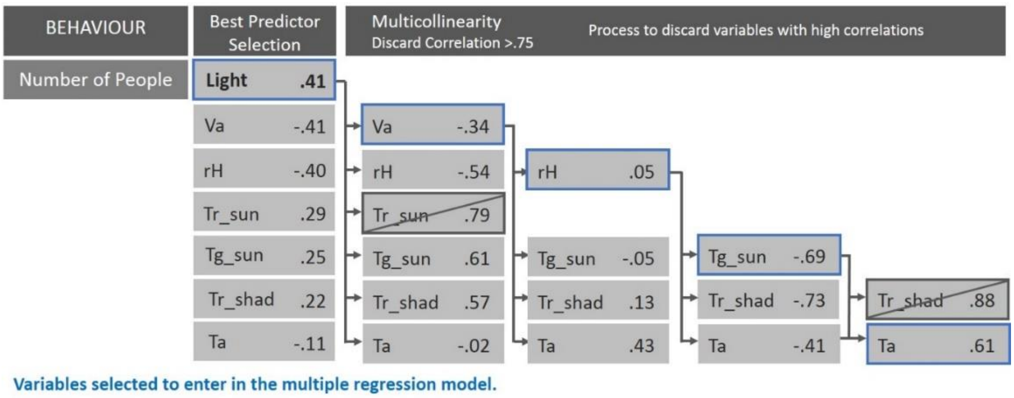
During this analysis, the environmental factors were treated as the independent variables or predictors. These were: air temperature (Ta), relative humidity (rH), globe temperature sun and shadow (Tg), mean radiant temperature sun and shadow (Tr), wind speed (Va) and illuminance (light). On the other hand, the dependant or predicted variables were the social behaviours: Number of People, groups of one (G1), groups of 2 (G2), groups of three (G3) and groups of four or more (G4more). Following the same procedure used in previous studies (Chapter 05 and 06), the data was split 60% used for training and 40% for validation.

The process to filter the predictors that would fit better into the model consisted of analysing the correlations between social and environmental factors. The independent variables (environment) presenting significant correlation with the predicted behaviour were selected. The environmental variable presenting the highest correlation was chosen as the best predictor.

Subsequently, a multicollinearity check was conducted to discard variables which were highly linearly related. The equation of a multiple regression model is made of a coefficient per predictor; "...so, each predictor variable has its own coefficient, and the outcome variable is predicted from a combination of all the variables multiplied by their respective coefficients plus a residual term" (Field, 2009, p. 210).

Model to Predict Number of People

Figure 110 presents the variables selected to predict the Number of People The best predictor was light, r = - .41, p < .001. Other variable contributing to the model were: wind speed (Va), relative humidity (rH), globe temperature in the sun (Tg_sun) and air temperature (Ta).



Acronyms: Illuminance (Light), wind speed (Va), relative humidity (rH), calculated mean radiant temperature (sun and shadow), globe temperature (sun and shadow), Air Temperature (Ta).

Figure 110 - Diagram of the variables filtered to predict Number of People.

Table 86 shows the regression models summary; each model correspond to one iteration of the 'Forward' process where a new variable was added. It is observed that the contribution of additional variables increased the simple correlation of the first model from r = .62 to r = .68, when adding wind, relative humidity and Globe Temperature_Sun. The R Square of the models increased from .39 to .46. This means that 39% of the variability of the Number of People is explained by light and 7% by wind speed and relative humidity. It is also observed that globe temperature in the sun did not add power to the third model, so the analysis of the results will be focused on the third model (highlighted in blue in Table 86).

Table 86 - Regression model summary. In blue is highlighted the model selected

Model Summary[e]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R	F	df1	df2	Sig. F
1	.62	.389	.388	5.12	.39	489	1	76	.000
2	.65	.422	.420	4.98	.03	44	1	76	.000
3	.68	.457	.455	4.83	.04	50	1	76	.000
4	.68	.464	.461	4.80	.01	10	1	76	.002

a. Predictors: (Constant), Light

b. Predictors: (Constant), Light, Va

c. Predictors: (Constant), Light, Va, rH

d. Predictors: (Constant), Light, Va, rH, Tg_Sun

e. Dependent Variable: N_People

It is observed that the value of the R^2 and the adjusted-R^2 in the third model were very close, .457 - .455 = .002. According to Field (2009), this indicates that if the model resulted from the real population, then the variance of the outcomes would be approximately less than 0.2%, meaning this a good generalisability.

Table 87 presents the coefficients table with the results of the four models. As previously mentioned this analysis will be focused on the third model, since it presents one of the highest $R^2 = .457$, $p < .001$ using less variables than the other models. The third column (B) of Table 87 corresponds to the b-values of the model. These fractions are the individual contribution of the variables to the prediction. The b-values were used in the regression equation to predict Number of People based on the light, wind speed and relative humidity (Equation 11).

Equation 11 - Model to predict Number of People - Winter

$$N\_People = b_0 + b_1 Light + b_2 Va + b_3 rH$$

$$\boldsymbol{N\_People = 19.328 + (0.001 * Light) + (-1.774 * Va) + (-0.158 * rH)}$$

Table 87 – Coefficients regression model Number of People - Winter

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
3	(Constan	**19.328**	1.52		12.7	.00	16.343	22.313
	Light	**.00080**	.00	.40	11.1	.00	.00066	.00094
	Va	**-1.774**	.22	-.25	-	.00	-2.203	-1.345
	rH	**-.158**	.02	-.22	-	.00	-.202	-.114

a. Dependent Variable: N_People

It is observed that the light (b = .00080) had a positive relationship with the Number of People, while the wind speed (b = -1.774) and relative humidity (b = -.158) were negative. These results were expected as the negative relationship was also observed in the correlation analysis. The t-test (t) showed that the predictors made significant contributions to the model, all ps < .001. The greater contributor to the model was light ($t(767) = 11.15$, $p < .001$). The Standardized Beta indicated that the wind speed and relative humidity had a similar degree of importance in the model because the results were close (-.25 and -.22).

The 95% Confidence Interval indicated the boundaries of the b-value. It is observed that none of the values obtained was below or above 0 (depending whether the b-value is positive or negative), this means that the model is representative of the true population (Field, 2009).

Validation of the Model to Predict Number of People

The validation of the results was done using the equation of the model:

$$N\_People = 19.328 + (0.001 * Light) + (-1.774 * Va) + (-0.158 * rH)$$

Figure 111 is the scatter plot of the predicted and real data, the results obtained of Predicted Number of People were correlated with the observed Number of People.

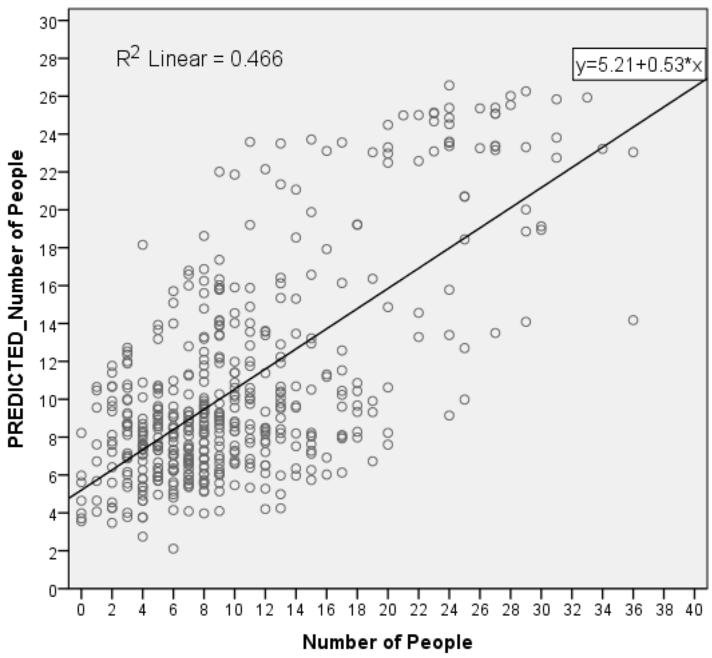


Figure 111 - Scatter plot Number of People and Predicted Number of People

Table 88 - Correlation Predicted Number of People and the real Number of People

Correlations (N = 489)

		PRED_N_Peop	N_People
PRED_N_People	Pearson Correlation	1	.68**
	Sig. (2-tailed)		.000
N_People	Pearson Correlation	.68**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the Number of People during winter was influenced by the light, wind speed and relative humidity. The model built with these variables accounted for 46% of the Number of People in the square (Table 86). The results were internally cross-validated and the correlation between the real Number of People and the Predicted number of People was $r = .68$, $p < .001$ (Table 88); this correlation coincides with the simple correlation of the model presented on Table 86.

Analysis of Number of Groups

The same method described in Chapters 5 and 6 was used to study the grouping of the occupants in the square. In this section the results of the models to predict Groups of one, two, three and four or more people will be summarised.

In order to filter the variables to be included in each model, the best predictor was identified and the environmental variables that presented strong correlation between them were discarded (Figure 112, Figure 113, Figure 114 and Figure 115).

The variables selected for the model to predict G1 were: globe temperature in the sun (Tg_sun), relative humidity (rH), light, wind speed (Va) and air temperature (Ta) (Figure 112).

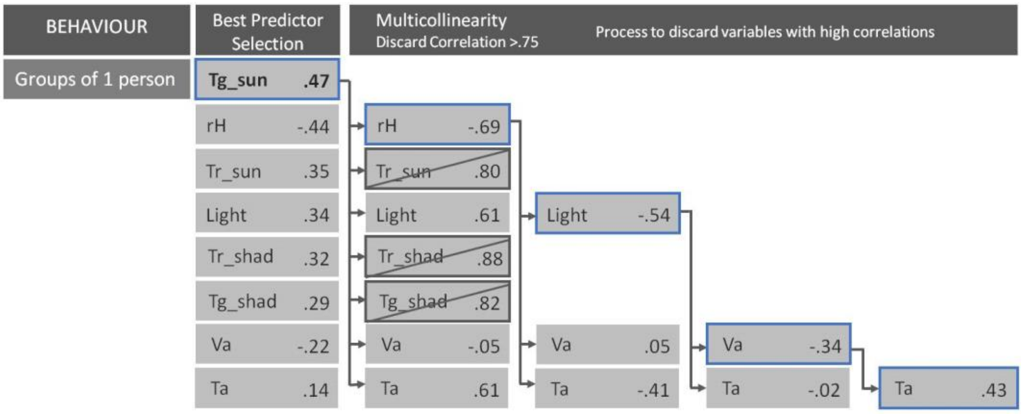


Figure 112 - Diagram selected variables to predict Groups of 1.

The variables selected to predict G2 were: wind speed (Va), relative humidity (rH), light and globe temperature in the sun (Tg_sun) (Figure 113). The predictors selected for the regression model of G3 were: light, wind speed (Va) and air temperature (Ta) (Figure 114).

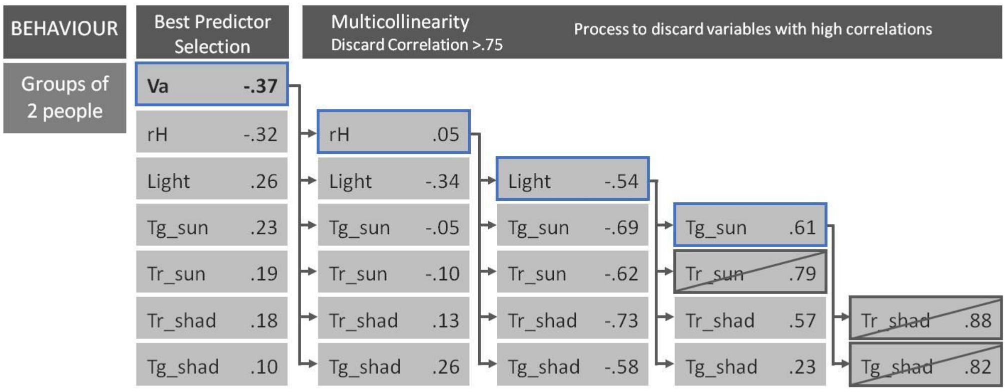


Figure 113 - Diagram selected variables to predict Groups of 2.

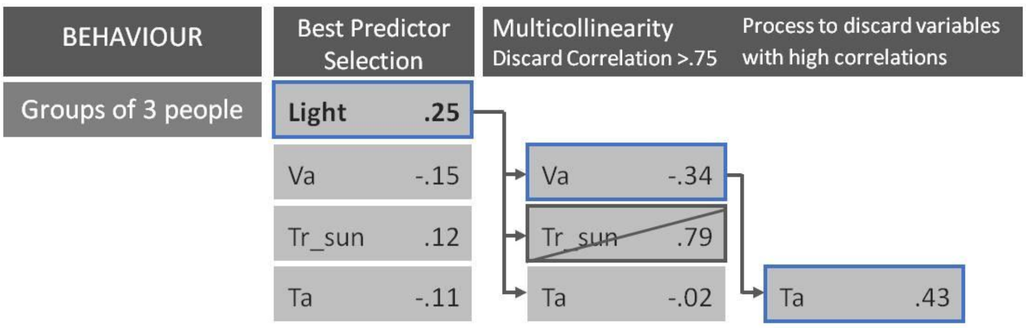


Figure 114 - Diagram selected variables to predict Groups of 3.

Finally, the variables selected for the model to predict Groups of 4 or more people were: air temperature (Ta), wind speed (Va), light and globe temperature in the sun (Tg_sun). Different variables were discarded according to the type of groups (Figure 115).

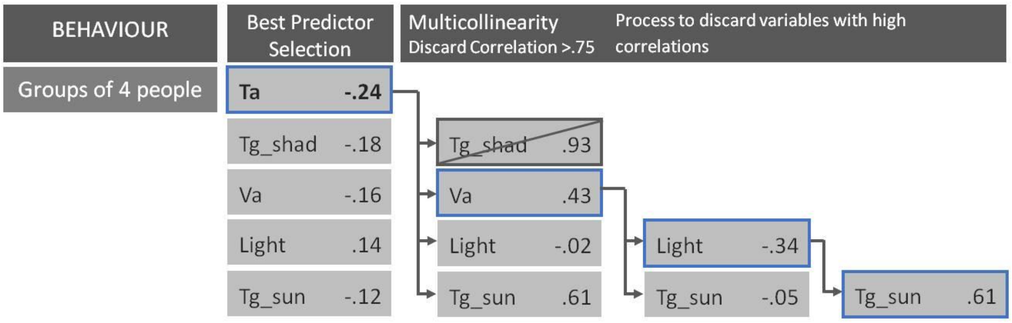


Figure 115 - Diagram selected variables to predict Groups of 2.

Model to Predict Number of Groups of one person (G1)

Table 89 presents the summary of the regression model to predict G1. From the iterations performed with the 'Forward' method in SPSS the model selected as the best predictor of G1 was based in the variables: light and relative humidity. According to the adjusted-R^2 of the model (Table 89), these two variables explained 37% of the variance of groups of one person ($p < .001$).

Table 89 - Regression model summary G1

Model Summary[e]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square	F	df1	df2	Sig. F
2	.6	.368	.366	1.97	.04	47	1	768	.000

b. Predictors: (Constant), Light, rH

e. Dependent Variable: G1

Table 90 presents the coefficients table of the model selected. The b-values of the model (B) are the individual contribution of the variables to the equation.

The t-test (t) presented a significant contribution of the predictors to the model, all ps < .001. The highest contributor was light ($t(768) = 13.89$, $p < .001$). The Standardized Beta indicated that the light had a higher degree of importance in the model ($\beta = .46$).

Table 90 - Coefficients of regression models G1 - Winter

Coefficients[a]

Model		Unstandardize B	Std.	Standardiz Beta	t	Sig.	95.0% Confidence Lower	Upper
2	(Consta	6.022	.56		10.8	.00	4.927	7.117
	Light	.0004	.00	.46	13.8	.00	.0003	.0004
	rH	-.061	.01	-.23	-	.00	-.079	-.044

a. Dependent Variable: G1

The b-values were used in the regression equation to predict G1 based on the variables light and relative humidity (Equation 12):

Equation 12 - Model to predict Groups of 1 - Winter

$$\boldsymbol{Groups\ of\ 1 = b_0 + b_1 Light + b_2 rH}$$

$$Groups\ of\ 1 = 6.022 + (0{,}0004 * Light) + (-0.061 * rH)$$

This interpretation is true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G1

The validation of the model was done using the 40% of data retained. A new variable was created in SPSS using Equation 12 and the measured values of light and relative humidity were forced to enter in order to test the model. Figure 116 presents a scatter plot between the predicted and real data. The Y axis correspond to the predicted Number of Groups of one person and the X axis correspond to the observed number of people in the square.

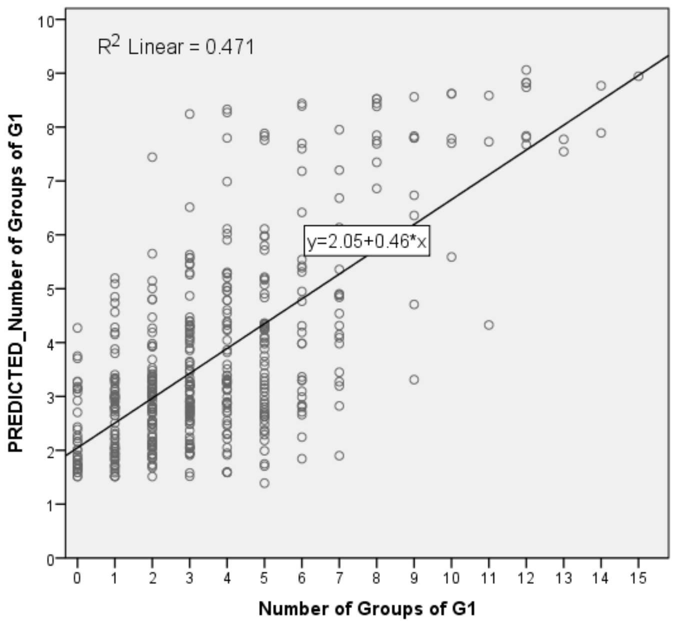


Figure 116 - Scatter plot Predicted G1 and G1

Table 91 shows the simple correlation of the model in comparison to the real data. The result r = .69, p < .001 is the same result obtained in the theoretical model on Table 89.

Table 91 - Correlation between the Predicted and real number of G1.

Correlations

		PREDICTED_G1	G1
PREDICTED_G1	Pearson Correlation	1	.69**
	Sig. (2-tailed)		.000
G1	Pearson Correlation	.69**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the presence of users alone was highly influenced by the light and relative humidity. The multiple regression model explained 37% of the occurrence of this behaviour. As the light increased and the relative humidity decreased, the number of people alone (G1) increased.

Model to Predict Number of Groups of two persons (G2)

Table 92 summarises the regression model to predict G2. The selected model was integrated by the variables: light, wind speed and relative humidity. According to the adjusted-R^2, these variables were able to explain 34.2% of the presence of couples ($p < .001$).

Table 92 - Regression model summary G2

Model Summary[d]

Model	R	R Square	Adjusted R	Std. Error of the	Change Statistics: R Square	F	df1	df2	Sig. F
3	.59[c]	.345	.342	1.39	.03	38	1	767	.000

c. Predictors: (Constant), Light, Va, rH

d. Dependent Variable: G2

Table 93 presents the coefficients of the regression model to predict G2 during winter. The t-test (t) had a significant contribution of the predictors to the model, all ps < .001. The greater contributor was light ($t(767) = 7.76$, $p < .001$). However, the Standardized Beta indicated that the three variables had similar degree of importance in the model (light $\beta = .30$, Va $\beta = -.25$ and rH $\beta = -.21$).

Table 93 - Coefficients of regression models G2 - Winter

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
3	(Constan	4.375	.44		10.01	.000	3.517	5.233
	Light	.0002	.00	.30	7.76	.000	.0002	.0003
	Va	-.468	.06	-.25	-7.46	.000	-.592	-.345
	rH	-.040	.01	-.21	-6.17	.000	-.052	-.027

a. Dependent Variable: G2

The model to predict G2 was built using the b-values of light, wind speed and relative humidity (Equation 13):

Equation 13 - Model to predict Groups of 2 - Winter

$$\boldsymbol{Groups\ of\ 2 = b_0 + b_1 Light + b_2 Va + \ b_3 rH}$$

$$Groups\ of\ 2 = 4.375 + (0{,}0002 * Light) + (-0.468 * Va) + (-0.040 * rH)$$

This interpretation is true only if the effects of the environmental variables are held constant.

Validation of the Model to Predict Number of G2

Equation 13 was computed in SPSS using the data of light, wind speed and relative humidity. Figure 117 presents the results of the predicted data and the observed number of couples.

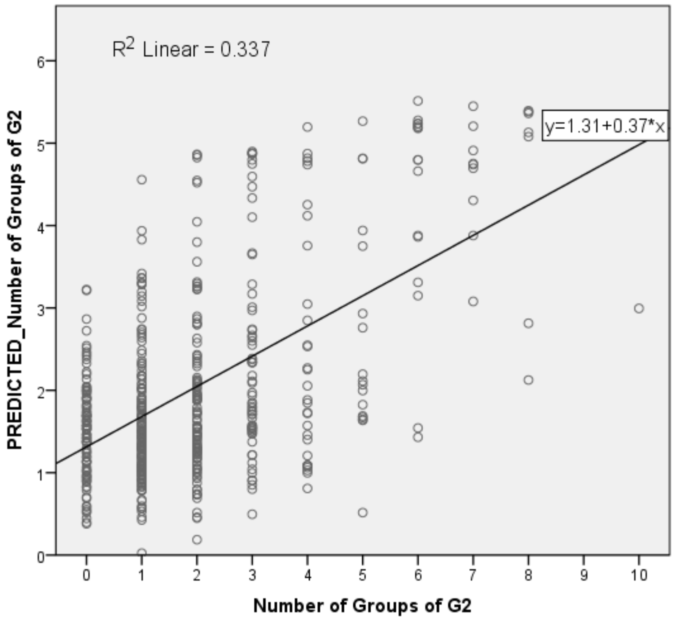


Figure 117 - Scatter plot of the Predicted and real number of G2

Table 94 is the correlation between the Predicted groups of 2 people and the observed Number of Groups of two. The result r = .58, p < .001 is similar to the simple correlation obtained in the theoretical model r = .59, p < .001, when the light increased and the wind and relative humidity decreased, the presence of G2 increased.

Table 94 – Correlation between the Predicted and observed number of G2

Correlations (N = 489)

		PREDICTED_G	G2
PREDICTED_G2	Pearson Correlation	1	.58**
	Sig. (2-tailed)		.000
G2	Pearson Correlation	.58**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the multiple regression model to predict the presence of people based in the light, wind speed and relative humidity explains 34% of the presence of couples. These three environmental variables affected the number of couples in the square.

Model to Predict Number of Groups of three people (G3)

Table 95 contains the regression model summary to predict G3. Despite being the best predictors, it was observed that the influence of light and air temperature G3 is very weak, adjusted-R^2 = .065, $p < .005$.

Table 95 – Regression model summary G3

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
2	.26	.068	.065	.68	.01	9	1	768	.003

b. Predictors: (Constant), Light, Ta

c. Dependent Variable: G3

According to Table 96, the highest contributor to the model was light (t(768) = 6.22, p < .001). Additionally, the Standardized Beta indicated that light had a higher degree of importance in the model (β = .22).

Table 96 - Coefficients of regression models G3 - Winter

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
2	(Constan	.619	.11		5.88	.000	.412	.826
	Light	4.757E-5	.00	.22	6.22	.000	.00003	.00006
	Ta	-.032	.01	-.11	-3.02	.003	-.052	-.011

a. Dependent Variable: G3

The b-values (B) of light and air temperature were used in the regression equation to predict G3 (Equation 14).

Equation 14 - Model to predict Groups of 3 - Winter

$$\boldsymbol{Groups\ of\ 3 = b_0 + b_1 Light + b_2 Ta}$$

$$Groups\ of\ 3 = 0.619 + (0{,}000047 * Light) + (-0.032 * Ta)$$

Validation of the Model to Predict Number of G3

The results of the model were validated with the 40% of data retained. Equation 14 was calculated with the data set of light and air temperature. Figure 118 presents the scatter plot of the predicted and observed number of G3.

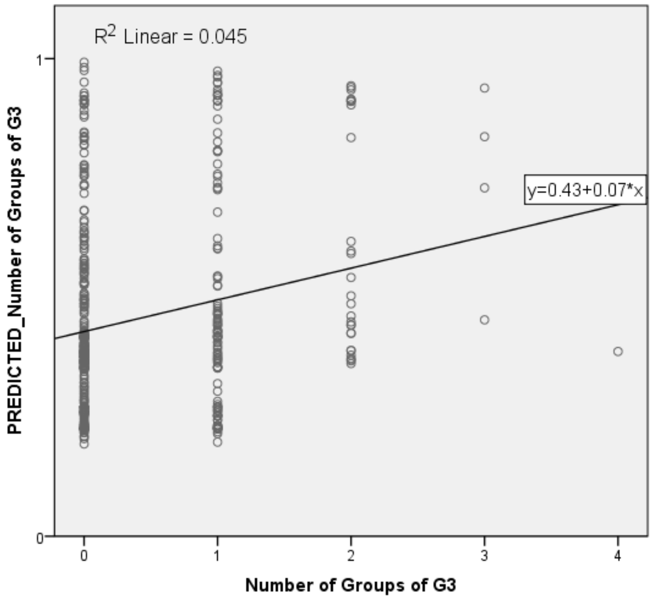


Figure 118 - Scatter plot of Predicted and observed number of G3

Table 97 contains the correlation between Predicted_G3 and observed G3. The result r = .21, p < .001 is lower than the simple correlation of the model r = .26, p < .001 (Table 95).

Table 97 - Correlation Number of G3 and Predicted G3

Correlations

		PREDICTED_	G3
PREDICTED_G3	Pearson Correlation	1	.213**
	Sig. (2-tailed)		.000
G3	Pearson Correlation	.213**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the multiple regression model to predict G3 presented poor results by only being able to explain 6.5% of the behaviour. Moreover, the scatter plot (Figure 118) evidenced that the predicted G3 did not reach values higher than 1 (y-axis), while the data observed achieved up to 4 (y-axis). The correlation also presented weak results when comparing it with the simple correlation of the model.

Model to Predict Number of Groups of four or more people (G4more)

According to Table 98, it is observed that the models tested presented a very weak power to predict the groups of four or more people. The adjusted-R^2 of the model including the air temperature as the only predictor was able to explain 3% of the variation of G4more ($p < .001$) and the second model adding wind speed raised the figure up to 4%.

Table 98 - Regression model summary G4more - Winter

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.18[a]	.032	.030	.57	.03	25	1	769	.000
2	.20[b]	.041	.039	.57	.01	8	1	768	.005

a. Predictors: (Constant), Ta

b. Predictors: (Constant), Ta, Va

c. Dependent Variable: G4more

In conclusion, due to the lack of relationship between the environmental variables with the presence of groups of four or more, a model to predict the number of G4more was not possible. This type of grouping was therefore not influenced by the environmental variables during winter. This may be due to a small sample of this type of groups in winter.

Multiple Regressions - Number of People and Groups: Key Findings

- The **Number of People** is explained in 46% by the influence of the light, wind speed and relative humidity.

$$N\_People = 19.328 + (0.001 * Light) + (-1.774 * Va) + (-0.158 * rH)$$

- **Groups of 1** is highly influenced by the light and relative humidity. The multiple regression model explained 37% of the number of people alone.

$$Groups\ of\ 1 = 6.022 + (0,0004 * Light) + (-0.061 * rH)$$

- **Groups of 2** is influenced by the light, wind speed and relative humidity. The model explained 34% of the presence of G2.

$$Groups\ of\ 2 = 4.375 + (0,0002 * Light) + (-0.468 * Va) + (-0.040 * rH)$$

- **Groups of 3** and **Groups of 4 or more** presented very weak relationships with the environmental variables. The model to predict G3 presented a poor power of prediction. In the case of G4more the data was not strong enough to run a model.

7.4.2.3. Cluster Analysis

The cluster analysis of winter was conducted using the same procedure of summer and autumn (Chapters 5 and 6). The continuous variables selected were: number of groups of 'G1', 'G2', 'G3' and 'G4 or more'. The variable evaluated was the Number of People. According to the predictors' importance (Figure 120), it is observed that groups of G4more and G3 were more important than groups of G2 and G1. Figure 119 presents the cluster quality rate; it is observed that the variables used presented a 'fair' quality for clustering the data.

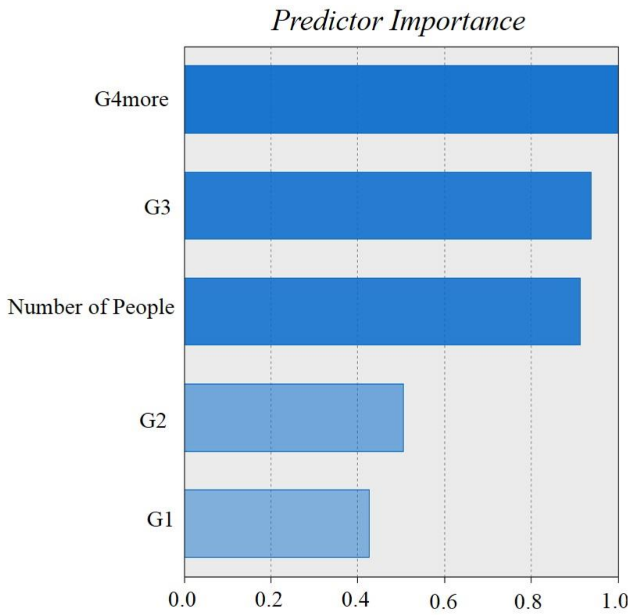


Figure 120 - Predictor Importance of variables for cluster analysis - Winter

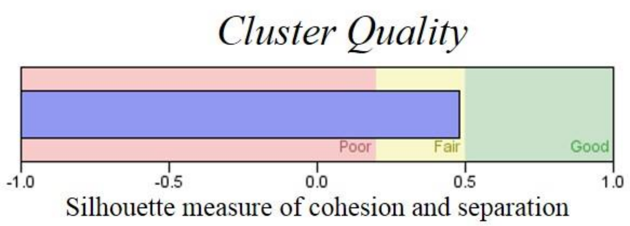


Figure 119 – Cluster Quality Rate

Figure 121 presents the relationship between Number of People, Number of Groups and Clusters (R^2 = 0.84). The clusters present a different distribution in comparison to the clusters generated in summer and autumn. Cluster 1 presents dispersed dot points, cluster 2 is located below fit line, cluster 3 is located above the fit line with the higher number of groups and people, and cluster 4 corresponds to the lowest number of groups and people over the fit line.

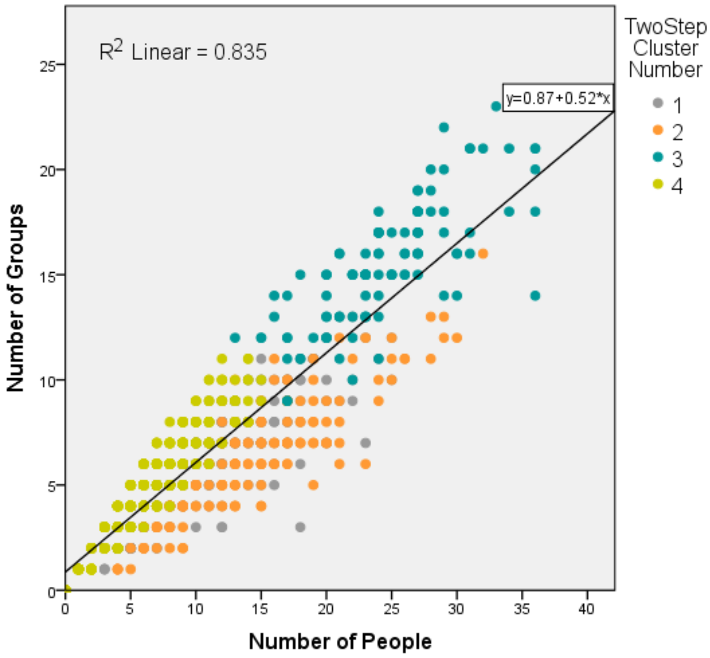


Figure 121 - Relationship between Number of People, Number of Groups and Clusters – Winter

Cluster Analysis: Key Findings - Number of People and Number of Groups presented a strong relationship (R^2 = 0.84). - The number of G4more and G3 were the main predictors to generate the clusters.

7.4.3. Individual Behaviour

7.4.3.1. Survival Analysis

The time of permanence was the time the users stayed in the urban public space. To analyse this behaviour the time of arrival and departure was recorded. The length of stay in minutes was evaluated using a survival analysis. This method was used in Chapter 5 and Chapter 6 to evaluate the Time of Permanence of people during summer and autumn.

The method used is the non-parametric Kaplan-Meier estimator, which displays a cumulative survival probability per variable. As mentioned in the previous two chapters, the results of the Kaplan-Meier also presents the means and medians of the survival time. Therefore in the cases where significant results were found or interesting patterns where observed, a summary table with the cumulative survival analysis at different times were plotted.

For this analysis, the population sample were the users that remained in the square during winter (N = 1127). The population consist of: 90% adults, 4.4% teenagers, 2.9% children, and 2% babies and mobility reduced (Table 78). From this population, 61% were male and 39% female (Table 79).

Time of Permanence and Gender

Figure 122 is the chart of the survival curve of the time of permanence according to the Gender. No difference between men and women was presented.

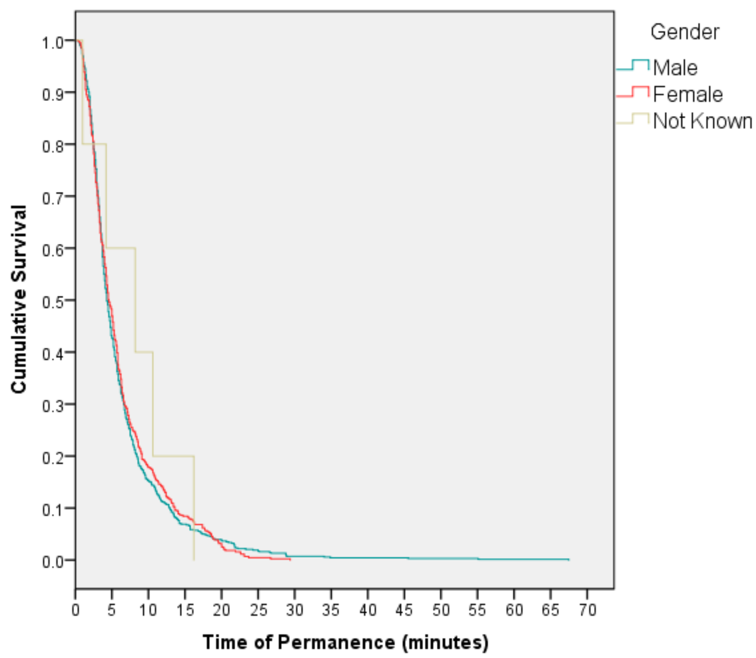


Figure 122 - Survival curve Time of Permanence - Gender

Table 99 contains the means and medians of the survival time obtained. The estimated median for men was 4.3 minutes and for women 4.6 minutes. The median is the time when 50% of the users left the place.

Table 99 – Means and medians for survival time during winter

Means and Medians for Survival Time

Gender	Mean[a]				Median			
	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper
Male	6.13	.23	5.69	6.58	4.30	.16	3.98	4.62
Female	6.70	.36	6.00	7.40	4.60	.22	4.17	5.03
Not	8.04	2.62	2.90	13.18	8.20	4.38	.00	16.79
Overall	6.36	.20	5.98	6.75	4.50	.14	4.23	4.77

a. Estimation is limited to the largest survival time if it is censored.

A similar time of permanence was observed in both curves, which indicates that the gender did not affect the time of permanence of the sample. The only difference observed occurred between 1% and 20% of the population, where the Time of Permanence of men was shorter than the time of permanence of women between minutes 8 to 20. In order to verify whether the curves of men and women were significantly different, a Log-rank test was performed. In Table 100 is observed a Log-rank $p > .05$. This result indicates that the gender survival curves did not present a significant difference in the Time of Permanence.

Table 100 - Log-rank test results

Overall Comparisons

	Chi-Square	df	Sig.
Log Rank (Mantel-Cox)	2.303	2	.316

Test of equality of survival distributions for the different

In conclusion, the gender did not affect significantly the time of permanence during winter. A small difference was however observed between the survival curves, which suggests women remained for a few minutes longer than men in permanencies between 8 and 20 minutes.

Time of Permanence and Environmental Factors

The Time of Permanence was analysed with each environmental variable. In this section the main results of the survival analysis will be highlighted.

Figure 123 presents the survival curves of the time of permanence according to the light level. It is observed that the longest permanencies occurred at the highest levels measured at 10,000 to 15,000 lx.

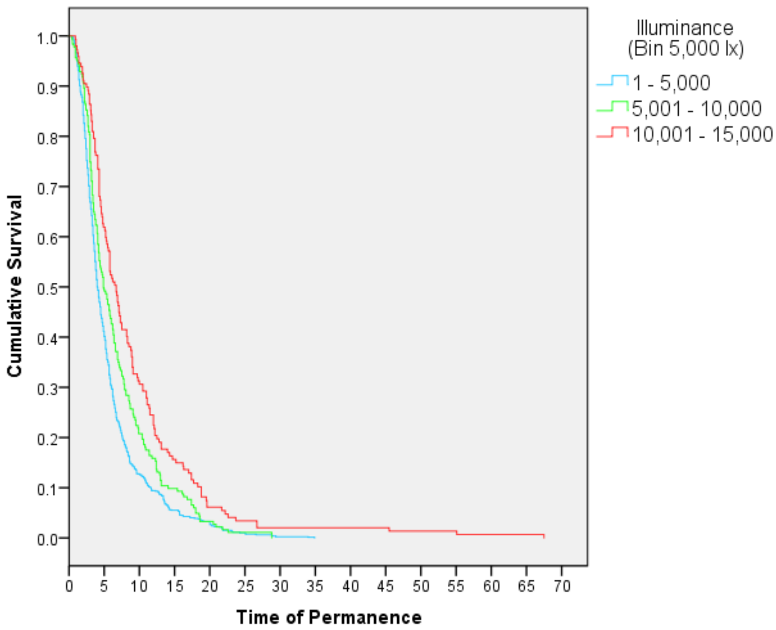


Figure 123 – Survival function of the time of Permanence and Light

Table 101 presents the detailed results of the survival curves when binning the data at 1,000 lx. It is observed that the highest estimated median occurred between 9,000 and 13,000 lx. This means that 50% of the people that stayed in the square under this level of light, decided to stay for more than 5.8 minutes.

Table 101 – means and medians for survival Time of Permanence according to Light during winter

Means and Medians for Survival Time

Light (Bin 1,000 lx)	Mean[a] Estimate	Mean[a] Std. Error	Mean[a] 95% Confidence Lower	Mean[a] 95% Confidence Upper	Median Estimate	Median Std. Error	Median 95% Confidence Lower	Median 95% Confidence Upper
1 – 1,000	5.35	.21	4.95	5.76	3.90	.17	3.56	4.24
1,001 – 2,000	6.81	.67	5.49	8.12	4.80	.59	3.65	5.95
2,001 – 3,000	6.15	.65	4.88	7.42	4.20	.36	3.50	4.90
3,001 – 4,000	5.74	.61	4.55	6.94	3.90	.52	2.87	4.93
4,001 – 5,000	4.95	.32	4.32	5.58	4.20	.54	3.14	5.26
5,001 – 6,000	6.19	.60	5.01	7.37	4.40	1.21	2.04	6.76
6,001 – 7,000	4.16	.47	3.23	5.08	3.20	.47	2.29	4.11
7,001 – 8,000	4.64	.38	3.88	5.39	3.70	.43	2.85	4.55
8,001 – 9,000	8.71	1.11	6.53	10.89	6.30	2.22	1.94	10.66
9,001 –	9.73	.95	7.88	11.59	7.70	1.45	4.86	10.54
10,001 –	13.19	1.89	9.48	16.89	12.10	3.62	5.01	19.19
11,001 –	10.71	2.17	6.46	14.95	5.90	.79	4.36	7.44
12,001 –	8.74	1.30	6.19	11.30	5.80	1.35	3.16	8.44
13,001+	7.98	.95	6.12	9.85	5.80	.87	4.09	7.51
Overall	6.36	.20	5.98	6.75	4.50	.14	4.23	4.77

a. Estimation is limited to the largest survival time if it is censored.

A pattern of higher means, medians and percentage of people remaining was observed when the light level was higher, between 8,000 lx and 12,000 lx. Therefore, it can be concluded that that the light influenced the time of permanence of people. It was also observed that under light condition between 0 and 1000 lx, 38% of the population remained for more than 5 minutes, but only 12% remained after 10 minutes.

The wind speed survival curves in Figure 124 presented and interesting pattern: as the wind speed decreases, the time of permanence increase. Moreover, the values in the middle ranges, 1.0 m/s to 2.5 m/s, presented similar curves suggesting similarities in the time of permanence between these air velocities.

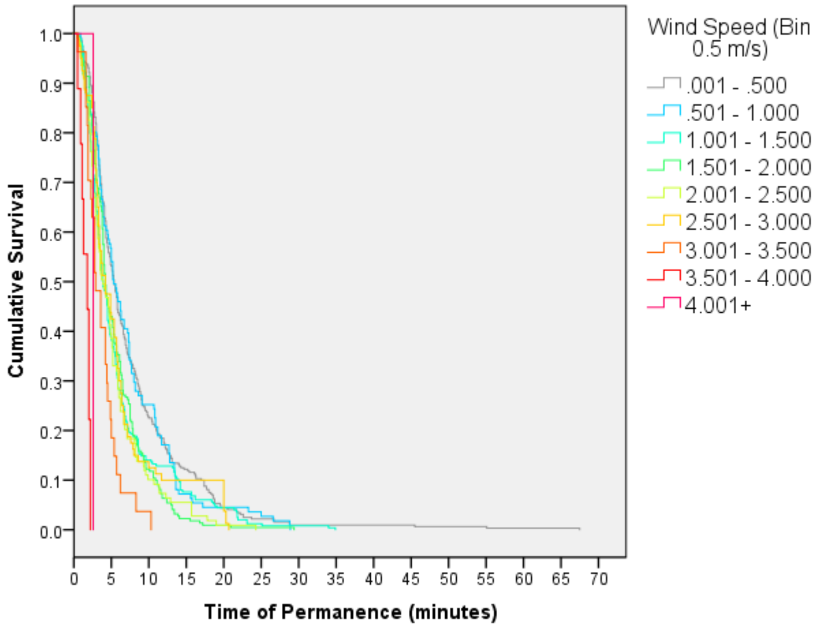


Figure 124 - Survival curves Time of Permanence according to wind speed

Table 102 contains the means and medians of the Time of Permanence according to different wins speed levels. The estimate median presents a diverse result since 50% of the population left the place before 18 and 5.4 minutes. However, when the results of the estimated mean are evaluated, a decrease is observed in the time of permanence when the air velocity increases.

Table 102 - Means and medians for survival time wind speed - winter

Means and Medians for Survival Time

Va (Bin 0.5 m/s)	Mean[a]				Median			
	Estimate	Std. Erro	95% Confidence Lower	95% Confidence Upper	Estimate	Std. Error	95% Confidence Lower	95% Confidence Upper
.001 - .500	8.12	.53	7.08	9.16	5.40	.26	4.88	5.92
.501 - 1.000	6.92	.53	5.88	7.96	5.20	.49	4.24	6.16
1.001 -	5.77	.35	5.09	6.46	3.80	.28	3.24	4.36
1.501 -	5.50	.26	4.99	6.01	4.20	.19	3.84	4.56
2.001 -	5.16	.40	4.37	5.95	3.90	.52	2.88	4.92
2.501 -	5.95	.59	4.79	7.11	4.20	.63	2.97	5.43
3.001 -	3.67	.42	2.84	4.50	2.90	.52	1.88	3.92
3.501 -	1.56	.21	1.15	1.96	1.80	.75	.34	3.26
4.001+	2.60	.00	2.60	2.60	2.60	.	.	.
Overall	6.36	.20	5.98	6.75	4.50	.14	4.23	4.77

a. Estimation is limited to the largest survival time if it is censored.

Table 103 is a summary of the percentage of people remaining at different time (minutes) and wind speed. This table summarises the curves described in Figure 124. As explained before, the time of permanence decreases when the air velocity increases in winter. In addition, it was observed that time of permanence over 15 minutes in winter occurred less frequently, and when it occurred it was mostly in low-wind conditions.

Table 103 - Summary cumulative proportion of people remaining Time and Wind

Cumulative proportion of people % - Winter

Time	0 m/s	0.5 m/s	1 m/s	1.5 m/s	2 m/s	2.5 m/s	3 m/s	3.5 m/s
1	99	96	99	97	95	95	96	67
5	53	56	39	43	39	43	19	0
10	23	23	14	12	10	13	0	0
15	13	6	7	2	6	10	0	0
20	5	4	4	1	1	4	0	0
25	3	3	1	1	0	0	0	0
30	3	0	1	0	0	0	0	0

Survival Analysis – Time of Permanence during winter: Key Findings

- **Gender** did not affect significantly the **Time of Permanence** during **winter**. Nevertheless, the **Time of Permanence** of women was observed to be a few minutes longer in permanencies between 8 and 20 minutes.
- The **Time of Permanence** was influenced by **Illuminance**. The duration of the permanence was longer for the higher light levels, since most of the people remained in the space at least 15 minutes when the illuminance levels exceeded 8,001 lx, and this time of permanence increased as the illuminance levels increased up to 13,000 lx (Figure 123).
- The **relative humidity** did not appear to present big differences of **Time of Permanence** between 46% and 65% of humidity.
- The **Time of Permanence** was highly influenced by the wind speed. Permanencies over 15 minutes are more likely to occur with wind speeds of 2.5 m/s or below. It was also found that the time of permanence in conditions between 1 m/s and 2.5 m/s did not present much variation.

7.5. Discussion

This study aimed to evaluate behaviour in outdoor public spaces during winter. In particular, the interest was in finding the relationship between the environmental conditions and the human behaviour, as well as quantify its influence and identify the variables influencing the behaviour of people during winter.

The main finding of this study was to identify that the environmental factors that influence the evaluated behaviours during winter were: light, relative humidity and wind speed. Other studies reported the relationship of the attendance of public spaces with the globe temperature and air temperature Nikolopoulou et al., (1999). However, the findings presented in this chapter evidenced that the motivation of users to attend and remain in a place during winter is influenced by different factors other than the temperatures.

According to Li (1994), the attendance to fifteen squares in New York during winter presented a weak correlation with the air temperature (r = .09). Similarly in this study the *Number of People* presented a weak correlation with the air temperature (r = -.11). The author reported that the only significant variables influencing the attendance were the recreational or commercial activities and the visual diversity. Contrary to the results of the study conducted in New York, this research found a model that explains 46% of the variance of the attendance based on the environmental variables: light, wind speed and relative humidity.

The relative humidity was an interesting factor inside the regression equations. It was reported by Nikolopoulou & Lykoudis (2006,) that "people are not very good at judging changes in humidity levels, unless relative humidity is very high or very low and normally in conjunction with temperature conditions indicating a second role for relative humidity in the overall comfort sensation" (p. 1459). The findings indicate a significant second role of the relative humidity to the regression models to predict number of people, presence of people alone and presence of couples. It was also identified that between 46% and 65% of relative humidity the *Time of Permanence* presents no significant changes, agreeing with the statement of (Nikolopoulou et al., 2004). Nevertheless, the results of this study contrasted with their statement, in the sense that humidity may be an influencer when related to temperature. The analysis showed that the influence of relative humidity during winter in conjunction with other variables such as light and wind speed was able to explain the occupancy of the public space.

The model to predict the number of Groups of one and Groups of two, accounted for 37% and 34% respectively of the variance of the attendance of these types of groups to the square. Groups of G3 presented a mean time of permanence of 6.36 minutes, but the frequency of big groups was rare in winter, so the model for Groups of G3 did not have the power necessary to predict the attendance of this kind of group. G4more was even more infrequent and the data was insufficient to run a model. It is therefore submitted that further studies are required to analyse the social behaviour of big groups in winter. Nevertheless, the cluster analysis suggests that the number of people has a relationship with G4more and G3 as they presented the highest rate of importance when clustering the data.

Accordingly, a 'Group Diversity Index' analysis (GDI) was conducted (Figure 125) to measure the variety of groups in the space, being 0 the rate given to a space with no groups present, 0.25 when at least one type of group is present, 0.5 when two types of groups are present, 0.75 for three types of groups, and 1 when all types of groups coexist in the square at the same time.

Table 104, presents the percentage of data in each cluster. It is observed that most of the time there were two types of groups present in the square (GDI: .50 = 49.1%). Three types of groups where present in the place 27.3% of the time. Accordingly the use of the space in winter is less successful than in summer or autumn as overall there is less variety of groups present in simultaneity in the square.

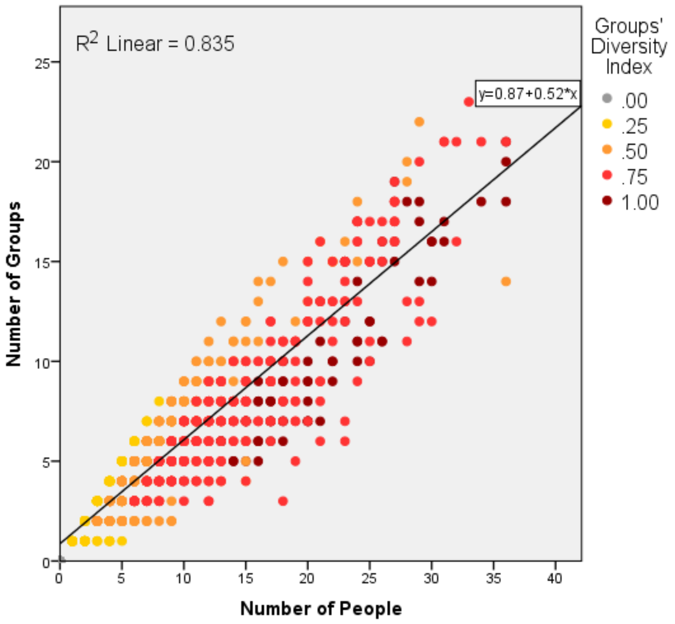


Figure 125 – Scatter Plot Number of Groups, Number of People and GDI - Winter

Table 104 - Groups Diversity Index (GDI) - Winter

Groups' Diversity Index			
		Frequency	Percent
Valid	.00	19	1.5
	.25	184	14.6
	.50	619	49.1
	.75	344	27.3
	1.00	94	7.5
	Total	1260	100.0

The results regarding wind speed as an influencer factor to use urban public spaces contributes to the findings from other authors. For instance, Eliasson et al. (2007) reported that the attendance to a public space in a Nordic city increased when the wind ceased. A similar negative relationship was reported in this chapter with number of people and the presence of couples. Moreover, the time of permanency increased with low wind speed or calm condition, but it is perceived similar between 1.5 m/s and 3.0 m/s.

According to the observations made by Li (1994), people stayed in the squares of New York when the temperature was around freezing point. The author reports that most of the users stayed for a couple of minutes, however, some of them stayed up to one hour. In the results of this chapter, it is observed that the maximum permanency recorded was up to 67.5 minutes, agreeing with the observations made by (Li, 1994). Nevertheless, the cumulative curves of the *Time of Permanence* did not present any pattern with the air temperature which was the variable reported by author. Whereas, the *Time of Permanence* presented a relationship with the light and wind speed. For instance, it was observed that during winter permanencies over 15 minutes are more probably to occur with wind speeds below 1 m/s.

As described by Li (1994), cities with seasons have conventionally adopted two strategies to cope with the thermal stress caused by winter in the use of outdoors: The first one consist of offering the maximum protection to the undesired conditions of the outdoors by creating artificial indoor environments which resemble outdoors-warm conditions (e.g. artificial environments created in shopping malls), and the second one consists of encouraging people to endure the external environment with the natural conditions of winter. Nevertheless, the author suggests that there must be an intermediate option, capable of balancing the experience of people in outdoors by enhancing the beneficial aspects of the season (e.g. furniture designed to protect against high wind speed and low air temperature in winter).

In order to contribute with the previous theory and based on the results of this chapter, it is thought that the environmental factors that are mainly influencing the attendance, time of permanence and use of the space during winter should be identified in order to propose an intervention of the built environment. For instance, it was observed during winter the variables affecting the social behaviour were light, wind speed and relative humidity, and the variables affecting time of permanence were light and wind speed. This season presented 60% of the data of light below 1,000 lx, the fluctuation of the wind speed was between 0 m/s to 4.5 m/s, and the relative humidity varied between 40% and 75%. The predictive models and the survival curves showed that light presented a positive relationship with the behaviour of people, whereas wind speed and relative humidity presented a negative relationship. This suggests that the strategies to improve the attendance, time of permanence and use of outdoors during winter should consider increasing the light availability during the darker periods with the urban artificial lighting and reducing wind velocities in the seating areas. The square where the study was conducted was equipped with lamps, but had no wind barriers. Therefore, despite most of the data of illuminance being in the range of 0 to 1,000 lx, the measurements above 8,000 lx presented a considerably higher time of permanence. Therefore, by increasing the illuminance in 5,000 lx, the time of permanence may be increased in around five minutes.

The relative humidity was a factor influencing the behaviour of users. Surprisingly, the air temperature presented low correlation with the behaviour, therefore it was not included in the models. Nevertheless, the air temperature is a factor that is negatively correlated with the relative humidity. Therefore, strategies related to increase the air temperature would increase the positive perception of users during winter.

This equation accounts for 46% of the variance of the behaviour, which is considerably high, considering the existence of multiple factors that also affect the human behaviour in outdoor public spaces. This means that during winter the thermal environment has a high influence in the attendance, however, the remaining percentage to explain the behaviour obey to other variables (e.g. social, economic, physiological, psychological, etc.). Therefore, these models are a guide in the understanding of the influence of the thermal environment but will not predict with high percentage of accuracy the human response.

The generalisability of the results in other locations could not be evaluated with the data gathered. To do this, the same procedure should be repeated. However, the study was conducted in a place that may allow comparison of results to cities with environments similar to Nottingham.

7.6. Conclusions

This study evaluated the influence of the thermal environment on human behaviour during winter. The main variables influencing the behaviours were light, wind speed and relative humidity. The models to predict number of people, groups of 1 and groups of 2 obtained a good validity. However, this model may be taken as a reference of the relationship between behaviour and environmental variables. It was identified that light, wind speed and relative humidity influenced the occupancy, and the presence of Groups of 2, as these variables contributed with the strength of the model to predict the variance of this behaviour (Table 86 and Table 92). The presence of Groups of 1 (G1) was only influenced by relative humidity and light as wind speed did not contributed to the model (Table 90). Finally, it was observed that wind speed and light have influence over the time of permanence (Figure 123 and Figure 124).

The urban design should consider strategies regarding light, relative humidity and wind speed to increase the use of outdoor spaces during winter. For instance, wind barriers, reflecting surfaces, artificial lighting, or regulating building's height near squares could improve the light levels and reduce the wind flows in urban outdoor spaces. The relative humidity is a factor difficult to modify through design; however, strategies such as allowing surfaces to dry with direct solar radiation and permitting water to drain by ensuring the flow through surfaces with slopes can improve the conditions of humidity after rainy periods.

In order to generalise the results obtained in this study, further research in other locations need to be conducted. The equations produced and the data collected may support software and simulations development regarding human behaviour in outdoor environments.

8. Human Behaviour in All-Seasons

8.1. Chapter Overview

After presenting the individual results for the studies conducted on summer, autumn and winter, this chapter presents the overall results of the three seasons analysed together in order to see the behaviour of people in a whole year scenario. The analysis continues from two perspectives: 1. The social behaviour analysis with a sample of 3780 minutes, in which the overall counts of social behaviours were analysed from the perspective of group activities and attendance to the square, and 2. The individual behaviour analysis with a total sample of 5330 individuals, in which the total count of individual behaviours observed during the three seasons was analysed. In addition, this chapter will present the analysis of the body postures, activities and adaptive actions observed during the seasons in accordance with the environmental factors. Finally, this chapter will present equations obtained to predict human behaviour based on multiple regression analysis and continuous probability curves, survival analysis and frequency of occurrence of behaviour. At the end, the capability to predict the behaviour in a square with similar environmental conditions is reported per behaviour.

8.2. Introduction

This analysis intends to obtain outcomes of human behaviour according to the thermal environment covering three representative seasons of the year: summer, autumn and winter. As explained before in Chapter 06, the environmental data in autumn resembles the conditions of spring, so no further studies were considered necessary in this last season. Notwithstanding this, the "all-seasons" analysis covers the ranges of environmental conditions normally observed in the place of study throughout the whole year, so it is expected that the data collected will be applicable to other squares with similar environmental conditions. For instance, the air temperature recorded varies from 5°C to 27°C, the relative humidity oscillated between 37% and 91%, and the wind speed varied from 0 m/s to 5 m/s, which is a range of environmental conditions which allows measuring and analysing the proposed human behaviours in outdoor public spaces according to the environmental factors.

Previous studies conducted in the United Kingdom regarding thermal comfort in public spaces highlighted the importance of globe temperature in the use of urban spaces. For instance, Nikolopoulou et al. (2001) described the correlation existing between the Number of People in different squares and the environmental measurements taken. In the same work, she identified a negative correlation between the clothing level and the air temperature. Most of the studies regarding thermal environment in outdoors are totalising the results in a whole year data set (Givoni et al., 2003; Nikolopoulou et al., 2001; Tacken, 1989). Therefore, a critical review of the results will be presented in this chapter.

8.3. Method

This chapter is focused on analysing the data collected during summer, autumn and winter to generate a database of human behaviour in the whole range of environmental factors measured. Therefore, the location, exclusion criteria, duration and season, announcement of the study, ethics approval and procedure, is the same as in the previous three chapters.

The statistical analysis methods are the same used for the seasonal studies, as well as the dataset, but this time including the totality of the data sample in order to obtain the variation over the seasons with the whole spectrum of environmental conditions.

Population and Time Sample

The total sample for the *Social Analysis* consisted in the minutes recorded, and the "all-seasons" analysis will include the total sample of the three seasons, consisting of 21 days, three random hours per day, for a total of 3780 minutes. For the *Individual Analysis* the sample consisted in 5330 persons who attended to the square in the days evaluated during the three seasons.

For the *Individual analysis*, the same demographics recorded in the three seasons were analysed in this section: gender (male, female or not known), age group (adult, teenager, child or baby, as well as, whether the participant required mobility aids, in which case he or she is categorised as "reduce mobility"). The global percentage of attendance to the square in the three seasons is shown in Table 105. As can be seen there, adults were the most common users, with a percentage of attendance of 89%.

Table 105 - Frequency distribution of the age groups

Age				
		Frequency	Percent	Cumulative Percent
Valid	adult	4736	88.9	88.9
	teenager	210	3.9	92.8
	child	231	4.3	97.1
	baby	53	1.0	98.1
	reduced mobility	100	1.9	100.0
	Total	5330	100.0	

Figure 126 presents the bar chart of the frequency distribution according to the age group. It is observed that the attendance was always higher in summer.

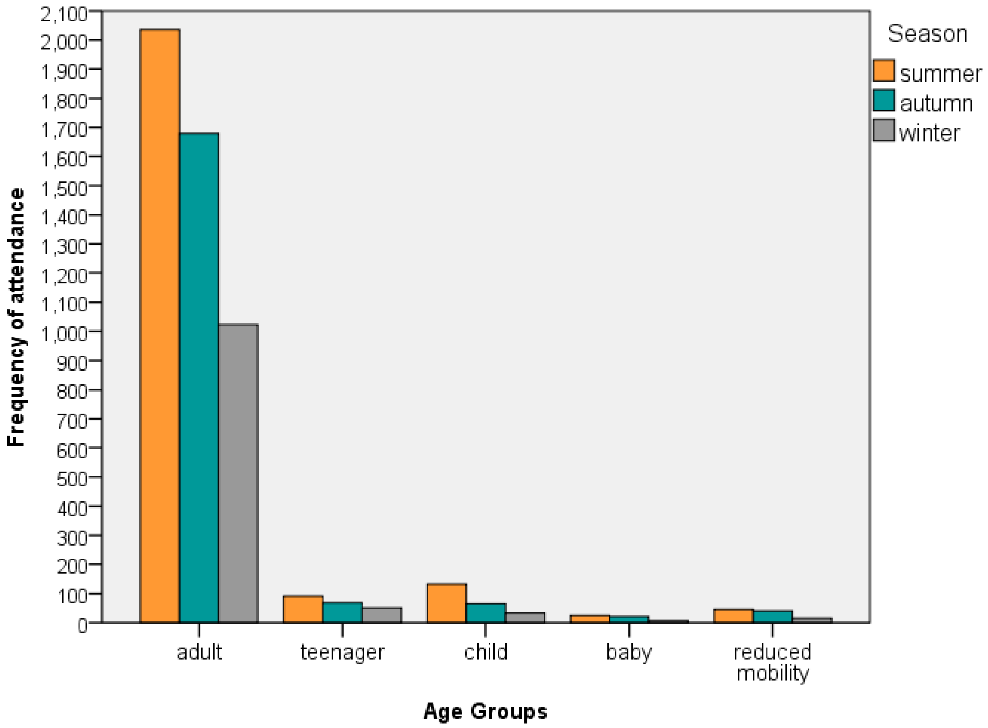


Figure 126 – Frequency of attendance according to the age group

In addition, 56% of the people that used the square were men, while 44% were women (Table 106). Figure 127 presents the bar chart of the number of attendants according to gender. It is observed that during the three seasons the majority of the population was men.

Table 106 - Frequency distribution according to the gender

Gender				
		Frequency	Percent	Cumulative Percent
Valid	Male	2977	55.9	55.9
	Female	2348	44.1	99.9
	Not Known	5	.1	100.0
	Total	5330	100.0	

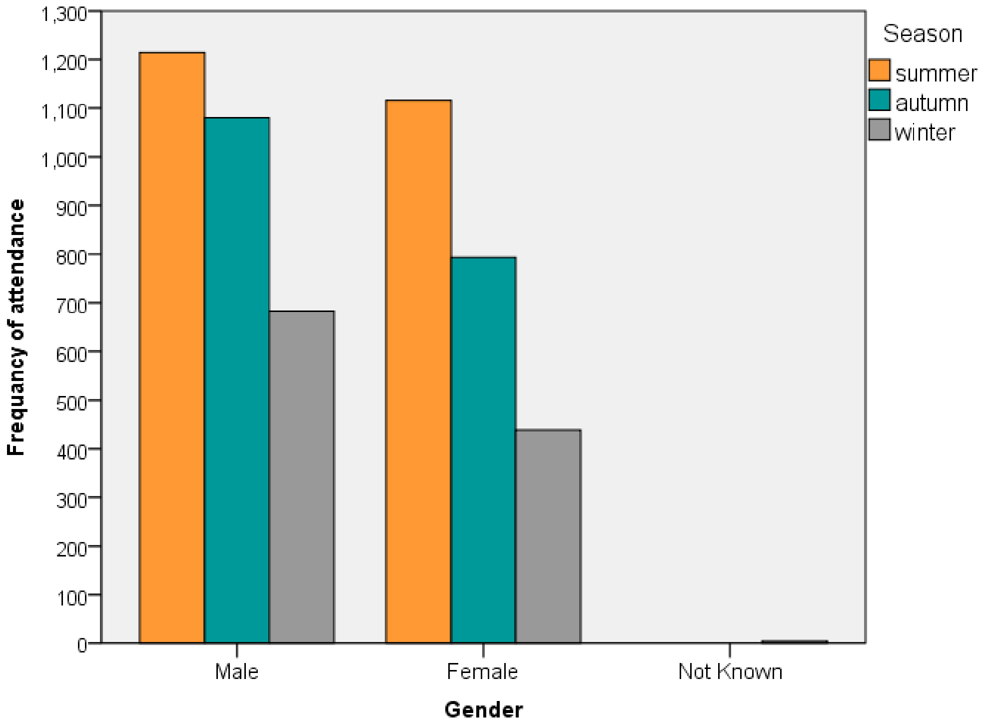


Figure 127 – Frequency of attendance according to the gender

Coding Individual Behaviour

As defined in the Pilot Study (Chapter 4), the behaviour of the users was recorded using a coding scheme created for this research. The behaviours were classified depending on the characteristic of the behaviour: state event, if the length of the behaviours needed to be recorded for the purposes of the analysis, or point event, if only the occurrence of the event was needed, independent of its length. This chapter will present, in addition to the Number of People, Groups' Size and Time of Permanence analyses, an analysis of additional behaviours observed, which will be also compared between seasons:

- *Body Postures:* As mentioned before, Fergus et al. (2013) stated that the postural changes can occur to improve the thermos-physiological response to the environment. In addition, according to (Whyte, 2009) "people tend to sit most where there are places to sit" (p. 110).

Accordingly, a place that allows people perform different postures is successful as it adapts better to the needs of the users. As described in the Pilot Study (Chapter 4), the body postures were recorded by indicating the postural changes of the person during his stay in the square. The body postures to be recorded were predefined according to other studies, the Pilot Study and taking into account the postures observed by the researcher during the data collection. The postures included in this analysis were: walking, standing, leaning, sitting standard, lotus (other postures observed with less frequency but also recorded were: sitting backrest, sitting with legs extended, laying down, running/jumping, kneeling, squat, biking/skating, carried, wheelchair/pram) (Figure 128).

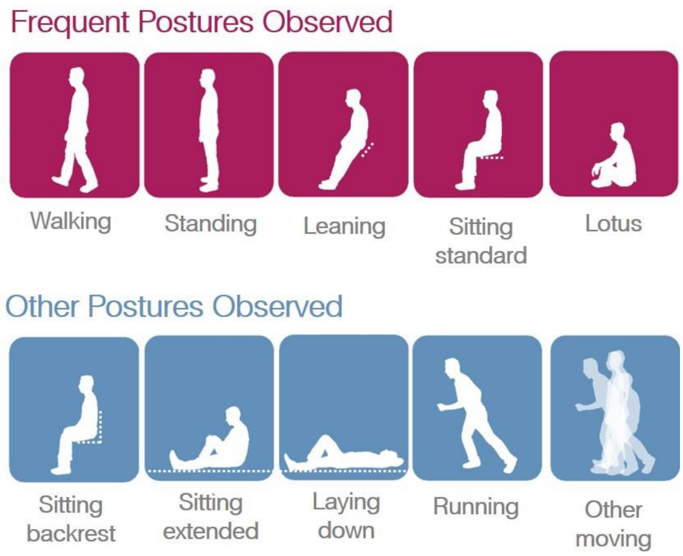


Figure 128 - Body Postures included in the coding scheme

For this analysis, the sample was filtered, so the users with no record of all the postural changes, due for example to an obstruction of the visual field, were excluded.

- *Adaptive Actions:* In the literature review (Chapter 2) and Pilot Study (Chapter 4) were explained the adaptive actions. In order to evaluate the Adaptive Actions occurred during the three seasons, it was recorded when the users: added or reduced clothes, wore or removed glasses, used a parasol or shading device, relocated and drunk a hot or cold beverage. These actions were recorded as a point event on the starting point of its occurrence (Figure 27).
- *Activities:* Similar to the Pilot Study (Chapter 4) the activities were studied during the three seasons. These were defined according to the notes taken during the recording periods. In addition, this list was increased as the coding process was conducted, since new activities were observed. The activities recorded were: playing, exercising, reading/writing, smoking, drinking, eating, using a device, talking by mobile, kissing/hugging, listening music, babysitting, taking photos, feeding or playing with pigeons. These activities were recorded as a point event at the starting point of its occurrence.

8.4. Results

The structure of the results for the “all-seasons” analysis is the same as the seasonal studies. The outcomes are classified in three sets of analysis: 1. Environmental Data, which consists of the analysis of the measurements recorded in Trinity Square during the three seasons; 2. *Social Behaviour*, which includes the analysis of events occurring in the square in relation to the place by counting the aggregates of general behaviours (number of people and grouping); and 3. Individual Behaviours which refers to the conduct of every user analysed individually, and the relationship of their behaviour with the environment. In this chapter the *Individual Behaviour* was analysed as: time of permanence, body postures, activities and adaptive actions.

8.4.1. Environmental Measurements

Table 107 shows the descriptive statistics of the environmental data collected during the three studies conducted in summer, autumn and winter 2015 and 2016 at Trinity square of Nottingham city. As in the previous studies, the variables measured were: air temperature (Ta, ^{o}C), relative humidity (rH, %), globe temperature in the sun and shadow (Tg_sun, Tg_shadow ^{o}C), mean radiant temperature in the sun and shadow (Tr_sun, Tr_shadow, ^{o}C), wind speed (Va, m/s) and illuminance (lx).

Table 107 - Descriptive statistics environmental data - All-seasons

Statistics N = 3780

	Ta (ºC)	rH (%)	Tg_sun (ºC)	Tg_sha (ºC)	Tr_sun (ºC)	Tr_sha (ºC)	Va (m/s)	Light (lx)
Mean	14.1	63	16.6	15.1	22.5	17.4	.990	3862
Median	14.3	63	15.6	14.7	17.9	15.7	.842	2511
Std. Deviation	4.9	13	6.2	5.4	13.4	8.1	.852	4208
Minimum	5.1	37	6.1	5.9	2.6	6.0	.000	12
Maximum	27.1	91	34.9	29.5	83.6	55.5	4.959	24325

Acronyms: Air temperature (Ta), relative humidity (rH), globe temperature in the sun (Tg_sun), globe temperature in the shadow (Tg_sha), mean radiant temperature in the sun (Tr_sun), mean radiant temperature in the shadow (Tg_sha), wind speed (Va).

Table 108 contains the bivariate correlation analysis of the environmental factors during the three seasons. As can be observed in the table below, there is a significant correlation of almost all the environmental variables in the three seasons. Interestingly, air temperature did not present correlation with light in the winter nor the autumn studies, but when considered along with the rest of the data collected in summer, overall there is a correlation between these two environmental variables ($r = .48$, $p < .001$).

Table 108 – Correlation between environmental variables during winter

Spearman's rho Correlations (N = 3780)

		Ta	rH	Tg_Sun	Tg_Sha	Tr_Sun	Tr_Sha	Va
Ta	Correlation Coefficient	1.000						
	Sig. (2-tailed)	.						
rH	Correlation Coefficient	**-.15****	1.000					
	Sig. (2-tailed)	.000	.					
Tg_Sun	Correlation Coefficient	**.88****	**-.24****	1.000				
	Sig. (2-tailed)	.000	.000	.				
Tg_Sha	Correlation Coefficient	**.97****	**-.14****	**.94****	1.000			
	Sig. (2-tailed)	.000	.000	.000	.			
Tr_Sun	Correlation Coefficient	**.70****	**-.34****	**.88****	**.77****	1.000		
	Sig. (2-tailed)	.000	.000	.000	.000	.		
Tr_Sha	Correlation Coefficient	**.88****	**-.25****	**.94****	**.93****	**.92****	1.000	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	
Va	Correlation Coefficient	-.03*	**-.27****	**-.21****	**-.13****	**-.06****	**-.08****	1.000
	Sig. (2-tailed)	.034	.000	.000	.000	.000	.000	.
Light	Correlation Coefficient	**.48****	**-.35****	**.72****	**.58****	**.81****	**.71****	**-.28****
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).

The highest correlation observed using the environmental data of the three seasons was between air temperature and globe temperature in the shadow ($r= .97$, $p <.001$). This agrees with each seasonal study, in which these two variables also had the most significant correlation, of all the variables ($r= .98$, $p <.001$ in summer, $r= .84$, $p <.001$ in autumn and $r= .92$, $p < .001$ in winter).

There were also strong relationships between air temperature and globe temperature in the sun (r= .88 p <.001) and mean radiant temperature in the shadow (r= .88 p <.001). Similarly, as expected, the globe temperature in the sun and shadow had a significant correlation with radiant temperature both in the sun and shadow. It is also worth mentioning that light presented significant correlations with all the other environmental factors, the highest being of radiant temperature in the sun (r= .81, p <.001). Interestingly, overall, light is negatively correlated with relative humidity, which has been the case in the winter and summer seasonal studies, but not in summer. Light is also negatively correlated to wind speed, which coincides with the negative relationship found during winter.

Figure 129 shows the percentage distribution of the air temperature using the data set gathered during the three seasons together. As in the previous studies, the data was binned at 1°C. The most common air temperature recorded was 8°C which consisted of 15% of the data recorded.

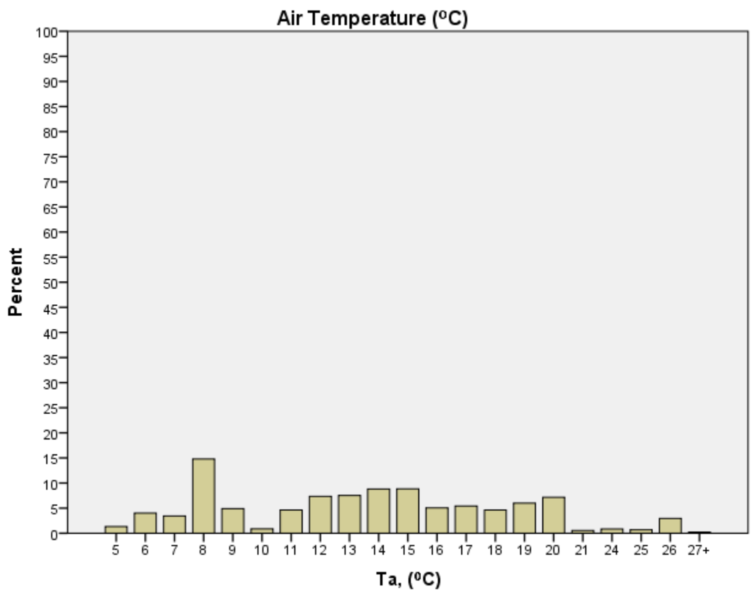


Figure 129 - Air Temperature (°C) percentage distribution - All-seasons

Figure 130 shows the percentage distribution of the relative humidity data binned at 5%, during the three seasons the study took place. The data measured is split mainly between 46 - 55%, 61 – 65% and 76 – 80% of relative humidity. There was however measurements starting from 36% and over 91% of relative humidity, which represents a good variety.

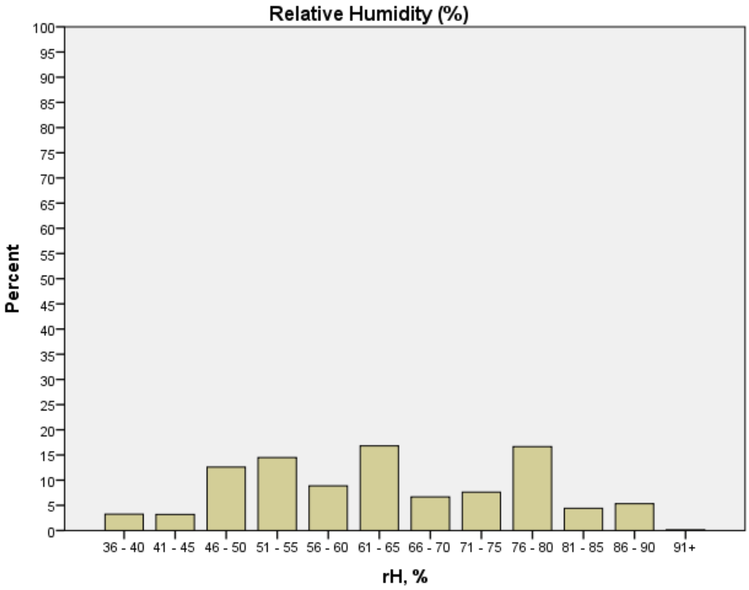


Figure 130 - Relative humidity (%) percentage distribution - All-seasons

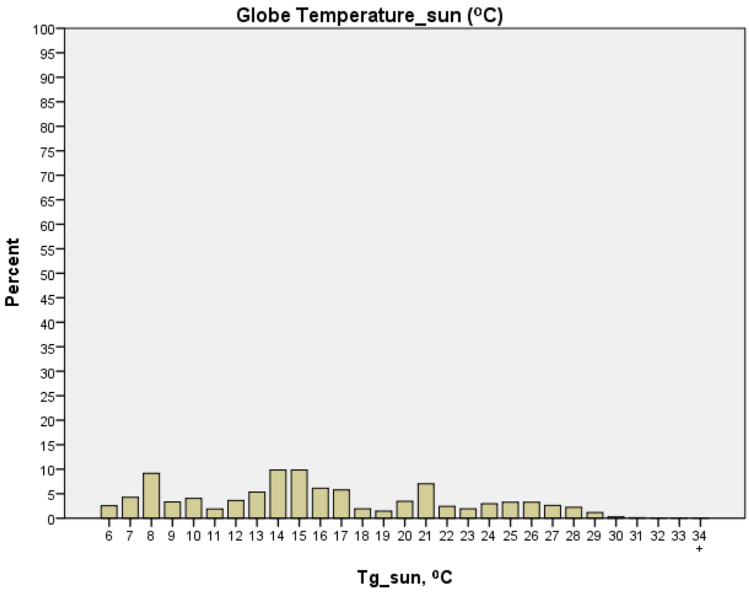


Figure 131 - globe temperature in the sun (°C) percentage distribution – All-seasons

Figure 131 shows the globe temperature in the sun distribution, binned at 1°C. In the three seasons considered together, the most common condition was 14°C and 15°C, followed closely by 8°C and 21°C. The globe temperatures in the sun recorded, varied within the ranges of 6°C and 34°C plus.

Regarding the globe temperature in the shadow, Figure 132 showed an overall distribution of the data, ranging from less than 6°C to over 29°C (binned at 1°C). 10% of the data measured was 8°C, while most of the other measurements, from 6°C to 20°C, reached or exceeded 5% of the data, except 18°C.

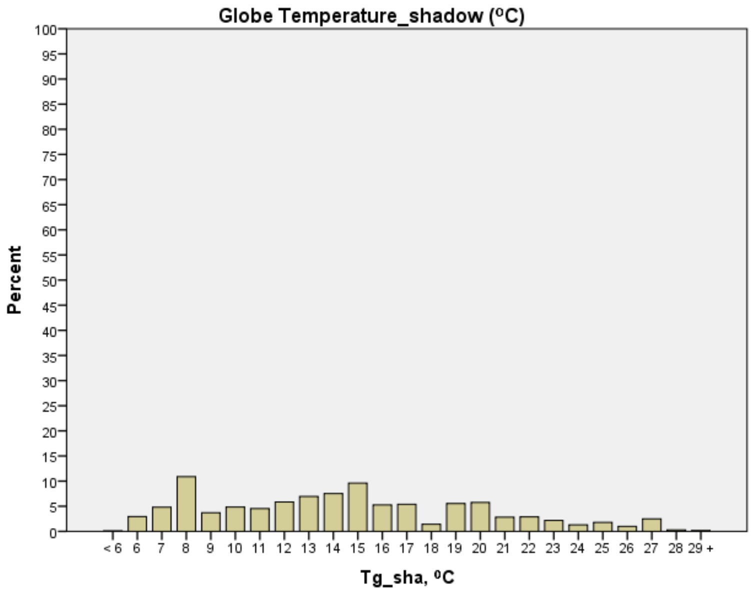


Figure 132 - Globe temperature in the shadow (°C) percentage distribution – All-seasons

Almost 30% of the mean radiant temperature in the sun was recorded within the range of 15°C to 20°C (Figure 134), binned at 5%. The second most frequent condition was 5.01°C to 10°C with around 18%, and apart from these two, the frequency of the measurements did not exceeded 10% of the data, and from this point started decreasing steadily from 10.01°C until almost 0%, at 65.01°C to 70°C.

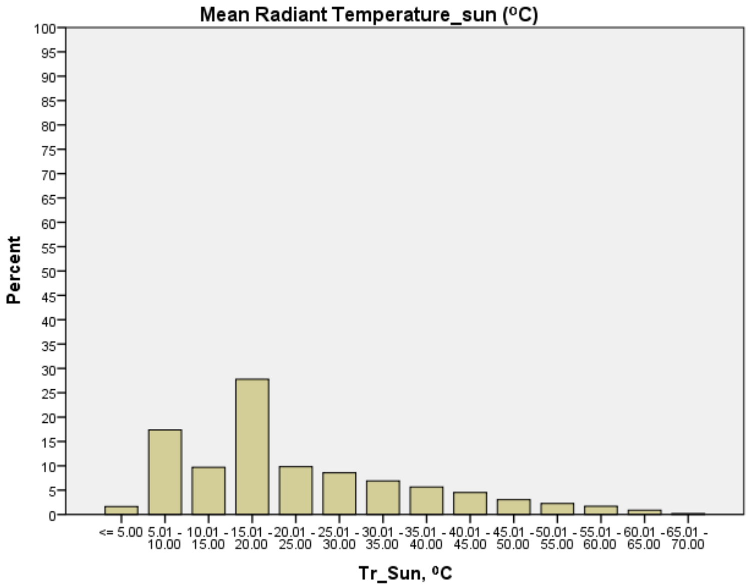


Figure 134 - mean radiant temperature in the sun (°C) percentage distribution – All-seasons

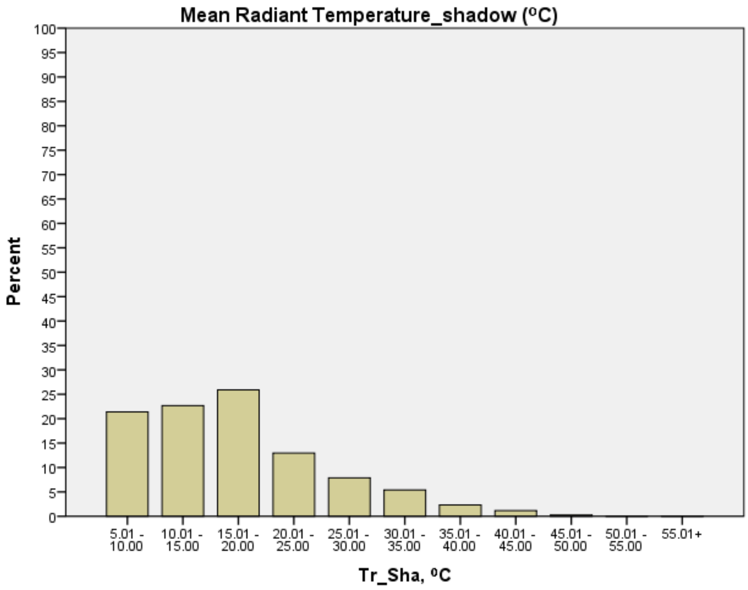


Figure 133 - Mean radiant temperature in the shadow (°C) percentage distribution - All-seasons

The frequency of the mean radiant temperature in the shadow presents a smaller range of temperatures than the mean radian temperature in the sun, as the majority of the data was gathered mainly within 5°C and 50°C.

Figure 135 shows the frequency of the wind speed measurements. The most frequent wind speed condition throughout the three seasonal studies was 0.0 to 0.5 m/s, representing more than 30% of the measurements. The two following measurements from 0.5 – 1.5 m/s and 1.5 – 2.0 m/s were each around 18% of the data.

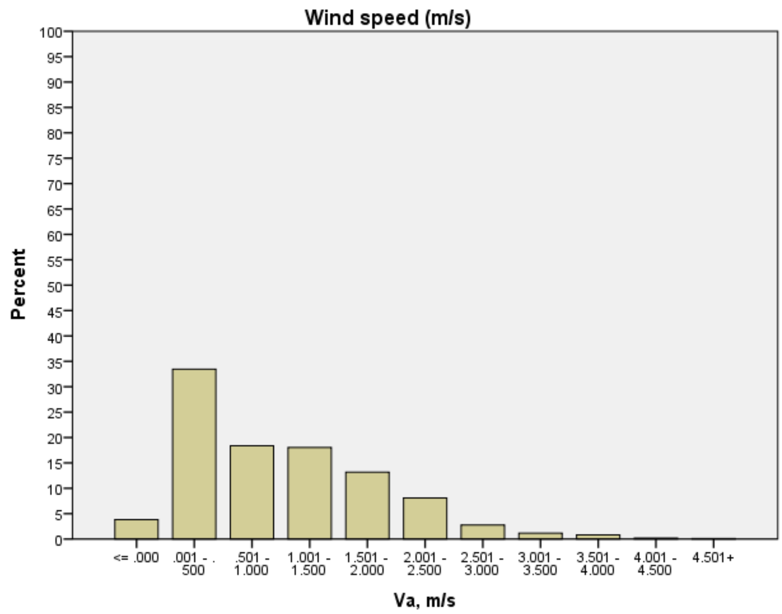


Figure 135 - Wind speed (m/s) percentage distribution - All-seasons

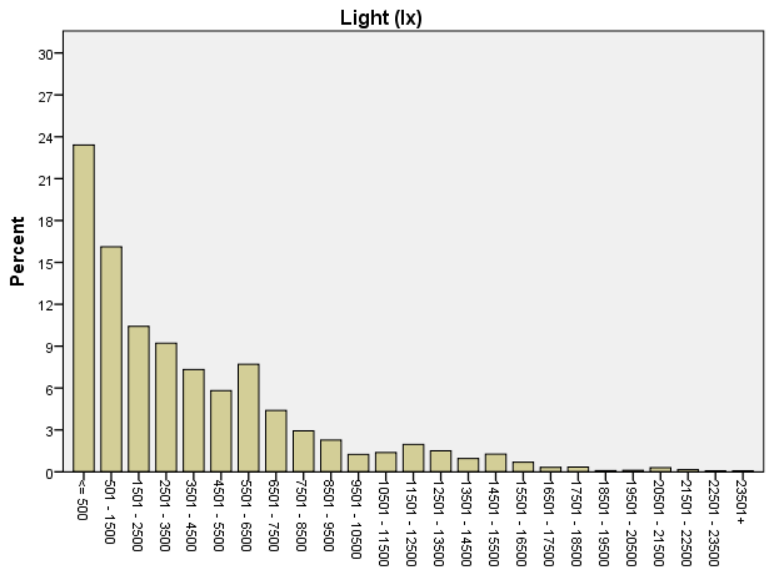


Figure 136 - Light (lux) percentage distribution - All-seasons

Finally, the illuminance measurements in the three seasons considered altogether were mainly observed within the range of 1 – 1,000 lx (Figure 136) binned at 1000 lx, which was the lowest value recorded. The rest of the measurements were mainly allocated within 1001 lx and 7000 lx.

8.4.2. Social Behaviour

As explained in previous chapters, social behaviours are events recorded as aggregates of behaviours. For example, all the individual attendances were added to obtain a general occupancy of the square per minute and added to a group of individuals present in the square if he was part of a group. The methodology is the same used in the seasonal studies. As in the previous studies, the groups were classified in groups of one (G1), groups of two (G2), groups of three (G3) and groups of four or more (G4more).

Table 109 presents the descriptive analysis per minute of the “all-seasons” Number of People, Number of Groups of G1, G2, G3 and G4more.

Table 109 – Descriptive statistics of the Number of People and Number of Groups

Statistics (N = 3780)					
	N_People	G1	G2	G3	G4more
Mean	18	6	3	1	0
Median	15	5	3	1	0
Std. Deviation	12	4	3	1	1
Minimum	0	0	0	0	0
Maximum	63	23	17	8	6
Sum	66428	21877	12703	3289	1853

The mean value shows the total Number of People or Number of Groups observed per minute, divided by the number of minutes. As can be observed, the mean for G1 is the highest of all the groups, and G4more had a mean and median of 0 which means that its occurrence was rare.

Figure 137 presents the total frequency distribution of the Number of People in the square during the three seasons evaluated. The x-axis correspond to the Number of People observed at the same time (per minute) and the y-axis is the frequency of occurrence of that Number of People. The three seasons are represented by different colours

It was observed that the square was recorded as empty up to 20 times (in the counts of people per minute during the three seasons), but this occurred only during winter and autumn. The minimum number of people recorded in summer was 4, which means that during summer there were at least four people in the square in the counts of people per minute. During winter, most of the data was collected between 4 and 9 people present in the square at the same time per minute. On the other hand, during summer most of the data was collected in a wider range, between 4 and 29 people present at the same time per minute. This means that it is more likely that the square is crowded, during summer than winter. Autumn is a transition between winter and summer, and this was reflected in the data since, although there were times when the place was empty, most of the data was recorded between 5 and 20 people at the same time per minute.

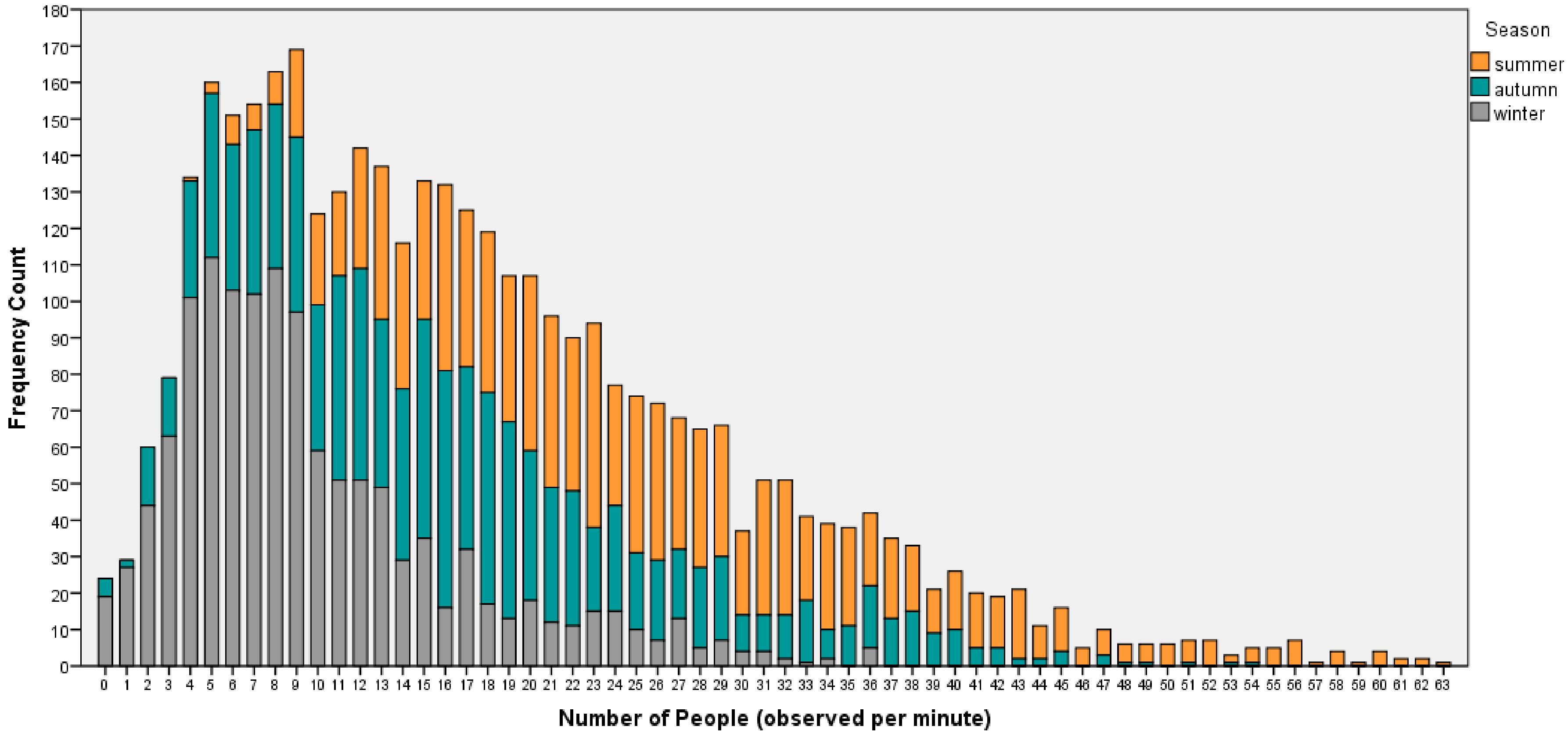


Figure 137 - Frequency of the total Number of People observed per minute according to the seasons

Figure 138 below shows the frequency distribution of the Number of Groups of G1, G2, G3 and G4more. The most common count per minute in the square of people alone (G1) was between 3 and 5 groups of 1. Winter presented the highest counts per minute of 1 group of 1 (G1) in the square, while the highest number of groups of 1 was observed in summer, when up to 23 groups of 1 were observed in the counts per minute.

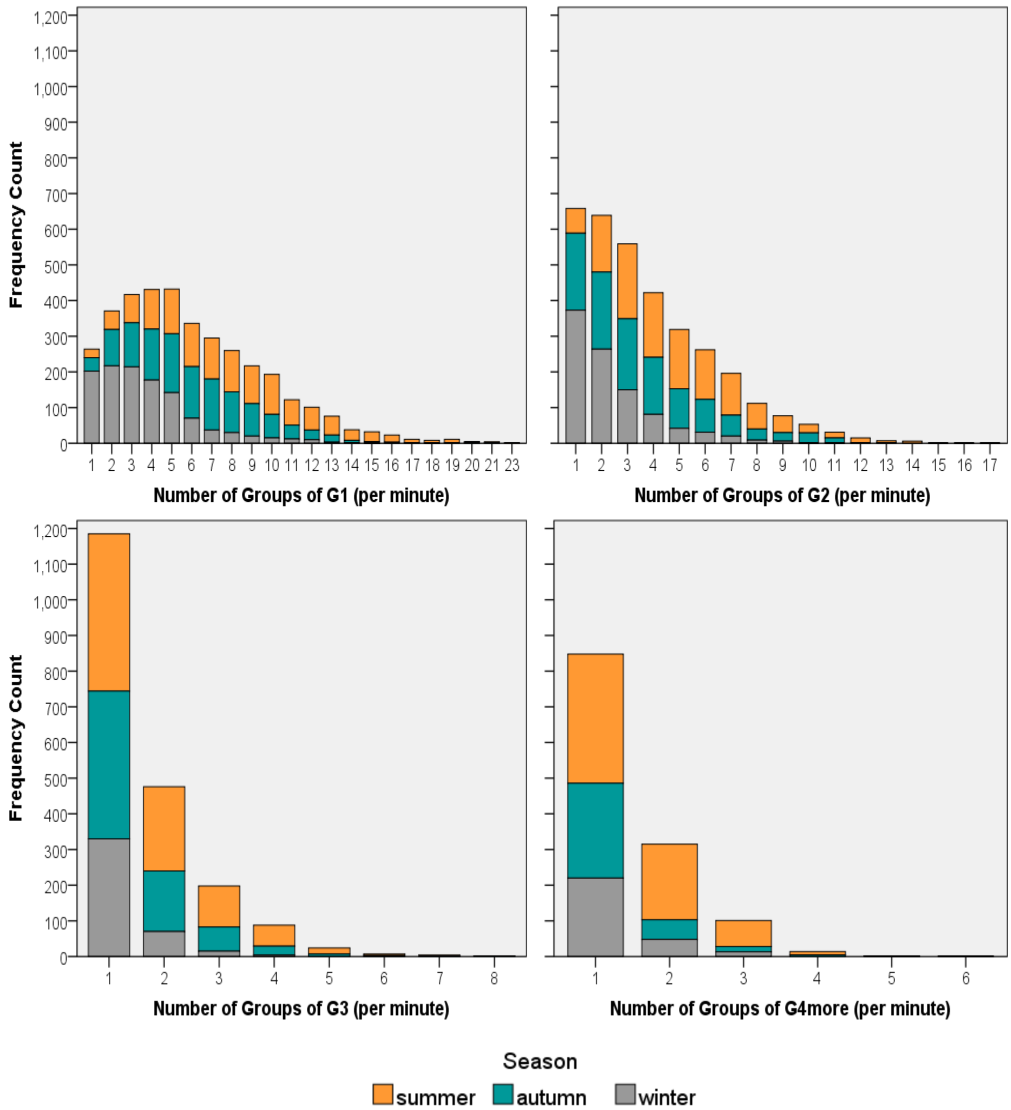


Figure 138 - Frequency distribution of the total Number of Groups observed per minute

The presence of 1 and 2 couples (G2) is similar when the data set of all-seasons is analysed together. However, the presence of only 1 couple was observed more frequently in winter than summer and autumn, contrary to the presence of four or more couples which was more frequent in summer.

Interestingly, the frequency of observing one group of G3 or one group of G4more was higher than the frequency of observing one group of G1 or one group of G2. This indicates the higher probability of finding just one big group present in the square compared to two or more big groups, as two or more big groups are less likely to happen than more than one small group or various persons alone in the square. The count of one group of G3 and G4more was similar during every independent seasonal study. However, more than 1 groups of G3 or G4more were more frequent in summer than in winter or autumn.

8.4.2.1. Correlation

A multiple regression analysis was also conducted for the whole social behaviour data set gathered during the three seasons. As explained in previous chapters, the analysis had the purpose of identifying the environmental variables which were the best predictors of the human behaviour. As in the individual seasonal analysis, the data was split in 60% and 40%, in order to validate the results. 40% percent of the data was therefore reserved, while 60% of the data was used to perform a Spearman's rho correlation analysis, following the process described by Stevens (2009). The highest correlations were filtered and a multiple regression model was built per behaviour in order to predict the behaviour according to the thermal environment variables. The outcome was then tested with the reserved 40% of the data, to validate the results. The data set was therefore randomly split on 2279 (60%) and 1501 (40%) minutes.

Before conducting the bivariate correlation analysis between the environmental variables, the number of people and the grouping, a Kolmogorov Smirnov test was undertaken to verify whether the distribution of the data was normal, and to select the type of correlation analysis required (Table 110).

Table 110 – Test of normality, Kolmogorov – Smirnov test for 60% of the data

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ta	.106	2279	.000	.961	2279	.000
rH	.088	2279	.000	.967	2279	.000
Tg_Sun	.075	2279	.000	.958	2279	.000
Tg_Sha	.074	2279	.000	.961	2279	.000
Tr_Sun	.147	2279	.000	.920	2279	.000
Tr_Sha	.126	2279	.000	.925	2279	.000
Va	.115	2279	.000	.926	2279	.000
Light	.180	2279	.000	.832	2279	.000
N_People	.094	2279	.000	.933	2279	.000
G1	.128	2279	.000	.944	2279	.000
G2	.157	2279	.000	.911	2279	.000
G3	.259	2279	.000	.766	2279	.000
G4more	.399	2279	.000	.639	2279	.000

a. Lilliefors Significance Correction

All the variables were significantly non-normal (Table 110), obtaining $D(2279) < .001$. Therefore, the type of correlation analysis required for the data set to study the relationship between the variables was a Spearman's Rho correlation. According to Field (2009) this test is used when the data is non-normally distributed.

Table 111 shows the Spearman's rho correlation test between the social behaviours and the environmental variables in all the seasons. The relationships between social behaviours and the environmental variables are presented in blue, with the significant correlations highlighted in blue. On the other hand the relationships between the environmental variables to each other are shown in black, with the significant correlations also highlighted in black. It is worth mentioning that the results of the environmental variables (black) is similar to the results on Table 108, but in this case the correlations correspond to the 60% of the data and the coefficients of this procedure will be used in the next analysis.

Table 111 presents the bivariate analysis between the environmental variables and the social behaviour variables. In general, there was a relationship between the social behaviours and the thermal environment variables, except relative humidity which presented low or null relationship with the social behaviours.

The strongest correlation found was between *Number of People* and globe temperature in the sun ($r = .67$, $p < .001$). In addition, globe temperature in the sun was the environmental factor with the highest correlation with *Number of* Groups of G1 ($r = .51$, $p < .001$), Number of Groups of G2 ($r = .56$, $p < .005$) and Number of Groups of G3 ($r = .36$, $p < .001$). Surprisingly, globe temperature in the sun did not have the highest correlation with *Number of Groups of G4more*, as this social behaviour presented a higher correlation with light ($r = .33$, $p < .001$).

Table 111 - Correlations between Social Behaviour and environmental variables

Spearman's rho Correlations (N = 2279)

		N_People	G1	G2	G3	G4more	Ta	rH	Tg_Sun	Tg_Sha	Tr_Sun	Tr_Sha	Va	Light
Ta	Correlation Coefficient	**.61****	**.50****	**.50****	**.33****	**.26****	1.000							
	Sig. (2-tailed)	.000	.000	.000	.000	.000								
rH	Correlation Coefficient	-.09**	-.02	-.08	-.02	-.06**	**-.18****	1.000						
	Sig. (2-tailed)	.000	.410	.000	.378	.004	.000							
Tg_Sun	Correlation Coefficient	**.67****	**.51****	**.56****	**.36****	**.29****	**.89****	**-.26****	1.000					
	Sig. (2-tailed)	.000	.000	.000	.000	.000	0.000	.000						
Tg_Sha	Correlation Coefficient	**.64****	**.50****	**.53****	**.35****	**.28****	**.97****	**-.17****	**.95****	1.000				
	Sig. (2-tailed)	.000	.000	.000	.000	.000	0.000	.000	0.000					
Tr_Sun	Correlation Coefficient	**.59****	**.46****	**.49****	**.32****	**.27****	**.72****	**-.35****	**.89****	**.78****	1.000			
	Sig. (2-tailed)	.000	.000	.000	.000	.000	0.000	.000	0.000	0.000				
Tr_Sha	Correlation Coefficient	**.64****	**.49****	**.53****	**.35****	**.29****	**.89****	**-.27****	**.95****	**.93****	**.93****	1.000		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	0.000	.000	0.000	0.000	0.000			
Va	Correlation Coefficient	**-.33****	**-.20****	**-.28****	**-.21****	**-.13****	-.06**	**-.25****	**-.22****	**-.15****	-.08**	**-.10****	1.000	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.005	.000	.000	.000	.000	.000		
Light	Correlation Coefficient	**.56****	**.37****	**.44****	**.34****	**.33****	**.50****	**-.36****	**.72****	**.59****	**.81****	**.72****	**-.29****	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	0.000	.000	0.000	0.000	.000	

Correlation is significant at the 0.01 level (2-tailed).

Correlation Analysis Environment and Behaviour: Key Findings

Regarding the influence of the season over the social variables:

- **Winter** influenced **Number of People** with smaller number of attendants being the most frequent condition.
- **Summer** and **autumn** presented similar frequencies of attendance or **Number of People**. However **summer** presented the highest occupancies of all the seasons.
- During winter, the frequency of one, two, three or four **Groups G1** was higher than in autumn and summer, but the frequency of six or more **Groups G1** was lower in winter than in autumn and summer.
- The frequency of one and two **Groups of G2** is similar when the whole data set of the three seasons is considered.
- The **Groups of G3** and **G4more** were not frequent over the seasons, compared to **G1** and **G2**.
- The presence of one group of **G3** or one of G4more was similar during the three seasons.

Regarding the relationship between the environmental variables:

- A strong relationship was found between the variables related to the temperature: **Globe Temperature, Mean Radiant Temperature** and **Air Temperature**, as expected.
- **Light** was highly correlated with the **Calculated Mean Radiant Temperature sun and shadow**.

Regarding the relationship between environment and social variables:

- The main environmental factor affecting most of the social variables was **Globe Temperature in the sun**.
- The **Number of Groups of G4more** was mainly influenced by **light**.

8.4.2.2. *Multiple Regression Analysis*

Following the procedure conducted in the previous chapters, during the analysis of the data set of the three seasons the environmental factors were treated as independent variables or predictors. The environmental variables analysed were: air temperature (Ta), relative humidity (rH), globe temperature in the sun (Tg_sun), globe temperature in the shadow (Tg_shad), mean radiant temperature in the sun (Tr_sun), mean radiant temperature in the shadow (Tr_shad), wind speed (Va) and light. On the other hand, the dependant or predicted variables were the social behaviours: Number of People, Number of Groups of G1, Number of Groups of G2, Number of Groups of G3 and Number of Groups of G4more.

As reported before, the data was split in 60% and 40% to perform the analysis including an internal cross-validation of the results at the end. The procedure used to select the variables for the multiple regression analysis consisted of performing a bivariate correlation analysis to identify the environmental variables that could better explain the occurrence of each behaviour. After this, a multicollinearity check was done to discard the variables presenting high correlations with each other. This process was conducted only between environmental variables to discard predictors highly correlated with other predictors. Subsequently, the variables selected were inserted in the multiple regression analysis, where the *Forward* method was used. This method selected only the variables that were contributing to the final model. At the end of the multiple regression analysis, the best model to predict the behaviour was selected according to two principles: the significance of the coefficients and the highest performance using fewer variables.

Model to Predict Number of People

The filter of the variables to predict Number of People presented in Figure 139 indicate that the globe radiant temperature in the sun was the main predictor, while light and wind speed were also selected to contribute to the model, as they did not present multicollinearity. The variables selected are highlighted in blue, while the variables discarded are crossed.

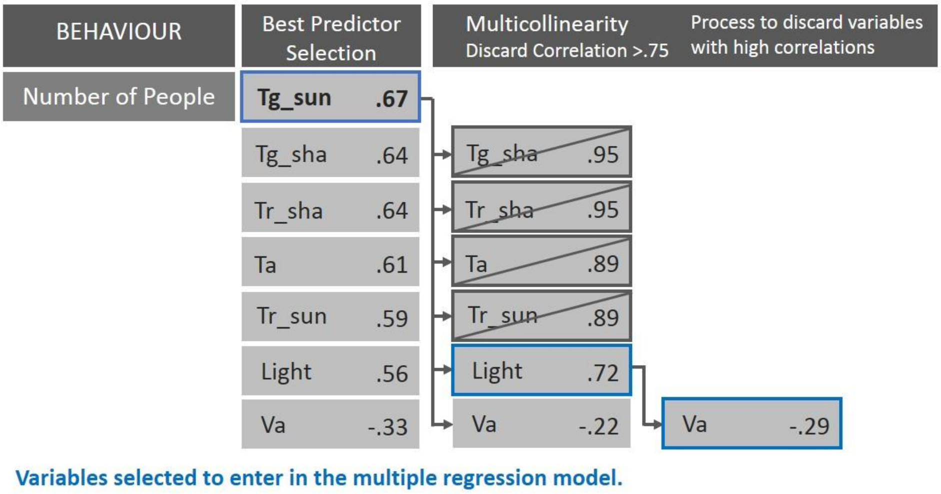


Figure 139 - Diagram of the variables filtered for the model to predict Number of People.

Table 112 presents the regression model summary to predict *Number of People*. It is observed that the biggest contributor was the globe temperature in the sun which explained 35% of the attendance (model 1). By adding light and wind speed the adjusted R^2 increased up to .39 ($p < .001$). Therefore, model 3 was selected for the next analysis.

Table 112 – Regression model summary to predict Number of People in All-seasons

Model Summary[d] (N = 2279)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.59[a]	.35	.35	9.3	.35	1229	1	2277	.000
2	.62[b]	.38	.38	9.1	.03	106	1	2276	.000
3	.63[c]	.39	.39	9.0	.01	56	1	2275	.000

a. Predictors: (Constant), Tg_sun

b. Predictors: (Constant), Tg_sun, Va

c. Predictors: (Constant), Tg_sun, Va, Light

d. Dependent Variable: N_People

Table 113 presents the coefficients to predict *Number of People*. The third column (B) contains the b-values that will be used for the regression equation. The Standardized Beta values are the contribution of each variable to the model. It is observed that the globe temperature in the sun made the highest contribution to the model (t (2275) = .44), while wind speed (t (2275) = -.17) and light (t (2275) = .17) had a similar contribution. The T-test showed that the three variables made a significant contribution to the model (all ps < .001).

Table 113 - Model to predict Number of People - All-seasons

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
3	(Constant)	4.744	.67		7.10	.000	3.433	6.056
	Tg_sun	.804	.04	.44	18.84	.000	.720	.887
	Va	-2.405	.23	-.17	-10.32	.000	-2.862	-1.948
	Light	.0005	.00	.17	7.47	.000	.000	.001

a. Dependent Variable: N_People

Equation 15 is the result of the multiple regression model. It is observed that globe temperature in the sun and light has a positive contribution in the equation, while the contribution of wind speed was expressed in negative terms. The negative coefficient of the wind speed means that the number of people is reduced as the wind speed increases.

Equation 15 - Model to predict Number of People - All-seasons

$$N\_People = b_0 + b_1 Tg_{sun} + b_2 Va + b_3 Light$$

$$N\_People = 4.744 + (0.804 * Tg_{sun}) + (-2.405 * Va) + (0.0005 * Light)$$

Validation of the Model to Predict Number of People

The cross-internal validation was done using the retained 40% of the data. This process consisted of using Equation 15 to predict *Number of People* by entering the environmental data reserved. The results of the *Predicted Number of People* were compared with the real *Number of People* recorded during the observations.

Figure 140 presents the scatter plot of the real and predicted *Number of People*. The x-axis corresponds to the *Number of People* observed in Trinity Square during the three seasons and the y-axis is the *Predicted Number of People* by using the globe temperature in the sun, wind speed and light as predictor variables.

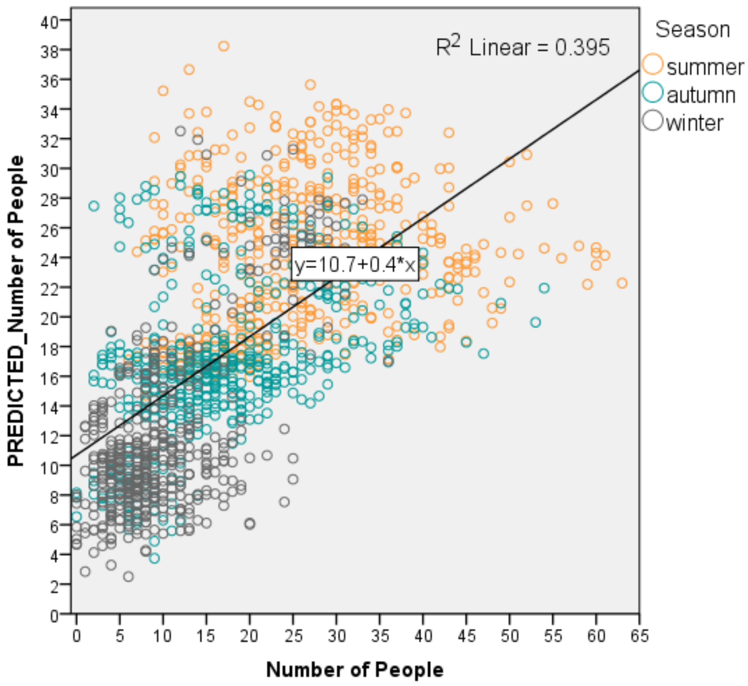


Figure 140 – Scatter plot of the Predicted Number of People and the Number of people

Table 114 contains the simple correlation between the *Predicted Number of People* and the real *Number of People* of the 40% of the data. A relationship was found between both variables of $r = .62$, $p < .001$.

Table 114 – Correlation between the Predicted Number People and the real Number of People

Correlations (N = 1501)

		PREDICTED N_People	N_People
PREDICTED N_People	Pearson Correlation	1	.63**
	Sig. (2-tailed)		.000
N_People	Pearson Correlation	.63**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the Number of People was influenced by the globe temperature in the sun, wind speed and illuminance. The model designed with these variables explained 39% of the occurrence of this behaviour (Table 112). The cross-validation of the results presented significant correlation of $r = .63$, $p < .001$ (Table 114).

Model to Predict Number of Groups of one person (G1)

Figure 141 presents the variables filtered to select the best predictors for model to predict Number of Groups of G1. Since the results obtained indicated that the main predictors for G1, G2 and G3 was the globe temperature in the sun, then the initial model for these three variables were similar since they were compound by the same variables: globe temperature in the sun, light and wind speed.

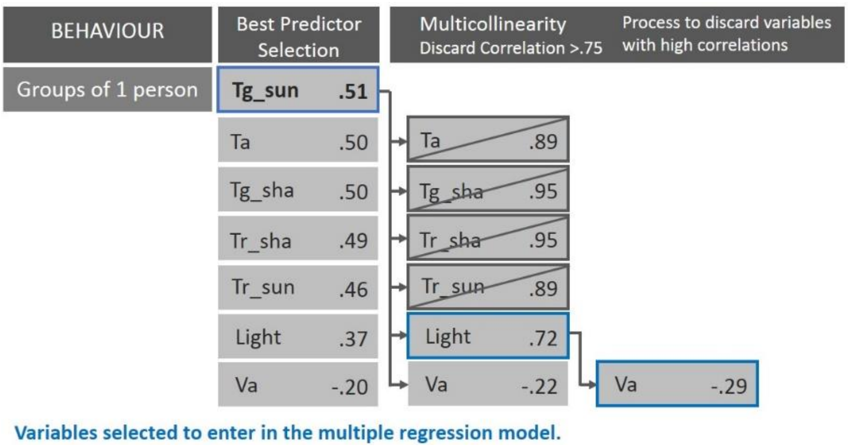


Figure 141 - Diagram of the variables selected to predict Number of Groups of G1 – All-seasons

Figure 141 presents the filter of the variables for G1, the filters made for *G2* and *G3* contained the same variables, therefore they are not presented.

The variables selected for the model to *Predict Number of Groups of G1* were: globe temperature in the sun, light and wind speed. Table 115 presents the regression model summary. It is observed that the biggest contributor was the globe temperature in the sun which explained 21% of *Number of Groups of G1*, when adding light and wind speed the adjusted R^2 increases up to .23 ($p < .001$).

Table 115 - Regression model summary to predict Number of Groups of G1

Model Summary[d]

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.46[a]	.21	.21	3.37	.21	608	1	2277	.000
2	.47[b]	.22	.22	3.35	.01	28	1	2276	.000
3	.48[c]	.23	.23	3.33	.01	27	1	2275	.000

a. Predictors: (Constant), Tg_Sun
b. Predictors: (Constant), Tg_Sun, Light
c. Predictors: (Constant), Tg_Sun, Light, Va
d. Dependent Variable: G1

Table 116 contains the coefficients of the model to predict *Number of Groups of G1*. The b-values (B) are the coefficients that will be used in the regression equation. The Standardized Beta suggest that the globe temperature in the sun made the highest contribution ($t(2275) = .34$, $p < .001$), followed by light ($t(2275) = .14$, $p < .001$) and the smaller contribution was done by the wind speed ($t(2275) = -.10$, $p < .001$).

Table 116 – Coefficients of the regression model to predict Number of Groups of G1 – All-seasons

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
3	(Constant)	2.307	.25		9.33	.000	1.82	2.79
	Tg_Sun	.207	.02	.34	13.14	.000	.18	.24
	Light	.0001	.00	.14	5.25	.000	.00	.00
	Va	-.451	.09	-.10	-5.23	.000	-.62	-.28

a. Dependent Variable: G1

Equation 16 is the result of the multiple regression model selected to predict *Number of Groups of G1*. It is observed a positive contribution from the globe temperature in the sun and the light, while the wind speed presented a negative coefficient as expected.

Equation 16 – Model to Predict Number of Groups of G1

$$Number\ of\ Groups\ of\ G1 = b_0 + b_1 Tg_{sun} + b_2 Light + b_3 Va$$

$$Number\ of\ Groups\ of\ G1 = 2.307 + (0.207 * Tg_{sun}) + (0.0001 * Light) + (-0.451 * Va)$$

Validation of the Model to Predict Number of G1

Following the same cross-validation procedure used in the previous chapters, Figure 142 presents the scatter plot of the data of *Predicted Number of Groups of G1* and *Number of Groups of G1*. It is observed that the model overestimates the presence of small amounts of groups of *G1*, since none of the predictions outcomes was 1 or 2. It is also observed that the data of summer is more spread in a horizontal which indicates a low variance for these data.

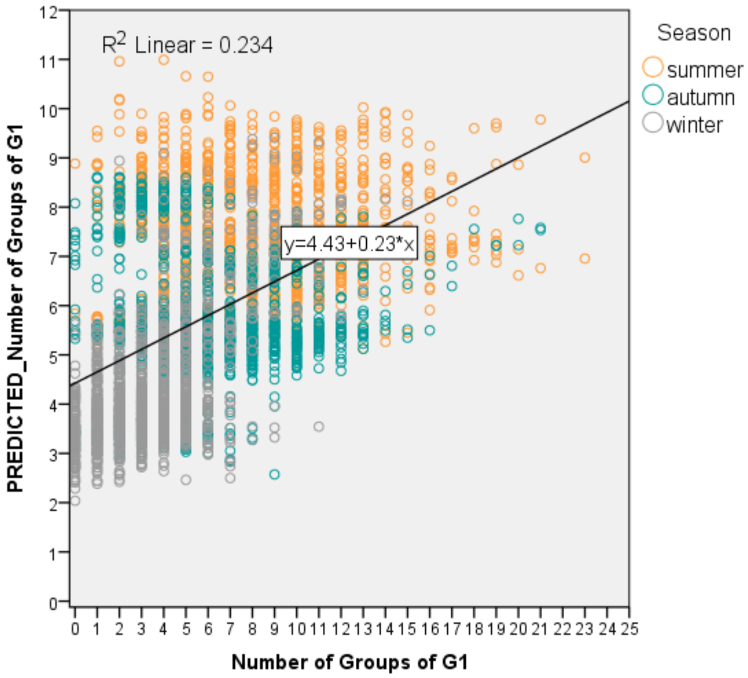


Figure 142 - Scatter plot Predicted Number of Groups of G1 and Number of Groups of G1 – All-seasons

Table 117 presents the correlation between the *Number of Groups of G1* and the *Predicted Number of Groups of G1*. The simple correlation obtained was r = .49, p < .001, which can be considered as a moderate relationship between both variables.

Table 117 – Correlation between the Predicted Number of Groups of G1 and observed Groups of G1

Correlations (N = 1501)

		PREDICTED_G1	G1
PREDICTED_G1	Pearson Correlation	1	.49**
	Sig. (2-tailed)		.000
G1	Pearson Correlation	.49**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the *Number of Groups of G1* was influenced by the globe temperature in the sun, light and wind speed. The model built with these variables explained 23% of the occurrence of this behaviour (Table 115). The cross validation of the model presented a moderate significant relationship r = .63.

Model to Predict Number of Groups of two persons (G2)

The variables selected for the model to predict *Number of Groups of G2* were: globe temperature in the sun, light and wind speed. Table 118 presents the regression model summary. It is observed that the biggest contributor was the globe temperature in the sun, which explained 27% of the attendance of people in couples; when adding wind speed and light the adjusted R^2 increased up to .30 ($p < .001$). Therefore, the third model with the three variables was selected to conduct the analysis.

Table 118 - Regression model summary to predict Number of Groups of G2

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.52[a]	.27	.27	2.28	.27	851	1	227	.000
2	.54[b]	.29	.29	2.25	.02	68	1	227	.000
3	.55[c]	.30	.30	2.24	.01	21	1	227	.000

a. Predictors: (Constant), Tg_Sun

b. Predictors: (Constant), Tg_Sun, Va

c. Predictors: (Constant), Tg_Sun, Va, Light

d. Dependent Variable: G2

Table 119 presents the coefficients of the model to predict *Number of Groups of G2*. The b-values (B) are the coefficients used in the equation of the models. The Standardized Beta suggests that the main contributor was the globe temperature in the sun, followed by wind speed and finally the light. This concurs with the t-test (t) which shows the contribution of each predictor to the model.

Table 119 -Coefficients of the model to Predict Number of Groups of G2 - All-seasons

Coefficients[a]

Model		Unstandardized B	Unstandardized Std. Error	Standardiz Beta	t	Sig.	95.0% Confidence Lower	95.0% Confidence Upper
3	(Constant)	.614	.17		3.69	.000	.29	.94
	Tg_Sun	.176	.01	.41	16.56	.000	.16	.20
	Va	-.475	.06	-.15	-8.18	.000	-.59	-.36
	Light	0.00007	.00001	.11	4.55	.000	.00004	.0001

a. Dependent Variable: G2

Equation 17 is the outcome of the regression model. It is observed that the globe temperature in the sun and light had positive contributions to the equation, while wind speed had a negative coefficient.

Equation 17 - Model to predict Number of Groups of G2 – All-seasons

$$Number\ of\ Groups\ of\ G2 = b_0 + b_1 Tg_{sun} + b_2 Va + b_3 Light$$

$$Number\ of\ Groups\ of\ G2 = 0.614 + (0.176 * Tg_{sun}) + (-0.475 * Va) + (0.00007 * Light)$$

Validation of the Model to Predict Number of G2

The validation was performed using the data retained for this procedure (40%) as described in previous chapters. Figure 143 presents the scatter plot between the predicted and the observed values of Number of Groups of G2. It is observed that the model could underestimate the presence of a high amount of couples present in the square at the same time, since the maximum value reached by the prediction was around 8 couples, while in the real observation up to 17 couples were recorded in the square at the same time. It is also observed that the best predictions occurred for occupancies between 6 and 8 couples present in the square.

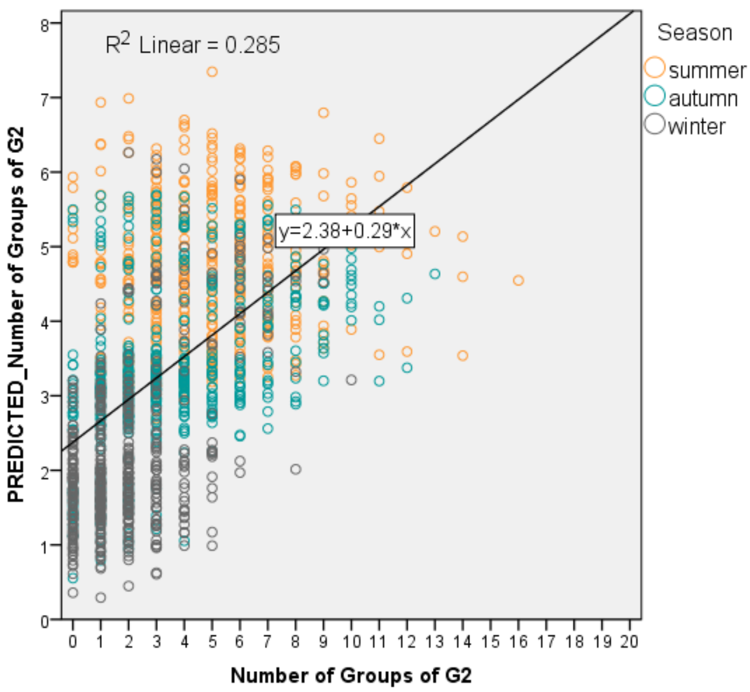


Figure 143 - Scatter plot Predicted Number of Groups of G2 and Number of Groups of G2

Table 120 presents the simple correlation between the predicted and observed data. The results indicate correlation between the variables, r = .53, p < .001.

Table 120 - Correlation between Predicted Number of Groups of G2 and Number of Groups of G2

Correlations (N = 1501)

		PREDICTED_G2	G2
PREDICTED_G2	Pearson Correlation	1	.53**
	Sig. (2-tailed)		.000
G2	Pearson Correlation	.53**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the globe temperature in the sun, wind speed and light affected the presence of *Groups of G2*.The model presented accounted for the 30% of the variance of this behaviour. The cross-validation indicated a moderate correlation between the predictions and the real data.

Model to Predict Number of Groups of three people (G3)

The variables selected for the model to *Predict Number of Groups of G3* were: globe temperature in the sun, light and wind speed. Table 121 presents the regression model summary. It is observed that the main contributor was the globe temperature in the sun which explained 11% of the attendance of groups of *G3*. By adding wind speed the adjusted R^2 increased up to .13 ($p < .001$). However, the model did not improve when light was added. Therefore, the model selected to predict *Number of Groups of G3* was integrated by the globe temperature in the sun and wind speed (model 2).

Table 121 - Model summary to predict the Number of Groups of G3

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.33[a]	.11	.11	1.03	.11	283	1	227	.000
2	.36[b]	.13	.13	1.03	.02	43	1	227	.000
3	.37[c]	.13	.13	1.02	.01	19	1	227	.000

a. Predictors: (Constant), Tg_Sun

b. Predictors: (Constant), Tg_Sun, Va

c. Predictors: (Constant), Tg_Sun, Va, Light

d. Dependent Variable: G3

Table 122 presents the coefficients of the model to predict Number of Groups of G3. The b-values (B) are used to generate the equation of the model. The Standardized Beta suggests the importance of the globe temperature in the sun for the model. The t-test (t) outcomes confirm that both variables are making significant contributions to the model.

Table 122 - Coefficients of the model to predict Number of Groups of G3

Coefficients[a]

Model		Unstandardized B	Std. Error	Standardize Beta	t	Sig.	95.0% Lower	Confidence Upper
2	(Constant)	.168	.07		2.37	.018	.03	.31
	Tg_Sun	.053	.00	.31	15.36	.000	.05	.06
	Va	-.175	.03	-.13	-6.59	.000	-.23	-.12

a. Dependent Variable: G3

Equation 18 is the outcome of the multiple regression model. As can be seen, there is a positive contribution of the globe temperature and a negative influence of the wind speed. This means that as the globe temperature in the sun increases and the wind speed decreases, there is a higher probability of presence of multiple groups of G3 at the same time.

Equation 18 - Model to predict Number of Groups of G3 - All-seasons

$$Number\ of\ Groups\ of\ G3 = b_0 + b_1 Tg_{sun} + b_2 Va$$

$$Number\ of\ Groups\ of\ G3 = 0.168 + (0.053 * Tg_{sun}) + (-0.175 * Va)$$

Validation of the Model to Predict Number of G3

The validation was conducted using the 40% of the data retained for those purposes. Equation 18 was used to calculate the predicted *Number of Groups of G3*, and this figure was then compared with the observed *Number of Groups of G3*. It is observed that the model underestimated the presence of *Groups of G3*, since the predicted data did not achieved more than 2 groups of

G3 while the observations recorded up to 7 groups of *G3* at the same time. However, it seems that low occupancies of *G3* are well estimated.

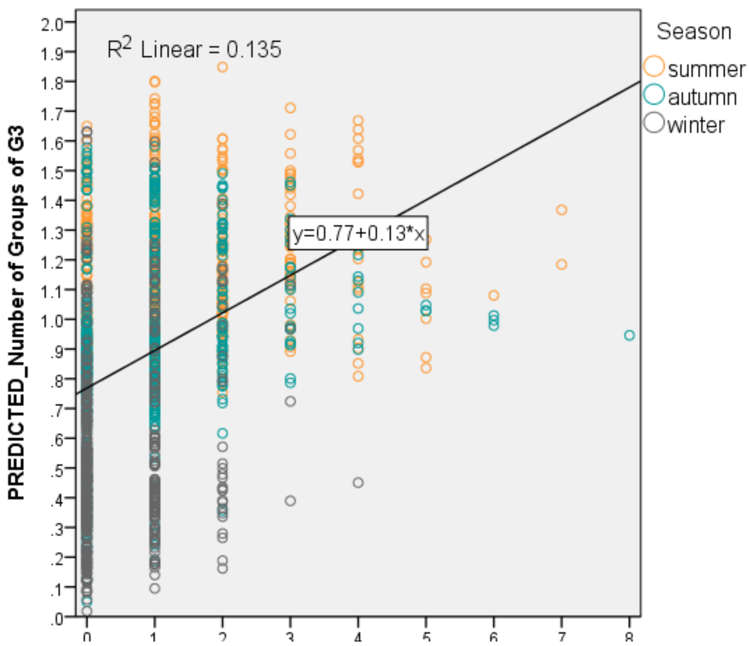


Figure 144 - Scatter plot Predicted Number of G3 and the real Number of G3

Table 123 presents the simple correlation between the predicted and the observed data. The results suggest a weak correlation between variables, r = .39, p < .001.

Table 123 – Correlation between Predicted Number of Groups of G3 and Number of Groups of G3

Correlations

		PREDICTED_G	G3
PREDICTED_G3	Pearson Correlation	1	.37**
	Sig. (2-tailed)		.000
G3	Pearson Correlation	.37**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the *Number of Groups of G3* was influenced by the globe temperature in the sun and the wind speed. 13% of the variance of the presence of groups of G3 is explained by these environmental variables (Table 121). The results were internally cross validated and the simple correlation obtained was r = .37, which is similar to the simple correlation of the theoretical model, r = .36 (Table 121).

Model to Predict Number of Groups of four or more people (G4more)

Figure 145 presents the diagram used to filter the variables to predict Number of Groups of G4more. It was found that the strongest correlation between G4more and the environmental variables was light, so this variable was selected as the main predictor. Subsequently, mean radiant temperature in the sun and wind speed were selected as the variables that presented correlation without multicollinearity conflicts.

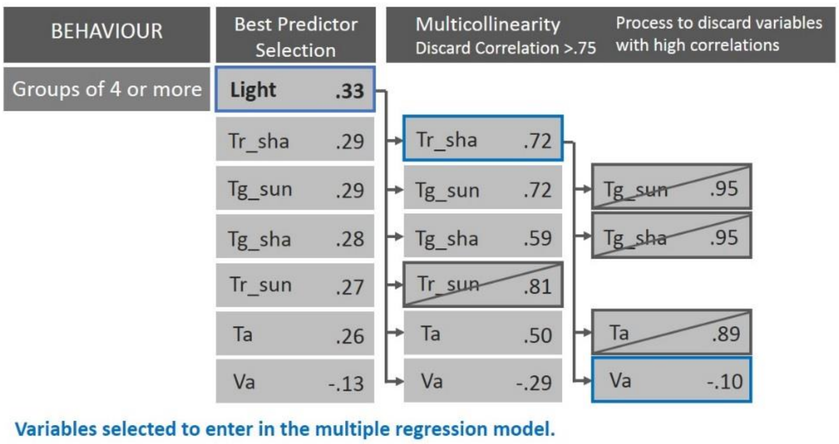


Figure 145 - Diagram of the variables selected to predict Number of Groups of G4more - All-seasons.

Table 124 presents the summary of the regression models. A low percentage of prediction of the variables to estimate the presence of groups of G4more was observed, being 9% the highest. The simple correlation and adjusted R2 increased by adding the mean radiant temperature in the shadow and wind speed. Therefore model 3 was selected to predict Number of Groups of G4more.

Table 124 – Regression model summary to predict Number of Groups of G4more

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the	Change Statistics				
					R Square	F	df1	df2	Sig. F
1	.2	.07	.07	.77	.07	179.87	1	227	.000
2	.2	.08	.08	.77	.01	26.80	1	227	.000
3	.3	.10	.09	.76	.01	28.72	1	227	.000

a. Predictors: (Constant), Light

b. Predictors: (Constant), Light, Tr_Sha

c. Predictors: (Constant), Light, Tr_Sha, Va

d. Dependent Variable: G4more

Table 125 presents the coefficients to predict Number of Groups of G4more. The unstandardized b-value (B) was used to create the equation to predict the presence of G4more. The t-test (t) confirmed the significant contribution of the variables to the model, but also showed that the most important contributor was the mean radiant temperature in the shadow (t (2275) = 5.91, p < .001) and not light (t (2275) = 4.61, p < .001) which was the best predictor in the analysis run at the beginning.

Table 125 - Coefficients of the regression model to predict Number of Groups of G4more

Coefficients[a]

Model		Unstandardized		Standardiz	t	Sig.	95.0% Confidence	
		B	Std. Error	Beta			Lower	Upper
3	(Constan	.191	.04		4.42	.000	.106	.276
	Light	.000026	.00	.13	4.61	.000	.000015	.000038
	Tr_Sha	.017	.00	.17	5.91	.000	.011	.022
	Va	-.106	.02	-.11	-5.36	.000	-.145	-.067

a. Dependent Variable: G4more

Equation 19 is the outcome of the multiple regression model conducted. It is observed that light and mean radiant temperature in the shadow are making a positive contribution, while wind speed presents a negative coefficient.

Equation 19 - Model to predict Number of Groups of G4

$$Number\ of\ Groups\ of\ G4 = b_0 + b_1 Light + b_2 Tr_{sha} + b_3 Va$$

$$Number\ of\ Groups\ of\ G4 = 0.191 + (0.00003 * Light) + (0.017 * Tr_{sha}) + (-0.106 * Va$$

Validation of the Model to Predict Groups of four or more people (G4more)

The internal cross-validation of the model was conducted using the 40% of data reserved. Figure 146 presents the scatter plot of the Predicted Number of Groups of G4more and the observed *Number of Groups of G4*. It is observed that the model underestimates high occupancies, since the observations recorded presences of up to 6 groups of G4more at the same time in the square, while the prediction did not reach values higher than 2.

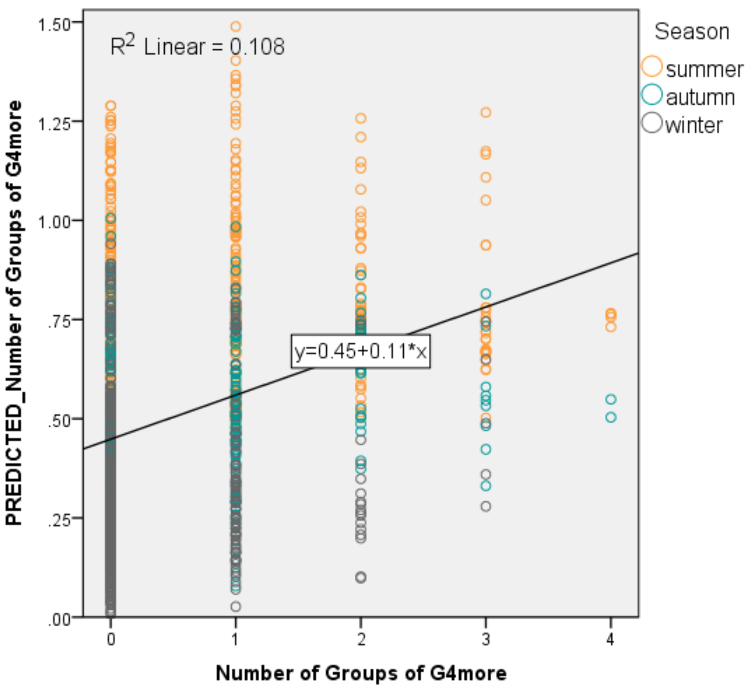


Figure 146 – Predicted Number of Groups of G4more and Number of Groups of G4more

Table 126 presents the simple correlation between the predicted and the observed data. The result suggests a weak relationship between both variables, r = .33, p < .001.

Table 126 - Correlation between Predicted Number of Groups of G4more and Number of Groups of G4more.

Correlations (N = 1501)

		PREDICTED_	G4more
PREDICTED_G4	Pearson Correlation	1	.33**
	Sig. (2-tailed)		.000
G4more	Pearson Correlation	.33**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

In conclusion, the Number of Groups of G4more was influenced by the calculated mean radiant temperature in the shadow, illuminance and wind speed. The model built accounted for the 9% of the variance of the Number of Groups of G4more (Table 124). The internal cross-validation indicated a weak relationship (r = .33) between the prediction and the observed Number of Groups of G4more.

Multiple Regressions - Number of People and Groups: Key Findings

- **Number of People** was influenced by the **globe temperature_sun**, **wind speed** and **light.** 39% of the variance was explained by this model:

$$Number\ of\ People = 4.744 + (0.804 * Tg_{sun}) + (-2.405 * Va) + (0.0005 * Light)$$

- **Number of G1** were influenced by the **globe temperature_sun**, **light** and **wind speed**. The model accounted for 23% of the variance of this behaviour:

$$Number\ \ G1 = 2.307 + (0.207 * Tg_{sun}) + (0.0001 * Light) + (-0.451 * Va)$$

- **Number of G2** was influenced by the **globe temperature_sun**, **light** and **wind speed**. The model explained 30% of the variance of this behaviour.

$$Number\ of\ G2 = 0.614 + (0.176 * Tg_{sun}) + (-0.475 * Va) + (0.00007 * Light)$$

- **Number of G3** were influenced by the **globe temperature_sun and wind speed**. The model accounted for 13% of the variance of this behaviour.

$$Number\ of\ Groups\ of\ G3 = 0.168 + (0.053 * Tg_{sun}) + (-0.175 * Va)$$

- **Number of G4more** were influenced by the **light, mean radiant temperature_shadow and wind speed**. The model accounted for 9% of the variance.

$$Number\ of\ G4 = 0.191 + (0.00003 * Light) + (0.017 * Tr_{sha}) + (-0.106 * Va)$$

8.4.3. Individual Behaviour

As mentioned in the previous chapters of human behaviour during summer, autumn and winter, the analysis of the behaviour was divided in Social and Individual Behaviour. The results of the Social Behaviour were described in the previous section and this section will be focused on the individual actions of the users. The total sample was 5330 people which consisted in all the individuals who chose to remain in the square and whose entrance and exit was recorded by the video camera. The sample consisted of 89% adults (56% men and 44% women), 4% teenagers, 4% children, 1% babies and 2% mobility reduced users.

The behaviour analysed per person were: Time of Permanence, Body Posture (main posture analysis), Adaptive Behaviour and Activities. This section will describe the results obtained by compiling the data from the three seasons.

8.4.3.1. Survival Analysis

The *Time of Permanence* is the period of time users remained in the square. This behaviour was evaluated by using survival analysis *Kaplan-Meier* estimator, which is a non-parametric technique to obtain the cumulative survival curve of the behaviour according to the influence of one of the environmental variables. This method of analysis was used in the previous chapters of the seasonal studies conducted in summer, autumn and winter. Table 127 contains the descriptive statistics of the *Time of Permanence* over the three seasons. A mean of 8.3 minutes is observed with a standard deviation of 7.8 minutes, indicating a high variability of the time people remained in the square.

Table 127 - Frequencies of Time of Permanence

Statistics

Time of Permanence

N	Valid	5330
Mean		8.3
Median		5.9
Std. Deviation		7.8
Minimum		.3
Maximum		81.4

Time of Permanence and Gender

The first analysis conducted was to evaluate whether there is any difference on the *Time of Permanence* of users according to their gender. Table 128 shows that the estimated mean *Time of Permanence* for men was 8.3 minutes, and 8.4 minutes for women. The median, which corresponds to the time when 50% of the users left the square, was 5.7 minutes for men and 6.1 minutes for women.

Table 128 - Means and Medians of survival time according to Gender - All-seasons

Means and Medians for Survival Time

	Mean[a]				Median			
			95% Confidence Interval				95% Confidence Interval	
Gender	Estimate	Std. Error	Lower Bound	Upper Bound	Estimate	Std. Error	Lower Bound	Upper Bound
Male	8.3	.1	8.0	8.6	5.7	.1	5.4	6.0
Female	8.4	.2	8.1	8.7	6.1	.1	5.8	6.4
Not Known	8.0	2.6	2.9	13.2	8.2	4.4	.0	16.8
Overall	8.3	.1	8.1	8.5	5.9	.1	5.7	6.1

a. Estimation is limited to the largest survival time if it is censored.

Figure 147 presents the survival curve of *Time of Permanence* for men and women. The y-axis of the graph represents the survival probability, where 1 is the survival of 100% of the users. The x-axis correspond to the *Time of Permanence*, as soon as the time increases, the cases of users leaving the square start to appear creating the survival curve. In the case of gender, it is observed that the time of permanence during all the seasons was almost identical.

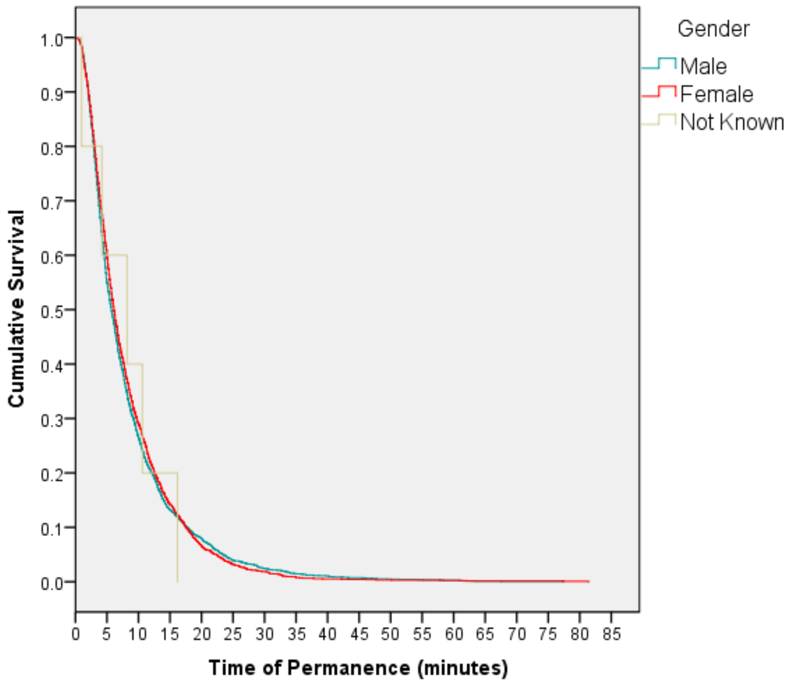


Figure 147 – Survival function Time of Permanence according to Gender

Time of Permanence and Environmental Factors

With the aim of analysing the influence of the environmental variables in the Time of Permanence of the users, an evaluation per variable was conducted. This section presents the results that evidenced the influence of the thermal environment over the time of permanence. Therefore, not all the independent variables will be displayed.

To conduct the survival analysis, pre-processing of the data was necessary to bin the results so they could be visualised by ranges (e.g. globe temperature was binned every 1°C, so the survival curves are plotted at 8.1 - 9.0°C, 9.1 - 10.0°C, 10.1 – 11.0°C, etc.). This was conducted in accordance to the procedure done by Haldi & Robinson (2009).

The globe temperature in the shadow presented a positive relationship with the Time of Permanence, as the time users remained increased when the globe temperature in the shadow increased. Figure 148 presents the survival curve of these two variables. The colour scale allows to visualise the data from the highest temperatures (magenta and red curves) to the lowest temperatures (blue and grey curves). It is observed that up to 0.1 of cumulative survival, 90% of the people, had longer Time of Permanence in highest temperatures, as the red and magenta curves are less steep until this point. From this point in time, all the curves merge, so there is no difference in the influence of the Globe Temperatures in the shadow over the permanencies of people.

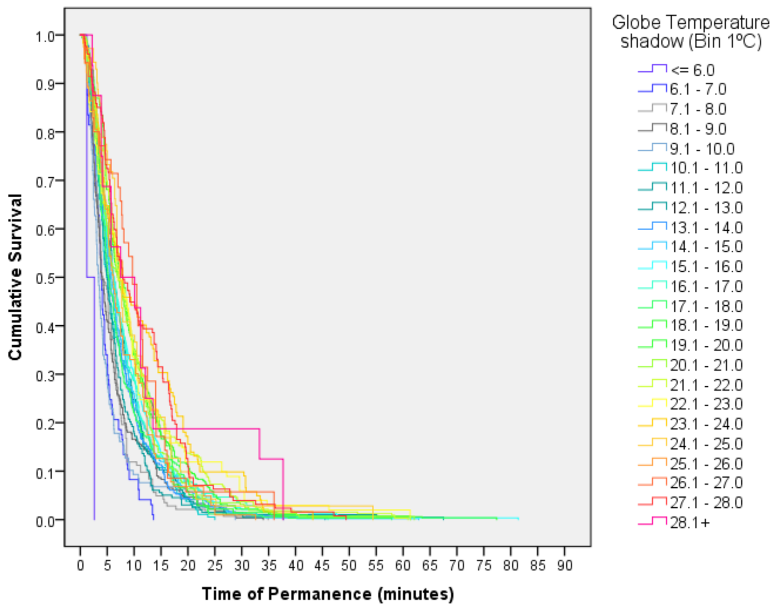


Figure 148 - Survival function Time of Permanence and globe temperature in the shadow (binned at 1ºC)

The general results of the means and medians are presented on Table 129. This table details the mean time for each grade centigrade of globe temperature between 6ºC and 28ºC. In the same way, it provides the mean time at which 50% of the people decided to leave the place (both highlighted in blue). It is observed that the mean and median increases as the temperature increases, with exception of a few cases: 9ºC, 17ºC, 24ºC and 25ºC where the result did not follow this pattern.

Table 129 - Means and Medians of the survival time according to the globe temperature in the shadow - All-seasons

Means and Medians for Survival Time

Globe Temperature shadow (Bin 1ºC)	Mean[a]				Median			
	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
<= 6.0	1.9	.7	.5	3.3	1.2	.	.	.
6.1 - 7.0	4.6	.3	4.0	5.3	3.9	.2	3.6	4.2
7.1 - 8.0	5.8	.4	5.0	6.6	4.0	.5	3.1	4.9
8.1 - 9.0	6.2	.4	5.5	6.9	4.1	.2	3.7	4.5
9.1 - 10.0	5.1	.5	4.2	6.1	3.4	.2	2.9	3.8
10.1 - 11.0	6.9	.4	6.1	7.7	4.9	.4	4.1	5.7
11.1 - 12.0	6.8	.5	5.8	7.8	5.0	.3	4.4	5.6
12.1 - 13.0	7.8	.4	7.0	8.6	6.1	.4	5.4	6.8
13.1 - 14.0	7.4	.3	6.8	8.1	5.5	.3	4.9	6.1
14.1 - 15.0	8.0	.3	7.4	8.5	5.7	.3	5.2	6.2
15.1 - 16.0	8.7	.4	8.0	9.4	6.2	.3	5.6	6.8
16.1 - 17.0	8.5	.4	7.8	9.2	6.2	.4	5.5	6.9
17.1 - 18.0	7.6	.4	6.8	8.3	5.3	.3	4.6	6.0
18.1 - 19.0	9.3	.6	8.1	10.6	7.1	.9	5.4	8.8
19.1 - 20.0	9.5	.4	8.8	10.3	7.1	.4	6.4	7.8
20.1 - 21.0	9.0	.5	8.1	9.8	6.9	.6	5.6	8.2
21.1 - 22.0	10.5	.5	9.4	11.5	7.7	.4	6.9	8.5
22.1 - 23.0	10.5	1.1	8.3	12.7	7.1	1.0	5.2	9.0
23.1 - 24.0	11.5	.9	9.8	13.2	7.9	1.1	5.7	10.1
24.1 - 25.0	10.4	1.1	8.2	12.6	7.4	.4	6.7	8.1

25.1 - 26.0	8.1	.6	6.8	9.3	6.1	.5	5.1	7.1
26.1 - 27.0	10.5	1.4	7.8	13.2	9.7	1.4	6.9	12.5
27.1 - 28.0	11.3	.8	9.7	12.9	7.9	1.0	5.9	9.9
28.1+	12.6	3.1	6.6	18.6	7.5	4.4	.0	16.1
Overall	8.3	.1	8.1	8.5	5.9	.1	5.7	6.1

a. Estimation is limited to the largest survival time if it is censored.

The wind speed also influence the *Time of Permanence*. Figure 149 corresponds to the survival curves of the time people remained in the square according to the wind speed. It is observed that the cyan and green curves which are wind velocities ranging from 0.001 m/s to 2 m/s, presented the longest *Time of Permanence*. It was observed that as the wind speed increased over 2 m/s the time of permanence was reduced considerably, and over 3 m/s and 4 m/s it was further reduced, being almost null for wind speeds above 4 m/s.

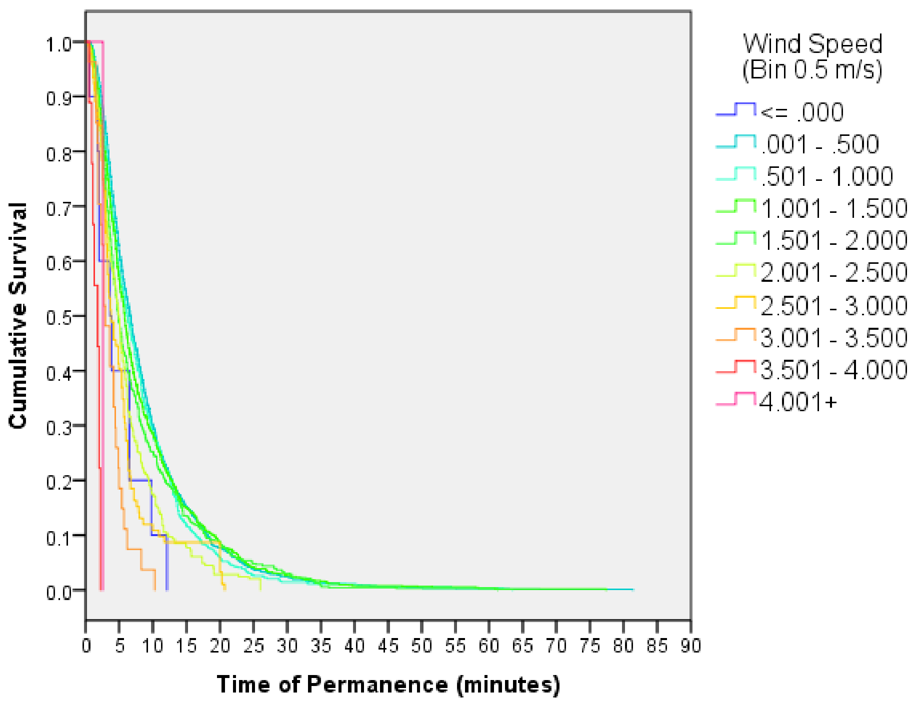


Figure 149 - Survival function Time of Permanence and Wind Speed

Table 130 contains the means and medians of the *Time of Permanence* according to the wind speed. This table details for how long people accepted to stay under each condition between 0 and 4 m/s of wind speed. It is observed that as the wind speed decreased the *Time of Permanence* increased. The only exception to this pattern was at 0 m/s.

Table 130 - Means and Medians of the survival time according to the wind speed - All-seasons

Means and Medians for Survival Time

	Mean[a]				Median			
			95% Confidence Interval				95% Confidence Interval	
Wind Apeed (Bin 0.5 m/s)	Estimate	Std. Error	Lower Bound	Upper Bound	Estimate	Std. Error	Lower Bound	Upper Bound
<= .000	4.9	1.2	2.5	7.2	3.6	1.5	.7	6.6
.001 - .500	8.9	.2	8.5	9.2	6.7	.2	6.3	7.0
.501 - 1.000	8.3	.2	7.8	8.8	6.2	.3	5.7	6.7
1.001 - 1.500	8.5	.3	8.0	9.0	5.8	.2	5.5	6.1
1.501 - 2.000	7.9	.3	7.3	8.5	4.9	.2	4.5	5.2
2.001 - 2.500	6.3	.3	5.6	6.9	5.0	.2	4.5	5.5
2.501 - 3.000	5.6	.5	4.6	6.6	3.8	.5	2.9	4.7
3.001 - 3.500	3.7	.4	2.8	4.5	2.9	.5	1.9	3.9
3.501 - 4.000	1.6	.2	1.1	2.0	1.8	.7	.3	3.3
4.001+	2.6	.0	2.6	2.6	2.6	.	.	.
Overall	8.3	.1	8.1	8.5	5.9	.1	5.7	6.1

a. Estimation is limited to the largest survival time if it is censored.

8.4.3.2. Body Postures Analyses

The postural analysis was conducted by analysing the main body posture of each person. The main posture was defined as the posture adopted for most of the time. For the postural analysis, the sample of 5330 people was filtered to 5245 people. The cases discarded corresponded to the observations where the researcher was not able to register the postural changes due to visual obstruction. Table 131 presents the frequencies of the main body postures adopted during the three seasons. It is observed that the most popular body posture was sitting standard, followed by standing and leaning. It was created a group of postures called 'other' which included a number of body postures that were also evaluated but did not have a high percentage representation (jogging/running, sitting with the legs extended, laying down, sitting with backrest, jumping, carried, kneeling, squat, skating, biking, climbing and wheel chair/pram); this group corresponded to 3.5% of the total sample of main body postures.

Table 131 - Descriptive statistics of the Main Body Postures

Main Body Postures		
	Frequency	Percent
sitting standard	3364	64.1
standing	1084	20.7
leaning	379	7.2
walking	188	3.6
other	186	3.5
lotus	44	.8
Total	5245	100.0

Body Postures and Gender

The first analysis conducted was to evaluate whether there was any difference on the Time of Main Posture according to the gender. The cumulative curves of the different body postures did not present substantial differences between men and women (Appendix 5), with exception of the leaning and lotus posture. Figure 150 presents the cumulative survival curve for men and women when their main posture was leaning and sitting lotus. Women presented a longer time of permanence than men in the posture lotus, whilst men had a longer time of permanence than women in the posture leaning. It is observed that both curves presented a time difference of around 4 minutes.

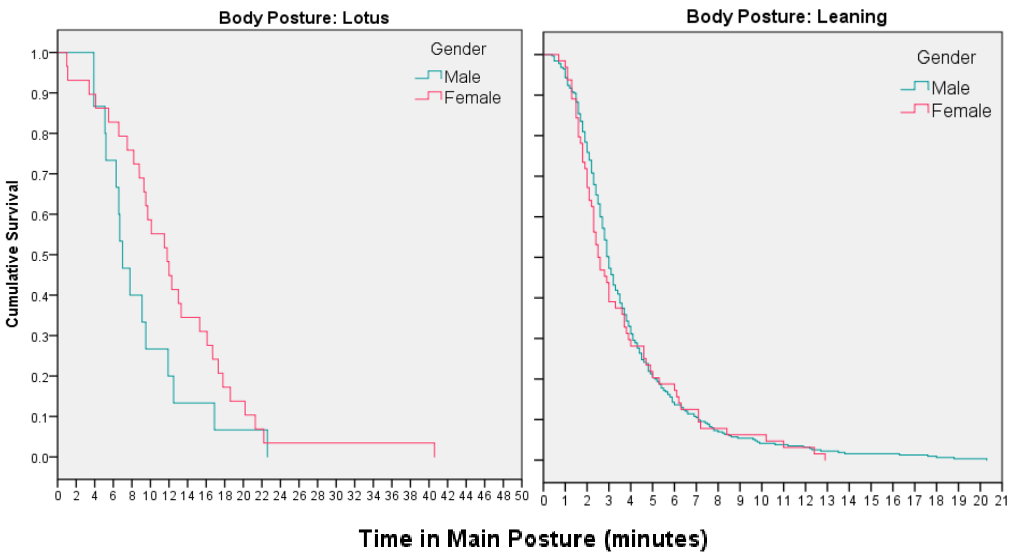
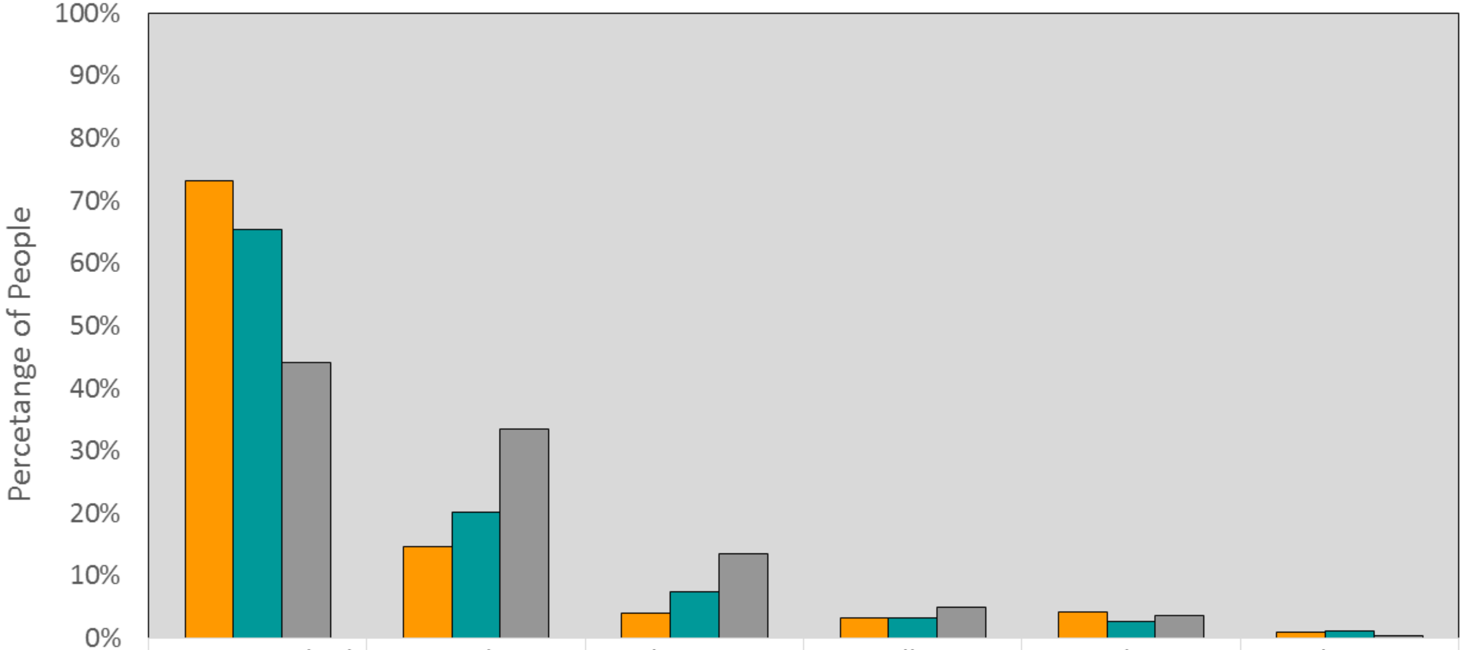


Figure 150 - Cumulative survival curve of Time Leaning and lotus according to the gender

Body Postures and Environmental Factors

Figure 151 presents the percentage distribution of the main body posture adopted across the seasons. Sitting standard was the most popular posture during the three seasons, with a higher percentage of occurrence during summer (73%). Standing, leaning and walking presented a higher percentage of occurrence during winter. The occurrence of postures such as lotus or other seemed to be similar over the three seasons.



	sitting standard	standing	leaning	walking	other	lotus
Summer	73.2%	14.7%	3.9%	3.2%	4.1%	0.9%
Autumn	65.3%	20.2%	7.4%	3.3%	2.7%	1.1%
Winter	44.1%	33.5%	13.5%	4.9%	3.6%	0.4%

Figure 151 – Percentage distribution of Main Posture per season

This section presents a survival analysis using the *Kaplan-Meier* estimator to identify the influence of the environmental variables on the *Time in Main Posture*. The body postures considered in this analysis were: sitting standard, standing, leaning, walking, lotus and other. The method consisted of analysing each posture and their relationship with the environmental variables. This section presents the results that showed a pattern in the cumulative curves indicating an influence of the environment in the body posture. The complete cumulative curves graphs are presented in the appendix section.

Sitting standard and standing were the only postures where it was observed a relationship with some of the environmental variables. Sitting standard presented relationship with globe temperature in the shadow, mean radiant temperature in the shadow, wind speed and light. Standing presented a relationship with the wind speed.

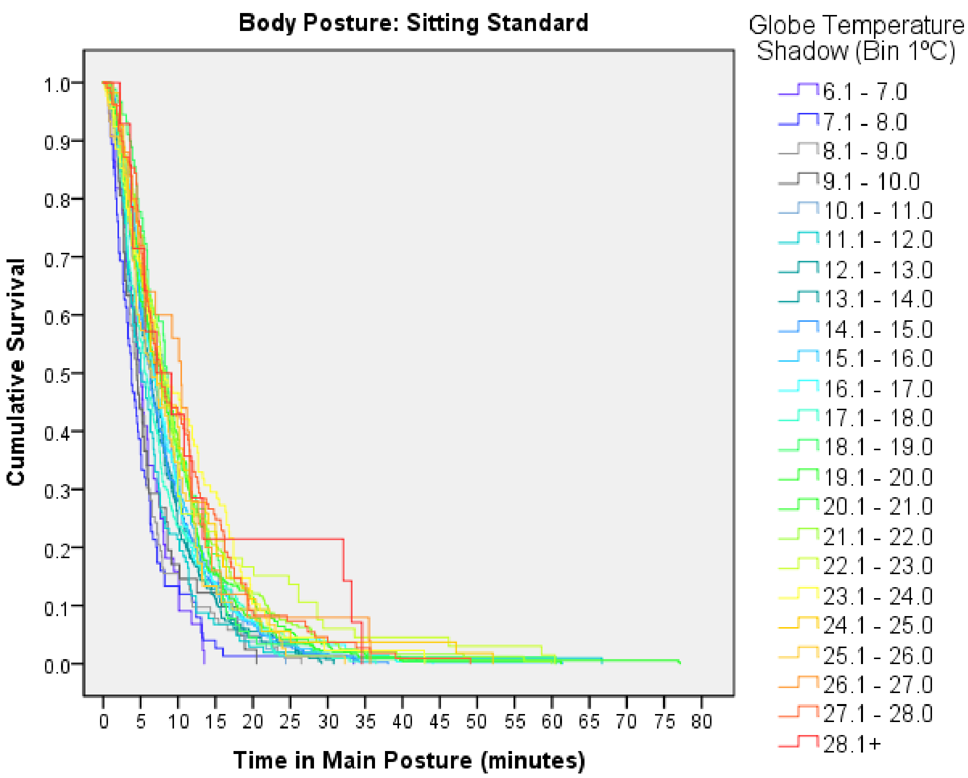


Figure 152 - Survival function Time Sitting according to the globe temperature in the shadow

Figure 152 presents the cumulative survival curve of the time adopting the posture sitting standard and the globe temperature in the shadow. The red, orange and yellow curves representing the highest temperatures (between 23ºC and 28ºC) presented some of the longest times sitting. However, the longest time sitting was achieved at 19ºC.

The mean radiant temperature in the shadow also presented a relationship with the time in the posture sitting standard. Figure 153 contains the cumulative survival curves, in this analysis is observed that the grey curves which represent temperatures between 5ºC and 15ºC presented the shortest time sitting. The green curves corresponding to the highest temperatures presented short time sitting between 40ºC and 45ºC, but the longest time sitting were observed in the other highest temperatures (between 30ºC and 40ºC).

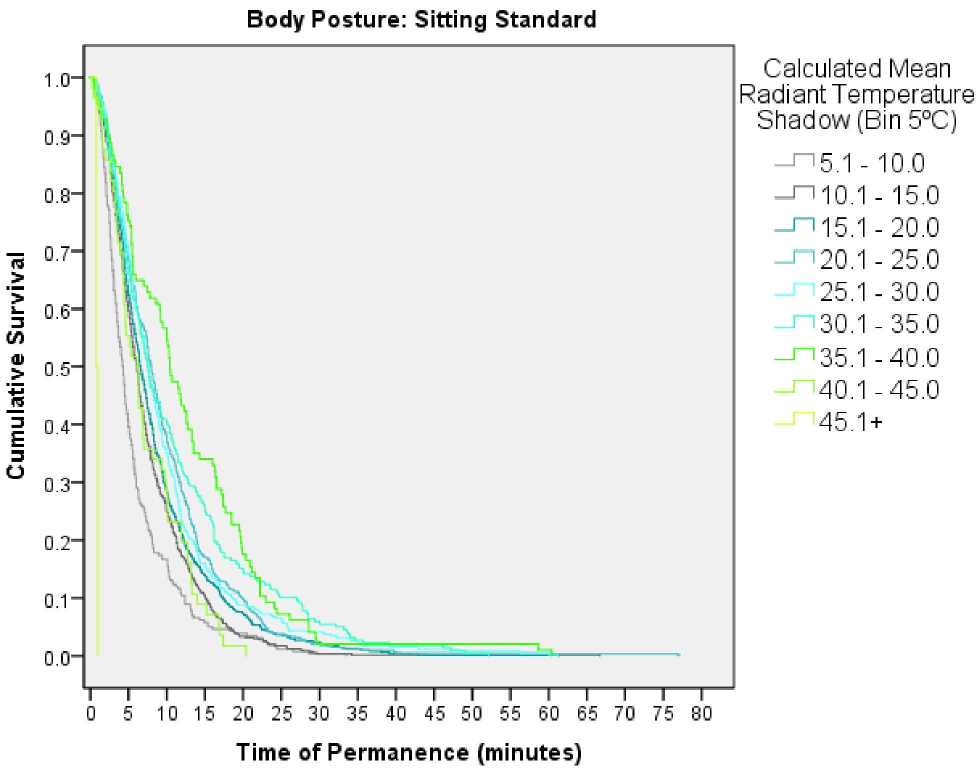


Figure 153 - Survival function Time Sitting according to the mean radiant temperature in the shadow

Similarly, the light presented the longest times sitting in some of the highest light level; with exception of the top measurements (between 15,000 lx and 17,000 lx) which presented the shortest times sitting (Figure 154). Despite the data being spread, it can be observed a tendency of the green curves presenting longest permanencies than the dark blue curves.

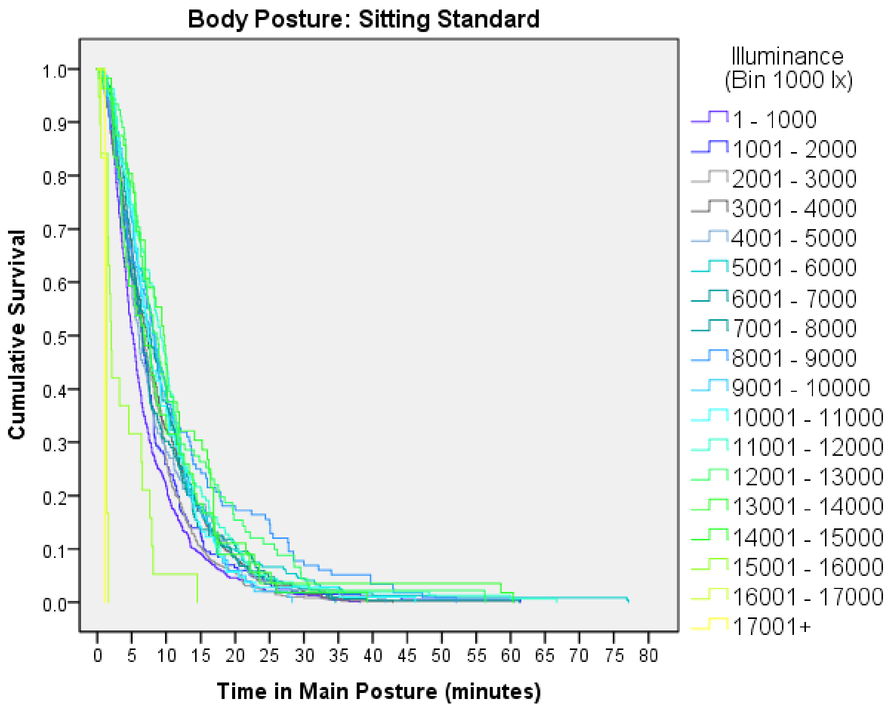


Figure 154 - Survival function Time in the Posture according to the illuminance

Figure 155 correspond to the cumulative curves of sitting posture and wind speed. This shows a homogeneous behaviour of the curves between 0.001 m/s and 2 m/s, meaning that the time sitting did not vary much under this condition. Additionally, the time sitting between 0.001 m/s and 2 m/s was the longest. As soon as the wind speed increased over 2 m/s the time sitting was reduced.

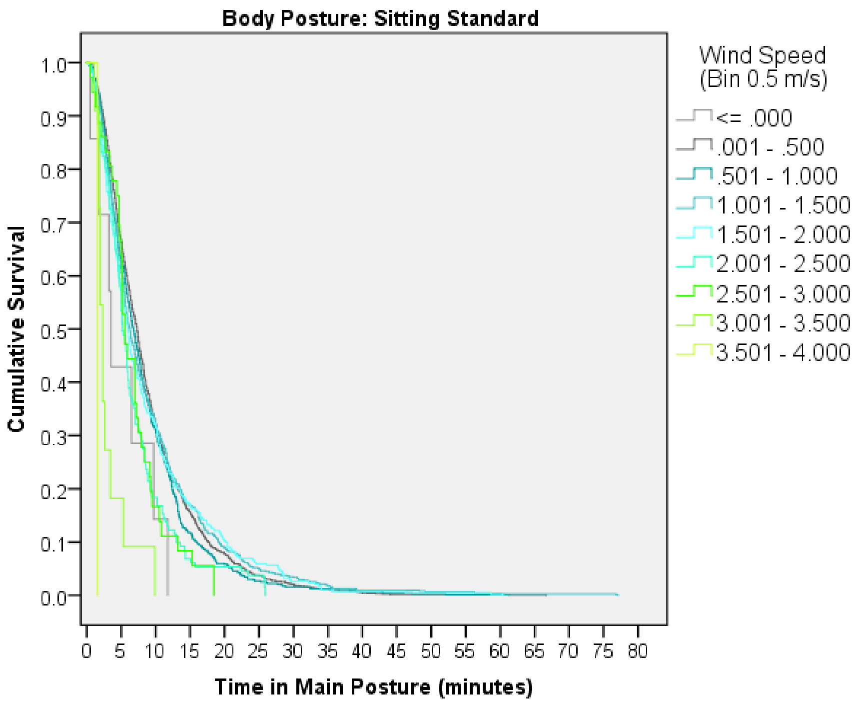


Figure 155 -Survival function Time Sitting according to the wind speed

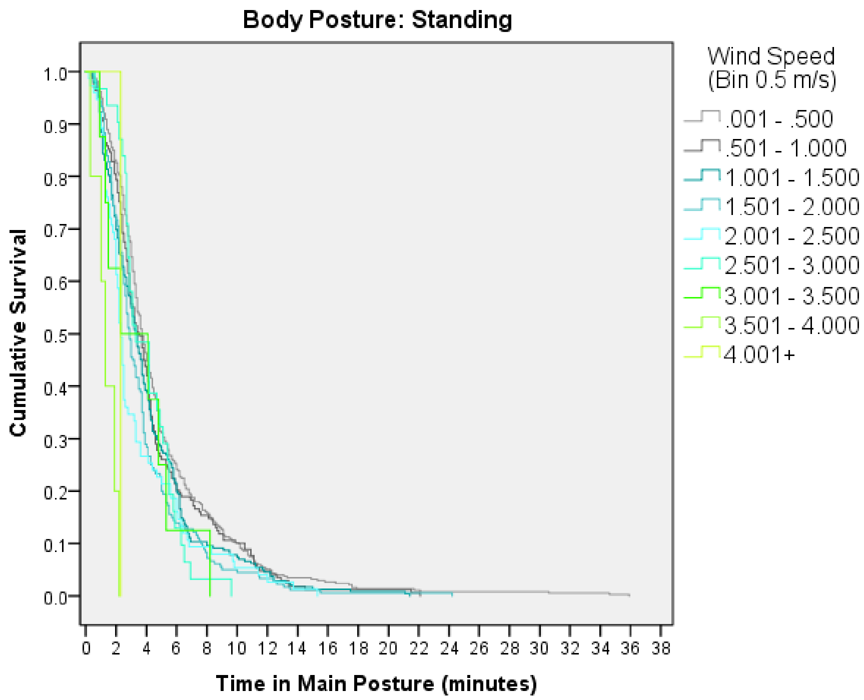


Figure 156 - Survival function Time Standing according to the wind speed

8.4.3.3. Activities

The activities were the actions users performed while being in the square. They were identified during the data collection and later recorded during the observational analysis as point events. The activities were recorded as point events in order to analyse their frequency of occurrence and the environmental conditions that allowed or motivated its occurrence. The duration was not recorded since most of the activities were intermittent behaviours without a clear beginning or end. The occurrence of the activity was recorded once per user.

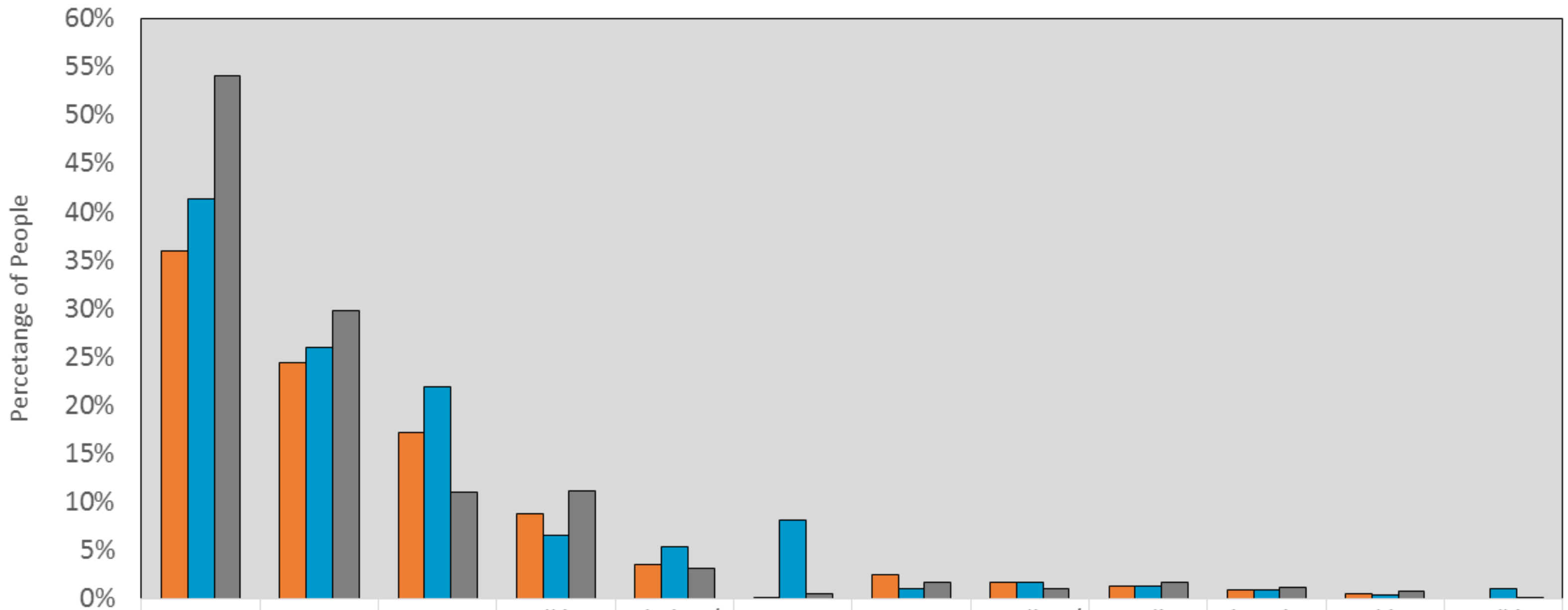
The activities selected for this analysis were: feeding pigeons, playing, reading/writing, exercising, smoking, eating, using a device, talking by mobile, kissing/hugging, listening music, taking photos, walking a dog. These were selected as they were the most frequent activities performed by users. Some activities such as chatting or staring where not recorded as they were performed most of the time. Table 132 presents the list of activities and the total number of times they were observed.

Table 132 - Sum of activities observed

Activities	*Sum*
feeding pigeons	77
playing	96
reading/writing	84
exercising	160
smoking	2222
eating	936
using a device	1390
talking by mobile	453
kissing/hugging	219
listening music	53
taking photos	29
walking a dog	22

Figure 157 presents the percentage distribution of the activities according to the season. It is observed that smoking was the principal activity performed in the square. It must be however noted that smoking was 54% of the activities registered in winter, whilst in summer smoking was only 34%. Similarly, using a device was more popular over winter than summer and autumn. On the other hand, eating accounted for a larger proportion of the activities during autumn, as it was kissing/hugging, exercising and walking a dog. Playing, reading, feeding pigeons, listening music and taking photos did not present differences on the percentage of occurrence over the seasons.

In order to analyse the influence of the environmental over the most popular activities (smoking, using a device and eating), it was performed an analysis of the sum of occurrence according to each environmental variable. The environmental data was binned using the same bin sizes described in previous chapters. The results that presented a pattern indicating a relationship between the environment and activities are displayed below.



	Smoking	Devicing	Eating	Talking Mobile	Kissing / Hugging	Exercising	Playing	Reading / Writing	Feeding Peagons	Listening Music	Taking Photos	Walking Dog
Summer	36%	24%	17%	9%	4%	0%	2%	2%	1%	1%	1%	0%
Autumn	41%	26%	22%	7%	5%	8%	1%	2%	1%	1%	0%	1%
Winter	54%	30%	11%	11%	3%	1%	2%	1%	2%	1%	1%	0%

Figure 157 - Percentage distribution of activities according to the three seasons

Smoking

According to Table 132, smoking was the most frequent activity performed in the square. This presented relationships with the wind speed, mean radiant temperature in the sun and light.

Figure 158 presents the sum distribution of people smoking according to the wind speed. The highest occurrence of this behaviour was at 0 m/s and it decreased as the wind speed increased. It is observed that the tolerance to high wind speed was greater during winter, as the number of occurrences slowly reduced.

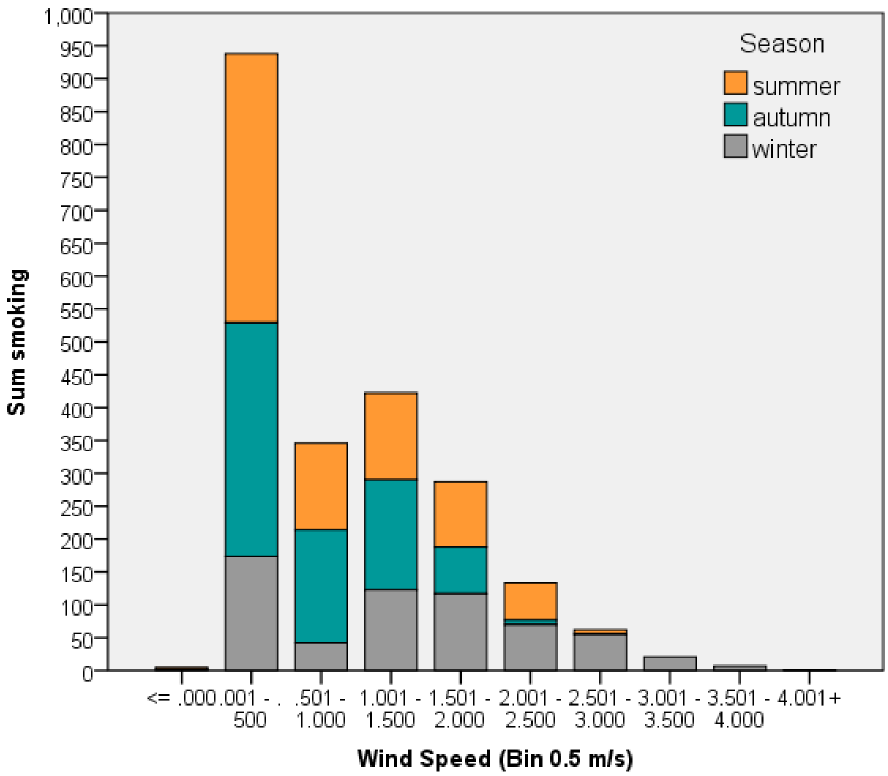


Figure 158 - Sum distribution of people smoking according to the wind speed

Figure 159 presents the sum of people smoking according to the mean radiant temperature in the sun. It is observed a registration of smokers between 15ºC and 20ºC and the highest proportion occurred during autumn. The highest proportion of people smoking between 5ºC and 10ºC and this proportion was reduced as the temperature increased. Over 25ºC the sum of people smoking decreased as the temperature increased.

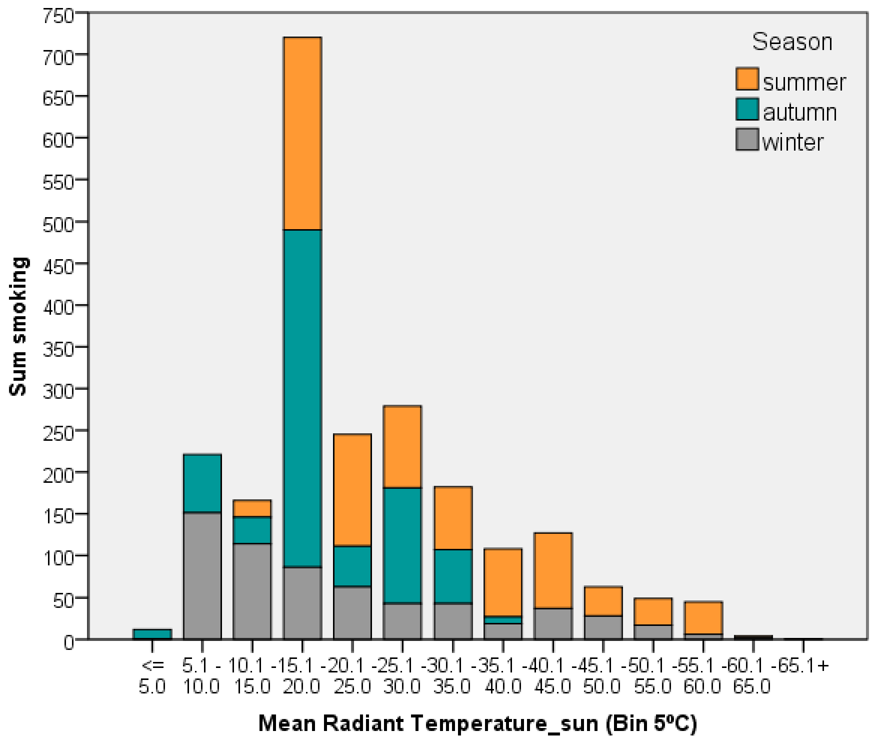


Figure 159 – Sum distribution of people smoking according to the mean radiant temperature in the sun

Figure 160 presents the distribution of the sum of people smoking according to the light level. The tendency of the chart indicates that as the light increased the activity of smoking occurred less.

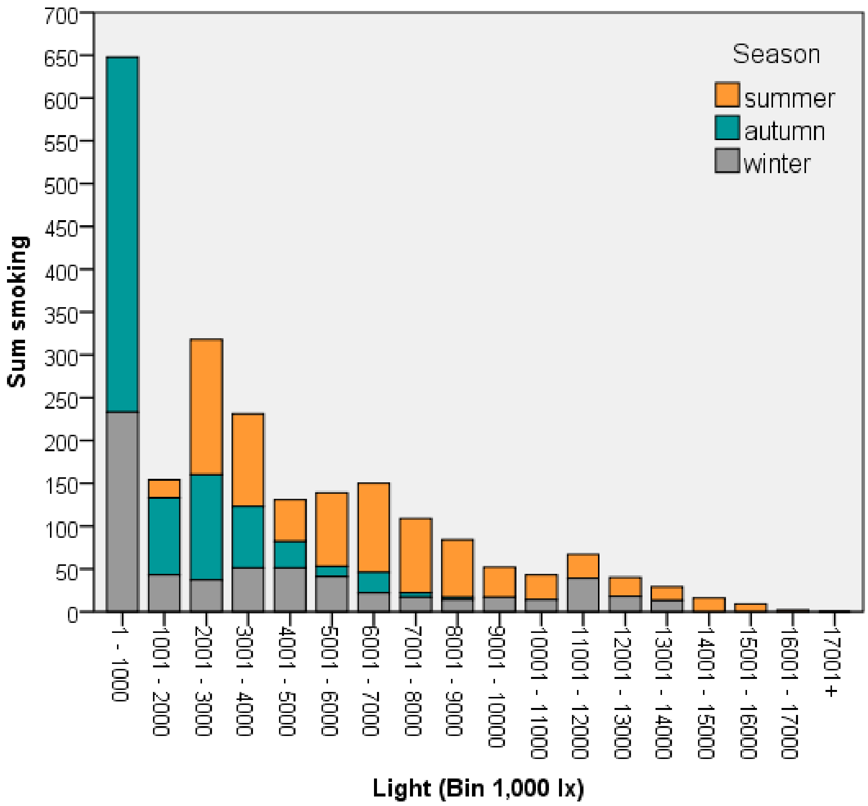


Figure 160 - Sum distribution of people smoking according to the light

Using a Device

According to Table 132, using a device was the second most popular activity. This activity was also influence by the wind speed, mean radiant temperature in the sun and light. The general tendency of the charts present a very similar behaviour to the results obtained for the activity smoking, but with a smaller frequency of occurrence.

Figure 161 presents the sum of people using a device at different wind speed ranges. The highest occurrence of this activity was at 0 m/s and this decreased as the wind speed increased.

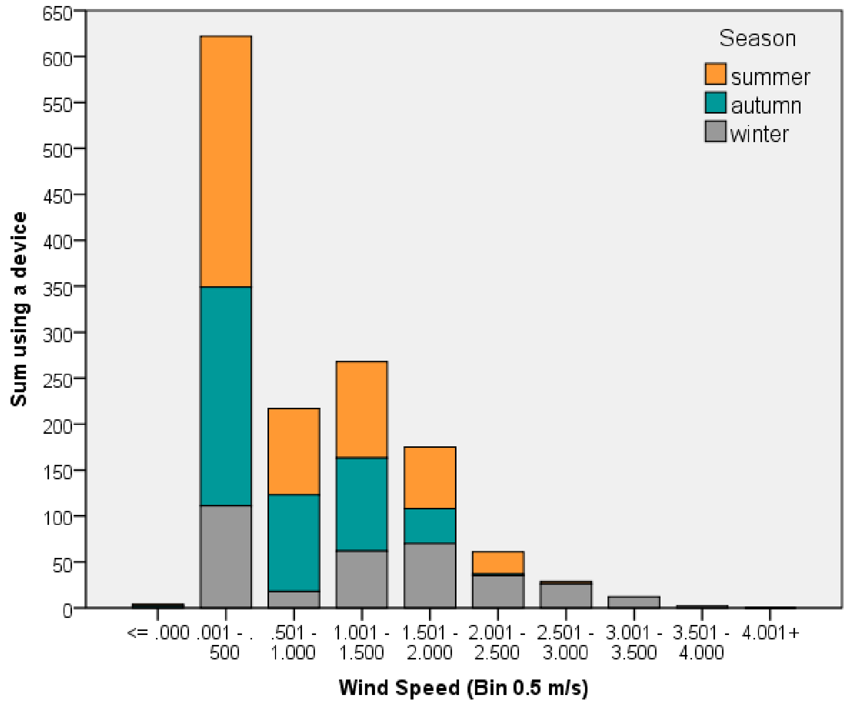


Figure 161 - Sum distribution of people using a device according to the wind speed

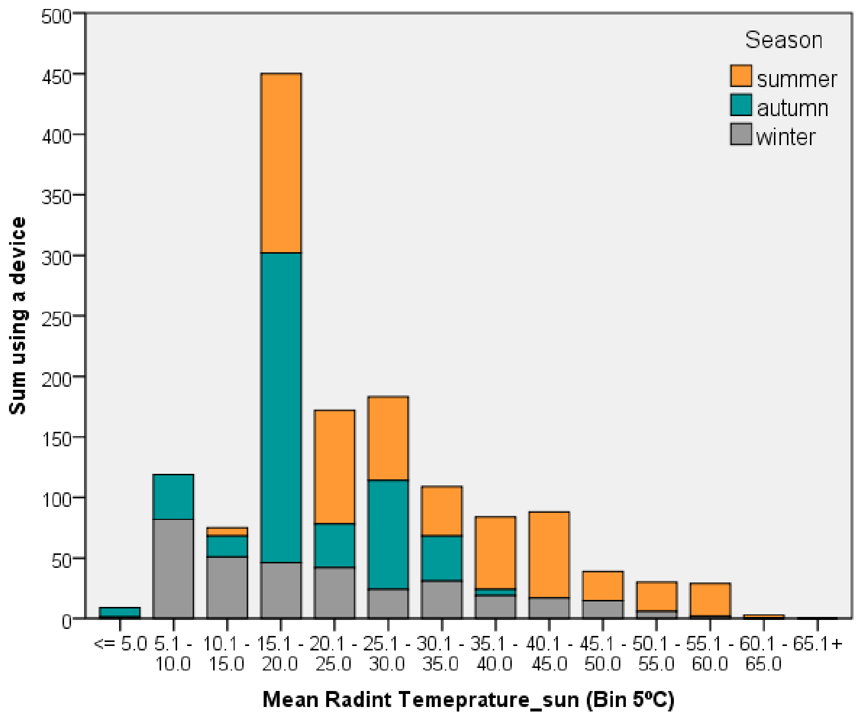


Figure 162 - Sum distribution people using a device according to the mean radiant temperature in the sun

Figure 162 correspond to the sum of people using a device according to the mean radiant temperature in the sun. Most of the data lay in 15ºC to 20ºC, over this temperature the number of people using a device decreased as the temperature increased.

Figure 163 presents the sum of people using a device according to the light level. Similar to the influence of the light over smoking, as the light increased the activity of using a device occurred less.

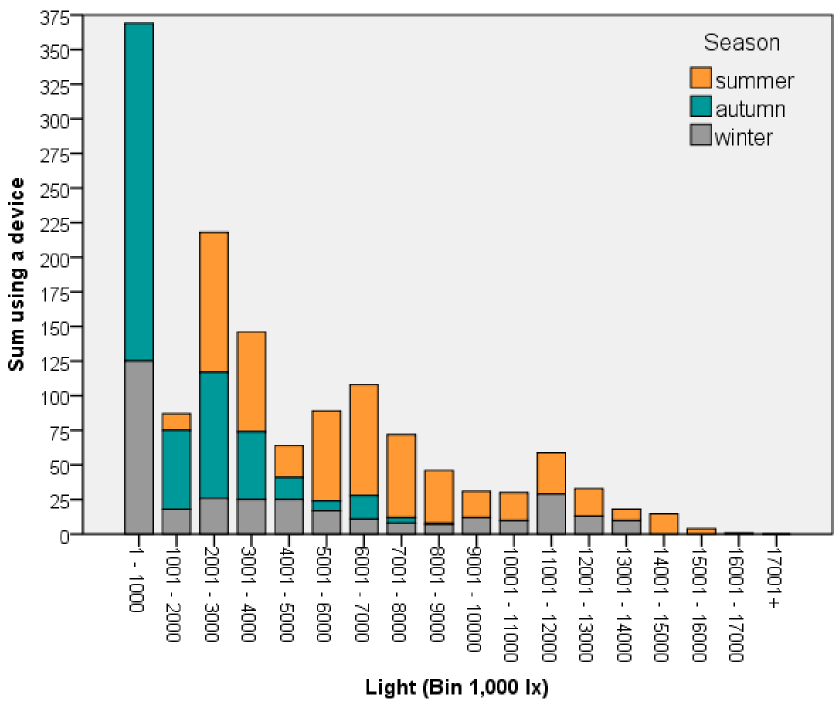


Figure 163 - Sum distribution of people using a device according to the illuminance

Eating

Figure 164 presents the sum of occurrence of people eating according to the wind speed. It is observed that the number of cases during winter is low in comparison to autumn and summer. The tendency shows that as the wind speed increased the number of occurrence of the activity eating decreased.

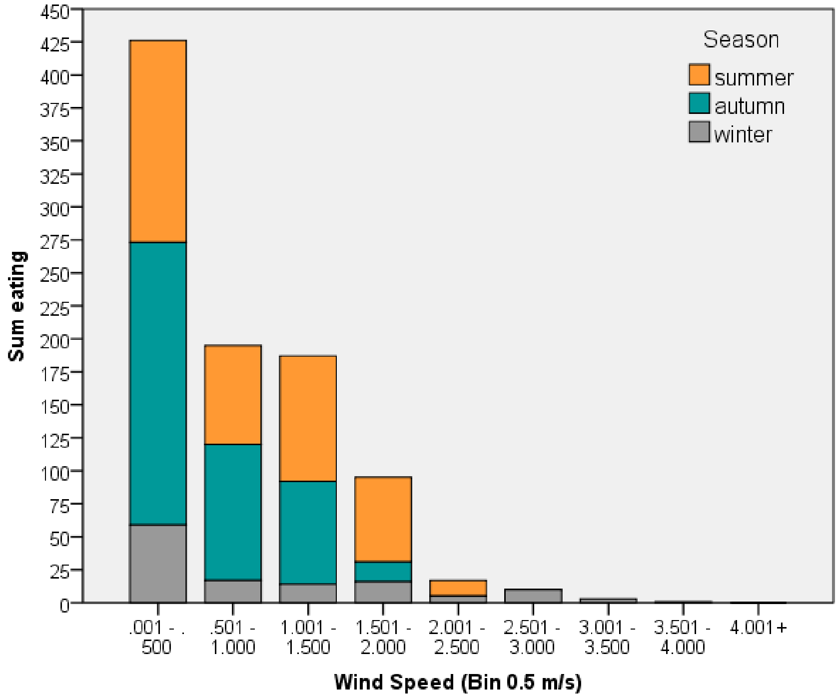


Figure 164 - Sum distribution of people eating according to the wind speed

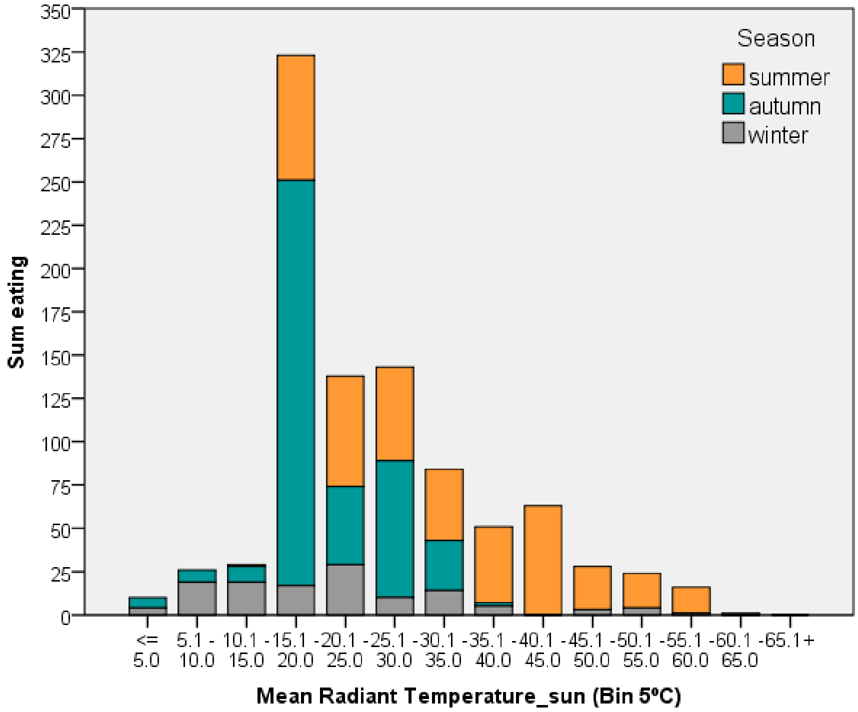


Figure 165 - Sum distribution people eating according to the mean radiant temperature in the sun

Figure 165 presents the sum of the activity eating according to the mean radiant temperature in the sun. It is observed a low frequency of this behaviour during winter where the number of cases were evenly spread between 5ºC and 35ºC. Similarly the occurrence of people eating during summer occurred between 15ºC and 60ºC without significant variation.

Adaptive Actions

The adaptive actions are the behaviours adopted by the users to improve their thermal conditions. This is based in the 'Adaptive Model' theory: "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" (Fergus et al., 2013, p. 29). This research focused the observational analysis in the adaptive actions of: having a cold or hot drink, adding or removing clothes, adding or removing glasses and relocating. This actions were selected as they were easily identified by observation.

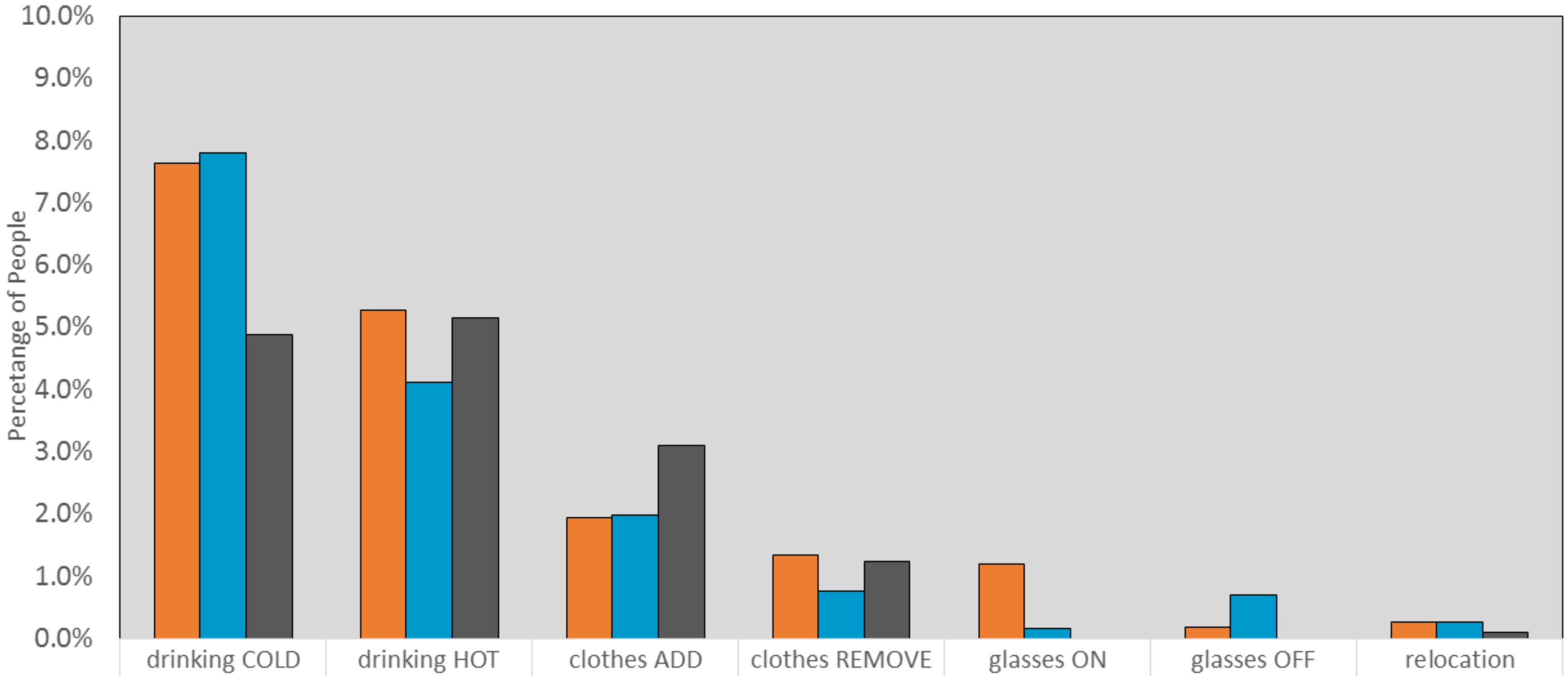
Similar to the activities, the adaptive actions were recorded as point events. This means that the frequency and the environmental conditions at the moment of occurrence were recorded. Table 133 presents the list of adaptive actions and the total number of times they were observed.

Table 133 - Sum of adaptive actions observed

Activities	*Sum*
drinking COLD	379
drinking HOT	258
ADD clothes	117
OFF clothes	59
glasses ON	31
glasses OFF	17
relocation	12

Figure 166 presents the percentage distribution of the adaptive actions according to the three seasons. It is observed that the most common actions were drinking a cold or hot beverage, and they were followed by adding or removing clothes.

Drinking a cold beverage occurred in a similar proportion during summer and autumn, as drinking a hot beverage occurred in a similar proportion during summer and winter. It was observed a higher frequency of adding clothes during winter and removing clothes during summer and winter. The adaptive action of using sun glasses did not occurred during winter.



	drinking COLD	drinking HOT	clothes ADD	clothes REMOVE	glasses ON	glasses OFF	relocation
Summer	7.6%	5.3%	1.9%	1.3%	1.2%	0.2%	0.3%
Autumn	7.8%	4.1%	2.0%	0.7%	0.2%	0.7%	0.3%
Winter	4.9%	5.1%	3.1%	1.2%	0.0%	0.0%	0.1%

Figure 166 - Percentage distribution of Adaptive Actions according to the three seasons

In order to analyse the influence of the environment over the most popular adaptive actions (drinking cold or hot and adding or removing clothes), an analysis of the total occurrence of each action was performed according to each environmental variable. The environmental data was binned using the same bin sizes described in previous chapters. The results that presented a pattern indicating a relationship between the environment and activities are displayed below.

Drinking Cold

Figure 167 correspond to the sum of people drinking a cold beverage in comparison to the wind speed of the place. The behaviour was codified by observing the type of glass containing the liquid and determine if it was a cold or a hot substance. It is observed that the highest frequency of this behaviour was observed at 0 m/s and it decreased as the air velocity increased. During winter the number of people drinking cold beverages did not varied much.

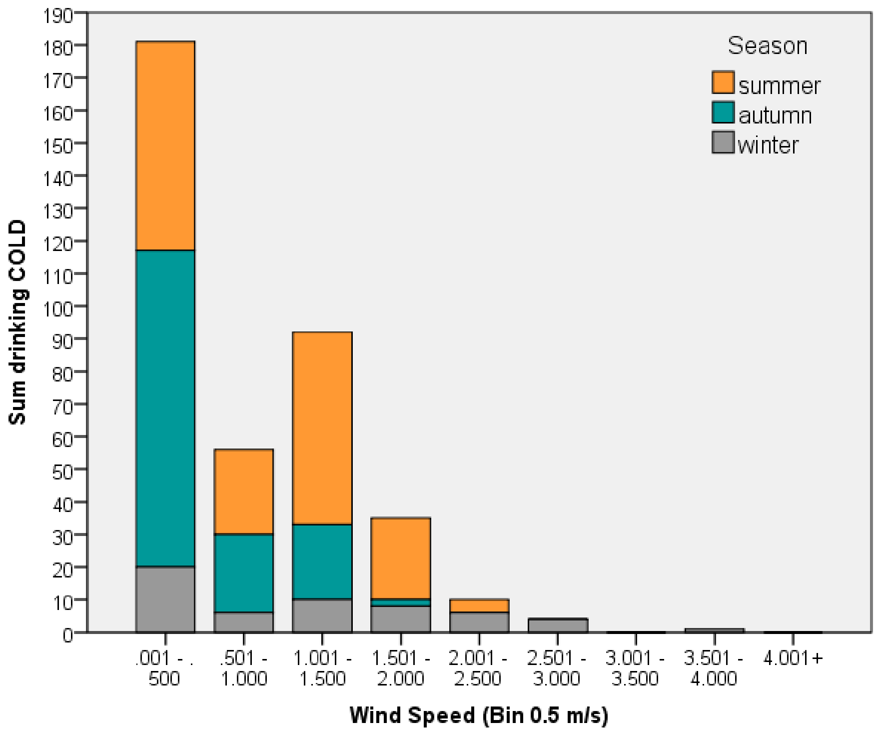


Figure 167 - Sum distribution of people drinking cold beverages according to the wind speed

Drinking Hot

Figure 168 presents the sum of occurrence of drinking hot beverages according to the mean radiant temperature in the shadow. It is observed that the highest occurrence of this behaviour was at 20ºC to 25ºC. However, the data per season suggests that during winter the highest proportion of people drinking a hot beverage occurred at 5ºC to 10ºC.

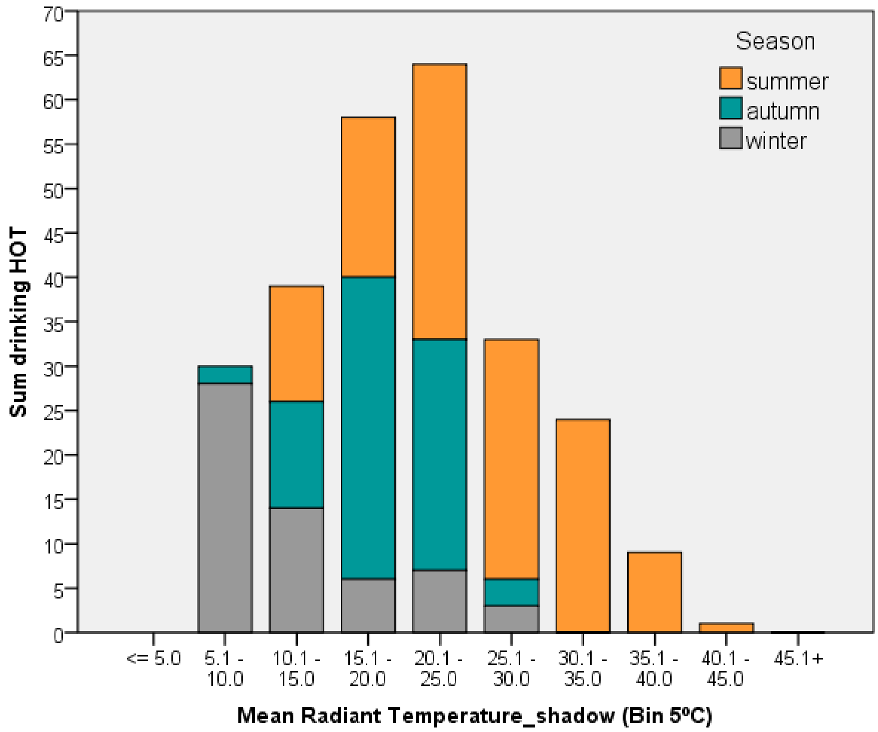


Figure 168 - Sum distribution people drinking hot beverages according to the calculated mean radiant temperature in the shadow

Figure 169 presents the sum of occurrence of drinking hot beverages according to the wind speed. It is observed that the highest occurrence of this behaviour was at 0 m/s to 0.5 m/s. As the wind speed increased the occurrence of this behaviour decreased. Nevertheless, it is observed a similar proportion of occurrence between 0 m/s and 2 m/s during summer and winter.

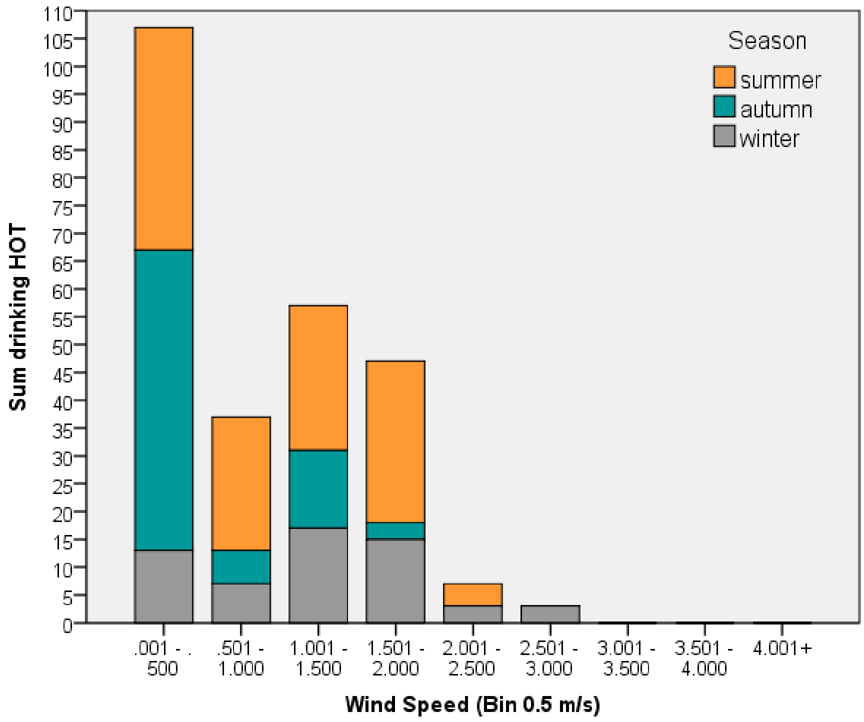


Figure 169 - Sum distribution of people drinking hot beverages according to the wind speed

Adding Clothes

Figure 171 presents the sum of people that increased their clothing level according to the calculated mean radiant temperature in the sun. It is observed that over 25ºC to 30ºC this behaviour decreased as the temperature increased. During winter, the highest occurrence of this behaviour was at the lowest temperatures recorded.

Figure 170 presents the sum of occurrence of adding clothes according to the light level variation. During winter this behaviour mostly occurred between 0 lx and 4,000 lx, whereas in summer the occurrence is spread between 1,000 lx and 15,000 lx.

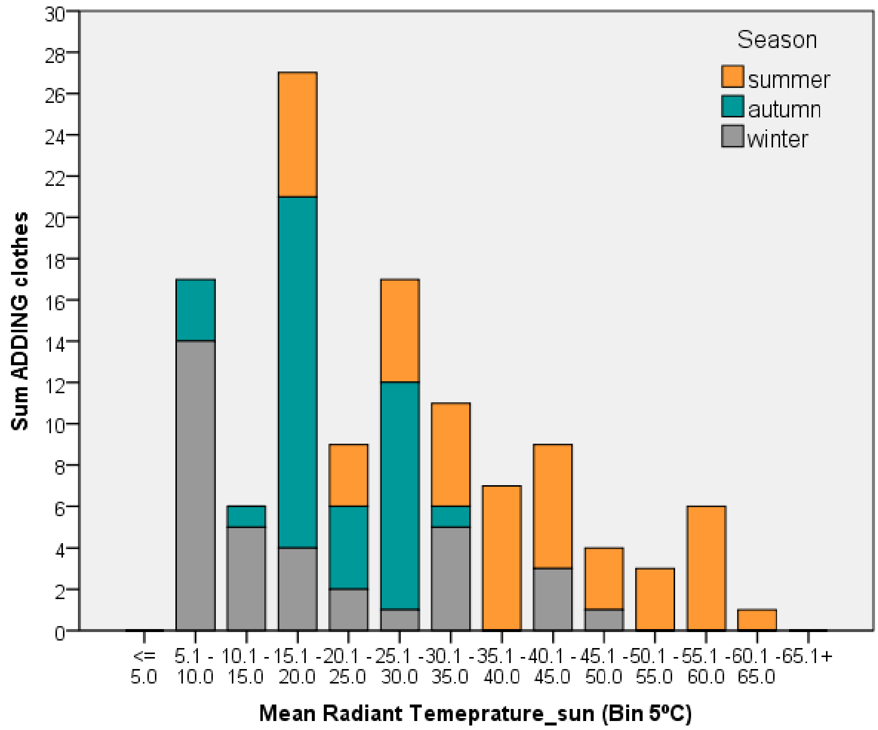


Figure 171 - Sum distribution people adding clothing according to calculated mean radiant temperature in the sun

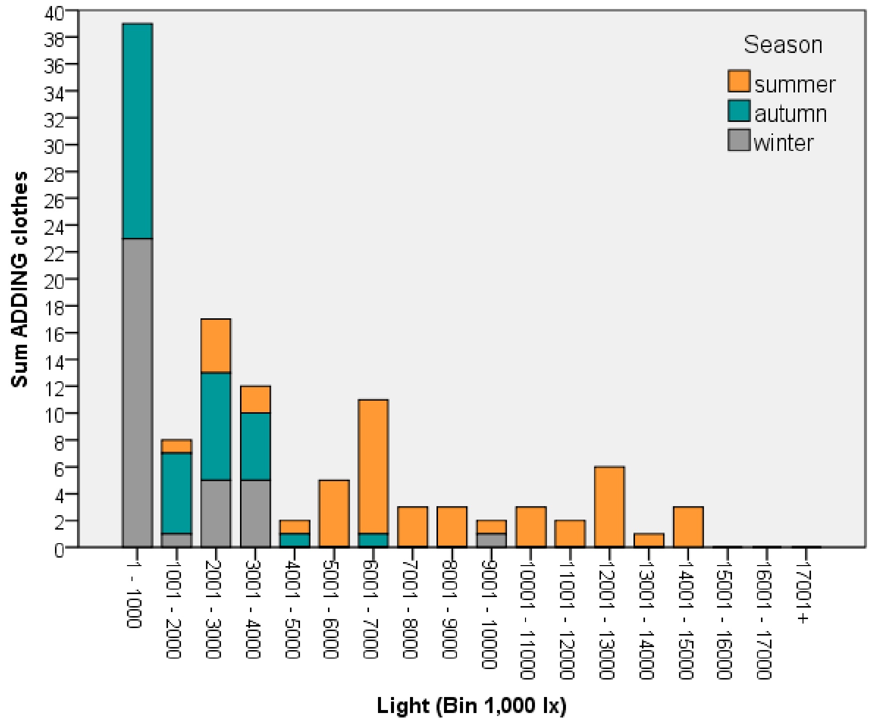


Figure 170 - Sum distribution of people adding clothing according to the illuminance

Removing Clothes

Figure 172 presents the sum of occurrence of the adaptive action removing clothes. It is observed that the frequency was similar between 0 m/s and 1.5 m/s. This behaviour mostly occurred during summer, however autumn presented a high frequency at 0 m/s to 0.5 m/s, and winter at 2.5 m/s to 3 m/s.

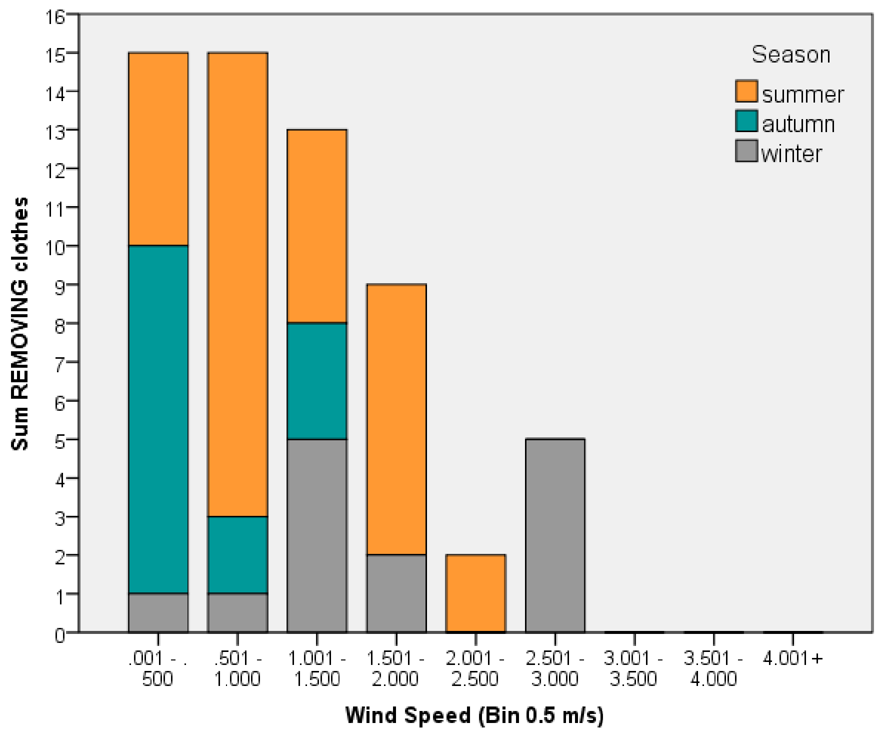


Figure 172 - Sum distribution of people removing clothing according to the wind speed

8.5. Discussion

This chapter presented analysis of the influence of the thermal environment on the human behaviour during summer, autumn and winter as a complete data set. The sample observed in Nottingham Trinity Square was mainly composed of adults (89%), teenagers (4.3%) and children (3.9%). The study also recorded the attendance according to gender, finding a higher attendance of men than women over the three seasons (56% men and 44% women). When analysing the data of each season independently, it was observed that the gap of attendance per gender was smaller in summer, attending 52% men and 48% women. Conversely, in winter the gap of gender attendance increased as the data distribution was 60% men and 40% women. This result suggests that during summer men and women were equally motivated to use the public space, while in autumn and winter women reduced their attendance. This result agrees with Parsons (2002) in their study about thermal perception indoors in simulated living room/office environments, where they reported that women perceive the spaces colder than men.

The gap in behaviour by gender was however not significantly present around the seasons. However, when analysing the body postures a difference was found in the lotus and leaning postures according to the gender of users, as the time of permanence in lotus was longer for women and time of permanence in leaning posture was longer for men. It was observed that around 70% of the women presented a longer time in the posture lotus (approx. 5 minutes more) in comparison to men.

In the seasonal studies conducted in this research, the influence of the thermal environment over the human behaviour presented particular characteristics to each season. When analysing the three season's data set as a whole, it was observed that some of the main influencers of the behaviours changed in comparison to the data of the seasons analysed independently. In the all-season analysis, globe temperature in the sun was the best predictor of almost all the social behaviours, while in winter, the best predictor of *Number of People* was light. During summer, the mean radiant temperature in the shadow also appeared to be important which can support the theories which state the importance of shadow availability during hot conditions. Conversely, during autumn, the mean radiant temperature in the sun was an important influencer agreeing with the theories of solar presence. As expected, the high percentage of relative humidity influenced some of the behaviours during winter.

It is also worth mentioning that the analysis of all the seasons together showed that globe temperature, wind speed and light contributed to the model to predict the number of groups of 1, groups of 2 and groups of 3. These environmental factors did not present multicollinearity while all three presented correlation with these social behaviours. The resulting equation to predict these behaviour contain the coefficients of these environmental factors. It was therefore interesting to see that the predictors of behaviour change when the seasons are treated independently vs. holistically.

The influence of globe temperature over the number of people and number of Groups of G1, G2 and G3 agrees with the findings presented by other authors who evidenced a strong relationship between the globe temperature and the attendance to different outdoor urban spaces (Nikolopoulou et al., 2001). For instance, Nikolopoulou reported that the occupancy of four different outdoor public spaces in Cambridge evaluated during spring, summer and winter at lunch time presented a relationship with the globe temperature (R^2 = .56). The correlation observed in this chapter between *Number of People* and globe temperature in the sun was of R^2 = .35. However, this study also showed that the prediction of *Number of People* can be improved when the model not only considers the influence of the globe temperature, but also takes into account the existing correlations of wind speed and light over the occupancy. The multiple regression model using these three variables increased the R^2 to .39, $p < .005$. According to this, when considering human behaviour, various factors should be assessed if possible, as people are not unidirectional receptors of the environmental conditions, but a multisensory being who respond to multiple environmental stimuli. As stated by Parsons (2015a): "The human body is not a passive system that responds to an environmental input in a way that is monotonically related to the level of physical stimulus. Any response depends upon a great number of factors" (p. 643).

The social behaviour analysis aimed to produce an understanding of the tendencies that influence the attendance of people to a public space. However, these tendencies are expressed in percentages of prediction rather than accurate numbers of attendance. Each analysis presented this percentage and its validation. It was observed that in the best case scenario (*Number of People* in winter), the model explained up to 46% of the variance of the occurrence of the behaviour, which indicates a strong relationship of the environmental variables with the occurrence of that behaviour under those circumstances. The rest can be accounted for multiple factors which also influence the human behaviour, such as: social, individual, economic, environmental (not considered in this research), physiological, psychological, among others. This information allows to determine and quantify some of the influencers of the human behaviour, that is, some of the environmental factors and their relationship to particular behaviours in outdoor public spaces.

The proposed equation to predict *Number of People* over the three seasons is integrated by the globe temperature in the sun, wind speed and light ($NP = 4.74 + 0.8Tg\_sun - 2.4Va + 0.0005Light$). Interestingly, wind speed and light were also predictors of the *Number of People* for the individual equations of summer, autumn and winter. However, the contribution of the wind speed to the models changed from being a positive coefficient during summer to be a negatively correlated during autumn, winter and all-seasons.

This change of the contribution of the wind speed coefficient to the equation according to the season can be explained by the fact that during summer the wind speed supports the thermoregulation of the body by helping to dissipate the heat through convection and evaporation of the sweat (Kroemer, Kroemer, & Kroemer-Elbert, 2001). Suggestions about how to increase the predicting power of the models will be presented in the General Discussion and Conclusions chapter (Chapter 10). Therefore wind speed favours the attendance to the public space, while in winter, the body is trying to preserve the heat produced and insulate it from the external conditions, according to which the increase of wind speed causes a decrease of the attendance to public spaces.

The cumulative survival curve for wind speeds between 1.0 m/s and 2.5 m/s were very similar, indicating that there were no high differences in the perception of people in these range of measurements. This range is higher than the range observed in autumn, which was 0.5 m/s to 1.5 m/s. As suggested by Nikolopoulou & Steemers (2003) in outdoors the ‘adaptation’ to the environment can occur by many factors. For instance, a higher tolerance to wind speed during winter could be explained by a physiological adaptation resulting from the repeated exposure to higher wind speed during winter. It could also apply the ‘naturalness’, which refers to the acceptance of the changes because they are produced naturally and the wind changes with the seasonal variations. It is also possible to think that the ‘expectations’ could influence the user behaviour, since the users accepted higher wind speed in winter than in autumn because they are expecting these conditions to occur.

As mentioned in Chapter 05, the study conducted by Givoni et al. (2003) also presented this negative relationship of the wind speed and the thermal satisfaction of the users under different conditions of sun, shade and wind over the four seasons. This chapter reveals that the overall models, such as the predictor of *Number of People* for all-seasons, or the *Thermal Satisfaction* (Givoni et al., 2003) can explain the general tendency of the behaviour, but they can also mislead individual calculations made in certain seasons.

In order to reinforce the statement presented above, the results of the correlation between the predicted and real *Number of People* during summer using the *summer equation* (*NP summer* = 18.39 + 0.001*Light* + 1.76*Va*), were compared with the predicted and real *Number of People* during summer using the *all-seasons equation* (*NP all-season* = 4.74 + 0.80*Tg_sun* – 2.40*Va* + 0.0005*Light*). The Pearson correlation indicated that the real *Number of People* and the *Predicted Number of People_summer* presented a correlation of $r = .30$ ($p < .001$), while the real *Number of People* and *Predicted Number of People_all-seasons* presented a correlation $r = .23$ ($p < .001$). These results mean that the prediction models covering different seasons can generalise the behaviour. However, an individual model per season would be required in order to understand more accurately the behaviour of users.

The models to predict the *Number of Groups of G1* and *G2* also presented a good percentage of prediction (23% for Groups of G1 and 30% for Groups of G2), which suggests that these type of groupings were highly influenced by the thermal environment. It was however observed that the presence of groups of three or more people (*G3* and *G4*) were more frequent during summer and autumn, which indicates a tendency for these groups to attend to the square in warmer conditions.

The previous chapters (5, 6 and 7) presented the analysis of the Groups' Diversity Index (GDI) which was created to evaluate the variety of types of groups occupying the square. According to Whyte (2009), it is possible to classify the 'best-used' plazas by observing the percentage of people in couples or groups. In his studies, Whyte classified the most-used plazas in New York with a proportion of couples and groups between 50 and 62% while the least-used had between 25 to 30%. Figure 173, presents the same analysis applied to Trinity Square. In this case the index was adjusted to three groups: least-used (0 to 30%), medium-used (31 to 49%) and most used (50 to 100%) presence of coupes and groups. According to this analysis, Trinity Square is a place with good variability of groups as most of the times during the three seasons, the square presented a proportion of couples and groups above 50% (most-used). In addition, winter is the season during which most of the time the square was "least-used" as the presence of groups was observed less than 30% of the times.

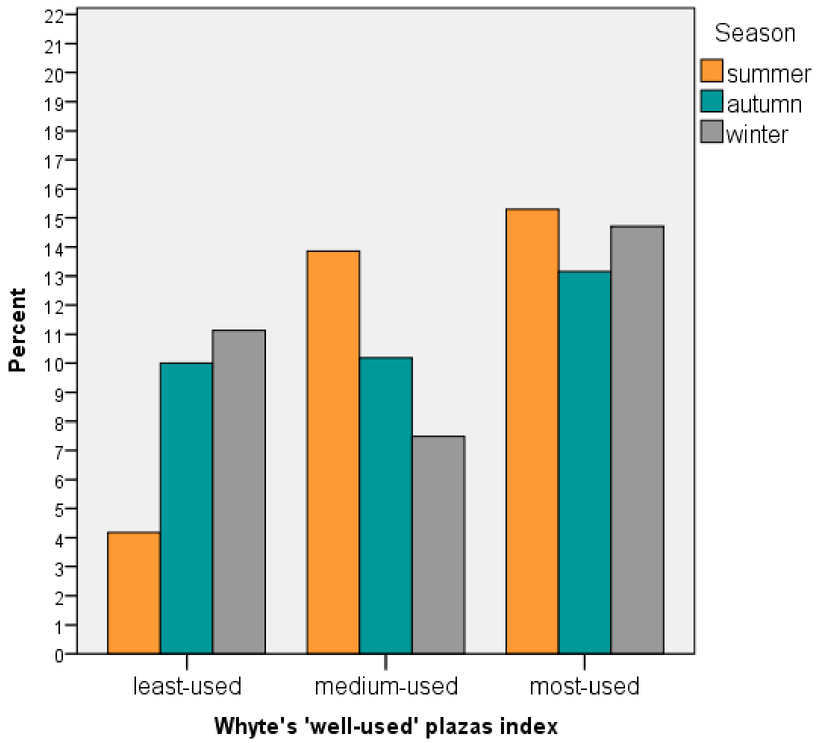


Figure 173 - "Best-Used" plazas Index by William Whyte according to groups in Trinity Square

This ‘well-used’ plazas index was originally made to make a comparison between different spaces. Here it is used it is proposed that it is made to evaluate this parameters across seasons for a same space.

Regarding the time of permanence, it was found that the globe temperature in the shadow and the wind speed influence the length of time people decided to remain in the square. It was observed that the survival curves were very similar for wind velocities between 0.001 m/s and 2 m/s, which suggests that people indifferent to these changes in the wind speed conditions. However, as soon as the wind speed increased over this value, the time of permanence reduced dramatically. This finding agrees slightly with Tacken (1989) who found that by reducing the wind speed in outdoor urban spaces to 1.5 m/s or less, the relaxation of people in urban spaces of Delft would increase. In the case of Nottingham, this would be viable for wind speeds below 2 m/s, as this way the users would remain longer in the urban space.

Regarding the postural analysis in the all-seasons’ analysis, it was found that the most frequent body posture adopted was sitting standard. However postures such as standing and leaning were more popular than sitting standard during winter and autumn. According to the adaptive actions suggested by Fergus et al. (2013), the postural changes observed as a response to the cold environments are curling or cuddling up. This is a natural reaction of the body to reduce the surface of the area available for heat loss. In the case of public spaces where the heat loss can occur by conduction through the contact with cold surfaces of the furniture, standing and leaning postures seem to be the choice selected by the users as the most efficient postures to keep the body heat. Additionally, these postures facilitate performing other activities such as jumping or walking, which also help to maintain the body heat.

As an example of people avoiding the direct contact with cold surfaces during winter, some of the notes from the observations conducted by Li (1994) in an observational study of adaptive actions of people in New York are recalled:

- "…a middle aged man in black overcoat came and stopped at the third southeast chair. He took out a cushion from his bag, put it on the wooden chair and sat on it. He lit a cigarette and watched pigeons looking for food on the ground. He stayed for 6 minutes" (p. 99).
- "…a leisurely dressed young man (mid 20s) with his lunch bag in hand came to sit on the south ledge. He ate and drank while listening to walkman. After eating, he laid on the ledge, but just a few seconds later he got up. It seemed that the stone ledge was still too cold to lie on. He stayed for 15 minutes" (p. 99).

These reported adaptive actions to isolate the body avoiding the contact with the furniture, or, to avoid losing heat in exchange of a more straight posture are some of the behaviours adopted by people to mediate their relationship with the place. Nevertheless, the urban spaces could provide different characteristics adaptable to these type of circumstances with the aim of increasing the use of outdoors during the periods of lowest attendance.

It was observed during winter that the time spent in the sitting posture was also influenced by the wind speed. As soon as the wind speed increased over 2 m/s the time of people sitting dropped. However, the tolerance in the posture standing was a bit higher, as they could withstand for more time with winds of up to 2.5 m/s.

According to the observations, the main activity performed was smoking followed by using a mobile device such as a phone or a tablet. These two activities were influenced similarly by the wind speed, mean radiant temperature in the sun and light. This is explained by the fact that both activities are usually occurring simultaneously. Smoking presented 54% of the attendant during winter, 41% of the attendants in autumn and 36% of the attendants in summer. According to Zacharias et al. (2001), the percentage of smokers of the different plazas in Montreal showed a different percentage of smokers changing from 4% in one plaza to 29% in another. Therefore, it is believed that the occurrence of this and other activities depends on the use of the surrounding buildings. As was observed in Trinity Square, most of the smokers were workers taking a break from the offices, restaurants or commercial shops.

In concordance with Zacharias et al. (2001), the presence of smokers was one of the most stable activities; this is confirmed in this research with the increment of percentage of smokers in winter since the occurrence of this behaviour continued happening despite the fact that the attendance was reduced. According to Gehl (2011), compulsory activities occur despite the quality of the urban space. Since smoking is an activity not allowed in indoors, it compulsorily occurs in the urban space despite the environmental circumstances.

The most frequent adaptive actions recorded were drinking hot and cold beverages. However, they did not present big differences among the seasons. The consumption of cold drinks was reduced during winter, while hot beverages were more frequent during this season in the lowest mean radiant temperatures. However hot beverages were also consumed in hotter seasons. Therefore, it is not possible to determine whether these actions are an adaptation to the outdoor thermal conditions since they could also respond to social conventions such as following the unspoken rules of certain meetings, for example.

Finally, this chapter compiled the data collected over summer, autumn and winter to examine the general tendencies. The results proved to be comparable with other studies in the field and contributed with higher detail in the findings as well as new conclusions which will allow further studies in the area.

8.6. Conclusions

The analysis of the *Social* and *Individual Behaviour* resulted validated models for predicting human behaviour according to the thermal environment. The models presented give an indication on the amount of people that would use the outdoor urban space, the length of time people would remain, and the activities that could be performed according to different thermal conditions presented during the three seasons. The models can be used as parameters for other studies; however, the individual conditions of other locations may change the components of the models proposed.

The internal-cross validation supported the reliability of the data, but external data in different environments would be required to test the generalisability of the results. However, as observed with other models of Thermal Sensation, the characteristics of each season, as well as, the characteristics of each location will define the behaviour of the users.

These results support the process of designing outdoor urban spaces, by predicting human behaviour in response to microclimatic conditions in a city with a wide range of environmental scenarios.

9. Human behaviour in a Mock Scenario

9.1. Chapter Overview

After analysing human behaviour in an outdoor public square of Nottingham City Centre during three different seasons, this chapter presents a study of the human behaviour according to the thermal environment in a set up scenario, in which the findings of the studies conducted during the different seasons are tested, and further considerations are made with regards to the interaction between the people and the furniture in an outdoor public space. The study showed that the equations to predict the human behaviour should be tested in places with similar environmental conditions to those where the initial study was conducted. In addition, further analysis will be conducted to study the influence of the type of furniture and shadow availability in the human behaviour.

9.2. Introduction

During the studies conducted in autumn, summer and winter, the methodology was based on analysing human behaviour in an existing square in Nottingham city (Chapters 5, 6 and 7). The studies were however conducted using observational methods, without altering the characteristics of either the space, the furniture or the environmental conditions. The data analysis and coding was the same, as was the statistical analysis. The study presented in this chapter was conducted to collect data in a semi-controlled scenario in which some of the characteristics of the space could be modified in order to observe the human environment in various environment-space-furniture configurations. It has been custom designed to conduct an external validation of the models obtained through the seasonal studies, but also to gather additional data of the human behaviour in a more controlled environment.

One of the most relevant referents for the 'mock scenario' was the installation arranged by Group in Gdansk, Poland, during summer 2013 (Gdyby, 2013) (Figure 174). In this particular case, the city council wanted to see the options for developing an abandoned parking area. To test possible uses for the place, the group of architects created temporary mobile modules which allowed people to develop different activities. The authors reported the increase of use of this underused space by placing furniture and proposing activities to the citizens.

Figure 174 - Installation done by Gdyby. Left: Main view of Targ by Wojciech_Ostrowski. Right: People interacting by Dominik Werner

For the mock scenario of this research, a seating area has been designed and arranged in a medium size open space within the Highfields Park at Nottingham. The proposed space and furniture were free to use by anyone passing by; however, a flyer indicated that in this place a study was taking place which included video recording.

This study was conceived as an external validation test of the data gathered and the outcomes obtained through the seasonal studies. The aim was to conduct a study of human behaviour and environmental conditions in a scenario specifically built for this purpose, to gather data of human behaviour applying the methodology designed for the seasonal studies conducted in an actual square of Nottingham city. The objectives were to test whether the data collected in this scenario shows the same results as those observed in the studies conducted in a public square and test the success rate of the models previously designed to predict the variance of the human behaviour, in order to determine their generalisability.

In addition, further analyses had been conducted to propose improvements on the data collection method by using pressure sensors within the furniture to measure time of use of the specific furniture.

9.3. Method

As mentioned, the methodology in this study varied slightly from the one used in the seasonal studies. A mock scenario was set up by installing furniture in an outdoor public area normally used as an empty circulation space within the Highfields Park of Nottingham. The sections: equipment, exclusion criteria, announcing the study and procedure are the same as defined in Chapter 6, and are therefore not reported here.

The data collection of this study was conducted with the assistance of Giovana Zacharias, from the program Science without Borders (Ciência Sem Fronteiras) funded by the Government of Brazil in partnership with the United Kingdom. Her participation was part of a summer project of her undergraduate course.

Mock Scenario

The mock scenario study consisted of selecting a public empty space which has pedestrian traffic and where it would be possible to set up movable furniture for two weeks. It also needed to have storage space close to it in order to be able to mount and dismount the furniture every day.

Location

The location selected was in an area between the University of Nottingham Park and Highfield Park in Nottingham, which is a public park attached to the University of Nottingham Park Campus. This place has a high traffic of people of different ages and it is active during all days of the week. The Lakeside Arts Centre is a building located in between the park and the university campus and manages the surrounding area of the building. This place was selected by the researcher as the outdoors characteristics, dispositions and facilities offered by the Lakeside Arts Centre made the experiment feasible.

This space also met the characteristics required to be compared with the previous studies conducted in this research, and to follow the literature parameters for studies of human behaviours in outdoors: to provide 'Routes' and 'Resting' areas (Gehl & Svarre, 2013; Nikolopoulouet al., 2001) or places to sit, walk and perform certain activities.

The place chosen to conduct the experiment was an area of approximately 35 square meters in front of the Lakeside Arts Centre building. This area was selected because it is a place where there is common transit of people of varied ranges of ages and backgrounds. It is also connected to the University of Nottingham campus and close to a museum, a playground and a lake frequently used for various types of activities.

The area is located close to a pedestrian pathway residually used for the transit of cars. At the opposite end, the area is enclosed by a structure overlooking the boating lake of Highfields Park. This structure provides shadow to part of the area of study at certain times of the day (Figure 175).

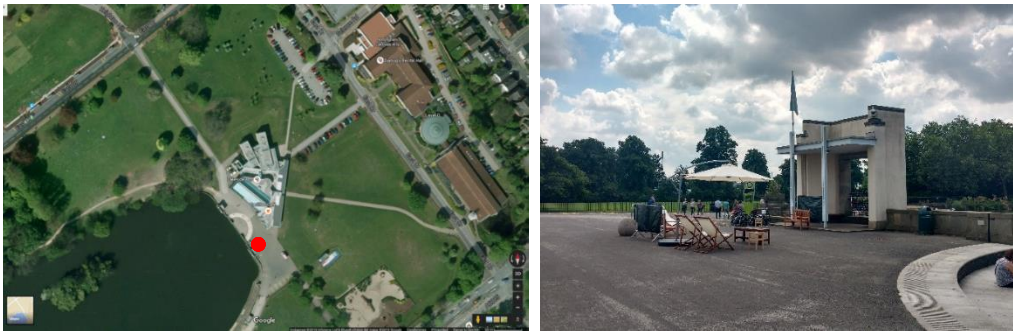


Figure 175 - Location of the selected are for the experiment

Population and Time Sample

Similarly to the analysis of the seasonal studies, two types of observations were also conducted during the mock scenario: Social behaviour and Individual behaviour. It must be noted that the scale of this experiment is smaller than the seasonal experiments: the time sample of the Social Behaviour analysis was 240 minutes per day during 13 days in summer 2016, totalling 3,351 minutes recorded.

For the Individual Behaviour analysis 648 people were evaluated. As in the previous studies, they corresponded to the people who chose to attend to the place and decided to remain there, and not just those transiting to another destination. In addition, the rest of the exclusion criteria were the same as in the previous studies: only people remaining in the evaluated area and whose permanence was recorded from beginning to end. Figure 176 shows an example of the people included and excluded from the experiment.

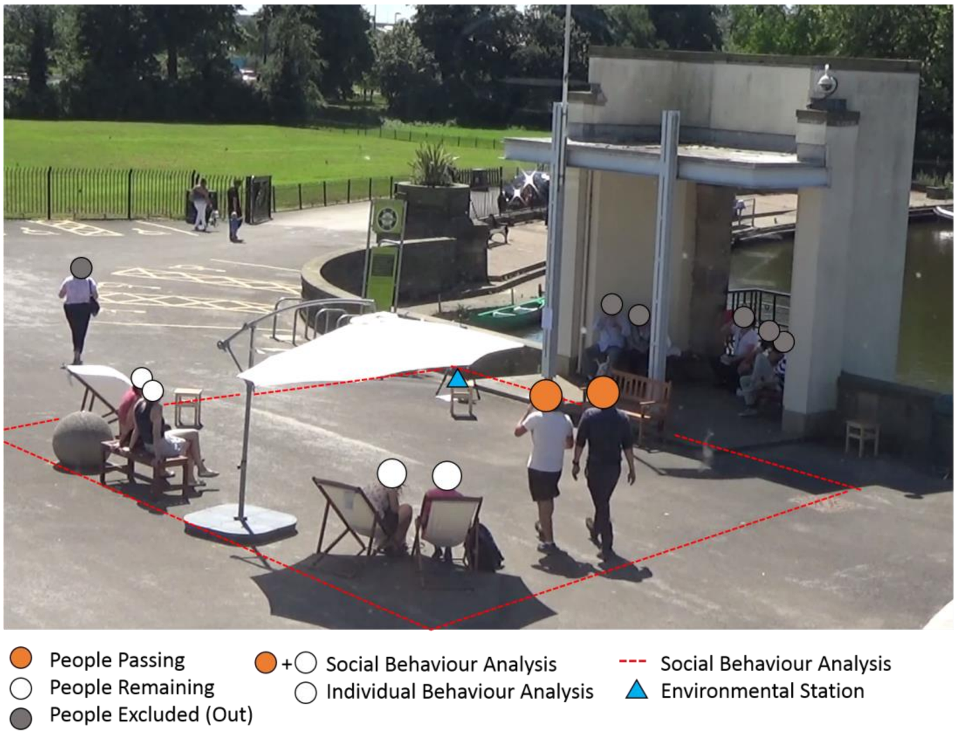


Figure 176 - Photo Mock Scenario July 19th 2016. People passing and remaining in the seating area.

The exclusion criterion was rainy days. According to Gehl (Gehl et al., 2013), people avoid sitting on a wet bench and refuse to remain in a place during rain. In addition, the study conducted in Trinity Square showed the low permanence of the people when the surfaces were still wet. Therefore one day of the two weeks recorded was excluded.

The individuals were also classified in age groups as in the seasonal studies. They were: baby, child, teenager, adult and mobility reduced. From the people analysed, 61.4% were adults, 15.7% teenagers, 16.7% children, 2.6% babies and 3.5% mobility reduced (Table 134).

Table 134 - Frequency distribution of the age groups - Mock Scenario

Age (N = 648)

		Frequency	Percent	Cumulative Percent
Valid	adult	398	61.4	61.4
	teenager	102	15.7	77.2
	child	108	16.7	93.8
	baby	17	2.6	96.5
	mobility	23	3.5	100.0
	Total	648	100.0	

Regarding gender, the mock scenario study presented almost equal attendance of men and women, which corresponded to 50% women and 48% men (Table 135).

Table 135 - Frequency table of gender

Gender

		Frequency	Percent	Cumulative
Valid	male	311	48	48
	female	324	50	98
	Not	13	2	100.0
	Total	648	100.0	

Equipment

The mock scenario study used the same equipment to video record, measure the environmental conditions and take notes as described in the seasonal studies (Chapters 5, 6, and 7). However, because it is a custom made scenario, the furniture within the space was supplied by the researcher, as well as additional pressure sensors attached to the furniture to obtain additional automated data. These elements were:

Garden Bench: Two wooden benches commonly found in public spaces of cities, capable of seating up to three people. These were equipped with pressure sensors to capture the length of use of the bench and the postures adopted. These were selected to allow people to sit leaning against the backrest.

Figure 177 - Left: Garden Bench, Centre: Sensors location, Right: wooden texture used to hide the sensors

Long Bench: One wooden long bench without back rest was placed in the mock scenario area. It was capable of seating up to four people, and was equipped with pressure sensors to measure the use of the bench. This bench was placed to allow people sitting with the standard posture.

Figure 178 - Long Bench, sensors and Arduino

Three wooden and fabric deck chairs were placed in the mock scenario area. Each of them was capable of seating one person and was also equipped with pressure sensors, to measure the use of the chairs. They were placed to motivate the sitting backrest posture.

Figure 180 - Left: Deck chair disassembled with arduino. Right: Deck chairs on the place

Stools: Three wooden stools were placed in the mock scenario, each of them capable of seating one person. Each one was adapted with one pressure sensor to measure the use of the furniture.

Figure 179 - Stools used in the experiment. Right: Plastic box attached below the stool with the Arduino

Parasol: One parasol was also installed in the area in order to generate shadow over a specific area of the scenario.

Figure 181 - Parasol installed in the mock scenario area

Wind Barriers: Up to three wind barriers were installed. They consisted of one plastic tarp attached to the structure of the building beside the area and two installed to metallic barriers which were placed to regulate the wind speed of certain areas of the scenario.

Figure 182 - Scenario with wind barriers

FSR Sensors: As explained before, hidden pressure sensors were installed on the surfaces of the furniture. These elements were not easily perceived by the users and were activated as soon as someone was sitting over them. The sensors were connected to the Arduino that recorded the pressure every three seconds.

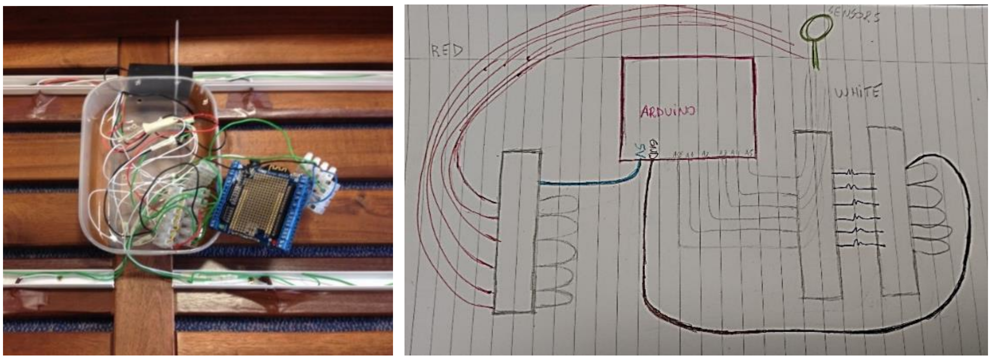


Figure 183 - Arduinos and the sensors. Scheme used to conenct the sensors

Duration and Season

The mock scenario study was conducted during 13 days in summer 2016, from the 18th of July to the 31st of July. The 28th of July was recorded but excluded as most of the time of the study, the day was rainy. The temperatures normally registered on those dates correspond to the following historical ranges:

The study took place for approximately 4 hours each day starting from 11:00 am until 3:00 pm, as this is the most active period. As in previous studies, in case one or more users were at the square at the time of the end of the study, recording was extended until their departure.

Ethics Approval and Advertisement

This study was approved by the Ethics Committee from the Faculty of Engineering from the University of Nottingham. As in previous studies, the information gathered was anonymised by blanking faces out. The study received the approval from the Lakeside Arts Manager, who authorised the installation of furniture and elements in the selected area, and in addition facilitated the storage of the furniture.

As in the previous studies, a poster was placed next to the video camera and the environmental station, to announce that a study was taking place and video recordings were being made in that area. Users were given the option to opt out of the study by contacting the researcher.

Scenario Compositions

The study analysed four different compositions of the scenario with different arrangements in the furniture, wind barriers and parasol in order to allow the study of different environmental conditions influencing the behaviours in the place.

Composition 1 (Figure 184): Shadow device + Wind Barrier + Furniture.

Figure 184 - Shadow + Wind Barrier + Furniture

In this disposition, the parasol was opened and providing shadow to some of the evaluated area permitting the option of having shadow. In addition, the structure located next to the experiment also provided shadow to the experiment area. The wind barriers were placed to give shelter covering the main wind flow coming from the lake. At all times, the users had the possibility of choosing between sitting in a sheltered area or an unprotected area.

Composition 2 (Figure 185): Shadow device + Furniture.

Figure 185 - Shadow + Furniture

This disposition followed the same arrangements of the previous composition, but excluding the wind barriers. The parasol continued providing shadow to the furniture, but no wind protection was available. In case the wind speed exceeded the maximum allowed by the specifications of the parasol, this element was closed and only the shadow from the structure was available.

Composition 3 (Figure 186): Wind Barrier + Furniture.

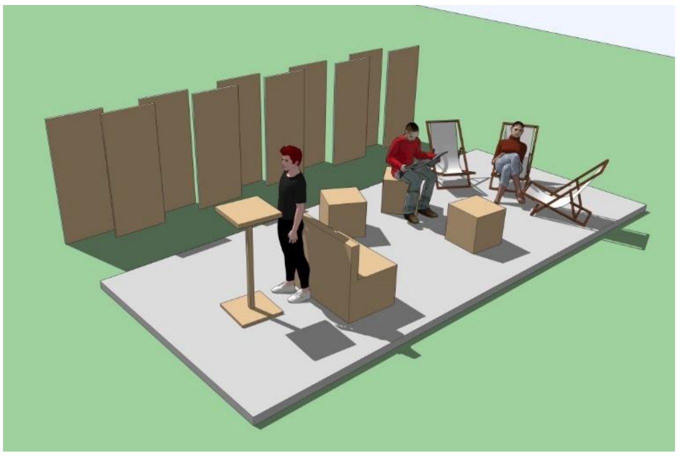


Figure 186 - Wind Barrier + Furniture

During this composition, some of the furniture was protected by the wind barrier, as explained in composition 1, but no solar protection from the parasol was available. There was however shadow projected from the structure near the place of study at certain hours.

Composition 4 (Figure 187): Furniture

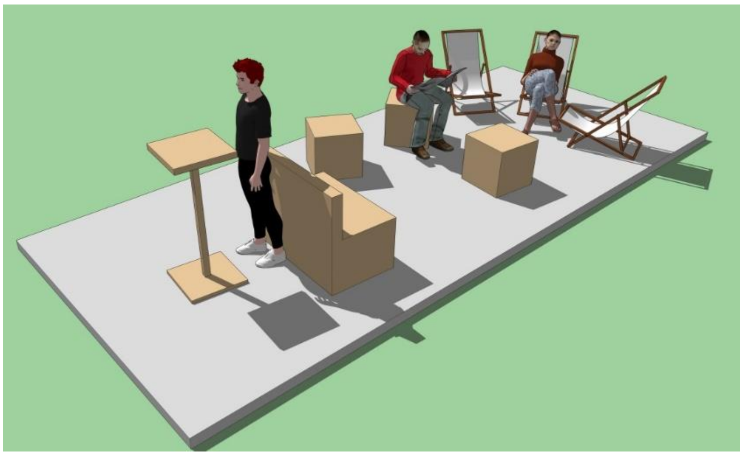


Figure 187 - Furniture

This composition left only the furniture in the scenario, without any shelter in terms of sun or wind. The conditions of the sets varied across the two weeks to allow that each composition was assessed at least one time in all the days of the week.

Table 136 presents the calendar distribution of the week and type of scenarios evaluated. In the cases when the wind speed was too high, the parasol was closed and only the shadow projected by the structure located next to the experiment was available.

Table 136 - Scenarios randomly selected

Scenarios Recorded

		Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*	*Sunda*
week 1	11:00 -	Furniture	Parasol	Furniture	Wind	Parasol	Wind	Wind
	13:00-	Parasol	Furnitur	Parasol	Furniture	Parasol	Parasol	Wind
week 2	11:00 -	Wind	Parasol	Parasol+	Excluded	Furnitur	Parasol	Paraso
	13:00-	Parasol +	Parasol	Parasol	Excluded	Wind	Furnitur	Paraso

Procedure

The researcher installed the set and the posters were placed in a visible place near to the recording area, next to the environmental station.

The procedure to collect the data was the same for every day:

1. Configuring the environmental station to start one hour before the starting time of the experiment.
2. Configuring the pressure sensors to start before the starting time of the experiment.
3. Placing the environmental station 20 minutes before the starting time of the experiment to allow the sensors to stabilise their measurements according to the real conditions of the environment. They were always located in the same place (Figure 176).
4. Placing the video camera in a hidden place.
5. Starting the video recording with a minimum duration of 2 hours for the morning and 2 hours for the afternoon (11:00 am to 3:00 pm). The starting and finishing time was registered in the Fieldwork Diary.
6. During the recording period, the researcher was outside the evaluated area, taking notes in the Fieldwork Diary.
7. Once the session was finished, the researcher removed the measurement equipment and furniture and installed it again the next day. After the recording session, the researcher downloaded the

information into the computer and configured the sensors for the next day.

8. As soon as the data collection was completed, the researcher synchronised the environmental data and video recordings, and performed analysis using the coding scheme designed in the Pilot Study (Chapter 4).
9. The researcher used the environmental data collected during the experiment to evaluate the prediction models of human behaviour under the circumstances registered. These data was compared with the real data of behaviours collected to see the similarity of the models with data from an external environment.

9.4. Results

The analysis of the data obtained of the Mock Scenario was also divided into Environmental data results, Social Behaviour analysis and Individual Behaviour analysis. However, the results were evaluated in comparison to the data obtained in summer and all-seasons (Chapter 5 and Chapter 8), as the Mock scenario study was conducted also in summer and the all-seasons model is meant to include a wider range of environmental factors. Additionally, the equations obtained in those chapters were used to compare the predicted data and the observed data in the Mock Scenario. The results sections are as follows: 1) Environmental Data: evaluating the correlations between environmental variables and description of the conditions recorded, 2) Social Behaviour: the environmental data measured in the mock scenario was used to calculate the predictions using summer and all-seasons equations, in order to compare the observed data with the predicted data in summer and the predicted data in all-seasons, 4) Individual Behaviour: the variables were analysed using survival analysis considering the different scenarios proposed and comparing the results with the data obtained in summer and all-seasons.

In addition, the Mock Scenario also included the analysis of the use of furniture obtained by pressure sensors data and included new adaptive behaviours for the individual analysis that will be described later.

9.4.1. Environmental Measurements

The microclimatic station recorded a total of 3351 minutes of environmental data, corresponding to an average of 4.3 hours per day during 13 days in summer 2016. Table 137 shows the descriptive statistics of the environmental data gathered during the Mock Scenario. The Environmental variables measured were the same as in the previous studies: air temperature, Ta (ºC); relative humidity, rH (%); globe temperature in the sun, Tg_sun (ºC); globe temperature in the shadow, Tg_shad (ºC); calculated mean radiant temperature in the sun, Tr_sun (ºC); calculated mean radiant temperature in the shadow, Tr_shad (ºC); wind speed, Va (m/s) and light, light (lx).

Table 137 - Descriptive statistics of the environmental variables

Statistics (N = 3351)

	Ta	rH	Tg_Sun	Tg_Sha	Tr_Sun	Tr_Sha	Va	Light
Mean	22.9	55	27.5	24.9	42.0	31.5	.945	9248
Median	22.6	56	26.1	24.3	38.3	30.1	.880	8629
Std.	3.0	7	4.7	3.4	12.6	5.9	.616	3359
Minimum	19.0	33	20.3	19.9	22.1	20.8	.000	3165
Maximum	31.4	73	38.6	33.3	81.6	51.9	3.480	20857

The Spearman's rho correlation analysis between the environmental variables measured during the Mock Scenario is presented in Table 138.

Table 138 - Correlations between environmental variables during the Mock Scenario

Spearman's rho Correlations (N = 3351)

		Ta	rH	Tg_Su	Tg_S	Tr_Sun	Tr_Sh	Va	Light
Ta	Correlation	1.00							
	Sig. (2-tailed)	.							
rH	Correlation	-	1.000						
	Sig. (2-tailed)	.000	.						
Tg_Sun	Correlation	.91**	-.25**	1.00					
	Sig. (2-tailed)	.000	.000	.					
Tg_Sha	Correlation	.98**	-.27**	.96**	1.000				
	Sig. (2-tailed)	.000	.000	.000	.				
Tr_Sun	Correlation	.57**	-.17**	.78**	.66**	1.000			
	Sig. (2-tailed)	.000	.000	.000	.000	.			
Tr_Sha	Correlation	.71**	-.22**	.83**	.78**	.95**	1.000		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.		
Va	Correlation	-.01	-.01	.01	-.01	.51**	.50**	1.000	
	Sig. (2-tailed)	.486	.692	.404	.545	.000	.000	.	
Light	Correlation	.45**	-.12**	.67**	.55**	.74**	.70**	.15**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

Acronyms: Air temperature (**Ta**), relative humidity (**rH**), globe temperature in the sun (**Tg_sun**), globe temperature in the shadow (**Tg_shad**), mean radiant temperature in the sun (**Tr_sun**), mean radiant temperature in tha shadow (**Tr_shadow**), wind speed (**Va**).

When comparing these results with the environmental data gathered in the seasonal study of summer 2015, it is observed that almost all the variables presented correlation with exception of wind speed, which was only significantly correlated to mean radiant temperature in the sun ($r = .51$, $p < .001$) and radiant temperature in the shadow ($r = .50$, $p < .001$). In general, relative humidity presented a lower significant correlation than the ones observed in the seasonal study of summer 2015. This could be due to the difference in microclimatic conditions regarding relative humidity existing between Nottingham city centre and the Highfields Park area. The highest correlation found was between air temperature and globe temperature in the shadow ($r = .98$, $p < .001$), which replicates the results obtained in the seasonal study conducted in summer 2015. It was followed by globe temperature in the shadow and globe temperature in the sun ($r = .96$, $p < .001$), and radiant temperature in the shadow and radiant temperature in the sun ($r = .95$, $p < .001$).

Figure 188 and Figure 189 present the percentage distribution of the data per environmental factor measured. It is interesting to observer that in this study, almost 70% of the relative humidity data is concentrated between 46 – 50%, 51 – 55% and 56 – 60%, while in the seasonal study 2015 conducted in Nottingham City centre, this ranges of relative humidity were only 48% of the data.

The Mock Scenario presented similar environmental conditions to the ones registered in city centre during summer, however warmer and brighter days were registered in the Mock Scenario with higher air temperature (max. 31.4^{o}C) and globe temperature (38.6^{o}C sun and 33.3 ^{o}C shadow) in comparison to the environmental data of summer (Chapter 8).

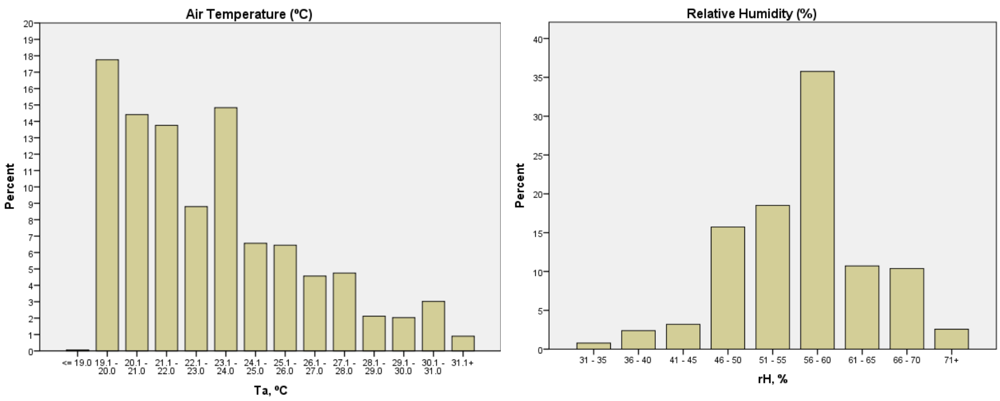


Figure 188 - Percentage distribution of the environmental variables: Air Temperature and Relative Humidity

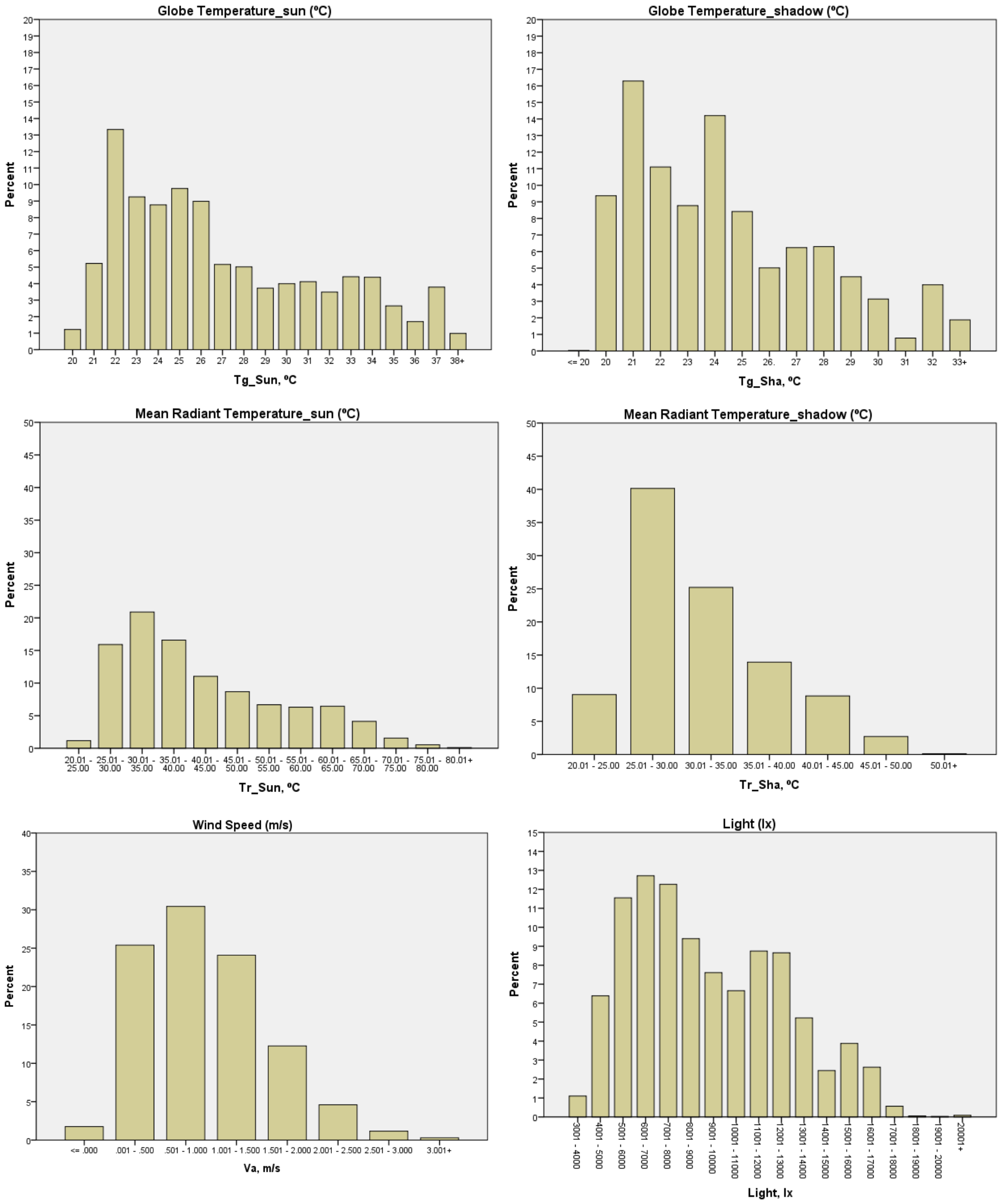


Figure 189 - Percentage distribution: Globe Temperature_sun, Globe Temperature_shadow, Mean Radiant Temperature_sun, Mean Radiant Temperature_shadow, Wind Speed and Light

9.4.2. Social Behaviour

Regarding the analysis of the Social behaviour in the Mock Scenario, the type of behaviours analysed and the methodology used was the same as in previous studies conducted in this research (Chapters 5 and 8).

Table 139 presents the descriptive analysis of Number of People, Number of Groups of G1, Number of Groups of G2, Number of Groups of G3 and Number of Groups of G4more, present in the square in the count per minute.

Table 139 - Descriptive statistics of the Number of People and Number of Groups

Statistics (N = 3351)

	N_People	G1	G2	G3	G4more
Mean	3	0	1	0	0
Std. Deviation	3	1	1	0	0
Minimum	0	0	0	0	0
Maximum	18	4	3	2	3

In general the amount of Number of People and Groups is much lower in the Mock Scenario than in previous seasonal studies, because the scale of the experiment is smaller. The maximum Number of People registered at the same time was 18 and the minimum 0 persons. The results of Trinity Square in summer presented in Chapter 5 were minimum 4 people and maximum 63 people. It is observed that G2 had a mean number of 1 group in the count per minute, while for the rest of the groups the mean was 0, which suggests that couples were frequently using the seating area.

Figure 190 presents the percentage distribution of the Number of People present in the square per minute in the mock scenario study. The most frequent observation of people present in the seating area, that is, without considering the counts of 0 people, was 2 persons present in the count per minute. It must be however mentioned that zero assistance was highly reported, which could be explained by the fact that this was a new installation and people was not used to it. There may be also spontaneity issues, because the smaller scale of the scenario made it more evident that a study of human behaviour was taking place there. The zero attendance was not observed in the summer experiment conducted in the city centre.

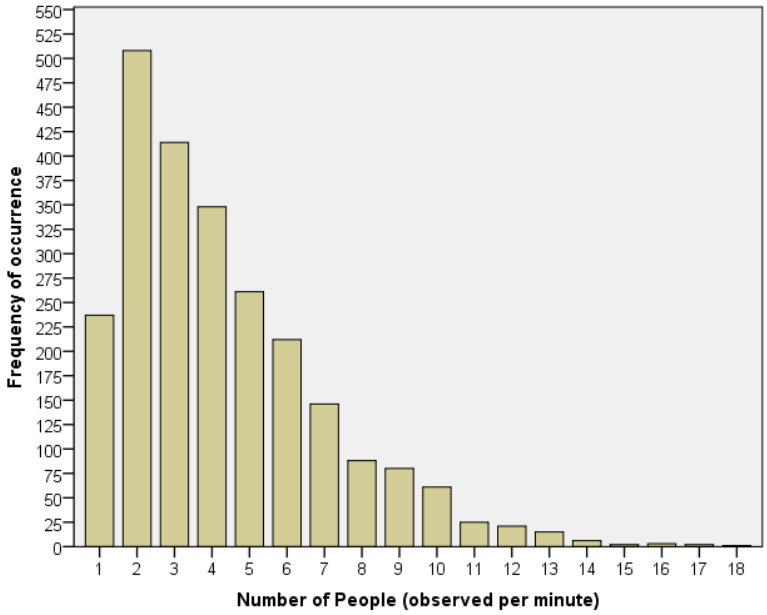


Figure 190 - Frequency distribution number of people per minute

Figure 191 presents the percentage distribution of the Number of Groups of G1, G2, G3 and G4more, present in the square in the count per minute. As can be seen the most frequent observation for all the groups was 1 group present in the square in the count per minute. The most frequent observation was groups of G2, followed by G1 and G4more.

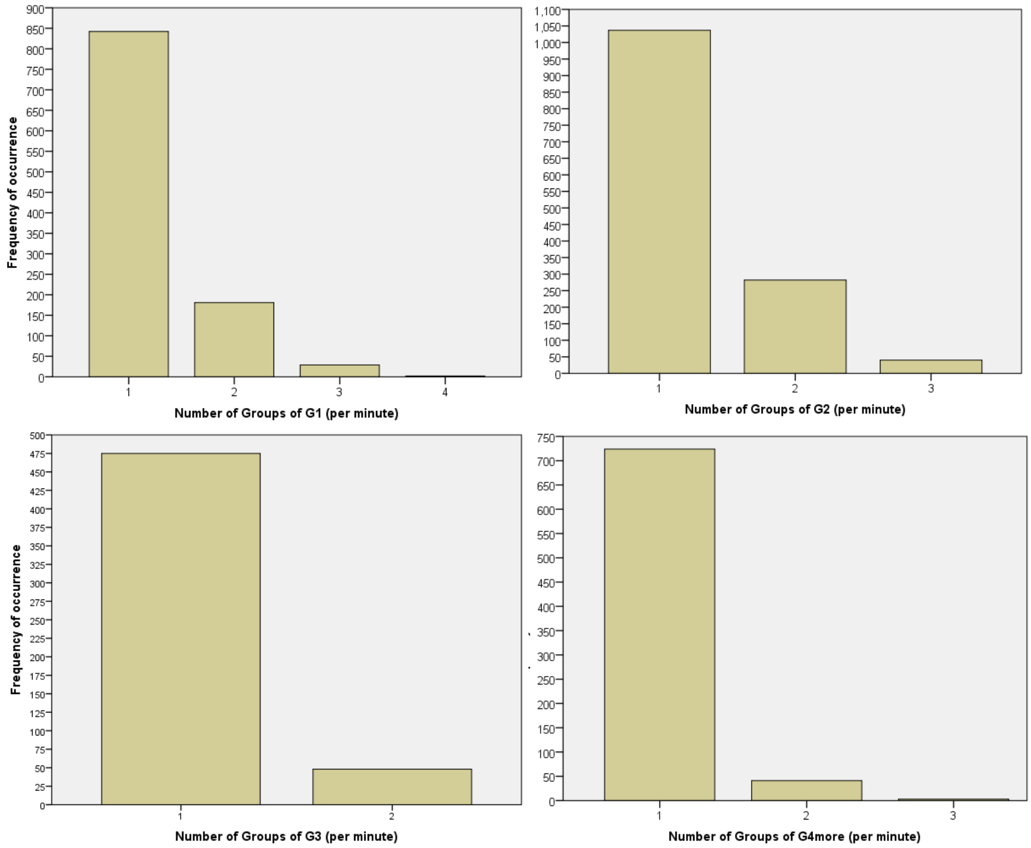


Figure 191 - Frequency of the accumulated number of groups of G1, G2, G3 and G4more

In Figure 191 is observed that the groups of 4 or more were more frequent than the groups of 3.

In this study, the data collected was used as a validation data set. This means that the environmental data was used to calculate the predictions of the models designed in summer and in the all-seasons studies (Chapter 5 and Chapter 8). The results of the data observed in the mock scenario, the data from the summer equations and the results from the all-seasons equations were evaluated.

9.4.2.1. Correlation

Replicating the process conducted in the seasonal studies, the environmental factors were initially correlated to each other and then analysed in relation to the Social Behaviours: Number of People and Number of Groups of G1, G2, G3 or G4 or more. A Kolmogorov-Smirnov test was performed to verify the distribution of the data in all the variables and select the appropriated type of correlation analysis (Table 140).

Table 140 - Test of normality, Kolmogorov - Smirnov test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ta	.098	3351	.000	.919	3351	.000
rH	.057	3351	.000	.985	3351	.000
Tg_Sun	.118	3351	.000	.925	3351	.000
Tg_Sha	.093	3351	.000	.929	3351	.000
Tr_Sun	.116	3351	.000	.925	3351	.000
Tr_Sha	.098	3351	.000	.938	3351	.000
Va	.062	3351	.000	.967	3351	.000
Light	.092	3351	.000	.960	3351	.000
N_People	.150	3351	.000	.885	3351	.000
G1	.414	3351	.000	.633	3351	.000
G2	.363	3351	.000	.709	3351	.000
G3	.504	3351	.000	.447	3351	.000
G4more	.471	3351	.000	.540	3351	.000

a. Lilliefors Significance Correction

As can be observed, all the variables were significantly non-normal, since all of them obtained D (3351) < .001. According to this, the type of correlation analysis required is Spearman's rho correlation.

Table 141 presents the correlations between the environmental factors and social behaviour. It is observed that the highest correlations with the Number of People were the relative humidity ($r = -.17$, $p < .001$) and light ($r = -.17$, $p < .001$); Number of Groups of G1 was mainly influenced by the air temperature ($r = .17$, $p < .001$); Number of Groups of G2 was influenced by the relative humidity ($r = -.15$, $p < .001$); Number of Groups of G3 was influenced by the light ($r = -.08$, $p < .001$) and the Number of Groups of G4more was influenced by the globe temperature in the sun ($r = -.11$, $p < .001$).

Table 141 - Spearman's rho Correlation, Mock Scenario.

		N_People	G1	G2	G3	G4mor	Ta	rH	Tg_Sun	Tg_Sha	Tr_Sun	Tr_Sha	Va	Light
Ta	Correlation Coefficient	.00	.17**	.11**	-.02	-.08**	1.000							
	Sig. (2-tailed)	.903	.000	.000	.222	.000	.							
rH	Correlation Coefficient	-.17**	-.09**	-.15**	-.06**	-.05**	-.26**	1.000						
	Sig. (2-tailed)	.000	.000	.000	.001	.003	.000	.						
Tg_Sun	Correlation Coefficient	-.07**	.08**	.06**	-.05**	-.11**	.91**	-.25**	1.000					
	Sig. (2-tailed)	.000	.000	.000	.002	.000	.000	.000	.					
Tg_Sha	Correlation Coefficient	-.03	.14**	.09**	-.04*	-.09**	.98**	-.27**	.96**	1.000				
	Sig. (2-tailed)	.090	.000	.000	.035	.000	.000	.000	.000	.				
Tr_Sun	Correlation Coefficient	-.12**	-.05**	-.02	-.06**	-.08**	.57**	-.17**	.78**	.66**	1.000			
	Sig. (2-tailed)	.000	.007	.309	.001	.000	.000	.000	.000	.000	.			
Tr_Sha	Correlation Coefficient	-.08**	.03	.03	-.05**	-.07**	.71**	-.22**	.83**	.78**	.95**	1.000		
	Sig. (2-tailed)	.000	.124	.107	.004	.000	.000	.000	.000	.000	.000	.		
Va	Correlation Coefficient	-.02	-.07**	-.01	.01	-.01	-.01	-.01	.01	-.01	.52**	.50**	1.000	
	Sig. (2-tailed)	.388	.000	.481	.409	.650	.486	.692	.404	.545	.000	.000	.	
Light	Correlation Coefficient	-.17**	-.07**	-.06**	-.08**	-.08**	.45**	-.12**	.68**	.55**	.74**	.70**	.15**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Regarding the comparison between the correlations of the mock scenario and the all-seasons (Chapter 8), an opposite tendency with regards to relative humidity was observed. It was reported in Chapter 8 that the relative humidity presented low or null correlations with the behaviour, while in Table 141 is observed that this variable presented relationship with most of the behaviours in the mock scenario. The mock scenario showed a negative correlation between light and all the other factors, while in previous studies this correlation was positive.

Validation of the Models of summer and all seasons to Predict Number of People

The accumulated Number of People of the Mock Scenario was compared with the predicted Number of People using the equations obtained in summer and in all-seasons. Chapter 5 presented the equation to predict Number of People in summer:

$$N\_People\_summer = 18.391 + (0.001 * Light) + (1.763 * Va)$$

Similarly, Chapter 8 presented the equation to predict Number of People in all seasons:

$$N\_People\_allseasons = b_0 + b_1 Tg_{sun} + b_2 Va + \ b_3 Light$$

In order to compare the results between Trinity Square and the Mock Scenario, the results were converted to percentage of occupancy, using the maximum occupancy in Trinity Square of 63 people (Table 109) as 100%, which would be equivalent to the maximum occupancy in the Mock Scenario of 18 people (Table 139).

Table 142 presents the correlations between the Number of People observed in the Mock Scenario, the Predicted Number of People using the summer equation and the Predicted Number of People using the all-seasons equation. It was observed that both equations presented a significant negative correlation. The correlation with the all-seasons equation was better (r = -.09, p<.001) than the one observed when using the equation of summer (r= -.09, p <.001).

Table 142 - Correlation between Number of People Mock Scenario, Predicted Number of People_summer and Predicted Number of People_all-seasons

Spearman's rho Correlations (N = 3351)

		Number of People (Mock Scenario)	Predicted Number of People	Predicted Number of People
Number of People (Mock Scenario)	Correlation Coefficient	1.000		
	Sig. (2-tailed)	.		
Predicted Number of People (Summer Equation)	Correlation Coefficient	-.17**	1.000	
	Sig. (2-tailed)	.000	.	
Predicted Number of People (All-seasons Equation)	Correlation	-.09**	.64**	1.000
	Sig. (2-tailed)	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 192 presents the scatter plot of the Predicted Number of People and the Observed Number of People. The results suggests that in both equations the predictions can over calculate the Number of People since the zero value was not achieved, while an empty square was a condition frequently observed in the Mock Scenario.

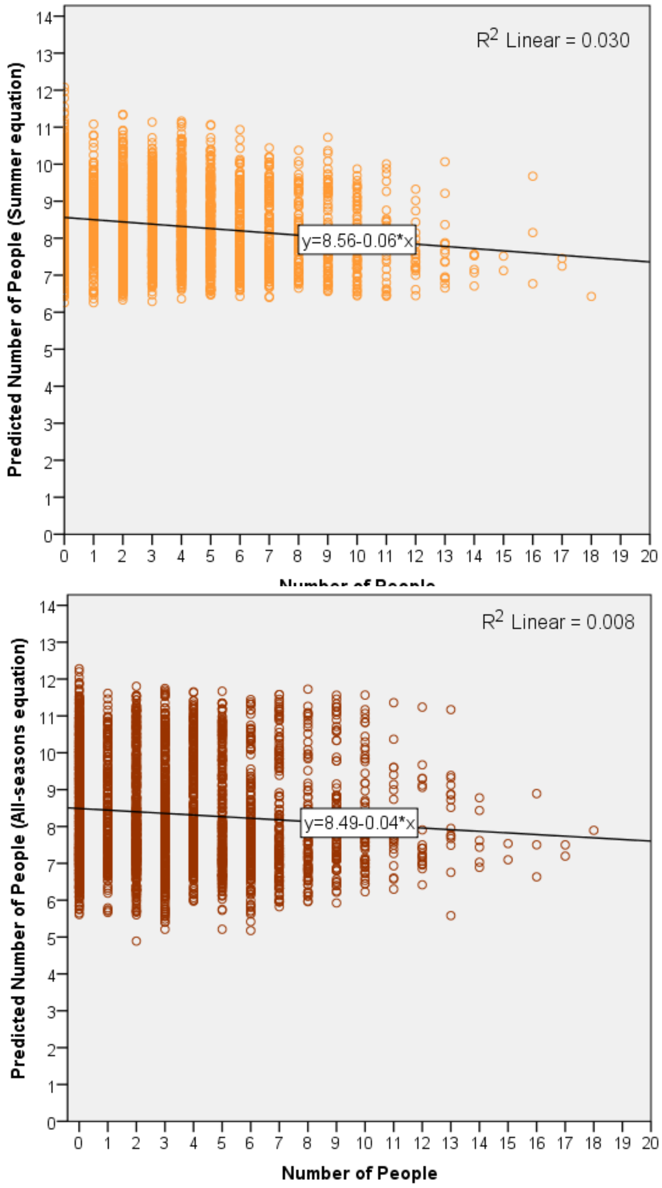


Figure 192 - Scatter plot Number of People and the Predicted Number of People. Top: Summer equation. Bottom: All-seasons equation

In conclusion, the summer and the all seasons' models had a low performance predicting the Number of People in the Mock Scenario. It is interesting to observe that the models are failing to calculate small amounts of people between 0 and 6, which was one of the most frequent conditions in the Mock Scenario but the less frequent conditions in the study of summer 2015.

Validation of the Models of summer and all seasons to Predict Number of G1

The procedure described in the previous section was also used regarding the Number of Groups of G1 in the Mock Scenario. The summer and all seasons' equations produced a predicted Number of Groups G1 which was compared with the observed Number of Groups G1 during the Mock Scenario. The maximum Number of Groups of G1 observed in Trinity Square was 23 while in the Mock Scenario it was 4; therefore, these values were used to adjust the calculations.

The equations produced in summer and all-seasons (Chapters 5 and 8) to calculate the Number of Groups G1, were as follows:

$$G1\_summer = 5.905 + (0.003 * Light)$$

$$G1\_allseasons = 2.307 + (0.207 * Tg_{sun}) + (0.0001 * Light) + (-0.451 * Va)$$

Table 143 presents the correlation between the Number of Groups of G1 observed in the Mock Scenario and the prediction using the equations obtained from the summer and the all seasons' studies.

It is observed that the correlation using the summer equation is negative ($r= -.08$, $p < .001$), while in the all-seasons equation it is positive ($r= .06$, $p < .001$). The all seasons' equation showed a higher relationship between the observed and the predicted values.

Table 143 - Correlation between Number of Groups of G1 Mock Scenario, Predicted Number of G1_summer and Predicted Number of G1_all-seasons

Spearman's rho Correlations (N = 3351)

		Number of Groups of G1 (Mock Scenario)	Predicted G1 (Summer)	Predicted G1 (All-seasons)
Number of Groups of G1 (Mock Scenario)	Correlation Coefficient	1.00		
	Sig. (2-tailed)	.		
Predicted Number of Groups G1 (Summer Equation)	Correlation Coefficient	-.08**	1.00	
	Sig. (2-tailed)	.000	.	
Predicted Number of Groups G1 (All-seasons Equation)	Correlation Coefficient	.06**	.76**	1.00
	Sig. (2-tailed)	.001	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

The scatter plots show that the results using the equation of summer are predicting up to 12 groups of G1, while the maximum for the mock scenario was 4. On the other hand, the equation of all seasons presented a more conservative result as it only predicted one or two groups of G1.

It is observed in Figure 193 that the model from summer is over calculating the Number of Groups of 1 with values between 3 and 12, while the observation presented values between o and 4, therefore the relationship was negative. On the other hand the model from all-seasons is more conservative by calculating values between 1 and 2. In conclusion, the models over and underestimated the results. This may be explained by the fact that the summer sample in Trinity Square never presented a condition of zero people while in the Mock Scenario this was a common state.

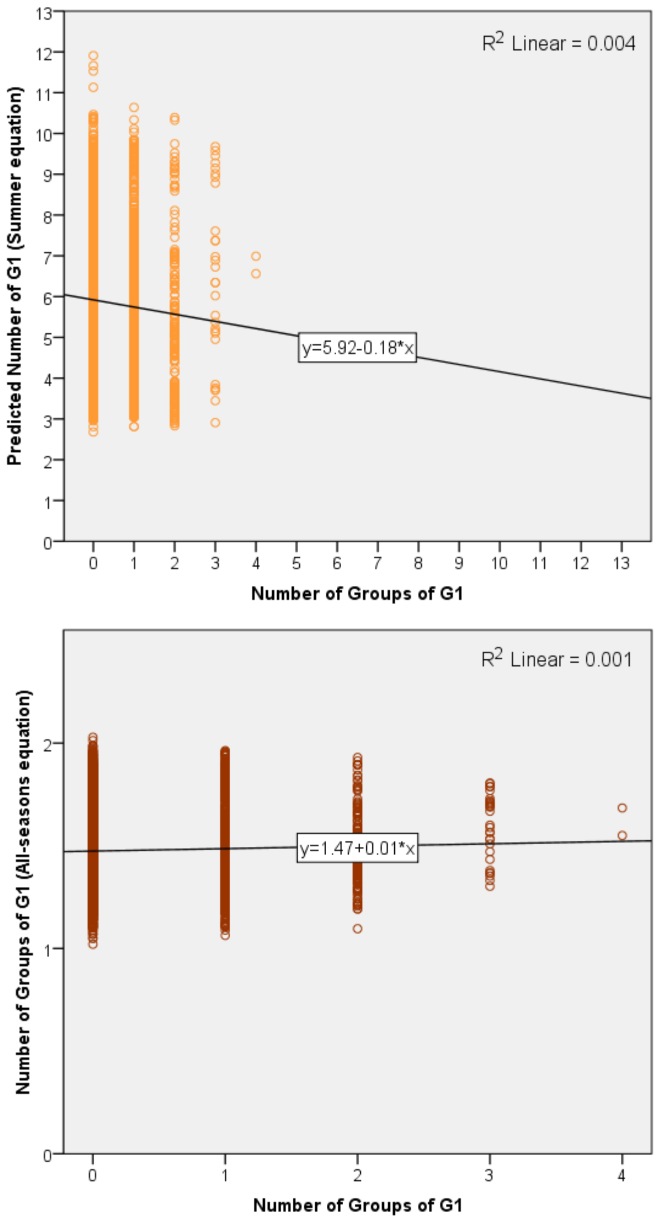


Figure 193 - Scatter plot of the Number of G1 and the Predicted Number of G1. Top: summer equation. Bottom: All-seasons equation

Validation of the Models of summer and all seasons to Predict Number of G2

The maximum Number of Groups of G2 observed in Trinity Square was 17 while in the Mock Scenario it was 3. These values were taken as reference to adjust the calculations. Table 144 presents the correlations between the Number of Groups of G2 and the predicted number of G2 using the summer and all-seasons equations. It is observed that there was no significant correlation using the summer equation and a weak significant relationship using the all-seasons equation ($r = .04$, $p < .001$).

Table 144 - Correlation between Number of Groups of G2 Mock Scenario, Predicted Number of G2_summer and Predicted Number of G2_all-seasons

Spearman's rho Correlations (N = 3351)

		Number of G2 (Mock Scenario)	Predicted G2 (Summer)	Predicted G2 (All-seasons)
Number of Groups G2 (Mock Scenario)	Correlation	1.000		
	Sig. (2-tailed)	.		
Predicted Number of Groups G2 (Summer Equation)	Correlation	.03	1.000	
	Sig. (2-tailed)	.107	.	
Predicted Number of Groups G1 (All-seasons Equation)	Correlation	.04*	.68**	1.000
	Sig. (2-tailed)	.011	.000	.

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 194 shows that the all seasons' model was not able to calculate occupancies of more than 1 group of G2, while the real data had up to three groups of G2.

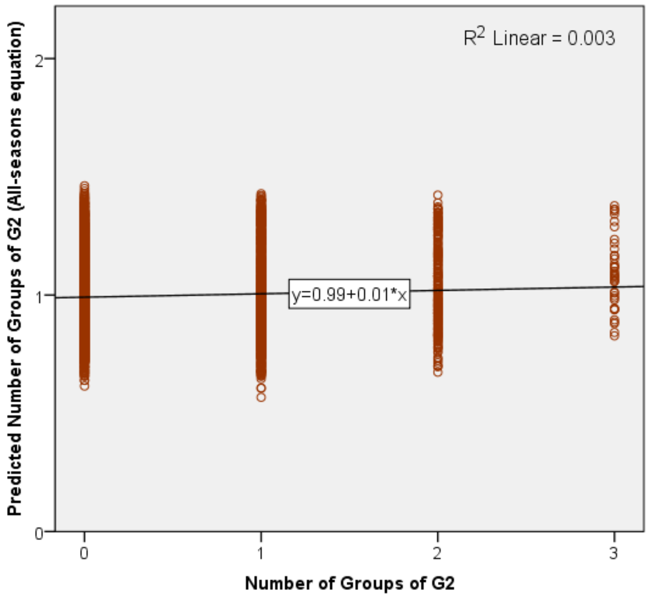


Figure 194 - Scatter plot of the Number of G2 and the Predicted Number of G2, all-seasons equation

Validation of the Models of summer and all seasons to Predict Number of G3

The maximum Number of Groups of G3 in Trinity Square was 8 and the maximum number of groups of G3 in the Mock Scenario was 2. Therefore, these values were used to adjust the calculations.

Table 145 presents the correlations between the Number of Groups G3 and the predictions of the summer and all-seasons' equation for this variable. The predictions presented a significant negative relationship with the behaviour.

Table 145 - Correlation between Number of Groups of G3 Mock Scenario, Predicted Number of G3_summer and Predicted Number of G3_all-seasons

Spearman's rho Correlations

		Number of G3	Predicted	Predicted G3
Number of Groups G3 (Mock Scenario)	Correlation Coefficient	1.000		
	Sig. (2-tailed)	.		
Predicted Number of Groups G3 (Summer Equation)	Correlation Coefficient	-.080**	1.000	
	Sig. (2-tailed)	.000	.	
Predicted Number of Groups G3 (All-seasons Equation)	Correlation Coefficient	-.049**	.564**	1.000
	Sig. (2-tailed)	.004	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 195 shows that the performance of both models was poor, since the prediction did not reach 1 Group of G3. However, this result was expected as these models had presented a weak performance to predict G3 during the internal cross-validation conducted in the seasonal studies, as reported in Chapters 5 and 8.

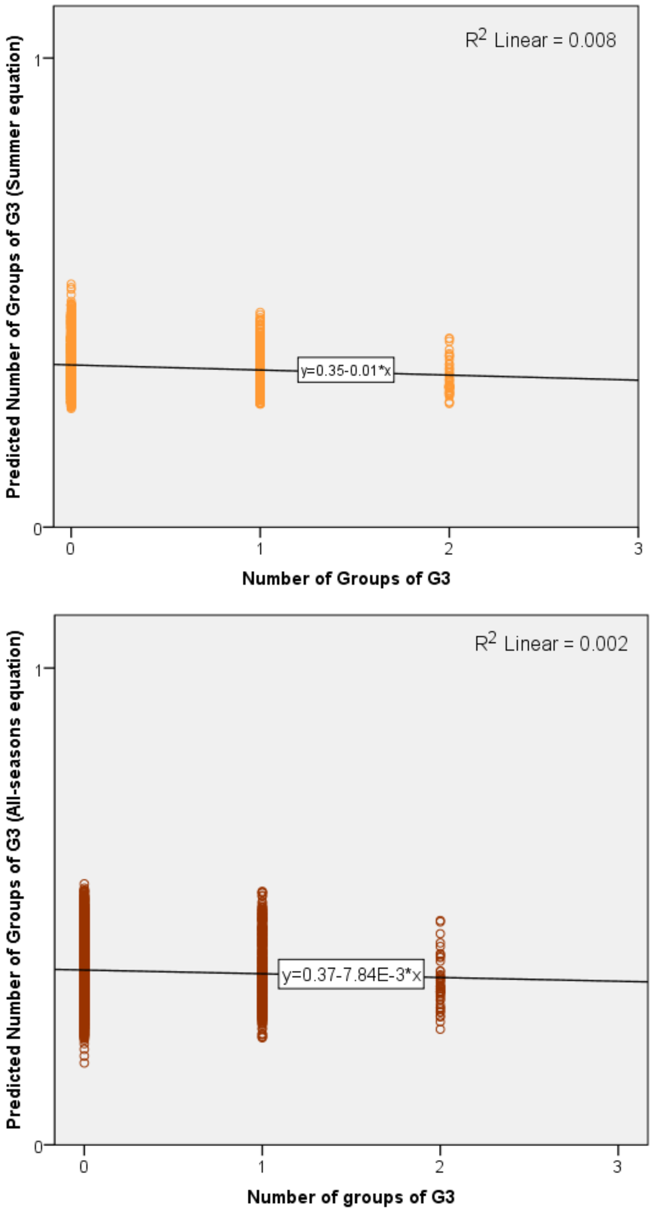


Figure 195 - Scatter plot of the Number of G3 and the Predicted Number of G3. Left: summer. Right: All-seasons.

Validation of the Models of summer and all seasons to Predict Number of G4more

The maximum Number of Groups of G4more observed in Trinity Square was 6, while in the Mock Scenario it was 3. These values were therefore taken as reference to adjust the calculations. Table 146 and Figure 196 present the correlations between the Number of Groups of G4more and the predictions using the summer and the all-seasons equations. A negative correlation was observed in both models.

Table 146 - Correlation between Number of Groups of G4 Mock Scenario, Predicted Number of G4_summer and Predicted Number of G4_all-seasons

Spearman's rho Correlations

		Number of G4more	Predicted G4	Predicted G4
Number of Groups G4 (Mock Scenario)	Correlation Coefficient	1.000		
	Sig. (2-tailed)	.		
Predicted Number of Groups G4 (Summer Equation)	Correlation Coefficient	-.076**	1.000	
	Sig. (2-tailed)	.000	.	
Predicted Number of Groups G3 (All-seasons	Correlation Coefficient	-.086**	.77**	1.000
	Sig. (2-tailed)	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

A similar performance was observed with the results reported in Chapter 5, where the correlation between the prediction and the Number of G4more was r= .065. The Mock Scenario presented a negative relationship but also overestimated the calculation of the number of groups of G4more. Conversely, the results from the all seasons underestimated the calculation, as happened in the internal cross-validation conducted in the all seasons experiment (Chapter 8).

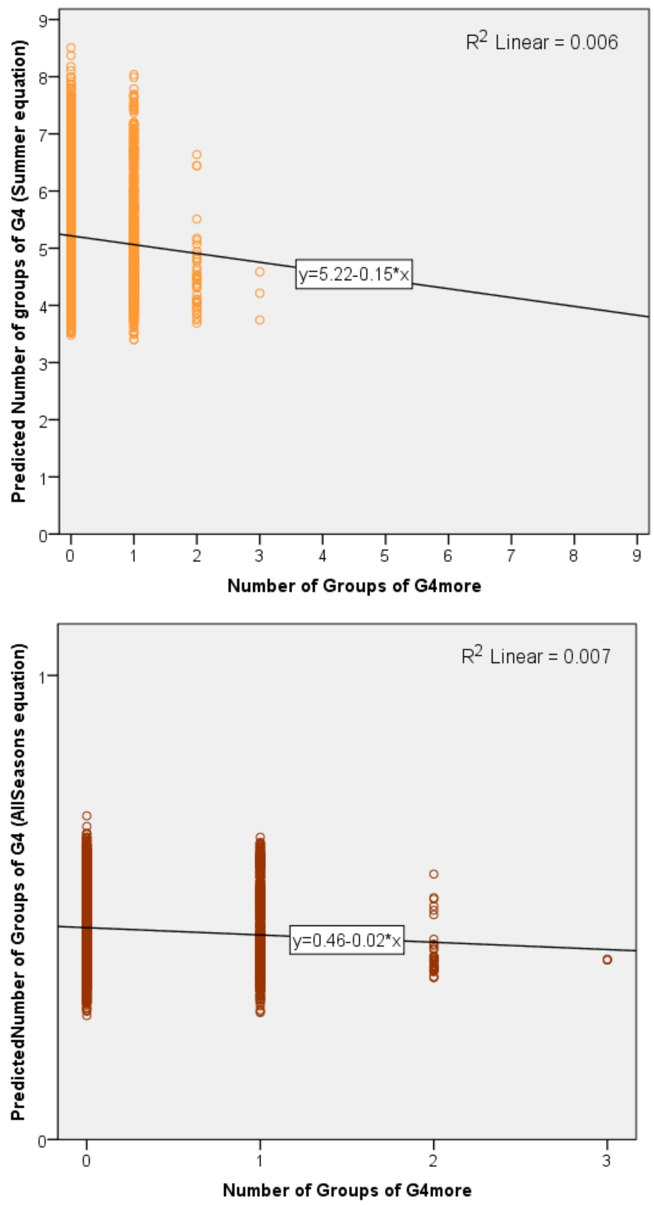


Figure 196 - Scatter plot of the Number of G4more and the Predicted Number of G4more. Top: summer. Bottom: All-seasons.

9.4.3. Individual Behaviour

This section will present a comparative analysis of the individual behaviour of the results in the Mock Scenario and the studies conducted in summer and all-seasons. The analyses were conducted using the same methods: survival analysis and frequencies.

9.4.3.1. Survival Analysis

Table 147 exposes the frequencies of the Time of Permanence during the Mock Scenario. A mean of 12.4 minutes was observed with a standard deviation of 13.2 minutes, which suggests a high variability.

Table 147 - Frequencies of the Time of Permanence

Statistics

Time of Permanence	
Mean	12.4
Median	8.3
Std. Deviation	13.2
Minimum	.3
Maximum	77.1

The first analysis conducted was the Time of Permanence per Gender and Age (Figure 197). It was observed that gender did not influence the time people decided to remain in the place. The Log Rank comparison was conducted to test whether there were differences between the male and female curves and the significance was $p > .62$, indicating no difference between both curves. The analysis per age presents a similar behaviour between adults and teenagers; however, the Time of Permanence of children and people with reduced mobility: Children presented a lower permanency than adults after 10 minutes in the square and Reduced Mobility a longer permanency than adults, starting from minute 5 of their presence in the square.

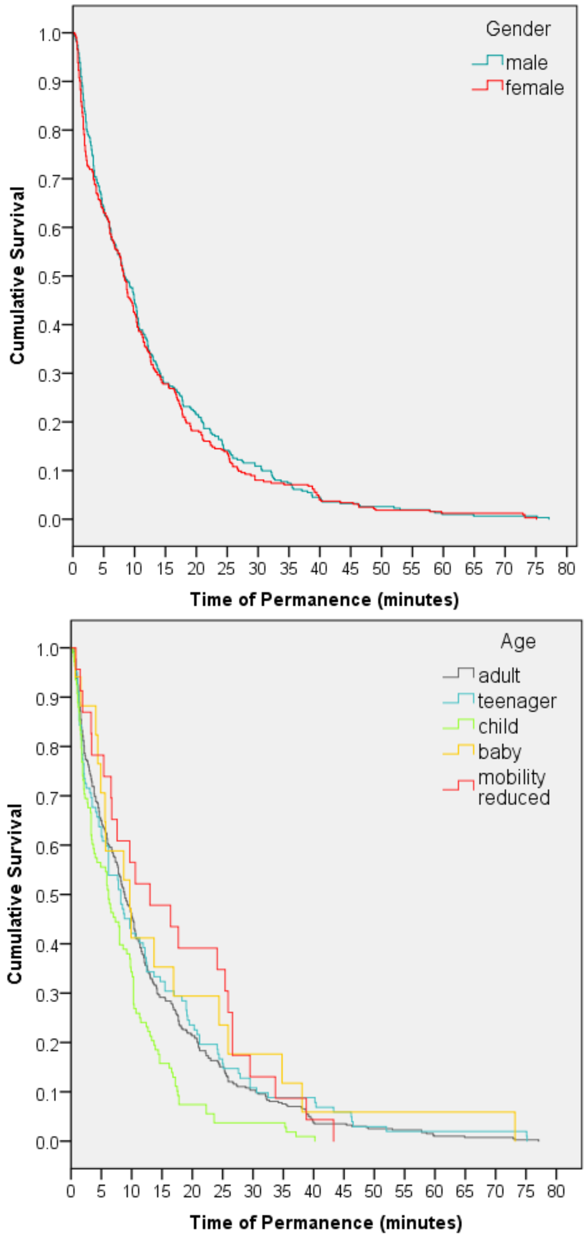


Figure 197 - Time of Permanence. Left: According to the Gender. Right: According to the Age

Subsequently, the relationship between environmental variables and Time of Permanence was evaluated. As reported in the seasonal studies, the environmental variables were binned in order to create the cumulative curves (e.g. air temperature was binned at 1^{o}C, and relative humidity was binned at 5%).

A high variation was observed between the curves with all the environmental factors (Figure 198). It was interesting to see that the users presented the longest permanencies at relative humidity between 30% and 40% rH, which are the medium values registered for this factor.

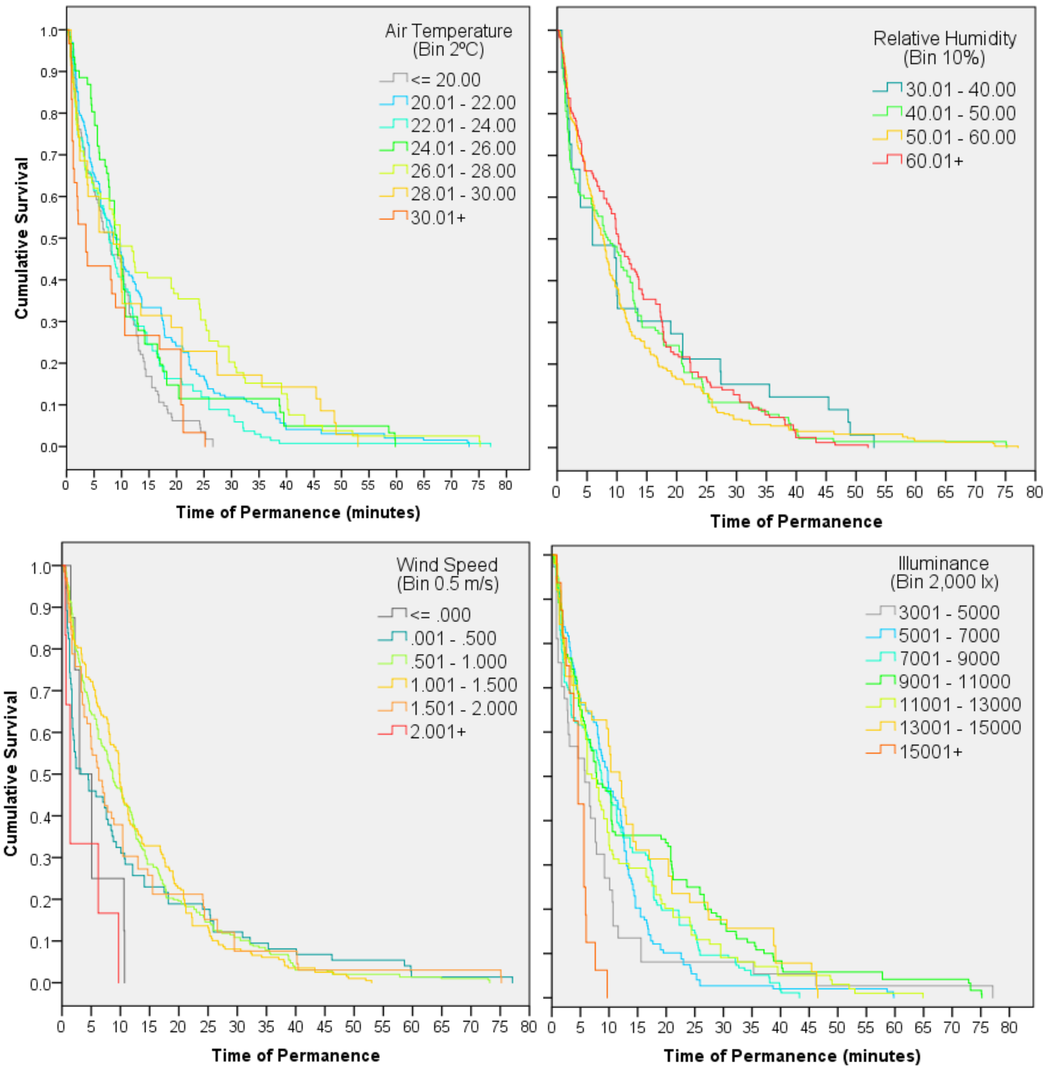


Figure 198 - Time of Permanence and air temperature, relative humidity, wind speed and illuminance

It was also observed that the survival curves of time of permanence were similar for almost all the ranges of wind speed, except for the highest and the lowest condition, during which the lowest permanencies were observed.

The globe and mean radiant temperatures presented high variability in the Time of Permanence. The curves were however more uniform in the mean radiant temperature in the shadow, which indicates more similar permanencies in the different ranges of this environmental factor. It is observed that up to 0.4 (which is the time when 60% of people had left the place) the curves between 25^{0} C and 45ºC presented similar behaviours. This indicates that the Time of Permanence was not affected by the mean radian temperature.

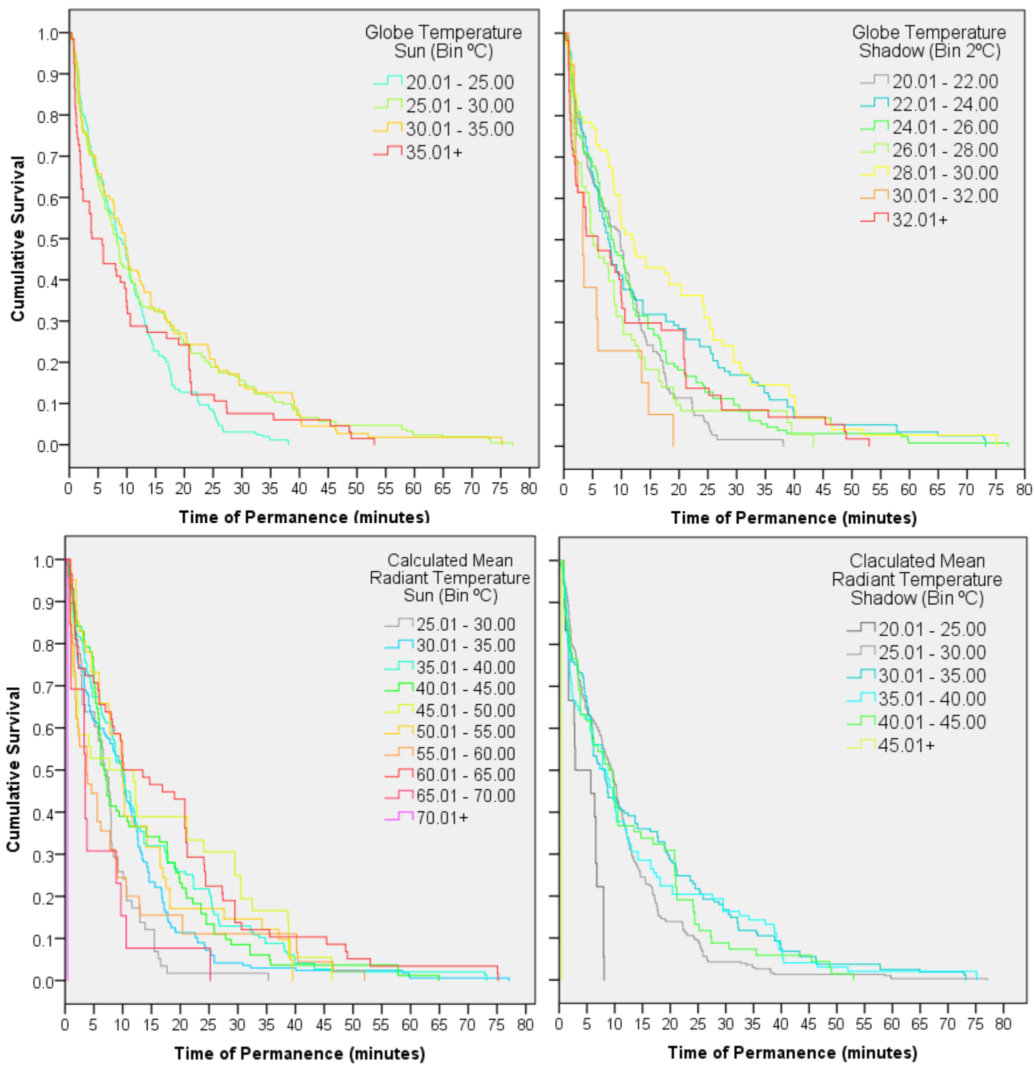


Figure 199 - Time of Permanence and globe temperature (sun and shadow) and mean radiant temperature (sun and shadow)

The Mock Scenario also included the analysis of the influence of the type of furniture over the Time of Permanence of the users. For this analysis, the maximum time spent per person in each bench was evaluated (Floor, Long Bench, Deck Chair, Garden Bench and Stool). Figure 200 presents the percentage of use of each type of furniture. It is observed that the stool was the less used chair, while the garden bench was the most preferred furniture to sit.

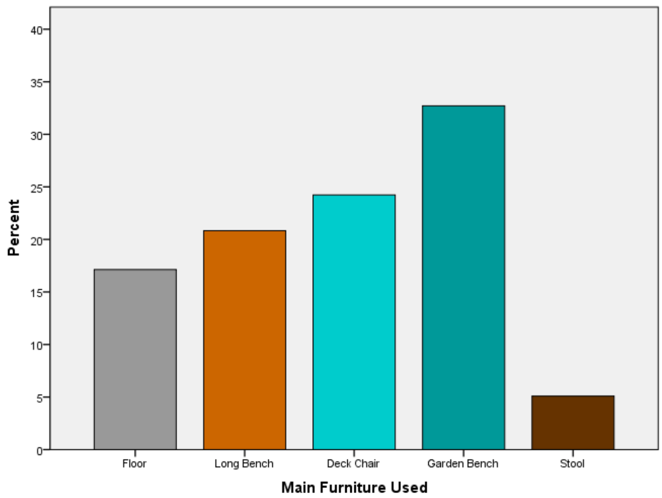


Figure 200 – Percentage distribution of the main furniture used per person

Figure 201 presents the cumulative survival of time of permanence according to the type of furniture. It was observed that people tend to remain longer while sitting in the stool. Nevertheless, the longest permanence was registered in the garden bench. In addition, the garden bench and the deck chair presented similar survival curves, while the long bench presented a curve slightly recessed indicating a shorter Time of Permanence.

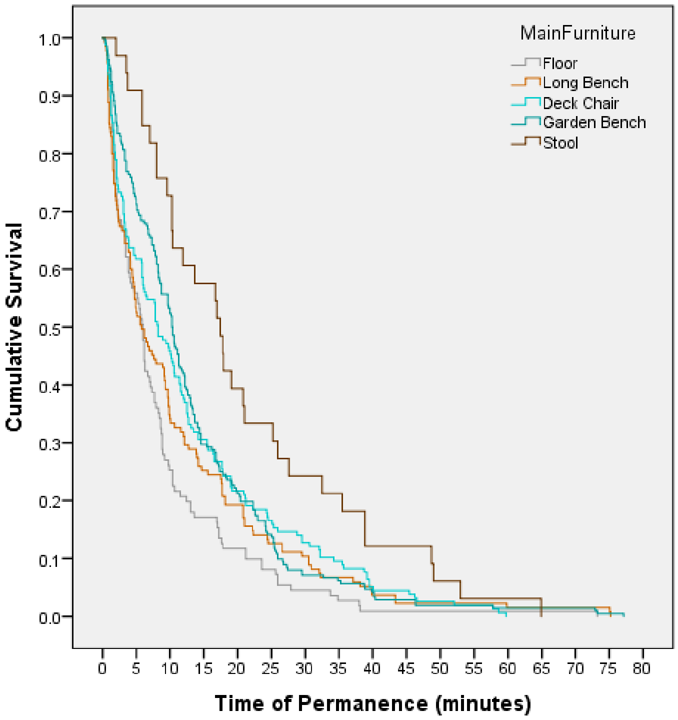


Figure 201 – Survival function curves of the Time of Permanency and Furniture type

Similarly, the time of permanence was analysed according to the type of protection or shelter available in the different scenarios. The options the users had when staying in the seating area were: 1. no protection, 2. parasol and wind barrier (shadow and wind protection), 3. parasol (shadow) and wind barrier (wind protection). Figure 202 presents what percentage of users chose protection or no protection during most part of their stay in the mock scenario. As can be observed, more than 75% of the attendants decided to sit in furniture without protection, while each protection were used approximately for a similar percentage of attendants. However, it must be said that the percentage of people using any protection did not exceed 10% and were very close in preference to each other.

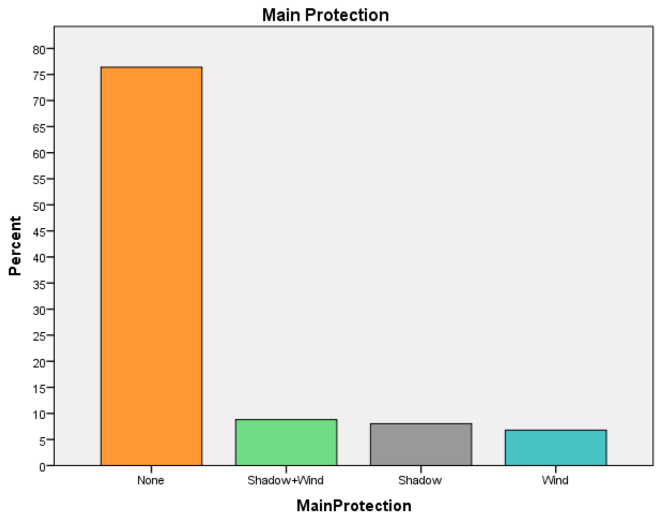


Figure 202 – Percentage distribution of the main protector used per person.

Figure 203 shows that the Time of Permanence was longer for the subjects deciding to stay in the 'shadow' and 'shadow+wind' protections. Conversely, users without any protection left faster the Mock Scenario than the users with any kind of protection. The wind barriers did not present a significant influence on the time of permanence, since the cumulative curve is similar to the curve of 'no protection'.

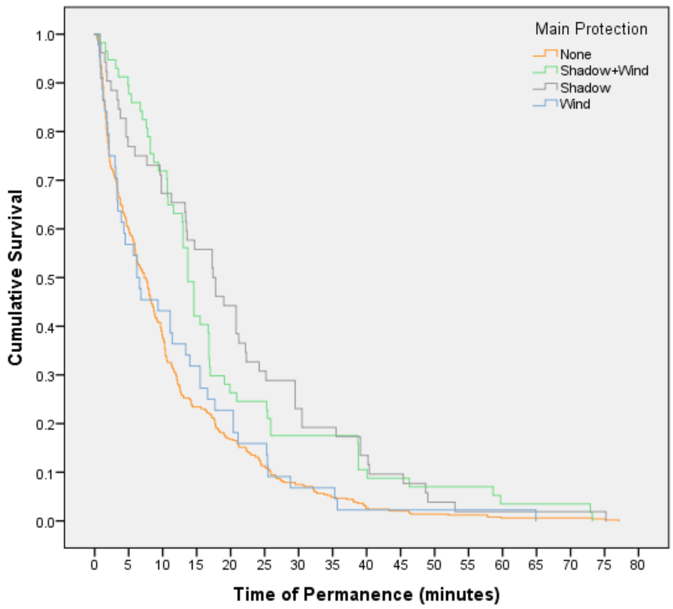


Figure 203 – Survival function of the Time of Permanence according to the protector

9.4.3.2. Activities

The activities observed in the Mock Scenario are listed in Table 148. New activities were considered in comparison with the seasonal studies, to include a more comprehensive set of activities.

Table 148 – Sum of Activities

Descriptive Statistics

Activities	Sum
Using a Device	192
Eating Ice Cream	175
Eating	85
Baby Sitting	67
Taking Photos	42
Talking Mobile	30
Kissing/Hugging	26
Pokemoning	24
Reading	15
Smoking	10
Climbing	10
Cuddling	7
Listening Music	6
Playing	3
Sleeping	2
Walking a Dog	2

In addition, Figure 204 presents the percentage of people performing each activity. From the people observed, around 30% were using mobile devices, which was the most common activity

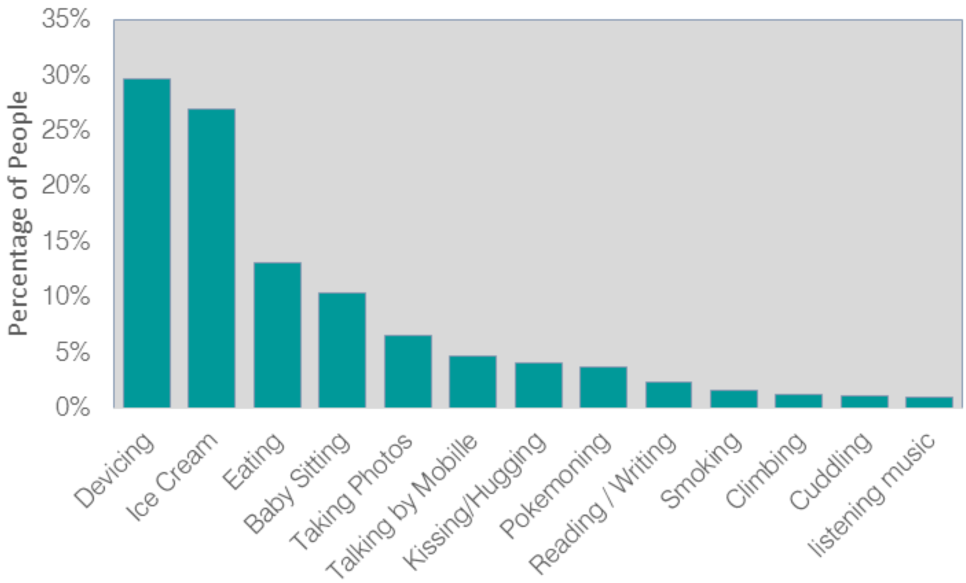


Figure 204 – Percentage of people that performed the activity

9.4.3.3. Adaptive Actions

The Mock Scenario also conducted a study of the frequency of occurrence of adaptive actions. Table 149 presents the sum of the number of people performing those adaptive actions and Figure 205 presents the equivalent percentage. It is interesting to observe that Drinking Hot was the most frequent Adaptive Action. Another interesting behaviour was relocating, which was codified when people changed the place of sitting. In addition, a simple behaviour like moving furniture, constituted the fourth more performed adaptive behaviour. It was codified when the user changed the location or orientation of the furniture in order to get it closer to other users or change the view among others.

Table 149 - Sum of Adaptive Actions

Descriptive Statistics	Sum
Drinking Hot	72
Relocation	53
Drinking Cold	50
Moving Furniture	42
Glasses On	20
Adding Clothes	17
Relocation to Shadow +	16
Glasses Off	13
Removing Clothes	12
Relocation to Wind	5
Relocation to Shadow	4

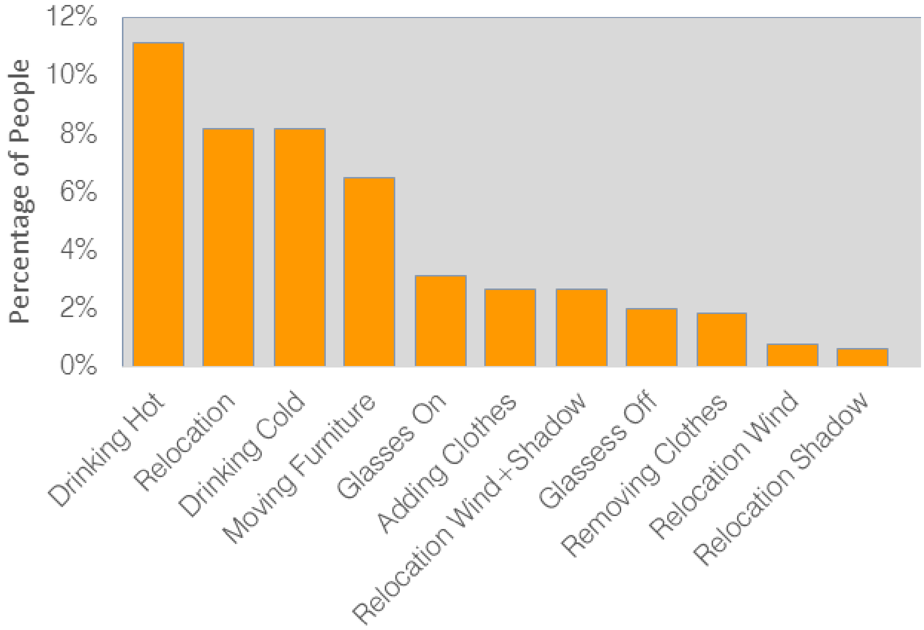


Figure 205 - Percentage of people that conducted the Adaptive Action

9.4.3.4. *Body Postures*

Table 150 presents the frequency and percentage of the people that adopted a main posture during their stay in the Mock Scenario. As can be observed, from all the postures, the highest percentage of people adopted Sitting Standard (35.5%), while sitting backrest was the second most adopted posture with 26.9%. Laying Down is considerably high despite being the fourth posture with most percentage of people in this position (9%).

Table 150 - Percentage of people that conducted the Adaptive Action

Body Postures

	Frequency	Percent	Cumulative
Total	648	100.0	
Sitting Standard	230	35.5	76.4
Sitting Backrest	174	26.9	40.9
Standing	102	15.7	92.4
Laying Down	58	9.0	13.9
Walking	49	7.6	100.0
Wheelchair/Pram	19	2.9	3.5
Other	16	2	104

9.5. Discussion

This experiment aimed to generate an external validation of the conclusions of the previous studies by comparing the results in a different context. Despite being in the same city, the location of the Mock Scenario was found to have dissimilarities regarding certain environmental factors, compared to the seating area where the seasonal study of summer 2015 was conducted (Trinity Square at Nottingham city centre). It was for instance observed that the recorded days were warmer and brighter in the Mock Scenario than in the seasonal study of summer. Additionally, the fact that the Mock Scenario is located near a lake appears to contribute in the difference of certain environmental conditions such as Relative Humidity, which is a factor that gained relevance among all the other environmental variables as an influencer of the human behaviour.

Since the environmental variables did not present enough homogeneity with the conditions observed in the seasonal studies conducted in Trinity Square, the Mock Scenario study did not test the performance of the equations produced in the Trinity Square studies, although the information obtained is valuable to analyse other environmental variables and human behaviours, as well as the use of pressure sensors to measure the time of use of furniture.

Regarding the influence of environmental factors, Light in summer 2015 (Chapter 5) as well as light in the Mock Scenario, presented correlation with all the variables, especially with Number of People. However, in the Mock Scenario this correlation was negative, suggesting that as the light levels increased the number of people and groups decreased. Strangely during the seasonal study of summer 2015 in Trinity Square this phenomena was inverse as the correlation was positive, meaning that the Number of People increased as the intensity of light also increased. It should be however remembered that during the Mock Scenario, the light intensity was much higher than the reported during the seasonal study of summer 2015: The minimum level registered in the mock scenario was 3,000 lx when in the summer seasonal study the minimum was 1,000 lx. This differences in the measurements could be explained by the differences in the time of the year during which these two studies were conducted and also because of the differences in the two locations regarding materials and surfaces' colours among others. Accordingly, the difference in the outcome could indicate a change in the perception of users when the levels of light exceed certain level, after which it stops influencing positively and starts to affect the occurrence of the behaviour. In consonance with, it has been reported by Lin et al., (2013) after reviewing several studies of thermal comfort in outdoors, that the relationship between attendance and thermal indices was positive in winter and summer for temperate regions (northern and southern latitudes), while it was positive in winter and negative in summer for subtropical regions. Therefore, this result may suggest that the positive perception of light can change during summer when the light levels surpass certain levels.

In general, the models to predict Number of People and Number of Groups did not perform well, since the correlations between the observed values and predicted values were low. The differences between the results helped to identify the reasons why these models did not perform as well as they did in the seasonal studies:

- **Scale:** The scale of the place in the Mock Scenario is an important factor to generalise environmental and human behaviour equations. It was observed that the models presented difficulties in calculating small amounts of people or groups, which suggest a problem of the equation regarding the size of the place and its capability to have more or less people. This means that these equations did not permit "stretching" their capabilities by using environmental data to be applied in a smaller (or bigger) space. Accordingly it would be expected a better performance of the model in spaces with similar sizes than the one in which it was made.
- **Occupancy of the place:** In addition to the scale of the place, the occupancy may also affect the predictions. It was for instance observed in the model to predict Number of People that the equation was not able to calculate values below 6 people (but performed well over this number). This coincides with the fact that during summer Trinity Square had at least 4 people present in the space evaluated and

was never found to be empty. In addition, most of the time it presented occupancies between 10 and 35 people (which is around 20% to 50% of the highest occupancy). Conversely, the Mock scenario zero people was observed in the place during at least 30% of the time. This means that the occupancy of the place also affects the predictability of the equation, since a model for the Mock Scenario would need to be able to register a high frequency of low or zero occupancy. This could have happened also with the illuminance, as the sampled data of the behaviour obtained in the mock scenario was obtained mostly between 4,000 (lx) and 18,000 (lx), while in the seasonal studies most of the data ranged between 1,000 (lx) and 21,000 (lx).

- **Constant Variables:** A multiple regression model is built under the premise that the interpretation of the results are true only if the predictor variables are held constant (Field, 2009). The Mock Scenario presented variability in the conditions exceeding the ranges of the predictor variables: The mock scenario presented warmer days than the seasonal study and the Relative Humidity presented an inverse influence over the behaviour compared with the seasonal study. This variation breaks the rule of the multiple regression model since the predictor variables were not held constant, affecting the performance of the model.
- **Spontaneous Behaviour:** The seasonal studies were focused in capturing the behaviour of people as spontaneous as possible. The Mock Scenario was an intervention that induced the behaviour of people to remain and sit in the place. Therefore, the data gathered lost spontaneity since the installation was a temporary seating space and the possible users were not used to it.

Regarding the time of permanence, the study reported no difference between men and women, or between adults and teenagers. Nevertheless, the curves of permanence were different between children, babies and people with reduced mobility. This could be explained by the fact that these users depend on other people to leave the place. In addition, these users tend to require more facilities such as toilet or transport, which can also affect the way they spend their time in the space.

A high variability was observed of the Time of Permanence with the environmental conditions. The relative humidity presented the longest permanencies in the mid values (between 45% and 55%), this agrees with the observations obtained from the study conducted in summer, where the mid and low values also presented the longest times. It also confirms the idea that people are not good at judging changes in the humidity levels unless they are too high or too low (Nikolopoulou & Lykoudis, 2006); therefore, the mid-values are found as acceptable conditions to remain.

The Time of Permanence was also influenced by the type of furniture. It was observed that the garden bench was the most popular furniture and presented the longest survival curve. This result may relate to the fact that the garden bench was an attractive seat for elderly since the armrest worked as a support to sit and stand. This bench was also constantly used by couples or families that wanted to share the seat. The stool was the less frequently used chair but presented long time of permanencies; however, this was flexible furniture that users tended to relocate. This behaviour of moving furniture was frequently observed, even if it was just to move them a few centimetres. William Whyte (2009) reported this action as a human declaration of their free will by adapting the space to the desired conditions.

It was also observed that the protection elements (parasol and wind barriers) also influenced the permanence of people. People had always the choice to remain in a protected or unprotected area. The condition most frequently registered was being unprotected by parasol or wind barrier. According to Gehl (2011) people in northern latitudes prefer to sit in sunlight areas which agrees with the frequency of use presented in the Mock Scenario. However, it was observed that the longest Time of Permanence occurred with 'shadow' and 'shadow + wind', which suggests that the exposition to the solar radiation can reduce the time people spent in the place.

It was interesting to find that the most popular activity observed in the city centre 'Smoking' was not frequently observed in the Mock Scenario. However the second activity during the seasonal study in summer 2015, 'Using a Device', was the most frequent activity registered in this Mock Scenario experiment. Hampton et al., (2010) conducted a study about the changes of the behaviour in public spaces over the last 30 years. The authors found that the use of phones was one of the main changes observed in the video analysis. The authors suggested that this behaviour can increase the social isolation. As an anecdotal reference of the data collection, a new behaviour was included for coding called 'Pokemoning'. This refers to the activity some people conducted of playing *Pokemon Go* on their devices, which was characterised by specific behaviour such as making a gesture up in the screen of their mobile device with one finger and standing still in the space, among others. This was a game that produced a new behaviour of users in the public space. The way of using the space through a device using augmented reality modified the interaction of users with the space. As exposed by Hampton et al., (2010) significant changes may occur in the behaviour through the time. In consequence, the interaction with objects and other factors are constantly generating new behaviours.

Finally, the most common adaptive action was 'Drinking Hot'. In Chapter 08, was reported that the most frequent Adaptive Actions among all the seasons were drinking hot and cold. However, it was said in this Chapter that the influence of the environmental variables was not observed. According to Fergus et al. (2013), having a hot drink in response to a hot environment can induce sweating which helps with the thermoregulation of the body.

9.6. Conclusions

The Mock Scenario was conceived as an external validation set in a custom made public space resembling the characteristics of a public seating area.

The same methodology was applied finding that it is possible to adequate the same equipment and processes to evaluate other public spaces. It was however observed that some of the environmental variables in the Mock Scenario space were considerable dissimilar than those in the Seasonal Study place. It was also observed that some other factors may have affected the behaviour in the Mock Scenario than they did in the seasonal study conducted in a Square in Nottingham city centre. It is suggested that there might have been a lack of spontaneity from some of the users of the Mock Scenario, or other factors not accounted in this research.

Further studies would be required to conduct an external cross-validation using the learning obtained from the Mock Scenario in order to guarantee that the conditions of the multiple regression models remain constant and that the external influence of unaccounted factors remains as low as possible. Finally, the external cross-validation should procure that the square of study is as similar as possible to the original study of Trinity Square in terms of size, scale and sample.

10. General Discussion and Conclusion

10.1. Chapter Overview

This chapter presents a summary of the main findings of this research. The outcomes obtained in the individual three seasonal studies, all-seasons together, and the mock scenario will be discussed. In addition, design recommendations are proposed for Trinity Square in Nottingham City, where the seasonal studies were developed. Moreover, the novel contributions of this work to the research field are presented. Limitations to the work are discussed and finally, suggestions for further studies are made.

10.2. Introduction

The overall aim of this research was to study human behaviour when people are exposed to different environmental conditions in outdoors. Throughout the research, the methods to study behaviour and environmental factors were assessed. A representative dataset was collected and a statistical analysis to predict the occurrence of the behaviour was conducted. Around 6000 people were codified for the individual behaviour analysis and more than 189 hours of video analysis was conducted to codify social behaviours.

The motivation to study the influence of the environmental factors on human behaviour emerged from the lack of previous data which could explain and quantify this relationship. Some of the previous research has studied the relationship from the perspective of thermal comfort and human behaviour. However, there was still a gap with regard to explaining the relationship between environmental data and the resultant behaviour. It was also recognised that the data collected in most studies focused on the perception of users, i.e. their subjective opinions. In consequence, there was a lack of information about the spontaneity of participant behaviour. The research conducted for this thesis aimed to apply a combination of behavioural methods, together with microclimatic measurements in order to gather sufficient combined data to produce a better understanding of the relationship between human behaviour and environmental factors.

The data collection was developed in three stages: 1. A pilot study: It was conducted in a seating area within the main campus of the University of Nottingham with the aim of testing the proposed methodology and the logistics of conducting a study in an outdoors space; 2. Seasonal studies were conducted in summer and autumn 2015 and winter 2016 to gather the highest possible range of environmental conditions during each season, and ensure that sufficient quantity and range of behavioural data was observed; 3. A mock scenario was conducted in a public space within the grounds of the University of Nottingham with the purpose of collecting data within a controlled set up which could be compared with the findings obtained from the previous studies. Figure 206 presents the aims and outcomes of each stage of this research.

These studies were analysed from two perspectives: social and individual behaviours. After running a multiple regression analysis for the social behaviours and survival analysis and frequency charts for individual behaviours, various models to predict the variance and probability of occurrence of the human behaviours were generated in accordance with the environmental factors.

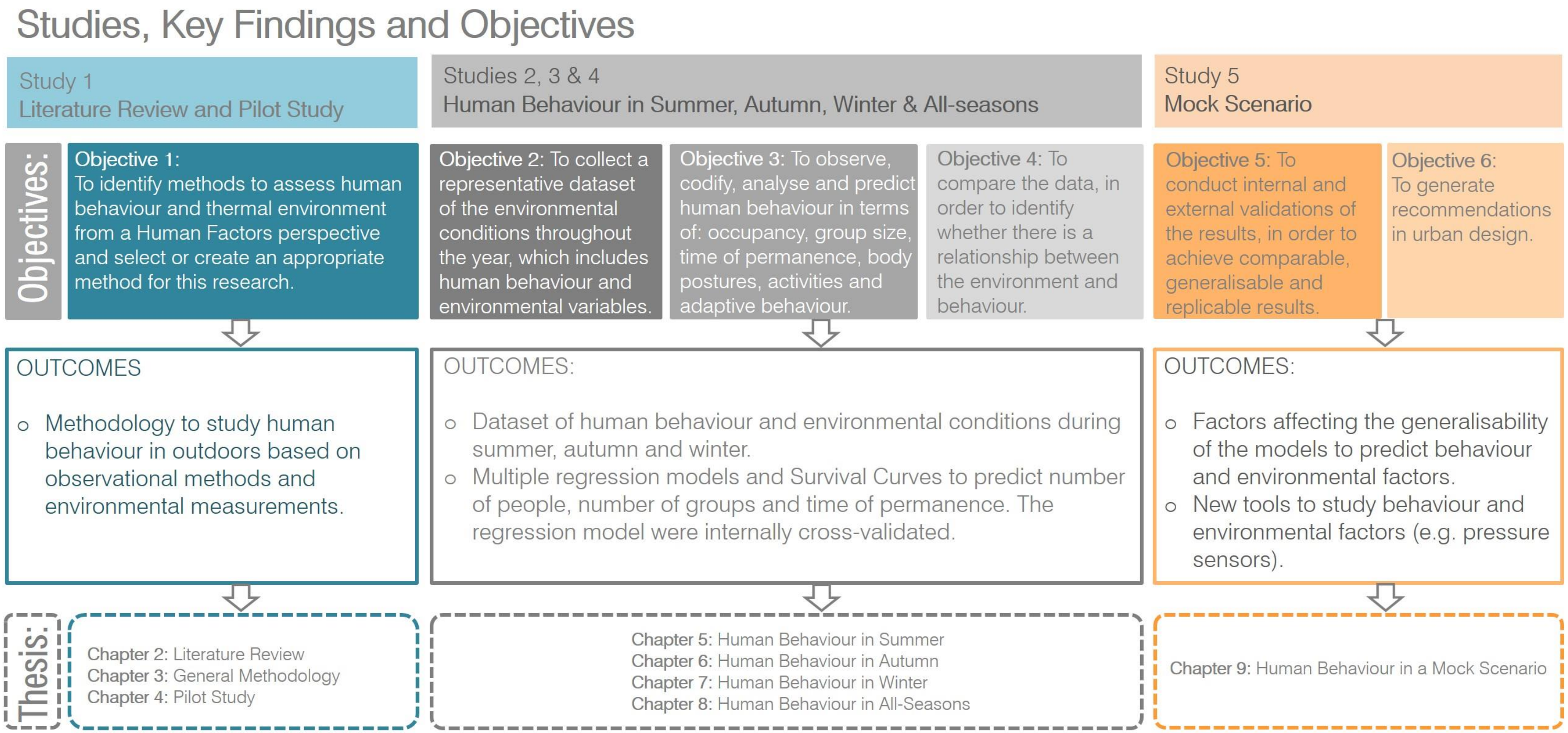


Figure 206 – Relationship between Studies, Key Findings and Objectives

10.3. Discussion of Research Findings

This section presents a critical discussion of the findings of this research, which can be divided in two types: 1. Contribution to the Methodology to study the Human Behaviour in accordance to the environmental factors; and 2. Findings regarding the relationship between Human Behaviour and the environmental factors.

10.3.1. Contributions to methodology to study Human Behaviour and the Environmental factors

This research applied a hybrid methodology based on methods used in previous studies, but adapted to the current needs and objectives. The environmental and behavioural measurement tools, coding scheme and analyses were adjusted and tested in a pilot study and then applied in the main studies. Key outcomes of this research regarding methodology, specifically with regard to measuring globe temperature, dealing with the sun and shadow, and establishing a coding structure to record human behaviour, are discussed in the following sections:

Measuring Globe Temperature

From an equipment perspective, the recommended procedures established in *Ergonomics of the thermal environment. Instruments for measuring physical quantities* (2001) were used to measure the environmental variables. The most complex environmental variable to evaluate was the globe temperature, since it has been conventionally recommended the use of a globe thermometer of 0, 15 m of diameter (Vernon, 1932), or “The most accurate, but also the most costly and complex measurement technique, is the performance of integral radiation measurements and the calculation of angular factors” (Thorsson et al., 2007, p. 1985). However, according to Nikolopoulou et al., (1999) the Vernon globe, which is the most accessible method, can take around 20-30 minutes for the globe to reach equilibrium with the temperature, while measurements outdoors require faster reaction times in order to register the rapid changes of the environmental conditions, especially when conducting measurements every minute. In order to improve these methods, Nikolopoulou et al., (1999) and Thorsson et al., (2007) conducted studies to determine the time and accuracy of response of different globes and found that an acrylic (tennis table) ball of 38 mm has a response time below 4 minutes. Therefore, this study integrated a 38 mm (tennis table ball) globe grey painted with an air temperature sensor in the centre in order to capture the rapid changes of the outdoor conditions. Their results showed that this is the most appropriated method to measure the globe temperature.

Registering sun and shadow

Previous studies registered the zones in the evaluated space with or without solar incidence (Eliasson et al., 2007; Nikolopoulou et al., 2001; Nikolopoulou et al., 2004; Thorsson et al., 2004; Zacharias, 2004; Zacharias et al., 2001). However, the pilot study conducted in this research evidenced that the registration of zones in the square that receive solar incidence or shadow, exclude times when the condition is overcast. Accordingly, this method of analysis is inaccurate as one person registered as arriving to the sunny area, could have arrived when it was overcast (see Figure 32, Chapter 4). In order to minimise the possibilities of error due to the interpretation of these variables, the seasonal studies of this research included two globe thermometers to measure the temperature: one located in the sun and the other in the shadow. By using this new methodology to measure the sun and shadow, the gain or loss of heat were registered in both conditions, which allowed analysing independently each one of them to determine their individual influence over the behaviour of interest.

Coding Behaviour

This research created a coding scheme to obtain a uniform set of data which includes two different types of behaviours, of which the second was not included in any of the previous studies that used observational methods: 1. The social behaviours, which has been defined in the literature as 'aggregates' and is collected by volume in the space (Gehl Institute, 2017); and 2. Individual behaviours, which has been defined by this thesis as the behaviour performed per individual for coding purposes.

The coding scheme covered two stages: observation and analysis of the data. A summary of these procedures are presented below:

As presented in the methodology section of the seasonal studies, two types of analysis were defined by this research, the Social Behaviour and the Individual Behaviour analyses (Figure 207).

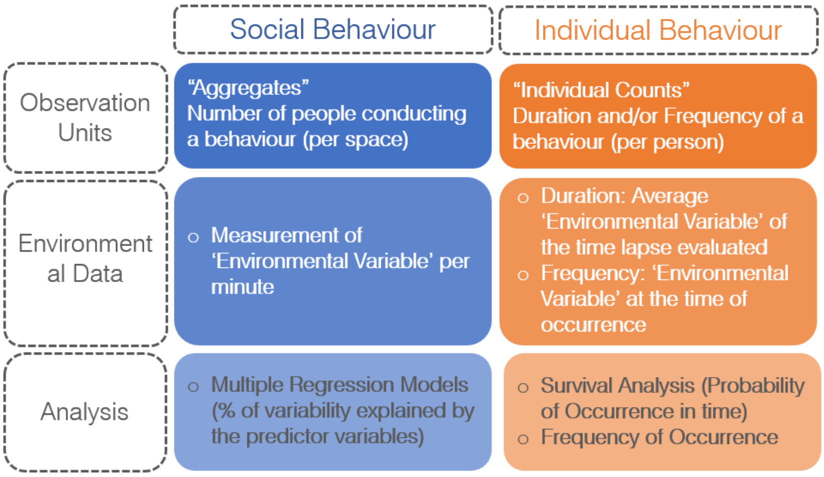


Figure 207 – Structure of the method to code behaviour

This classification constitutes a new methodology to codify the human behaviour in outdoors according to the environmental factors using behavioural or observational methods.

The *Social Behaviour* analysis refers to the count per minute of the number of people and the number of groups present in the place, which is recorded simultaneously with environmental measurements also taken every minute. Most previous studies reported similar techniques but with lower granularity. For example, Nikolopoulou et al. (2001) registered the number of people every 10 minutes by counting people on site, and Zacharias et al. (2001) mapped the number of people six times in four hours by visiting the place and mapping the position of users. Other authors have counted the number of people remaining in certain locations, performing specific activities, or counted demographic aspects such as age or gender (Maruši, 2011; Nasar & Yurdakul, 1990; Zacharias, 2004).

The second type of analysis conducted was the *Individual Behaviour* which consisted of analysing the behaviour per person. The literature review showed an absence of individual analysis in behavioural studies outdoors. However authors such as Whyte (2009), Li (1994) and Gehl (2011) made notes from their observations which included adaptive actions or preferences observed. This research has contributed with a new methodology for coding the human behaviour as it proposed to include in the observational analysis the behaviour of each individual. This is an innovation in the field, as no study has performed before an observational coding and analysis of behaviours per individual, using behavioural methods.

For coding purposes in Observer XT this required creating two types of individual behaviours: state and point events. The state events were defined by this research as individual human behaviours performed in a period of time (e.g. Time of Permanence or Time in the Main Posture) These behaviours were compared with the average of the environmental measurements registered during the time evaluated. On the other hand, the point events were actions registered only once when the event occurred (e.g., smoking or drinking where registered as point events). Point events were compared with the environmental data registered at the moment of the event.

During the data analysis, the Social Behaviour data was evaluated using multiple regression models which permitted generating models capable of predicting up to a certain degree the variance attendance of individuals and groups in the evaluated space, according to certain environmental conditions (i.e. the model to predict the Number of People in winter accounts for 46% of the variance of the behaviour). The Individual Behaviour was analysed using survival analysis for the state events, generating the means and cumulative survival curves of each behaviour, and frequency charts for the point events. The coding scheme developed in this research provides a contribution to the research field as it provides more detailed observations of human behaviour in the outdoor environment than had been conducted previously. Moreover, it also offers the creation of more uniform data sets of human behaviour, as it is flexible and adaptable, as demonstrated in the mock scenario study conducted in this research. This has value to the research community as evidenced by the call from the Gehl Institute (2017) for the development of a protocol of public data aimed to gather data of human behaviour.

10.3.2. Relationship between Human Behaviour and the Environmental Factors

The environmental and social data gathered in each season presented individual outcomes which were different from the results obtained from analysing the whole data set with the environmental data of the three seasons. This is an important difference from previous studies which failed to analyse the environmental and human behaviour data in each season, and instead conducted a general analysis of the data collected. For instance, the regressions conducted by Givoni et al., (2003) and Nikolopoulou et al., (2001) which presented some of the highest correlations with the thermal environment, reported the aggregation of the whole year dataset. Chapter 8 (Human Behaviour in All-Seasons), discussed the power of prediction of the model to predict number of people in summer compared to the model to predict the number of people using the all seasons' data set. The results of the correlation between the predicted and the real number of people using the summer equation were compared with the results of the correlation between the predicted and the real number of people using the all seasons' equation. It was observed that the correlation between predicted number of people and observed number of people was stronger with the summer equation than with the all seasons' equation ($r = .30$ ($p < .001$) for the summer equation and $r = .23$ ($p < .001$) for the all seasons' equation). This means that the summer model performs better than the all seasons' model to predict the variance of the Number of People in summer. This exercise proved that models made using the all seasons' dataset can generalise the behaviour, in which case a seasonal model would be required to understand more accurately the behaviour in that specific season.

This research identified that the relationship between human behaviour and the environmental variables in some seasons were none existent, reduced or presented an inverse behaviour, compared to other seasons. Table 151 presents a list of the environmental variables and behaviours per season, and in the all-seasons analysis. The variables that presented relationships were marked with a plus sign (+) if the correlation was positive or a minus sign (-) if the correlation was negative. One example is globe temperature (Tg_sun and Tg_sha) which was not a main predictor in any of the seasons when considered independently but, when considered using the whole data set, this environmental factor was found to have the strongest relationship with the behaviour analysed. Nikolopoulou et al. (2001) had reported the relationship of globe temperature with the all-seasons dataset, but did not report results per season analysed independently. As mentioned in the discussion of the all seasons study (Chapter 8), sometimes using the model made with the all seasons' dataset could have less predictive power than the model made with the seasonal environmental data, because the seasonal data may explain better the variation of the behaviour in that season. Another example is relative humidity which did not reveal a relationship with human behaviour in the all year data set, but was an important factor during winter. Therefore, this research has shown that the power of the prediction of all-seasons' models of human behaviour could vary depending on season and can also be different when all the data is analysed together. If that is the case, models for the corresponding season should be used to guarantee that the model with the highest power of prediction is used to predict the variance of the human behaviour in the particular season. Accordingly, any study should consider the specific outcomes from each seasonal study in addition to the general outcomes of the whole data set when analysed together before recommendations are made for the design of public spaces. Finally, the time of permanence which were influenced by environmental factors are marked with an 'x' sign in Table 151, as there is no positive or negative relationship between the time dependant variables and the behaviour. Therefore, the survival curves were selected when a pattern was observed in their distribution.

Table 151 - Environmental variables influencing Human Behaviour

Summer								
Behaviour	Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sha	Va	Light
Number of People							+	+
Number of Groups of G1								+
Number of Groups of G2						+		
Number of Groups of G3								+
Number of Groups of G4		+				+		
Time of Permanence		x			x			
Autumn								
Behaviour	Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sha	Va	Light
Number of People					+		-	+
Number of Groups of G1	+							
Number of Groups of G2					+		-	
Number of Groups of G3					+		-	
Number of Groups of G4								+
Time of Permanence	x						x	
Winter								
Behaviour	Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sha	Va	Light
Number of People		-					-	+
Number of Groups of G1		-						+
Number of Groups of G2		-					-	+
Number of Groups of G3	-							+
Number of Groups of G4	-							
Time of Permanence							x	x
All Seasons								
Behaviour	Ta	rH	Tg_sun	Tg_sha	Tr_sun	Tr_sha	Va	Light
Number of People			+				-	+
Number of Groups of G1			+				-	+
Number of Groups of G2			+				-	+
Number of Groups of G3			+				-	
Number of Groups of G4						+	-	+
Time of Permanence				x			x	
Standing							x	
Sitting Standard				x		x	x	x

Acronyms: Air Temperature (Ta), Relative Humidity (rH), Globe Temperature (Tg), Mean Radiant Temperature (Tr), Wind Speed (Va).
'+' Positive Relationship, '-' Negative Relationship, 'X' Pattern of the survival curve

As can be seen in Table 151, the influence of the environmental variables on the behaviour was different in each season, which resulted in different models to predict the variance of the human behaviour for each season and for the all season's data set.

Light and wind presented relationship with behaviour across the seasons. As mentioned in the discussion of Chapter 5 (Human Behaviour in Summer), the finding of light as a predictor of behaviour is an interesting finding because, conventionally, studies of the environment outdoors only consider factors affecting the temperature of the body. Nevertheless, a correlation was also found between light and both globe and calculated mean radiant temperature. This finding supports other findings about the human beings such as the circadian rhythm, which refers to the internal clock that regulates physiological functions, and is highly influenced by light (Emery et al., 1998). This reaction of the human body naturally brings cycles to the urban environment where the peak of use occurred during daylight periods and could be related to the rhythm of the illuminance availability (e.g. as the light increases, the number of people increases).

Table 152 presents the percentage of variability explained by each model of the *Social Behaviour* analysis (which corresponds to the adjusted R^2 of the multiple regression models). As can be observed, the models in summer can explain the lowest percentages of variations of the behaviours in comparison to the other seasons. It was also found that winter presented some of the highest prediction capability models (e.g. the *Number of People* model accounted for 46% of the variance of the behaviour).

Table 152 - Percentage of variability explained by each multiple regression model

Social Behaviour	summer	autumn	winter	all-seasons
Number of People	12%	33%	46%	39%
Number of Groups of G1	9%	10%	37%	23%
Number of Groups of G2	11%	27%	34%	30%
Number of Groups of G3	5%	16%	6%	13%
Number of Groups of G4	5%	10%	3%	9%

Table 151 suggest that the social behaviour was more influenced by the environmental variables during autumn and winter. This may be explained by the fact that summer is a season in which the users remain outdoors notwithstanding changes in the environmental factors as much as they would do in other seasons, due to the preconception of 'good weather' attached to this season, which agrees with the idea of Li (1994) of focusing the urban planning strategies for winter and marginal seasons (autumn and spring) to increase the use of outdoors in these conditions.

It is observed that the model to predict *Number of People* in winter presented an adjusted $R^2 = .46$, $p < .001$ which means that the illuminance levels, wind speed and relative humidity had an important prediction capability of the presence of people during winter. In the study conducted by Zacharias et al. (2001), the authors did not take into account relative humidity as a variable to analyse attendance, activities and body postures of the users of squares in Montreal. This decision was made based in data obtained from indoors, where the relative humidity only affected comfort at higher temperatures. The present research has also shown that relative humidity plays an important role at low temperatures outdoors when considered in combination with other variables during winter (Chapter 8). This variable produced correlation with the *Number of People* ($r = -.40$, $p < .001$), and the presence of groups of one and two persons (*G1* $r = .-44$ and *G2* $r = -.32$, $p < .001$). Therefore, the study of human behaviour outdoors should not be based on indoor comfort parameters as the context and perception of the users is different.

An important contribution of this research is the proposal of a method to identify which variables affect the behaviour of people in outdoor public spaces. As has already been mentioned, some of the research presented in previous studies, has been based on predictor variables with lower relationships compared to the findings of this research for the situation of interest (e.g. the use of data derived from indoor comfort studies Zacharias et al. (2001)). Similarly, Givoni et al. (2003) decided to include in their model air temperature, solar radiation and wind speed to predict thermal satisfaction, because most of the previous studies had used these variables to predict thermal comfort in outdoors. As an example of other variables not commonly used to predict human behaviours, in Chapter 5, it was shown that illuminance has a strong influence over the variance of human behaviour in summer.

The literature review indicated a lack of consensus with regard to environmental variables affecting human behaviour in outdoor public spaces, despite some degree of consensus regarding some aspects of measures of user perception of the thermal environment (Chapter 2, Table 2). Therefore, in this research the method of analysis developed includes a model to filter the variables to be considered to predict the behaviour. This method is called a waterfall scheme (Houghton et al., 2015, p. 225), in which every step leaded naturally to the next step to select the best predictors (Chapter 5, Figure 52). The selection of the best predictor was based on the simple correlation and from there other predictors which also correlated with the behaviour were included or discarded, depending upon whether or not they showed multicollinearity with the other environmental variables. At the end, the Forward method used for the multiple regression analysis also allowed the identification of the influence of each environmental variable on the models created.

This research also identified an important relationship between body postures and the thermal environment. For instance, it was found that the sitting standard posture was the most frequently adopted posture during the three seasons. Zacharias et al. (2001) reported a strong relationship between the presence of people sitting and the air temperature ($r = .92$). The present research did not total the aggregates of people according to body postures per census; however, in the postural analysis, it was found that the variables of illuminance levels, wind speed, globe temperature and calculated mean radiant temperature in the shadow had more influence over the time spent in the sitting posture. The results suggest that the perception of wind by the users was not significant between 0 m/s and 2 m/s; however velocities over this range influenced negatively the time people decided to spend in this posture. In the case of the globe and calculated mean radiant temperature in the shadow, it was found that the highest temperatures presented the longest permanencies in the sitting posture.

It is important to highlight that there is a lack in the analysis of furniture design in terms of location, materials and type of furniture required for people of different ages and for different activities. As an example, Figure 208 presents a tourist public space in Prague and the furniture available for tourists to rest during summer. In the present research it was found that the globe and the calculated mean radiant temperature in the shadow influenced positively the permanence of people sitting, which suggests that shading devices are important to promote this posture as the temperature increases.

Figure 208 – Seating areas in Prague, summer 2014. Furniture designed to sit is abandoned and other type of leaning surfaces are preferred.

The results across the seasons suggest that the furniture design can be enhanced by including parameters of sun and shadow, wind permeability or protection, and materials to improve the thermal relationship of the body with the surfaces.

10.4. Recommendations for Trinity Square considering Environmental Factors and Human Behaviour

The observational stage of the research enabled the researcher to reflect in qualitative terms about the conditions of the square and its environmental conditions. As mentioned before, Trinity Square is located in Nottingham city centre. It is a medium sized square surrounded by commercial buildings on the ground floor. The main commercial activities of the buildings are restaurants and shops. It can be accessed through pedestrian paths which connect the square with two main roads of the city centre. Trinity Square was retrofitted in 2012, the current design has various seating furniture (benches with and without backrest, different heights, individual benches, low walls and stairs) and a stage. The finishing material of the furniture and floor is black granite on the seats and stage, and light grey tile on the floor.

Regarding the bioclimatic conditions of the square, it was observed that, due to its shape and the height of the surrounding buildings, solar access is restricted for various zones of the square depending upon the time of the day and the season. The wind speed coming from the narrow pedestrian pathways can increase the wind levels in some areas of the square such as the stage, as presented in Table 3, but in general the mass of the buildings generate a wind shadow. The colour of the floor (light grey) allows reflectance of the light around the square. Conversely, the illuminance level in the seating area of the stage is lower due to the dark colour of the surfaces. In addition, the square presents a lighting system consisting of floor recessed lights and street lamps.

The environmental data identified a wide range of conditions occurring in the place. For instance the temperatures ranged between 5.1°C to 27.1°C, while the wind speeds varied from 0 m/s to 5 m/s. Therefore, it is suggested that some elements could be placed in the square in order to allow the users to adapt themselves, or the space, by modifying certain characteristics according to the seasonal changes. It must be however acknowledged that allowing adaptations by the users to an urban outdoor space according to the environmental factors presents difficulties; as stated by Nikolopoulou & Lykoudis (2006): "Due to the nature of the majority of open spaces, interactive physical adaptation is very limited and requires the presence of specific elements, such as movable shading devices, or panels for wind direction" (p. 13). Elements like shadow devices and wind barriers will work for some seasons but not for others; therefore, at the moment of installing urban furniture there must be considered the conditions of each season.

Moreover, a positive relationship was observed between the attendance of couples and the calculated mean radiant temperature in the shadow during summer. This result suggests that shading devices during hot periods can motivate the presence of this type of groups.

On the other hand, protecting the seating areas from wind drafts over 1.5 m/s by creating wind barriers (e.g. bushes, furniture with high backrests) could reduce the negative influence that wind speed has over the behaviour when it exceeds this limit.

According to the number of people and the demographics obtained throughout this study, it was observed that most of the users of Trinity Square are adults and the main activities performed are smoking, using a device and eating. A strategy that could help to attract a wider public would be placing furniture and facilities providing more services for other kinds of users. Various examples of this would be placing toilets near the square, installing water fountains, public internet, kids' playground, etc. This diversity of services could accordingly attract a diversity of users such as teenagers, families or people with reduced mobility. Ward Thompson (2013) stated that the open spaces should provide "sufficient environmental quality and variety to encourage children's play" (p. 91) and promote greater activity levels. As an example of this, it was observed that during summer two tennis tables were installed at the square. These movable furniture encouraged users of different ages to engage with a different activity and stay in the place. Moreover, it was observed that people alone started to interact with others in order to participate in the game.

During autumn the mean radiant temperature in the sun was a strong influencer of attendance. Therefore, maximising the solar radiation of the square is recommended. Accordingly it is suggested not to use the stage roof during autumn or winter; this is a removable element that is apparently used for special occasions and would generate a large area of shadow over the square that could affect the presence of users in the colder seasons.

The behaviour of people during winter showed strong relationships with wind speed, light and relative humidity. The relative humidity is a factor difficult to control from the built environment perspective, since it is the percentage of water retained by the air according to its temperature. However, the negative effects produced by relative humidity can be compensated by modifying other variables working in conjunction with this factor (e.g. air temperature or wind speed). The data gathered showed that the lowest levels of humidity were observed during winter, which can increase the perception of low temperatures, so the space will feel even colder than it really is. Some strategies could reduce the heat loss of the body and increase the time of permanence or the attendance to the square. These strategies could be, for example: installing wind barriers to protect some of the seating areas of the square and providing low conductance surfaces in the seats (e.g. wood, plastic), since steel and granite furniture may increase the heat loss from the body when the skin is in contact with these cold surfaces.

In the all-seasons analysis a strong relationship was reported with the globe temperature in the sun and this result was also reported in other studies (e.g. Nikolopoulou et al., (2001)). Therefore, it is considered that the direct solar radiation is an important factor to look after in order to keep the activity of this square during all seasons, especially during autumn. As described earlier, with the current conditions of the surrounding buildings the square has several shadow patches. In consequence, it would be advisable to restrict the maximum height of the surrounding buildings to three floors in order to guarantee that the solar access will not be lost with the densification of the city. These type of restrictions in urban planning have been applied in other cities (e.g. San Francisco 1985 (Arens & Bosselmannt, 1989)) in order to protect the microclimatic conditions of public spaces (Zacharias, 2004).

10.5. Novel contribution to knowledge

In general, this study has provided a more comprehensive investigation of the influence of environmental factors on human behaviour outdoor public spaces. As discussed in the literature review and evidenced throughout this thesis, the study of human behaviour in outdoor spaces started with qualitative analysis of the behaviours using mainly observational methods (Gehl, 2011; Gehl & Svarre, 2013; Nasar & Yurdakul, 1990; Whyte, 2009). However, as technology evolved and devices to measure the environment became available, various studies started to analyse the relationship between human behaviour and the thermal environment (Chen & Ng, 2011). These studies presented however a lack of agreement on the best method to collect data and analyse the relationship between environment and human behaviour. Whilst previous research studied human behaviour from different perspectives, e.g. studies in thermal comfort (Nikolopoulou et al., 1999; Nikolopoulou & Lykoudis, 2007; Thorsson et al., 2007) and studies in sociology (Hillier & Julienne, 1970; Whyte, 2009), none have applied a systematic approach to register and analyse the behaviour and environmental conditions with the detail presented in this research.

Consequently, this research has provided a new perspective by analysing the relationship using a hybrid method for collecting the behavioural data set and for analysing the results, which allowed obtaining models that explain to a certain point the variance of human behaviour outdoors according to the environmental conditions.

The main contribution of this research is the seasonal analysis of human behaviour and the statistical models produced to explain in more detail the influence of the environmental conditions on the behaviour of people. Moreover, the results obtained in this research provide new findings in the field with regard to the equations to predict the behaviours and the probability models. The study showed that the environmental data of individual seasons analysed independently, can explain better the occurrence of some behaviours in that season than the environmental data of the all seasons dataset. It was concluded that seasonal models may have a better performance to predict the variance of a human behaviour in that season, as the all seasons' model can explain a wider range of environmental data, but may provide a limited prediction about some behaviours which are influenced by particular environmental characteristics of the given season. Accordingly, this research proposed a methodology which includes individual analysis of the data for each season, in addition to the complete analysis of the all seasons' data set.

The new methodology proposed in this thesis for the study of human behaviour in the outdoors according to the environmental conditions is also a contribution to the knowledge. The method is mainly based on observation but it also includes simultaneous measurements of the microclimatic environmental conditions using an environmental station. The coding scheme created not only considers the aggregates of individual behaviours (in this thesis called Social Behaviour), as it also contemplates registering individual behaviours consisting in behaviour per individual. The coding of this individual behaviours using observational methods, allowed running survival analyses for the state events (time dependant individual behaviours) and frequency charts for the point events (non-time dependant individual behaviours). The methodology also contemplated a higher granularity in the coding of the social behaviours than in previous studies, as the data was codified every minute.

Another contribution consists of the dataset obtained through the application of a method based on observational parameters, combined with simultaneous environmental measurements. This dataset may be used for further studies in cities with similar characteristics to Nottingham city or they could be used for comparative studies in different environments.

This research provides a set of recommendations for urban design based on the analysis performed to Trinity Square. The strategies presented provide guidance to consider environmental conditions when shaping the urban design of Trinity Square, or propose new developments in the surrounding buildings in accordance to the environmental factors that could affect the use of this public space. The recommendations can also indirectly inform architects wishing to consider how the behaviour of users fluctuates between seasons in places with similar environmental characteristics to Nottingham.

10.6. Limitations

As happens with every study of the human behaviour, the main limitation consists of the complexity of the decisions of human beings, which are motivated by multiple factors not easily ascertainable. The lack of uniformity is one of the virtues of this specie and that affects the studies oriented to produce models to predict the behaviours. The model to predict the Number of People in winter, which had the best performance among all the models, accounted for 46% of the behaviours. It remains however unknown whether the generalisability of the models could still be affected by other factors not accounted for, such as: other environmental factors not considered in this study, cultural background of the user, external motivations such as work or group activities, socio-cultural conventions, personal preferences of the user, their health conditions, etc. In addition, other architectural factors or issues in the built environment were not considered in this study, such as, the thermal conductivity of the materials or aesthetics, among others.

Adding to this, it was noticed during the development of this study, that as more intrusive the study was, like in the case of the mock scenario, the less spontaneous the behaviour of the users is. For instance, attendance of people to the place in the mock scenario conducted in a built public space in summer 2016 was significantly lower than the attendance to Trinity Square during the seasonal study of summer 2015, which can be explained by the presence of temporary elements in an otherwise empty public space, as well as the scale of the mock scenario and the reduced availability of seating areas, compared with Trinity square. During the first one, there were many times when the square was empty, while in the second, the square was never observed empty. This condition may be explained due to the fact that the installation of the Mock Scenario was not a familiar place for the users; therefore, they did not plan to attend to this seating place. Conversely, the familiarity of Trinity Square to its users is very high, which guarantees a frequent use of this space. This circumstance also affects the possibility of conducting external validations using built scenarios unless it tackles this issue of spontaneity and familiarity, so the results in these two types of study can be compared. In addition, the issue of lack of spontaneity is a further disadvantage of subjective and objective studies, as people are fully aware of the research and can become self-conscious in their behaviour or in the answers given in questionnaires.

There is still room to try to define the correct balance between observation and spontaneity, although the seasonal studies constitute a step forward in the right direction, as the observational methods proposed in this research are the less intrusive possible. However, this kind of studies conducted in situ, lack the versatility to allow modifying elements to compare different reactions of the users to wider environmental stimuli.

There is also a limitation about comparing studies in places with different socio-cultural background or idiosyncrasy. Previous studies reported different perception of users to the thermal environment according to latitude. For instance, Nikolopoulou & Lykoudis (2007) found that people reported dissatisfaction with the increase of wind speed in summer in northern latitudes, while people in southern latitudes reported a positive perception with the increase of wind speed in summer. In this research it was found that the wind speed presented a negative coefficient during autumn and winter, so the attendance of people decreased while the wind speed increased and a positive relationship in summer. It is important to highlight that not only the thermal perception caused by the different variations of each place, but also the type of activities, garment and cultural aspects can determine the accepted condition of a place. Therefore, the equations presented in this research are an indication of tendencies, and not an accurate calculation of behaviour in terms of quantities.

The variety of factors influencing the decisions of the users in an outdoor public space has another consequence in this field of study: the lack of agreement by the authors in the type of method to collect and analyse the data. This study has proposed a methodology to collect, codify, analyse and validate data of human behaviour and environmental factors, as none of the methods previously proposed were adequate for the aims of this study. The aim now would be to achieve uniformity in the data of human behaviour, and this can be done by agreeing in a protocol of public data as proposed by the Gehl Institute (2017).

Moreover, the amount of time required to conduct the video analysis constitutes a further limitation to the application of the proposed methodology. It has been estimated that the coding of one hour of video in the Social Behaviour takes up to three hours of video analysis, which means that this process has taken more than 189 hours. This issue is more accentuated regarding the Individual Behaviours, where it was estimated that coding one person took up to 10 minutes. As the sample of this research was almost 6000 persons, the video analysis for this was of 60,000 minutes, which is around six months of work dedicating 8 hours per day.

Finally, the length of time required to gather the environmental data constitutes a further limitation for the application of the proposed methodology. It has been stated that identifying the environmental factors influencing the behaviours is the initial step towards building a model to predict the human behaviour. This however requires gathering a considerable amount of environmental data covering the widest range possible of environmental conditions. This study excluded one season from the data collection, spring, as it resembled the same environmental ranges as the season autumn. Still, the data collection process took around seven months for the seasonal studies of summer, autumn and winter, plus two additional months for the pilot study and the mock scenario.

10.7. Suggestions for future research

According to the Urban Design Guide of Nottingham City Centre (Urbed & Nottingham City Council, 2009), some of the parameters established to define the urban characteristics from an environmental perspective include: urban lighting, tree planting, buildings height, sky view factor (to quantify the natural light available), among others. All of these factors are important to enhance the urban conditions at human scale, however their relationship with the user's perception through the seasons is not considered in this report. For instance, the natural light, wind speed and globe temperature are directly related to the building height and seating areas of the city. This lack of relationship between thermal environment and human behaviour is frequent in urban design parameters due to the complexity of identifying the influence of physical factors into the human vagaries. Therefore, the equations and probabilities presented in this research could support future tools of analysis based on thermal comfort models, environmental analysis or human behaviour analysis. The environmental analysis of buildings is frequently based on CFD, solar gaining, lighting and thermal simulations among other tools, which are used by analysing empty spaces where the interpretation of the results is subjected to the understating of the Designer. On the other hand, pedestrian flow simulations are frequently designed using equations of gases and fluids which may present analogy with the movement of crowds (e.g. Helbing & Molnár (1995)). These approaches to simulate environment or human behaviour are leaving one or the other side of the group of variables of this research outside of the analysis. Therefore, the data presented in this research contributes to develop new ways of analysing human behaviour according to the environmental variables.

As mentioned in the general methodology, the modelling methods are not robust enough yet to explain non-physiological factors with regards to the thermal environment. For instance, thermal comfort simulations are based on multi-agent reaction to thermal conditions based on comfort models (e.g. Bruse (2005)). It is also submitted that human behaviour relates to multiple variables and this study only accounts for the variance of the behaviour according to the studied environmental factors. As expressed by Carmona (Carmona, 2014): "... the process being examined typically focus on the vagaries of human actions and are therefore subject to continual change and varied interpretation as, in essence, they are unpredictable and poorly understood (unlike the laws of physical science)".The variables unaccounted and the characteristics of the studies conducted in this research are opportunities for further researches to increase the prediction power of the models. Some of the actions to achieve this could be: 1. To include in the models, the statistical analysis of the influence over the human behaviour of other environmental factors not accounted in this study, such as: level of noise (unexpected sounds), air quality, rain and snow; 2. Take into account the time and date of the data of human behaviour gathered, in order to determine the level of contribution of the time factor in the strength of the model. This may require conducting further data collection to obtain a more comprehensive data which includes more times of the day and days of the week; 3. To gather data of human behaviour according to environmental factors in different locations, which could allow determining the relevance of the characteristics of the space in the outcome of the models; 4. To increase the exclusion criterion in order to include users of the space which do not act according to the environmental factors, such as, for instance, people working in the public space. 5. Conduct particular analysis of the users, depending on characteristics such as, age, gender or activity among others. 6. Using data mining techniques such as cluster analysis to identify other patterns of the data collected; for instance, the cluster analysis of the groups here conducted could be further studied by performing logistic regression analysis.

Moreover, the data set produced for this research contains information that can be analysed using other techniques such as Poisson models or numerical techniques to generate other models of prediction. Therefore, this study leaves an opportunity for future studies to use a data set of human behaviour and thermal environment.

It is also suggested that a further study to perform an external validation is conducted, guaranteeing that the same environmental conditions are conserved and considering the influence of other factors not accounted in this study. It would also be important that this external validation keeps the scale of the study similar to the experiment in which the model was created in order to procure obtaining a similar sample.

10.8. Conclusions

This research presented a study of human behaviour according to the thermal environment in outdoor public spaces.

An extensive literature review was conducted to determine the state of the field in terms of methodology to study human behaviour and environment in outdoors and to analyse the data of human behaviour. It was observed that in general there is no agreement in the literature in the methods to study the human behaviour, so this research developed a hybrid methodology to measure simultaneously human behaviour and microclimatic thermal environment. However, the research focused mainly in observational methods, as they offer an objective perspective of the data, taking into account that this research was not oriented to study thermal comfort and that spontaneity was deemed important.

In terms of coding scheme, this study presented a new perspective of analysing human behaviour in outdoor in accordance to the thermal environment. Previous studies had conducted studies counting the aggregates of individual behaviours (Gehl Institute, 2017) in order to measure collective behaviour such as the number of people present in a square. This thesis has proposed to divide the coding into two types of behaviour, the Social Behaviours, which covers all the aggregates of behaviour with relation to a place, but also individual behaviours, which consist of behaviour performed per individual in the place. This different approach allowed conducting a series of statistical analysis regarding individual behaviours in public spaces according to the thermal environment, apart from the analysis of the social behaviours that had been done in the past, although with a lower granularity and using a different methodology.

The study of the human behaviour conducted, produced an equation to predict the variance of each of the 5 social behaviours (Number of People, Number of Groups of 1, Number of Groups of 2, Number of Groups of 3 and Number of Groups of 4 and more), in each season and using the all seasons' data set; except for Number of Groups of 4 and more in summer, as for this season the model was not strong enough to predict this behaviour. In terms of individual behaviours, survival analyses allowed to find the highest environmental influencers over individual behaviour by determining the rate of duration of the behaviour (Time of Permanence and postures) per environmental factor. Regarding the adaptive behaviours, such as adding cloths or wearing glasses, a frequency chart showed the probability of occurrence according to the thermal environment.

This study conducted individual analysis of the environmental data collected during each season, before conducting the general analysis of all the data gathered. Interestingly, the models made with the environmental data of one specific season had some times better performance to predict some behaviours of that season, than the model built with the all seasons' data set. It is recommended that future studies of human behaviour in outdoors according to the thermal environment perform the analysis using exclusively the environmental data collected during the season in which the behaviour to predict would occur, and then conduct a second analysis performed with the data set collected during the complete duration of the study (which this research recommends to be of at least three seasons). The model with the best performance should be used to predict the variance of human behaviour according to the thermal environment.

On the other hand, the equations produced in this study account up to a certain point for the variance of the human behaviour predicted, and may the used to predict human behaviours in other places as long as the conditions are the same. It remains to be seen how this conditions can be matched in a different place other than where the seasonal studies took place. In the Mock Scenario built to conduct a further study and validate the data, it was found that despite being a place within the same city, and having similarities in some environmental factors, there were also considerable differences in certain variables which affected the outcome to validate the results of the previous studies. It was considered that this study presented also other variables not included in this study which affected the behaviours which created a doubt about the generalisability of the models.

10.8.1. Review of Aims

The following lines present how this study has achieved the aims it was set to fulfil, describing the novel contributions to the field.

Aim 1: To study methods to assess Human Behaviour from Ergonomics and Human Factors perspective and selecting an appropriated method for this research.

This study developed a hybrid methodology, using observational or behavioural methods for gathering the data, whilst simultaneously taking environmental measurements using technological aids. As mentioned in Chapter 03 (General Methodology), the behavioural methods in previous studies had been mainly used in conjunction with qualitative analyses such as questionnaires, drawings of the place or field diaries (Nikolopoulou & Lykoudis, 2006; Whyte, 2009). This study focused on objective methods, using tools such as Observer XT to generate a video-analysis per individual.

Aim 2: To gather a representative data set of human behaviour and environmental conditions during summer, autumn and winter.

This research defined a method to gather and analyse data of human behaviour and environmental variables that was tested in a pilot study and repeated through different seasons. The observations conducted were extensive, as the recordings took place every day for one month in each of the three seasons. Of the recordings, seven days were selected for each season, including each day of the week, to perform the coding and analysis. Two different types of samples were obtained due to the requirements of the analyses. For the Social Behaviour, the sample for the seasonal studies consisted of 3780 minutes, and for Individual Behaviour the sample consisted of 5330 persons. Individual Behaviours have not been codified before in a study of human behaviour in outdoor urban spaces of this scale, according to which this data could be used for further analyses regarding the study of human individual behaviour in outdoors according to the thermal environment.

Aim 3: To observe, codify, analyse and ultimately predict human behaviour in terms of: occupancy, grouping, time of permanence, body postures, activities and adaptive behaviour.

This research created a coding scheme that was validated (Chapter 04) and replicated (Chapter 09). As explained in Chapter 05 the analysis was focused on two different categories of behaviours: 1. Social Behaviour, which consisted of the aggregates of the behaviours occurring in relation to the place; and 2.

Individual Behaviours, consisting of the activities performed by each individual. The coding scheme was specific to this research as no other study analysed behaviours, postures or activities per individual in a study of human behaviour outdoors according to the thermal environment.

Regarding Social Behaviour, the granularity of the analysis is greater in this study as the behaviours were coded every minute, whilst other studies had coded the behaviours at most every 10 minutes (Goličnik & Ward Thompson, 2010; Nikolopoulou et al., 2001; Zacharias et al., 2001). This allowed registering more variations in behavioural activities, which was ultimately reflected in the strength of the statistical analysis.

The methodology designed to produce statistical models to predict the variance of human behaviour according to the thermal environment following specific steps of analysis, is also an outcome of this research. This study proposed a methodology for the study of the human behaviour consisting on the following steps: 1. Gathering environmental data and human behaviour data in simultaneity using observational methods, 2. Coding the Social and Individual Behaviours using a validated method, 3. Analysing the correlations between the environmental variables and behaviour, 6. Running a multiple regression, survival analysis or frequency analysis to predict the variability or probability of occurrence of the behaviour according to the different variables, and 7. Performing an internal cross-validation validation and external validation by comparing the results with other contexts.

Aim 4: To compare the data gathered in different seasons, in order to identify whether there is a relationship between the thermal environment and human behaviour.

Chapters 05, 06, 07 and 07 present the individual analysis and comparison conducted for each independent data set gathered during summer, autumn and winter, but also the analysis of all the data collected during the three seasons. This produce a more detailed understanding of factors influencing human behaviour in outdoor thermal environment than previously available, since previous studies reported only all-season results. In addition, this research showed that the analysis of the whole data set may result in models with less predictive power than those models including the seasonal data, as some environmental factors influence human behaviour differently depending on the season analysed.

Aim 5: To validate the study conducted, in order to achieve generalisable and replicable results.

This study has undertaken two types of validation: 1. An internal cross-validation, using 40% of the data reserved and 2. An external validation, obtaining further data in a different place. The internal cross-validation contributed to the generalisability of the results by comparing the predicted and real data and identifying the percentage of power of each model. The external cross-validation was used to define the replicability of the conclusions to other environments. It was observed that the equations to predict human behaviour, should be applied in places with similar environmental conditions to those where the initial study was conducted.

Aim 6: To generate recommendations in urban design based on the results obtained from the data gathered.

Finally, this study has presented various recommendations and analysis as a result of the application of the different findings of conducting this study of the human behaviour in an outdoor public square, such as regulating the height of buildings, providing a better illumination system to generate nocturnal activities in the users or paint enclosed places to create a transition between dark and naturally illuminated open spaces. In addition, particular suggestions are made to the square where the seasonal studies were conducted as parameters to improve the usage of the square by modifying architectural elements or environmental conditions.

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Appendix 1: Pilot Study

Participants Information Form

Consent Form

Poster

Survey

The Human Response to the Outdoors, based on the Built Environment and Weather Conditions

Participant Information Sheet

You are invited to take part in a research project. Before you start to take part it is important for you to understand why the research is being done and what will be involved. Please take some time to read through this information sheet carefully and ask questions if anything is unclear or if you would like more information.

This study is being run by Julie Waldron of the Human Factors Research Group, The University of Nottingham, United Kingdom.

Purpose of the study

This research is focused in obtaining observable patterns of human behaviour in the outdoors, and aims to find the relationship of these patterns with the weather conditions and the built environment.

The information collected during this study will be used as part of Julie Waldron's PhD thesis and for academic publications; for example as part of a journal article or a conference paper/presentation.

What will happen if I decide to take part?

We will ask you some questions related to your thermal perception and experience while you were occupying the Coates' Square. For instance, we would like to know if you felt comfortable, which activities were you doing in the square and if you preferred to stay in the shadow or the sunny areas. We will also ask you to select some condition related to the weather. If you agree to take part, we will provide you with full instructions. You will also be given the opportunity to ask any questions. You may ask questions at any time if you do not understand something.

What will happen to my information?

All information provided will be stored in a locked filing cabinet at the University of Nottingham and destroyed seven years after any publication arising from the work in accordance with the university data storage policy. Your name (i.e. signature on consent form) will be kept separate from your questionnaire responses.

Electronic data will be kept on a password protected computer, for the duration mentioned above.

The information collected will be used for Julie Waldron's PhD thesis and for academic publications and conferences.

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any time without having to provide a reason. If you do withdraw, any information that you have collected will be destroyed and will not be included in the study. You also do not have to answer any particular question.

Regardless of whether you wish to participate or not, upon your request we will not analyse any data related to your behaviour.

Will my taking part in this study be kept confidential?

Yes. The information that we gather will be used in academic publications and conferences. None of these reports will name you as a participant. We may include quotes from you in these reports to illustrate our findings, but these will be anonymised.

The videos taken for this study could be used for dissemination of the academic results. The identity of participants will be always anonymised blanking the faces out.

Who is organising and funding the research?

This research is being conducted by The University of Nottingham - Human Factors Research Group (Arch. Julie A. Waldron – PhD Student and Supervised by Dr Glyn Lawson and Professor Darren Robinson).

Who has reviewed the study?

This study has been reviewed and approved by The University of Nottingham Faculty of Engineering Research Ethics Committee.

Who do I contact if I have questions or require further information?

If you have any questions or concerns about the study, please contact:

Julie Andrea Waldron

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The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

The Human Response to the Outdoors, based on the Built Environment and Weather Conditions

Consent Form

I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason ☐

I understand that I have been videoed and the video clips may be used for academic dissemination. I understand that my data will be anonymised and the faces of the videos will be blanked out. ☐

I understand that my information will be used by researchers involved in the project for PhD thesis, academic publications and conferences. I understand that my data will be anonymised. ☐

I understand that the information will be kept in a locked filing cabinet and a password protected computer at the University of Nottingham; and the information will be destroyed seven years after any publication arising from the work in accordance with the university data storage policy. ☐

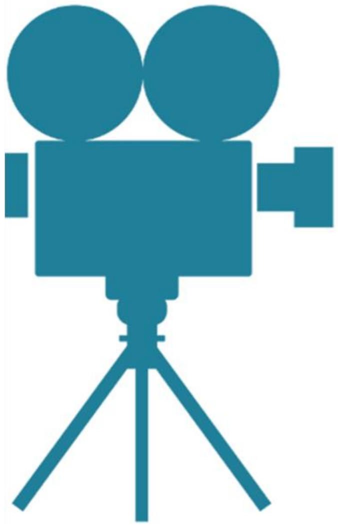
I agree to take part in the above study

Name of Participant	Date	Signature

Participant ID *{researcher to complete}*:_________________________

STUDY OF HUMAN BEHAVIOUR IN

A study of Human Behaviour in Outdoors will be held during the morning, midday and afternoon in the **second and third week of September 2014 in this area.** For this study, some videos, photos, environmental measurements, notes and questionnaires will be taken in the Coates Square.



My name is Julie Waldron and my PhD research is focused in obtaining observable patterns of human behaviour in the outdoors, and aims to find the relationship of these patterns with the weather conditions and the built environment.

Upon your request, we will not analyse any data related to your presence in the square. For this, or if you have any other questions about the study, please contact:

julie.waldron@nottingham.ac.uk
glyn.lawson@nottingham.ac.uk

Summary of Outdoors Survey Answers

	P1	P2	P3	P4	P5
Date	27/08/2014	27/08/2014	28/08/2014	29/08/2014	02/09/2014
Entry	1-5:44	P1-20:26	P1-6:38	P2-23:51	1-39:37
Exit	1-18:28	P2-16:24	P2-2:02	P4-+3min afte	2-7:06
Permanence	12:44	08:36	24:26	40:52	16:34
Table					
	12.73	8.60	24.43	40.87	16.57
Participant Information					
Country of origin	Germany	Pakistan	Romania	USA	UK
Age	46	30	31		53
Sex	Male	Male	Female	Female	Female
Occupation	Researcher	Student	PhD Student	Admin recepti	Tutor
Height (cm)	183	156	167		
Weight (Kg)	85	72	63		
Prior Activities Information					
Location 20 minutes before	Indoors Office	Indoors	Indoors Office	Indoors	Indoors
Main activity 20 minutes prior	Sedentary acti	Seated relax	Sedentary acti	Sedentary acti	Sedentary acti
Time to walk to coates (min)	2	1	3	3	5
Conditions in previous activity					
Air quality					
Dry → Humid	4	3	2	7	4
Fresh → Stuffy	3	3	6	7	7
Odourless → Smelly	1	2	3	3	4
Temperature					
Hot → Cold	4	4	4	1	3
Comfortable → Uncomfortable	1	2	4	7	4
Current Environmental Condition					
Conditions while sitting in coates					
Temperature					
Hot → Cold	5	2	3	4	3
Comfortable → Uncomfortable	1	1	2	5	5
Sun					
Sunny → Overcast	6	2	1	7	5
Air					
Still → Draughty	6	2	6	7	5
Dry → Humid	1	4	4	5	5
Fresh → Stuffy	1	3	6	3	6
Odourless → Smelly	1	2	1	4	4
Natural light					
Light → Dark	1	1	1	6	3
Noise					
Noisy → Quiet	3	5	2	6	3
Cleanness					
Clean → Dirty	2	3	1	6	6

Safety					
Safe → Unsafe	1	1	1	6	4
Accessibility					
Accesible → Inaccesible	1	5	1	6	4
Aesthetic					
Attractive → Unattractive	4	3	2	5	7
Feeling while staying in coates					
Comfortable → Uncomfortable (overall)	2	2	2	5	2
Comments					The seating area is scruffy old tables + chairs and not well defined space
Future Activities Information					
Destination after being in coates	Indoors Office	Indoors	Indoors Office	Indoors	Indoors
Main activity inmediately after leaving	Sedentary acti	Seated relax	Sedentary acti	Sedentary acti	Sedentary acti
Additional Information					
Why have you come to Coates?	Coffee Break	Coffee and to chat with friend	For Lunch	Lunch Break	To scape the office/fresh air
Frequency of use of this space	Per day	Per week	Per week	Per week	Per day
Reason for leaving	Return to work	Finished with coffee and chat	Return to work	Back to work	To go back to work
Comments					The university needs more outdoor space - winter option? Same experience

Summary of Outdoors Survey Answers

	P6	P7	P8	P9	P10
Date	02/09/2014	04/09/2014	05/09/2014	05/09/2014	08/09/2014
Entry	P2- 24:08	P1-0:00	P1-13:56	P2-10:54	P1-37:14
Exit	P3-6:56	P1-40:24	P1-25:21	P2-21:48	P2-6:00
Permanence	17:33	40:24	11:25	11:54	09:29
Table	3	3	3	8	11
	17.55	40.40	11.42	11.90	9.48
Participant Information					
Country of origin	Netherlands	Taiwan	England	Jordan	Italy
Age	24	37	26	30	31
Sex	Female	Male	Male	Male	Male
Occupation	PhD Student	PhD Student		Post Doc Engin	Researcher
Height (cm)	180	182	178	178	180
Weight (Kg)	75	97	85	70	70
Prior Activities Information					
Location 20 minutes before	Outoors	Indoors	Indoors	Indoors	Indoors
	Biking	CBS Building	Working	In the lab doin	Office
Main activity 20 minutes prior	Cycling	Sedentary acti	Walking Norm	Standing, light	Sedentary acti
Time to walk to coates (min)	2	5	5	3	2
Conditions in previous activity					
Air quality					
Dry → Humid	4	3	4	3	3
Fresh → Stuffy	6	6	4	6	6
Odourless → Smelly	2	5	5	3	6
Temperature					
Hot → Cold	4	4	4	2	4
Comfortable → Uncomfortable	5	6	4	3	2
Current Environmental Condition					
Conditions while sitting in coates					
Temperature					
Hot → Cold	3	5	4	4	4
Comfortable → Uncomfortable	3	3	4	4	2
Sun					
Sunny → Overcast	7	4	6	5	1
Air					
Still → Draughty	4	5	5	4	4
Dry → Humid	4	2	5	4	4
Fresh → Stuffy	6	2	5	2	2
Odourless → Smelly	2	2	1	1	2
Natural light					
Light → Dark	2	2	4	2	1
Noise					
Noisy → Quiet	3	4	2	7	3
Cleanness					
Clean → Dirty	4	5	2	2	1

Safety					
Safe → Unsafe	2	4	1	1	1
Accessibility					
Accesible → Inaccesible	1	2	2	2	1
Aesthetic					
Attractive → Unattractive	3	4	4	3	2
Feeling while staying in coates					
Comfortable → Uncomfortable (overall)	2	3	3	2	1
Comments		Fresh air, feel relaxed, can smoke			
Future Activities Information					
Destination after being in coates	Outoors Cycling	Indoors	Indoors	Indoors To the lab in E	Indoors Office
Main activity inmediately after leaving	Cycling	Sedentary acti	Walking Norm	Standing, light	Sedentary acti
Additional Information					
Why have you come to Coates?	For WiFi	Eat my lunch	Coffe Break	Main break for coffee	To have lunch
Frequency of use of this space	Per day	Per month	Per day	Per year	Per day
Reason for leaving	Shopping	Go back to work	To return to work	To go to my office	To go back to work
Comments					

Summary of Outdoors Survey Answers

	P11	P12	P13	P14	P15
Date	08/09/2014	08/09/2014	09/09/2014	09/09/2014	09/09/2014
Entry	P1-30:28	P1-27:32	P1-19:23	P1-17:21	P2-16:04
Exit	P2-24:08	P2-24:08	P2-13:01	P2-13:01	P4-9:41
Permanence	40:23	43:19	40:52	42:54	45:03
Table	2 & 3	2 & 3	3	3	6 & 9
	40.38	43.32	40.87	42.90	45.05
Participant Information					
Country of origin	China	UK	UK	England	Northern Irlan
Age	24	23	40	32	23
Sex	Male	Female	Female	Female	Female
Occupation	Student	PhD Student	Media officer	Media relation	Postgraduate s
Height (cm)	173	160	163	165	160
Weight (Kg)	58	71	64	66	57
Prior Activities Information					
Location 20 minutes before	Indoors	Indoors	Indoors	Indoors	Indoors
	Lab	Lab	Office	Office	Between the o
Main activity 20 minutes prior	Standing, light	Standing, medi	Sedentary acti	Walking Norm	Standing, light
Time to walk to coates (min)	5	5	3	3	2
Conditions in previous activity					
Air quality					
Dry → Humid	4	4	4	1	2
Fresh → Stuffy	2	4	6	6	4
Odourless → Smelly	3	4	4	4	2
Temperature					
Hot → Cold	3	5	4	2	4
Comfortable → Uncomfortable	2	5	3	4	2
Current Environmental Condition					
Conditions while sitting in coates					
Temperature					
Hot → Cold	2	2	2	4	3
Comfortable → Uncomfortable	1	3	3	4	3
Sun					
Sunny → Overcast	1	2	2	3	2
Air					
Still → Draughty	6	3	4	5	3
Dry → Humid	3	5	3	2	2
Fresh → Stuffy	2	3	4	3	2
Odourless → Smelly	2	2	7	4	2
Natural light					
Light → Dark	1	2	3	2	1
Noise					
Noisy → Quiet	4	3	3	5	3
Cleanness					
Clean → Dirty	2	3	4	3	2

Safety					
Safe → Unsafe	1	1	3	1	1
Accessibility					
Accesible → Inaccesible	1	1	4	2	1
Aesthetic					
Attractive → Unattractive	2	2	4	5	5
Feeling while staying in coates					
Comfortable → Uncomfortable (overall)	2	1	3	2	2
Comments			Someone smoking next to me		Comfortable enjoying the sunshine and lunch with friends
Future Activities Information					
Destination after being in coates	Indoors	Indoors	Indoors	Indoors	Indoors
	Lab	Lab	Office	Office	Office and lab
Main activity inmediately after leaving	Standing, light	Standing, medi	Sedentary acti	Sedentary acti	Standing, light
Additional Information					
Why have you come to Coates?	For lunch	For lunch	Lunch break	For lunch	Close to my office and the sunshine brought us outside for lunch
Frequency of use of this space	Per week	Per week	Per month	Per month	Per week
Reason for leaving	I need to go back to work	To go back to work	Return to office following lunch break	End of lunch	Need to go back to work
Comments					(use per week depending on weather)/Use the space when its sunny so we can enjoy our luch break outside

Summary of Outdoors Survey Answers

	P16	P17	P18	P19	P20
Date	09/09/2014	10/09/2014	10/09/2014	10/09/2014	17/09/2014
Entry	P4-17:04	P2-8:11	P2-11:30	P2-11:30	P2-13:41
Exit	P4-21:05	P2-24:39	P2-35:57	P2-35:57	P3-43:00
Permanence	04:01	16:28	24:27	24:27	01:08:18
Table	1	6	8	8	2
	4.02	16.47	24.45	24.45	68.30
Participant Information					
Country of origin	Ireland	UK	England	England	Iraq
Age	51	55	22	21	40
Sex	Male	Male	Male	Male	Female
Occupation	Proff	Lecturer	Student	Student	Engineer
Height (cm)		170		182	
Weight (Kg)		55		89	
Prior Activities Information					
Location 20 minutes before	Indoors	Indoors	Indoors	Indoors	Indoors
	Office		House	House	Laboratory
Main activity 20 minutes prior	Sedentary acti	Sedentary acti	Seated relax	Seated relax	Sedentary acti
Time to walk to coates (min)		5	15	15	2
Conditions in previous activity					
Air quality					
Dry → Humid	5	5	3	3	1
Fresh → Stuffy	7	6	2	3	4
Odourless → Smelly	4	5	2	3	4
Temperature					
Hot → Cold	2	3	3	4	4
Comfortable → Uncomfortable	5	5	2	2	3
Current Environmental Condition					
Conditions while sitting in coates					
Temperature					
Hot → Cold	3	4	3	5	5
Comfortable → Uncomfortable	1	2	2	5	3
Sun					
Sunny → Overcast	1	2	3	4	4
Air					
Still → Draughty	3	2	2	3	3
Dry → Humid	2	4	2	3	1
Fresh → Stuffy	1	2	2	2	1
Odourless → Smelly	1	3	1	2	2
Natural light					
Light → Dark	1	2	1	1	1
Noise					
Noisy → Quiet	4	4	5	6	5
Cleanness					
Clean → Dirty	2	3	2	2	4

Safety					
Safe → Unsafe	1	2	1	1	1
Accessibility					
Accesible → Inaccesible	1	2	2	1	1
Aesthetic					
Attractive → Unattractive	2	5	2	3	4
Feeling while staying in coates					
Comfortable → Uncomfortable (overall)	1	3	2	2	4
Comments					It depend on my mood after work and study
Future Activities Information					
Destination after being in coates	Indoors Office	Indoors	Indoors Computer roo	Indoors Computer wor	Indoors Home
Main activity inmediately after leaving	Sedentary acti	Sedentary acti	Sedentary acti	Seated relax	Standing, medi
Additional Information					
Why have you come to Coates?	Lunch	To get out of office/avoid work distraction/to get fresh air	Hopefully to work	To do some work on the computer	Drink a tea and meet a friend
Frequency of use of this space		Per week	Per week	Per week	Per month
Reason for leaving	Go back to work	To continue work	Finished eating	To work/go home	Going home
Comments					

Summary of Outdoors Survey Answers

	P21	P22	P23	P24	P25
Date	17/09/2014	17/09/2014	17/09/2014	18/09/2014	18/09/2014
Entry	P3-1:42	1-32:36	1-32:36		
Exit	P3-43:00	2-6:17	2-6:17		
Permanence	41:28	22:25	22:25		
Table	2	1	1		
	41.47	22.42	22.42		
Participant Information					
Country of origin	Iraq	China	China	Hong Kong	Bulgaria
Age	33	20	20	26	23
Sex	Female	Female	Female	Female	Female
Occupation	Student	Student	Student	Student	Student
Height (cm)		164	160	155	176
Weight (Kg)		44	49	60	
Prior Activities Information					
Location 20 minutes before	Outoors	Outoors	Outoors	Outoors	Outoors
		Cripps Hall	Cripps Hall	Outside ESLC	Walking from j
Main activity 20 minutes prior	Walking Fast	Walking Norm	Walking Norm	Sedentary acti	Walking Norm
Time to walk to coates (min)	10	15	15	1	40
Conditions in previous activity					
Air quality					
Dry → Humid	4	2	4	4	5
Fresh → Stuffy	2	1	4	2	1
Odourless → Smelly	1	2	5	2	2
Temperature					
Hot → Cold	2	5	4	5	5
Comfortable → Uncomfortable	2	2	2	4	2
Current Environmental Condition					
Conditions while sitting in coates					
Temperature					
Hot → Cold	3	6	4	6	5
Comfortable → Uncomfortable	1	3	2	3	2
Sun					
Sunny → Overcast	3	6	5	6	6
Air					
Still → Draughty	2	3	4	2	6
Dry → Humid	3	2	4	3	6
Fresh → Stuffy	2	3	5	2	2
Odourless → Smelly	1	2	5	2	2
Natural light					
Light → Dark	1	4	3	1	1
Noise					
Noisy → Quiet	5	6	5	2	3

Cleanness					
Clean → Dirty	2	2	3	2	1
Safety					
Safe → Unsafe	1	1	2	2	1
Accessibility					
Accesible → Inaccesible	2	2	4	2	1
Aesthetic					
Attractive → Unattractive	3	3	5	3	3
Feeling while staying in coates					
Comfortable → Uncomfortable (overall)	2	1	2	3	1
Comments					
Future Activities Information					
Destination after being in coates	Indoors Laboratory	Outoors Jubilee Campu	Outoors Jubilee	Indoors ESLC	Indoors Portland Buildi
Main activity inmediately after leaving	Sedentary acti	Walking Norm	Walking Norm	Sedentary acti	Sedentary acti
Additional Information					
Why have you come to Coates?	To meet my friend	Just look around, for the preparation of next days studies	For rest	Lunch	To meet a friend
Frequency of use of this space	First time	First time	First time	Per day	Per week
Reason for leaving	To go to my work	Just because I have finished the visit	Rested for enough time	End of lunch	Have work to do elsewhere
Comments					

Summary of Outdoors Survey Answers

	P26	P27	
Date			
Entry			
Exit			
Permanence			
Table			
Participant Information			
Country of origin	UK	UK	
Age	26	20	
Sex	Male	Female	
Occupation	PhD Student	Clinical Support worker	
Height (cm)	172	165	
Weight (Kg)	70		
Prior Activities Information			
Location 20 minutes before	Indoors	Indoors	
	Office	Bus	
Main activity 20 minutes prior	Seated relax	Seated relax	
Time to walk to coates (min)	2	10	
Conditions in previous activity			
Air quality			
Dry → Humid	5	5	
Fresh → Stuffy	5	6	
Odourless → Smelly	5	1	
Temperature			
Hot → Cold	3	4	
Comfortable → Uncomfortable	6	4	
Current Environmental Condition			
Conditions while sitting in coates			
Temperature			
Hot → Cold	5	3	
Comfortable → Uncomfortable	2	5	
Sun			
Sunny → Overcast	7	7	

Air		
Still → Draughty	6	3
Dry → Humid	4	5
Fresh → Stuffy	2	3
Odourless → Smelly	1	1
Natural light		
Light → Dark	3	4
Noise		
Noisy → Quiet	5	6
Cleanness		
Clean → Dirty	2	1
Safety		
Safe → Unsafe	1	1
Accessibility		
Accesible → Inaccesible	1	1
Aesthetic		
Attractive → Unattractive	3	1
Feeling while staying in coates		
Comfortable → Uncomfortable (overall)	1	2
Comments		
Future Activities Information		
Destination after being in coates	Indoors Office	Indoors Coates Building
Main activity inmediately after leaving	Seated relax	Walking Slow
Additional Information		
Why have you come to Coates?	Lunch	Lunch
Frequency of use of this space	Per week	Per month
Reason for leaving	Go back to work	Finished Lunch

Appendix 2: Human Behaviour in Summer

Poster advertising the study (same for all seasons and Mock Scenario)

Letter to Nottingham City Council

Additional Calculations of multiple regression models: Kolmogorov Test, Variables Entered and ANOVA.

Survival Curves of the Time of Permanence

The University of Nottingham

Study of human behaviour in public spaces

A study of Human Behaviour in Public Spaces will be held during **January and February 2016 in this area**. For this study, some videos, photos, environmental measurements and notes will be taken in Trinity Square, Nottingham.

My name is Julie Waldron and my PhD research is focused in obtaining observable patterns of human behaviour in outdoors, and aims to find the relationship of these patterns with the weather conditions and the built environment.

This research was approved by the Ethics Committee from the University of Nottingham. Additionally, the authorities of the city were notified about this.

Upon your request, we will not analyse any data related to your presence in the square. For this, or if you have any other questions about the study, please contact:

Julie Waldron
Architect.
PhD Student in Human Factors
Human Factors Research Group
The University of Nottingham
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Dr Glyn Lawson
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20th May 2015

Nottingham City Council
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http://hfrg.nottingham.ac.uk

Dear Sir or Madam:

RE: request on behalf of Julie Waldron, PhD Student, The University of Nottingham

I am the supervisor of Julie Waldron, a PhD student at The University of Nottingham. Julie is currently conducting research on Human Behaviour in public spaces as part of her studies within the Human Factors Research Group.

To progress Julie's research she must undertake studies in public spaces to observe and record in an anonymous way the behaviour of people using that space. Accordingly, Julie would like to conduct a study in Nottingham's Market Square during the summer of 2015, as this important public space of Nottingham City meets the criteria for her study. Julie's study will involve video recording people whilst they remain in and cross the square during different days and times. Simultaneously, she will be measuring weather conditions (temperature, humidity and wind speed). Her research is focused in obtaining observable patterns of human behaviour in public spaces, and aims to find the relationship of these patterns with the weather conditions and the built environment.

To communicate the study, Julie will place posters in the surrounding areas explaining the experiment to the community. In order to guarantee the confidentiality and to anonymize the data collected, the video files will be analysed according to patterns gathered from the observation of the people, which means that individual characteristics of the observed people will not be taken into consideration for this study. Additionally, the faces of the people will be anonymised in the publication of the results and they will be only used for the purpose of this research.

It is important to mention that this study will not start until it has been approved by The University of Nottingham Faculty of Engineering Ethics Committee.

I am contacting you to politely request authorisation to conduct this study by placing the video camera in the balcony of the 1st floor of the main façade of Nottingham City Council's building. This would only point towards the square; no footage would be taken within the Council building.

I would be pleased to provide further information about the study or answer any other question.

Yours sincerely,

Dr Glyn Lawson C.ErgHF FIEHF
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School of Mechanical Materials
Manufacturing Engineering
and Management
UNIVERSITY OF NOTTINGHAM

This sections contains additional calculation performed during the data analysis of the data set collected in summer, which helped to test the distribution and performance of the multiple regression models to predict Number of People and Number of Groups.

Tests of Normality - Summer

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ta	.137	771	.000	.930	771	.000
rH	.136	771	.000	.940	771	.000
Tg_Sun	.110	771	.000	.938	771	.000
Tg_Sha	.103	771	.000	.954	771	.000
Tr_Sun	.082	771	.000	.951	771	.000
Tr_Sha	.080	771	.000	.962	771	.000
Va	.113	771	.000	.919	771	.000
Light	.132	771	.000	.897	771	.000
N_People	.092	771	.000	.953	771	.000
G1	.094	771	.000	.965	771	.000
G2	.136	771	.000	.952	771	.000
G3	.243	771	.000	.849	771	.000
G4more	.301	771	.000	.774	771	.000

a. Lilliefors Significance Correction

Number of Groups of G1 – Summer: Variables entered and ANOVA

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G1

ANOVA[a]

Model		Sum of	df	Mean	F	Sig.
1	Regression	1126	1	1126	80	.000[b]
	Residual	10882	769	14		
	Total	12008	770			
2	Regression	1684	2	842	63	.000[c]
	Residual	10324	768	13		
	Total	12008	770			
3	Regression	1870	3	623	47	.000[d]
	Residual	10138	767	13		
	Total	12008	770			

a. Dependent Variable: G1

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, rH

d. Predictors: (Constant), Light, rH, Va

Model to Predict G2 – Summer: Variables entered and ANOVA

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tr_Sha	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	659	1	659	99	.000[b]
	Residual	5139	769	7		
	Total	5798	770			
2	Regression	712	2	356	54	.000[c]
	Residual	5086	768	7		
	Total	5798	770			

a. Dependent Variable: G2

b. Predictors: (Constant), Tr_Sha

c. Predictors: (Constant), Tr_Sha, rH

Model to Predict G3 – Summer: Variables entered and ANOVA

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G3

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	659	1	659	99	.000[b]
	Residual	5139	76	7		
	Total	5798	77			
2	Regression	712	2	356	54	.000[c]
	Residual	5086	76	7		
	Total	5798	77			

a. Dependent Variable: G2

b. Predictors: (Constant), Tr_Sha

c. Predictors: (Constant), Tr_Sha, rH

Model to Predict G4 – Summer: Variables entered and ANOVA

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Tr_Sha	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G4more

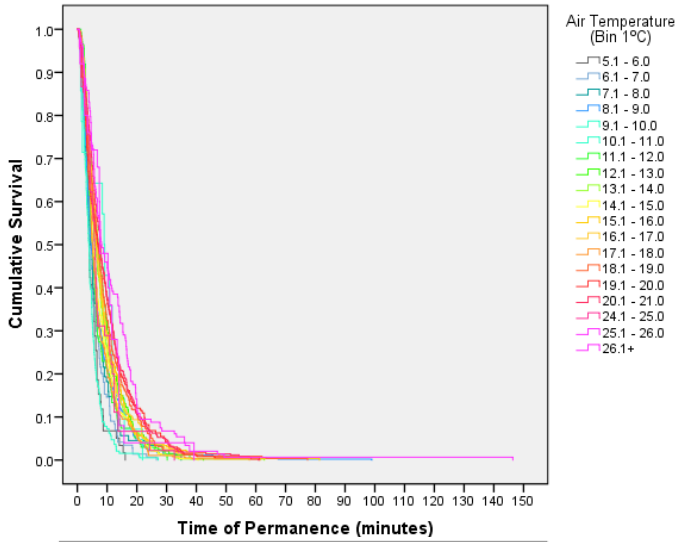
ANOVA[a]

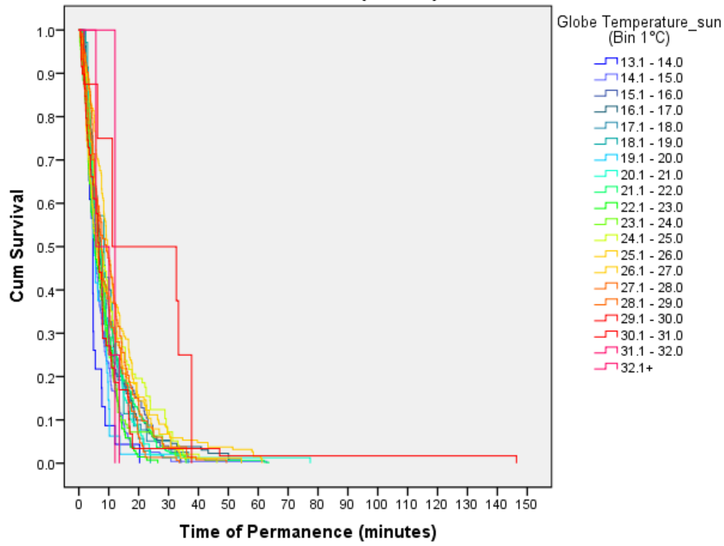
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.396	1	10.396	10.762	.001[b]
	Residual	742.844	769	.966		
	Total	753.240	770			
2	Regression	41.559	2	20.780	22.424	.000[c]
	Residual	711.680	768	.927		
	Total	753.240	770			

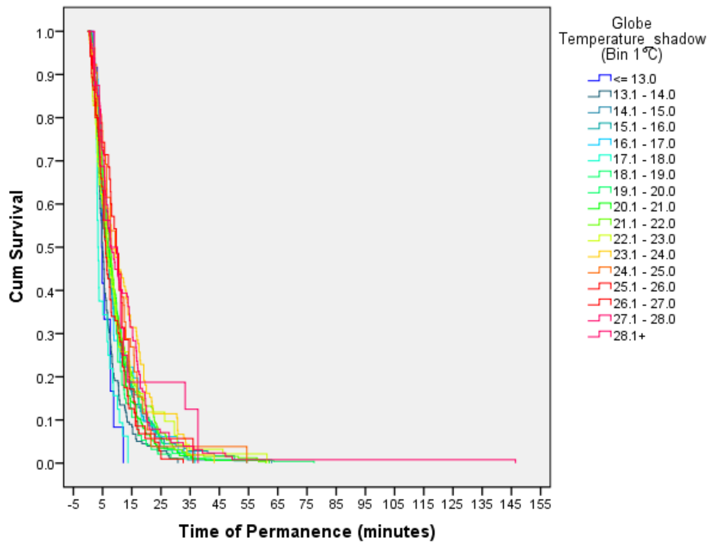
a. Dependent Variable: G4more

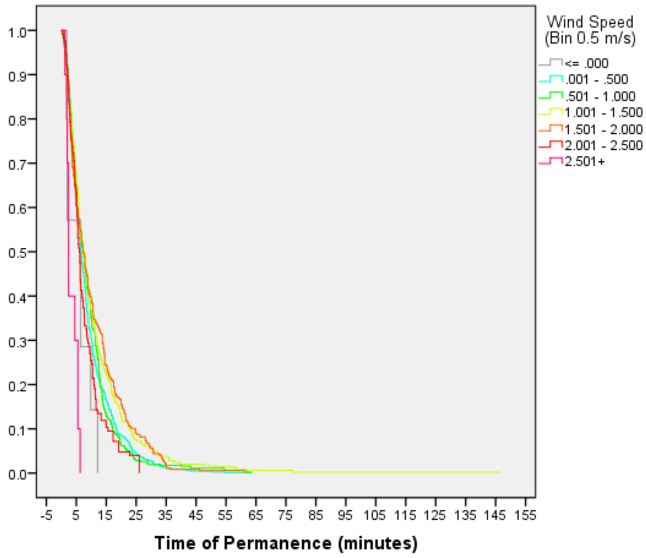
b. Predictors: (Constant), rH

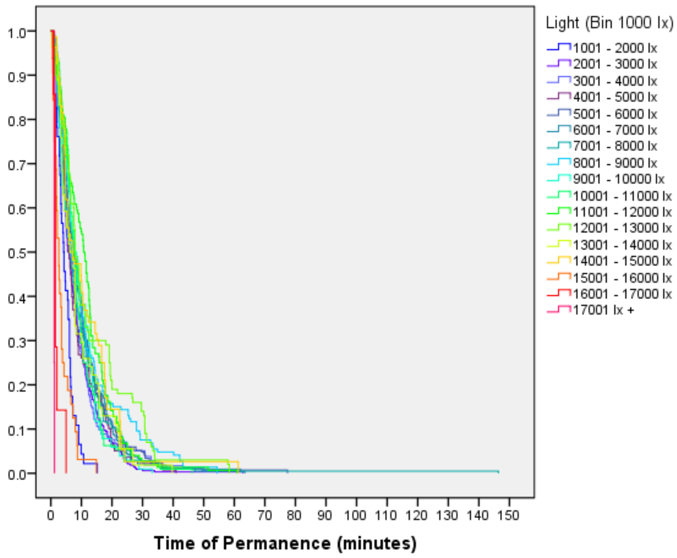
c. Predictors: (Constant), rH, Tr_Sha

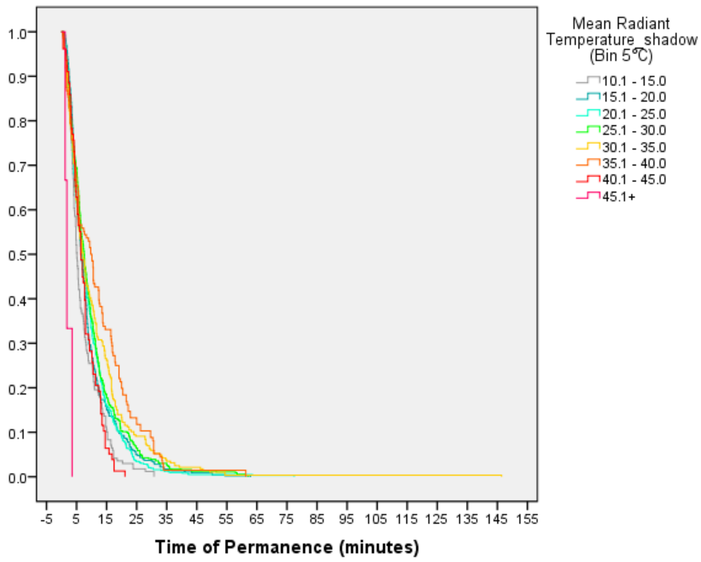







Wind Speed
(Bin 0.5 m/s)
<= .000
.001 - .500
.501 - 1.000
1.001 - 1.500
1.501 - 2.000
2.001 - 2.500
2.501+
Time of Permanence (minutes)


Light (Bin 1000 lx)
1001 - 2000 lx
2001 - 3000 lx
3001 - 4000 lx
4001 - 5000 lx
5001 - 6000 lx
6001 - 7000 lx
7001 - 8000 lx
8001 - 9000 lx
9001 - 10000 lx
10001 - 11000 lx
11001 - 12000 lx
12001 - 13000 lx
13001 - 14000 lx
14001 - 15000 lx
15001 - 16000 lx
16001 - 17000 lx
17001 lx +
Time of Permanence (minutes)


Mean Radiant
Temperature_shadow
(Bin 5℃)
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 30.0
30.1 - 35.0
35.1 - 40.0
40.1 - 45.0
45.1+
Time of Permanence (minutes)

Appendix 3: Human Behaviour in Autumn

Additional Calculations of multiple regression models: Kolmogorov Test, Variables Entered and ANOVA.

Survival Curves of the Time of Permanence

This sections contains additional calculation performed during the data analysis of the data set collected in autumn, which helped to test the distribution and performance of the multiple regression models to predict Number of People and Number of Groups.

Tests of Normality - Autumn

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
N_People	.097	737	.000	.953	737	.000
G1	.111	737	.000	.955	737	.000
G2	.156	737	.000	.920	737	.000
G3	.246	737	.000	.778	737	.000
G4more	.432	737	.000	.567	737	.000
Ta	.155	737	.000	.907	737	.000
rH	.190	737	.000	.902	737	.000
Tg_sun	.103	737	.000	.953	737	.000
Tg_shad	.115	737	.000	.949	737	.000
Tr_sun	.157	737	.000	.946	737	.000
Tr_shad	.116	737	.000	.931	737	.000
Va	.140	737	.000	.897	737	.000
Light	.192	737	.000	.811	737	.000

a. Lilliefors Significance Correction

Model Number of People - Autumn:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tr_sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: N_People

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19335.674	1	19335.674	264.620	.000[b]
	Residual	53706.188	735	73.070		
	Total	73041.862	736			
2	Regression	22012.754	2	11006.377	158.315	.000[c]
	Residual	51029.108	734	69.522		
	Total	73041.862	736			
3	Regression	24152.376	3	8050.792	120.706	.000[d]
	Residual	48889.486	733	66.698		
	Total	73041.862	736			

a. Dependent Variable: N_People

b. Predictors: (Constant), Tr_sun

c. Predictors: (Constant), Tr_sun, Va

d. Predictors: (Constant), Tr_sun, Va, Light

Model to Predict G1 – Autumn:

Variables Entered/Removed[a]

Model	Variables	Variables	Method
1	Ta	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Tr_sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G1

ANOVA[a]

Model		Sum of	df	Mean	F	Sig.
1	Regression	752	1	752	77	.000[b]
	Residual	7166	735	10		
	Total	7918	736			
2	Regression	799	2	400	41	.000[c]
	Residual	7118	734	10		
	Total	7918	736			

a. Dependent Variable: G1

b. Predictors: (Constant), Air_T, Rad_T_Sun

c. Predictors: (Constant), Ta, Tr_sun

Model to Predict G2 – Autumn:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tr_sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Light	.	Forward (Criterion: Probability-of-F-

a. Dependent Variable: G2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1257	1	1257	250	.000[b]
	Residual	3695	735	5		
	Total	4952	736			
2	Regression	1332	2	666	135	.000[c]
	Residual	3620	734	5		
	Total	4952	736			
3	Regression	1441	3	480	100	.000[d]
	Residual	3511	733	5		
	Total	4952	736			

a. Dependent Variable: G2

b. Predictors: (Constant), Tr_sun

c. Predictors: (Constant), Tr_Sun, Va

d. Predictors: (Constant), Tr_Sun, Va, Light

Model to Predict G3 – Autumn:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Tr_sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G3

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	125.0	1	125.0	113	.000[b]
	Residual	812.2	735	1.1		
	Total	937.1	736			
2	Regression	146.5	2	73.2	68	.000[c]
	Residual	790.7	734	1.1		
	Total	937.1	736			

a. Dependent Variable: G3

b. Predictors: (Constant), Va

c. Predictors: (Constant), Va, Tr_sun

Model to Predict G4 – Autumn:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Wind	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G4more

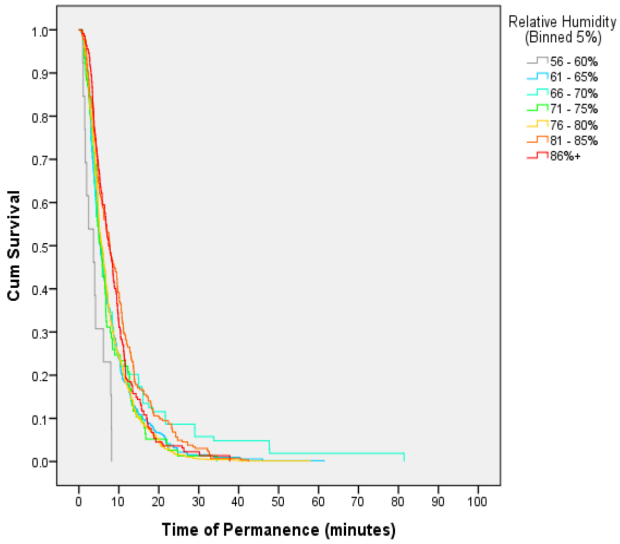
ANOVA[a]

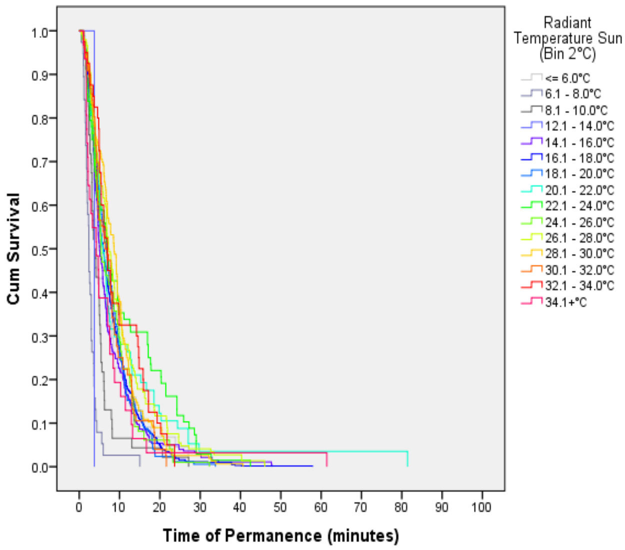
Model		Sum of	df	Mean Square	F	Sig.
1	Regression	32.250	1	32.250	81.119	.000[b]
	Residual	292.211	735	.398		
	Total	324.461	736			
2	Regression	34.015	2	17.007	42.980	.000[c]
	Residual	290.447	734	.396		
	Total	324.461	736			

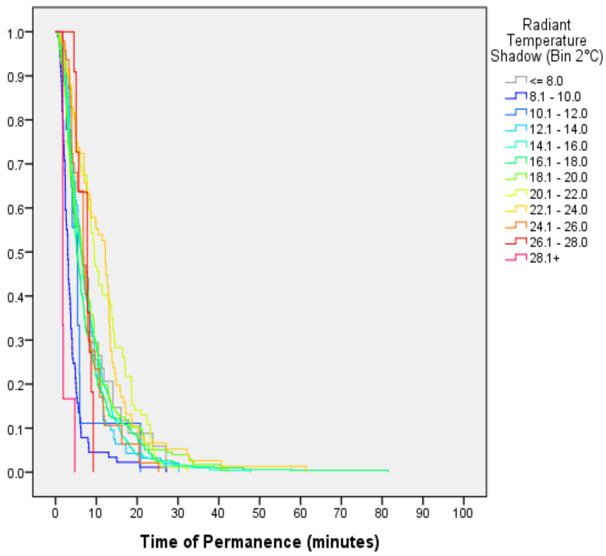
a. Dependent Variable: G4more

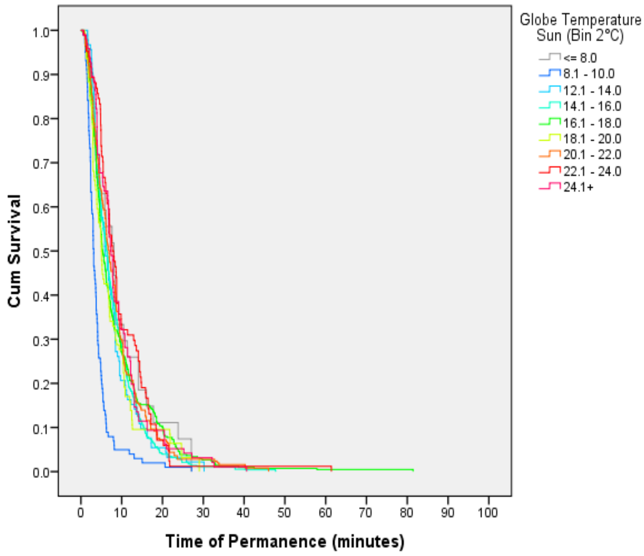
b. Predictors: (Constant), Light

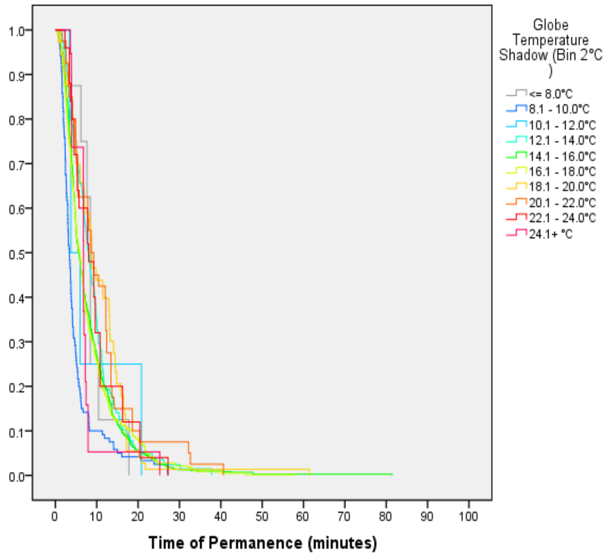
c. Predictors: (Constant), Light, Wind

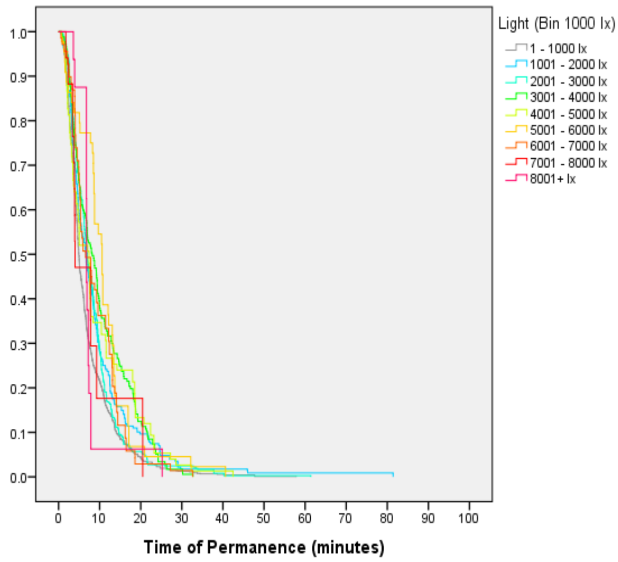

Relative Humidity (Binned 5%)
56 - 60%
61 - 65%
66 - 70%
71 - 75%
76 - 80%
81 - 85%
86%+
Cum Survival
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
0 10 20 30 40 50 60 70 80 90 100
Time of Permanence (minutes)


Radiant Temperature Sun (Bin 2°C)
<= 6.0°C
6.1 - 8.0°C
8.1 - 10.0°C
12.1 - 14.0°C
14.1 - 16.0°C
16.1 - 18.0°C
18.1 - 20.0°C
20.1 - 22.0°C
22.1 - 24.0°C
24.1 - 26.0°C
26.1 - 28.0°C
28.1 - 30.0°C
30.1 - 32.0°C
32.1 - 34.0°C
34.1+°C
Cum Survival
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
0 10 20 30 40 50 60 70 80 90 100
Time of Permanence (minutes)


Radiant Temperature Shadow (Bin 2°C)
<= 8.0
8.1 - 10.0
10.1 - 12.0
12.1 - 14.0
14.1 - 16.0
16.1 - 18.0
18.1 - 20.0
20.1 - 22.0
22.1 - 24.0
24.1 - 26.0
26.1 - 28.0
28.1+
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
0 10 20 30 40 50 60 70 80 90 100
Time of Permanence (minutes)


Cum Survival
Time of Permanence (minutes)
Globe Temperature Sun (Bin 2°C)
<= 8.0
8.1 - 10.0
12.1 - 14.0
14.1 - 16.0
16.1 - 18.0
18.1 - 20.0
20.1 - 22.0
22.1 - 24.0
24.1+


Time of Permanence (minutes)
Globe Temperature Shadow (Bin 2°C)
<= 8.0°C
8.1 - 10.0°C
10.1 - 12.0°C
12.1 - 14.0°C
14.1 - 16.0°C
16.1 - 18.0°C
18.1 - 20.0°C
20.1 - 22.0°C
22.1 - 24.0°C
24.1+ °C


Time of Permanence (minutes)
Light (Bin 1000 lx)
1 - 1000 lx
1001 - 2000 lx
2001 - 3000 lx
3001 - 4000 lx
4001 - 5000 lx
5001 - 6000 lx
6001 - 7000 lx
7001 - 8000 lx
8001+ lx

Appendix 4: Human Behaviour in Winter

Additional Calculations of multiple regression models: Kolmogorov Test, Variables Entered and ANOVA.

This sections contains additional calculation performed during the data analysis of the data set collected in winter, which helped to test the distribution and performance of the multiple regression models to predict Number of People and Number of Groups.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ta	.200	771	.000	.913	771	.000
rH	.152	771	.000	.937	771	.000
Tg_Sun	.131	771	.000	.905	771	.000
Tg_Shad	.153	771	.000	.944	771	.000
Tr_Sun	.201	771	.000	.771	771	.000
Tr_Sha	.150	771	.000	.834	771	.000
Va	.062	771	.000	.972	771	.000
Light	.242	771	.000	.726	771	.000
N_People	.162	771	.000	.893	771	.000
G1	.143	771	.000	.913	771	.000
G2	.212	771	.000	.849	771	.000
G3	.393	771	.000	.647	771	.000
G4more	.467	771	.000	.522	771	.000

a. Lilliefors Significance Correction

Model to Predict Number of People – Winter:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
4	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: N_People

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12797.371	1	12797.371	489.055	.000[b]
	Residual	20122.834	769	26.168		
	Total	32920.205	770			
2	Regression	13880.964	2	6940.482	279.963	.000[c]
	Residual	19039.241	768	24.791		
	Total	32920.205	770			
3	Regression	15044.020	3	5014.673	215.161	.000[d]
	Residual	17876.185	767	23.307		
	Total	32920.205	770			
4	Regression	15263.794	4	3815.949	165.550	.000[e]
	Residual	17656.411	766	23.050		
	Total	32920.205	770			

a. Dependent Variable: N_People

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, Va

d. Predictors: (Constant), Light, Va, rH

e. Predictors: (Constant), Light, Va, rH, Tg_Sun

Model to Predict Number of G1 – Winter:

Variables Entered/Removed[a]

Model	Variables	Variables	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
4	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1548	1	1548	378	.000[b]
	Residual	3151	769	4		
	Total	4699	770			
2	Regression	1729	2	864	223	.000[c]
	Residual	2970	768	4		
	Total	4699	770			
3	Regression	1756	3	585	153	.000[d]
	Residual	2942	767	4		
	Total	4699	770			
4	Regression	1787	4	447	118	.000[e]
	Residual	2912	766	4		
	Total	4699	770			

a. Dependent Variable: G1

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, rH

d. Predictors: (Constant), Light, rH, Tg_Sun

e. Predictors: (Constant), Light, rH, Tg_Sun, Va

Model to Predict Number of G2 – Winter:

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	rH	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regressi	626	1	626	296	.000[b]
	Residual	1627	769	2		
	Total	2253	770			
2	Regressi	703	2	352	174	.000[c]
	Residual	1550	768	2		
	Total	2253	770			
3	Regressi	776	3	259	134	.000[d]
	Residual	1476	767	2		
	Total	2253	770			

a. Dependent Variable: G2

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, Va

d. Predictors: (Constant), Light, Va, rH

Model to Predict Number of G3 – Winter:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Ta	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G3

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regre	21	1	21	46	.000[b]
	Resid	354	769	0		
	Total	376	770			
2	Regre	25	2	13	28	.000[c]
	Resid	350	768	0		
	Total	376	770			

a. Dependent Variable: G3

b. Predictors: (Constant), Light

c. Predictors: (Constant), Light, Ta

Model to Predict Number of G4 – Winter:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Ta	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G4more

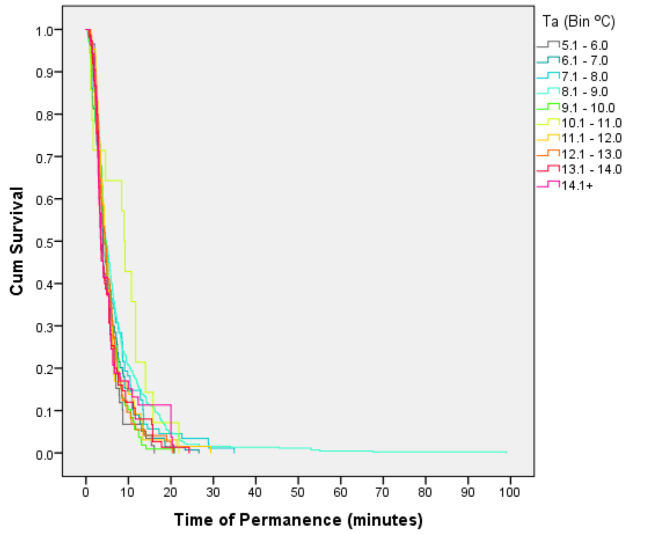
ANOVA[a]

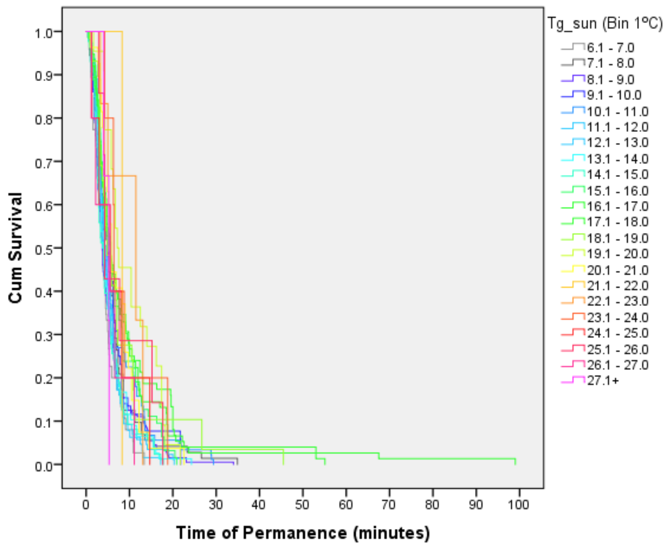
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regressi	8	1	8.10	25	.000[b]
	Residual	248	769	.32		
	Total	256	770			
2	Regressi	11	2	5.32	17	.000[c]
	Residual	246	768	.32		
	Total	256	770			

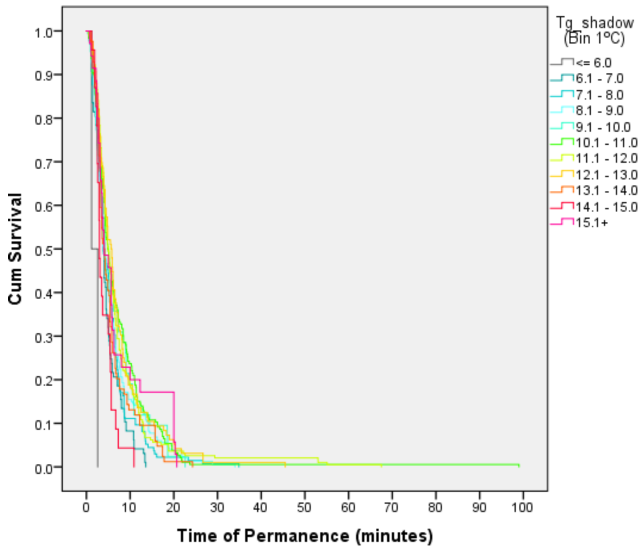
a. Dependent Variable: G4more

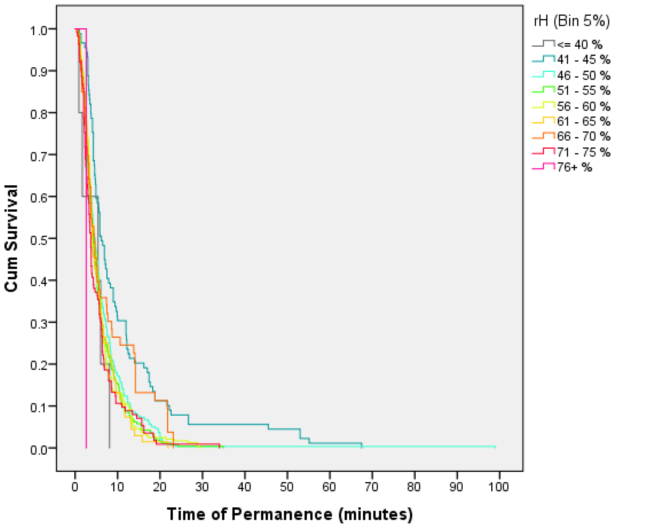
b. Predictors: (Constant), Ta

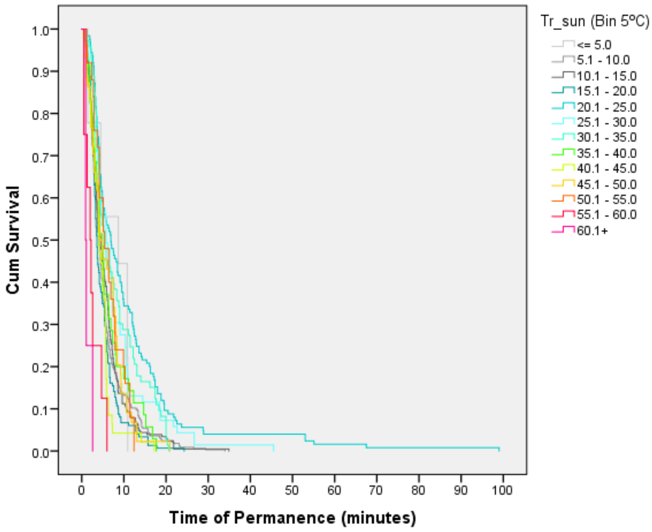
c. Predictors: (Constant), Ta, Va

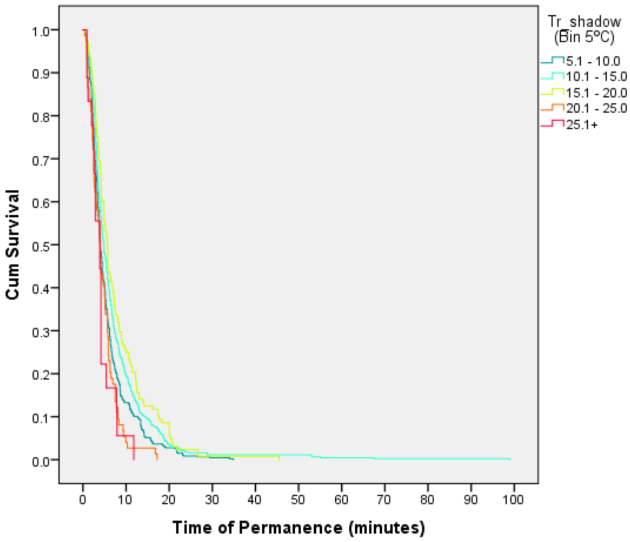

Ta (Bin ºC)
5.1 - 6.0
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
11.1 - 12.0
12.1 - 13.0
13.1 - 14.0
14.1+
Cum Survival
Time of Permanence (minutes)


Tg_sun (Bin 1ºC)
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
11.1 - 12.0
12.1 - 13.0
13.1 - 14.0
14.1 - 15.0
15.1 - 16.0
16.1 - 17.0
17.1 - 18.0
18.1 - 19.0
19.1 - 20.0
20.1 - 21.0
21.1 - 22.0
22.1 - 23.0
23.1 - 24.0
24.1 - 25.0
25.1 - 26.0
26.1 - 27.0
27.1+
Cum Survival
Time of Permanence (minutes)


Tg_shadow (Bin 1ºC)
<= 6.0
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
11.1 - 12.0
12.1 - 13.0
13.1 - 14.0
14.1 - 15.0
15.1+
Cum Survival
Time of Permanence (minutes)


rH (Bin 5%)
<= 40 %
41 - 45 %
46 - 50 %
51 - 55 %
56 - 60 %
61 - 65 %
66 - 70 %
71 - 75 %
76+ %
Cum Survival
Time of Permanence (minutes)


Tr_sun (Bin 5ºC)
<= 5.0
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 30.0
30.1 - 35.0
35.1 - 40.0
40.1 - 45.0
45.1 - 50.0
50.1 - 55.0
55.1 - 60.0
60.1+
Cum Survival
Time of Permanence (minutes)


Tr_shadow (Bin 5ºC)
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1+
Cum Survival
Time of Permanence (minutes)

Appendix 5: Human Behaviour in All-Seasons

Additional Calculations of multiple regression models: Kolmogorov Test, Variables Entered and ANOVA.

This sections contains additional calculation performed during the data analysis of the all-seasons data set, which helped to test the distribution and performance of the multiple regression models to predict Number of People and Number of Groups.

Model to Predict Number of People – All-seasons:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: N_People

ANOVA[a]

Model		Sum of	df	Mean Square	F	Sig.
1	Regression	106709.503	1	106709.503	1228.883	.000[b]
	Residual	197722.292	22	86.835		
	Total	304431.795	22			
2	Regression	115543.337	2	57771.669	696.116	.000[c]
	Residual	188888.457	22	82.991		
	Total	304431.795	22			
3	Regression	120064.150	3	40021.383	493.843	.000[d]
	Residual	184367.645	22	81.041		
	Total	304431.795	22			

a. Dependent Variable: N_People

b. Predictors: (Constant), Tg_Sun

c. Predictors: (Constant), Tg_Sun, Va

d. Predictors: (Constant), Tg_Sun, Va, Light

Model to Predict Number of G1 – All-seasons:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G1

ANOVA[a]

Model		Sum of	df	Mean	F	Sig.
1	Regression	6899	1	6899	608	.000[b]
	Residual	25837	2277	11		
	Total	32735	2278			
2	Regression	7214	2	3607	322	.000[c]
	Residual	25522	2276	11		
	Total	32735	2278			
3	Regression	7517	3	2506	226	.000[d]
	Residual	25218	2275	11		
	Total	32735	2278			

a. Dependent Variable: G1

b. Predictors: (Constant), Tg_Sun

c. Predictors: (Constant), Tg_Sun, Light

d. Predictors: (Constant), Tg_Sun, Light, Va

Model to Predict Number of G2 – All-seasons:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4437.408	1	4437.408	850.700	.000[b]
	Residual	11877.256	2277	5.216		
	Total	16314.663	2278			
2	Regression	4779.555	2	2389.777	471.529	.000[c]
	Residual	11535.109	2276	5.068		
	Total	16314.663	2278			
3	Regression	4883.739	3	1627.913	323.990	.000[d]
	Residual	11430.925	2275	5.025		
	Total	16314.663	2278			

a. Dependent Variable: G2

b. Predictors: (Constant), Tg_Sun

c. Predictors: (Constant), Tg_Sun, Va

d. Predictors: (Constant), Tg_Sun, Va, Light

Model to Predict Number of G3 – All-seasons:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Tg_Sun	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G3

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	302.630	1	302.630	282.532	.000[b]
	Residual	2438.969	2277	1.071		
	Total	2741.599	2278			
2	Regression	348.255	2	174.128	165.590	.000[c]
	Residual	2393.344	2276	1.052		
	Total	2741.599	2278			
3	Regression	367.602	3	122.534	117.424	.000[d]
	Residual	2373.997	2275	1.044		
	Total	2741.599	2278			

a. Dependent Variable: G3

b. Predictors: (Constant), Tg_Sun

c. Predictors: (Constant), Tg_Sun, Va

d. Predictors: (Constant), Tg_Sun, Va, Light

Model to Predict Number of G4 – All-seasons:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Light	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
2	Tr_Sha	.	Forward (Criterion: Probability-of-F-to-enter <= .050)
3	Va	.	Forward (Criterion: Probability-of-F-to-enter <= .050)

a. Dependent Variable: G4more

ANOVA[a]

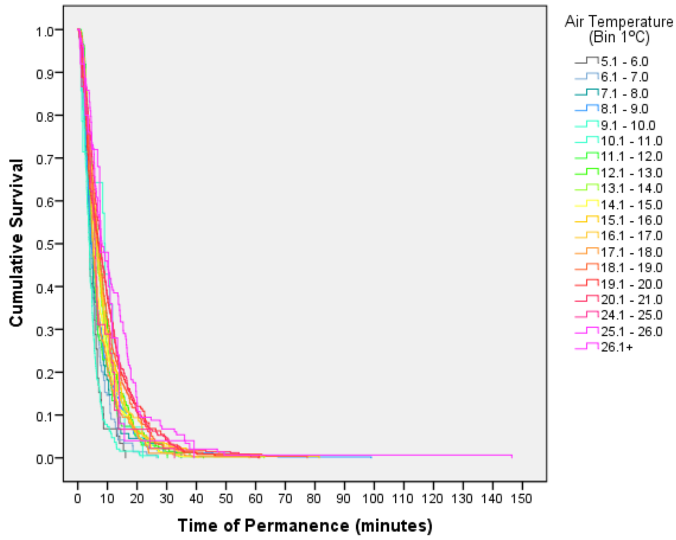
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	106.900	1	106.900	179.86	.000[b]
	Residual	1353.297	2277	.594		
	Total	1460.197	2278			
2	Regression	122.652	2	61.326	104.35	.000[c]
	Residual	1337.544	2276	.588		
	Total	1460.197	2278			
3	Regression	139.325	3	46.442	79.988	.000[d]
	Residual	1320.872	2275	.581		
	Total	1460.197	2278			

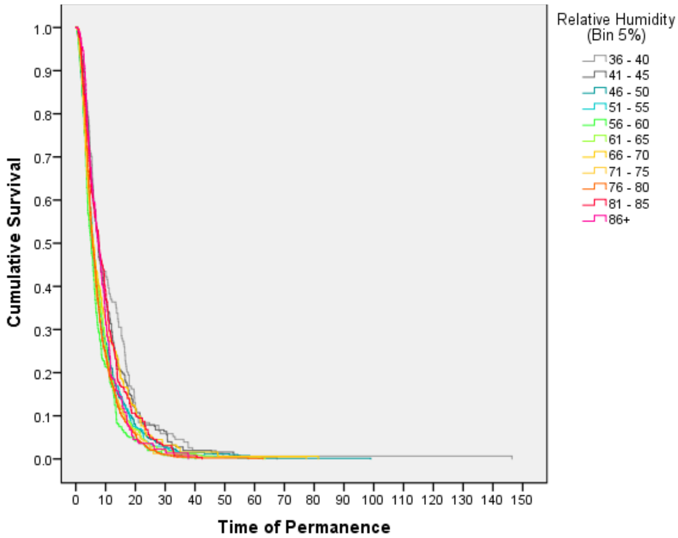
a. Dependent Variable: G4more

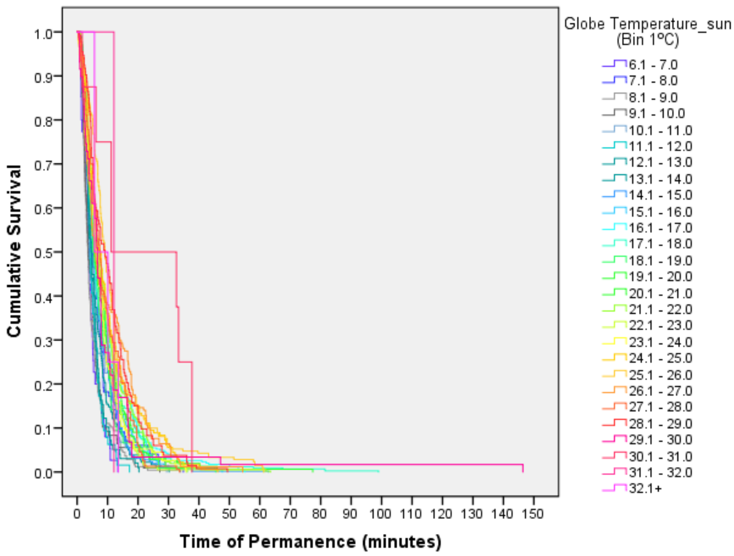
b. Predictors: (Constant), Light

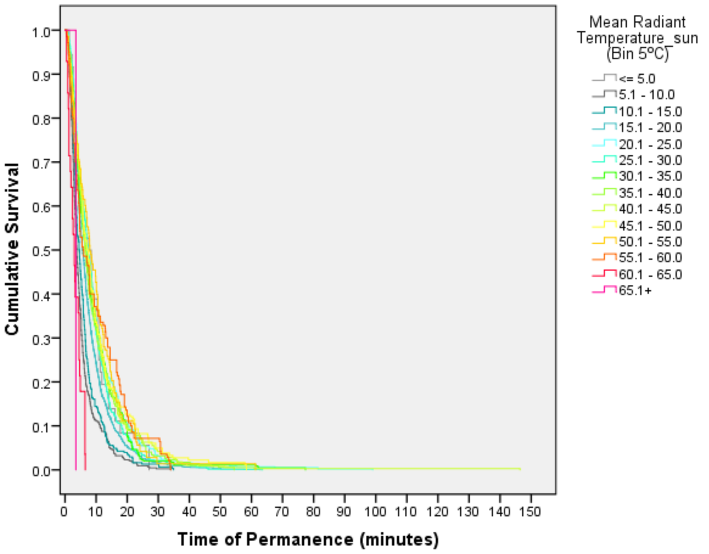
c. Predictors: (Constant), Light, Tr_Sha

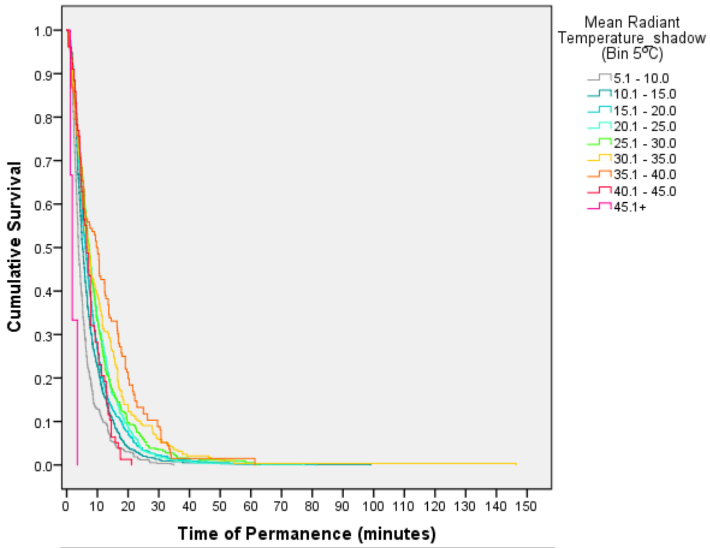
d. Predictors: (Constant), Light, Tr_Sha, Va

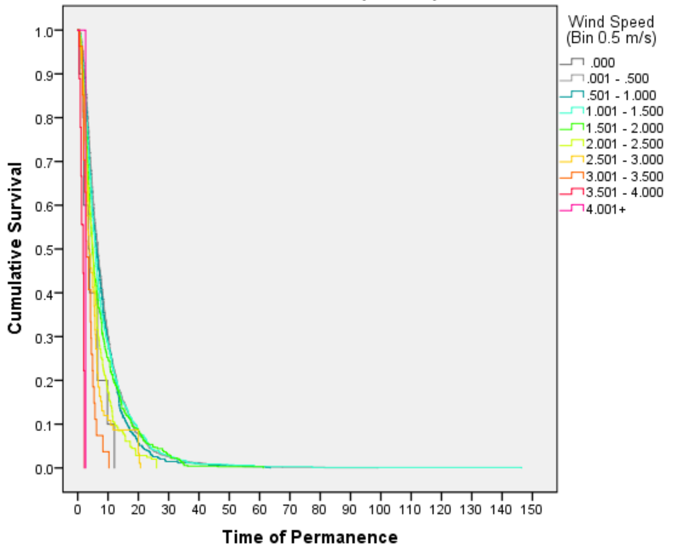

Cumulative Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Time of Permanence (minutes)
Air Temperature (Bin 1ºC)
5.1 - 6.0
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
11.1 - 12.0
12.1 - 13.0
13.1 - 14.0
14.1 - 15.0
15.1 - 16.0
16.1 - 17.0
17.1 - 18.0
18.1 - 19.0
19.1 - 20.0
20.1 - 21.0
24.1 - 25.0
25.1 - 26.0
26.1+

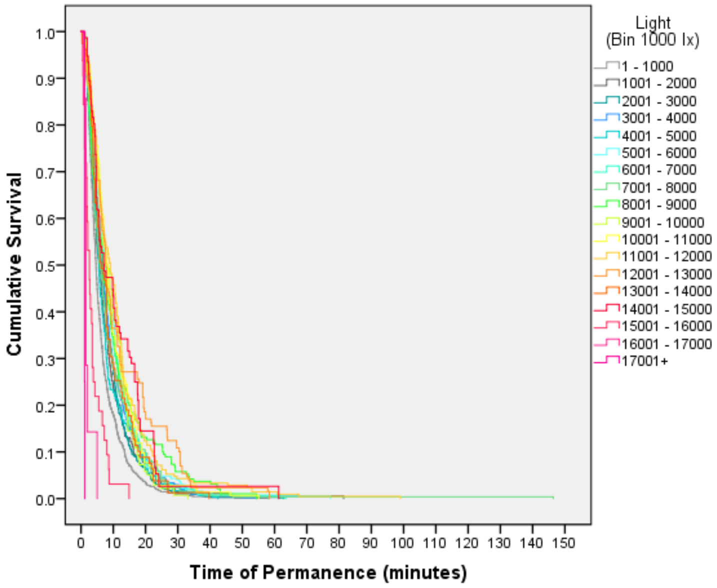

Cumulative Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Time of Permanence
Relative Humidity (Bin 5%)
36 - 40
41 - 45
46 - 50
51 - 55
56 - 60
61 - 65
66 - 70
71 - 75
76 - 80
81 - 85
86+

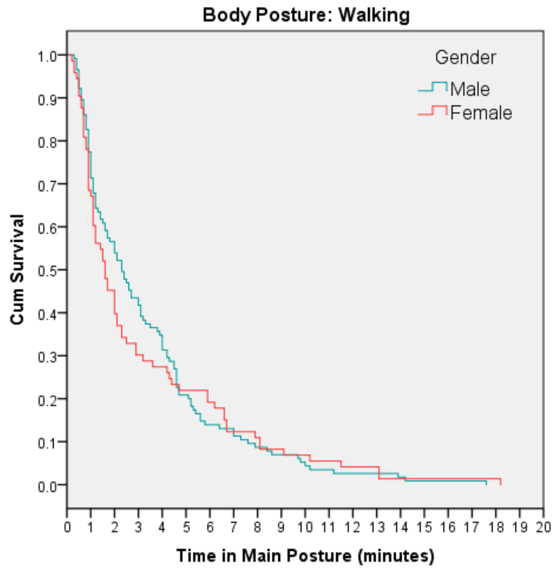

Cumulative Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Time of Permanence (minutes)
Globe Temperature_sun (Bin 1ºC)
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
11.1 - 12.0
12.1 - 13.0
13.1 - 14.0
14.1 - 15.0
15.1 - 16.0
16.1 - 17.0
17.1 - 18.0
18.1 - 19.0
19.1 - 20.0
20.1 - 21.0
21.1 - 22.0
22.1 - 23.0
23.1 - 24.0
24.1 - 25.0
25.1 - 26.0
26.1 - 27.0
27.1 - 28.0
28.1 - 29.0
29.1 - 30.0
30.1 - 31.0
31.1 - 32.0
32.1+

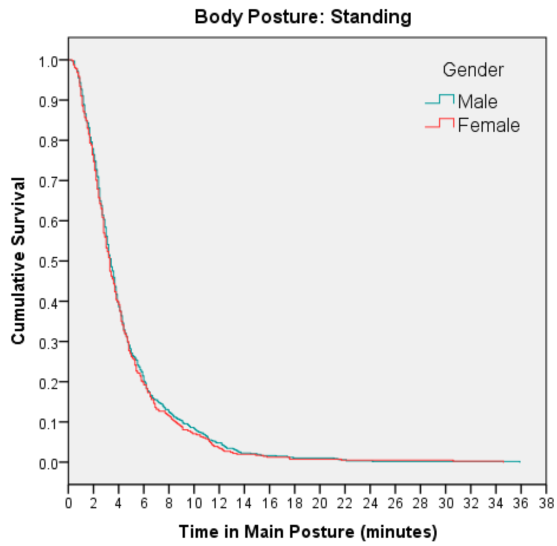

Mean Radiant Temperature_sun (Bin 5ºC)
<= 5.0
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 30.0
30.1 - 35.0
35.1 - 40.0
40.1 - 45.0
45.1 - 50.0
50.1 - 55.0
55.1 - 60.0
60.1 - 65.0
65.1+
Cumulative Survival
Time of Permanence (minutes)

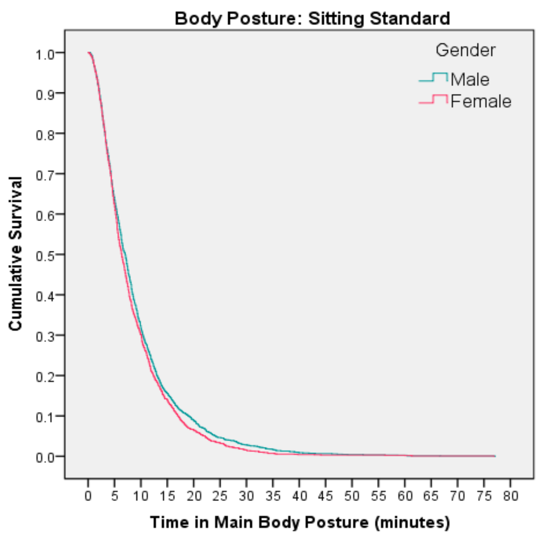

Mean Radiant Temperature_shadow (Bin 5ºC)
5.1 - 10.0
10.1 - 15.0
15.1 - 20.0
20.1 - 25.0
25.1 - 30.0
30.1 - 35.0
35.1 - 40.0
40.1 - 45.0
45.1+
Cumulative Survival
Time of Permanence (minutes)


Wind Speed (Bin 0.5 m/s)
.000
.001 - .500
.501 - 1.000
1.001 - 1.500
1.501 - 2.000
2.001 - 2.500
2.501 - 3.000
3.001 - 3.500
3.501 - 4.000
4.001+
Cumulative Survival
Time of Permanence


Light
(Bin 1000 lx)
1 - 1000
1001 - 2000
2001 - 3000
3001 - 4000
4001 - 5000
5001 - 6000
6001 - 7000
7001 - 8000
8001 - 9000
9001 - 10000
10001 - 11000
11001 - 12000
12001 - 13000
13001 - 14000
14001 - 15000
15001 - 16000
16001 - 17000
17001+
Cumulative Survival
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Time of Permanence (minutes)


Body Posture: Walking
Gender
Male
Female
Cum Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time in Main Posture (minutes)


Body Posture: Standing
Gender
Male
Female
Cumulative Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Time in Main Posture (minutes)


Body Posture: Sitting Standard
Gender
Male
Female
Cumulative Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Time in Main Body Posture (minutes)