The optimum form for acoustics: a study of the relationship between office designs and noise

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Abstract

This study investigates the relationship between office designs, acoustic measures and employee satisfaction. Cellular workspaces tend to have low noise disturbances which have been previously associated with enhanced employee satisfaction in past studies but the relationship between varying office size and employee satisfaction is unknown in cellular offices. The increase in size of open-plan workspaces generally implies an increase in occupancy and noise level because more noise disturbances tend to occur due to increase in office activities. But the increase in size of open-plan spaces also implies an increase in reverberation time because the latter is directly proportional to volume of space. The aim of this study is to provide some indication of workspace sizes for different office types that are related to acoustic measures and employee satisfaction and can be used during early design stages of office developments. In this study, acoustic measures are comprised of two indicators: 1) noise level which indicates the intensity of background noise in the workplace and 2) reverberation time which reflects the acoustic quality of the workspace. Two common office types are investigated in this study – cellular and open-plan workspaces and the formulated hypotheses for each office type are as follows: i) Hypothesis A: the increase in workspace floor areas will be associated with a decrease in values of at least one indicator of acoustic measures and with an increase in employee satisfaction in cellular workspaces and ii) Hypothesis B: the increase in workspace floor areas will be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction in open-plan workspaces.

A cross-sectional research framework was adopted in this study to investigate the association between workspace floor area, acoustic measures and employee satisfaction in cellular offices and open-plan offices with the following occupancy levels: 1) less than 10 employees, 2) between 10 and 25 employees and 3) more than 25 employees. The study made use of both objective and subjective data to correlate employee perception with physical work environment. Subjective data consisted of acoustic and work performance satisfaction ratings acquired from questionnaire survey and objective data consisted of noise levels, and reverberation time and workspaces areas. Furthermore, the study also investigated the differences in noise perception in

contrasting countries and two samples were collected; one from UK (Glasgow) and another from Mauritius.

Results from correlation analysis for Glasgow sample indicated that there were coherent associations between workspace floor areas, acoustic measures and employee satisfaction in all open-plan categories but not in cellular offices. The creation of a visual index in open-plan workspaces further supported the aforementioned associations when making use of shape descriptors in the detailed analysis of Glasgow sample. Certain similarities and differences were observed between Glasgow and Mauritius sample thereby eliminating the expectations that all workspaces in the investigated office categories in a developing country had inferior values of acoustic measures. The study here has a cross-sectional framework but a longitudinal one is considered to be more revealing especially when investigating noise perception in relation to the visual index, noise geometry. More cross-cultural studies focusing on noise in the workplace are required to further develop appropriate guidelines in varying cultures.

Preface

Office buildings are ubiquitous in cities and are synonymous of the local work culture and economic advancements. This study investigates the relationship between office size, acoustic measures and employee satisfaction. Office sizes vary greatly in organisations and it is considered that they are associated with acoustic measures because the latter are dependent on spatial volume and the number of occupants in them. Intensity of noise is commonly known to influence employees in the workplace but the associations between office size, acoustic measures - noise level and reverberation time - and employee satisfaction are yet to be determined. The interest of this study arose after the author investigated the variability of noise level within Glasgow's urban context and the perception of noise during her Masters in Architecture (by Conversion) course at the Mackintosh School of Architecture, Glasgow School of Art. This doctoral study was intended to provide more insight of the perception of noise in the workplace associated with the size of workspaces to architects and designers.

A three-year long cross-sectional study was carried out in Glasgow by the author to investigate the association between office size, acoustic measures and employee satisfaction. The first year of the study focused on the research context of workspaces in Glasgow and research materials were collated mostly from the City Archives at the Mitchell Library, Glasgow and the Glasgow School of Art Library. The second year of the study was dedicated to field study. Different types of workspaces (cellular and open-plan offices) were investigated in Glasgow and Mauritius. The data collection method included questionnaire surveys and sound level measurements in each workspace. The study was approved by the Glasgow School of Art Research Ethics Committee. The last year of the study was dedicated to the analysis of data collected and to writing up the results obtained.

The results obtained in this study begins to shed light on the relationship between office size, acoustic measures and employee satisfaction and starts to highlight how acoustics can be incorporated at early design stages of workspaces. Furthermore, the study indicates certain similarities and differences in the association of employee satisfaction with varying office sizes and acoustic measures in contrasting cultures. So far, only partial results obtained in Mauritius sample were published by the author in the Journal of Contemporary Management Sciences (Jahangeer 2014). This study presented here is an original piece of work by the author investigating acoustics in the workplace and encourages further study in that area to improve employee satisfaction in the workplace.

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The production of this doctoral thesis has been a very challenging and insightful one and I would like to gratefully acknowledge those who have provided support, advice and assistance during the last few years. I would like to express the deepest appreciation to the following people without whom none of this work would have been possible: first, to my beloved parents and family who have always been present in times of hardship and provided me with endless support during my studies and secondly to Dr Raid Hanna, who has always challenged me throughout my studies and taught me all the great qualities of an academic. It has truly been a privilege being supervised by Dr Hanna. I would also like to extend my gratitude to the following organisations for the collation of research sources and materials: the staff of Mackintosh School of Architecture and the staff of Glasgow School of Art library. I also thank my friends who have shown sincere interest in my studies.

Table of Contents

Chapter 7 - Glasgow Case Study 2: Analysis of noise geometry & employee behaviour

Chapter 8 - Mauritius Case Study: Analysis of spatial settings & employee behaviour

List of Figures

Number *Page*

List of Tables

Number *Page*

List of Tables & Figures in Appendices

Number *Page*

Chapter 1

Introduction

1.1 Research context and problem

This study is an investigation of the relationship between office design, acoustic measures and employee satisfaction. The principal interest in this study was to investigate the perception of noise in different types of workspaces. Newly-built workspaces in central areas, such as the new Selgas Cano office in London with its sound absorbing acrylic coloured walls (Moore 2014), could allegedly be described as an artwork but the majority of workspaces do not have the same special design features and innovative acoustic treatments like the aforementioned office and instead tend to have a homogenous appearance: rectangular office with acoustic ceiling tiles, carpet floor and plastered walls pierced with windows. However, the size of workspaces in the UK varies greatly depending on the number of occupants. The average employee in UK reportedly spends 44 hours per week in offices which indicates that office employees spend more time at work than at home (Office for National Statistics 2010). In 2011, it was reported that the central area of Glasgow contained 197 700 employees of which 59.5% were considered to be working in organisations occupying office premises (Office for National Statistics 2011). The long office hours undertaken by a large population of employees necessitates optimum comfort at the workplace. This study looks at ways of improving acoustic comfort in the workplace by examining the variation in acoustic measures with office designs.

In retrospect, the need to separate public life from **a** private one led to the rise of office spaces in the 19th C (Pelegrin-Genel 1995). The office building remains a significant building type in Glasgow city with architectural styles varying from eclectic classicism to contemporary ones. In addition to the varying exterior designs of office buildings, workspace interiors also changed with time. The early workspaces dating back to 19th C were predominantly enclosed rooms occupied by one or two workspaces known as the *cellular* or *private* office but towards the end of the 19th C there was the need to cater for growing businesses and the increase in workforce which led to the creation of the *open-plan* office. An example of the latter is seen in Frank Llyod Wright's Larkin building (Quinan 1987). Several other office concepts were created after the introduction of open-plan office and according to Meel (2010) there are 9 different office concepts on the current market but the two most common office types remain the cellular and open-plan because not all organisations are financially equipped to re-design workspaces according to latest office trend on the market. Furthermore, Duffy (2008) pointed out that changes in the interior of office buildings tend to occur every five years. Both cellular and open-plan workspaces have advantages and disadvantages – the cellular workspace is costly and restricts collaboration among employees whereas the open-plan office reduces overhead expenses and allegedly increases collaboration but has also often been associated with noise disturbances. The association between open-plan workspace and noise disturbance was analysed by several researchers including Brookes & Kaplan (1972), Nemecek & Grandjean (1973), Sundstrom et al. (1994), Brennan et al. (2002), and Danielsson & Bodin (2009). Despite the increasing evidence of noise disturbances and inferior work performance associated with open-plan workspace, the latter workspace continues to be popular in organisations because high density of employees can be accommodated in comparison to cellular workspaces thus reducing costs (Davis et al. 2011). In this study, the historical analysis of workspaces in Glasgow showed that more acoustic treatments, such as acoustic ceiling tiles and carpet flooring, were present in contemporary workspaces than in those constructed prior 1960s which shows the intention to improve acoustic comfort of employees on behalf of workspace designers and managers. Moreover, several guidelines and recommendations for acoustic measures are in place for office designers and managers but lack certain depth in the provision of acoustic comfort guidelines. For instance, British Council for Offices (2009) recommends average daily noise level for only two workspaces cellular (less than 40 dBA) and open-plan workspaces with multi-occupancy (between 40 and 50 dBA). In the latter workspaces, occupancy and sizes of workspaces tend to vary and recommended noise level should most likely correspond to the size and occupancy of open-plan workspaces. British Standards Institute (1999) recommends different values for reverberation time depending on the volume of workspaces but also does not refer to the occupancy of workspaces. The size of open-plan workspace usually determines the number of occupants within the workspace but the association between acoustic measures - noise level and reverberation time - and size of workspaces is not clear.

Nonetheless, acoustic satisfaction ratings in open-plan workspaces remains inferior (Burkeman 2013) and necessitates further investigation of the workplace to improve this. Vischer (2008) previously mentioned that satisfaction with the work environment is associated with work performance of employees and their commitment to organisations in which they work. The variables associated with employee satisfaction in the workplace are manifold and in this study the relationship of office design with acoustic measures and employee satisfaction are being investigated. To determine the scope of studies investigating noise in the workplace, reading resources from Glasgow School of Art and University of Glasgow libraries were used for the literature review in addition to scholarly articles obtained from the following online research databases; JSTOR (www.jstor.org), Wiley (onlinelibrary.wiley.com), ScienceDirect (www.sciencedirect.com), Sage Journals (online.sagepub.com), RIBA online library (www.architecture.com), Art and Architecture complete (www.ebscohost.com), World Cat (www.worldcat.org) and Google Scholar. A rise in the number of studies investigating noise dissatisfaction in the open-plan workspaces in the last decades was observed in Europe and America from psychological and acoustical perspectives and Figure 1.0 illustrates briefly this rise in the number of studies reviewed by the author.

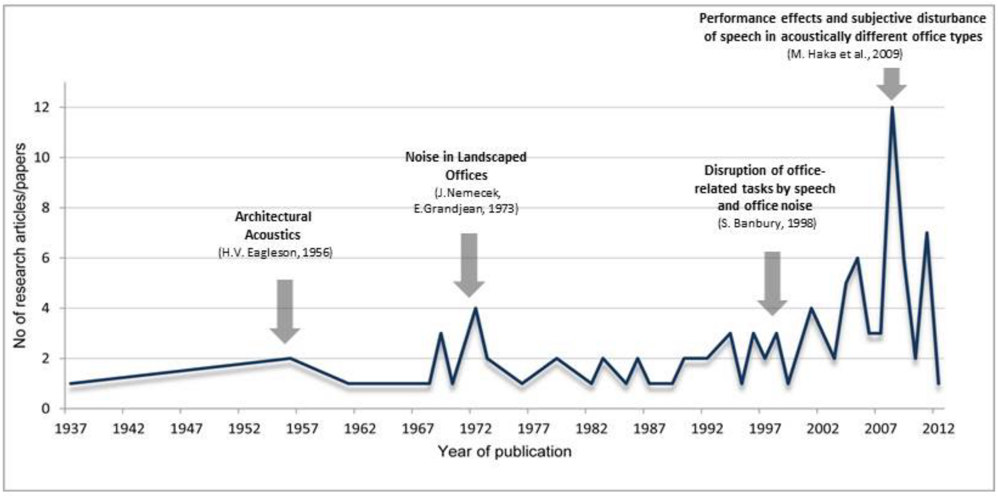


Figure 1.0 Graph produced by the author indicating the number of studies focusing on acoustics in the workplace in the last decades obtained from the above mentioned research databases when searching for 'office noise'

Several studies have indicated that intermittent noise sources, such as people talking, are recurring sources of noise dissatisfaction in the workplace (Hay & Kemp 1972a; Nemecek & Grandjean 1973; Danielsson & Bodin 2009). But the means of dealing with intermittent noise in the workplace is yet to be developed. Several different aspects of noise in the workplace have been investigated in relation to work performance of employees - the intensity of noise, irrelevance of speech in noise, clarity of speech in office, masked noise and reverberation time suggesting different ways of improving acoustic satisfaction and perceived work performance in the office but the results in studies are not always coherent with each other thus creating a disparity in ways of dealing with office noise. For instance, Bryan & Tolcher (1976) mentioned that the acceptability of noise intensity was dependent on the nature of task being performed whereas Colle (1980) observed that in conditions with noise level increasing above 40 dBA, the number of errors present in tasks tended to increase by 13.3%. Keighley (1970) and Waller (1969) highlighted that constant loud noise was more acceptable than intermittent noise in the workspace. Different research frameworks have been used in the investigation of acoustics in relation to employee satisfaction and work performance. Intensity of noise in relation to work performance and employee satisfaction are often investigated in studies with experimental set-ups for great in-depth analysis of variables. Among the aforementioned studies are those carried out by Salamé & Baddeley (1982), Loewen & Suedfeld (1992), Banbury & Berry (1998), Haka et al. (2009) which are discussed in more details in Chapter 2. Access restrictions to office spaces are a great setback in field studies focusing on acoustic in the workplace which is possibly why cross-sectional field studies are not as common as experimental ones. Also variables investigated in experimental studies are not always similar to those investigated in field studies. For instance Banbury & Berry (1998) measured performance of employees by accuracy of answers for given tasks and time taken to complete these tasks but in a field study by Banbury & Berry (2005) only questionnaire survey was carried out to indicate work performance satisfaction. The restricted access to workspaces and employees limits the possibility of measuring certain variables but nonetheless more field studies are necessary in office environment to bridge the gap between perception of work environment and actual performance of office space. It is considered that more robust field studies are required in the investigation of employee satisfaction in the workplace to provide in-depth knowledge on adequate values of acoustic measures (noise level and reverberation time) in the workplace.

Other studies have suggested that certain spatial characteristics of the workplace is associated with the perception of noise (Nemecek & Grandjean 1973; Danielsson & Bodin 2008; Hua et al. 2011; Frontczak et al. 2012). Some of these spatial characteristics include layout type (cellular versus open-plan), gross floor area of workspaces and occupancy density. The studies of Nemecek & Grandjean (1973) and Danielsson & Bodin (2009) showed that acoustic satisfaction varied according to the size of workspaces and number of occupants but in both these studies the association between office size and acoustic measures were not investigated. Intermittent noise in the workplace, as mentioned previously, is considered a nuisance to employees. Kaarlela-Tuomaala et al. (2009) investigated noise variability which reflects intermittent noise in relation to acoustic satisfaction in cellular and open-plan workspaces and the results indicated that noise variability was similar in both office types but ratings of acoustic satisfaction associated with noise variability tended to vary with office types – cellular workspaces had higher acoustic satisfaction ratings than those in open-plan workspaces despite the similarity in noise variability. However, the latter study had a prospective field design in which variables from only one organisation was analysed and therefore was considered to weaken the external validity of the study. Furthermore, the size of workspace was also not included in the aforementioned study. Frontczak et al. (2012) investigated the relationship between occupancy density and individual workspace satisfaction whereas Hua et al. (2011) analysed the association between occupancy density and perceived collaboration in open-plan workspaces. Frontczak et al. (2012) observed no significant association between occupancy density and individual workspace satisfaction but Hua et al. (2011) observed that open-plan workspaces with few employees were associated with an increase in perceived collaboration between employees. However, gross floor area of workspaces and occupancy determines occupancy density by dividing the gross floor area by number of occupants. It was therefore considered that gross floor area had precedence over occupancy density during the design process of spaces. In the study of spatial characteristics of workspaces, subjective measures, such as satisfaction rating, are often used. However, the use of both spatial characteristics and acoustic measures are not commonly investigated in workspaces.

Several gaps have been identified in studies focusing on acoustics in the workplace. To begin with, it was observed in the literature review that most studies tend to stem from psychological or acoustic field. Hardly any studies are carried out within the architectural field which is considered a weakness because the built environment generally influences behaviour of individuals. The reverberation time guidelines provided by the British Standards Institute (1999) begin to articulate the type of workspace associated with the reverberation time by referring to the volume of spaces. However, there was no mention of number of occupants in the latter guidelines which does not indicate the appropriate reverberation time for occupied workspaces. Another issue with acoustics in architecture is the stage at which noise and treatment of noise is being considered during design of offices. The process of architectural design is plainly described by the Royal Institute of British Architects where stages of design evolve from brief statement to conceptual design, building design and construction of building or space (2013). However, acoustics is a non-visual form and is usually considered at the later stages of building design and often with add-on solutions, such as the use of noise absorbing partitions or study booths in open-plan workspaces. The use of acoustics in early conceptual stages of design needs to be stressed on because just like Newman (1961) said: " We are involved with acoustics everyday". Therefore, there is the need to develop some form of indication for acoustic comfort associated with spatial characteristics of office designs. As mentioned previously, two distinct research frameworks were observed in studies focusing on acoustic and perception of noise in the workspace: experimental studies or cross-sectional field studies. It is considered that more effort should be made to increase cross-sectional studies in this research area because this type of study provides more insight of the behaviour of employees in actual workspaces. The investigation of objective variables with subjective ones in studies focusing on acoustics is also not common and requires more analysis. The increase in studies looking at acoustic measures and their associations with acoustic perception in workspaces is likely to increase the understanding of acoustic comfort in the workplace.

In relation to the variables that have been investigated in studies analysing acoustics in the workplace, certain links are considered to be missing. In the analysis of spatial characteristics of offices, more emphasis is placed on the association between workplace spatial indicators, such as occupancy density with employee satisfaction. Alternately in past studies investigating acoustics in the workplace, there is great emphasis on the association between acoustic measures and noise perception whilst neglecting spatial characteristics of the workplace which consequently tends to isolate the findings. In the author's opinion the size of workspaces, acoustic measures and employee satisfaction are all interrelated. There is the need to establish the relationship between the three variables.

Another aspect which is considered to be missing in studies investigating acoustics in the workplace is that of culture. Studies focusing on acoustic satisfaction in the office environment tend to stem from America or Europe with very few in the UK. Furthermore, hardly any studies focusing on acoustic in the workplace have been carried out in developing countries. Meel (2001) highlighted that work culture tends to vary in different countries and for that reason results from studies investigating perception of noise in the workplace in alternate countries are not likely to be suitable for the UK. Also, cross-cultural field studies investigating the noise perception in the workplace is scarce and necessitates further studies. Namba et al. (1991) investigated the perception of noise in various countries but the results from the study are considered to be inapplicable to the office environment because the study focused entirely on residents. There is the need to also consider culture in studies focusing on acoustic measures and perception of noise in the workplace.

Therefore the aim of this study is to develop some form of indication of employee satisfaction associated with different office sizes and acoustic measures and also to highlight the differences and similarities of the aforementioned variables in contrasting countries.

1.2 Focus of research

As mentioned in the previous section, spatial characteristics of offices and acoustic measures have both been investigated in relation to employee satisfaction and perceived work performance but the link between spatial characteristics of offices and acoustic measures is unclear for different office types. The sizes of workspace and occupancy levels in workspaces define the workspace area attributed to each individual. It is conjectured that the size of workspaces, acoustic measures and employee satisfaction levels are interconnected. Height of workspaces was considered to vary in different workspaces and especially with age of buildings but the variation in height was not as considerable as that of workspace floor area. Two types of workspaces are being considered in this the study: cellular and open-plan offices. Acoustic measures in this study initially included noise level and reverberation time. Two variables of employee satisfaction were considered in this study: acoustic satisfaction and work performance satisfaction. The main research questions were formulated as follows and addressed in this study:

1. *Are differences in the size of workspaces associated with variations in acoustic measures and employee satisfaction in cellular and open-plan offices?*

2. *In contrasting countries, is the relationship between workspace floor area, acoustic measures and employee satisfaction similar?*

1.2.1 *Hypotheses*

In this study it was expected that the size of workspaces, acoustic measures and employee satisfaction levels were interconnected as shown in Figure 1.1 regardless of the office type. As mentioned above the size of workspace tends to determine the number of occupants within the space and the work area attributed to each individual in organisations. It is initially considered in this study that size of workspaces is linked with indicators of acoustic measures - noise level and reverberation time - because the increase in workspace size generally implies an increase in the number of occupants and in spatial volume. The latter is directly proportional to reverberation time which therefore would imply an increase in reverberation time too. Given that two different types of workspaces were analysed – cellular and open-plan offices – two different hypotheses were tested in the study because occupancy levels differed greatly for both office types. Cellular workspaces contained one to three occupants. Open-plan workspaces were subdivided into three different categories: 1) open-plan workspaces with less than 10 occupants, 2) open-plan workspaces with occupancy between 10 and 25 occupants and 3) more than 25 occupants. The hypothesis for each office type is as follows:

i) Hypothesis A: the increase in workspace floor areas will be associated with a decrease in values of at least one indicator of acoustic measures (noise level and reverberation time) and with an increase in employee satisfaction in cellular workspaces

ii) Hypothesis B: the increase in workspace floor areas will be associated with an increase in values of at least one indicator of acoustic measures (noise level and reverberation time) and a decrease in employee satisfaction in open-plan workspaces.

A cross-sectional field study was designed and data was collected with the use of sound level meter, floor plans, tape measures and questionnaire surveys. The research methods and analysis of data are further described in Chapter 5. To further investigate the association between physical workspace and employee satisfaction, the geometry of open-plan workspaces which tended to vary considerably was analysed in relation to perceived noise sources with the use of shape factors. It was conjectured that the shape and size of floor plans determined the layout of workspaces which in turn influenced employee satisfaction. The use of shape factors in the investigation of noise perception is unusual but was considered a starting point for future analysis of noise perception.

As mentioned above, cultural difference in the perception of noise was considered to be another interesting area of research in this study. Samples from two countries were investigated: UK (Glasgow) and Mauritius. In the investigation of the relationship between sizes of workspaces, acoustic measures and employee satisfaction in the two samples it is hypothesised that the association between workspace floor area, acoustic measures and employee satisfaction would be different because of the difference in organisational culture existing in the two samples.

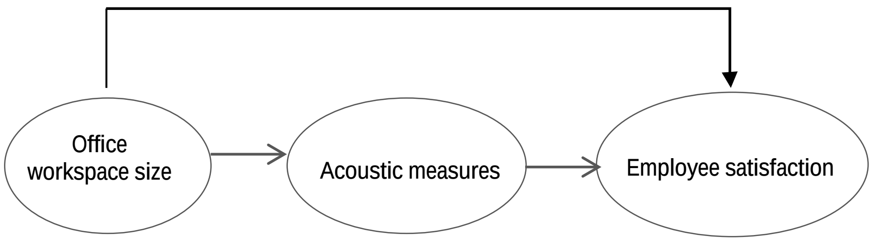


Figure 1.1 Diagram indicating the conjectured association between the size of workspaces, acoustic measures and employee satisfaction in workspaces

1.3 Thesis structure

The thesis consists of three main parts: 1) the research context and problem, 2) research methodology and analysis of data and 3) conclusion and recommendations. The first part of the thesis looks at past studies investigating noise in relation to individuals, the development of the office space as a typology and the relationship between noise and office design. Chapter 2, 3 and 4 are included in the first part of the thesis. Chapter 2 looks at past studies investigating the association of noise with individual behaviour, health and possibilities of habituation to noise. Chapter 2 also begins to shed light on the common types of research designs and methods used in the study of acoustics and individual satisfaction. Chapter 3 describes the development of office buildings and workspaces in Glasgow throughout time and indicates how the office workspace as a typology has remained in place over the past decades. Chapter 3 also mentions the relationship of the workspaces with acoustic treatments in detailed analysis of three case studies located in Glasgow. Chapter 4 looks at alternate office designs and their associations with employee workspace satisfaction and acoustic measures and once again describing the different research designs and methods used.

The second part of the thesis focuses on the research methodology and the analysis of data collected during field studies. Chapters 5 to 9 are included in the second part of the thesis. Research questions based on the gaps identified in Chapters 2, 3 and 4 are articulated in Chapter 5. The research methods and research design are further described in Chapter 5. The latter also provides details on the outcome of the pilot study carried out prior to field study and the alterations made to research methods. Chapter 6 discusses the results obtained from the analysis of the workspace size, acoustic measures and employee satisfaction in Glasgow sample. As mentioned in Section 3.2.1, shape factors were used to investigate another aspect of workspaces with noise perception and the results of the latter are presented in Chapter 7. Cultural difference in this study is determined by analysing another sample in Mauritius. The results for the analysis of the relationship between workspace size, acoustic measures and employee satisfaction for Mauritius sample with a similar research framework to that used in Glasgow sample in Chapter 6 are displayed in Chapter 8. In Chapter 9, the results from the comparative analysis of the two samples are presented. The study concludes in Chapter 10 and suggests guidelines for the design of future workspaces. Recommendations for future studies focusing on acoustics in the workplace are also mentioned.

Chapter 2

The torment of noise

2.1 Introduction

This chapter discusses the predicament of noise in the workplace. Noise is commonly defined as unwanted sound (Schafer 1977) but the most compelling definition is that by Kryter (1984) which states that noise is sound signals without information because it begins to question the content of sound in relation to acoustic satisfaction. According to the World Health Organisations (Berglund et al. 1999), community noise pollution in general has been associated with several diverse effects on human health which include noise-induced hearing impairment, interference with speech communication, mental-health and performance effects. Noise within the workplace tends to be a recurring issue and this review looks at the issue of noise from three perspectives: 1) behaviour and attitude of employees towards noise in the office 2) work performance in relation to office noise and 3) and individual health in relation to noise.

At the beginning of this study, it was initially hypothesised that office designs influenced both acoustic quality and acoustic perception of employees in workspaces. The studies being reviewed are interdisciplinary and lie within the fields of occupational health, indoor environmental studies, psychology, acoustics and architecture. Journals and articles reviewed in this chapter were obtained from online research database – Wiley, ScienceDirect, Sage Journals, WorldCat and Google Scholar through the Glasgow School of Art library and University of Glasgow library when searching for keywords: ‘office noise’, ‘office acoustic’ and ‘office environment’. Studies are analysed in relation to variables used, methodology, subjects and results obtained. The first three sections in the chapter address the influence of noise on individual satisfaction, work performance and health. The possibility of habituation to noise and cultural influence on the perception of noise is also looked at in Section 2.5 and 2.6.

The literature review showed that several aspects of noise have been investigated in relation to work performance - types of noise, intensity of noise, variability of noise, contents of noise and clarity of speech in noisy conditions. Each of these lines of enquiry provides further knowledge on the association between acoustic and individual work performance but so far no optimum acoustic condition in relation to work performance or acoustic satisfaction has been reached in the workplace. It was considered that studies analysing the effect of noise on individuals outweighed those demonstrating that habituation to noise is likely to occur after a certain period of exposure to noise. Noise sources that were deemed uncontrollable and unpredictable were considered to be the most annoying noise sources in the workplace. Several gaps in the review were observed in the variables being analysed and methodology used. For instance, noise level was more frequently analysed in relation to work performance and acoustic satisfaction than other acoustic measures, such as reverberation time, and studies analysing the relationship between acoustic measures and work performance occurred mostly in experimental designs which puts into question the external validity of the results. Based on these observations, the research interest focused on the intensity of noise level and acoustic quality of spaces in relation to acoustic and work performance satisfaction in actual workspaces.

2.2 Noise and individual satisfaction

Dissatisfaction is generally referred to as a certain discontent or something failing to give pleasure (Cabanac 2000). Variables affecting individual satisfaction in the workplace are manifold. Different aspects of the physical environment, such as light and noise, contribute to the overall workplace satisfaction. Specific noise sources identified in the workplace and their association with acoustic dissatisfaction are reviewed in this section.

2.2.1 *Specific noise sources*

The perception of the surrounding environment is unique to each individual and is dependent on physical stimuli captured by the senses. The sonic environment has the ability to alter the perception of the physical space and contributes to the subjective judgement of the overall spatial experience. Several past studies have focused on the physical stimulus of sound and its relation to occupants' satisfaction with the work environment (Hay & Kemp 1972a; Sundstrom et al. 1994; Danielsson & Bodin 2009). Acoustic satisfaction has been described as a state of contentment with acoustic conditions in spaces (Navai & Veitch 2003). In the workplace, the origin of noise sources is considered to be from work activities, mechanical ventilation or external traffic.

Background conversations are one of the common noise sources in the workplace. In the study of Nemecek & Grandjean (1973), background conversations were rated the most disturbing noise source in the workplace and contents of conversations were observed to be the most annoying factor. In another study, more than 40% of 469 employees were found to be disturbed by voices (Danielsson & Bodin 2009). Hay & Kemp (1972) observed that 24% of 190 employees were often bothered by people talking face-to-face. Several articles have been published to provide possible solutions to noise dissatisfaction caused by conversation and one example is that by Kjellberg & Landström (1994) who suggested simple steps like; restricting the number of people working together or increasing the distance between workers and making more use of sound absorbers in ceilings, walls and floors. Nevertheless, these simple steps might not be considered cost-effective if the rental prices of offices are based on floor area. It is needless to say that the choice of layout and materials used in offices remain within the hands of managerial bodies who most of the time are concerned with profit-making and savings. Only those who can afford it will improve their workspace by implementing findings of research. Restrictions on conversations cannot be imposed on the workplace which makes this noise source difficult to control.

The introduction of office machines and equipment on the office scenes were considered to be another noise source. Keighley (1970) observed that offices containing computer systems with old-fashioned punch card system at that time had a higher noise level than other offices with no machines. The offices with card-punching systems in place at that time (1970s) had an average noise level of 72 dBA which is similar to that of a vacuum cleaner at a distance of three meters. To further highlight the differences in noise intensities among different office machines, Grandjean (1988) analysed noise from inkjet printer, conventional typewriter and electronic typewriter and the following was observed: an ink jet printer on standby mode had a noise level between 57 to 59 dBA and a peak noise level between 61 to 62 dBA; an old typewriter was 70 dBA and the electronic typewriter was 60 dBA. However, the rapid progression of office machines has reduced the high noise level associated with them. For instance the Hewlett Packard (HP) printer (HP LaserJet 4240, 4250) has a peak noise level of 55 dBA when printing (Anon n.d.) which is less than the peak noise levels observed by Grandjean (1988). It is to be highlighted that the types of machines used in the office over the past decades have varied according to advances in technology. For instance, desktop computer with keyboards have currently replaced typewriters which are less noisy than typewriters. Given the constant and rapid improvement of office machines, the analysis of noise associated with them was deemed unnecessary.

Telephone rings are another noise source within the workplace which has been associated with acoustic dissatisfaction. Waller (1969) observed that telephones rings were more annoying than constant loud noise. Sundstrom et al. (1994) surveyed 38 offices before an office renovation and 40 offices after renovation. Eight noise sources were included in the survey; telephones ringing, people talking face to face, people talking on the phone, typewriters, ventilation systems, background music, office equipment and external noise. The results showed that the telephones ringing were the most annoying noise within the workplace before and after the renovation. Similar to Sundstrom et al. (1994), the study of Banbury & Berry (2005) included noise from: telephones ringing, telephones ringing at vacant posts, printer noise, typewriter/keyboard noise, computer noise, external noise, other people's conversations and other people's phone conversations. The results showed that telephones left ringing at vacant posts and other people's phone conversations were identified as the main noise sources causing dissatisfaction (Banbury & Berry 2005). Typewriter/keyboard noises were found to be worse than external noise. According to Waller (1969), the intermittent peak noise levels produced by telephones were considered to be the annoying element in telephones. Similar to conversations, controlling phone rings is difficult and unpredictable.

Mechanical ventilation and heating systems were also identified as another noise source in offices. Past studies focusing on air conditioning have shown that noise from air conditioning (AC) units does not contribute to peak noises in offices but instead contributes to the overall steady background noise of offices (Hay & Kemp 1972a; Hay & Kemp 1972b). According to the correlations between office noise levels and AC noise levels, Hay and Kemp (Hay & Kemp 1972b) predicted that 19% of office workers were expected to notice the noise of AC units when it reaches a level of 58 dBA at 90% of the time. In another survey of 250 employees, it was reported that air conditioning noise in room with one individual prevailed over office activity noise and the contrary occurred when workspaces were occupied by numerous individuals (Ayr et al. 2001). In this case, it can be argued that noise perception is very subjective and dependent upon occupancy. On the other hand, there is the argument for effective use of air conditioning sounds. Given the absence of auditory patterns (such as speech) and the flat frequency, air conditioning sounds are being used to mask annoying noise sources such as conversations in the workplace (Holbrook 1996) and are often referred to as 'white noise' (Boyles 2003). However, noise from air ducts or vents can be dampened with the use of sound absorbers and was therefore not considered to be as uncontrollable as conversations and phone rings in the workplace which were also deemed as intermittent noise sources.

The ingress of external traffic noise either through window openings or building skin is another noise issue in the workplace. According to Warren & Parkins (1984), window-opening is considered a sign of control exerted by occupants on their thermal environment but is also considered as a noise source. A sound map published by the Scottish Government indicated that noise level from traffic varied between 65 to 75 dBA throughout day and night periods in Glasgow's business district, St Vincent Street (Hamilton, McGregor. 2007). Long-term daily noise exposure to noise level above 65 dBA are likely to influence nervous system responses in individuals (Goines & Hagler 2007). Other techniques for natural ventilation have been sought by De Salis et al. (2002) who suggested hybrid system of active noise cancellation and treated duct inlet in windows.

From the above, noise sources that are intermittent and unpredictable were considered to be the most problematic in the workspace, such as conversations and phone rings. The reason for differences in perceived annoying noise sources in alternate studies is yet to be determined and the annoyance with intermittent and unpredictable noise source requires further investigation given that no definite solution has yet been sought for these in the workplace.

2.2.2 *Workspace and job satisfaction*

Individual contentment has been associated with the ability to exert some degree of control over personal life whether at work or at home (Cabanac 2000). As seen in the previous section, noise sources associated with acoustic dissatisfaction differ considerably. However, this dissatisfaction with noise tends to lead to further issues in the workplace. According to Vischer (2008), the way people feel about their environment affects their work performance and their commitment to their organisations. Comfort and satisfaction within the workplace have been extensively surveyed in the past by the use of Post-Occupancy Evaluation (POE) questionnaires (Vischer 2008). Conversely, POE in architecture has not been efficiently used to inform design and tend to occur three to five years after construction of buildings (Spring

2011). Alternately, Vischer (2008) emphasised on the importance of evaluating comfort in relation to difficulties faced during task completion rather than looking at general comfort which is less specific to work performance.

Several studies have analysed acoustic satisfaction in relation to work performance and workspace satisfaction. Klitzman & Stellman (1989) investigated the extent to which the physical environment influences psychological well-being in four organisations with a total of 2412 employees (Klitzman & Stellman 1989). Self-completed questionnaires were used to evaluate environmental and psychological factors. Environmental factors consisted of air quality, noise, ergonomic conditions and lack of privacy. Psychological factors consisted of job satisfaction, office satisfaction, distress, fatigue and irritation. The results indicated that air quality and noise were the strongest predictors of psychological well-being among the other environmental factors. Among the correlations between noise and psychological factors, the increase in perceived noise was associated with a decrease in both office and job satisfaction and an increase in irritation. Klitzman & Stellman (1989) made no use of acoustic measures in the study which showed that the results were purely subjective and could not be related to the physical environment.

In line with the study of Kliztman & Stellman (1989), Sundstrom et al. (1994) surveyed 58 workspaces before and after their renovation from cellular workspaces to open-plan ones to determine if satisfaction with office noise was related to job satisfaction and physical environmental satisfaction. Similar to Klitzman & Stellman (1989), self-completed questionnaires were distributed to a total of 2391 employees to evaluate noise disturbance, job satisfaction and performance. Job category (managerial, professional-technical and secretarial-clerical) was taken into consideration and no acoustical measures were collected during the survey. The results indicated that the increase in perceived noise disturbances was associated with a decrease in environmental satisfaction and with a decrease in job satisfaction but not with performance ratings. According to Sundstrom et al. (1994) the absence of correlation between noise disturbances and performance ratings were possibly related to employees adapting to acoustic environment after move to open-plan spaces. Perceived noise disturbances also did not vary among the three job categories. Workspaces that had been re-modelled into open-plan workspaces did not show any significant increase in environmental satisfaction.

Interestingly, both Klitzman & Stellman (1989) and Sundstrom et al. (1994) surveyed actual workspaces, however they made use of only subjective data collected by self-reported questionnaires which did not indicate the relationship between perception of sound and actual environment performance. Klitzman & Stellman (1989) and Sundstrom et al. (1994) suggested that dissatisfaction with acoustic in the workspace led to further negative perceptions in individuals, such as a decrease in job satisfaction, if not improved. The relationship between noise and work performance are discussed in the following section.

2.3 **Noise and work performance**

Cognition refers to any process which acquires knowledge and is associated with thinking, memorising and learning (Stedman's Medical Dictionary 2006). In the past, different aspects of noise have been studied in relation to work performance in individuals, such as relevance of noise contents and duration of noise because work performance is vital for business. Some of these studies are reviewed here.

2.3.1 *Relevance of noise contents*

As mentioned at the beginning of this chapter, Kryter (1984) defined noise as sound signals without relevant information. Several studies extensively analysed the relevance of speech on mental performance. Salamé & Baddeley (1982) designed a series of experiments to determine the influence of relevant and irrelevant monosyllable words on mental performance during specific tasks. In the first part of the experiment, 15 participants (average age of 30 and 73% were women) were asked to read aloud nine random digits shown on a screen and recall these digits in writing while monosyllable words (in the order of relevant to not relevant) were played at 75 dBA on stereo. A control experiment was carried out for comparison in which tasks were to be completed by subjects in silence where noise level was 37 dBA. Work performance was assessed by the number of errors obtained during task. The professional background of participants was unknown. The results indicated that tasks performed in the presence of words, whether relevant or irrelevant, were associated with greater percentage error (more than 20%) than those carried out in silence. In other parts of the study, the length of irrelevant words was investigated in 23 subjects (16 female and 7 male with average age of 32) and the results also showed that no significant relationship was observed between long and short irrelevant words but both types of words were linked to greater percentage error in comparison to participants in silent condition (Salamé & Baddeley

1982). The significance of age or gender in the study was not reported. Alternatively, the study by Salamé & Baddeley (1982) did not make use of varying noise level, aside of 37 and 75 dBA. It is possible that lower percentage errors during task completion are obtained if the experiments by Salamé & Baddeley were replicated at 40 to 50 dBA which is the recommended average daily noise level in offices by the British Council for Offices (2009).

A more detailed studied was carried out by Banbury & Berry (1998) on the influence of noise on employee performance in comparison to Salamé and Baddeley (1982). 48 university students (unknown age and gender) were individually requested to complete mental arithmetic tasks and recall a written passage whilst being subjected to four noise scenarios: i) only noise from clerical activities in an office, ii) sporadic conversations and noise from clerical activities in an office and iii) broadcasted speech from radio and iv) no noise recordings. The noise from clerical activities referred to keyboard, printer noise, telephone rings and fax machine. All noise recordings were played at 65 dBA on a stereo and noise level for scenario without recordings was not mentioned in the paper. A soundproof laboratory was used for the study. Performance was measured by time taken to complete tasks and accuracy of answers which were more detailed than the measurements used by Salamé & Baddeley (1982) as mentioned above. The results indicated that in recall task, participants' scores were the lowest when subjected to broadcasted speech (8.92 over 26) and noise from clerical activities with sporadic conversations (8.42 over 26) in comparison to results from other noise scenarios (13.6 in scenario with noise from clerical activities in office and 15.9 in scenario without noise). Performance in mental arithmetic tasks, on the other hand, was found to be influenced by all scenarios containing noise even when speech was not present. It was expected by the authors that speech would be detrimental to work performance in both noise scenarios where speech was present. The results also indicated that subjects performing mental arithmetic tasks in conditions with office only (no speech) had similarly low work performance scores to those in conditions with office noise and speech which suggest that both office noise with and without speech present are likely to be detrimental to work performance. Like Salamé & Baddeley (1982), the revelance of speech was also analysed in relation to work performance in the study of Banbury & Berry (1998). However, in the latter's study a foreign language was used instead of nonsense words; 84 English students were subjected to broadcasted radio speech in Greek at 65 dBA while completing memory recall and mental arithmetic tasks. The results showed that for both tasks scores were inferior in scenarios with Greek broadcasted speech and noise from clerical activities only (less than 15 over 26 for both scenarios during the two tasks) to scores obtained in scenario without noise (above 15 over 26). Based on the results obtained in the study of Banbury & Berry (1998), work performance weakened when participants were subjected to clerical office noise with and without speech present. The studies by Salamé & Baddeley (1982) and Banburry & Berry (1998) made reference to the sound level at which speech was being tested but no further association was made between intensity of sound and work performance in both studies and great focus was given to contents of sound in relation to work performance.

Another acoustic property of speech - acoustical variation of irrelevant speech - was also investigated on work performance by Campbell et al. (2002) to further test the hypothesis that changing state of noise is more disruptive to work performance than steady state of noise formulated by Jones et al. (1992). The study of Campbell et al. (2002) had an experimental setup with 24 participants who were required to memorize and recall in writing digits visually presented to them while subjected to different background speech conditions. The latter consisted of quiet condition – no speech, steady state speech condition – one word was repeatedly played on headphones of participants at around 70 dBA and changing state speech condition – random words were consecutively presented on headphones at the same noise level as the steady state condition. Performance was measured by the number of errors produced during serial recall. The results showed that more errors were obtained in changing state condition (mean error probability of 0.60) than in steady state (mean error probability of 0.54) or quiet condition (mean error probability of 0.44).

Furthermore the association between changing state of irrelevant speech in background noise and reverberation time was investigated by Perham et al. (2007) and Beaman & Holt (2007) in relation to the office environment. Reverberation time is defined as the time taken for sound level in a room to decrease by 60 dB and determines the decay of noise reflections over time (Mommertz 2009). Perham et al. (2007) hypothesised that acoustical variation or changing state of speech from numerous individuals would be cancelled if reverberation time increased in workspaces. The latter authors designed an experimental study where 42 undergraduate students aged between 18 and 25 years were required to complete serial recall tasks when subjected to pre-recorded noise conditions of workspaces. Noise recordings consisted of telephone rings, door slams, photocopiers, printers, conversations ventilation and computer humming in spaces with reverberation time either 0.70s or 0.90s and noise level varied between 65 and 75 dBA. The two values of reverberation time (0.70s and 0.90s) were considered to be similar to that present in workspaces with acoustic ceiling treatment (0.70s) and without acoustic ceiling treatment (0.90s). To provide clearer understanding of reverberation time in spaces, Figure A.1 in Appendix A shows reverberation time in relation to different spaces. The results showed that there were no significant differences in work performance scores for noise conditions with varying reverberation time but workspaces with reverberation time of 0.70s were reportedly more pleasant than those with reverberation time of 0.90s. According to Perham et al. (2007) it was considered that high reverberation time possibly gave the impression that noise level was higher which was likely to lead to acoustic dissatisfaction in subjects. Beaman & Holt (2007) carried out another investigation in the same line of thought as that of Perham et al.(2007) – determining the influence of reverberation on distraction due to irrelevant speech. Beaman & Holt (2007) also carried out an experimental study with 24 participants who were subjected to pre-recorded speech with varying reverberation time while completing serial recall tasks. Reverberation time was 0.50s (± 0.20s). The results showed that the increase in reverberation time decreased distraction associated with irrelevant speech in background noise which was contradictory to those obtained in the study of Perham et al. (2007).

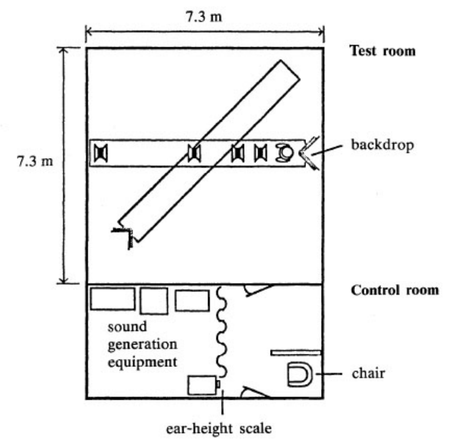


Figure 2.1 Layout of experimental room indicating axis along which speakers were placed (Mershon et al. 1989)

Figure 2.2 Layout of room with location of dummy and noise speakers in which background noise was recorded (Cabrera & Gilfillan 2002)

The perceived distance of noise sources in varying reverberation time was also previously analysed by Mershon & King (1975) and Cabrera et al. (2002). Mershon & King (1975) investigated the association between egocentric (distance between listener and noise source) and exocentric (distance between noise sources) distances in relation to reverberation and noise intensities. An experimental research framework was used with

80 students who were blindfolded and requested to write the perceived distance of noise signal in two types of workspaces – an anechoic chamber and space with only acoustic panels. No average reverberation time figures were reported for both spaces. Noise levels varied between 45 and 65 dBA. The results indicated that students in anechoic room perceived small distances to noise sources than those in spaces with acoustic panels – reverberation time was considered to be more relevant to egocentric distances than exocentric ones. Noise levels were not relevant to any of the two types of distances. Mershon et al. (1989) carried out a more detailed study of auditory perceived distance in relation to reverberation time and noise levels than the aforementioned study. This time reverberation of 0.36s and 1.36s and orientation of noise source were also included in the study. Similar to the previous study (Mershon & King 1975), 192 subjects were blindfolded and required to report the perceived distance of noise signal. Only two noise levels were tested in the study in relation to auditory perception – 45 and 65 dBA. The layout of the experimental room is shown in Figure 2.1. Subjects were also required to draw their perception of room shape and dimension after exposed to different reverberation time and noise levels. Similar to the above study, Mershon et al. (1989) reported that the difference between perceived distance to noise source and actual noise source was associated with reverberation time – space with reverberation time of 1.36s had overestimations of perceived distance in relation to actual distance than in spaces with reverberation time 0.36s. The perceived layout was also described mostly as non-rectangular when reverberation was 0.36s and in condition with reverberation time of 1.36s, spaces were judged more spacious than those in condition with 0.36s.

Cabrera & Gilfillan (2002) also pursued the aforementioned line of investigation but this time making use of speech instead of noise signals. Varying noise levels and reverberation time were used in parallel with pre-recorded speech at different distances to recording microphone. 19 subjects were required to listen to the different recordings and report the perceived distance of speech being listened. Figure 2.2 shows that layout of the room in which noise was recorded. The results indicated that the increase in either reverberation time or noise level increased perceived distance of speech. There was no mention of possible associations between auditory distance perception and layout or spaciousness of room. Moore et al. (1999) highlighted that auditory distance perception was not static and was dependent on the acoustic properties of spaces and ability of individuals to adapt to noise. These studies by Mershon et al. (1989; 1975) and Cabrera

& Gilfillan (2002) highlighted the association between the perception of noise with spatial context and acoustic quality but it was also observed that noise was investigated along a specific axis or angle as shown in Figure 2.2 in the study of Cabrera & Gilfillan (2002). These aforementioned experimental studies were also not directed to any specific field or profession and did not take into consideration organisational behaviour which, in the author's opinion, undermined the applicability of these results in actual workspaces to improve acoustic comfort. Therefore, further studies are required to determine the association between the perception of noise and the actual spatial setting in the work environment.

2.3.2 *Effect of masking noise*

Aside of the relevance of speech in background noise, the effect of masked and unmasked noise on mental performance was also analysed in past studies. Masked noise refers to the use of one sound to cover another (1992). Sounds with different frequencies, for example white noise and pink noise, are used in acoustic testing (Watson & Downey 2008). White noise refers to a random signal with a flat frequency while pink noise is sound with a decreasing frequency (Watson & Downey 2008). In contrast to Banbury & Berry (1998), Loewen & Suedfeld (1992) investigated the influence of both masked and unmasked office noise on simple and complex mental tasks in a group of 15 university students within a laboratory set-up. Office noise used in the experiment was a recording of clerical library office which contained typing, phone rings, footsteps and audible words part of a background conversation and was played at an average of 54 dBA with intermittent noise at 60 to 66 dBA. According to Loewen & Suedfeld (1992), an average of 54 dBA was an acceptable workplace noise level. Office noise was masked by playing white noise in parallel to office noise which resulted in an increased average sound level of 61 dBA. Similar to Banbury & Berry (1998), a control scenario without noise was also used but no reference to noise level was made. Participants were required to identify numbers within a field of numbers in the simple task while noise was playing in the background which was similar to the study of Bryan & Tolcher (1976) where participants had to cross out words in a passage. In the complex tasks, participants were asked to complete a sentence within a paragraph and add further two sentences while noise played in the background. Performance was measured by the accuracy of answers in both tasks which was similar to the measurement used by Banbury & Berry (1998). In contrast with the studies mentioned above, the study by Loewen & Suedfeld (1992) made use of self-completed questionnaire which asked subjects to rate their distraction by the background noise and their mood state during the experiment in addition to measured performance. The results showed that work performance in masked office noise scenario, despite having higher noise level than control, had more favourable scores for both simple (21.5 over 30) and complex tasks (2.8 over 7) in comparison to those in unmasked office noise scenario (15.6 for simple task and 2.2 for complex task). Participants also reported less environmental distraction and stress in the scenario with masked office noise than those in unmasked office noise. The influence of age or gender on the perception of noise was not investigated in that particular study. According to Loewen & Suedfeld (1992), office noise that was perceived to be stressful and distracting was associated with a decrease in measured work performance which showed that subjective perception of work performance also affected actual work performance.

In other studies, the degree to which speech was comprehensible was examined in relation to work performance. Speech intelligibility is generally quantified by Speech Transmission Index (STI) which is defined as the measurement and prediction of how speech is easily understood in a room (Watson & Downey 2008). The determination of values for STI is derived by analysing modulations of noise signals between transmitter and receiver which vary according to noise reflection within rooms. STI values vary between 0 and 1, where 0 means speech is very unclear and 1 means speech is very clear. Hongisto (2005) examined past studies where work performance differed significantly between silent work conditions and those where speech was present to indicate the decrease in performance when STI varied. In comparison to the studies mentioned above, no experimental values were collected in that particular study by Hongisto (2005) but instead values from literature review were used. The decrease in performance was obtained by calculating percentage error difference for work performance between speech and silence conditions examined in the literature review. According to Hongisto's (2005) model for prediction of decrease in performance, STI above 0.60 (clear speech) led to a decrease of 7% in the performance of complex tasks and STI was inversely proportional to reverberation time (i.e. STI is higher when reverberation time is lower).

In another study, Haka et al. (2009) deployed a more experimental approach than Hongisto (2005) to investigate the influence of STI on work performance on 37 participants (24 females and 13 males) within an office setting. All participants were required to complete a series of tasks while subjected to three different noise conditions; STI=0.10, STI=0.35 and STI=0.65. Similar to Loewen & Suedfeld (1992), self-completed questionnaires were also distributed to participants to rate the perception of participants on acoustic and work performance. The experiment took place in a simulated open-plan office workspace which was not the case in the other studies reviewed here. Figure 2.3 shows the plan of the simulated open-plan office with speakers located in ceiling (Ms) and on the sides of partitions (Ss). Noise used during the experiment contained only snippets of a pre-recorded radio broadcast sentences and were masked by pink noise to generate different levels of STI. Contrary to Loewen & Suedfeld (1992) no other background noise, such as typing, were added to the noise recordings. All noise conditions were maintained at an intensity of 48 dBA which, according to Haka et al. (2009), was typical to that of open-plan offices. The results indicated significant decrease in work performance between noise conditions with STI=0.35 and STI=0.65. The subjective rating obtained from the questionnaires indicated that the employees were more disturbed by speech when STI increased from 0.10 to 0.65 which suggests that employees are more likely to be disturbed by speech when speech is more intelligible or clear.

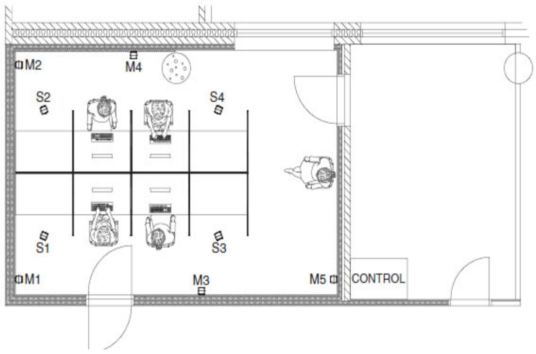


Figure 2.3 Plan of simulated office space with speakers located in ceiling (Ms) and on sides of partitions (Ss) (Haka et al. 2009)

2.3.3 *Influence of noise level*

The impact of noise level on the cognitive is longstanding. Bryan & Tolcher (1976) intended to determine the appropriate noise level for varying task complexity on a group of university students and staff. An experimental setup was used for the aforementioned study which was divided into two parts; in the first experiment 25 students (6 females and 19 males with average age of 21) were asked to complete simple mental arithmetic tasks while listening to different types of noise and in the second one 30 members of staff (5 females and 25 males with an average age of 36.3 years) were asked to complete tasks with four varying levels of complexity (reading, crossing-out words, mental arithmetic and writing précis) while listening to different types of noise. Subjects in both experiments were given the ability to adjust the intensity of the noise they were subject to and selected noises were white noise, traffic noise, orchestral music and recorded conversations in refectories. In addition to noise exposure, participants were also required to complete questionnaires that assessed their sensitivity to noise by rating noise annoyance. The results in the first of the experiment indicated that students preferred listening to high levels of music at 53.4dBA and conversations at 59.8 dBA. The preferred noise level was much lower than those used in the study carried out by Salamé & Baddeley (1982) (75 dBA) and Banburry & Berry (1998) (65 dBA) which possibly led to the high task percentage errors in the aforementioned studies. The results indicating a preference of conversations during task in Bryan &Tolcher's (1976) study could also be viewed from another angle: the refectory environment in which the conversation was recorded created a masking effect to the conversation which did not make it annoying to students but rather pleasing and the music used in study was purely orchestral which, once again, was perhaps considered to be more appealing than other noises because it had no word contents. Results for the second part of the study indicated that varying levels of task complexity was associated with different preference for noise levels – 62.6 dBA for crossing out words in passage and 45.6 dBA when writing précis. Participants with different age groups and professional background were used in each experiment but according to Bryan & Tolcher (1976), the influence of age, gender and professional background were insignificant in the study.

Alternatively, Colle (1980) observed that disturbance by speech was dependent on the noise level that speech occurred. 80 female undergraduate students were subjected to conditions with different noise intensities associated (20 dBA, 40 dBA, 50 dBA and 70 to 76 dBA) to a foreign voice speaking in earphones and were requested to recall letters visually presented to them. At a range of 40 to 76 dBA, speech condition was associated to an increase in errors (average of 13.3%) during recall tasks in comparison to quiet conditions while speech at 20 dBA was not significantly associated with recall errors. The presence of same speech in both ears (binaural) or same speech with time lag between the ears (dichotic) were also considered during the experiments. Binaural or dichotic speech conditions were not relevant to the percentage errors in results.

Noise levels vary throughout the day depending on the type of activities occurring within the workspaces. Woodhead (1964) investigated the impact of intermittent noise on arithmetic tasks in 84 men. Subjects were required to individually memorize two sets of digits, mentally substract them and write down the answer. Performance was measured by the number of correct answers obtained. Noise consisted of loud burst of 100 dB similar to a rocket explosion with duration of 1s. Two noise conditions were tested – noise was presented during memorization of digits and noise presented during calculation period. The results indicated that arithmetic performance significantly decreased by 13% in condition where noise was presented during memorization in comparison to quiet control condition. There was no significant association between quiet noise condition and that in which noise was presented during calculation period. The noise investigated here was different from office noise and the relationship between variability of office noise and work performance is yet to be determined. According to Kryter (1984), sounds were considered to be impulsive when intensity was above 10 dB for less than1 sec.

2.4 Noise and health

The studies above showed that different aspects of noise have the ability to influence work performance and behaviour in offices. The regulations of noise in workplaces have become more thorough over the last decades. Noise levels at industrial workplace have precedence over noise at workplaces because there is less possibility of developing hearing impairments in an office than on industrial sites (Concha-Barrientos et al. 2004). Nonetheless, past studies have related office noise to heart problems and stress.

2.4.1 *Stress & fatigue*

Stress is one of the common problems caused by noise (Evans & Johnson 2000). Past studies have shown that the appropriate indication of stress levels in the body is epinephrine which is present in urine and the presence of cortisol acts as a psychological stress indicator. Epinephrine is responsible for the flight and fright responses in our body (Cashin-Garbutt n.d.). Several studies have been conducted to investigate the physiological effect that noise has on the human body (Evans & Johnson 2000; Powell 1976). Evans & Johnson (2000) designed an experiment with 40 female clerical workers in an open-plan office simulated in a laboratory. The experiment was designed to examine the physiological measures and their aftereffects under low intensity noise which was recorded from an open plan office and contained conversation segments, typing sounds, ringing phones, drawers opening and closing which played during the tasks. The participants were asked to type a manuscript of unknown contents. To monitor stress levels, urine samples were collected before and after sessions. Their performance was rated by the total number of words typed per minute and the percentage errors. The results showed an elevated level of epinephrine in urine samples after each session, even if the participants did not report any signs of stress and there was a decrease in motivation. Evan & Johnson (2000) argued that it was not the intensity of sound that was stressful but rather the uncontrollability of the noise. This statement was in line with the other studies mentioned in Section 2.2.1 in which the unpredictability and variability of noise was the plausible source of acoustic dissatisfaction. The scope of control on acoustics within the office environment is yet to be researched and defined.

In another study by Kristiansen et al. (2009), the variability in heart beat and blood pressure was further investigated in relation to cognitively demanding tasks and presence of office noise. 10 women were subjected to office noise recordings (which contained voices, keyboard sounds, doors opening, telephone rings etc.) while completing tasks on the computer in a simulated office setting. Two types of tasks were given: first consisted of connecting dots to reproduce a certain figure and second task required participants to recall the order of consonants presented in a range of letters. Two noise conditions were used – quiet one and noise condition in which office recording played at an average of 65 dBA. Participants were required to complete questionnaires assessing their perception of stress and energy levels. Cardiovascular responses were measured during task completion by the use of a Finometer (a blood pressure measuring instrument) and electrocardiogram. Similar to Evans & Johnson (2000), samples of saliva were collected at the end of sessions. The results indicated that physiological and psychological stress was related to cognitively demanding tasks but not to noise intensity presented in the study.

Noise also has the capacity of modifying human behaviour and attitude. In an experiment carried out by Jahnck et al. (2011) it was observed that participants who were subjected to a movie of river flowing for 7 minutes, after having achieved two hours of work in a noisy office environment (51 dBA), were more energised and motivated than those who continued to listen to the office noise (Jahncke et al. 2011). The study was conducted in a simulated open-plan office setting with 38 participants. Similar to Banbury & Berry (1998), Jahnck et al. (2011) played a pre-recorded tape of office noise with voices in native language during which participants were required to complete a series of tasks. Participants who were subjected to office noise felt tired and unmotivated.

2.4.2 *Sick Building Syndrome*

Burt (1996) carried out an experiment to investigate the relationship between low-frequency noise and health symptoms associated with Sick Building Syndrome (SBS). The later refers to a cluster of symptoms that are believed to be work-related and have no definite cause. The symptoms are: eye/nose/throat irritation, sensation of dry mucous membranes and skin, skin rash, mental fatigue, headaches, high frequency of airway infections and cough, nausea, dizziness, hoarseness, wheezing, itching and unspecified hypersensitivity (Bain & Baldry 1995). In Burt's (1996) experiment, a questionnaire survey was carried out in an office building to identify those symptoms and to find out if they were work-related or building-related. Sound levels and frequencies at ventilation grilles and workstations were measured. The average sound level was 55 dBA, with occasional peaks of 66 dBA. It was noted that the recorded noise levels were higher at the ventilation grilles than at workstations. The results from questionnaire survey of 56 respondents reported that their (similar to the list of symptoms above) symptoms were work-related. Low frequency noise of 7Hz from the ventilation units was found to occur in several rooms of which many of the occupants reported SBS symptoms. Burt (1996) believed that this low-frequency noise was a possible explanation for SBS occurrence and suggested more investigation within the field.

However, another study by Hedge (1988) showed that reported SBS symptoms were strongly related with the negative perception of the work environment (ventilation, temperature, noise and ventilation, job stress and lighting). Hedge (1988) carried out an investigation in 6 offices to find out the relation between work-related illness, job satisfaction and job stress. Questionnaires were used to identify symptoms and satisfaction with ambient factors. The results showed that the reported illnesses were linked to dissatisfaction with certain office environment conditions; temperature, noise, ventilation and lighting. In brief, those who are unhappy with ambient factors of the office environment are likely to report SBS symptoms.

2.5 **Habituation to noise**

According to Kryter (1970), the ear has the capacity to mask unwanted noise which suggests that there is the possibility of adapting to noisy environments. Langdon & Keighley (1968) investigated noise in 35 offices with more than 50 occupants. It was observed that offices had transient peak noise levels which were caused by the flow of work and varied on a daily basis. The transient peak sounds, on the other hand, were found to be less acceptable as the peak levels increased. In the study of Keighley (1970) 40 offices were surveyed. Self-completed questionnaires were distributed to employees and noise levels were recorded. Noise acceptability ratings obtained from the questionnaire and peak noise index obtained from actual noise recordings were coherent with the exception of four offices. These four workspaces had deviating noise acceptability ratings which, according to Keighley (1970), were due to the general satisfaction with the work environment. One of the four offices were found to have high acceptability rating which was thought to be related to the high satisfaction of the quality of office design, even if it were a typing centre. In another research paper that discussed the use of background noise, Waller(1969) went even further stating that average noise levels of 70 dBA (similar to a vacuum cleaner 1m away) were not bothersome provided it were kept constant so that it could drown peak noise levels.

Further research supporting the theory of noise acceptability was that of Banbury & Berry (1997) who argued that office noise, after a certain time, could be habituated to. Two experiments were carried out in a simulated open-plan office to find out if: 1) disruption on memory could be reduced after 20 minutes of exposure to certain types of speech 2) noise without speech could be habituated to. In the first experiment a group of 60 students were individually given a passage which they were asked to read and recall while different background noises played at an average level of 65 dBA. The same tasks were given to the students after a habituation period of 20 minutes during which no tasks were given. Their performance was measured by the accuracy and time taken to recall. Different background noise conditions were used which consisted of recorded radio broadcast speech that was i) repeated ii) played entirely and iii) randomized by deleting certain words and played on a stereo system. The results for the first experiment indicated that performance in the task where different background noises were present were slightly better after the habituation period. However, both passages had the lowest scores when exposed to normal (control) speech recordings. It could be possible that the other modified recordings; random, repeated, continuous and quiet very quickly became predictable and therefore were easily habituated to. The second experiment had the same procedure as the first one and was carried out with 48 students. The only difference was that the noise recorded was from an office of 4 occupants that contained only background noise (keyboard, telephone etc.) and no speech. The results showed that task performance was better after habituation period in all 4 scenarios.

As part of another investigation, satisfaction with intermittent noise - phones ringing, co-workers talking, typewriters and office machinery - was hypothesised to be inversely proportional to job performance (Sundstrom et al. 1994). The investigation consisted of a questionnaire survey distributed in 26 organisations before and after scheduled renovations in each organisation. The results showed that there was no correlation between satisfaction with intermittent noise and job performance. One of the likely explanations given for this, was the possibility that unconscious habituation had occurred to these noise sources in the workspace.

In line with the acceptability studies carried out above, another research carried out by Powell (1976) showed that workers expected that the office environment would be noisy. The study compared the perception of the acoustical environment of offices and residential flats and was carried out in a simulated office set-up with 10 staff members from University of Salford. The participants were given reading and writing tasks for a whole working-day session while background noise (typewriter, adding machine and ventilation) between 65 dB to 105 dB, played alternately on speakers. Results showed that subjects in the office setting had a higher noise tolerance than participants in flats (Powell 1976) which indicated possibility of habituation to office noise.

As mentioned in Section 2.2.1, unpredictability and intermittency of noise was possibly the source of noise dissatisfaction. The ability to control intermittent noise was further investigated by Reim et al. (1971). 40 participants were given a series of numerical and verbal tasks to complete while being subjected to noise bursts of 108 dBA. The physiological adaptation to noise was measured by phasic skin conductance and vasoconstriction. A control button was installed on chairs of participants who were told that it would terminate the noise if pressed. Out of 40 participants, only one person pressed the button. The results indicated that the perceived control over noise reduced the physiological impact even if task scores were less in the noise conditions than in the quiet condition.

On the other hand, the possibility of habituation to office noise was ruled out by a later study of Banbury & Berry (2005). 280 employees were given questionnaires to evaluate their work environment and their reactions in actual open-plan workspaces. Sound level measurements were also recorded. There were 88 respondents and only one correlation was found between time spent at their desks and noise from keyboards; the longer time spent at their desks, the more they were disrupted by the keyboards. The results showed that there were no negative correlations between time spent at their desks and the degree of disruption. Therefore, there was no evidence of habituation occurring within the office to the noise environment. This leads us to question the reliability of experiments and investigation carried out in experimental rooms and laboratories; how much of these results can actually be applied to the real office conditions? Perhaps, more investigations should be carried out in actual offices before the affirmations of psychological theories. It is intended in this study to survey actual workspaces to provide more accurate information within field.

2.6 Cultural influence and noise

The above section showed that there is the possibility of habituating to noise. However, other variables are possibly linked to this ability to habituate to noise. According to Hofstede (1981):

> *Culture is the collective programming of the human mind that distinguishes the members of one human group from those of another.*

Hofstede (1985) further demonstrated in a lengthy cross-sectional study that organisational values were dependent on culture. Altogether 53 countries were analysed and were found to vary in values attached to hierarchy, conformity, individualism versus collectivism and importance of success in organisations. The study showed that organisations in the UK tended to less support hierarchy and conformity which was contrary to Arab countries. As seen in Section 2.2, the identification of annoying noise source tends to differ. Schafer (1977) carried out a survey to determine the preference of sounds in the natural and man-made environment in New Zealand, Canada, Jamaica and Switzerland. The percentage of participants unsatisfied with voices was as follows: 43% in New Zealand, 35% in Canada, 60% in Jamaica and 16% in Switzerland. The possibility of cultural influence on noise was further investigated by Namba et al. (1991) in 5 different countries – Japan, Germany, USA, Turkey and China. A cross-sectional survey was deployed to determine the difference in perception of noise in residents. The results showed that Germans were more intolerant to neighbourhood noise than their Japanese counterparts. The definition of noise had a neutral meaning in Japanese but a negative connotation in English and German. The results from the study of Namba et al. (1991) can hardly be applied to the workspace given that expectations of noise for residents and employees are different as Powell (1976) highlighted. But this incites one to further investigate the possibly of cultural influence in noise perception within the workspace.

The author of this study is of Mauritian origin and according to Liu & Sudweeks (2003) the organisational culture in Mauritius tends not to support hierarchy which is similar to UK as mentioned above by Hofstede (1985) but in the UK there was higher preference for individual work than in Mauritius. Liu & Sudweeks (2003) carried out a field study in an office in Mauritius to determine the work culture by making use of similar research framework to that of Hofstede (1985). 128 employees in an organisation were requested to complete an online survey which examined the values attached to hierarchy, conformity, individualism versus collectivism and importance of success. The results showed that there was little support for hierarchy in the workplace and strong collectivist culture. In the author's opinion, the perception of noise would also vary if one were to compare acoustic perception in UK to that in Mauritius. Noise in office spaces, among one of the many physical environment variables, was previously studied in Mauritius in relation to variables of Sick Building Syndrome (SBS) (such as eye, noise and throat irritation, lethargy, headaches, difficulty concentrating, dizziness, nausea, chest tightness and dry skin) etc.) by Bholah et al. (2000). The latter study showed that the mean noise level was 45 dBA in 254 offices but no significant associations were observed between noise level and variables of SBS and no further description of behaviour of sound in Mauritian offices was provided. Awareness of the influences of office noise on behaviour and work performance of employees is minimal in Mauritian offices and to further support this the Ministry of Environment and Sustainable Development (1997) establishes noise level guidelines only for industrial and neighbourhood noise. It is considered that more studies are required in Mauritius to determine the association between acoustics, employee satisfaction and work performance in offices given that the work culture, as mentioned above, is different from American and European offices.

2.7 Discussion

The studies that have been reviewed in this chapter have shown that conversations and telephone rings were the two most common noise sources in the workplace and annoyance associated with them are thought to be linked to their unpredictable and intermittent nature. The ability to control unpredictable noise has been associated to greater acceptability of noise in laboratory set-up but the scope of control on conversations and telephone rings in the workplace is very limited. The relationship between work performance and noise has been extensively researched with both subjective and objective data but no optimum noise level has been determined so far in relation to work performance. However, the literature review indicates that intensity of noise and changing state of noise properties (such as speech) are directly associated with measured work performance. The key studies in this chapter are summarised in Table 2.0.

According to Bryan & Tolcher (1976), acceptable noise levels depend on the nature of task been carried out; below 50 dBA for complex task, such as precis writing and mental arithmetic tasks and above 50 dBA for simple tasks such as crossing out words. Furthermore, Colle (1980) observed that in conditions with noise level between 40 and 76 dBA, there was an increase in percentage errors for recall tasks in comparison to the conditions with noise level less than 20 dBA. These aforementioned studies begin to articulate the intensity of noise level suitable for completion of different types of tasks. On the other hand, masked noise was associated with an increase in measured work performance in offices because intelligibility of speech was reduced but average noise level of masked sounds was 61 dBA which recalls into question the association between noise level and work performance. The literature review indicates that both intensity of noise and changing state of noise contents are associated with work performance despite the fact that these two variables seem to contradict each other - masked noise has high noise intensity which renders speech less intelligible which enhances work performance but high noise level was also associated with poor work performance. There is the need to further clarify the association between acoustic measures, acoustic and work performance satisfaction.

It was also observed that most of the studies in the literature review made use of noise level as an acoustic measure when investigating work performance which was possibly because average noise level is easily obtained with the use of sound level meter. The study of Perham et al. (2007) and Beaman & Holt (2007) begin to demonstrate some association between reverberation time and work performance of employees and in the study of Mershon et al. (1989) the association between reverberation time and egocentric distances (distance between individual and noise source) of noise sources and perception of workspace begin to transpire. The use of reverberation time as another acoustic measure in the workplace was considered to be significant and required further investigation in relation to acoustic and work performance satisfaction.

Several factors in the literature review are called into question; the method of investigation and the relationship between office design and acoustic measures. Two types of research designs have been observed in this review – cross-sectional and exprimental research designs. The cross-sectional designs, such as the study of Nemecek et al. (1973) was less rigorous than those carried out in laboratory set-ups (e.g Loewen & Suedfeld (1992)) most probably because variables can be easily controlled in laboratories. Also, work performance and acoustic satisfaction ratings associated with varying noise levels were not measured in the study of Nemecek et al. (1973) However, the external validity of the results from laboratory experiments are questioned. For instance, Banbury & Berry (1998) observed in an experimental study that work performance decreased when subjects were in the presence of office background noise containing sporadic conversations but in a field study of offices, the same authors observed that there was no significant relationship between the degree of disruption and the time spent in the office (Banbury & Berry 2005). Based on the first study by the authors it could be expected that the degree of disruption would decrease with time because employees would be subjected to longer periods of office noise and sporadic conversations but this was not the case in the later study and the difference in these two studies showed that there is the need for more study in actual offices in relation to employee satisfaction and work performance. The series of tasks being performed by individuals or groups in laboratories are not necessarily identical to those in current workspaces because work nowadays tend to be knowledge-based and collaborative as highlighted by Vischer (2008). Furthermore, it is considered that results obtained in laboratory experiments tend to be isolated because the actual context or appearances of offices are usually not taken into consideration. For instance, interior décor are not taken into consideration in laboratory set-ups which determines reverberation time because of the noise-absorbing qualities of surface materials.

The studies listed in Table 2.0 indicates that the type of office design being investigated was primarily open-plan offices. The latter office types are known to be distracting to work performance as will be further discussed in Chapter 3 and 4 but both field and experimental studies investigating work performance and acoustic satisfaction in offices focused mostly on open-plan workspaces and also lacked description of the layout of these spaces. Haka et al. (2009), for example provided some visual description of the simulated office space (Section 2.3.2) but this type of layout with tight spacing for such a small number of occupants is rarely seen in actual offices; there is a greater co-worker distance with larger circulation spaces and storage areas. It is considered that in actual workspaces different associations will be observed between acoustic measures and employee satisfaction because the area of workspaces will be related to acoustic measures. The location of the key studies in Table 2.0 tend to stem from European and American countries. Namba et al. (1991) showed that noise perception vary in residents located in different countries and Hofstede (1985) showed that organisational behaviour varied in different cultures. It is likely that acoustic perception in the workplace also differs in different countries. In this study, it was intended to survey two countries, UK and Mauritius.

The literature review showed that noise has the capacity of influencing behaviour, work performance and health. The study being conducted here makes use of both subjective and objective measures to highlight the relationship between office design, two acoustic measures (noise level and reverberation time) and employee satisfaction. The next chapter looks at the origins of offices and Chapter 4 discusses issues associated with different office types.

Study	Location	Population	Investigation Area	Method	Data Analysis	Results
Langdon et al. (1963)	35 open-plan offices (UK)		Noise problems and acceptability	Questionnaire survey and sound measurements	Multiple regression analysis	Acceptability levels decreased with longer exposure to high peak noise levels
Keighley (1970)	40 open-plan offices (UK)	1902	Noise acceptability	Questionnaire survey and sound measurements	Multiple regression analysis	Noise poorly rated in general and sources found to be within office.
Nemecek & Grandjean (1973)	15 open-plan offices (Switzerland)	519	Noise disturbance and its relation to physical office data	Questionnaire survey and physical measurements	Chi ^{2} Test	Conversation was most disturbing and difficult to concentrate in open-plan office
Bryan & Tolcher (1975)	Simulated office (UK)	55	Preferred noise levels in relation to mental tasks	Performace rating and accurracy	Pearson's Correlation	No relation between preferred level of noise and amount of work done. White noise least acceptable and convestation most preferred noise type
Salame & Baddeley (1982)	Simulated office	33	Disruption of short-term memory by unattended speech	Analysis of errors	Newman Keul's Test	Unattended speech and noise alone both cause disruption on recall tasks
Loewen & Suedfeld (1992)	Simulated office (Canada)	15	Cognitive and arousal effects of masked noise	Questionnaire survey, Topic Completion Test	MANOVA and ANOVA	Masked office had highest arousal and performance on simple tasks
Sundstrom et al. (1994)	78 combination and open-plan offices (USA)	2391	Office noise, satisfaction and performance	Questionnaire surveys	Pearson's Correlation and ANOVA	Dissatisfaction with noise was related with office environment satisfaction and job satisfaction
Banbury & Berry (1998)	Simulated open-plan office (UK)	180	Disruption of office noise and speech on mental performance	Accuracy and time taken for performance rating	Newman Keul's Test	Office noise and speech condition worse than other conditions. Speech, whether relevant or not, still affected performance
Banbury et al. (2005)	2 open-plan offices (UK)	280	Disruption of office noise on concentration	Questionnaire survey and sound measurements	Pearson's Correlation	Telephone ringing at vacant posts most disturbing source and no habituation to noise occuring.
Haka et al. (2009)	imulated open-plan office (Finlan	37	Disruption of speech on work performance in offices with varying indices of speech intelligibility	Questionnaire survey and performance rating	ANOVA	Disturbance by speech increased when Speech Transmission Index increased
Jahnck et al. (2011)	Simulated open-plan office (Sweden)	38	Cognitive performance and restoration	Performance rating, accuracy, urine and blood sample	Mauchly's sphericity test	Better cognitive performance with low noise. Less motivated after listening to office noise.

Table 2.0 Summary of key studies in literature review

Chapter 3

The origins of the office

3.1 Introduction

This chapter looks at the historical development of office buildings and workspace layouts since the 19th C in Glasgow to determine the driving forces behind the shape and appearances of workspaces. The office building is a form that is constantly being reinvented by designers. Throughout the past centuries, the office building was mostly portrayed as a grim piece of architecture by both architects and the public but yet proved to be advantageous to firms and enterprises (Meel 2001). A possible reason for this attitude could be that offices were not places that aroused a sense of community, pleasure, spirituality or surprise (MacCormac 1992). Based on Cruickshank's research in the origins of offices in the UK, it was not until the 19th C that the office was categorised as building type (Cruickshank 1983). However, even after the 19th C, offices were still being overlooked. The well-known architectural historian, Nikolaus Pevsner, also had a similar attitude towards offices in the late 1970s. In *A History of Building Types*, Pevsner (1979) categorised both warehouses and offices under one chapter and mentioned how they greatly resembled each other with the exception of their usage. Regardless of the criticisms, the office developed on a very large scale and is still relevant to businesses today. The aim of the historical research is to gain clear understanding of the development of offices and any pattern or relationship existing in Glasgow offices which is necessary when determining the acoustic quality of workspaces.

Written materials describing the coherent historical development of offices in Glasgow are scarce. To further understand the current layout of workspaces in Glasgow it is necessary to look at the historical development of workplaces in the city. Research materials used in this chapter were obtained from the Glasgow School of Art library, University of Glasgow library and Mitchell Archives when searching for keywords: 'office building history', 'urban development history in Glasgow' and 'architectural history in Glasgow' in library catalogues. In this study, the evolution of office buildings in Glasgow was described in relation to technological changes during the Industrial Revolution, the Modern Movement and the Digital Age. A more in-depth analysis of office buildings from the aforementioned eras is carried out in Section 3.5 with aid of diagrams to compare architectural style, height, materiality, office layout and size of the offices.

The literature review showed that offices remained a significant architectural space for organisations and recently built workspaces indicated a shift in emphasis for employee comfort. The design of workspaces within the last five decades suggested some awareness of noise issues in the workplace. Analysis of buildings from three different periods showed that there are certain relationships between various physical factors of office buildings. For instance, both gross floor areas and workspace floor areas tended to increase together and the amount of glazing and workspace floor area also tended to increase together. However, the association between acoustic comfort and size of workspaces was not clear and necessitate further investigation.

3.2 Classicism and Multi-storeys

The Industrial Revolution of the late 18th C had transformed Glasgow into a powerful and flourishing city by the turn of the century. The rapid evolution of Glasgow in the mid-19th C was so impressive that it was described as one of the most powerful cities in Europe and was referred to as the 'Second City' of the British Empire (Glendinning et al. 1996).The city saw an increase in businesses and a high influx of workers migrating to Glasgow. The local architects attributed various classical styles (such as Greek, Gothic, Roman, etc.) to new buildings giving rise to eclectic classicism in Glasgow. The ostentatious classical buildings were designed with the intention of reflecting the power and wealth of the capitalist city (Glendinning et al. 1996). Glasgow saw the emergence of new buildings dedicated to the sole purpose of conducting business, namely the office building. Bankers and insurance companies led the way in the construction of ornate office buildings all over the city (Glendinning et al. 1996). Between 1750 and 1850, 13 banks were opened in the city (Cullan 1834).

One of the early banks of the 19th C was the Royal Bank of Scotland built in 1817 and was part of the Royal Exchange Square (Cullan 1834; Fisher 1994). The building was constructed in cream ashlar sandstone and had a Greek Temple front which protruded a majestic appearance. The grand architectural style was imitated by later banks and to follow the lead of banks and insurance companies, commercial and business owners also invested in the construction of offices.

By mid-18th C, Glasgow's industrial expansion was said to have "…produced revolutionary new building materials: cast and wrought iron, and, later steel" (Glendinning et al. 1996). In the late 18th C, two Scottish brothers, James and William Carswell, introduced the use of cast iron in the construction of buildings (Carswell 2011). The use of iron for building structures and the introduction of the lift in the 1850s encouraged architects to experiment with the design and height of buildings. One of the innovative designs was the lightweight building structure with a plethora of glazing for the maximisation of light which was inspired by the Venetian Renaissance buildings. An example of this in the commercial sector was the Ca'd'Oro on Union Street in Glasgow by John Honeyman in 1872 (Doak & Young 1983).

Together with the industrial revolution, there was also the remarkable growth of the service sector (Knox 1999). This increase in service sector led to the rise of office numbers in the city. Throughout the progress of office design, a new type of office emerged in the 19th C known as the *speculative office* which was a repetition of floor plans stacked on top of each other rented by firms and enterprises. London City designer, Edward I'Anson, described the 19th C speculative office as '… a financial venture rather than for a specific user and which was intended to make its owner a handsome profit (Cruickshank 1983). This new concept of office altered the approach of architects towards office buildings. In the design of this new building type, the importance of aesthetics and quality was replaced by the urge of increasing client's profit. The land scarcity of 1870s' Glasgow city centre further encouraged the use of this new office type and an example of this multi-storey office was the Lancashire Insurance building by James Thomson in 1896 (Glendinning et al. 1996).

It was not too long before the local Scottish architects were creating their own versions of the American skyscraper which begun their ascension a few decades earlier (Korom 2008). Taller and slender buildings were beginning to appear in Glasgow city's skyline in the late 1800s. An example of this was the Atlantic Chambers, a speculative office on Cadogan Street which was designed by John James Burnet in 1899. The design of the building was said to have been influenced by his visit to Chicago in 1896 (Macaulay 2011).

In addition to the increasing number of offices in Glasgow, a new work technique was being introduced on the work scene; typewriting. Offices began adopting the typewriter on a commercial scale in 1890s in Glasgow after noticing how it increased the speed of work process and workspaces were consequently designed to cater for cumbersome typewriters (Guerriero Wilson 1998). Shortly after the introduction of typewriters, typists were widely sought and became an expanding workforce. The decline of the industrial sector in the early 20th C led to a fast growth in the service sector (Knox 1999). According to Guerriero Wilson (1998), the offices had "noisome and insanitary conditions.." which resulted from poor ventilation systems and work activities. Furthermore, Building Regulation Act 1892 (Glasgow Police Department 1895) placed great emphasis on means of escapes during fire but none on workplace environment. Noise within workspaces were not emphasized in the description of workspaces by Knox (1999) or Guerriero Wilson (1998); testimonials in the written work of the aforementioned authors indicated greater dissatisfaction with sanitary conditions than with acoustics.

Towards the end of the 19th C, several secular architectural styles were emerging in Glasgow which introduced new monumental multi-storey building blocks with integrated sculptural forms (Glendinning et al. 1996). It could be argued that multi-storeys were a solution for space-provision for the growing workforce. There was a tendency for less ornamented and simpler buildings. Most of these new building forms were inspired by the Modern Movement which lasted until the 1970s in Glasgow (Glendinning & Muthesius 1994).

3.3 Modernism and Monumentalism

The most radical changes in office building designs occurred in the 20th C. The First World War in 1914 led to a shortage of skilled labours in the city. It was reported that there was a count of 10 000 stonemasons in 1914 and by 1939 there were records of none (Glendinning et al. 1996). There was the need for reconstruction both on a social level and in the built environment. The Modern Movement promoted optimism and socialism which was ideal for a fresh start. It enforced the use of new technology, standardisation and neo-classical style in its designs. Modernism was not adopted in Glasgow until the 1930s which transformed the city's commercial area with massive palazzo-style office blocks (ibid.). The architects would build as high as the authorities would allow. A pioneer of this type of office building was architect James Miller, a strong advocate of American architecture in Scotland and his first prototype of monumental office building was the Union Bank of Scotland Headquarters on St Vincent Street built in 1925 (ibid.).

In the 1920s, considerable attention was being given to the office building as a whole and to productivity in America. By the mid-1920s a new set of American values and work method known as *Scientific Management*, had filtered into the UK's office managerial system which was devised by engineer, Frederick W. Taylor (1917). Based on personal observations and work experience in factories, he put forward the theory that productivity of workers could be increased with the right science, training and equal division of work tasks combined with a financial incentive under the supervision of intelligent managers (Taylor 1917). Businessmen widely sought this theory to increase productivity of their workers in the office and the first office building to embody these principles was the Larkin building by Frank Llyod Wright in 1904 (Anthony 1980). The traditional cellular office layouts were replaced by large open plan working areas to cater for numerous clerks who were to be positioned according to their associated work activity (Quinan 1987). According to Anthony (1980), the Larkin was to be the new model for 'Modern offices'. The 'Taylor' concept was similar to the factory where 'blue-collar' workers were substituted for 'white-collar' ones and was adopted on a smaller scale in the UK mainly because of the deep-rooted traditional business culture and of the small sizes of offices in comparison to American ones (Meel 2001).

After the Second World War in 1939, the Scottish Development Department promoted the need for reform and social change which would be tackled by a re-construction programme of the central areas (Glendinning et al. 1996). The growth of the local authority service involved in re-construction programmes of the city and rise in the number of private companies led to an unprecedented demand for white collar workers in 1945 (Knox 1999). By 1964, the city was divided up into twenty-nine Comprehensive Development Areas with re-construction programmes lasting to 1980s (Taylor 1964). Modernism was a vehicle for this social change and re-definition of national style which peaked by the 1960s.

The concept of standardisation and homogeneity was rapidly transferred to the regular construction of buildings, including the design of offices. The advent of the building crane in 1951 together with the use of prefabricated building section panels greatly increased the construction of tower block (Glendinning & Muthesius 1994). The development of new construction techniques and technology was a catalyst for the heavy construction of bulky concrete tower blocks in Glasgow, be it for residential or commercial purpose.

The 1960s and the following decades demonstrated a rising interest in the work space both on a macro and micro level. New spatial workspace configurations were being sought as alternatives to open-plan and cellular offices in Europe (Meel 2001). In 1960s Germany, the office-furniture manufacturing Schnelle brothers, invented a new office layout known as the *Bürolandschaft*, which was translated as *office landscape* (Duffy 1997). Desks were laid out in a large room at any angles according to the work flow of people working in teams or on the same field. This new office type was thought to be an improved version of the open-plan office with the elimination of status boundaries and rigid office layout which were once dominating the work space. It was considered as a more 'humane' adaptation of the Taylor open-plan office. This layout was intended to promote more communication among workers, accommodate new office technology (such as main frame computers used at that time) and make more efficient use of office floor areas. *Office landscape* was adopted in several countries throughout Europe and America mostly because of its communication advantage and financial savings. At first glance of this office, one might be inclined to believe that the office is in a complete state of chaos.

St Andrew's House built by Arthur Swift & Partners in 1962 was the first and tallest commercial tower block constructed in city centre at that time (Williamson et al. 1990). The floor plans of St Andrew's suggested the use of open-plan *office landscape*; no barriers or internal walls were allocated for cellular offices. Another example of commercial tower block in Glasgow was Heron House by Derek Stephenson and Partners in 1967 (Glendinning et al. 1996). The advent of personal computers during that period also encouraged the use of open-plan *office landscape* for easy wiring installation and access (Eley & Marmot 1995).

The concept of *office landscape* was ephemeral in the UK, which is somewhat expected given the persistent managerial hierarchy system in place in most offices. Businesses and companies were not ready to accept an egalitarian work system and demanded more rooted traditions which reverted back to Taylor's open-plan office and to another novel office layout – the *combi-office* (Meel 2001). The latter was a mixture of both extremes - cellular and open-plan layout - invented in Sweden and was another greatly appreciated office design. The years following the introduction of the *office landscape* proved to be tumultuous for the office industry. Employees greatly complained about various health issues which were believed to be associated with the working conditions in open-plan office environment. The complaints varied from noise to health problems.

In the late 1960s and early 1970s, several articles were being published to create greater awareness of environmental issues existing within open-plan and landscaped open-plan workspaces; employees were obliged to tolerate uncomfortable indoor temperature during summer because natural ventilation led to great annoyance from external traffic noise in London workspaces but no reference was made to the intensity of noise level (Anon 1965). Brookes & Kaplan (1972) observed that landscaped workspaces had higher noise and conversational privacy complaints in comparison to workspaces with a mixture of cellular and open-plan spaces.

In-depth research of the office environment gained magnitude after 1960s with the aim of improving the workplace. One of the early research studies on the office highlighted that temporary high noise level caused by work procedures was a major source of disturbances (Langdon & Keighley 1968). Langdon & Keighley (1968) suggested the possibility of noise reduction through the use of suitably designed office furniture and equipment. Furniture design was further developed in relation to acoustic and privacy problems of open-plan offices by American office designer, Robert Propst (Miller 2012). The latter referred to the open plan office as "…a wasteland. It saps the vitality, blocks talent, frustrates accomplishments" (Miller 2012). He designed modular office components which could be combined into various modules. This new system was known as the Herman Miller Action Plan (or in more modern terms the 'cubicle'). This system was believed to provide a balance between open-plan shared space and work privacy. In others' opinion it could be viewed as a Taylorist plan but with extra furnishing because the work style and management system remains untouched except for the appearance of the office.

At the beginning of the 1970s, Scottish authorities and designers was questioning the forms and standards of the Modern Movement after being negatively criticised by the public for its mass construction programme (Glendinning et al. 1996). The re-construction programme set by the government was still on-going but with less enforcement from the local authorities (ibid.). By that time, local architects were differentiating the new from the old building stock by the use of new construction techniques such as pre-fab slabs combined with steel, innovative materials and colours. Another derivation of the concrete tower block was the 'glass-box' which could be described as office blocks with excessive glazing. This office type had made its first appearance in late 1950s in America and for the following decades it would be the most copied office type throughout Europe (Meel 2001). One of America's finest 'glass-box' office buildings would be the Seagram Building by Mies van der Rohe in 1958 which was 38-storeys high. An example of the Glaswegian ‘glass-box’ was the Scottish Amicable Life Assurance building in 1973 built by King Main & Ellison (Glendinning et al. 1996). However, Glasgow’s office buildings were very small scale in comparison to the American skyscrapers and the Scottish Amicable’s grandeur was expressed horizontally instead of vertically as in the St Andrew’s (mentioned previously). This constant expression of size over the past decades could be argued as a reflection of corporate image of offices; the bigger the office, the more powerful the business. To further support the latter, Korom (2008) articulated that “…skyscraper was a symbol of wealth, the worthiness of the corporations that built or inhabited it”.

The Oil Crisis in the early 1970s was another influencing factor of the office environment. The soaring prices of oil led to a forced reduction of energy usage throughout America and Europe. Buildings were built according to new ‘air-tight’ specifications; more insulation, no open-able windows and complete reliance on mechanical ventilation (Bain & Baldry 1995). This rational construction system was thought to reduce energy bills and continued throughout the next decades.

The 1980s was described as the revival of visual and decorative elements and was known to be the Post-modernism era (Glendinning et al. 1996). This new era was the complete opposite of the Modernist ideology; it promoted traditionalism, ‘human’ scale and mixed use development. ‘Air-tight’ building systems used since the Oil Crisis were considered to be dysfunctional. Studies began to shed light on the relationship between occupants’ health and behaviour in relation to physical work environment. The World Health Organisation in 1982 finally recognised the existence of health issues (such as eyes, nose, throat irritation, dry skin, erythema, mental fatigue, headaches, hypersensitivity & nausea) in relation to office environments and was labelled as the ‘Sick’ Building Syndrome (SBS) (World Health Organization 1983).The main causes for the sickness were associated with numerous aspects of the workplace: air circulation system, room temperature, office material finish and structure of the building. The Building Research Establishment (1990) provided more detailed guidelines in methods of improving air quality and eradicating diseases (such as Legionnaire’s Disease) within office environment. The atrium feature in office buildings was once again popular in office designs because of its passive ventilation and energy saving qualities but mostly because of its visual qualities (ibid).

By the mid-1980s, The boundaries of the central commercial area had extended to the region of St Vincent St, Bath St, George Square and Argyle Street (Ellis 1986). Well-reputed commercial real estate advisor, Richard Ellis (1986) carried out a survey on Glasgow city's office stock which showed that Glasgow had approximately 50,000 office employment. Offices were categorised according to their quality and accommodating facilities regardless of their building age - Grade A, B and C. Grade A was defined as recent development or extensively modernised old buildings that offered unit spaces of not less than 557m², Grade B was described as well-maintained offices built within the last 15 years which provide open plan space of 278m² and Grade C were buildings which failed to provide Grade A and B spaces (ibid.). 8% of the office stock was classified as Grade A and 59% of the developments were newly built or refurbished since 1960 (ibid.).

By the 1990s, the appearance of offices had not evolved significantly. The new buildings built in the following years were given similar appearance to that of Scottish Amicable (mentioned earlier in this section). On the other hand, the whole of Europe was experiencing an unprecedented revolution which was known as the Digital Age. This new era saw the widespread use of personal computers convenient for fast manipulation and sharing of information. The fast-pace evolution of computer technology and its daily use completely altered people's lifestyle and ways of working; people could work anytime and anywhere. Office design consultant, Francis Duffy, described the advance of technology as "… invisible cloud of electronic connectivity that now surrounds us all"(Duffy 2008).

In the mid-1990s, J. Eley and A.Marmot (1995) acknowledged that the office was the biggest asset after its workers in organisations. The past concerns of office environment and performance had led to panoply of new office styles and designs which were no longer influenced by American and European designers (as in the 19th C) but mostly by the end-users of offices. There was more emphasis on how workspace was being used instead on the overall office appearance. The rapid technological transformations created new working patterns which in return affected the design of offices. New hybrids of the office workspaces mushroomed throughout the work scenes and were thought to be tailored to suit the work pace and styles of modern businesses. According to Duffy (1997), there were four types of workspaces by - the *hive*, the *cell*, the *den* and the *club* which represented different ways work was being done. It could be argued that the *den* and *club* office layouts were reverting back to the period when business was being conducted in a social setting in the early 1800s which could lead to a less productive atmosphere. It was a fact that each company used their office space differently and this required architects and company clients to invest in flexibility, permeability and good office management to accommodate the unpredictable market outcomes.

3.4 **Virtuality and Transparency**

Towards the beginning of the 21^{st} C, office buildings were widespread within the central area of Glasgow. The commercial boundary was further extended from Argyle Street to the River Clyde by the construction of new commercial buildings and was associated with a new project known as International Financial Services District in early 2000s (IFSD 2012) . According to the IFSD (2012), the office buildings covered an approximated area of one square kilometre. Office buildings in the 21^{st} C were more modest to their predecessors in the 1960s but with an added dynamism. Despite the pervasive presence of office buildings in Glasgow city, office building as a typology still did not spark great interest. According to Duffy (1997), a plausible reason for this could be because most offices did not produce any physical outcomes – information data was invisible and uninteresting. A slight shift in architectural styles occurred since the late 1990s; workspaces were more transparent than ever but more dynamic forms were attributed to the office building and interior workspaces. An example of this would be the Capella building on York Street designed by local firm, BDP in Glasgow 2009; the building was entirely glazed with a curved façade overlooking a public square and had a mixture of both open-plan and cellular workspaces. Another example of a glazed building with a dynamic form is the Aurora building by Cooper Cromar built in 2006 which had a concave glazed façade (Welch 2010). It could allegedly be said that building regulations were more detailed and varied according to building type than in the late 19^{th} C. To tackle the issue of noise in the workplace alone, noise level limits of 85 dBA were put in place by The Control of Noise at Work Regulations (2005) and the British Council for Offices (2009) recommended no more than 50 dB_{LAeq} for open-plan workspaces. The presence of numerous guidelines and regulations regarding office environment acknowledged the noise issues occurring in these areas but did not necessarily imply that all workspaces following these guidelines had ideal levels of comfort.

The on-going evolution of technology in this Digital Age triggered a need for flexibility and adaptability in the built environment which led to the invention of the *virtual* office. The latter lacked proper definition and was described as a no-office business that functioned with the use of telecommunication but had a physical office address associated to it and benefitted from certain services such as receptionist, mail forwarding etc. The physical address and other services were provided by other companies to on-line businesses and companies. An example of this would be Blue Squares (2011) on Bath Street which offered service packages for a minimal price of £60 per month. This office type could be criticized as a fictional business that created the impression that it actually had physical office space. In a way this showed, that to some extent, the physical aspect of offices was necessary for a business to function; it cannot be entirely invisible.

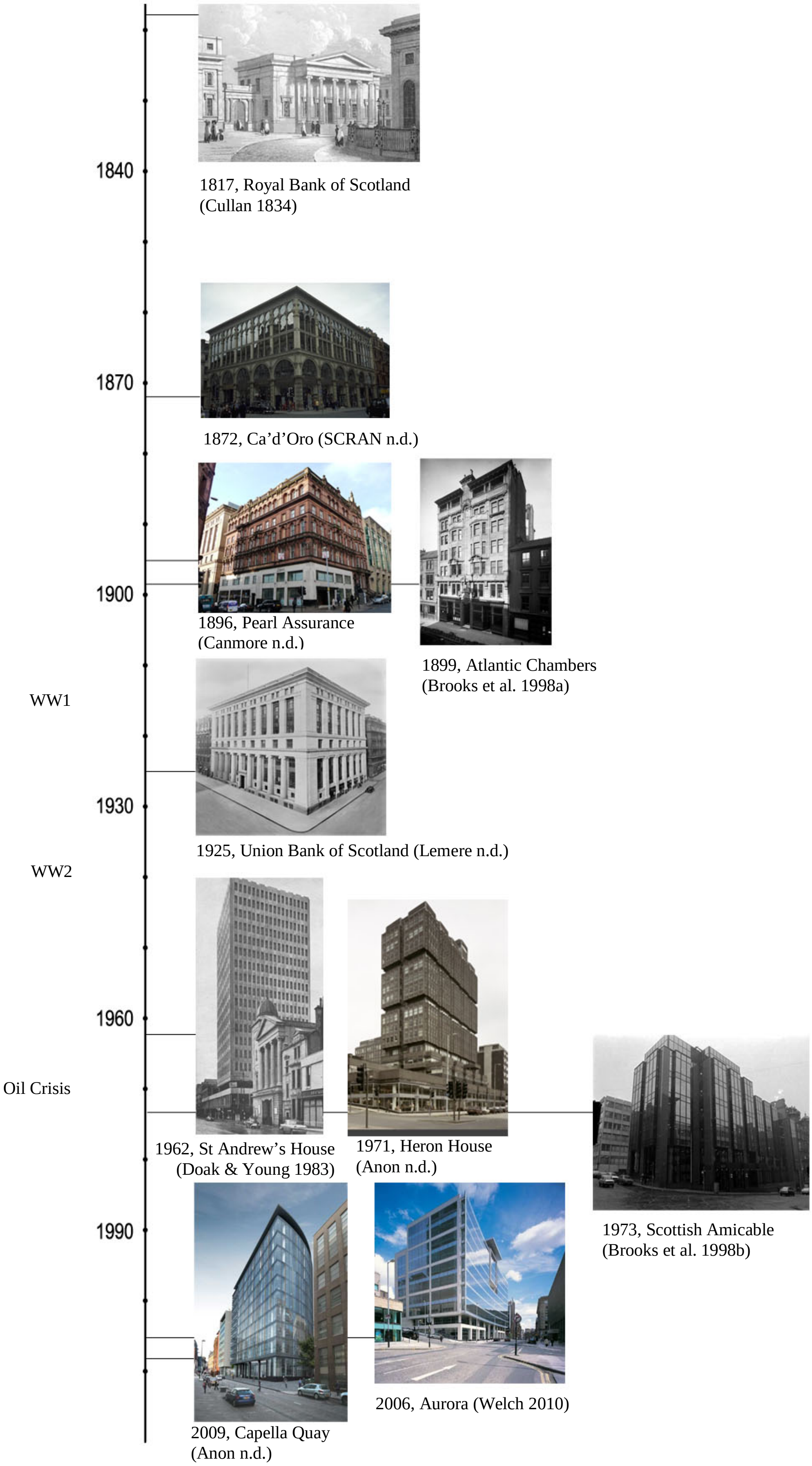
Another form of office that increased in the 20^{th} C was the *business park.* The latter could be referred to as a large-scale construction of speculative offices usually built outside city peripheries. An example of a business park in Glasgow was the Westpoint Business Park, near Glasgow Airport. Instead of offices within limited space in busy city centre, several new offices were being designed in a park setting with generous floor spaces at more affordable prices than those in central areas. Business parks became very appealing to large corporate companies. They easily embraced the latest technology and were allegedly more energy efficient than old refurbished city buildings. These new office types also had the possibility of expressing the office image (either in terms of height or materiality) which in central area is very difficult to achieve given that most of the buildings are listed for conservation.

By 2010, the four work space types mentioned by Duffy (1997)(mentioned above) had evolved to nine types according to office consultant, Meel (2010). These were: the *open space*, the *team space*, the *cubicle*, the *private office*, the *shared office*, the *team room*, the *study booth*, the *work lounge* and the *touch down area*. The spaces differed according to number of people, type of work being carried out and the concentration level required. In order to find out which workspaces businesses required some design offices, such as Alexi Marmot Associates, carried out surveys to obtain a more specific brief. However, it is a personal belief that staff participation in office design is more beneficial and a very good example of this would be the Centraal Beheer in Netherlands by Herman Hertzberger in 1972 (Mellor 1974). The office was laid out in such a way that each occupant had a generous personal space which could be modified according to their taste. The architect was highly awarded for the democratic values and flexible use that the office represented (Curtis, William 2011).

Despite the various new office types and innovative work methods, these workspaces defined by Duffy (1997) and Meel (2010) have not yet infiltrated all offices to this present day. The *den*, *lounge, study booth* described by the aforementioned authors tend to be located in very large corporate offices, in other words, those that can invest in such types of experimental layouts. One main reason for this could be the lack of investment within the business sector due to the recent recession. Based on the author's previous visits to offices in Glasgow, most offices tended to have either open-plan or cellular layouts.

A timeline was drawn (see Figure 3.0) to highlight the significant differences in the prevailing architectural styles and building height of office buildings in Glasgow throughout time as discussed in the sections above. The following section dissects three office buildings that were mentioned in Sections 3.2 to 3.4 - Atlantic Chambers, St Andrew's House and Capella with the aid of diagrams and computer-aided drawings.

Figure 3.0 Timeline indicating development of office buildings in Glasgow



3.5 **Comparative analysis of buildings**

The historical development of office buildings in Glasgow were described in relation to three architectural impressions – classicism and multi-storeys, modernism and monumentalism and virtuality and transparency. Three buildings previously mentioned in these sections and in the timeline with the relevant prevailing architectural styles were further analysed in relation to their architectural styles, building height, materiality, workspace layout and size. The buildings used in this comparative analysis were

- Speculative classical multi-storey office: Atlantic Chambers (1899)
- Modern tower block office: St Andrew's House (1962)
- Contemporary office : Capella (2009)

The building plans for Atlantic Chambers and St Andrew were obtained from Glasgow City Archive at the Mitchell Library and those for Capella were obtained directly from the architects, BDP. The floor plans for each office were redrawn by the author and are shown in Figures 3.2.1 to 3.4.7 with detailed description of each office. A breakdown of floor areas for each office type is shown in Appendix B.

3.5.1 *Architectural style*

The three buildings being analysed here had very distinctive appearances. Atlantic Chambers was designed by John James Burnet in neoclassical Beaux-Art style in 1899 - a style that was prevailing in America at that time. As seen in Figure 3.2.2, the central bay of the building was decorated with winged figurines on relief panels which indicated the main entrance to the building and also equally divided the façade into two main parts that contained windows. Balconies and bay windows were used to create an animated façade. In the author's opinion, at first glance of the building viewers tend to be attracted to the playful and slim façade. St Andrew's House, on the other hand, was completely stripped of any decoration or dynamic features which projected a very cold and hostile appearance in the author's view (Figure 3.3.2). St Andrew's House was designed by Arthur Swift & Partners in 1962 and consisted of a tower block resting on a long three-storey podium which cantilevered over shop fronts on Sauchiehall Street (Glendinning et al. 1996). The façade of the tower block was equally divided by small windows thus rendering a cage-like appearance. The height of the tower was considered to be more impressive than the architectural style of the building. The Capella building was completely different from the Atlantic Chambers and St Andrews and was a visually striking element. The shiny and transparent façade created by the excessive glazing compelled visitors to look at the interior spaces (Figure 3.4.2). The façade had no decorative elements like the Atlantic Chambers or repetitive elements like St Andrew's House but was still considered interesting because it visually connected individuals outside to those inside of the building. BDP also included some colourful panels in line with structural elements to create some playfulness in the façade and to break the monotony of repetitive structural elements.

From the very intricate facades to completely glazed facades, this change in appearance of office buildings could tentatively be associated with the evolution in expression of business wealth and social beliefs. In a few simple words allegedly Atlantic Chambers was designed for a conservative society, St Andrew's reflected the *tabula rasa* attitude and boldness of local authorities after the war and finally Capella represented the fragility and openness of the actual society.

3.5.2 *Height*

Height of structures has great impact on an individual's perception and is one of the most common means of expression in architecture. It was reported that the Burnet (Glendinning et al. 1996) had been influenced by the style and heights in buildings designed by Louis Sullivan during his visit to Chicago which consequently led to the creation of Atlantic Chambers. An example of buildings in 1896 Chicago was the Guaranty Building by Sullivan and was 46.3m high with thirteen floors (Korom 2008). The Atlantic Chambers was at a slightly modest height of 33.5m in comparison to the Guaranty building and contained only seven storeys. The perception of height in Atlantic Chambers was further accentuated by the tall central chimney above the main entrance which divided the façade into two parts. Atlantic Chambers was serviced by only one lift which was located in the central circulation core as shown on the floor plan (Figures 3.2.3 & 3.2.4). The elevations indicated that the floor-to-ceiling height on ground level was higher than the above floors which was usually done to indicate public spaces and also to allow more daylight within the ground floor spaces. The floor-to-ceiling height on the office floors was 2.50m according to the original drawings.

St Andrew's tower block was built in 1962, more than six decades after the Atlantic Chambers. The tower block was 62.6m with 18 stories which was almost twice that of the Atlantic Chambers (Figure 3.3.6 & 3.3.7). The floors were serviced by three lifts located at the central core (Figures 3.3.3 & 3.3.4). Similar to the Atlantic Chambers, the floor-to-ceiling height at ground level was higher than the other floors which were also associated with public commercial activities. The floor-to-ceiling height for offices spaces was 3.0m which was slightly higher than that of the Atlantic Chambers. There was no mention of specific buildings or architects influencing the design of St Andrew's House. However, during that period American skyscrapers had reached further extremes in relation to height and an example was the Rockfeller Centre built in 1933, New York by Associated Architects which had a height of 260m and no less than seventy stories (Korom 2008).

After the 1970s building height tended to be lower than that of St Andrew's House in Glasgow which was possibly due to the restriction being placed by local authorities in the UK. According to Meel (2001), local planners in London were not greatly impressed by tall commercial buildings. To this present day, Glasgow City Council DES-11 Tall Building Policy (2012) insists that tall buildings be erected only within specific parts of the city, such as the financial district in city centre within the vicinity of other tall buildings. The height restrictions and objections certainly weakened the influence of American office blocks on those of Glasgow. An example of a recent building was Capella constructed in 2009 by BDP. The building was 51.9m high (between Atlantic Chambers and St Andrew's House) with eleven stories (Figure 3.4.7). Similar to Atlantic Chambers and St Andrew's House, the building had a central circulation but with four lifts servicing the floors and the floor-to-ceiling height was also higher at ground level than the other floors. The floor-to-ceiling height was 3.0m which was similar to that of St Andrew's.

Among the three buildings, certain similarities and differences were observed in relation to height. The building height itself tended to vary according to the prevailing architectural styles prior to 1970s and after that building heights were more modest and related to those in neighbouring buildings. The increase in the size of central cores and lifts were considered to be linked to the size of floor plans – as the floor plans increased the size of circulation cores and number of lifts being used also increased which was possibly linked to the provision of rapid means of escape and fast vertical transfer to relevant floors. The height of workspaces slightly increased in both post-modern and contemporary block in comparison to the classical Atlantic Chambers workspace.

3.5.3 *Office layout and size*

The floor plan of Atlantic Chambers was divided into a series of cellular rooms with each office having adequate natural brought in by windows overlooking adjacent streets or external light well as shown in Figure 3.2.3. The office floors had a gross floor area of 376m² of which 79% was office space (Figure 3.2.3 & 3.2.4). The typical office floor contained 8 offices with an average gross floor area of 18.5m². However, Burnet noted 'probable divide of offices' on his floor plans which was an indication that there was the possibility of altering the office sizes according to the demands of occupants. The number of occupants in each workspace was not indicated on the original drawings and according to the Glasgow Building Regulations Act (1910) there was no indicator of occupancy load used during that period that could possibly suggest the number or permissible users within the workspaces. Given the boxed layout of workspaces in Atlantic Chambers, background noise and privacy was not considered to be an issue in these workspaces.

The St. Andrew's typical office floor plan was designed as a rectangular plan with a central circulation core. The floors had no partitions as seen in Figure 3.3.4 which suggested the probable use of *office landscape* layout. The office plan had a gross floor area of 494m² which was greater than that of Atlantic Chambers with 81.4% of gross floor plan occupied by workspaces (Figure 3.3.5 & 3.3.6). The numerous windows in St Andrew's House provided employees with greater external view than those in Atlantic Chamber in which some offices overlooked the light well. The absence of internal partitions in St Andrew's also created large flexible open workspace in comparison to Atlantic Chambers which gave the impression of being a restricted workspace. However, noise propagation and lack of visual privacy in that workspace is questioned. The occupancy load factor used during the period is unknown and only appeared in Building Standards (Scotland) Regulations (1981) as 5.1m² in open-plan workspaces.

The layout of office floor plan in Capella, on the other hand, could be considered a design combination of both Atlantic Chambers and St Andrew's. The floor plan had both cellular and open-plan workspaces (Figure 3.4.4). Twelve cellular workspaces were located along the perimeter of the floor plan with mean gross floor area of 17.2m² which was slightly smaller than that of Atlantic Chambers. However, the use of the cellular offices was not indicated on the floor plan and it was possible that some of them were used as meeting rooms. The gross internal area of the office was 1251m² of which 75% was designed for working space. The ancillary office spaces were located at the centre of the plan with office spaces located around it. According to the British Council for Offices (2009), the occupancy load factor was $10m^2$ per individual which would result in approximately 125 occupants in Capella workspace.

The layout of office workspace could be said to have developed from two distinct layouts (cellular and open-plan) to a combination of both over time. In relation the size of cellular offices tended to be slightly smaller when comparing those present in Capella to the one in Atlantic Chambers. Nonetheless, the overall gross floor area and individual workspace was found to increase considerably over the three distinct periods which perhaps reflected the size of business organisations and also increase in comfort of workers.

3.5.4 *Materiality and transparency*

In the 19th C, most of the buildings in the city were built out of deep red sandstone which was imported from Ayrshire and Dumfries (Gomme & Walker 1987). The Atlantic Chambers was built out of polished red ashlar which rested on a granite plinth. The cast iron produced since the industrial revolution in Glasgow had hastened the construction pace of multi-storeys. The Atlantic Chambers had steel structural components instead which were heavier than cast iron but had more strength and tensile qualities than cast iron (Baden-Powell 2001). The finish floor material was not highlighted on the floor plans but was considered to be timber flooring board which was a common finish material during that period (Gourlay 1903). No structural detailing was indicated in the original drawing set but given the common construction technique at that time, the walls and ceiling possibly had plaster finish on lathes (Gourlay 1903). The Atlantic Chambers had light wells which were faced with white glazed tiles most probably because of their reflective qualities, hence bringing more light into the workspaces located in the middle of the floor plan.

During the Modernist period, concrete was a highly favoured material as mentioned in Section 3.3. The St Andrew's podium and tower block solid facades had an exposed concrete aggregate finish. The building had a steel structure with un-modulated concrete slab. The latter structural components were used because it shortened the construction time length in comparison to traditional building materials and methods (steel structure with stone finish). The workspaces were thought to have carpet flooring which was common at that time in offices (Pile 2000) and concrete ceiling.

The Capella had a steel structure and glazed curtain walling with colourful opaque vertical bands for solar gain reduction. Some parts of the building contained aluminium rain-screen cladding and black granite which was used for partial cladding on the ground level façades. According to the information provided by the architects, the interior workspaces had carpet flooring, plasterboard walls and acoustic ceiling tiles. The presence of noise absorbing materials in the workspaces indicated the awareness of background noise in open-plan workspaces and suggested that effort was being made to tackle noise issue.

Construction techniques of office buildings have evolved over the years and the building regulations indicated a change from solid wall construction to insulated cavity wall. The transmission of sound was also allocated separate sections in the regulations to demonstrate how noise, either airborne or impact noise in dwellings was significant and had an impact on health of individuals. However, it was not until the 20^{th} C that regulations for noise in non-domestic buildings appeared.

The amount of glazing in offices increased over the centuries which are most certainly due to the growing emphasis on natural light building regulations in the Glasgow Building Regulations Act in 1892 and the Building Standards (Scotland) Regulations from 1990. The Atlantic Chambers had two light wells and tall narrow windows which resulted in glazing-to-office floor area of 47.3%. Half of the offices in Atlantic Chambers were placed around the light well which gave straight-on views of the other offices. Despite the floor plan indicating glazing around the perimeter of St Andrews, one would expect that glazing-to-office floor-area ratio would be higher than that of Atlantic Chambers but this was not the case because the floor area of offices was much bigger than that of Atlantic Chambers which led glazing-to-floor area of 27.8%. As seen in Table B.1 in Appendix B, Capella had the largest glazing area in comparison to Atlantic Chambers and St Andrews. However, the area of offices was also very large which resulted in the glazing-to-office floor area of 34.4%. The increase in glazing indicated an increased appreciation for natural daylight and for visual connection within social context.

Atlantic Chambers 1899
43-47 Hope Street
Architect:John James Burnet
(Re-drawn by author)

Description

The seven-storey building had a symmetrical façade with a narrow central entrance underneath a prominent chimney stack on Hope Street. The façade was divided into three sections and was composed of a series of paired rectangular windows and bay windows with balconies and extra detailing. The central section had Tuscan columns with pediments supporting winged fugurines. The speculative office was divided up into a series of equal-sized rooms.

Building Area

GFA	-	375.9	sqm
Office Area	-	296.7	sqm
Ancillary spaces	-	4.68	sqm
Circulation Area	-	47.7	sqm
Office Area Range	-	11.7 sqm - 26.1sqm	
Office Length range	-	2.9 m - 10.6 m	

Key

- Gross Floor Area (GFA)
- Office Area
- Ancillary Spaces
- Commercial Area
- Circulation Area

Glazing

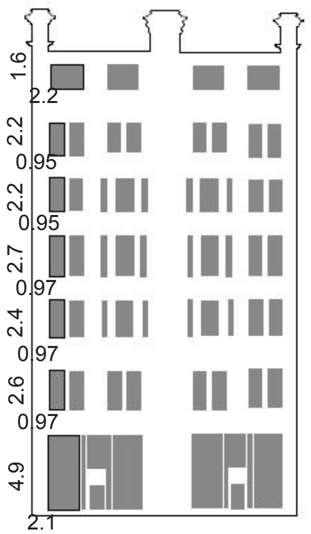


Fig 3.2.1 The building has a glazing-to-office floor area ratio of 47.3% in a typical office floor

Fig 3.2.4 Third floor plan
Scale 1:500

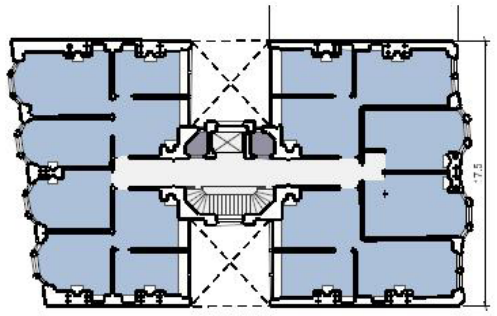


Fig 3.2.3 Ground floor plan

Scale 1:500

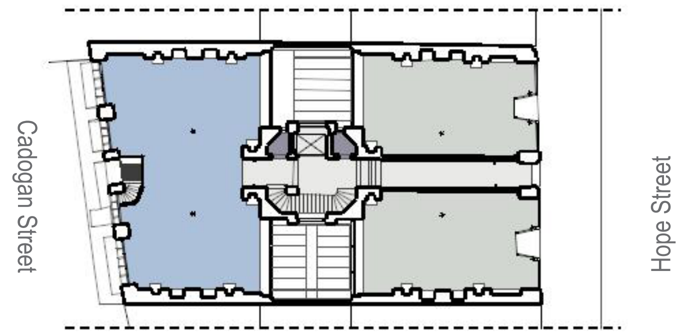
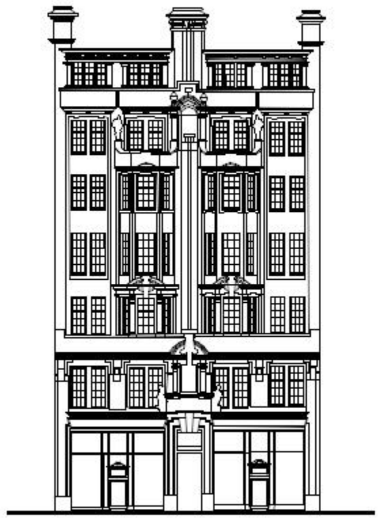


Fig 3.2.2 Hope Street elevation
Scale 1:500



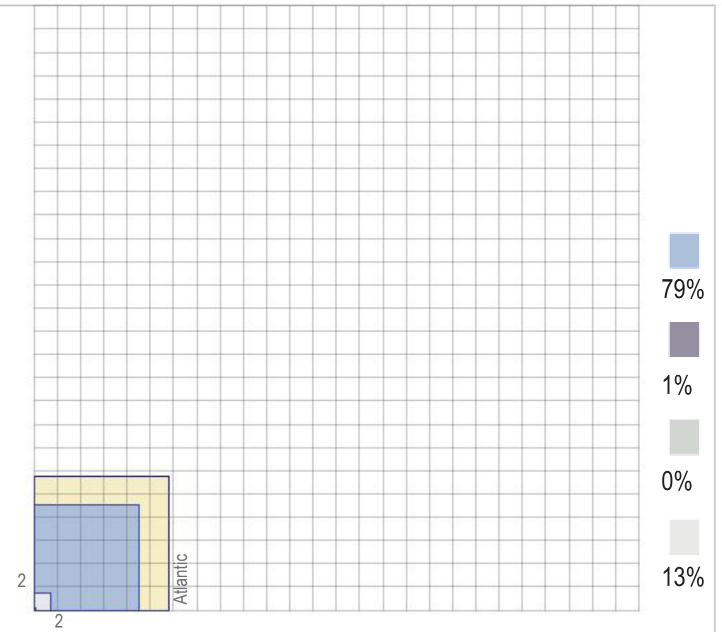


Fig 3.2.5 Typical office floor area comparison diagram

Fig 3.2.6 Ground floor area comparison diagram

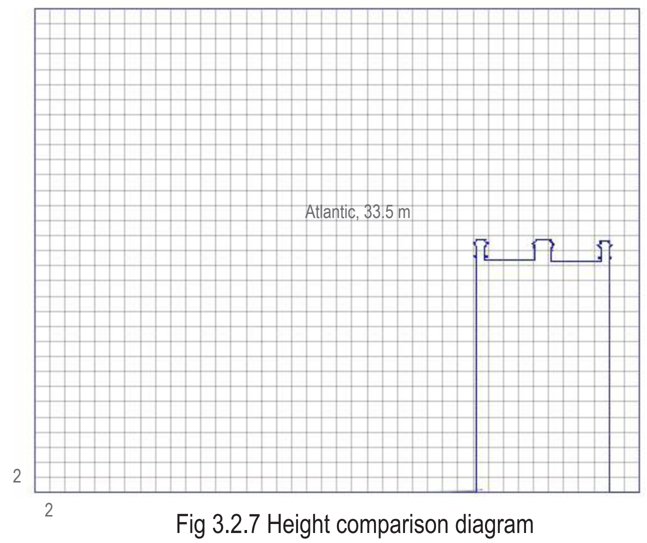


Fig 3.2.7 Height comparison diagram

Figure 3.2 Atlantic Chambers 1899
43-47 Hope Street

(Source:Scran)

St Andrew's House 1962
141 West Nile Street

Architect: Arthur Swift & Partners

(Re-drawn by author)

Description

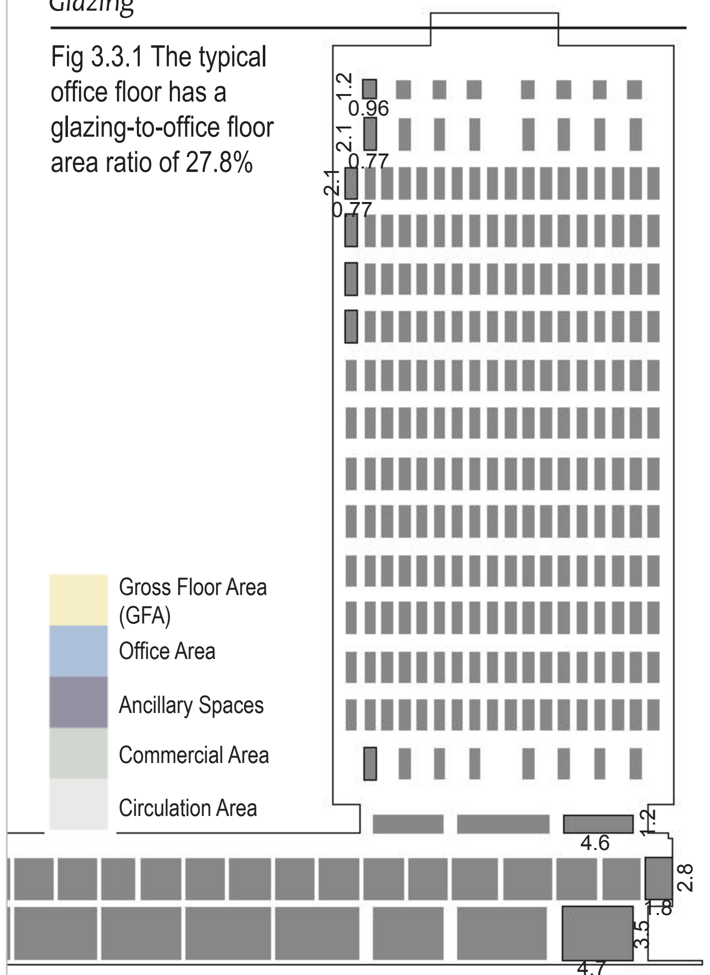
This was a Modern style building which consisted of a tower block resting on a long three-storey podium with cantilevers over shop fronts. The building had a steel structure with un-modulated concrete slab with an exposed concrete aggregate finish. The office layout was open plan landscaped .

Building Area

GFA	-	494.2	sqm
Office Area	-	402.2	sqm
Ancillary spaces	-	9.83	sqm
Circulation Area	-	67.4	sqm
Office Area Range	-	(open-plan)	
Office Length range	-		

Glazing

Fig 3.3.1 The typical office floor has a glazing-to-office floor area ratio of 27.8%



Gross Floor Area (GFA)

Office Area

Ancillary Spaces

Commercial Area

Circulation Area

Fig 3.3.3 Ground floor plan

Scale 1:500

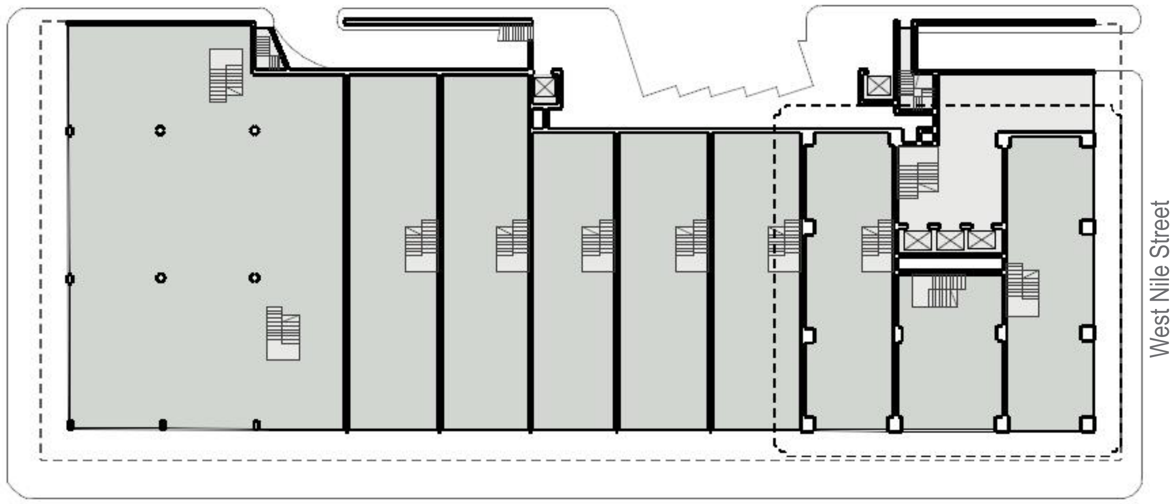


Fig 3.3.4 Fifth floor plan

Scale 1:500

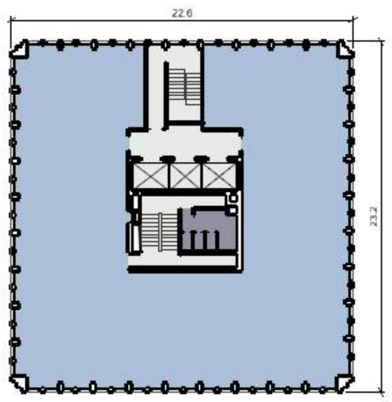
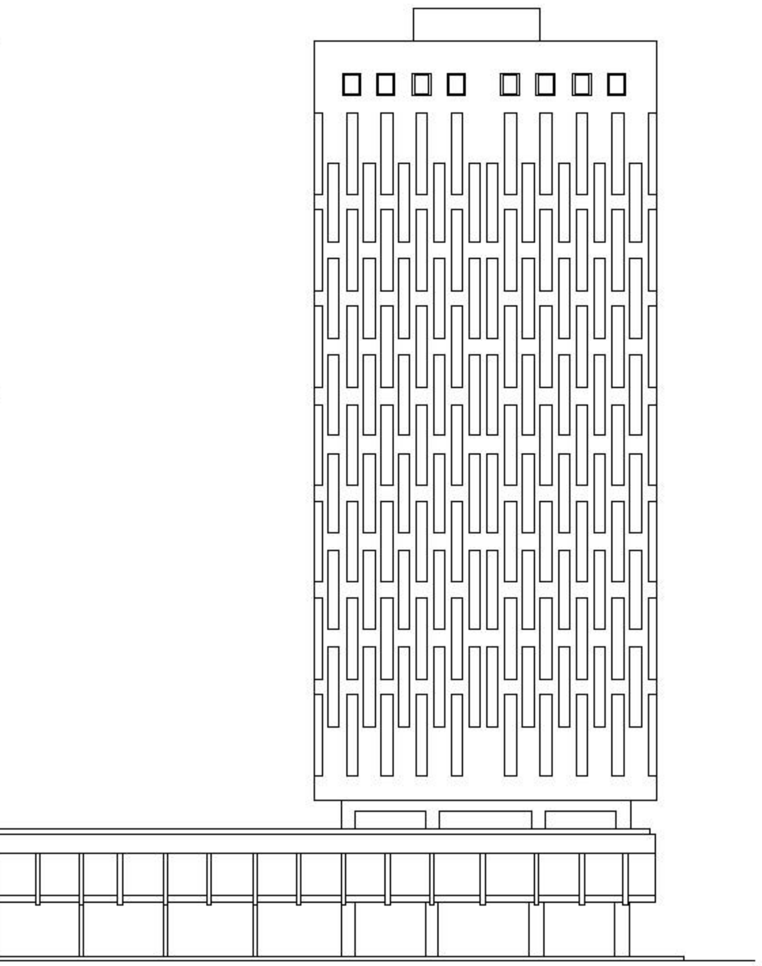


Fig 3.3.2 Sauchiehall Street elevation

Scale 1:500



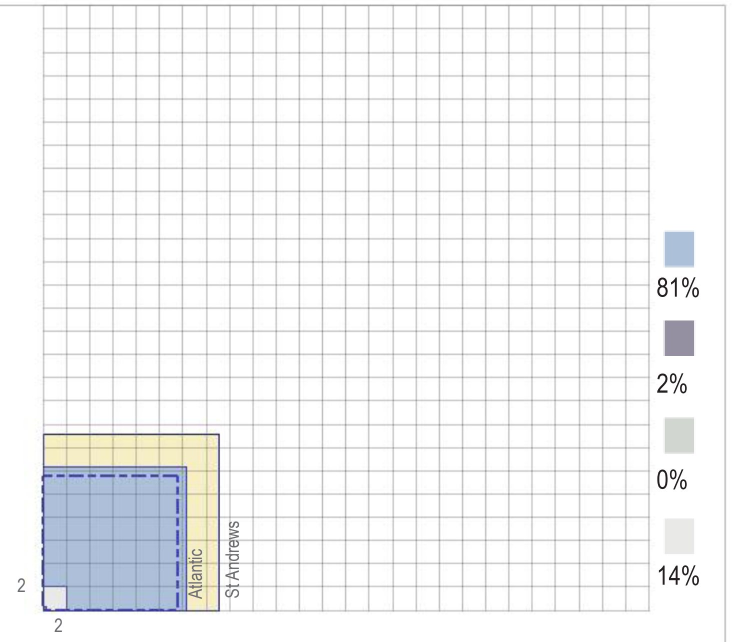


Fig 3.3.5 Typical office floor area comparison diagram

Fig 3.3.6 Ground floor area comparison diagram

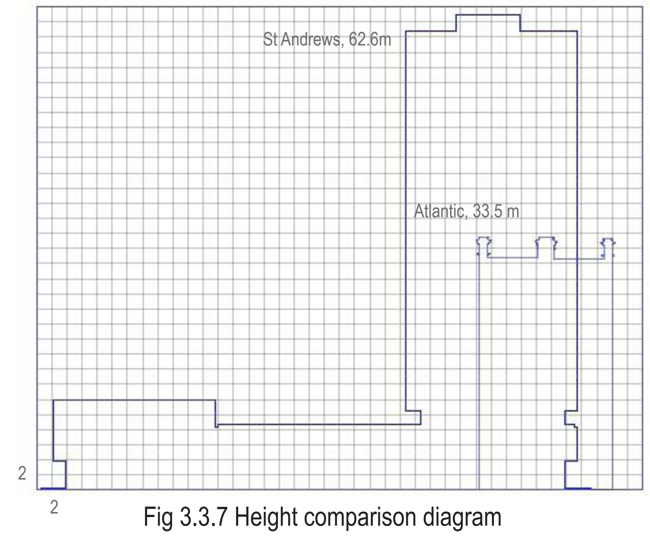


Fig 3.3.7 Height comparison diagram

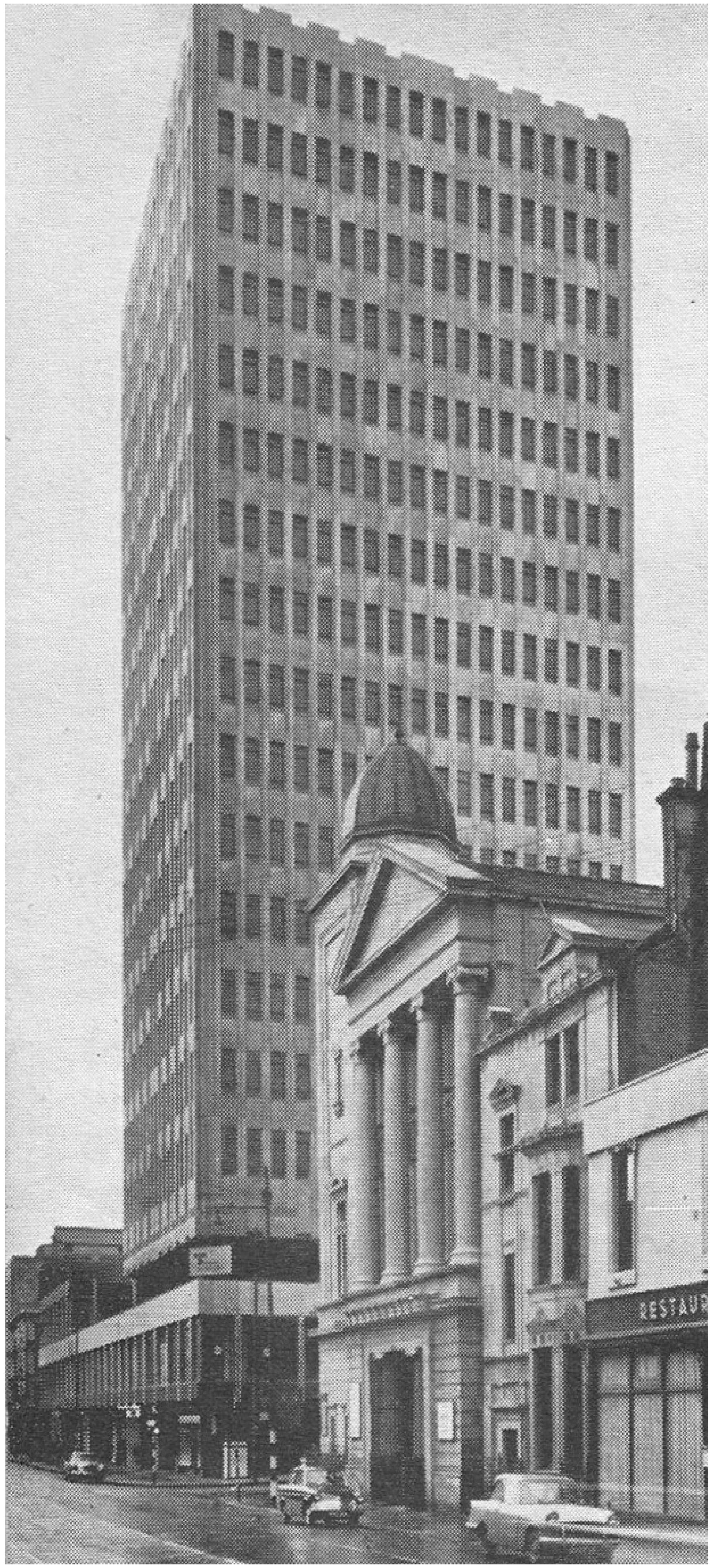


Figure 3.3 St Andrew's House 1962
141 West Nile Street

(Source: Doak, Young 1983)

Capella
5 Atlantic Quay, York Street

Architect: BDP

(Re-drawn by author)

Description

The eleven- storey building had a quadrant shape which was located on York Street. The building had a glazed curtain walling with aluminium and granite cladding on some parts and levels. The facade had vertical opaque materials for solar gain reduction. The office was designed with a combination of open-plan and cellular offices.

Building Area

GFA	-	1250.8 sqm
Office Area	-	940.5 sqm
Ancillary spaces	-	135.4 sqm
Circulation Area	-	97.5 sqm
Office Area Range	-	11.5 sqm - 22.8 sqm
Office Length range	-	1.9 m - 26.2 m

Key

- Gross Floor Area (GFA)
- Office Area
- Ancillary Spaces
- Commercial Area
- Circulation Area

Fig 3.4.4 Third floor plan
Scale 1:500

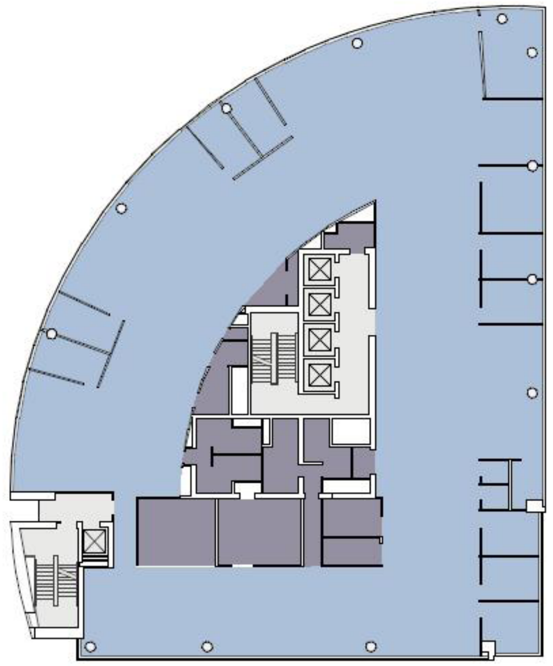
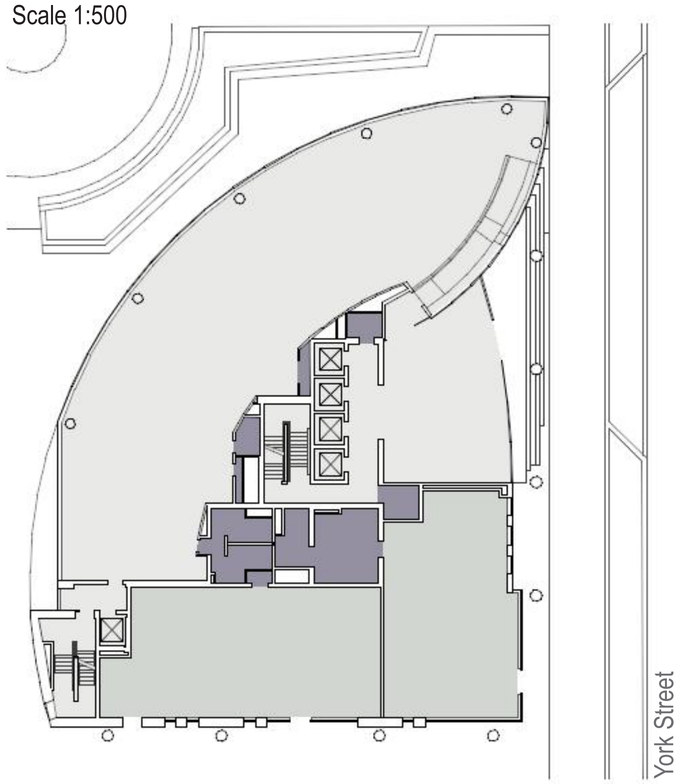


Fig 3.4.3 Ground floor plan
Scale 1:500



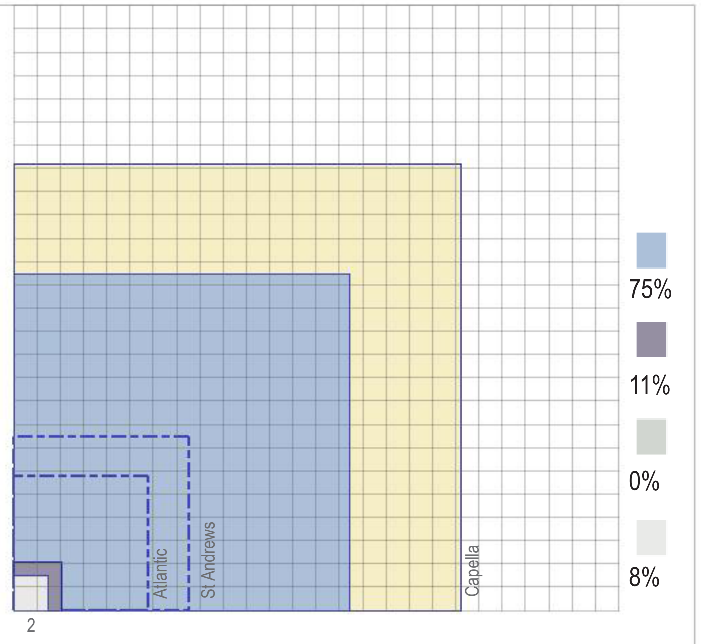


Fig 3.4.5 Typical office floor area comparison diagram

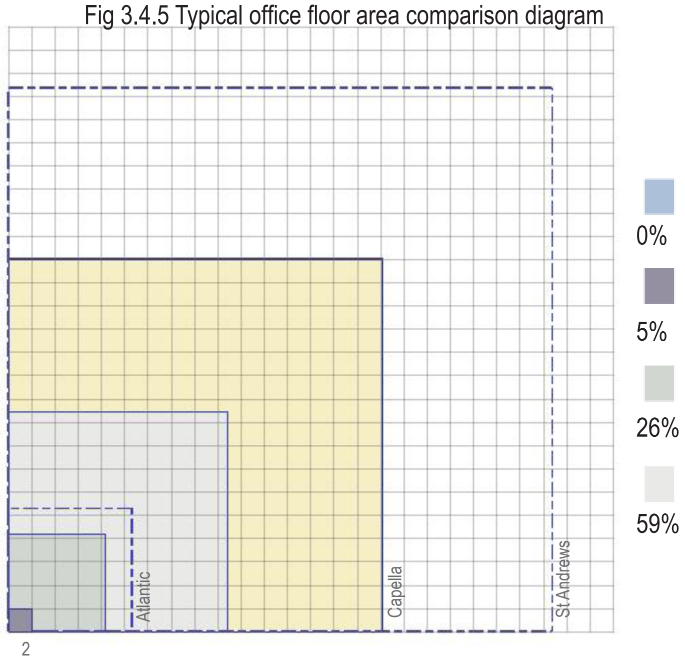


Fig 3.4.6 Ground floor area comparison diagram

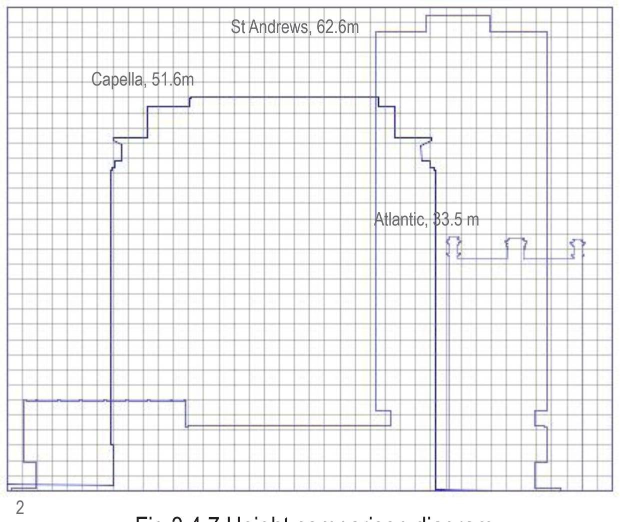
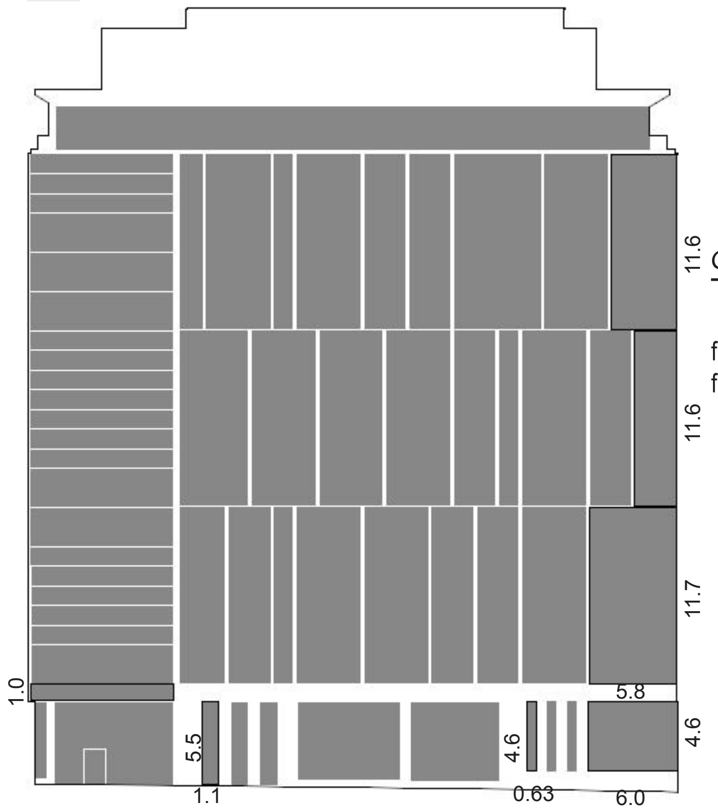


Fig 3.4.7 Height comparison diagram



Glazing

Fig 3.4.1 The typical office floor has a glazing-to-office floor area of 34.4.%

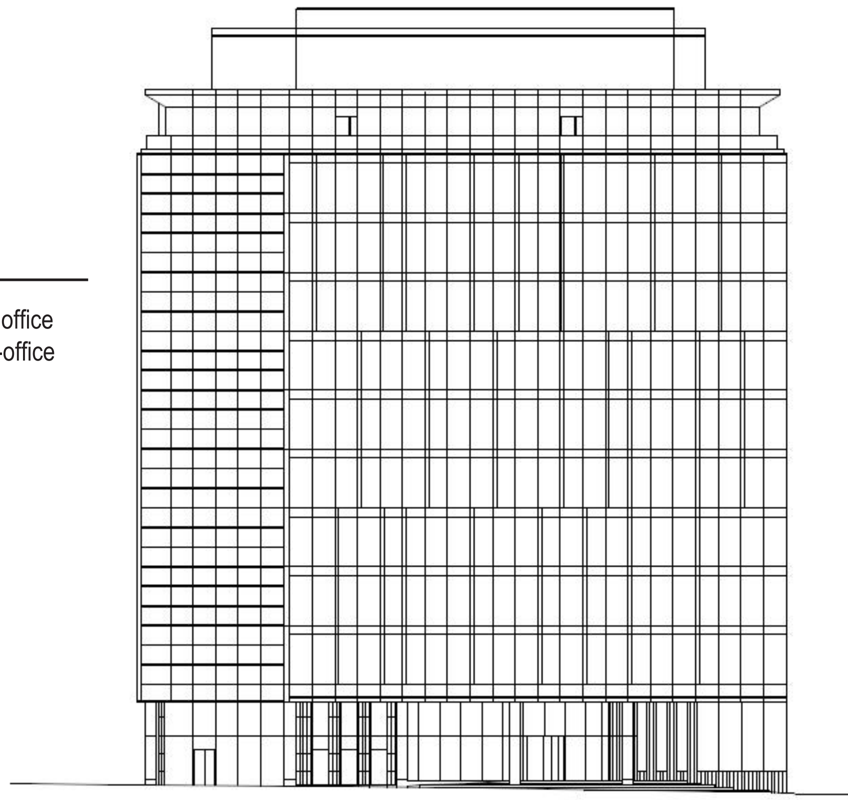


Fig 3.4.2 York Street elevation
Scale 1:500

Fig 3.4 Capella
5 Atlantic Quay, York Street

(Source: Glasgowarchitecture website)

3.6 Discussion

The literature review in this chapter showed that despite the variation in architectural styles of office buildings over the years, the workspace remains a significant space for organisations. The study highlighted that prior to 1900s, cellular office layouts were prominent in office buildings but after 1900s, alternate office layouts were being sought, such as the open-plan office layout which is another significant layout to this day. The different office layouts were considered to have been invented out of necessity and in relation to new work methods prevailing at that time. According to Duffy (1997), the workspace is expected to keep on evolving because there is the need for finding new ways to accommodate "...unstable and unpredictable business environment". In parallel with the rise of new office layouts, issues with the work environments, such as Sick Building Syndrome and noise dissatisfaction, also began to appear on the work scene.

More detailed analysis was carried out in office buildings reflecting different architectural styles to investigate the differences in building height, materiality, workspace layout and size of workspaces. Two main observations were made: 1) there was the tendency for office floor area to increase with gross floor area as indicated below in Figure 3.5 and 2) the area of glazing in facades also increased together with workspace floor area as shown in Figure 3.6. The transition of solid opaque building fabric to slick transparent ones was observed in three distinct building types; the 19^{th} C multi-storey stone office, the Modern concrete office and the highly glazed office. The increase in both gross floor area and workspace areas over the three periods showed that occupancy in offices tended to increase which tends to create more work activity noise and as seen in Chapter 2, the increase in office noise was associated with a decrease in work performance (Banbury & Berry 1998). The three buildings also showed that there was an increase in acoustic treatments present in workspaces. For instance, Atlantic Chambers had no sound absorbing ceiling tiles or carpet flooring used to absorb noise but in the Capella building both of the aforementioned were present. The height of office workspaces also tended to increase over the three periods but the variation in height was not considered to be as significant as the change in workspace floor areas because workspace heights was similar in buildings after 1960s but workspace floor area, on the other hand, was not similar.

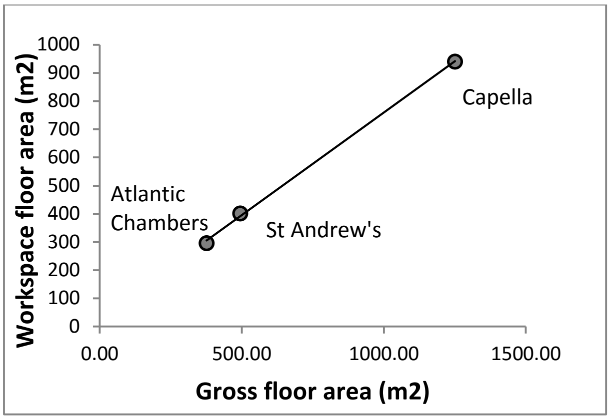


Figure 3.5 Graph showing relationship between gross floor area and workspace floor area in the three buildings analysed in Section 3.5

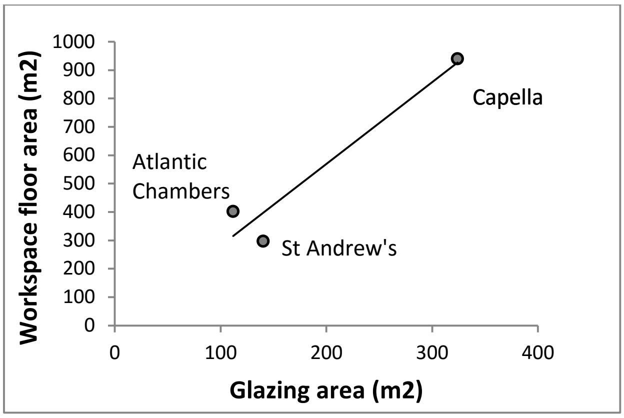


Figure 3.6 Graph showing relationship between glazing area and workspace floor area of offices analysed in Section 3.5

The variation in architectural styles of office buildings among the three examples could be viewed from two different angles. The first, being the expression of wealth and prestige through architecture. It is evident that buildings from the 18th and 19th C used rich classical Renaissance architecture to express the purpose of the building and the wealth of the company. According to Glendinning et al. (1996), "Banks and insurance companies built ever more grandiose headquarters…". Besides the use of ornamentation, height and scale was also another means deployed to show off prestige. The St Andrew's House is an example of this. Duffy (2008) talked about the Modern Movement which led to this new addiction to large scale. According to Meel (2001), tall commercial buildings were reflections of the power of corporate world. The Capella building was also described to be the largest speculative office in Glasgow in its advertisements (IFSD 2012). The latter showed that height and area were both important factors in the office world to attract potential clients.

The second angle from which the changes mentioned above could be viewed was social values. The transition of building materials from solid stones to sheer transparency could be seen as a reflection of a conservative society to a more liberated and open society. Jarosinski (2004) intensely discussed the use of transparency as a metaphor for social democracy which in his belief still has not yet been achieved. It is known that abundant glazing, such as the Capella, provide greater visual communication but on the other hand it over-exposes employees. The internal office walls were symbols of the hierarchical system in place which were taken down to create more open shared spaces, hence into a more democratic work environment. A model of this democratic system was the Larkin Building (1987) where the small offices were replaced with large open space, as seen previously. The office landscape layout was also a result of the breakdown of this hierarchical system in which "Employees, regardless of their rank or position, had to be accommodated in the same space…" (Meel 2001).

During the 1960s and the 1970s, the growing use of glazing in offices also coincided with the increased complaints and investigations of noise within the office environment. Past study has shown that there was an increase of 4% for reported dissatisfaction with exterior noise when the percentage of building glazing increase from 18% to 62% in landscaped open-plan offices (Hay & Kemp 1972a). As seen in Figure 3.6, both glazing-to-floor area ratio and workspace floor areas tended to increase together. It is commonly known that glass does not have the noise absorption qualities as stone and brick do and is more likely to transmit noise from the exterior. In the construction of a highly glazed building such as the Capella, there were no special features used to enhance the office acoustics except for the use of double glazing which was tested in a lab prior construction stage. According to the architect of Capella, BDP, the building was said to meet the acoustic requirements of the clients which implies that the office is unlikely to suffer from noise.

As mentioned above in Section 3.5.4, it was only in the 20th C that building regulations included clauses for acoustics in non-domestic which highlights the need for more research in this recently featured topic. Chapter 2 showed that influence of the noise on employee satisfaction and work performance. In this chapter, the historical description of workspaces showed that the changes in office layouts with time were not only intended to improve productivity but also to improve employee comfort; there was an increased use in glazing and ancillary spaces in offices. However, the association between workspace area and acoustic comfort is questioned because the increase in workspace floor areas implies an increase in occupancy and yet large workspace areas, such as Capella, tended to have increased presence of acoustic treatments and glazing in the workspaces. The following chapter looks at the association between office layouts and employee satisfaction.

Chapter 4

The predicament of office layouts

4.1 Introduction

This chapter is a review of past studies that investigated the impact of office layouts on the psychology of employees and acoustic quality of workspaces. In Chapter 2, it was observed that acoustic properties of noise, such as type of noise, intensity of noise and contents of noise, are related to behaviour, work performance and health of employees. However, little reference was made to the design of workspaces in studies discussed in the previous chapter. In this chapter we look at the associations of office design with perception of workspace and acoustic measures observed in past studies. Here, the office layout is described with reference to the definition provided by Oldham et al. (1995): the office layout is the way in which the workspace is being arranged and the boundaries are laid out within it. Different work styles have given rise to various office concepts that influence the office layout and are as follows: the open-plan office, the landscaped office, the team office, the cubicle office, the private office, the shared private office, the team room, the combination office, the flexible office, the work lounge and the study booth which are being described here.

Glasgow City currently contains 7160 offices (SAA 2013). The choice and use of office designs in most offices are mostly dictated by the following; cost of building, comfort and security of occupants, new technology, work styles, corporate or organisational structure, attracting workers and sustainability (Duffy et al. 1993; Davis et al. 2011). These factors rest mostly within the hands of managers whose main role is to supervise the flow of business (Eley & Marmot 1995). Davis et al. (2011) argued that managers may not have the right expertise or knowledge when it comes to choosing the appropriate office layout. However, it is up to designers and researchers to provide all vital information to facilitate selection of appropriate layout in organisations.

Despite the various office concepts emerging on the office market, cellular and open-plan workspaces remain the most common office type. Research journals reading resources referred to in this section were obtained from the following research databases – RIBA online library (www.architecture.com), Art and Architecture Complete (www.ebscohost.org), ScienceDirect, Wiley, Sage Journals, WorldCat and Google Scholar, Glasgow School of Art library and University of Glasgow library when searching for keywords: 'office noise', 'office acoustic', 'office satisfaction' and 'office spatial parameter'. Past studies focusing on both office types highlighted that employees were more satisfied with their workspace in cellular offices than in open-plan ones but values of noise level were not necessarily lower in cellular workspaces than in open-plan offices. Most studies focusing on acoustics in the workplace in this review failed to correlate subjective and objective data collected during surveys and the most common acoustic measure was noise level. To indicate the significance of the studies within the literature review and to highlight the gap in knowledge of office acoustics an evaluation of the relevant studies was carried out at the end of the chapter. The chapter begins by looking at different office concepts and satisfaction with the workplace.

4.2 Definition of office types

Different types of offices have emerged over the past decades and are considered to be mostly derived from the open-plan and cellular offices, except for the combination office. This section gives a concise textual and visual description of the two main office types, open-plan and cellular offices, that exist to this day and their derivatives. The different types of open-plan and cellular offices described in the following sections are considered to promote new working styles. It was also observed that the terminology of office types tended to vary in different countries. For instance, a large workspace with a pool of desks in America is commonly known as the 'bullpen' while in UK it is referred to as 'open-plan' office (Meel 2001; Lee 2010; Danielsson & Bodin 2008). To obtain a more accurate and specific description of office types, two sets of description provided by Danielsson & Bodin (2009) and Meel (2001) were combined. The office types are described according to the following categories: a) number of occupants, b) desk arrangement, c) level of interaction and privacy d) and perceived level of concentration associated with the space. The latter refers to the level of attention that work requires and is defined as; high, medium and low. An example of a low concentration work would be a 'number search' task (looking for a specific number in a field of 2000 numbers) and an example of a high concentration work would be the completion of an unfinished written paragraph (Loewen & Suedfeld 1992). Floor areas were not included in the description provided by the authors and no official area guidelines were provided for each of these office layouts. Health and Safety Executives (2013) only mentions that each individual should have a minimum workspace volume of 11 m^3. The drawings depicting the office type have been re-drawn by the author and the office descriptions are as follows:

4.2.1. *Open-plan office*

The open-plan office refers to a common workspace or a large room that is shared by more than four people (Figure 4.1.0). The employee desks are arranged either in clusters or in rows. Certain desks in open-plan offices might include low screen dividers or partitions (as in the other types of open-plan offices below) to provide some acoustical and visual privacy. The purpose of the open-plan office is to create a flexible space organisation with an easy communication flow. Status demarcation is not possible in open-plan offices which, on the other hand, promote a more egalitarian workplace. The space is suitable for work demanding a low level of concentration and stimulates socialising among work colleagues.

a) *Landscaped office*

The landscaped office (Figure 4.1.1) has a similar layout to that of the open-plan office except that desks are arranged according to work groups or to tasks in order to create a more enhanced work flow. There are no screen dividers at desks. At first glance, the workspace may appear chaotic.

b) *Team office*

The team space (Figure 4.1.2) is a cluster of desks semi-enclosed by low partitions in a large open room. The team space is usually occupied by groups of six to ten people working on the same projects or similar tasks. The space is suitable for a medium level of concentration and provides easy communication among different groups.

c) *Cubicle*

The cubicle is a semi-enclosed space by low partitions for one person only (Figure 4.1.3). The space is convenient for medium level of concentration and interaction. It is also suitable for workers who require some visual privacy during task completion. Cubicles are usually located within the centre of floor plans and can be designed with low or high partitions (below or above 1.52 m).

d) *The flexible office*

Flexible or hot-desking offices refer to workspaces with desks being shared by employees. Desks are usually located within an open-plan workspace where employees have no allocated seating (Figure 4.1.4). The workspace functions on a ‘first come, first served’ basis. It is suitable for jobs requiring low level of concentration and privacy. One employee occupies the hot-desk or touchdown space at a time.

e) The work lounge

As the name implies, the work lounge is an informal and relaxed seating space where two to six employees can conduct work on short-term basis (Figure 4.1.5). The space is ideal for informal collaboration and for work requiring a low level of concentration. Similar to the flexible office, there is no allocated seating within the space.

f) Team room

The team room is an enclosed workspace that is occupied by four to ten workers who deal with confidential work and require frequent communication (Figure 4.1.6). Desks are usually grouped together to facilitate interaction. The space has a higher level of privacy than the team space and is suitable for tasks requiring a medium level of concentration.

4.2.2. *Cellular office*

The cellular office is an enclosed workspace for one individual and is also known as the conventional, traditional or private office (Figure 4.2.0). This type of office is ideal for workers who require a high level of concentration and privacy to deal with confidential matters.

a) Shared office

The shared office is an enclosed workspace for two to three workers where collaborative work and confidentiality is required (Figure 4.2.1). Desks are usually located at the perimeter of the room. The space is suitable for high level of concentration and privacy. It is often used for group work on a specific project.

b) Study booth

The study booth is an enclosed workspace for one employee where work can be conducted on a short-term basis (Figure 4.2.2). The space is ideal for work requiring a high level of concentration or confidentiality.

The description provided by Meel (2001) and Danielsson & Bodin (2009) made no reference to height, workspace area or acoustical measures, such as noise level, in each workspace. Based on the aforementioned description of offices provide by Meel (2001) and Danielsson & Bodin (2009), the two most distinctive layouts are open-plan and cellular offices around which office concepts tend to revolve in the author's opinion. In Figures 4.1.0 to 4.1.6 we find that large spaces with occupancy of more than 4 tend to have similar appearances but with different desk organisations. The same was observed in Figures 4.2.0 to 4.2.2 for cellular offices. Meel (2001) hinted that work cultures differed in various countries but no reference to cultures were made in his description of different office concepts and therefore were not necessarily applicable to all countries.

Large workspaces accommodating more than four occupants

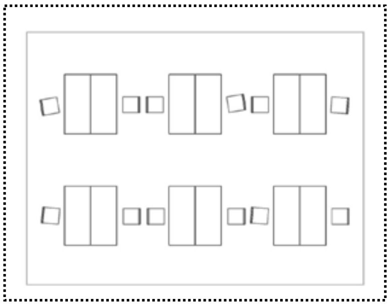


Figure 4.1.0 Open-plan office

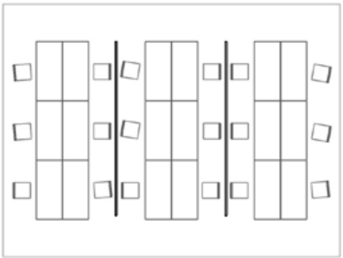


Figure 4.1.2 Team office

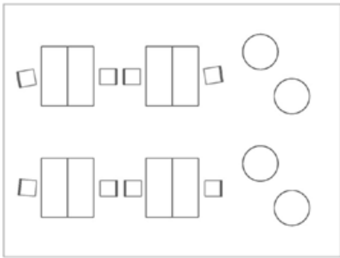


Figure 4.1.4 Flexible office

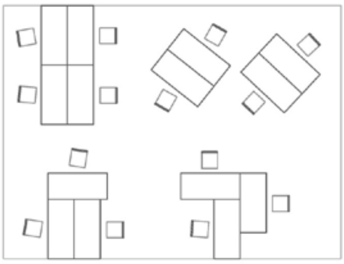


Figure 4.1.1 Landscaped office

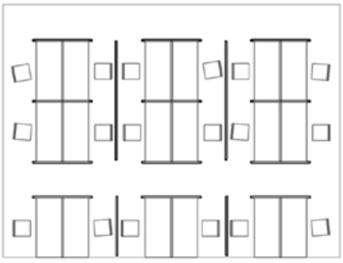


Figure 4.1.3 Office with cubicles

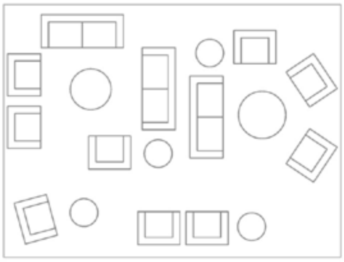


Figure 4.1.5 Work lounge

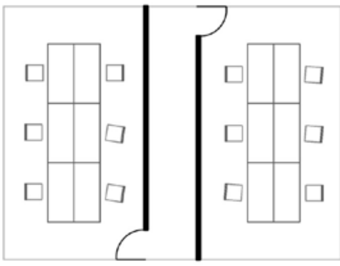


Figure 4.1.6 Team room

Small enclosed workspaces accommodating less than four occupants

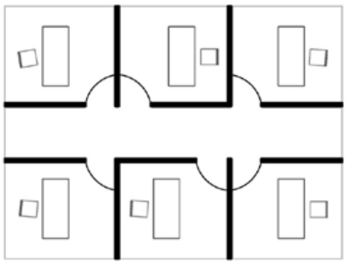


Figure 4.2.0 Cellular office

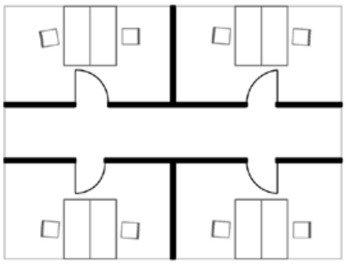


Figure 4.2.1 Shared office

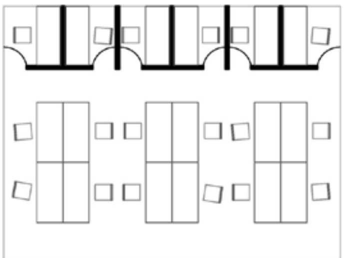


Figure 4.2.2 Study booth

4.3 **Workspace satisfaction in alternate offices**

Past studies have demonstrated that certain office layouts have the ability to generate either positive or negative attitudes in employees towards their work environment. The debate between open-plan and cellular offices is longstanding. As discussed previously in Chapter 3, open-plan workspaces became more popular after 1960s and most studies at that time tended to focus on the unusual open-plan landscaped office layout to determine how efficient it was for businesses. One of these studies was by Brookes & Kaplan (1972) who investigated the impact of open-plan landscaped office layout on the behaviour of employees. The study observed 120 employees who moved from a rectilinear floor plan containing semiprivate, private and open-plan offices to a newly built open-plan landscaped office. The new open-plan office population sample had roughly the same amount of male and female employees and the office status ranged from managerial to clerical posts. Questionnaires were distributed to the employees and interviews were held before announcement of the relocation and nine months after the relocation. The results showed that the open-plan landscaped office was more aesthetically pleasing than cellular offices but the removal of partitions reduced speech privacy that in turn was reported to decrease acoustic satisfaction. It was also observed that men tolerated less conventional and conservative surroundings than women in the study. Noise levels were apparently recorded in the study before and after the change but there was no association made between measured noise level and satisfaction ratings. There was also no visual description of the workspaces that were surveyed.

Brennan et al. (2002) carried out a similar study to that of Brookes & Kaplan (1972) but with a more in-depth analysis of employee perception after relocation to open-plan workspaces to determine the relationship perceived work performance and office type. The study surveyed a group of employees transferring from shared office, cellular office and team space to open-plan offices to evaluate their workplace satisfaction and perceived productivity. A questionnaire survey was carried out with a sample group of 80 employees and a group of 20 employees were interviewed at different stages of the relocation (before relocation, 1 month after relocation and 6 months after relocation). Prior to the relocation, 76% of the participants worked in cellular or shared private offices. After the move, 81% of participants worked in open spaces displayed in

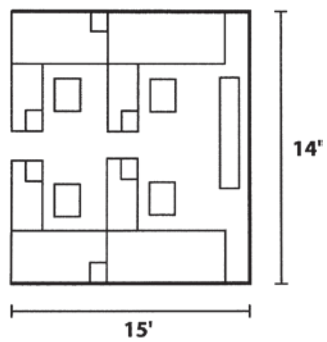


Figure 4.3 open-plan office type occupied by employees after relocation in the study of Brennan et al. (2002)

Figure 4.3. No visual description of cellular workspaces prior to relocation was provided in the study. The results showed that employees were dissatisfied with the new open-plan workspace. This dissatisfaction level remained the same after six months in the new office, which showed that there was no habituation to the physical environment. Contrary to the findings of Brookes & Kaplan (1972) employees were less satisfied with team member relationship which was expected to improve in open-plan offices. No in-depth analysis was carried out to test any association of age, gender and status with dissatisfaction levels. Noise levels were also not considered in the study. The open-plan office described by Brennan et al. (2002) in Figure 4.3 would be considered as a small open-plan if one were to use the occupancy values provided by Danielsson & Bodin (2009) according to whom small open-plan workspaces had higher acoustic satisfaction level than larger open-plan workspaces (more than 24 employees). The layout of open-plan office in the study of Brennan et al (2002) was possibly a source of dissatisfaction with co-worker interpersonal relationship that was not considered in the study – the employees were in close proximity to each other and yet were placed in repetitive rows facing away from each other. Perhaps interpersonal relationship among co-workers would have improved if they were facing each other and were given more opportunities for conversations to take place. According to Wineman (1982), employees facing each other were more likely to engage in conversations than those not facing each other. The study of Brennan et al. (2002), was similar to the aforementioned study in the establishing the relationship between negative employee attitude with open-plan workspaces. However, the study was considered to lack certain depth when relating to the physical workspaces; no further analysis was carried with noise level or reverberation time. In Chapter 2, intermittent and unpredictable noise sources were observed to be the most annoying noise sources. Alternately, the study indicated that the possibility of habituation to noise was almost non-existent which further supports the argument in Chapter 2, Section 2.5, where habituation to noise was not likely to occur in actual workspaces.

Brookes & Kaplan (1972), Brennan & al. (2002) and Danielsson & Bodin (2009) showed that workspace satisfaction and perceived performance decreased when there was a shift from cellular to open-plan workspaces. But interestingly Danielsson & Bodin (2009) observed that not all open-plan workspaces were equally low acoustic satisfaction ratings when seven types of offices were analysed in relation to occupant satisfaction with physical office environment: cellular office, shared room office, small open-plan office, medium open-plan office, large open-plan office, flexible office and combination office. Even if small (4-9 people), medium (10-24 people) and large (more than 24 people) open-plan offices refer to the same office type, it was perceived by the authors that the varying sizes would generate different satisfaction levels. The ambient factors (light, thermal comfort, air quality and noise), privacy and design-related factors (workstation design, workspace design and general office design) were assessed by questionnaires. The results showed that the medium open-plan offices had the highest number of employees dissatisfied with the general physical work environment. 73% of employees in the medium plan offices reported that workspace design was not contributing to job satisfaction and it was considered to be related to high noise and physical work environment. The percentage of employees reporting disturbances by voices and office equipment in each office type was as follows: 12% in cellular office, 40% in small open-plan, 45% in medium open-plan and 50% in large open-plan offices. The percentage of employees who were not satisfied with their physical work environment was as follows: 6% in cellular, 33% in small open-plan, 52% in medium open-plan and 46% in large open-plan spaces. According to Danielsson & Bodin (2009), a possible reason for the high dissatisfaction level with workspace in medium open-plan offices could be that workers were subjected to stronger peer pressure than those in small or large open-plan offices which would lead to greater dissatisfaction with the work environment. Among the three types of open-plan offices, the small offices were found to have the highest satisfaction levels for both acoustic and physical work environment. The study indicated that open-plan offices could be successful provided that they were occupied by a small group of employees. Unlike Brennan et al. (2002), no architectural description of the open-plan layouts investigated in the study was provided. Size in this particular study referred to the number of occupants which was possibly linked to easy accessibility of data - access to floor areas prior to survey are usually not easily obtained. The study was considered to be an initial step in indicating that different office sizes have varying associations with employee satisfaction.

In the study of Block & Stokes (1989), further analysis was carried out to investigate the relationship between workplace dissatisfaction and individual traits in open-plan and cellular offices. The study was laboratory-based and a sample of 169 (86 female, 83 male) subjects was used. Questionnaires were issued to the subjects before the start of the experiment to determine their personality (introvert or extrovert) after which they were given simple and complex clerical tasks for 20 minutes. Another set of questionnaires was re-issued after the completion of tasks to determine job and workspace satisfaction. The cellular office accommodated only one subject and the open-plan office accommodated four subjects with all desks facing one direction. The results showed that there was a general preference to work in the cellular office than in open-plan one. Subjects in the open-plan office were more distracted than those in the cellular ones. The authors expected that introverts (both male and female) would have a greater workspace satisfaction in cellular offices but statistical analysis showed no significant results of this. There was also no correlation between males, male introverts and cellular office satisfaction. No significant analysis was reached for the relationship between sex and privacy levels. The study indicated that gender and personality of individuals did not influence workspace and privacy satisfaction. There was no mention of architectural description of workspace layouts except for the arrangement of desk and chair and no reference to noise levels was made which was considered to isolate the studied variables. Open-plan workspaces with only four occupants could not be considered as crowded in comparison to other open-plan offices with more than 25 employees as in the study of Danielsson & Bodin (2009) and the relationship between individual trait and workspace satisfaction would perhaps differ if carried out in open-plan workspaces with more than 25 individuals. In the study of Brookes & Kaplan (1972), as mentioned at the beginning of this section, women were less tolerant to open-plan workspaces than men in a field study with 120 employees. The study by Block & Stokes (1989) here only made use of open-plan workspaces with 4 occupants within an experimental study and contrasting results were obtained to that of Brookes & Kaplan (1972) which, once more calls into question the external validity of results obtained from experimental studies. The latter observations were also similar to those in Chapter 2 when looking at studies investigating the influence of noise on work performance in both experimental and field studies.

The physical space available to occupants for personalisation was found to influence physical work environment satisfaction regardless of gender (Wells 2000). A study showed that occupants of cellular and shared offices were more satisfied with the possibility of personalising their workspace than employees in large open-plan workspaces (Danielsson & Bodin 2009). It can be expected that touchdown workspaces would have less space for personal belongings but their impact on job and work environment satisfaction is yet to be determined. The open-plan office is often perceived as a reflection of an egalitarian work organisation and promotes a sense of communal belonging (Zalesny & Farace 1987). Zalesny and Farace (1987) carried out a questionnaire survey with 472 employees who transferred from a cellular office layout to open-plan workspaces. No objective measurements were taken because the authors strongly believed that perceived measures had greater influence on individuals than objective ones. After the change from traditional office layout to open-plan, it was observed that clerical employees were more satisfied with the frequency of interaction within the workplace than managerial and professional employees. This indicated that employees within different job categories and different job status had a varying perception of the work environment.

Other spatial parameters were further investigated in relation to employee satisfaction. Frontczak et al. (2012) analysed the relationship between workplace satisfaction and the following indoor environmental parameters: the office layout, thermal comfort, air quality, lighting, acoustic quality, distance to window and gross floor area size. The study made use of existing data from the Centre of Built Environment and analysed responses from 52,980 office occupants. The office types included in the study were; cellular, shared open-plan, cubicle with high partition (above 1.50 m) and cubicle with low partition offices (below 1.50 m). In line with Block & Stokes (1989) and Danielsson & Bodin (2009), the results indicated that there was a higher workspace satisfaction level in cellular offices than in other office types. The second office with high satisfaction rating was the shared open-plan office. The perceived amount of workspace and storage area was also found to greatly influence workspace satisfaction regardless of age, gender and office type. Interestingly, it was observed that correlation between this workspace area satisfaction and calculated gross workspace area occupied by each individual was almost non-existent. The calculated gross workspace area occupied by each individual varied between 8 to 86 m^2 in the survey and was obtained by dividing the overall area of the office by the number of occupants. Similar calculation method was used by Nemecek and Grandjean (1973), but unlike Frontczak et al. (2012), they found that the calculated individual workplace area was associated to reported noise disturbances – occupancy density between 9 to 11m^2 was associated with a decrease in noise disturbances. The British Council for Offices (2009) also used the same methodology to determine the occupancy density within the workplace and recommended a minimum value of 8m^2. However, Frontczak et al. (2012) believed that the weak correlation between perceived workspace area satisfaction and calculated gross area occupied by individuals would have been stronger if the actual areas occupied by individuals were used for the analysis. No further visual description of the workspaces in the study of Frontczak et al. (2012) was provided and it is possible that the study would have yielded different results if occupancy density was analysed in relation to acoustic satisfaction in employees instead of general workspace satisfaction.

The type of office layout was also considered to improve co-worker relations. In Hedge's (1982) study, 55% of the sample group (649 employees) reported that they were disturbed by other staff talking and yet 89% reported that they had a better relationship with colleagues in the open-plan office than in cellular offices. It was also noted in Hedge's (1982) study that socialising went beyond working hours in the open-plan office. De Croon et al. (2010) observed that close distances between co-workers intensified the individual's cognitive workload and desk-sharing in flexible work environments stimulated communications between workers to some extent. However, De Croon et al. (2010) made use of no objective measurements for distances.

Hua et al. (2011) further analysed co-worker collaboration in relation to measured distances in open-plan and cellular offices. Perceived support for collaboration in relation to different types of distances from workspaces was examined in a field study where 27 workspaces with a total of 308 occupants were examined. Questionnaires were distributed to employees and orthogonal measurements for distances between co-workers, distance from workstation to coffee area, distance from workstation to print areas and distance from workstation to meeting rooms were taken. The spatial density was also used in the study of Hua et al. (2011) but the calculation method differed from that of Frontczak et al. (2012) – spatial density in the study of Hua et al. (2011) referred to the number of employees within 25 feet radius (there was no mention of reference point for the radius). Similar to Frontczak et al. (2012) no architectural description was provided for the layout of workspaces. Results from correlation analysis indicated that the increase in co-worker distances and low spatial density (few workers within 25ft) were associated with an increase in perceived facilitation of collaboration in open-plan workspaces. In line with the study of Hua et al. (2011), Zahn (1991) previously observed that less communication among co-workers tended to occur when physical distance among employees increased. The study of either Hua et al. (2011) or Zahn (1991), however, did not make any association between the size of overall workspace area and individual workspace satisfaction or perceived collaboration in either open-plan or private office. The layout of workspace also was not taken into consideration in either study. No further association between spatial parameters and acoustic were made in the study and it was likely that collaboration among employees in open-plan workspaces were influenced by acoustic quality or perception of noise.

4.4 Acoustic quality of offices

Keighley (1970) investigated the level of intermittent noise that was deemed acceptable by occupants in open-plan workspaces. Forty offices with 1902 employees participated in a questionnaire survey and noise levels were measured within the workspaces (Keighley 1970). A new term was coined during the study known as the ‘peak index’ and referred to the average number of times that noise level was above 5 dBA. The results indicated that 68% of employees were satisfied with noise in open-plan workspaces when an average of 50 dBA was associated with a peak index of 44 and peak index tended to decrease below 44 when noise level increased above 50 dBA. The latter results were considered to be indicative of the masking effect of high noise level because less intermittent noise was obtained when noise level increased. Furthermore, the majority of employees described the noise sources to be located within the office space and some of the identified sources were conversations, phone rings and office machines.

In another study by Nemecek & Grandjean (1973), it was observed that 411 employees out of 519 in open-plan offices reported that they were disturbed by noise within the office (Nemecek & Grandjean 1973). The measured average noise level was between 48 to 53 dBA and the identified noise sources were similar to those observed in Keighley’s (1970) study. However, in Nemecek & Grandjean’s (1973) study floor area, heights and occupancy density of workspaces were further investigated in relation to perceived noise disturbances. The results indicated that reported noise disturbances were lower in open-plan workspaces with floor areas between 475 to 1355m^2, room heights between 2.5 and 2.7m and occupancy density between 9 and 11m^2 than in smaller workspaces with floor areas between 252 and 445m^2 and heights between 2.96 and 3.30m. Occupancy density was calculated only for offices with low noise disturbances in the study and similar calculation methods to that of British Council for Offices (2009) and Frontczak et al. (2012) were used in which gross floor area was divided by the number of workspaces. In the study of Nemecek & Grandjean (1973) the relationship between acoustic measures and acoustic perception was not further correlated and no architectural description were provided in relation to layout of workspace. All offices surveyed were treated as one sample regardless of different occupancy levels unlike the study of Danielsson & Bodin (2009). The British Council for Offices (2009) made reference to two types of open-plan workspaces: open-plan spaces in deep-plan building referred to spaces where the distance between external windows on adjacent walls was between 15 to 21m and open-plan spaces in shallow plan building referred to spaces where the distance between external windows on adjacent walls was between 12 to 15m. The British Council for Offices (2009) specified that the height of deep plan offices should be between 2.60 to 2.75 m and that of shallow plan offices should be between 2.60 to 3.00m. The discrepancies in guidelines and suggestions for office dimensions call into question the relationship between workspace size and noise acceptability. Nemecek & Grandjean (1973) also did not investigate reverberation time in relation to reported noise disturbances.

Unlike Keighley (1970) and Nemecek & Grandjean (1973), Kaarlela-Tuomaala et al. (2009) investigated noise levels in both cellular and open-plan office. The study focused on a company of 85 workers who relocated from an old office building with cellular offices to a newly built open-plan office. The employees were asked to complete questionnaires two months before the move and four months after. In addition to questionnaires, sound levels were also recorded at various workstations before and after the move and Speech Transmission Index (STI) were measured. Figure 4.4 was provided in the study to indicate the different layouts before and after the relocation. The questionnaire survey had 31 participants who moved from cellular to open-plan office. The results from the questionnaire showed that there was a decrease in acoustic satisfaction and increased in difficulty in completing mathematical tasks in open-plan office. Voice and laughter were reported as annoying noise sources in both cellular and open-plan offices (Kaarlela-Tuomaala et al. 2009). The cellular offices had an average sound level of 52 dBA and STI of 0.20 when doors were closed and in open-plan offices average sound level was 50 dBA and STI was 0.76. The latter indicated that noise levels were similar in both cellular and open-plan offices but speech was more intelligible in open-plan spaces than in cellular offices where little noise could be heard through walls from surrounding offices. Noise was reportedly more disturbing after relocating to open-plan workspaces. Similar average noise levels in cellular offices to that of open-plan spaces was explained by sound and human behaviour observed during the study – in cellular offices close proximity of walls was considered to amplify noise and occupants of cellular offices had the tendency of speaking in a louder tone than those in open-plan workspaces. In the private office, the occupant allegedly had a greater control over the noise sources located within the room. The aforementioned results indicated that occupants in cellular offices had different behaviour from those in open-plan workspaces therefore the use of using cellular as control in studies looking at acoustics in workspaces was undermined.

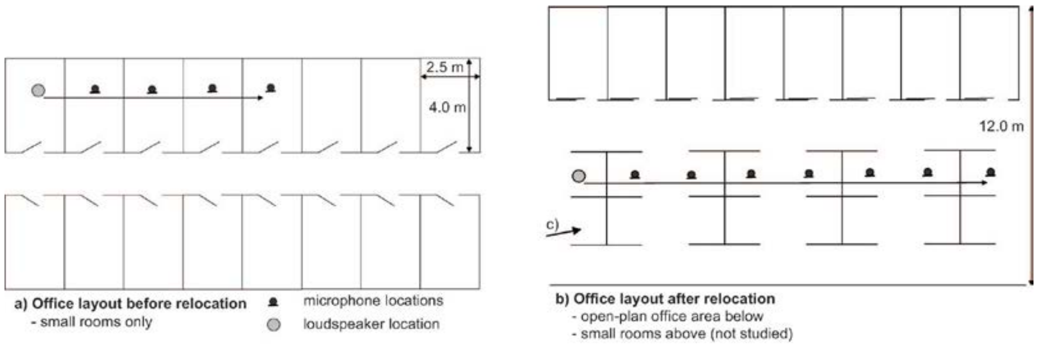


Figure 4.4 Floors plans indicating cellular layout on the left and new open-plan workspace on the right in the study by Kaarlela-Tuomaala (2009)

The acoustic quality of rated sustainable office buildings was also previously investigated. Lee (2010) analysed the noise satisfaction in relation to different LEED (green building certification used in America) office types. The Centre for Built Environment (CBE) database was used to retrieve web-based questionnaire survey responses for five office types: open-plan, enclosed private, enclosed shared, low cubicle and high cubicle for the period between 2002 and 2007. No measured sound levels were used in this study. The results showed that the enclosed private offices had the highest noise level satisfaction ratings. Occupants in enclosed offices were also more satisfied with the ease of interaction between co-workers and it was also observed that cubicle with partitions, whether low or high, did not provide better acoustic satisfaction rating than open-plan offices (Lee 2010).

Speech interference and sound privacy is another common issue within the workplace and varies according to office types. Cellular, shared, cubicle with low partitions, cubicle with high partitions and open-plan offices were surveyed in relation to speech privacy satisfaction and acoustic quality satisfaction (Jensen et al. 2005). The results showed that cellular and shared offices had a higher noise level satisfaction than the other office types. The prominent noise sources in workspaces with cubicles were: phone conversations, overheard private phone conversations and surrounding conversations. Interestingly, it was found that employees in cubicles were more dissatisfied with speech privacy and noise level than open-plan occupants. As an explanation for this, Jensen et al. (2005) suggested that occupants might expect both visual and speech privacy to be proportional. In the same vein, it was also found that office occupants in open-plan offices were more troubled by the fact of being heard and seen than those in cellular, flexible and combination offices (Danielsson & Bodin 2009). This indicates that both open-plan and cubicle offices are flawed when it comes to speech privacy and visual privacy.

However, several attempts are being made to resolve noise issues within open-plan workspaces. Certain regulations and guidelines have been published to provide an indication of how the acoustics of different types of workspaces can be improved. For instance, the British Council for Offices (2009) recommends the following average daily noise level; less than 40 dBA for single occupancy offices and 40 to 50 dBA for multi-occupancy offices. British Standards Institute (1999) recommends different reverberation time according to the volume of workspaces.

The office design market is currently experiencing an increase in the development of more innovative furniture design attempting to improve acoustic privacy in the workplace. Traditional free-standing partitions or desk screens are being re-invented into different forms, such as the study booth. The recent design of the study booth (as mentioned previously in Section 4.2.2) is an example of this and can be described as a small enclosed space where no noise disturbances are likely to occur. In one study it was observed that the study booth was the most used workspace (Meijer et al. 2011). The On Office magazine portrays a good selection of recent furniture designs dealing with acoustics in the workplace including study booths and pods than can be adapted in the open-plan office (Gibson 2012). Newly refurbished and new-built offices tend to embrace trendy concepts of ‘break-out’ spaces which are used for coffee breaks and informal conversation (Meel et al. 2010). ‘Break-out’ spaces are meant to provide an alternative area for office conversations which are believed to be the most disturbing noise sources in the workspace. Meel et al. (2010) provided an illustrative example of how different work spaces could be implemented on one floor (Figure 4.5). However, the influence of these experimental designs on employee acoustic satisfaction and acoustic quality has not yet been determined. It was also to be noted that these new and trendy office concepts are seen in only a few workspaces but have not yet reached the same popularity of cellular or open-plan spaces. It was therefore considered that more investigation was required in the aforementioned types of workspaces.

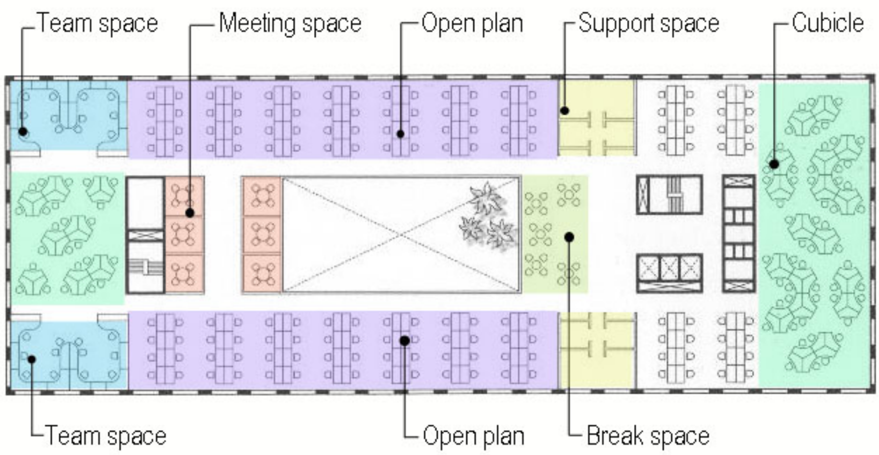


Figure 4.5 Example of different office concepts provided by Meel (2010)

4.5 Evaluation of review

A systematic evaluation of key studies in the literature review of this chapter is carried out in this section to highlight their significance in relation to the research being conducted here, to identify the gap in knowledge and to assist in the development of a methodology for this research. Meta-analysis, which is an aggregation of statistics in similar studies (Egger et al. 1997), was initially considered a useful method of evaluating the studies in this review but given the variety of statistical techniques and variables used, it was not considered appropriate and an alternative was sought. The method of evaluation developed by Slavin (1995) was an alternative to meta-analysis and reviewed research studies based on four principles: 1) refer to studies with similar terminology of variables, 2) refer to studies with reliable statistical analysis methods, 3) results obtained should be both internally and externally valid and 4) explanations should be given for well-design studies that had been omitted in the review. Slavin's (1995) method was further utilised in the review of different office concepts in relation to occupant's health by De Croon (2010) whose study was previously reviewed in this chapter. De Croon (2010) assessed the impact of office concepts on job demands, job resources, short and long-term health reactions. Studies in the review were selected according to the originality of research, office layout used as an independent variable in the study, type of study (field study or laboratory-based) and short/long-term reactions of office occupants as dependent variables. Studies were classified into three criterions (high, medium or low) according to response rate, adequacy of statistical test and quality of study design. A similar method to that of De Croon (2010) and Slavin (1986) was used to synthesise key studies in this chapter and was thought to be ideal given that statistical methods used in all of the studies varied. The studies were categorised according to their; 1) study location, 2) research design approach, 3) the number of participants, 4) the response rate of the study, 5) the independent variables, 6) the dependent variables, 7) and the statistical tests used (see Table 4.0). There were four different types of research designs that were used for office surveys:

a) Cross-sectional field designs (CRO): the study of two different groups of employees in two different work environments.
b) Laboratory designs (LAB): the study of a group of individuals in a simulated office environment in a controlled condition.
c) Prospective field design (PRO): the study of a group of employees before and after a change in the office environment
d) Retrospective field design (RET): the study of a group of employees who are asked to compare the current office environment to a previous one.

The independent variables taken into consideration here were; the office layout types (L) and physical dimensions of the workplace (S). The dependent variables considered here were; the workplace design satisfaction (W), the perceived acoustic satisfaction (A), the perceived job performance, (P) and the acoustic quality (AQ). One point was attributed to each independent and dependent variable present in every study. The total score for each literature classifies the study into high, medium or low quality study as follows:

1) High quality study (HQ) – total score of 5 to 6
2) Medium quality study (MQ) – total score of 3 to 4
3) Low quality study (LQ) – total score of 1 to 2

The key studies and attributed scores are shown in Table 4.0. It was observed that most of the studies were medium quality studies (MQ) and only two studies fulfilled the criteria of high quality studies (HQ). The majority of the studies assessed office layouts together with perceived acoustic quality and workspace satisfaction. Only two relevant studies made use of actual noise measurements. Most studies made use of self-administered questionnaire surveys. According to Oppenheim (1992), self-administered questionnaire surveys ensure an increase in response rate and more accurate sampling than other data collection method such as mail questionnaires or group-administered questionnaires. Perceived noise and job performance were the most commonly assessed dependent variables. Four studies included physical dimensions of the workspace together with perceived acoustic quality. Work performance was mostly rated by employees via self-administered questionnaires. The response rate varied between 26 to 100% and most of the studies were cross-sectional field studies. The low number of studies making use of prospective research design was considered to be related to the difficulty in gaining access to actual business organisations for long periods and the external validity of studies carried out in laboratories possibly explained its unpopularity. This evaluation showed that there is the need for further research to investigate the association between office layout, physical dimensions of workspaces, perceived noise, perceived performance and measured acoustic quality of offices. It was also noticed that most of studies in the evaluation were located in USA while only one study was based in the UK. According to Meel (2001), the working culture between these two countries is different and highlighted that organisations in the UK tend to be more traditional and hierarchical than those in USA which further questions the application of results from American studies to workspaces in UK.

Number	Study	Country	Research Design	No. of Participants	Response Rate (%)	Independent Variable		Dependent Variable				Statistical Test	Total Score	Quality
						L	S	W	A	P	AQ			
1	Brookes & Kaplan (1972)	USA	PRO	120	83.3	✔		✔	✔			Chi-squared	3	MQ
2	Nemecek & Grandjean (1973)	Switzerland	CRO	519	_	✔	✔		✔	✔	✔	Spearman Rank Correlation & Chi-squared	5	HQ
3	Hedge (1982)	UK	RET	896	72.4	✔		✔	✔	✔		Factor Analysis	4	MQ
4	Block & Stockes (1989)	USA	LAB	169	100	✔		✔		✔		MANOVA	3	MQ
5	Brennan et al. (2002)	Canada	PRO	80	26	✔		✔	✔	✔		MANOVA & Bonferroni Alpha	4	MQ
6	Jensen & Arens (2005)	USA	CRO	23450 (CBE)	_	✔			✔	✔		Mann-Whitney U-test & Wilcoxon Ranks	3	MQ
7	Danielsson & Bodin (2009)	Sweden	CRO	491	72.5	✔		✔	✔			Poisson Regression	3	MQ
8	Kaarlela-Tuomaala et al. (2009)	Finland	PRO	69	45	✔		✔	✔	✔	✔	Wilcoxon paired test & Paired samples T-test	5	HQ
9	Lee (2010)	USA	CRO	3533 (CBE)	_	✔	✔		✔	✔		ANOVA F-Tests and Bonferroni Alpha	4	MQ
10	Goins et al. (2010)	USA	CRO	(CBE)	_	✔	✔	✔	✔			Intercooled Stata 9.	4	MQ
11	Frontczak et al. (2012)	USA	CRO	52980 (CBE)	_	✔	✔	✔	✔			Wald Test & Spearman Rank Correlation	4	MQ

Note: CRO = Cross-sectional field design; LAB = Laboratory design; PRO = Prospective field design; RET = Restrospective field design; Independent Variable: L = Layout of the workplace; S = physical dimensions of the workplace; Dependent variable: W = perceived workplace design satisfaction; A = perceived acoustic satisfaction; P = perceived job performance; Total Score = Number of fullfilled quality criteria (1-6); LQ = Low quality study (1-2); MQ = Medium quality study (3-4); HQ = High quality study (5-6); CBE= Center for Built Environment database

Table 4.0 Evaluation of studies focusing on spatial characteristics of the workplace, acoustic measures and perception of noise

4.6 Discussion

In the literature review it was observed that despite the creation of different office concepts, cellular and open-plan workspaces remain the most common office layouts. A wide range of studies have focused on perception of noise and acoustic quality of cellular and open-plan workspaces. Most of the studies indicate that there is a distinct satisfaction rating between cellular and open-plan offices – cellular offices have higher rating of acoustic and work performance satisfaction than open-plan workspaces. Sociability and interpersonal relationship among co-workers increase in open-plan workspaces but perceived disruption due to noise remain higher than that in cellular offices. It was strongly emphasised that office layout was associated with employee satisfaction (acoustic or work performance) but the link between workspace size and acoustic satisfaction requires further investigation because only one type of office was investigated in the study by Nemecek & Grandjean (1973). Several points stood out in the literature review: type of acoustic measures, reference to office size and spatial parameters and cultural influence on office design.

In the evaluation of past research studies it was observed that most studies assessed acoustic satisfaction but not acoustic measures. Two of the studies that made use of acoustic measures were Nemecek & Grandjean (1973) and Kaarlela-Tuomaala et al. (2009). The former study made use of noise level and acoustic satisfaction ratings but did not correlate the two types of data. Kaarlela-Tuomaala et al. (2009) made use of noise level and noise variability and mentioned the associated acoustic satisfaction rating without any correlation method given that only one organisation was surveyed in comparison to Nemecek & Grandjean (1973) who surveyed 15 offices. The evaluation in Section 4.5 also indicated that cross-sectional studies made of use of mostly questionnaire survey to indicate acoustic and work performance satisfaction. It was considered that the issue of access to business organisations possibly limited the collection of both objective and subjective data in the workplace. Further investigation was required in which noise level and reverberation time were investigated in relation to acoustic satisfaction in actual offices.

The review shows that past studies focused mostly on two types of offices: cellular and open-plan. However, the variation in cellular and open-plan floor sizes had not been previously associated with employee satisfaction. Danielsson & Bodin (2009) begin to indicate the difference in open-plan workspaces with varying occupancy for acoustic and workplace satisfaction and interestingly showed that small open-plan offices with less than 10 occupants had higher acoustic satisfaction than those with higher occupancy levels. The latter was considered to be related to good interpersonal relationship among co-workers. BCO (2009) recommends a minimum occupancy density of $8m^2$ while in the study of Frontczak et al. (2012), occupancy density varied between 8 to 86 m^2 for 351 offices which showed that occupancy density was not kept constant throughout different offices. The overall floor plan area was considered to be relevant to employee satisfaction and supported the findings of Nemecek & Grandjean (1973) in which reported noise disturbances varied with the size of floor plan areas. Another discrepancy observed in the study, was the lack of architectural details describing the floor plans. Only few studies made use of floor plans. It was considered that the way in which workspaces were organised also influenced acoustic satisfaction. Wineman (1982) highlighted that face-to-face positions increase interaction among co-workers and Zahn (1991) indicated that employees within close proximity tended to participate in more conversations than those further away. But the overall size of workspace floor areas was considered to influence both the ability to arrange desks in different layouts and individual workspace area. Further studies were required to investigate the association between the area of floor plans and acoustic satisfaction.

It was observed in Chapter 2 that noise perception has the possibility of being influenced by culture. It was considered that office sizes are also similarly influenced by culture; variations tend to occur in proportions of building spaces, architectural concepts, method of work in organisations and local materials used in buildings. The evaluation in Section 4.5 indicated that most of the studies were located in USA and with very few in the UK or in developing countries which indicated the necessity to study the variation in acoustic quality and acoustic perception in different office sizes in both developed and developing countries. More cross-cultural investigations focusing on acoustic in the workplace was required. The following chapter articulates the research questions being addressed in this study based on the gaps identified in the literature review and discusses the methodology being used in this research to address these questions.

Chapter 5

Research questions & methodology

5.1 Introduction

This chapter describes the methodology used in this study to investigate the relationship between office design, acoustic measures and employee satisfaction which, as highlighted in Chapters 2 and 4, is elusive. A cross-sectional quantitative research was designed to investigate the relationship between workspace floor area, acoustic measures and employee satisfaction in cellular and open-plan workspaces in Glasgow and Mauritius. The intention of this research was to provide sufficient knowledge to the field of building acoustics and help enhance acoustics and employee satisfaction in the workplace. The use of samples in two different countries was considered to provide more indication of the perception of noise and variety in the design of workspaces in different cultures.

At the beginning of the field study it was hypothesised that the size of workspace, acoustic measures and employee satisfaction ratings for acoustic and work performance were all interrelated. To test the hypothesis in several workspaces, a cross-sectional research framework was applied to the study to investigate the aforementioned hypothesis in cellular and open-plan workspaces. Given that open-plan workspaces had varying occupancy, three sub-categories of open-plan workspaces were used in the study; WLO1 – less than 10 occupants, WLO2 - between 10 and 25 occupants and WLO3 - more than 25 employees.

Two kinds of data were analysed within this research: subjective and objective. Subjective data was collected by self-administered questionnaires in which satisfaction ratings of acoustic, work performance and workspace in offices were evaluated. The definition of ‘satisfaction’ in environmental research was previously referred to as a positively aroused state caused by a specific stimulus (Warr et al. 1979; Bechtel 1987; Cabanac 2000). However, this research investigated the appropriateness of specific stimuli in the office environment. Therefore, ‘satisfaction’ was referred to as the degree to which an individual believed that the experienced state caused by a certain stimulus was appropriate. Objective data consisted of dimensions of workspaces that were obtained from drawings or measured on-site and noise levels measured by sound level meters. The association between subjective and objective data was considered to provide more knowledge of the performance of physical workspace environment and its perception. Adjustments to the methods used were carried out based on observations from a pilot study. The chapter begins with the articulation of research questions and hypotheses in Section 5.2 followed by description of the research design and sampling methods.

5.2 Research questions and hypotheses

In Chapter 2, it was observed that most of the key studies were laboratory-based which questioned the external validity of the results. In both Chapter 2 and 4 it was also noticed that the most common acoustic measure used when investigating the perception of noise and work performance was intensity of noise. A few other studies, such as that of Jones & al. (1992) and Mershon & al. (1989) made use of reverberation time when analysing work performance and perceived distance of noise sources. However, studies investigating both noise level and reverberation time in varying sizes of workspaces in relation to employee satisfaction were scant in the literature review. According to Perham et al. (2007) the increase in reverberation time increases the perceived intensity of noise. Based on the latter, it could therefore be argued that increase in both noise level and reverberation time is likely to be associated with a decrease in employee satisfaction. Furthermore, acoustic satisfaction ratings were reportedly dependent on the size of open-plan workspaces in the study by Danielsson & Bodin (2009). It was also noted in Chapter 2 that acoustic satisfaction and work performance satisfaction were not related in the study of Sundstrom et al. (1994) but in the study of Banbury & Berry (1998) measured work performance decreased when office noise was present in audio recordings which indicates some contradiction among studies for the relationship between acoustic and work performance satisfaction ratings. In this study, office size was analysed in relation to two acoustic measures, noise level and reverberation time and to two indicators of employee satisfaction – acoustic and work performance satisfaction. As mentioned in Chapter 2, there was also an interest in investigating the noise perception in different cultures and therefore identical investigation was carried out in two locations – Glasgow and Mauritius. The following research questions were articulated and addressed in this study:

1. *Are differences in the size of workspaces associated with variations in acoustic measures and employee satisfaction in cellular and open-plan offices?*
2. *In contrasting countries, is the relationship between workspace floor area, acoustic measures and employee satisfaction similar?*

Initially, it was hypothesised that in both cellular and open-plan workspaces the increase in the size of workspace will be associated with a decrease in at least one of the indicators of acoustic measures (noise level and reverberation time) and a decrease in employee satisfaction ratings (acoustic and work performance satisfaction). Figure 5.0 indicates the hypothesised association between the variables in this study. For samples in a contrasting country like Mauritius, it is expected that the relationship between the size of workspace, acoustic measures and employee satisfaction would be different because it is assumed that habituation would occur to perceived high noise level present in both cellular and open-plan spaces because of the lack of acoustic treatment present in most offices. In Chapter 4, it was observed that different sizes of open-plan existed and, as mentioned above, they were also linked to varying employee satisfaction levels. Three sub-categories of open-plan offices were used in this study: open-plan with less than 10 occupants (WLO1), open-plan with occupancy between 10 and 25 (WLO2) and open-plan with more than 25 employees (WLO3). The hypotheses were further refined based on observations made during the survey and are further discussed in Chapter 6, 7 and 8.

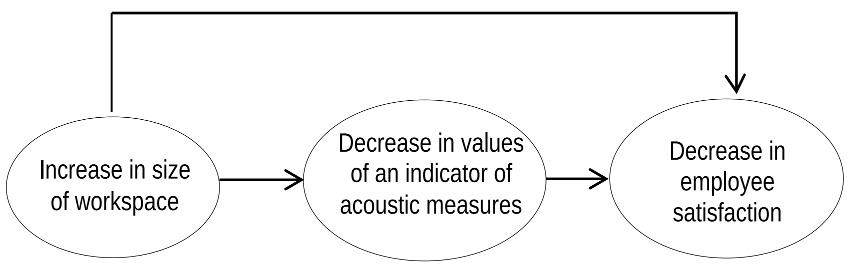


Figure 5.0 Hypothesised links between variables being investigated in this study for both cellular and open-plan workspaces

5.3 Research Design

A quantitative approach was deployed in this research in an attempt to provide robust evidence on the relationship between the indoor work environment and the perception of employees. A cross-sectional research design was thought to be appropriate given that it allowed the survey of several cases studies in parallel and had greater external validity than longitudinal or experimental research design (Bryman 2004). Cross-sectional field studies also offered the possibility of surveying a large sample size within a limited amount of time. It was previously argued that in the study of human behaviour in the built environment, longitudinal field studies provided more valuable information than cross-sectional or experimental research studies but the use of a limited specific sample was also argued to weaken the external validity of these types of studies (Bechtel 1987; Bryman 2004). It is considered that the artificial settings in experimental research designs and the absence of environmental factors present in real-life situations undermine the results obtained in these studies. The research process framework that was used throughout this study is illustrated in Figure 5.1. The data collected from the case studies are discussed in Chapters 6, 7 and 8.

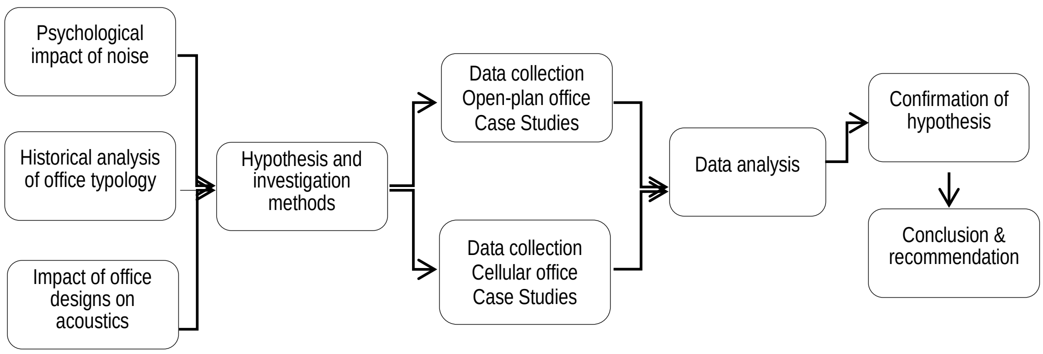


Figure 5.1 Framework for the research process applied in this study

5.4 Research Sample

The criteria according to which offices in both Glasgow and Mauritius selected were based on the type of office layout type (cellular or open-plan) and office occupancy. The offices were divided into four different categories according to the office layout type and occupancy within the workspace (see Table 5.0). The offices selected for case studies were also to be located within the urban context of Glasgow city so that there was similar external noise level in each case study. The same criteria were applied to the selection of offices in Mauritius.

	Workspace			
Office type	**Cellular - WLC**	**Open-plan - WLO1**	**Open-plan - WLO2**	**Open-plan - WLO3**
No. of occupants	1-3	Less than 10	Between 10 & 25	More than 25

Table 5.0 Selection criteria for offices in this study

Scottish Assessors Association (2013) indicated that 7,438 offices (including banks) were located in Glasgow City but provided no further details of the area of workspaces, occupancy or layout types. Office for National Statistics (2011) reported that Glasgow City contained 225,100 employees of which 86,700 were located in professional and service sectors and were considered to be located in offices. Jobs in the professional sector were more knowledge-based and was considerably supported by the use of computers (Powell & Snellman 2004). Almost every employee in offices had access to computers to perform certain, if not all, tasks. In this research, businesses in which work was mostly computer-based were being used as case studies. Call centres were excluded from this study on the basis that the nature of work required employees to deal with high noise levels from headsets and the average background noise level was slightly higher than those in other types of offices as highlighted by Patel & Broughton (2002) and Taylor et al. (2003). According to the official Mauritian statistics, there was an estimated total of 88,200 employees in the financial, real estate and business and public administration activities throughout the entire country (Central Statistics Office 2012). Breakdown of the number of employees within these aforementioned areas was not readily available. Business organisations within the aforementioned categories were contacted for participation in the study.

As mentioned above, information about the area of workspace, occupancy and layout were not accessible at first hand from business organisations. The Scottish Assessors Association (2011) provided data about the rateable area of buildings and their tenants. A rough estimate of occupancy of organisations was obtained by dividing the rateable area figure by the value of $8m^2$ which is the minimum occupancy density suggested by the British Council for Offices (2009). A random list of possible offices fitting the four office categories (WLC, WLO1, etc.) was done by the aforementioned process. Layout of office type was only affirmed once participation of organisation was confirmed and office visit was carried out. Invitations for survey participation were sent by post and e-mail with an attached information leaflet (see Appendix C) describing the survey procedure in Glasgow. Some offices were also contacted by phone. The mode that yielded the highest response rate was postal invitations in Glasgow. Even though e-mails were considered as an efficient mode of communication, it was possible that survey e-mails were regarded as ‘junk mail’ or were not considered of high importance which led to a weak response rate. Companies that were contacted replied by either phone or e-mail to show their interest in the study and confirmed their participation in Glasgow. Once offices confirmed their participation in the survey, the most recent floor plans of the respective offices were retrieved from the Mitchell Archives or Glasgow City Council to gain some notion of the workspace and to obtained dimensions of the workspaces. The actual number of occupants was only confirmed once offices accepted to participate in the survey. The response time-frame for each invitation sent out was 1 to 4 weeks. Altogether 62 invitation letters and e-mails to each organisation were sent in Glasgow and 16 organisations participated in the study.

In Mauritius, fewer steps than in Glasgow were taken when selecting offices given that there was a greater established network of connections within organisations. Verbal descriptions of office layouts and occupancies were obtained via personal contacts. Managers or directors within offices that were thought to be appropriate were contacted by phone and e-mail to provide a brief description of the research and to confirm dates for the survey. Similar to Glasgow, visits to the office premise were arranged prior the survey to ensure that the occupancy figures and layout were as described initially.

Numerous researches have debated on what qualified as an acceptable response rate. According to Baruch and Holtom (2008), the acceptable response rate for surveys carried out in organisations was between 35 to 40%. Mangione (1995), on the other hand, argued that response rates below 50% are not acceptable. In this research, a response rate above 35% was considered to be acceptable given that access to organisations was restricted. Research studies generally make use of samples with 30 cases (Cohen et al. 2013) and in this study samples with a minimum of 30 cases were targeted in both Glasgow and Mauritius. A period of 11 months was dedicated to the survey of offices in Glasgow and 1 month in Mauritius. The final sample consisted of 30 in WLC, 33 in WLO1, 34 in WLO2 and 86 in WLO3 for Glasgow. In Mauritius, due to limited time for survey period, a smaller sample than that in Glasgow was obtained: 21 in WLC, 30 in WLO1, 37 in WLO2 and 24 in WLO3. Response rates to questionnaire surveys were above 35% in both Glasgow and Mauritius offices.

5.5 **Pilot Study: West of Scotland Science Park**

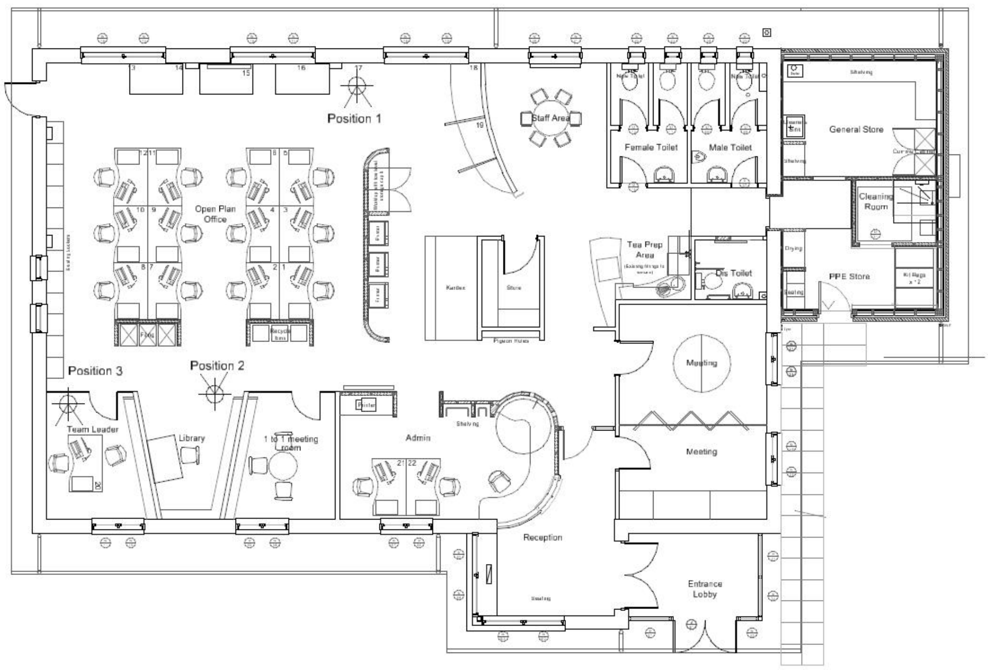


Figure 5.2 Ground floor plan of office surveyed in pilot study with 'Position 1,2 & 3' as the location of the sound level meter (courtesy of HAA Design)

A pilot study was carried out in a West of Scotland Science Park office to test the adequacy of methods for data collection used in the survey. The office had an open-plan space with 15 occupants and 1 occupied cellular office (see Figure 5.2). The single-storey office was located on the ground floor and benefitted from both artificial and natural light. The floor within the workspace area had a carpet finish and the suspended ceiling was lined with acoustic cork tiles. Conventional radiators were used to heat the space during winter periods and natural ventilation was used during summertime. The office was visited two days before the survey to confirm the number of occupants, to view the office layout and to identify possible locations of the instruments being used for data collection. One of the administrative members was designated as point of contact (POC).

5.5.1 *Data collection methods*

As mentioned above, this research focused on both subjective and objective data. A self-completed questionnaire and structured interviews were thought appropriate to collect subjective data (Bechtel et al. 1987). Objective data were to be collected by the use of the following apparatus; a sound level meter and tape measure (or floor plan drawings). Self-completed web questionnaires with only close-ended questions were used to gather individual perspectives on the following key areas: acoustic satisfaction, work performance satisfaction and workspace satisfaction.

The use of web self-completed questionnaires was thought to be more practical than paper questionnaires; it was cost-effective, had short completion time and data could easily be uploaded in statistical software. The web survey tool, Survey Monkey was used to produce the questionnaires. Each questionnaire had 20 close-ended questions with answers in a vertical format. Questions in the survey were adapted from literature review and in instances where more information was required, further questions were articulated by the author. Pre-existing questions were considered to be suitable indicators in previous studies, such as that of Keighley (1970), Nemecek & Grandjean (1973) and Sundstrom et al. (1994) when assessing acoustic in the workplace because they had previously yielded precise answers in the related field of enquiry. It is considered that the use of pre-existing questions also increases the amount of data in the inquiry of the specific area of acoustic satisfaction in the workplace. This enables future comparison of data from different locations and also provides researchers with the possibility to analyse how perceived noise satisfaction varies with time when comparing with pre-existing data. The following variables were initially evaluated in the questionnaire: acoustic satisfaction, work performance satisfaction and workspace satisfaction which were considered to be interrelated. Questions dealing with satisfaction and attitude of employees were attributed a Likert-type scale with 5 points; very unsatisfactory - very satisfactory; very inadequate – very adequate; strongly disagree – strongly disagree. A five-point ordinal scale was thought to provide sufficient degrees of satisfaction to express participants' attitude and feelings. Certain questions regarding personal description or certain aspects of the workplace had categorical answer groups, such as, age group; 18 to 29, 30 to 39, 40 to 49 and 50 or above. When evaluating acoustic satisfaction, it was intended here to obtain a general rating of acoustic satisfaction at the individual's workspace, to identify the main noise source in the workspaces and the level of perceived disturbance associated with the noise source. Questions were adapted from the surveys previously carried out by Keighley (1970) and Sundstrom et al.(1994) and were as follows:

- How would you rate the background noise of the office?
- What do you think is the most annoying noise source in the office?

And to determine exposure to noise source and its effect on individuals the following questions were composed which were not found in the literature review:

- How many times in the past month have you been absent because of noise in the office?
- On average, how many hours do you spend at your desk?

Similar to the above, when assessing work performance satisfaction questions were adapted from the studies of Nemecek & Grandjean (1973) as follows:

- Would you have a better concentration level if you worked in a private office?
- How often does the noise make it difficult for you to complete your daily tasks?

To further understand if perceived work productivity is related to noise the following questions were asked:

- What time of the day do you feel more productive?
- Does noise have anything to do with it?

In addition to acoustic and work performance satisfaction, workspace satisfaction was also rated because as shown by Sundstrom et al. (1994), workspace satisfaction was related to acoustic satisfaction. The following questions were adapted from the studies of Frontczak et al.(2012) and Lee (2010):

- How would you rate the appearance of the office?
- How spacious is your workspace?
- How would you rate the distance between you and your co-workers?

To further determine if participants associated their perception of noise to the layout of workspaces the following questions were asked:

- How would you rate the general layout of the office in terms of functional performance?
- How would you rate the general layout of the office in terms of acoustical performance?

The possibility of carrying out structured interviews with a few employees was discussed with the person of contact who rejected it.

For objective measures, a calibrated CEM DT- 8851/8852 sound level meter with measuring range between 30 and 130 dB was used to record data in decibels (dB) with A-weighting and accuracy of ±1.4 dB over a period of 7 hours. The meter was placed on a tripod of 1.2m high (which was the average sitting height of individuals) at an angle of 90 degrees to noise source at locations marked 'Position 1, 2 and 3' on the floor plan (Figure 5.2). The most apparent noise source in the office was voices from colleagues. The meter was placed along the office perimeter at 90 degrees to the pool of desks (as shown in Figure 5.2). The sound level meter had a data logger with the capacity to store 32700 readings and stored data every second. It was assumed that the meter would have sufficient battery life and storage capacity to store data for more than 7 hours. The area of the office space and individual desks were measured by a tape measure and for distances out of reach, a Ryobi SW104AA5L ultrasonic tape measure was used which had an accuracy of ±0.05m.

The survey was carried out on three separate days. It was initially thought that three days of recorded data would provide an average of how background noise varied in case of apparatus malfunction. The apparatus was set up in the morning after 9am at the different positions on each day (Positions 1, 2 and 3 marked on Figure 5.2) and re-collected after 4.30 pm as requested by the POC. A link to the web survey was created and sent to the POC who was in charge of e-mailing the link to all staff. The questionnaire responses were downloaded after the survey period.

5.5.3 *Observations from pilot study*

The web self-completed questionnaire survey had a very poor response rate. Only 4 participants out of 15 (a response rate of 26.6%) took the time to complete the survey. The link was e-mailed once more on another occasion by the POC but no further responses were obtained. The use of web-survey was considered to be weak and other survey methods were sought. Given the low response rate, it was not feasible to carry out any statistical analysis on the questionnaire responses.

The data collected from the sound level meter was downloaded via a specific computer program (Sound Level Meter) in a text format. The data was then tabulated in Microsoft Excel where the variation in noise level was analysed. The ultrasonic tape measure was used to measure long distances within the workspace. It was observed that the tape measure provided inaccurate readings when it was pointed towards uneven or soft materials; only plain hard surfaces provided accurate readings.

5.5.4 *Alterations to methodology*

The pilot study was successful in highlighting certain unforeseen issues with the methods. The use of web survey questionnaires were considered to be unsuccessful despite the practical advantages it offered and the use of self-administered paper questionnaires was being sought. It had been previously argued that web surveys had a low response rate in comparison to paper and drop-in interviews (Baruch & Holtom 2008; Sax et al. 2003). Responses from web surveys tended to be dependent on the frequency that employees checked their email and on the amount of time they could dedicate to answering all questions. Possible reasons for low response rates from web surveys were the depreciation of excessive web survey links sent by emails and the fear of revealing answers and personal identity online (Sax et al. 2003). Paper surveys were very straight forward and had a greater possibility of increasing response rate than web-survey. The refusal of carrying out interviews indicated that collection of subjective data would be done through self-administered questionnaires solely in this study and more refined questions were added to provide more indicators on acoustic satisfaction, work performance satisfaction and workspace satisfaction that could be later cross-checked during analysis. The new set of questionnaire had 38 questions (see Appendix C.4). As mentioned above, the initial set of questions evaluated the following variables: acoustic satisfaction, work performance satisfaction and workspace satisfaction. Further questions were added for acoustic satisfaction and work performance which were considered to be insufficient. Questions used in the study of Frontczak et al.(2012) were adapted for acoustic. Further questions were articulated by the author to evaluate work performance satisfaction and another new variable - environmental satisfaction - was also included. The added questions for each variable was as follows:

Acoustic:

- How often can you hear the entire conversation contents of other work colleagues when you are at your desk?
- How would you rate the communication level between you and your co-workers?
- How often do you have to raise your voice when speaking to the colleague close to you?

Work performance:

- Do you think that noise has the ability to affect work performance?

- How often can you stay focused on work when you are at your desk?
- How often does the noise in the office disturb you when you are working?
- How distracted are by other's conversations in the office?

To determine the importance of acoustic quality in relation to other variables in the office environment, similar to the study of Keighley (1970), participants were also asked to rate their satisfaction with air quality and workspace temperature. They were also asked to state how often they opened windows at their workspace (which was considered to be related to noise ingress in workspaces). Respondents were instructed to complete the entire questionnaire by ticking an answer for each question and to leave the completed questionnaire in the survey box provided.

Recent floor plans of some offices were obtained after the survey period from the architects who designed the office space. Prior to survey periods, previously issued floor plans were retrieved from the Mitchell Archives or from the Glasgow City Council with special permission from the relevant architects to provide some notion of the office space. It was observed that the use and layout of the office did not always correspond to those on the up-to-date and previous architectural plans. Therefore, the use of space and the layout had to be measured by ultrasonic tape measure and traditional tape measure (where necessary) and the plans had to be revised accordingly to provide more precise information about the office layout and use. In the case where no plans were obtained, the office space was measured and drawn. During the visit of each office, a profile sheet containing necessary background information on the offices during obtained during the office visits was designed (Appendix C). This included information about the number of occupants, ventilation system, ceiling and floor finish, the location of office machines, glazing and lighting about the workspace. The apparent noise sources from personal observation were also sketched on the floor plans of each workspace. Occupancy density was obtained by dividing the gross floor area value of workspace by the number of workspaces which was similar to the method used by the British Council of Offices (2009). The ratio of glazing-to-floor area was also included because it was observed that amount of glazing varied considerably in difference offices.

In relation to acoustic measures, noise level measured throughout a 7-hour period was considered to be adequate for further calculations and analysis. Reverberation time was calculated by using Sabine's formula (Furrer 1964) $R = \frac{0.16V}{A}$, where V is the volume of room and A is total absorption of surface areas and R is the reverberation time. To further demonstrate the association between gross floor area and acoustic measures, each workspace in the survey was rated on a scale of 1 to 5 based on acoustic measures and the number of noise sources present in the office. A visual scale was provided for each office category to indicate how workspaces differed from each other. More details of the office ratings are provided in Chapter 6 and Chapter 8.

5.6 Data Analysis

As mentioned above in Section 5.5, data from pilot study could not be analysed due to very low response rate. For all samples surveyed in field study, the data collected from instruments and questionnaires were coded in the statistical tool, Statistical Package for Social Sciences (SPSS) which was used to analyse the data collected. The choice for the use of SPSS was based on the advantages it offered in comparison to other programs, such as Excel; it allowed more data entry and easier data manipulation than other programs.

The survey contained nominal, ordinal and continuous data. The five point Likert-type attitude and satisfaction scales in the questionnaires were coded with values from 1 to 5; ‘1’being ‘very unsatisfactory’ and ‘5’ being ‘very satisfactory’. Questions with nominal answers were coded in an ascending order from 1. Questions with categorical answers, such as age group, are coded in ascending orders starting from 1. Both questionnaire answers and measurements were coded and inserted in SPSS (version 21). Given the small sample size in each office category, the 5-point scale for all variables was further collapsed into 3-point scale which was more apt for in-depth analysis. The 5-point attitude and satisfaction scale (1 for very unsatisfied to 5 for very satisfied) was collapsed and re-coded into three categories (1 for unsatisfied to 3 for satisfied). The missing data were coded as 9, 999 or 9999 and were excluded during the analysis. The values attributed to each answer in the questionnaire and to objective data are shown in the codebook in Appendix C.5.

Each respondent to the questionnaire survey was considered as a case in the dataset. Previous studies dealing with objective and subjective data correlated single average figures of noise level to average acoustic satisfaction rating of a workspace (Mahdavi 2005, Farina 2000). The aforementioned method was not considered to be reflective of the acoustic atmosphere and an alternative method was sought. In other studies, a case-oriented approach instead of a variable-oriented one where subjective ratings for each individual case is analysed in relation to objective values. Examples of this in the literature review is that of Perham et al. (2007) where acoustic satisfactions ratings of 42 individuals were analysed in relation to two spaces with different reverberation times (0.70s and 0.97s) (Chapter 2 Section 2.3). Another example of individual case analysis in the literature review (Chapter 4 Section 4.3) is that of Hua et al. (2011) where ratings of perceived support for collaboration in the workplace was correlated with work spatial characteristics, such as workspace area. The method of analysis in these aforementioned studies were considered to be similar to the ones used in randomized clinical trials in the field of medicine where behaviour or physiological improvements of individual patients are correlated with the presence of specific medication being tested. Selvin (2001) provides an example of this in which Alzheimer patients are tested for a decrease in cognitive loss in conditions when they were induced with a specific drug in comparison to conditions without the drug.

The study here aims to shed light on the associations between subjective and objective variables, a case-oriented approach where the number of cases are being used is considered to be more revealing in statistical analysis than variable-oriented approach where number of offices are being used mostly because more in-depth association between variables can be investigated. Using N=number of offices in statistical analysis was considered to yield vague and possibly erroneous results without further indicating possible relationships between objective variables and employee satisfaction ratings. It was also considered that by using N=number of cases, the results would be more representative of the sample where variations in individual satisfaction ratings were being used rather than in analysis using N=number of offices where aggregates of satisfaction ratings are used. In this study, office type was treated as a categorical variable within which employee satisfaction were analysed in relation to objective measures. Given that dosimeters on each employee were not used in this study, values from the noise level data collected throughout a day were randomly attributed to each individual case.

The analysis in this study was concerned with associations between subjective and objective variables and included three different stages of analysis; 1) univariates, 2) bivariates and 3) bivariates in special subgroups. Univariate analysis consisted of using frequency and median to indicate central tendency of the three primary variables – workspace floor area, acoustic measures and employee satisfaction. Kruskal-Wallis test was used to indicate any difference between the four office types for the variables (workspace floor area, acoustic measures and individual satisfaction). According to

Leys et al. (2013), absolute deviation from median was observed to be more appropriate for small sample sizes than the use of standard deviation around mean – use of mean assumed that distribution of sample was normal which also included outlier while median did not assume that distribution was normal and was more appropriate for detection of outliers in small samples than mean. In this study, median absolute deviation was used and values out-with 2 absolute deviations from the median value were considered as outliers for 95% confidence interval. Samples with outliers were tested for correlation with and without outliers and if difference in correlation values occurred then outliers were excluded from sample in further analysis. At the bivariate analysis stage, main variables (workspace floor area, acoustic measures & individual satisfaction) were tested for associations with non-parametric tests; Spearman's Rho. Non-parametric tests were chosen in this study because the data contained ordinal and nominal data and the distribution in the sample was not considered to be normal. Significance value (*p-value*) below 0.05 obtained during correlation analysis was considered to be indicative of strong association between variables being analysed and was based on the significance criterion discussed by Cohen (1988; 1990). Sub-groups with high and low satisfaction ratings were further analysed in relation to workspace floor area and acoustic measures and other measured variables, such as occupancy density, to shed further light on the correlations obtained during bivariate analysis.

The hypothesis tested was confirmed when associations existed between workspace floor area, an acoustic measure and a satisfaction variable in the same way that was predicted for the relevant office type. It was intended in this research to provide some index reflecting acoustic and employee satisfaction in this study that could be used during the design process of workspaces. In the analysis of sub-groups, values for workspace floor area and acoustic measures associated with employee satisfaction ratings were provided. Throughout the analysis possible associations with other variables were also taken into consideration, such as the shape of floor plans and employee satisfaction which were further investigated. It was considered that the shape of floor plans and shape formed by the noise perceived on the plan were both related to employee satisfaction. Shape factors, such as area and elongation, were used to further describe the shape of floor plans. Elongation was calculated by dividing the area of the bounding box formed around the shape by the square length. Further details of this shape descriptor are provided in Chapter 7. In Chapter 9, a comparative analysis was performed between Glasgow and Mauritius to indicate, if any, differences in office sizes, acoustic quality and employee satisfaction. Kruskal-Wallis was the main test used for the comparative analysis.

5.7 Summary

A cross-sectional research design was used to investigate the relationship between workspace floor area, acoustic measures and employee satisfaction in cellular offices and open-plan workspaces with different occupancies. In addition to different office categories, cultural difference was also taken into consideration and the investigation was carried in two contrasting locations Glasgow and Mauritius. It was intended in this study to obtain some indication of office size that would reflect employee satisfaction associated with acoustic measures for both locations and that could be used in the design of offices. The research questions were articulated as follows:

1. *Are differences in the size of workspaces associated with variations in acoustic measures and employee satisfaction in cellular and open-plan offices?*
2. *In contrasting countries, is the relationship between workspace floor area, acoustic measures and employee satisfaction similar?*

Business organisations in Glasgow were contacted by email, phone and letter inviting them to participate in the study. Letters yielded higher response rates than email or phone and 16 organisations with a total of 183 employees were obtained in the sample. Four office types were investigated in the study in both countries: cellular office (WLC), open-plan office with less than 10 occupants (WLO1), open-plan office with occupancy between 10 and 25 (WLO2) and open-plan office with more than 25 occupants (WLO3). The type of layout and occupancy of organisations were confirmed once participation in the study was affirmed. In Mauritius, organisations were contacted by phone and email only and total of 12 organisations with 101 employees were obtained.

A pilot study was carried out to test the survey methods and instruments in Glasgow. Initial instruments consisted of web survey questionnaire, sound level meter and ultrasonic tape measure. Web survey yielded very low response rate and instead was substituted for self-administered paper questionnaires. Given that the possibility of carrying out structured interviews was erased, more indicators were added to questionnaires. Traditional tape measure was also used where ultrasonic tape measure did not function properly.

Data collected were coded in SPSS program which was used for the analysis of subjective and objective variables. The analysis process of data consisted of three stages; univariate, bivariate and bivariate of sub-groups. Univariate analysis consisted of median values frequency distribution of primary variables. Non-parametric tests were used for bivariate analysis of primary variables; Spearman’s Rho and Kruskal-Wallis. Chapter 6,7 and 8 presents the results obtained during analysis of variables for both countries.

Chapter 6

Glasgow Case Study 1: Analysis of spatial settings & employee behaviour

6.1 Introduction

This chapter presents the results for the analysis of Glasgow sample in the study of the relationship between workspace floor area, acoustic measures and employee satisfaction. Floor areas of offices vary greatly and it is generally known that the increase in workspace floor area is linked with an increase in occupancy and in office activities possibly leading to more noise disturbances. The increase in workspace floor area also leads to an increase in workspace volume which is directly proportional to reverberation. It was expected that there would be some associations between workspace floor areas, acoustic measures and employee satisfaction. The aim of the study was to provide some indication of workspace spatial setting that is related to acoustic measures and employee satisfaction and could be used in the design of workspaces.

Two common types of workspaces were investigated in the study: cellular (WLC) and open-plan offices. The latter office type was divided into further three sub-categories: open-plan office with less than 10 occupants (WLO1), open-plan office with occupancy between 10 and 25 (WLO2) and open-plan office with more than 25 employees (WLO3). Both subjective and objective data were collected in each office type. Subjective data consisted of ratings of acoustic satisfaction and work performance satisfaction and objective data consisted of sound level and workspace dimensions. Two hypotheses were articulated and tested in the study: 1) in cellular workspaces the increase in workspace floor area would be associated with improved acoustic measures and an increase in both acoustic and work performance satisfaction and 2) in open-plan workspaces it was hypothesised that the increase in workspace floor area would be associated with deterioration in acoustic measures and decrease in acoustic and work performance satisfaction.

The findings indicated that cellular workspaces had the highest rating of acoustic and work performance satisfaction in comparison to open-plan workspaces. Among the three open-plan categories, open-plan offices with less than 10 occupants had the highest acoustic satisfaction rating. Different associations between subjective and objective variables were observed in each office type and results from only one open-plan office type supported the hypothesis. Section 6.2 provides further description of the sample and data collected and Section 6.3 looks at the research question and the refinement of hypotheses. The results for each office type are presented in Section 6.4.

6.2 Field study observations

A cross-sectional research design was used to investigate the relationship between workspace floor areas, acoustic measures and employee satisfaction in Glasgow. A cluster sampling method based on office types was used during the study which resulted in the survey of 310 employees in Glasgow over a period of eleven months. As mentioned in Chapter 5, four types of workspaces were surveyed in this research and the selection criteria were based on occupancy (as shown in Figure 6.1). The number of workspaces surveyed was as follows: 22 in WLC, 8 in WLO1, 3 in WLO2 and 4 in WLO3. The locations of workspaces surveyed in Glasgow are shown in Appendix D.1. Throughout the field study, certain observations between occupants and their physical environment transpired which also reflected in the collected data. Prior to the field study it was hypothesised that the increase in the size of workspace would be associated with a decrease in at least one indicator of acoustic measures and a decrease in employee satisfaction because occupancy is likely to increase with increase in workspace size which in turn would lead to more noise disturbances and to the increase in reverberation time because the latter was directly proportional to the size of space. Indicators of acoustic measures initially included noise level and reverberation time. However, the observations made during the field studies led to the refinement of the research hypotheses. The observations and adjustments to the hypotheses are highlighted in the Sections 6.2.3, 6.2.4 and 6.2.5.

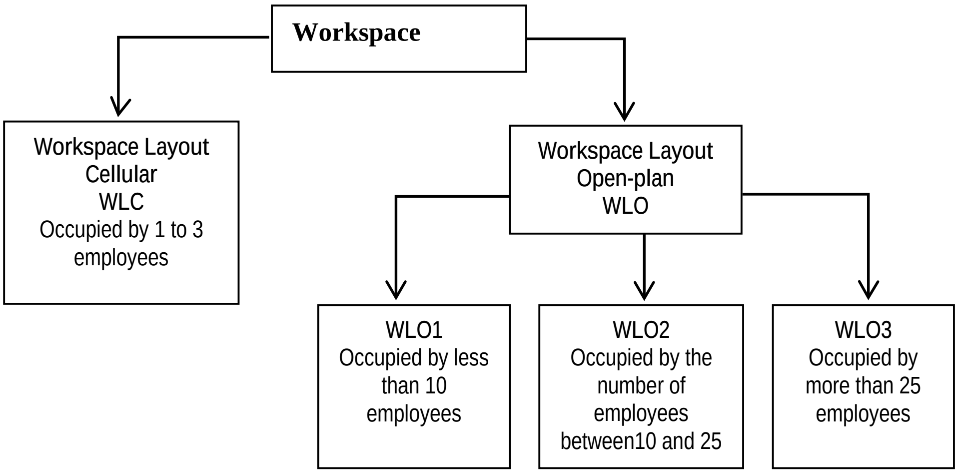


Figure 6.1 Office types that were surveyed during field studies in Glasgow

6.2.1 *Sample size*

The sample size used in the study consisted of 183 respondents. Questionnaires were sent to 310 employees of whom only 183 responded which yielded a response rate of 59% and was higher than the set benchmark of 35% as discussed previously in Chapter 5. The number of respondents in each office type was; 30 in WLC, 33 in WLO1, 34 in WLO2 and 86 in WLO3 workspaces. The latter figures in each office type were also higher than the benchmark of 30 cases per office type also mentioned previously in Chapter 5. Throughout the survey, several managers mentioned the migration of staff from cellular offices to large open-plan spaces which was thought to be more beneficial to their business and to occupants.

6.2.2 *Demography of sample*

The number of males and females in each office type was as follows: 13 males and 17 females in WLC, 7 males and 26 females in WLO1, 13 males and 21 females in WLO2 and 53 males and 33 females in WLO3. The median age group for each office type was as follows: 40-49 years in WLC, 30 to 39 years in WLO1, 40 to 49 years in WLO2 and 40 to 49 years in WLO3.

6.2.3 *Office characteristics*

The offices that were surveyed in Glasgow were situated in multi-story buildings and the majority of the buildings (61.6%) were constructed prior 1950s. The architectural styles varied from neo-classical to glazed contemporary buildings which provided a good mix of heavyweight and lightweight buildings. Concrete and steel frame constructions with stone claddings were more prominent within the sample. All of the buildings had been refurbished within the last ten years and most of the offices had carpet flooring with painted plasterboard walls. The ceilings in most offices had either suspended metallic or cork acoustic panels. All workspaces within the sample benefitted from both natural and artificial lighting. More than a third of the offices had single-glazed windows while the rest of the workspaces had double or triple glazing. Appendix D.2 gives a more detailed description of each office surveyed and Appendix D.1 indicates the location of each workspace.

As mentioned earlier in this section, it was initially hypothesised that the increase in the size of workspace would be associated with a decrease in values of at least an indicator of acoustic measures and a decrease in employee satisfaction. To further understand the implication of variations in the size of workspaces, other variables, such as height, occupancy density and type of desk arrangement were also considered in the study. Here, workspace floor area is defined as the internal floor area of the work zones including circulation and structural elements in this study and is considered to influence the size of individual floor areas. Height was analysed in this study because it was perceived that changes in room height altered volume of space which alternately would also vary reverberation time. Occupancy density in this study was defined as the area of individual workspace area which was obtained by dividing the workspace floor area by the number of workspaces present in the office. So far in the literature review, no guidelines have been provided in relation to area of workspaces; Meel (2010) and Danielsson & Bodin (2009) emphasised on the number occupants in relation to enhancing comfort in work environment and employee satisfaction. British Council of Offices (2009), however indicates that a minimum value of $8m^2$ should be used for occupancy density in general for workspaces. The arrangement of desks was also observed to vary according to workspace floor area during field studies in open-plan spaces and was also considered in the analysis. Two distinct types of desk arrangements were predominant in workspaces; linear and non-linear. Linear desk arrangements were described as workspaces with repetitive rows of desk facing each other and non-linear referred to desks not in rows facing different directions. Table 6.0 indicates that median values for workspace floor area, occupancy density and height of offices in each office category. As mentioned in Chapter 5, values out-with 2 standard deviations from the median were considered as outliers and in the sample no outliers were observed.

The workspace variables - floor area, occupancy density and height - were analysed in the Kruskal Wallis test in SPSS to indicate significant differences among office type for the variables. The results highlighted significant differences for workspace floor area and occupancy density in different office types as shown in Appendix D.3. Height values in Table D.3 in Appendix D did not vary significantly with office type but rather with construction age of buildings with the following mean ranks: before 1950 – 85.70, between 1950 and 2000 – 87.42 and after 2000 – 155.00, $X^2(2) = 23.456$, $p<0.01$. The latter findings were in line with observations made in the historical analysis of office building in Glasgow in Chapter 3 where taller workspaces were observed in more recently built offices.

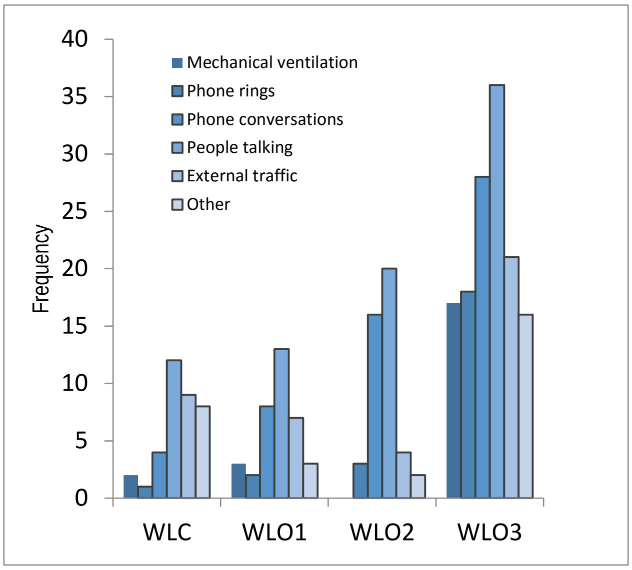


Figure 6.2.0 Ratings of noise sources in each office type

Table 6.0 Median values and median absolute deviation (MAD) for workspace variables

	WLC		WLO1		WLO2		WLO3	
	Median	*MAD*	Median	*MAD*	Median	*MAD*	Median	*MAD*
Workspace floor area	15.8	*6.43*	57.5	*28.2*	98.6	*37.1*	265.6	*161.11*
Height of workspaces	2.64	*0.24*	2.70	*0.04*	2.70	*0.62*	2.57	*0.25*
Occupancy density	7.98	*2.83*	4.81	*1.41*	6.57	*2.94*	6.18	*0.55*

6.2.4 Acoustics in the workplace

As part of the questionnaire survey, employees were asked to identify the most annoying noise sources within their workspaces. Figure 6.2.0 indicates the noise sources deemed to be most annoying in each office type. In addition to the questionnaire survey, noise sources perceived by the author were noted on floor plans for each workspace which are discussed later in Section 6.4. Figure 6.2.0 indicates that people talking was the most annoying in all office types. In WLC offices, external traffic noise was the next most annoying noise source after people talking while in open-plan offices (WLO1, WLO2 & WLO3) phone conversations were the next most annoying noise sources after people talking.

Two acoustic measures were considered in this research – noise level and reverberation time. Reverberation time, which is a measure commonly used in room acoustic, was included in the study and was calculated by using Sabine's (Furrer 1964) formula $R = \frac{0.16V}{A}$. The two variables for acoustic measures were tested in Kruskal-Wallis to determine if they differed significantly among office types. The results showed that noise level and reverberation time varied significantly between different office types (see Appendix D.3). The median noise levels for each office type was as follows: 44.6 dBA (MAD ±8.38) in WLC, 44.4 dBA (MAD ±6.67) in WLO1, 48.0 (MAD ±4.23) dBA in WLO2 and 50.1 dBA (MAD ±3.48) in WLO3 offices. British Council for Offices (2009) recommended a maximum daily average noise level of 40 dBA for cellular offices and 50 dBA for open-plan spaces. Median noise levels in cellular workspaces were above the recommended value but median noise levels in all three types of open-plan workspaces were considered to support the suggested value of 50 dBA. The frequency of noise levels are shown in Figure 6.2.1 to 6.2.4 for all four office types. The major roads within Glasgow City had noise levels that varied between 65 to 70 dBA from day to night according to the noise map produced by Scottish Government (2007) and would contribute mostly to background noise in workspaces when windows were open. Median reverberation times for each office type were as follows: 0.34s (MAD ±0.08) in WLC, 0.52s (MAD ±0.27) in WLO1, 0.95s (MAD ±0.49) in WLO2 and 0.88s (MAD ±0.05) in WLO3 offices. Based on the recommendations provided by the British Standards Institute (1999), the following values were used as benchmark for each office type: less than 0.40s in WLC, less than 0.60s in WLO1 and less than 0.70s in WLO2 and WLO3 offices. Median reverberation time values in WLC and WLO1 were below the recommended values but median values for WLO2 and WLO3 workspaces were very high.

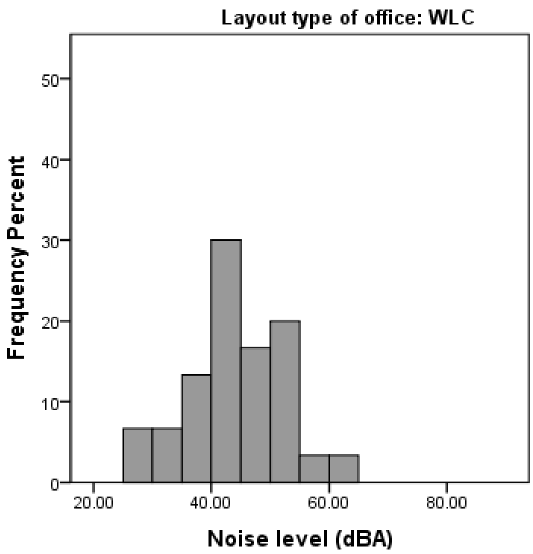


Figure 6.2.1 Frequency of measured noise level in WLC offices, Glasgow

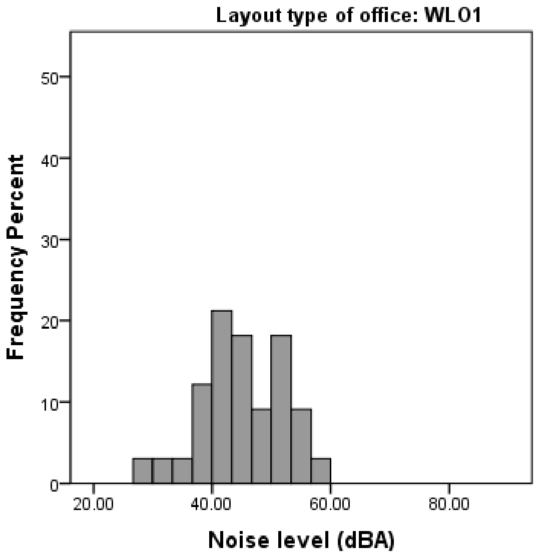


Figure 6.2.2 Frequency of measured noise level in WLO1 offices

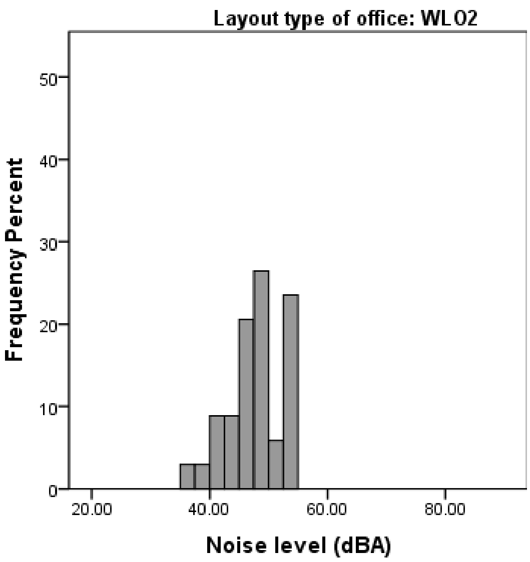


Figure 6.2.3 Frequency of measured noise level in WLO2 offices

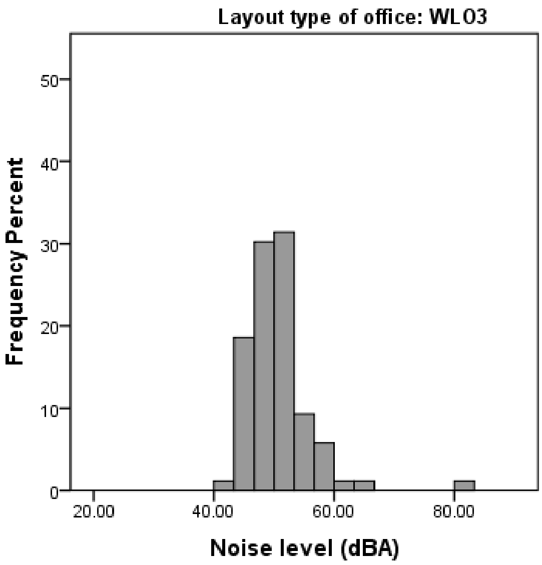


Figure 6.2.4 Frequency of measured noise level in WLO3 offices

6.2.5 Rating of workspaces

A rating scale was devised in this study to further indicate how workspace floor area varied with ratings of acoustic quality in workspaces. Workspaces were rated on a scale of 1 to 5 for reverberation time and the number of perceived noise sources when present in room. As mentioned in the previous section, different reverberation time values were recommended by the BSI (1999) and different rating scales were used for each office type. In WLC category scores were as follows: *1*; ≥ 0.50s, *2*; 0.40 - 0.50s, *3*; 0.40s - 0.30s, *4*; 0.30s - 0.20s and *5*; ≤ 0.20s. In WLO1 category, the scores used were: *1*; ≥ 0.70s, *2*; 0.70 - 0.60s, *3*; 0.60 -0.50s, *4*; 0.50- 0.40s and *5*; ≤0.40s. In WLO2 and WLO3 categories the scales were: *1*; ≥0.80s, *2*; 0.80-0.70s, *3*; 0.70-0.60s, *4*; 0.60-0.50s and *5*; ≤0.50s. The number of noise sources perceived was counted in each workspace and the following scale was used in all office types: 1; ≥ 5 noise sources, 2; 4 noise sources, 3; 3 noise sources, 4; 2 noise sources and 5; ≤ 1 noise source. The median score was attributed to each office and scores equal to or above 3 were considered to be satisfactory. The median scores for each office are shown in Table D.2 in Appendices. Kruskal-Wallis in Table D.3 (see appendices) indicated significant differences for office rating among the four offices types with cellular offices scoring the highest rating followed by WLO1 workspaces. WLO2 and WLO3 offices scored the lowest ratings among the four office categories. WLC category had a median of 3.5 for office rating while WLO1 had median ratings of 3.0, 1.0 in WLO2 and 1.0 in WLO3.

6.2.6 *Questionnaire responses*

Based on the author's observation during field study, noise in open-plan workplaces was annoying which was further supported by questionnaire ratings. Self-administered questionnaires were used to evaluate acoustic and work performance satisfaction. During data coding, it was observed that employees who reported being satisfied with background noise in the workplace were also satisfied with their work performance regardless of the office type which suggested some association between them. Percentage ratings of 50% and above were considered to be generally satisfactory for each office type. Table 6.1 indicates that satisfaction with acoustics in general was below 50% in WLO2 and WLO3 offices and the lowest in WLO2 workspaces which perhaps reflected the fact that more boisterous conversations were observed in that office type than in the others. Less than 50% of employees in all open-plan workspaces agreed that that office type was suitable for work completion. Differences in the rating of preference of office type to perform task was found to vary significantly among the four offices types on Kruskal Wallis test (see Table D.3 in appendices) which suggested that employees in cellular workspaces preferred their workspace more than those in open-plan offices when performing their tasks. These ratings highlighted the strong dissatisfaction with acoustics in some open-plan workspaces and the high preference for alternate office type. As seen in the previous section (Section 6.2.4), reverberation time in WLO2 and WLO3 workspaces were above the recommended values and was considered to be possibly linked to low acoustic satisfaction in these office types.

Table 6.1 Satisfaction rating for acoustic and preference for alternate office type when working in cellular and open-plan offices

	WLC	WLO1	WLO2	WLO3
	%	%	%	%
Satisfied with acoustics in general	61.7	59.1	36.8	41.3
Agree that current office type is suitable for work completion	76.7	39.4	48.5	40.7

6.3 Research questions and revised hypotheses

From the initial observations and preliminary data analysis in Section 6.2, one can find that acoustic measures and employee satisfaction varied according to office type. The main focus of this study was to investigate the relationship between workspace floor area, acoustic measures and employee satisfaction. It was expected that there would be some associations between workspace floor areas and the two indicators of acoustic measures – noise level and reverberation time because the increase in floor area generally implies that occupancy increases which in turn leads to further noise disturbances from increase in work activities. Also, the increase in workspace floor area increases volume of space which is directly proportional to reverberation time. The literature review in Chapter 2, shows that the increase in noise level tends to disturb employees but the association between reverberation time and employee satisfaction in different office types is unknown. Two variables of employee satisfaction were used in this study; acoustic and work performance satisfaction. According to Kiltzman & Stellman (1989) acoustic satisfaction was considered to be an indicator of work performance satisfaction. In this study, acoustic satisfaction was only considered an indicator of work performance satisfaction if both subjective variables were similarly correlated with objective variables. The intended outcome of this study was to establish some form of workplace spatial index that could be related to employee satisfaction and acoustic measures in cellular and open-plan spaces. As mentioned in the Chapter 5, the main research question was articulated as follows:

> ***Are differences in the size of workspaces associated with variations in acoustic measures and employee satisfaction in different office types?***

Prior to field study it was hypothesised that the increase in workspace area would be associated with a decrease in values of at least an indicator of acoustic measures and a decrease in employee satisfaction levels in all types of workspaces. However, certain observations made during field study, such as interior décor difference, led to more refined hypothesis for cellular and open-plan workspaces. As previously mentioned in Section 6.2, workspaces had different material finishes and reverberation time was considered to be an appropriate measure of acoustic quality in different offices. In cellular workspaces employees usually have greater ability to personalise their workspace with more furniture and different finishes than those in open-plan workspaces which was considered to decrease reverberation in cellular workspaces. The occupancy levels between cellular and open-plan offices vary greatly and were also expected to affect noise levels to some extent. The initial hypothesis was further refined into two hypotheses which were tested in this study:

1) Hypothesis A: the increase in workspace floor area will be associated with a decrease in values of at least one indicator of acoustic measures and an increase in employee satisfaction in cellular offices (WLC)
2) Hypothesis B: the increase in workspace floor area will be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction in all open-plan workspaces (WLO1, WLO2 & WLO3)

The hypothesised links between the variables for each office type in this study are shown in Figures 6.3.1 and 6.3.2. A correlation analysis was carried out with workspace floor area, acoustic measures and employee satisfaction for each office type in Spearman's Rho. The results are displayed in Table D.4, D.5 and D.6 in appendices. As mentioned in Chapter 5, significance values (*p-values*) above 0.05 obtained during correlation analysis were not considered to be significant in this study.

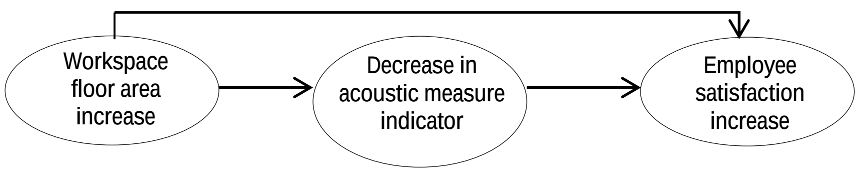


Figure 6.3.1 Hypothesised links between variables for WLC workspaces in Glasgow

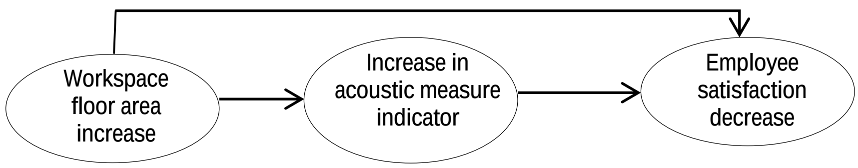


Figure 6.3.2 Hypothesised links between variables for WLO1, WLO2 & WLO3 workspaces in Glasgow

6.4 Correlation Analysis of variables

Past studies, such as Danielsson & Bodin (2009) and Kaarlela-Tuomaala et al. (2009) have shown that cellular workspaces have greater acoustic satisfaction levels than open-plan workspaces. Before looking at each office type individually, correlation analysis was performed on the sample to indicate the difference between cellular and open-plan workspaces in general for the association between workspace floor area with acoustic measures and employee satisfaction. The results indicated that in cellular workspaces there was no significant association between workspace floor area and noise level but in open-plan workspaces, both workspace floor area and noise level increased together ($r=0.402$, $N=153$, $p<0.01$). The latter result was considered to be related to the increase in occupancy levels in open-plan workspaces. Alternately, the increase in workspace floor area in cellular workspaces was associated with an increase in reverberation time ($r=0.690$, $N=30$, $p<0.01$). The latter was considered to be related to the fact that the increase in workspace floor area in cellular offices was associated with an increase in the amount of glazing-to-floor area ratio ($r=0.709$, $N=30$, $p<0.01$) indicating that the increase in workspace floor area tended to be related to an increase in window glazing which increases reverberation time. In open-plan offices, no significant correlation was observed between workspace floor area and reverberation time. There was also no significant association between satisfaction with background noise and workspace floor area in cellular offices but in open-plan workspaces it was observed that background noise satisfaction ratings were negatively correlated with workspace floor area ($r=-0.269$, $N=153$, $p<0.01$). These aforementioned results begin to indicate the difference in the behaviour of sound and employee satisfaction between cellular and open-plan offices and each office category was further analysed in following sections.

6.4.1 WLC workspaces

The workspace floor area in this office category had a median value of 15.8m^2. For acoustic measures, the median noise level was 44.6 dBA which was higher than the recommended value of 40 dBA by the BCO (2009) and median reverberation time was 0.34s which was below the value of 0.40s as suggested by the BSI (1999). 61.7% of employees in WLC were satisfied with acoustics at their workplace which was found to be the highest among the four office types and 76.7% agreed that their current office type was suitable for work completion. Among employees who were dissatisfied with noise at their workplace, 50% agreed that people talking was the most annoying noise source. The noise sources deemed annoying in each workspace in WLC category are shown below in Figure 6.4. It was possible that the high rating of acoustic satisfaction was related to low reverberation time in WLC workspaces. The median value for office rating in WLC was 3.5 and was satisfactory. The office ratings scale is illustrated in Figure 6.6 and a slight decrease in office size was observed when ratings increased. The relationship between acoustic measures and workspace floor area was further examined in Spearman's Rho.

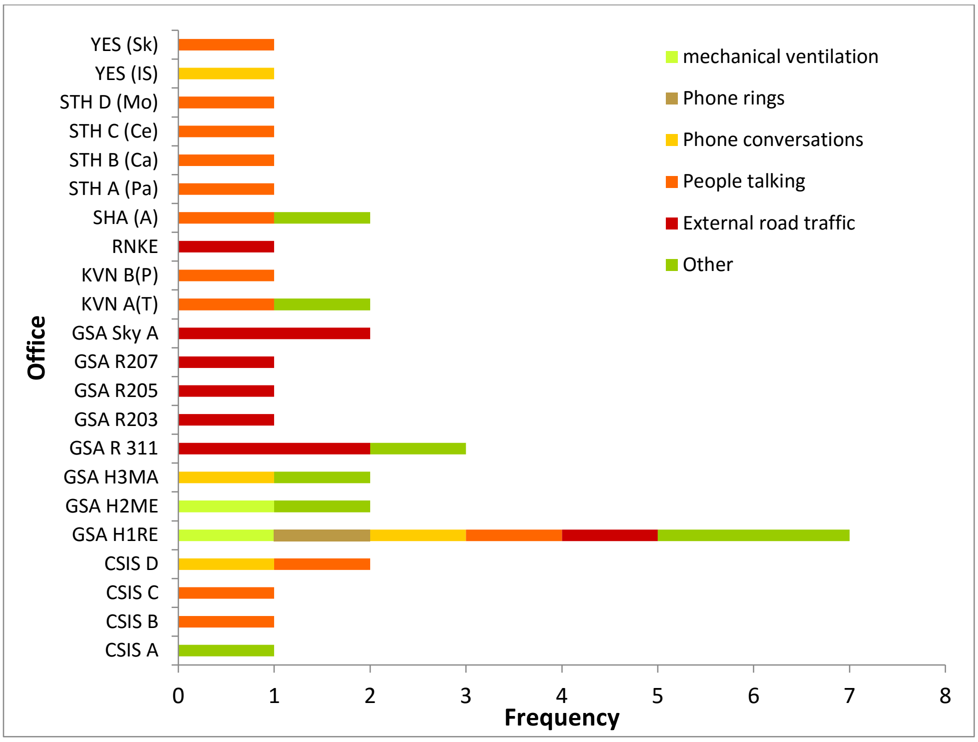


Figure 6.4 Ratings of noise sources in WLC workspaces

It was hypothesised that the increase in workspace floor area would be associated with a decrease in values of at least one indicator of acoustic measures and an increase in employee satisfaction. The results showed that the increase in workspace floor area was significantly associated with an increase in reverberation time ($r=0.690$, $N=30$, $p<0.01$) which was coherent with the initial observations of the rating scale as mentioned earlier but contrary to what was hypothesised. In reference to Sabine's (Furrer 1964) formula for reverberation time (RT), volume and total noise absorption of surface materials are significant to RT. In WLC offices, height of workspaces ($r=0.383$, $N=30$, $p<0.05$) and the amount of glazing-to-floor area ratio ($r=0.492$, $N=30$, $p<0.01$) were both positively associated with RT. Glazing has low noise absorption qualities and reflect noise more than plasterboard walls (Wilkes & Cavanaugh 1999). The increase in workspace floor area was significantly associated with an increase in glazing-to-floor area ratio ($r=0.709$, $N=30$, $p<0.01$) and workspace height ($r=0.567$, $N=30$, $p<0.01$) which in turn were correlated with increasing values of RT. The office rating scale in Figure 6.6 further highlights the deterioration in acoustic quality with increasing workspace floor area: GSA (R203) office had larger workspace area and more glazing than GSA (R207) office. Table D.2 in Appendix D further indicates the materials present in the aforementioned workspaces and office rating. Noise level had no significant associations with workspace floor area, the amount of glazing present in workspaces, frequency of window opening or the number of noise sources present. It was possible that the variations in noise level were related to office activities, such as phone conversations etc.

In regards to the relationship between objective and subjective variables, no significant association was observed between workspace floor area and acoustic satisfaction. Workspace floor area and acoustic satisfaction ratings did not vary linearly which led to the absence of significant associations between the two. Despite having no associations with acoustic satisfaction, the increase in workspace floor area was significantly correlated with a slight increase in the perceived ability of remaining concentrated on work ($r=0.390$ $N=30$, $p<0.05$). The percentage of employees who were usually able to concentrate on work increased slightly from 80.1% to 90.1% when workspace floor area increased above $15.8m^2$. As mentioned above, workspace floor area and RT were positively correlated and it was expected that RT would also have a significant correlation with work performance satisfaction but instead RT was significantly associated with acoustic satisfaction which indicated that the increase in RT was associated with a decrease in background noise satisfaction ($r=-0.442$, $N=29$, $p<0.05$). 86.7% of employees in WLC office category were satisfied with background noise when RT was below 0.34s and 57.2% of employees were satisfied with background noise when RT was above 0.34s.

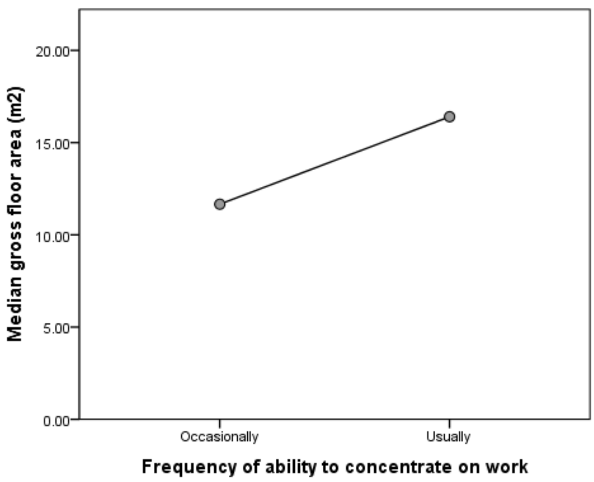


Figure 6.5 Relationship between workspace floor area and the ability to concentrate on work in cellular offices

The association between reverberation time and acoustic satisfaction was as expected because high reverberation time created resonating workspaces. Further analysis was carried out to provide clarity on the association between workspace floor area and work performance satisfaction. Correlation coefficients indicated that employees were less distracted during task completion when there was less annoyance from people talking ($r=-0.447$, $N=28$, $p<0.05$). The reported annoyance with people talking tended to decrease when both RT and perceived annoyance from external traffic noise increased - in offices with workspace floor area below 15.8m^2 and RT was below 0.34s, 66.7% of employees were annoyed with people talking and 13.3% were annoyed with external traffic noise. Alternately, 13.3% of employees were annoyed with people talking and 46.7% were annoyed with external traffic noise when workspace floor area was above 15.8m^2 and RT was above 0.34s. The results suggested that resonating traffic noise in workspaces with high reverberation possibly dampened conversations deemed to be distracting hence increasing work performance satisfaction. Furthermore, most of the offices with workspace floor area below 15.8m^2 as seen in Figure 6.6 had one side of the workspaces completely glazed and overlooked open-plan offices where people talking were easily heard hence creating greater annoyance with people talking than in workspaces with workspace floor area above 15.8m^2.

Acoustic and work performance satisfaction had different associations with objective variables in the study and acoustic satisfaction was therefore not considered to be an indicator of work performance satisfaction in cellular workspaces. The office ratings highlighted workspaces with suitable acoustic quality and the increase in workspace floor area was associated with a decrease in office ratings ($r=-0.704$, $N=30$, $p<0.01$). Cellular offices with workspace floor area below 15.8m^2 had median office rating of 4.0 and those with area above 15.8m^2 had median rating of 3.0. Age and gender were also taken into consideration for subjective variables but no significant differences were observed among different age groups or gender during correlation analysis.

Hypothesis A was not supported in the Glasgow sample. The increase in workspace floor area above 15.8m^2 was associated with an increase in RT above 0.34s which was contrary to what was expected but the increase in workspace floor area was correlated with a slight increase of 10% (from 80.1 to 90.1%) in the perceived ability to concentrate on work which was also contrary to what was hypothesised. The increase in reverberation time above 0.34s was associated with a decrease of 29.6% (from 86.7 to 57.2%) in acoustic satisfaction. It was considered that the decrease in reported annoyance from people talking in workspace floor area above 15.8m^2 was related to the high reverberation time in offices which amplified external noise in the workspaces hence dampening conversations among co-workers and increasing work performance satisfaction. Therefore, in WLC category, offices with workspace floor area below 15.8m^2 and reverberation times below 0.34s was associated with enhanced acoustic satisfaction. Work performance satisfaction was found to have stronger associations with ratings of distraction caused by people talking than acoustic quality of workspace.

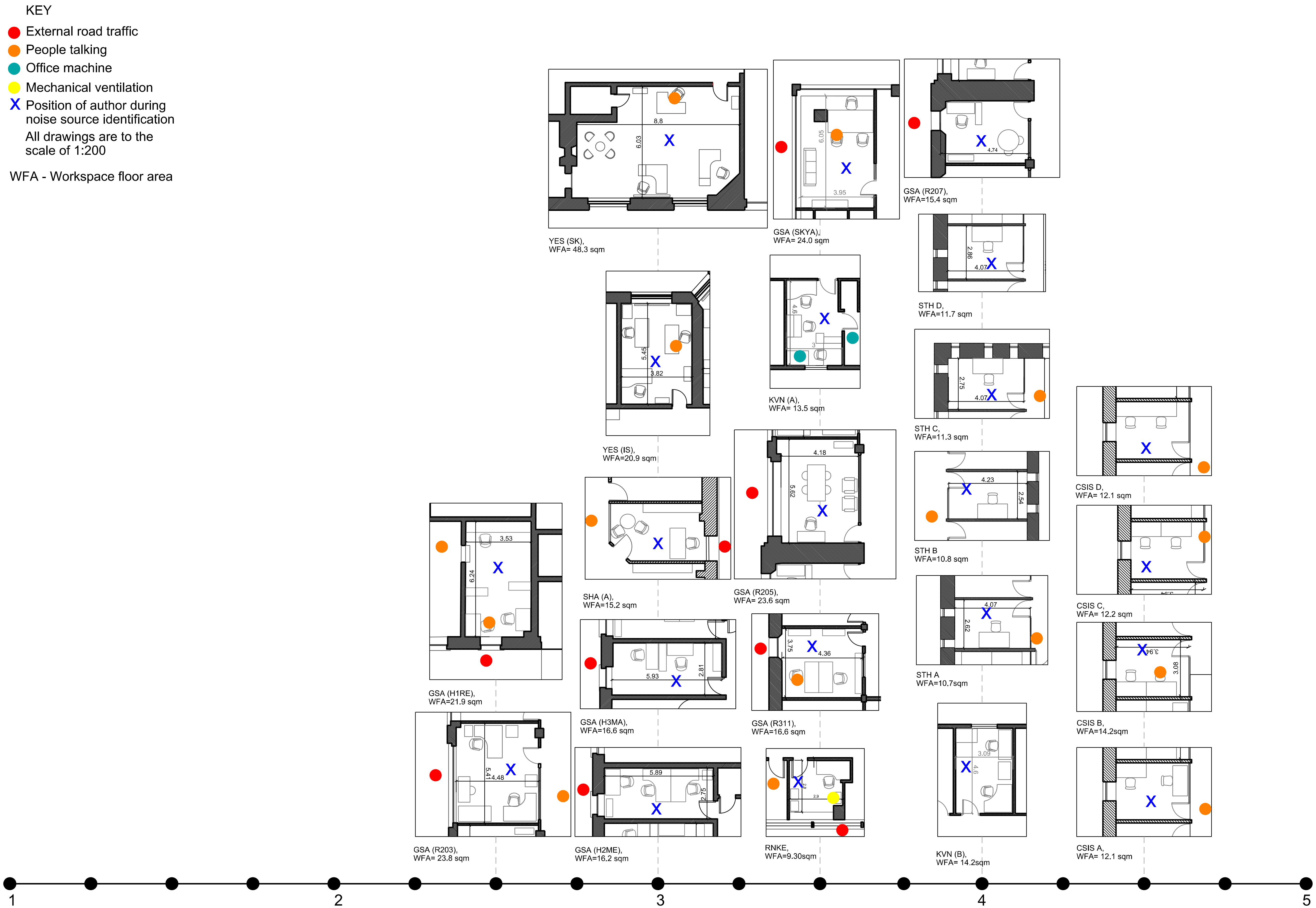


Figure 6.6 Office rating scale for WLC workspaces, Glasgow

6.4.2 WLO1 workspaces

WLO1 workspaces were the smallest in the open-plan category. The median workspace floor area was $57.5m^2$. The median values for noise level was 44.4 dBA and that of reverberation time was 0.52s and both values were below recommended values – between less than 50 dBA for noise level (British Council for Offices 2009) and less than 0.60s for reverberation time (British Standard 1999). The percentage of employees satisfied with acoustics at their workplace (59.1%) in WLO1 was slightly less than that of WLC offices (61.7%) but considered adequate because the value was still above 50%. Despite the high acoustic satisfaction rating, only 39.4% of employees agreed that their current office type was suitable for work completion. Among the employees who were dissatisfied with acoustic, most of the employees reported being annoyed by people talking (62.5%). The ratings of annoying noise sources in each office in WLO1 category are shown below in Figure 6.7. The median office rating for WLO1 was 3.0 which was slightly less than that of WLC (3.5). The office ratings for each workspace are shown on the scale in Figure 6.10. The median rating of reverberation time in that office was 3.0 and that for the number of noise sources present was 2.0. In workspaces with office rating equal to or above 3.0, office sizes were smaller than those with rating below 3.0. The relationship between office size and acoustic measures was further analysed. The number of noise sources present did not seem to decrease greatly with office ratings. Variation in reverberation time ratings was considered to contribute more to the total office ratings in WLO1 workspaces than the rating of number of noise sources. As seen in Table D.2 in Appendix D, most WLO1 offices had higher reverberation time ratings than number of noise source rating.

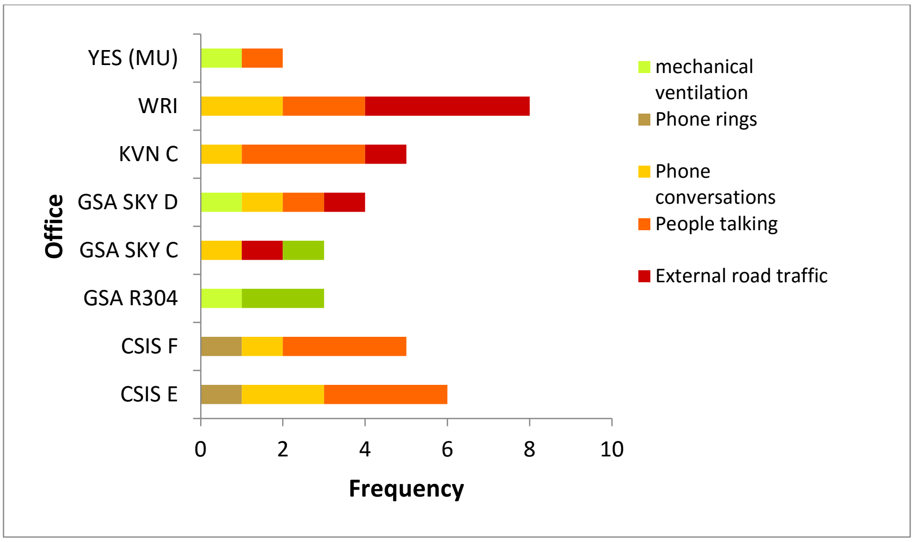


Figure 6.7 Ratings of noise sources in WLO1 workspaces

In WLO1 category, it was hypothesised that the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction. The correlation analysis indicated that the increase in workspace floor area was associated with an increase in both reverberation time (RT) ($r=0.545$, $N=33$, $p<0.01$) and noise level ($r=0.493$, $N=33$, $p<0.01$) which was as expected. The increase in RT was also associated with a decrease in total noise absorption of surface materials ($r=-0.496$, $N=33$, $p<0.01$) which suggested that more reflective surfaces were present in large offices and can be seen in the examples of CSIS(E) and KVN(C) in Figure 6.10 and in Table D.2 in Appendix D. CSIS(E) open-plan space had no acoustic ceiling tiles present and surrounding offices had glazed partitions overlooking open-plan areas whereas in KVN(C) office, acoustic ceiling tiles and no glazed partitions were present. In Table D.2 shows that CSIS(E) has plasterboard ceiling whereas KVN(C) has acoustic ceiling tiles. If acoustic ceiling tiles were present in CSIS(E) then RT would have been reduced from 1.02 to 0.62s. Noise level had no significant correlations with reported annoying noise sources, the number of noise sources present or glazing-to-floor area ratio. Table D.2 in Appendix D also indicates that different desk arrangements are present in these WLO1 offices. Alternately, the results indicated that workspaces with linear desk arrangements had higher noise levels (median of 48.7 dBA) than those with non-linear arrangements (median of 43.3 dBA) ($r=-0.361$, $N=33$, $p<0.05$). The increase in RT was also associated with linear desk arrangement ($r=-0.825$, $N=33$, $p<0.01$). The possibility of certain layouts being associated with co-worker interaction and noise level was further investigated and discussed in the following paragraphs.

The relationship between objective and subjective variables was tested in Spearman's Rho (see Table D.4 to D.6 in appendices). It was expected that the increase in workspace floor area would be associated with a decrease in acoustic satisfaction and work performance satisfaction because increase in workspace floor area was associated with increase in RT and noise level. As expected, the increase in workspace floor area was associated with a decrease in acoustic satisfaction ($r=-0.464$, $N=33$, $p<0.01$) (see Figure 6.8). Acoustic satisfaction decreased from 75% to 47.4% when workspace floor area increased above 57.5m^2. Employees also reported more noise disturbances when workspace floor area increased ($r=0.424$, $N=33$, $p<0.05$). The increase in workspace floor area above 57.5m^2 was significantly correlated with the increase of 30.9% (from 3.55 to 34.5%) in perceived difficulty during work completion ($r=0.429$, $N=32$, $p<0.05$).

Given that workspace floor area was positively associated with RT, it was expected that RT would be significantly correlated with acoustic and work performance satisfaction. However, no further associations were observed between RT and acoustic or work performance satisfaction and the absence of correlations were considered to be possibly due to the fact that RT values were generally low (below 0.60s) in that office type. Noise level, on the other hand, had several associations with acoustic and work performance satisfaction. The increase in noise level was associated with a decrease in acoustic satisfaction (r=-0.495, N=33, p<0.01) (see Figure 6.9) and an increase in the preference for alternate office type during work completion (r=0.374, N=33, p<0.05).

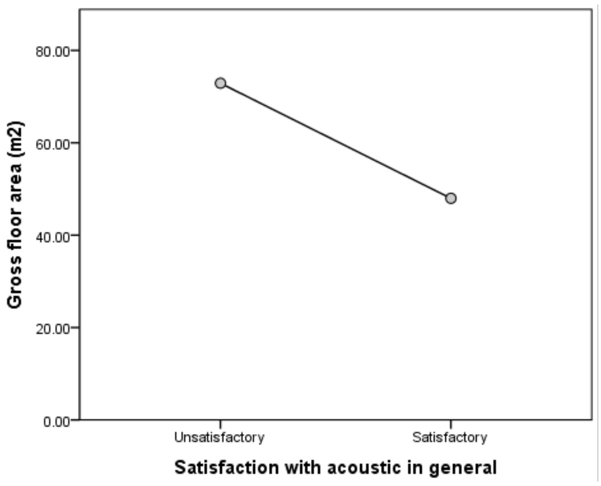


Figure 6.8 Relationship between workspace floor area and acoustic satisfaction in WLO1 offices

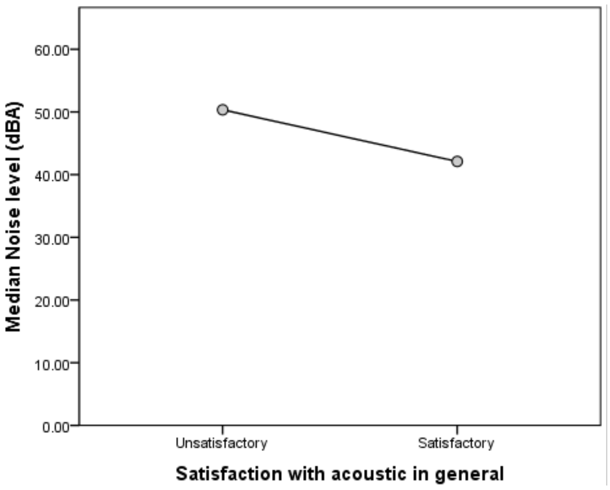


Figure 6.9 Relationship between noise level and acoustic satisfaction in WLO1 offices

As observed above, the increase in workspace floor area was associated with an increase in both noise level and reverberation time. Workspaces with workspace floor area below 57.5m^2 had median noise level was below 44.4 dBA, median RT was below 0.60s and the percentage of employees complaining about people talking was only 35%. In workspaces with workspace floor area above 57.5m^2, median noise level was above 44.4 dBA, median RT was above 0.60s and the percentage of reported annoyance from people talking was 50%. Based on the correlation coefficients obtained in WLO1 workspaces, noise level was considered to be more relevant to acoustic and work performance satisfaction than reverberation time. As mentioned at the beginning of this section, desk arrangement was significantly associated with noise level and workspace floor area (r=-0.825, N=33, p<0.01) indicating that linear desk layouts tended to be used when workspace floor areas increased. In offices with floor area less than 57.5m^2, workspaces had non-linear desk arrangement and those with floor area above $57.5m^2$ had linear arrangements (see Figure 6.10). The type of desk arrangement was also significantly associated with occupancy density indicating that linear layouts also had smaller occupancy density than those in non-linear ($r=0.675$, $N=33$, $p<0.01$). According to Hedge (1982), interpersonal relationship among co-workers are improved in open-plan spaces in comparison to cellular offices. Zahn (1991) highlighted that close proximity among employees was associated with an increase in communication and Wineman (1982) mentioned that employees are more likely to engage in conversations when they are facing each other. In linear arrangements employees faced each other and had closer proximity than those in non-linear arrangements where fewer employees faced other and were more distant from other co-workers. During field study of STH (E) which contained a linear desk arrangement, an employee casually mentioned during a conversation: "…I sometimes use headphones or avoid making eye contact when I want to avoid engaging in a conversation with my colleagues. I also find whispers to be the most annoying here because you wonder if the person is talking about you or someone else and it is too low to understand!". Furthermore, Kruskal-Wallis test showed that employees in linear arrangements perceived more noise disturbances than those in non-linear (X^2 (1) = 5.345, $p<0.05$). The results suggested that improved acoustic and work performance satisfaction occurred in offices with workspace floor area below $57.5m^2$ with non-linear desk layout in which noise level was below 44.4 dBA.

The results also indicated that both acoustic satisfaction and work performance satisfaction ratings had similar correlations with noise level and workspace floor area and were therefore considered to be coherent with each other. It was also mentioned at the beginning of this section that workspace floor area was observed to decrease with increasing office ratings. Correlation coefficients supported the latter observations ($r=-0.703$, $N=33$, $p<0.01$). As seen above workspaces with workspace floor area below $57.5m^2$ had enhanced satisfaction ratings and the associated office rating was 3.00. Gender and age group were analysed in relation to subjective ratings but no significant differences were observed in the analysis for both gender and age groups.

The results obtained in WLO1 offices showed that increase in workspace floor area was associated with an increase in noise level and a decrease in acoustic and work satisfaction which supported Hypothesis B. Workspace floor areas above $57.5m^2$ was associated with a decrease of 27.6% (from 74 to 47.4%) in acoustic satisfaction and a decrease of 30.9% (from 34.5 to 3.55%) in work performance satisfaction. Median noise level above 44.4 dBA was associated with workspace floor area above 57.5m^2. Reverberation time increased with workspace floor areas but had no significant associations with acoustic or work performance satisfaction. Non-linear desk arrangements were considered to contribute to improved acoustic satisfaction. In WLO1 category, workspaces with workspace floor area below 57.5m^2 with non-linear desk layouts and noise level below 44.4 dBA were associated with enhanced acoustic and work performance satisfaction.

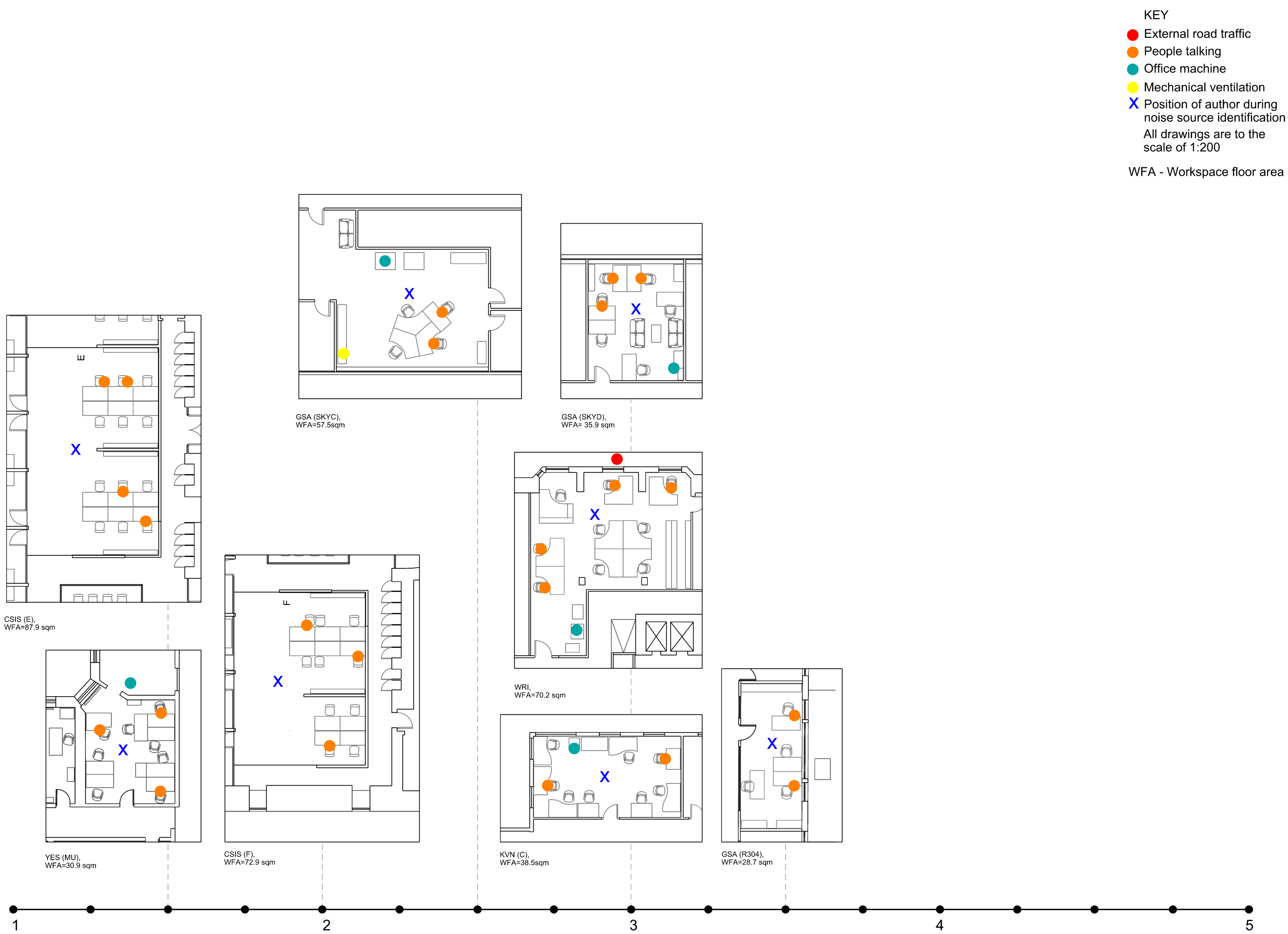


Figure 6.10 Office rating scale in WLO1 workspaces, Glasgow

6.4.3 WLO2 workspaces

WLO2 office category was the intermediary open-plan size between WLO1 and WLO3 office categories. The median workspace floor area was 98.6m^2 and median values for acoustic measures were as follows: 48.0 dBA for noise level and 0.95s for reverberation times. Median noise level was considered to be satisfactory because it was less than 50 dBA as recommended by BCO (2009) but median reverberation time was found to be inferior because it was higher than the suggested value of 0.70s by BSI (1999). 36.8% of employees in WLO2 were satisfied with background noise and 48.5 % of employees agreed that their current office type was appropriate for work completion. Among those who were dissatisfied with acoustics, 83.3% of employees were annoyed with people talking. The noise sources perceived as annoying in each workspace are shown below in Figure 6.11. Similar to WLC and WLO1 offices, the workspaces were rated based on median reverberation time and number of noise sources present in the office. The median rating was 1.0 for WLO2 offices which was very inferior to those in WLC and WLO1 workspaces. The median ratings for both reverberation time and noise sources present were 1.0 which were lower than those of WLC (3.5) and WLO1 (3.0) offices and was considered to contribute to the low overall office rating. The latter can be seen in Table D.2 in Appendix D. Figure 6.14 shows the office ratings associated to each workspace in WLO2 and it was noticed that neither the size of the office nor the number of noise sources present tended to decrease with increasing ratings on the scale.

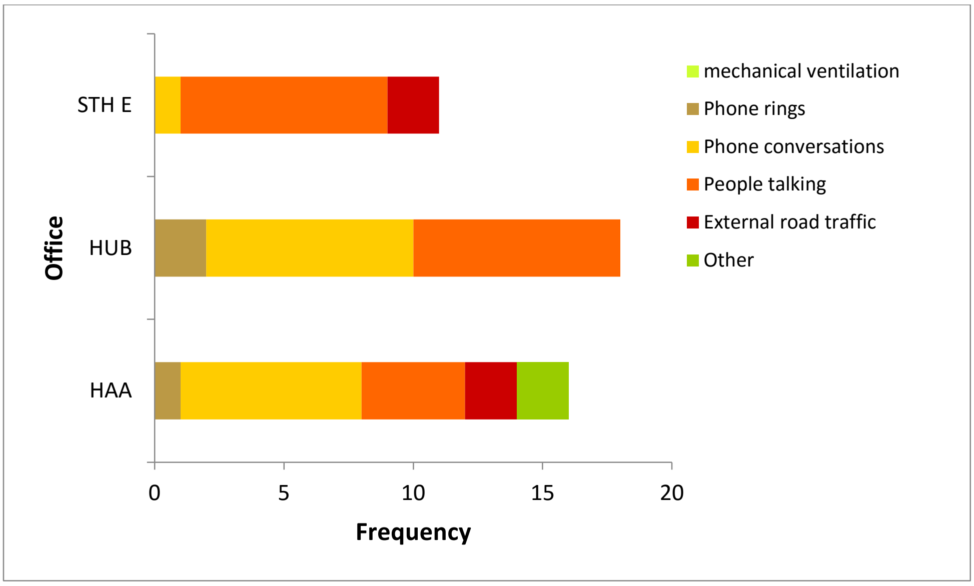


Figure 6.11 Ratings of noise sources in WLO2 offices

Similar hypothesis to that of WLO1 was tested in WLO2 offices and stated the following: the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction. Both acoustic measures were analysed for correlations with workspace floor area and the results indicated that only reverberation time decreased when workspace floor area increased (r=-0.664, N=34, p<0.01) which was contrary to what was expected. The increase in workspace floor area was associated with an increase in total noise absorption of surface materials (r=0.664, N=34, p<0.01) which in return was associated with a decrease in RT (r=-1.00, N=34, p<0.01). Given that reverberation time was dependent on volume and absorption qualities of materials in spaces, height was also found to be positively related to RT (r=1.00, N=34, p<0.01). Examples of the aforementioned correlations were seen in HAD and STH (E) offices (Figure 6.14). In Table D.2 it is seen that both workspaces had similar finish materials and HAD office had smaller floor area and was expected to have a lower RT value than STH (E) office but the contrary was observed because HAD office had larger areas of window glazing present and taller ceiling which are known to increase noise reflection. Noise level was not significantly associated with workspace floor area or with the number of noise sources present but instead with the ability to open windows in workspaces (r=-0.413, N=34, p<0.05).

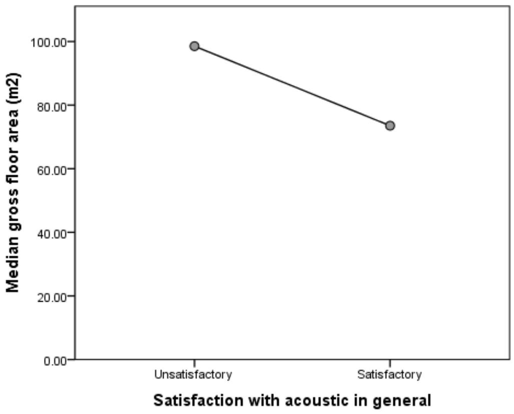


Figure 6.12 Relationship between acoustic satisfaction and workspace floor area in WLO2 offices in Glasgow

Workspace floor area and acoustic satisfaction were analysed in Spearman's Rho and the results indicated that the increase in workspace floor area was significantly associated with a decrease in acoustic satisfaction (r=-0.529, N=34, p<0.01). The percentage of employees satisfied with acoustics at their workplace decreased from 60.8% to 6.25% when workspace floor area increased above 98.6m^2 (Figure 6.12). Workspace floor area was also significantly correlated with work performance satisfaction - the percentage number of employees with the ability to usually concentrate on work decreased from 88.5 % to 37.5% when workspace floor area increased above 98.6m^2 (r=-0.494, N=33, p<0.01). Given that workspace floor area and RT were significantly correlated it was expected that both acoustic and work performance satisfaction would also be correlated with RT. Correlation coefficients supported the latter argument and indicated that the decrease in RT was significantly associated with a decrease in acoustic satisfaction (r=0.370, N=34, p<0.05) and an increase in the preference for alternate office type for work completion (r=-0.355, N=34, p<0.05) which was uncommon. The decrease in RT below 0.95s was associated with a decrease in acoustic satisfaction from 60.5% to 29.2% (Figure 6.13) and the reported preference for alternate office type for work completion increased from 25% to 58.4%. The latter findings supported the arguments of Perham et al. (2007) and Beaman & Holt (2007) where high reverberation time was considered to be linked with low disturbances from background noise in the workplace because high reverberation time implied multiple noise reflection which was considered to dampen acoustical variation in background noise.

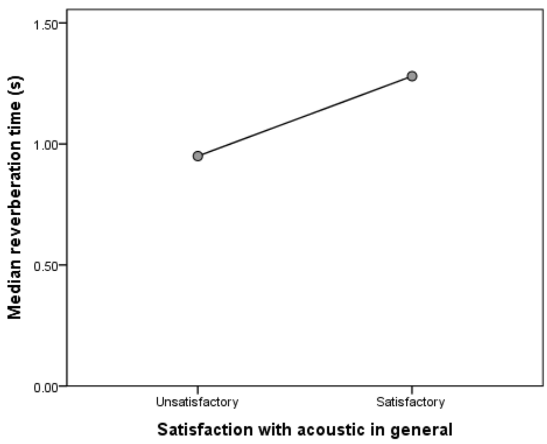


Figure 6.13 Relationship between acoustic satisfaction and reverberation time in WLO2 offices, Glasgow

Further analysis was performed to investigate the unusual significant association between RT and employee satisfaction. Correlation coefficients indicated that the increase in RT in WLO2 workspaces was also significantly associated with a decrease in perceived annoyance from people talking (r=-0.365, N=34, p<0.05). In workspaces with workspace area below 98.6m^2 and RT was above 0.95s, 28.6% of employees were annoyed with people talking and in workspaces with floor area above 98.6m^2 and RT below 0.95s, 66.7% were annoyed with people talking. It was also observed that the decrease in reported annoyance from people talking was associated with a decrease in employees being distracted during task completion by background noise (r=-0.340, N34, p<0.05). The latter findings suggested that the increase in reverberation time in WLO2 workspaces was associated with less annoyance from people talking which were linked to an increase in both acoustic and work performance satisfaction. In WLO1 workspaces, it was previously observed that the type of desk arrangement was associated with reported annoyance with people talking. Here, in WLO2 workspaces, all workspaces, including HUB office, were considered to have a linear desk arrangement given that most of the employees were arranged in rows and faced each other (see Table D.2 in Appendix D). HUB office had the lowest RT value of 0.50s while HAD and STH (E) had RT values 1.28s and 0.95s respectively. It was observed that reported annoyance with people talking and phone conversations were above 65% in HUB offices and less than 65% in the other two WLO2 offices. According to Campbell et al. (2002) and Beaman & Holt (2007), measured work performance is disturbed by changing state of background irrelevant speech and Beaman & Holt (2007) further observed that the increase in reverberation time reduced variations in background irrelevant speech and increased work performance scores. The results in this study appeared to support the latter studies. In WLO1 workspaces, it was previously observed that linear desk layouts were also significantly associated with a decrease in occupancy density. Here in WLO2 workspaces only linear desk arrangement was seen and the same could not be said because occupancy density varied as follows: 4.60m^2 in HAD office, 6.60m^2 in HUB office and 10.6m^2 in STH (E) office.

Both acoustic satisfaction and work performance satisfaction ratings were similarly associated with workspace floor area and reverberation time. Office ratings were generally low in WLO2 offices with median value 1.00. Unlike, WLC and WLO1, workspace floor area in WLO2 offices did not increase with office rating. Offices with workspace floor area below 98.6m^2 and RT above 0.95s had enhanced acoustic satisfaction and reduced annoyance with people talking. Both age and gender were taken into consideration and no significant differences were observed for correlations between workspace floor area, reverberation time, acoustic satisfaction and work performance distraction.

From the results presented here, it was observed that the increase in workspace floor area was associated with a decrease in reverberation time and a decrease in acoustic and work performance satisfaction. The results did not support Hypothesis B because it was expected that the decrease in reverberation time would be associated with an increase in employee satisfaction and not the contrary. Workspace floor area above 98.6m^2 had median reverberation time below 0.95s and was associated with a decrease from 60.8% to 6.25% in acoustic satisfaction and only 47.2% of employees agreed that their current office type was suitable for work completion. Changes in reverberation time were mostly associated to variations in the size of workspace and the presence of reflective materials, such as glazing. The type of desk arrangement was not considered to vary significantly in WLO2 workspaces given that most of the employees were placed in rows facing each other. However, reverberation time below 0.95s was considered to contribute to an increase in perceived distraction due to background conversations occurring in these workspaces with linear desk layout. Enhanced acoustic and work performance satisfaction was observed in WLO2 workspaces where workspace floor area was below $98.6m^2$ and reverberation time above 0.95s.

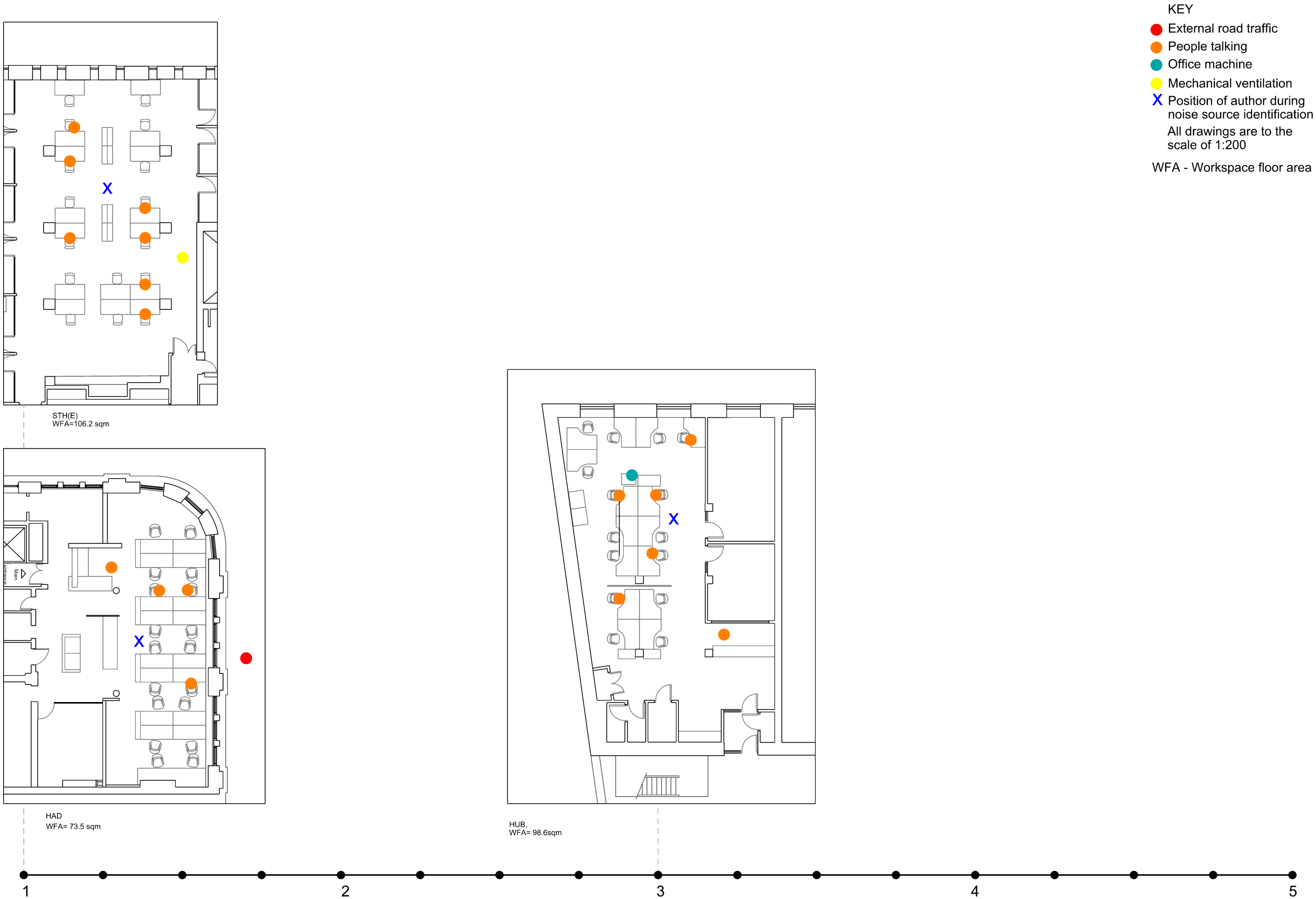


Figure 6.14 Office rating scale for WLO2, Glasgow

6.4.4 WLO3 workspaces

WLO3 office category was the largest among the three open-plan office categories. The median workspace floor area was 265.6m^2. The median values for acoustic measures in WLO3 were as follows; 50.1 dBA for noise level and 0.88s for reverberation time. Median noise level was approximately similar to the recommended value of 50 dBA by BCO (2009) and median reverberation time was above the suggested value of 0.70s (British Standard 1999). The percentage number of employees satisfied with acoustics at their workplace was 41.3% which, similar to WLO2, was below 50%. Only 40.7% of the employees in WLO3 workspaces agreed that their current office type was appropriate for the completion of task. Among the employees who were dissatisfied with acoustics at their workplace, 39% were annoyed with people talking and 24.4% were annoyed with phone conversations. The noise sources that were perceived as annoying in each office type are shown in Figure 6.15. The median office rating for WLO3 workspaces was 1.0 which was considered to be very low and similar to that in WLO2 workspaces. The associated ratings for each workspace are shown in Figure 6.16 and also in Table D.2 in Appendix D. Median ratings for both number of noise sources present and reverberation time were 1.0. Initial observations indicated that the increase in office ratings seemed to also be linked to an increase in workspace floor area. Further analysis was performed to determine the association between office floor area and acoustic measures.

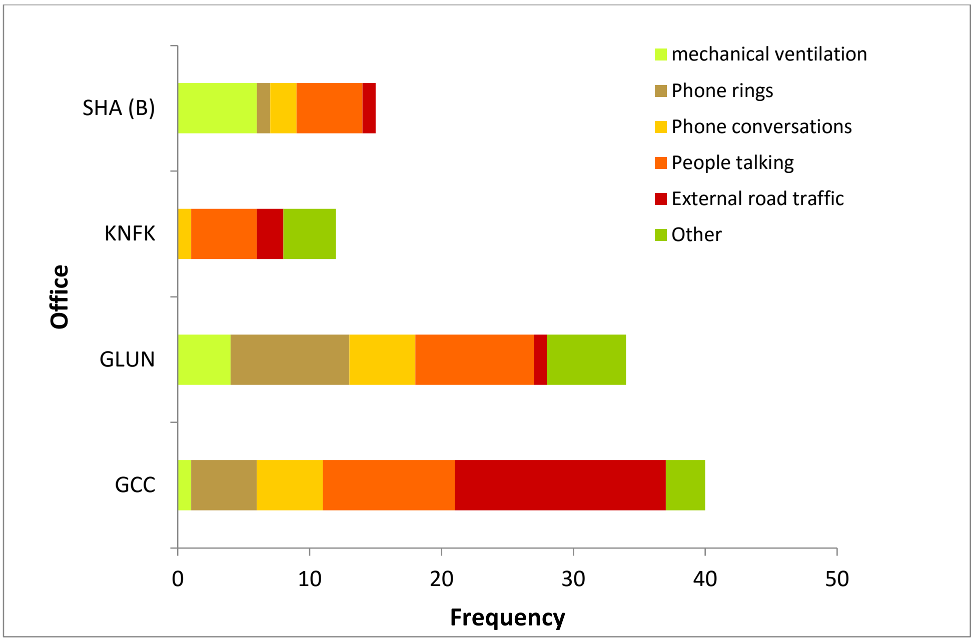


Figure 6.15 Ratings of noise sources in WLO3 offices

Hypothesis B stating that the increase in workspace floor area would be associated with an increase in values of at least one acoustic measures and a decrease in acoustic and work satisfaction was tested in WLO3 workspaces. Correlation coefficients indicated that the increase in workspace floor area was associated with an increase in noise level ($r=0.353$, $N=86$, $p<0.01$) and a decrease in reverberation times ($r=-0.887$, $N=86$, $p<0.01$). It was also observed that both noise level increased with perceived annoyance with external traffic noise ($r=0.343$, $N=86$, $p<0.01$) and with glazing-to-floor area ratio ($r=0.455$, $N=86$, $p<0.01$). The increase workspace floor area was also associated with an increase in the frequency of window opening which possibly ($r=0.803$, $N=86$, $p<0.01$) explained the increase in noise level. Like WLO2 offices, reverberation time (RT) decreased when workspace floor area increased. In reference to Sabine's formula (Furrer 1964), RT is dependent on the volume of spaces and the noise absorption qualities of surface materials within the space. In WLO3 offices, decrease in RT was associated with an increase in total noise absorption of surface materials ($r=-1.00$, $N=86$, $p<0.01$) and a decrease in room height ($r=1.00$, $N=86$, $p<0.01$). Table D.2 in appendices indicated that finish materials for floors and walls were similar in all WLO3 offices but ceiling finishes varied between acoustic ceiling tiles and painted plasterboard finish which was considered to be linked to the variations in total noise absorption of workspaces. The increase in workspace floor area was associated with an increase in total noise absorption of surface materials ($r=0.877$, $N=86$, $p<0.01$) and a decrease in room height ($r=-0.877$, $N=86$, $p<0.01$). KNFK office had the highest RT value (1.24s) despite having a smaller floor area than that of GCC workspace but was devoid of acoustic ceiling tiles and had higher ceiling than that of GCC. If acoustic ceiling tiles were present in KFNK office, RT would decrease from 1.24s to 0.80s and even more if ceiling height was also reduced.

The objective variables were analysed in relation to subjective ratings of acoustics and work performance. As expected, the increase in workspace floor area was associated with a decrease in acoustic satisfaction ($r=-0.385$, $N=86$, $p<0.01$). Acoustic satisfaction decreased from 72.3% to 30.4% when workspace floor area increased above 265.6m^2. However, no significant associations were observed between workspace floor area and work performance satisfaction. Given that workspace floor area was significantly correlated with both noise level and RT earlier, it was expected that noise level and RT would be similarly associated with acoustic and work performance satisfaction. Noise level had no significant correlation with acoustic satisfaction but the increase in noise level above 50.1 dBA was associated with an increase from 76.8% to 96.5% in the perceived ability to concentrate on work ($r=0.429$, $N=86$, $p<0.01$). Despite the high preference for alternate office type when completing task (as mentioned at the beginning of this section), the reported ability to usually concentrate on work in WLO3 workspaces in general was 86.7% which was very high. The increase of 19.8% in the rating of ability to concentrate on work associated with increase in noise level was considered unsubstantial because the rating was already very good. Reverberation time, on the other hand, increased together with acoustic satisfaction ($r=0.250$, $N=86$, $p<0.05$) which was similar to what was observed in WLO2 offices. The increase in RT above 0.85s was associated with increase in acoustic satisfaction rating from 47% to 63.2%. No significant association was observed between RT and work performance satisfaction.

In workspaces with floor area below 265.6m^2, RT values were above 0.88s, 72.3% of employees were satisfied with acoustic at their workspace and 14.8% reported annoyance with phone conversations and phone rings. In workspaces with floor area above 265.6m^2, RT values were below 0.88s, 30.4% of employees were satisfied with acoustic at their workspace and 33.4% reported annoyance with phone conversations and phone rings. The aforementioned figures indicated that reported annoyance with phone conversations and phone rings in workspaces tended to increase with workspace floor area and with decreasing values of reverberation time. Furthermore, the decrease in acoustic satisfaction was associated with an increase in perceived annoyance with phone conversations ($r=-0.223$, $N=86$, $p<0.05$). In WLO1 workspaces, it was previously observed that the type of desk layout was significantly associated with reported annoyance with people talking. As seen in Table D.2 in Appendix D, half of the workspaces surveyed in WLO3 offices had linear desk arrangements and in workspaces with linear desk layouts only, acoustic satisfaction increased from 30.3 to 80.1% was observed when RT increased from 0.35s to 1.24s. There was no significant association between workspace floor area and type of desk arrangement in WLO3 offices, unlike WLO1 offices. Like WLO2 workspaces, increasing values of RT were associated with enhanced acoustic satisfaction in linear desk layouts because it was possible that background conversation, when in close proximity to employees, became less irritating to employees than in workspaces with linear desk layout and low RT values. Nemecek & Grandjean (1973) observed that it was the contents of conversations and not the intensity of noise that annoyed employees. Campbell et al. (2002) observed that the changing state of irrelevant speech (random speech) was more disturbing to work performance in employees than steady state of speech (repetitive speech) and Beaman & Holt (2007) observed that high reverberation time was associated with less disturbance from irrelevant speech. The results obtained in WLO3 were in line with the latter studies. In WLO3 workspaces with non-linear desk arrangement, it was observed that satisfaction with background noise decreased when RT increased ($r=-0.485$, $N=38$, $p<0.01$) which was contrary to workspaces with linear desk arrangement. In WLO1 workspaces it was observed that linear desk layouts were also associated with a decrease in occupancy density indicating that employees were in closer proximity in linear desk layouts than in those in non-linear desk layouts. In WLO3 spaces, correlation coefficients indicated that linear desk layouts tended to have greater occupancy density than non-linear ones but the difference in occupancy density between the two desk layouts were considered negligible; median of 6.98m^2 in linear desk layouts and median of 6.18m^2 in non-linear desk layouts.

Acoustic satisfaction was not considered to be an indicator of work performance satisfaction in WLO3 because different associations were observed with objective variables - contrary to work performance satisfaction, acoustic satisfaction was related only to workspace floor area and RT. Office ratings in WLO3 were generally below 3.0 but tended to increase together with workspace floor area ($r=0.884$, $N=86$, $p<0.01$). Reverberation time contributed mostly to office ratings in WLO3. The results above indicated that acoustic satisfaction increased when there were fewer phone conversations. It could therefore be suggested a rating of more than 3.0 for the number of noise sources present in WLO3. Age and gender were taken into consideration during the correlation analysis and similar to the other office types, no significant differences were observed for different age groups and gender.

The results displayed for WLO3 workspaces indicated that the increase in workspace floor area was correlated with a decrease in RT and a decrease in acoustic satisfaction. The results did not support Hypothesis B because it was expected that the increase in workspace floor area would be associated with an increase in RT and that acoustic satisfaction would decrease when RT increased. Workspaces with floor area above 265.6m^2 were associated with a decrease in reverberation time below 0.88s and a decrease of 41.9% (from 30.4 to 72.3%) in acoustic satisfaction. Similar to WLO2 offices, less perceived annoyance from phone conversations and phone rings were observed in workspaces with linear layouts when floor area was smaller and RT increased. Work performance satisfaction was generally low in all workspaces and was not associated with workspace floor area or RT. In WLO3 workspaces, enhanced acoustic satisfaction was observed in workspaces with floor areas above 265.6m^2 with reverberation time above 0.88s.

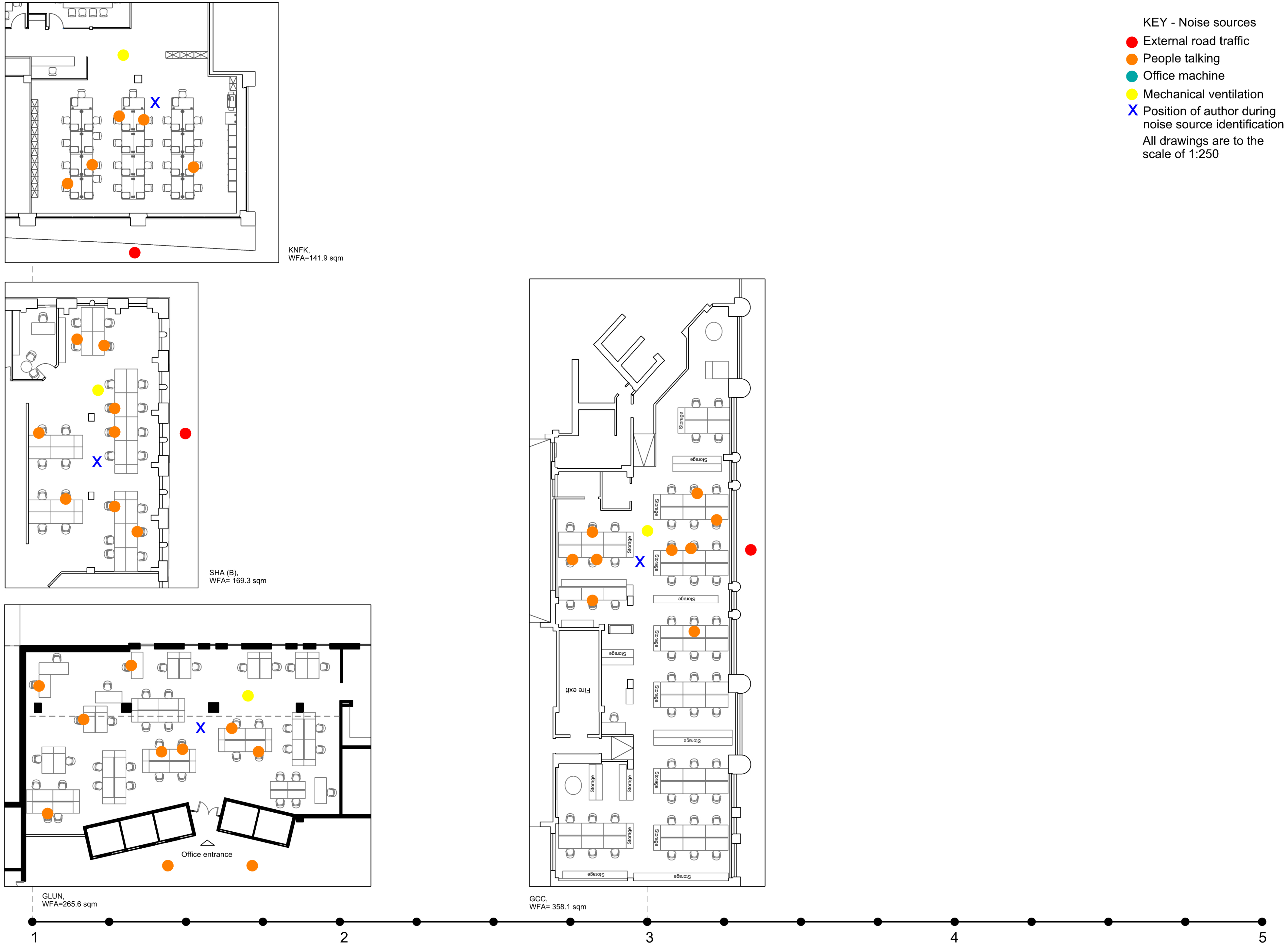


Figure 6.16 Office rating scale for WLO3 offices, Glasgow

6.5 Summary

The analysis in this chapter focused on the relationship between workspace floor area, acoustic measures and employee satisfaction in four types of workspaces; WLC, WLO1, WLO2 and WLO3. In WLC offices, Hypothesis A was tested and stated that the increase in workspace floor areas would be associated with enhanced acoustic measures and an increase in employee satisfaction. In open-plan workspaces, Hypothesis B was tested and stated that the increase in workspace floor area would be associated with deterioration in acoustic measures and a decrease in employee satisfaction. A correlational analysis in Spearman's Rho was performed between the variables. The most annoying noise source among employees who were dissatisfied with acoustics was people talking in all four office types.

Among the four office types, acoustic satisfaction rating was the highest in cellular workspaces and the majority of the employees in that office type agreed that their workspace was appropriate for work completion. The increase in workspace floor area above 15.8m^2 was associated with an increase in reverberation time above 0.34s and a slight increase from 80.1 to 90.1% in work performance satisfaction. The size of cellular workspaces was not relevant to acoustic satisfaction but the increase in RT above 0.34s was associated with a decrease from 86.7 to 57.2% in acoustic satisfaction. Enhanced work performance satisfaction in workspaces with floor area above 15.8m^2 and high RT above 0.34s was considered to be related to the reduced annoyance with conversations linked to resonating workspaces. Noise level was not relevant to employee satisfaction in cellular workspaces and Hypothesis A was not supported.

Acoustic satisfaction rating in WLO1 workspaces was the highest among the three open-plan categories but more than 50% of employees preferred alternate office type for work completion. Nonetheless, both subjective variables were correlated with objective variables - acoustic satisfaction decreased by 27.6% (from 75 to 47.4%) and work performance satisfaction decreased by 30.9% (from 3.55 to 34.4%) when workspace floor areas increased above 57.5 m^2 in which noise level was above 44.4 dBA. Workspaces with non-linear desk layouts had noise level below 44.4 dBA and a decrease of 15% (from 50 to 35%) in reported annoyance with people talking in comparison to workspaces with linear desk layout. Hypothesis B was supported in WLO1 workspaces.

WLO2 workspaces had the lowest rating for acoustic and work performance satisfaction among the four office types. The increase in workspace floor area above $98.6m^2$ was associated with a decrease in reverberation time from 1.28s to 0.95s and a decrease of 54.6% (from 60.8 to 6.25%) in acoustic satisfaction and a decrease from 88.5 to 37.5% in work performance satisfaction which failed to support Hypothesis B. Only linear desk layout was present in WLO2 offices but the decrease in workspace floor area below $98.6m^2$ and an increase in RT above 0.95s were linked with a decrease in perceived annoyance with people talking and phone conversations. Workspaces with floor area below $98.6m^2$ and reverberation time above 0.95s had an increase in employee satisfaction in comparison to workspaces with floor area above $98.6m^2$, RT below 0.95s and linear desk layout. Noise level was not significant to employee satisfaction.

Similar to WLO2 workspaces, both acoustic and work performance satisfaction ratings were below 50% in WLO3 workspaces. The increase in workspace floor area above $265.6m^2$ was associated with a decrease in reverberation time below 0.88s and a decrease in acoustic satisfaction of 41.9% (from 72.3 to 30.4%) which failed to support Hypothesis B. Workspace floor area and reverberation time were not significantly associated with work performance satisfaction. Most of the workspaces in WLO3 category had linear desk arrangement and it was further observed that in linear desk arrangements with RT above 0.88s, there was less perceived annoyance with people talking.

6.6 Discussion

This study was designed to determine the relationship between office design, acoustic measures and employee satisfaction in cellular and open-plan offices. Workspace floor area was analysed in relation to two acoustic measure indicators – noise level and reverberation time - and also in relation to acoustic and work performance satisfaction in four types of workspaces in Glasgow sample. The correlation analysis indicated that in all open-plan workspaces there were significant associations between workspace floor areas, acoustic measures and employee satisfaction and the hypothesis was confirmed in only one office type (WLO1). The type of association between the aforementioned variables tended to differ in each office type. Acoustic satisfaction ratings in cellular workspaces were higher than those in open-plan workspaces. Among the three types of open-plan workspaces, open-plan with less than 10 occupants had the highest rating in comparison to the other two open-plan workspaces and was in line with the findings of Danielsson & Bodin (2009). People talking was the most annoying noise source in all four types of workspaces which was in line with the findings of Nemecek & Grandjean (1973) and Danielsson and Bodin (2008).

Based on the findings of Klitzman (1989) where acoustic satisfaction was considered an indicator for work performance satisfaction, it was expected prior to the analysis that ratings for both acoustic satisfaction and work performance satisfaction would be similarly correlated with objective variables. However, the results indicated that the different associations with objective measures were obtained for acoustic and work performance satisfaction in varying office types. Therefore, it cannot be said that acoustic satisfaction is an indicator of work performance satisfaction in cellular and open-plan workspaces. Job satisfaction or job status was not investigated in relation to objective measures in this study. According to Sundstrom et al. (1994), job satisfaction was a greater indicator of acoustic satisfaction than work performance satisfaction and Zalesny & Farace (1987) previously observed that satisfaction with the physical environment tended to vary among employees occupying different organisational positions (e.g. clerical, managerial etc.) in open-plan workspaces. It is possible that in cellular offices and open-plan workspaces, stronger associations are observed between job satisfaction and acoustic measures than between work performance satisfaction and acoustic measures.

The association between employee satisfaction and acoustic measures in this study suggest that different attitude towards noise are adopted in varying office types. In cellular workspaces, it was expected that the increase in floor area would not necessarily imply an increase in reverberation time because more furnishings are likely to be present in cellular workspaces than in open-plan spaces. But the results indicated the opposite – the increase in the size of offices was also associated with an increase in glazing which in turn was associated with an increase in reverberation time. The increase in glazing in the latter observation was perhaps linked to more access to natural daylight and ventilation than in smaller cellular offices. Furthermore, acoustic satisfaction rating tended to decrease when reverberation time increased in cellular workspaces and no association between noise level and employee satisfaction was observed which suggest that employees were sensitive to noise reflections within the confined space.

In open-plan workspaces, it was expected that the increase in workspace floor area would be associated with an increase in reverberation time but the latter was observed only in workspaces with less than 10 employees. In open-plan workspaces with less than 10 employees (WLO1), the increase in size was associated with both an increase in reverberation time and noise level. However, noise level was more significant to acoustic and work performance satisfaction than reverberation time despite both indicators of acoustic measures being within recommended values of BCO (2009) and BSI (1999) respectively. The results in WLO1 suggest that employees are more annoyed with noise disturbances caused by people talking than with acoustic quality of workspaces. To further support the latter, the association between type of desk layout and perceived noise disturbances indicates that employees in WLO1 offices prefer greater distances to co-workers with limited face-to-face interaction in non-linear desk layout.

In the other two types of open-plan workspaces (WLO2 and WLO3), contrary to what was expected the increase in workspace floor area was significantly associated with a decrease in reverberation time and an increase in acoustic satisfaction. The decrease in reverberation time in the latter workspaces was associated with the increased presence of noise-absorbing materials, such as acoustic ceiling tiles. But the association between increasing reverberation time and enhanced acoustic satisfaction is considered to be supportive of the observations made by Perham et al. (2007) and Beaman & Holt (2007) where high reverberation time was associated with less noise disturbances from background noise and improved work performance. However, it was also noted that the association between reverberation time and employee satisfaction occurred in workspaces with linear desk arrangements which was not investigated in the experimental studies of Perham et al. (2007) and Beaman & Holt (2007). The positive association between reverberation time and acoustic satisfaction in this study also occurred in open-plan workspaces with more than 10 occupants and it is considered that further investigation are to be carried out in open-plan workspaces with less than 10 occupants to further establish the association between the two variables and also with desk arrangement.

The use of noise level in this study was not considered to be revealing except in WLO1 offices because very few significant correlations were observed between noise level and employee satisfaction. The British Council for Offices (2009) suggested average daily noise level below 40 dBA for cellular workspaces and below 50 dBA for open-plan workspaces. Cellular workspaces had median noise level above the recommended value while in open-plan spaces, all three office categories had median noise level coherent with the suggested values mentioned above. Variations in acoustic and work performance satisfaction were associated with noise level only in small open-plan spaces with less than 10 employees. In larger open-plan workspaces with more than 10 occupants, variations in acoustic and work performance satisfaction had significant associations with reverberation times instead of noise level. The disparity in associations between employee satisfaction and noise level suggested that noise level itself was not adequate as an indicator of acoustic satisfaction.

In open-plan offices, the number of workspaces surveyed was less than that of cellular offices but the number of occupants exceeded that in cellular workspaces. In statistical analyses, the use of N=number of cases was considered to be more revealing of individual’s attitude to noise than the use of N=number of offices. By using N=number of offices, aggregates of variable scores would have to be used which would deflect from true variance in scores present in actual survey of satisfaction ratings. The latter method is also likely to lead to less reliable correlations between variables. For instance, in WLO3 offices only three workspaces were used and if N=3 was used in statistical analysis then it would not have been fully representative of satisfaction ratings from the 34 participants in that office category. However, to determine cause and effect between the variables when analysing cases more samples would have to be analysed.

This study made use of only questionnaire survey due to limited access to workspaces. However, it is considered that more in-depth knowledge of acoustic perception can be acquired in individual interviews. The cross-sectional research framework allowed for data collection at one point in time and it is considered that different attitudes are observed in relation to acoustic measures in longitudinal study. For instance, noise level is likely to vary during summertime due to increased frequency in window opening but its relation to employee satisfaction at that specific time is not clear. Sabine’s formula (1964) used in this study does not take into account the shape of workspaces which was observed to vary considerably in this study. The next chapter looks at the relationship between variation in the shape of floor plans and employee satisfaction.

Chapter 7

Glasgow Case Study 2: Analysis of noise geometry & employee behaviour

7.1 *Introduction*

This chapter presents the results obtained during the correlation analysis performed to determine the relationship between noise geometry, geometry of workspace and employee satisfaction. The term ‘noise geometry’ in this study is defined as the extent to which noise sources are discernible in open-plan workspaces. Geometry and proportions are generally key factors in architectural designs and initial stages of space development in architectural design revolve around abstract models and two-dimensional sketches. It was intended to devise a two-dimensional index - noise geometry - that would inform designers of the perception of noise in open-plan workspaces. Shape descriptors, area and elongation were used to quantify geometries in this chapter.

Noise geometry was generated in each workspace by drawing the convex hull for noise sources present on each open-plan drawing. Cellular workspaces were excluded from this part of research because noise geometries could not be created due to insufficient noise sources present in workspaces. A correlation analysis in Spearman’s Rho was deployed to determine the nature of the associations between 1) the area of noise geometry and workspace floor area 2) elongation of noise geometry and that of workspace geometry and 3) noise geometry and employee satisfaction. Three hypotheses were articulated; Hypothesis C: the increase in area of noise geometry will be associated with an increase in workspace floor area, Hypothesis D: elongation values of noise geometry will increase with those of workspace geometry and Hypothesis E: the increase in noise geometry indicators will be associated with a decrease in employee satisfaction.

Different results were obtained in each open-plan category where some hypotheses were supported and others rejected. All hypotheses were supported in open-plan workspaces with less than 10 occupants (WLO1) suggesting that noise geometry was a suitable indicator of employee satisfaction. In open-plan workspaces with occupancy between

10 and 25 (WLO2), Hypotheses C and E were supported and in open-plan workspaces with more than 25 employees (WLO3) only Hypothesis E was supported. The chapter begins by providing a clear description of noise geometry followed by the research questions that were being addressed and detailed results obtained during the analysis.

7.2 Visual index of auditory perception

In the previous chapter (Chapter 6), the workspace floor area was investigated in relation to acoustic measures and employee satisfaction but was not considered to be a sufficient two-dimensional index that could be used during design stages to indicate acoustic perception. Further investigation was required to link auditory perception and spatial context of workspace. According to Mershon et al. (1989) and Cabrera et al. (2002), background acoustics, such as reverberation time and noise level influenced an individual's ability to judge the distance between noise source and the individual – the increase in reverberation time and noise intensity was associated with overestimations of distances of the listener to noise sources. Cabrera et al. (2002) further observed that the increase in noise intensity degraded perceived speech quality present during experiment. The aforementioned was considered to be possibly linked to the fact that noise sources identified during field study were located within different proximities as seen on the floor plans in Chapter 6 for WLO1, WLO2 and WLO3 workspaces. WLO3 workspaces were observed to have more scattered noise sources than those in WLO1 and WLO2 offices. The studies of Mershon et al. (1989) and Cabrera al. (2002) were discussed in details in the literature review (Chapter 2) but it was to be reiterated that both studies were experimental and analysed only point sources of sound along a specific axis. These studies were considered a starting point in assessing auditory perception of noise in different office types. It was therefore considered that the perception of noise sources would have some connection to the geometry of workspace and to acoustic measures in the workspaces. It was conjectured that the extent to which noise sources would be discernible would depend on the location of noise source which varied according to the size of the workspace. But it was also expected that the extent to which noise sources would be discernible would also vary according to reverberation time of the workspace and to intensity of noise – small reverberation time would make noise sources more discernible than increasing values of reverberation time and high noise level would also be associated with greater ability to identify noise sources.

For the purpose of this study, a new variable known as ‘noise geometry’ was introduced and investigated in relation to varying workspace geometry, acoustic measures and employee satisfaction. ‘Noise geometry’ referred to the extent to which noise sources were discernible when momentarily present in workspace. Different techniques were initially sought to measure noise geometry. The use of mean distance to noise sources from the listener’s position (marked X on Figure 7.1) was thought appropriate but it was then considered that the mean distance was a weak indicator because it was not related to the workspace geometry and had no significant associations with subjective ratings in majority of workspaces. Alternately, ‘noise geometry’ was obtained by joining noise sources identified in Chapter 6 floor plans with segments to form the smallest polygon that contains all noise source points which is also known as ‘convex hull’ (Thomson Leighton 1992). The increase in noise geometry was interpreted as an increase in the extent to which noise was discernible. An example of the geometry derived from the location of noise sources is shown in Figure 7.1. Noise sources identified in the study were external road traffic, people talking (phone or with other co-workers), office machine and mechanical ventilation. The latter noise sources were also colour-coded (see Figure 7.1) to determine the most prominent ones in the workspaces. To measure the variation in geometries in this study shape descriptors, area and elongation, were used and are further described in the following section (Section 7.3).

Architectural design itself is a process which involves several logical sequences (Lawson 1997). The plan of work established by the Royal Institute of British Architects describes the process of architectural design as briefing, sketching of concepts, production of working drawings and construction phase (Lawson 1997). Solving acoustic issues in the workplace is often tackled with add-on solutions, such as the use of partitions or study booths. The use of noise geometry, in the author’s opinion, is intended to encourage workspace designers to approach acoustic at early stages of design. It is to be highlighted that noise geometry was not synonymous to the intensity of noise present in workspace but was rather describing the individual’s perception of noise in the workspace which is related to acoustic quality of space and to intensity of noise sources. In this study, variations in noise geometry were further investigated in relation to the geometry of floor plans, acoustic measures and employee satisfaction.

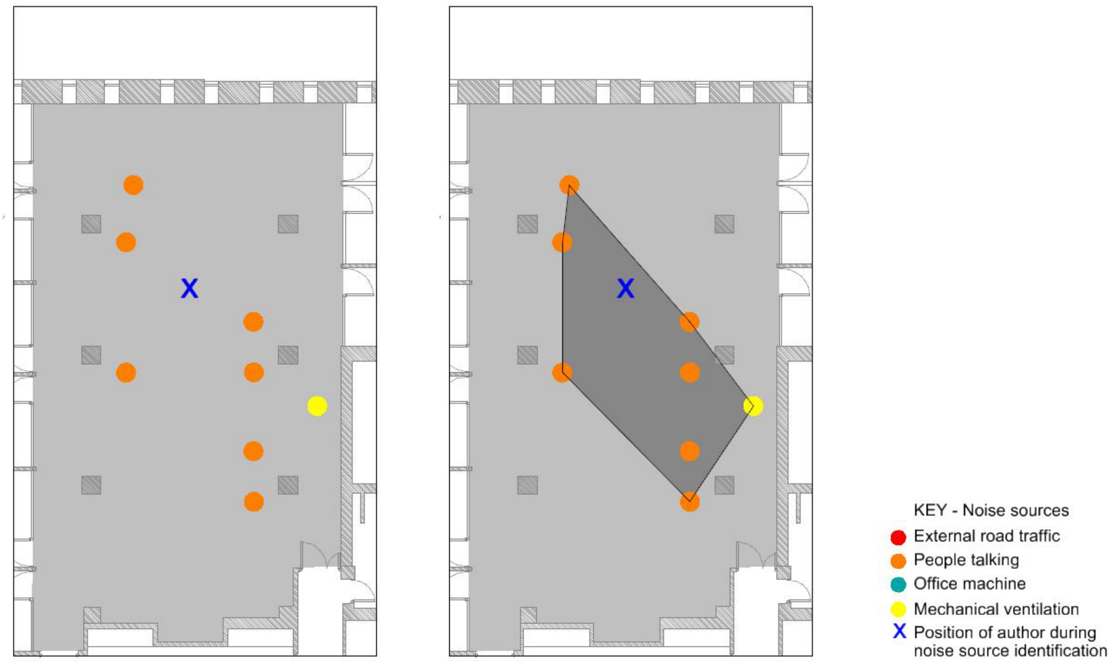


Figure 7.1 Floor plan of STH (E) office with noise sources initially identified (left image) and geometry formed (right image)

7.3 Use of shape descriptors

Shape descriptors or factors are widely used within the fields of Geographic Information Systems (GIS) to describe the shape of land formation or patches and in microscopy to describe cells and organisms. The most common types of shape descriptors within the aforementioned fields are area, compactness ratio, circularity ratio and elongation (Rumor et al. 1996). Area of the shapes refers to the size of the geometry. Compactness ratio is usually obtained by the formula $\frac{P^2}{A}$, where P is the perimeter and A is the area of the geometry. However, the comparison of compactness ratio values is more significant if the area of the geometries is invariant which was unlikely in this study. Circularity ratio was initially perceived to be a suitable method for describing the geometries in this study and is obtained by $\frac{4\pi A}{P^2}$, where A is the area of the shape and P is the perimeter (Rumor et al. 1996). The aforementioned method is the ratio of area polygon to that of area of circle both with identical perimeter and Figure 7.2 shows the two shapes. Circularity Ratio was considered to provide a brief notion of how circular the geometry and no notion of length or dimension and was therefore deemed irrelevant to the study here.

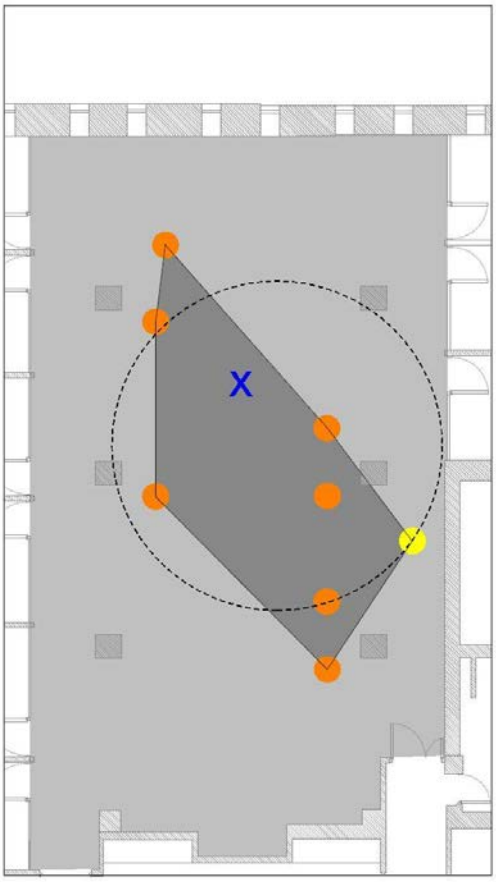


Figure 7.2 Diagram illustrating circle with same perimeter as noise geometry but with different areas which are used in Circularity Ratio

Elongation is determined by two methods; the ratio of maximum length to the maximum width of the bounding box around the geometry (Sonka et al. 1996 cited in Rumor et al., 1996) or by using the equation $\frac{A}{L^2}$, where A is the area of the geometry and L is the maximum length of the geometry (Dauwalter & Rahel 2011). The elongation method determined by ratio of maximum length to maximum width was considered to be weak because only one indicative value could be used - 1 indicated that the geometry was a perfect square and values greater than 1 indicated that the geometry was rectangular (Jiao et al. 2012). Alternately, in the method of Dauwalter & Rahel (2011) values for elongation varied between 0 and 1, where values close to 0 indicated very elongated shape and 1 represented a perfect square. The two shape descriptors that were considered to be convenient for this study was area and elongation because area indicated that size of the shape and elongation provide some notion of the form of shape. The method of Dauwalter & Rahel (2011) was used for elongation in this study.

Figure 7.3 indicates the two geometries that are being assessed by the use of area and elongation – geometry of workspace and noise geometry.

To determine the maximum length of the geometries in this study, bounding boxes around the geometries were used. Different techniques for the bounding boxes are generally used and here the box with the smallest area was considered to be appropriate given that it would it be closest to the area of geometry. The method established by Toussaint (Chan & Tan 2001), also known as the 'rotating calliper technique' used the minimum area of the bounding box collinear to the convex hull. Elongation values below 0.5 were considered to be very elongated geometries and values above 0.5 were interpreted as less elongated than those above 0.5.

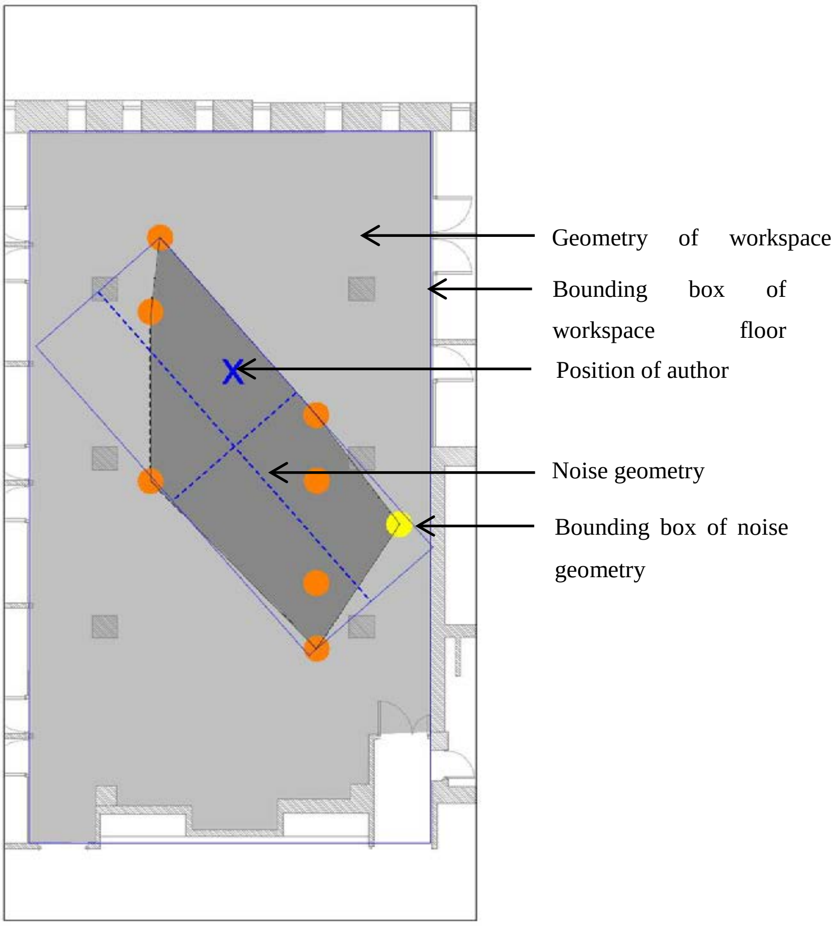


Figure 7.3 Diagram illustrating geometry of workspace and noise geometry. Bounding box based on Toussaint's (Chan & Tan 2001) technique around the noise geometry is also shown for STH (E) office

7.4 Research questions and hypotheses

Open-plan offices in Glasgow sample were further analysed to determine the association between noise geometry, geometry of workspace and employee satisfaction. As mentioned in the previous section (Section 7.3) two variables for geometry were taken into consideration, area and elongation because both shape descriptors varied considerably when analysing the floor plan drawings of each office. The latter observation was further supported by the results obtained in Kruskal-Wallis where area and elongation of workspace geometry and noise geometry differed significantly for different open-plan workspace categories (see Table E.1 in appendices). For workspaces, the mean ranking of workspace floor area in Kruskal-Wallis increased from WLO1 to WLO3 indicating that WLO3 had the largest area among the three office categories but the contrary was observed for elongation of workspace geometry – the WLO1 had the highest values and WLO3 the lowest. The latter indicated that workspaces in WLO3 offices were more elongated than those in WLO1 office category. The median values for workspace floor area were: 57.5m^2 in WLO1, 98.6m^2 in WLO2 and 265.6m^2 in WLO3 and median values for elongation of workspace geometry were: 0.65 in WLO1, 0.51 in WLO2 and 0.45 in WLO3. On the other hand, both area and elongation of noise geometry increased linearly from WLO1 to WLO3 as indicated in Kruskal–Wallis (see Table E.1 in appendices). The median values for area of noise geometry were: 16.0m^2 in WLO1, 31.2m^2 in WLO2 and 76.6m^2 in WLO3 workspaces and median values for elongation of noise geometry were: 0.24 in WLO1, 0.31 in WLO2 and 0.69 in WLO3. The area of noise geometry values tended to be twice bigger when shifting from one office type to the next.

Area and elongation are considered as two variables that indicate different aspects of geometries in this study – area relates to the size of the geometry while elongation refers to the degree to which geometry is extended. It was not expected that area and elongation of workspaces would increase together because external factors such as location of site and division of floor plan tends to affect the area and elongation of workspaces. Given that area and elongation of workspace did not increase proportionally, area and elongation were analysed individually. It was expected that workspace floor area would be associated with area of noise geometries and elongation of workspace geometries would be associated with elongation of noise geometries. The following research questions were formulated to investigate the associations between workspace geometry indicators, noise geometry indicators and employee satisfaction:

1. *Is the area of noise geometry associated with workspace floor area in all open-plan workspaces?*
2. *Is the elongation of noise geometry associated with the elongation of workspace geometry in all open-plan workspaces?*

3. *Is employee satisfaction related to the indicators of noise geometry in all open-plan workspaces?*

Based on the results obtained in Chapter 6, it was observed that the increase in workspace floor area was associated with a decrease in acoustic satisfaction in all three office open-plan office categories which was considered to be linked to increase in noise disturbances present. It was initially conjectured that these increase in noise disturbances would be further reflected in the increase of noise geometry. Therefore, in relation to the first question listed above, it was hypothesised that the increase in area of noise geometries would be associated with an increase in workspace floor area of workspaces in all open-plan workspaces (Hypothesis C). Elongation of workspace geometry or noise geometry had not been previously investigated in relation to noise disturbances in open-plan workspaces but given that the increase in elongation value indicated an increase in expansion of shape it was hypothesised that elongation values of workspace geometry and noise geometry would increase together in all open-plan workspaces (Hypothesis D). Since the increase in noise geometry indicators was intended to represent an increase in perceived noise, it was hypothesised that the increase in noise geometry indicators would be associated with a decrease in acoustic and work performance satisfaction (Hypothesis E). The diagram below (Figure 7.4) indicates the hypothesised associations between the variables being analysed in this chapter. The variables were analysed in Spearman's Rho and the results for each office type are presented in the following section.

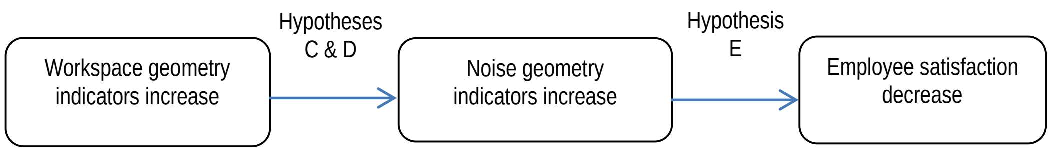


Figure 7.4 Hypothesised links between workspace geometry, noise geometry and employee satisfaction for all open-plan workspaces

7.5 Correlational analysis between variables

In the analysis of the sample as a whole, both area of noise geometry and workspace floor area increased together ($r=0.791$, $N=153$, $p<0.01$) but the elongation of noise geometry tended to increase when the elongation of workspace geometry decreased ($r=-0.204$, $N=153$, $p<0.05$) which indicated that noise geometries grew in size but not in elongation when workspace floor geometries increased in both size and elongation. It was to be reiterated that the increase in values of elongation implied a decrease in expansion of shape because elongation values close to 0 signified that the shape was very elongated while those close to 1 signified that the shape was similar to a square (Dauwalter & Rahel 2011). In the overall sample, employee satisfaction was also analysed in relation to workspace floor geometry and noise geometry. These early correlation coefficients also indicated that acoustic satisfaction decreased when workspace geometry increased in size (r=-0.329, N=153, p<0.01) and elongation of workspace floor geometry was not relevant to acoustic satisfaction. In relation to noise geometry, acoustic satisfaction in general tended to decrease when noise geometry increased in size (r=-0.242, N=153, p<0.01) and was less elongated (r=-0.180, N=153, p<0.05). In Chapter 6, an office rating scale based on reverberation time and number of noise sources observed was used to rate each workspace. An identical scale to that used in Chapter 6 was also used here but with the addition of noise geometry on the floor plans to indicate the perception of noise in workspaces with varying workspace floor area and acoustic quality. Spearman's Rho indicated that there was no significant changes in office ratings when area of workspace geometry increased but office ratings tended to increase when workspace geometry were more elongated (r=-0.333, N=153, p<0.01). In relation to noise geometry, office ratings increased when noise geometry decreased in size (r=-0.289, N= 153, p<0.01) and was more elongated r=-0.271, N=153, p<0.01). Given that the noise geometries varied among office types, the association between noise geometry indicators, workspace geometry indicators and employee satisfaction were further analysed individually.

7.5.1 *WLO1 workspaces*

As mentioned previously in Chapter 6, 59.1% of employees were satisfied with acoustics at their workplace and only 39.4% agreed that their current office type was suitable for work completion. The median value for workspace floor area was 57.5m^2 and that of area of noise geometry was 16.0m^2. The median elongation value for workspace geometry was 0.65 and that for noise geometry was 0.24. Noise geometries in WLO1 offices were considered to be very elongated in comparison to workspace geometry because the median value was below 0.50. There was no significant association between workspace floor area and elongation of workspace floor geometry to suggest that workspaces were more elongated when they increased in size but when analysing noise geometry, both area and elongation ratio increased together (r=0.765, N=33, p<0.01) indicating that noise geometry was more expanded (or bulged) when its area increased. The median office rating in WLO1 office category was 3.0 and it was observed on the rating scale (Figure 7.6) that noise geometry tended to be smaller when office ratings increased, with the exception of WRI office.

In WLO1 offices, both area (r=0.681, N=33, p<0.01) and elongation ratio (r=0.684, N=33, p<0.01) of workspace floor geometries and noise geometries increased together. In the analysis of workspace floor geometry and acoustic measures, it was observed that the increase in size of workspace (r=0.545, N=33, p<0.01) was associated with an increase in reverberation time and an increase in noise level (r=0.493, N=33, p<0.01). As mentioned previously in Chapter 6, reverberation time in WLO1 offices was related to the presence of reflective surfaces, such as glazed partitions, in large WLO1 offices and noise level was associated with the type of desk layout significant to communication among employees. There was, however, no significant correlation between the elongation of workspace with any indicator of acoustic measures in WLO1 offices.

For noise geometries, the increase in area of noise geometries was associated with an increase in noise level (r=0.607, N=33, p<0.01). Despite the fact that workspace floor area was previously associated with an increase in reverberation time (RT), area of noise geometry had no significant associations with reverberation time because no linear relationship was present between the two variables – RT values tended to fluctuate with increasing values of noise geometry area. On the other hand, the increase in elongation **ratio** values of noise geometry was associated with an increase in both noise level (r=0.447, N=33, p<0.01) and RT (r=0.378, N=33, p<0.05) but the difference in correlation coefficient values indicated that elongation of noise geometry had stronger correlation with noise level than with RT. These aforementioned associations therefore indicated that indicators of noise geometries were proportional to that of workspace geometry. Also the increase in size and decrease in elongation (as indicated by increasing values of elongation ratio) of noise geometry was also associated with an increase in noise level. Given that this study focused on associations between variables it was difficult to establish a causal relationship between noise geometry and noise level. Workspaces with noise geometry area above 16.0m^2 and elongation values above 0.24 had noise level above 44.4 dBA. In addition to workspace geometry, area (r=-0.383, N=33, p<0.01) and elongation values (r=-0.565, N=33, p<0.01) of noise geometry also tended to increase when office ratings decreased which indicated that workspaces with more noise sources and poor acoustic quality had large and less elongated (as indicated by increasing values of elongation ratio) noise geometry.

It was previously observed in Chapter 6 that the increase in the size of workspaces was associated with a decrease in acoustic satisfaction but in the analysis of geometry there was no significant association between the elongation of workspace floor geometry and acoustic satisfaction. No further correlations were observed between elongation of workspace geometry and work performance satisfaction. The variables for noise geometry were further investigated in relation to employee satisfaction. The increase in the area of noise geometry was also associated with a decrease in acoustic satisfaction ($r=-0.377$, $N=33$, $p<0.05$) (see Figure 7.5) and with an increase in preference for alternate office type for completion of task ($r=0.511$, $N=33$, $p<0.01$). Workspaces with noise geometry areas below $16.0m^2$ had 75% of employees satisfied with acoustics at their workspace and 53.6% reported that their office type was appropriate for work completion. In workspaces with noise geometry area above $16.0m^2$, 47.4% of employees were satisfied with acoustics and 29% found that their office type was appropriate for work completion. Alternately, elongation of noise geometry in WLO1 had no significant correlations with acoustic or work performance satisfaction. It was considered that variation in elongation values were not proportional to those of acoustic and work performance ratings in WLO1 offices.

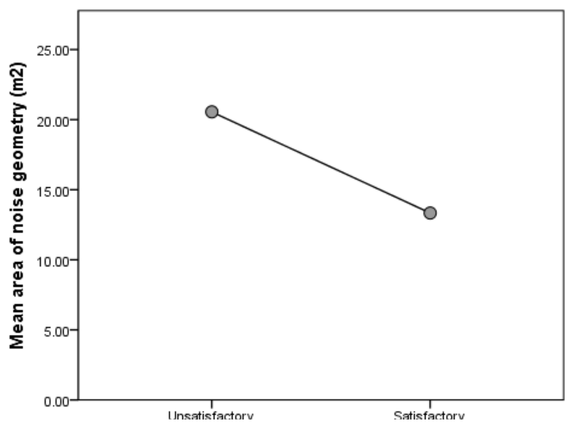


Figure 7.5 Relationship between acoustic satisfaction and area of noise geometry in WLO1 offices

The results indicated that the increase in workspace floor geometry indicators was also associated with increase in noise geometry indicators which in turn was also associated with increasing noise level. It was previously observed in Chapter 6 that the increase in workspace floor area and noise level in WLO1 was both significantly correlated with the type of desk layout - linear arrangements were located in workspaces with area above $57.5m^2$ and noise level above 44.4 dBA and were also associated with more noise disturbances than in workspaces with non-linear desk arrangements. These findings were considered to be linked to the possibility that in linear arrangements employees were in closer proximity than those in non-linear desk layouts which likely increased conversation levels and perceived noise in workspaces with linear desk layouts. There was no significant association between elongation of workspace geometry and type of desk layout to suggest that linear desk arrangements were located in elongated workspaces. However, in the analysis of noise geometry in Kruskal-Wallis, it was observed that area and elongation values were higher in workspaces with linear desk arrangements than those with non-linear desk layouts with $X^2(1) = 6.476$, $p<0.05$ for area and $X^2 (1) = 7.495$, $p<0.01$ for elongation. Therefore, it could be said that noise geometries tended to expand (increase in size but decrease in elongation) in large workspaces where workspace floor area was above 57.5m^2 with linear desk arrangements and further supported the argument that acoustic satisfaction was very low in open-plan workspaces with linear desk arrangements and with occupancy below 10 employees.

Three hypotheses were articulated at the beginning of this section and were all supported by the results obtained in WLO1 offices. Hypothesis C stated that the increase in area of noise geometry would be associated with an increase in workspace floor area which is supported here – the increase area of noise geometry was significantly associated with an increase in workspace floor area and noise level. Offices with workspace floor area above 57.5m^2 had noise geometry areas above 16.0m^2 and noise level above 44.4 dBA. Hypothesis D was similar to Hypothesis C but was related to elongation of geometries – the increase in elongation of workspace floor geometry would be associated with an increase in elongation of noise geometry. The results indicated that elongation ratio values for both noise geometry and workspace geometry increased together in WLO1 offices. The increase in elongation ratio values of noise geometry was associated with an increase in both noise level and reverberation time. Hypothesis E stated that increase in noise geometry indicators would be associated with a decrease in employee satisfaction. The relationship between area of noise geometry and employee satisfaction supported Hypothesis E but not the association between elongation and employee satisfaction. The increase in area of noise geometry above 16.0m^2 was associated with a decrease in acoustic satisfaction from 75% to 47.4% and a decrease in work performance satisfaction from 53.6% to 29%. No significant associations were observed between elongation ratio values of noise geometry and acoustic or work performance satisfaction. Therefore it could be said that in offices with workspace floor area above 57.5m^2 and linear desk arrangements, noise level was above 44.4 dBA and there was an increase in the extent to which noise sources were perceived in comparison to offices with workspace floor area below $57.5m^2$ and non-linear desk layouts.

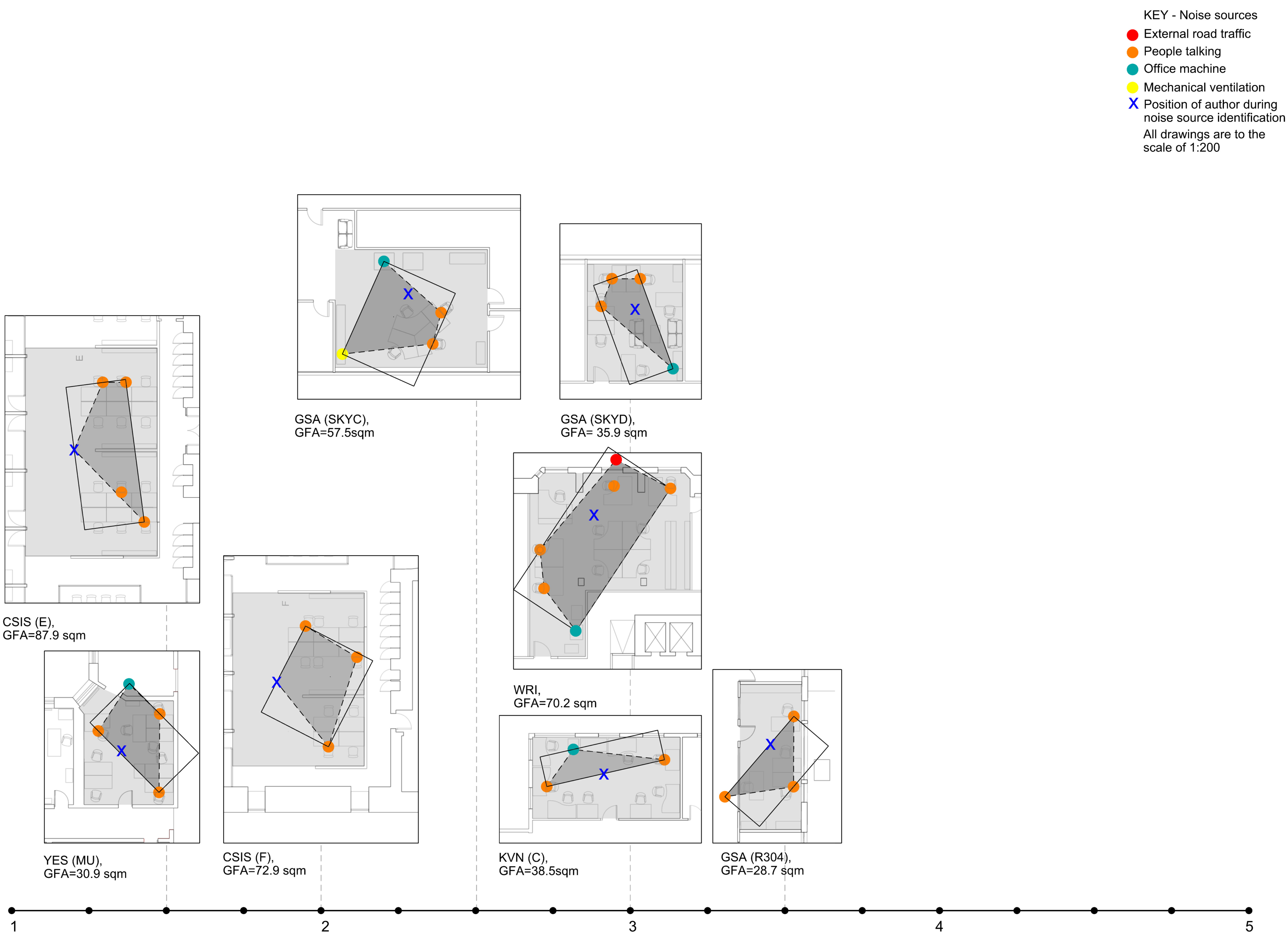


Figure 7.6 Office rating scale with noise geometry in WLO1 offices, Glasgow

7.5.2 *WLO2 workspaces*

In WLO2 workspaces, both acoustic satisfaction (36.8%) and work performance satisfaction (48.5%) ratings were below 50% and considered poor. The median workspace floor area value was 98.6m^2 and that of area of noise geometry was 31.2m^2. The median elongation value for workspace geometry was 0.51 and that of noise geometry was 0.31. Similar to WLO1 offices, noise geometries in WLO2 offices were considered to be very elongated given that the median value for elongation was below 0.50. Correlation coefficients indicated that both area and elongation of workspace floor geometry increased together suggesting that workspace floor geometry was more expanded (increased in size and was less elongated) when its area increased ($r=1.00$, $N=34$, $p<0.01$). Similarly, area of noise geometry increased together with elongation ratio values ($r=0.569$, $N=34$, $p<0.01$). As mentioned in the above section, identical office rating scale to that used in Chapter 6 was also used here. The median office rating in WLO2 office category was 1.0 which was very inferior and it was observed on the rating scale that noise geometry tended to be larger when office rating increased (see Figure 7.8).

It was initially expected that indicators of workspace floor geometry would be associated with those of noise geometry. The results indicated that both area of noise geometry and that of workspace floor area increased together ($r=0.664$, $N=34$, $p<0.01$) but no significant association was observed between elongation of workspace floor geometry and that of noise geometry. It was previously observed in Chapter 6 that workspace floor area also had no significant association with noise level which was considered to be related to external road traffic and less with activities within workspace. Here, no significant correlations were present between indicators of workspace floor geometry and noise level in WLO2 offices. However, it was observed that the increase in reverberation time was associated with smaller ($r=-0.664$, $N=34$, $p<0.01$) and less elongated ($r=-0.664$, $N=34$, $p<0.01$) workspace floor geometry as indicated by the negative correlation coefficient values obtained.

The results indicated that the increase in area of noise geometry was associated with a decrease in reverberation time ($r=-0.569$, $N=34$, $p<0.01$). Similar to workspace floor geometry, no significant correlation was observed between area of noise geometry and noise level. But the increase in elongation values of noise geometry was significantly associated with a decrease in reverberation time ($r=-0.569$, $N=34$, $p<0.01$). The aforementioned results indicated that the increase in both area and elongation values of noise geometry was associated with decreasing reverberation time – area above 31.2m^2 and elongation value above 0.31 was associated with RT below 0.95s. The results suggested that the extent to which noise sources were discernible increased in size but decreased in elongation when RT was low which was possibly linked to the fact that noise sources were easily identified in spaces with low sound reflections. The most common noise source in WLO2 workspaces was people talking and in reference to Beaman & Holt (2007) changing state of irrelevant background speech is associated with disturbances when reverberation time is low. The expansion (increase in size but less elongation) of noise geometry in workspaces with decreased reverberation time below 0.95s was considered to support the aforementioned study by indicating that the extent to which noise sources were discernible was greater when reverberation time decreased because of low background noise reflection. In Chapter 6 it was observed that workspaces with median office rating below 3 had enhanced acoustic satisfaction ratings which were contrary to WLO1 workspaces. As mentioned at the beginning of this section, it was observed that noise geometry was visibly larger when office rating increased. The results obtained here further supported the observations in Chapter 6 for WLO2 offices - both area (r=0.886, N=34, p<0.01) and elongation (r=0.886, N=34, p<0.01) values of noise geometries increased together with office ratings.

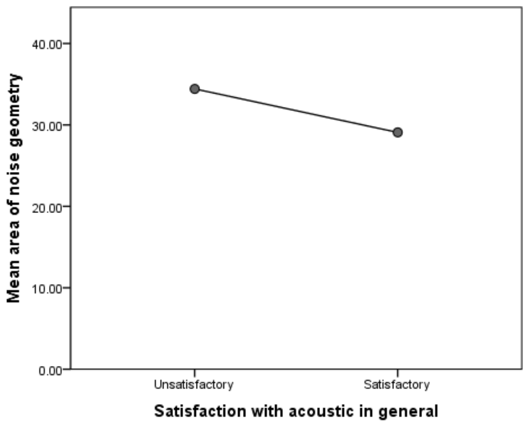


Figure 7.7 Relationship between acoustic satisfaction and area of noise geometry in WLO2 offices

It was previously observed in Chapter 6 that the increase in the size of floor area was associated with a decrease in both acoustic and work performance satisfaction. Here, the correlation coefficients showed that the increase in elongation of workspace geometry (as indicated by negative correlation coefficient value) was associated with an increase in acoustic satisfaction (r=-0.529, N=34, p<0.01) and with an increase in the perceived ability to concentrate on work (r=-0.494, N=33, p<0.01). The increase in acoustic and work performance satisfaction in the latter observations was considered to be related to the fact the elongated workspaces also had higher reverberation time than less elongated workspaces which dampened background noise hence increasing employee satisfaction.

Noise geometry indicators were analysed in relation to employee satisfaction and the results indicated that the increase in area of noise geometry was associated with a decrease in acoustic satisfaction ($r=-0.370$, $N=34$, $p<0.05$) (see Figure 7.7) and an increase in the preference for alternate office type task to complete tasks ($r=0.355$, $N=34$, $p<0.05$). In workspaces with area of noise geometry below 31.2m^2, 60.8% of employees were satisfied with acoustics at their workplace and 75% agreed that their office type was suitable for task completion. In workspaces with area of noise geometry above 31.2m^2, 29.2% of employees were satisfied with acoustics at their workplace and 41.7% agreed that their office type was suitable for task completion. On the other hand, elongation of noise geometry was not significantly associated with acoustic satisfaction or with the preference for alternate office type for work completion. Similar to WLO1, the variations in elongation values of noise geometry was not proportional to acoustic and work performance satisfaction ratings.

In WLO1 workspaces, it was observed that the type of desk layout was significantly associated with workspace area, noise level and noise geometry indicators – linear desk arrangement in offices with workspace area above 57.5m^2 was associated with an increase in noise level above 44.4 dBA and an increase in noise geometry. In WLO2 offices, all workspaces had linear desk arrangements but it was observed in Chapter 6 that the increase in reverberation time was associated with an increase in acoustic and work performance satisfaction. Here, the results suggested that in linear desk arrangements in WLO2 offices, the increase in reverberation time was associated with a decrease in values of noise geometry indicators indicating that the extent to which noise sources were discernible was smaller and more elongated than those in workspaces with decreasing reverberation time (as shown in the previous paragraphs).

Similar to WLO1 workspaces, three hypotheses were tested in WLO2 offices and the results obtained supported only two of them. Hypothesis C stated that the increase in area of noise geometry would be associated with an increase workspace floor area. The results in WLO2 workspaces indicated that the increase in area of noise geometry was associated with an increase in workspace floor area which supported Hypothesis C. In Hypothesis D, it was conjectured that both elongation of noise geometry and that of workspace geometry would increase together and the results presented here indicated that no significant association was observed between elongation values of noise geometry and that of workspace geometry which failed to support the hypothesis. The increase in elongation value of noise geometry was associated with a decrease in reverberation time. Hypothesis E stated that the increase in values of noise geometry indicators would be associated with a decrease in acoustic and work performance satisfaction. The results showed that the increase in area of noise geometry was significantly associated with a decrease in acoustic satisfaction and an increase in preference for alternate office type for completion of task which supported Hypothesis E. Similar to WLO1 workspaces, the use of area was more indicative of the association between workspace geometry, noise geometry and employee satisfaction than elongation ratio. WLO2 offices with workspace floor area above $98.6m^2$ and RT below 0.95s had an increase in area of noise geometry above $31.2m^2$ which was associated with a decrease of 31.6% (from 60.8 to 29.2%) in acoustic satisfaction.

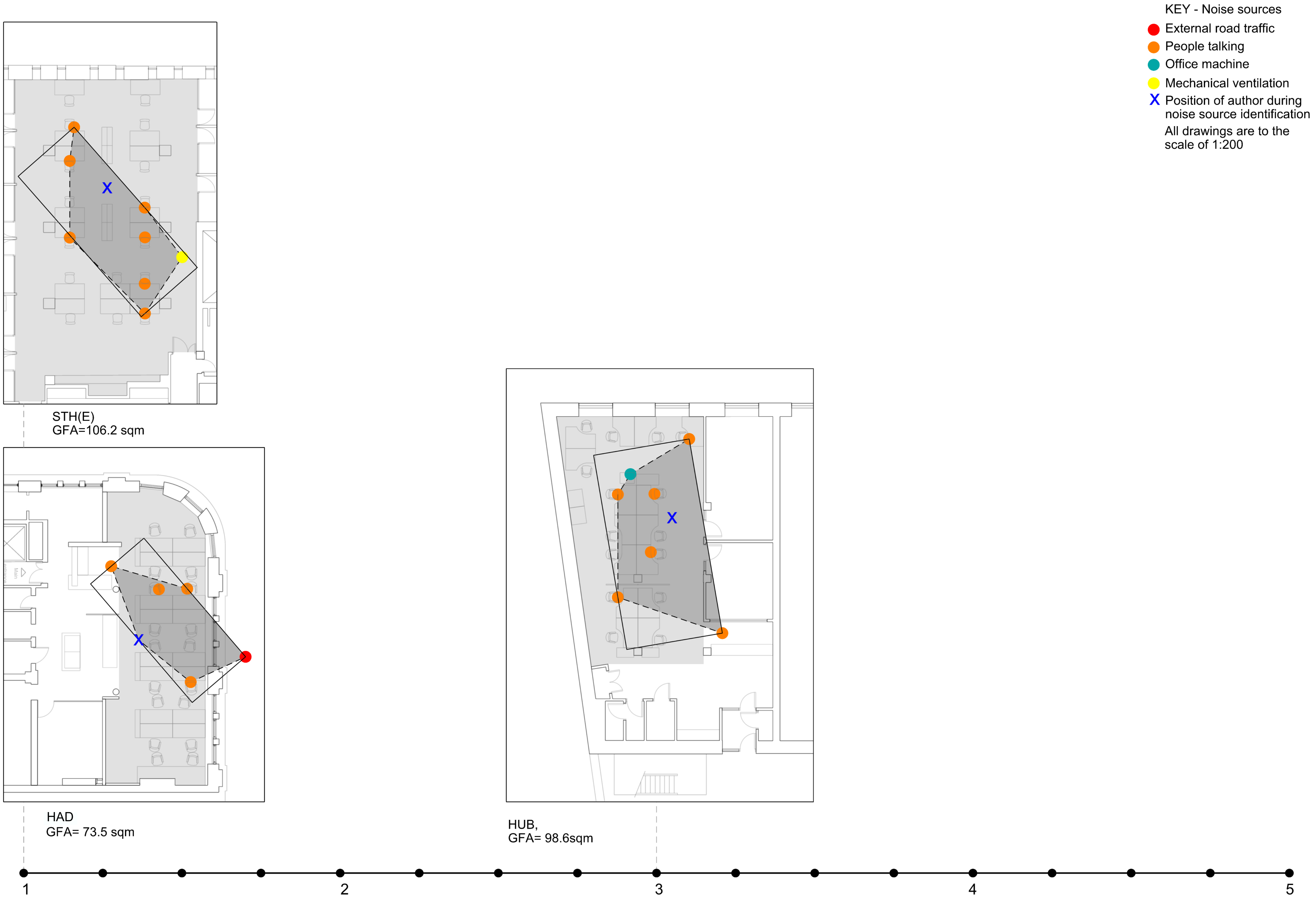


Figure 7.8 Office rating scale with noise geometry in WLO2 offices, Glasgow

7.5.3 *WLO3 workspaces*

In WLO3 workspaces, ratings for acoustic satisfaction and work performance were both below 50% and considered inferior which was similar to WLO2 offices. The median workspace floor area was 265.6m^2 and that of noise geometry area was 76.6m^2. Median elongation value for workspace geometry was 0.45 and that of noise geometry was 0.69. Contrary to WLO1 and WLO2 workspaces, workspace geometry was more elongated than noise geometry because its median value was below 0.50. The three hypotheses formulated in Section 7.4 were also tested in WLO3. The median office rating in WLO3 office category was 1.0 and it was observed that noise geometry was more expanded with decreasing values of office rating on the scale in Figure 7.10.

In the analysis of geometry indicators, the coefficient correlations in Spearman's Rho indicated that no significant associations were present between workspace geometry and noise geometry. The increase in workspace floor area was not significantly correlated with the increase in area of noise geometry and the increase in elongation values of workspace geometry was not significantly associated with those of noise geometry. In Chapter 6, it was observed that the increase in workspace floor area was associated with an increase in noise level and a decrease in reverberation time. Here also, the increase in elongation of workspace floor geometry was associated with an increase in noise level ($r=-0.603$, $N=86$, $p<0.01$) and a decrease in reverberation time ($r=1.00$, $N=86$, $p<0.01$).

Both area and elongation of noise geometry were associated with noise level indicating that the increase in noise level was associated with a decrease in noise geometry area ($r=-0.455$, $N=86$, $p<0.01$) and an increase in elongation of noise geometry ($r=-0.455$, $N=86$, $p<0.01$)(as indicated by the negative correlation coefficient values for elongation ratio). No significant associations were observed between noise geometry indicators and reverberation time in WLO3 workspaces. In WLO1 workspaces, it was observed that both area of noise geometry and noise level increased together but in WLO3 the results indicated the opposite – increase in noise level was associated with smaller and more elongated noise geometry. WLO3 workspaces had higher noise level (median of 50.0 dBA) than WLO1 offices (median of 44.4 dBA) and it was considered that the higher noise level in WLO3 workspaces possibly created a masking effect hence decreasing the extent to which noise sources were discernible as indicated by noise geometry. The absence of significant correlation between workspace geometry indicators and those of noise geometry was due to the fact that they did not increase linearly. An uncommon feature was noticed in one of the workspaces which possibly influenced the association between workspace floor area and area of noise geometry - in GLUN office (shown in Figure 7.10), partitions with the main entrance to the office were not full-height, i.e. there was a gap between the partitions and ceiling which made noise outside the office noticeable thus increasing the size of noise geometry. Despite the absence of significant associations between workspace floor geometry and noise geometry indicators, the latter was significantly associated with office ratings – office ratings decreased when area ($r=-0.384$, $N=86$, $p<0.01$) and elongation values ($r=-0.384$, $N=86$, $p<0.01$) of noise geometry increased. The latter associations indicated that noise sources were more discernible when acoustic quality of workspace deteriorated and more noise sources were present which was coherent with WLO1 findings.

Despite the fact that indicators of workspace floor geometry and those of noise geometry were not associated in WLO3 offices both types of geometries were associated with employee satisfaction. The increase in the size ($r=-0.385$, $N=86$, $p<0.01$) and elongation ($r=0.250$, $N=86$, $p<0.05$) (as indicated by the positive correlation coefficient for elongation ratio which suggests that elongation ratio and acoustic satisfaction rating decrease together) of workspace floor geometry was associated with a decrease in acoustic satisfaction. However, indicators of workspace floor geometry were not significantly correlated with work performance satisfaction in WLO3 workspaces. This decrease in acoustic satisfaction when workspace floor geometries increased in size and elongation was considered to be related to the increase in noise level and decrease in reverberation time when workspace floor geometry increased in elongation and size.

Noise geometry indicators were analysed in relation to employee satisfaction and it was initially expected that the increase in both noise geometry indicators would be associated with a decrease in employee satisfaction. The results showed that the increase in area of noise geometry was associated with a decrease in acoustic satisfaction ($r=-0.317$, $N=86$, $p<0.01$) (see Figure 7.9) and a decrease in the perceived ability to remain usually concentrated on work ($r=-0.461$, $N=86$, $p<0.01$). Similar results were obtained for elongation values of noise geometry – the increase in elongation values was associated with a decrease in acoustic satisfaction ($r=-0.317$, $N=86$, $p<0.01$) and in the perceived ability to remain usually concentrated on work ($r=-0.461$, $N=86$, $p<0.01$). In WLO3 workspaces with area of noise geometry below $76.6m^2$ and elongation value below 0.69, 80% of employees were satisfied with acoustics at their workplace and all of the employees were usually able to remain concentrated on work. In WLO3 workspaces with area of noise geometry above $76.6m^2$ and elongation value above 0.69, 35.5% of employees were satisfied with acoustics at their workspace and 75% of employees were usually able to remain concentrated on work. The decrease in work performance satisfaction rating from 100% to 75% could be considered as unsubstantial because the rating was above 50% in both cases but the decrease in acoustic satisfaction was considered significant. These aforementioned associations indicated that the increase in the extent to which noise sources were discernible, as indicated by noise geometry, was related to a decrease in acoustic satisfaction.

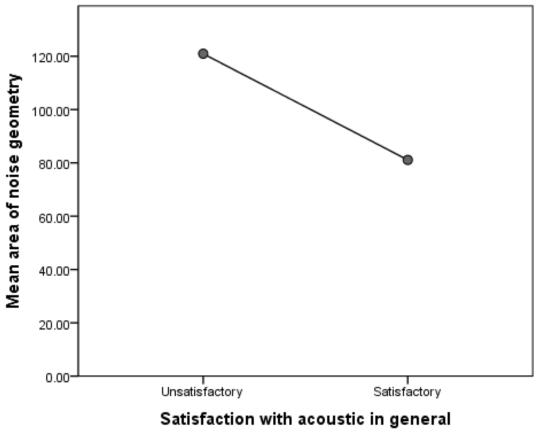


Figure 7.9 Relationship between acoustic satisfaction and area of noise geometry in WLO3 workspaces.

The increase in area (r=-0.339, N=86, p<0.01) and elongation (decrease in elongation ratio) (r=0.339, N=86, p<0.01) of workspace floor geometry was associated with linear desk layouts in WLO3 offices. In WLO1 workspaces it was observed that linear desk arrangements were associated with a decrease in acoustic satisfaction and an increase in both area and elongation of noise geometry. In WLO3 offices, the opposite association was observed; linear desk arrangements were associated with a decrease in area of noise geometry (r=0.903, N=86, p<0.01) and an increase in elongation of noise geometry (decrease in elongation ratio value) (r=0.903, N=86, p<0.01). The latter findings also failed to support the findings in Chapter 6 where acoustic satisfaction in WLO3 offices increased with reverberation time in workspaces with linear desk arrangements because no significant association was observed between noise geometry indicators and reverberation time. On the other hand, the results also suggested that noise geometry was less expanded in offices with linear desk layouts which indicate that the extent to which noise sources were discernible was smaller and more elongated in linear offices than in non-linear ones. These contradictory findings for desk arrangements and noise geometry were considered to be linked to the differences in office design, such as gaps between office partitions, as mentioned in the above paragraph.

The results obtained from the correlation analysis in WLO3 office category supported only one hypothesis – Hypothesis E. In Hypothesis C it was articulated that the increase in noise geometry area would be associated with an increase in workspace floor area.

Area of noise geometry had no significant association with workspace floor area which failed to support Hypothesis C. Hypothesis D stated that both elongation values of noise geometry and workspace geometry would increase together. Similar to area, no significant correlation was observed between the elongation values of noise geometry and that of workspace geometry which failed to support Hypothesis D. Hypothesis E stated that the increase in noise geometry indicators would be associated with a decrease in employee satisfaction which was supported here. In WLO3, the increase in area of noise geometry above 76.6m^2 and elongation ratio values of noise geometry above 0.69 was associated with a decrease in acoustic satisfaction below 50% (from 80 to 35.5%).

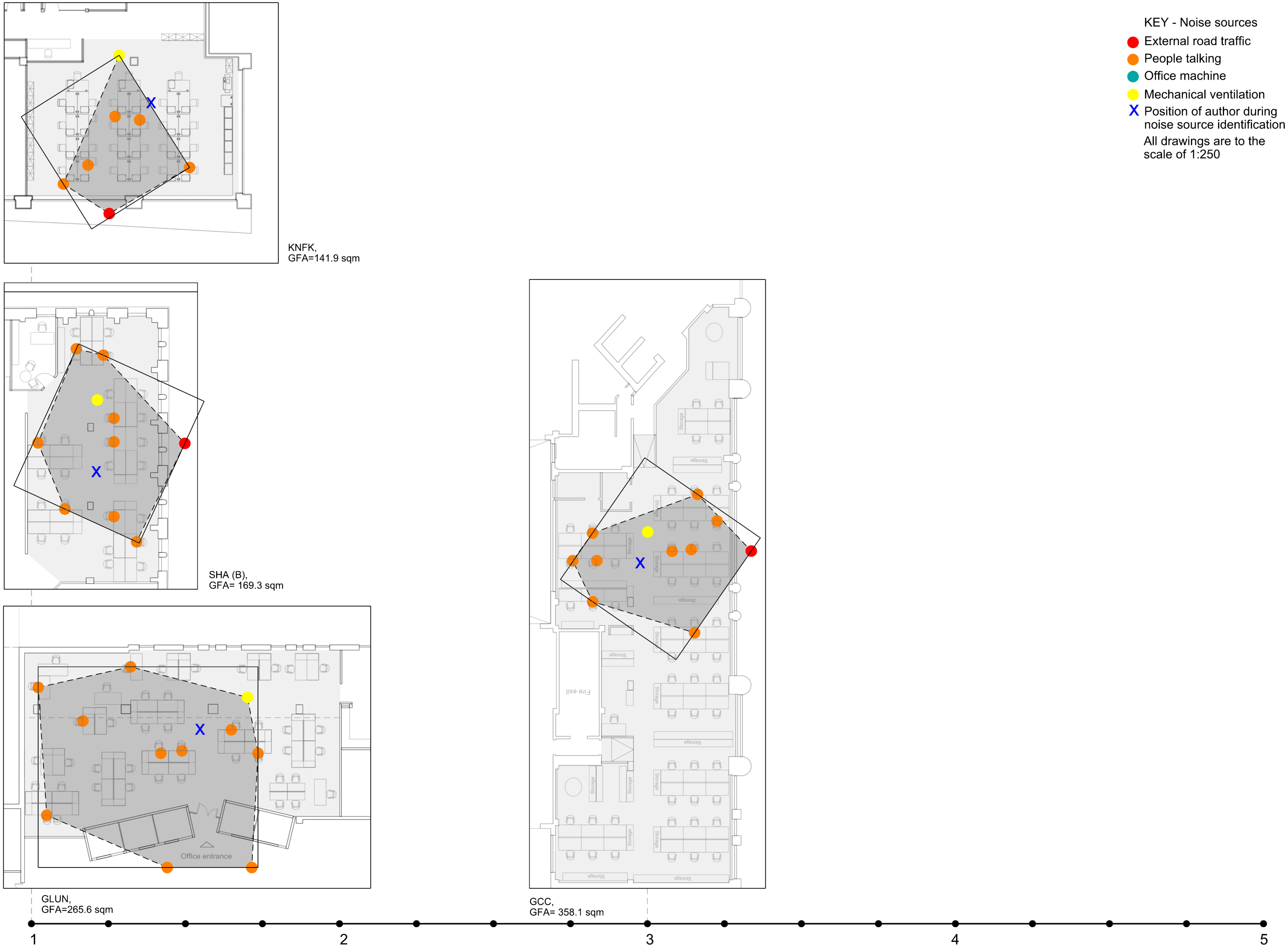


Figure 7.10 Office rating scale with noise geometry for WLO3 offices, Glasgow

7.6 Synthesis of area and elongation of noise geometry

The intended use of noise geometry was to indicate the perception of noise in open-plan workspaces and how it was related to office design and acoustic measures. In Chapter 6, it was observed that workspace floor area in all three types of open-plan workspaces was associated with acoustic measures and acoustic satisfaction. The analysis of noise geometry further supported the findings in Chapter 6 for WLO1 and WLO2 workspaces. In WLO1 offices, the decrease in workspace floor area was associated with a decrease in noise level and a decrease in the area of noise geometry which in turn was associated with an increase in acoustic and work performance satisfaction levels. In WLO2 workspaces, the decrease in workspace floor area was associated with an increase in reverberation time and a decrease in area of noise geometry which in turn was associated with an increase in acoustic and work performance satisfaction. In WLO3 workspaces the increase in noise geometry area and elongation ratio values were both associated with a decrease in acoustic and work performance satisfaction but not with indicators of workspace geometry. It was also observed that the type of desk layout was significant to acoustic satisfaction and noise geometry in WLO1 and WLO2 offices. In WLO1 workspaces, non-linear desk layouts were significantly correlated with enhanced acoustic satisfaction and smaller and less elongated noise geometry than offices with linear desk layouts. In WLO2 offices, all offices had linear desk layouts in this study but the increase in reverberation time was then associated with enhanced acoustic satisfaction and a decrease in values noise geometry indicators. Based on the results obtained in this chapter, the technique used for noise geometry could be used to indicate acoustic and work performance satisfaction ratings in WLO1 and WLO2 workspaces. Table 7.0 indicates the values corresponding to increase in acoustic and work performance satisfaction in WLO1 and WLO2 workspaces. It was observed that the median value of noise geometry area in WLO1 was almost twice that of WLO2 workspaces.

Office type	Workspace floor area (m^2)	Acoustic measure	Noise geometry area (m^2)	Satisfaction level
WLO1 – open-plan with less than 10 employees	<57.5	Noise level below 44.4 dBA	<16.0	>50%
WLO2 – open-plan with 10 to 25 employees	<98.6	RT above 0.95s	<31.2	>50%

Table 7.0 Values for noise geometry and workspace geometry associated with employee satisfaction

7.7 **Summary**

In this chapter, it was intended to make use of a visual index known as 'noise geometry' to indicate perception of noise in WLO1, WLO2 and WLO3 open-plan workspaces. 'Noise geometry' was defined as the extent to which noise was perceived when momentarily present in a space. Area and elongation was used as indicators of geometry in the study. Three research questions were addressed in this chapter: 1) is the area of noise geometry associated with workspace floor area in all open-plan workspaces? 2) Is the elongation of noise geometry associated with the elongation of workspace geometry in all open-plan workspaces? 3) Is employee satisfaction related to the indicators of noise geometry in all open-plan workspaces? Three hypotheses were articulated for each question: Hypothesis C stated that the increase in area of noise geometry would be associated with an increase in workspace floor area. Hypothesis D stated that the increase in elongation values of noise geometry would be associated with an increase in elongation values of workspace geometry. Hypothesis E articulated that the increase in noise geometry indicators would be associated with a decrease in employee satisfaction. Hypothesis C was supported only in WLO1 and WLO2 offices. Hypothesis D was supported in only WLO1 office type and Hypothesis E was supported in all three open-plan categories.

In WLO1 workspaces the increase in noise geometry above $16.0m^2$ was associated with an increase in workspace floor area above $57.5m^2$ and noise level above 44.4 dBA. In WLO2 workspaces, the increase in area of noise geometry above $31.2m^2$ was associated with an increase in workspace floor area above $98.6m^2$ and with a decrease in reverberation time below 0.95s. In WLO3 workspaces, there were no significant associations between the indicators of noise geometry and that of workspace geometry. In WLO3 offices, increase in area and elongation of noise geometry was associated with an increase in noise level.

Hypothesis D was supported only in WLO1 workspaces where elongation values of both noise geometry and workspace geometry increased together and the increase in elongation value of noise geometry was associated with an increase in noise level. In WLO2 and WLO3, the increase in elongation values of noise geometry had no significant correlations with those of workspace geometry.

The results also indicated that the increase in area of noise geometry was associated with a decrease in acoustic satisfaction in all three categories of open-plan workspaces

(WLO1, WLO2 & WLO3). It was considered that in WLO1 and WLO2 offices, noise geometry could be potentially used as indicators of acoustic satisfaction because the correlations obtained in this chapter supported the findings in the previous chapter, Chapter 6. Elongation, on the other hand, was not considered a suitable indicator of employee satisfaction because insufficient significant correlations were observed between elongation of noise geometry, elongation of workspace geometry and employee satisfaction.

7.8 Discussion

The results presented in this chapter showed that noise geometry was an adequate indicator of noise perception in open-plan workspaces in all three types of open-plan workspaces highlighting that the increase in size of noise geometry was associated with a decrease in acoustic and work performance satisfaction. However, the association between noise geometry and workspace geometry tended to vary according to office type. In open-plan workspaces with less than 10 occupants (WLO1) both area and elongation of noise geometry were respectively correlated with the area and elongation of workspace geometry. In open-plan workspaces with occupancy between 10 and 25 (WLO2), only area of noise geometry was correlated to area of floor plan (workspace floor area) – no significant associations were present between elongation values of noise geometry and those of workspace geometry. In open-plan workspaces with more than 25 employees (WLO3) no significant associations were present between area and elongation of noise geometry and those of workspace geometry. Given the sparse presence of associations between elongation values of noise geometry and that of workspace geometry and employee satisfaction throughout the three open-plan office categories, elongation was considered to be a weak indicator of noise perception. Other shape descriptors, such as Shape Index (SI) which uses the formula $\frac{4*A}{\pi*(L)^2}$, where A is area of shape and L is the length of the longest axis across the polygon (Kitchin & Blades 2002), could be investigated in future studies in relation to acoustic measures and employee satisfaction. The significant and coherent associations between noise geometry indicators and acoustic satisfaction in all three office types are a starting point in the development of a visual index representing perception of noise. However, the relationship between noise geometry and the geometry of workspaces requires further investigations, especially in workspaces with more than 25 employees, given that the relationship between area and elongation of workspaces were not linear. It was expected that the association between area and elongation of workspace geometries would differ because external factors, such as location of workspace on building floor plan, most likely influenced the workspace geometries.

Different sizes of workspaces were investigated by Danielsson & Bodin (2009), Nemecek & Grandjean (1973) and Frontczak et al. (2012) in relation to employee satisfaction as mentioned in the literature review (Chapter 4). The results obtained here were coherent with those of Danielsson & Bodin (2009) who observed that the acoustic satisfaction was higher in open-plan workspaces with occupancy less than 10 than in those with higher occupancy. Here, the results in this study indicated that perception of noise was greater in open-plan workspace with more than 10 occupants than in those in open-plan spaces with less than 10 occupants. The perception of noise in these aforementioned offices (WLO1 and WLO2) was also related to acoustic measures which Danielsson & Bodin (2009) failed to investigate because the study focused entirely on subjective data. The increase in noise level was associated with an increase in perception of noise in WLO1 workspaces and in WLO2 workspaces the decrease in reverberation time was associated with an increase in perception of noise. The findings in WLO2 were considered to be in line with the results of Mershon et al. (1989) and Cabrera et al. (2002) where noise sources were more distinct in low reverberation time than those in conditions with high reverberation time. In WLO2 workspaces distinct noise in low reverberation time were found to be annoying which was also in line with the study of Beaman & Holt (2007) where irrelevant background speech was found to be disturbing during task completion when reverberation time was low. In open-plan workspaces with more than 25 employees (WLO3), the use of noise geometry needs to be further developed in relation to certain characteristics of office design, such as partition height and the results for this specific office type was considered inconclusive because of the lack of consideration for the aforementioned visible details in the workspace.

Several guidelines have been placed forward by the British Council for Offices (BCO)(2009) to indicate suitable sizes for workspaces in relation to environmental aspects such as lighting, ventilation etc. In regards to acoustic, only average noise level in unoccupied workspaces were mentioned. Noise geometry in this study also indicated the perception of noise in relation to acoustic measures when workspaces were occupied for different office types. The BCO (2009) provided generic guidelines for all open-plan workspaces - an average noise level of less than 50 dBA but was considered to be in appropriate because the study here indicated that different acoustic measures at different levels were related to acoustic satisfaction. In WLO1, workspaces noise levels above 44.4 dBA were associated with an increase in noise geometry area and a decrease in acoustic satisfaction. In WLO2 workspaces, variations in noise level were not relevant to acoustic satisfaction but instead reverberation time above 0.95s was associated with a decrease in noise geometry area and an increase in acoustic satisfaction. In WLO3 workspaces, the increase in reverberation time above 0.88s was associated with an increase in acoustic satisfaction and noise level above 50 dBA was associated with a decrease in area of noise geometry. It was to be emphasized that both reverberation time and noise level were necessary when analysing acoustics in workspaces and workspaces with different occupancies have different perception of noise in relation to acoustic measures which can be seen by comparing WLO1 and WLO2 offices in this study.

In reference to the using N=number of cases instead of number of offices it was considered only rational that noise geometry, which is derived mostly from employee activities (as seen in the drawings of WLO1, WLO2 and WLO3), be correlated with individual satisfaction ratings instead of an aggregated satisfaction ratings where N=number of offices is used in statistical analysis. As already mentioned in the previous chapter on page 148, by using N=number of cases, more variance was observed in satisfaction ratings than if N=number of offices had been used and is more representative of the sample than in the latter method.

The concept of noise geometry requires further investigation. To begin with, only three types of open-plan workspaces were investigated in a cross-sectional study. Other office emerging office concepts in relation to noise geometry are yet to be tested. Meel et al. (2010) suggests more than 5 different office concepts that vary according to occupancy, floor area, type of office work and location of workspace within the floor plan. These different types are yet to be investigated in relation to acoustic quality and noise geometry. Given limited access to workspaces, only a cross-sectional study was carried in this study but a longitudinal study of the different types of open-plan workspaces investigating the association between acoustic measures, individual satisfaction and noise geometry was considered to be more revealing than a cross-sectional one. It was expected that noise geometry would vary across different times of the day depending on the performance of individual – noise geometry would possibly decrease when employees were performant. The use of other shape descriptors, as mentioned earlier, also requires further investigation when analysing noise geometry. There are significant associations between area of noise geometry, workspace geometry and employee satisfaction which support the findings in Chapter 6. However, further investigation is required to obtain optimum noise geometry index in each open-plan office type.

Chapter 8

Mauritius Case Study: Analysis of spatial settings & employee behaviour

8.1 Introduction

This chapter presents the findings of the analysis investigating the association between size of workspace, acoustic measures and employee satisfaction in a foreign country, namely Mauritius. In the Glasgow sample several significant correlations were observed between office size, acoustic measures and employee satisfaction ratings. In this part of the analysis it was intended to investigate similar variables with an identical research framework to Glasgow but in an alternate geographical location to determine if noise perception varied in different cultures. Mauritius had an estimated workforce of 559 700 employees with 88,200 employees working mostly in offices (Central Statistics Office 2012). The survey was carried out within one month in both cellular and open-plan offices. Similar to Glasgow, the types of offices were based on occupancy and were subdivided as follows: 1-3 occupants in cellular office, less than 10 in open-plan offices, 10-25 in open-plan offices and more than 25 in open-plan offices. Given that large organisations with more than 25 occupants in an open-plan were unpopular in Mauritius, that specific office category was excluded from the analysis.

Self-completed questionnaires and sound level meters were used to collect data in each workspace. The sample size consisted of 88 participants from 12 organisations. Preliminary analysis indicated that acoustic satisfaction was the lowest in cellular workspaces but surprisingly very high in open-plan workspaces. In all office types, the majority of employees who were dissatisfied with acoustics at their workplace reported people talking as the most annoying noise source. It was hypothesised in cellular workspaces that the increase in workspace floor areas would be associated with a decrease in values of at least one indicator of acoustic measures and increase in acoustic and work performance satisfaction. For all open-plan workspaces, it was hypothesised that the increase in workspace floor areas would be associated with an increase in values of at least one indicator of acoustic measures and decrease in acoustic and work performance satisfaction.

A correlation analysis was performed with the variables and the results highlighted different significant associations between the variables but none supported the hypotheses articulated here for both cellular and open-plan workspaces. The chapter begins by looking at the sample size and initial observations made during field study in Section 8.2. Detailed results obtained from the correlation analysis are presented in Section 8.4 for each office type.

8.2 Field study observations

A cross-sectional research framework similar to that used in Glasgow was applied in Mauritian offices to investigate the relationship between workspace floor area, acoustic measures and employee satisfaction. Identical methods to those applied in Glasgow sample were used here to maintain consistency when comparing the two samples later in Chapter 9. It was intended to determine the differences in the association between employee satisfaction, acoustic measures and workspace size and the use of geometry indicators as seen in the previous chapter were not used in this sample. A cluster sampling method based on office occupancy was also deployed in Mauritius. Four types of workspaces were surveyed during a one-month period – cellular office with 1 to 3 occupants (WLC), open-plan office with less than 10 occupants (WLO1), open-plan office with occupancy between 10 and 25 (WLO2) and open-plan workspace with more than 25 occupants (WLO3). Participating employees were asked to complete questionnaires which rated their perception of acoustic and work performance. In parallel to the questionnaires, noise level meters were placed in each workspace to record noise levels and workspace areas were measured with tape measures. A total of 112 participants were obtained at the end of the survey period. A few drawbacks were encountered during the survey. Firstly, open-plan workspaces with more than 25 occupants were not easily found in Mauritius which was possibly linked to the fact that organisations in that country tended to be mostly small or medium-sized ones (Schaper & Goupille 2003). Only one workspace with more than 25 employees was accessed during the field study and the use of WLO3 category in this sample was therefore considered impractical thus reducing the sample size to 88. The types of workspaces that were analysed in Mauritius are shown in Figure 8.1. Secondly, local municipal authorities prevented third parties from viewing floor plans. Workspaces in Mauritius had to be measured in more details than those in the Glasgow sample which lengthened the survey period for each workspace. The same hypotheses formulated for the Glasgow sample was being tested here to determine the differences, if any, in attitude between the two countries. It was expected that the size of workspaces would be associated with acoustic measures, acoustic satisfaction and work performance satisfaction. The following sections provide further details about the sample and initial observations made during field study.

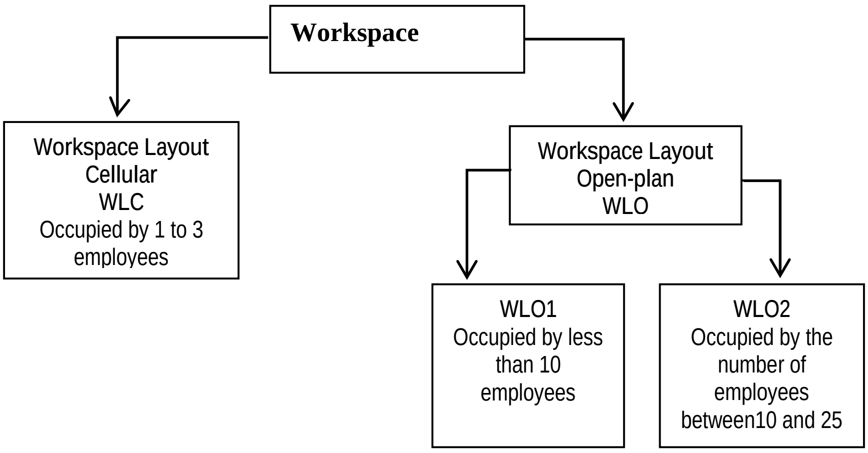


Figure 8.1 Office types being analysed in Mauritius sample

8.2.1 *Sample size*

Questionnaires were sent to a total of 101 occupants from 22 workspaces (excluding WLO3 office). The sample size used in this study consisted of 88 employees which resulted in a response rate of 87.1%. The number of respondents in each office type was as follows: 21 in WLC, 30 in WLO1 and 37 in WLO2. As mentioned in Chapter 5 and 6, the benchmark for the number of participants in each office category was 30 and as seen here, WLC workspaces had less than 30 participants. The latter was considered to be related to the fact that cellular offices were more difficult to obtain than open-plan workspaces with less than 25 employees because of financial cost required in maintaining cellular workspaces.

8.2.2 *Demography of sample*

In the total sample of 88 employees, there were 39 females and 49 males. The gender in each office type was as follows: 9 females and 12 male in WLC, 17 females and 13 males in WLO1 and 13 females and 24 males in WLO2 offices. The median age group was 30 to 39 years in the total sample.

8.2.3 *Office characteristics*

Based on the construction date provided by managers in offices, most of the buildings in the sample were built between 1950 and 2000. Offices in two business districts were surveyed; Port Louis and Ebène. Port Louis is the capital city of the island and was initially developed as the main business hub of the island after the country's independence in 1968. Ebène, on the other hand, is a recent master-plan creation fostering numerous contemporary office buildings. Prior to the country's independence, Mauritius embraced French and British colonial architectural style. After 1968, towns and cities were transformed by the use of brutal concrete 'boxes' used for both commercial and residential purposes. Appendix F.1 indicates the location of offices and those in Port Louis had mostly reinforced concrete structures. Those located in Ebène had been built within the last decade with sheer resemblance to European and Middle Eastern skyscrapers. The interior of workspaces in both old and contemporary offices tended to vary - old offices had more hard surfaces (painted concrete wall, vinyl floor etc.) while recently built ones tended to have more soft finishes (such as carpet flooring). Refurbishment and maintenance are not common practices of contractors and building owners which are considered to be the possible reason for differences in interior finishes of workspaces. Most offices benefitted from both natural and artificial lighting. Single-glazed windows were present in the majority of workspace and the preference for single over double-glazed in these workspaces was linked to cost saving instead of environmental performance. As a means of achieving thermal comfort in workspaces, mechanical ventilation was used in alternation with natural ventilation. The office characteristics for each workspace are listed in Table F.2 in appendices.

Prior to field study, it was conjectured that varying floor areas would be associated to acoustic measures and employee satisfaction. Similar to Glasgow sample, workspace floor area was recorded for each office together with room height and occupancy density. Similar to the Glasgow sample in Chapter 6, median absolute deviation (MAD) was used to indicate variations in the sample for objective data. Occupancy density in this study is referred to as the area of individual workspace which is obtained by dividing the workspace floor area by the number of workspaces. It was observed that workspace floor areas increased according to office types which were indicated by the median values in Table 8.0 – WLO2 offices had the largest median value for workspace floor area while WLC had the smallest workspace floor area. In this study, values within 2 standard deviations from median values were used for 95% confidence interval and those outside out-with 2 standard deviations from median values were considered as outliers. In the Mauritius sample no outliers were observed for workspace floor area. Kruskal-Wallis test showed significant differences in workspace floor area across different office types, $X^2(2) = 77.587$, $p=0.00$ (Table F.3 in appendices). The design guidance provided by the Mauritian government makes no mention of minimum floor area or room height for office spaces (Ministry of Housing and Lands 2004). Height of workspaces, however, significantly varied for different periods of construction in Kruskal-Wallis – buildings with tallest ceilings were constructed after 2000 and the lowest ceiling heights were in buildings constructed between 1950 and 2000 ($X^2(2) = 14.797$, $p<0.01$).Two types of desk arrangements in open-plan workspaces were observed during field studies – linear and non-linear arrangements which were also considered during the analysis. Linear arrangements referred to desks arranged in a repetitive row layout with employees facing each other and non-linear referred to desks organised in different directions with employees facing different directions.

Table 8.0 Median and median absolute deviation (MAD) for workspace floor area, occupancy density and height of workspaces in each office category

	WLC		**WLO1**		**WLO2**	
	Median	*MAD*	Median	*MAD*	Median	*MAD*
Workspace floor area	13.7	*1.75*	52.5	*7.70*	142.1	*0.00*
Occupancy density	13.7	*1.75*	7.33	*1.68*	3.30	*0.00*
Height of workspaces	2.79	*0.16*	2.65	*0.04*	3.10	*0.00*

8.2.4. *Acoustics in the workplace*

During field study, employees were asked to identify the most annoying noise sources within their workspaces and in parallel to this, the author also noted perceptible noise sources within the workspaces which were indicated on office floor plans. Examples of these annotated floor plans for each workspace are illustrated and discussed later in Section 8.3. In cellular workspaces, the author perceived external traffic noise as the most perceptible sound because windows were often opened during visits. In open-plan workspaces, people talking were the most obvious noise sources during office visits. Furthermore, reports from employees highlighted other annoying noise sources in addition to those identified by the author which can be seen in Figure 8.2.0 In WLC, phone rings were considered to be more annoying than external traffic noise. In WLO1, both people talking and external traffic noise were found to be equally annoying and in WLO2 offices people talking were the most annoying noise sources.

In regards to acoustic data collected in all three office types, the median noise level in WLC was 50.6 dBA (MAD ±8.30, 50.4 dBA (MAD ±4.37) in WLO1 and 45.0 dBA (MAD ±2.37) in WLO2. No noise levels were suggested by local authorities for cellular or open-plan offices in Mauritius. The frequency of noise level measured in each office type in Mauritius sample are shown in Figures 8.2.1 to 8.2.2. Suggestions for noise level by the British Council for Offices (BCO)(2009) were used as benchmark in the sample - below 40 dBA in cellular and between 40 and 50 dBA in all open-plan offices. Only WLO2 workspaces had median noise levels coherent with the suggestions of BCO (2009). The mean external traffic noise in Port Louis (region where most of the offices were located) during working hours was 77.2 dBA. The occurrence of high noise level was possibly linked to the absence of noise-absorbing materials, such as acoustic ceiling tiles, which were seldom seen in WLC and WLO1 workspaces. Reverberation time was also used in the analysis of Mauritius sample and identical methods of calculation to that in Glasgow was used; Sabine's (Furrer 1964) formula $R = \frac{0.16V}{A}$, where V is the volume of room and A is total absorption of surface areas, was used for reverberation time. The median reverberation time for each office was as follows: 0.67s (MAD ±0.31) in WLC, 0.84s (MAD ±0.04) in WLO1 and 0.58s in WLO2. No reverberation time guidelines were provided for offices in Mauritius and the ones established by the British Standards Institute (1999) were also used as benchmark – less than 0.40s in WLC, less than 0.60s in WLO1 and less than 0.70s in WLO2 offices. The difference in both noise levels and reverberation times were further investigated in relation to office design and employee satisfaction in Section 8.4.

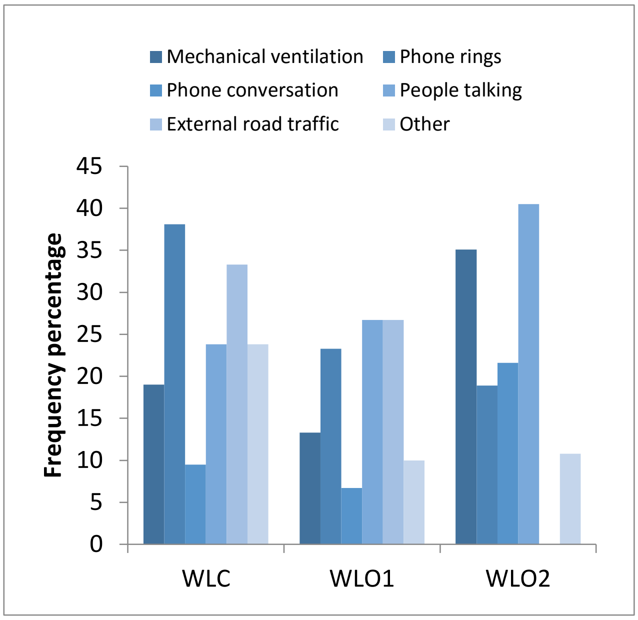


Figure 8.2.0 Frequency of noise sources rated as annoying in each office category

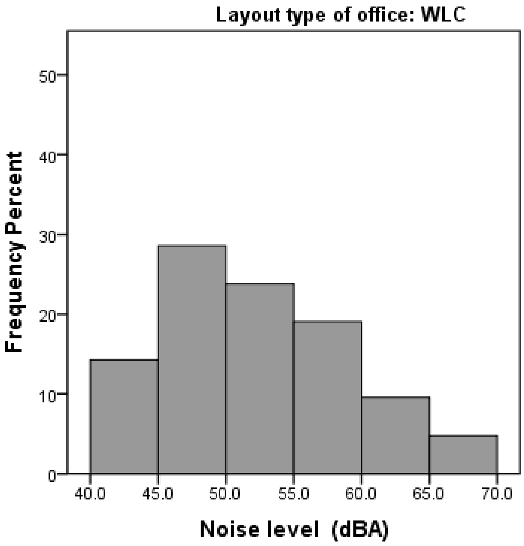


Figure 8.2.1 Frequency of measured noise level in WLC offices in Mauritius

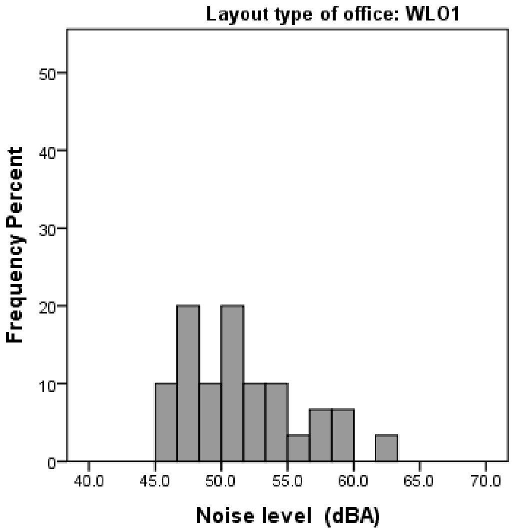


Figure 8.2.2 Frequency of measured noise level in WLO1 offices in Mauritius

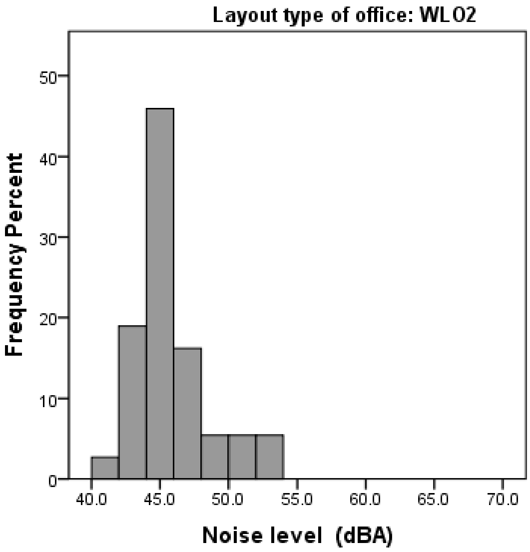


Figure 8.2.3 Frequency of measured noise level in WLO2 offices in Mauritius

8.2.5 *Rating of workspaces*

The initial observations in Section 8.2.4 have shown that acoustic quality varied in the different office types. Acoustic quality of workspaces for each workspace was rated on a 5-point scale in each office category to provide an indication of how the size of workspaces varied with acoustic quality. The office rating was a combination of reverberation time and number of noise sources perceived in the workspace during the author's office visit. Given that acceptable values for reverberation time varied among office types as mentioned in Section 8.2.4, different rating scales were used in each office type similar to that used in Glasgow sample; in WLC rating score of 1 was for reverberation time values more than 0.50s and 5 was for values below 0.20s, in WLO1 rating score of 1 was for values higher than 0.70s and 5 was for values less than 0.40s, in WLO2 score of 1 was for values higher than 0.80s and 5 was for values less than 0.50s. The number of noise sources perceived in the workspaces was possibly linked to employee satisfaction and was also rated (1 for 5 or more perceived noise sources and 5 for less than 1 perceived noise source). Office rating equal to or above 3.00 were considered as satisfactory. The maximum score for each category was 5 and the median score was calculated for each office. The average scores in each office category are shown in Table F.2 in appendices. In the overall sample most workspaces had office ratings below 3, only 22.7% of the offices in the entire sample had office ratings equal to or above 3. The median office ratings for each office type were as follows: 2.5 in WLC offices, 1.0 in WLO1 offices and 2.5 in WLO2 workspaces.

8.2.6 *Questionnaire responses*

Identical questionnaire to that used in Glasgow surveys were distributed to participants in Mauritius offices. Given that English was spoken in all workspaces surveyed, no further translation of questionnaire was necessary. The questionnaires evaluated the perception of acoustic and workspace. The data was coded in similar ways to that in Glasgow. Preliminary analysis indicated that the percentage rating for acoustic satisfaction was above 50% in all open-plan workspaces except for WLC offices which were contrary to what was initially expected (see Table 8.1). Despite the low acoustic satisfaction rating in cellular workspaces, 83.3% of employees agreed that their current office type was suitable for work completion. The percentage of employees agreeing that their current office type was suitable for work was also above 50% in WLO1 and WLO2 offices. Acoustic and work performance satisfaction indicators were tested in Kruskal-Wallis (Table F.3 in appendices) which showed no significant differences in satisfaction ratings for different office types. Further analysis was carried out in Section 8.4 to determine the relationship between acoustic measures, work performance and acoustic satisfaction.

Table 8.1 Percentage of rating for acoustic satisfaction and preference for alternate office type

	WLC	WLO1	WLO2
	%	%	%
Satisfied with acoustics in general	47.6	68.4	55.4
Agree that current office type is suitable for work completion	83.3	70	77.1

8.3 Research questions and revised hypotheses

The relationships between workspace floor area, acoustic measures and employee satisfaction are yet to be determined in Mauritius. Therefore, the same research framework to that used in the Glasgow sample was applied to the Mauritius sample and the research question being addressed in both cellular and open-plan spaces was as follows:

> *Are differences in workspace floor areas associated with varying acoustic measures and employee satisfaction in different office types?*

In cellular workspaces it was expected that the increase in workspace floor areas would be associated with a decrease in at least one of the indicators of acoustic measures and an increase in employee satisfaction, as shown in Figure 8.3.1 (Hypothesis A). Noise level in WLC was expected to be lower than that in open-plan offices because of the great difference in occupancy level. Reverberation time in WLC was also considered to be low because employees in that specific office type have greater ability to personalize workspace with furniture than those in open-plan spaces. In open-plan workspaces, it was expected that the increase in workspace floor areas would be linked to an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction as indicated in Figure 8.3.2 (Hypothesis B). The following sections present the results obtained from correlation analysis in Spearman's Rho for each office type in Mauritius – WLC, WLO1 and WLO2 offices. Similar to the Glasgow sample, correlation coefficient were considered significant when *p-value* for significance was equal to or below 0.05. The correlation coefficient values are displayed in Table F.5 to F.7 in appendices.

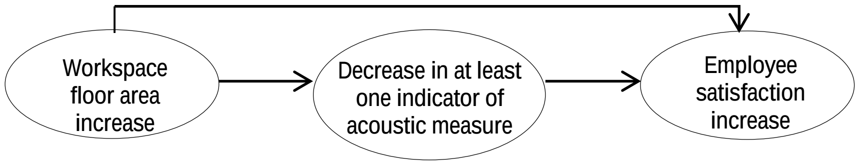


Figure 8.3.1 Hypothesised links between variables in WLC workspaces in Mauritius

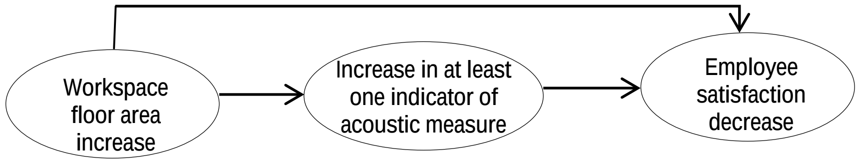


Figure 8.3.2 Hypothesised links between variables in WLO1 & WLO2 workspaces in Mauritius

8.4 Correlation analysis between variables

It is commonly known that cellular workspaces are quieter than open-plan offices because of the reduced office activities occurring in cellular workspaces due to low occupancy (Danielsson & Bodin 2009). As mentioned in Section 8.2.6, ratings for acoustic satisfaction was slightly below 50% in cellular offices and above 50% in both open-plan office types (WLO1 & WLO2) which did not support the argument of Danielsson & Bodin (2009), Kaarlela-Tuomaala et al. (2009), Lee (2010) and Jensen et al. (2005) where cellular workspaces had higher acoustic satisfaction levels than open-plan workspaces. In this study, several similarities and differences were observed between cellular and open-plan workspaces in general and the association between workspace floor area and acoustic measures tended to conflict with the associations between workspace floor area and acoustic satisfaction ratings. In cellular offices, the increase in workspace floor area was associated with a decrease in noise level ($r=-0.586$, $N=21$, $p<0.01$) which was as expected. When analysing all two types of open-plan workspaces together (WLO1 & WLO2), the increase in workspace area was also associated with a decrease in noise level ($r=-0.496$, $N=67$, $p<0.01$) and reverberation time ($r=-0.807$, $N=67$, $p<0.01$). The increase in workspace area was associated with a decrease in acoustic satisfaction only in cellular workspaces ($r=-0.473$, $N=21$, $p<0.05$) which was unexpected because noise level tended to decrease. In open-plan workspaces there was no significant association between workspace floor area and employee satisfaction when both types of open-plan offices were analysed together despite the fact that noise level also tended to decrease. Each office type was further analysed individually and the results are presented in the sections below.

8.4.1 *WLC workspaces*

It was hypothesised for cellular workspaces (WLC) that the increase in workspace floor area would be associated with improved acoustic measures and an increase in employee satisfaction. The median workspace floor area was 13.7m^2. In the WLC sample, both acoustic measures were poor - median noise level was 50.6 dBA which was higher than the maximum value of 40 dBA suggested by BCO (2009) and median reverberation time was 0.67s which was above the maximum value of 0.40s suggested by the BSI (1999). The average cellular workspace had more than 5 noise sources present. Satisfaction rating with acoustic in general was slightly below 50% (47.6%) but 83.3% of employees in cellular workspaces agreed that their current office type was suitable for work completion. Among employees who were dissatisfied with acoustic at their workplace, 42.9% reported that people talking was the most annoying noise source followed by phone rings (28.6%). Figure 8.4 shows noise sources deemed to be annoying by occupants in each office in the WLC category. In WLC category, office rating reflected the poor acoustic quality and numerous noise sources present - the median score was 2.5 which considered slightly low because the value was below the satisfactory value of 3. As seen in Table F.2 in Appendix F, the majority of WLC offices had reverberation time ratings and number of noise source ratings below 3. Initial observation of the rating scale in Figure 8.7 indicated that higher office ratings above 2.5 had slightly smaller floor areas in comparison to those with ratings below 2.5.

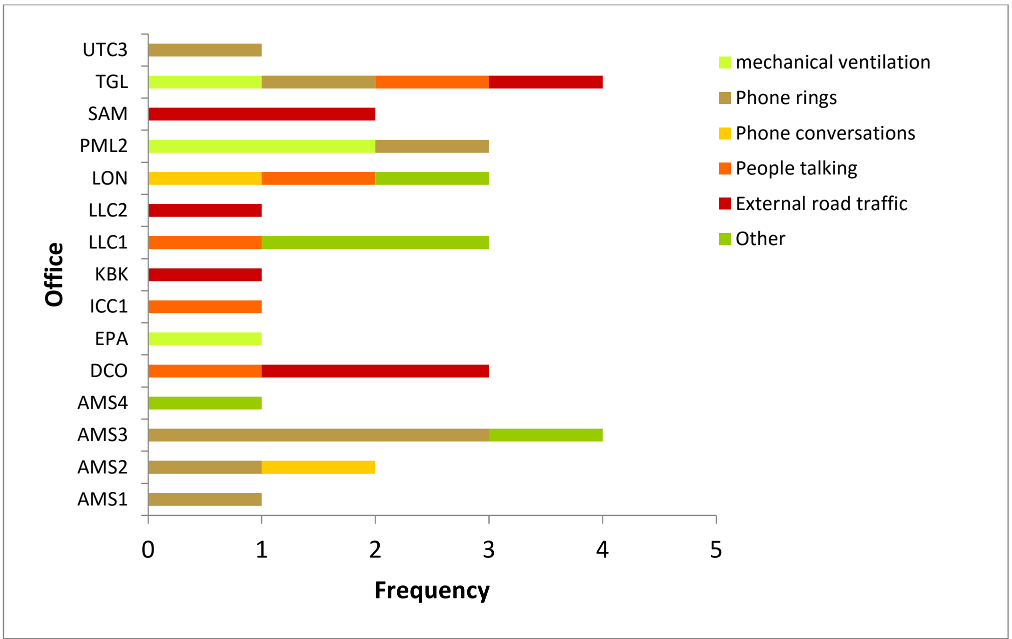


Figure 8.4 Ratings of annoying noise sources in each office type

Correlations between variables were analysed in Spearman's Rho to test Hypothesis A. The results obtained here showed no significant correlation between workspace floor area and reverberation time (RT). RT increased when total noise absorption of surface materials decreased (r=-0.778, N=21, p<0.01) but total noise absorption of surface materials did not increase together with workspace floor area which was considered to be linked to the absence of correlation between workspace floor area and RT. Reverberation time is dependent on both volume and total noise absorption of surface materials and it was observed that height of workspaces tended to decrease when workspace floor area increased (r=-0.437, N=21, p<0.05). Furthermore, no significant association was observed between reverberation time and ratio of glazing-to-floor area. However, neither height nor workspace floor area were significantly associated with RT which suggests that reverberation time in WLC workspaces was mostly dependent on noise absorbing quality of materials present in workspaces. Table F.2 in Appendix F indicates the different finishes present in WLC offices in Mauritius sample.

Alternatively, a significant correlation was observed between workspace floor area and noise level (r=-0.586, N=21, p<0.01) which suggested that noise level was lower when workspace floor area increased in WLC offices. The office rating scale in Figure 8.7 indicated a decrease in noise sources present when office ratings increased. The number of noise sources present, amount of window glazing and the frequency of window opening were analysed in relation to noise level but no significant associations were observed between them. Given that people talking was the most annoying noise source in WLC offices it was possible that noise levels were dependent on the type of activity occurring within workspaces.

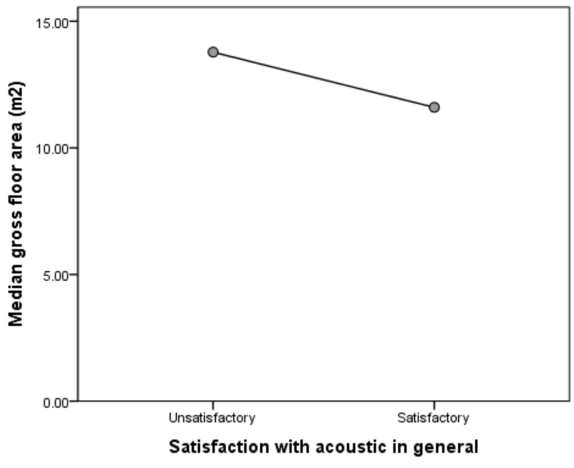


Figure 8.5 Relationship between workspace floor area and acoustic satisfaction in WLC offices

In relation to the associations between objective and individual perception, workspace floor area was moderately associated with acoustic satisfaction (r=-0.473, N=21, p<0.05) which suggested that the increase in workspace floor area was linked to a decrease in acoustic satisfaction (see Figure 8.5). The percentage of employees satisfied with acoustic at their workplace decreased from 77.8% to 26.5% when workspace floor area increased above the median value of 13.7m^2. No significant associations were observed between workspace floor area and work performance satisfaction. Further analysis indicated that the rating of number of noise sources present was positively associated with background noise satisfaction (r=0.506, N=20, p<0.05). The number of noise sources present in workspaces with workspace floor area above 13.7m^2 was higher than in those with workspace floor area below 13.7m^2 – 75.1% of workspaces with workspace floor area above 13.7m^2 had more than 2 noise sources and only 44.4% of workspaces with workspace floor area below 13.7m^2 had more than 2 noise sources. On the other hand, work performance satisfaction was not significantly associated with the number of noise sources present in workspaces with workspace floor area below or above 13.7m^2. As mentioned earlier, noise level tended to decrease when office sizes increased; the median noise level was 57.7 dBA for workspaces with workspace floor area below 13.7m^2 and 49.8 dBA for workspaces with workspace floor area above 13m^2 and was considered to be high in both cases because noise levels were above 40 dBA (recommended value by BCO (2009)). There were no significant correlations between acoustic satisfaction and noise level for both groups (workspace floor area above or below 13.7 m^2) possibly because noise level was high in both instances. The percentage of employees rarely distracted by noise during task completion was considered to have negligible variation between the two groups; 44.4% of employees were rarely distracted in workspaces with workspace floor area below 13.7m^2 and 41.7% were rarely distracted in workspaces with workspace floor area above 13.7m^2. No further

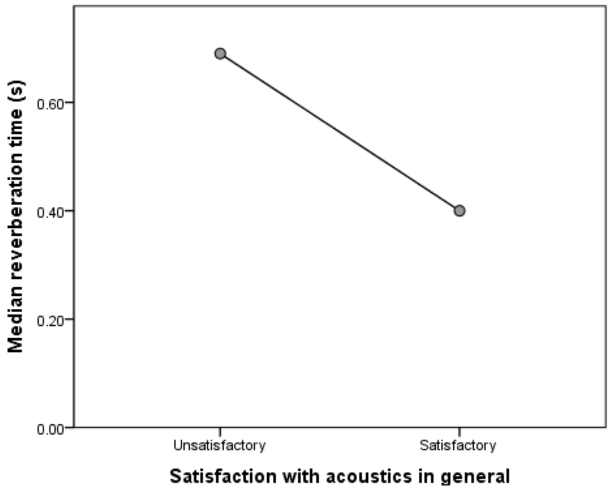


Figure 8.6 Relationship between acoustic satisfaction and reverberation time in WLC offices, Mauritius

correlations were observed between the ratings for frequency of distraction during task completion and noise level in both groups below and above $13.7m^2$.

Despite having no association with workspace floor area, reverberation time was relevant to acoustic and work performance satisfaction. The increase in RT was associated with a decrease in acoustic satisfaction (r=-0.457, N=21, p<0.05) (see Figure 8.6). Perham et al. (2007) and Beaman & Holt (2007) conjectured that high reverberation time is associated with less disturbances from irrelevant background noise because the changing state in speech is reduced in spaces with multiple reflections. In this sample for cellular workspaces increase in reverberation time was associated with a decrease in acoustic satisfaction but an increase in work performance satisfaction. WLC offices with RT less than 0.67s had acoustic satisfaction rating of 60% while those with RT above 0.67s had acoustic satisfaction ratings of 22.2%. Given that the increase in RT was associated with a decrease in acoustic satisfaction, it was expected that the increase in RT would be associated with a decrease in work performance satisfaction. However, the results indicated that the increase in RT was associated with a decrease in reported distraction due to other's conversations during task completion (r=0.481, N=21, p<0.05) which was unusual. 10% of employees were rarely distracted during work completion when RT was below 0.67s and 77.8% of employees were rarely distracted when RT was above 0.67s. The decrease in annoyance with people talking was considered to be related to the ability of being less distracted during work completion - 30% of employees were annoyed with people talking when RT was below 0.67s and 22.2 % was reportedly annoyed with people talking. It was most likely that resonating workspaces dampened background conversations which in turn enhanced work performance satisfaction. The dissatisfaction with acoustic when reverberation time increased was possibly linked to the type of noise source present in the cellular offices. In WLC offices with RT above 0.67s, phone rings (44.4%) and external traffic noise (33.3%) were the most annoying noise sources which tend to be amplified in resonating workspaces. Waller (1969) and Keighley (1970) highlighted that intermittent noise sources were more annoying that constant background noise and here in cellular offices both phone rings and external traffic noise are considered as intermittent noise sources.

The results in WLC offices showed that acoustic satisfaction was not considered an indicator of work performance satisfaction because both variables had different associations with the objective variables in the study. Unlike acoustic satisfaction, work performance satisfaction was not significantly correlated with workspace floor area and work performance satisfaction tended to increase with RT. As mentioned at the beginning of this section, office ratings appeared to be associated with a decrease in workspace size, for instance LLC2 and KBK in Figure 8.7. The analysis indicated that offices with more than 2 noise sources and RT above 0.67s were associated with low acoustic satisfaction which was equivalent to median office rating of 1.75. Age and gender of participants was taken into account for subjective variables. Kruskal-Wallis test showed no significant difference for acoustic and work performance satisfaction for different age groups and gender in WLC offices.

The results presented for WLC workspaces in Mauritius indicated that the increase in workspace floor area was significantly correlated with a decrease in both noise level and acoustic satisfaction which failed to support Hypothesis A because the decrease in noise level was expected to be correlated with an increase in acoustic satisfaction. Both workspace floor area and reverberation time were significant to acoustic satisfaction in WLC workspaces. Acoustic satisfaction decreased from 77.8 to 26.5% when workspace floor area increased above 13.7m^2. Offices with workspace floor area above 13.7m^2 had more noise sources present than workspaces with workspace floor area below which was associated with a decrease in acoustic satisfaction. The increase in reverberation time above 0.67s was associated with a decrease of 37.8% (from 60 to 22.2%) in acoustic satisfaction but with an increase of 67.8% (10 to 77.8%) in ratings of distraction perceived during work completion. The variation in noise level was not significant to acoustic or work performance satisfaction. It can therefore be said that in the surveyed Mauritian cellular workspaces employees had high acoustic satisfaction in offices with workspace floor area smaller than 13.7m^2 and reverberation time below 0.67s but enhanced work performance occurred in workspaces with reverberation time above 0.67s regardless of office size. The increase in perceived work performance in spaces with high reverberation time was linked to the decrease in annoyance with people talking in the background.

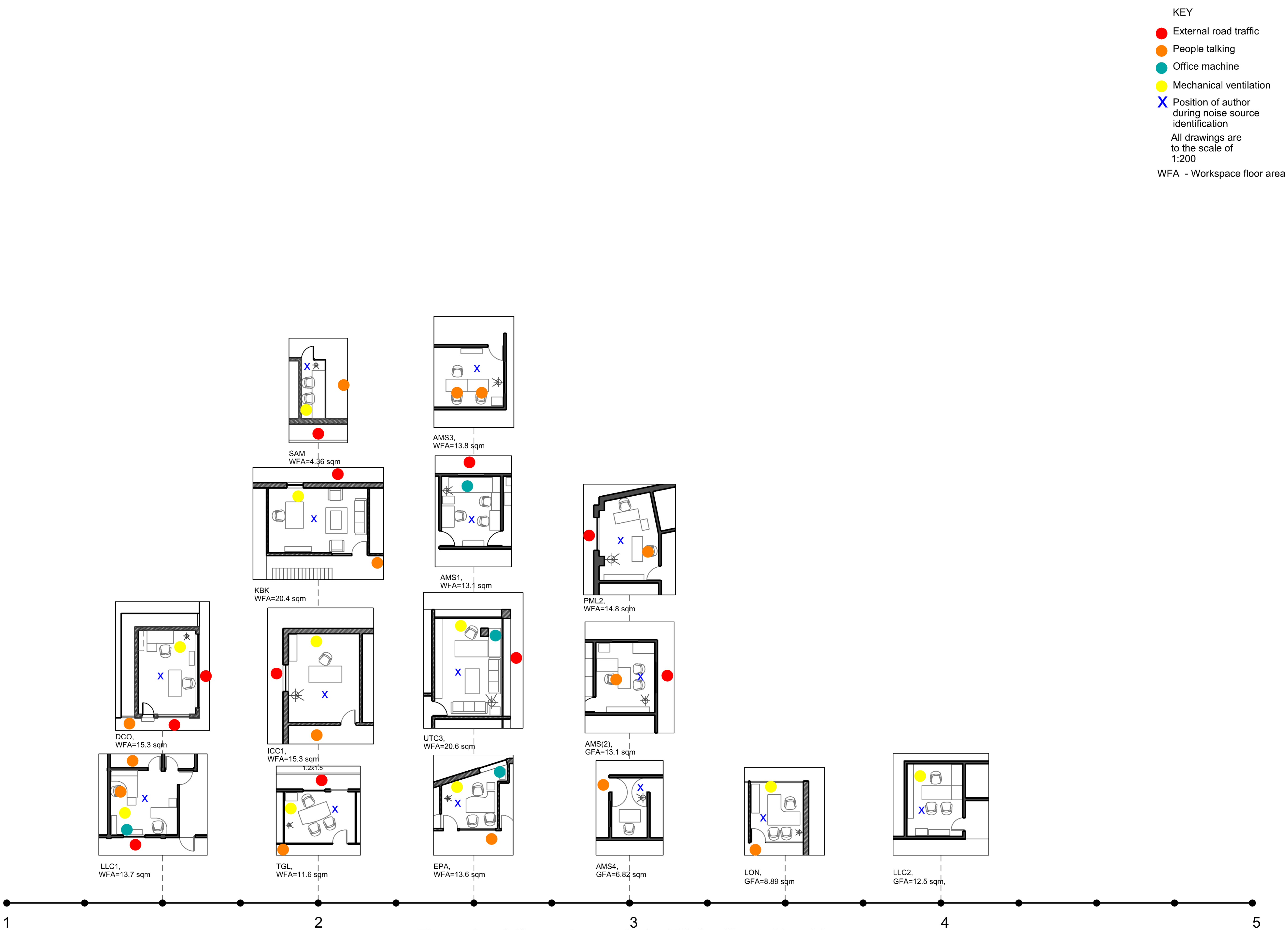


Figure 8.7 Office rating scale for WLC offices, Mauritius

8.4.2 *WLO1 workspaces*

In WLO1 offices, Hypothesis B stating that the increase in workspace floor area was associated with deterioration in acoustics and a decrease in employee satisfaction was tested. The median workspace floor area was 52.5 m^2. For acoustic measures, the median noise level was 50.4 dBA which was very close to recommended value of 50 dBA and reverberation time was 0.84s which was very high in comparison to the recommended value of 0.60s. 83.3% of the workspaces in the sample had equivalent of 5 or more than 5 noise sources. The rating for acoustic satisfaction (68.4%) was above 50% indicating a general satisfaction with acoustics in WLO1 workspaces which was unexpectedly higher than the acoustic satisfaction ratings for WLC workspaces. For work performance too the rating was also above 50% - 70% of occupants in WLO1 offices agreed that their current office type was suitable for work completion. Figure 8.8 below highlights the annoying noise sources in each office. Among employees who were dissatisfied with acoustics, 66% were annoyed with people talking. Individual offices were rated based on reverberation time and the number of noise sources present which are shown in Figure 8.9 at the end of this section. The median office rating in WLO1 was 1.00 which was very low on the scale of 5. Table F.2 in Appendix F indicates that the majority of WLO1 offices had reverberation time and number of noise source ratings below 3. Both reverberation time and the number of noise sources present in workspaces had median ratings of 1.00 which contributed to the poor office rating in WLO1 offices. Unlike WLC offices, WLO1 workspaces with higher ratings tended to have larger floor areas.

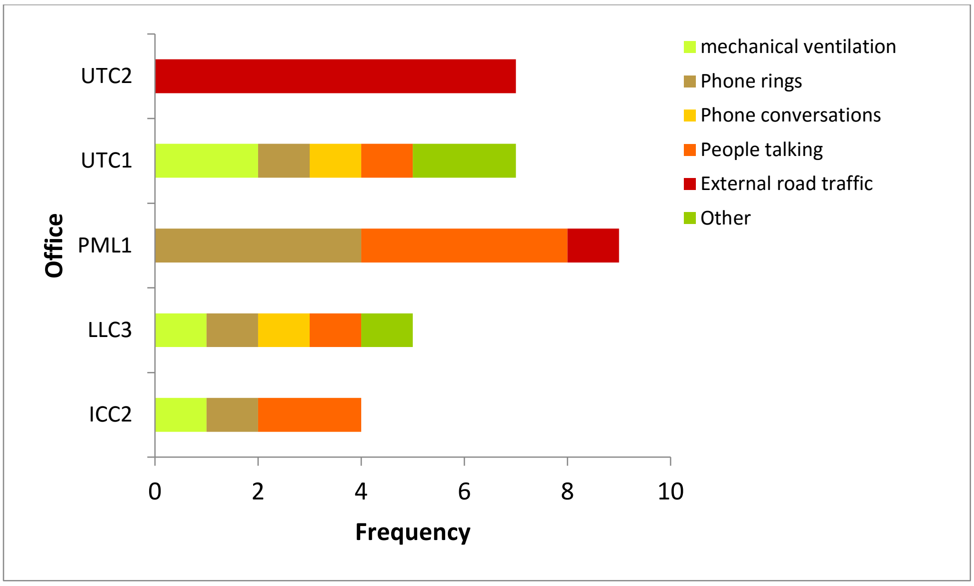


Figure 8.8 Rating of annoying noise sources in WLO1 workspaces

The variables were analysed in Spearman's Rho to test Hypothesis B. It was expected that the increase in workspace floor area would be associated with a decrease in values of at least one indicator of acoustics and a decrease in employee satisfaction. The results indicated that the increase in workspace floor area was significantly associated with a decrease in RT ($r=-0.528$, $N=30$, $p<0.01$) which was the opposite of what was hypothesised. Reverberation time is determined by the total absorption of surfaces and volume of spaces. In WLO1 offices, workspace floor area, height ($r=0.635$, $N=30$, $p<0.01$) and total absorption ($r=-0.635$, $N=30$, $p<0.01$) of surface materials were relevant to reverberation times. However, workspace floor area varied more than height in the overall sample.

Contrary to WLC, both workspace floor area and total absorption of surfaces increased together ($r=0.959$, $N=30$, $p<0.01$) which contributed to the decrease in reverberation time. Unlike WLC offices, no significant correlation was observed between noise level and workspace floor area in WLO1 offices. Noise level was also not significantly associated with amount of glazing, the perceived frequency of window opening or number of noise sources present. Once more, it was possible that changes in noise level were more job-related and not associated to physical characteristics of WLO1 offices.

Two workspaces with extreme office ratings were ICC2 office and PML1 office as shown in Figure 8.9. Based on the size of workspaces (see Figure 8.9), at first glance it would be expected that ICC2 office would have lower reverberation time than PML1 office because ICC2 offices was a smaller workspace than PML1 office. However, the difference in reverberation time was associated to surface materials present in the workspaces - ICC2 office had floor tiles, painted concrete walls and ceilings while PML1 office had carpet flooring, acoustic ceiling tiles and painted concrete walls (as seen in Table F.2 in Appendix F). The number of noise sources present in workspaces was more or less similar in most WLO1 offices and the difference in rating values was associated mostly with reverberation times. If ICC2 office had acoustic ceiling tiles and carpet flooring, the reverberation time would decrease from 0.99s to 0.41s. The increase in the use of noise absorbing materials was also considered to be linked to the construction age of the workspaces; PML1 office (after 2000) was more recently built than ICC2 office (before 2000) which contained more popular workspace features, such as acoustic ceiling tiles.

In the analysis of employee satisfaction, workspace floor area was not significantly associated with either acoustic or work performance satisfaction. The absence of significant associations between workspace floor area and acoustic or work performance satisfaction was linked to the fact that workspace floor area and satisfaction did not increase linearly. As mentioned earlier in this section, the median for workspace floor area was $52.5m^2$ and satisfaction with acoustic was high in workspaces below and above the median workspace floor area – 76.7% in workspaces with floor area below $52.5m^2$ and 60% when workspace floor area was above $52.5m^2$. Similarly, the percentage of employees who reported to being rarely distracted by noise during task completion was 56.7% when workspace floor area was below the median and 60% when workspace floor area was above median. No further significant associations were observed between noise level and employee satisfaction. Given that reverberation time was significantly associated with workspace floor area, reverberation time was also not associated with either acoustic or work performance satisfaction.

Given that no significant association was observed between employee satisfaction and workspace area or acoustic measures, it was considered that variation in acoustic and work performance satisfaction ratings in WLO1 were possibly related to other workspace features such as the type of desk arrangement. Table F.2 in Appendix F indicates that different desk arrangements are present in the WLO1 offices. Figure 8.9 indicates that linear desk arrangements are located in large workspaces and the latter was further supported by the significant correlation indicating that the increase in workspace floor area was associated with linear desk layouts ($r=-0.786$, $N=30$, $p<0.01$). Linear desk arrangements were located in offices with floor area above $52.5m^2$ and non-linear desk arrangements were found in offices with floor area below $52.5m^2$. Furthermore, linear desk arrangements were associated with an increase in acoustic satisfaction ($r=-0.411$, $N=30$, $p<0.05$). 77.3% of employees were satisfied with acoustics in workspaces with linear desk arrangements and 37.5% of employees in offices with non-linear desk arrangements were satisfied with acoustics. It was also observed that in workspaces with linear desk arrangements, 22.7% of employees were reportedly annoyed with people talking while in non-linear workspaces, 37.5% were annoyed with people talking. Hedge (1982) previously observed that interpersonal relationship among co-workers were enhanced in open-plan workspaces and Wineman (1982) highlighted that employees facing each other were more often likely to engage in conversations than those facing away from each other. In WLO1 Mauritius offices, it was considered that employees were more satisfied with interpersonal relationship when in linear desk layouts which implied close proximity to co-workers despite the fact that communication increased when facing each other than in non-linear desk arrangements. No further significant correlation was observed between work performance satisfaction and the type of desk arrangement.

Unlike WLC workspaces, acoustic and work performance satisfaction was coherent with each other in WLO1 workspaces when analysed with objective variables. It was initially observed that both office rating and size of floor areas increased together and this was further supported by the correlation coefficient, $r=0.521$, $N=30$, $p<0.01$. The influence of age and gender on subjective variables was considered in this study and no significant differences were observed in the associations between objective and subjective variables for different age groups and gender.

The results displayed here for WLO1 offices showed that the increase in workspace floor area was associated with a decrease in reverberation time but not with acoustic or work performance satisfaction which failed to support Hypothesis B. The increase in workspace floor area was associated with a decrease in reverberation time and was considered to be linked to the presence of noise absorbing materials. None of the acoustic measures were associated with either acoustic or work performance satisfaction despite the fact that reverberation time was quite high in most workspaces and noise level varied more than reverberation time. The absence of significant associations between acoustic measures and employee satisfaction suggested a possibility of habituation to acoustic measures in WLO1 offices. Alternately, acoustic satisfaction in WLO1 offices increased when employees were located in offices with linear desk layouts. No further significant associations were observed between work performance satisfaction and the type of desk arrangements. Based on the results obtained in this section, enhanced acoustic satisfaction occurred in workspaces with linear desk arrangements in WLO1 office category.

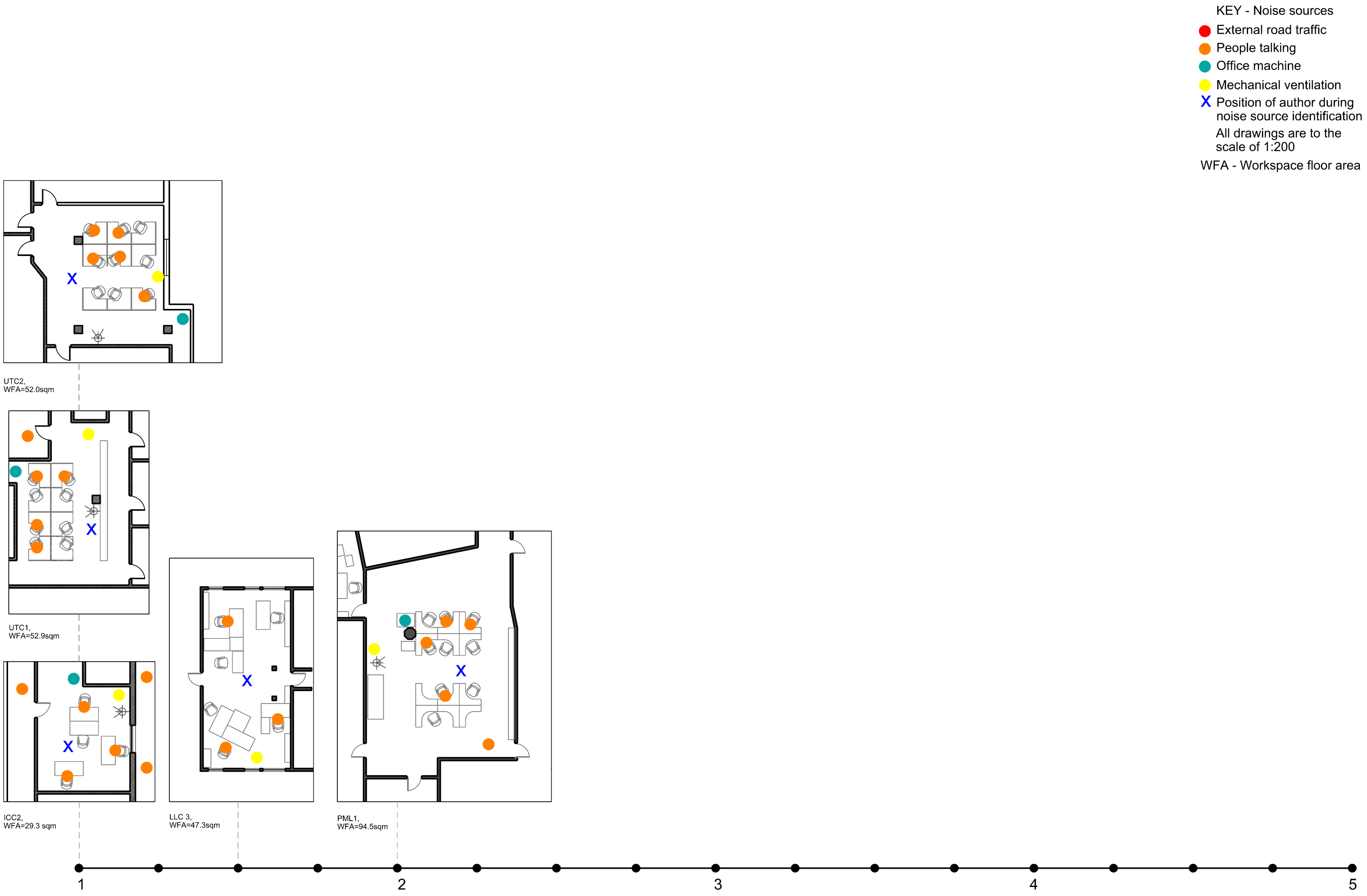


Figure 8.9 Office rating scale for WLO1 offices, Mauritius

8.4.3 *WLO2 workspaces*

Similar to WLO1 offices, Hypothesis B was tested in WLO2 offices. It was expected that the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction. The median workspace floor area in WLO2 was 142.1m^2. Both acoustic measures, noise level and reverberation time, had median values of 45.0 dBA and 0.58s respectively which were below the recommended values in Section 8.3 (50 dBA for noise level and 0.70s for reverberation time). Ratings for acoustic satisfaction and work performance satisfaction were generally above 50% - 55.4% of employees in WLO2 offices were satisfied with acoustic at their workspace and 77.1% of employees agreed that their current office type was suitable for work completion. The low noise level and reverberation time were possibly associated to the high employee satisfaction in WLO2 and required further analysis to determine the nature of the relationship between workspace floor area and employee satisfaction. Among the occupants who were dissatisfied with acoustics, 33% reported people talking as the most annoying noise source followed by noise from mechanical ventilation (25%). Figure 8.10 below indicates the annoying noise sources in each workspace in WLO2. The median value for WLO2 office rating was 2.50 almost near to the acceptable value of 3. Numerous noise sources were present in the workspaces which results in median score of 1 but reverberation, on the other hand, was very low which resulted in median score of 4. The latter can be seen in Table F.2 in Appendix F. The scale in Figure 8.12 at the end of the section indicated that workspace with smaller workspace floor area had lower office rating than that with larger floor area which was similar to initial observations made in WLO1 offices.

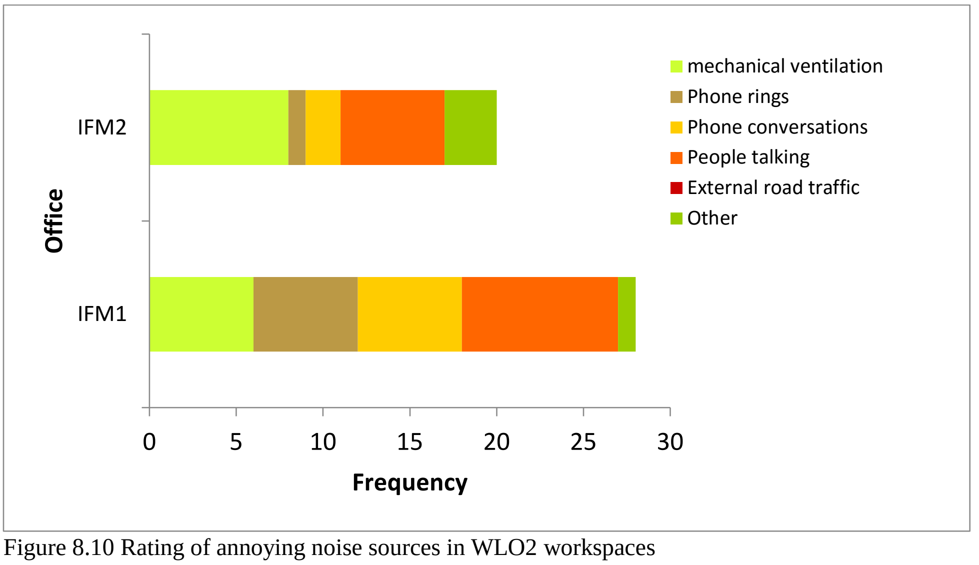


Figure 8.10 Rating of annoying noise sources in WLO2 workspaces

Variables were analysed in Spearman's Rho to test Hypothesis B. The results revealed that the increase in workspace floor area was associated with an increase in noise level (r=0.473, N=37, p<0.01) and with a decrease in RT (r=-1.00, N=37, p<0.01). The association between workspace floor area and noise level was as hypothesised in WLO2 offices. It was initially expected that the increase in noise level was possibly linked to the number of noise sources present but given that both workspaces had the same number of perceived noise sources, there was no correlation in Spearman's Rho for noise level and the number of noise sources present. A small difference existed between the median noise level values - 45.8 dBA in IFM1 office and 44.2 dBA in IFM2 office. The increase in noise level was associated with an increase in the ratio of glazing-to-floor area (r=0.473, N=37, p<0.01). It was initially expected that the increase in workspace floor area would be associated with an increase in RT but the opposite was observed in WLO2. IFM1 office had RT of 0.58s while that of IFM2 office was 0.60s and both values were considered to be within the limits suggested by BSI (1999). The small difference in reverberation time was mostly linked to the difference in materials present because room heights for both workspaces were identical (3.10m); reverberation time increased when total absorption of surfaces decreased (r=-1.00, N=37, p<0.01). After a closer look at the floor plans in Figure 8.12, one would expect RT value for IFM2 office to be much smaller than 0.60s given the size of the workspace. The plywood cubicle present in IFM2 office tended to absorb noise thus reducing RT value – reverberation time would have been 1.12s if no plywood partitions were present.

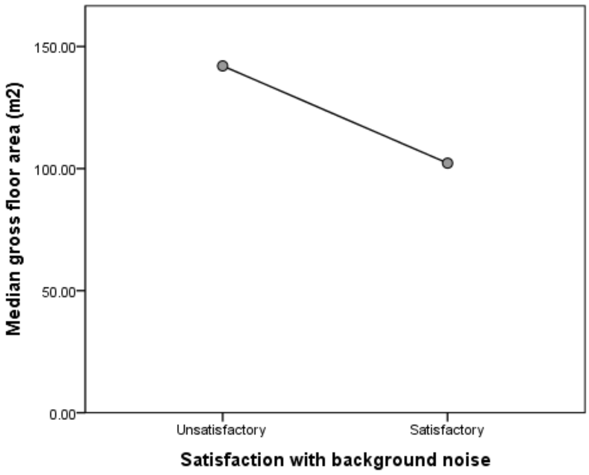


Figure 8.11 Relationship between background noise satisfaction and gross floor area in WLO2

The increase in workspace floor area was associated with a decrease in satisfaction with background noise (r=-0.326, N=37, p<0.05) as shown in Figure 8.11. No significant correlation was observed between noise level and acoustic or work performance satisfaction. The increase in background noise satisfaction was associated with an increase in RT (r=0.326, N=37, p<0.05). Work performance satisfaction was not significantly associated with either workspace floor area or RT. In WLO2 offices, work performance satisfaction was high in both cases when workspace floor area was below or equal to 142.1m^2 – the ability to complete tasks with occasional difficulty was above 80% in both instances. The percentage of employees satisfied with background noise decreased from 87.6% to 59.6% when workspace floor area increased to the median of 142.1m^2. Satisfaction with background noise was 59.6% in IFM1 office and 87.6% in IFM2 office and, as mentioned above, reverberation time between the two workspaces differed by 0.02s. The positive correlation between reverberation times and acoustic satisfaction was not considered to be substantial because, firstly reverberation time was low (below 0.70s) and ratings for acoustic satisfaction were above 50% in both IFM1 and IFM2 offices. No further significant association was observed between noise level and employee satisfaction in WLO2 offices.

In WLO1 workspaces it was observed that the type of desk arrangement was associated with acoustic satisfaction. Here in WLO2 workspaces, the same could not be said because only linear desk layouts were observed in WLO2 offices. However, the increase in acoustic satisfaction in smaller open-plan could be seen from another aspect; there was an increased distance among co-workers in IFM2 office which was supported by the use of plywood partitions dividing the employees into small sub-groups of four thus creating more enhanced acoustic satisfaction and visual privacy than IFM1 office. In IFM1 workspace, people talking (42.9%) and phone conversations (28.6%) were the most annoying noise sources and most likely because employees sat near each other as seen in Figure 8.12. Furthermore, the noise level in IFM1 office (45.8 dBA) was slightly higher than that in IFM2 office (44.2 dBA) which was possibly due to people talking. Satisfaction with background noise in IFM1 office increased when annoyance with phone conversations decreased ($r=-0.577$, $N=21$, $p<0.01$). Employees in IFM1 office also reported to being more frequently disturbed by noise when employees had to raise their voice more often during conversations ($r=0.611$, $N=21$, $p<0.01$). In IFM2 office, on the other hand, mechanical ventilation was the most annoying source (50%). The increase in background noise satisfaction in IFM2 office was significantly associated with an increase in satisfaction with co-worker communication ($r=0.617$, $N=11$, $p<0.05$). No further associations were observed between occupancy density and work performance satisfaction.

In WLO2 workspaces, acoustic and work performance satisfaction was not coherent with each other. The type of desk arrangement was considered irrelevant in WLO2 offices because they were all similar. The median office rating was 2.5 in both instances when workspace floor area was below 142.1m^2 and equal to 142.1m^2. Gender and age groups were also taken into consideration when analysing subjective variables and no significant differences were observed during correlation analysis for different gender and age groups.

The results presented for WLO2 offices indicated that the increase in workspace floor area was associated with a decrease in RT and a decrease in acoustic satisfaction which did not support Hypothesis B. Acoustic satisfaction decreased from 87.6% to 59.6% when workspace floor area increased to 142.1m^2. The number of noise sources present in workspaces was not relevant to acoustic or work performance satisfaction. Also, work performance satisfaction was not associated with any of the objective variables analysed here or with acoustic satisfaction. Unlike, WLO1 offices, the type of desk arrangement was not significant to employee satisfaction in WLO2 given that only linear layouts were present. Therefore, employees in WLO2 offices were more satisfied with acoustics when office floor areas were below 142.1m^2 and employees had greater co-worker distance between them as shown by the differences in occupancy density.

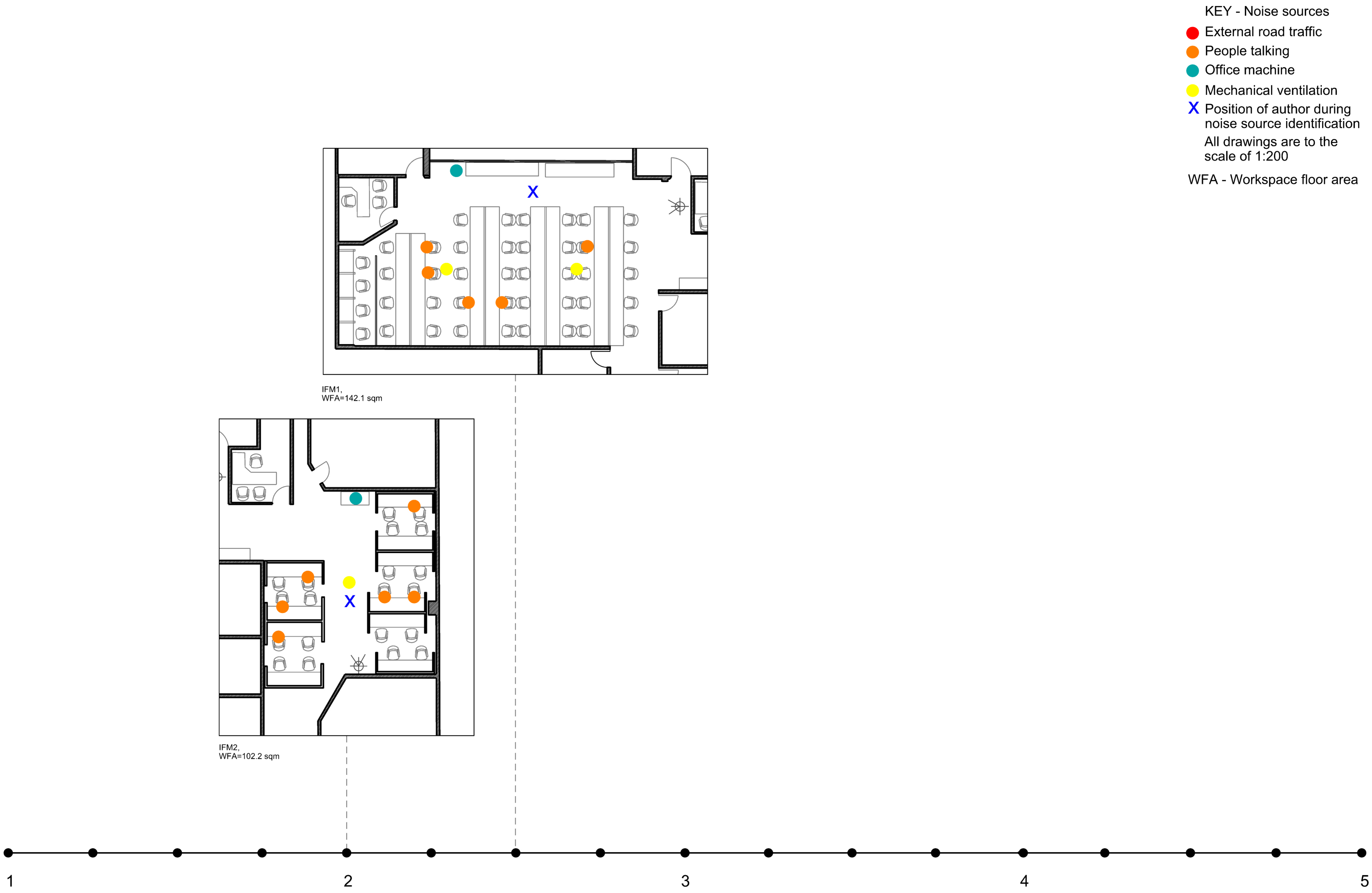


Figure 8.12 Office rating scale for WLO2 offices, Mauritius

8.5 Summary

Three office types were investigated in Mauritius – WLC, WLO1 and WLO2 to determine the relationship between workspace floor area, acoustic measures, and employee satisfaction. Different levels of satisfaction were observed in the three office types. WLC workspaces had the lowest acoustic satisfaction ratings among the three office types (below 50%) but rating for work performance satisfaction was above 50%. WLO1 and WLO2 offices were the contrary of WLC workspaces and had that highest acoustic and work performance satisfaction (above 50% for both variables in WLO1 and WLO2). In cellular workspaces, the following hypothesis was tested: the increase in workspace floor area would be associated with improved acoustic measures and an increase in employee satisfaction. In open-plan workspaces (WLO1 and WLO2) it was hypothesised that the increase in workspace floor area would be associated with a decrease in acoustic measures and a decrease in employee satisfaction. In this sample, none of the hypotheses were supported. Workspace floor area, reverberation time and noise level varied significantly among different office types but reverberation time had more significant associations with employee satisfaction than noise level in general.

In WLC offices, the decrease in workspace floor area below 13.7m^2 was associated with an increase of 51.3% (from 77.8 to 26.5%) in acoustic satisfaction. Workspace floor area was not relevant to work performance satisfaction. Reverberation time below 0.67s was also correlated with an increase of 37.8% (from 22.2 to 60%) in acoustic satisfaction but with a decrease of 67.8% (from 77.8 to 10%) in work performance satisfaction. The decrease in work performance satisfaction rating with reverberation was considered to be linked to the increased annoyance with people talking when reverberation time decreased in cellular offices. No significant associations were observed between workspace floor area and reverberation time. The latter was considered to be more related to total absorption of materials than the size of workspaces. Hypothesis A was not supported in WLC offices.

In WLO1 offices, the increase in workspace floor area above 52.5m^2 was associated with a decrease in reverberation time below 0.84s. Neither workspace floor area nor any acoustic measures were significantly associated with employee satisfaction. Alternately, the type of desk layout was associated with acoustic satisfaction – linear desk layout in which employees were in close proximity to co-workers was associated with enhanced acoustic satisfaction in comparison to non-linear workspaces. In WLO1 offices, employee satisfaction was also not correlated with the number of noise sources present.

The increase in workspace floor area or reverberation time was not significantly associated with a decrease in employee satisfaction which failed to support Hypothesis B.

In WLO2 offices, workspace floor area, RT and employee satisfaction were inter-correlated but in different ways to what was expected. The increase in workspace floor area above 102.2 m^2 was associated with a decrease in RT below 0.60s and a decrease from 87.6 to 59.6% in acoustic satisfaction ratings which failed to support Hypothesis B. Noise level was not relevant to acoustic or work performance satisfaction in WLO2 offices.

8.6 Discussion

The association between office size, acoustic measures and employee satisfaction were investigated in three types of workspaces in Mauritius - WLC, WLO1 and WLO2 and the results presented for each office type supported none of the hypotheses articulated in this study. The findings highlighted a few points; satisfaction ratings in cellular offices versus that of open-plan, satisfaction ratings in different sizes of open-plan workspaces and acoustic measures used in relation to satisfaction ratings. The studies of Kaarlela et al. (2009), Brennan et al. (2002) and Jensen et al. (2005) investigated satisfaction ratings in both cellular and open-plan workspaces and the results of these studies coherently showed that open-plan workspaces had greater noise dissatisfaction associated with them than cellular workspaces. In this study, acoustic satisfaction ratings were observed to be higher in open-plan workspaces than in cellular offices. Kaarlela-Tuomaala et al. (2009) and Jensen et al. (2005) highlighted that people talking were the most annoying noise sources in open-plan workspaces. These findings were coherent with the results in the study here in which the minority of employees who were dissatisfied with acoustic in open-plan spaces were also annoyed by people talking. The number of noise sources present in open-plan workspaces was also more diverse than those present in cellular workspaces in Mauritius. It was possible that employees in open-plan workspaces associated more importance to interpersonal relationship among co-workers in open-plan workspaces than to acoustics thus leading to a general satisfaction with the workspace. According to Sundstrom et al. (1994) employees who were satisfied with their workspace in general tended to also be satisfied with acoustics.

According to the findings presented by Nemecek & Grandjean (1973), larger open-plan workspaces with workspace floor areas above 475 m^2 was associated with fewer noise disturbances than offices with areas below 475m^2. In this study, floor areas did not exceed 142.1m^2 given that most workspaces in Mauritius were for small or medium-sized organisations. Nevertheless, the results in this study indicated that fewer noise disturbances were associated with smaller open-plan areas; in WLO1 workspaces, acoustic satisfaction was high in workspaces with occupancy density less than 7.33m^2 which was associated with workspace floor area less than 52.5m^2 and in WLO2 offices, high acoustic satisfaction was associated with workspace floor areas less than 142.1m^2. It was possible that the preference of workspace size varied in different cultures given that the study of Nemecek & Grandjean (1973) was European-based and there was a preference for larger workspaces in general.

In regards to the type of acoustic measure used, the literature review indicated that among the few studies that measured both acoustic measures and acoustic satisfaction commonly assessed noise level. Kaarlela-Tuomaala et al. (2009) and Nemecek & Grandjean (1973) made use of noise level to assess the difference acoustic quality in workspaces but made no mention of associations between subjective and objective measures. In this study, acoustic measures consisted of noise level and reverberation times which were correlated with employee satisfaction. In cellular workspaces, work performance satisfaction increased when reverberation time was above 0.67s and in open-plan workspaces with occupancy between 10 and 25 employees acoustic satisfaction increased when reverberation time was 0.58s and in both these aforementioned office types the increase in reverberation time was associated with a decrease in annoyance with people talking. The latter findings are in line with the study of Beaman & Holt (2007) where high reverberation time was found to decrease disturbance with irrelevant background speech. Furthermore, the number of noise sources perceived by the author during office visits was also used in the analysis of acoustic satisfaction. The rating scale used in this study was a combination of both reverberation time and number of noise sources present and was coherent with the findings. However, most of the workspaces had office ratings below 2.5. It is considered that recommended values for reverberation time and noise levels provided in alternate regions were not suitable for Mauritian workspaces. Construction techniques used in workspaces surveyed here are influenced by economic factors and were devoid of acoustical treatments which led to high reverberation times. It is considered appropriate to perhaps determine new criteria for noise level and reverberation time which are related employee satisfaction in Mauritius.

The research design applied here was a cross-sectional one and it was possible that other results are obtained in longitudinal surveys of the workspaces. The perception of number of noise sources is likely to vary across working hours which might possibly indicate some pattern in relation to office activities and acoustic satisfaction. Unlike the study of Block & Stokes (1989) the complexity of work was not measured in relation to workspace satisfaction here. It is possible that if work performance is measured in relation to satisfaction then results might provide clearer description of how acoustic quality present in cellular and open-plan spaces affects performance. Another factor is considered to be potentially useful in future studies was job category. According to Zalesny & Farace (1987) employees with clerical tasks are more prone in accepting to work in open-plan workspaces than employees with managerial positions. Based on personal observations, most of the cellular offices in Mauritius were occupied by managers and executives and possibly led to more criticism of their workspaces thus resulting in lower acoustic satisfaction ratings than open-plan workspaces.

Similar to analysis performed in Glasgow sample, statistical analysis was carried out using number of cases for *N* instead of number of offices to increase reliability in correlation coefficients. The correlation coefficients began to indicate certain patterns of behaviour in each office type. However, to further support the results from the statistical analysis performed here, a larger sample than the one used here is required in future statistical analysis in each office category.

Based on the results obtained in this chapter, the increase in cellular office size tends to be associated with more perceived noise sources which decrease acoustic satisfaction ratings and on the other hand the decrease in reverberation time was associated with a decrease in work performance satisfaction. It is therefore considered that small workspaces below 13.7m^2 might be appropriate to enhance acoustic satisfaction but careful consideration should be given to choice of material finish because they influence determine reverberation time which is related to work performance satisfaction. In open-plan workspaces with less than 10 occupants, the perception of co-worker proximity had precedence over perception of acoustic measures or size of office because workspaces with linear desk arrangements, which are known to increase communication among co-workers, had higher acoustic satisfaction ratings than workspaces with non-linear desk arrangements. In open-plan workspaces with occupancy between 10 and 25, employees were satisfied with acoustic satisfaction when they had additional visual and acoustic privacy provided by partitions. In the analysis of Glasgow sample in Chapter 6, hypotheses were confirmed in one of the office type but in the Mauritius sample none of the hypotheses were supported. The differences between Glasgow and Mauritius samples are further analysed in the following chapter.

Chapter 9

A comparative analysis of Glasgow and Mauritius samples

9.1 Introduction

This chapter discusses the differences and similarities between Glasgow and Mauritius samples when analysing the association between workspace areas, acoustic measures and employee satisfaction. In the extensive literature focusing on acoustic in office environments, hardly any cross-cultural studies have been carried out in relation to acoustic in workspaces. Studies focusing on acoustic in residential settings have shown that noise perception tend to vary in different samples (Namba et al. 1986; Namba et al. 1991). The aim of this analysis was to shed further light on the differences, if any, on the association between employee satisfaction in relation to workspace floor area and acoustic measures between Glasgow and Mauritius. It was hypothesised that the association between employee satisfaction, workspace floor areas and acoustic measures would be different between the two samples for each office type.

To further test this hypothesis a comparative analysis was performed with both samples in Kruskal-Wallis to demonstrate the differences in both subjective and objective measures. Cellular offices (WLC), open-plan workspaces with less than 10 employees (WLO1) and open-plan workspaces with occupancy between 10 and 25 were analysed (WLO2). Workspaces with more than 25 employees (WLO3) were not analysed in this chapter because insufficient data in WLO3 office category were present in Mauritius sample. The comparative analysis of Glasgow and Mauritius sample for the association between objective and subjective variables are presented according to office types.

The results indicated certain similarities and differences between the two samples. Intermittent noise sources - people talking and phone rings - were observed to be pervasive noise sources in both samples for all office types. Workspace floor areas and acoustic measures in Mauritius sample for each office type were not always inferior to those in Glasgow sample. The hypothesis was supported only in workspaces with less than 10 employees. The following section (Section9.2) addresses the similarities and differences in objective and subjective data collected in both samples and the relationship between subjective and objective variables are further discussed in Section 9.4.

9.2 **Differences in field study observations**

There is a meagre body of text from which information can be drawn when analysing cross-cultural acoustic perception in the workplace. However, extensive studies have focused on organisational values and communication in varying cultures. Vaughn (2010) highlighted that there are three types of organisations in general: 1) one where bureaucracy and hierarchy are important and tend to be located in samples such as Eastern European ones 2) one where bureaucracy still occurs but there is less emphasis on hierarchy and tend to be located in samples such as northern European samples and 3) finally one where bureaucracy is not important but hierarchy is important. Mauritius could be considered in the first aforementioned category and Scotland in the second. In addition to the differences in types of organisations, it was also perceived during field surveys that acoustic treatments were rarely used in Mauritius as mentioned previously in Chapter 8. It was also mentioned previously in Chapter 8 that organisations tended to be either small or medium-sized. It was therefore initially expected that workspace floor areas and acoustic quality of workspaces in all office types in Mauritius would be inferior to those in Glasgow. The following sections compare office characteristics, acoustic quality, office ratings and subjective ratings of the two samples. WLO3 office category sample was excluded from the analysis given that insufficient data was available in Mauritius sample for that category.

9.2.1 *Office characteristics*

Similar variables were investigated in both samples - workspace floor area, occupancy density and room heights. Kruskal-Wallis was used to analyse the differences between both samples for the workspace setting variables in the three office types; WLC, WLO1 and WLO2. It was initially expected that all workspace variables would have higher values in Glasgow sample than those in Mauritius because workspaces in Glasgow were perceived to be more spacious than those in Mauritius samples by the author. The results and median values are displayed below in Table 9.0 and the expectation that offices in Mauritius would be smaller than those in Glasgow was only supported in cellular workspaces. In WLO1 workspaces, no significant differences in the size of workspaces were observed between the two samples. In WLO2 office category, workspaces in Glasgow sample were smaller than those in Mauritius sample which was unexpected. Occupancy density differed significantly in all three types of offices indicating that values of individual workspace area was smaller in Glasgow than in Mauritius in WLC and WLO1 offices. The contrary to the latter was observed in WLO2 offices. Height was found to vary significantly only in WLO1 workspaces indicating that workspaces in Glasgow sample had a slightly higher ceiling than those in Mauritius sample. No further significant differences were observed for room heights in the other office types. Therefore, it cannot be conjectured that workspaces in Mauritius sample in each office category were smaller than those in Glasgow sample.

	WLC				WLO1				WLO2			
	G	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*
Workspace floor area	15.8	13.7	*4.120*	*0.042**	57.5	52.5	*0.422*	*0.516*	98.6	142.1	*15.482*	*0.000***
Occupancy density	7.98	13.7	*9.744*	*0.002***	4.81	7.33	*11.274*	*0.001***	6.57	3.30	*22.900*	*0.000***
Height	2.64	2.79	*3.059*	*0.080*	2.70	2.65	*4.413*	*0.036**	2.70	3.10	*1.932*	*0.164*

Table 9.0 Median values for spatial characteristics in Glasgow (G) and Mauritius (M) samples and significant differences shown in Kruskal-Wallis test where **p<0.01 and * p<0.05

9.2.2 *Acoustics in the workplace*

As mentioned in the previous section, very few workspaces in Mauritius sample had acoustic treatments in comparison to those in Glasgow sample. It was therefore expected that values for acoustic measures would be higher in Mauritius offices than in Glasgow ones. Similar to the above section, Kruskal-Wallis was used to determine differences in acoustic measures in varying office types between the two samples and the results are displayed in Table 9.1. The frequency of noise levels for each office type in both samples are shown in Figure 9.1.0 to 9.1.2. The results in some office types supported that hypothesis only when analysing acoustic measure, noise level. Noise level in WLC and WLO1 offices were lower in Glasgow sample than in Mauritius sample which was as expected. Noise level in WLO2, however, was higher in Glasgow than in Mauritius which was contradictory to what was expected. Reverberation time was found to differ significantly between the two samples only in WLC and WLO2 offices. Reverberation time in Glasgow sample in WLC offices was lower than that in Mauritius sample and reverberation time in WLO2 in Glasgow sample was higher than that in Mauritius sample which was unexpected. In WLO1 workspaces no significant differences were observed for reverberation time when comparing the two samples and this was considered to be possibly linked to the fact that workspace floor area, which is used in the calculation of reverberation time, did not vary significantly as mentioned in the previous section. In Glasgow sample the most annoying noise sources were people talking in all three office types. In Mauritius sample, the most annoying noise sources were as follows: phone rings in WLC offices, people talking in WLO1 & WLO2 offices. In both samples, it was considered that uncontrollable and unpredictable noise sources, such as phone rings and people talking, were the most annoying noise sources. Similar to the previous section, it cannot be conjectured that for all three office types, acoustic quality in Mauritius sample was inferior to that in Glasgow sample.

	WLC				WLO1				WLO2			
	G	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*
Noise level	44.6	50.6	*9.205*	*0.002***	44.4	50.4	*13.557*	*0.000***	48.0	45.0	*6.014*	*0.014**
Reverberation time	0.34	0.67	*12.427*	*0.000***	0.52	0.84	*2.525*	*0.112*	0.95	0.58	*4.778*	*0.029**

Table 9.1 Median values for acoustic measures in Glasgow (G) and Mauritius (M) samples and significant differences shown in Kruskal-Wallis test where **p<0.01 and * p<0.05

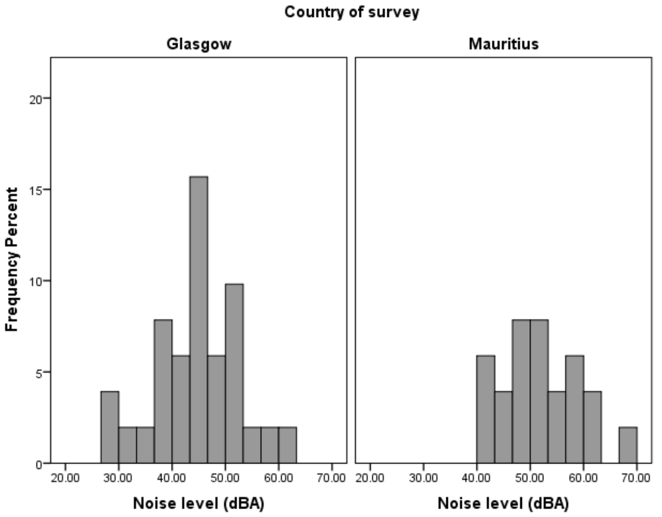


Figure 9.1.0 Frequency of measured noise level in WLC offices in Glasgow and Mauritius

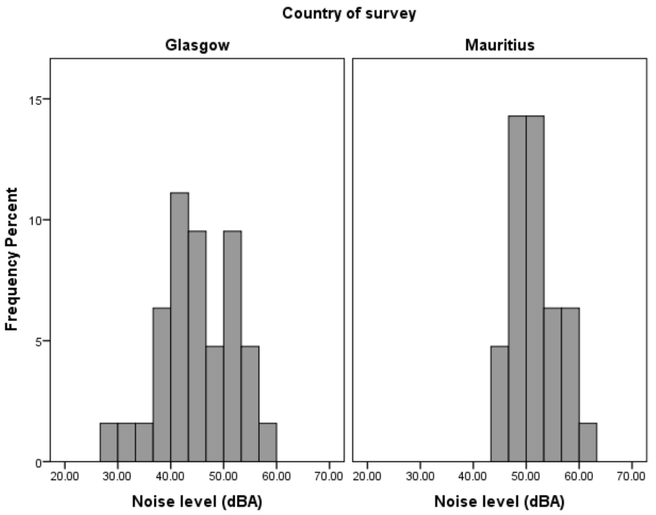


Figure 9.1.1 Frequency of measured noise level in WLO1 offices in Glasgow and Mauritius

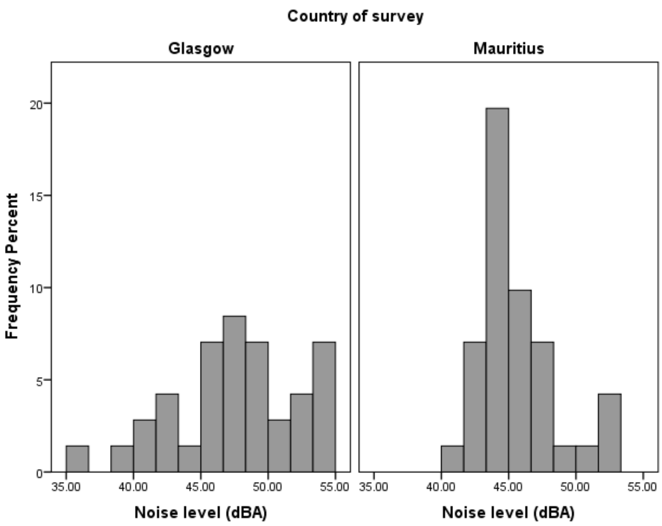


Figure 9.1.2 Frequency of measured noise level in WLO2 offices in Glasgow and Mauritius

9.2.3 *Rating of workspaces*

All office types in Glasgow and Mauritius samples were rated for the number of noise sources present and reverberation time. Ratings for both samples were compared in Kruskal-Wallis. It was initially expected that office ratings would be inferior in Mauritius sample because workspaces in the latter were perceived to be noisier than those in Glasgow and also lacked acoustic treatments. The results were coherent with Section 9.2.1 and 9.2.2 where ratings tended to vary differently in each office type (see Table 9.2). In WLC and WLO1 workspaces, higher ratings were observed in Glasgow sample than in Mauritius sample. However, in WLO2 workspace the office ratings were higher in Mauritius sample than those in Glasgow sample. The ratings also highlighted that more noise sources were present in WLC and WLO1 offices in Mauritius sample than those in Glasgow sample. In WLO2 offices, the rating of number of noise sources was similar for both Glasgow and Mauritius samples but reverberation time differed significantly which contributed to the high office rating in Mauritius.

	WLC				WLO1				WLO2			
	G	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*	*G*	*M*	*Chi²*	*Sig*
Rating of number of noise sources present	5.0	3.0	*16.652*	*0.000***	2.0	1.0	*30.850*	*0.000***	1.0	1.0	*0.00*	*1.000*
Rating of reverberation time	3.0	1.0	*9.499*	*0.002***	3.0	1.0	*9.516*	*0.002***	1.0	1.4	*4.885*	*0.027**
Total office rating	3.5	2.5	*20.102*	*0.000***	3.0	1.0	*31.383*	*0.000***	1.0	2.5	*4.885*	*0.027**

Table 9.2 Median values for office ratings in Glasgow (G) and Mauritius (M) samples and significant differences shown in Kruskal-Wallis test where **p<0.01 and * p<0.05

9.2.4 *Questionnaire responses*

Similar questionnaires were distributed in both samples to evaluate acoustic and work performance satisfaction and a few differences in ratings were highlighted in Kruskal-Wallis (see Table G.1, G.2 and G.3 in appendices). In WLC workspaces, employees in Mauritius sample reported greater frequency of raising voices during conversations than those in Glasgow cellular offices. In WLO1 workspaces, no significant difference was observed for acoustic satisfaction rating between Glasgow and Mauritius samples. In WLO2 workspaces, employees in Glasgow sample reported more noise disturbances than those in Mauritius sample. The ability to remain concentrated on work most of the time was higher in Glasgow sample than in Mauritius sample in all three office types (WLC, WLO1 and WLO2). Despite higher ratings for the ability to remain concentrated on work in Glasgow than in Mauritius, employees in Glasgow in WLO1 and WLO2 offices had a higher preference for alternate office type when completing tasks than those in Mauritius. Similar to workspace floor areas and acoustic measures, the perception of acoustic quality varied according to office type in both samples and these initial observations showed no indications that all three types of workspaces in Mauritius had inferior objective and subjective values to those in Glasgow. The following sections analyse the differences between Glasgow and Mauritius for the association between objective and subjective variables.

9.3 Research question and revised hypothesis

Identical research framework was used during the investigation of samples in Glasgow and Mauritius samples as seen in Chapter 6 and 8 to maintain consistency when comparing the two samples. Similar hypotheses for cellular and open-plan workspaces were used in both Glasgow and Mauritius samples - Hypothesis A stated that the increase in workspace floor area in cellular offices would be associated with a decrease in values of at least one indicator of acoustic measures and increase in employee satisfaction and Hypothesis B stated that the increase in workspace floor area in open-plan workspaces would be associated with an increase in values of at least one indicator of acoustic measures and decrease in employee satisfaction. European and American countries have extensive literature focusing on the field of acoustic perception within the different types of workspaces but not in Mauritius. The issue of noise in Mauritius is mostly affiliated with Sick Building Syndrome as shown in the study of Bholah et al. (2000). However, several studies focusing on organisational behaviour have been carried out in both samples. In a cross-cultural study of organisation value, Hofstede (1985) highlighted significant differences in varying samples for preferences of hierarchy, degree of uncertainty and type of social framework (individualism or collectivism) in organisations. In another study conducted by Hofstede (1985), it was observed that employees who were satisfied in organisations were also content with cooperation and communication among co-workers. According to Hofstede (1985), employees in UK organisations preferred individualism and less hierarchy while Liu & Sudweeks (2003) observed that in Mauritian offices employees preferred collectivism and less hierarchy. It was possible that the different preferences of social framework between UK and Mauritius influenced the perception of acoustic and workspaces. In the same line of thought, Namba et al. (1991) highlighted that acoustic perception tended to vary in different samples with some cultures being more tolerant than others in residential area. The findings of the latter study are not applicable here given that it focused on residences but nonetheless, the possibility of differences in acoustic perception in workspaces should not be easily dismissed. As seen in Section 9.2, office characteristics, acoustic measures and employee satisfaction tend to vary in different office types between Glasgow and Mauritius samples. The following section (Section 9.4) compares associations between workspace floor area, acoustic measures and employee satisfaction between Glasgow and Mauritius samples for each office type to address the following question:

> *In contrasting countries, is the relationship between workspace floor area, acoustic measures and employee satisfaction similar?*

Based on the previously established contrast in organisational values between UK and Mauritius and the differences in objective and subjective values as mentioned previously, it was hypothesised that there would be no similarities between the two samples in the association of employee satisfaction with workspace floor area and acoustic measures for all three office types. It was expected that acoustic satisfaction in Mauritius sample in all office types would not decrease with increasing values of acoustic measure indicators because of habituation to noise occurring. Section 9.4 discusses the results obtained from both samples.

9.4 Comparative analysis of the association between objective and subjective variables

9.4.1 *WLC workspaces*

Several significant differences were observed between the two samples in cellular workspaces for employee satisfaction, workspace size and acoustic measures. The size of cellular workspaces differed significantly as seen in Section 9.2.1 – Glasgow sample had larger cellular offices than those in Mauritius sample with median values of 15.8m^2 and 13.7m^2 respectively. Median noise level and reverberation time were higher in Mauritius sample than in Glasgow sample – 50.6 dBA in Mauritius sample and 44.6 dBA in Glasgow sample and reverberation time of 0.67s in Mauritius sample and 0.34s in Glasgow sample. However, median noise level in both Glasgow and Mauritius samples were considered poor because they were both above the recommended value of 40 dBA by the BCO (2009). In relation to reverberation time only that of Glasgow sample was below the suggested value of 0.40s by the BSI (1999) while that of

Mauritius sample was well above the suggested value. The difference in reverberation time was considered to be related to the fact that more noise absorbing surfaces were present in Glasgow sample than in Mauritius one ($X^2(1) = 20.263$, $p<0.01$). Based on the description of workspaces in appendices, 81% of cellular offices in Glasgow sample had both carpet flooring and acoustic ceiling tiles while in Mauritius sample only 20% of cellular offices had similar finishes. The difference in the presence of noise absorbing materials was considered to be linked to climate differences – materials that store heat, such as carpet, are ubiquitous in all Glasgow offices whereas in Mauritius offices vinyl or tiles, which store less heat, are usually preferred because of high temperature. Table G.1 in appendices also showed that employees in Mauritius tended to raise voices during conversations more and had lower ability of remaining concentrated on work than those in Glasgow. The difference in ratings of raising voice level during conversation between Glasgow and Mauritius was considered to be related to the difference in noise level between the two samples. Liu & Sudweeks (2003) pointed out that employees in Mauritius offices had a great preference for collectivism and it was possible that the inability to work within close proximity to employees when in cellular offices led employees to increase voice levels when communicating with other colleagues. Based on the differences in acoustic measures between Glasgow and Mauritius samples, the cellular offices in Mauritius would be considered inferior to Glasgow sample because noise levels and RT values were higher than that of Glasgow sample and the recommendations by the BCO (2009) and BSI (1999). The inferiority of acoustic quality in Mauritius sample was further observed in the office ratings – Kruskal Wallis showed that office ratings were significantly lower in Mauritius sample than in Glasgow and can be seen in Figure 9.3 ($X^2(1)=20.102$, $p<0.01$).

The relationship between workspace floor area and acoustic measures also differed in both samples. In Glasgow sample, the increase in workspace floor area was associated with an increase in the ratio of glazing-to-floor area which in turn was associated with an increase in RT. The increase in workspace floor area above 15.8m^2 was associated with RT values above 0.34s in Glasgow sample. In Mauritius sample, the variations in workspace floor area had no significant associations with total absorption of surface materials or ratio of glazing-to-floor area. Instead RT was considered as an independent variable in Mauritius sample which was negatively associated with total noise absorption of surface materials. In Glasgow, noise level had no significant correlation with workspace floor area and was considered to be related to activities occurring within cellular offices because 'people talking' was reported as the most annoying source among those who were dissatisfied with acoustics. In Mauritius, the increase in workspace floor area was associated with a decrease in noise level but, here too, noise level was considered to be task-related because no further correlation was observed with possible noise sources such as number of noise source present, etc. In Section 9.2.3, it was highlighted that more noises sources were present in cellular offices in Mauritius than those in Glasgow. However in both samples there was no direct association between acoustic measures and number of noise sources present. The association between office rating and workspace floor area in both samples are shown in Figure 9.3 where in Glasgow sample the increase in office rating is associated with a decrease in area and in Mauritius no linear relationship can be observed between workspace floor area and office rating.

Certain similarities and differences were observed in the relationship between subjective and objective for both samples. In both Glasgow and Mauritius, acoustic satisfaction decreased when RT increased which is shown in Figure 9.2. However, variations in workspace floor areas in both samples were related to different subjective variables. In Glasgow, the increase in workspace floor area was associated with enhanced work performance satisfaction and in Mauritius the increase in workspace floor area was associated with a decrease in acoustic satisfaction. The increase in RT was also associated with an increase in work performance satisfaction in Mauritius. However, in both samples regardless of its association with objective variables, the increase in work performance satisfaction was related to a decrease in annoyance with people talking. In Glasgow, it was observed that increasing values of workspace floor area above 15.8m^2 was associated with a decrease in annoyance from people talking (from 66.7% to 13.3%) and it was considered that the high RT correlated with increasing values of workspace floor area hampered conversations which in return led to enhanced work performance satisfaction. The decrease in acoustic satisfaction ratings related to RT

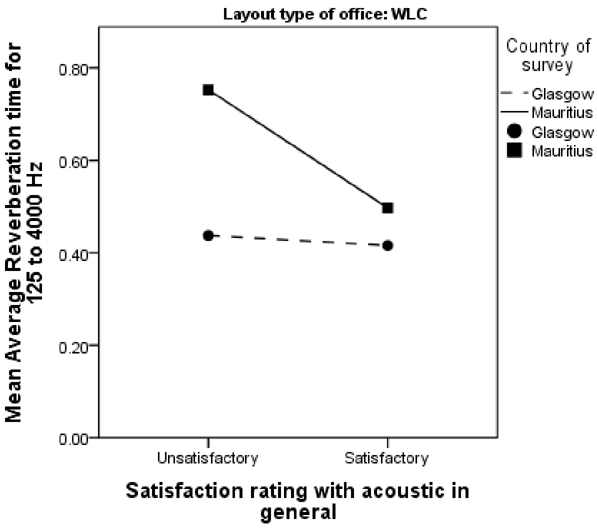


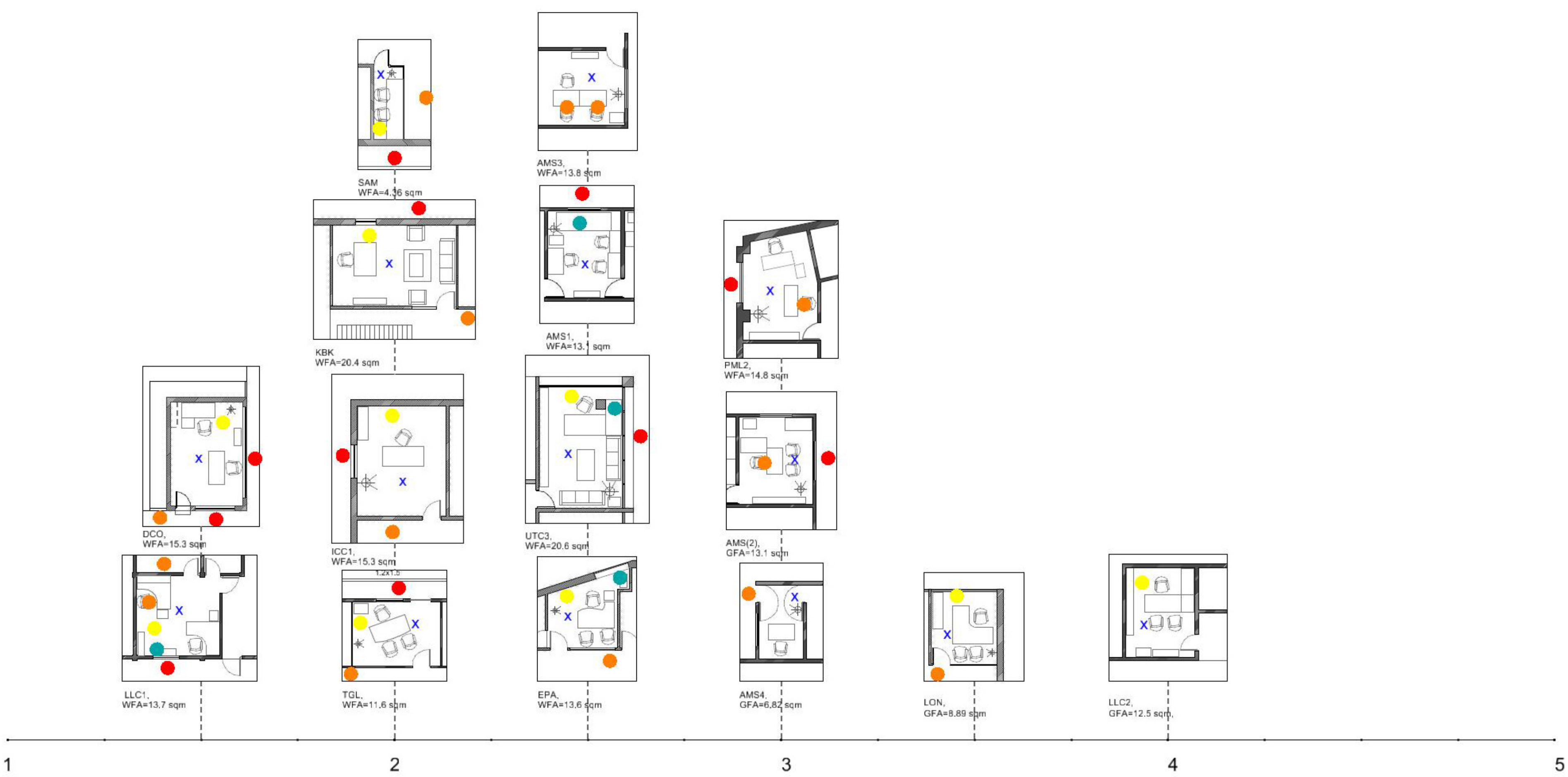
Figure 9.2 Relationship between acoustic satisfaction and reverberation in both samples for WLC offices

above 0.34s in Glasgow cellular offices were not considered to be detrimental to acoustic satisfaction because variations in RT was still associated with acoustic satisfaction ratings above 50%. In Mauritius, it was observed that the increase in RT above 0.67s was associated with a decrease in acoustic satisfaction but an increase work performance satisfaction. In Mauritius workspaces, employees reported that they were less distracted by other’s conversations during task completion when RT was above 0.67s. Similar to Glasgow, it was considered in cellular offices in Mauritius that the increase in RT dampened conversations which in return enhanced work performance satisfaction. Acoustic satisfaction decreased from 60% to 22.2% when RT increased above 0.67s in Mauritius and was considered to be linked to high resonance occurring within cellular offices with high RT. Regardless of the similarity in the association between reverberation time and acoustic satisfaction in both samples, it was considered that the tolerance to high noise reflection was different in both samples because in Glasgow, acoustic satisfaction occurs below 0.34s while in Mauritius acoustic satisfaction occurs below 0.67s which is almost twice the value of that of Glasgow. To further support the latter argument, it was also observed that despite the fact that median noise level in Mauritius cellular offices was 6 dBA higher than that in Glasgow sample (which is almost twice as loud), there was no significant association between noise level and employee satisfaction which suggests that employee in cellular offices in Mauritius might be habituated to the high intensity of noise.

It was therefore considered in cellular workspaces in both samples that reverberation time was relevant to acoustic satisfaction and that work performance satisfaction was more related to annoyance from people talking but tolerance to noise was higher in Mauritius cellular offices than in Glasgow ones. Reverberation time values below 0.35s are thought to be more convenient to achieve acoustic satisfaction instead of workspace floor areas in cellular offices for both samples but background conversations in spaces with low reverberation time require further measures to prevent perceived work performance from decreasing. The comparative analysis indicated that similar attitude towards increasing reverberation occurred in both samples and work performance satisfaction tended to increase when conversations were hampered which did not support the hypothesis stating that no similarities would be observed between employee satisfaction, workspace floor areas and acoustic measures in both samples.

Figure 9.3 Office rating for WLC offices in Glasgow and Mauritius

WLC offices in Glasgow



WLC offices in Mauritius

9.4.2 *WLO1 workspaces*

No significant differences were observed between Glasgow and Mauritius for workspace floor area in WLO1 workspaces – median workspace floor area in Glasgow was 57.5m^2 and that for Mauritius was 52.5m^2. Similar to WLC offices, noise level was higher in Mauritius than in Glasgow – median noise level was 50.4 dBA in Mauritius and 44.4 dBA in Glasgow. There were no significant differences between the two samples for reverberation time in Kruskal-Wallis – median RT in Glasgow was 0.52s and 0.84s in Mauritius. Values for acoustic measures in Glasgow were within the below the recommended value of 50 dBA (BCO, 2009) and 0.60s (BSI 1999) while in Mauritius both noise level and median reverberation time were above the aforementioned values. The absence of significant differences for reverberation time between the two samples was considered to be related the lack of difference in the size of floor areas as mentioned at the beginning. Similar to WLC offices, total noise absorption of surface materials was higher in Glasgow than in Mauritius but did not contribute to the difference in RT values between the two samples. In relation to employee satisfaction ratings, there were no significant differences for acoustic satisfaction ratings between the two samples but Kruskal-Wallis indicated that more employees in Glasgow sample preferred alternate office type to complete task (61.1%) than employees in Mauritius sample (30%)(see Table G.2 in appendices). It was also observed that employees in Glasgow sample reported greater ability to concentrate on tasks than those in Mauritius sample. The office rating scales in Figure 9.5 indicate that WLO1 offices in both samples tended to be equal to or less than 3.0 and the association between workspace floor area and acoustic quality could be seen in both – large workspace floor areas tended to have lower ratings in Glasgow and in Mauritius large workspace floor areas tended to have higher ratings than smaller workspaces.

Different associations between workspace floor area and acoustic measures were observed between the two samples in WLO1 offices. In Glasgow, the increase in workspace floor area was associated with an increase in RT which in turn was correlated with increasing room heights and less noise absorbing materials. Workspaces in Glasgow with workspace floor area below 57.5m^2 had median RT of 0.50s while those with workspace floor area above 57.5m^2 had median RT of 1.00s. In Mauritius, contrasting relationship between workspace floor area and RT existed – the increase in workspace floor area was associated with a decrease in RT which in turn was associated with a decrease in room heights and an increase in noise absorbing materials.

Workspace floor area above 52.5m^2 was associated with RT below 0.84s in Mauritius sample. In relation to noise level, an association between workspace floor area and noise level was observed only in Glasgow sample – the increase in workspace floor area was significantly associated with an increase in noise level which was also significantly correlated with the type of desk arrangement. Workspaces with workspace floor area below 57.5m^2 and non-linear desk arrangements were associated with noise level below 44.4 dBA and with a decrease in noise disturbances. In Mauritius, no significant correlation was observed between noise level and workspace floor area or other possible noise sources such as amount of glazing or type of desk arrangement. Variations in noise level in Mauritius were considered to be task-related (similar to cellular offices). The findings suggested that in both samples, the workspace floor areas and presence of noise absorbing materials were relevant to reverberation times.

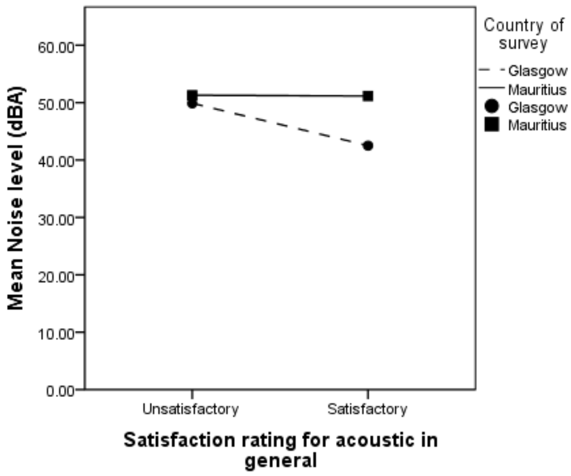
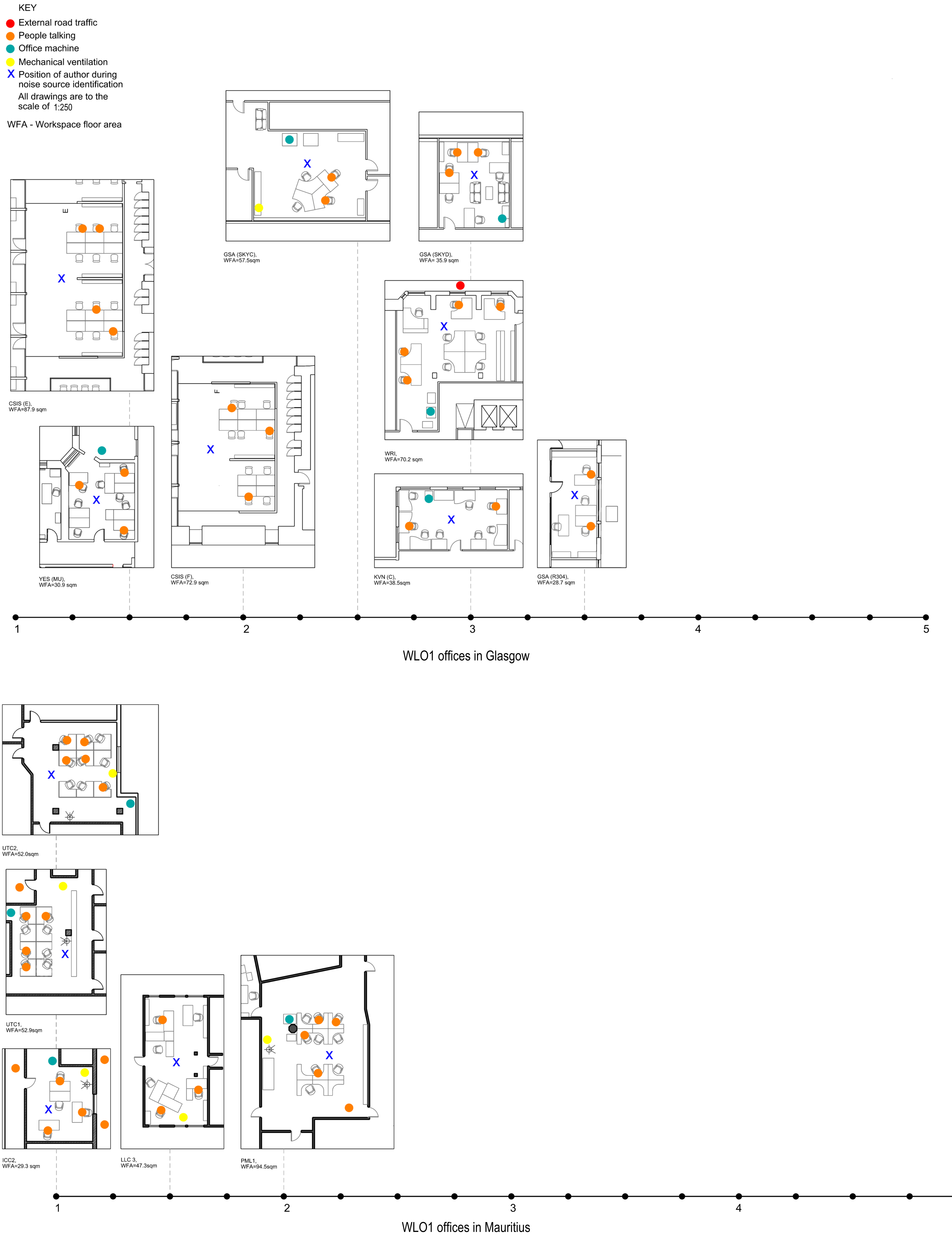


Figure 9.4 Relationship between acoustic satisfaction and noise level in both samples for WLO1 offices

Different associations between objective and subjective variables were observed between the two samples in WLO1 office category. In Glasgow, the increase in workspace floor area above 57.5m^2 was associated with an increase in noise level above 44.4 dBA which in turn was associated with a decrease of 27.6% (from 75 to 47.4%) in acoustic satisfaction and a decrease of 30.9 % (from 3.55 to 34.5%) in work performance satisfaction. Linear desk arrangement in Glasgow sample which tended to occur in offices with workspace floor area above 57.5m^2 also contributed to a decrease in acoustic satisfaction - linear layouts was associated with high noise disturbances as mentioned above. In Mauritius, the increase in workspace floor area was not significantly correlated with acoustic satisfaction, work performance satisfaction or noise level (see Figure 9.4). Despite the fact that noise level was significantly higher in Mauritius than in Glasgow sample (as mentioned at the beginning of this section) there were no further significant correlations between noise level and employee satisfaction indicators which begin to suggest some form of habituation occurring to noise in the WLO1 workspaces in Mauritius sample. Similar to WLO1 offices in Glasgow, the increase in workspace floor area above 52.5m^2 was associated with linear desk arrangements in Mauritian offices but the association between type of desk arrangement and employee satisfaction was contradictory to that in Glasgow sample. In Mauritius sample, linear desk arrangement was associated with an increase of 39.8% (from 37.5 to 77.3%) in acoustic satisfaction and a decrease of 14.8% (from 37.5 to 22.7%) in reported annoyance with people talking. Furthermore it was observed that WLO1 employees in Glasgow found close proximity (occupancy density below 4.81m^2) to be disturbing to work performance while those in Mauritius with closer proximity to employees (with occupancy density below 7.33m^2) perceived greater work performance. It could therefore be conjectured that employees in WLO1 offices in Mauritius had a preference for collectivism which is supported by enhanced acoustic and work performance satisfaction ratings in workspaces with small occupancy densities. It was to be highlighted that BCO (2009) recommends a minimum occupancy density of 8m^2 and was possibly more convenient for WLO1 employees in Glasgow than those in Mauritius. Based on the aforementioned findings, it was considered that proximity and opportunity for interaction among co-workers were significant to employee satisfaction in open-plan workspaces with less than 10 employees and varied in these two cultures.

The results in the comparison of WLO1 offices indicated different associations between employee satisfaction, workspace floor areas and acoustic measures. In Glasgow sample, the increase in workspace floor area was associated with an increase in noise level which was correlated with a decrease in acoustic and work performance satisfaction. In Mauritius sample neither workspace floor area nor acoustic measures were associated with variations in acoustic and work performance satisfaction which confirmed the hypothesis and also suggested higher noise tolerance than employees in Glasgow sample. In both samples, occupancy density and desk arrangement were significantly associated with employee satisfaction and acoustic measures indicating contrasting preferences for proximity of workers and desk layouts. To further enhance employee satisfaction in Glasgow, WLO1 offices with non-linear desk arrangements in office floor areas below 57.5m^2 with an increase in occupancy density above 8m^2 and noise level below 50 dBA are perhaps convenient. In Mauritius, WLO1 offices with linear desk arrangements and occupancy density below 8m^2 are possibly adequate but the size of workspace and acoustic measures were not found to be relevant to employee satisfaction in WLO1 offices Mauritius.

Figure 9.5 Office rating scale for WLO1 offices in Glasgow & Mauritius



9.4.3 *WLO2 workspaces*

Workspace floor areas in WLO2 offices differed significantly between Glasgow and Mauritius sample. Workspace floor areas in Glasgow were smaller than that of Mauritius in WLO2 offices with median values of 98.6m^2 and 142.1m^2 respectively. Acoustic measures also differed significantly between Glasgow and Mauritius – median noise level (48.0 dBA) and reverberation time (0.95s) in Glasgow were higher than those in Mauritius (median noise level of 45.0 dBA and reverberation time of 0.58s). Despite the difference in noise levels between both samples, median noise levels in both samples were still considered as adequate because they were below the maximum value of 50 dBA (BCO 2009). Reverberation time, on the other hand, was considered very high in Glasgow because it was above the suggested value of 0.70s (BSI 1999) but that of Mauritius in WLO2 offices was satisfactory. The difference in reverberation time was considered to be linked to the significant difference in total noise absorption between the two samples ($X^2(1) = 26.662$, $p<0.01$) – Glasgow WLO2 workspaces had lower noise absorbing surface materials than those in Mauritius sample. In relation to employee satisfaction ratings, it was observed that employees in Glasgow sample in WLO2 offices reported more noise disturbances than those in Mauritius sample (see Table G.3 in appendices). The office ratings for WLO2 offices in both countries are shown in Figure 9.7 and as shown in Kruskal-Wallis (see Table G.3 in appendices), office rating in Mauritius was higher than that of Glasgow for WLO2 offices.

In both samples, the increase in workspace floor area was associated with a decrease in RT which was correlated with an increase in total noise absorption of surface materials present. In Glasgow, workspaces with workspace floor area above 98.6m^2 had RT equivalent to 0.95s and in Mauritius, workspaces with workspace floor area above 142.1m^2 had RT equivalent to 0.58s. It was considered that in both samples, WLO2 workspaces had similar finishes: carpet flooring and painted plasterboard walls. In relation to the associations between noise level and workspace floor area, different relationships were observed in the two samples. In Glasgow, workspace floor area was not significantly correlated with noise level which instead was associated with the frequency of window opening. In Mauritius, the increase in workspace floor area was associated with an increase in noise level which in turn was significantly correlated with an increase in the ratio of glazing-to-floor area.

Several similarities were observed in the associations between objective and subjective variables between Glasgow and Mauritius. In both samples, the increase in workspace floor area was associated with a decrease in RT and acoustic satisfaction (see Figure 9.6). The decrease in acoustic satisfaction when workspace floor area increased and RT decreased was considered to be related to annoyance with people talking. In Glasgow, workspace floor areas below 98.6m^2 was associated with median RT above 0.95s and 28.6% of employees were annoyed with people talking and in offices with workspace floor areas above 98.6m^2 and median RT below 0.95s, all of the employees were annoyed with people talking. In Mauritius offices it was observed that in workspaces with floor areas equal to 142.1m^2, RT was 0.58s and 42.9% of employees were annoyed with people talking and when workspace floor area was below 142.1m^2 (RT=0.60s), 37.5% were annoyed with people talking. According to Mershon et al. (1989) & Cabrera et al. (2002) noise sources are more distinguishable when RT decreases and it was considered that the decrease in RT in WLO2 in both samples was linked with greater annoyance because conversations were intelligible and became distracting. Work performance satisfaction, however, had different correlations with objective variables – in Glasgow work performance satisfaction was associated with both RT and occupancy density but in Mauritius work performance satisfaction was not significantly correlated with any of the objective variables. The absence of correlation between RT and work performance satisfaction in Mauritius sample was possibly related to other variables such as job satisfaction. The correlation analysis for both samples indicates that acoustic satisfaction decreases with decreasing reverberation time because as mentioned above the changing state of background noise is greater in spaces with less noise reflections. However, it was also observed in Table G.3 that ratings of perceived of noise disturbances were less in Mauritius sample than in Glasgow sample and in Mauritius sample there was lower RT values than in Glasgow sample as seen in Figure 9.3. It was expected that there would be higher ratings of noise disturbances in Mauritius sample than in Glasgow because of the significant difference in reverberation time but it is considered that this low rating of noise disturbances in spaces with low reverberation time is possibly related to higher noise tolerance in Mauritius sample.

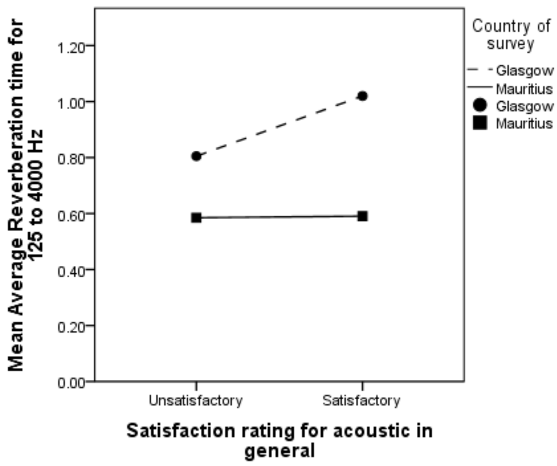


Figure 9.6 Relationship between acoustic satisfaction and workspace floor area in WLO2 offices in both samples

In both samples, WLO2 offices had linear desk arrangements as seen in Figure 9.7. In Glasgow WLO2 offices, the increase in reverberation time was associated with a decrease in reported annoyance with people talking in linear desk arrangements. In Mauritius WLO2 offices, visual and acoustic privacy was provided by partitions in one of the workplaces, IFM2 offices (as mentioned in Chapter 8) and high acoustic satisfaction (87.6%) was observed in that office in comparison to other workspace with linear desk arrangement (59.6%) and no partition. The latter observation contradicted the findings of WLO1 offices in Mauritius where workspaces with linear desk layouts and close proximity to employees had enhanced acoustic satisfaction. It was considered that this high acoustic satisfaction in Mauritius WLO2 workspaces with linear desk layout and restricted visual and acoustic privacy was possibly convenient for collective work in workspace with more than 10 employees. The relationship between workspace floor area and occupancy density was opposite when comparing the two samples and was also not similar to those mentioned in WLO1 offices. In Glasgow, the increase in workspace floor area above $98.6m^2$ and occupancy density above $6.57m^2$ was associated with a decrease of 54.6% in acoustic satisfaction and 50% in work performance satisfaction. In Mauritius, the increase in workspace floor area above $142.1m^2$ and decrease in occupancy density below $3.30m^2$ was associated with a decrease of 28% in acoustic satisfaction. The results suggest that in both samples the increase in workspace areas tends to be associated with a decrease in reverberation which was considered to be linked to the presence of more noise absorbing materials present, such as acoustic ceiling tiles or carpet flooring. In both Glasgow and Mauritius samples, the decrease in RT was associated with a decrease in acoustic satisfaction which was in line with the findings of Beaman & Holt (2007) where the decrease in reverberation time was associated with an increase in annoyance with irrelevant speech in the background.

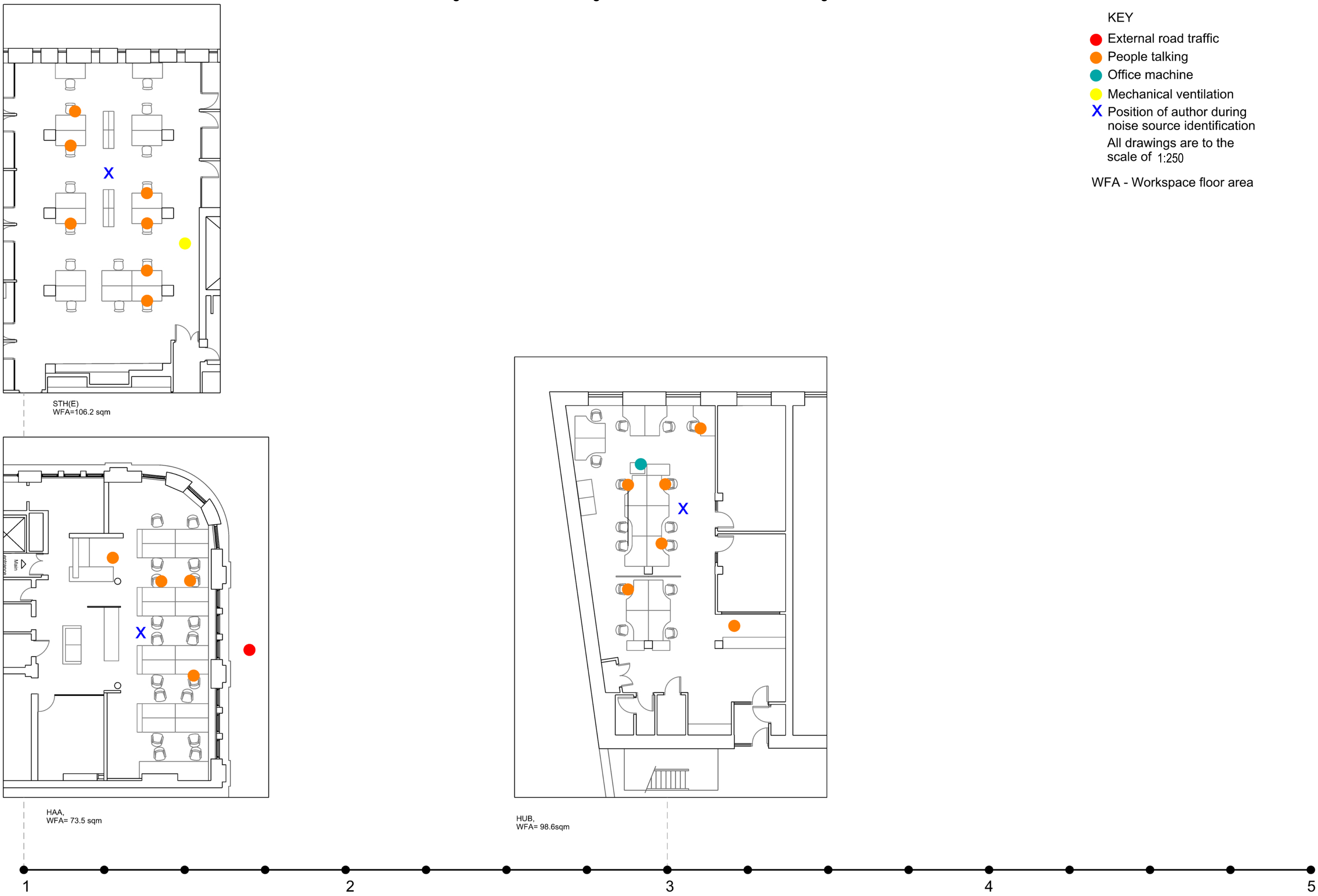
The hypothesis stated that there would be no similarities between the two samples in the association of employee satisfaction with workspace floor area and acoustic measures. The results in both samples showed that the association between employee satisfaction, workspace floor areas and acoustic measures in WLO2 workspaces were similar in both Glasgow and Mauritius which did not support the hypothesis. For WLO2 workspaces in Glasgow, it was considered that enhanced acoustic satisfaction would occur in offices with workspace floor areas below $98.6m^2$ and RT above 0.95s and for WLO2 workspaces in Mauritius workspace floor areas below $142.1m^2$ and RT above 0.60s were considered to be appropriate.

Figure 9.7 Office rating scale for WLO2 offices in Glasgow & Mauritius

KEY
- External road traffic
- People talking
- Office machine
- Mechanical ventilation
- X Position of author during noise source identification

All drawings are to the scale of 1:250

WFA - Workspace floor area



WLO2 offices in Glasgow

WLO2 offices in Mauritius

9.6 Summary

In this research, two samples from different locations - Glasgow and Mauritius - were analysed and the results were compared in this chapter. Based on the fact that organisational values differed in both samples, it was hypothesised that no similarities would exist between the two samples for the association between workspace floor areas, employee satisfaction and acoustic measures. Results from the comparative analysis indicated that the hypothesis was supported only in open-plan workspaces with less than 10 employees.

In cellular (WLC) offices, similar behavioural pattern was observed between the two samples despite the fact that office size and acoustic quality were superior in Glasgow than in Mauritius. No significant association was observed between workspace floor areas and acoustic satisfaction in both samples. The increase in reverberation time was associated with a decrease in acoustic satisfaction and work performance satisfaction tended to be related to noise disturbances caused by people talking in both samples. Given the similarities in associations between subjective and objective variables, the hypothesis was not confirmed.

In open-plan offices with less than 10 employees (WLO1) completely different relationships were observed between subjective and objective variables. Glasgow workspaces had larger floor areas and lower values for acoustic measures than those in Mauritius. In Glasgow, the increase in workspace floor area was associated with an increase in noise level which was associated with a decrease in employee satisfaction. In Mauritius, neither workspace floor area nor acoustic measures were associated with employee satisfaction which instead increased when occupancy density decreased and workspaces had linear desk arrangements. In Glasgow, both occupancy density and employee satisfaction increased together which was opposite to the findings in Mauritius sample. The results presented for open-plan workspaces with less than 10 employees supported the hypothesis.

In open-plan offices with 10 to 25 employees (WLO2) similar associations between subjective and objective variables were observed in Glasgow and Mauritius samples despite the fact that Mauritius sample had larger workspaces and lower values for acoustic measures than Glasgow. In both samples, the increase in workspace floor area was associated with a decrease in reverberation time and with a decrease in acoustic satisfaction. Like the findings in WLO1 workspaces, the associations between occupancy density and acoustic satisfaction were different in both samples – In Glasgow, the increase in occupancy density was associated with a decrease in acoustic satisfaction and in Mauritius the increase in occupancy density was associated with an increase in acoustic satisfaction. Based on the association of employee satisfaction with workspace floor area and acoustic measures in both samples, the hypothesis was not supported in open-plan workspaces with occupancy between 10 and 25 employees.

9.7 Discussion

In this comparative study it was hypothesised that no similarities between Glasgow and Mauritius samples would exist for the associations between workspace floor area, employee satisfaction and acoustic measures but the results indicated otherwise. Certain similarities and differences occurred between Glasgow and Mauritius samples which started revealing certain patterns of behaviour. In cellular workspaces (WLC) in both samples, it was observed that there was no significant association between workspace floor area and acoustic satisfaction despite the fact that workspace floor areas were associated with acoustic measures in both samples. Reverberation time, which was low in Glasgow sample and high in Mauritius sample, was negatively associated with acoustic satisfaction in both samples and work performance satisfaction tended to increase in workspaces with high reverberation in both samples in cellular offices. Reported annoyance from people talking were found to be associated with a decrease in work performance satisfaction but annoyance with people talking tended to decrease in cellular workspaces with high reverberation time. It was considered that highly resonating cellular workspaces decreased annoyance with people talking by reducing the changing state of background speech as described by Perham et al. (2007) and Beaman & Holt (2007). The annoyance with people talking was coherent with the studies of Danielsson & Bodin (2009), Kjellberg & Landstrom (1994), Salamé & Baddeley (1982). Based on the results obtained for WLC workspaces in both samples, it is considered that employees in that specific office type have low tolerance to noise disturbances despite cultural differences and high reverberation time seems to dampen background conversations but not necessarily providing an acoustically pleasing work environment. Therefore, further studies are required to investigate other possibilities of reducing annoyance with background speech.

In open-plan workspaces with less than 10 employees (WLO1) it was observed that the associations between subjective and objective variables were not alike in both samples but proximity of employees was related to acoustic satisfaction in both samples. In Glasgow sample it was observed that the increase in occupancy density was associated with an increase in acoustic satisfaction and a decrease in noise level. The increase in occupancy density in Glasgow sample was also associated with non-linear desk arrangements which were associated with fewer reported noise disturbances than workspaces with non-linear desk arrangements. It was further observed in Glasgow sample that greater distance between co-workers and less of face-to-face communication (due to non-linear desk arrangements) was associated with less reported annoyance with people talking. In Mauritius sample, the increase in occupancy density and non-linear desk arrangements were associated with a decrease in acoustic satisfaction. Despite the fact that close proximity to employees and linear desk arrangements increased communication, it is considered that employees in Mauritius sample are more tolerant to this increase in co-worker communication which supports the findings of Liu & Sudweeks (2003) where employees in Mauritian offices had a greater preference for collectivism than individualism in the workplace.

In open-plan workspaces with occupancy between 10 and 25 employees (WLO2), similar associations were observed between the two samples and this was considered to be related to the fact that similar interior finishes were present in both samples – carpet flooring and plasterboard walls. Ceilings in both samples were either plasterboard ceiling or acoustic ceiling tiles. The relationship between reverberation time and acoustic satisfaction in both samples in WLO2 was considered to be different to that observed in WLC offices. In cellular offices, as mentioned at the beginning of this section, it was observed that the increase in reverberation time was associated with a decrease in acoustic satisfaction but here in open-plan workspaces with occupancy between 10 and 25 we find that the increase in reverberation time was associated with a decrease in acoustic satisfaction. It is considered in open-plan workspaces with more than 10 employees and decreasing reverberation times, noise sources that are easily discerned tend to lead to greater acoustic dissatisfaction because they become more distracting regardless of the cultural background. It was previously mentioned in the Glasgow sample (Chapter 6), that an employee reported that conversations in low voice levels were more annoying because the content of conversation becomes of interest to listeners and distracted and in the study of Nemecek & Grandjean (1973) conversation contents were reportedly more annoying than the intensity of conversations. In both samples, it is considered that the increase in reverberation time decreases annoyance with people talking because according to Beaman & Holt (2007) multiple reflections in resonating workspaces dampen background speech. It is possible that in workspaces with homogenous interior workspaces, attitude of employees towards noise are likely to be similar.

In the workspace environment, it is considered that acoustic measures tend to vary when comparing Glasgow sample to that of Mauritius. There are also some similarities in the attitude towards acoustic measures in both cellular and open-plan workspaces with occupancy between 10 and 25. Significant differences between both cultures were observed in open-plan workspaces with less than 10 employees; in Glasgow sample there was a preference for limited co-worker interaction and low intensity of noise while in Mauritius sample, there was a preference for co-worker interaction and close proximity to workers and acoustic measures were not relevant to employee satisfaction. This cross-sectional study examined only two countries and more cross-cultural studies investigating noise perception at work are required to help further develop acoustic guidelines relevant to local work culture.

Chapter 10

General conclusion

This research is a cross-sectional study that investigated the association between the size of workspaces, acoustic measures and employee satisfaction in cellular and open-plan offices located in two distinct countries. The aim of this study is to provide some form of indication of acoustic and work performance satisfaction associated with office sizes and acoustic measures in cellular and open-plan offices which can be used at early stages of workspace design to further enhance employee comfort and satisfaction levels in offices. Acoustic measures in this study consist of two parameters – noise intensity level and reverberation time. The increase in workspace floor area generally implies an increase in occupancy which increases intensity of noise and reverberation time because the latter is directly proportional to volume. The following research questions were addressed in this study:

1. *Are differences in the size of workspaces associated with variations in acoustic measures and employee satisfaction in cellular and open-plan offices?*
2. *In contrasting countries, is the relationship between workspace floor area, acoustic measures and employee satisfaction similar?*

At the beginning of the study, it was expected that sound behaviour would be different in cellular and open-plan workspaces because of contrasting workspace size related to occupancy levels and reverberation time. The following hypotheses were tested in the study 1) Hypothesis A: the increase in workspace floor area would be associated with a decrease in values of at least one indicator of acoustic measures (noise intensity and reverberation time) and an increase in employee satisfaction in cellular workspaces and 2) Hypothesis B: the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction. Altogether four categories of workspaces were surveyed: i) cellular offices (WLC), ii) open-plan offices with less than 10 employees (WLO1), iii) open-plan offices with occupancy levels between 10 and 25 (WLO2) and iv) open-plan offices with more than 25 employees (WLO3). Both subjective and objective data were collected in these aforementioned office categories. Subjective data consisted of acoustic satisfaction and work performance satisfaction ratings that were collected from self-administered surveys. Objective data consisted of noise levels recorded by sound level meter, reverberation time calculated with the use of Sabine's formula (Furrer 1964) and workspaces dimensions that were obtained from floor plans and actual measurements. To further investigate the perception of noise in relation to geometry of workspaces, two shape descriptors were analysed – area to indicate the size of geometry and elongation to describe the shape of geometry. In addition to Glasgow sample, another sample from Mauritius was also analysed to determine differences and similarities in noise perception in contrasting countries. In relation to Question 2, it was hypothesised that the association between workspace floor area, acoustic measures and employee satisfaction would not be similar in both samples because of the difference in culture. The findings obtained in Chapter 6, 7, 8 and 9 are summarized in Section 10.1 and certain patterns of behaviour began to transpire among the office categories that were investigated.

10.1 **Research findings**

The varying results obtained in the analysis of the four office categories in this study indicate that cellular and open-plan workspaces cannot be treated as one sample when analysing perception of noise in the workplace; satisfaction ratings associated with acoustic measures differed greatly among office categories. The results obtained in each office category in Glasgow and Mauritius samples are summarized below.

10.1.1 *Glasgow sample*

To begin with, cellular workspaces in Glasgow sample had the highest acoustic (61.7%) and work (76.7%) performance satisfaction ratings among the four office categories. The results suggest that variation in the size of workspaces is unlikely to be associated with intensity of noise level. Furthermore, the absence of significant associations between noise level and employee satisfaction indicate that employees are not bothered with intensity of noise level possibly because only a few noise sources were present in cellular offices and also noise level were considered to be task-related. The quality of sound, which was indicated by reverberation time, was significant to acoustic satisfaction ratings suggesting that employees in cellular workspaces do not tolerate high noise reflections. Work performance satisfaction, on the other hand, tends to vary according to perceived noise disturbances caused by people talking, i.e. work performance satisfaction decreased when employees in cellular offices perceived more noise disturbances caused by background conversations. Hypothesis A stating that the increase in workspace floor area of cellular offices would be associated with a decrease in values of at least one indicator of acoustic measures and an increase in employee satisfaction was not supported because the increase in the size of cellular workspaces above $15.8m^2$ was associated with an increase in reverberation time above 0.34s which was correlated with a decrease in acoustic satisfaction. The association between workspace floor area and reverberation time was contrary to what was initially expected mostly because the increase in the size of cellular workspaces above $15.8m^2$ was associated with an increase in the ratio of glazing-to-floor area (above 0.10) and in room height (above 2.63m) which increased reverberation time above 0.34s. It was also observed that offices with workspace floor area below $15.8m^2$ tended to have fewer noise disturbances than those with larger workspace floor area above $15.8m^2$ because the increase in window glazing allowed greater external noise ingress in cellular workspaces. It is therefore deemed that cellular workspaces in Glasgow with floor area above $15.8m^2$ and ceiling with no acoustic tiles and height above 2.63m tend to have more window-glazing (glazing-to-floor area ratio above 0.10) hence increasing reverberation time above 0.34s and decreasing acoustic satisfaction rating. Work performance satisfaction is considered to be related to the frequency of background noise conversations and not to acoustic measures.

In open-plan workspaces a different hypothesis from that in cellular workspaces was tested because of the varying occupancy levels and shape of floor plans in comparison to cellular workspaces. In open-plan workspaces it was initially hypothesised that the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction (Hypothesis B). The latter was articulated based on the general concept that increase in open-plan workspace size implied an increase in occupancy level which would be associated with increasing noise intensity levels and an increase in reverberation time because the latter was directly proportional to workspace volume. Furthermore, it was observed that the varying shapes of floor plans influenced the location of noise sources which possibly varied perception of noise in workspaces. To investigate the latter, geometry of workspace and noise geometry (index indicating the extent to which noise sources are discernible) were correlated with employee satisfaction. For both geometries, area was used to indicate size of geometry and elongation was used to describe geometry. Noise geometry is a different concept from acoustic measures because it is based on the extent to which noise sources are discernible but is also considered to be related to acoustic measures – the increase in noise geometry size is considered to be associated with a decrease in reverberation time because less noise reflections tend to occur in the latter situations and with an increase in noise level because for noise sources to be discernible at increasing distances they would have to have higher noise intensity. The hypotheses being tested in relation to noise geometry were as follows: 1) Hypothesis C stated that areas of both workspace geometry and noise geometry increased together, 2) Hypothesis D stated that the elongation ratio of both workspace geometry and noise geometry increased together and 3) Hypothesis E articulated that the increase in noise geometry indicators would be associated with a decrease in employee satisfaction.

WLO1 offices in Glasgow had the highest acoustic satisfaction rating (59.1%) among the three open-plan office categories which was considered to be linked to the enhanced social cohesion among co-workers due to small occupancy in comparison to the other two open-plan office categories. Work performance satisfaction rating, on the other hand was below 50% in all open-plan office category. The results indicate that employees in WLO1 office category are more concerned with intensity of noise disturbances which was related to the arrangement of desks and size of workspaces instead of acoustic quality of workspace. The workspaces with floor area above 57.5m^2 had linear desk layouts and were associated with an increase in noise level above 44.4 dBA and a decrease of 27.6% (from 75 to 47.4%) in acoustic satisfaction. The increase in size of noise geometry with floor area indicated that there was an increase in the extent to which noise sources were discernible when workspace floor area increased above 57.5m^2. The linear desk arrangement associated with floor area above 57.5m^2 is considered to increase face-to-face communication among co-workers hence increasing perceived noise disturbances in these workspaces. Neither the shape of workspace nor that of noise geometry is considered to be relevant to acoustic or work performance satisfaction because no significant associations were observed between elongation ratio and employee satisfaction for both workspace floor geometry and noise geometry. However, the size of floor area was significant to that of noise geometry and to employee satisfaction. Hypotheses B, C, D and E were supported in WLO1. It is deemed that great importance be given to interaction among co-workers in WLO1 open-plan workspaces with less than 10 employees which tends to be indirectly proportional to employee satisfaction. It is therefore considered that in open-plan workspaces with less than 10 employees, workspaces with floor area above 57.5m^2 including linear desk arrangements are likely to cause an increase in noise intensity level and a decrease in acoustic satisfaction which can be shown by an increase in size and shape of noise geometry.

WLO2 workspaces in Glasgow sample had the lowest acoustic satisfaction rating (36.8%) among all four office categories. Work performance satisfaction rating was 48.5%. The results for WLO2 offices suggest that employees are more concerned with communication among co-workers than with intensity of noise. All offices in WLO2 category had linear desk arrangements which, as mentioned previously in WLO1 offices, increased face-to-face interaction among employees. The ability to discern noise sources in linear desk layouts, as shown by noise geometry, increased when floor areas increased above 98.6m^2 and is considered to be linked to the decrease in reverberation time. In other words, the decrease in reverberation time implied a decrease in noise reflections which made the changing state of background noise more distinct in linear desk layouts where employees were in close proximity hence increasing the extent to which noise sources were discerned. Furthermore, it was expected that the increase in floor size in WLO2 offices would be associated with an increase in reverberation time but the contrary was observed because more noise-absorbing materials, such as acoustic ceiling tiles were present. Hypothesis B stating that the increase in workspace floor area would be associated with an increase in values of at least one indicator of acoustic measures and a decrease in employee satisfaction was not supported in WLO2 offices. The size of workspaces was significant to the size of noise geometry and employee satisfaction but the shape of workspace geometry was not relevant to the shape of noise geometry. In WLO2 workspaces only Hypotheses C and E were supported. Intensity of noise level was not considered relevant in WLO2 offices because median noise intensity level was generally low (48 dBA - which was below the value recommended by BCO (1999)). It is deemed that open-plan workspaces with 10 to 25 employees and floor area above 98.6m^2 are likely to be associated with reverberation time below 0.95s because there is a tendency to include more noise-absorbing materials, such as acoustic ceiling tiles, hence decreasing acoustic and work performance satisfaction.

In WLO3 workspaces, acoustic satisfaction rating (41.3%) was slightly higher than that of WLO2 offices but was still inferior to that of WLO1 workspaces. Work performance satisfaction rating was 40.7%. Similar to WLO2 offices, employees were more concerned with the interaction among employees than with intensity of noise. WLO3 workspaces in Glasgow had both linear and non-linear desk arrangements and different associations were observed between the type of desk arrangement and reverberation time. In workspaces with linear desk arrangements, acoustic satisfaction ratings decreased when reverberation time decreased while in workspaces with non-linear desk arrangements, acoustic satisfaction increased when reverberation time decreased. The latter differences in the associations in varying desk arrangements were considered to be related to the ability to communicate between co-workers and to the ability to discern noise sources in the background. For instance, in workspaces with linear desk layout employees are in closer proximity with face-to-face interaction than those in non-linear desk layout and the increase in reverberation time decreases the ability to discern noise sources in the background due to multiple sound reflections occurring simultaneously. Similar to WLO2 offices, the increase in the size of workspaces above 265.6 m^2 was associated with a decrease in reverberation time below 0.88s which was considered to be linked to the increased presence of noise-absorbing materials, such as acoustic ceiling tiles. Unlike WLO2 offices, the analysis of the geometry of workspace showed that the size and shape of workspace floor geometry is relevant to the type of desk arrangement being used in the WLO3 workspaces – increase in size and elongation of floor plan was associated with linear desk layouts. However, the type of desk arrangement used in WLO3 workspaces is significant to variations in noise geometry – linear desk layouts were associated with a decrease in both area and elongation ratio values of noise geometry suggesting that noise geometry was larger and more elongated in linear desk layouts than in non-linear desk arrangements. There was no direct correlation between workspace floor geometry and that of noise geometry in WLO3 offices but nonetheless indicators of noise geometry were significantly correlated with acoustic satisfaction - the increase in area of noise geometry above 76.6m^2 and a decrease in elongation of noise geometry (elongation ratio above 0.69) in WLO3 offices were associated with a decrease of 44.5% (from 80 to 35.5%) in acoustic satisfaction. It is therefore deemed that open-plan offices with more than 25 occupants arranged in linear desk layouts and floor area above 265.6m^2, reverberation time tends to be below 0.88s because of excessive noise absorbing materials present and acoustic satisfaction rating is likely to decrease which is shown by the enlarged and elongated noise geometry. To further improve workspaces in the four office categories in this study, some suggestions for practice are described in Section 10.2.

10.1.2 *Cultural difference*

To investigate cultural difference in the perception of noise in the workspace, another sample in Mauritius was collected. Identical research framework to that used in Glasgow sample was used in Mauritius sample to investigate the association between workspace floor area, acoustic measures and acoustic satisfaction. It was initially hypothesised that there would be no similarities in the associations between workspace floor area, acoustic measures and employee satisfaction between the two samples because of the different acoustic quality of workspaces and also because of the preference of employees for collectivism in Mauritian organisations as highlighted by Liu & Sudweeks (2003). The results for the comparative analysis supported the hypothesis in only one office category – WLO1.

The analysis indicated that cellular workspaces in Mauritius tended to be smaller than those in Glasgow and the reported frequency of raising voices during conversations was higher in Mauritius than in Glasgow sample which was likely to be related to high median values of acoustic measures present in Mauritius cellular offices - median noise level 50.6 dBA and RT 0.67s in Mauritius and median noise level 44.6 dBA and RT 0.34s in Glasgow. But despite these differences, similar association was observed between reverberation time and acoustic satisfaction in both samples – employees were more satisfied with acoustics when reverberation time decreased. In Glasgow sample, employees were satisfied with acoustics when RT was below 0.34s and in Mauritius sample employees were satisfied with acoustics when RT was below 0.67s. In relation to noise level, significant differences were observed between the two samples where median noise level in Mauritius (50.6 dBA) was almost twice louder than that in Glasgow (44.6 dBA) and yet no further correlation was observed between noise level and acoustic satisfaction in Mauritius. However, the absence of association between high noise level and acoustic satisfaction and the high value of RT (0.67s) below which acoustic satisfaction occurs suggest that employees in Mauritius sample are more tolerant to noise than those in Glasgow. The interior finishes of the majority of cellular workspaces in Mauritius had less noise-absorbing qualities than those in Glasgow offices which led to significant differences in the median reverberation time - cellular workspaces in Mauritius mostly had vinyl or tile flooring with painted concrete walls whereas in Glasgow cellular offices had carpet flooring with plasterboard walls. Furthermore, work performance satisfaction was more related to noise disturbances caused by people talking in the workspaces than to intensity of noise in both samples.

Based on the findings obtained in cellular offices, it is reckoned that employees have high sensitivity to noise and low tolerance of noise disturbances caused by people talking regardless of cultural differences. Therefore, more consideration should be given to the decrease of reverberation time below 0.34s in cellular workspaces in both locations.

In WLO1 offices, the associations between workspace floor area, acoustic measures and employee satisfaction were different when comparing Glasgow and Mauritius samples which supported the hypothesis stating that the associations between the aforementioned variables would be different between the two samples. The median values for noise level and reverberation times were higher in Mauritius than in Glasgow but no significant differences were observed in the size of workspaces between the two samples. The association between workspace floor area, acoustic measures and employee satisfaction indicated that in WLO1 offices in Glasgow, employees were more satisfied with background noise in smaller workspaces with floor area below 57.5m^2 with non-linear desk layouts because noise intensity was lower due to fewer noise disturbances caused by people talking. But in WLO1 offices in Mauritius neither the size of workspace nor indicators of acoustic measures were associated with employee satisfaction. The latter was instead strongly associated with the type of desk layouts in workspaces – offices with linear desk layouts were associated with an increase in workspace floor area and high acoustic satisfaction. These aforementioned differences in the two samples indicated two things. Firstly, it is likely that employees in Mauritius sample have habituated to high noise level and reverberation time because no significant associations were observed between indicators of acoustic measures and acoustic satisfaction. Secondly, the association between acoustic satisfaction and linear desk arrangements suggest that employees prefer close proximity to employees and easy face-to-face interaction in Mauritius sample while in Glasgow the contrary was observed. The presence of materials differed greatly in both workspaces thereby influencing reverberation time but the latter was irrelevant to acoustic satisfaction in both Glasgow and Mauritius samples. However, it is to be noted that in both samples, the increase in floor area was associated with linear desk arrangements but different attitude towards noise were observed in that specific desk arrangement. Therefore, more consideration should be given to perception of co-worker communication when deciding the size of workspace and the type of desk layout in organisations with less than 10 employees in both countries because it affects acoustic satisfaction and perception of noise tends to vary in different cultures.

In WLO2 office category, both noise level and reverberation time were unexpectedly higher in Glasgow sample than in Mauritius sample. Despite the significant difference in noise level, median values were still below the recommended values of 50 dBA by the BCO (2009). The difference in reverberation time, on the other hand, was linked to the size of workspaces and the presence of noise absorbing materials – Glasgow WLO2 offices had smaller floor area and less noise absorbing materials present than in Mauritius WLO2 offices. Regardless of the latter differences, presence of acoustic ceiling tiles tended to increase when size of offices increased in both samples which once more were considered to be related to the common concept that more noise absorbing materials are required when open-plan workspaces increase in size. In WLO2 workspaces, similar associations between workspace floor areas, acoustic measures and employee satisfaction were observed in both Glasgow and Mauritius samples which are considered to be related to the similarity of office appearance in both samples. In both Glasgow and Mauritius samples, the increase in workspace floor area was associated with a decrease in reverberation time (below 0.95s in Glasgow and below 0.60s in Mauritius) and acoustic satisfaction. As seen previously in WLO1 offices, there was a difference in perception of noise disturbances in linear desk arrangements. In both samples in WLO2 office category, all workspaces had linear desk arrangements. In Glasgow sample for WLO1 and WLO2 workspaces there is the coherent observation that acoustic satisfaction decreased in offices with linear layouts. In Mauritius sample we find conflicting results – in WLO1 offices acoustic satisfaction increased in linear desk layouts but in WLO2 offices acoustic satisfaction also decreased in linear desk layouts. The latter association in WLO2 offices is considered to be related to the fact that group conversations or co-worker communications are less appreciated in spaces with linear desk layouts when occupancy increases above 10 occupants hence the decrease in acoustic satisfaction in WLO2 workspaces. It was also observed that the RT value at which acoustic satisfaction occurred in Mauritius sample (0.58s) was lower than in Glasgow sample (0.95s) and less noise disturbances were reported which hints at the possibility of greater noise tolerance in Mauritius sample than in Glasgow because low reverberation time made noise sources more discernible as discussed previously in WLO2 offices in Section 10.1.1. It is conjectured that WLO2 office employees in both Glasgow and Mauritius samples are more satisfied with acoustics when workspace sizes including linear desk layouts decrease below 98.6m^2 and 142.1m^2 respectively and with reverberation time above 0.95s in Glasgow sample and above 0.58s in Mauritius sample.

10.2 Implication for practice

10.2.1 *Office design*

The different associations present in this study between workspace floor area, acoustic measures and acoustic satisfaction begin to indicate the necessity of careful planning of workspaces when trying to improve acoustic satisfaction in offices. In this study, it was observed that acoustic satisfaction was not a suitable predictor of work performance satisfaction because both variables tended to have conflicting associations in some office types and work performance satisfaction ratings were not significantly associated with acoustic measures in all office types in both Glasgow and Mauritius samples. More emphasis is placed on the implication of the results to improve acoustic satisfaction. The following paragraphs provide some guidelines for the design of workspaces for both Glasgow and Mauritius.

Glasgow workspaces

As mentioned previously in Section 10.1.1, the increase in workspace floor area above 15.8m^2 in cellular offices was associated with an increase in reverberation time above 0.34s and a decrease in acoustic satisfaction. It was also observed that materials present and the amount of glazing in these workspaces influenced reverberation time. BSI (1999) suggests a reverberation time below 0.40s for the cellular workspaces in this study but it is considered that a lower value of 0.34s be used because acoustic satisfaction ratings begin to decrease when reverberation time increases above 0.34s. The increase in reverberation time in cellular workspaces in this study was linked to the absence of acoustic ceiling tiles and an increase in the ratio of glazing-to-floor area above 0.10. The rest of the surface materials present in cellular offices is considered to be generic because they were present in most offices – carpet flooring with plasterboard walls. The increase in the amount of glazing when the size of cellular offices increased is considered to be linked to increased access to natural ventilation and daylight. Companies and organisations tend to occupy speculative workspaces and refurbish offices according to number of workspaces required. In these refurbished workspaces, height of workspaces and amount of glazing are fixed. Therefore, in refurbished workspaces it is recommended to make use of noise-absorbing materials such as partitioning, flooring and suspended ceiling and area of workspace to reduce reverberation time below 0.34s. In the design of newly proposed office spaces, more consideration should be given to volume of space, noise absorption of materials and area of glazing being used to reduce reverberation time below 0.34s. Glazed cellular offices which are often considered as stylish contemporary offices poses certain issues and requires careful consideration to acoustics when being proposed; glazing tends to reflect noise rather than absorb it thereby increasing the reverberation time and also noise from outside the workspace is easily heard and, as seen in this study, people talking in the background was found to be the most annoying noise source in cellular offices and was related to a decrease in work performance satisfaction.

In open-plan workspaces, the results obtained in this study indicate that different approaches are required in the design of offices with varying occupancy. In open-plan workspaces with less than 10 occupants, reverberation time was not associated with acoustic satisfaction and was generally low (median RT of 0.52s) which possibly led to the absence of correlation between the two variables. However, as mentioned previously in Section 10.1.1, perceived noise disturbances and the intensity of noise level were more relevant to acoustic satisfaction than reverberation time in WLO1 offices. From a design aspect, two factors are considered to contribute to noise disturbances and should be carefully considered: 1) the size of workspaces and 2) the layout of desks. In open-plan workspaces with less than 10 occupants, offices with floor area below 57.5m^2 contained non-linear desk arrangements and were associated with less noise disturbances, a decrease of 5 dBA in noise level and an increase of 27.6% (from 75 to 47.4%) in acoustic satisfaction. As mentioned previously in Section 10.1.1, in linear desk arrangements employees are more likely to engage in face-to-face communication when at their workstations than in spaces with non-linear arrangements and employees are also in closer proximity than in the latter arrangements which have been associated with an increase in perceived noise disturbances. It is therefore considered that in open-plan workspaces with less than 10 employees, more workspaces are to be designed to accommodate non-linear desk layouts to limit co-worker communication which in return should be associated with noise level below 45 dBA in order to yield high acoustic and work performance satisfaction. In newly proposed open-plan workspaces, floor areas below 57.5m^2 could be used where non-linear desk arrangements are likely to occur. In refurbished workspaces, floor areas are fixed and therefore partitions could be used to break down workspaces into smaller areas where non-linear desk arrangements can be accommodated because in this study it was observed that floor areas above 57.5m^2 had linear desk arrangements which were associated with great noise disturbances. Given that reverberation time was not relevant to acoustic satisfaction in this specific open-plan office category, the selection or choice of surface materials was not significant but can be maintained below 0.60s as suggested by the British Standards Institute (1999). The continued use of common materials present in WLO1 workspaces (carpet flooring, plasterboard walls with a glazing-to-floor area ratio of 0.09) together with acoustic ceiling tiles are likely to reduce reverberation time below 0.60s.

In WLO2 and WLO3 office categories, three variables are considered to be important for acoustic satisfaction when designing open-plan workspaces: 1) size of workspace, 2) type of desk layout and 3) reverberation time. In open-plan workspaces with occupancy between 10 and 25 (WLO2) and more than 25 occupants (WLO3) similar relationship between office design, acoustic measures and acoustic satisfaction was observed – the increase in floor area of workspaces was associated with a decrease in reverberation time and a decrease in acoustic satisfaction. Given that noise level was generally low and irrelevant to employee satisfaction in WLO2 offices, more consideration should be given to reverberation time in the design of open-plan workspaces with more than 10 employees. The differences in reverberation time in open-plan offices with more than 10 occupants (WLO2 & WLO3) were linked to the presence of acoustic ceiling tiles and height of workspaces. There is a tendency to increase the presence of acoustic ceiling tiles in large open-plan workspaces which is possibly linked to the common concept that open-plan workspaces are noisy and consequently require more noise absorbing materials, such as acoustic panels and ceiling tiles. As mentioned in Section 10.1.1, in WLO2 offices the increase in workspace floor area above 98.6m^2 was associated with reverberation time below 0.95s and a decrease of 54.6% (from 60.8 to 6.25%) in acoustic satisfaction. In WLO3 offices the increase in workspace floor area above 265.6m^2 was associated with a decrease in reverberation time below 0.88s and a decrease of 41.9% (from 72.3 to 30.4%) in acoustic satisfaction. In design of newly proposed open-plan workspaces with more than 10 employees, the area of workspaces should be maintained below 98.6m^2 with linear desk layouts where reverberation time is maintained above 0.88s to enhance acoustic satisfaction. To increase reverberation time, the notion of area of acoustic ceiling tiles being proportional to floor area should be reconsidered because as seen in this study, high noise reflections in the background dampens the changing state of noise sources.

Mauritius workspaces

Cellular workspaces in Mauritius are located in either purposely-built office buildings or converted houses and more attention to acoustics tend to occur in office buildings. The results in Mauritius sample showed that cellular workspaces had lower acoustic satisfaction rating than open-plan workspaces in the sample which was contrary to the results obtained in Glasgow sample but despite this difference in acoustic satisfaction rating, similar correlation was observed between acoustic measures and acoustic satisfaction rating in both samples. In both samples, the increase in reverberation time was associated with a decrease in acoustic satisfaction and noise intensity was not relevant to either acoustic or work performance satisfaction. In Glasgow sample, the size of workspaces and the presence of noise-absorbing materials were significant to variations in reverberation time but in Mauritius sample only noise-absorbing materials were relevant to reverberation time possibly because cellular workspaces in Mauritius were usually smaller than those in Glasgow spaces. It is therefore deemed that more consideration be given to the materials used in cellular workspaces in Mauritius and reverberation time should be maintained below 0.34s just like Glasgow sample. Most of the cellular offices in Mauritius had tiles or vinyl flooring with painted concrete walls. In order to reduce reverberation time below 0.34s, materials such as acoustic ceiling tiles and noise-absorbing wall partitions and finishes could be used for workspaces with average floor area of $13.7m^2$. The use of carpet is not considered to be efficient in Mauritius given that it absorbs heat and is likely to increase dependence on mechanical ventilation.

In WLO1 workspaces, acoustic satisfaction rating was the highest among open-plan workspaces in both Glasgow and Mauritius samples but the perception of noise in relation to office design was different and was deemed to be linked to cultural differences. In Mauritius sample, the increase in size of workspaces was associated with linear desk arrangements which in return were associated with high acoustic satisfaction. In Glasgow sample, noise intensity was relevant to acoustic satisfaction and furthermore, linear desk arrangements were associated with a decrease in acoustic satisfaction. Therefore, in the design of WLO1 offices, similar design concepts for workspaces should not be adopted in alternate countries. The results suggest that employees have a preference for closer proximity to colleagues and for layouts with increase in face-to-face interaction and consequently workspaces should be designed in such a way with floor areas above 52.5m^2 allowing for more linear desk layouts. The type of materials being used in WLO1 workspaces in Mauritius was not particularly relevant to employee satisfaction and therefore could be maintained below 0.60s as recommended by the BSI (1999) with the use of noise-absorbing materials and acoustic ceiling tiles. Noise intensity was generally low in WLO1 offices in Mauritius (50.4 dBA) and was not significant to employee satisfaction and therefore did not require further improvement.

In WLO2 workspaces in the Mauritius sample, it was observed that the increase in workspace floor area above 102.2m^2 was associated with a decrease in reverberation time below 0.60s and a decrease in acoustic satisfaction. Median reverberation time in WLO2 workspaces was higher than that in WLO1 workspaces and this difference was considered to be linked to the design and appearance of workspaces in WLO2 - carpet flooring, plasterboard walls, acoustic ceiling tiles and linear desk layouts. The latter office design was similar to European office spaces, such as Glasgow offices, and furthermore similar associations between the variables to those in Glasgow were observed. It is deemed that in the design of WLO2 workspaces in Mauritius three factors are relevant: 1) the size of workspace 2) the materials used within workspaces and 3) the type of linear desk arrangement. To enhance acoustic satisfaction in workspaces with more than 10 employees in Mauritius offices, workspaces should have floor area below 142.1m^2 with linear desk layouts and reverberation time be kept below 0.70s as recommended by the BSI (1999) with the use of noise-absorbing materials (such as carpet flooring, acoustic ceiling tiles with plasterboard walls) when designing new workspaces.

10.2.2 *Acoustic measures*

In this study two acoustic measures were used; noise level and reverberation time. Noise level was associated with employee satisfaction only in one office category – WLO1 in Glasgow sample and in Mauritius no significant associations were observed between noise level and employee satisfaction. In Glasgow sample, noise level in general was either below or approximately 50 dBA in all open-plan workspaces and in cellular workspaces noise level was much higher than the prescribed value of 40 dBA by the British Council for Offices (2009) and yet had no significant relationship with employee satisfaction. This significant association present between noise level and employee satisfaction in Glasgow sample was linked to the type of desk arrangement which varied with the size of workspaces. In open-plan workspaces with more than 10 employees, the findings suggest that noise level was satisfactory despite the varying occupancies. In the analysis of noise geometry, variations in noise level were significantly associated with an increase noise perception only in WLO1 workspaces in Glasgow and no further significant associations were observed between noise levels in noise geometry variables in other open-plan workspaces. In Mauritius sample, median noise levels tended to be higher than that in Glasgow sample in WLC and WLO1 workspaces but were not significantly associated with employee satisfaction in either of these office categories. Based on the sparse associations of noise level with employee satisfaction present in both Glasgow and Mauritius office categories it is considered that noise level is not an adequate sole indicator of employee satisfaction.

Reverberation time, on the other hand, had several significant associations with employee satisfaction in both Glasgow and Mauritius. The British Standards Institute (1999) suggested reverberation times for workspaces based on volume of workspaces and in Glasgow sample only WLC and WLO1 workspaces had median reverberation times below these recommended values and in Mauritius sample none of the workspaces had reverberation times supporting these recommended values. Despite the excessive median reverberation times present in WLO2 and WLO3 offices in Glasgow sample and in WLC and WLO1 Mauritius workspaces, reverberation time had several significant associations with employee satisfaction in most of the office types. The findings also suggested that in Glasgow open-plan workspaces with more than 10 employees, the increase in reverberation time above 0.85s was associated with an increase acoustic satisfaction. Similarly in the Mauritius sample, both reverberation time and employee satisfaction tended to increase together in workspaces with more than 10 employees. It is considered that reverberation time is a suitable indicator of acoustic satisfaction in cellular and open-plan workspaces with more than 10 employees, but in open-plan workspaces with less than 10 employees, proximity of employees tends to have greater importance than acoustic measures.

Studies focusing on acoustics in the workplace tend to make use of mostly sound intensity and further guidelines, like the BCO (2009) place great emphasis on noise levels. Based on the findings obtained in this study, reverberation time was more significant to employee satisfaction and should therefore be included in future acoustic measures when analysing office workspaces in the UK and in Mauritius. Reverberation time not only begins to highlight annoyance with acoustic quality in workspaces but also starts to indicate how adequate communication levels are in workspaces, especially open-plan offices.

10.2.3 *Employee satisfaction*

Data from questionnaire surveys or post-occupancy evaluations (POE) in the workplace are not very often used in designs because workspaces have already been designed and they do not have great effect on altering the design of workspaces after construction. However, here the use of questionnaires informed the author a lot about acoustic and work performance satisfaction and the use of both objective and subjective were considered to be essential in future workspaces because it provided further information on acoustic measures that were considered acceptable. And as observed from this study, different values for acoustic measures were associated with acoustic satisfaction, for example, the median values of reverberation time in cellular workspaces were different from those in open-plan workspaces with more than 10 employees. The difference in acoustic satisfaction rating in contrasting cultures was observed from data collected during questionnaire survey. There is the need to emphasise the use of POE in all workspaces, regardless of country of origin of offices, to enable the assessment of the comfort of employees in relation to the work environment irrespective of the construction age of the workspace.

10.3 **Limitations**

It was intended in this study to collect substantial objective and subjective data from actual workplaces in Glasgow and Mauritius to further analyse acoustic in the workplace instead of using experimental research designs observed in Section 2.7. However, gaining access to workplaces was considered to be a significant limitation in this study and was thought to influence the sample size and methodology used in this here. Firstly, establishing contact with directors or managers of organisations proved to be challenging because invitations to participate in surveys were discarded at first contact with assistants either by phone or email. Other modes of communication, such as addressed letters to heads of organisations, had to be sought which took longer than expected but were more successful in obtaining replies for survey invitations. Certain organisations that had shown previous interest in the survey declined participation in the study because of fear for privacy intrusion during sound level measurement when using the sound level meter. It is considered that more offices in each office category would have been obtained during the survey period if there were more interest on behalf of directors or managers to participate in the study. Secondly, in volunteering organisations, restrictions were placed by managers and directors on methods for data collection; no interviews were allowed, the author alone could only be present within workspaces when dropping off and re-collecting questionnaires and equipment and no audio recordings during working hours were permissible.

The aforementioned limitations of access in workspaces was considered to define the methodology used in this study. Longitudinal research designs were initially considered appropriate in determining acoustic comfort throughout different periods of the year, however, given the restricted access to workspaces, a cross-sectional research design was thought to be more appropriate. To ensure that sufficient data was available for the future analysis stage, a broad range of variables were measured even if not directly related to the topic of interest in this study. For subjective data acoustic satisfaction, work performance satisfaction, workspace satisfaction and office environment satisfaction were evaluated in the questionnaires. For objective data sound level, workspace areas and temperature were measured. The association between temperature and acoustic comfort was considered a possible area of investigation when samples from areas with contrasting climates were being used in the study. Access restrictions were also considered to limit certain areas of investigation. In regards to acoustical analysis of workspaces, the duration of annoying noise sources in workspaces from audio recordings could not be analysed in relation to acoustic dissatisfaction to further determine annoying factor of noise sources. Therefore the author had to rely on the identified noise sources from self-completed questionnaires and personal notes highlighting location of noise sources when present in workspaces. Participants were also not comfortable in providing personal details such as job status which hindered the possibility of investigating noise perception in relation to job status similar to the study of Sundstrom et al. (1994).

In regards to statistical analysis of variables, restricted access limited the number of offices obtained in the study where in some office categories only three offices were surveyed (e.g. WLO2 office category in Glasgow sample). However, the limitation in accumulating number of offices in each category was not considered a weakness because as stated in Chapter 5 Section 5.6, the study was considered to be case-oriented instead of variable-oriented where N=number of cases was used rather than number of offices. The intention here was to highlight the relationships between subjective and objective variables. The use of case studies instead of number of offices further indicated the attitude of employees towards noise in each office because variance in satisfaction ratings was more noticeable when using N=number of cases than if N=number of offices was used. In Glasgow sample, each office category had 30 or more cases and the addition of one more office in each category was considered to further support the correlation coefficients already present in the majority cases. In Mauritius sample, both time and access restriction was considered to influence the number of cases available in each office category but similar to Glasgow samples, 30 or more cases were obtained in open-plan office categories and further addition of survey would possibly support the correlation coefficients present in the study here. However, to support findings in cellular offices in Mauritius, a larger sample would have to be used in the future given that less than 30 workspaces were analysed here.

Given that only a few offices were surveyed in open-plan offices in both samples, the comparability of objective measures could be questioned but it was observed that workspaces surveyed in general had common physical characteristics as mentioned in Table D.2 and F.2. For instance, certain finish materials were commonly used in Glasgow offices; carpet flooring, plasterboard or acoustic ceiling tiles and plasterboard walls. These trends in use of common finish materials contributed to the calculation of reverberation time which became comparable.

The samples obtained in both Glasgow and Mauritius are considered to be representative of the office categories surveyed in both countries and the generalisation of results can only be extended to the cases analysed. Despite the challenge in acquiring access to offices, the study begins to establish some pattern of behaviour in relation to office size and acoustic measures in different office categories. However, to define a general pattern of behaviour and causal relationship between the variables in both countries, more offices throughout different periods of time would have to be surveyed.

10.4 **Final remarks**

This study begins to indicate the presence of the association between the size of workspaces with acoustic measures in Glasgow and Mauritius samples but the association between acoustic measures and employee satisfaction varies upon office type, size and culture. The results also begin to show that the size of workspaces is associated with the size of noise geometries in some types of open-plan workspaces (WLO1 & WLO2). Noise level was generally low in open-plan workspaces and was not considered to be significant to employee satisfaction. It is therefore deemed that more importance be attributed to reverberation time by office designers and managers because in this study it was observed that reverberation time was relevant to employee satisfaction in most office categories. Noise perception in the workplace was investigated from different aspects; office size and office type, acoustic measures, noise geometry and culture but more investigation focusing on the aforementioned variables is required to further develop indications related to acoustic comfort for workspace designers. So far, the results indicate that acoustic satisfaction rating is the highest in cellular offices in Glasgow sample and for Mauritius sample, open-plan workspaces with less than 10 employees have the highest acoustic satisfaction ratings among the different office categories investigated in this study. In cellular and open-plan workspaces with more than 10 employees, annoyance with people talking in the background appears to be a considerable issue in the offices surveyed. Based on the association between reverberation time and employee satisfaction observed in this study, it is possible that manipulation of reverberation time is a means of dealing with annoyance caused by background conversations.

10.5 **Future research**

Acoustic and work performance satisfaction ratings have been investigated in relation to different variables in this study – size of workspaces, acoustic measures, noise geometry, geometry of floor plans and cultural differences. However, further studies are required in the workplace to develop optimum acoustic comfort. To begin with, it would be interesting if longitudinal studies could be carried out in actual workspaces because this starts to determine behaviour of employees throughout days and seasons – employees tend to open windows more often during summertime than in winter which is likely to increase noise level in the workspace because of external noise ingress. But does this mean that employees are more likely to accept traffic noise during summertime than in winter? It would also be interesting to observe how noise geometry varies throughout a day which might begin to develop a pattern of noise perception in offices.

In this study, area of noise geometries and workspace geometries were investigated in relation to employee satisfaction and area as a shape descriptor had a stronger association with employee satisfaction than elongation. The shape of floor plans varied significantly and it is considered that perhaps another shape descriptor, such as Shape Index could be used instead of elongation and further analyse its association with employee satisfaction. Also, noise geometry was only analysed in Glasgow sample in this study and it would be interesting to determine, if any, the differences in noise geometry in a cross-cultural study.

This study investigated employee satisfaction only in two countries; UK and Mauritius and the results have shown that there are certain similarities and differences in the associations between workspace floor area, acoustic measures and employee satisfaction. It is considered that a cross-cultural study on a larger scale, just like that of Hofstede (1985), would be more insightful of the associations of workspace areas with acoustic measures and employee satisfaction. Here, in this study it was observed that workspace sizes in Mauritius were not always inferior to those in Glasgow. The design of open-plan offices with more than 10 employees in both countries was homogenous. According to Meel (2001), office designs vary according to national context but we begin to see similar office designs in different countries. It is therefore essential to further investigate these homogenous offices designs for the association of workspace design with acoustic measures and employee satisfaction to determine the optimum acoustic comfort in these workspaces.

Also, the aforementioned variables are only a few among the data collected during field studies. Due to access limitations and prior to refinement of hypotheses, numerous variables were collected to ensure that sufficient objective and subjective data were available at the analysis stage. Objective data included: type of office layout, size of workspace, height of workspace, co-worker distance, occupancy density, material finishes present in workspace, temperature, relative humidity, type of ventilation system present, sound level and reverberation time. Subjective data included: acoustic satisfaction, workspace satisfaction, work performance satisfaction, and satisfaction with ambient factors (including light and thermal comfort). The study here is considered to be a starting point in the analysis of acoustic comfort in the workplace where the relationship between acoustic satisfaction and all the data collected are yet to be determined. A few studies, such as the study by Witterseh et al. (2004), have looked at the association between noise dissatisfaction and heat stress in the workplace. It is possible that significant differences are observed when analysing acoustic satisfaction in the workplace in relation to thermal comfort in countries with contrasting climates.

This thesis falls into multi-disciplinary fields; acoustics, architecture and organisational behaviour and the findings obtained here are intended to be published in different academic journals focusing on different aspects of the study; Journal of Architectural and Planning Research, Journal of Architecture, Environment and Behaviour, Building Acoustics and Architectural History. The topics of initial publication in the relevant aforementioned journals are intended to focus on: 1) the use of geometric measure in relation to acoustic satisfaction and acoustic measures in the workplace, 2) the comparative analysis of acoustic satisfaction in workspaces from countries with contrasting cultures 3) office worker satisfaction ratings in relation to guidelines present and actual acoustic measures and 4) the development of spatial characteristics of offices in Glasgow in the past decades in relation in acoustic.

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Appendices

Appendix A

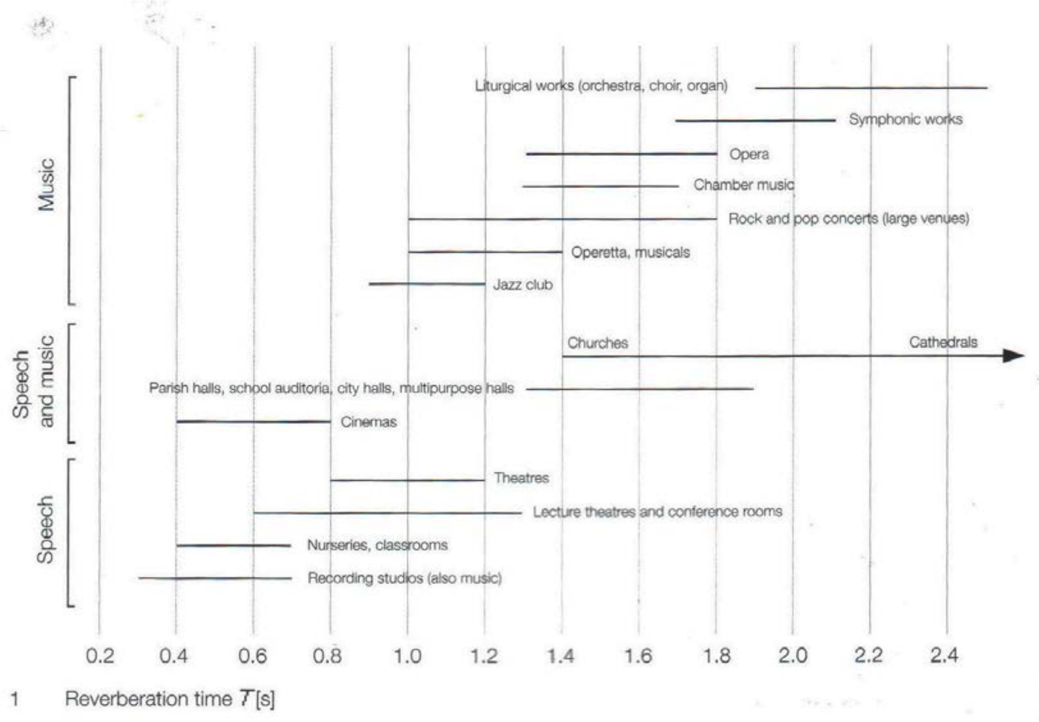


Figure A.1 Recommended reverberation time according to room function (Mommertz 2009)

Appendix B

Table B.1 Description of floor areas for Atlantic Chambers, St Andrews and Capella building

Area (m2)	Atlantic Chambers (1899)	St Andrews (1962)	Capella building (2009)
Gross floor area	375.9	494.2	1250.8
Workspace floor area	296.7	402.2	940.5
Ancillary spaces	4.68	9.83	135.4
Circulation	47.7	67.4	97.5
Glazing area on typical floor	140.2	111.9	323.9
Internal wall area	634.7	320.2	387.5
Office size range (m2)	11.7 - 26.1	-	11.5 - 22.8
Building height (m)	33.5	62.6	51.9
Office height (m)	2.50	3.00	3.00
Area percentage (%)			
Workspace floor area	78.9	81.4	75.2
Ancillary	1.25	1.98	10.8
Circulation	12.7	13.6	7.79
Glazing-to-office floor area ratio	0.47	0.29	0.34

Appendix C

C.1 Participant information leaflet enclosed in invitation letters

Participant Information Leaflet

Investigator's name : Farrah Jahangeer
Investigator's email : f.jahangeer1@student.gsa.ac.uk
Educational Institution: Mackintosh School of Architecture, Glasgow School of Art
Project Title: Optimum Form for Acoustics: A study of the relationship between office design and noise.

You are invited to take part in a research that focuses on the work performance, noise and office design.

- ***Why is this study being done?***
  This research is being conducted to find out the scope of improving the office environment for workers. Very few researches in this specific field have been done in the UK in comparison to European countries and America.

- ***Who is organising this study?***
  This research is the focus of a PhD research degree in Architectural Studies at the Glasgow School of Art.

- ***Why am I being asked to take part?***
  You have a first-hand experience of how office spaces function and encourage the development of office design. Also, your office falls into the specific categories of:

  1) Open-plan office [X]
  2) Cellular office [X]

- ***How will the study be carried out?***
  The study of each office will be carried out only by Farrah Jahangeer over a period of 8 hours during which:

  1) The background noise level will be measured by a sound level meter (8 hours)
  2) A questionnaire survey paper will be distributed at the start of the survey day for completion by voluntary participants (5 minutes) and re-collected at the end of the day
  3) The office floor area will be measured (10-15 minutes)

  Background noise level is measured by a sound level meter which will be positioned on a tripod installed at 9am and picked up at 5pm for the 2 days. No voices will be recorded.

- ***What will it cost me to take part?***
  Participation in this survey is free and voluntary.

- ***Is the study confidential?***
  Yes, this study is strictly confidential. All answers obtained from the questionnaires will be dealt anonymously and questionnaire results will be securely kept and unidentifiable. Results and data are only for research purpose. Collated and tabulated data can be viewed anonymously by participants should they wish to.
  This research has been approved by GSA Research Ethics Committee.

- ***What are the benefits?***
  By participating in this survey, you can contribute to the improvement of office designs and work performance in UK offices. At the end of the survey, a summary report of the findings is issued to the office.

For further information on this research, please contact: Mackintosh School of Architecture on +44 (0) 141 353 4500.

C.2 Example of email confirming participation in noise survey

-----Original Message-----
From: P.B
Sent: Fri 03/05/2013 17:02
To: Jahangeer, Farrah 1
Cc: S.P
Subject: office design and noise study

Dear Farrah,

Thank you for discussing your request with me on the phone. As discussed I have confirmed with our assistant director S.P that CXXXXS will be happy to accommodate your study.

We will make every effort to assist you and with this in mind may I confirm my request to you that you forward an electronic version of your participant information leaflet and a draft of an introductory and explanatory email that S.P could personalise and then distribute out to staff with your participant information leaflet.

From our conversation yesterday I understood that you hoped we could accommodate you next week but understand now from our telephone conversation today that you may be able to delay until week beginning 28th May in view of the shortage of notice for our colleagues. Please confirm your wishes/availability in your covering note with the items requested above and Steven Paterson will confirm final arrangements with you.

I do hope your study goes well and that CXXXS can contribute in some small way to its progress. We will of course look forward to your report when it is available.

Regards

P.B
Professional Advisor

C.3 Profile sheet using during each office visit

OFFICE NUMBER : ……………………………………..

DATE : ……………………………………..

STREET : ……………………………………..

OFFICE PHYSICAL DESCRIPTION

Open-plan:	**Combi:**	**Cellular:**	
Number of workers:		**Male:**	**Female:**
No of workstations:		**Ventilation system:**	
Sound masking:	**Partitions:**	**Office machines location:**	
Ceiling finish:		**Floor finish:**	
Window glazing:		**Artificial:**	**Natural light:**

FLOOR PLAN MEASUREMENTS

C.4 Questionnaire used in field study

Glasgow Office Noise Research

PhD Architectural Research for Glasgow School of Art

Only 5 minutes is required to complete this survey.

Gender

- ○ Female
- ○ Male

Age group

- ○ 20-29
- ○ 30-39
- ○ 40-49
- ○ 50 or above

How would you rate the background noise of the office?

- ○ Very satisfactory
- ○ Satisfactory
- ○ Neither
- ○ Unsatisfactory
- ○ Very unsatisfactory

What do you think is the most annoying noise source in the office?

- ○ Mechanical ventilation
- ○ Phone rings
- ○ Phone conversations
- ○ People talking
- ○ External road traffic
- ○ Other (please specify) ____________________

How often does the noise make it difficult for your to complete your daily tasks?

- ○ Never
- ○ Occasionally
- ○ About half of the time
- ○ Usually
- ○ Always

Page 1

Glasgow Office Noise Research

How often does the noise cause you stress?

- ◯ Never
- ◯ Occasionally
- ◯ About half of the time
- ◯ Usually
- ◯ Always

How many times in the past month have you been absent because of noise in the office?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ More than 4

What time of the day do you feel more productive?

- ◯ 9 am to 11 am
- ◯ 11 am to 1 pm
- ◯ 1 pm to 5 pm

Does noise have anything to do with it?

- ◯ No
- ◯ Maybe
- ◯ Yes

On average, how many hours do you spend at your desk everyday?

- ◯ 1 hour
- ◯ 2 hours
- ◯ 3 hours
- ◯ 4 hours
- ◯ 5 hours
- ◯ 6 hours
- ◯ 7 hours or more

Page 2

Glasgow Office Noise Research

Would you have a better concentration level if you worked in a private office ?

- ◯ I strongly disagree
- ◯ I disagree
- ◯ I am not sure
- ◯ I agree
- ◯ I strongly agree

Do you think that noise has the ability to affect work performance?

- ◯ I strongly disagree
- ◯ I disagree
- ◯ I am uncertain
- ◯ I agree
- ◯ I strongly agree

How often can you stay focused on your work when you are at your desk?

- ◯ Always
- ◯ Usually
- ◯ About half of the time
- ◯ Occasionally
- ◯ Never

How often does the noise in the office disturb you when you are working?

- ◯ Never
- ◯ Occasionally
- ◯ About half of the time
- ◯ Usually
- ◯ Always

How distracted are you by others' conversations in the office?

- ◯ Not distracted at all
- ◯ Rarely distracted
- ◯ I am uncertain
- ◯ Occasionally distracted
- ◯ Very distracted

Glasgow Office Noise Research

How would you rate the appearance of the office?

- ◯ Very satisfactory
- ◯ Satisfactory
- ◯ Neither
- ◯ Unsatisfactory
- ◯ Very unsatisfactory

How spacious is your workspace?

- ◯ Very spacious
- ◯ Slightly spacious
- ◯ Neither
- ◯ Slightly cramped
- ◯ Very cramped

Do you believe that added partitions at your desk would provide sufficient acoustical privacy?

- ◯ I strongly disagree
- ◯ I disagree
- ◯ I am not sure
- ◯ I agree
- ◯ I strongly agree

How often can you hear the entire conversation contents of other work colleagues when you are at your desk?

- ◯ Never
- ◯ Occasionally
- ◯ About half of the time
- ◯ Usually
- ◯ Always

How would you rate the communication level between you and your co-workers?

- ◯ Excellent
- ◯ Good
- ◯ Neutral
- ◯ Poor
- ◯ Very bad

Glasgow Office Noise Research

How often do you have to raise your voice when speaking to the colleague close to you?

- ◯ Never
- ◯ Occasionally
- ◯ About half of the time
- ◯ Usually
- ◯ Always

On a typical day, when would be the noisiest time at the office?

[ ]

How satisfied are you with the desk arrangement in the office?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ I am uncertain
- ◯ Unsatisfied
- ◯ Very unsatisfied

How would you rate the distance between you and your co-workers?

- ◯ Too far
- ◯ Slightly far
- ◯ Neither
- ◯ Slightly close
- ◯ Too close

How often do you modify your workspace layout?

- ◯ Once every 3 months
- ◯ Once every month
- ◯ Once every week
- ◯ Everyday
- ◯ Never

Can you adjust your workspace according to your work style?

- ◯ I strongly agree
- ◯ I agree
- ◯ Neither
- ◯ I disagree
- ◯ I strongly disagree

Page 5

Glasgow Office Noise Research

How satisfied are you with your work space?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ Neither
- ◯ Unsatisfied
- ◯ Very unsatisfied

To what extent can you personalize your work space?

- ◯ A great extent
- ◯ Some extent
- ◯ Neither
- ◯ Very limited extent
- ◯ No extent at all

How adequate is your surface area for you to work?

- ◯ Very adequate
- ◯ Adequate
- ◯ Neither
- ◯ Inadequate
- ◯ Very inadequate

How would you rate the general layout of the office in terms of functional performance?

- ◯ Very satisfactory
- ◯ Satisfactory
- ◯ Neither
- ◯ Unsatisfactory
- ◯ Very Unsatisfactory

Would you prefer to have low partitions at your desk?

- ◯ No
- ◯ Maybe
- ◯ Yes

Glasgow Office Noise Research

How satisfied are you with your work space?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ Neither
- ◯ Unsatisfied
- ◯ Very unsatisfied

To what extent can you personalize your work space?

- ◯ A great extent
- ◯ Some extent
- ◯ Neither
- ◯ Very limited extent
- ◯ No extent at all

How adequate is your surface area for you to work?

- ◯ Very adequate
- ◯ Adequate
- ◯ Neither
- ◯ Inadequate
- ◯ Very inadequate

How would you rate the general layout of the office in terms of functional performance?

- ◯ Very satisfactory
- ◯ Satisfactory
- ◯ Neither
- ◯ Unsatisfactory
- ◯ Very Unsatisfactory

Would you prefer to have low partitions at your desk?

- ◯ No
- ◯ Maybe
- ◯ Yes

Page 6

Glasgow Office Noise Research

How would you rate the layout of the office in terms of acoustical performance?

- ◯ Very satisfactory
- ◯ Satisfactory
- ◯ Neither
- ◯ Unsatisfactory
- ◯ Very unsatisfactory

How often do you open the windows in your office?

- ◯ Always
- ◯ Usually
- ◯ About half of the time
- ◯ Occasionally
- ◯ Never

How adequate is the fresh air supply in the office?

- ◯ Very adequate
- ◯ Adequate
- ◯ Neutral
- ◯ Inadequate
- ◯ Very inadequate

How satisfied are you with the temperature at your workspace?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ Neither
- ◯ Unsatisfied
- ◯ Very unsatisfied

How satisfied are you with the air quality of the office?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ Neither
- ◯ Unsatisfied
- ◯ Very unsatisfied

Glasgow Office Noise Research

Which one of the following environmental factors do you think is the most important in achieving a comfortable work space?

◯ Adequate sound level

◯ Comfortable lighting

◯ Comfortable room temperature

◯ Adequate ventilation

Would you recommend this office design to a friend?

◯ Yes

◯ Maybe

◯ No

Time : ....

Date : ....

Please leave the questionnaire in the survey box

THANK YOU!

C.5 SPSS Codebook

The tables below describe the variables that have been analysed and the values that have been used to code the answers for each question prior to being collapsed into small categories.

Variable Name	*Variable description*	*Code*	*Value*	*Data*
COUNTRY	Country of survey	1	Glasgow	Nominal
		2	Mauritius	
LAYTType	Layout type of office	1	WLC	Nominal
		2	WLO1	
		3	WLO2	
		4	WLO3	
GENDER	Sex of participants	1	Female	Nominal
		2	Male	
AGE	Age group	1	18-29 years	Nominal
		2	30-39 years	
		3	40-49 years	
		4	50 years or above	
NOISEBackgrd	Background noise rating	1	Unsatisfactory	Ordinal
		2	Neither	
		3	Satisfactory	
NOISEMechn	Mechanical ventilation as annoying noise source	1	No	Nominal
		3	Yes	
NOISERings	Phone ring as annoying noise source	1	No	Nominal
		3	Yes	
NOISEConv	Phone conversations as annoying noise source	1	No	Nominal
		3	Yes	
NOISETalk	People talking as annoying noise source	1	No	Nominal
		3	Yes	
NOISERoad	External road traffic as annoying noise source	1	No	Nominal

		3	Yes	
NOISEOther	Other annoying noise source	1	No	Nominal
		3	Yes	
PERFTAskCompl	Frequency of difficulty faced during task completion	1	Occasionally	Ordinal
		2	About half of the time	
		3	Usually	
PERFAbsence	Absence due to noise	1	0	Nominal
		2	1	
		3	2	
		4	3	
		5	4	
		6	more than 4	
PERFProd9	Productive from 9am to 11 am	1	No	Nominal
		3	Yes	
PERFProd1	Productive from 11am to 1pm	1	No	Nominal
		3	Yes	
PERFProd5	Productive from 1pm to 5pm	1	No	Nominal
		3	Yes	
PERFNoiseReltn	Productive time related to noise	1	No	Nominal
		2	Maybe	
		3	Yes	
NOISEExposure	Number of hours at desk in a typical day	1	1hr	Nominal
		2	2hrs	
		3	3hrs	
		4	4hr	
		5	5hrs	
		6	6hrs	
		7	7hrs or more	
PERFOfficeType	Better concentration in alternate office type	1	I disagree	Ordinal
		2	I am not sure	
		3	I agree	

PERFNoiseAbility	Ability of noise to affect performance	1	I disagree	Ordinal
		2	I am uncertain	
		3	I agree	
PERFWorkFocus	Frequency of remaining concentrated on work	1	Occasionally	Ordinal
		2	About half of the time	
		3	Usually	
PERFNoiseDistrb	Frequency of noise disturbance	1	Occasionally	Ordinal
		2	About half of the time	
		3	Usually	
PERFNoiseDistract	Frequency of distraction by conversation	1	Distracted	Ordinal
		2	I am uncertain	
		3	Rarely distracted	
LAYTOfficeAppear	Rating of office appearance	1	Unsatisfactory	Ordinal
		2	Neither unsatisfactory or satisfactory	
		3	Satisfactory	
SIZESpace	Rating of spaciousness at workplace	1	Cramped	Ordinal
		2	Neither cramped nor spacious	
		3	Spacious	
COMMLevel	Rating of communication level between workers	1	Poor	Ordinal
		2	Neutral	
		3	Good	
COMMClarity	Frequency of need to raise voice during conversation	1	Occasionally	Ordinal
		2	About half of the time	
		3	Usually	

NOISETime	Noisiest time in the office	1	Morning	Nominal
		2	During lunch	
		3	Afternoon	
		4	All day	
LAYTArrangmnt	Rating of desk arrangement	1	Unsatisfied	Ordinal
		2	I am uncertain	
		3	Satisfied	
SIZEDistance	Rating of distance between workers	1	Slightly close	Ordinal
		2	Neither close nor far	
		3	Slightly far	
SIZEModify	Frequency of individual layout modification	1	Once every 3 months	Ordinal
		2	Once every month	
		3	Once every week	
SIZEStyle	Ability to adjust workspace according to workstyle	1	I disagree	Ordinal
		2	Neither disagree nor agree	
		3	I agree	
SIZESatisf	Rating of workspace	1	Unsatisfied	Ordinal
		2	Neither unsatisfied nor satisfied	
		3	Satisfied	
SIZEPersonal	Extent of space personalisation	1	Very limited	Ordinal
		2	Neither	
		3	Some extent	
SIZESuface	Adequacy of work surface area	1	Inadequate	Ordinal
		2	Neither inadequate nor adequate	
		3	Adequate	
LAYTFunction	Rating of space in terms of work performance	1	Unsatisfactory	Ordinal

		2	Neither unsatisfactory or satisfactory	
		3	Satisfactory	
LAYTAcoustic	Rating of space in terms of acoustic	1	Unsatisfactory	Ordinal
		2	Neither unsatisfactory or satisfactory	
		3	Satisfactory	
CLIMwindow	Frequency of window opening at work	1	Occasionally	Ordinal
		2	About half of the time	
		3	Usually	
LAYTRecomd	Possibility of recommending layout	1	No	Nominal
		2	Maybe	
		3	Yes	
NOISELevel	Noise level (dBA)			Scale
RTAverage	Average reverberation time for 125 to 4000 Hz			Scale
TOTALAbsorp	Total absorption of surface area			Scale
SIZEArea	Individual workspace area (m2)			Scale
SIZEVolume	Individual workspace volume (m3)			Scale
DISTworker	Nearest distance to co-worker			Scale
VENTMech	Use of mechanical ventilation in workspace	1	No	Nominal
		2	Yes	
SIZEFloorarea	Gross floor area of workspace (m2)			Scale
SIZEDensity	Occupancy density			Scale
HEIGHT	Height of workspace (m)			Scale

ELONGShape	Elongation ratio of noise geometry			Scale
ELONGLayout	Elongation ratio of workspace geometry			Scale
AREAShape	Area of noise geometry			Scale
AGEBuilding	Construction age of building	1	Prior to 1950	Nominal
		2	Between 1950 and 2000	
		3	After 2000	
GLAZRatio	Window glazing to floor area ratio			Scale
DESKLayout	Type of desk arrangement	1	Linear	Nominal
		2	Non-linear	
REVRatingWC	Rating of reverberation time in cellular offices	1	Equal to or more than 0.5	Ordinal
		2	0.5 to 0.4	
		3	0.4 to 0.3	
		4	0.3 to 0.2	
		5	Equal to or less than 0.2	
REVRatingW1	Rating of reverberation time in WLO1 offices	1	Equal to or more than 0.7	Ordinal
		2	0.7 to 0.6	
		3	0.6 to 0.5	
		4	0.5 to 0.4	
		5	Equal to or less than 0.4	
REVRatingW2	Rating of reverberation time in WLO2 & WLO3 offices	1	Equal to or more than 0.8	Ordinal
		2	0.8 to 0.7	
		3	0.7 to 0.6	
		4	0.6 to 0.5	
		5	Equal to or less than 0.5	
NOISERating	Rating of number of noise sources present	1	Equal to or more than 5	Ordinal
		2	4	

		3	3	
		4	2	
		5	equal to or less than 1 noise source	
TOTALRating	Median scores of reverberation time and number of noise sources present			Scale

Appendix D

D.1 *Location of offices surveyed in Glasgow city*

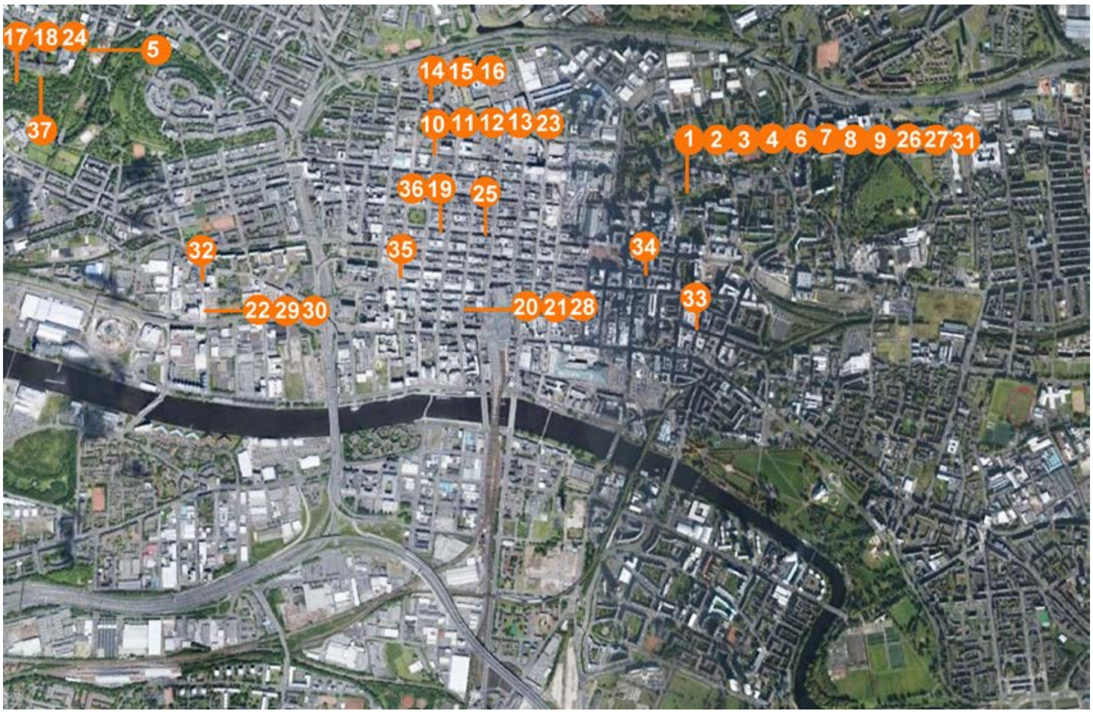


Figure D.1 Plan of offices surveyed in Glasgow City

1. CSIS A, James Watt Road
2. CSIS B, James Watt Road
3. CSIS C, James Watt Road
4. CSIS D, James Watt Road
5. RKNE, Oakfield Street
6. STH A (Pa), James Watt Road
7. STH B (Ca), James Watt Road
8. STH C (Ce), James Watt Road
9. STH D (Mo), James Watt Road
10. GSA R (207), Rose Street
11. GSA R (203), Rose Street
12. GSA R (311), Rose Street
13. GSA R (205), Rose Street
14. GSA H1 (Re), Hill Street
15. GSA H2 (Me), Hill Street
16. GSA H3 (Ma), Hill Street
17. KVN A (T), University Avenue
18. KVN B (P), University Avenue
19. SHA (A), St Vincent Street
20. YES (Is), Wellington Street
21. YES (Sk), Wellington Street
22. GSA Sky A, Elliot Street
23. GSA R (304), Rose Street
24. KVN (C), University Avenue
25. WRI, West George Street
26. CSIS F, James Watt Road
27. CSIS E, James Watt Road
28. YES (Mu), Wellington Street
29. GSA Sky C, Elliot Street
30. GSA Sky D, Elliot Street
31. STH E, James Watt Road
32. HUO, Elliot Street Mews
33. HAD, Bell Street
34. GCC, George Street
35. KNFK, Bothwell Street
36. SHA (B), St Vincent Street
37. GLUN, University Avenue

Table D.2 *Characteristics and rating of offices in Glasgow City with low office ratings highlighted in grey*

Offices	Occupancy during survey	Construction period	Construction type	Wall finish material	Floor finish material	Ceiling finish material	Desk arrangement	Glazing ratio	Glazing type	Ventilation system	Reverberation time rating	Noise sources rating	Total Rating
1. CSIS A	2	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	4	5	4.5
2. CSIS B	2	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	4	5	4.5
3. CSIS C	2	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	4	5	4.5
4. CSIS D	2	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	4	5	4.5
5. RKNE	1	Before 1950	Prefab. concrete	Painted plasterboard	Carpet	Acoustic cork tiles	-	0.39	Double	A/c & window	4	3	3.5
6. STH A (Pa)	1	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	3	5	4
7. STH B (Ca)	1	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.09	Double	A/c & window	3	5	4
8. STH C (Ce)	1	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.13	Double	A/c & window	3	5	4
9. STH D (Mo)	1	1950-2000	Concrete framed	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.04	Double	A/c & window	3	5	4
10. GSA R (207)	1	Before 1950	Masonry &steel frame	Painted plasterboard& glass	Carpet	Acoustic cork tiles	-	0.14	Single	A/c & window	3	5	4
11. GSA R (203)	2	Before 1950	Masonry & steel frame	Painted plasterboard& glass	Carpet	Acoustic cork tiles	-	0.35	Single	A/c & window	1	4	2.5
12. GSA R (311)	2	Before 1950	Masonry & steel frame	Painted plasterboard& glass	Carpet	Acoustic cork tiles	-	0.13	Single	A/c & window	3	4	3.5
13.GSA R (205)	1	Before 1950	Masonry & steel frame	Painted plasterboard& glass	Carpet	Acoustic cork tiles	-	0.78	Single	A/c	2	5	3.5
14.GSA H1 (Re)	2	Before 1950	Masonry & steel frame	Painted plasterboard	Carpet	Acoustic cork tiles	-	0.14	Single	A/c	2	3	2.5
15.GSA H2 (Me)	3	Before 1950	Masonry & steel frame	Painted plasterboard	Carpet	Painted plaster	-	0.15	Single	A/c	1	5	3
16.GSA H3 (Ma)	2	Before 1950	Masonry & steel frame	Painted plasterboard	Carpet	Painted plaster	-	0.15	Single	A/c	1	5	3
17. KVN A (T)	3	Before 1950	Reinforced concrete	Painted plasterboard	Carpet	Painted plasterboard	-	0.09	Double	A/c & window	3	4	3.5
18. KVN B (P)	2	Before 1950	Reinforced concrete	Painted plasterboard	Carpet	Acoustic cork tiles	-	0.1	Double	A/c & window	3	5	4
19.SHA (A)	1	Before 1950	Stone & masonry	Painted plasterboard& glass	Carpet	Metallic acoustic panels	-	0.14	Double	A/c & window	2	4	3
20.YES (Is)	2	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Painted plaster	-	0.13	Single	A/c & window	1	5	3
21.YES (Sk)	3	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Painted plaster	-	0.17	Single	A/c & window	1	5	3
22.GSA Sky A	3	1950-2000	Steel frame	Painted plasterboard	Carpet	Acoustic cork tiles	-	0.63	Double	A/c & window	3	4	3.5
23.GSA R (304)	5	Before 1950	Masonry & steel frame	Painted plasterboard	Carpet	Acoustic cork tiles	Cluster	0.28	Single	A/c & window	3	4	3.5
24.KVN (C)	8	Before 1950	Reinforced concrete	Painted plasterboard	Carpet	Acoustic cork tiles	Cluster	0.18	Double	A/c & window	3	3	3
25.WRI	6	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Acoustic cork tiles	Cluster	0.09	Single	A/c & window	5	1	3
26.CSIS F	9	1950-2000	Concrete frame	Painted plasterboard	Carpet	Painted plasterboard	Row	0.3	Double	A/c	1	3	2
27.CSIS E	6	1950-2000	Concrete frame	Painted plasterboard	Carpet	Painted plasterboard	Row	0	Double	A/c	1	2	1.5
28.YES (Mu)	7	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Painted plaster	Cluster	0.07	Single	A/c & window	1	2	1.5
29.GSA Sky C	4	1950-2000	Steel frame	Painted plasterboard	Carpet	Acoustic cork tiles	Cluster	0.24	Double	A/c & window	3	2	2.5
30.GSA Sky D	6	1950-2000	Steel frame	Painted plasterboard	Carpet	Acoustic cork tiles	Cluster	0.25	Double	A/c & window	4	2	3
31.STH E	15	1950-2000	Brick & masonry	Painted plasterboard	Carpet	Painted plasterboard	Row	0.24	Double	A/c	1	1	1
32. HUO	14	1950-2000	Brick & masonry	Painted plasterboard	Carpet	Acoustic cork tiles	Row	0.04	Double	A/c & window	5	1	3
33.HAD	16	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Painted plaster	Row	0.34	Single	A/c & window	1	1	1
34. GCC	56	Before 1950	Concrete frame	Painted plasterboard	Carpet	Metallic acoustic panels	Row	0.22	Double	A/c & window	5	1	3
35.KNFK	27	After 2000	Steel frame	Painted plasterboard	Carpet	Metallic acoustic panels	Row	0.4	Triple	A/c	1	1	1
36.SHA B	27	Before 1950	Stone & masonry	Painted plasterboard	Carpet	Metallic acoustic panels	Cluster	0.15	Double	A/c & window	1	1	1
37.GLUN	67	1950-2000	Concrete frame	Painted plasterboard& glass	Carpet	Painted concrete	Cluster	0.11	Double	A/c	5	1	3

Table D.3 *Kruskal-Wallis significance values for variables being investigated in Glasgow sample*

			Mean Rank			
	Chi-squared value (H)	Asymp.Sig (p)	WLC	WLO1	WLO2	WLO3
Acoustic satisfaction						
Satisfaction with noise in general	9.410	0.025*	108.63	105.98	80.29	85.46
Frequency of noise disturbance	2.230	0.526	79.73	91.50	93.05	92.65
Co-worker communication level rating	4.115	0.249	89.67	97.26	95.44	85.11
Frequency of raising voice in office	7.211	0.065	108.63	105.98	80.29	85.46
Acoustic measures						
Noise level	26.286	0.000**	64.88	68.94	88.26	111.78
Reverberation time	48.810	0.000**	37.38	84.11	124.91	101.07
Workspace						
Workspace floor area	150.891	0.000**	15.97	48.70	84.79	137.99
Occupancy density	19.769	0.000**	128.63	74.94	80.09	90.48
Height	1.106	0.776	93.15	95.50	97.91	87.92
Desk arrangement	7.219	0.027	-	92.00	68.00	74.80
Office rating	66.115	0.000**	150.78	111.52	69.94	72.73
Work performance satisfaction						
Frequency of difficulty to complete tasks due to noise	3.967	0.265	83.47	95.53	99.71	89.56
Frequency of staying concentrated on work	2.710	0.439	93.70	82.92	84.32	93.61
Frequency of distraction by others' conversations	0.316	0.957	93.68	93.36	89.72	89.73
Agree to perform task in alternate office type	19.724	0.000**	54.95	101.58	91.12	100.11

Table D.3 Kruskal-Wallis results between acoustic satisfaction, work performance satisfaction, acoustic measures and workspace in different office types in Glasgow sample. Significant where **p<0.01, *p<0.05

Table D.4 *Spearman's Rho Correlation Coefficient Table for workspace floor area in Glasgow sample*

	Workspace floor area			
Acoustic satisfaction	WLC	WLO1	WLO2	WLO3
1. Satisfaction with noise in general	-0.074	-0.464**	-0.529**	-0.385**
2. Frequency of noise disturbance	-0.158	0.424*	0.444**	0.059
3. Co-worker communication level rating	-0.123	-0.350*	-0.060	0.043
4. Frequency of raising voice in office	-	0.231	0.407*	0.083
Acoustic measures				
1. Noise level	0.129	0.493**	0.060	0.353**
2. Reverberation time	0.690**	0.545**	-0.664**	-0.877**
Work performance satisfaction				
1. Frequency of difficulty to complete tasks due to noise	0.042	0.429*	0.326	0.209
2. Frequency of concentrating on work	0.390*	-0.165	-0.494**	-0.069
3. Frequency of distraction by others' conversations	0.139	-0.215	-0.183	-0.084
4. Agree to perform task in alternate office type	0.192	0.442**	0.558**	0.036
Workspace				
1. Occupancy density	0.236	-0.328	1.000**	1.000**
2. Height	0.567**	-0.263	-0.664**	-0.877**
3. Desk arrangement	-	-0.825**	0.242	-0.339**
4. Glazing-to-floor ratio	0.709**	-0.881**	-0.664**	-0.075

Table D.4 Spearman's Rho Correlation Coefficient results between workspace floor area, acoustic measures, acoustic satisfaction and work performance in Glasgow sample, significant where **p<0.01, *p<0.05

Table D.5 *Spearman's Rho Correlation Coefficient for noise level in Glasgow sample*

	Noise level			
Acoustic satisfaction	WLC	WLO1	WLO2	WLO3
1. Satisfaction with noise in general	0.005	-0.495**	0.089	0.119
2. Frequency of noise disturbance	0.173	0.433*	0.102	-0.357**
3. Co-worker communication level rating	0.122	0.035	-0.279	0.174
4. Frequency of raising voice in office	-	0.164	0.130	-0.235*
Acoustic measures				
Reverberation time	0.217	-0.064	0.099	-0.603**
Work performance satisfaction				
1. Frequency of difficulty to complete tasks due to noise	-0.071	0.243	0.075	-0.133
2. Frequency of concentrating on work	-0.245	-0.156	-0.149	0.429**
3. Frequency of distraction by others' conversations	0.028	-0.123	-0.266	0.171
4. Agree to perform task in alternate office type	0.056	0.374*	0.079	-0.177
Workspace				
1. Occupancy density	-0.056	-0.042	0.060	0.353**
2. Height	0.017	-0.357**	0.099	-0.603**
3. Desk arrangement	-	-0.361*	-0.166	-0.498**
4. Glazing-to-floor ratio	0.224	-0.318	0.099	0.455**

Table D.5 Spearman's Rho Correlation Coefficient results between noise level, acoustic satisfaction and work performance in Glasgow sample, significant where **p<0.01, *p<0.05

Table D.6 *Spearman's Rho Correlation Coefficient for reverberation time in Glasgow sample*

	Reverberation time			
Acoustic satisfaction	WLC	WLO1	WLO2	WLO3
1. Satisfaction with noise in general	-0.327	-0.086	0.370*	0.250*
2. Frequency of noise disturbance	-0.039	0.178	-0.157	0.085
3. Co-worker communication level rating	-0.185	-0.166	-0.179	-0.089
4. Frequency of raising voice in office	-	-0.137	-0.146	0.048
Work performance satisfaction				
1. Frequency of difficulty to complete tasks due to noise	0.148	0.282	-0.192	-0.093
2. Frequency of concentrating on work	0.083	-0.012	0.030	-0.137
3. Frequency of distraction by others' conversations	-0.079	-0.017	-0.040	-0.003
4. Agree to perform task in alternate office type	0.135	0.248	-0.355*	0.006
Workspace				
1. Occupancy density	0.203	-0.656**	-0.664**	-0.877**
2. Height	0.383*	0.549**	1.000**	1.000**
3. Desk arrangement	-	-0.825**	-0.886**	0.339**
4. Glazing-to-floor ratio	0.492**	-0.638**	1.000**	-0.048

Table D.6 Spearman's Rho Correlation Coefficient results between reverberation time, acoustic satisfaction and work performance in Glasgow sample, significant where **p<0.01, *p<0.05

Appendix E

Table E.1 *Kruskal-Wallis test for area and elongation of geometries in Glasgow sample*

	Chi-squared value (*H*)	Asymp.Sig (*p*)	WLO1	WLO2	WLO3
Workspace					
Workspace floor area	108.85	0.000**	19.12	54.79	107.99
Elongation of workspace	41.502	0.000**	120.42	62.67	65.88
Area of noise geometry	120.59	0.000**	20.33	47.26	110.50
Elongation of noise geometry	114.30	0.000**	33.48	34.50	110.50

Table E.1 Kruskal-Wallis test for area and elongation of workspace geometry and noise geometries in Glasgow sample, significant where **$p<0.01$, *$p<0.05$

Table E.2 *Spearman's Rho correlation coefficients for area of noise geometry, employee satisfaction and acoustic measures in Glasgow sample*

	Area of noise geometry		
Acoustic satisfaction	WLO1	WLO2	WLO3
5. Background noise satisfaction	-0.358*	-0.230	-0.314**
6. Frequency of noise disturbance	0.372*	0.157	0.507**
7. Co-worker communication level rating	-0.220	0.179	-0.199
8. Frequency of raising voice in office	0.339	0.146	0.277**
9. General satisfaction with office acoustics	-0.377*	-0.370*	-0.317**
Work Performance			
5. Frequency of difficulty to complete tasks due to noise	0.277	0.192	0.185
6. Frequency of concentrating on work	-0.043	-0.030	-0.461**
7. Frequency of distraction by others' conversations	-0.127	0.040	-0.212
8. Preference to working in cellular office to increase concentration	0.511**	0.355**	0.285**
Acoustic measures			
1. Noise level	0.607**	-0.099	-0.455**
2. Reverberation time	0.096	-1.00**	0.048
Workspace			
Workspace floor area	0.681**	0.664***	0.075

Table E.2 Spearman's Rho correlation coefficients for area of noise geometry, employee satisfaction and acoustic measures in Glasgow sample, significant where **p<0.01, *p<0.05

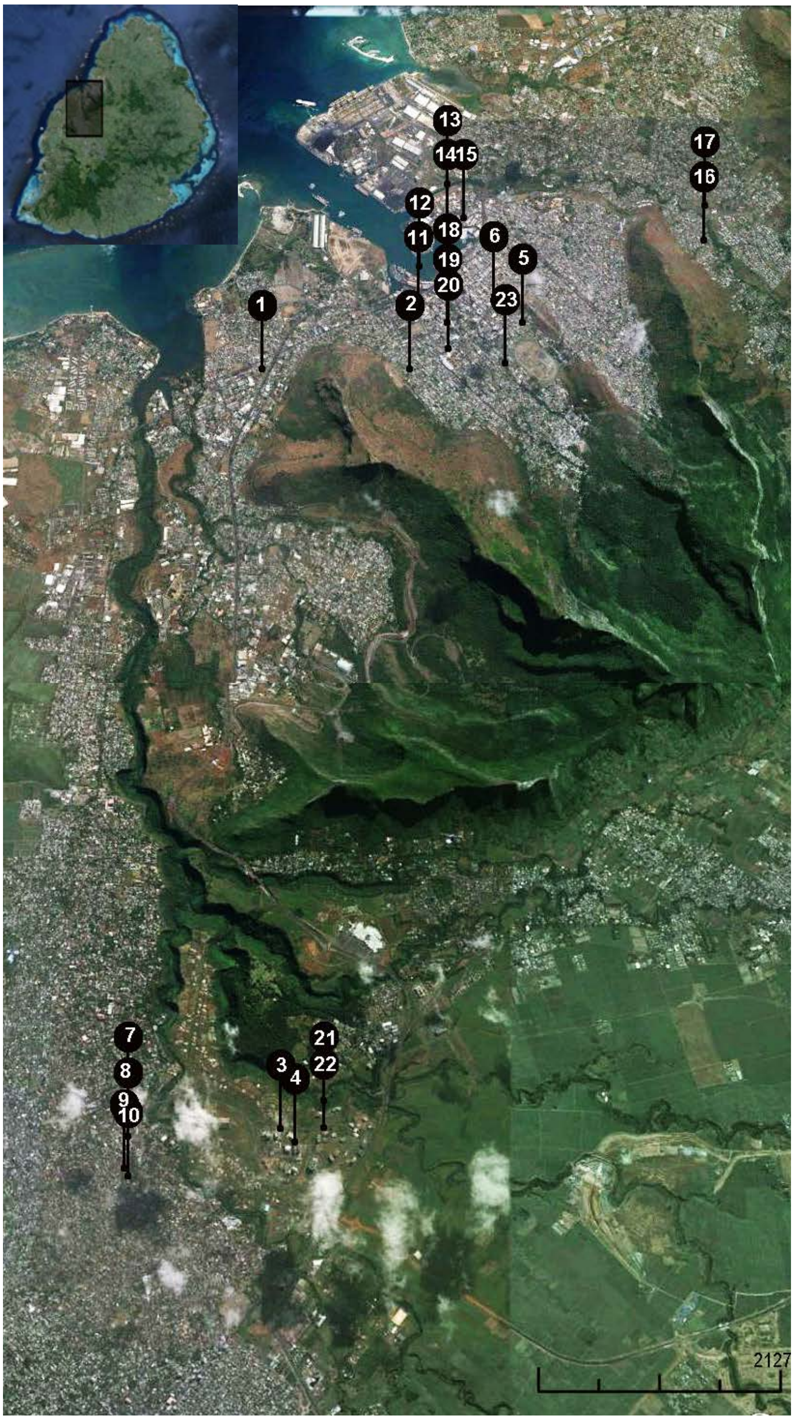
Table E.3 *Spearman's Rho correlation coefficient for elongation of noise geometry, employee satisfaction and acoustic measures in Glasgow sample*

	Elongation of noise geometry		
Acoustic satisfaction	WLO1	WLO2	WLO3
1. Background noise satisfaction	-0.222	0.043	-0.314
2.Frequency of noise disturbance	0.221	-0.270	0.507**
3.Co-worker communication level rating	0.013	0.299	-0.199
4.Frequency of raising voice in office	0.041	-0.257	0.277
5.General satisfaction with office acoustics	-0.193	0.101	-0.317**
Work Performance			
1.Frequency of difficulty to complete tasks due to noise	0.146	-0.108	0.185
2.Frequency of concentrating on work	0.107	0.481**	-0.461**
3.Frequency of distraction by others' conversations	0.049	0.253	-0.212
4. Preference to working in cellular office to increase concentration	0.285	-0.152	0.285**
Acoustic measures			
1. Noise level	0.447**	-0.195	-0.455**
2. Reverberation time	0.378**	-0.569**	0.048
Workspace			
1. Area of noise geometry	0.765**	0.569**	1.000**
2. Elongation of workspace geometry	0.684**	-0.236	0.048

Table E.3 Spearman's Rho correlation coefficient for elongation of noise geometry, employee satisfaction and acoustic measures in Glasgow, significant where **p<0.01, *p<0.05

Appendix F

F.1 *Location of offices surveyed in Mauritius*



1. KBK office, Menagerie Street
2. DCO office, D'Artois Street
3. EPA office, Nexteracom
4. LON office, Nexteracom
5. SAM office, Dr Eugene Laurent Street
6. TGL office, Lislet Geoffrey Street
7. AMS1 office, Hurdowar Street
8. AMS2 office, Hurdowar Street
9. AMS3 office, Hurdowar Street
10. AMS4 office, Hurdowar Street
11. PML1 office, John Kennedy Street
12. PML2 office, John Kennedy Street
13. LLC1 office, Approach Road
14. LLC2 office, Approach Road
15. LLC3 office, Approach Road
16. ICC1 office, Sofia Lane
17. ICC2 office, Sofia Lane
18. UTC1, Vieux Conseil Street
19. UTC2, Vieux Conseil Street
20. UTC3, Vieux Conseil Street
21. IFM1, Cybercity
22. IFM2, Cybercity

Table F.2 *Characteristics and ratings of workplaces in Mauritius with low office ratings higlighted in grey*

Offices	Occupancy during survey	Construction period	Construction type	Wall finish material	Floor finish material	Ceiling finish material	Desk arrangement	Glazing ratio	Window glazing	Ventilation system	Reverberation time rating	Noise source rating	Total rating
1. KBK	1	After 2000	Rein. Concrete & glass	Painted Concrete	Carpet	Painted Concrete	-	0.07	Single	A/c	1	3	1
2. DCO	2	After 2000	Rein. Concrete & glass	Painted Concrete	Tiles	Painted Concrete	-	1.15	Single	A/c & window	1	2	1.5
3. EPA	1	After 2000	Steel frame, Concrete & glass	Glass & Painted plasterboard	Carpet	Acoustic cork tiles	-	0.24	Double	A/c & window	2	3	2.5
4. LON	1	After 2000	Steel frame, Concrete & glass	Glass & Painted plasterboard	Carpet	Acoustic cork tiles	-	0.84	Double	A/c	3	4	3.5
5. SAM	2	1950-2000	Rein. Concrete & glass	Painted Concrete	Tiles	Painted Concrete	-	0	Single	A/c	1	3	2
6. TGL	1	1950-2000	Rein. Concrete	Lacquered plywood	Vinyl	Painted Concrete	-	0.32	Single	A/c & window	1	3	2
7. AMS(1)	1	1950-2000	Rein. Concrete	Painted Concrete	Vinyl	Painted Concrete	-	0.17	Single	A/c & window	1	4	2.5
8. AMS(2)	1	1950-2000	Rein. Concrete	Painted Concrete	Vinyl	Painted Concrete	-	0.38	Single	A/c & window	2	4	3
9. AMS(3)	3	1950-2000	Rein. Concrete	Painted Concrete	Vinyl	Painted Concrete	-	0.2	Single	A/c & window	1	4	2.5
10.AMS(4)	1	1950-2000	Rein. Concrete	Painted Concrete	Vinyl	Painted Concrete	-	0.33	Single	A/c & window	1	5	3
11.PML(1)	8	After 2000	Rein. concrete	Painted concrete	Carpet	Acoustic cork tile	Linear	0	Single	A/c	3	1	2
12.PML(2)	2	After 2000	Rein. concrete	Painted concrete	Carpet	Acoustic cork tile	-	0.19	Single	A/c	3	3	3
13.LLC(1)	1	Before 1950	Rein. concrete	PVC	Vinyl	PVC	-	0.16	Single	A/c	2	1	1.5
14.LLC(2)	2	Before 1950	Rein. Concrete	PVC	Vinyl	PVC	-	0	Single	A/c	3	5	4
15.LLC(3)	8	Before 1950	Rein. Concrete	Painted concrete	Tiles	Painted concrete	Non-linear	0.02	Single	A/c	1	2	1.5
16.ICC(1)	1	1950-2000	Rein. concrete	Painted concrete	Tiles	Painted concrete	-	0.09	Single	Window	1	3	2
17.ICC(2)	4	1950-2000	Rein. concrete	Painted concrete	Tiles	Painted concrete	Non-linear	0.06	Single	Window	1	1	1
18.UTC(1)	6	1950-2000	Rein. concrete	Painted concrete	Carpet	Painted concrete	Linear	0.02	Single	A/c	1	1	1
19.UTC(2)	9	1950-2000	Rein. concrete	Painted concrete	Carpet	Painted concrete	Linear	0.04	Single	A/c	1	1	1
20.UTC(3)	1	1950-2000	Rein. concrete	Painted concrete	Carpet	Painted concrete	Linear	0.5	Single	A/c	2	3	2.5
21.IFM(1)	25	After 2000	Steel frame, Concrete & glass	Painted Plaster-board	Carpet	Painted concrete	Linear	0.16	double	A/c	4	1	2.5
22.IFM(2)	20	After 2000	Steel frame, Concrete & glass	Painted Plaster-board	Carpet	Painted concrete	Linear	0.06	double	A/c	3	1	2

F.3 *Kruskal-Wallis significance values for subjective and objective variables in Mauritius sample*

Table F.3. Chi-squared and significance values for objective and subjective variables for different office types in Mauritius sample, significant **p<0.01 and *p<0.05

			Mean Rank		
	Chi-squared value (*H*)	Asymp.Sig (*p*)	WLC	WLO1	WLO2
ACOUSTIC					
Satisfaction with noise in general	2.384	0.304	38.30	48.28	42.40
Frequency of noise disturbance	5.356	0.069	41.49	50.20	41.76
Co-worker communication level rating	0.394	0.821	43.26	44.53	45.18
Frequency of raising voice in office	2.214	0.331	47.30	41.36	43.12
Noise level	30.561	0.000**	55.50	58.53	26.88
Reverberation time	18.511	0.000**	41.52	59.87	33.73
WORKSPACE					
Workspace floor area	77.587	0.000**	11.00	36.50	70.00
Room height	63.477	0.000**	44.40	18.05	66.00
Occupancy density	59.666	0.000**	70.80	55.30	21.00
PERFORMANCE					
Frequency of difficulty to complete tasks due to noise	4.065	0.131	44.26	49.37	40.69
Frequency of staying concentrated on work	2.637	0.268	46.81	40.73	46.24
Frequency of distraction by others' conversations	1.768	0.413	42.79	48.97	41.85
Agree to perform task in alternate office type	5.850	0.054	34.88	50.10	43.99
Reported absence per month	0.000	1.000	44.50	44.50	44.50

F.4 *Spearman's Rho correlation coefficient for workspace floor area and employee satisfaction in Mauritius sample*

Table F.4 Correlation coefficient values for workspace floor area, acoustic and work performance satisfaction in all three office types in Mauritius sample, significant when **p<0.01 and *p<0.05

	Workspace floor area		
Acoustic satisfaction	WLC	WLO1	WLO2
1. Background noise satisfaction	-0.194	0.315	-0.326*
2. Frequency of noise disturbance	0.242	-0.034	0.128
3. Co-worker communication level rating	-0.240	-0.111	0.033
4. Frequency of raising voice in office	0.163	-0.134	0.142
5. General office noise satisfaction	-0.473*	-0.062	-0.247
Acoustic levels			
Reverberation time	0.251	-0.528**	-1.00**
Noise level	-0.586**	0.051	0.473**
Work Performance			
5. Frequency of difficulty to complete tasks due to noise	0.315	0.038	-0.038
6. Frequency of concentrating on work	-0.228	-0.322	0.047
7. Frequency of distraction by others' conversations	-0.094	0.046	-0.116
8. Preference for alternate office type	-0.261	-0.101	0.148

F.5 *Spearman's Rho correlation coefficient for reverberation time (RT) and employee satisfaction in Mauritius sample*

Table F.5 Correlation coefficient values for reverberation, acoustic and work performance satisfaction in all three office types in Mauritius sample, significant when **p<0.01 and *p<0.05

	Reverberation time		
Acoustic satisfaction	WLC	WLO1	WLO2
6. Background noise satisfaction	-0.184	-0.055	0.326*
7. Frequency of noise disturbance	-0.403	0.224	-0.128
8. Co-worker communication level rating	-0.077	0.144	-0.033
9. Frequency of raising voice in office	-0.207	0.033	-0.142
10. General office noise satisfaction	-0.457*	0.191	0.247
Acoustic levels			
Noise level	-0.053	0.175	-0.473**
Work Performance			
9. Frequency of difficulty to complete tasks due to noise	-0.230	-0.143	0.038
¤ Frequency of concentrating on work	-0.336	0.359	-0.047
10. Frequency of distraction by others' conversations	0.481*	0.207	0.116
11. Preference for alternate office type	0.050	-0.109	-0.148

F.6 Spearman's Rho correlation coefficient for noise level and employee satisfaction in Mauritius sample

Table F.6 Correlation coefficient values for noise level, acoustic and work performance satisfaction in all three office types in Mauritius sample, significant when **p<0.01 and *p<0.05

	Noise level		
Acoustic satisfaction	WLC	WLO1	WLO2
11. Background noise satisfaction	0.067	0.083	-0.024
12. Frequency of noise disturbance	0.000	0.227	0.069
13. Co-worker communication level rating	0.204	0.125	0.157
14. Frequency of raising voice in office	-0.022	-0.320	-0.142
15. General office noise satisfaction	0.280	-0.052	-0.072
Work Performance			
12. Frequency of difficulty to complete tasks due to noise	0.165	0.152	0.070
¤ Frequency of concentrating on work	0.134	-0.046	0.069
13. Frequency of distraction by others' conversations	0.302	0.026	0.110
14. Preference for alternate office type	0.165	0.118	0.254

Appendix G

Table G.1 *Differences for employee satisfaction between Glasgow and Mauritius samples in Kruskal-Wallis for WLC offices, significant where **p<0.01 and *p<0.05*

WLC				
	Chi-squared value (*H*)	Asymp.Sig (*p*)	Mean Rank	
Acoustic satisfaction			Glasgow	Mauritius
Satisfaction with noise in general	0.933	0.334	27.02	23.23
Frequency of noise disturbance	0.776	0.387	25.95	23.74
Co-worker communication level rating	0.609	0.435	23.65	25.60
Frequency of raising voice in office	5.982	0.014*	22.50	23.23
Acoustic measures				
Noise level	9.205	0.002**	20.72	33.55
Reverberation time	12.427	0.000**	19.87	34.76
Workspace				
Workspace floor area	4.120	0.042*	29.53	20.95
Occupancy density	9.744	0.002**	20.57	33.76
Height	3.059	0.080	22.97	30.33
Office rating	20.102	0.000**	33.70	15.00
Work performance satisfaction				
Frequency of difficulty to complete tasks due to noise	0.985	0.321	24.97	27.47
Frequency of staying concentrated on work	26.436	0.000**	33.09	14.21
Frequency of distraction by others' conversations	0.500	0.480	23.93	26.43
Agree to perform task in alternate office type	0.414	0.520	25.86	23.75

Table G.2 *Differences for employee satisfaction between Glasgow and Mauritius samples in Kruskal-Wallis for WLO1 offices, significant where **p<0.01 and *p<0.05*

WLO1				
	Chi-squared value (*H*)	Asymp.Sig (*p*)	Mean Rank	
Acoustic satisfaction			Glasgow	Mauritius
Satisfaction with noise in general	0.960	0.327	30.02	34.18
Frequency of noise disturbance	0.168	0.682	32.73	31.20
Co-worker communication level rating	0.114	0.736	31.65	32.38
Frequency of raising voice in office	0.089	0.765	31.80	31.16
Acoustic measures				
Noise level	13.557	0.000**	23.90	40.92
Reverberation time	2.525	0.112	28.52	35.83
Workspace				
Workspace floor area	0.422	0.516	30.58	33.57
Occupancy density	11.274	0.001**	24.64	40.10
Height	4.413	0.036*	36.55	27.00
Office rating	31.383	0.000**	44.05	18.75
Work performance satisfaction				
Frequency of difficulty to complete tasks due to noise	0.675	0.411	30.11	32.98
Frequency of staying concentrated on work	28.122	0.000**	42.08	20.22
Frequency of distraction by others' conversations	3.475	0.053	28.21	36.17
Agree to perform task in alternate office type	10.639	0.001**	38.64	24.70

Table G.3 *Differences for employee satisfaction between Glasgow and Mauritius samples in Kruskal-Wallis for WLO2 office, significant where **p<0.01 and *p<0.05*

WLO2				
	Chi-squared value (*H*)	Asymp.Sig (*p*)	Mean Rank	
Acoustic satisfaction			Glasgow	Mauritius
Satisfaction with noise in general	3.508	0.061	31.15	39.61
Frequency of noise disturbance	5.735	0.017*	39.91	31.57
Co-worker communication level rating	0.913	0.339	34.82	37.08
Frequency of raising voice in office	1.333	0.248	37.85	39.61
Acoustic measures				
Noise level	6.014	0.014*	42.26	30.24
Reverberation time	4.778	0.029*	41.44	31.00
Workspace				
Workspace floor area	15.482	0.000**	26.21	45.00
Occupancy density	22.900	0.000**	47.91	25.05
Height	1.932	0.164	32.74	39.00
Office rating	4.885	0.027*	30.56	41.00
Work performance satisfaction				
Frequency of difficulty to complete tasks due to noise	2.897	0.084	39.06	33.19
Frequency of staying concentrated on work	24.175	0.000**	46.76	25.46
Frequency of distraction by others' conversations	1.243	0.265	33.56	38.24
Agree to perform task in alternate office type	7.411	0.006**	42.43	30.09