Environmentally sustainable acoustics in urban residential areas

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May 2008

Thesis submitted for the fulfilment of the degree of Doctor of Philosophy

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Abstract

The main aim of this thesis is to examine environmentally sustainable acoustics, considering mainly urban residential areas. The study has systematically examined the three essential aspects of environmentally sustainable acoustics, namely, people, buildings and resources. The investigations are focused on three aspects: (1) the effects of urban acoustics on people: a systematic field survey on people's perceptions which considered people's living experiences, sound preferences and social factors; (2) a series of buildings' life cycle assessments which examined the environmental impact from cradle to grave of the building's lifespan and tried to further comprehend acoustic sustainability of residential buildings; (3) various possibilities concerning the use of wind turbines around and above the residential buildings in an attempt to discover how to regenerate renewable wind energy and to avoid serious noise effects. The study has then been expanded from the three aspects, by revealing potential to achieving environmentally sustainable acoustics. Overall, it has been proved that environmentally sustainable acoustics is an essential part of the environmentally sustainability development.

The thesis makes a positive contribution to urban residential areas through the illustration of a sustainable acoustics approach to environmentally sustainable development, and demonstrates how these factors should be associated with each other. Acoustics and sustainability is a rather new field this study only reveals some key issues. More systematic and in-depth study in other aspects is still needed.

Acknowledgements

I would like to express my appreciation to a number of people, who have been greatly helpful to my study: to my supervisor Professor Jian Kang for his supervision and encouragement; to my family for their unlimited support and incredible patience; to Mr. Trevor Lea for his time and help; to Dr. George Finlay Turner for his encouragement and friendship; to BRE Envest team and Mr. Ian Ward for useful discussion; to Dr. Mei Zhang for her invaluable discussion on questionnaire design; to Mrs. Meng Yan for her invaluable input in web-based questionnaires; to the staffs and friends in the School of Architecture, the University of Sheffield; to Mrs. Rachel Grantham and Mr. Christopher Lamb for the help in proofreading; to all of respondents who give precious time to fill in questionnaires and oral interviews; and to the University for offering me scholarships.

CONTENTS

Chapter 1

Introduction

1.1 RESEARCH BACKGROUND

In many regions, urban environments are invariably densely populated which often results in increases in various types of environmental pollution. Accordingly, environmentally sustainable acoustics have become an important concern with more attention being paid to the problem, especially in urban residential areas. In urban areas there can exist continuous mechanical noise such as traffic noise, construction noise and activity noise which can damage people's physical and psychological health. Such noise pollution can thus result in harmful and unsustainable levels of environmental acoustics. Although it is unrealistic to completely prevent these disturbances, it is possible to manage, control, and improve current environment in order to significantly reduce noise pollution.

In the busy urban environment, environmentally sustainable acoustics can be influenced by building arrangements, environmental factors and resources. The urban residential area, especially, can be described as a sensitive area which has well established living spaces which should provide multiple functions of a certain quality. People, as well as the overall environment in urban residential areas, can be seriously affected. From the viewpoint of the urban residential area, it is necessary to consider environmentally sustainable acoustics in terms of environmentally sustainable development. Furthermore, environmentally sustainable acoustics is one of the essential concerns for environmentally sustainable development as sound exists everywhere and cannot be completely eliminated. The assessments of environmentally sustainable acoustics are combined with human perception and environmental aspects, due to the fact that no single aspect can stand alone in terms of environmentally sustainable development. And these tend to be linked to aspects of human perception. However, it is necessary to find acceptable and comfortable levels of acoustic quality. This can be described as a long term acoustic sustainable development which may not be easy to determine from a few factors but it must take into account terms of environmentally sustainable development. It should always try to find the essential, as well as typical factors, as considering all these factors may achieve a better balance. On the other hand, a number of urban acoustic studies have concentrated on problematic issues such as traffic noise, noise propagation, vibrations, and noise effects but may not deliver environmentally sustainable acoustics. Creating environmentally sustainable acoustics in urban residential areas covers a range of related topics. The existing literature is rather limited due to the focus on either acoustic problems or environmentally sustainable development. For this purpose, this thesis focuses on the possibility to develop these essential and typical factors of environmentally sustainable acoustics. It is important to note that the fulfilment of these main factors of environmentally sustainable development should involve: people's perception, buildings' sustainability, as well as renewable resources, as these are the three essential environmental aspects.

1.2 AIM AND OBJECTIVES OF THE STUDY

The aim of this thesis is to establish a systematic framework for developing environmentally sustainable acoustics in urban residential areas. To achieve this, the study investigates a number of factors: how various environmental factors can work together; to discover the effects which might have influence on people's perception, and the environmental impact of various environmental factors, it is thus important to understand the effects they may have, or may not have, through investigative research, and also to break new ground in trying to reach environmentally sustainable acoustics. In terms of environmentally sustainable development, the environmental impact such as from various building types, building materials and renewable wind energy are investigated. These are mainly considered in terms of actual needs, which cannot be ignored, but can be dealt with in a more sustainable manner. This thesis combines aspects of human perception, building sustainability and renewable wind energy. This is because the connection between urban environment and human perception are considered essential components in terms of environmentally sustainable acoustics. The detailed research objectives are to:

- Identify the essential and typical factors in urban residential areas;
- Identify the key components of environmentally sustainable elements in urban residential areas;
- Examine how people perceive urban acoustic comfort in residential areas;
- Explore the influence of social factors on urban acoustic comfort;
- Examine the sounds preferences within the living environment;
- Identify the significant environmental impacts throughout the lifespan of various types of buildings;
- Systematically assess the environmental impact of building elements;
- Examine how acoustic materials may affect environmental sustainability;
- Examine the sound distributions within a wind farm's surrounding areas using hypothetical and existing cases;
- Expand the study to examine sound distributions in wind farms' surrounding areas on two existing sites with hypothetical conditions;
- Put environmentally sustainable acoustics into a framework of environmentally sustainable development;
- Consider ways to create environmentally sustainable acoustics in urban residential areas.

1.3 THESIS OUTLINE

Chapter 2, the '*Literature Review*', reviews possible theories relating to urban sustainable acoustics; the concepts of positive sound environment and previous research which focus on the levels of acoustics comfort; human perception and social aspects of acoustics; a number of environmentally sustainable assessments on building lifespan and acoustic analysis methods. Overall, within the review, the framework of methodology and concept of environmentally sustainable acoustics are defined.

Chapter 3, the *'Methodology: An Overview'*, gives an overall framework of methodology. The first section focuses on field survey and describes the methodology used in the three stages of questionnaire surveys and the statistically analytical methods which are mainly used in Chapter 4. A particular focus is the examination of how people's perceptions vary according to social factors and the difference of cultural backgrounds between the UK and Taiwan. Secondly, there is a comparison, using various analytic software packages, of environmental sustainability which focuses on buildings' life cycle assessments. This is an attempt to determine what different environmental impacts might arise from building types, building elements and acoustic materials which were used in the building. Finally, a number of advantages and disadvantages are discussed with the focus on existing wind farms in order to learn from the experiences of various cases. The study then tries to find the potential for using wind turbines in urban residential areas. The aim is to investigate and assess the potential environmental acoustics through the urban environmental factors, and to identify this potential.

Chapter 4, the *'Perception of urban sound environment'*, focuses on the interaction between people's perceptions and social factors of the urban residential areas, such as the influence of sound on environmental sustainability, which might have certain effects on the positive concepts of environmentally sustainable acoustics. This chapter examines people's perceptions of their living environment; how people evaluate the environmental sounds in their living areas; the different perceptions that might arise from social factors and cultural differences between the two countries, and the interaction between sound preference and ambient acoustics.

Chapter 5, the *'Acoustic sustainability, environmental impact and buildings' life cycles'*, focuses on the building types, building elements, number of building storeys and acoustic materials of residential buildings. These include an examination of building sustainability and acoustic performance which tries to find an interrelationship between environmentally sustainable development and acoustic sustainability. This aims to demonstrate that environmentally sustainable acoustics are an essential part in terms of environmentally sustainable development by examining various features of residential buildings.

Chapter 6, the *'Environmentally Sustainable Acoustics –Wind Turbine Study'*, focuses on wind turbines, a kind of renewable energy which has great potential from environmentally sustainable development viewpoints but also has some disadvantages which need consideration: such as the noise distributed in a wind farm's surrounding areas. In the first part of the study, a number of hypothetical cases focus on simulation of various landforms, building arrangements and height of wind turbines. In order to know the real sound distribution caused by the wind farm, measurements were then taken at existing wind farms. This is attempting to know that sound power levels and discover the potential noise problems. In terms of objective assessment, the noise mapping software CADNA was applied to simulate the wind farm and further comparison was made between measured data and simulated results which tried to find the approximate sound spectrum of wind turbines. In order to understand the sound distribution around wind turbines, further simulations are made on different hypothetical landforms, numbers of sources and various source heights. Overall simulation and measurement examined potential acoustic problems in the wind farms' surrounding areas. This is considered a key point for further studies. The aim here is to discover the positive way of environmental sustainability by use renewable wind energy and how to avoid potential acoustic problem.

With the objective of benefiting environmentally sustainable acoustics, in the following chapter the main factors and the principles which were found are considered in an integrated way. Chapter 7, the '*Integrated consideration of urban acoustic sustainability*', examines how environmental factors influence the ambient sound in urban residential areas through hypothetical conditions. Firstly, further examination is made of the sound distribution of building facades of six surveyed areas, and this is analysed in further with the results in perception in Chapter 4. Secondly, this chapter further examines environmental impact in terms of buildings' life cycles and their sound distributions of eight building shapes, various numbers of storeys which attempting to make comparisons with the results in Chapter 5 and to discover the potential sound effects. Finally, this chapter examines the possible effects of using wind turbines in two existing residential areas. This discussion aims to explore ways to integrate environmentally sustainable development and sustainable acoustics.

Finally, in Chapter 8, '*Conclusions*', the contributions of the study are summarised in terms of study methodology: the theory of environmentally sustainable acoustics: the perception of various environmental sounds and evaluation of environmental factors, and the positive concept of environmentally sustainable acoustics. Suggestions for further studies are also provided.

Chapter 2

Literature review

This chapter reviews the existing literature relevant to various aspects of urban environments, with a particular focus on the theories and applications of acoustics in sustainable development. Issues covered include factors for perception, acoustic simulations, environmental sustainability simulations, renewable wind energy and overall environmental acoustic sustainability.

The first section, Section 2.1, reviews urban acoustic environments: the aim is to gain understanding of various effects in urban environments and possibly to apply solutions. Section 2.2 reviews sound effects on humans in terms of health and psychological effects. Section 2.3 reviews a number of acoustic simulations, including micro-scale and macro-scale simulations. Section 2.4 reviews a number of different life cycle assessment (LCA) software packages which can analyse a building's environmental impact. The interrelation between section 2.3 and 2.4 proves that acoustic sustainability is a key part of environmental sustainability, utilising acoustic theory and LCA theory. Section 2.5 reviews the effects of environmental acoustics, in order to improve its sustainability. Section 2.6 reviews the sound effects of wind turbines on surrounding areas, attempting to find out potential sound trends in wind farm areas and the potential to use wind turbines in general. Finally, Section 2.7 is a summary of environmental acoustic sustainability, examining the fundamental factors which comprise it, and also providing possible solutions for the future. Environmental acoustic sustainability is a complex framework involving multiple interrelated factors in that no factor can work completely independently of any other. The literature review attempts to identify a framework containing the underlying factors of environmentally sustainable acoustics and their interplay. This can be achieved by applying the relevant concepts in urban planning and at improvement stages. Furthermore, as people, buildings and renewable resources are essentials elements of the living environment, it is necessary to include these three factors in any framework for considering the sustainable development of acoustics.

2.1 URBAN ENVIRONMENTS

2.1.1 Introduction

It is estimated that approximately 50% of the global population are living in urban areas and the population rates are set to increase in the future (United Nations Population Division, 2003). In terms of urban sustainability, the increases in urban population and buildings have had a significant impact on certain levels of urban acoustics and environmental sustainability. According to The United Nation's Conference on Environment and Development (1992), its first principle states that:
'*Human beings are at the centre of concerns for sustainable development'. They are entitled to a healthy and productive life in harmony with nature* (Agenda21, 1992).
The Encyclopaedia Britannica (2005) defines sustainable development as:
'*an approach to economic planning that attempts to foster economic growth while preserving the quality of the environment for future generations'*.
Similarly, the quality of the living environment is an essential aspect of the sustainability of the living environment, the aim of which is an attempt to avoid long term effects and damage to the environment. Furthermore, environmental sustainability cannot be dealt with by analysing any of the various factors within the framework in isolation. Instead, all the factors need to be dealt with, as they all play a part; and this sort of improved balance, can produce better environmental sustainability. However, serious problems have appeared in the urban environment due to its high population density, high pollution levels and other forms of environmental damage. As mentioned above, environmental sustainability consists of a complex framework of interrelated factors, and these all need to work together harmoniously in order to work out potential solutions.

2.1.2 Environmental Acoustics

In terms of urban environmental acoustics, the increases in noise pollution can seriously undermine sustainable development. A number of studies have shown that noise is the third most hazardous form of pollution after air and water pollution in large cities (WHO, 1999). Environmental acoustics have thus become an essential consideration in terms of environmental sustainability (Cowell, 2005; Peyton, 2005). The UK Building Research Establishment (1999-2000) carried out a series of surveys of national noise incidence and attitudes. The survey revealed that noise was one of the top five problems from a list of twelve environmental problems and about 18% of the respondents reported that personally affected them. In the survey, noise was ranked ninth on the list of main problems and approximately 21% of the respondents reported that noise spoilt their home life to some extent, and about 8% reported that their home life was spoilt either 'quite a lot' or 'totally'. Furthermore, the survey pointed out that the majority (84%) of respondents were exposed to noise from road traffic; 81% from neighbours or other people nearby; 71% from aircraft; and 49% from building construction, demolition, renovation or road work. The proportion of respondents shown to be bothered, annoyed or disturbed to some extent by these noise types were 40%, 37%, 20%, and 15% respectively. The evening (19:00 – 23:00) and night-time (23:00 – 07:00) periods saw a particularly high proportion of respondents bothered, annoyed or disturbed by most types of noise from neighbours or other people nearby. In contrast, when compared to other environmental problems, noise pollution continues to grow as the number of complaints from people exposed to noise continues to rise. Noise pollution is unsustainable as it often involves an effect on health which is not always visible, and may be cumulative over time. It also adversely affects future generations, and has socio-cultural, aesthetic and economic effects (WHO, 1999).

It is clear that acoustics is an important factor involved in environmental sustainability, as determining how to manage and avoid noise pollution is a serious issue. In terms of environmental sustainability, the levels of pollution cannot totally disappear, but problems can be dealt with more constructively. Furthermore, noise itself is not a simple concept to define acoustically as it is produced by various sources at different times, in different places, and its effects are not always immediately apparent.

2.1.3 Negative Sound

Environmental noise sources contain a range of different factors including: cultural factors, social factors, those related to construction, the influence of the community, and various vehicles types. Environmental conditions have changed due to a variety of factors producing a variety of noises. In large cities, the increases in population have resulted in serious public health problems in many communities around the world. Since the 1980s, the World Health Organization has addressed the problems of community noise, providing basic guidelines for managing noise standards (WHO, 1999). In terms of human physiological processes, sound is a sensory perception produced in the auditory brain, and so this means that there is no distinction between sound and noise. From the viewpoint of environmental acoustics, community noise can be defined as all sound emitted from environmental sources around living areas, such as transportation, industries, construction, public work, activities, home appliances and the neighbourhood (WHO, 1999).

A study focusing on the annoyance levels involved with sound (Pedersen and Persson, 2002) showed that as noise effects increase, annoyance levels increase in direct proportion. It found that levels of annoying noise increase when the sound pressure goes above 32.5dBA (LAeq), and about 20% of residents felt significantly annoyed when sound pressure levels were between 37.5 and 40dBA (LAeq). About 36% responded that they were annoyed when the levels were above 40dBA (LAeq). Results also shows that a high percentage of people believe they are more sensitive to noise than other people. When the noise levels dipped below 35dBA (LAeq) only a small group of people felt annoyance, but when the noise levels were high, a high percentage of people felt annoyed. This study indicated that people's perceptions of different annoyance levels must be taken into account when planning ambient sound.

The WHO has shown how negative sounds can affect people's health. This is a useful guideline for the community as well as a good reference point for measuring the sustainable dimension of environmental acoustics. Also, it can be seen that the annoyance levels are different when the sound pressure levels change.

In urban areas, there are multiple sources of noise, mainly originating from transportation noise such as highways, railways, the underground and aircraft. Traffic pollution tends to irritate people, especially in the areas around the main roads, hillsides, airports, hospitals, traffic lights, bus stops, railway stations and so on. Generally, traffic noise generated by vehicles and road surfaces is mainly due to the speed of vehicles. A number of studies have indicated that different levels of annoyance due to noise originate from different types of transportation. According to WHO (1999), when the vehicle speeds are above 60 km/h, the noise from contact with the road is higher than that from the actual vehicle's engine noise. It is important to keep in mind the types of noise levels and their comparative effects. For example, Hall et al (1981) point out that aircraft noise is more annoying than road traffic noise. Fields and Walker (1982) indicated that road noise is more annoying than railway noise. Comparisons between traffic noise annoyance levels showed that the most annoying mode of transportation is buses, followed by cars, then mopeds and trucks (Sattler and Rott, 1996). Bertoni et al (1993) surveyed various noise sources and results showed that the average SPL of traffic noise at day and night time are over 60-62dBA and the survey also demonstrated that traffic noise is more annoying than other kinds of noise.

Research into the levels of the traffic noise reveals that daytime traffic noise annoyance can be divided into three levels: <55dBA, no annoyance; 55-60dBA, some annoyance; and >65dBA, definite annoyance (Lambert et al, 1984). Fields (1993) indicated that it can be very annoying for people when levels are even as low as DNL (day-night level) <55dBA. Furthermore, the investigations by WHO (1999) indicated that traffic noise could be seriously affecting people around the world. It is estimated that about 40% of the European Union population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55dBA in the daytime, and that 20% are exposed to levels exceeding 65dBA. When all transportation noise is considered, more than half of all European Union citizens are estimated to live in zones that do not ensure acoustic comfort for residents. During the night-time, more than 30% are exposed to equivalent sound pressure levels exceeding 55dBA, which disturbs sleep. This is mainly caused by traffic and alongside densely travelled roads, equivalent sound pressure levels over 24 hours, can reach 75–80dBA.

Noise generated by construction machines and site works can cause considerable noise emissions. A study on the sound emissions from construction machinery showed that they were more unpleasant sounds, more powerful and sharper sounds, than those produced by the scenery/soundscape (Hatano et al, 2001).

A number of surveys on cultural differences have suggested that annoyance levels vary between different cultures and noise sources. The comparative surveys of cross-cultural communities have shown that people in Japan and Sweden get more annoyed by traffic noise than people from other countries, and non-acoustic factors, such as different nationalities and different housing types, were important for annoyance evaluation (Sato et al, 1998). Another cross-cultural survey in Japan, Germany, USA and China, focused on the factors of environmental sound quality and used semantic differential analysis to demonstrate notable differences between the four countries (Kuwano et al, 1999).

Annoying noise from nearby neighbourhoods or facilities tends to reduce people's quality of life. Neighbourhood noises result from people talking, loud music, activities involving movement and home appliances, and in some countries, the noise generated from air-conditioners, fans and typical vehicle movements.

In terms of environmental acoustics, clearly, noise pollution is one of the most serious acoustic problems, caused by traffic, machines, landforms, activities and so on. Noise pollution is an existing problem which can affect people's living quality, both physically and psychologically. Noise pollution is complex and so might not be easy to deal with, but it can be controlled by understanding ways of managing it. For the purposes of noise management, it is important to develop noise control techniques which involve the measurement and control of sources, receivers and transmission paths. From the viewpoint of environmentally sustainable acoustics, noise is an un-sustainable sound effect, and needs close attention if it is to be overcome. On the other hand, in terms of environmental sustainability, noise pollution not only affects acoustics, but also interferes with the quality of the environment.

2.1.4 Positive Sound

A large amount of research demonstrates that a number of positive sounds are in existence in the environment and these can be described as positive sound factors, improving acoustic sustainability and containing great potential for developing environmental sustainability. A soundscape is formed from many different factors, and is essentially a positive phenomenon. Therefore, in an attempt to understand soundscapes better, research has focused on soundscapes as a positive factor which can help to design a better living environment through better understanding.

Soundscape

Soundscapes contain multiple factors which are relevant to acoustic issues. Schafer (1977) suggests that designing a comfortable sound environment must include a conception of the soundscape. The meaning of soundscape is derived from social, historical, cultural and environmental factors and also can be applied in practice in urban environmental planning, architectural and equipment design (Kang, 2006). Furthermore, soundscapes are related to a range of disciplines including acoustics, aesthetics, anthropology, architecture, ecology, ethnology, communication, design, human geography, information, landscape, urban planning among others (Karlsson, 2000; Kang, 2006). The world forum for acoustic ecology (WFAE, 1993) was founded for members who share a common concern about the state of the world soundscape as an ecologically balanced entity. They also represent an interdisciplinary approach to the study of the scientific, social and cultural aspects of natural and man-made sound environments (Kang, 2006). Moreover, the relationship between health and soundscape has been studied in Sweden, showing that soundscape has directly affected people's health (Kihlman, 2001; Kang, 2006). An investigation of mental health and the acoustic environment showed that there are still some unknown effects on people's mental health (Lercher and Widmann, 2001).

The field research on soundscape evaluation by Southworth (1969) was an investigation of individual perceptions in various urban environments. The investigation can be divided into three subject areas including auditory, visual and visual-auditory. The results showed that when visual and auditory elements existed together, attention to the visual form was reduced, and vice versa. The interactions between visual and auditory perception, especially when the sounds accompany the scenes, give people a sense of involvement and lead to more pleasant feelings.

A study of soundscape evaluation showed that sound is related to people's activities such as group dancing and also showed considerable influences from activities (Kang and Zhang, 2005). Social and demographic factors of the users may play an important role in soundscape evaluation (Kang, 2003). Furthermore, individual perceptions are also important factors in considering sound sensitivity (Zimmer and Ellermeier, 1999).

As can be seen above, several studies have demonstrated that soundscape can be a significant aspect in overall acoustic design and performance and are directly linked to physiological and psychological factors. It is clear that soundscape are not only relevant to acoustics but also to human effects and environmental sustainability. Furthermore, several effects can affect soundscapes, such as people's activities and human visual factors. Soundscape is a complicated aspect, which may involve various acoustical factors and have environmental impact. Therefore in terms of soundscape of urban environments, this study attempts to discover what effects soundscapes might have on people's perceptions of their living environments and also, whether these effects can come from social, demographics, living experiences, and various environmental factors.

2.2. EFFECTS OF NOISE

Noise pollution has been increased in urban areas which may have effects on people's physiology and psychology, social factors, as well as affecting people's health, and producing a series of other adverse effects (The Noise Association 2006). This section reviews a series of studies in this respect. From the viewpoint of sustainability, as mentioned previously, the acoustical aspect is a vital part of the overall urban environmental sustainability. It is thus related to a number of environmentally complex factors and can not be considered in a single aspect.

2.2.1 Health Effects

A number of studies have shown that noise has both physical and mental effects on humans. In terms of environmentally sustainable acoustics, factors affecting people are significant, due to the fact that people's perception is a key consideration. WHO (1999) claimed that after long-term exposure to air noise and road traffic noise environment with LAeq 24h values of 65 to 70dBA, cardiovascular disease could result. It also pointed out that heart disease is more serious than hypertension. Furthermore, the long term effects of noise also included digestive problems, sensitive annoyance, unintelligibility of speech, the interference of communication, the disturbance of information extraction, sleep disturbance, hearing impairment and so on. Figure 2.1 shows the critical health effects from different noise levels.

Figure 2.1 *Critical health effects from different noise levels. (Source: WHO, 1999).*

A field survey, carried out in residential areas, claims that noise could cause irritability, difficulty to concentrate, sleeping disorders and headaches which in turn stem largely from traffic disturbance and neighbourhood noise (Zannin, 2002). Studies examining how people's health is affected by noise in Tokyo, Japan, indicate that it has the greatest effect in areas of heavy traffic. The effects are also significant in terms of an increased incidence of disease when the noise levels reach 65 to 70dBA (Yoshida et al, 1997; Kang, 2006).

A number of studies found that during the night-time, when people are exposed to noise, they can resort to sedatives or sleeping pills more often, and the quality of sleep suffers (Frusthorfer, 1983; Kang, 2006). Furthermore, exposure to noise from the surrounding environment at night-time can have several social effects. (Kihlman, et al 2001; Kang 2006). In terms of temporary exposure, the body usually returns to a normal state after it has been exposed to the noise. With longer term exposure, when the body is exposed to noise of sufficient intensity without being prepared, the body can be affected in a variety of different ways, including hormonal and cardiovascular effects, and these in turn increase heart rate, peripheral vascular resistance, changes in blood pressure, blood viscosity, blood lipids, shifts in electrolyte balance and hormonal levels (Kang, 2006). Furthermore, when noise is accompanied by vibrations and contains low frequency components, these can cause stronger reactions in the human body (Paulsen and Kastka, 1995).

From the perspective of human health, noise can have short term as well as long term effects. These may not be directly observable. The effects from noise on health can vary according to the time of day. In terms of environmentally sustainable acoustics, the effects of noise can be serious, and the aim is to always try to decrease the levels of harm and to achieve greater acoustic sustainability. However, this study aims to determine the effects of noise on human health which might help in working out how to improve the sustainability of urban acoustics in advance.

2.2.2 Long Term Effects

A great deal of research has indicated that long term exposure to noise can have psychological impact. In contrast, the development of certain mental disorders may not be directly observable in the short term (Kang, 2006). One field survey concerning the effects on sensory neural hearing in Bangkok, Thailand, indicates that 21.4% of the population was suffering from sensory neural hearing loss (Prasanchuk, 1997; Kang, 2006). Another study on psychoacoustics observed that systematic differences in the volume of sounds produced in the natural environment can cause differences in how unpleasant a sound can be felt. The study also indicated that the effects of noise are both psychological and physical. How sensitive a person is to noise is primarily due to what they judge a noise to be (Kang, 2006). Furthermore, the difference between constant and temporary sounds has different psychoacoustic effects (Genuit, 2001). A study on psychoacoustics has pointed out that people may feel significant annoyance at a source of noise when they believe that it may affect their health (Nelson, 1987).

The relationship between loudness and pleasantness has been examined and results showed a positive correlation between relatively high levels of loudness and intermediate levels of loudness, but when one evaluates intermediate levels alone, there is no significant effect (Zeitler and Hellbrück, 1999). The relationship between loudness and memory has certain effects on people's perception and cognizance (Hellbrück *et al*, 2001). People's attitudes may be affected by loudness, and by reduced volume which can encourage good behaviour and have less significant effects (Gifford, 1996). Clearly, loudness is not only an unwanted sound, but also causes of psychological and physiological effects. Furthermore, pleasant sounds not only allow people to enjoy their living environment, but also affect environmentally sustainable development.

Sounds affect different genders in different ways, with significant differences found under certain conditions (Christie and Glickman, 1980). The relationship between human sounds and the sounds produced by nature has been studied extensively. The results show a significant correlation between human sounds and natural sounds which can affect people's experience (Yuki, 2000; Kang, 2006). Exposure to noise in the environment can affect personality traits and personal patience. Furthermore, exposure to high levels of noise in the environment can change a person's personality (Moreira and Brya, 1972).

Bertoni, et al., (1993) demonstrated that people's subjective experience of noise can have a significant influence on their levels of annoyance. Living alone in the long term can create a significant amount of annoyance due to social isolation (Schulte-Fortkamp, 1996). How long a person has stayed in a house has no bearing on their subjective experience of noise (Fields, 1993; Tonin, 1996). The correlation between property ownership and the degree of annoyance in terms of tenants and owners is a weak one (Fields, 1993; Kang, 2006). The existence of soundproof windows has, on the other hand, been shown to have an effect (Maurin and Lambert, 1990). Gjestland (1998) indicated that regional differences such as cultural heritage, urban texture, construction methods, weather, lifestyle, personal experience, and cultural factors may influence annoyance levels. Furthermore, since 1980, studies on the effects of noise on the community by the WHO indicate that about 120 million people around the world have disabling hearing problems as a result.

Overall, the effects of noise on the community are said to include annoyance, unintelligible speech, impeded communication, disturbances to how the brain processes information, sleep disturbance and hearing impairment (WHO, 1999). Long term exposure to noise as a product of loudness, personal differences, and difference in the subjective interpretation of noise in the living environment can have a serious impact in terms of psychological health. Long term effects can be more serious than those in the short term.

2.3 ACOUSTIC SIMULATION

Since the 1960s, computerised acoustic analysis and simulation has become more popular and useful (Kang, 2006). A variety of software has been developed and utilised on both a micro and macro scale. The simulation methods can be applied on both these scales and produce accurate results. In order to investigate an appropriate method for use in the urban living environment, two different scales are considered below. These attempt to find an appropriate method to discover what will happen to sound distributions in the future, as well as examining existing ones. This can be set as a base line for sound trend assessment which can help to find the problems involving noise.

2.3.1 Micro-scale Simulation

A number of modelling techniques have been developed which can be used in micro-scale areas (Kang, 2002) including image source method, ray tracing, beam tracing, the radiosity method, the finite element method (FEM) and boundary element method (BEM). Micro-scale method is mainly used in small areas such as a street or square in order to yield accurate results. In terms of micro-scale method, it is more closely related to acoustic theory than the macro-scale, as it has been developed for accurately predicting the distribution of sound. A number of models are useful for strategic design in small areas such as a single street. These can predict the distribution of noise emitted by traffic and also can be used in micro-scale areas and applied to more complicated configurations. Furthermore, it is important to choose a suitable method for simulation according to the situation.

2.3.2 Macro-Scale Simulation And Noise Mapping

Noise Mapping

Noise mapping technology, which models different kinds of noise locally, has been developed by performing calculations from the most significant sources of noise on the macro-scale. This method can yield results within an acceptable time and cost, but is only suitable for large areas and produces only rough calculations due to the fact that the statistical methods and simplified algorithms it uses are based only on approximations. Noise mapping can be useful for assessing the effects of noise of both existing and expected sources of sound in the environment, and has been used worldwide. It is an effective way to present as well as assess the acoustic environment, and also objective judgements can be made. The last two decades have seen the extensive use of noise-mapping techniques at city or town scale as well as at national levels for road and rail networks, as a means of representing the acoustic environment. In Europe, noise-mapping has been hugely popular especially in the Netherlands, which saw a plan to map populations of all towns over 50,000, realised before1998 (Kang, 2006). A body of research focuses on how to improve the accuracy of noise mapping in recent years by improving its flexibility. There is a good opportunity to monitor and assess sound trends successfully in noise mapping by using accurate data.

Using noise-mapping software

This thesis attempts to analyse sound trends in the urban living environment, by showing how noise mapping software can simulate current situations and future ones. A number of noise mapping programs can be used for this, such as Cadna/A, SoundPLAN, Mithra, Noisemap and so on. To carry out a simulation, it is essential to provide a layout of the area, geographical information, related environmental factors, topography, sources of sound in the area, traffic data, the setting of intervals in the calculation grid, the setting of the reflection order, whether it is produced in the day or night time and so on. Then, when starting the calculation process, the colour coded map should display noise distributions, and these can be divided into twelve groups of colours. As previously mentioned, various noise mapping software packages can be applied in different situations according to what standards are adopted. In recent years, noise mapping software has been widely used in managing environmental noise, but the accuracy of the results still needs to improve (Kang, 2006). Furthermore, noise mapping might not be suitable for simulating combined/complex situations such as different arrangements of environmental factors.

Accuracy of results

There is considerable disagreement about how accurate results are from simulation. A study which simulated the relationship between the type of building facade and the amount of traffic noise (Tompsett, 2002), found that the type of façade made a ±2 dBA difference. The parameters used to calculate noise mapping might be inappropriate in all of the cases. For example, using intervals of 10 m and a reflection order of 1 might yield inaccurate results (Stocker, 2002). Stapelfeldt (2001) suggested that in order to produce more accurate results, the appropriate method for calculating the various factors in the area must be found. Furthermore, it is also important to be accurate with the data as otherwise it may cause incompatibility with the software packages (RPS, 2002). A variety of data can also be used in noise mapping. For example, data assessing air quality can be used to simulate road noise (Stocker and Carruthers, 2003). On the other hand, Turner and Hinton (2002) showed that the advantage of noise mapping is that it can evaluate how the use of an area will produce different amounts of noise.

Procedure

In order to understand the principle and procedures of noise mapping, this thesis tries to review how its underlying calculations work when performing proper simulations. Noise mapping is based on a series of algorithms utilising different variables depending on the source of noise. The international standards set for noise mapping can also be applied for aircraft, roads, railways, and industrial noise. As a consequence, different methods of calculation have been developed in different countries, based on different standards and different situations (Kang, 2006). The procedures compare various sources, atmospheric absorption, ground effect, screening, reflections, meteorological correction, miscellaneous attenuation, and other effects which are based on ISO9613 (1993). Generally, the calculation procedure is based on each point source, and this divides each point source into cells in order to determine its sound characteristics. The propagation from each cell can be calculated on an individual basis or as an equivalent point of a group of cells. In terms of geometrical divergence, the sound spreads from any point source in a spherical manner (Kang, 2006). In summary, the main uses of ISO9613 in the noise mapping are:

- The atmospheric absorption is relevant with the distance of propagation and octave band atmospheric attenuation coefficient in dB/km.
- Ground effects generally produce horizontal effects and constant gradient effects.
- Ground attenuation is separated into three regions, namely: source region, receiver region, and middle region. The attenuation of each region is calculated by octave band and then they are added to give the total ground attenuation per octave band.
- Screening effects depend on the surface density of the screen being >10 kg/m^2, and having a closed surface without gaps, and the horizontal dimension of the screen from the line source to the receiver being larger than the wavelength of the sound at the octave band centre frequency.
- Image sources were considered when specular reflections occur, the surface reflection coefficient is greater than 0.2, and the surface is sufficiently large; these can be applied on the reflections of outdoor ceilings or building facades.
- The meteorological conditions of downwind were defined in two ways: a wind speed of 1 to 5 m/s at a height of 3 to 11 m above the ground, with wind blowing from source to receiver at an angle of ± 45 degrees.
- The propagation of miscellaneous sound considered sound propagation through foliage, which mainly concerns foliage density and distances from the source or receiver.

The above factors all have certain effects on sound distribution in macro-scale areas. However, this thesis attempts to use noise mapping software to calculate sound trends in current situations and work out potential sound distributions in future situations. From the point of view of environmentally sustainable acoustics, it is crucial to manage and develop sound environment in an appropriate way, considering the fundamental factors.

2.4 BUILDING LIFE CYCLE MODELLING TECHNIQUES

2.4.1 Background

Building life cycle assessment (LCA) software packages are developed for analysing the environmental impact of a building's entire lifespan from cradle to grave. In order to assess the appropriate method for simulating a building's life cycle, a brief review of a number of different building LCA software is provided below. The building life cycle considered in the assessment can be roughly divided into three stages; firstly, acquisition of raw materials to be used to make building materials; secondly there is the construction process, and the final stage is to assess the usage of the building's lifespan. In terms of these three stages of LCA, the first stage is the acquisition and processing of the raw building materials, testing the material's performance, and the transportation of the materials to the construction site. Secondly, the construction process must occur, including the structural building work, the installation of building elements, the finishing touches applied to all surfaces, and disposal of waste. Finally, the LCA focuses on the building's entire lifetime and includes both energy use within it and the maintenance of the building.

However, the factors involved in the building life cycle can involve, and be derived from, a number of environmental factors which might be against environmental sustainability. In an attempt to achieve environmentally sustainable acoustics, buildings' LCA method must be considered alongside other factors and not alone.

2.4.2 Building LCA Software

Due to their complexity, key building LCA software may assist in assessing the environmental impact of buildings. In this section, a number of different building LCA software packages are assessed, attempting to find the appropriate software for use in the UK, given its environment and conditions.

The Athena model was developed by Athena Sustainable Materials Institute (Athena, 2006; U.S. Department of Energy, 2006), Canada and can be used to evaluate various environmental conditions, such as how various design options combine together and so on. It requires the input of current, reliable and comparable environmental data, and also building data. The output tables and figures show various environmental effects across six environmental measures. Furthermore, it can be applied to comparison of different conceptual designs.

BEES was developed by the National Institute of Standards and Technology, USA (NIST, 2002; U.S. Department of Energy, 2006) and was developed for assessing the environmental impact, as based on ISO 14040. Economic performance is measured using the ASTM standard life-cycle cost method. In terms of environmental performance, it mainly analyses the acquisition of raw materials, manufacturing, transportation, installation, use, recycling and waste management. In terms of economic performance, it can cover the costs of initial investment, replacement, operation, maintenance, repair and disposal. BEES combines environmental impact and economic factors, mainly focusing on 200 building products and covering 23 building elements.

The Building Greenhouse Rating is used for Australian office buildings only and mainly evaluates energy efficiency and the running costs of buildings (Sustainable Energy Development Authority, 2005; U.S. Department of Energy, 2006). Results are shown on five scales and given one to five stars; more stars equals greater environmental sustainability. It was developed by the Sustainable Energy Development Authority in Australia, and its main function is to attempt to help property owners to evaluate their property.

ECO-BAT was developed by the Laboratory of Solar Energy and Buildings Physics, Switzerland, and can evaluate the environmental impact during the entire lifespan of a building from construction to its dismantling, and including fabrication, replacement, waste management and transportation (Laboratory of Solar Energy and Buildings Physics, 2006; U.S. Department of Energy, 2006). Furthermore, it can define various elements used in the building such as walls, windows, roofs, and building shapes.

Envest is mainly used to estimate office buildings, and was developed by Building Research Establishment (BRE, 2006), UK. The output results show in Ecopoints: one hundred Ecopoints are equivalent to the environmental impact of the average UK citizen per year. Results can be divided into two categories, namely the construction of the building and its operational use. It can directly compare different building designs but some of the extraneous materials might not be covered.

EQUER was developed by Ecole des Mines de Paris, CEP, France (CEP, 2004; U.S. Department of Energy, 2006). It mainly estimates annual building performance. The data used focuses on the manufacturing of building materials, and was from a project called "European Regener". This software also has links to another energy simulation tool called "COMFIE".

GaBi 4 was developed by PE Europe GmbH, Germany (PE Europe GmbH, 2006; U.S. Department of Energy, 2006). It is based on DIN ISO 14040 ff and uses parallel methods to assess environmental problems by evaluating a building's life cycle. Also, it can be used to analyse complex and data-intensive process networks, attempting to find the balance between various factors.

KCL-ECO is a linear function of the building life cycle method which was developed by Oy Keskuslaboratorio (Oy, 2006; U.S. Department of Energy, 2006), Finland. It can handle large systems and produce multiple results including environmental impact assessment, sensitivity levels analyses, agglomeration functions, graphic processing of results, etc.

LISA is a streamlined method which was developed by the Centre for Sustainable Technology, University of Newcastle, Australia (Centre for Sustainable Technology, 2003; U.S. Department of Energy, 2006). It can assist in the design stages and help users to simplify building LCA, but it cannot be used for modelling thermal analysis.

Umberto was developed by the Institute for Environmental Informatics and Institute for Energy and Environmental Research (ifu and ifeu, 1993; U.S. Department of Energy, 2006). It is based on the concept of material flow networks and the calculation algorithm is a very powerful one which can compare various scenarios. Users can select materials and energy flows in the system but it is not suitable for application in evaluating a building's operation.

A number of different building life cycle software packages have been examined in this thesis above. Each method attempts to help in understanding and reducing environmental impact. It can be noted that the differences between various methods depend on the variety of regulations, building types, building elements. In addition, some methods try to find out the impact of various environmental problems. However, the complex environmental factors and regional differences affect the method of calculation and the results yielded. Such results might be different in different regions due to different building types, building elements, common materials, construction methods and environmental conditions. Choosing suitable LCA software needs to bear in mind realistic conditions and the accuracy of the results. Clearly, it is necessary to find the appropriate building LCA software to understand the exact results as well as the environmental impact.

2.4.3 Building LCA And Acoustic Sustainability

The concept of sustainable living provides a number of significant challenges for producing viable building designs. The concept of environmental sustainability has been expanded to wider areas and various fields need to work together. Overall, in terms of environmental sustainability, it is clear to say that acoustic factors are a central part of environmental sustainability, and should form an important part of sustainable development. Due to the fact that the buildings are always a large proportion of the built environment, they have a large impact on the perception of acoustic comfort in terms of overall acoustic sustainability. However, little attention has been paid to the impact on environmental sustainability of using various acoustic materials and the different elements of the building. Therefore this study investigates various LCA software packages, attempting to find suitable software for use with various building types, different elements of buildings, acoustic materials and to examine the potential impact, too, from buildings. This attempts to add the viewpoint of buildings to the framework of environmental acoustic sustainability.

2.5 ENVIRONMENTAL ACOUSTIC SUSTAINABILITY

2.5.1 Background

The acoustic sustainability of the urban environment has been developed in recent years to contain a wide range of subjects including the monitoring and improving of existing situations. In terms of acoustics, this contains urban textures, social factors, sound sources, regulations/standards, and predictions for sound propagation, all of which are relevant to acoustic comfort. Hellström (2006) indicated that in terms of urban environmental sustainability, acoustics must be integrated into the complex area of urban planning and development, and it is especially important to integrate acoustic and architectural analysis. Clearly, acoustic sustainability is a central factor in the overall sustainable development of the urban environment which can not be ignored. It also needs to be examined alongside many other factors.

How to manage environmental sound and create acoustic comfort are key factors in developing environmentally sustainable acoustics. Voichita (2006) suggested three main steps to manage environmental sounds. Firstly, it is preferable to understand existing acoustics in the environment. It then determines the acceptable and comfortable sound levels. Finally discover existing unwanted sounds, as well as currently acceptable and comfortable sound levels. It can be seen that environmentally acoustic sustainability requires multi-dimensional considerations, including the economy, society and various environment factors. However, noise pollution can create a number of serious problems in the environment, and so acoustics should be included in any framework of environmental sustainability.

2.5.2 Natural Means Of Noise Reduction

From the 1970s to 1990s, a number of studies found that vegetation can reduce sound, but since then there have been very few studies on this subject (Voichita, 2006). As a proactive method of reducing sound through vegetation, almost all countries around the world have plenty of green areas, formally recognising protected green spaces. Green areas provide environmental protection, social, aesthetic, cultural, educational, and climatic benefits. The European Commission (1996) indicated that various aspects of environmental protection are generally accepted but better management strategies and more development of green urban areas are still required. Clearly, planning the use of vegetation is highly relevant to environmentally sustainable development. Moreover, from the point of view of urban landscape, Voichita (2006) suggested that a positive impression of the urban landscape is produced by the existence of large vegetation areas such as green belt areas of trees, public gardens, open spaces, and parks.

However, the green areas provide a benefit to the visual appearance of the landscape rather than from the noise screening provided (Watts, et al., 1999; Kang, 2006). For the point of view of the urban landscape, green areas can be used to decrease the amount of environmental noise, as well as contributing to environmentally sustainable development. It can be of benefit in terms of aesthetic, environmental quality, sound mitigation, etc, all of which can be described as green factors involved in environmentally sustainable development. These green benefits are also significant factors in terms of urban living areas.

In terms of acoustics, the effect of vegetation arises through three mechanisms: sound absorption and sound diffusion, which can occur when a sound wave impinges on the vegetation and is then reflected back; also sound level reduction, when a sound wave is transmitted through the vegetation (Yu and Kang, 2005). Vegetation can be grown around the boundaries of a street canyon or a square, and also on building façades and on the ground. The effectiveness of absorption can be greatly enhanced since there are multiple sound reflections. Similarly, with multiple reflections, the diffusive effect of vegetation on sound is significant even when the diffusion coefficient is relatively low. Furthermore, these factors can assist as part of producing a positive design, combining artificial noise barriers and natural vegetation. This latter concept includes various plant shapes, types, and arrangement (Van Renterghem and Botteldooren, 2002; Kang, 2006).

In an attempt to find out how vegetation can be used in efficient ways, this study reviews the various possibilities for utilising vegetation. A number of different research studies have demonstrated that bands of trees can be used to screen traffic sound emissions along the main roads and comparisons between tall vegetation and open grassland show that tall vegetation is more efficient than open grassland (Kang, 2006). Attenborough (2004) suggested that it is more important to arrange vegetation specifically rather than have a random arrangement. On the other hand, no precise manner can be used to assess the effect of vegetation on sound distribution (Kang, 2006). It is vital to consider that proper management of vegetation can be helpful in terms of environmentally sustainable acoustics.

Vegetation in urban areas

A number of plants have survived from the forest before urbanization, and these plants have been accepted as part of the urban environment. These sorts of trees can become associated especially with the region in which they occur. In terms of plant species, it may be better to use the vegetation which has always existed in that region. Otherwise, people there may suffer ill-health as a result of being unaccustomed to them. Voichita (2006) suggested that retaining the original kinds of trees is essential in urban morphology. The first concept of the urban forest has been proposed in Canada since the 1960s (Voichita, 2006). This mainly concerns a global approach to tree management, and attempts to integrate all urban activity with the population. Voichita (2006) suggested planning for vegetation should pay further attention to reducing environmental pollution by improving aesthetic effects, reducing effects of sounds, and reducing air pollution. Mecklenberk et al (1972) have pointed out that noise attenuation is dependent on the capacity of the trees.

This tends to be related to the plants' density as well as the size of planting zones. Voichita (2006) suggested that planting in an efficient manner to reduced noise attenuation should involve mixing plants species up in a zone rather than having simply a single plant species. The sound attenuation between mixed plants species and single species is about 0.36 dB/m and 0.17 dB/m respectively. In terms of the configuration of plants, that different effect has been found to stem from combining vegetation and configuring the terrain. Plants closer to noise sources might be able to reduce sound by about 5 to 10 dB (Voichita, 2006a). Furthermore, a number of studies show that different distances between noise sources and plants can have different sound attenuation effects.

It is clear that when planning the use of green areas in the urban environment, it is imperative to consider the denseness of plants, the size of the planting zone, the presence of mixed plants, the use of original plants and so on. These elements can increase efficiency when using vegetation. However, a green area can offer various green and natural benefits, and, as mentioned earlier in this study, planning environmentally sustainable acoustics should combine various factors. Vegetation is one such factor which not only reduces sound but also benefits the visual landscape.

2.5.3 Artificial Means Of Noise Reduction

Building components

Due to the existence of highly populated urban areas, there have been increases in various environmental loads. As a consequence, environmental loads have become a serious issue in recent years; a number of different studies try to approach sustainable development. Brown and Ulgiati (1999), proposed a formulation constructing an environmental sustainability index, and this is the ratio between the emergy yield ratio and the environmental loading ratio.

$$\text{Sustainability Index} = \frac{\text{Emergy Yield Ratio}}{\text{Environmental Loading Ratio}} = \frac{EYR}{ELR}$$

Emergy Yield Ratio = environmental output

Environmental Loading Ratio = load of environment

The equation shows that all of the emersion might become environmental loads relating to long term environmental effects. It is therefore necessary to consider them from various aspects and to find a balance. In urban areas, a large proportion of buildings may have various environmental impacts as well as acoustic effects. Consequently, to evaluate the components of building is part of environmental sustainability. Overall a building sustainability, such as the design of buildings envelopes, is often related to acoustic issues. For example, a window with two or more layers of glass could bring benefits in both energy saving and noise reduction. Encouragingly, use of the natural ventilation is an important aspect of the green building movement; but opening windows can often cause noise problems. It is thus important to develop window systems that reduce noise transmission whilst allowing the natural ventilation as well as efficient use of daylight, thus increasing the overall sustainability of the building stock. A number of techniques have been developed to produce suitable systems for passive controls (Field and Fricke, 1998) and active controls (Jakob and Möser, 2003) as well as their combinations (Oldham, et al., 2002). Recently a window system has been developed where the core idea is to create a ventilation path by staggering layers of glass (Kang and Brocklesby, 2004). Micro-perforated absorbers may be used along the path created to reduce noise. The system is fibre-free and with smooth surfaces, which are preferred from the combined aspects of health and ventilation respectively. Moreover, the system is transparent, so it has less effect on daylight and there is far more freedom when positioning the system within a façade. Furthermore, it considers the need for occupant comfort by means of airflow, rather than just the minimum air exchange.

A number of studies have shown that building components can be combined with benefits of acoustics and ventilation, as well as daylight provision (Field and Fricke, 1998; Jakob and Möser, 2003; Oldham, et al., 2002). It is clear to say that building components have a great potential to help in environmental sustainability development as well as acoustic sustainability. This was mentioned in the context that various aspects should work together to achieve environmental acoustic sustainability as a net framework.

Acoustic materials

Various acoustic materials including absorbers, insulators, and diffusers, may have similar acoustic performances but very different characteristics in terms of sustainability. Recently a lifecycle analysis was proposed for various materials of environmental noise barriers, and significant differences have been found (Joynt, 2005). Furthermore, acoustic materials are also related to energy use and building sustainability. In terms of energy use in residential areas, two important factors can determine the amount of energy use in residential buildings, namely building structures and the type of energy (EIA 2005). The building size is the most important factor in determining the amount and the type of energy used in the building. Consequently, residential buildings have higher proportions of energy use than other functional buildings. For overall environmentally acoustic sustainability, a building cannot exist alone, it should always be considered with various aspects such as buildings, people and resources. However, with the increases in noise pollution, environmental acoustics become an essential consideration of environmental sustainability (Cowell, 2005; Peyton, 2005).

2.6 SUSTAINABLE WIND POWER

2.6.1 Wind Turbines

For the purpose of generating renewable energy, various new techniques have been developed but on the other hand, some of the techniques may also bring noise problems and thus affect the overall sustainability, a typical example being wind farms. Wind power is an important source of renewable energy, which has many advantages for environmental sustainability (Pawlisch, et al., 2003). Wind energy is a fast growing energy source in the world which offers many advantages. It is fuelled by the wind, namely a clean fuel source; the land can combine usage with agricultural production; no air pollution or water pollution and it also limits greenhouse gas emissions. With the wind speed over 5m/s, it can operate for electricity generation (Barton, 1995). Studies in domestic renewable energy applications suggest that wind energy has considerable potential for domestic use but they are less common than the use of solar panels (DC LG, 2007). Melet (1999) proposed to building wind farms in urban areas.

From a negative viewpoint, wind turbines may generate significant noise pollution, especially low frequency noise. The noises emitted by wind turbines are mechanical and aerodynamic and include the swishing sound of the blades' rotation and the whirring sound from the gearbox and generator. And, while wind speed increases can make generators work efficiently, this also has direct noise effects (Barton, 1995). Furthermore, the wind is an intermittent source which may have uncertain running performance, noise effects and visual impact. Comparing land usage of wind farms with other energy sources, the latter may be more efficient than wind farms; and although wind power plants have relatively little environmental impact compared to other conventional power plants, further attention still needs to be paid to its noise effects.

Effects of Wind Turbines

In an attempt to know the effects of wind farms on surrounding areas, the review focuses on a number of studies which try to discover its existing effects. In the early 1990s, essential surveys in the Netherlands, Germany and Denmark, in residential areas (Wolsink et al., 1993; The Noise Association, 2006) were carried out in which sizable numbers of residents reported experience of noise from nearby wind farms, when sound pressure levels were around 35 dB which made it an official concern that sound levels of around 35dB might be a serious problem for certain people. Studies have pointed out that about 6.4% of people have felt annoyance in Germany and The

Netherlands; and in Denmark about 7% of people reported being rather annoyed and 4% reported significant annoyance.

The British Wind Energy Association (1994) carried out a study in a residential area where 250 local residents lived near 12 wind turbines at Kirkby Moor, Yorkshire; it was reported that about 83% responded with insignificant concern towards wind farm noise.

MORI Social Research Institute (2003) surveyed a number of wind farm's surrounding areas, within 20 kilometres of each Scottish wind farm. The survey used a general approach, which avoided asking people directly if they were disturbed by wind farm noise. A study was carried out of the advantages and disadvantages of wind farms and results showed that without being asked specifically about wind farms, respondents expressed rather insignificant annoyance, about 0.5% less than when wind farms were mentioned. On the other hand, when asked specifically about the noise from wind farms, about 20% residents had a broadly positive feeling towards their existence in their area; about 7% had a negative feeling, and 1% had significant noise annoyance. Clearly, this demonstrated that most peoples had positive or negative attitudes towards wind farms which do have noise effects on their living experiences.

A study of human perception and wind turbine noise was carried out and showed that when the noise and annoyance levels increased, this might affect personality and attitudes (Pedersen and Kerstin, 2005). Studies also pointed out noticeable differences between people who have city living experience and those with no city living experience. Comparisons between noise annoyance and shadow annoyance from wind turbines show the correlation to be $p<0.001$. On the other hand, effects relative to the noise effects have been found to arise from noise sensitivity and noise attitudes, especially in terms of the wind turbine's impact on the landscape. In terms of visual effect, comparison between noise annoyance and visual impact results show that audio perception has interference with visual impact and also that rotor blades' constant movement has visual effects. It can be seen that acoustic and visual effects exist due to the operation of wind turbines.

A wind farm survey of residential areas in New Zealand (Charmaine et al., 2005), was carried out that showed high proportions of the residents accepted wind farms being built near their living area but a sizable proportion of residents responded with perceptions of noise. The study suggested proper public education should be given before building wind farms as this might be helpful in alleviating such perceptions.

A study on mitigation of noise from wind turbines (Berg, 2005) was carried out that showed insignificant noise annoyance in the daytime but significant noise annoyance at night-time; this is mainly because of lower background noises at night which make wind turbine noises become more annoying. Furthermore, the study proved that atmospheric stability can increase wind turbine noise, and the distinctive beating sound from blades also can increase noise annoyance.

The Noise Association (2006) reported that the swishing noise of wind turbines has caused most complaints. And also, when comparing equivalent levels of traffic noise and wind farm noise, wind farm noise gives rise to more complaints. It was reported that wind turbines have caused significant noise effects which should lead to the improvement of wind turbines. In terms of wind farm location, before building the wind farm, it is necessary to verify no serious noise effects will be caused by wind turbines. The report suggested that further study is still needed to identify the causes of annoyance which might arise from noises or the flickering of blades and also to deal with the potentially harmful effects.

A number of wind turbines have been developed, including: horizontal turbines, vertical turbines, free standing and roof mounted turbines. Several manufacturers and developers claimed that roof mounted wind turbines may have vibrational and noise effects. A report (Dutton and Halliday, 2005) was carried out that showed mounting wind turbines on buildings may have some technical issues which need further attention, such as: noise reductions, low frequency airborne vibration, structurally transmitted vibration, minimisation of vibration and determining prevailing ambient noise levels. Asfar et al. (2005) suggested sizeable advantages in sitting wind turbines above the building, which include savings in construction cost; saving space; ease of transfer of power from generator to consumer. It can be seen that installing wind turbines on buildings' roofs may impact on various factors such as site situation, health, safety, ducting, connection turbulence, vibration and cost which might act against environmentally sustainable development and need further attention.

Wind energy clearly has significant potential in terms of environmentally sustainable development. On the other hand, a number of effects still need further attention, such as aerodynamic noise, mechanical noise, swishing noise and flickering effects from blades. However, a number of wind farm projects are ongoing to produce renewable energy; they are intended not only to supply energy but also to decrease environmental impacts, as a main principle of environmental sustainability is to always find the balance between various aspects.

2.6.2 Existing Cases In Urban Areas

A number of existing cases show the possibilities of using wind turbines in urban areas, which can have great benefits in building environmental sustainability. Existing cases have shown that wind turbines have made the least environmental impact and have high efficacy in regeneration of wind energy. Moreover, continuous development of wind turbines attempted to improve on that high efficacy and low environmental impact by decreasing climate change effect, and producing quieter rather than large scale wind turbines. Approximately 40% of the energy used in European countries is produced by wind turbines and solar panels, which also produce renewable energy, have tremendous potential for future energy generation (Anderson, 2004).

In order to ascertain the possibility of setting up wind turbines in urban areas, the study focuses on existing cases and tries to learn from experience and assess the possibility to use wind turbines more widely in urban areas. Table 2.1 shows existing examples of wind turbines in urban areas; it can be seen that wind turbines have great potential for improving urban sustainability. The cases also show that turbines could be mounted on roofs and the generated power could supply home electricity directly which might supply from 15% to one third of electricity needs. On the other hand, existing cases also show that when the wind turbine does not work properly it might cause a number of problems such as vibration, noise and unexpected waste materials and cost. Apparently, it is very important to simulate, survey and plan before using wind turbines. Although using wind turbines in urban areas may have some disadvantages, it is a principle of sustainable development to deal properly with prudent techniques and to always find a balance between various environmental factors.

Table 2.1 Some existing wind turbines in urban areas.

Case	Location	Wind turbine	Description
Thames Valley University	London, UK	Two 2.5kW turbines roof mounted	produces around 2% of the electricity the building uses
Donnachadh's house	London, UK	One 400W turbine roof mounted	no noise; vibration has been overcome
CIS building	Manchester, UK	Nineteen 1kW turbines roof mounted	reduced one ton of carbon dioxide emission per annum
Westergate Business Centre	Brighton, UK	One 5kW freestanding turbine	electricity for lighting and power use
Roof Top Windsave	Scotland, UK	One turbine mounted on side wall	installed in wrong location
Brian Wilson's house	Glasgow, UK	One turbine roof mounted	wind power straight into the household supply
The Green Building	Temple Bar, Dublin	Three 1.5kW turbine roof mounted	vibration and cracked blades have been rectified
The largest building	Netherlands	Three 2kW turbine roof mounted	vibration at high speed
The Exhibition Place Wind Turbine	Toronto, Canada	One 750kW freestanding turbine	generated electricity for 250 homes; no ecological impact
Daito Bunka University building	Japan	Five 600W turbines roof mounted	can fully supply small lighting systems
Taku High School building	Japan	One 2.5kW turbine roof mounted	turbine survived a typhoon (wind speed 60m/s), can fully supply small lighting systems

2.6.3 Standards And Suggestions

Standards

In terms of standards of wind turbine, various standards have been established which try to restrict environmental impact. Noise measurement standard IEC 61400 -11 (1998), established the standardized conditions of emissive sound pressure level at integer wind speeds 10 m above ground level from 6 to 10 m/s. Sloth (2005) has pointed out that except for in conditions of standard IEC 61400 -11, there is no information for other wind speeds. For example, standardized values may be 1/1 octave or 1/3 octave but a real measurement situation may have various audible tones at a reasonable distance behind the turbine. Consequentially, when the conditions change it may not be suitable to use standards. Haddad and Benoit (2005) pointed out that IEC61400-11 does not provide enough data to establish all of the noise emissions of wind turbines which may have more noise effects overall in a global sound environment. They also suggested overall consideration of sound effects from wind turbines at global levels and definition of methods of measurement.

IEC 61400-14(1998) is a related standard which is based on the principle for declaring the sound pressure levels and tonality of the wind turbines. This is useful for comparison with noise limits or verification of declared or specified values in tenths of decibels: even minor flaws in the method can confirm results accurately (Søndergaard, 2005).

Suggestions

Barton (1995) suggested that wind farms should be located in a place at least 200 to 400m from the nearest dwelling, 1000m from a village, and 2000m from a town. The Noise Association (2006) recommended that daytime noise levels outside the properties nearest the wind turbines should be under 35-40dBA or 5dBA above the prevailing background noises and at night noise limits should not exceed 43dBA or 5dBA above the prevailing background. Furthermore, regulation should be applied to predicted noise levels, while incorporating a tonal component into noise level assessment should aid proper judgement.

A study on wind turbine installations (DCLG, 2007) shows the high potential to use wind turbines above a building. Approximately, 15-20% of annual domestic electricity can be generated by a 1 kilowatt wind turbine with a rotor blade diameter of 1.75 m but it depends on wind speed and conditions of location. The study showed that when using wind turbines above buildings, they should be installed approximately 3 meters above the highest part of the building's roof. And also, the height of free-standing wind turbine should be about 11 meters. In terms of the numbers of wind turbines, when installing one wind turbine above the building the height should be 15 meters or less and when installing four wind turbines it should be higher than 15 meters.

Clearly, standards and suggestions are intended to decrease environmental impacts but certain conditions might not be included. It is necessary to know the site situations and wind turbines' conditions which can help to simulate future situations.

2.7 SUMMARY

This chapter aimed to show that environmentally acoustic sustainability is an important aspect which should combine with multiple aspects in terms of environmental sustainable development. However, most of the existing studies have concentrated mainly upon acoustic aspects such as pleasantness of sound, unpleasantness of sound. Furthermore, existing research into acoustic sustainability aspects is rather limited, not only by the above mentioned focus on acoustic aspects, but also due to its treatment of environmental acoustics as a pure aspect of the acoustics environment. Furthermore, previous field surveys on acoustic quality mainly dealt with certain areas and sound effects such as airports' surrounding areas, train station areas, industrial areas, and so on. Apparently, further attention still needs to be paid to environmental acoustic sustainability.

In an attempt to approach environmental acoustic sustainability, this chapter introduced positive concepts of acoustics from the viewpoint of a sustainable approach: aiming to lead acoustics into complete environmental sustainability by examining fundamental and essential aspects. Review focuses on three main aspects, namely: people, buildings and resources, which are fundamental and essential aspects in the living environment. In terms of environmentally acoustic sustainability, it is important to carry out a systematic study of various aspects to form a net framework which contains fundamental and essential aspects. To further define such a net framework, it can be described as a cyclical environment which always contains various aspects in the circuit, due to the fact that no aspect can work alone. For this purpose, the research first focuses on the perceptions of urban residents rather than studying the environmental acoustics of living areas. It then conducts a study of buildings' whole life cycle impact on environment and acoustic performances as well. Finally, it focuses on the possibility of generating renewable wind power in existing residential areas. Such a study will benefit urban sustainability development for further understanding of environmental acoustic sustainability.

In terms of people's perceptions, acoustic sustainability is not only relevant to the sense of hearing; it covers multidimensional concerns of human senses and environmental impact. In order to know what impacts a building's acoustics might have on environmental sustainability, the study reviewed buildings' life cycle assessment methods. Overall, among methods of buildings' life cycle assessment Envest software has the appropriate advantage of simulating extensive impact in the UK. Therefore, Envest has been selected and is mainly used for measurement of complex factors of the environment which is necessary for the assessment of buildings' sustainability in the UK. In terms of sound distributions, the study reviewed noise mapping methods and the noise mapping software; CADNA, is mainly used to simulate sound trends of urban areas in both current situations and future situations. In an attempt to know the possibilities of introducing wind turbines into urban areas, the study reviewed numbers of existing cases and surveys: trying to further understand the potential benefits and decrease impact.

Overall, the review suggests that people's sound perceptions of their living environment depend on environmental factors and the user's experiences. Thereby, it is essential to consider interactions between people's perception of sounds and environmental sustainability. From the viewpoint of complete urban sustainability, it is necessary to put the acoustics into a specific scheme, as a part of a sustainable urban plan, considering environmental impacts and social aspects. In terms of acoustic sustainability in urban residential areas, it is more appropriate to carry out on-site surveys, given the complexity of simulating multiple sound sources, and the interaction between environmental impact and relevant factors. Therefore the focus of this research has been limited to three typical aspects, namely: people, buildings and resources. This is because creation of a sustainable living environment should always be relevant to fundamental and essential aspects. Of more relevance to urban sustainability, are the overall characteristics of a residential area, which comprise various aspects such as people's perceptions, building elements and resources. It is evident that environmental acoustic sustainability should create physical and psychological comfort at a high level. As mentioned above, environmental acoustic problems can be remedied but it might expensive or inefficient to improve; consequentially, this will significantly affect sustainable development.

Chapter 3

Methodology: an overview

3.1 INTRODUCTION

As previously mentioned in the review in Chapter 1 and Chapter 2, the context of this research is wide-ranging and its aims are broad. It does not intend to be investigative only in the acoustic environment, but also regarding environmental sustainability. The basis for the research is an attempt to find a balance of environmental acoustic sustainability through an understanding of three aspects: people, buildings and resources. Current methods of environmental noise evaluation tend to focus on acoustic aspects which may not be complete in terms of acoustic sustainability development. A number of studies have focussed on acoustic aspects and attempted to approach acceptable levels acoustic comfort (WHO, 1999). From an urban environmental sustainability point of view, the literature has demonstrated that acoustic sustainability is an important aspect of urban environment sustainability. Also, the literature indicates that methods used in the current situations tend not to be consistent or complete in terms of environmental acoustic sustainability. Moreover, they mainly focus on acoustic targets, rather than overall planning/design achievements.

Consequently, this research attempts to illustrate environmental acoustic sustainability from the following: essential aspects of people's perceptions; the environmental impact of buildings and renewable wind power. Surveys and analyses of existing situations, and simulations are examined in order to of further possibilities. The main reason for choosing these three aspects is to develop an overall framework to evaluate environmental sustainability. These evaluations can be set as a base line which examines each aspect from an objective viewpoint as well as a subjective viewpoint. They can also provide an overview of realistic environmental acoustic sustainability, as each aspect has its own fundamentality. Figure 3.1 illustrates the relevant factors of urban acoustic sustainability which represent the three main aspects of the research and the key components to achieving a sustainable approach to the urban acoustic environment. It can be seen that the subjects of the overall environment are people, buildings and resources.

Figure 3.1 Key factors in the urban acoustic environment.

The research includes objective examinations and subjective surveys in considering how various aspects could interact in a completely sustainable acoustic approach. The objective analysis methods have been widely used to examine various aspects as a fundamental examination method of overall sustainability development. Furthermore, the objective method is a significant tool which can evaluate the environmental impacts from a number of environmental factors of living quality and impact quantities. This subjective examination inquires into people's perceptions of their living environment and attempts to assess current situations, as well as investigating how acoustic sustainability development can be achieved.

However, overall methods in this research can be described as an examination of essential aspects which are based on environmental sustainable development. In order to find a balance of environmental acoustics sustainability, the research defines the quality of sound. It also investigates a number of relevant experiences and the various environmental impacts, rather than focusing solely on levels of acoustics comfort. This approach can provide a more insightful perspective as it analyses a realistic contexts of environmental acoustic sustainability. In these contexts components should work cooperatively, and relate to primary aspects in terms of environmental sustainability development. From an urban planning point of view, a more successful project can be created as it differs from the traditional practical approach. This approach tends only to listen to communities and use their responses as the principle for development (Bryman, 2001; Kumar, 2002). Figure 3.2 illustrates an overview of the aims of the research and the considered methodology to approaching acoustic sustainability in urban areas.

3.2 PEOPLE'S PERCEPTIONS OF THEIR LIVING ENVIRONMENT

In order to know people's actual perceptions of their living environment in urban areas any survey should focus on people's perceptions: the methods available for use are both subjective and objective methods, namely the questionnaire survey and the measurement of environmental sound. The survey of people's perceptions utilises questionnaire surveys in the cities of low density population in the UK and cities of high density population in Taiwan. The respondents were randomly selected from the urban residential areas and of varying ages, education levels, occupations and cultural backgrounds. The questionnaires focused on people's living experiences, perceptions, preferences and several social factors, and surveyed various urban areas of the two countries. This was an attempt to understand such different cultural factors as living experiences, environmental perceptions, sound preferences and several of the social factors which may have effects on people's perceptions.

The questionnaires were organised into three stages; combined with oral interview on six selected sites in residential areas, three sites in Sheffield, UK and three sites in Taipei, Taiwan; with survey but without oral interview in Sheffield and Taipei, with simplified questionnaire and on-line survey in urban areas of the UK and Taiwan. The first stage attempted to identify any correlations between the differences of cultural backgrounds of the residents, on how respondents perceived their living environment, including essential social factors, sound preferences and evaluative quantities of environmental pollution. Therefore for this stage of the survey the cultural background was an important aspect, and the respondents were asked to rank and evaluate each of the environmental factors, in order of their perceptions of sound in their living environment. The second part was planned to reconfirm the results carried out in first stage, the uniformity questionnaire was used again which attempted to identify the possible correlations between the differences of cultural backgrounds of the residents; for this stage of survey the cultural backgrounds of respondents showed significant differences. The final stage attempted to identify further correlations between the different cultural backgrounds of residents, by means of a simplified questionnaire with identically themed questions and increased numbers of samples. These attempted to discover how respondents perceived their living environment overall. The questionnaire mainly focuses on ranking/evaluating numbers of the essential factors, in order of their perceptions of sound in their living environment. Hence, for this stage of survey the social factors were an important component.

The statistic software utilised was the SPSS version 13, which was applied on an ordinarily configured Windows operating PC. The choice of software was based on the analysis of statistic data which produced overall results of such multi-subjectivity factors as bivariate correlations, means, independent-samples test and paired-samples test.

For the surveyed areas noise maps were produced. The sound evaluation software utilised the CadnaA version 3.2. The reason for utilising noise mapping software was an attempt to assess objective sound propagations of survey areas and to compare these with survey results. On the other hand, the noise mapping can provide assessments of sound effects and directionality which not only produce important information but also give some idea which areas might have further possibilities of combining with other aspects towards achieving a sustainable balance.

All the details of the methods used in the cultural study are defined in Chapter 4 which attempts to clarify and examine the overall acoustics effects of urban sustainable environmental development. The main reason to overview from this aspect is because the urban areas are of major importance in terms of overall environmentally sustainable development; but attention was also focused on a number of noticeable visual effects. In terms of environmentally sustainable acoustics, there may not be noticeable visual effects in the short term. Environmentally sustainable development is, however, a long term management issue which attempts to find a better balance through long term development. Furthermore, a residential area can be described as a sensitive area which contains various social effects which cannot be evaluated on the basis of just a few objective or subjective factors. More importantly, it should address existing problems. This chapter achieves this through a series of comparative studies, regarding people's perceptions of their living environment in low density cities and high density cities.

3.3 ENVIRONMENTAL IMPACTS OF BUILDINGS

Promoting environmental acoustic sustainability requires a shift from acoustic aspects towards various environmental factors. It seeks to develop a framework by improving environmental acoustic quality and decrease environmental impacts. It also aims to discontinue negative environmental impacts by understanding a building's performance throughout its whole life cycle. In terms of environmental acoustic sustainability, the environmental impacts of residential buildings can be correlated with the environmental acoustics sustainability. This is due to the fact that various building elements can also have effects on acoustic performances as well as overall environmental sustainability. In order to analyse the environmental impacts of a building's life cycle, the various, possible methods were investigated and discussed in Chapter 2.

The software utilised was the Envest version 2 which is web based. It allows users to store their simulated data on a website. Envest is based on estimation utilising default environmental and financial data of the whole life performance of the building. Furthermore, it is suitable for the fundamental design stage which can assess environmental impacts of a building's life cycle and also can make comparisons between different designs. The choice of the software was made on the basis of availability and reliability in the UK's current environment, as subsequent use of the alternative packages including Ecotect, ATHENA and LISA has revealed that Envest provides an availability package which is suitable for use in buildings in the UK. It is comparable with other available products and capable of producing established results. All the details of the methods used in this work are provided in Chapter 5. In brief, the method was intended to illustrate and examine the impacts of the environment during the building's lifetime. It also serves as a tool for evaluating these impacts and for describing the differences in terms of environmental sustainability.

Five common types of residential buildings have been considered and the effects of various building elements, heights and acoustic materials have been examined.

The main reason for attempting a study of buildings' characteristics is because buildings are the most significant elements in living areas: they cannot be dispensed with, and have the potential for improvement. A similar principle is applied to acoustic sustainability which also has the potential to be dealt with in a positive manner.

3.4 RENEWABLE WIND POWER

Due to climate change and increases in environmental pollution, the dilemma of how to generate renewable resources is increasingly important. A wide range of renewable energy technologies have been developed, such as solar power, wind power, hydroelectricity, and so on. Wind power is a renewable energy source which effectively uses natural resources and is naturally replenished. As previously mentioned in Chapter 2, a number of benefits/advantages can be derived from renewable wind power but there are disadvantages as well. Furthermore, wind power is sometimes criticized for being unreliable, unsightly or having undesirable effects; its sound effect is a typical example. In terms of environmental acoustics sustainability, there might be some apparent faults but they can be treated in a positive way in order to find a balance.

In an attempt to discover the sound effects on surrounding areas of the wind farm, both current and hypothetic cases were examined, and the possibility of utilising noise maps was investigated. The software utilised was once again the CadnaA version 3.2. The choice of software was based on analysis of a macro-scale area and also it can be used on existing cases and hypothetical cases.

In terms of a current wind farm survey, the research measures a wind farm which is located near Sheffield. The measuring of an existing wind farm was for the examination of both the wind farm and its surrounding areas; furthermore, it attempts to define the further potential which may determine the development of prospective wind farms.

All the details of the methods used in this work are defined in Chapter 6. In summary, the examination attempted to illustrate and assess the feasibility of applied wind turbines in urban residential areas, and to measure the possible sound effects in surrounding areas.

The main reason for examining the possibility of using wind turbines in urban residential areas can be divided into two categories. Firstly, the sound levels of urban areas are almost always higher than those in rural areas, which is to be expected, while at the same time wind turbines in urban areas might have less sound effects than those in rural areas. Moreover, one of the urban characteristics is the high resource consumption which always exists in urban areas. Hence, by examining the possibility of using wind turbines in urban areas, the acoustic effects on surrounding areas can be identified. Furthermore, this examination combines acoustic sustainability and environmental sustainability consideration. It can thus evaluate the possibility of generated wind power to help decrease climate change and to reduce its various impacts on the environment. All this is part of a long term development of environmental sustainability. This was achieved through the evaluation and simulation of realistic demands, regarding the effective use of urban land as well as renewable energy technology.

In addition, the noise maps with the wind turbine, and varying heights of the wind turbine, arrangements of buildings and positions of landforms were modelled. This allowed both for comparison of varying arrangements and evaluation of sustainable arrangements. It also enabled an assessment of the extent to which it would be possible to build up environmental sustainability.

3.5 INTEGRATED EXAMINATIONS OF ENVIRONMENTAL ACOUSTIC SUSTAINABILITY

The last section of methodology focused on the potential for urban acoustic sustainability, the mixture of three aspects identified as fundamental to the cycle of acoustic sustainability development.

Firstly, the study was expanded to review the sound influences of survey areas: these are mainly focused on survey results on acoustic aspects. Thus, through a brief review of results from Chapter 4, with further examination of sound distributions in people's living areas the study attempted to compare the subjective perceptions and objective simulations. Further comparison of people's sound perceptions and the objective factors of their current environment aimed to discover people's perceptions of their living environment. A number of building facades in survey areas have been simulated which show different sound trends in each area. The objective is to compare results with those in the literature. This study's findings suggest that noise experiences may have a considerable influence on people's perception of their living environment.

However, it was discovered that the development of urban acoustic sustainability should be considered on the basis of certain fundamental aspects and also it is important to consider people's perceptions.

Secondly, the study examines the effect of varying building shapes on both environmental impacts and sound distributions. The link between these two examinations is that aspect tributes to the sustainable development of the acoustic environment. But they cannot be simplified in terms of a few factors; rather, they should always be considered as a long term management and development issue. However, it was discovered that any consideration of the sustainable development of environmental acoustics should combine a series of methods which may have different effects in terms of environmental sustainability.

Finally, the research focuses on the possibility of using wind turbines in existing residential areas; it examines the sound distributions of existing sites, with varying types of buildings and two residential areas were modelled. This allowed both for comparison of existing situations and simulation of further possibilities and enabled an assessment of the potentially extendable possibility to build up urban environmental sustainability in residential areas.

3.6 OVERVIEW OF THE METHODOLOGY

A brief summary of the methodologies of this research is presented below. The purpose of this research was to understand better the potential for building a sustainable urban acoustic environment in residential areas on the basis of three aspects. The research focused on three aspects; people's perception; buildings' life cycle assessment and evaluation of acoustic performances; examination of acoustic sustainability of wind turbines.

The first aspect attempted to identify any correlations between different cultural backgrounds of the residents, on how respondents perceived their living environment, including essential social factors, sounds preferences and evaluation of pollution. Cultural background was considered an important factor when the respondents were asked to rank each of the environmental factors in order of their perceptions of sound in their living environment.

The second aspect was planned to examine environmental impacts of buildings as well as acoustic performances of buildings and includes five building types, various building elements, number of storeys, acoustic materials and acoustic performances of rooms. Hence, for the building's life cycle played an important part in terms of environmental sustainability, and the building's elements were examined in terms of the impacts on the environment as well as acoustics sustainability. This can be described as a fundamental examination of environmental sustainability which demonstrated environmental sustainability should be holistic.

The final aspect attempted to identify any potential for generating renewable wind power in urban areas. This can be considered as a functional correlation between resource use and supply. This is one of the important relationships in terms of environmental sustainability; neither can be discounted, but it might possible to find a better balance. A number of renewable energy technologies have been developed which attempt to approach environmental sustainability but in terms of acoustic sustainability, further efforts still need to be made. Thus, for this aspect the acoustic effect was a significant aspect in terms of regenerative wind energy, and the existing sites were examined in order to assess the sound impacts on surrounding areas of wind turbines. The research attempts to measure the acoustic effects as well as environmental sustainability development.

In summary, the methodologies utilised in this research span a range of aspects of environmental sustainability. All of them were based on developing a systematic framework for a sustainable approach to acoustic sustainability. This is a reconsideration of environmental acoustics which form the interrelationship between acoustic and environmental sustainability. Furthermore, it is a useful concept for utilising these methodologies which attempt to lead acoustic sustainability into environmental sustainability. The methodology used can be interpreted as a net framework of environmental acoustics sustainability, while considering the relevant acoustics and acoustics sustainability. A diagram is presented in Figure 3.2, which illustrates the serial connection of the methods and aims.

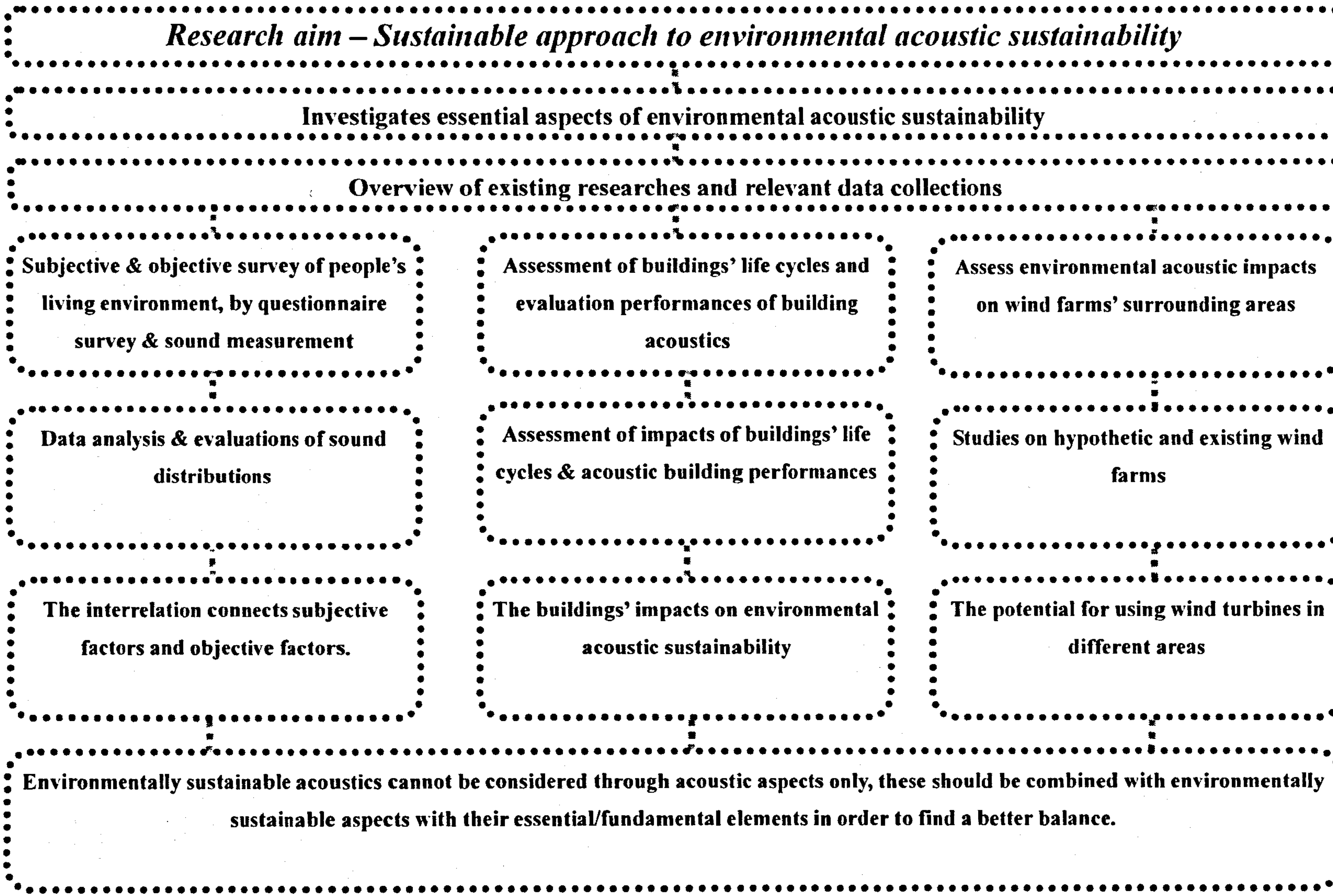


Figure3.2 An overview of aims and methods of the research

Chapter 4

Perception of urban sound environment

As previously reviewed in Chapter 2, a number of studies have demonstrated that cultural differences and sound experiences all have considerable effects on the perception of urban sound environments. The high population density of urban areas and residential areas can seriously affect people's sound perception and their quality of life. Furthermore, urban living has become increasingly popular, which might affect urban sustainable development. Consequently, sound quality in our living environment is becoming ever more important, whilst the noise level is continuously increasing (Kuwano, 1999; Kang, 2006). A survey comparing the levels of noise annoyance of residential areas in small towns and large scale urban areas showed a tendency of less annoyance in urban areas (Guski, 1997). In regard to sound quality, it has been pointed out that three factors should be considered: compatibility of the sounds, pleasantness of the sounds as well as identifiability of sounds (Guski, 1997). The compatibility of the sound can be considered a functional factor of the sound. In this sense, the pleasantness of the sound is based on an overall instantaneous impression which can be caused by various sound sources. These include individual preference and experience and the identification of the sound sources which allow people to know what is happening around them.

Moreover, the differences in urban texture, including building density, dimensions and boundaries of the areas can lead to different urban sound fields. These are important elements when assessing/considering the sound environment. Environmental urban acoustics have been studied for a number of years but currently there are no such methods for examining environmentally sustainable acoustics in a direct way. The context of environmentally sustainable acoustics is a movement in a complete framework which needs to examine various essential factors and, furthermore, to evaluate different impacts; it then requires an appropriate judgment in order to approach environmentally sustainable development.

Therefore people's perception is an important factor which cannot be ignored and should always be treated in a positive way. From the point of view of people's perception, this chapter examines this perceptive effect through a comparative study of cultural differences in urban residential areas of two countries. It also investigates existing social factors, the wider environmental implications and their inherent factors.

This chapter starts from a discussion of survey results of the first, second and third stages where the focus is on various social factors in urban living environments. Finally, a comparative analysis, going through the three stages, examined the differences of social factors between the two countries. The purpose in investigating these social factors was to achieve a better understanding of people's perceptions of their current living environments and try to show significant acoustic differences in living environments as well as the possibility of creating prospective sound in terms of environmentally sustainable development.

The general aim of this chapter is to examine how people perceive sound environment as well as the current acoustic situations in their living areas, and to identify the essential components of comfortable and pleasant sounds in terms of developing environmentally sustainable acoustics.

4.1 OVERALL METHODOLOGY

In an attempt to determine people's perceptions of their living areas, three stages of questionnaire surveys were applied in the urban residential areas with a number of representative questions concerning cultural background, with various social factors, pollution ranking, personal perceptions and personal sounds preferences. The first stage of the field survey examines six selected sites through questionnaires and interviews. In terms of six residential areas, they all present typical styles of urban living in each country, three of them in Sheffield, UK, and the other located in Taipei, Taiwan. The second stage survey was extended to cover further urban areas in Sheffield and Taipei and tried to identify the results from the first stage and to gain further knowledge of existing situations. The questionnaire used was same as first stage survey but with no interviews in this stage. In the third stage, the survey was extended to other urban areas in the two countries with an identically structured questionnaire which attempted to reconfirm those results from the first and second stages and further to establish the main effects within two different cultures. The questionnaires were used in the first and second stages were considered rather long. Therefore in the third stage the questionnaire was simplified with an increase in the sample numbers. During the three stages of questionnaires survey, there were around 80, 200 and 300 respondents, respectively, in each country and all respondents are selected at random.

4.1.1 Six Selected Sites

The six selected sites were chosen as typical residential areas in Sheffield and Taipei in an attempt to determine the differences between cities of low and high density populations. The population ratio between Sheffield and Taiwan is about 1:5 which is rather different (Sheffield City Council, 2007; Taipei City Government, 2007) Furthermore, the observations of current situations include: density of buildings, residential styles, street elements, street width, main vehicles, the function of surrounding areas, leisure facilities around sites, landforms, and noise protection around sites. These observations investigate the characteristics of each site and also attempt to discover whether these factors might have effects. However, the main concern with the selected sites is to find out the differences in: cultures, urban densities, urban textures and living styles, which might have different sound effects in terms of sound perception.

Selected sites in Sheffield, UK

Sheffield is in South Yorkshire and comprises 0.52 million (Sheffield City Council, 2007) population living in its urban area. Sheffield consists of seven hills, with various slopes in different areas. Of the three selected survey sites in Sheffield, as illustrated in Table 4.1, site 1 and site 2 were located in representative residential areas: Crookes and Walkley, and site 3 is in the city centre. Typical residential buildings include detached houses, semi-detached houses, terraced houses and apartment buildings in sites 1 and 2. Whilst newly developed apartment buildings and traditional commercial buildings are typical of site 3. Three maps of the selected sites in Sheffield are listed in Table.4.1 as well as the data related to each site.

Table 4.1 Three field survey sites in Sheffield

		Site plan	General information
Survey sites in Sheffield	Site 1		• Main survey street: Springvale Road • Detached, semi-detached, terraced houses and apartment buildings • Site slope around 1/12 • Traffic count: 57/hr(daytime)
	Site 2		• Main survey street: Highton Street • Detached, semi-detached, terraced houses and apartment buildings • Site slope around 1/7 • Traffic count: 54/hr
	Site 3		• Main survey street: Cavendish Street • Apartment buildings mixed with traditional terraced houses • Site slope around 1/20 • Traffic count: 84/hr

Selected survey sites in Taipei, Taiwan

Taipei is the capital city of Taiwan, comprising 2.63 million in population in 271.80km^2; it is the most highly populated city in Taiwan (Taipei City Government, 2007).

Table 4.2 Three survey sites in Taipei

		Site plan	General information
Survey sites in Taipei	Site 4		• Main survey street: JianGuo S Road • Apartment buildings mixed with some retail shops on ground floor. • Flat ground • Traffic count: 8837/hr
	Site 5		• Main survey street: GuoXing Road • Apartment buildings mixed with some retail shops on ground floor. • Each apartment contained a balcony, except apartments on ground floor. • Flat ground • Traffic count: 3861/hr
	Site 6		• Main survey street: ZhangXing E Road • Apartment building mixed with some retail shops on ground floor. • Each apartment contained a balcony, except apartments on ground floor. • Flat ground • Traffic count: 7335/hr

In terms of landforms, Taipei city is a basin shape with a number of mountains surrounding the urban area; and it is located in north Taiwan. There are twelve districts in Taipei, and all of the field survey sites are located in different districts. In general, the most typical residential building in Taipei is the apartment building. The three selected sites were located in Hsin-yi district, Chung-cheng district and Ta-an district. In terms of traffic conditions, in all of the sites there are major roads around the area with busy viaducts nearby.

The field work of the sites was conducted and observation of site conditions was carried out and the data collected. It can be seen that there are different living styles in each city as well as different sound distributions. There is a range of noises in urban areas which are mainly from vehicles and those can be caused by significantly different noises produced by various vehicles. Comparison between the vehicle use in Sheffield and Taipei shows that the main vehicles are cars and motorcycles, respectively. According to the observation survey, it was noted that when cars go uphill they produce more engine noise, which might cause significant noise annoyance to nearby residential buildings. Also, motorcycles can cause significant noise annoyance, when running, especially as, being rather smaller than cars, they can easily run through small lanes that might be close to residential buildings and can thus cause further annoyance. These differences between the two cities can be described as the differences of the regions as well as different social aspects which might have effects in terms of environmentally sustainable acoustics.

4.1.2 Questionnaire Design

In an attempt to find out the existing situations of urban living areas, identical and systematic questionnaires were developed and used in English or Chinese in two survey countries. The questionnaires used in the three stages focussed on people's perceptions of their living environment and the questionnaire of each stage is provided in the appendix A1.-A4. They were with a number of structured questions, including demographic data, evaluation and preference of various sound/noise sources, and perception of general living environment. In general, the questionnaire surveys were divided into two parts, namely detailed survey which was used in the first and second stages, whilst the third stage was a simplified questionnaire with identical questions. In terms of detailed survey, the questionnaire was designed to comprehend people's satisfaction with their living environment, including how they perceived environmental pollution, the quality of the ambient sound and identification of preferred sounds. In order to comprehend the cultural differences between high or low densely populated cities, a series of statistical analyses were made between the two countries. Also, questionnaire results were compared using objective measurement of sound distributions.

A five level linear scale has been used generally in the questionnaires surveys to evaluate the comfortable levels, significant levels and preferable sounds. For example, on the question regarding current living environment, five scales were supplied: 1, very good; 2, good; 3, average acceptable; 4, bad; and 5, very bad; while the questions concerning comfort levels of sound environment in living areas and at home were asked with the five linear scale consisting of: 1, very comfortable; 2, comfortable; 3, neither comfortable nor uncomfortable; 4, uncomfortable; and 5, very uncomfortable. It has also been used in ranking the most annoying noise sources when staying at home: 1, not very annoying; 2, occasionally; 3, medium; 4, annoying; 5, very annoying.

The structure of questionnaires

Several general questions have been asked regarding the variety of occupation groups, education level, gender, age group, personal income and family income. A series of questions focused on living experiences, including: ownership, numbers of people living in the same house, how many rooms in the house, local inhabitants, how many years respondents had been living in the survey area and in their current house. Then the respondents were asked to evaluate the main concerns arising from eleven factors, when choosing a living environment.

Further questions focused on people's perceptions of living quality, such as sound quality in their living area and home, personal health conditions, the effects of environmental pollution on their health conditions and ranking of a number of environmental pollution factors. Other questions were related to noise protection around living areas and in the house itself, such as any noise barriers or insulation in or outside the house or any insulation currently in the house, and any requirement for additional noise insulation in the house. Other questions regarding noise effects at different times have been asked, such as time spent at home, main activities when staying at home, sleep quality, frequency of use sleeping pills, comfortable levels of natural ventilation at home and frequency of use of an air conditioner, ventilator, heater or open windows. Beyond those questions described above, some of the personally preferred sounds around living areas and when staying at home have been investigated. In the final section of the questionnaire respondents were asked to evaluate noise sources at different annoyance levels, namely: significant levels of source effects, annoyance levels and sleep disturbance levels.

Questionnaire survey and on-site interview were used in stage one, which tried to comprehend people's reactions to their living environment via answered questionnaire and observation. In stage two, a questionnaire was used in Taipei city and Sheffield city in randomly selected areas, which attempted to reconfirm the results of the first stage. The respondents were selected at random in Taipei city and Sheffield city.

A further, simplified questionnaire was used for the survey undertaken in stage 3, based on questionnaires used in stages one and two: with the same structure but more concise questions. In this stage, the study attempts to increase the amount of data through both paper samples and on-line responses. The goal was to further understand people's perceptions via increased numbers of samples and the respondents were selected at random in urban areas of both countries. In the first part of the simplified questionnaire, a series of questions have been asked, on occupation group, education level, gender and age group. Following questions asked respondents to select the three most important factors when choosing a living environment. Typical questions relating to area situations were asked, on topics such as road types, distance of the nearest opening in the house to the front road, building types, and what kind of road noise would be heard when respondents stayed at home.

Living experiences might have effects on choice of living environment. The questions covered a number of areas, such as: how long respondents had been living in the same house and area; what respondents thought about their living environment; how comfortable sound levels were in the living area and at home. Different noises around respondents' homes might have effects when they stay at home or might change activities at home. Therefore systematic questions were asked, such as what the most annoying noise sources are and what the main activities are when they stay at home.

There are some positive sounds which people might like to hear in their living environment, such as natural sounds: birdsong, water, insect sounds, quiet; or artificial sounds: church bells, music, traffic; questions were asked concerning personally preferred sounds in the living area and when staying at home. Final questions regarding family income and personal income have been asked and these try to comprehend the difference between personal perception and income.

Overall, the urban sound environment and quality might be significantly influenced by a number of factors, including objective factors such as building types, urban textures, building elements and sound sources, as well as subjective factors such as social and economic aspects. The survey considered objective and subjective measurements of sound pressure levels (SPL), questionnaire surveys and noise mapping assessments, mainly in an attempt to understand the existing situations.

4.1.3 Noise Distribution Of Six Surveyed Sites

In attempts to identify the sound trends of six selected sites, the measurement focused on sound pressure levels and also, the noise maps of sites are considered which try to survey and simulate current situations, as well as to compare results from measurement and questionnaires.

As previously mentioned in Chapter 2, the Cadna/A Version 3.2 is mainly applied to simulate the sound distributions in the context of this thesis. It can be used for prediction and assessment of environmental noise in different functional areas, such as industrial areas, leisure areas, roads and railways, airports, and so on. The software enables prediction and pre-management of environmental acoustic effects and the results can be shown in twelve different colours with different sound distributions. Moreover, the sound simulations attempt to show the sound distributions in current situations and, further, to provide comparison with results of questionnaire surveys. In order to know the sound distribution of six selected sites, this chapter describes the results gained from use of the noise mapping software, Cadna/A in modelling. A series of simulations were made using noise mapping software, and the main calculating parameters measured results containing traffic counts, sound distributions, the storeys of buildings and so on; and the reflection order was set as 1 and 3 respectively.

For selected receiver points, SPL measurements were made, to identify the SPL, and also to validate the noise maps.

4.1.4 Data Analyses

Social factors

In terms of analyses of survey data, the software, SPSS (Statistical Package for the Social Sciences) has been used to further comprehend results in the three stages. SPSS is statistical software which can be widely used to run statistical analyses in social science and related data. It can be applied to multiple research uses which are relevant to such social aspects as comparisons between complex factors, mean values, correlations between factors, significant levels and so on. The functions of SPSS include descriptive statistics, bivariate statistics, non-parametric tests, prediction of numerical outcomes and predictions for identified groups. In order to analyse each survey site, the software, SPSS is used to find the interrelationship between multiple factors from social aspects and cultural differences. A number of systematic comparisons try to find out people's perceptions of their living environment and how their life experiences affect their lifestyles.

Sound distributions

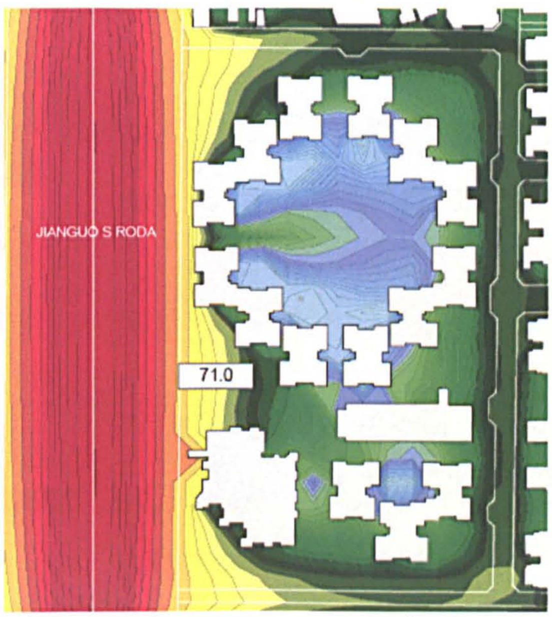
In order to know the current situations of sound distributions on the selected sites, the measured data have been applied to noise maps. Another benefit of using noise mapping to simulate these sites is that it can predict sound distributions in each site which can be helpful in terms of discovering the potential sound distributions: in other words in defining potential sound effects from noise sources.

4.2 FIRST STAGE - COMPARISON BETWEEN SELECTED URBAN RESIDENTIAL AREAS IN SHEFFIELD AND TAIPEI

4.2.1 Noise Mapping Of Six Sites

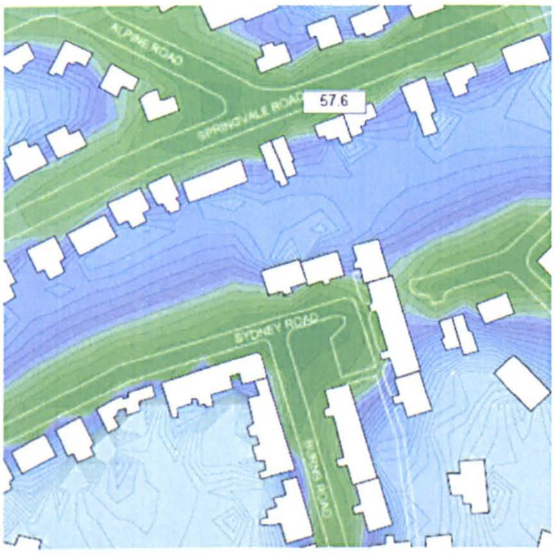
The noise maps of the six case study sites are shown in Figure 4.1. In general, it can be seen that the sound distributions of the Taipei sites were about 10dBA higher than on the sites in Sheffield. It can be noted that very densely populated urban areas have significant effects on noise levels. Comparison of sound distributions between site 1 and site 2, showed rather similar sound tendencies, this is probably because of similar population densities, building types and landforms in both sites. When compared to site 3, the highest sound distribution appeared. This can be attributed to high density of population, and a different mixture of building types, as well as traffic density. It is interesting to note that the three sites in Sheffield presented different sound tendencies, which showed that urban building type, landforms, traffic density and population density have significant effects on

Cavendish Street (site 3), Sheffield

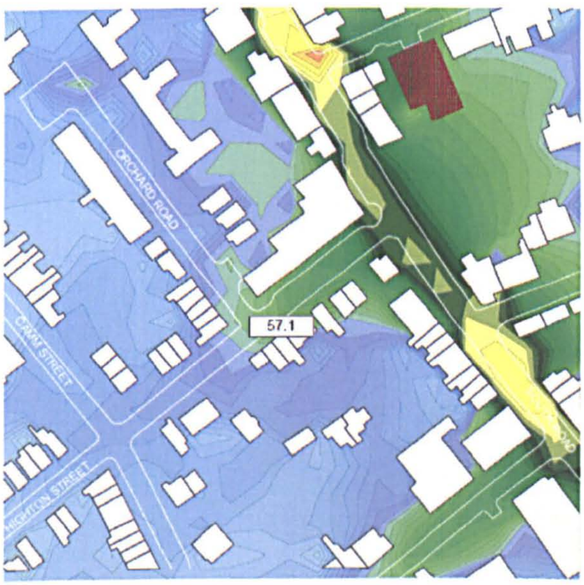


JianGuo S Road (site4), Taipei

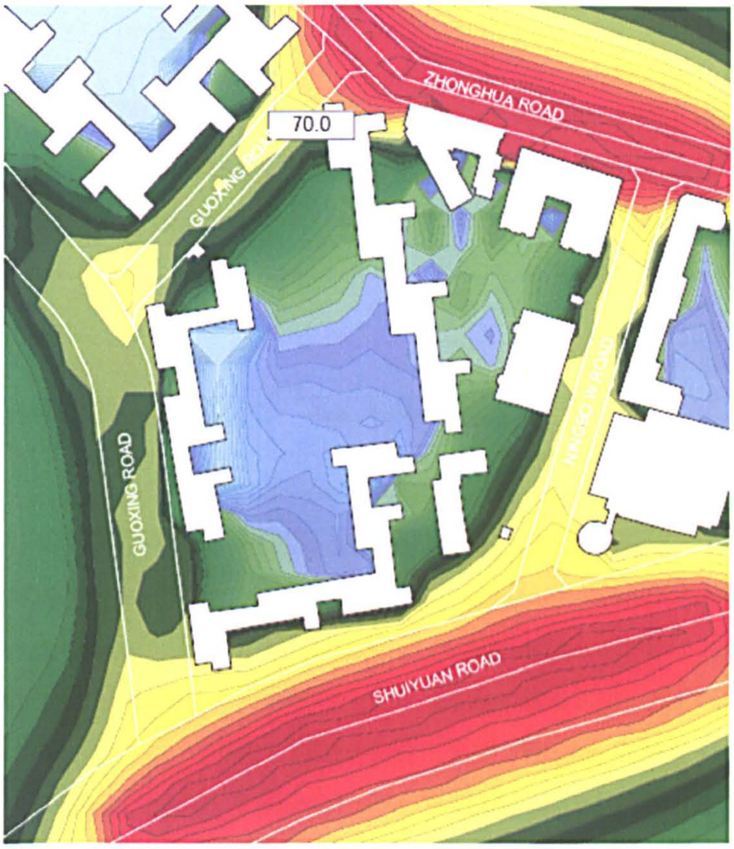
environmental acoustics. Comparison of sound distributions between site 4 and site 5, showed rather similar sound tendencies: this is probably because of similar building layouts, building types and traffic densities in both sites. When studying site 6, the highest sound distribution was shown, and it can be noted that this area is most affected by high traffic density. It is interesting to note that the three sites in Taipei presented different sound tendencies, all of which showed that traffic noise is a main source of pollution in urban areas (Yu and Kang, 2006a; Yu and Kang, 2006b).



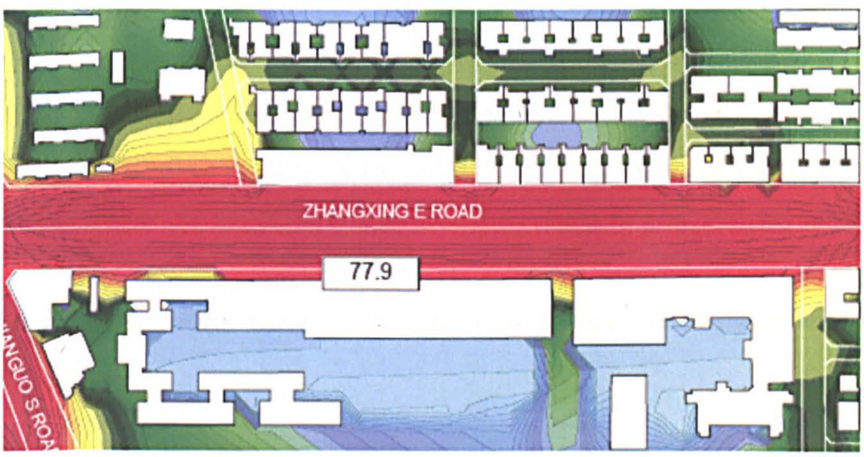
Springvale Road (site 1), Sheffield



Highton Street (site 2), Sheffield



GuoXing Road (site 5), Taipei



ZhangXing E Road (site 6), Taipei

Figure 4.1 Plan of case study sites and noise maps.

When comparing Sheffield and Taipei, as low and high density cities, there are certain factors such as different landforms, building types, traffic density and vehicle types which presented different effects on environmental acoustics.

4.2.2 Results Related To Choice Of Living Environment

Previous studies show that regional differences, including cultural heritage, construction methods, lifestyle and weather, may influence noise annoyance (Gjestland, 1998; Huang, 2004; Xing and Kang, 2006). Moreover, the economic effects of community noise have been examined, especially from the viewpoint of compensation payable on depreciation in property value that can be attributed to noise, among other physical factors (Rosen, 1974; Walters, 1975; Nelson, 1982; Hufschmidt, 1983; Turner, 1994; Hawkins, 1999; Bateman, 2001; Navrud, 2002; Wardman and Bristow 2004). Consequently, in the subjective survey, questions were asked about the importance of various factors when people choose a living environment. As mentioned above a five-level linear scale was used, from -2, do not mind, to 2, very important. The results in Sheffield and Taipei are compared in Table 4.2, through the Independent Samples Test, It can be seen that there were generally significant differences between the two cities. In terms of the order of importance of various factors, there were some similarities between the two cities, for example, safety was at the top of both lists. It is interesting to note that the factor 'quiet' was ranked as the 4th most important factor in Sheffield, and 3rd in Taipei, suggesting that in both cities, the sound environment was an important consideration compared to other factors.

Table 4.2 Importance of various factors when choosing a living environment: comparison between Sheffield and Taipei.

			Sheffield		Taipei		Sig.
				Ranking		Ranking	
Convenient	for work	Mean Std.	0.83 1.08	3	1.54 0.76	2	0.002
	Transport	Mean Std.	0.65 1.17	5	1.54 0.76	2	0.003
	school, shopping	Mean Std.	0.83 1.19	3	1.39 0.74	5	0.003
Recreational space		Mean Std.	0.61 1.16	6	1.08 0.87	7	0.002
Sociable neighbourhoods		Mean Std.	0.60 1.16	7	0.54 0.95	9	0.048
Safety		Mean Std.	1.24 0.85	1	1.66 0.65	1	0.013
Property price		Mean Std.	1.00 1.09	2	1.46 0.75	4	0.072
Quiet		Mean Std.	0.71 0.97	4	1.49 0.71	3	0.006
Views		Mean Std.	0.15 1.23	8	1.08 0.94	7	0.058
House size		Mean Std.	0.83 0.99	3	1.15 0.80	6	0.035
Interior decoration		Mean Std.	-0.06 1.02	9	1.05 1.01	8	0.389

4.2.3 Effect Of Occupation, Education, And Age When Choosing A Living Environment

Social and demographic factors are important considerations when studying the subjective evaluations, although results of previous studies varied (Rylander, 1972; Fields, 1993; Sato, 1993; Tonin, 1996; Miedema and Vos, 1999; Yang and Kang, 2005a; Yang and Kang, 2005b; Kang, 2006). In Table 4.3 the differences between various occupations, education levels and age groups are examined, through the significance test of correlations. It is seen there was generally no significant difference in terms of these social and demographic factors when choosing a living environment.

Table4.3 Effect of occupation, education, and age when choosing a living environment.

Sig. (2-tailed)		Occupation		Education		Age	
		Sheffield	Taipei	Sheffield	Taipei	Sheffield	Taipei
Convenient	for work	0.12	0.10	0.80	0.98	0.39	0.19
	for transport	0.05	0.10	0.10	0.98	0.07	0.19
	for school, shop	0.91	0.14	0.04	0.67	0.43	0.50
Recreational		0.00	0.02	0.00	0.38	0.01	0.09
Social		0.03	0.46	0.00	0.01	0.09	0.47
Safety		0.71	0.54	0.94	0.67	0.30	0.83
Property price		0.10	0.11	0.13	0.71	0.00	0.43
Quiet		0.02	0.55	0.13	0.91	0.00	0.52
Views		0.02	0.93	0.44	0.17	0.00	0.67
House size		0.24	0.95	1.00	0.06	0.00	0.17
Interior decoration		0.37	0.62	0.31	0.06	0.76	0.74

4.2.4 General Living Environment

Table 4.4 compares the perception of interviewees in Sheffield and Taipei of their general living environment, sound quality of their living area, and sound quality at home, where a five-level linear scale was again used, from 1, comfortable, to 5, very uncomfortable. It is interesting to note that the scores in Taipei were all significantly higher than those in Sheffield, by about 0.5, which corresponded to the noise level difference between the two cities, as shown in Figure 4.1. Although the interviewees in Sheffield and Taipei were all urban residents, most interviewees in Taipei lived within or close to the central areas, whereas the Sheffield interviewees were in the outer areas of the Sheffield city centre. In Table 4.4 the evaluation of general health level is also shown. Corresponding to the evaluation of their living environment and sound quality, Taipei residents also found their state of health less satisfactory compared to those in Sheffield.

Table 4.4 Evaluations of living environment and sound quality, as well as health status.

		Sheffield	Taipei	Sig.
General living environment	Mean	1.81	2.43	0.000
	Std.	0.53	0.90	
Sound quality of living area	Mean	2.16	2.44	0.000
	Std.	0.65	0.93	
Sound quality of home	Mean	1.95	2.59	0.000
	Std.	0.53	0.88	
Health	Mean	1.75	2.54	0.852
	Std.	0.83	0.75	

4.2.5 Environmental Pollution

While in Table 4.4 it is shown that the evaluation of general living environment corresponds to the evaluation of sound quality; the evaluation of noise pollution was compared with other types of pollution. In the questionnaire the interviewees were asked to rank various types of pollution, and Table 4.5 shows the mean ranking order and standard deviation. It is important to note that in both Sheffield and Taipei noise was perceived as the second most serious pollutant, with a slightly lower score than air pollution. The importance of noise pollution in the overall sustainable urban environment has also been demonstrated by other researchers (Peyton, 2005; Cowell, 2005).

Table 4.5 Ranking of various types of environmental pollution.

		Sheffield	Taipei	Sig.
Water pollution	Mean	3.26	2.81	0.123
	Std.	0.96	1.30	
Air pollution	Mean	2.09	2.29	0.957
	Std.	0.90	1.01	
Noise pollution	Mean	2.12	2.33	0.491
	Std.	1.20	1.12	
Waste pollution	Mean	2.53	2.94	0.010
	Std.	1.02	1.34	

4.2.6 Main Activities

Since noise may be more disturbing for certain activities, such as oral communication, listening to radio and intellectual tasks, than for other activities, the main activities of the interviewees when they stay at home were asked about and the results are shown in Table 4.6. It can be seen that there was a high percentage of activities which could potentially be disturbed by noise.

Table 4.6 Main activities at home (%).

Activities	Sheffield	Taipei
Reading	**61**	35
TV	54	**85**
Music	55	9
Others	41	29

4.2.7 Annoyance From Noise Sources

Various sources in an urban soundscape could have rather different impact on people, and this could vary according to different cultural environments. In the questionnaire the noticeability, annoyance level and sleep disturbance of typical sound sources in residential areas were examined. The comparative difference between Sheffield and Taipei is shown in Table 4.7, where a five-level linear scale was again used, from -2, none, to 2, very significant. It can be seen that there were generally significant differences between Sheffield and Taipei. It is interesting to note that people living in Sheffield had a higher noticeability of traffic noise, especially heavy vehicles, although their SPL was actually much lower than that in Taipei. In Taipei the noise sources at the top of the list were two wheelers, as well as talking, music and TV, both from neighbours and from their own home. This highlights the importance of considering cultural factors as well as urban structure and building types when evaluating noise.

The annoyance levels of various noise sources are compared, with a five-level linear scale, from -2, not annoyed, to 2, very annoyed. Generally speaking, the annoyance level corresponded to the noticeability as shown in Table 4.7. Traffic noise was again at the top of the list in Sheffield, whereas in Taipei two wheelers and talking/music/TV were the most annoying. Noise sources from nearby facilities and activities were generally not annoying, mostly with negative values.

Table 4.7 Noticeability of various noise sources.

Noise sources			Sheffield		Taipei	
				Ranking		Ranking
Traffic	Light vehicle	Mean Std.	-0.45 1.11	3	0.34 1.71	4
	Medium vehicle	Mean Std.	-0.26 1.21	2	0.24 1.26	5
	Heavy vehicle	Mean Std.	-0.09 1.36	**1**	0.18 1.33	6
	Two wheeler	Mean Std.	-1.29 0.93	10	0.56 1.26	**1**
Nearby	School	Mean Std.	-1.46 0.95	11	0.13 1.36	7
	Shops	Mean Std.	-1.28 1.07	9	0.11 1.36	8
	Recreation, leisure facilities	Mean Std.	-1.03 1.41	7	-0.11 1.37	12
	Transportation stations	Mean Std.	-1.26 1.09	8	-0.30 1.31	13
	Events	Mean Std.	-0.96 1.28	6	0.05 1.37	10
Neighbours	Talking, music, TV	Mean Std.	-0.93 1.26	5	0.35 1.24	3
	Air-conditioning	Mean Std.	-1.76 0.82	13	0.10 1.11	9
Own home	Talking, music, TV	Mean Std.	-0.76 1.22	4	0.43 1.18	2
	Air-conditioning	Mean Std.	-1.75 0.74	12	-0.01 1.17	11

The results in Table 4.7 and 4.8 do not fully correspond to the SPL of the noise sources. According to Guski (1998), the noise annoyance to inhabitants depends on approximately 33% of the acoustic parameters such as acoustic energy, number of sound events, and length of moments of calm between intermittent noises. Moreover, annoyance may increase if a neighbourhood is perceived in a negative way, and it is also influenced by the lifestyle chosen by certain people, for whom a certain quantity of noise is part of their life. Moreover, people may get used to certain noises and thus become less annoyed (Kang, 2006). It is particularly interesting to note that the values in Table 4.8 are generally systematically lower than those in Table 4.7, showing people's overall tolerance, which is similar to the case in urban open public spaces (Kang, 2006).

Table 4.8 Annoyance from various noise sources.

Noise sources			Sheffield		Taipei	
				Ranking		Ranking
Traffic	Light vehicle	Mean	-0.68	2	-0.18	5
		Std.	1.20		1.33	
	Medium vehicle	Mean	-0.68	2	-0.16	4
		Std.	1.36		1.22	
	Heavy vehicle	Mean	-0.28	1	-0.19	6
		Std.	1.58		1.29	
	Two wheeler	Mean	-1.26	6	-0.05	2
		Std.	1.13		1.30	
Nearby	School	Mean	-1.74	10	-0.38	9
		Std.	0.57		1.37	
	Shops	Mean	-1.60	9	-0.41	10
		Std.	0.81		1.32	
	Recreation, leisure facilities	Mean	-1.20	5	-0.51	11
		Std.	1.28		1.32	
	Transportation stations	Mean	-1.38	7	-0.73	12
		Std.	1.02		1.24	
	Events	Mean	-1.14	4	-0.29	7
		Std.	1.28		1.37	
Neighbours	**Talking, music, TV**	Mean	-0.98	3	0.09	1
		Std.	1.29		1.33	
	Air-conditioning	Mean	-1.78	11	-0.31	8
		Std.	0.76		1.16	
Own home	Talking, music, TV	Mean	-1.44	8	-0.08	3
		Std.	0.87		1.20	
	Air-conditioning	Mean	-1.78	11	-0.38	9
		Std.	0.75		1.18	

The evaluation of sleep disturbance is shown in Table 4.9, where the five linear scales are from -2, not disturbing, to 2, very disturbing. Generally speaking, the results correspond to Table 4.7 and 4.8.

Table 4.9 Sleep disturbance by various noise sources.

Noise sources			Sheffield		Taipei	
				ranking		ranking
Traffic	Light vehicle	Mean Std.	-1.36 1.06	3	-0.30 1.44	4
	Medium vehicle	Mean Std.	-1.23 1.23	2	-0.30 1.33	4
	Heavy vehicle	Mean Std.	-0.94 1.32	1	-0.33 1.34	5
	Two wheeler	Mean Std.	-1.44 0.97	7	-0.29 1.34	2
Nearby	School	Mean Std.	-1.75 0.61	10	-0.60 1.33	9
	Shops	Mean Std.	-1.74 0.69	9	-0.70 1.24	10
	Recreation, leisure facilities	Mean Std.	-1.54 0.94	6	-0.68 1.25	11
	Transportation stations	Mean Std.	-1.65 0.86	8	-0.84 1.20	12
	Events	Mean Std.	-1.51 0.94	5	-0.54 1.36	6
Neighbour	Talking, music, TV	Mean Std.	-1.28 1.19	4	-0.20 1.38	1
	Air-conditioning	Mean Std.	-1.81 0.73	11	-0.40 1.31	7
Own home	Talking, music, TV	Mean Std.	-1.74 0.65	9	-0.18 1.34	3
	Air-conditioning	Mean Std.	-1.84 0.54	12	-0.46 1.28	8

4.2.8 Preferred Sounds

Urban soundscape includes not only negative, but also positive sounds. Sound preference was therefore also studied through the questionnaire survey, where the interviewees were asked to select the sounds they prefer from a list. Table 4.10 shows the results, where if a sound was selected, value 1 is assigned, otherwise value 2 is given. It can be seen that there were significant differences in sound preference between Sheffield and Taipei. The preference level of bird and water sounds was much higher in Sheffield than in Taipei, by 0.38 and 0.2, respectively. In other words, the percentage of people who preferred those two sounds in Sheffield was 38% and 20% higher than that in Taipei. On the other hand, in Sheffield, insect sounds and music from outside were hardly ever selected, with a mean score of 1.96, whereas this score was about 0.2 lower in Taipei. There was also a higher percentage of people in Sheffield who suggested other preferred sounds.

Table 4.10 Sound preference. 1-yes (selected); 2-no.

		Sheffield	Taipei	Sig.
Birdsong	Mean	1.30	1.68	0.795
	Std.	0.46	0.48	
Insect sounds	Mean	1.96	1.79	0.000
	Std.	0.19	0.42	
Water	Mean	1.69	1.89	0.000
	Std.	0.47	0.32	
Music from outside	Mean	1.96	1.74	0.000
	Std.	0.19	0.45	
Other sounds	Mean	1.71	1.89	0.606
	Std.	0.46	0.57	

4.2.9 Summary

The comparative study in Sheffield and Taipei reveals the importance of considering cultural factors as well as urban texture and building types in evaluating urban sound environment. This is reflected in a number of aspects, from noise noticeability, annoyance and sleep disturbance, to sound preference. On the other hand, it was demonstrated that both in both cities, sound environment is an important consideration of the overall urban environment.

4.3 SECOND STAGE - COMPARISON BETWEEN SHEFFIELD AND TAIPEI

This section is based on the results of Stage 2 survey, namely surveys based randomly selected samples in Sheffield and Taipei (Yu and Kang, 2006c).

4.3.1 Choosing A Living Environment

Identical subjective survey questions were asked about the importance of various factors when people chose a living environment, where the five-point linear scale was from -2, do not mind, to 2, very important. The results in Sheffield and Taipei are compared in Table 4.11. Through the Independent Samples Test, it can be seen that there were significant differences between the two cities for nearly all factors ($p<0.01$). It seems that interviewees in Taipei gave considerably higher scores, by about 0.6 points on average, than the interviewees in Sheffield, which might be a reflection of cultural difference, although in both cities the standard deviations are rather high.

Table 4.11 Important factors in choosing a living environment: comparison between Sheffield and Taipei.

Factors	Sheffield			Taipei			Sig.
	Mean	Std.	Rank	Mean	Std.	Rank	
Convenient for work	0.82	1.06	4	1.60	0.68	2	0.000
Convenient transport	0.67	1.18	7	1.60	0.70	3	0.000
Convenient school, shopping	0.80	1.19	5	1.40	0.78	5	0.000
Recreational space	0.64	1.16	9	1.00	1.03	9	0.001
Sociable neighbourhoods	0.65	1.15	8	0.50	1.10	11	0.183
Safety	**1.23**	**0.82**	**1**	**1.70**	**0.67**	**1**	**0.000**
Property price	1.01	1.07	2	1.39	0.88	6	0.000
Quiet	0.73	0.96	6	1.45	0.77	4	0.000
Views	0.17	1.21	10	1.01	1.00	8	0.000
Size of the house	0.85	0.99	3	1.21	0.80	7	0.000
Interior decoration	-0.03	0.99	11	0.97	1.00	10	0.000
Mean	*0.68*	*1.07*		*1.25*	*0.86*		

On the other hand, in terms of the order of importance of various factors, there were many similarities between the two cities, for example, safety was at the top of the list. The correlation coefficient between the two rankings is R^2=0.46. It is interesting to note that the factor 'quiet' was ranked as the 6th most important factor in Sheffield, and 4th in Taipei, suggesting in both cities sound environment was an important consideration, although in Taipei the mean evaluation score was 1.45: significantly higher that in Sheffield, 0.73 ($p<0.000$).

4.3.2 Effect Of Social And Demographic Factors When Choosing A Living Environment

Differences between various education levels, age groups, current living environments, sleep quality, gender and occupations were examined, and some results are shown in Table 4.12, with correlations and associated significance level. Generally speaking, the correlation coefficients are rather low.

It is of particular interest to examine the effects of the above social and demographic factors on the evaluation of 'quiet' when choosing a living environment. Figure 4.2 shows the differences between various groups. In terms of occupation, as illustrated in Figure 4.2e, it can be seen that in Sheffield there were significant differences between students, working people and pensioners ($p<0.01$), with mean evaluation scores of 0.11, 0.83 and 1.58 respectively, whereas in Taipei such differences were not significant. In terms of current living environment, as shown in Figure 4.2c, in Sheffield there was a slight trend that with a better current environment, people tended to think 'quiet' was more important, with a correlation coefficient of 0.166. In Taipei there was no such tendency. In terms of age, it is interesting to note in Figure 4.2b that the age group 18-24 had a significantly lower score than the other groups ($p<0.000$) in Sheffield, whereas in Taipei the differences between different age groups were not significant. The effects of education level and gender were generally not statistically significant, although there were some differences in the mean evaluation scores, as shown in Figure 4.1a and 1f respectively. It is somewhat unexpected that the correlation between sleep quality and choosing a quiet environment was not high, as can be seen in Table 4.12 and Figure 4.2d.

Table 4.12 Effect of education, age, current living conditions, and sleep quality when choosing a living environment.

		Education		Age		Current living		Sleep quality	
		Shef	Taip	Shef	Taip	Shef	Taip	Shef	Taip
Convenient for work	Correlation	0.039	-0.013	-0.079	0.055	0.189	-0.087	-0.100	-0.013
	Sig.	0.586	0.855	0.269	0.435	0.007	0.222	0.158	0.859
Convenient transport	Correlation	-0.192	-0.016	0.218	0.084	-0.043	-0.098	-0.063	0.019
	Sig.	0.006	0.823	0.002	0.236	0.543	0.169	0.378	0.785
Convenient school/ shopping	Correlation	-0.278	0.011	0.142	-0.005	-0.043	-0.168	-0.083	-0.115
	Sig.	0.000	0.874	0.045	0.940	0.546	0.017	0.244	0.106
Recreational space	Correlation	-0.368	-0.086	0.315	0.131	-0.019	-0.152	0.030	-0.090
	Sig.	0.000	0.226	0.000	0.065	0.790	0.032	0.674	0.206
Sociable with neighbours/friends	Correlation	-0.412	-0.101	0.177	0.103	-0.238	-0.126	-0.063	-0.101
	Sig.	0.000	0.156	0.012	0.146	0.001	0.074	0.376	0.156
Safety	Correlation	0.016	-0.080	0.156	0.019	0.237	-0.131	-0.060	0.017
	Sig.	0.821	0.262	0.027	0.784	0.001	0.065	0.397	0.814
Property price	Correlation	-0.171	-0.083	0.379	-0.027	0.154	-0.053	-0.079	-0.003
	Sig.	0.016	0.244	0.000	0.699	0.030	0.457	0.269	0.972
Quiet	Correlation	-0.182	0.024	0.568	-0.016	0.166	-0.038	-0.150	-0.041
	Sig.	0.010	0.735	0.000	0.825	0.018	0.597	0.034	0.563
Views	Correlation	-0.099	-0.139	0.389	0.029	0.220	-0.109	-0.292	-0.069
	Sig.	0.162	0.049	0.000	0.688	0.002	0.126	0.000	0.330
Size of the house	Correlation	0.008	-0.210	0.406	-0.053	0.165	-0.153	-0.357	-0.069
	Sig.	0.911	0.003	0.000	0.452	0.019	0.031	0.000	0.328
Interior decoration	Correlation	-0.107	-0.116	-0.049	-0.052	0.058	-0.200	0.139	-0.072
	Sig.	0.132	0.103	0.489	0.468	0.414	0.005	0.049	0.313

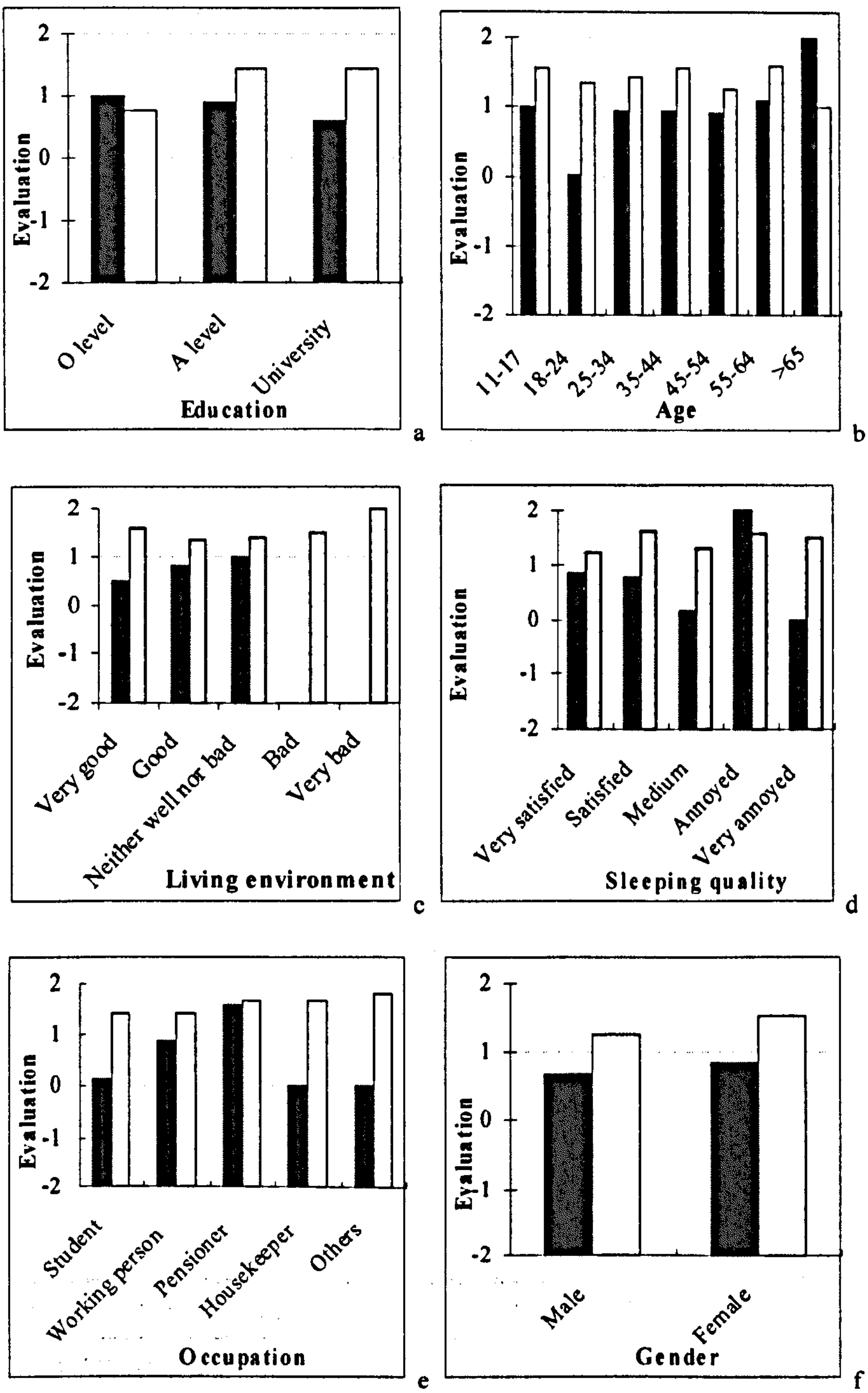


Figure 4.2 Effects of social and demographic factors when choosing a living environment, in terms of 'quiet'.

4.3.3 General Living Environment

Table 4.13 compares the perception of interviewees in Sheffield and Taipei on their general living environment, sound quality of their living area, and sound quality at home, where the five-point linear scale was from 1, comfortable, to 5, very uncomfortable. It is interesting to note that the scores in Taipei were all significantly higher than those in Sheffield, by about 0.5 to 0.7, which corresponded to the noise level difference between the two cities, which was about 10dBA. A possible reason is that although the interviewees in Sheffield and Taipei were all urban residents, most interviewees in Taipei lived within or close to the central areas, whereas the Sheffield interviewees were in the outer areas of the Sheffield city centre. The evaluation of general health conditions is also shown in Table 4.13, from 1, very good, to 5, very bad. It can be seen that Taipei residents found their health condition less satisfactory compared to those in Sheffield, with a difference of 0.72 in the mean evaluation score.

Table 4.13 Evaluations of living environment and sound quality of the living area and home, as well as health status.

	Sheffield		Taipei		Sig.
	Mean	Std.	Mean	Std.	
General living environment	1.82	0.53	2.36	0.87	0.000
Sound quality of living area	1.79	0.86	2.49	0.78	0.000
Sound quality of home	2.13	0.60	2.65	0.96	0.000
Health	1.97	0.53	2.69	0.89	0.000

4.3.4 Environmental Pollution

Four types of pollution, namely: water, air, noise and waste were to be ranked in the questionnaire. The results are shown in Table 4.14. It is important to note that noise was perceived as the most serious pollutant in Sheffield and the second most serious in Taipei, and in the two cities there was no significant difference.

Table 4.14 Ranking of various types of environmental pollution.

	Sheffield			Taipei			Sig.
	Mean	Std.	Rank	Mean	Std.	Rank	
Water pollution	3.06	1.13	4	2.49	1.25	3	0.001
Air pollution	1.96	0.91	2	1.92	0.97	1	0.782
Noise pollution	1.81	1.12	1	2.08	1.08	2	0.051
Waste pollution	2.20	1.09	3	3.07	1.18	4	0.000

4.3. 5 Main Activities

The results of the main activities when interviewees stayed at home are shown in Table 4.15. It can be seen that in both cities there was a high percentage of activities which could potentially be disturbed by noise, although in Sheffield the percentage of reading and music was considerably higher than that in Taipei, suggesting that Sheffield people could be more sensitive in terms of disturbance of activities.

Table 4.15 Main activities at home (%), where multiple choices were allowed.

	Sheffield	Taipei
Reading	63	38
Television	57	81
Music	57	5
Others	45	29

4.3. 6 Annoyance Due To Noise Sources

In the questionnaire the noticeability, annoyance level and sleep disturbance from typical sound sources in residential areas were examined, and the results are shown in Table 4.16, where the five-point linear scale was from -2, none, to 2, very significant, for noticeability, for example. It can be seen that there were generally considerable differences between Sheffield and Taipei, with Taipei having significantly greater scores, namely higher noticeability. This reflected the difference in noise levels in the two cities. As mentioned previously, the sound pressure levels in the Taipei sites were about 10dBA higher than those in Sheffield at typical road-side receivers, due to the difference in landforms, building types, and more importantly, traffic density. Between the three sites in Sheffield the SPL varied by about 6dBA, and the variation range in Taipei was similar. It is interesting to note that in terms of ranking of various noise sources, people living in Sheffield had a higher noticeability of traffic noise, especially heavy vehicles, although their SPL was actually much lower than that in Taipei (Yu and Kang, 2006c). In Taipei the noise sources at the top of the list were two wheelers, as well as talking, music and TV, from neighbours. This strongly demonstrates the importance of considering cultural factors as well as urban structure and building types when evaluating noise.

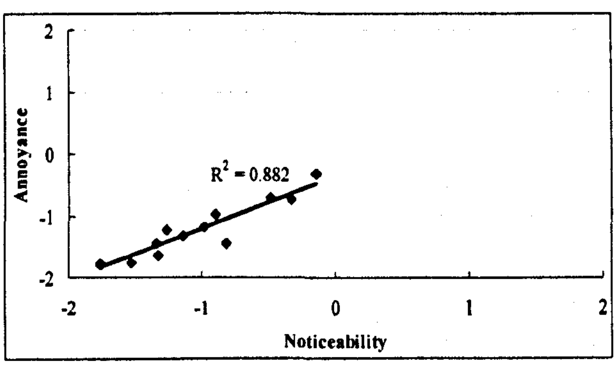
Table 4.16 Noticeability, annoyance and sleep disturbance due to various noise sources.

Noise sources			Noticeability				Annoyance				Sleep			
			Sheffield		Taipei		Sheffield		Taipei		Sheffield		Taipei	
Traffic	Light vehicle	Mean	-0.48	3	0.24	3	-0.70	2	-0.08	3	-1.37	4	-0.24	4
		Std.	1.13		1.52		1.19		1.34		1.05		1.44	
	Medium vehicle	Mean	-0.32	2	0.14	6	-0.74	3	-0.16	5	-1.24	2	-0.26	5
		Std.	1.20		1.23		1.34		1.22		1.22		1.31	
	Heavy vehicle	Mean	-0.14	1	0.22	4	-0.32	1	-0.12	4	-0.91	1	-0.23	3
		Std.	1.33		1.33		1.55		1.26		1.32		1.31	
	Two wheeler	Mean	-1.26	8	0.40	1	-1.22	6	0.07	1	-1.43	5	-0.18	1
		Std.	0.94		1.34		1.16		1.36		0.97		1.37	
Nearby	Nearby school	Mean	-1.53	11	-0.05	9	-1.76	10	-0.38	8	-1.77	10	-0.55	10
		Std.	0.88		1.35		0.56		1.37		0.59		1.36	
	Nearby shops	Mean	-1.33	9	-0.05	9	-1.65	9	-0.39	9	-1.77	10	-0.57	11
		Std.	1.02		1.29		0.77		1.31		0.65		1.30	
	Recreation/leisure facilities	Mean	-1.14	7	-0.19	11	-1.31	7	-0.46	11	-1.56	7	-0.63	12
		Std.	1.32		1.28		1.21		1.30		0.92		1.26	
	Transportation stations	Mean	-1.34	10	-0.32	12	-1.43	8	-0.63	12	-1.68	8	-0.75	13
		Std.	1.06		1.26		0.98		1.25		0.84		1.20	
	Events	Mean	-0.98	6	0.14	7	-1.18	5	-0.08	3	-1.51	6	-0.30	7
		Std.	1.28		1.38		1.26		1.44		0.95		1.42	
Neighbours	Talking, music, TV	Mean	-0.89	5	0.26	2	-0.97	4	0.02	2	-1.25	3	-0.19	2
		Std.	1.26		1.25		1.33		1.31		1.21		1.37	
	Air-conditioning	Mean	-1.76	13	-0.01	8	-1.77	11	-0.30	7	-1.81	11	-0.38	8
		Std.	0.81		1.10		0.77		1.20		0.73		1.29	
Own house	Talking, music, TV	Mean	-0.81	4	0.19	5	-1.43	8	-0.18	6	-1.75	9	-0.29	6
		Std.	1.20		1.18		0.87		1.20		0.63		1.36	
	Air-conditioning	Mean	-1.76	12	-0.15	10	-1.78	12	-0.40	10	-1.83	12	-0.50	9
		Std.	0.73		1.14		0.72		1.17		0.56		1.24	

From Table 4.16 it can be seen that the annoyance level generally corresponded to the noticeability level, and the evaluation of sleep disturbance also corresponded to noticeability and annoyance level. In terms of annoyance, traffic noise was again at the top of the list in Sheffield, whereas in Taipei two wheelers and talking/music/TV were found most annoying, as well as the annoyance caused by nearby events. In terms of sleep disturbance, traffic noise was also at the top of the list in Sheffield, as well as talking/music/TV, from neighbours, whereas in Taipei two wheelers and talking/music/TV were found most disturbing, as well as heavy vehicles.

It is particularly interesting to note in Table 4.16 that the scores of noticeability were generally systematically lower than those of annoyance level, showing people's overall tolerance. Moreover, various sources in an urban soundscape could have a rather different impact on people, and this could differ with different cultural environments.

The above relationships are further demonstrated in Figure 4.3 and 4.4, and the high correlations between noticeability, annoyance and sleep disturbance are illustrated.



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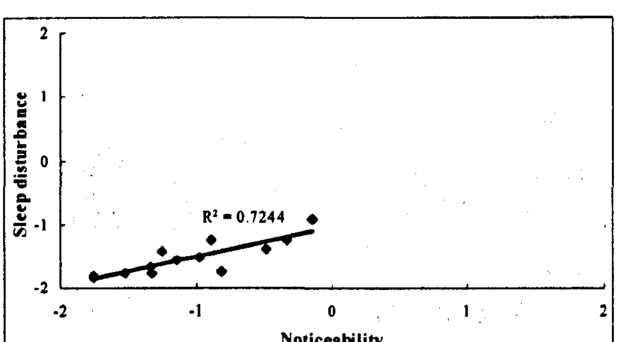

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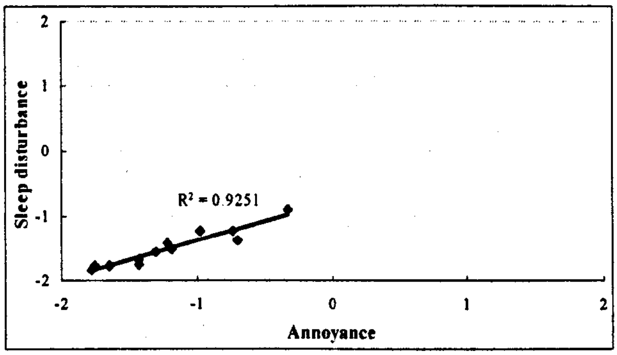

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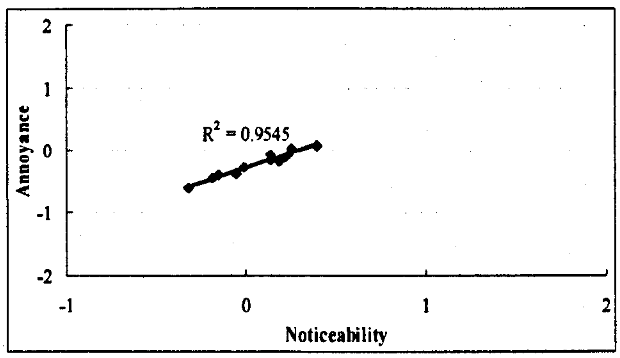
Figure 4.3 Relationships between noise noticeability, annoyance and sleep disturbance in Sheffield.



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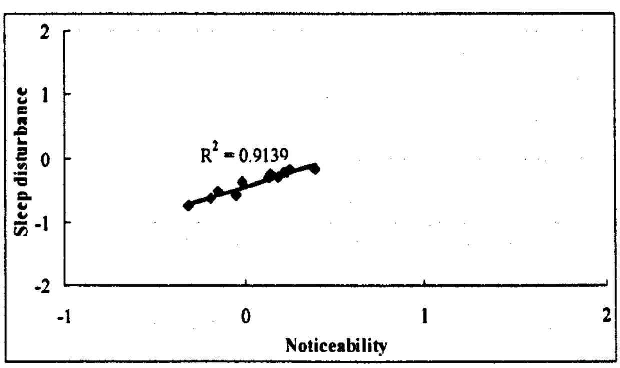

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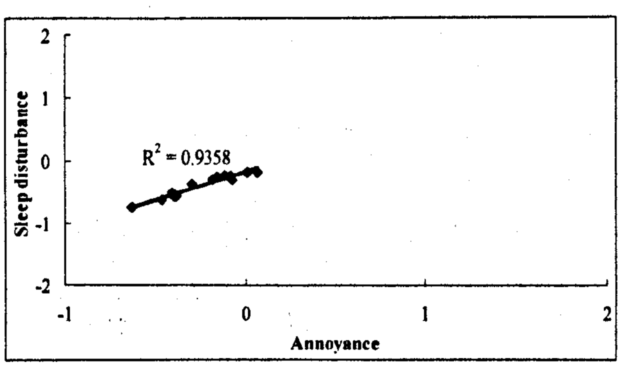

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Figure 4.4 Relationships between noise noticeability, annoyance and sleep disturbance in Taipei.

4.3.7 Sound Preference

Given the effects of various sound sources shown above, sound preference was also studied through the questionnaire survey, where the interviewees were asked to select the sounds they would prefer from a list. Table 4.17 shows the results, where if a sound was selected, value 1 was assigned, otherwise value 2 was given. It can be seen that there were significant differences in sound preferences between Sheffield and Taipei. The preference level of bird sounds and water sounds was much higher in Sheffield than in Taipei, by 0.42 and 0.2, respectively. In other words, the percentage of people who preferred those two sounds in Sheffield was 42% and 20% higher than in Taipei. On the other hand, in Sheffield, music from outside and insect sounds were hardly ever selected, with a mean score of 1.97, whereas this score was about 0.04 higher than that in Taipei. There was also a higher percentage of people in Sheffield who suggested other preferred sounds.

Table 4.17 Preference of various potential positive sounds, with 1 as yes (selected) and 2 as no.

	Sheffield		Taipei		Sig.
	Mean	Std.	Mean	Std.	
Birdsong	1.28	0.45	1.70	0.88	**0.000**
Insect sounds	1.97	0.18	1.93	0.80	0.489
Water	1.73	0.45	1.93	0.96	0.008
Music from outside	1.96	0.21	1.65	0.89	**0.000**
Other Sounds	1.71	0.45	1.94	0.65	0.004

4.3.8 Summary

In the second part of the study, comparative results are shown: which are similar to the first part. They reflect the significant differences between the two cultures in a number of aspects, including choosing and evaluating living environment, noise noticeability, annoyance and sleep disturbance, activities, and sound preference.

4.4 THIRD STAGE - COMPARISON BETWEEN THE UK AND TAIWAN

In this part of the study, a further examination was made of the effects of cultural factors on the evaluation of sound ambience in the urban living environment. The further survey uses a simplified comparative questionnaire which has the same structure as the previous sections: 4.2 and 4.3. It was carried out in the UK and Taiwan, each with 300 samples, focusing on how people perceive acoustic quality in their living environment (Yu and Kang, 2007b).

4.4.1 Choosing A Living Environment

Again, questions were asked about the importance of various factors when people choose a living environment, with 1 as yes (selected) and 2 as no. The results in the UK and Taiwan are compared in Table 4.18, through the Independent Samples Test. Since only three factors could be chosen, most mean values in the Table are greater than 1.5.

Table 4.18 Importance of various factors when choosing a living environment, comparing the UK and Taiwan, where the significance level $p<0.01$ is marked with ** and $p<0.05$ is marked with *.Importance of various factors when choosing a living environment.

	UK			Taiwan			Sig.
Factors	Mean	Std.	Rank	Mean	Std.	Rank	
Convenience for work	1.57	0.50	2	1.60	0.49	2	0.07
Convenient transport	1.64	0.48	3	1.24	0.43	1	0.00**
Convenient school, shopping	1.71	0.45	6	1.61	0.49	3	0.00**
Recreational space	1.85	0.35	7	1.98	0.13	10	0.00**
Sociable, friendly neighbourhood	1.70	0.46	5	1.98	0.13	10	0.00**
Safety	1.66	0.47	4	1.62	0.49	4	0.02*
Property price	1.46	0.50	1	1.71	0.45	6	0.00**
Quietness	1.91	0.29	8	1.64	0.48	5	0.00**
Views	1.91	0.29	8	1.81	0.40	7	0.00**
Size of the house	1.66	0.47	4	1.87	0.33	8	0.00**
Interior decoration	1.91	0.28	8	1.95	0.23	9	0.00**
Mean	1.73	0.41		1.73	0.37		

Table 4.18 shows that there were significant differences between the UK and Taiwan for nearly all factors. Whilst the average evaluation scores in the UK and Taiwan were very close, in the UK the standard deviations (std.) are 0.04 higher than in Taiwan. In terms of the ranking of various factors, there were significant differences between the UK and Taiwan ($p<0.01$).

The correlation coefficient between the two rankings is $R^2=0.2052$, as shown in Figure 4.5, and this correlation fails to achieve a significant level ($p<0.01$). It is interesting to note that 'quietness' is ranked as the 8th most important factor in the UK, and the 5th in Taiwan. The mean value is 1.91 in the UK, considerably higher than that in Taiwan, 1.64. These ranking orders are relatively lower than those in the stage one and two results, especially in the UK, possibly because the previous results are based on Sheffield, where there are many low density population areas and people might be more concerned with quietness.

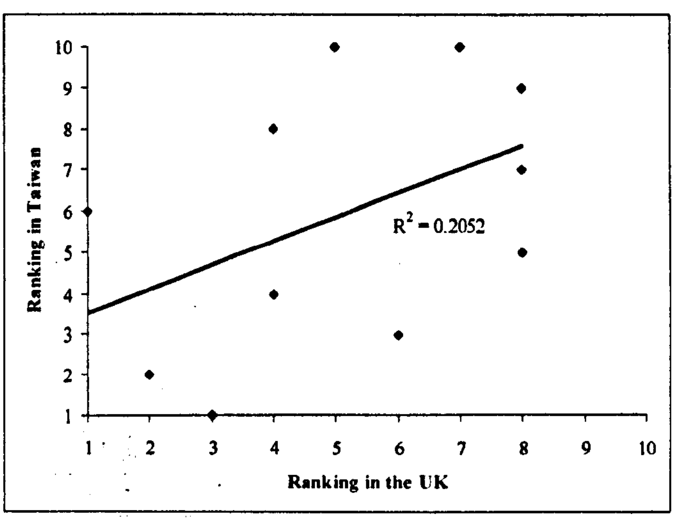


Figure 4.5 Correlation between the factor rankings in the UK and Taiwan when choosing a living environment.

4.4.2 Effects Of Social And Demographic Factors When Choosing A Living Environment

In Table 4.19 the differences between various occupations (student, working person, pensioner, housekeeper, others), education levels (O level, A level, university), age groups (11-17, 18-24, 25-34, 35-44, 45-54, 55-64, >65) and current living condition/environment (very good, good, neither good nor bad, bad, very bad) are examined, using the one-way ANOVA analysis of variance. It is interesting to note that in the UK the effects of social and demographic factors on choosing a living environment are considerably less than in Taiwan.

Table 4.19 Effects of occupation, education level, age, and current living environment/conditions when choosing a living environment, where the significance levels of one-way ANOVA analysis of variance are shown.

The significance levels p<0.01 are marked with ** and p<0.05 marked with *.

Factors	Occupation		Education		Age		Living condition	
	UK	Taiwan	UK	Taiwan	UK	Taiwan	UK	Taiwan
Convenient for work	0.27	0.00**	0.66	0.00**	0.44	0.00**	0.97	0.10
Convenient transport	0.58	0.01**	0.28	0.44	0.00**	0.18	0.25	0.49
Convenient school /shopping	0.70	0.01**	0.03*	0.62	0.18	0.20	0.57	0.00**
Recreational space	0.82	0.03*	0.24	0.39	0.40	0.00**	0.08	0.38
Sociable, friendly neighbourhoods	0.72	0.00**	0.57	0.00**	0.19	0.00**	0.09	0.14
Safety	0.32	0.00**	0.20	0.01**	0.09	0.00**	0.50	0.31
Property price	0.00**	0.00**	0.58	0.04*	0.00**	0.13	0.15	0.03*
Quietness	0.00**	0.00**	0.00**	0.00**	0.14	0.00**	0.09	0.30
Views	0.00**	0.00**	0.44	0.00**	0.03*	0.00**	0.24	0.00**
Size of the house	0.32	0.00**	0.32	0.59	0.06	0.35	0.53	0.00**
Interior decoration	0.49	0.26	0.45	0.00**	0.22	0.17	0.67	0.00**

In terms of the importance of 'quietness' when choosing a living environment, in Table 4.19 it is interesting to note that between different occupations and education levels there are significant differences both in the UK and Taiwan, whereas the age effect is only significant in Taiwan. The effect of the current living condition/environment seems to be insignificant.

To further examine the effects of social and demographic factors when choosing a living environment in terms of quietness, Figure 4.6 shows the differences between various social and demographic groups. In terms of occupation, as shown in Figure 4.6a, both in the UK and Taiwan there are notable differences between students and working people.

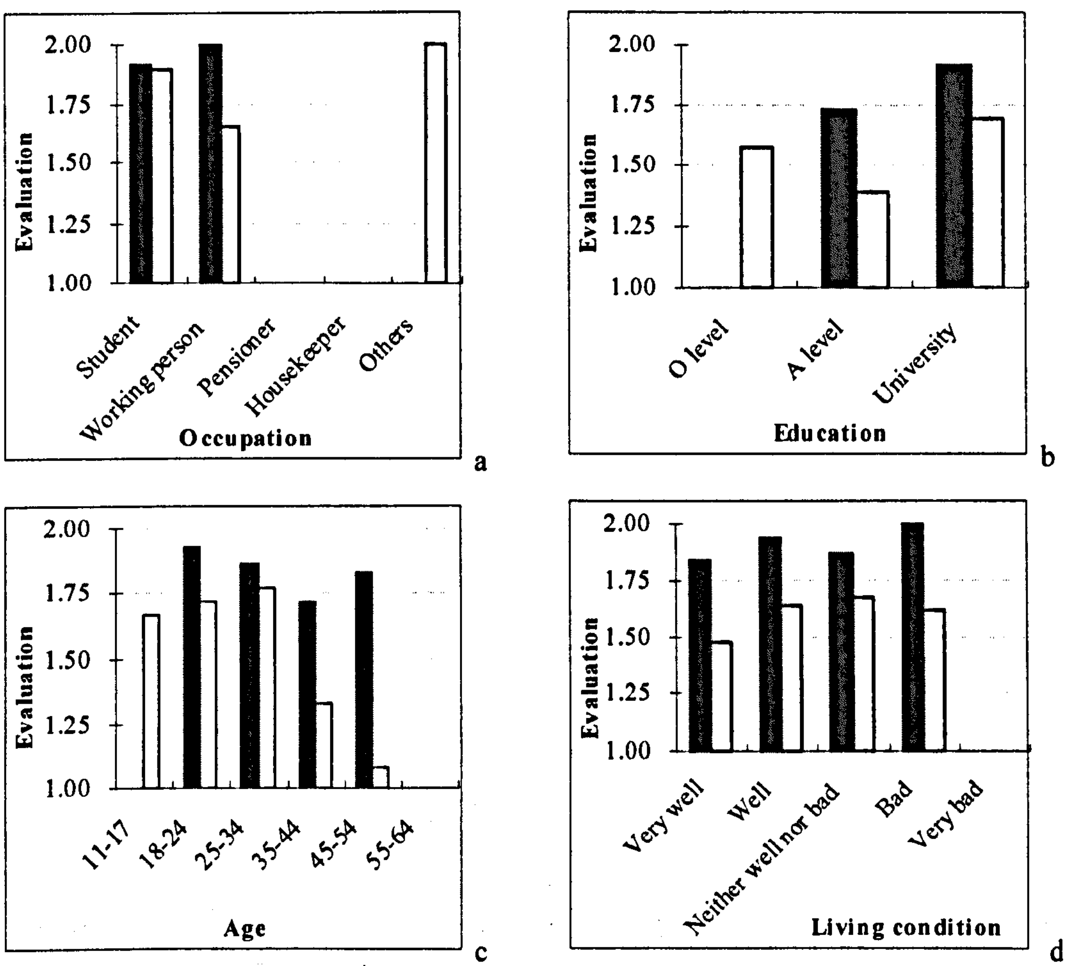


Figure 4. 6 Effects of social and demographic factors when choosing a living environment, in terms of 'quietness'. Evaluation 1: yes (selected); 2: no (not selected). Black bars: UK; white bars: Taiwan.

The results of pensioners and housekeepers are not presented due to the low sample number. In Figure 4.6b it can be seen that both in the UK and Taiwan there are significant differences between various education levels, but it seems that there is no clear tendency in evaluation score related to increasing/decreasing education level. Figure 4.6c seems to suggest a tendency that with increasing age, people are more concerned about the quietness, especially in Taiwan. It should be noted, however, that further examination is still needed since the results of age group 55-64 and >64 are not presented due to the low sample number. In terms of current living condition/environment, as shown in Figure 4.6d, in Taiwan there seems to be a very slight tendency, with a better current living condition/environment, for people to think 'quietness' is more important, although this does not reach a significant level, as shown in Table 4.19, whereas in the UK there is no such tendency. The comparison between genders shows that in the UK there is no significant difference between males and females, and the mean evaluation scores are both 1.9. In Taiwan, conversely, it seems that males are more concerned with quietness, with a significantly ($p<0.01$) higher score than that of females, by about 0.15.

4.4.3 Current Living Environment

Table 4.20 compares the evaluation of current general living condition/environment, sound quality of the living area and the sound quality at home between the UK and Taiwan, where the five-point linear scale was: 1, very comfortable; 2, comfortable; 3, neither comfortable nor uncomfortable; 4, uncomfortable; 5, very uncomfortable.

Table 4.20 Evaluations of the current living environment, and the sound quality of the living area and at home.

		UK	Taiwan	Sig.
General living environment	Mean	2.26	2.65	0.009
	Std.	0.71	0.79	
Sound quality of living area	Mean	2.23	2.95	0.197
	Std.	0.88	0.88	
Sound quality of home	Mean	2.25	2.74	0.003
	Std.	0.93	0.75	

It is interesting to note that the scores in Taiwan are all significantly higher than those in the UK, by about 0.4 to 0.7, indicating that the general living condition/environment and the acoustic environments are less comfortable in terms of people's perception.

4.4.4 Main Activities

The main activities when people stay at home were asked about and the results are shown in Table 4.21, where multiple choices were allowed. In both in the UK and Taiwan there was a high percentage of activities which could potentially be disturbed by noise, including reading, watching television and listening to music. In the UK, however, the percentage of people who listen to music was considerably higher than that in Taiwan, by 23%, and in Taiwan the percentage of people watching television was higher than that in the UK by 30%. It is therefore possible that UK people could be more sensitive in terms of disturbance of activities by noise.

Table 4.21 Main activities when people stay at home (%), where multiple choices were allowed.

%	UK	Taiwan
Reading	47.33	55.33
Television	53.00	83.00
Music	61.33	38.00
Others	34.67	60.33

4.4.5 Annoyance Level And Sleep Disturbance From Noise Sources

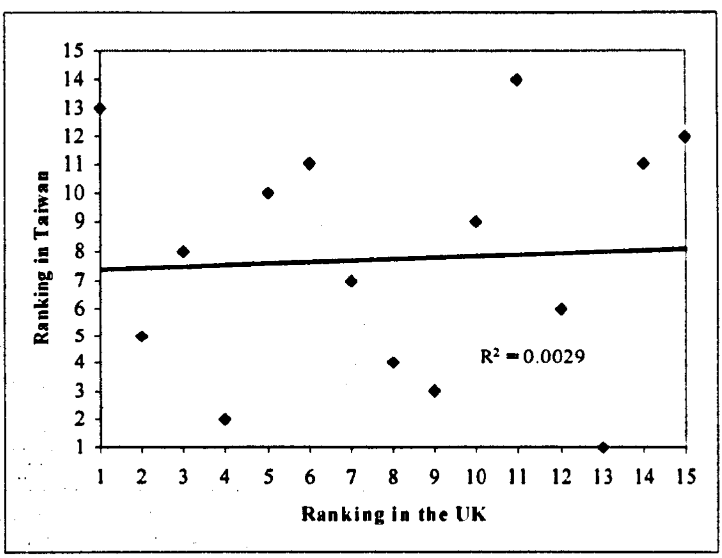
In the questionnaire the annoyance level and sleep disturbance of typical sound sources in residential areas were examined, and the results are shown in Table 4.22, where the five-point linear scale was: -2, not very annoyed; -1, occasional; 0, medium; 1, annoyed; 2, very annoyed. It can be seen that there are generally considerable differences between the UK and Taiwan, with Taiwan having significantly higher scores, namely higher annoyance levels.

Table 4.22 Annoyance and sleep disturbance of various noise sources in the UK and Taiwan.

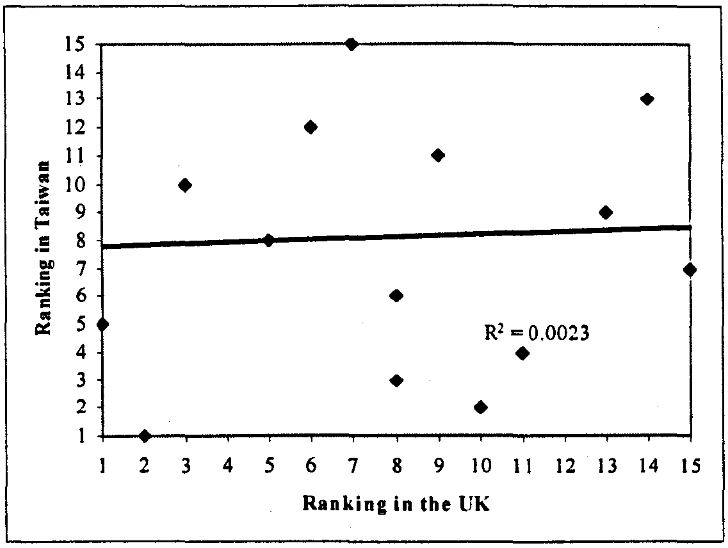
Noise sources			Annoyance				Sleep			
			UK		Taiwan		UK		Taiwan	
				Rank		Rank		Rank		Rank
Traffic	Light vehicle	Mean	-0.69	8	-0.23	4	-0.77	11	-0.29	4
		Std.	0.68		1.05		0.62		1.13	
	Medium vehicle	Mean	-0.69	9	-0.11	3	-0.76	10	-0.12	2
		Std.	0.72		1.14		0.66		1.23	
	Heavy vehicle	Mean	-0.51	4	-0.08	2	-0.47	2	0.07	1
		Std.	0.96		1.17		0.97		1.32	
	Two wheeler	Mean	-0.73	13	0.00	1	-0.77	8	-0.19	3
		Std.	0.73		1.06		0.71		1.15	
Nearby facilities	School	Mean	-0.49	3	-0.55	8	-0.60	5	-0.62	8
		Std.	0.85		0.77		0.90		0.76	
	Shops	Mean	-0.68	7	-0.52	7	-0.76	9	-0.69	11
		Std.	0.57		0.86		0.54		0.75	
	Recreation/leisure facilities	Mean	-0.70	11	-0.77	14	-0.61	6	-0.72	12
		Std.	0.63		0.62		0.66		0.67	
	Transportation stations	Mean	-0.40	1	-0.73	13	-0.51	3	-0.66	10
		Std.	0.93		0.68		0.94		0.78	
	Events	Mean	-0.46	2	-0.48	5	-0.47	1	-0.43	5
		Std.	0.84		0.93		0.87		0.92	
Neighbours	Talking	Mean	-0.71	12	-0.51	6	-0.70	8	-0.59	6
		Std.	0.63		0.82		0.70		0.72	
	Music, TV	Mean	-0.56	5	-0.66	10	-0.51	4	-0.74	16
		Std.	0.81		0.72		0.86		0.64	
	Air-conditioning	Mean	-0.82	15	-0.69	12	-0.78	13	-0.66	9
		Std.	0.47		0.69		0.52		0.68	
Own home	Talking	Mean	-0.80	14	-0.69	11	-0.79	15	-0.61	7
		Std.	0.49		0.54		0.53		0.78	
	Music, TV	Mean	-0.60	6	-0.69	11	-0.68	7	-0.75	15
		Std.	0.75		0.57		0.69		0.56	
	Air-conditioning	Mean	-0.69	10	-0.65	9	-0.79	14	-0.73	13
		Std.	0.73		0.62		0.50		0.55	
Mean			-0.64		-0.49		-0.66		-0.52	

This is reflected in the different noise levels in the UK and Taiwan, especially in urban areas. It is interesting to note that in terms of annoyance of various noise sources, people living in the UK have a relatively high annoyance level caused by nearby transportation stations, followed by events, schools and heavy vehicles. On the other hand, in Taiwan two-wheel, and various other vehicles are at the top of the list. For sleep disturbance, the results were similar. The significant differences between the two rankings strongly indicate the importance of considering cultural factors as well as urban structure and building types when evaluating noise.

The correlations between the rankings in the UK and Taiwan are shown in Figure 4.7a and 4.7b, for annoyance and sleep disturbance, respectively. It can be seen that the correlation coefficients are very low. On the other hand, the correlations between annoyance and sleep disturbance are rather high, as illustrated in Figure 4.8 and 4.9, for the UK and Taiwan, respectively.



a. annoyance



b. sleep

Figure 4.7 Correlations between the rankings of noise sources in the UK and Taiwan.

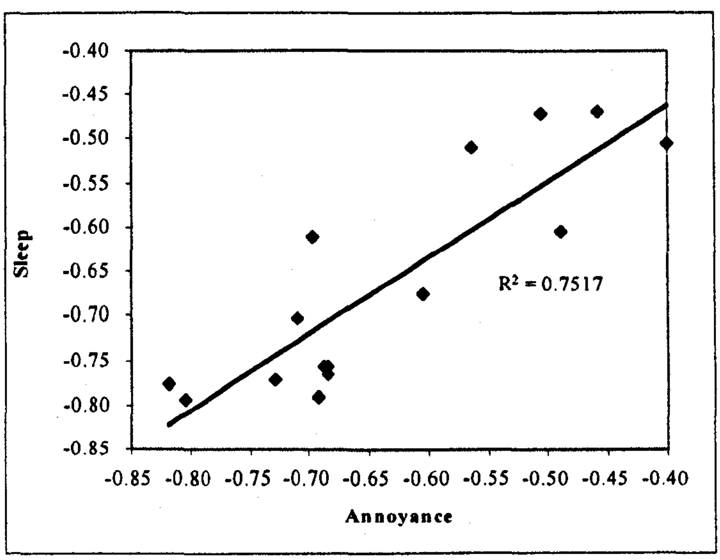


Figure 4. 8 Correlations between the UK noise annoyance and sleep disturbance rankings

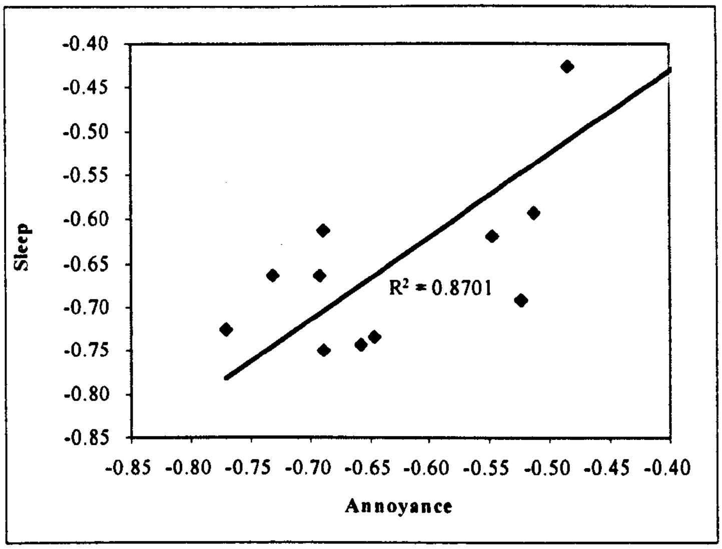


Figure 4.9 Correlations between the noise annoyance and sleep disturbance rankings in Taiwan.

4.4.6 Sound Preference

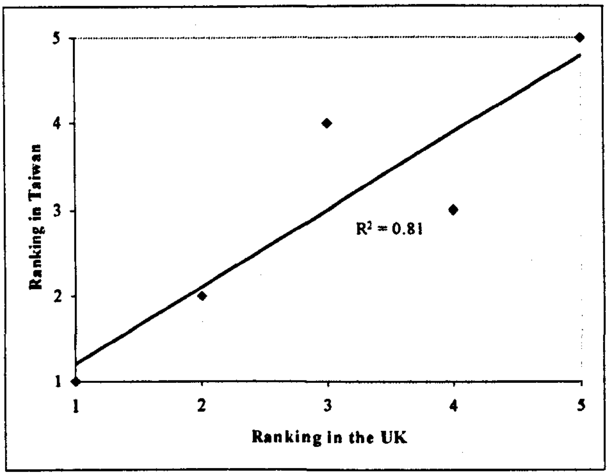
In the survey, people were asked to select the sounds they would prefer, both in the living area and at home, from a given list, including both natural sounds and artificial sounds. Table 4.23 shows the results, where if a sound was selected, value 1 is assigned, otherwise value 2 is assigned. Through the Independent Samples Test, it can be seen that there are significant differences between the UK and Taiwan for nearly all sounds listed.

In terms of the ranking of preferred sounds the differences between the UK and Taiwan are generally insignificant. The correlations between the UK and Taiwan rankings are shown in Figure 4.8, for natural sounds and artificial sounds, in the living area and at home, respectively. It can be seen that the correlations are rather high, with R^2=0.5-1. It is interesting to note that both in the UK and Taiwan, 'quiet' is highly preferred both in the living area and at home. This is followed by birdsong and water sounds, although it is interesting to note that these two sounds are less preferred at home compared to the living area, both in the UK and Taiwan. Insect sounds are less preferred in the UK compared to Taiwan, similar to the results obtained in the stage-two study.

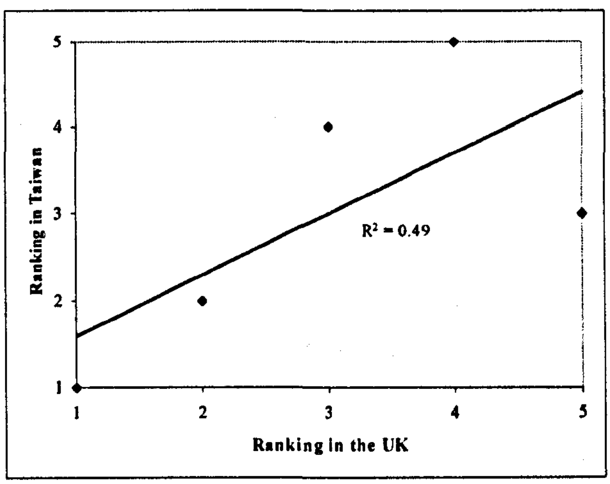
Table 4.23 Preference for various natural sounds and artificial sounds, with 1 as yes (selected) and 2 as no.

			Area					Home				
			UK	Rank	Taiwan	Rank	Sig.	UK	Rank	Taiwan	Rank	Sig.
Natural sounds	Birdsong	Mean	1.59	2	1.49	2	0.00**	1.76	2	1.69	2	0.00**
		Std.	0.49		0.50			0.43		0.46		
	Water	Mean	1.71	3	1.83	4	0.00**	1.78	3	1.91	4	0.00**
		Std.	0.45		0.37			0.41		0.29		
	Insect sounds	Mean	1.95	4	1.71	3	0.00**	1.98	5	1.78	3	0.00**
		Std.	0.23		0.45			0.15		0.42		
	Quiet	Mean	1.51	1	1.41	1	0.00**	1.44	1	1.40	1	0.04*
		Std.	0.5		0.49			0.50		0.49		
	Others	Mean	1.97	5	2	5	0.00**	1.97	4	2	5	0.00**
		Std.	0.17		0			0.16		0		
Artificial sounds	Church bells	Mean	1.77	2	1.95	2	0.00**	1.93	2	1.99	2	0.00**
		Std.	0.42		0.22			0.26		0.08		
	Music	Mean	1.52	1	1.83	1	0.00**	1.31	1	1.41	1	0.00**
		Std.	0.5		0.37			0.46		0.49		
	Traffic sound	Mean	1.95	3	1.98	3	0.00**	1.99	4	2	3	0.25
		Std.	0.22		0.14			0.08		0.06		
	Others	Mean	1.98	4	2	4	0.00**	1.97	3	2	3	0.00**
		Std.	0.13		0			0.18		0		

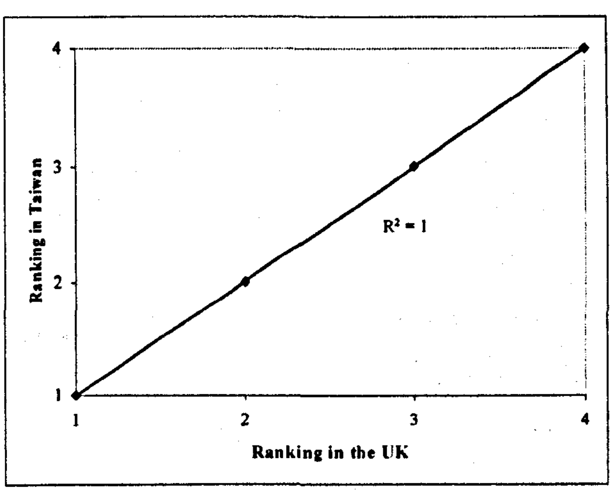
Church bells are less preferred in Taiwan compared to the UK: probably due to cultural differences. Music is generally preferred both in the living area and at home, although the preference level is higher at home. It is interesting that the preference level for music is higher in the UK than that in Taiwan, which corresponds to people's activities, as shown in Table 4.23. As expected, traffic sounds are generally least preferred (Kang, 2006). Moreover, it is important to note that the standard deviation for traffic sounds is much less than that for other more preferred sounds.


Ranking in Taiwan
Ranking in the UK
R² = 0.81
1
2
3
4
5

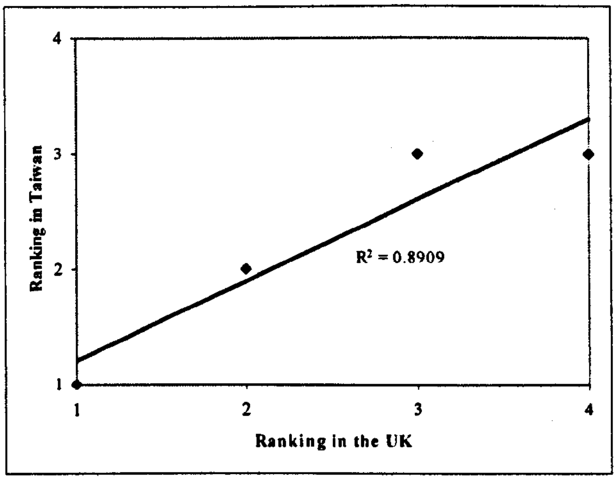
a


Ranking in Taiwan
Ranking in the UK
R² = 0.49
1
2
3
4
5

b


Ranking in Taiwan
Ranking in the UK
R² = 1
1
2
3
4

c



d

Figure 4.8 Correlations between the sound preference rankings in the UK and Taiwan. (a) Natural sounds in the living area; (b) natural sounds at home; (c) artificial sounds in the living area; (d) artificial sounds at home.

4.4.7 Summary

Both in the UK and Taiwan, it has been demonstrated that acoustic environment and soundscape are important aspects of the sustainable urban living environment. The comparative study of the UK and Taiwan reveals the importance of considering cultural factors. This is reflected by the significant differences between the two cultures in a number of aspects, including choice of living environment, effects of social and demographic factors, perception/evaluation of current living environment, main activities, noise annoyance and sleep disturbance, and sound preferences. Generally speaking, these cultural differences correspond to the overall differences found in stages one and two of this research. It is interesting to note that in both cultures a quiet environment is highly preferred, followed by some positive/natural sounds. Conversely, traffic sounds are least preferred, as expected.

4.5 COMPARISONS BETWEEN THE THREE STAGES

In order to determine the differences between the three stages, a series of comparisons are made in this section. This proceeds through the different stages in order to further understand how social factors might have certain effects on environmentally sustainable acoustics.

4.5.1 Choosing A Living Environment

Table 4.24 shows rankings of the three stages, and it can be seen that the most important factor in stage 1 and 2 is safety. Different results appeared in stage 3: the highest value in the UK is property price and in Taiwan it is convenience for work. In general, the ranking results are similar between the first and second stages.

Table 4.24 Important factors in choosing a living environment: comparison between the three stages.

	Stage 1		Stage 2		Stage 3	
	Shef	TP	Shef	TP	UK	Taiwan
	Stage1	Stage1	Stage2	Stage2	Stage3	Stage3
Convenient for work	**3**	**2**	**4**	**2**	**2**	**2**
Convenient transport	5	**2**	7	**3**	**3**	**1**
Convenient school shopping	3	5	5	5	6	3
Recreational space	6	7	9	9	7	10
Sociable, friendly neighbourhoods	7	9	8	11	5	10
Safety	**1**	**1**	**1**	**1**	4	4
Property price	**2**	4	**2**	6	**1**	6
Quiet	**4**	**3**	**6**	**4**	**8**	**5**
Views	8	7	10	8	8	7
Size of the house	**3**	6	**3**	7	4	8
Interior decoration	9	8	11	10	8	9

The correlations between the rankings re choosing a living environment in the three stages are shown in Figure 4.9. Between stage 1 and 2 the correlation is rather high, and between stage 2 and 3 the correlation is also high, whereas between stage 1 and 3 the correlation is the lowest.

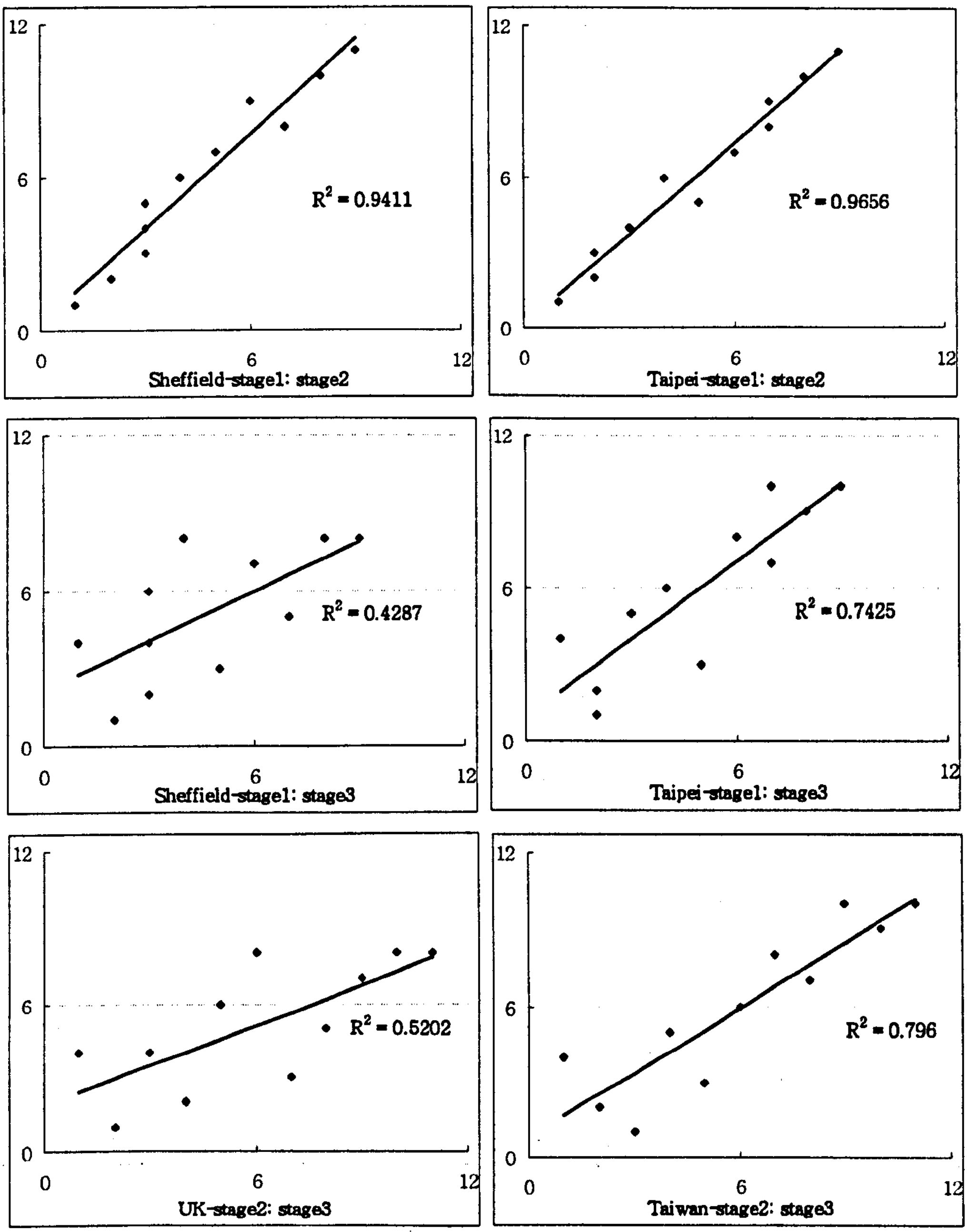


Figure 4.9 Correlations between the rankings of choosing a living environment in the UK and Taiwan in the three stages

On the other hand, it is interesting to note that in stage 1 and 2, the factor 'quiet' was ranked as the 4th and 6th most important factor in Sheffield, and 3rd as well as 4th in Taipei. When comparison is made between the UK and Taiwan (stage 3), the factor 'quiet' was ranked as 8th and 5th respectively. It is clear that different urban texture and social factors can have significant effects on choosing a living environment.

4.5.2 Effects Of Social And Demographic Factors When Choosing A Living Environment

To further understand the differences of demographic factors in the three stages, the significant correlations were examined and are shown in Table 4.25.

Table 4.25 The significance level of the correlations between education level and choosing a living environment.

Sig.		Education					
		Stage 1		Stage 2		Stage 3	
		Sheffield	Taipei	Sheffield	Taipei	UK	TW
Convenient	for work	0.12	0.10	0.59	0.86	0.86	**0.00**
	for transport	0.05	0.10	**0.01**	0.82	0.16	0.26
	for school, shop	0.91	0.14	**0.00**	0.87	0.01	0.52
Recreational		**0.00**	**0.02**	**0.00**	0.23	0.10	0.39
Social with neighbours		0.03	0.46	**0.00**	0.16	0.67	**0.00**
Safety		0.71	0.54	0.82	0.26	0.72	0.28
Property price		0.10	0.11	0.02	0.25	0.39	0.60
Quiet		0.02	0.55	**0.01**	0.74	**0.00**	**0.00**
Views		0.02	0.93	0.16	0.05	0.21	**0.01**
House size		0.24	0.95	0.91	**0.00**	0.26	0.61
Interior decoration		0.37	0.62	0.13	0.10	0.22	**0.01**

In general, a number of factors have significance correlations, such as being close to recreational places in stage 1, living within a convenient distance of work, transport, school and shops of stage 2. It is interesting to note that results in stage 2 showed significant correlations on convenient transport, convenient schools and shops, recreational factors, sociable neighbourhoods and quiet in Sheffield but no such tendencies were seen in Taipei. Similar results were shown in stage 1 and stage 2 but different tendencies were seen in stage 3, probably because the survey in the third stage covers all the regions and each region might have different social factors.

In order to know the significant differences between age groups the significant levels between various age groups and choosing a living were examined and are shown in Table 4.26. It can be seen that similar results were shown in stage 1 and stage 2 but in stage 3 the factors of convenient transport, property price and good views are important in the UK, and such factors as convenience for work, nearby recreational areas, socialising with friends or family, property price, quiet and good views are significant in Taiwan. It can be seen that when the survey was extended to different urban areas it showed very different tendencies in terms of age groups.

Table 4.26 The significance level of the correlations between age and choosing a living environment.

Sig.		Age					
		Stage 1		Stage 2		Stage 3	
		Sheffield	Taipei	Sheffield	Taipei	UK	TW
Convenient	for work	0.39	0.19	0.27	0.44	0.47	**0.00**
	for transport	0.07	0.19	0.00	0.24	**0.00**	0.36
	for school, shop	0.43	0.5	0.05	0.94	0.74	0.29
Recreational		**0.01**	**0.09**	**0.00**	**0.07**	0.89	**0.00**
Social		0.09	0.47	0.01	0.15	0.04	**0.00**
Safety		0.3	0.83	0.03	0.78	0.11	0.7
Property price		**0.00**	0.43	**0.00**	0.70	**0.00**	**0.00**
Quiet		**0.00**	0.52	**0.00**	0.83	**0.04**	**0.00**
Views		**0.00**	0.67	**0.00**	0.69	**0.03**	**0.00**
House size		**0.00**	0.17	**0.00**	0.45	0.05	0.37
Interior decoration		0.76	0.74	0.49	0.47	0.05	0.44

In order to know the differences concerning the effects current living experiences might have on choosing a place to live, the differences between current living environments and choosing a living environment in stages 2 and 3 are examined, as shown in Table 4.27. It can be seen that there are different factors in both stages and countries. Again, this makes clear that different regions can have differences, in terms of environmentally sustainable acoustics, which should always be considered in the development of each area. It is clear THAT culture affects people's perception in terms of choosing a living environment and also that demographic factors can have different effects in different regions.

Table 4.27 The significance level of the correlations between current living condition and choosing a living environment.

Sig.		Living environment			
		Stage 2		Stage 3	
		Sheffield	Taipei	UK	TW
Convenient	for work	**0.01**	0.22	0.84	0.25
	for transport	0.54	0.17	0.60	0.15
	for school, shop	0.55	**0.02**	0.91	0.70
Recreational		0.79	0.03	0.21	0.67
Social		**0.00**	0.07	0.19	0.89
Safety		**0.00**	0.07	0.70	0.79
Property price		0.03	0.46	0.10	**0.02**
Quiet		0.02	0.60	0.94	0.52
Views		**0.00**	0.13	**0.09**	**0.00**
House size		0.02	0.03	0.70	0.17
Interior decoration		0.41	**0.01**	0.94	0.13

4.5.3 General Living Environment

Table 4.28 compares the different perception of general living environment in the three stages. Comparison between stage 1 and stage 2 results shows insignificant difference between the two stages. Comparison between stage 2 and stage 3 shows a noticeable difference on sound quality in living areas in both countries. A possible reason is that survey areas were focused on Sheffield and Taipei in stage 2 and spread through the UK and Taiwan in the urban areas of stage 3. In other words, the urban texture and social aspects might have affected responses, but there are no certain answers which can explain the effect on people's perceptions.

Table 4.28 Evaluations of living environment and sound quality of the living area and home.

Mean	Stage1		Stage2		Difference %		Stage2		Stage3		Difference %	
	Shef	TP	Shef	TP	Shef	TP	Shef	TP	UK	TW	Shef-UK	TP-TW
General living environment	1.81	2.43	1.82	2.36	0.55	-2.97	1.82	2.36	2.26	2.65	19.47	10.94
Sound quality of living area	2.16	2.44	1.79	2.49	-21.00	2.01	1.79	2.49	2.23	2.95	19.73	15.59
Sound quality of home	1.95	2.59	2.13	2.65	8.45	2.26	2.13	2.65	2.25	2.74	5.33	3.28

4.5.4 Environmental Pollution

Table 4.29 compared rankings from stage 1 and stage 2; it can be seen that there was a sizable response on noise pollution as well as on air pollution, for both stages.

Table 4.29 Ranking of various types of environmental pollution.

	Stage1		Stage2	
	Sheffield	Taipei	Sheffield	Taipei
	Rank	Rank	Rank	Rank
Water pollution	4	3	4	3
Air pollution	**1**	**1**	**2**	**1**
Noise pollution	**2**	**2**	**1**	**2**
Waste pollution	3	4	3	4

4.5.5 Main Activities

The differences in main activities when the interviewee stayed at home are shown in Table 4.30; it can be seen that there is insignificant difference between stage 1 and stage 2 in both cities. Conversely, there are noticeable differences between stage 2 and stage 3 in both countries. Interestingly, similar activities are shown among local inhabitants but there are differences when surveying the whole of the UK and Taiwan.

Table 4.30 Main activities at home (%), where multiple choices were allowed

	Stage1		Stage2		Difference %		Stage2		Stage3		Difference %	
Activities	Shef	TP	Shef	TP	Shef	TP	Shef	TP	UK	TW	Shef-UK	TP-TW
Reading	61	35	63	38	3.17	7.89	63	38	47	55	-33.11	31.32
TV	54	85	57	81	5.26	-4.94	57	81	53	83	-7.55	2.41
Music	55	9	57	5	3.51	-80.00	57	5	613	38	7.06	86.84
Others	41	29	45	29	8.89	0.00	45	29	35	60	-29.80	51.93

4.5.6 Noise Sources: Noticeability, Annoyance, And Sleep Disturbance

In terms of the comparison between stage 1 and stage 2, the ranking of noticeability of sound sources is shown in Table 4.31. It can be seen that the main effects are from traffic noise sources in Sheffield and the most noticeable noise is from two wheelers in Taipei, in both stages.

Table 4.31 Ranking of noticeability noise sources.

		Noticeability			
		Stage1		Stage2	
		Sheffield	Taipei	Sheffield	Taipei
Traffic	Light vehicle	3	4	3	3
	Medium vehicle	2	5	2	6
	Heavy vehicle	1	6	1	4
	Two wheeler	10	1	8	1
Nearby	School	11	7	11	9
	Shops	9	8	9	9
	Recreation, leisure facilities	7	12	7	11
	Transportation stations	8	13	10	12
	Events	6	10	6	7
Neighbours	Talking, music, TV	5	3	5	2
	Air-conditioning	13	9	13	8
Own home	Talking, music, TV	4	2	4	5
	Air-conditioning	12	11	12	10

In order to determine the correlation between the results of stage 1 and stage 2, the correlations between stage 1 and stage 2, in both cities are shown in Figure 4.10. It can be seen that significant correlation was shown in Sheffield, R^2=0.96 as well as Taipei. This demonstrates that noticeable noise sources in an area can have very different effects on people's perception and this requires better understanding of how these noise sources can affect people in terms of planning environmentally sustainable acoustics.

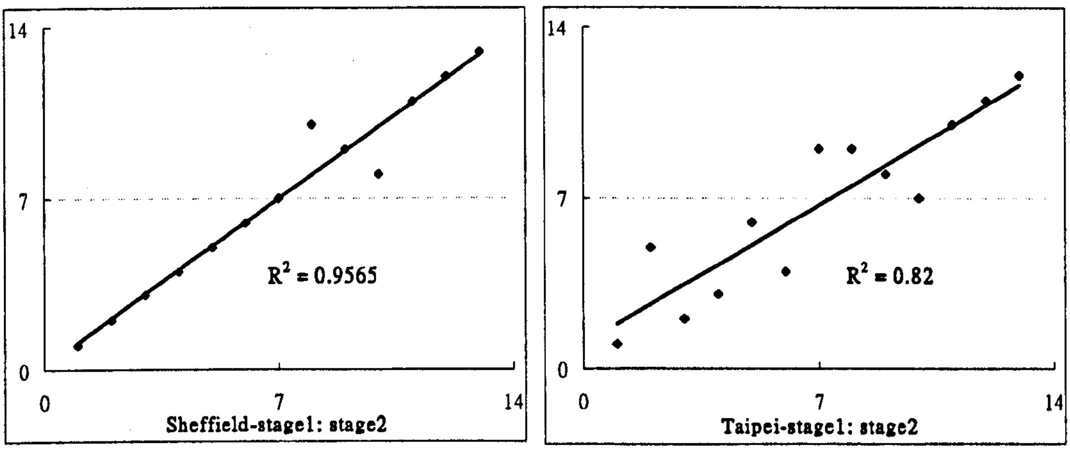


Figure 4.10 Correlations between the rankings of noticeable noise sources in Sheffield (left) and Taipei (right), in the two stages.

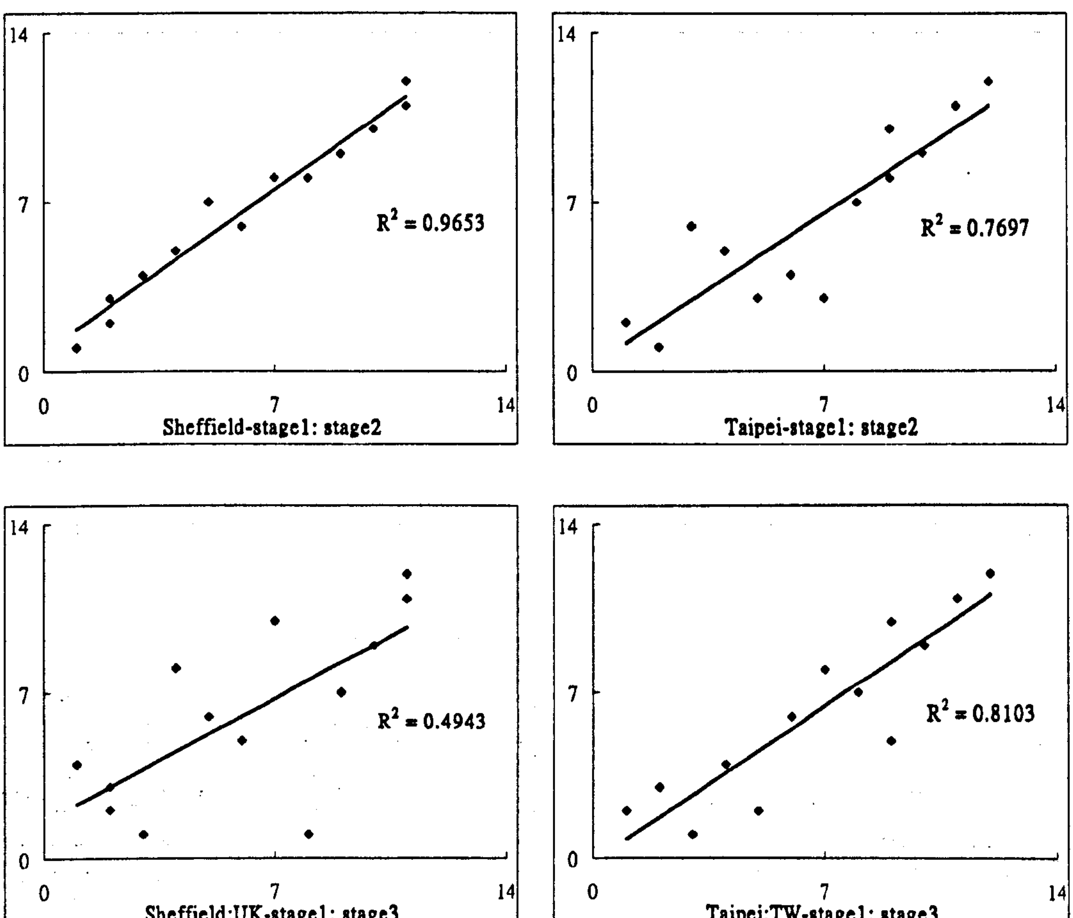
Table 4.32 shows the differences in all three stages of annoying noise sources and the insignificant differences between stage 1 and stage 2 is again shown.

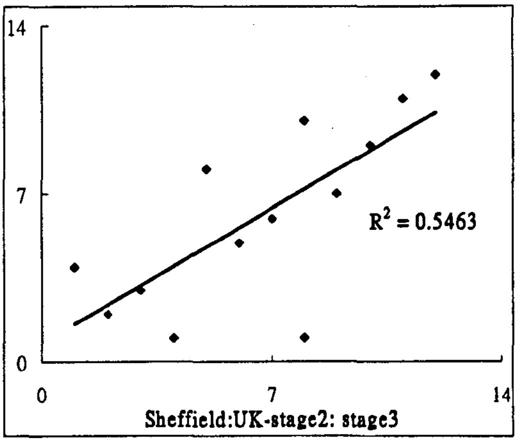
Table 4.32 Ranking of annoyed noise sources.

		Annoyance					
		Stage1		Stage2		Stage3	
		Sheffield	Taipei	Sheffield	Taipei	UK	Taiwan
Traffic	Light vehicle	2	5	2	3	2	2
	Medium vehicle	2	4	3	5	3	4
	Heavy vehicle	1	6	1	4	4	6
	Two wheeler	6	2	6	1	5	3
Nearby	School	10	9	10	8	9	10
	Shops	9	10	9	9	7	9
	Recreation, leisure facilities	5	11	7	11	6	11
	Transportation stations	7	12	8	12	10	12
	Events	4	7	5	3	8	8
Neighbours	Talking, music, TV	3	1	4	2	1	2
	Air-conditioning	11	8	11	7	11	7
Own home	Talking, music, TV	8	3	8	6	1	1
	Air-conditioning	11	9	12	10	12	5

It is interesting to observe the similar ranking results in both the UK and Taiwan. Comparing stage 2 and stage 3, the most annoying level changed from heavy vehicles to neighbours and own homes in UK, and two wheelers changed to own homes in Taiwan.

In terms of annoying noise source ranking between the three stages in two countries, further correlation is illustrated in Figure 4.11. There was a significant correlation as seen between stage 1 and stage 2 in Sheffield but there is no such a strong tendency when comparing stage 1 with stage 3, and stage 2 with stage 3. The correlations of Taiwan show that strong correlations appear between stage 1 and stage3, as well as stage 1 and stage 2, and relatively insignificant correlation shows between stage 2 and stage 3.





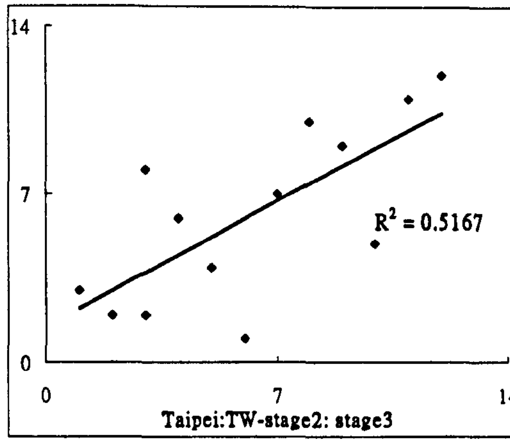


Figure 4.11 Correlations between the rankings of annoyingly noise sources in the UK and Taiwan, in three stages.

The results from ranking of sleep disturbance from various noise sources are illustrated in Table 4.33. Similar results are shown between stage 1 and stage 2, in both cities but no clear correlation between stage 1 and stage 3, or stage 2 and stage 3 in either country.

Table 4.33 Sleep disturbance of various noise sources.

		Sleep disturbance					
		Stage1		Stage2		Stage3	
		Shef	TP	Shef	TP	UK	TW
Traffic	Light vehicle	3	4	4	4	2	2
	Medium vehicle	2	4	2	5	4	4
	Heavy vehicle	1	5	1	3	3	7
	Two wheeler	7	2	5	1	5	3
Nearby	School	10	9	10	10	10	10
	Shops	9	10	10	11	7	9
	Recreation, leisure facilities	6	11	7	12	6	11
	Transportation stations	8	12	8	13	9	12
	Events	5	6	6	7	8	8
Neighbours	Talking, music, TV	4	1	3	2	1	1
	Air-conditioning	11	7	11	8	12	6
Own home	Talking, music, TV	9	3	9	6	1	1
	Air-conditioning	12	8	12	9	11	5

In order to evaluate the correlation between the three stages, Figure 4.12 shows the correlation of sleep disturbance. It can be seen there is strong correlation between stage 1 and stage 2 in both cities. Comparison between stage 1 and stage 3 shows less strong correlation in the UK and rather strong correlation appears in Taiwan but there was a lower tendency between stage 2 and stage 3 in either country.

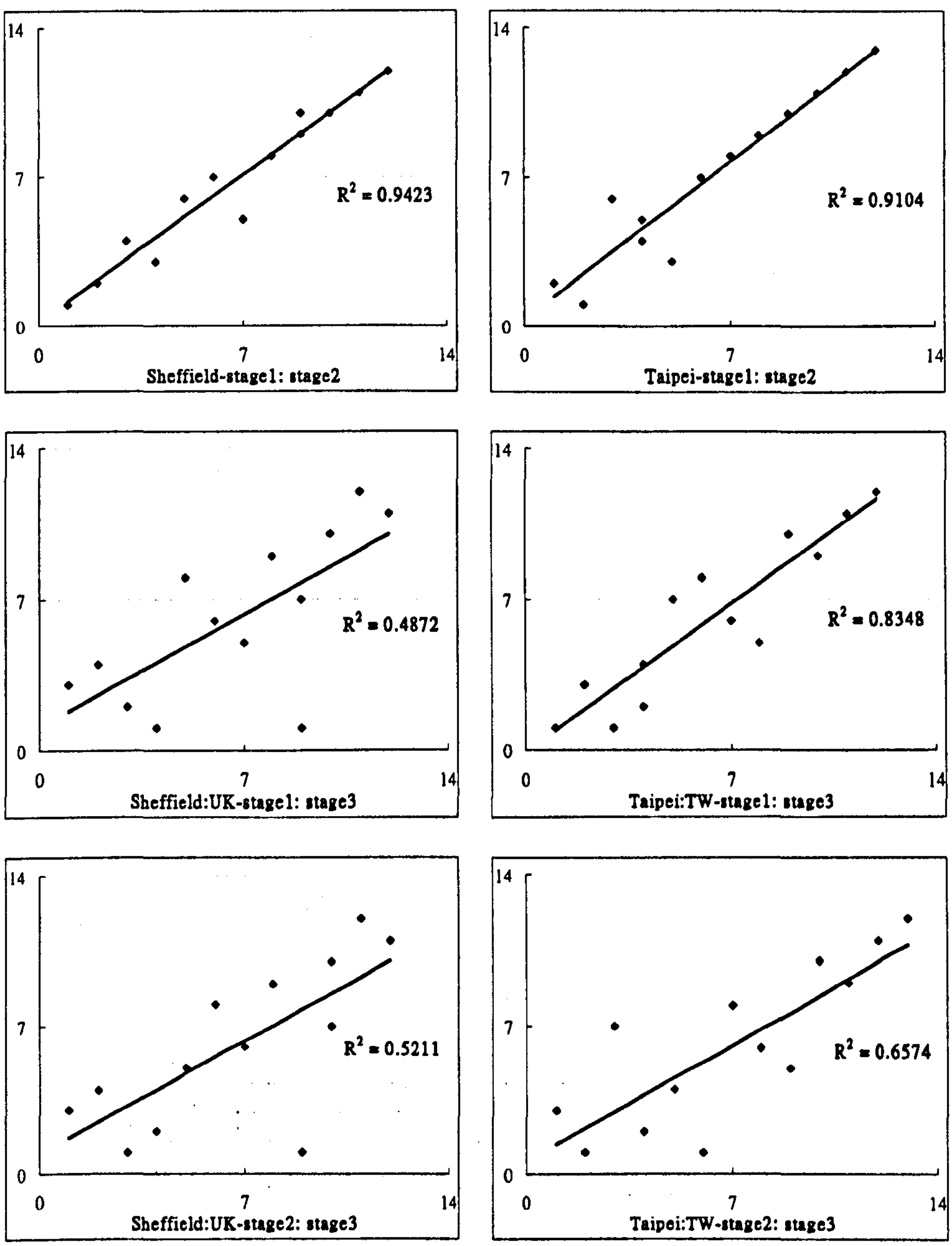


Figure 4.12 Correlations between the rankings on noise sources of sleep disturbance in the UK and Taiwan, in three stages

In regard to the ranking of noticeability, annoyance level and sleep disturbance with typical sound sources in residential areas, showed similar results between various noise sources in particular, between stage 1 and stage 2 but no less strong tendency between stage 1 and stage 3, or stage 2 and stage 3. This is possibly because stage 3 contains samples from a wider range of residents.

4.5.7 Sound Preference

In order to create environmentally sustainable acoustics in urban residential areas, the preferred sounds have been investigated. Table 4.34 shows the ranked results of most preferred sound as well as second most preferred sound across the three stages. It can be seen that a sizable number of interviewees in Sheffield responded that insect sounds are their most preferred sound in both stage 1 and stage 2 and they were the second most preferred sound in Taipei. A particularly interesting point was attempting to look at people's attitudes towards preferred sounds, which can be divided into two categories, namely artificial sound and natural sound. Overall, across the three stages, results showed no clear tendency for people to prefer artificial sound or natural sound.

Table 4.34 Preference for various, potentially positive sounds, with 1 as yes (selected) and 2 as no.

Stage1				Stage2				Stage3			
Shef		TP		Shef		TP		UK		TW	
Insect sounds	1	**Water**	1	**Insect sounds**	1	**Other sounds**	1	**Other sounds**	1	**Other sounds**	1
Outside music	1	Insect sounds	2	Outside music	2	Insect sounds	2	Water	2	Insect sounds	2
Other sounds	2					Water	2				

4.5.8 Summary

In the final part of the chapter, the comparative results show similar tendencies between stage 1 and stage 2 in both cities but such strong similarities in stage 3. This is mainly because the third stage survey was carried out in different regions in each country and presents different tendencies in different cities. The different tendencies should be considered in environmentally sustainable acoustics at the early planning stage.

4.6 DISCUSSIONS AND CONCLUSIONS

Overall, the survey results show that people's perceptions of their living environment can be affected by different cultural and social factors, as well as their living experiences. It is therefore essential to consider objective and subjective factors in terms of environmentally sustainable acoustics. This is because the creation of a sustainable living environment should taken into consideration to a number of factors which cannot be determined from one single factor. Clearly, environmental acoustic sustainability must maintain a good balance of physical comfort and psychological comfort.

The interactions between people's perception and environmental acoustics have been examined by considering various social factors. Both subjective and objective factors were considered. The social factors within two different cultural backgrounds were noted: these showed the significance of considering environmentally sustainable acoustics. The main results are:

1. In stage 1, the comparative study in the UK and Taiwan reveals the importance of considering cultural factors as well as urban texture and building types in evaluating urban sound environment.
2. In second stage, the comparative results are similar to those of the first stage and there are significant differences between the two cultures in a number of aspects, including choosing and evaluating living environment, noise noticeability, annoyance and sleep disturbance, activities, and sound preference.
3. A number of social factors were included, and demographic factors, personal perception and experience, unwanted sounds and sound preferences all have certain effects.
4. Throughout all the stages, it can be seen that a quiet environment is greatly preferred in both cultures, followed by certain positive sounds, and the most unwanted sounds are traffic sounds, as expected.
5. Overall, in the three stage surveys, it can be demonstrated that environmental acoustics is an important aspect of the urban living environment.

Chapter 5

Acoustic sustainability, environmental impact and buildings' life cycles

5.1 INTRODUCTION

The concept of sustainable living provides a number of significant challenges. In the UK the concept is being converted into viable building designs, as well as industrial standards (Yu and Kang, 2007c). In recent years, people have become more concerned about environmental sustainability, and the concept of sustainability has been expanded to much wider areas. As mentioned previously, a number of specialists in different fields need to work together in order to remove technical obstacles and to enable the delivery of sustainable living. Whilst acoustics often present obstacles to the sustainability process rather than solutions at present, there is a need to begin to resolve the challenges of delivering sustainable living, and simultaneously improve our quality of life and provide better acoustic comfort. Clearly, acoustics alone cannot provide all of the solutions, but are a crucial part of the step towards building a more complete picture for sustainable living (Yu and Kang, 2005; Yu and Kang, 2006a; Yu and Kang, 2006b; Rogers, 2006).

From the environmental impact point of view, the building industry has had significant impact on the overall environment. Residential buildings represent a large proportion of the built environment, and their design is vital for overall sustainability. Acoustics are an important consideration in residential buildings, in terms of sound insulation of external and internal noises, as well as sound absorption in various rooms. However, little attention has been paid to the sustainability and environmental impacts of various acoustics-related materials and building elements. When an acoustic target is given, there is often a range of materials which could have similar acoustic performances, and consequently, the choice of materials could be based on their sustainability performances.

In terms of environmentally sustainable acoustics, the viewpoint of building sustainability provides the potential to explore the means of having minimum impact on the environment. As a number of building elements are relevant to creating a sustainable building, a consultation document (DCLG, 2006) was produced which aimed to improve daytime lighting, sound insulation, and security. Part E of the British Building Regulations (2003) established a number of regulations which can provide protection against sound within residential and school buildings. Such regulations, relevant to sound effects of building elements include internal walls, internal floors, ceilings and doors as well as various acoustic materials, and room acoustic performances. Environmentally sustainable acoustics have a significant relevance to building sustainability. As mentioned in the context of this thesis, environmentally sustainable development can never stand alone; rather, it should always be considered with its essential and typical features.

Furthermore, one of the major influences on using sustainable building techniques to examine sustainable acoustics is the fact that acoustic materials and performances are always relevant to a building's lifespan. Different elements should always work together to focus on decreasing environmental impact and providing sustainability to the environment. Moreover, it would be an unsustainable development if different components worked only individually.

This chapter attempts to explore the growing importance of environmental sustainable development from the viewpoint of buildings' life cycle assessment. In this context, it focuses on examination of the essentially current situation from the wider aspect of a building's lifespan, as well as relating to a number of factors of environmentally sustainable acoustics. The study of environmentally sustainable acoustics is currently rather narrow compared with the wider range of environmentally sustainable development. However, buildings' sustainability can be a very appropriate example as it highlights environmentally sustainable impacts as the most important consideration. It also has similar principles to environmentally sustainable acoustics. The aim of this chapter is therefore to examine the differences in sustainability between various architectural acoustic materials/elements, in various situations, from external envelopes to interior finishing. Section 5.2 describes the methods used in this chapter. Section 5.3 is a series of comparative studies on five building types. In Section 5.4, a number of typical building envelopes are considered. Section 5.5 is a series of comparative studies of typical rooms. The final section describes the results overall from the various sections and attempts to show that environmentally sustainable acoustics has a significant relationship to a building's sustainability, which, in its wider significance, relates not only to building acoustics but also to overall environmental sustainability.

5.2 METHODOLOGY

A building's lifespan has various impacts from different environmental factors. Consequentially, it is difficult to compare one environmental impact with another impact and give an overall evaluation regarding which one is more hazardous than another. In an attempt to evaluate each standard unit of building impact, the Building Research Establishment (BRE) has divided each standard unit into five parts, namely, extraction, production, distribution, use and disposal which are main procedures used in construction. Those five parts include extraction of minerals, waste to landfill, total primary energy, carbon dioxide to air, sulphur dioxide to air, oxides of nitrogen, heavy metals to air, heavy metals to water, particulates, water use, financial costs, maintenance frequency and costs, transportation at all stages and its associated pollutants, end of life recycling potential, and final disposal (Anderson, et al., 2002). Complex environmental factors cannot be evaluated using one simple method, but it might be possible to find a balance between them.

5.2.1 Buildings' Life Cycle Assessment Software

Envest

Envest is a buildings' LCA software which was developed by BRE; it has established a weighting system to evaluate the overall environment and the results are shown in Ecopoints (BRE, 2000). In order to illustrate that weighting system each Ecopoint takes the normalized data and compares it to a weighted factor illustrating the essentials of the pollution problems and the factors are surveyed by the BRE. These weighted factors were measured and gathered through extensive survey across the UK in the construction industry and incorporated into a research program which offers consensus on weight sustainable construction issues. The weighting system covers most essential issues, such as environmental, social, as well as economic issues, and each UK Ecopoint score is a measure of the overall environmental impact of a particular product or process (BRE, 2000). A number of normalization factors in the weighting system, include climate change, fossil fuel depletion, ozone depletion, freight transport, human toxicity to air, human toxicity to water, waste disposal, water extraction, acid deposition, ecotoxicity, eutrophication, summer smog and mineral extraction, were all considered in the weighting system. To aid interpretation, Ecopoints are derived so that the annual environmental impact caused by a typical UK citizen creates 100 Ecopoints. More Ecopoints indicate higher environmental impact. The results can be shown in embodied Ecopoints in structure/construction and operational Ecopoints are also considered. The range of options provided means for Envest to assess different impact issues and display their results in many different pollution categories; to sum up the results included:

1. The proportion, embodied and operational
2. The whole life costs, embodied and operational
3. Embodied environmental breakdown
4. Embodied elemental breakdown
5. Embodied whole life cycle elemental breakdown
6. Operational elemental breakdown
7. Operational whole life cycle elemental breakdown
8. Embodied environmental breakdown
9. Operational environmental breakdown
10. Ecopoints environmental breakdown
11. Services, embodied and operational
12. Services whole life cycle, including embodied and operational
13. Services, embodied
14. Services whole life cycle, embodied

15. Services, operational

In this chapter, the software package Envest (2006) was used to assess the environmental impacts of entire buildings as well as individual rooms. In Envest the input parameters are divided into three categories: (1) building details including geological location, building length, building width, number of storeys, floor areas, storey height, external wall areas, internal wall areas, internal door areas, glazing ratio, internal door ratio, percentage of cellular space, operational life time, and occupancy area per person; (2) building fabric and structure, including material details for each building component, divided by layers and with maintenance details; (3) building services including heating, lighting and ventilation, both installation and maintenance. Whilst Envest is mainly used for office buildings, in this thesis the input parameters were adjusted so that relative comparisons could be made for residential buildings.

Except where indicated, parameters and configurations used in this study included natural ventilation, gas central heating radiators, 10W lighting per m^2, 365 days per year, building operational life of 60 years, and the UK Thames Valley location. On the other hand, the system does not indicate indoor quality conditions such as air, room temperature, and sound. Therefore, for the sake of convenience, building services and maintenance were kept to a minimum, as the comparisons were mostly relative.

Ecotect

Ecotect v5.20 (2005) is a buildings' analysis software which can illustrate building design in a visual 3D model. The software package contains a wide range of performance analyses and simulation functions that can assess the early stages of conceptual design as well as reconfirming final designs. The performance analyses' main components are building shading, shading design, solar exposure, building lighting, thermal performance, building heating and cooling loads, building cost, environmental impact, embodied energy, greenhouse gas emissions, and acoustic analysis. For example, it can start analysis from a detailed climatic analysis to assess the potential environmental impacts by processing various factors: such factors as solar, light and wind resources. During the design process, these ideas can be illustrated in visual 3D models then gradually developed to an advanced stage, which can help in each idea to actually know what environmental impact it might have and what is behind the idea. This can be described as a similar principle to environmentally sustainable development which cannot be considered from a single aspect but should always try to cover all aspects. Furthermore, Ecotect can be an interactive approach to assessment; for example, when a design replaces a finished layer of the floor then related effects, including acoustic, light and thermal effects are all changed. On the other hand, from the acoustics point of view, for this chapter, the use of Ecotect was considered for showing building sustainability in a 3D model. It has a clear visual display, but after a number of cases were analysed, some invalid acoustic results were detected. Consequentially, the study uses Ecotect only in relation to certain environmental factors.

5.2.2 Analysis

The analysis in this chapter was carried out at three levels, in terms of building types, building envelopes of a typical building type (apartments), and individual rooms. It tries to view from residential buildings and then into spaces. These three levels are all relevant to environmentally sustainable acoustics and can therefore illustrate that acoustic aspects are part of environmentally sustainable development.

Building types

Five typical residential building types were first compared, including bungalow, detached, semi-detached, terraced, and apartments. The aim was to examine the differences in Ecopoints between various building types, so that a base line could be set. For each building type similar configurations were assumed, including three bedrooms, a lounge, a dining room, a kitchen and toilets. In Figure 5.1 the plans of each building type are illustrated. They are all based on typical layouts/designs in the UK. Correspondingly, the relevant parameters are given in Table 5.1.

For each building type, two typical wall materials were compared, brick and stone, which have similar acoustic performance. Building envelopes are often related to acoustic issues, especially for reducing external noise. For each building type, three levels of glazing ratio were considered, the ratios from the actual design of each building type, namely, 15% for bungalows, 8% for detached, 14% for semi-detached, 7% for terraced houses, and 13% for apartments; and two nominal ratios, 10% and 20% the former was approximately based on the average glazing ratio of various building types, and the latter represented increased ratios in contemporary buildings. Glazing ratio is related to many sustainability issues including lighting, ventilation, heat loss and noise. Encouraging the use of natural ventilation is an important aspect of the green building movement, but opening windows can often cause noise problems. On the other hand, a window with two or more layers of glass could bring benefits in both energy saving and noise reduction.

Building envelopes

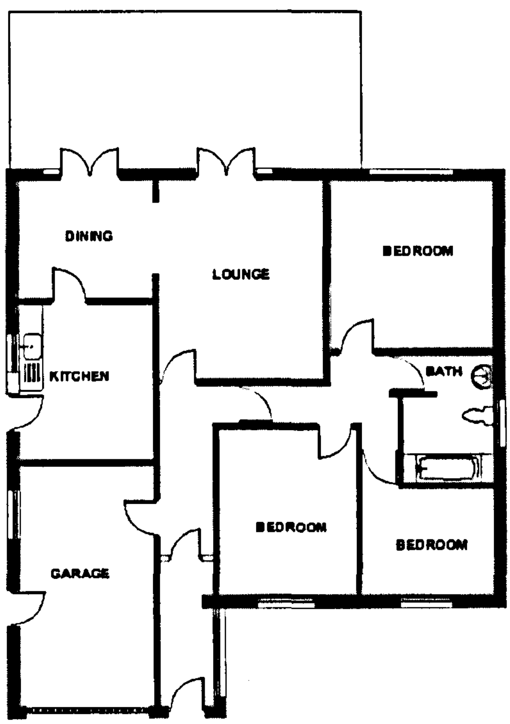
More detailed analysis was made of the apartment buildings studied above, given that in recent years, living in apartments has become increasingly popular, especially in urban areas. The effects of wall type (brick, concrete, and glass curtain), roof type (pitched and flat) and number of storeys (2-4) were examined.

Typical rooms

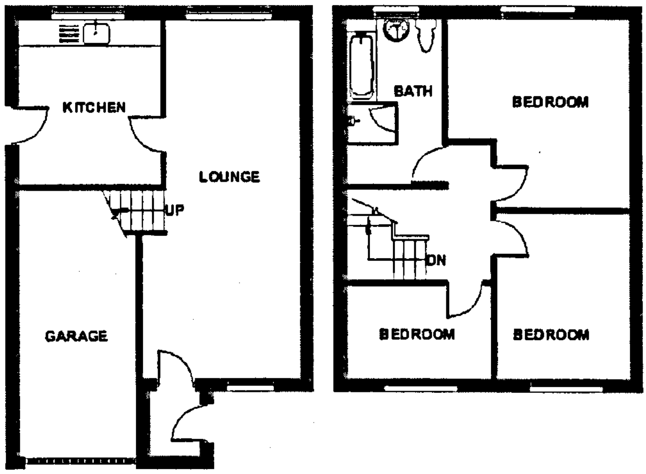
Detailed analysis was made of two typical rooms, a living room and a bedroom, with a given reverberation time (RT) and sound transmission loss but different combinations of materials. This is important since in recent building regulations there are more strict requirements for residential buildings. For example, according to the Building Regulations Part E (2000), the common internal parts of buildings containing dwellings and buildings containing a room or rooms for residential purposes shall be designed and constructed so as to prevent more reverberation than is reasonable around the common internal parts. In the recent consultation document "Proposals for Introducing a Code for Sustainable Homes" (2005), acoustic issues including reverberation and sound insulation were also considered. For each room, a number of scenarios were considered, in terms of single components such as wall/ceiling/floor, and their combinations. The RT was evaluated using the Eyring formula, and the sound insulation was evaluated using the sound transmission loss of the whole room envelope:

$$R = 10\log(\sum_{n=1}^{6} S_n / \sum_{n=1}^{6} \tau_n S_n) \qquad (1)$$

where τ_n and S_n are the sound transmission coefficient and surface area of element n.



BUNGALOW



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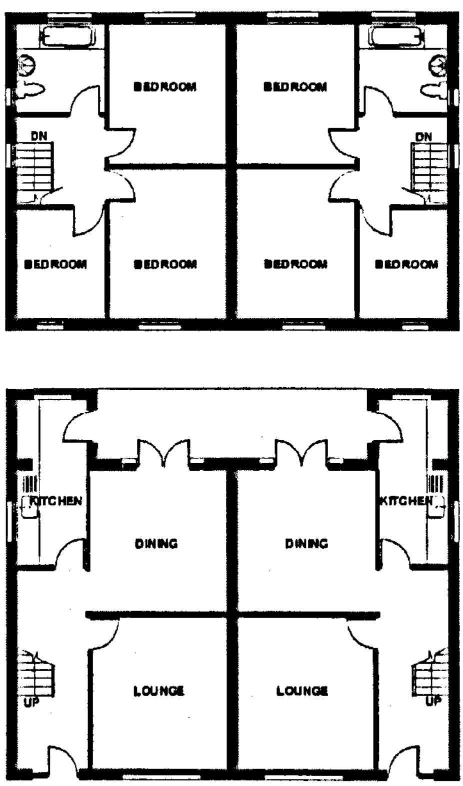

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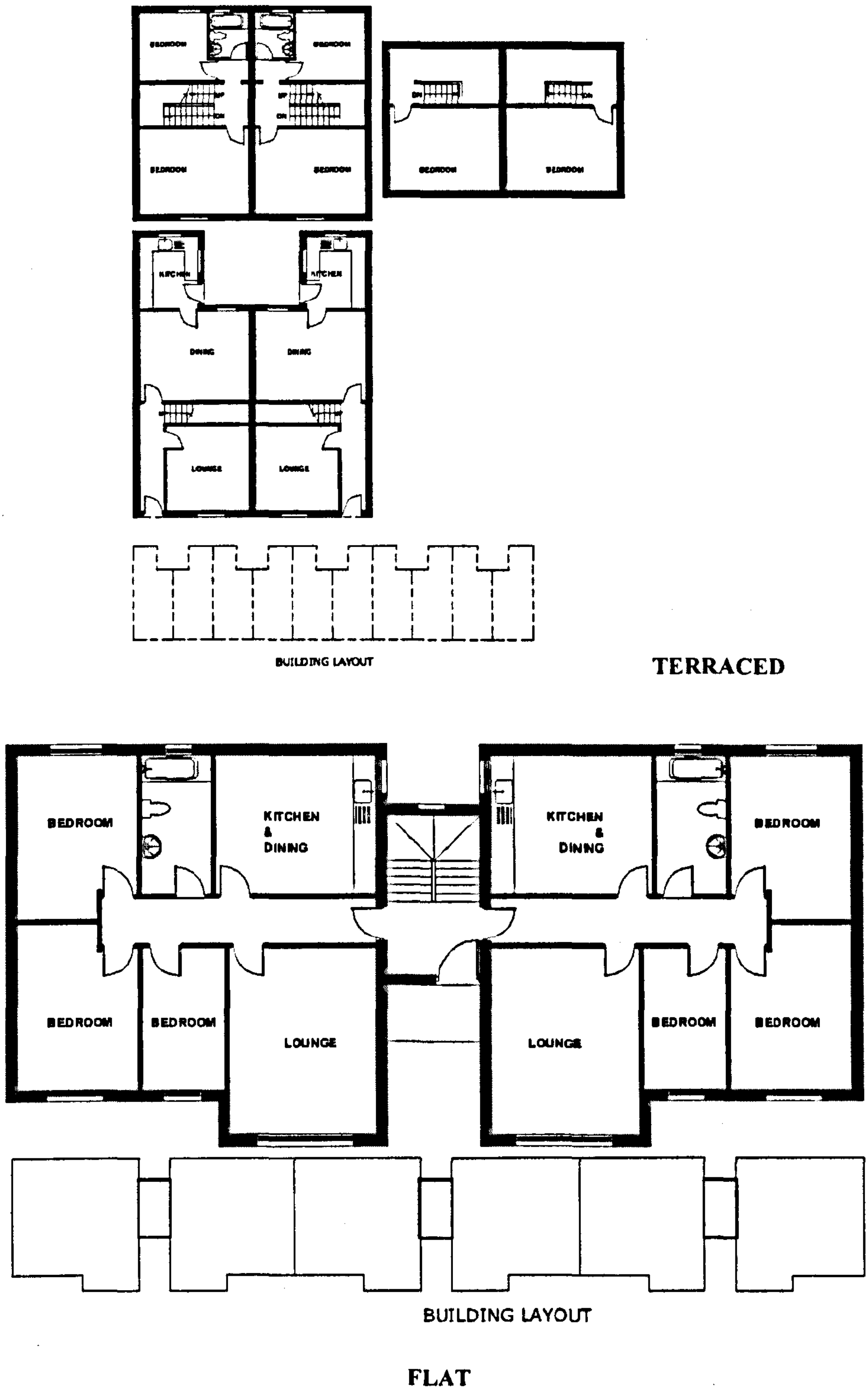


Figure 5.1 Plans of various building types.

Table 5.1 Building types and details used in the calculation.

		Bungalow	Detached	Semi-detached	Terraced	Apartment
Floor area, m^2		148	132	231	1530	1892
Storey		1	2	2	3	3
Building height, m		3	6	6	9	9
External wall area, m^2		155	200	258	1244	1775
Internal wall area, m^2		151	83	249	1811	1831
Window area, m^2		23	15	36	93	232
Glazing ratio %		15	8	14	7	13
Internal door area, m^2		19	12	29	157	220
Internal door ratio %		12	14	12	9	12
Occupancy, m^2/per person		50	40	40	50	35
Structures		column base foundation				
External walls	Brick	brick 205mm thick and sand cement 13mm thick				
	Stone	sandstone 275mm thick and sand cement 13mm thick				
Internal walls		brick 102.5mm thick and sand cement 13mm thick				
Ground floor		concrete 225mm thick and sand cement 25mm thick				
Upper floor		precast concrete slab 150mm thick and sand cement 25mm thick				
Window		double glazed PVCu windows				
Roof		pitched roof				
Floor finishing		nylon carpet				
Wall finishing		gloss paint				
Ceiling finishing		joint less lightweight plaster on metal suspended, emulsion paint				

5.3 BUILDING TYPES

5.3.1 Building Types

Table 5.2 compares the Ecopoints per m^2 of building area among the five building types. It can be seen that in terms of embodied Ecopoints in structure/construction, the ranking of the five building types is terraced (brick 3.57, stone 3.70), apartment (brick 4.14, stone 3.73), semi-detached (brick 4.27, stone 4.58), bungalow (brick 4.34, stone 4.80) and detached (brick 4.58, stone 4.81), which corresponds to the common understanding. In terms of operational Ecopoints, the ranking is rather different, namely bungalow (brick 12.95, stone 13.16), semi-detached (brick 13.48, stone 13.67), detached (brick 14.82, stone 15.48), apartment (brick 15.08, stone 15.26), and terraced (brick 15.56, stone 16.33). This is probably due to the effect of building shapes. Further comparison between the detached and terraced houses shows that the heat loss of each component is walls 55%, roof 20%, floor 20% and windows 5% for the former; and walls 49%, roof 23%, floor 23% and windows 4% for the latter.

Table 5.2 Embodied and operational Ecopoints per m^2 of building area with five building types, considering both brick and stone external walls.

	Embodied									
	Bungalow		Detached		Semi-detached		Terraced		Apartment	
	Brick	Stone	Brick	Stone	Brick	Stone	Brick	Stone	Brick	Stone
Climate Change	1.29	1.22	1.42	1.14	1.33	1.28	1.13	0.99	1.49	1.1
Acid Deposition	0.25	0.28	0.27	0.28	0.25	0.33	0.21	0.22	0.24	0.23
Ozone Depletion	0.01	0.01	0.01	0.01	0	0	0	0	0.01	0.01
Human Toxicity Air	0.24	0.32	0.25	0.35	0.23	0.31	0.19	0.24	0.22	0.26
Ozone Creation	0.09	0.09	0.08	0.08	0.09	0.09	0.08	0.08	0.05	0.04
Human Toxicity Water	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01
Eco Toxicity Water	0.04	0.2	0.05	0.27	0.03	0.23	0.02	0.15	0.04	0.17
Eutrophication	0.09	0.14	0.09	0.14	0.08	0.13	0.07	0.1	0.09	0.11
Fossil Fuel Depletion	0.42	0.39	0.46	0.36	0.43	0.39	0.37	0.32	0.38	0.3
Mineral Extraction	1.11	1.33	1.24	1.41	1.13	1.19	0.94	1.02	0.92	0.93
Water Extraction	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.02
Waste Disposal	0.75	0.76	0.67	0.73	0.64	0.59	0.53	0.54	0.66	0.56
Subtotal	4.34	4.8	4.58	4.81	4.27	4.58	3.57	3.7	4.14	3.73
Rank	4	4	5	5	3	3	1	1	2	2
	Operational									
	Bungalow		Detached		Semi-detached		Terraced		Apartment	
	Brick	Stone	Brick	Stone	Brick	Stone	Brick	Stone	Brick	Stone
Climate Change	6.95	7.08	7.98	7.83	7.26	7.38	8.73	8.84	8.12	8.24
Acid Deposition	1.59	1.59	1.77	1.77	1.6	1.61	1.36	1.95	1.78	1.78
Ozone Depletion	0	0	0	0	0	0	0	0	0	0
Human Toxicity Air	1.68	1.69	1.88	1.87	1.7	1.71	2.06	2.06	1.88	1.88
Ozone Creation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Human Toxicity Water	0	0	0	0	0	0	0	0	0	0
Eco Toxicity Water	0	0	0	0	0	0	0	0	0	0
Eutrophication	0.39	0.4	0.45	0.44	0.41	0.41	0.49	0.49	0.45	0.46
Fossil Fuel Depletion	2.14	2.2	2.49	2.42	2.27	2.32	2.72	2.77	2.56	2.61
Mineral Extraction	0	0	0	0	0	0	0	0	0	0
Water Extraction	0.18	0.18	0.23	0.23	0.23	0.23	0.18	0.18	0.26	0.26
Waste Disposal	0	0	0	0	0	0	0	0	0	0
Subtotal	12.95	13.16	14.82	14.58	13.48	13.67	15.56	16.33	15.08	15.26
Rank	1	1	3	2	2	3	5	5	4	4
Total Ecopoints/ m^2	17.29	17.96	19.4	19.39	17.75	18.25	19.13	20.03	19.22	18.99
Rank	1	1	5	4	2	2	3	5	4	3

From Table 5.2 it is also evident that the ratio between embodied and operational Ecopoints is about 1:9 on average, showing the significance of considering operational sustainability. The overall ranking, considering both embodied and operational

Ecopoints, is: bungalow (brick 17.30, stone 17.96), semi-detached (brick 17.76, stone 18.25), terraced (brick 19.13, stone 20.03), apartment (brick 19.22, stone 18.99), and detached (brick 19.39, stone 19.39). It should be noted that this ranking is only indicative and relative since the detailed building plans are not considered in Envest. Overall, it seems that the differences between the five building types are not very significant.

When comparing various embodied environmental impact factors, it can be seen that the Ecopoints in climate change and mineral extraction are significantly higher than those of the others. The UK Government has established a Climate Change Programme which contains international targets for monitoring of greenhouse gas emissions, carbon dioxide emissions and so on (BRE, 2006). This aims to reduce emissions to below 1990 levels by 2008-2012 (BRE, 2006). The mineral extractions are of ore and quarried materials which are natural resources. Mineral extraction can reduce the amount of resources, create dust, noise and local nuisance, reduce land availability for other uses, and potentially disrupt valuable ecosystems above and surrounding the mineral resource (BRE, 2006). In terms of building operational Ecopoints, climate change again has much greater effects than other factors.

Table 5.3 compares two external wall materials, brick and stone, in terms of both embodied and operational Ecopoints. For embodied Ecopoints, there are significant differences between brick and stone, in terms of Ecotoxicity: water, at about 80-85%; eutrophication, at about 20-35%; and human toxicity air, at about 13-28%. Toxicity water is related to aquatic and terrestrial ecosystems and might be caused by heavy metals, volatile organic contaminants, hydrofluorocarbons, chlorofluorocarbons, dioxins, nitrogen dioxide, polychlorinated biphenyls, pesticides, and herbicides. Also, it might have effects on both acute and chronic toxicity in ecosystems (BRE, 2006).

Table 5.3 Difference (%) in Ecopoints between brick and stone external walls.

	Bungalow		Detached		Semi-detached		Terraced		Apartment	
	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational
Climate Change	6.11	-1.81	23.84	1.94	4.05	-1.58	13.75	-1.33	36.37	-1.46
Acid Deposition	-9.76	-0.42	-2.70	0.00	-24.68	-0.54	-5.64	-30.39	4.65	-0.15
Ozone Depletion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	0.00
Human Toxicity Air	-25.00	-0.40	-28.26	0.40	-23.94	-0.51	-21.92	-0.19	-12.55	-0.17
Ozone Creation	0.00	0.00	0.00	0.00	-4.76	0.00	-0.79	-2.94	27.14	-2.56
Human Toxicity Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.91	0.00
Eco Toxicity Water	-80.00	0.00	-82.86	0.00	-85.19	0.00	-85.46	0.00	-79.39	0.00
Eutrophication	-35.00	-1.69	-36.84	1.72	-34.48	-1.05	-31.54	-0.93	-20.20	-0.93
Fossil Fuel Depletion	6.90	-2.77	29.79	3.13	11.24	-2.05	13.36	-1.91	25.17	-2.08
Mineral Extraction	-16.75	0.00	-11.83	0.00	-4.73	0.00	-7.70	0.00	-1.13	0.00
Water Extraction	0.00	0.00	0.00	0.00	16.67	0.00	5.56	0.00	38.46	0.00
Waste Disposal	-1.77	0.00	-9.28	0.00	8.82	0.00	-1.59	0.00	18.34	0.00
Subtotal	-9.44	-1.59	-4.88	1.66	-6.71	-1.36	-3.48	-4.73	11.05	-1.21
Embodied+Operational	-3.69		0.04		-2.70		-4.50		1.20	

For operational Ecopoints, the difference between brick and stone is much less, as expected. Overall, the differences between the buildings with the two envelope materials are insignificant, within about 5% for all building types, although between various building types the differences vary considerably.

5.3.2 Glazing Ratio

The comparisons in Table 5.2 are based on different glazing ratios. In order to determine the different environmental impact from different glazing ratios, a series of comparisons of the five building types are considered. In Table 5.4 a further comparison is made, with brick walls, between various building types with a constant glazing ratio, 10% or 20%. Compared with Table 5.2, it can be seen that the rankings of various building types are generally similar with the three glazing ratios, although the similarity is greater between 10% and 20%, than that between Table 5.2 and 5.4.

Table 5.4 Embodied and operational Ecopoints per m^2 of building area of five building types -comparison between different glazing ratios.

Embodied										
	Bungalow		Detached		Semi-detached		Terraced		Apartment	
	10%	20%	10%	20%	10%	20%	10%	20%	10%	20%
Climate Change	1.26	1.33	2.01	1.34	1.3	1.39	1.15	1.2	1.47	1.54
Acid Deposition	0.24	0.26	0.33	0.25	0.24	0.26	0.21	0.23	0.23	0.25
Ozone Depletion	0.01	0.01	0.01	0.01	0	0	0	0	0.01	0.01
Human Toxicity Air	0.24	0.25	0.32	0.23	0.23	0.25	0.19	0.2	0.22	0.24
Ozone Creation	0.09	0.09	0.14	0.08	0.09	0.09	0.08	0.08	0.05	0.05
Human Toxicity Water	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02
Eco Toxicity Water	0.03	0.05	0.05	0.03	0.03	0.04	0.02	0.03	0.03	0.04
Eutrophication	0.09	0.09	0.11	0.08	0.08	0.09	0.07	0.07	0.08	0.09
Fossil Fuel Depletion	0.41	0.43	0.64	0.43	0.42	0.45	0.37	0.39	0.37	0.4
Mineral Extraction	1.11	1.11	1.32	1.23	1.13	1.14	0.94	0.95	0.92	0.93
Water Extraction	0.04	0.04	0.05	0.03	0.03	0.03	0.02	0.02	0.03	0.03
Waste Disposal	0.75	0.75	0.7	0.67	0.64	0.64	0.53	0.53	0.66	0.66
Subtotal	4.28	4.44	5.7	4.39	4.2	4.39	3.6	3.74	4.1	4.25
Rank	4	5	5	4	3	3	1	1	2	2
Operational										
	Bungalow		Detached		Semi-detached		Terraced		Apartment	
	10%	20%	10%	20%	10%	20%	10%	20%	10%	20%
Climate Change	7.59	6.8	8.09	7.33	7.92	6.94	8.06	7.38	8.14	7.44
Acid Deposition	1.76	1.55	1.8	1.61	1.77	1.52	1.77	1.6	1.77	1.61
Ozone Depletion	0	0	0	0	0	0	0	0	0	0
Human Toxicity Air	1.86	1.65	1.91	1.7	1.88	1.61	1.88	1.7	1.88	1.7
Ozone Creation	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Human Toxicity Water	0	0	0	0	0	0	0	0	0	0
Eco Toxicity Water	0	0	0	0	0	0	0	0	0	0
Eutrophication	0.43	0.39	0.45	0.41	0.45	0.39	0.45	0.41	0.45	0.41
Fossil Fuel Depletion	2.32	2.09	2.52	2.3	2.46	2.18	2.53	2.33	2.57	2.36
Mineral Extraction	0	0	0	0	0	0	0	0	0	0
Water Extraction	0.18	0.18	0.23	0.23	0.23	0.23	0.18	0.18	0.26	0.26
Waste Disposal	0	0	0	0	0	0	0	0	0	0
Subtotal	14.17	12.68	15.03	13.6	14.73	12.88	14.9	13.62	15.1	13.79
Rank	1	1	3	5	2	2	4	3	5	4

Compared to the 10% glazing ratio, with the 20% glazing ratio, the embodied Ecopoints have generally slightly increased by about 3-4%; whereas the operational Ecopoints have decreased, by about 8-13%: possibly due to the use of natural light and ventilation.

5.4 BUILDING ENVELOPES

Based on the layout of the apartment building shown in Figure 5.1, a number of scenarios were considered, examining the effects of wall materials, roof type and the number of storeys. In the calculation steel frame was used, and other configurations were the same as those in Table 5.1, except where indicated.

5.4.1 Walls

Three wall materials were considered, brick (205mm thick), concrete (150mm thick), and glass curtain wall (two layer 6mm thick panes separated by a 100mm thick air gap). For the sake of convenience, the thickness of the walls was adjusted, so that their sound transmission loss was similar, as shown in Figure 5.2. The comparison of embodied and operational Ecopoints between the three wall types is shown in Table 5.5. In terms of the embodied Ecopoints, brick and concrete walls are similar, both lower than glass, by about 10%. In terms of operational Ecopoints, concrete is the highest, by about 20% greater than brick.

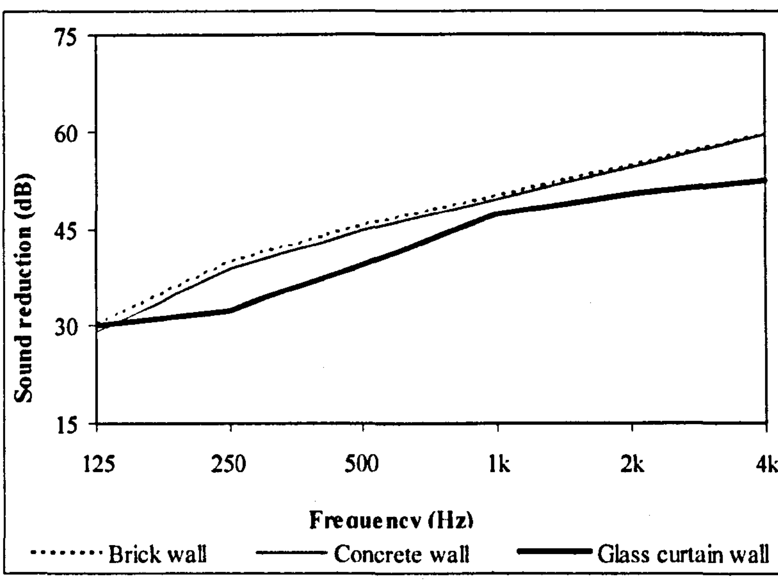


Figure 5.2 Sound transmission loss of three wall materials: brick, concrete and glass curtain wall.

Table 5.5 Comparison of Ecopoints (m^2) for apartment buildings using three wall materials.

	Embodied			Operational		
	Brick	Concrete	Glass	Brick	Concrete	Glass
Climate Change	1.72	1.63	1.94	8.12	10.50	9.53
Acid Deposition	0.26	0.25	0.33	1.78	1.86	1.60
Ozone Depletion	0.01	0.01	0.01	0.00	0.00	0.00
Human Toxicity Air	0.25	0.25	0.37	1.88	1.96	1.68
Ozone Creation	0.07	0.07	0.05	0.02	0.03	0.03
Human Toxicity Water	0.02	0.02	0.03	0.00	0.00	0.00
Eco Toxicity Water	0.04	0.04	0.13	0.00	0.00	0.00
Eutrophication	0.10	0.10	0.14	0.45	0.54	0.48
Fossil Fuel Depletion	0.44	0.40	0.52	2.56	3.62	3.35
Mineral Extraction	0.96	0.89	0.75	0.00	0.00	0.00
Water Extraction	0.04	0.04	0.04	0.26	0.26	0.26
Waste Disposal	0.68	0.82	0.63	0.00	0.00	0.00
Subtotal	4.58	4.52	4.95	15.08	18.78	16.93

If only the external walls are considered, the Ecopoints between various walls can differ more significantly: 1192 with brick, 1297 with concrete and 1761 with glass. Further simulation was made using Software Ecotect (2004), showing that compared to the envelope with brick walls, with concrete the greenhouse gas effect is 38% higher, and the embodied energy is 24% higher.

5.4 .2 Roof Type

In Table 5.6 comparisons are made between flat roofs and pitched roofs. For the flat roof, the main structure is concrete (150mm thick), with asphalt covering (20mm thick), and mineral wool insulation (80kg/m3, 150mm thick). The pitched roof uses timber and has a gabled end structure, covered with interlocking clay tiles, and the insulation is polyurethane (150mm). For embodied Ecopoints a pitched roof is generally more sustainable than a flat roof in terms of climate change, acid deposition, human toxicity air, ecotoxicity water, eutrophication, and waste disposal. Although in terms of human toxicity water and water extraction, the flat roof has fewer Ecopoints.

For operational Ecopoints, the difference between the two kinds of roof is insignificant, with an overall difference of about 0.3%.

Table 5.6 Comparison of Ecopoints (m^2) of apartment buildings between two different roof types.

	Embodied			Operational		
	Flat	Pitched	Difference %	Flat	Pitched	Difference %
Climate Change	1.81	1.72	5.54	8.10	8.12	-0.34
Acid Deposition	0.28	0.26	9.20	1.78	1.78	-0.06
Ozone Depletion	0.01	0.01	0.00	0.00	0.00	0.00
Human Toxicity Air	0.28	0.25	10.62	1.88	1.88	-0.06
Ozone Creation	0.07	0.07	-0.75	0.02	0.02	0.00
Human Toxicity Water	0.01	0.02	-27.03	0.00	0.00	0.00
Eco Toxicity Water	0.05	0.04	37.14	0.00	0.00	0.00
Eutrophication	0.10	0.10	8.33	0.45	0.45	-0.23
Fossil Fuel Depletion	0.46	0.44	3.70	2.54	2.56	-0.50
Mineral Extraction	1.03	0.96	7.31	0.00	0.00	0.00
Water Extraction	0.03	0.04	-14.29	0.26	0.26	0.00
Waste Disposal	0.76	0.68	12.37	0.00	0.00	0.00
Subtotal	4.90	4.58	7.13	15.03	15.08	-0.29

5.4.3 Number Of Storeys

Table 5.7 shows a comparison of apartment buildings with two, three and four storeys.

Table 5.7 Comparison of Ecopoints (m^2) of apartment buildings with different number of storeys.

	Embodied		
	2 storeys	3 storeys	4 storeys
Climate Change	1.75	1.72	1.75
Acid Deposition	0.26	0.26	0.26
Ozone Depletion	0.01	0.01	0.01
Human Toxicity Air	0.26	0.25	0.25
Ozone Creation	0.07	0.07	0.07
Human Toxicity Water	0.02	0.02	0.02
Eco Toxicity Water	0.04	0.04	0.04
Eutrophication	0.1	0.1	0.1
Fossil Fuel Depletion	0.46	0.44	0.45
Mineral Extraction	1	0.96	1
Water Extraction	0.04	0.04	0.04
Waste Disposal	0.71	0.68	0.67
Subtotal	4.72	4.58	4.65

	Operational		
	2 storeys	3 storeys	4 storeys
Climate Change	7.94	8.12	8.32
Acid Deposition	1.77	1.78	1.78
Ozone Depletion	0	0	0
Human Toxicity Air	1.88	1.88	1.89
Ozone Creation	0.02	0.02	0.02
Human Toxicity Water	0	0	0
Eco Toxicity Water	0	0	0
Eutrophication	0.45	0.45	0.46
Fossil Fuel Depletion	2.48	2.56	2.64
Mineral Extraction	0	0	0
Water Extraction	0.26	0.26	0.26
Waste Disposal	0	0	0
Subtotal	14.79	15.08	15.38

The number of storeys is relevant to the urban sound environment, in terms of source-receiver distance, as well as sound propagation in street canyons. From Table 5.7 it can be seen that in terms of Embodied Ecopoints, 3 storeys has the fewest, followed by 4 storeys and 2 storeys, although the differences are generally insignificant, within about 3%. In terms of operational Ecopoints, the Ecopoints increase with increasing storey number, although the increase is only within about 4%.

5.5 TYPICAL ROOMS

Two typical rooms, a living room (5.6m long, 3.2m wide and 3m high) and a bedroom (3.5m long, 4m wide and 3m high), were considered. Whilst the effect of each component was studied, typical configurations were: 205mm thick brick for external wall; 102mm thick brick for internal wall; 150mm thick concrete slab for floor; steel frame building structure; PVCu double glazed windows, and wooden doors. Firstly the effect of each component, including ceiling, floor and wall, was examined, and then a number of combinations of various components were considered. It should be noted that since Envest is mainly used for the analysis of a whole building, the analysis below, based on single rooms, is for relative comparisons only.

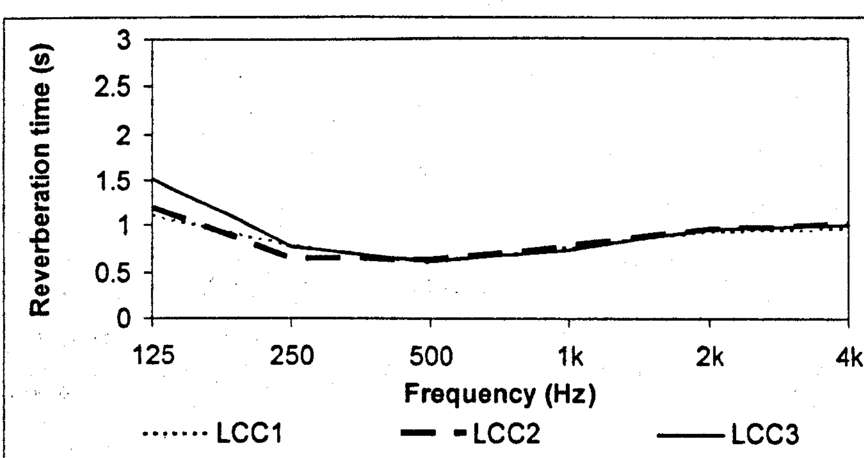
5.5.1 Living Room

Effect of each component

Table 5.8 compares the total Ecopoints (embodied and operational) between various finishes of each component, namely ceiling, floor and wall. In the table the embodied Ecopoints of each component are also shown. Correspondingly, the RT of various configurations is shown in Figure 5.3, where it can be seen that the acoustic performances are very similar.

Table 5.8 Comparison of the total Ecopoints (embodied and operational) between various finishes of each component: ceiling, floor and wall, in the living room. The Ecopoints of each component are also shown (in brackets, embodied Ecopoints only).

element	Element / Room no.	Wall	Floor	Ceiling	Total Ecopoints
Ceiling	LCC1	plaster	carpet, thin	plaster tiles (1)	468
	LCC2			plywood tiles (3)	470
	LCC3			plasterboards (1)	468
Floor	LFC1	Plaster	terrazzo tiles (4)	wood panel	460
	LFC2		linoleum tiles (5)		461
	LFC3		wood parquet (14)		470
Wall	LWC1	fibreboards (12)	carpet, thin	plaster panel	449
	LWC2	plasterboards (3)			441
	LWC3	plywood panels (4)			442



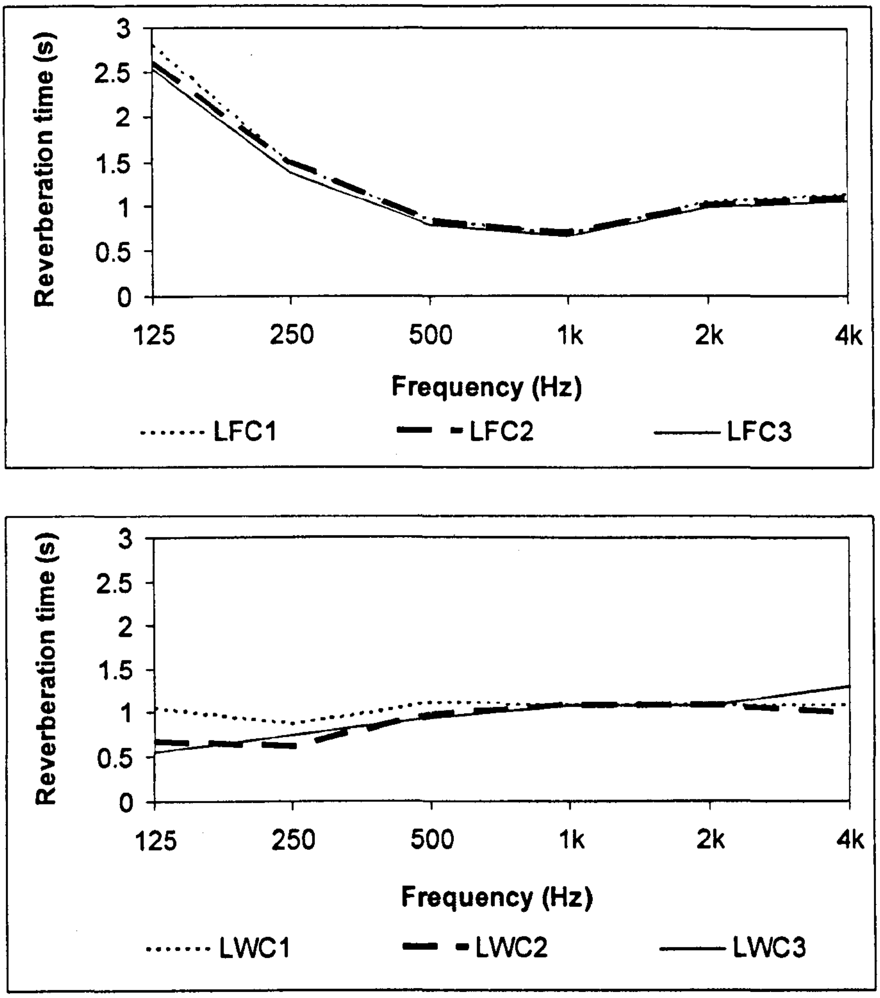


Figure 5.3 Comparison of RTs between various finishes of each component in the living room.

Considering the three ceiling materials the total Ecopoints of the room are 468, 470 and 468 respectively, which are rather similar, whereas when only the ceiling is considered, the differences are rather significant – for example, with plywood tiles the Ecopoint total is two times higher than that of plaster tiles and plasterboard. With the three floor materials the total Ecopoints of the room are 460, 461 and 470 respectively, which are again rather similar, but when only the floor is considered, the Ecopoints differ significantly: with a wood parquet floor the Ecopoints are much higher than with terrazzo tiles and linoleum tiles. For various wall finishes the conclusions are similar. The Ecopoints of fibreboards are approximately three to four times higher than those of the plasterboards and plywood panels. Overall, the comparison between various finishes of each component demonstrates that in terms of environmental sustainability, various materials could be rather different, although their acoustic performances are similar.

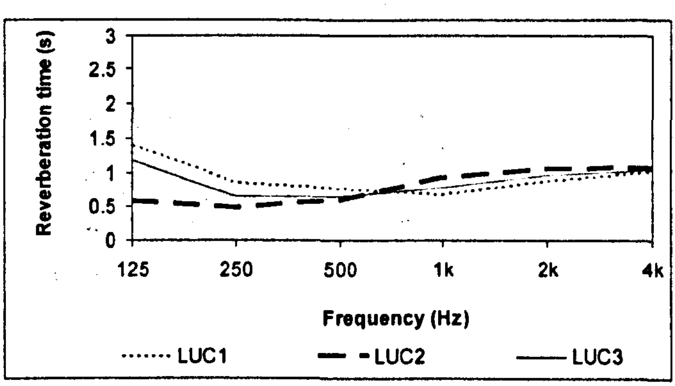
Combinations

Six different commonly used combinations of materials are compared for the living room, based on a small scale survey of users and designers. The material details and the corresponding Ecopoints are shown in Table 5.9. It can be seen that the differences in the total Ecopoints between the six configurations are generally within about 7%, which is insignificant. On the other hand, the differences between the finishing materials themselves are rather significant, ranging from 9 to 39, with a difference of up to 300%.

Table 5.9 Comparison of the total Ecopoints (embodied and operational) between various combinations of interior finishes in the living room. The Ecopoints of each component are also shown (in brackets, embodied Ecopoints only).

Element Room no.	Wall	Floor	Ceiling	Total Ecopoints
LUC1	wood fibre board (3)	terrazzo tiles (4)	wood panels (22)	458
LUC2	Plasterboard (4)	wood parquet (14)	gypsum tiles (1)	448
LUC3	Plaster (5)	carpet, thin (9)	medium density fibreboard (3)	445
LPC1	wood boards (3)	wood parquet (14)	wood panels (22)	468
LPC2	Plasterboard (4)	terrazzo tiles (4)	gypsum tiles (1)	438
LPC3	wood boards (3)	carpet, thin (9)	gypsum tiles (1)	444

The RT of the six configurations is compared in Figure 5.4. It can be seen that their acoustic performance is generally similar. It is noted that the current RTs are slightly long, for relative comparison, but these can be further reduced when furniture is considered.



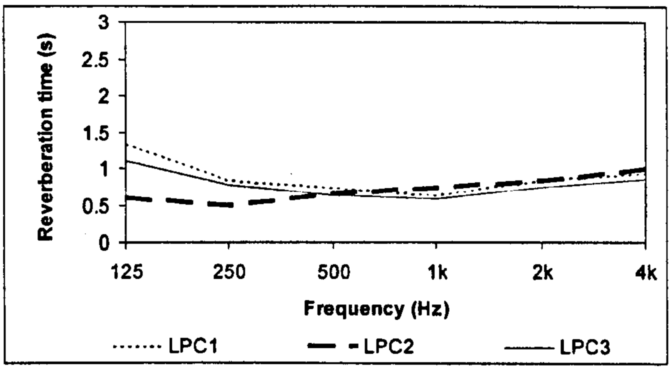


Figure 5.4 Comparison of RTs between various combinations of interior finishes in the living room.

5.5.2 Bedroom

Effect of each component

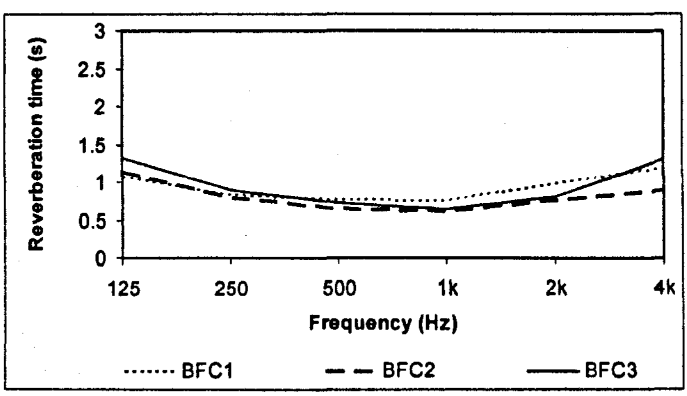
Table 5.10 compares the total Ecopoints (embodied and operational) between various finishes of each component, namely, ceiling, floor and wall. In the table the embodied Ecopoints of each component are also shown. Correspondingly, the RT of various configurations is shown in Figure 5.5, where it can be seen that the acoustic performances are very similar.

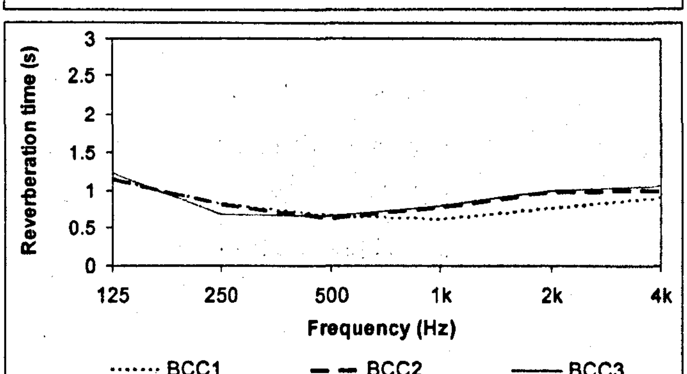
With the three ceiling materials the total Ecopoints of the room are 364, 365 and 366 respectively, which are rather similar, whereas when only the ceiling is considered, the differences are significant – for example, with mineral wool tiles the Ecopoints are two times higher than those of gypsum tiles. With the three floor materials the total Ecopoints of the room are 368, 364 and 362 respectively, which are again rather similar, but when only the floor is considered, the Ecopoints differ significantly. With the wood parquet the Ecopoints were much higher than that those achieved by thin carpet and cork tiles. For various wall finishes the results WERE similar. The Ecopoints of chipboard were over five times higher than those of the wood boards.

Table 5.10 Comparison of the total Ecopoints (embodied and operational) between various finishes of each component, ceiling, floor and wall, in the bedroom. The Ecopoints of each component are also shown (in brackets, embodied Ecopoints only).

Element	Element / Room no.	Wall	Floor	Ceiling	Total Ecopoints
Ceiling	BCC1	Plaster	carpet, thin	gypsum tiles (1)	364
	BCC2			medium density fibreboard (2)	365
	BCC3			mineral wool tile (3)	366
Floor	BFC1	plaster	wood parquet (11)	gypsum tiles	368
	BFC2		carpet, thin (7)		364
	BFC3		cork tiles (5)		362
Wall	BWC1	Chipboard (16)	carpet, thin	plaster tiles	375
	BWC2	Plywood (9)			368
	BWC3	wood boards (3)			362

Overall, in a similar way to the analysis of the living room, the comparison of individual components in the bedroom again demonstrated that the environmental sustainability of various materials could be rather different.





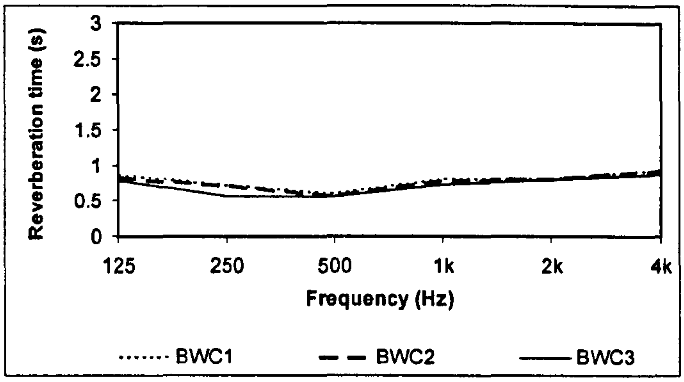


Figure 5.5 Comparison of RTs between various finishes of each component in the bedroom.

Combinations

As with the living room, six commonly used combinations of materials are compared for the bedroom, again based on a small scale survey of users and designers. The material details and the corresponding Ecopoints are shown in Table 5.11. It can be seen that the differences in the total Ecopoints between the six configurations are generally within about 5%, which is insignificant. On the other hand, the differences between the finishing materials only were very significant, ranging from 12 to 31, namely, with a difference of up to 160%.

Table 5.11 Comparison of the total Ecopoints (embodied and operational) between various combinations of interior finishes in the bedroom. The Ecopoints of each component are also shown (in bracket, embodied Ecopoint only).

Element / Room no.	Wall	Floor	Ceiling	Total Ecopoints
BUC1	Plaster (4)	carpet, thin (7)	gypsum tiles (1)	364
BUC2	wood boards (3)	wood parquet (11)	gypsum tiles (1)	366
BUC3	plaster panels (4)	carpet, thin (7)	gypsum tiles (1)	363
BPC1	wood boards (3)	wood parquet (11)	wood panels (17)	383
BPC2	Plasterboard (4)	wood parquet (11)	mineral wool tiles (3)	369
BPC3	Plaster (4)	carpet, thin (7)	gypsum tiles (1)	364

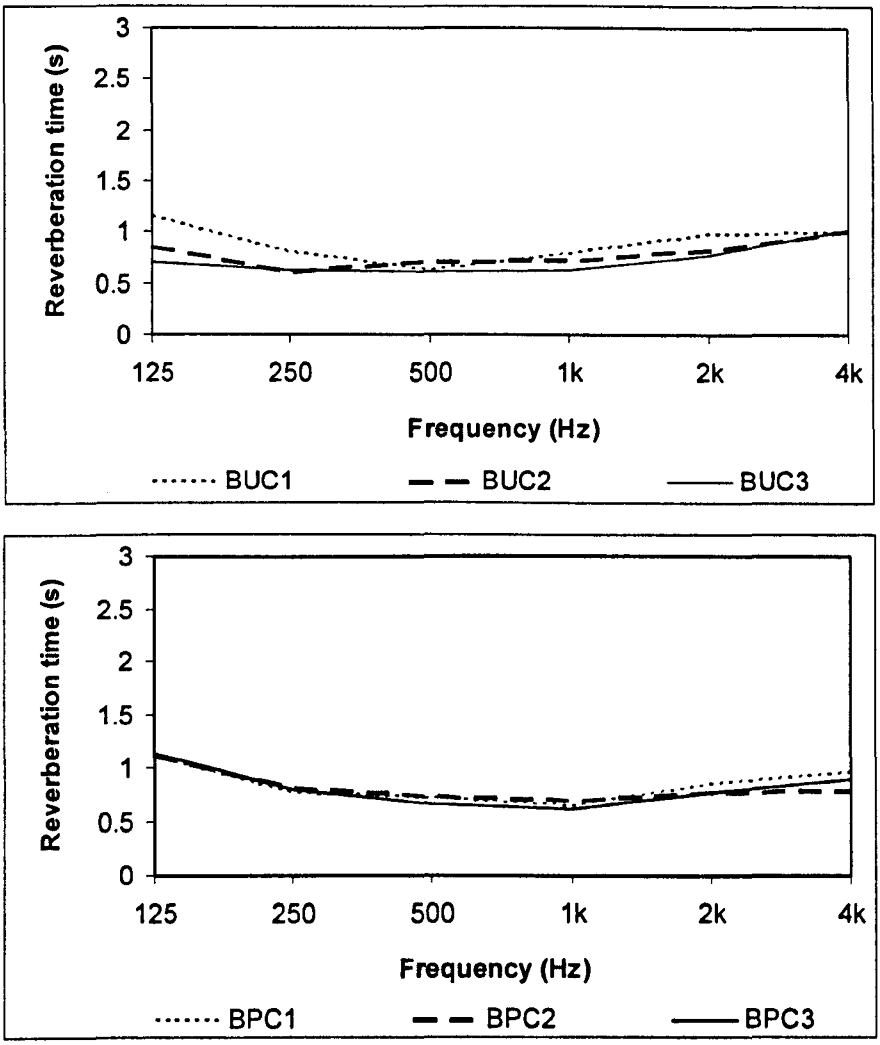


Figure 5.6 Comparison of RTs between various combinations of interior finishes in the bedroom.

The RT of each of the six configurations is compared in Figure 5.6. It can be seen that their acoustic performance is generally similar. Again, it is noted that the current RTs in the bedroom are slightly long, for relative comparison, but these will be further reduced when furniture is considered.

5.6 DISCUSSIONS AND CONCLUSIONS

The interactions between acoustic performance and environmental sustainability have been examined by comparing various building types, envelopes, and interior finishes. Both embodied and operational Ecopoints have been considered and it is noted that the ratio between them is about 1:9 in average, showing the significance of considering operational sustainability. The above simulations results are as follows.

Firstly, a number of comparisons with building types showed that results of Ecopoints between five building types were generally insignificant. In terms of embodied and operational Ecopoints, the rankings among the building types were different.

Secondly, in terms of building envelopes of the five building types, there were significant differences in embodied Ecopoints between brick and stone walls but insignificant difference in operational Ecopoints. Furthermore, while the difference in total Ecopoints of the whole building with various envelope materials was generally within about 20%. When considered the envelope materials only, the differences in Ecopoints might have been more significant.

Thirdly, in terms of the embodied Ecopoints of the apartment building, the results of brick and concrete walls are similar and they both are lower than glass wall, by about 10%. In terms of operational Ecopoints, the result of concrete has the highest Ecopoints which is about 20% higher than brick.

Fourth, in terms of building opening, when compared with the 10% opening/glazing ratio, with the 20% ratio the embodied Ecopoints are generally slightly increased, by about 3-4%; whereas the operational Ecopoints are decreased, by about 8-13%.

Fifth, when comparing typical flat and pitched roofs for the apartment building that embodied Ecopoints of the pitched roof is generally less than the flat roof. On the other hand, the differences between flat and pitched roofs WERE insignificant in operational Ecopoints.

Sixth, comparisons between 2-4 storey apartment buildings showed that the difference was generally insignificant, within about 4%.

In addition, analysis of the typically sized living room and bedroom showed that the total Ecopoints of the whole room with various interior finishes were similar. However, when only the finishing components were considered, such as on the ceiling, floor and walls, the differences were more marked but their acoustic performances are similar.

Overall, the results of this study demonstrate the importance of considering environmental sustainability of various materials which could have similar acoustic performances. Individual components may not significantly affect the total Ecopoints, especially when every acoustics-related component/material in a building is taken into account. However, significant differences in Ecopoints could be achieved with a better selection of those components/materials from the viewpoint of environmental sustainability. It should be noted that creating/developing sustainable living environments is a rather complex process, and it is important to consider various relevant factors and achieve a good balance. Whilst this study has examined the effects of various building elements, the effects of other factors such as land use, which affects noise source distribution; and quality of open public spaces, including soundscapes and acoustic comfort, must also be taken into account. With those factors considered, the sustainability rankings/comparisons derived from this study may change considerably.

Chapter 6

Environmentally sustainable acoustics – wind turbine study

In terms of environmentally sustainable development, with the recognised need to create a potentially sustainable environment, there are a number of new techniques through which regenerative energy has been developed, such as solar panels, and wind turbines. As previously mentioned in the literature review, renewable energy can be derived from regenerative resources and they have a number of benefits in terms of environmentally sustainable development. Wind turbines are used to produce wind energy as a source of renewable energy which causes less pollution and is highly efficient. In December 2006, the UK Government gave permits for the construction of the two largest offshore wind farms in the world situated in the lower Thames Estuary. When in operation, they will benefit a third of London homes (Environment News Service, 2006). This demonstrates that renewable wind energy has great potential in terms of environmentally sustainable development. On the other hand, some of the techniques may also bring noise problems and may affect overall environmental sustainability. A wind farm is a typical example of this: it can make considerable noise. Assessment of the negative effects, such as reduction of useable land and decrease in land values is important as these factors can affect overall environmental sustainability. As the wind farm might affect environmentally sustainable acoustics, further attention should be paid to maintaining the acoustic environment of the surrounding areas and decrease sound effects at the early design stage. It is also a principle of environmentally sustainable development, in that where there might be a number of advantages and disadvantages. In other words, an appropriate and effective balance needs to be found.

This chapter focuses on environmentally sustainable acoustics of the wind farm and its surrounding areas. Section 6.1 introduces the effects from wind turbines. Section 6.2 is a series of hypothetical studies which examine different environmental situations of wind farm areas and various conditions of wind turbine positions. Section 6.3 focuses on the survey of existing wind farms and an examination of sound distributions on one particular wind farm. The final section is a series of expanded studies which focus on wind farm survey sites through a number of hypothetical arrangements and various installation conditions of wind turbines. This chapter examines environmentally sustainable development through potential sound effects in wind farms' surrounding areas and aims to further evaluate the sound effect implications for changing environmental arrangements and installation conditions of wind turbines. This chapter can be considered as a part of fundamental examination of environmentally sustainable acoustics and as an effort in terms of regenerate renewable resource. It is closely linked to the previous chapters, as well as the data used in Chapter 7.

6.1 WIND TURBINES

The wind turbine is an important renewable resource which has many advantages from the viewpoint of environmentally sustainable development. Therefore it is necessary to gain better understanding of how to use it in a more sustainable manner. On the other hand, wind farms can generate significant noise levels, especially at low frequency. When the wind is stronger than usual, it will increase the generative efficiency as well as the noise level. A number of relevant studies show that distance between settlements and wind turbine farms is necessary (IOA, 2007) but this might decrease land usage.

A consultation report, focused on dwellings (IOA, 2007), suggested that the wind turbines mounted on buildings should be lower than 3m above the ridge. The diameter of blades should be under 2m with up to 4 turbines, on buildings below 15m in height. In terms of noise and vibration effects, internal noise should be under 30dB, externally it should be under 40dB, when measured in the garden the noise should be under 40dB and the vibrations should be under 0.5mm/s. The report further stated that free-standing wind turbines should be under 11m (including the blade) high and the diameter of blades under 2m. The report also mentioned the British Standard BS EN 61400-11 (1998): "Wind turbine generator systems - Part 11: Acoustic noise measurement techniques, which provide detailed noise measurement and assessment methodology to ensure that the noise emissions from a wind turbine can be measured in a consistent and accurate manner."

But there are some types and sizes that are not referred to specifically in the standard, for instance, wind speed is quantified at a height of 10m, not at the hub height. The actual, observed noise levels report that a turbine would increase SPL to 46dBA; while eight turbines would result in levels of 50-51dBA (IOA, 2007). This is a kind of cumulative effect which can result in a perceptible change in the ambient sound and also change noise levels to above the WHO criterion for limiting sleep disturbance.

In terms of frequency, low frequency is a problem in residential areas close to wind turbines. The amount of vibration causes people to feel disturbance or pulsation from wind turbines, especially in their chests. The undesirable sound effects of low frequency noise might be those of hearing loss and bodily vibrations (Leventhall, 2003; Pierpont, 2006). Moreover, there are some risk factors from wind turbines in the form of syndromes affecting the human body, such as sleep problems, headaches, dizziness, exhaustion, learning problems and tinnitus (Pierpont, 2006). A field survey (Cooper, 2005; Pierpont, 2006) based in the Appalachian valleys, showed that residents felt disturbance around 1.2 miles away from wind turbines.

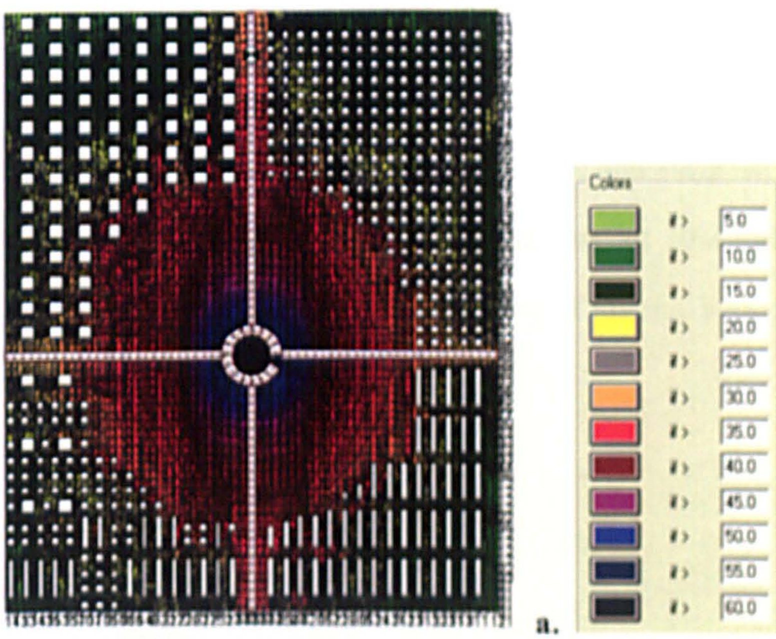
In terms of people's attitudes towards wind farms, a survey in Scotland found that sizable numbers of people responded with negative opinions (Braunholtz, 2003). Conversely, results in another survey in a UK community showed that about three quarters of local residents supported wind farms and a number of local residents responded that wind farms have many benefits for the environment (RBA Research, 2002). It is evident that there are different attitudes in terms of different regions, even though both surveys were completed in the UK.

6.2 SIMULATION IN HYPOTHETICAL RESIDENTIAL AREAS

6.2.1 Methodology

Case studies regarding the noise impact of wind turbines on typical residential areas were carried out using noise-mapping software package (CADNA, 2005). The effects of land form, building type, building arrangement and source height are examined, as well as the effects of some calculation parameters.

The noise influence of wind turbines on hypothetical residential areas is shown in Figure 6.1 and Table 6.1; a site of 600m by 700m is considered, with five basic land forms features: 2D convexly sloped (_/_), 2D concavely sloped (‾\/‾), 3D convexly sloped (_/_), 3D concavely sloped (‾\/‾), and flat ground (——). The height difference of each slope is 75m. In the middle of the site a small area of ground is assumed to be flat for all landforms, as can be seen in Table 6.1. Building arrangements are of two types: with buildings (Type 2) and without buildings (Type 1) within 200m of the centre of the site. The site is divided into four areas by two crossroads, each area with a different building arrangement. Three types of building are considered, including terraced houses (6m by 44m, 12m high), detached houses (8m by 8m, 12m high) and flats (15m by 15m, 36m high).



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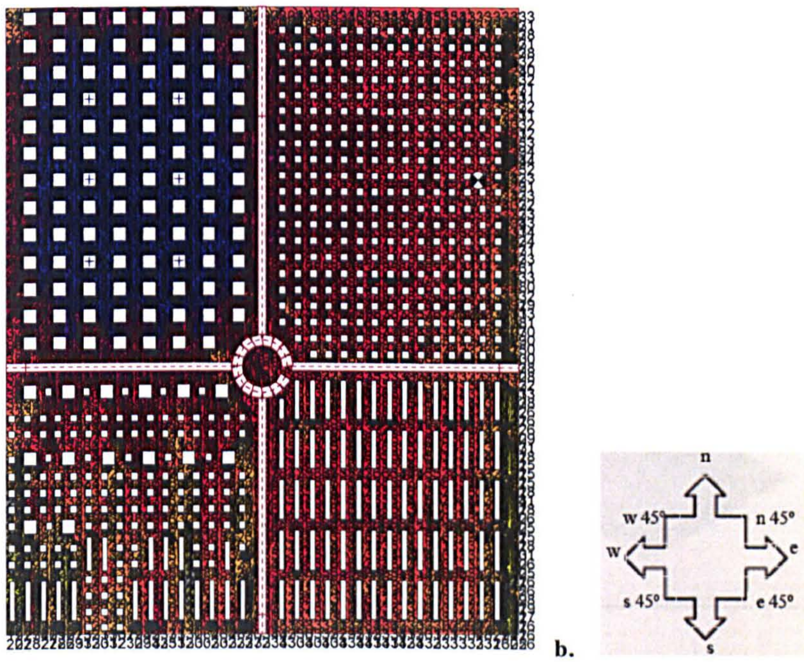
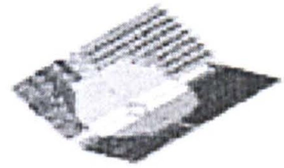
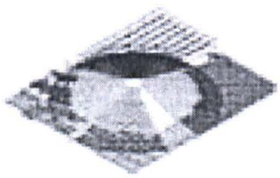
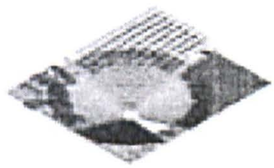
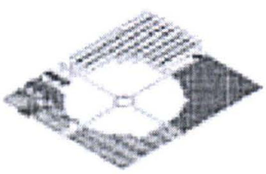
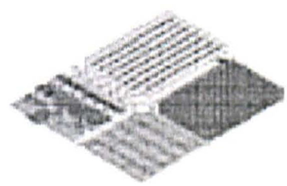
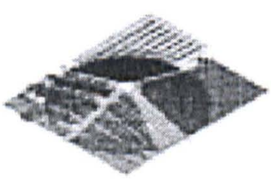


Figure 6.1 Site plan and noise-map. (a) Type 1 building arrangement, Case A. (b) Type 2 building arrangement, Case K, where the locations of the six point sources are shown with '+'. ▭, terraced house, 6m by 44m, 12m high; ▭, detached house, 8m by 8m, 12m high; □, flat, 15m by 15m, 36m high.

Two source situations are considered: a single point source located at the centre of the site, with two heights above the ground, 10m and 46m; and six point sources (see Figure 6.1b) each located on the top of a flat building, at 10m above the roof. Receivers are utilised along eight lines from the centre of the site, with a 45° interval, as shown in Figure 6.1. The receiver height is 4m.

Table 6.1 Configurations used in the calculation.

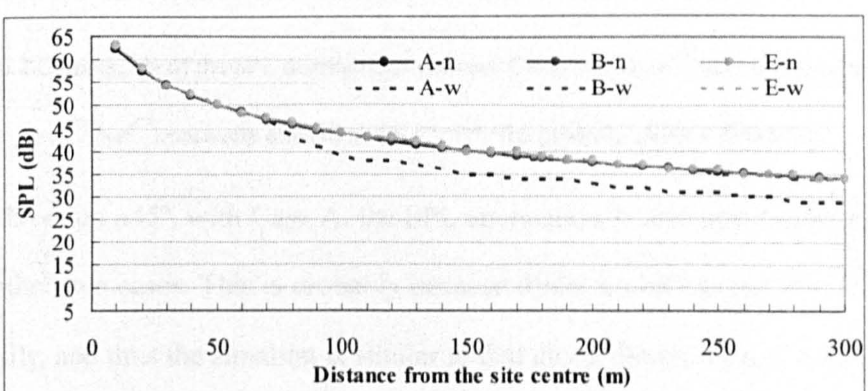
A 	Type 1 arrangement Turbine at centre and h=10m 2D convexly sloped	B 	Type 1 arrangement Turbine at centre and h=10m 2D concavely sloped
C 	Type 1 arrangement Turbine at centre and h=10m 3D convexly sloped	D 	Type 1 arrangement Turbine at centre and h=10m 3D concavely sloped
E 	Type 1 arrangement Turbine at centre and h=10m Flat ground	F 	Type 2 arrangement Turbine at centre and h=10m Flat ground
G 	Type 2 arrangement Turbine at centre and h=10m 3D convexly sloped	H 	Type 2 arrangement Turbine at centre and h=10m 3D concavely sloped
I	Same as E but h=46m	I'	Same as I but 125Hz
J	Same as F but h=46m	J'	Same as J but 125Hz
K	Same as E but with six sources at 10m above the roof (Figure 1b). The height of all the flat buildings is 36m	K'	Same as K but the height of all the flat buildings is 12m

In the calculation, the wind effect and the absorption from ground and vegetation, are not considered, given that the study is mainly concerned with the effects of landforms and building arrangements. Except where indicated, a reflection order of 3 and a single frequency band of 500Hz are used. For the sake of convenience, the sound power level of each point source is assumed as 95dB.

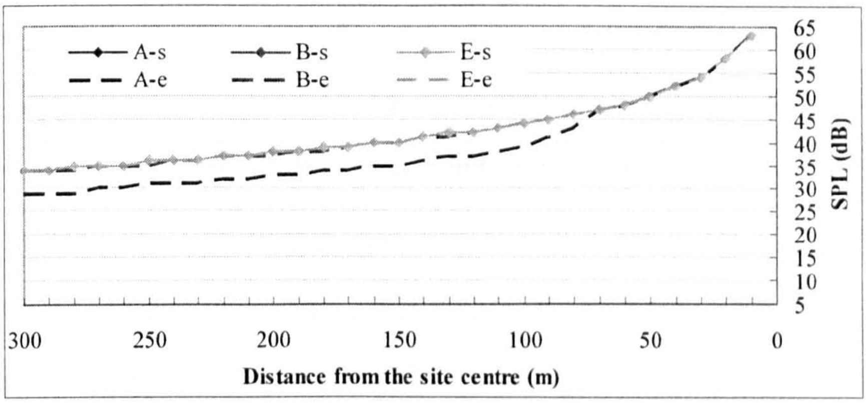
6.2.2 Results

Landforms

Figure 6.2 compares the SPL distribution between Cases A, B and E along the eight directions illustrated in Figure 6.1. In the figure the source-receiver distance refers to the horizontal distance. It can be seen that within about 80m of the wind turbine, the SPL distribution in the three cases are almost identical, due to the fact that they are all on flat ground in this region and also, the direct sound plays a dominant role. Beyond this region, along directions n, e, s and w, as shown in Figure 6.2a and 6.2b, with Case A, the SPL attenuation is about 5dB greater than in Cases B and E. The main reason is that in Case A the flat part of the ground has a noise barrier effect due to the wind turbine location. Between Cases B and E the SPL difference is negligible, suggesting that the effect caused by the difference in actual source-receiver distance (non-horizontal) is insignificant.



a



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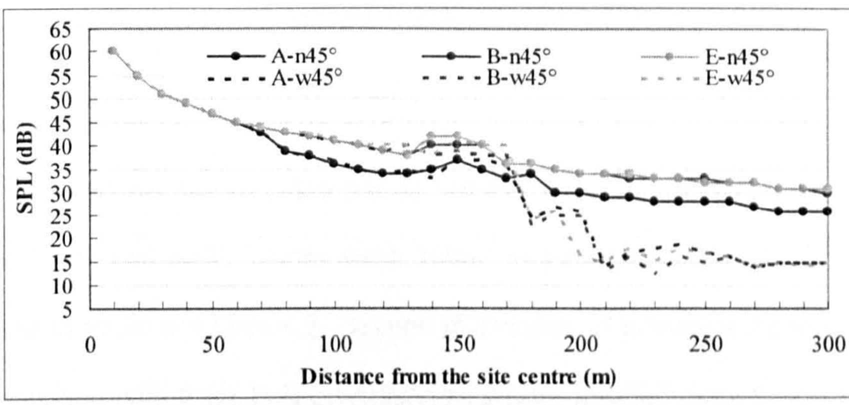
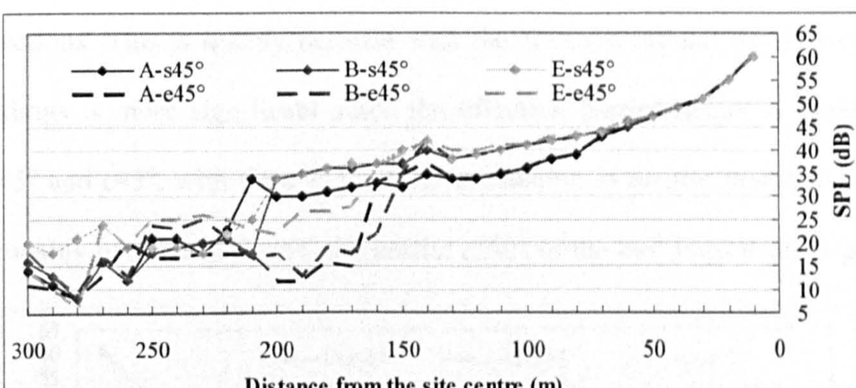


c

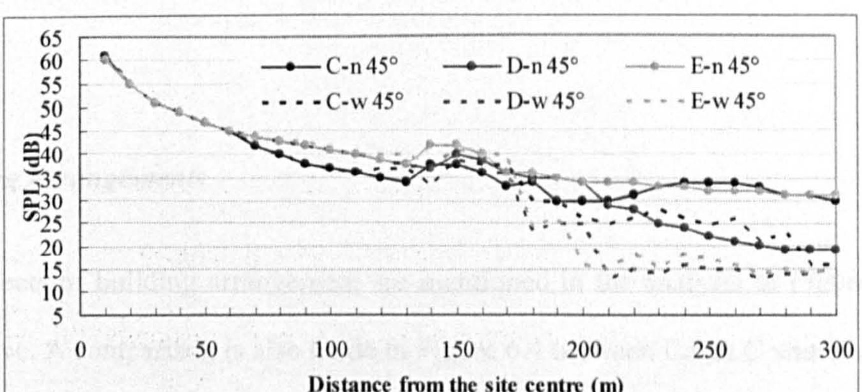


d

Figure 6.2 Comparison of the SPL distributions between Cases A (2D convexly sloped), B (2D concavely sloped) and E (flat ground), along 8 directions.

Along direction n45°, with Case A, the SPL attenuation is also about 5dB greater than in the other two cases. This is probably because direct sound can get into this built-up area easily, and thus the situation is similar to that along directions n, e, s and w. Along directions w45° and s45°, conversely, due to the higher building density, diffraction plays a more important role and consequently, there is no clear tendency in differences between the three cases. Along direction e45°, it is interesting to note that in case E, namely, on flat ground, the SPL attenuation is much less than in Cases A and B, at over 10dB. This is possibly because in this built-up area the buildings are rather long and act as good noise barriers, and in Case E the effective barrier height is relatively small, given the source height is 10m and the building height is 12m.

Figure 6.3 compares the SPL distribution between Cases C, D and E along directions n45°, e45°, s45° and w45°. Within about 200m from the site centre, the SPL variations are similar to those in Figure 6.2. Beyond this region, it is interesting to note that the SPL attenuation with Case D is considerably greater than in Cases C and E along the four directions. This is mainly because with the concave ground the barrier effect of the buildings is more significant since the effective barrier height is greater. Along w45°, s45° and e45°, with Case E the SPL attenuation is greater than that of Case C, again probably because in Case C the barrier effect of the buildings is less significant.



a

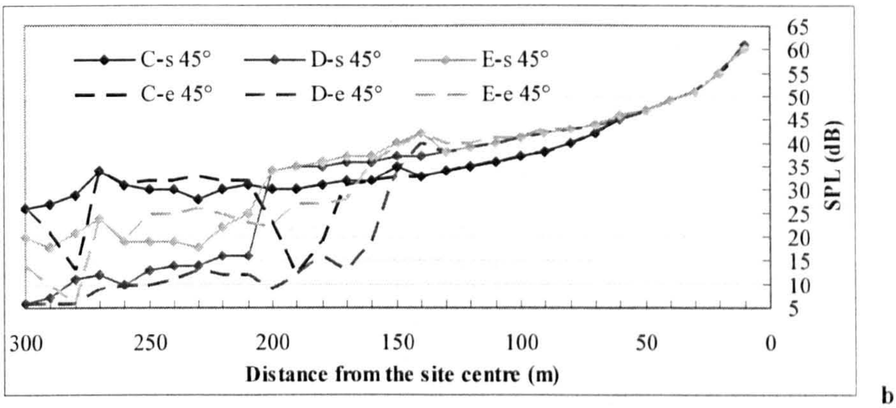


Figure 6.3 Comparison of the SPL distribution between Cases C (3D convexly sloped), D (3D concavely sloped) and E (flat ground), along 4 directions.

Along n45°, conversely, due to the low building density, the difference between Cases C and E is much less. Along directions n, e, s and w, it has been shown that the SPL differences between C, D and E are similar to those between Cases A, B and E. Overall, from Figures 6.2 and 6.3 it can be seen that compared to 10m, the SPL attenuation is about 25dB at 100m, and 30-45dB at 200-300m.

Building Arrangements

The effects of building arrangement are mentioned in the analysis of Figures 6.2 and 6.3 above. A comparison is also made in Figure 6.4 between Cases C and G, and D and H, namely, with and without buildings within 200m from the source.

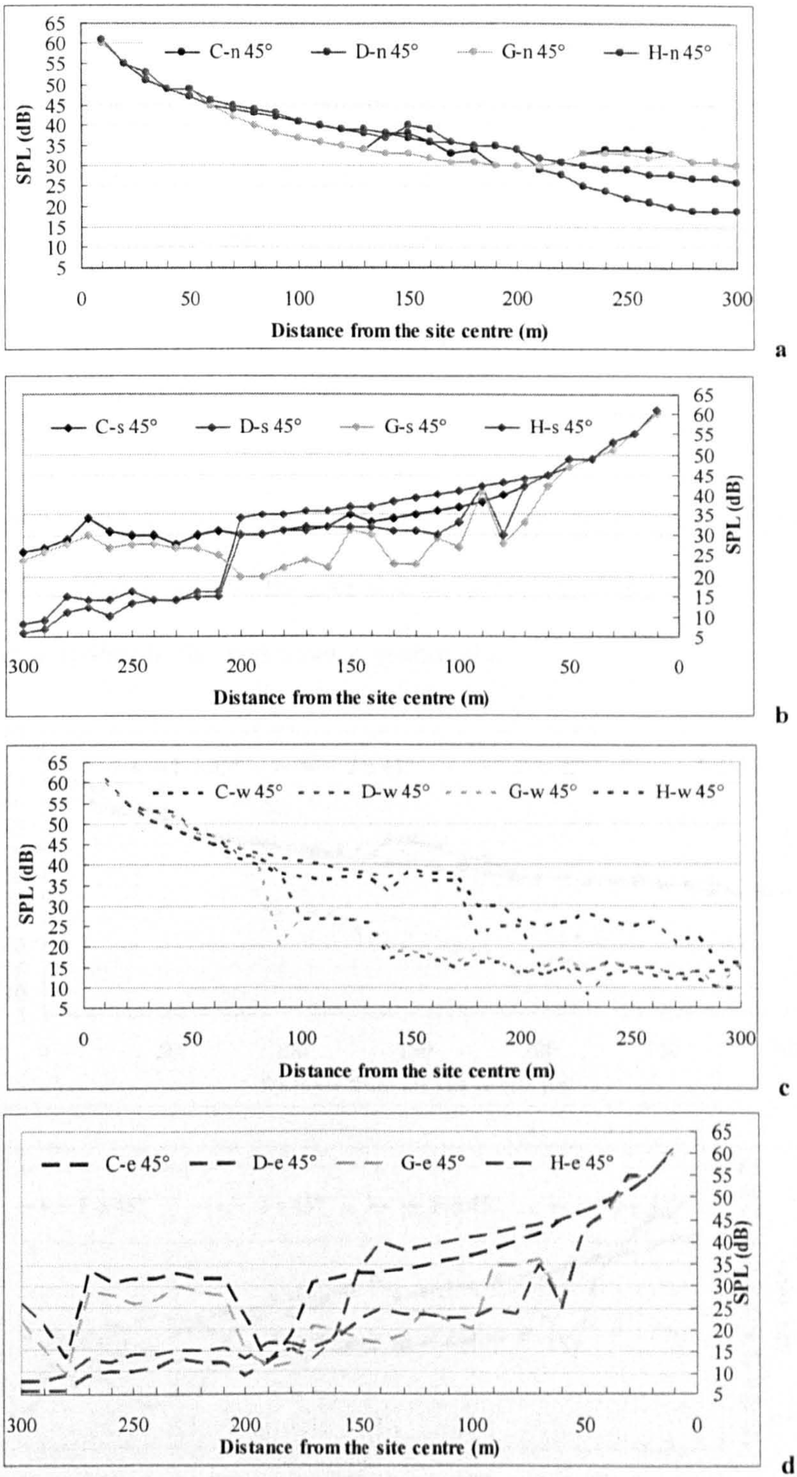
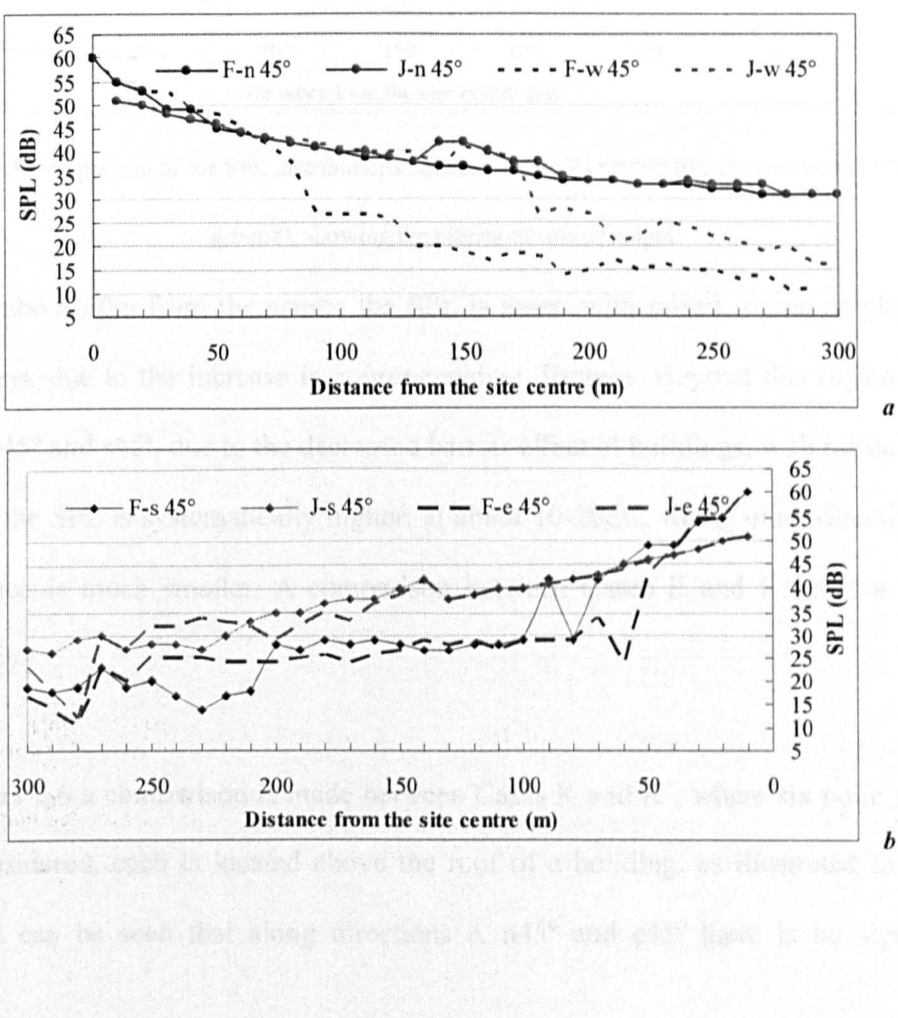


Figure 6.4 Comparison of the SPL distribution between Cases C and G (3D convexly sloped), and D and H (3D concavely sloped).

By comparing Cases C and G, or Cases D and H, it can be seen that the buildings within 200m bring a considerably higher SPL attenuation, typically over 5-15dB, especially in the region of about 80-200m from the source. Along direction n45°, as expected, the extra SPL attenuation is less significant, due to the low building density.

Source Height

To examine the effect of source height, a comparison is made between Cases F and J, as shown in Figure 6.5, where the source is located at the centre of the site and the height is 10m and 46m in the two cases respectively.



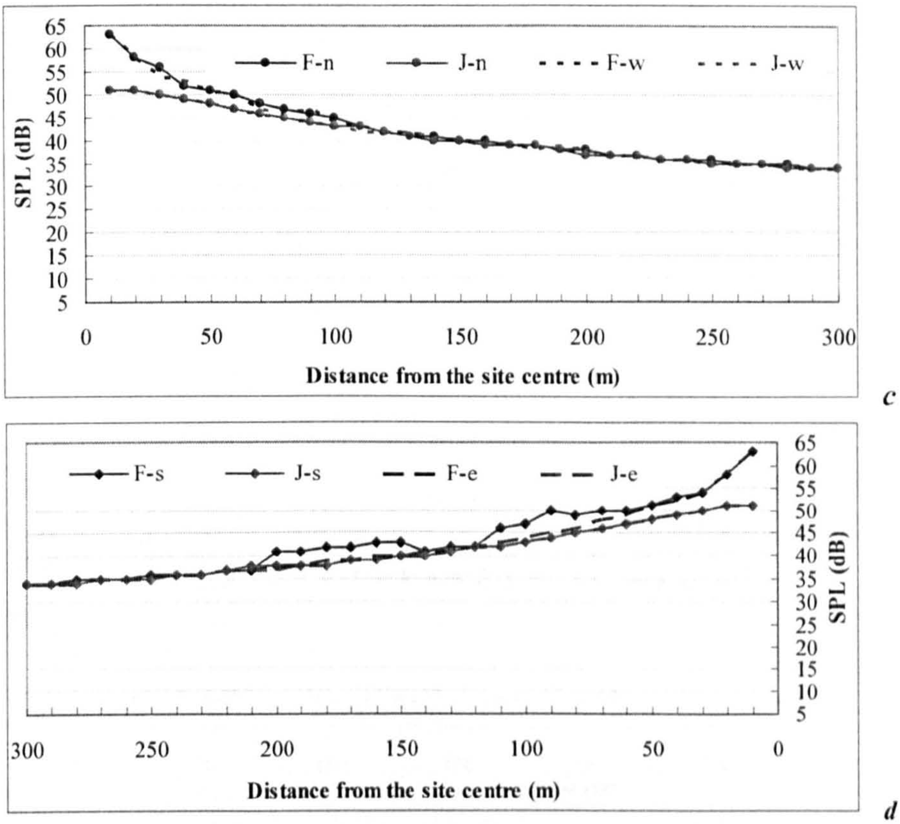
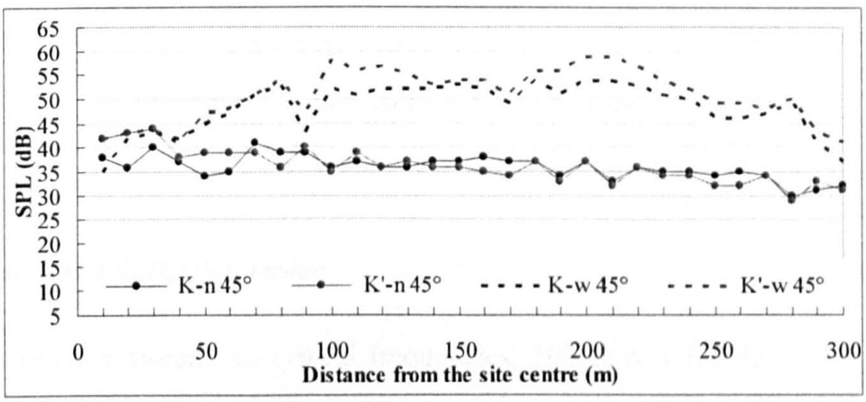


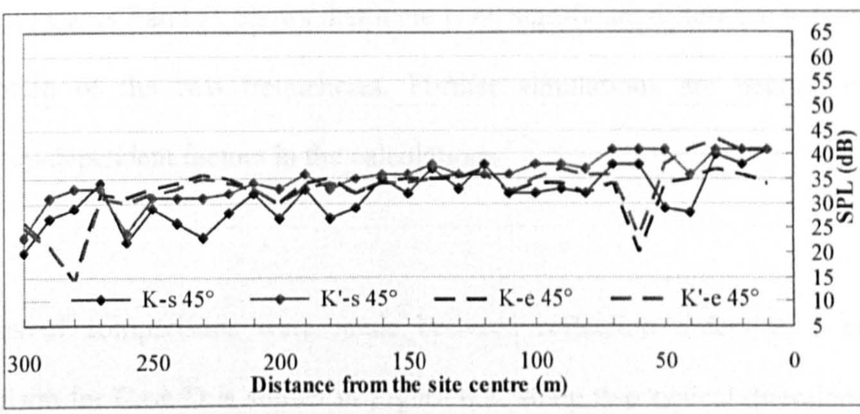
Figure 6.5 Comparison of the SPL distributions between Cases F (——flat ground) and J (——flat ground), showing the effects of source height.

Within about 40m from the source the SPL is lower with raised source height, in all directions, due to the increase in source-receiver distance. Beyond this region, along w45°, e45° and s45°, due to the decreased barrier effect of buildings, with raised source height, the SPL is systematically higher: at about 10-20dB. Along other directions the difference is much smaller. A comparison between Cases E and I shows a similar tendency.

In Figure 6.6 a comparison is made between Cases K and K', where six point sources are considered, each is located above the roof of a building, as illustrated in Figure 6.1b. It can be seen that along directions e, n45° and e45° there is no significant difference between the SPLs of the two source heights, since they are rather far from the sound sources. In directions n, s, w, s45° and w45°, with h=46m the SPL is generally lower than at h=22m, possibly due to the barrier effect of the raised flat buildings as well as the increased source-receiver distance. It is interesting to note that compared with a single point source, with six sources the SPL attenuation is much less significant, only about 20dB at 200-300m.



a



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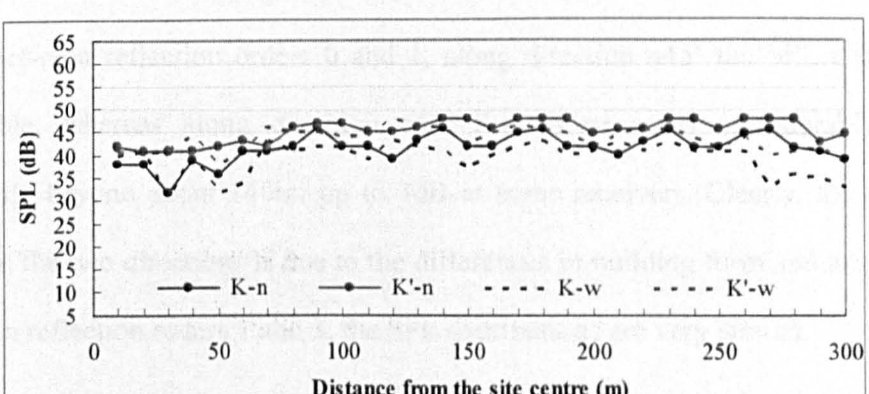

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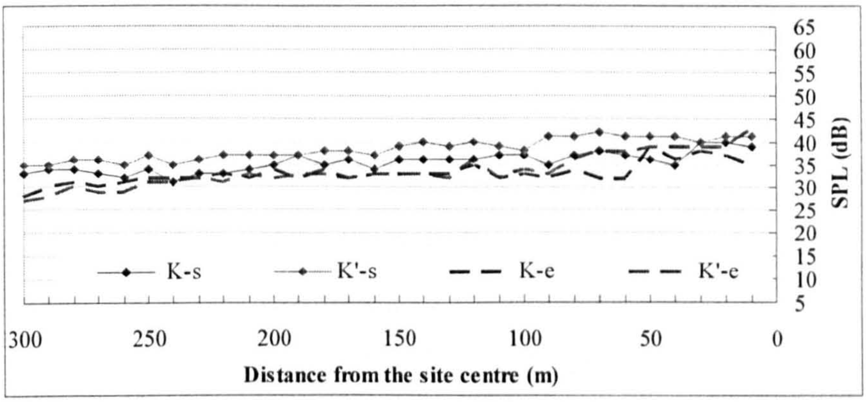


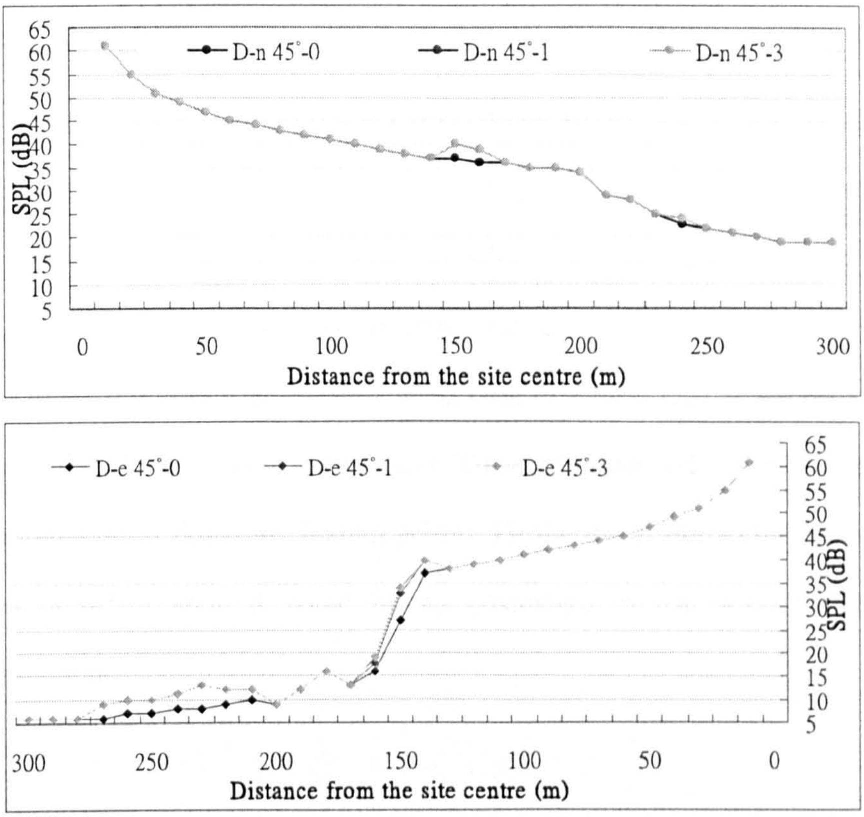
d

Figure 6.6 Comparison of the SPL distribution between Cases K (——flat ground) and K' (——flat ground): showing the effects of source height.

Frequency and Reflection Order

A comparison between two typical frequencies, 500Hz and 125Hz, namely, Cases I and I' and Cases J and J', shows that there is no significant difference between the SPL distribution of the two frequencies. Further simulations are needed using more frequency-dependent factors in the calculations.

A series of comparisons were made between reflection orders 0, 1 and 3. The comparison for Case D is shown in Figure 6.7, along two typical directions, n45° and e45°. Between reflection orders 0 and 1, along direction n45° the SPL difference is negligible, whereas along direction e45° the difference is considerably greater, especially beyond about 140m: up to 7dB at some receivers. Clearly, the difference between the two directions is due to the differences in building form and arrangement. Between reflection orders 1 and 3, the SPL distributions are very similar.



a

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Figure 6.7 Comparison of the SPL distribution between reflection orders 0, 1 and 3, for Case D (3D concavely sloped). Note the result for reflection order 1 almost overlaps that of reflection order 3.

6.2.3 Summary

The case study shows that a wind farm could have significant noise effects over a large area: especially in the case of multiple sources. The effect of landform is insignificant in terms of the difference caused in source-receiver distance, but various landforms can bring considerable SPL differences in terms of noise barrier effects of buildings and ground profile. In terms of turbine height, when h is increased from 10m to 46m, the SPL increase could be 10-20dB at long distance.

6.3 MEASUREMENT OF AN EXISTING WIND FARM

In order to comprehend the sound distributions around an existing wind farm, survey work was conducted at Royd Moor Wind Farm. This is because no established sound power levels of wind turbines were available. The study compared the measured and simulated results, and the derived sound power levels of the wind turbines. On the other hand, it is useful to survey a wind farm in a rural area as the background noises are normally lower than in urban areas. The study intended to measure a wind farm in urban area but it failed to obtain a permit. Furthermore, due to the higher background noise in urban area, it could be an advantage to use wind turbines in a city environment.

6.3.1 Royd Moor Wind Farm and The Measurement Method

Figure 6.8 shows the Royd Moor Wind Farm; there are thirteen wind turbines, located in Penistone, in the Peak District of South Yorkshire, situated on a ridge 320m above sea level. They measure 35m in height to the hub and 54m to the top.

Figure 6.8 Royd Moor Wind Farm

Royd Moor Wind Farm has been in operation since 1993 and the total power capacity is 6.5MW per year. On the surrounding land there is crop growing and a plant nursery.

Ten selected measuring points are shown in Figure 6.9: between each measuring point the interval was 20m and they were located along the Whitley Road. The 01dB dBBATI32 system was used, with the meter readings taken at regular intervals and automatically recorded into a laptop. The local weather was rather windy and humid and the slope of the ground is about 1/35.

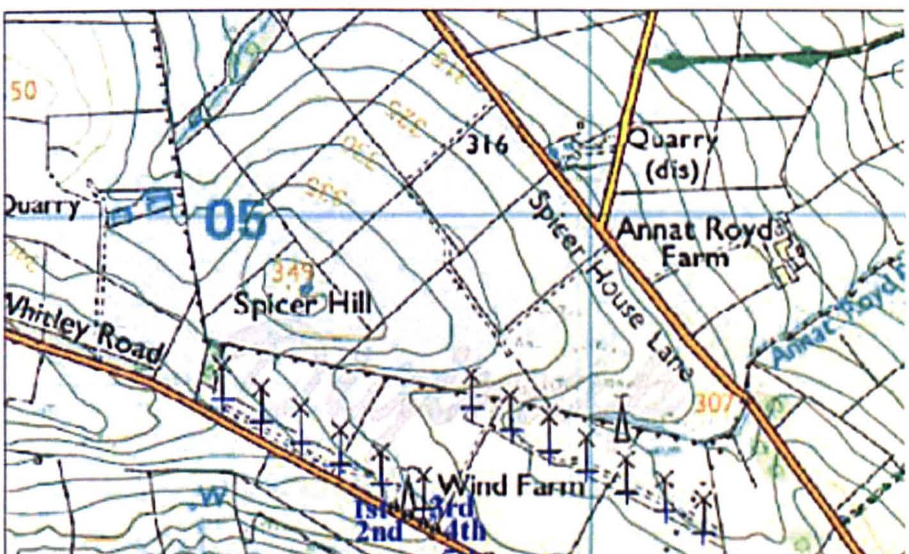


Figure 6.9 The layout of site and the ten receivers are shown with '⧓', the point sources are shown with '┼'. (map from EDINA Digitmap)

6.3.2 Measured Results

Figure 6.10 shows a typical measured SPL of wind turbines from frequencies of 12.5Hz to 20kHz. It can be seen the SPLs are rather high between 16Hz and 63Hz but beyond 125Hz the SPLs decreased significantly.

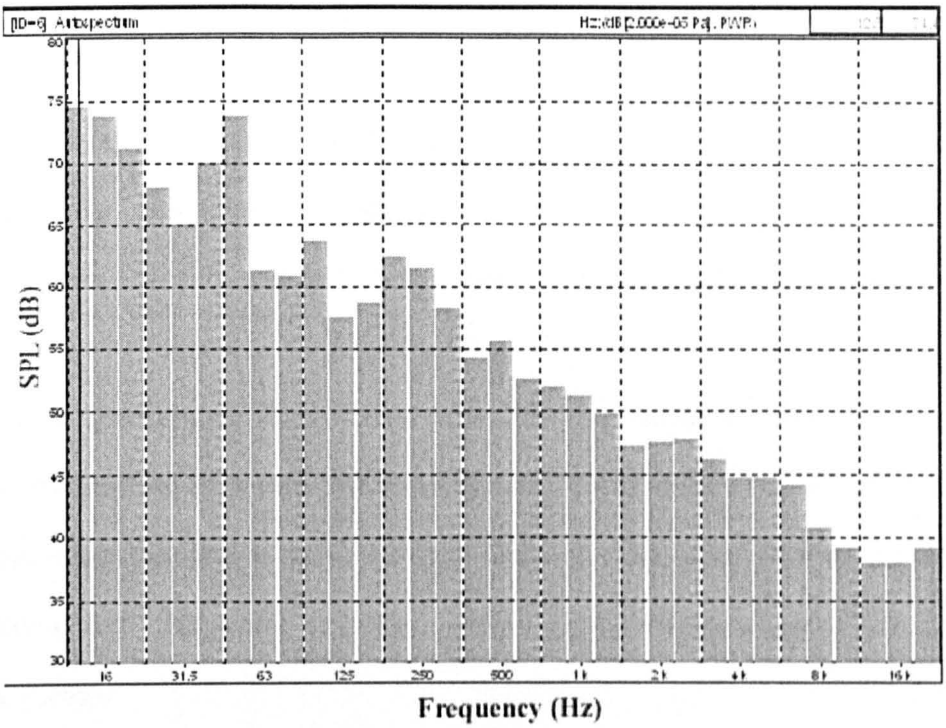


Figure 6.10 Typical SPL of the wind turbines.

Table 6.2 and Figure 6.11 show more detailed measured data. It can be seen that the ranges of SPL between frequencies of 12.5Hz to 8kHz were about 33dB to 77dB which is a rather large variation. When comparing low frequency and median frequency, namely, frequencies of 31.5Hz, 63Hz and 250Hz, 500Hz the average difference is about 17dB which shows high SPLs in low frequency and low SPLs in median frequency. On the other hand, when considering low frequency only, the SPL is lower at the first measured point and higher at the 10th point, with variations in the middle, but when considering median frequency only, sound distribution shows a contrary tendency to the low frequency. This is possibly because low frequency sound has significantly longer distance effect and the median frequency sound is mitigated by source-receiver distance.

After analysing the findings from on-site measuring, noise mapping simulation and correctional coefficient, it is clear that the noise effect from wind farms can be a major problem. This is especially the case at lower frequencies, and they cannot be easily avoided. This is highly relevant to the issues of how to handle existing problems or how to prevent problems at the planning stage, which is a principle of environmentally sustainable development. Furthermore, as previously mentioned in the context of this thesis, the goal of environmentally sustainable development is to achieve a better understanding and find a more effective balance. The same principle applies to environmentally sustainable acoustics: which should always examine the various salient factors.

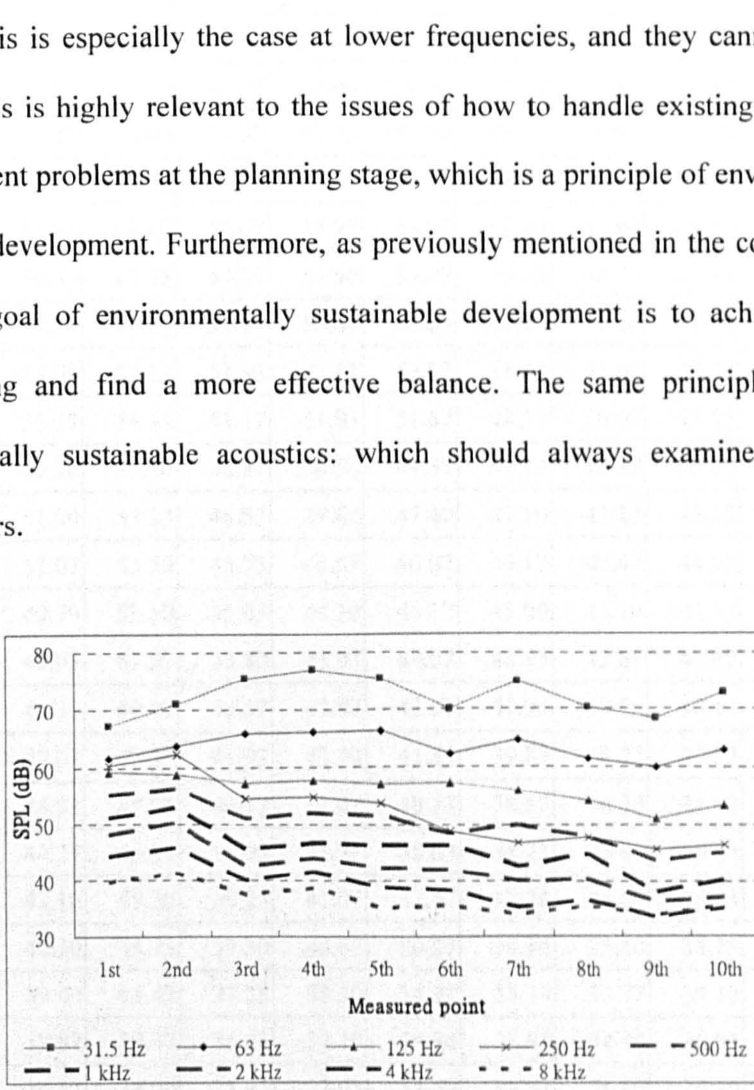


Figure 6.11 The measured SPL across frequencies at ten selected points at Royd Moor Wind Farm.

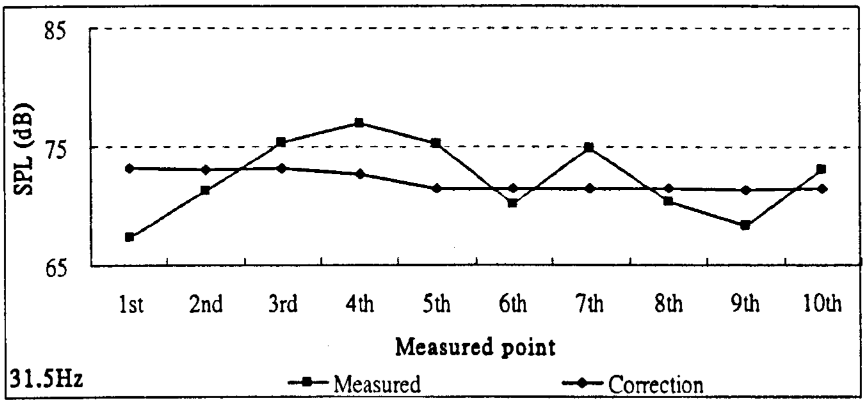
Table 6.2 The measured SPL across frequencies at ten selected points at Royd Moor Wind Farm.

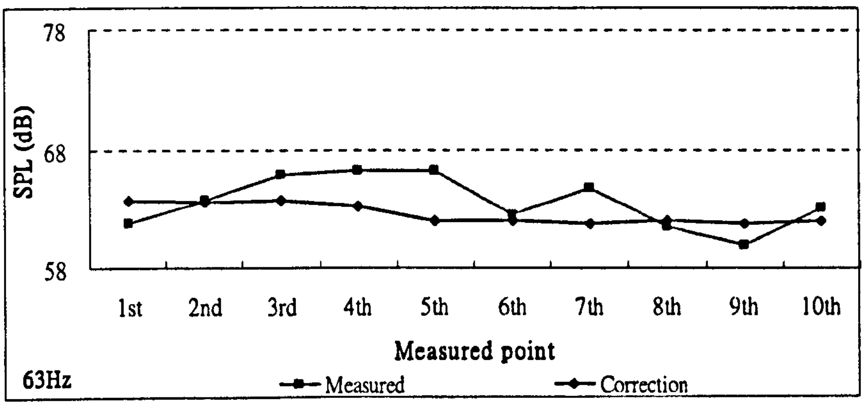
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
12.5 Hz	78.20	82.23	88.07	83.53	80.07	81.10	83.80	79.17	76.94	80.54
16 Hz	76.07	80.80	84.23	83.57	79.30	78.23	82.23	77.60	74.84	78.70
20 Hz	74.50	77.50	81.90	81.73	78.23	76.37	81.13	75.70	72.92	76.52
25 Hz	72.53	73.97	78.43	79.47	77.27	74.17	78.27	73.23	71.02	75.26
31.5 Hz	67.33	71.17	75.40	76.97	75.30	70.13	74.83	70.33	68.24	73.02
40 Hz	68.00	72.13	72.67	73.20	72.13	67.73	71.57	66.63	64.86	70.24
50 Hz	70.53	74.43	71.27	70.97	69.97	65.30	68.67	65.33	62.52	67.34
63 Hz	61.70	63.70	65.83	66.20	66.27	62.43	64.80	61.50	59.88	63.04
80 Hz	59.77	62.73	62.80	63.20	62.93	60.97	61.50	59.80	57.40	60.50
100 Hz	60.63	64.03	62.00	63.00	60.90	59.43	59.13	57.30	54.70	57.00
125 Hz	59.27	58.93	57.37	57.73	57.07	57.23	55.93	54.33	51.14	53.34
160 Hz	61.23	59.50	55.47	55.70	54.50	55.47	52.77	52.20	47.44	49.84
200 Hz	61.83	63.10	56.67	54.97	53.97	52.10	51.07	50.37	45.78	47.56
250 Hz	60.33	62.43	54.77	54.90	53.77	49.03	46.70	47.83	45.58	46.46
315 Hz	57.00	59.23	51.57	53.83	52.63	47.63	47.60	48.30	45.22	45.38
400 Hz	56.03	55.13	51.93	52.37	52.57	48.80	51.97	47.80	45.00	45.76
500 Hz	55.27	56.33	51.17	51.93	51.67	48.57	50.03	47.87	43.38	45.06
630 Hz	52.70	53.80	48.87	50.53	49.57	47.20	46.37	45.60	40.76	44.66
800 Hz	51.80	53.23	46.53	49.67	47.40	47.10	43.13	45.53	39.32	43.38
1 kHz	51.07	53.20	45.73	46.57	46.07	46.17	42.47	44.53	37.96	40.08
1.25 kHz	49.70	52.10	45.03	44.10	45.17	45.00	43.10	41.83	36.70	39.20
1.6 kHz	49.03	51.57	43.80	43.03	44.07	44.13	42.83	41.67	36.12	38.24
2 kHz	48.30	50.27	42.57	43.87	42.07	41.93	39.90	40.17	36.12	37.00
2.5 kHz	47.67	49.37	41.93	43.30	41.83	39.87	38.73	39.33	34.46	35.90
3.15 kHz	45.83	47.93	40.77	41.47	40.13	38.57	36.53	38.43	33.52	35.84
4 kHz	44.27	45.87	39.90	41.37	38.63	38.23	35.03	36.40	33.22	35.14
5 kHz	43.10	45.20	39.23	41.07	37.47	37.20	34.00	35.53	33.12	34.90
6.3 kHz	42.10	44.23	39.30	40.67	36.27	36.10	33.60	35.13	33.26	34.98
8 kHz	39.40	41.13	37.23	38.30	34.93	35.33	33.77	35.30	33.72	35.42
10 kHz	37.87	39.37	36.23	37.10	34.80	35.83	34.40	35.93	34.38	36.04
12.5 kHz	36.47	38.00	35.93	37.03	35.50	36.67	35.40	36.80	35.58	36.80
16 kHz	36.77	37.97	36.67	37.83	36.57	37.77	36.40	37.87	36.34	37.94
20 kHz	37.47	38.93	37.60	38.97	37.43	39.03	37.43	38.80	37.48	38.78

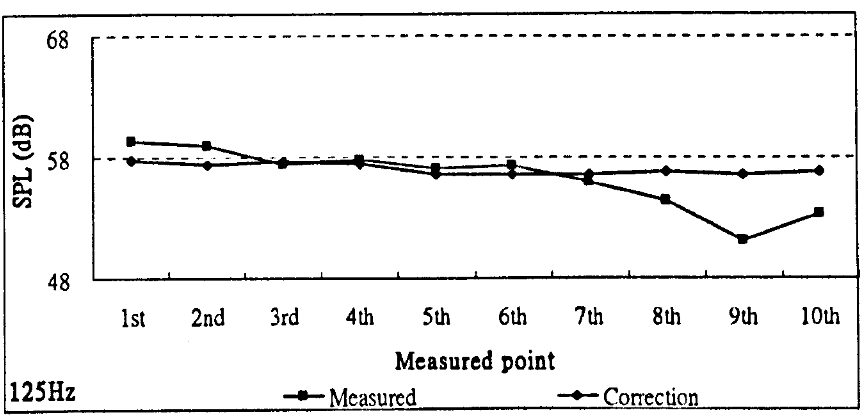
6.3.3 Determination Of Sound Power Levels Of Wind Turbines By Comparing Measured And Simulated Data

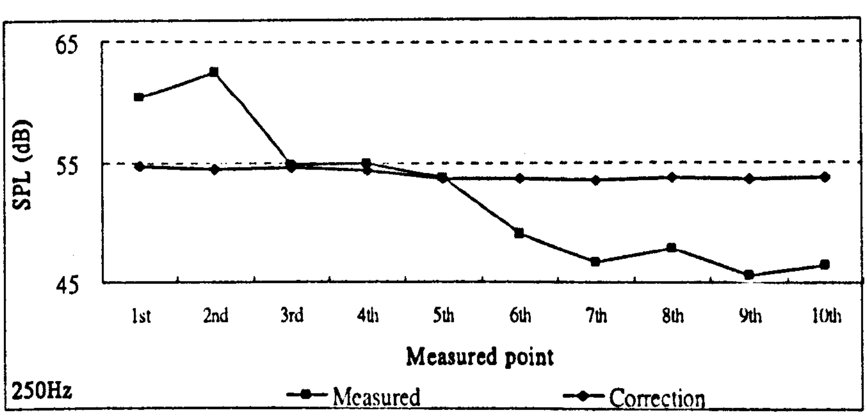
A main reason for this examination is that no manufacturers can currently provide sound spectra and most of them merely point out that the wind turbines they make are tested and conform to regulations. In order to determine the approximate sound power level of the wind turbines, a comparison is made between measured SPL and simulated SPL using noise mapping software. In the simulation a nominal sound power level of 100dB was assumed at beginning. By trying to relate the measured and simulated data at each frequency, the actual sound power level can be approximately determined. In the simulation the road and other noise sources were not considered, since the measurements were made without the presence of those sources. Each wind turbine was considered as a point source.

In Figure 6.12 the comparison between measured and simulated SPL are shown after the simulated SPL are adjusted. It is noted that the measured SPL vary considerably more than the simulated, perhaps due to the simplified results in the simulation software. After the adjustment process, the sound power levels at 31.5Hz to 2kHz were 117, 105, 105, 100, 98, 93 and 93dB, respectively. It can be seen that the highest sound power level is at a frequency of 31.5Hz, namely, in the range of low frequency. When the frequency increased, such as from 31.5Hz to 63Hz the sound power level decreased by about 12dB and the frequencies above 63Hz show a further reduced range of sound power level.


85
75
65
SPL (dB)
1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th
Measured point
31.5Hz
Measured
Correction


78
68
58
SPL (dB)
1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th
Measured point
63Hz
Measured
Correction


68
58
48
SPL (dB)
1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th
Measured point
125Hz
Measured
Correction


65
55
45
SPL (dB)
1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th
Measured point
250Hz
Measured
Correction

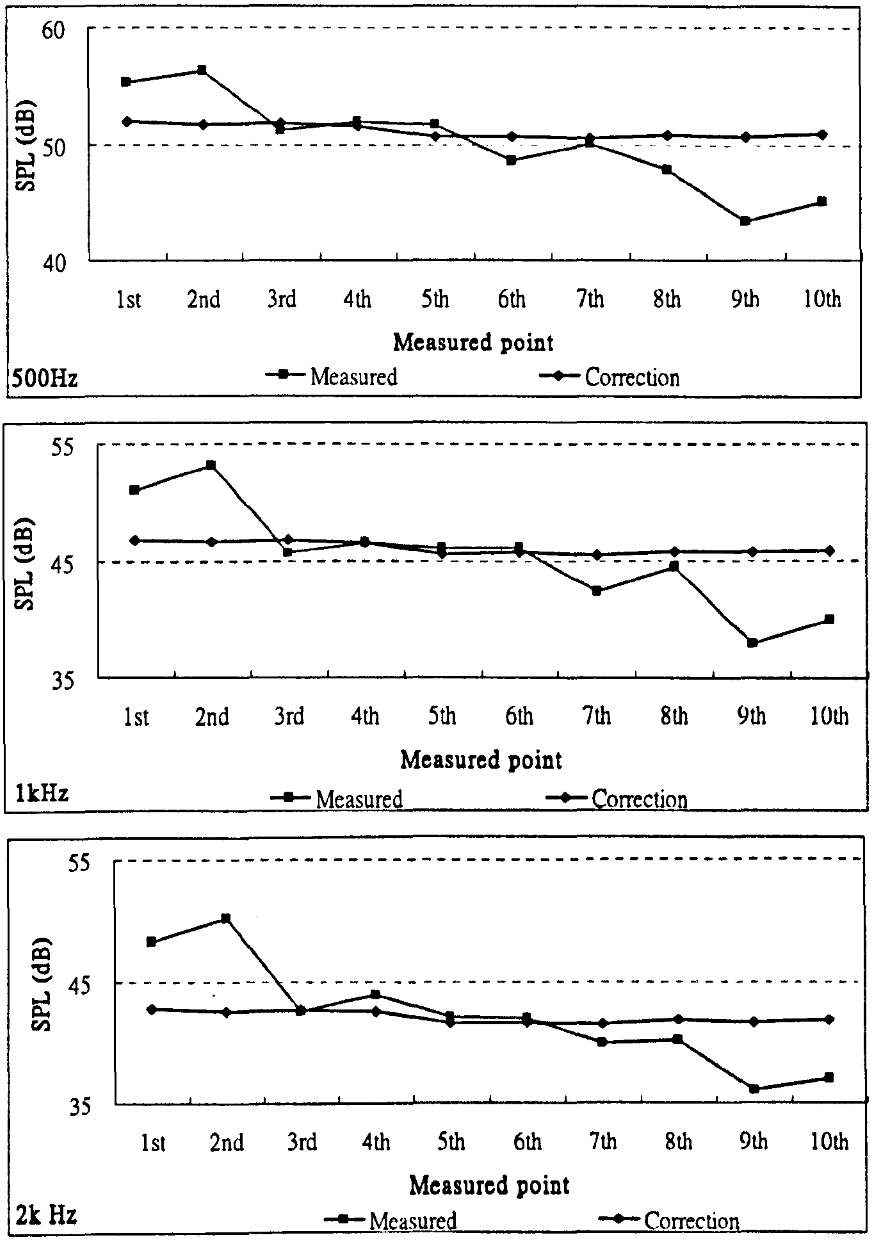


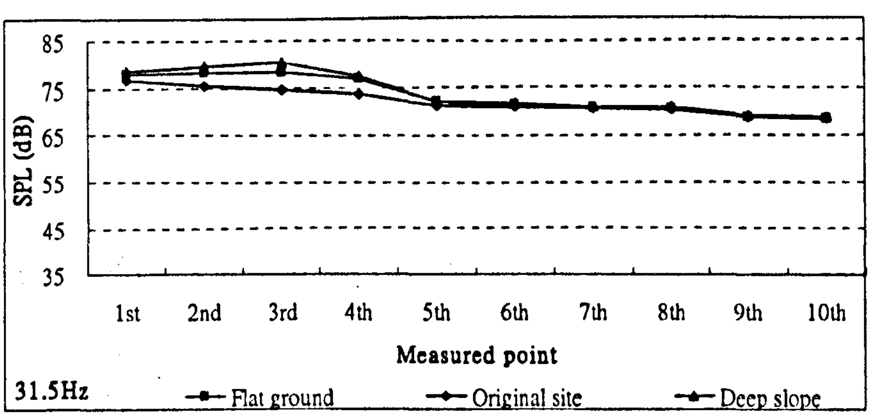
Figure 6.12 Adjustment processes of the simulated results against the measured data.

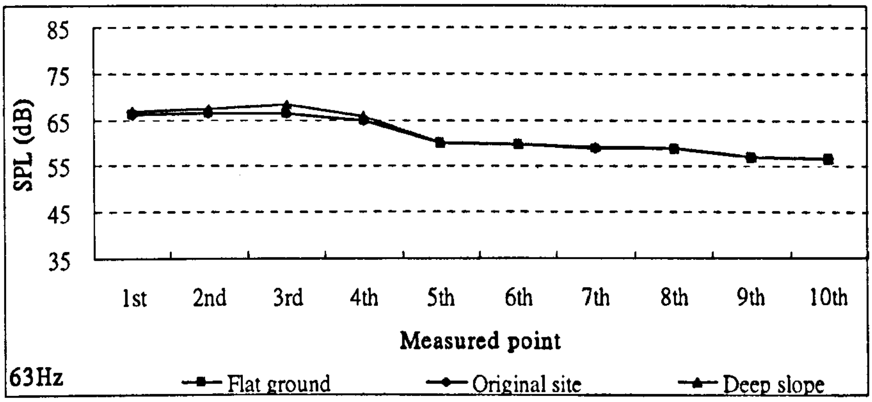
6.4 FURTHER EXAMINATION OF THE WIND FARM WITH HYPOTHETICAL ARRANGEMENTS

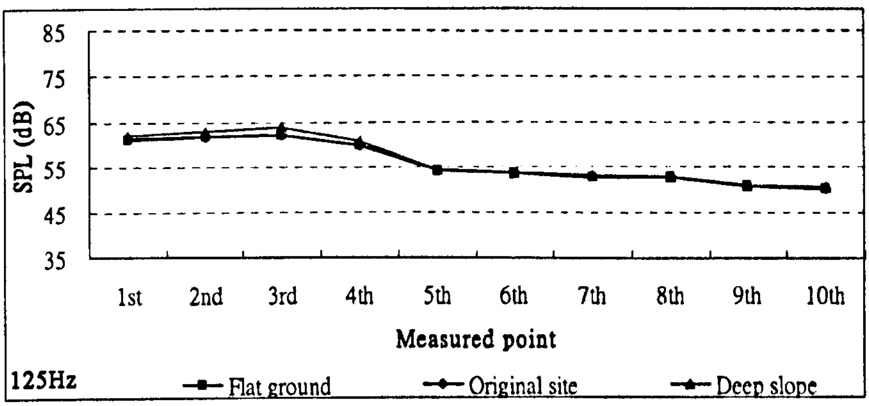
The above determined sound power levels were used in further simulations, with various hypothetical arrangements in the relevant area, in order to determine what kind of arrangements might cause serious sound effects in the wind farm's surrounding area. The sound sources are again considered as point sources only. The objective is to find the potential sustainability in terms of building a wind farm. The arrangements considered were different landforms, height of turbines, source number and source location.

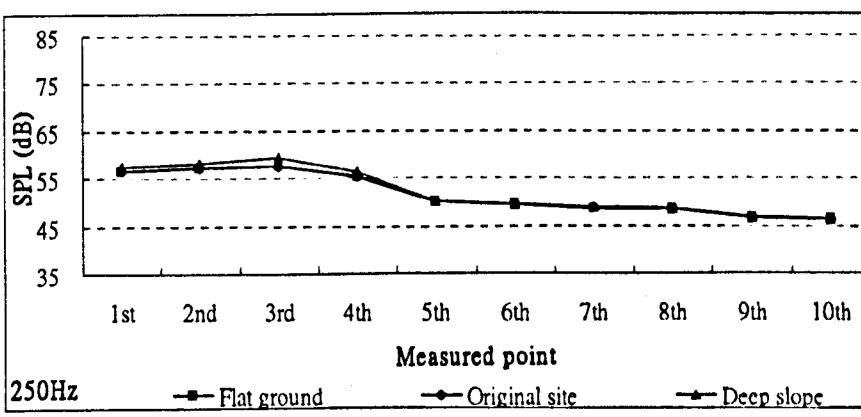
6.4.1 Landform

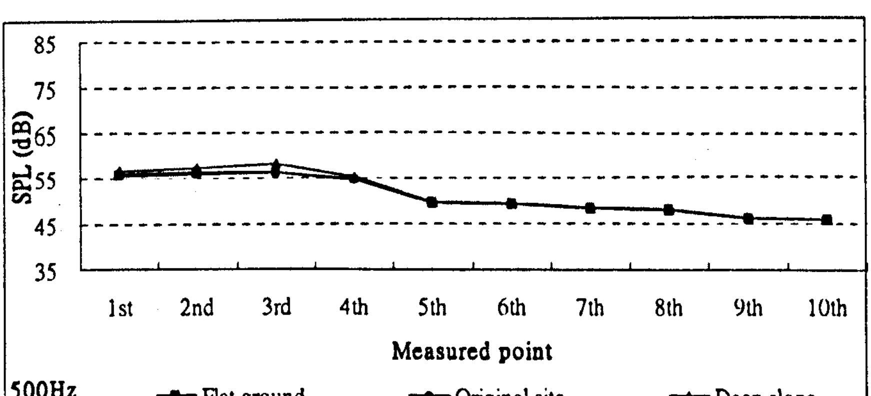
Different landforms were simulated, bearing comparison with the original landforms of deep slope and flat ground of Royd Moor Wind Farm and results are shown in Figure 6.13 with various frequencies from 31.5Hz to 2kHz respectively. In general, the SPLs of original ground and flat ground are rather similar, this is possibly because the original landform is rather flat, only about 1:35 in slope. When changing the slope to 1:25, namely, a deep slope, more noticeable differences are apparent. The average sound pressure levels are 54.75dB on the original slope, 54.91dB on flat ground and 55.42dB on a deep slope. Overall, the sound effect of landforms within the investigated range does not seem significant.




85
75
65
55
45
35
SPL (dB)
1st
2nd
3rd
4th
5th
6th
7th
8th
9th
10th
Measured point
63Hz
Flat ground
Original site
Deep slope


85
75
65
55
45
35
SPL (dB)
1st
2nd
3rd
4th
5th
6th
7th
8th
9th
10th
Measured point
125Hz
Flat ground
Original site
Deep slope


85
75
65
55
45
35
SPL (dB)
1st
2nd
3rd
4th
5th
6th
7th
8th
9th
10th
Measured point
250Hz
Flat ground
Original site
Deep slope


85
75
65
55
45
35
SPL (dB)
1st
2nd
3rd
4th
5th
6th
7th
8th
9th
10th
Measured point
500Hz
Flat ground
Original site
Deep slope

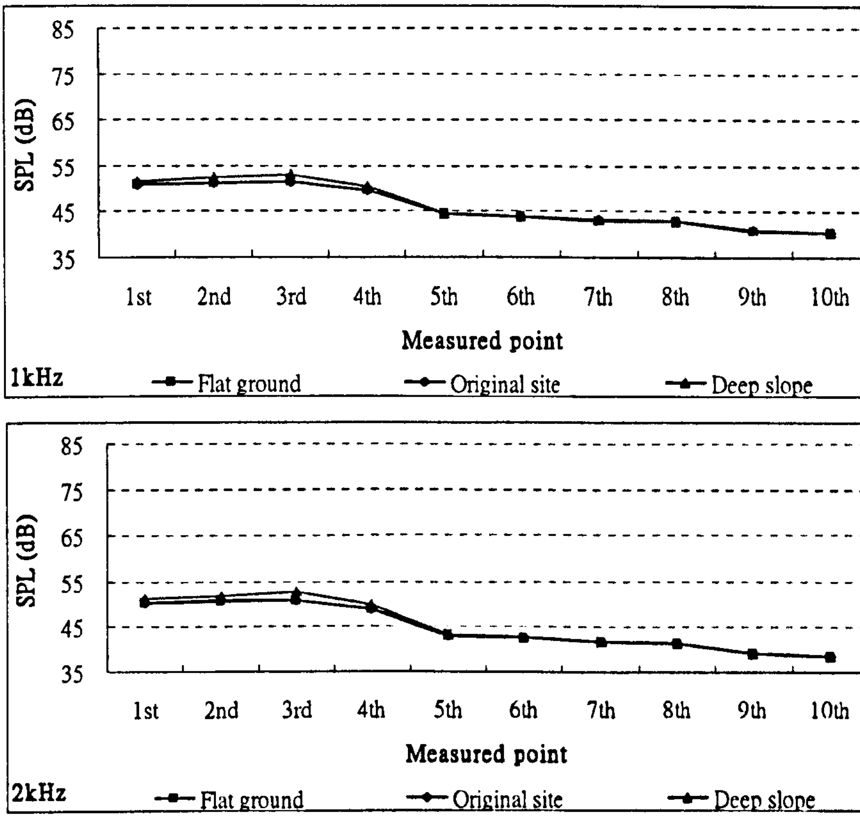


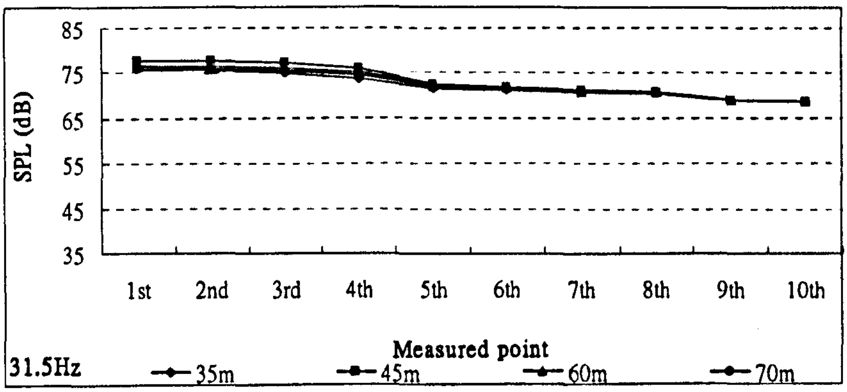
Figure 6.13 Comparison in SPLs between three landforms.

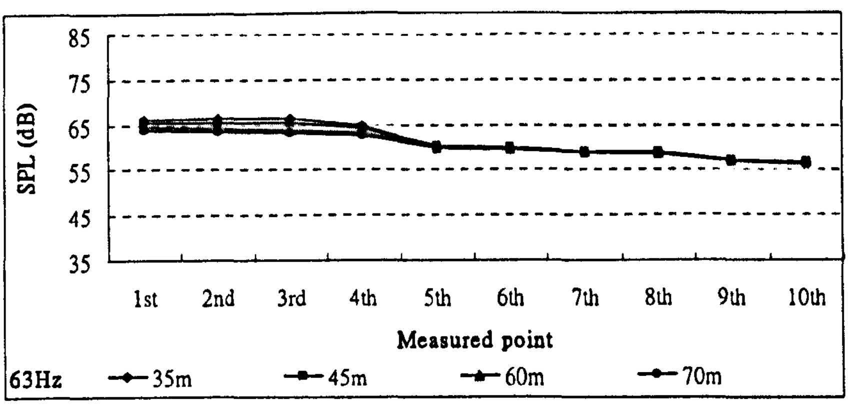
6.4.2 Source Height

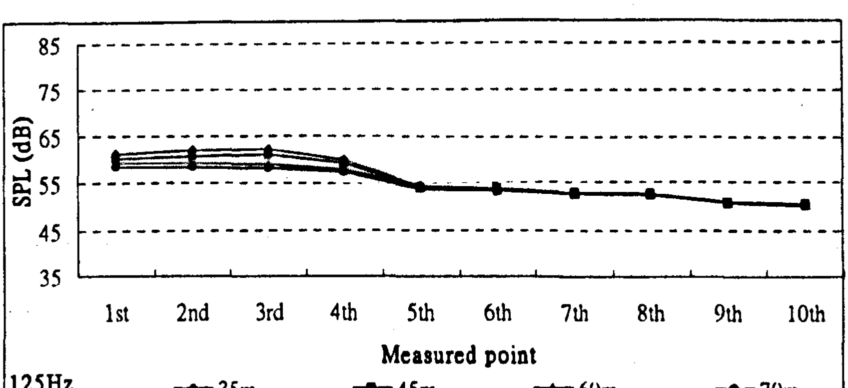
In order to find out if different heights of wind turbines might cause different sound effects, source heights at 35m, 45m, 60m and 70m were considered and the sound levels are simulated at the ten receiver points. The results are shown in Table 6.3 and Figure 6.14. It can be seen that considering various frequencies between 31.5Hz and 2kHz, the SPL decreases with increasing wind turbine height. The differences, however, between the different heights are insignificant, within about 1-2dB. The main reason is that although the change in turbine height is significant, the actual change in source-receiver distance is much less.

Table 6.3 SPL with different source heights.

		Frequency (Hz)						
		31.5	63	125	250	500	1 k	2 k
Height	35m	72.21	61.57	56.09	51.68	51.19	45.85	44.69
	45m	73.22	61.20	55.67	51.26	50.80	45.45	44.27
	60m	72.70	60.67	55.11	50.69	50.26	44.89	43.63
	70m	72.39	60.35	54.78	50.37	49.94	44.56	43.26







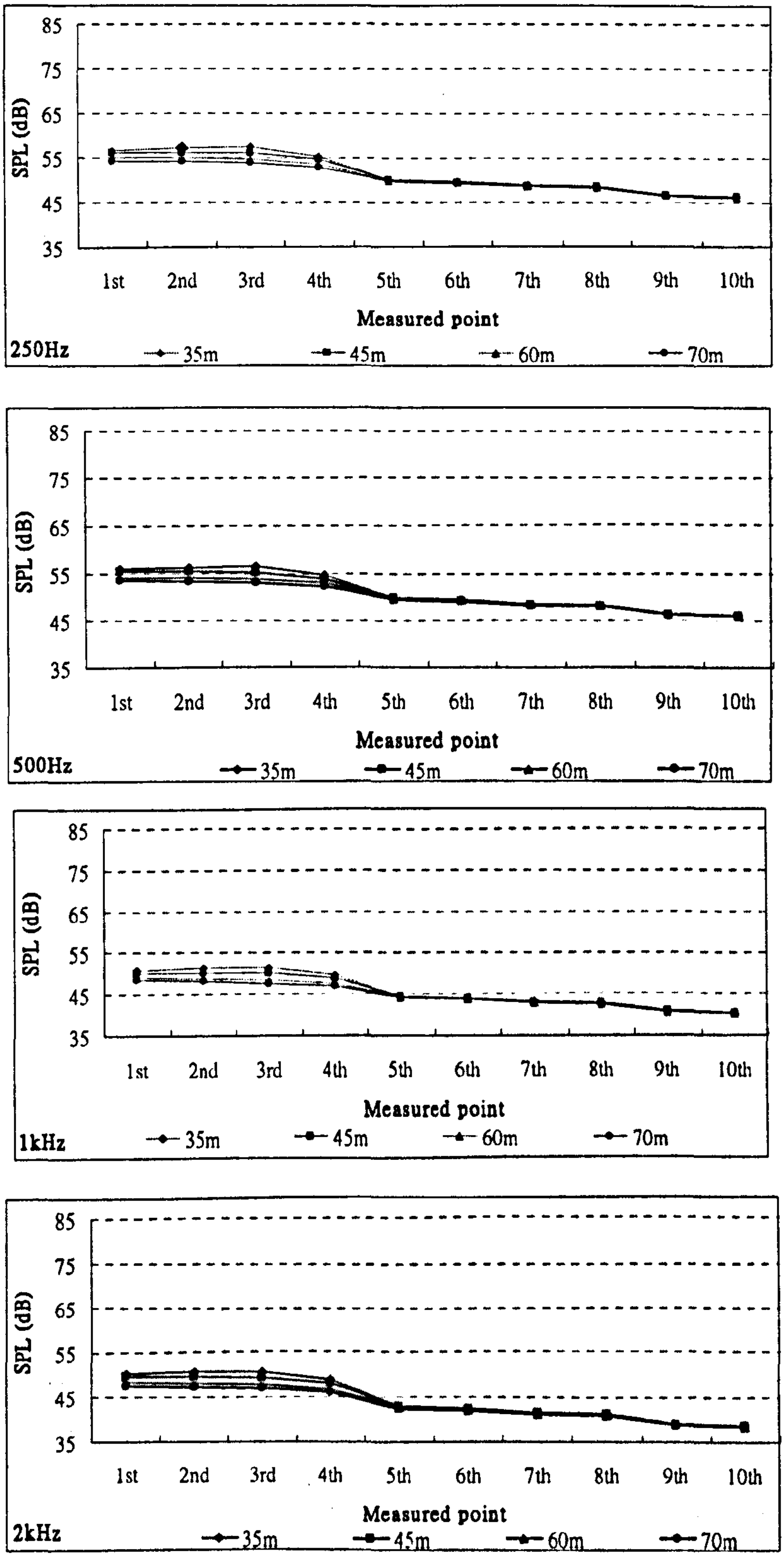


Figure 6.14 SPL distributions with source heights of 35m, 45m, 60m and 70m.

6.4.3 Numbers Of Sources And Different Source Locations

In order to ascertain the difference between numbers of sources and different source locations, one to twelve sources, located in the middle of the land and along the road, were considered and illustrated in Figure 6.15 and 6.16, respectively. The simulation was mainly focused on the low frequency of 31.5Hz and this attempted to examine how wind turbines in different locations might cause different low frequency effects. Table 6.4 and Table 6.5 show the SPL differences between a single source (source 1) and multiple sources, considering receiver locations 1-10. It can be seen that the effects of adding sources could range from about 1dB to 23dB, depending on the receiver location.

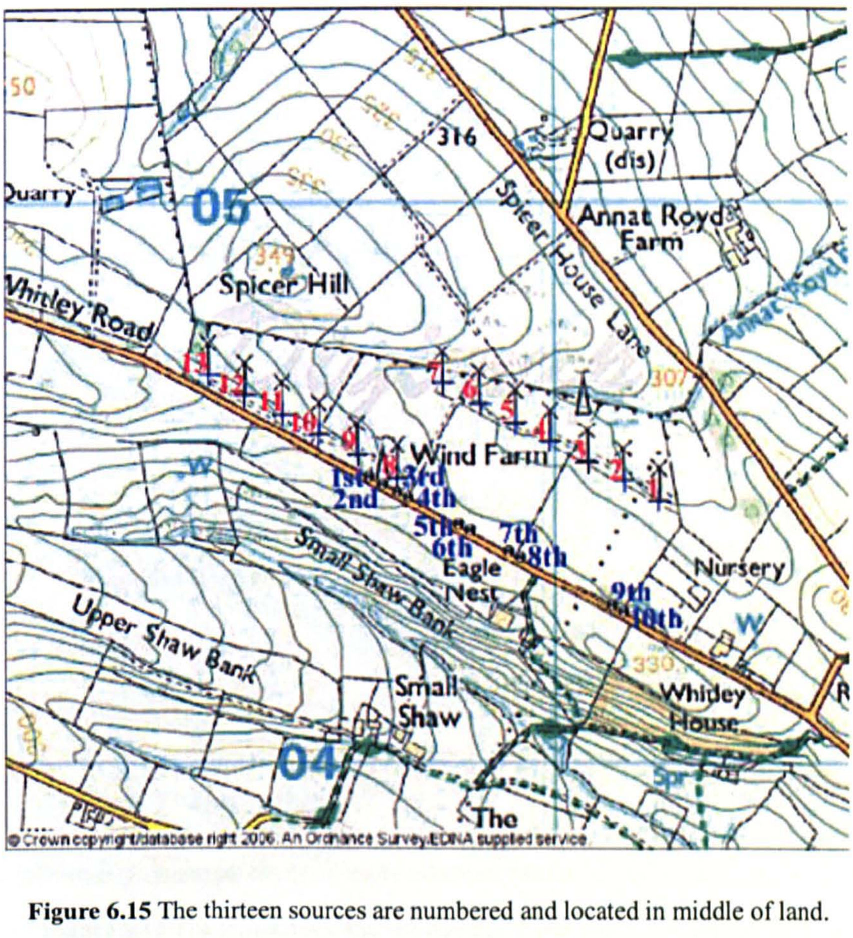


Figure 6.15 The thirteen sources are numbered and located in middle of land.

Table 6.4 Comparison between one source and multi-sources, the sources are shown in Figurer 6.15.

at source point	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Source (1~2)-1	3.7	3.6	3.7	3.7	3.8	3.8	3.8	3.8	2.6	2.6
Source (1~3)-1	6.2	6.1	6.2	6.2	6.5	6.4	6.3	6.1	3.9	3.8
Source (1~4)-1	8.2	8.2	8.3	8.4	8.5	8.4	7.9	7.6	4.6	4.5
Source (1~5)-1	10.1	10.1	10.2	10.2	10.1	9.9	8.9	8.4	5.1	4.9
Source (1~6)-1	11.8	11.8	11.8	11.8	11.1	10.8	9.5	9.0	5.4	5.2
Source (1~7)-1	13.3	13.1	13.1	12.9	11.8	11.4	9.9	9.3	5.6	5.4
Source (1~8)-1	20.1	21.9	22.3	20.1	13.4	12.6	10.5	9.8	5.8	5.7
Source (1~9)-1	23.1	23.0	22.8	20.6	13.9	13.1	10.8	10.1	6.0	5.8
Source (1~10)-1	23.5	23.3	23.0	20.8	14.2	13.3	11.0	10.3	6.1	5.9
Source (1~11)-1	23.6	23.4	23.0	20.9	14.4	13.5	11.1	10.4	6.2	6.0
Source (1~12)-1	23.7	23.5	23.1	21.0	14.5	13.6	11.2	10.5	6.3	6.1
Source (1~13)-1	23.8	23.5	23.1	21.0	14.5	13.6	11.3	10.6	6.3	6.2

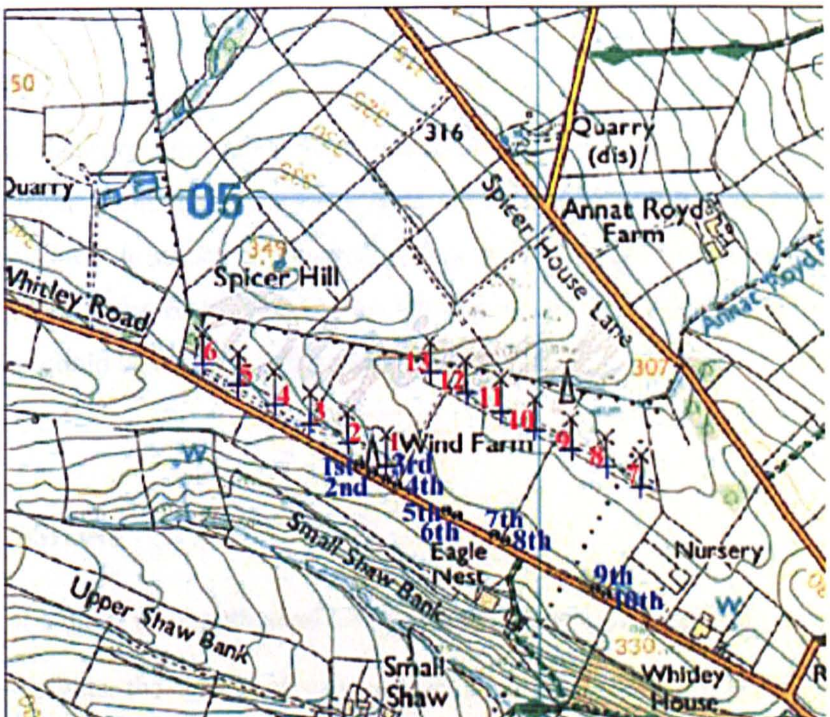


Figure 6.16 The thirteen sources are numbered and located along the road.

Table 6.5 Comparison between one source and multi-sources, the sources are shown in Figurer 6.16.

at source point	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Source (1~2)-1	3.5	1.4	0.6	0.6	1.5	1.6	1.9	2	2.3	2.3
Source (1~3)-1	4.0	1.7	0.8	0.9	2.1	2.3	2.8	2.9	3.5	3.6
Source (1~4)-1	4.1	1.8	0.9	1.0	2.5	2.7	3.4	3.5	4.2	4.3
Source (1~5)-1	4.2	1.8	0.9	1.0	2.7	2.9	3.7	3.9	4.8	4.9
Source (1~6)-1	4.3	1.9	1.0	1.1	2.8	3.1	4.0	4.2	5.2	5.3
Source (1~7)-1	4.3	1.9	1.0	1.1	3.2	3.6	5.1	5.5	9.0	9.3
Source (1~8)-1	4.3	1.9	1.0	1.2	3.6	4.1	6.2	6.8	10.7	11.0
Source (1~9)-1	4.3	2.0	1.1	1.3	4.1	4.8	7.4	8.1	11.7	11.9
Source (1~10)-1	4.4	2.0	1.1	1.4	4.7	5.5	8.3	9.0	12.3	12.4
Source (1~11)-1	4.5	2.1	1.2	1.5	5.3	6.2	9.0	9.6	12.6	12.8
Source (1~12)-1	4.5	2.2	1.3	1.7	5.8	6.7	9.4	10.0	12.9	13.0
Source (1~13)-1	4.7	2.3	1.4	1.8	6.1	7.0	9.7	10.3	13.0	13.2

6.4.4 Summary

Overall, the measurement survey and simulation reconfirm that a wind farm could have significant sound effects over a large area, especially in the case of multiple sources in different locations. The sound effects from different landforms are generally insignificant. In terms of turbine height, when it is increased from 35m to 70m, the SPL increase could be about 1-2dB around the wind farm.

6.5 DISCUSSIONS

By means of studies of hypothetical landforms, building types, building arrangements, and source heights, the effects of wind turbines were examined. An operational wind farm was examined in an attempt to comprehend the existing situation around wind farm.

This hypothetical case study demonstrated that wind farms could have significant acoustic effects on the surrounding area, especially in the case of multiple wind turbines. Wind turbines could have different sound effects according to landform, source height and frequency. With different building arrangements, there are about 10dB difference between built-up areas and areas without buildings around wind farms. This is mainly because of good barrier effects which affect the sound pressure level attenuation. When the buildings' density increases, it makes a significant difference to sound distribution.

The next chapter discusses integrated considerations of people's living environment, residential buildings and hypothetical situations of wind turbine which are further evaluated in regard to environmentally sustainable acoustics. These concerns can be applied to the urban residential areas in terms of environmentally sustainable development.

Chapter 7

Integrated consideration of urban acoustic sustainability

Environmentally sustainable acoustics are not limited to a few factors: they are invariably related to various and complex environmental factors. In Chapter 4, Chapter 5 and Chapter 6 the focus was on three essential aspects, namely, people, buildings and resources, and examined environmentally sustainable acoustics. These three chapters demonstrated that environmentally sustainable acoustics are an important part of environmentally sustainable development. It was argued that these elements should always be considered when attempting to find a proper balance. In order to ascertain how to create a good balance between environmentally sustainable development this chapter further develops and expands the findings of previous chapters. It also further explores their potential in terms of approaching environmentally sustainable development.

This chapter study can be divided into four parts. Section 7.1 briefly reviews the results of Chapter 4. It is concerns acoustic effects and focuses on people's perception. In order to determine the contrast between perception and sound distributions in their living environment, the expanding study examines the sound distributions of building façades in six selected survey sites. The aim is to further examine results from Chapter 4 which might have further possibilities when reconfirming people's perceptions. In this way it is possible to assess how to establish environmentally comfortable and sustainable acoustics in existing sites. Section 7.2 examines sound distributions of various building shapes, as the huge quantity of residential buildings which exist in the urban areas might have different environmental impacts, as well as acoustic effects. The objective is to further understand environmental effects from a more generic viewpoint. It then examines various building storeys and their sound distributions, which also corresponds with sustainability assessments of various building storeys in Chapter 5. The previous results showed insignificant differences in Ecopoints between various storeys but in terms of sound distributions there might be different tendencies. In Section 7.3, in order to examine the possibility of setting wind turbines in the residential areas studied, a series of studies were carried out, using two case study sites in Sheffield. It attempts to find a potential balance between generation of renewable wind energy and environmentally sustainable acoustics in order to find an approach environmentally sustainable development.

In this chapter, the noise mapping software package is mainly used to assess the sound distributions in hypothetical situations. The software package Envest is used to assess environmental impact. The goal of this chapter is to make further examination in terms of environmentally sustainable acoustics which could possibly be considered in early developmental stages.

7.1 SOUND DISTRIBUTION ON FAÇADES IN SIX SELECTED SITES

A significant feature of urban living is that a high density population has serious sound effects on environmentally sustainable development. On the other hand, people are the main object of the space and their perceptions should always be considered. Therefore from the environmentally sustainable acoustics point of view it is vital to understand people's perceptions and requirements of their living environment which is based on the relation between existence and sustainable approach. Overall, the results of the Chapter 4 culture study show that people have different opinions, perceptions and needs of their living environment. In order to determine the sound distributions of their buildings, they are examined on the six survey sites. This section starts with a brief review of results found from the Chapter 4 culture study; it then focuses on a series of simulations of building façades of main survey streets.

7.1.1 People's Perceptions

The results of Chapter 4 showed different tendencies in the UK and Taiwan: this is mainly caused by different cultural backgrounds which have significant effects on people's perceptions. In terms of choosing a living environment, results show the most important factor is safety in both countries. When asked to evaluate their living environment, results showed that people in Taipei were more concerned about their living environment and less satisfied with their health condition. This can be corresponded to measured results which show high sound trends in three of the survey sites in Taipei. In terms of ranking of urban pollution, results show that noise pollution was perceived as the second most serious pollutant in both countries. It was also considered a serious hindrance to environmentally sustainable acoustics. In terms of main activities when respondents stay at home, results show that a high percentage of activities could be potentially disturbed by noise, especially in Taiwan. This also corresponds to results from evaluations of noise sources which indicated significant noise annoyance from neighbours' houses. The results, which were evaluated on noticeability, annoyance and sleep disturbance from typical sound sources, showed that people living in Sheffield had higher awareness of traffic noise and in Taipei people responded that the most noticeable noise source from vehicles is from two wheeled vehicles, such as mopeds and motorbikes. In terms of preferred sounds, people in Sheffield responded that bird and water sounds were preferable and the results in Taipei showed more people preferred insect sounds and music from outside of the house. In order to show sound evaluations in six surveyed sites, Figure 7.1 illustrates sound perceptions of those six sites. In terms of sound evaluation, a higher value means more significant perception towards a negative direction. It can be seen that Taipei has higher values overall in terms of environmental sound.

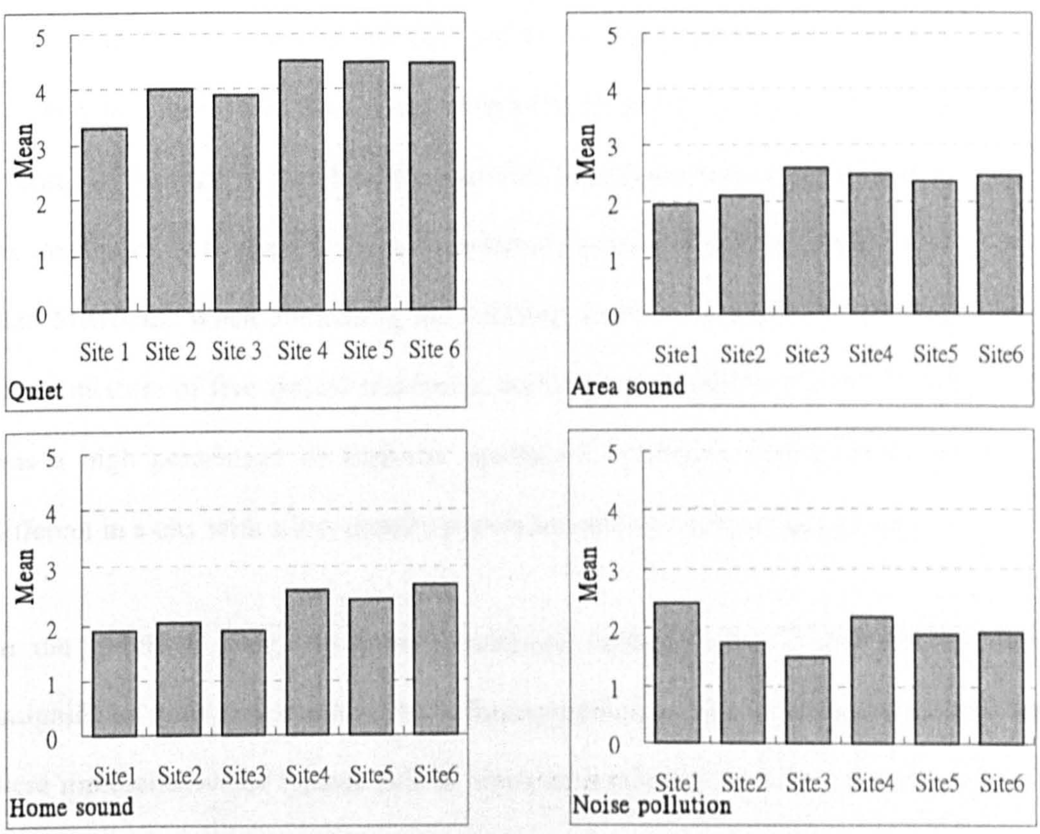


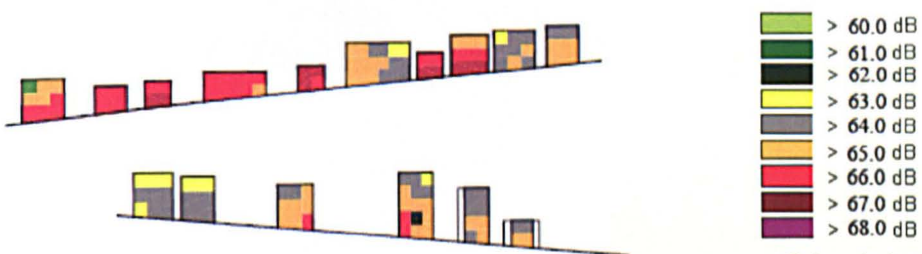
Figure 7.1 The sound evaluations of living environment in six sites.

7.1.2 Sound Distribution On Building Façades

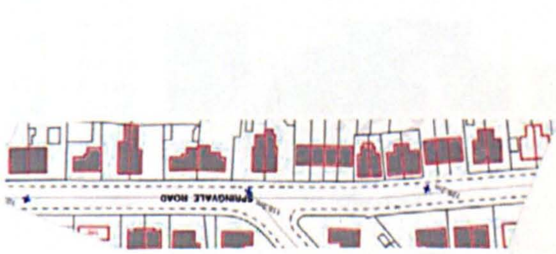
To correlate the sound perception with actual sound levels, the sound distributions of six surveyed sites, especially the building façades sound levels, have been examined. This aims to determine if objective sound effects might have different tendencies from people's subjective evaluations. In the simulations, buildings along the main roads were considered. The average sound distributions of building façades along the road-side in the three Sheffield survey sites are 65.7dBA, 65dBA, 59.2dBA, respectively, and those figures in the three Taipei sites are 66dBA, 65dBA, and 71dBA. Although the difference in average level is not very high but that is average sound level which can be effect by building height. Furthermore, the colour coded map can be seen in Figure 4.1. The sound distributions along the roads were higher then average of the façades and the differences are significant between Sheffield and Taipei. As mentioned in Chapter 4, Taipei is a densely populated city with higher noise levels than Sheffield. When comparing the building features of Sheffield and Taipei, there was a mixture of five typical residential buildings in Sheffield and but in Taipei there was a high percentage of high-rise apartment buildings. Sound levels are clearly different in a city with a low density population and one with a high density.

In the Sheffield sites, the sound variations between sites 1 and 2 were rather insignificant with only about 1dBA difference: this was mainly because these two sites were representative of typical British styles of residential buildings. Conversely, with regard to sound trends in site 3, the average sound difference from sites 1 and 2 is considerable. This is because the main building type in site 3 is apartment building. They represent contemporary styles and have longer and higher building shapes than other building types. Therefore the building itself can act as a good noise barrier. Figure 7.2 illustrates sound distributions of building façades of the six sites.

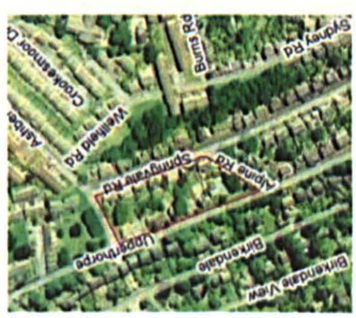
In the Taipei sites, rather similar sound distributions are shown in site 4 and site 5: this is because the building types and site layouts were rather similar in both sites. The average sound distributions of site 6 show the highest average SPLs when compared to the other five sites. This is because in this site the main roads are rather close to buildings and thus affects the sound level. It should be noted that the sound distributions of the site may different sound effects from building types, site layouts and traffic conditions in a similar way to the assessed results in Chapter 5. However, the various building characteristics may have different impacts on the environment. In other words, building densities, shapes, types and traffic conditions can have significant effects on sound environment as well as environmental sustainability. This should be taken into account when considering environmentally sustainable development.



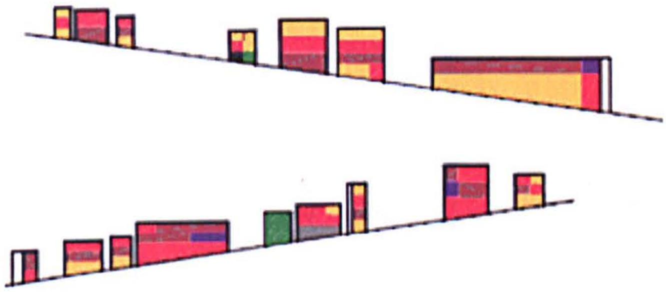
Colour index

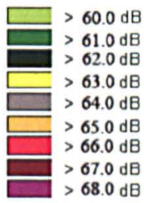


Site plan



Site 1, Springvale Road, Sheffield.





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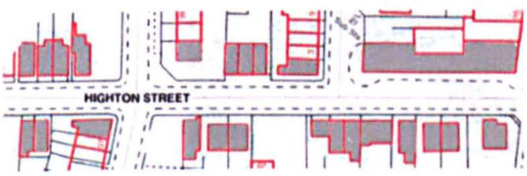
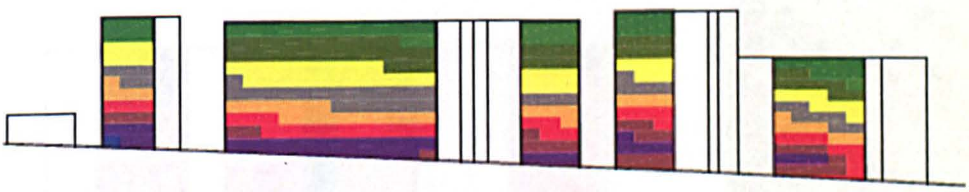
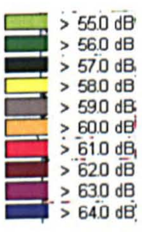
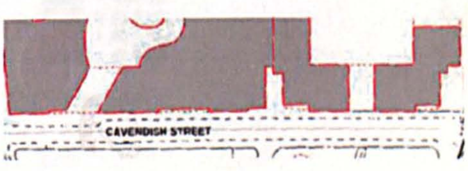


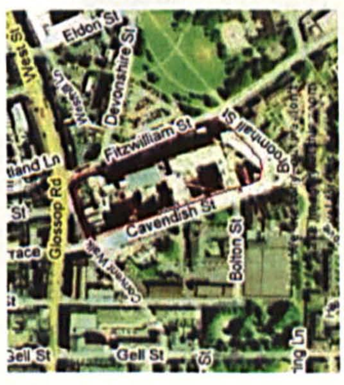
Site plan

Site 2, Highton Street, Sheffield.





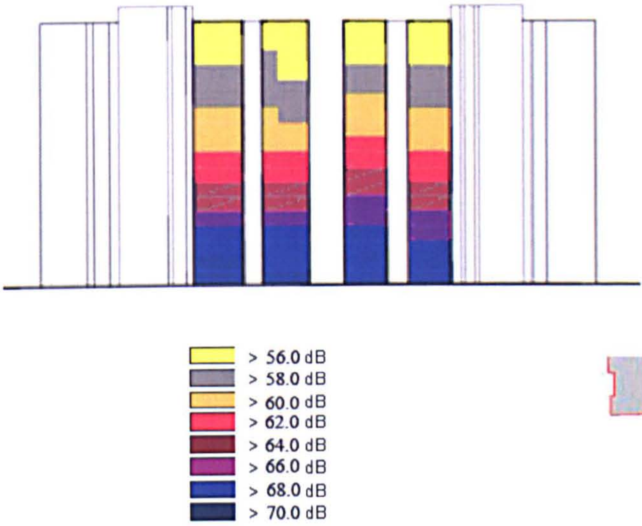




Colour index

Site plan

Site 3, Cavendish Street, Sheffield.



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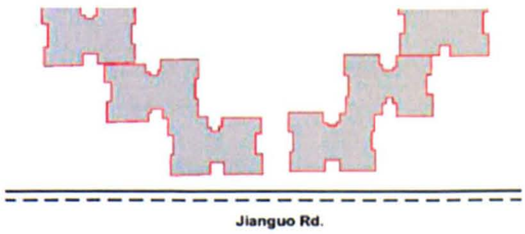
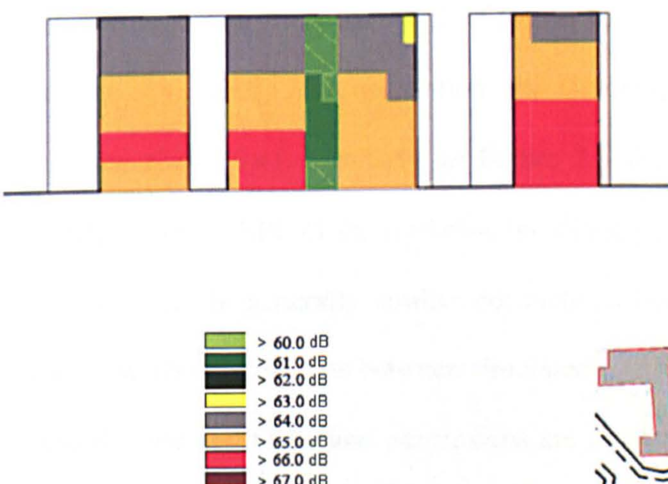


Site plan

Site4, Jianguo Rd., Taipei.



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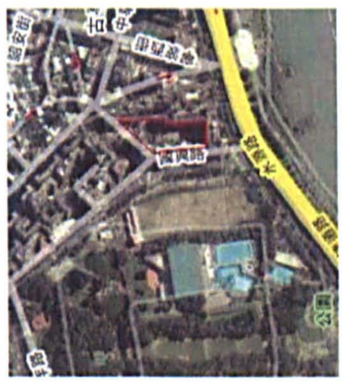
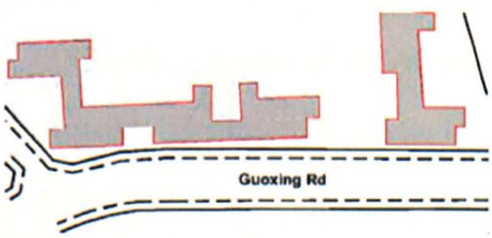
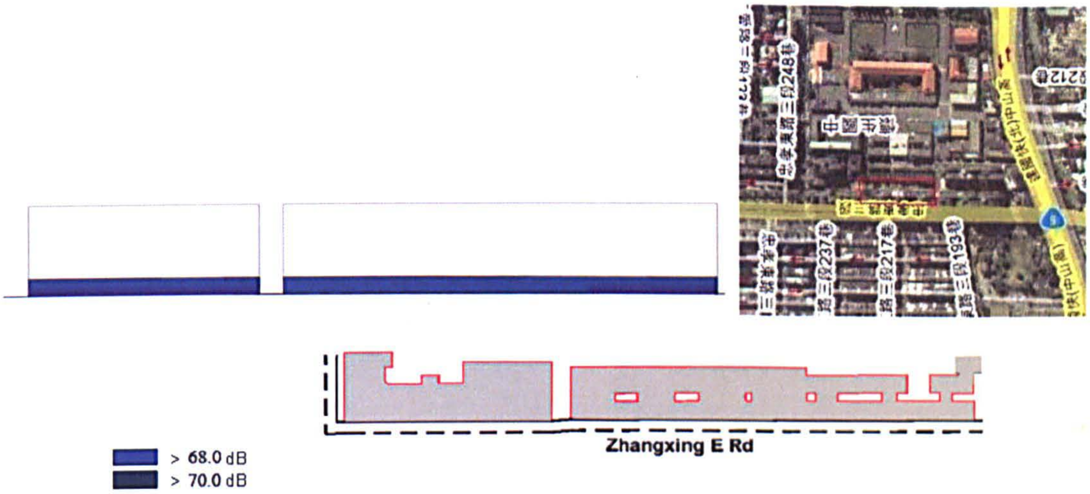




Site plan

Site 5, Guoxing Rd., Taipei.



Colour index

Site plan

Site 6, Zhangxing E Rd., Taipei.

Figure 7.2 The sound distributions of coloured building façades in six sites.

7.1.3 Correlation Between Average SPL And Sound Perception

The correlations between the measured average SPL and sound perceptions are illustrated in Figure 7.3, where each of the six sites is used as a sample. It can be seen that there is generally high correlation. For factors quiet, area sound and home sound all R^2 are above 0.45. Similarly, in Figure 7.4 the correlations are shown between simulated average SPL of the road-side buildings and the sound perceptions. It can be seen that there is generally similar correlations but the correlation coefficients are rather low. The correlations between simulated averages SPL considering all buildings across the site and the sound perceptions are illustrated in Figure 7.5. It can be seen that for quietness, area sound and home sound the relationships are at converse direction as those in Figure 7.3. This suggests that an average of all buildings on the site may not be a good indicator for subjective evaluation.

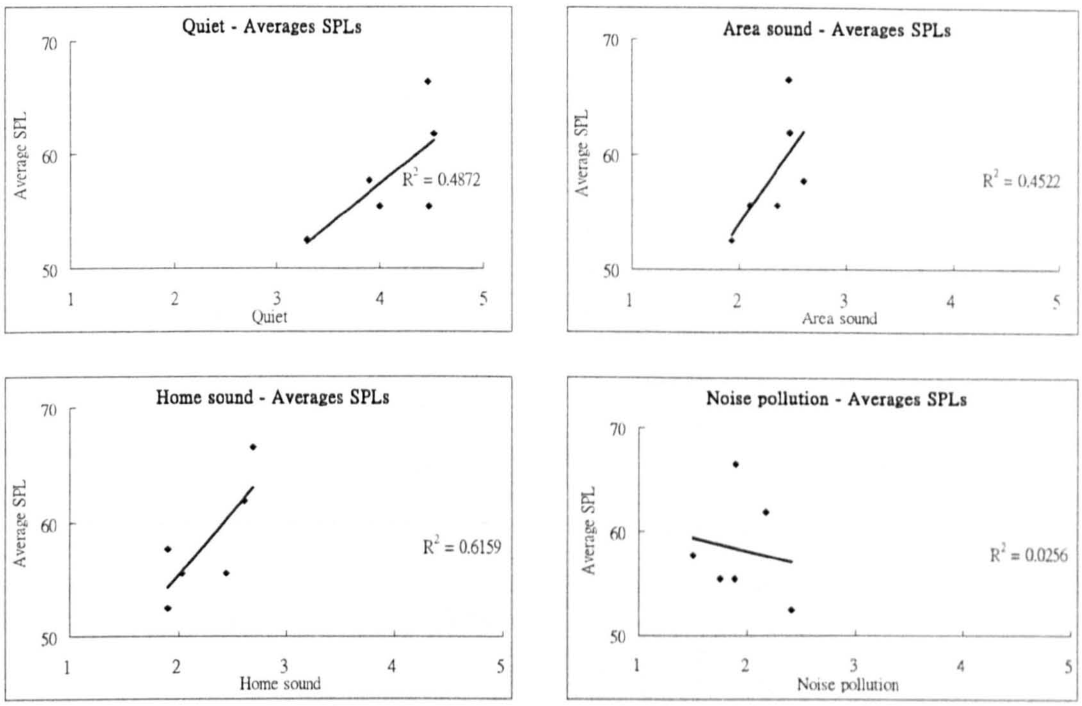


Figure 7.3 Correlation between measured averages SPLs and sound perceptions in six sites.

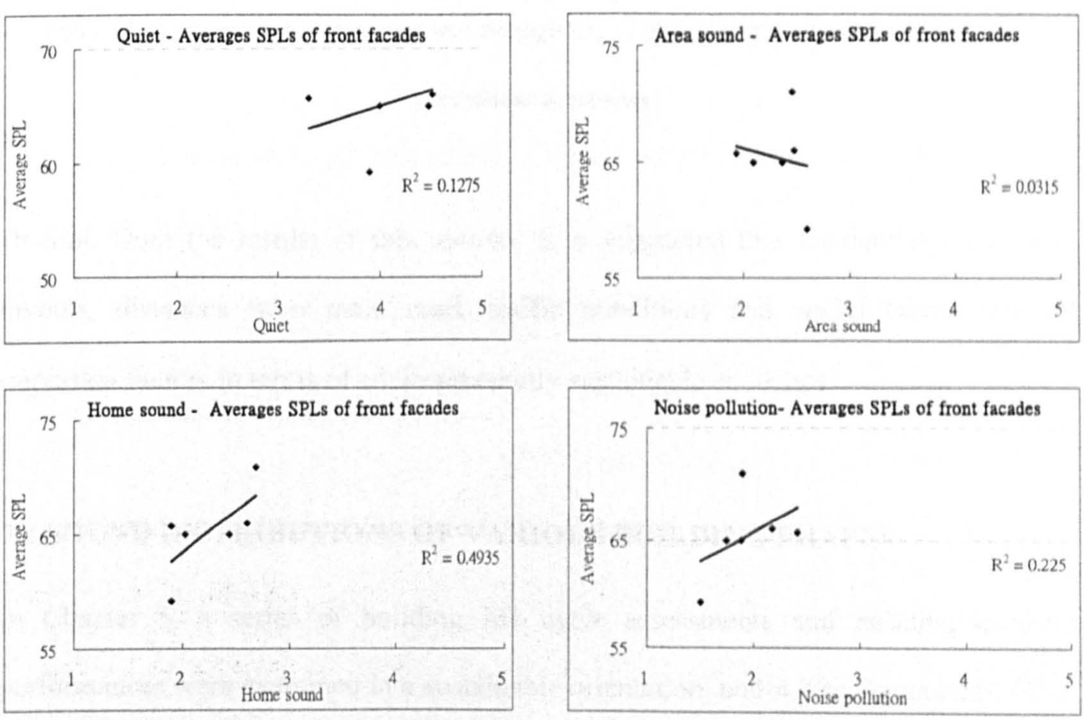


Figure 7.4 Correlation between simulated averages SPLs of road-side buildings and sound perceptions in six sites.

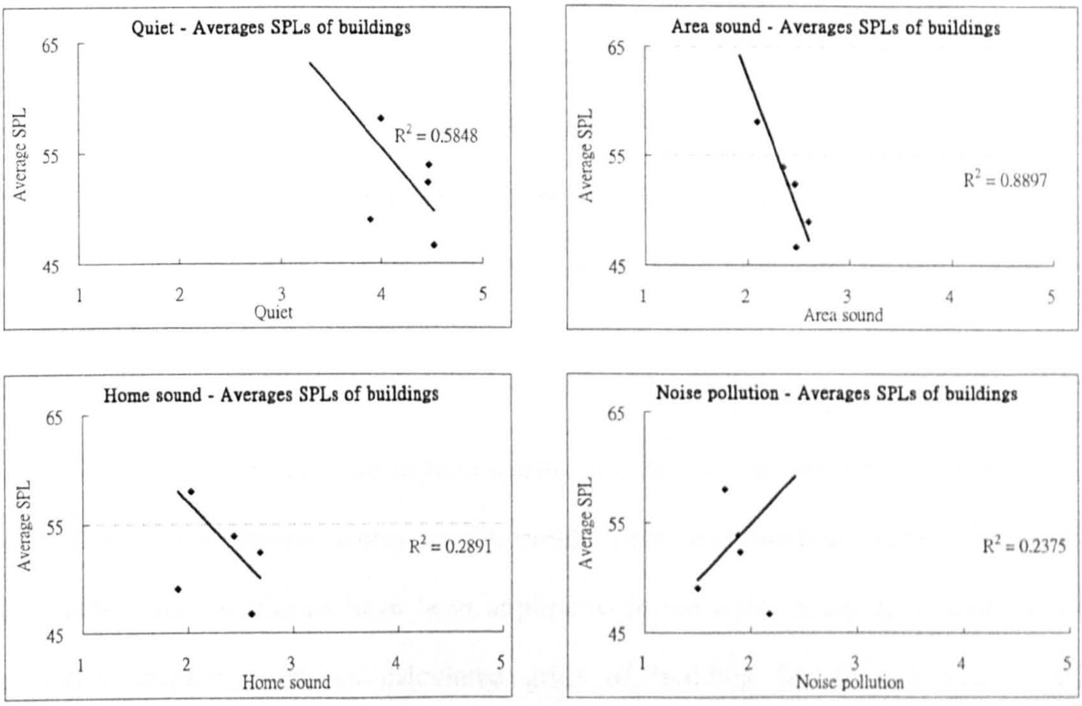


Figure 7.5 Correlation between simulated average SPL of all buildings across the site and sound perceptions in six sites.

Overall, from the results of this section, it is suggested that residential styles, site layouts, distances from main road, traffic conditions and social factors are all important factors in terms of environmentally sustainable acoustics.

7.2 SOUND DISTRIBUTIONS OF VARIOUS BUILDING SHAPES

In Chapter 5, a series of building life cycle assessments and building acoustic performances were examined in a sustainable orientation, and it was demonstrated that acoustic sustainability should be combined into an overall environmentally sustainable development. It is important to discover whether different building shapes might have a different environmental impact as well as sound distribution. Therefore further simulations were been made, focusing on buildings' life cycle assessment and sound distributions of various generic building shapes. In other words, the focus of this section concerns the relationships between sound distributions and Ecopoints of different building shapes. Considerations are given from individual building shape to combined building shapes.

The same parameters are used in the acoustic simulations and the Envest calculation, including building height, storey height, building size and building shapes. The same parameters and conditions have been applied as in the noise mapping simulation in previous chapters, such as calculated grids of building façade and main road conditions.

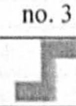
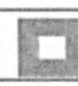
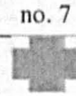
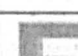
In this section, a number of comparisons are made of eight building shapes with front, rear and whole building façade. It then focuses on five building groups which have different building combinations. Further simulation focuses on the number of building storeys and examines to link building heights in terms of environmentally sustainable acoustics.

7.2.1 Building Shapes

In the analyses, similar calculation parameters and conditions are applied, such as three storeys in each building, storey height of 3.5m, building height of 10.5m, gross area 10800m^2, occupancy 12m^2/per person, sixty years of building life and location in the

Thames Valley. For each building shape, typical wall material of brick and opening glazing ratio of 30% were considered. As previously mentioned, Envest is mainly used for office buildings; in this section the input parameters were adjusted so that relative comparisons could be made for various building shapes. In terms of traffic conditions, it was assumed a speed of 100 km/h, traffic count 500 Veh/18h and 16m road in front of the building. Eight typical building shapes were first compared, including square, rectangle and six irregular forms. Table 7.1 shows the eight layouts/plans of building shapes and where the Ecopoints are also listed. It can be seen that buildings with regular shapes presented least Ecopoints, namely, were more environmentally friendly than irregular building forms. This is probably due to the fact that regular building shapes (square and rectangular) can be relatively easier to construct as well as to operate. From Table 7.1 it is also seen that the ratio between embodied and operational Ecopoints is about 1:5 on average, showing the significance of considering operational sustainability. Comparing the eight building shapes, the one with the highest Ecopoints was building no.8. This is because the building shape is more complex than the others.

Table 7.1 Layouts of building shapes considered and their Ecopoints.

Building number	no. 1	no. 2	no. 3	no. 4
Building shape				
Embodied Ecopoints	60497	61078	64119	64444
Operational Ecopoints	385334	386802	395355	396213
Total Ecopoints	445831	447880	459474	460657
Building number	no. 5	no. 6	no. 7	no. 8
Building shape				
Embodied Ecopoints	64222	64222	62308	65008
Operational Ecopoints	396011	395986	390831	397931
Total Ecopoints	460233	460208	453139	462938

Generally speaking, in terms of total Ecopoints between different building shapes, insignificant differences were shown, within 4% variance. It is noted that building orientation was not considered, so the actual difference could be larger, in terms of lighting, for example.

The percentage of Ecopoint distributions of buildings' components are listed in Table 7.2. The embodied Ecopoints of floor, roof, and finishes showed higher ratios of Ecopoints than other elements. In terms of operational Ecopoint distributions, lighting and heating showed higher Ecopoints distributions which might mainly be caused by local weather. Overall, when examining the building elements, it can be noted that there is different environmental impact from each element of a building which is why these high percentage elements should always be considered first. The difference due to building shapes might only be slight but when looking at individual elements, significant differences between them could be greater.

Table 7.2 Ecopoints percentage distribution, embodied and operational, where the difference compared to building no. 1 is also shown - a more negative value signifies more environmental impact.

	Building no.	1	2	3	4	5	6	7	8
Embodied Eco distribution %	**Floors**	**33**	**33**	**31**	**31**	**32**	**32**	**33**	**31**
	Walls	8	8	12	12	11	11	10	12
	Windows	2	2	3	3	3	3	2	3
	Roof	**24**	**24**	**23**	**23**	**23**	**23**	**24**	**23**
	Finishes	**15**	**15**	**14**	**14**	**14**	**14**	**14**	**14**
	Structures	14	13	13	13	13	13	13	13
	Services	4	4	4	4	4	4	4	4
	Ecopoints differences compared to no.1	0.00%	-0.96%	-5.99%	**-6.52%**	-6.16%	-6.16%	-2.99%	**-7.46%**

	Building no.	1	2	3	4	5	6	7	8
Operational Eco distribution %	**Heating**	**19**	**19**	**21**	**21**	**20**	**20**	**20**	**21**
	Ventilation	14	14	14	14	14	14	14	14
	Refrigeration	14	14	14	14	14	14	14	14
	Water	2	2	2	2	2	2	2	2
	Lighting	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**
	Catering	9	8	8	8	8	8	8	8
	Others	19	20	18	18	18	18	18	18
	Ecopoints difference compared to no.1	0.00%	-0.38%	-2.60%	**-2.82%**	-2.77%	-2.76%	-1.43%	**-3.27%**

In order to compare the differences between environmental impact and sound trends the ranked results of Ecopoints and average sound levels are listed in Table 7.3. Again, a more negative value signifies a greater environmental impact. It is interesting to note that building no.8 has the highest environmental impact in both embodied and operational terms but converse results are shown in average sound distributions of the whole building envelope. It has a better performance in both daytime and night-time. This is mainly because a complex building shape can have different sound diffraction. Comparing ranking results of eight building shapes, the one with the least environmental impact was building no.1, followed by building no.2 which was both shaped in regular building forms. In terms of sound distributions ranking, a rather similar sound tendency was apparent between building no. 1 and 2. This is because the similar building layouts have similar noise barrier effects. By comparing building sustainability and sound distributions, it can be noted that in terms of environmentally sustainable development the various essential aspects should always be measured.

Table 7.3 Ecopoints and average SPLs of eight building shapes.

building no.	1	2	3	4	5	6	7	8
Embodied	60497	61078	64119	**64444**	**64222**	**64222**	62308	**65008**
Operation	385334	386802	395355	**396213**	**396011**	395986	390831	**397931**
Ecopoints difference compared to no.1	0.00%	-0.46%	-3.06%	-3.33%	-3.23%	-3.22%	-1.64%	-3.84%
Ecopoints ranking	**1st**	**2nd**	4th	7th	6th	5th	**3rd**	8th
Average SPL of building envelope (Daytime)	50dBA	50dBA	46dBA	**51dBA**	46dBA	46dBA	46dBA	46dBA
Average SPL of building envelope (Night-time)	43dBA	43dBA	**39dBA**	44dBA	**39dBA**	**39dBA**	**39dBA**	38dBA
SPL of building envelope ranking	3rd	3rd	2nd	4th	2nd	2nd	2nd	**1st**

Overall, the results showed that when comparing different building shapes there might be relatively insignificant differences in environmental impact but when considering acoustic performances, significant differences between environmental impact and acoustic performances could be shown.

The noise mappings of eight building shapes are illustrated in Figure 7.6; the different colours show different sound distributions. In general, differences between the eight building shapes are about 1-5dBA. Different sound distributions are evident in different directions of building façades. It can be seen that different building shapes have different sound tendencies which are mainly caused by traffic noise. Therefore further simulations on buildings' front façades were considered; due to the varying sound values.

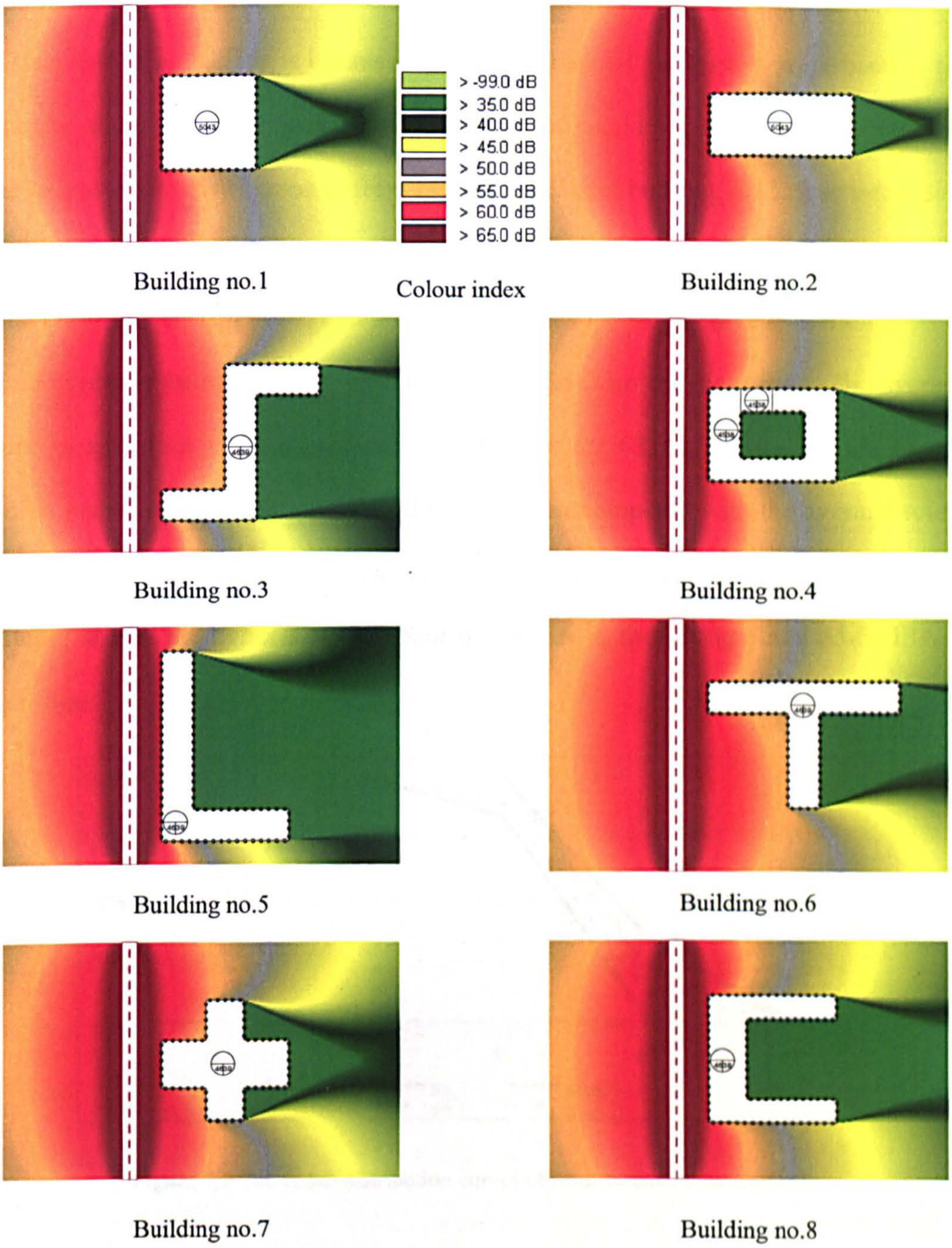


Figure 7.6 Building noise map of eight building shapes.

Figure 7.7 shows the sound distribution curves of front façades of eight building shapes. The SPLs of façade are measured every 3.5m in height and 3m in width. It can be seen that curves presented rather similar sound trends between buildings no.1, 2, 4, 6, 7 as well as no.8. This is because similarly calculated parameters were used in the simulation and also the Figure shows the range of sound values of building façades. The lowest sound distribution is from building no.5 and building no.3. It is interesting to note that building no. 1 has the same curve as building no. 4, building no. 2 has the same curve as building no. 7, and building no. 6 has the same curve as building no. 8; this is probably because of the similar sound effect from the main road. The average sound distributions of front façades in the daytime are 63, 63, 62, 63, 62, 63, 63 and 63dBA respectively which are rather different when compared with the average sound trends of whole building envelopes. In general, the average sound distributions of building shapes are rather similar: about 62-63dBA in the daytime and 55-56dBA at night-time.

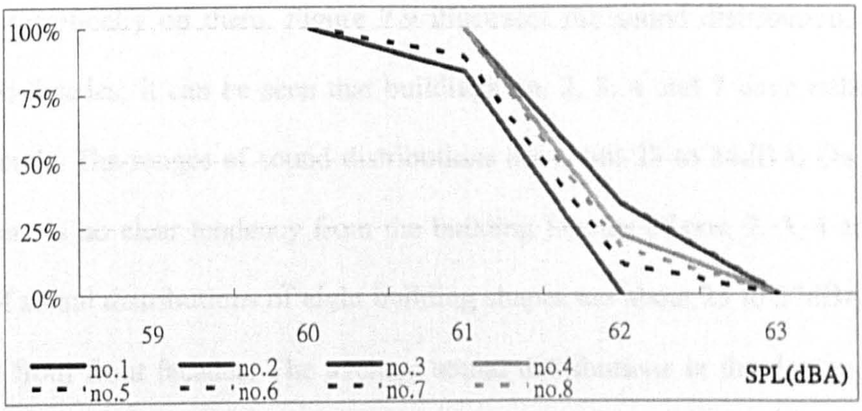


Figure 7.7 The sound distribution curves of front façade in the daytime.

In order to reconfirm different sound distributions in different building shapes of front façades, the sound values of front building façades are mainly considered and these sound values are converted to coloured drawings, as shown in Figure 7.8. It can be seen that when the building façade is close to the road, the sound levels go higher than in the other cases, as expected. Building 3 has better sound trends in front; again, this is mainly because the distance between front façade and road is greater than in the other cases.

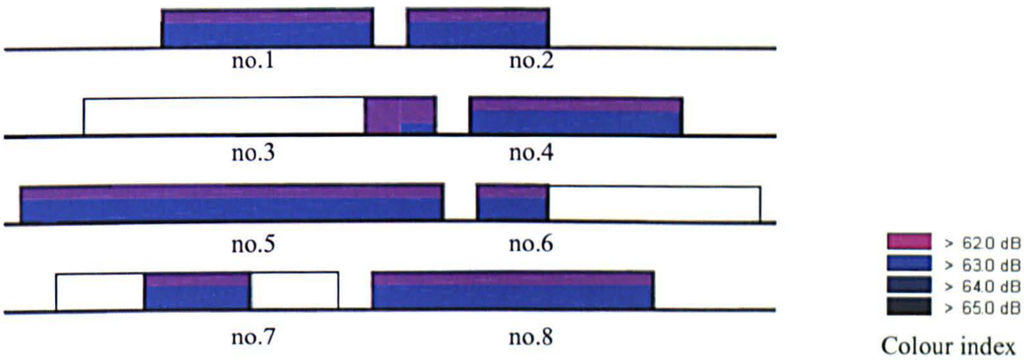


Figure 7.8 Colour maps of buildings' front façades.

In order to know the sound distributions of rear façades, further examinations are focused specifically on them. Figure 7.9 illustrates the sound distribution curves of eight rear façades; it can be seen that buildings no. 2, 3, 4 and 7 have rather similar sound trends. The ranges of sound distributions are about 23 to 34dBA. On the other hand, there is no clear tendency from the building layouts of nos. 2, 3, 4 and 7. The ranges of sound distributions of eight building shapes are about 23 to 37dBA which is different from front façades. The average sound distributions in the daytime of eight rear façades are 31, 29, 29, 30, 28, 28, 30 and 29dBA, respectively which are rather different from whole building façades (as shown in Table 7.3). On the other hand, to rank the sound distributions of rear façades: the lowest sound levels are nos.5 and 6, as well as nos.2, 3 and 8. These are different from the sound distributions of front façades, as well as differing in terms of environmental impact.

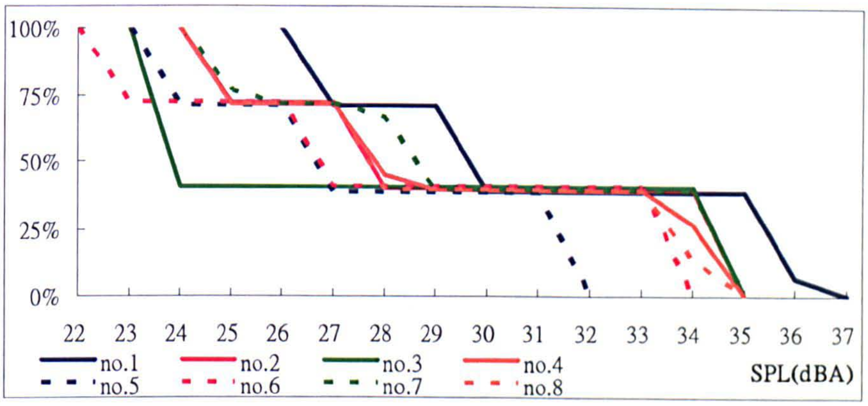


Figure 7.9 Sound distribution curves of rear façades.

In order to gain further knowledge of the sound distributions of rear façades, the coloured noise map of rear façades are shown in Figure 7.10. The sound distributions are similar in buildings no.2, 4, 5, 6, 7 and no.8. This might be because the distance from main roads to rear façades are similar in these cases and the sound effect mainly comes from the road. It is interesting to note that sound distribution is generally higher in high storeys, perhaps partly due to the diffraction effects.

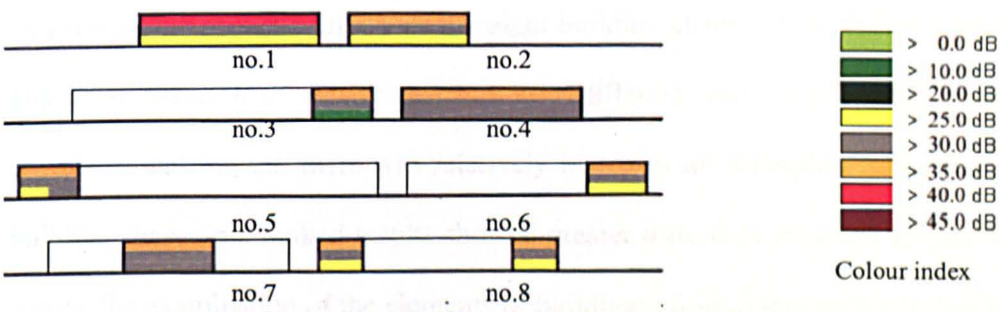


Figure 7.10 Colour maps of buildings' rear façades.

Comparing sound distributions of front and rear façades, widely differing results are produced. In order to know the sound differences of eight buildings, all directions of building façades are considered and results shown in Figure 7.11.

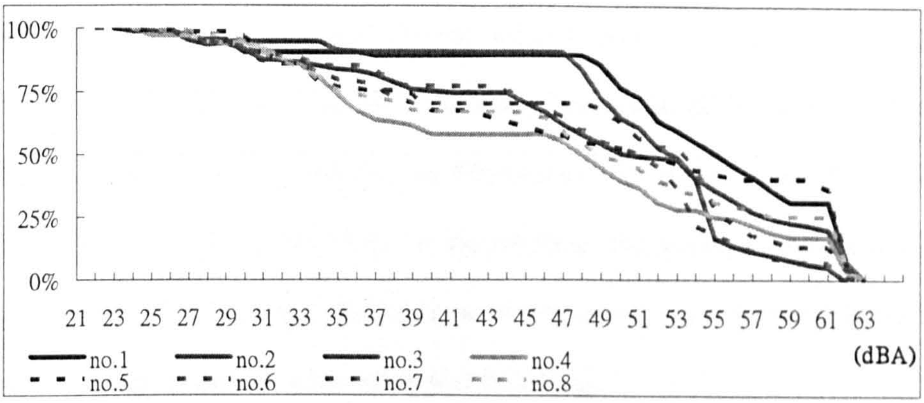


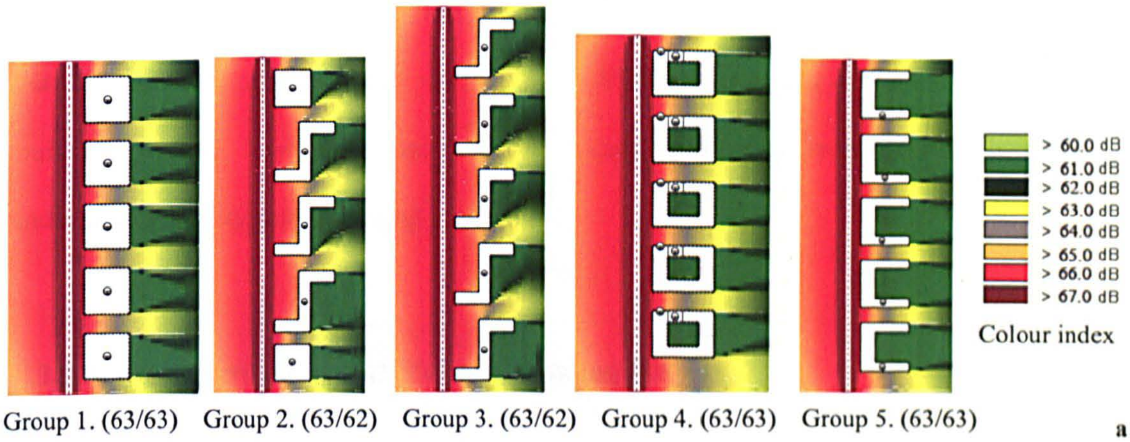
Figure 7.11 Sound distribution of all building façades.

The ranges of sound distributions between eight buildings were from 23 to 63dBA which is rather a significant difference. Comparing the eight building façades, building no.4 presented a better sound trend than other building façades. This is because the shape of no.4 is a squarer surround with a squarer void space in the centre which acts with good barrier effects on the outside border.

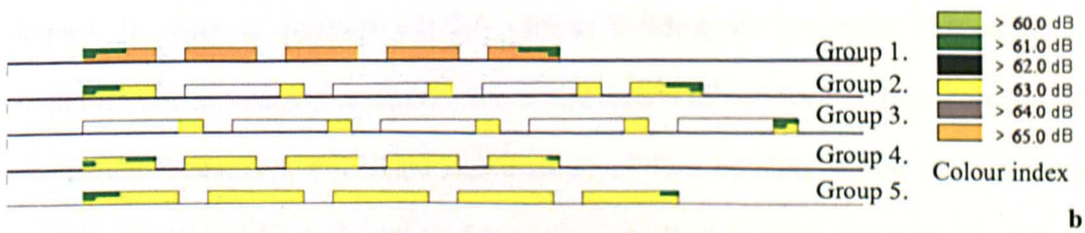
In general, the acoustic effects of the eight building shapes show different tendencies and each direction of façade also has very different sound tendencies. In terms of environmental impact, there was relatively insignificant difference between the eight building shapes but ranked results showed greater difference between shapes. In other words, the examination of the elements of buildings showed that consideration of these different elements can be helpful in terms of environmentally sustainable development.

7.2.2 Various Building Combinations

To determine the different sound distributions of building groups, due to buildings shading each other, five building groups were considered. The building groups included five no.1 buildings, two no.1 buildings and three no.3 buildings, five no.3 buildings, five no.4 buildings, and five no.8 buildings. The noise maps of five building groups are illustrated in Figure 7.12a. In the daytime, the average sound distributions of groups are 50, 47, 47, 45 and 46dBA respectively which show rather different sound distributions when compared with individual buildings.



The site layouts of group buildings with average SPLs of front façades (groups/ individual buildings)



Front façades of building groups

Figure 7.12 Noise maps of daytime SPLs of building groups.

Figure 7.12b shows the sound distributions of front façades; it can be seen that differences in sound distributions shown on various building groups were about 4dBA. The SPLs of the building groups were similar when compared to individual buildings. Comparing front façades with rear façades, the sound distributions differed; mainly because of the distances between the building and noise source and the diffraction effects.

From overall comparisons between the eight building shapes and building groups it can be seen that sound effects can be very different in terms of each direction of building façade. However, very similar sound tendencies were shown between individual buildings and building groups.

7.2.3 Sound Distributions Of Various Building Storeys

With the growth of densely populated urban areas, environmentally sustainable development becomes a serious issue, especially with the fact that buildings are becoming higher. As previously simulated in Chapter 5, a series of building life cycle analyses of various building storeys showed evidence of different environmental impact. In order to discover whether various building storeys might have different sound trends, this section examines the sound trends of various building storeys. The simulation focuses on the sound distributions of five building storey arrangements, namely, two, three, four, six and twelve storeys which are mainly considered on typical residential buildings. The same building shapes and calculated parameters which were used in section 7.3 are applied in this section.

Table 7.4 sound distributions of front building façades.

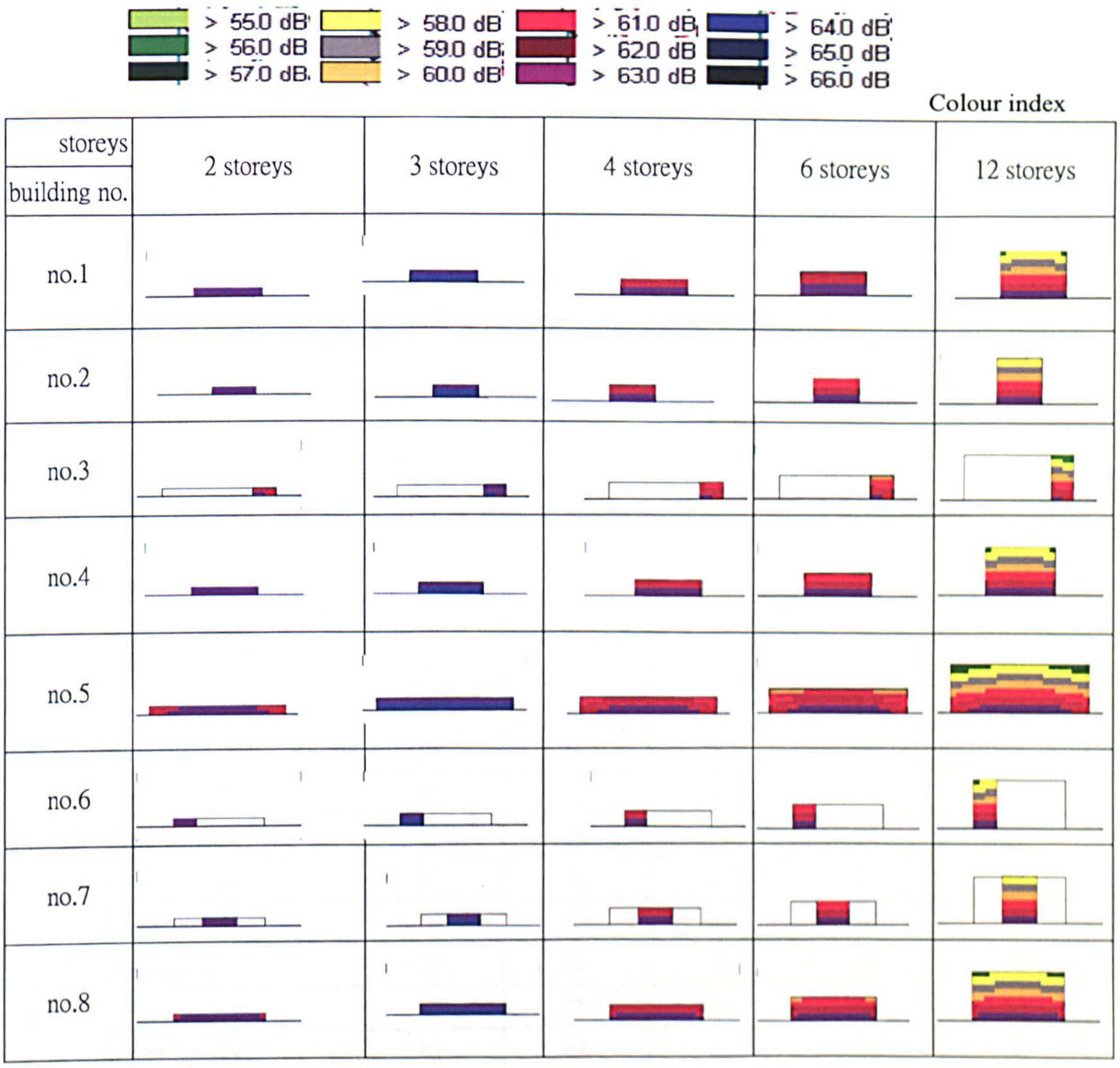


Table 7.4 shows the noise mapping of eight building façades; it can be seen there are similar sound distributions for the eight building shapes. In general, the highest sound distribution is for the two storey building and the lowest sound distribution is at twelve storeys: this is mainly because the sound distribution is decreased in higher storeys. A comparison of the sound distribution of building shapes shows that there were similar tendencies with building shapes. It also revealed high sound levels in lower storeys and lower sound levels in higher storeys. This is contrary to the results from the building

sustainability study in Chapter 5 and it can be noted that it is important to consider various essential aspects in terms of achieving environmentally sustainable acoustics.

The average sound distributions of front, rear and whole building façades are listed in Table 7.5; it can be seen that the different SPLs of front façades are generally within 3dBA, and on the rears façades the differences are much greater.

Table 7.5 The average SPLs of front, rear and whole building façades.

building no. \ storeys		2 storeys	3 storeys	4 storeys	6 storeys	12 storeys
no.1	Front façade	63	63	62	62	60
	Rear façade	**35**	**31**	**29**	**26**	**24**
	Whole façade	**51**	50	49	49	47
no.2	Front façade	63	63	62	62	60
	Rear façade	33	29	27	24	22
	Whole façade	**51**	50	50	49	48
no.3	Front façade	63	62	62	61	60
	Rear façade	32	29	27	24	21
	Whole façade	47	46	45	44	42
no.4	Front façade	63	63	62	62	60
	Rear façade	33	30	27	24	22
	Whole façade	50	**51**	**51**	**51**	**50**
no.5	Front façade	63	62	62	62	60
	Rear façade	32	28	25	23	22
	Whole façade	48	46	45	43	42
no.6	Front façade	63	63	62	62	60
	Rear façade	31	28	26	23	20
	Whole façade	47	46	45	44	42
no.7	Front façade	63	63	62	62	60
	Rear façade	33	30	27	25	22
	Whole façade	48	46	45	43	42
no.8	Front façade	63	63	62	62	60
	Rear façade	33	29	27	24	22
	Whole façade	47	46	44	43	41

Comparisons between the rear façades show that highest SPLs are shown in building no.1. The results show that building no.1 had less environmental impact (as shown in Table 7.1) but conversely, the noise levels were higher. In terms of whole building façades, there are different sound tendencies between various shapes and storeys. It can be seen that building no.4 has the highest SPLs for the various storeys as well as significant environmental impact (as shown in Table 7.3). When compared with building storeys only, sound distribution was better when building height is increased. This is because the distance between sound source and receiver is increased and also, when the area of building façade is close to the source, it can act as a good barrier effect.

Some of building shapes presented less environmental impact but higher SPLs. In terms of environmentally sustainable acoustics, a number of environmental factors such as building shapes, the distance between building and noise sources, and numbers of storeys were examined. The results showed it should always be considered those environmental factors.

7.3 ADDING WIND TURBINES IN EXISTING SITES

In order to find a sustainable manner to design/plan urban residential areas, this section examines the possibility of adding wind turbines in existing residential areas. As mentioned previously, environmentally sustainable acoustics is a complex framework which should always consider various essential factors. Examination of the sound effects of wind turbines in residential areas is an attempt to explore the possibilities of using renewable wind energy in residential areas. The examination has been made on three levels, based on sound distribution of traffic and wind turbines in two residential areas in Sheffield, the sound distribution of immediate surrounding buildings from the wind turbines, and the difference between traffic sound and wind turbine sound. This section aims to find a balance between use wind turbines and avoid noise.

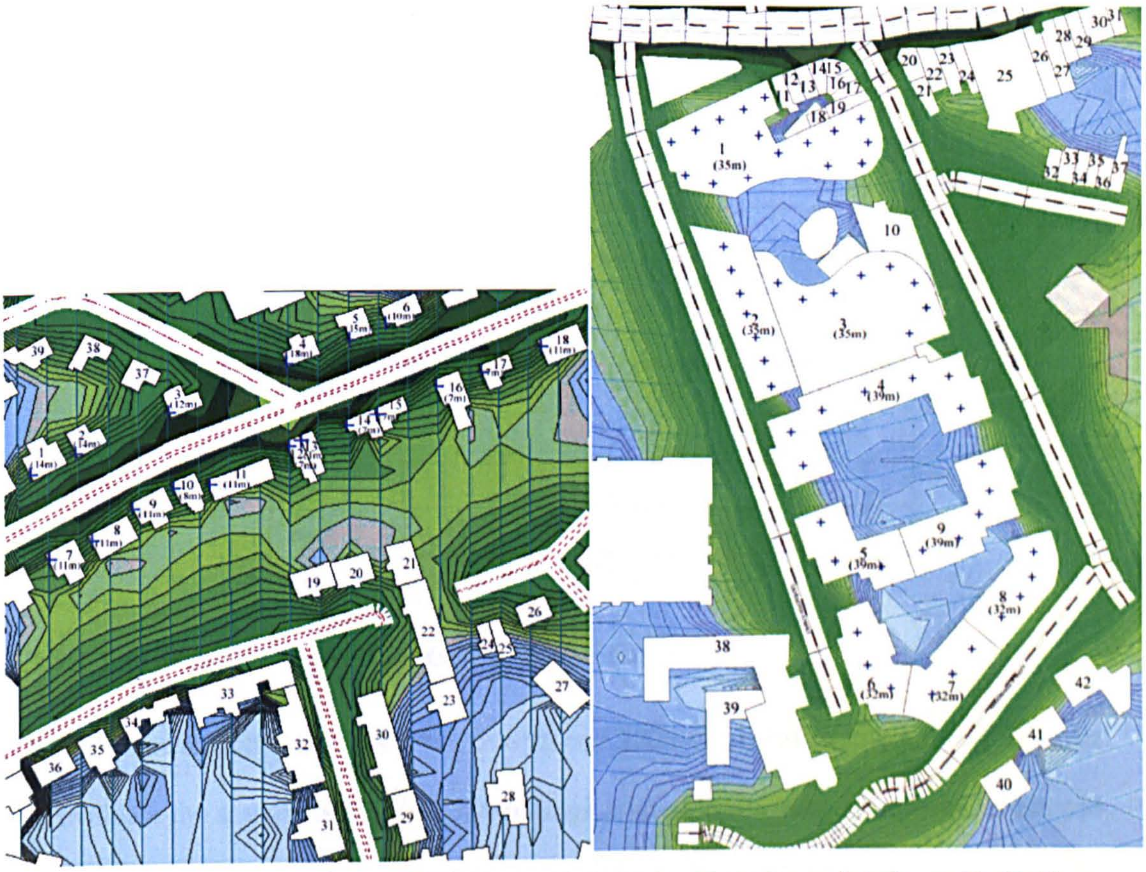
7.3.1 Methodology

A series of comparisons are made on the sound distribution of two residential areas with traffic and wind turbine sound. In the simulation the wind turbine with the highest wind speed at 12m/s is mainly considered. According to a number of complaints from the surrounding areas of existing wind farms, low frequency effect at night-time has rather significant impact. On the other hand, according to the DEFRA night-time low frequency noise criteria at third octave band centre frequency 31.5Hz, it is suggested that low frequency should be below 56dBA at night. As low frequency sound has significant effect on certain sensitive people, in the simulation the frequency of 31.5Hz is mainly examined, although other frequencies are also considered.

According to a wind turbine brochure from the technical manual of a manufacturer, (Cyclone, 2007), wind turbine noise might not be in direct ratio to turbine size. That is probably why small wind turbine may cause more vibration than larger wind turbines. There is a significant interrelation between the wind turbine sound and wind speed: when the wind speed increased it was accompanied by more noise. Some of the turbines are designed to cut out when the wind is over about 12m/s. According to reference data from the manufacturer, quietrevolution, "multiple turbines should be placed at least three rotor diameters apart to eliminate interference" (Quietrevolution, 2007), due to the fluent effect from the wind.

A small size roof mounted wind turbine was used in the simulation, the size of wind turbine is 1m in rotor diameter, 8m/s in rated wind velocity, 85 watts in rated output, 250 watts in maximum output, 800 times in rated rpm, 5.5kg in weight, and 3m in hub height. As the manufacturer did not specify the sound performance in the brochure; simulation is assumed at sound power level at 100dB for each wind turbine, at all frequencies considered. This is acquired from Chapter 6 which assumes an approximate sound power level and also, because they are all relative comparisons. According to reference data from the manufacturer, a 2.5kW wind turbine can generate 2500-5000kWh electricity per annum and can contribute to the electrical appliances in a standard 3 bedroom house, excluding heating system (Proven, 2007). Regarding the wind turbine used in the simulation, it can generate 85-250kWh electricity per annum which can supply about 5% of a house's electricity or light up the building's public areas. It seems to be a very small contribution but in terms of environmentally sustainable development, the environment should be considered and various aspects must be balanced.

Two point source situations are considered, each single point source located on the roof of the eighteen selected buildings in site 1, and with multi-point sources located on the top of nine selected apartment buildings in site 3. The distance between wind turbines is about four times the rotor diameters. The layouts and building numbers of site 1 and site 3 are illustrated in Figure 7.13: it can be seen that low building density shows in site 1 and high building density shows in site 3. This compares the different sound distribution between low building density areas and high building density areas.



Site 1, Springvale Road, Sheffield Site3, Cavendish Street, Sheffield

Figure 7.13 The noise maps showing building numbers and selected building heights of site 1 and site 3, where the locations of the point sources (wind turbines) are shown with '+' .

In order to know the sound distribution over surrounding areas, the simulation was divided into four groups in each site which are sorted according to spacing and distance from the location of wind turbines: all groups are listed in Table 7.6. This can discover the sound effects on the wind turbines' surrounding buildings. Except where indicated, a reflection order of 3 is used. This section examines both the current situation and the possible effects of additional wind turbines, namely, further development towards acoustic sustainability. Technically, it can find the balance between regenerating electricity and achieving environmental acoustic sustainability

Table 7.6 The sorting of building groups.

		Building number											
Site 1	Group a	37	38	39									
	Group b	19	20	21									
	Group c	33	34	35									
	Group d	24	25	26									
Site 3	Group a	11	12	13	14	15	16	17	18	19			
	Group b	20	21	22	23	24	25	26	27	28	29	30	31
	Group c	32	33	34	35	36	37						
	Group d	40	41	42									

7.3.2 The Sound Distributions Of In The Areas

Four frequencies of 31.5Hz 125Hz, 500Hz and 2000Hz are taken into account in order to evaluate the sound distribution of buildings. Figure 7.14 shows thirty-nine evaluated buildings with traffic noise and turbines respectively. Figure 7.14a shows that a similar sound tendency is presented at each frequency; this is because Figure 7.14a simulates the current situation only, namely, noise sources from roads. The sound power levels of traffic are generated from the software itself.

Figure 7.14b shows wind turbine sound at four frequencies. It can be seen that there are considerable differences between frequencies in each building. This is because the wind turbine is mounted on the building's roof and the building below acts with noise barrier effect. Comparisons of sound distributions between traffic and wind turbine, showed differently distributed tendencies. The sound from road noises relatively more similar between frequencies, in terms of distribution patterns rather than the absolute levels.

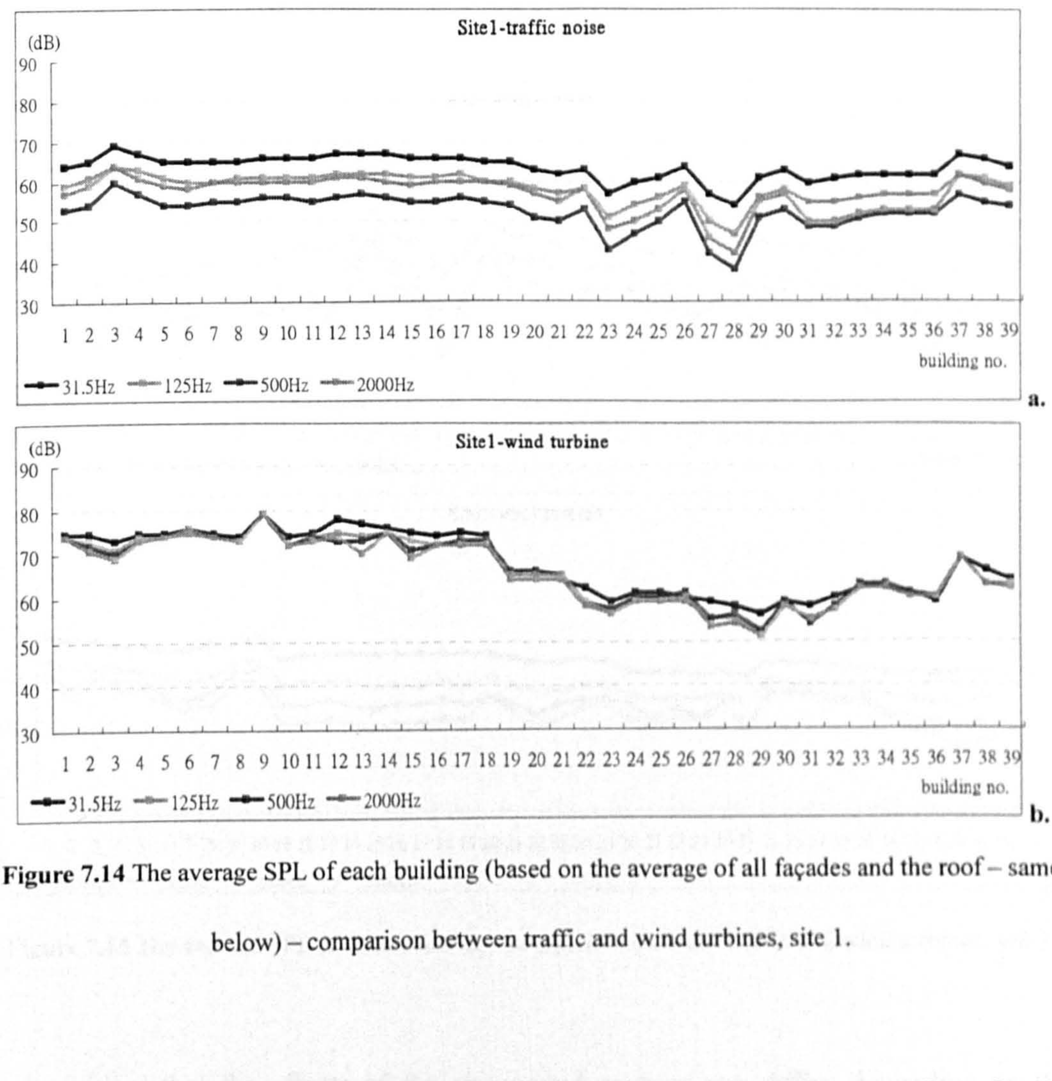


Figure 7.14 The average SPL of each building (based on the average of all façades and the roof – same below) – comparison between traffic and wind turbines, site 1.

Figure 7.15 shows forty-two evaluated buildings in site 3, according to traffic and wind turbine sound respectively. Figure 7.15a shows that traffic sound distribution is rather similar between buildings no. 1-9 and 30-42; this is mainly because buildings in this area front roads with similar traffic densities. Between surrounding buildings nos. 11-29, the SPLs are different. Comparing SPLs of wind turbines between frequencies of 500Hz and 2000Hz, the differences are by about 2-5dBA and buildings no.20, 25 and 29-37 show rather similar sound distributions although the sound levels are much lower at higher frequencies. This is because these buildings have similar height and the wind turbines mounted on apartment buildings are at similar distances from the buildings.

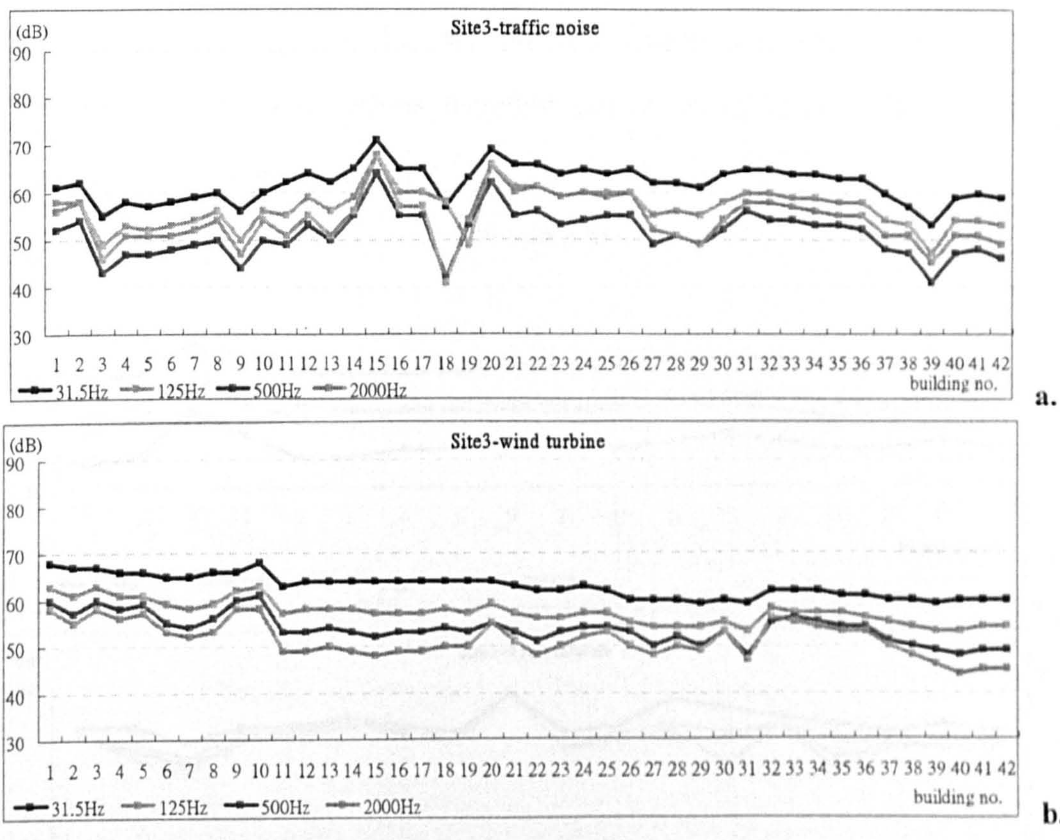


Figure 7.15 The average SPL of each building – comparison between traffic and wind turbines, site 3.

It is evident that the effects of the two sound sources can differ, depending on the source/building configurations and frequencies. The distances between wind turbines are also an important consideration which might change the sound effect in the area where the wind turbines are located.

7.3.3 The Sound Distribution On The Buildings With Wind Turbines

Figure 7.16 illustrated eighteen evaluated buildings which have wind turbines mounted on their roofs. It can be seen that while similar sound tendencies are shown in terms of traffic sound (Figure 7.16a), with wind turbines the sound distribution is very different, from traffic sound, and also between different frequencies, due to differences in diffraction. Different sound effects, therefore, can be caused by the features of sound sources and wind turbine location.

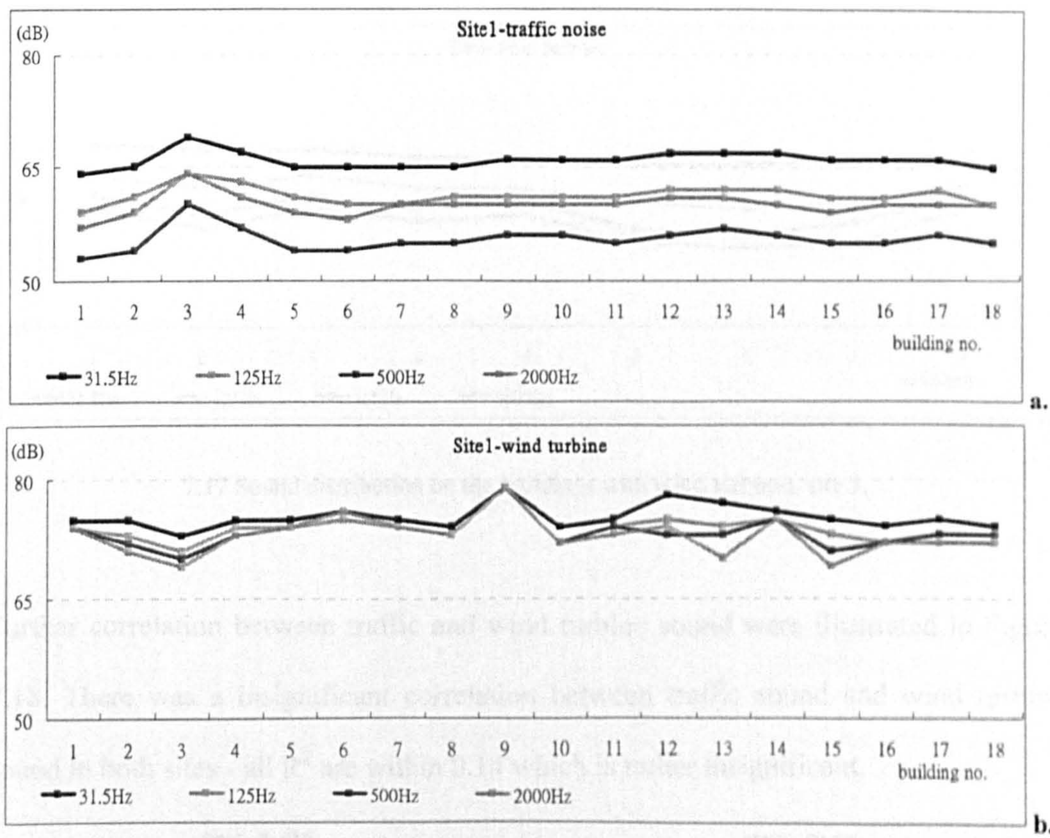
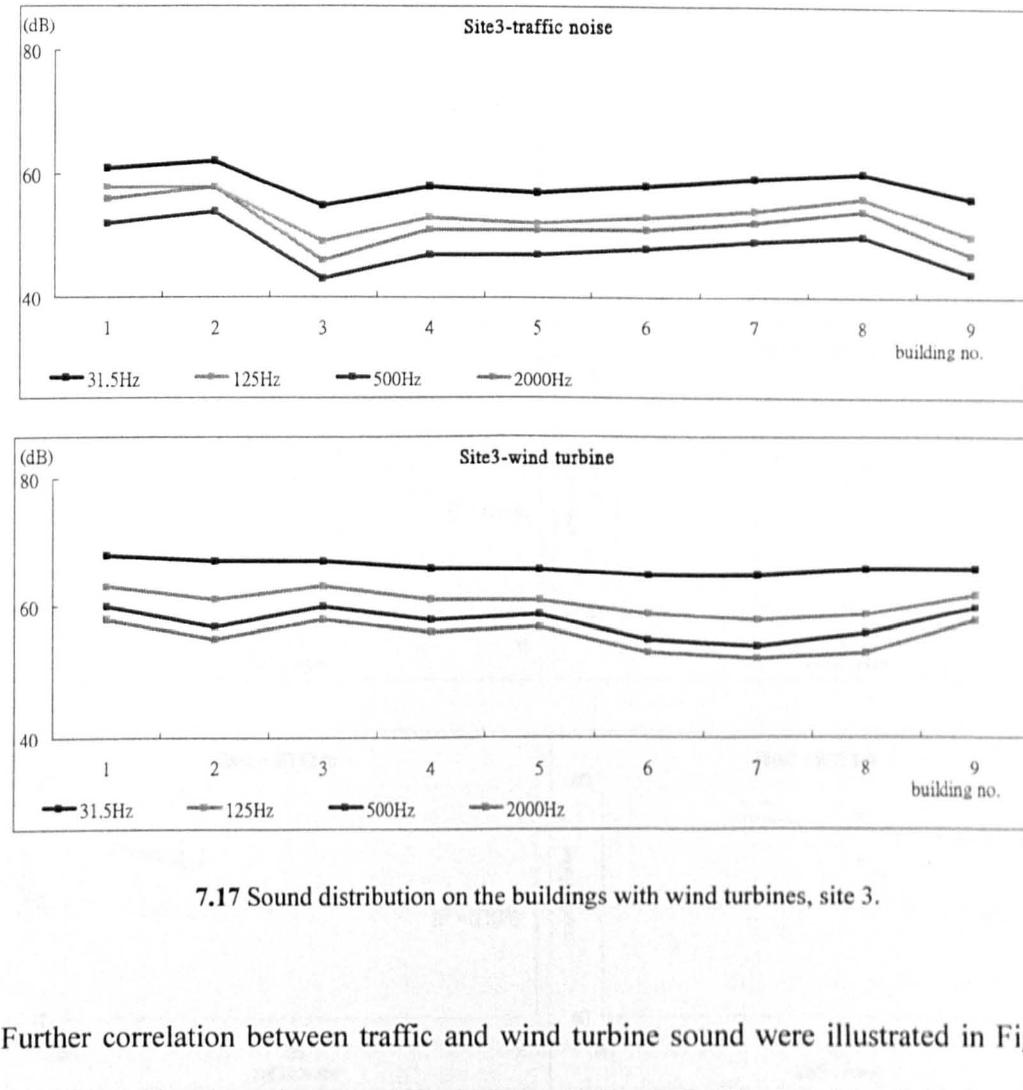


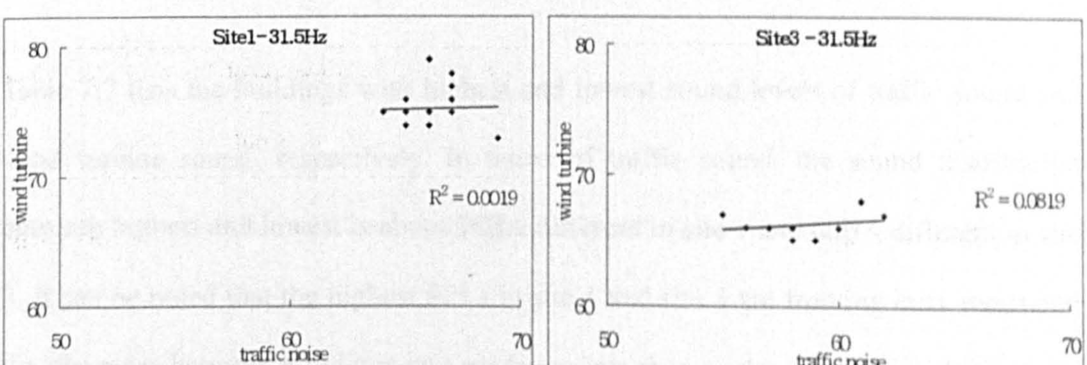
Figure 7.16 Sound distribution on the buildings with wind turbines, site 1.

Figure 7.17 shows the situation in site 3. It can be seen that with wind turbines the differences between different frequencies are much greater than that in site 1. This is mainly because the buildings are larger; thus the diffraction effects are stronger.



7.17 Sound distribution on the buildings with wind turbines, site 3.

Further correlation between traffic and wind turbine sound were illustrated in Figure 7.18. There was a insignificant correlation between traffic sound and wind turbine sound in both sites - all R^2 are within 0.14 which is rather insignificant.



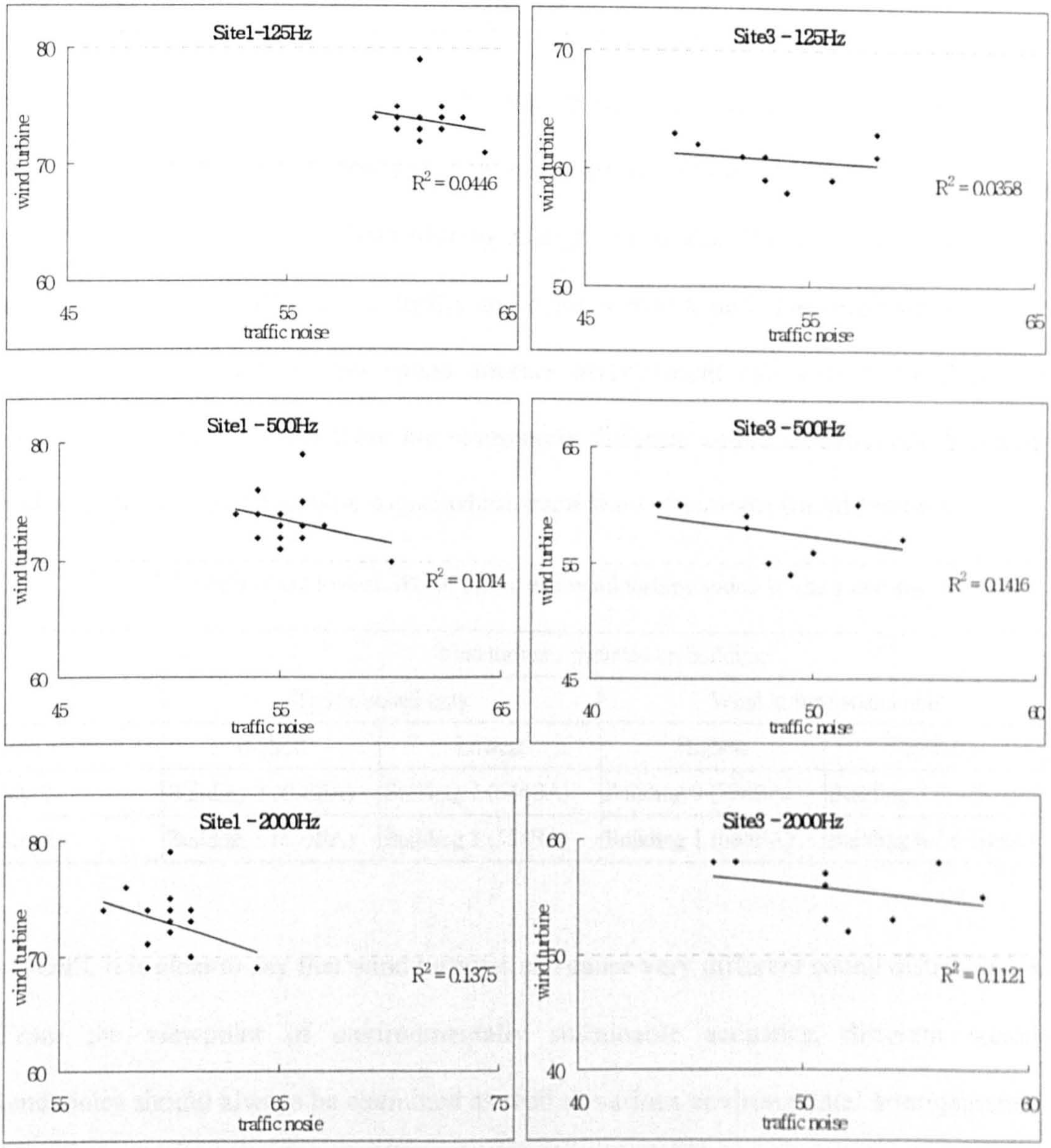


Figure 7.18 Correlations between the effects of traffic sound and wind turbine sound in site 1 and site 3.

Table 7.7 lists the buildings with highest and lowest sound levels of traffic sound and wind turbine sound, respectively. In terms of traffic sound, the sound distribution between highest and lowest is about 5dBA different in site 1 and 6dBA different in site 3. It can be noted that the highest SPLs in site 1 and site 3 are fronting busy roads and the distances between buildings and roads are less than in the other cases. In terms of wind turbine sound, the differences in SPLs between highest and lowest were by about 6dBA in site 1 and 3dBA in site 3. The highest traffic sound was in building no.3 of site 1 but there was a converse result in wind turbine sound. This may be due to the different effects of various sound sources change sound distribution. In site 3, building no.1 has the highest SPL in both traffic and wind turbine sound. The noise sources may have different tendencies but sound sources arrangement can also cause different effects. It can be seen that there are completely different sound distributions between traffic sound and wind turbine sound which each show their own sound features.

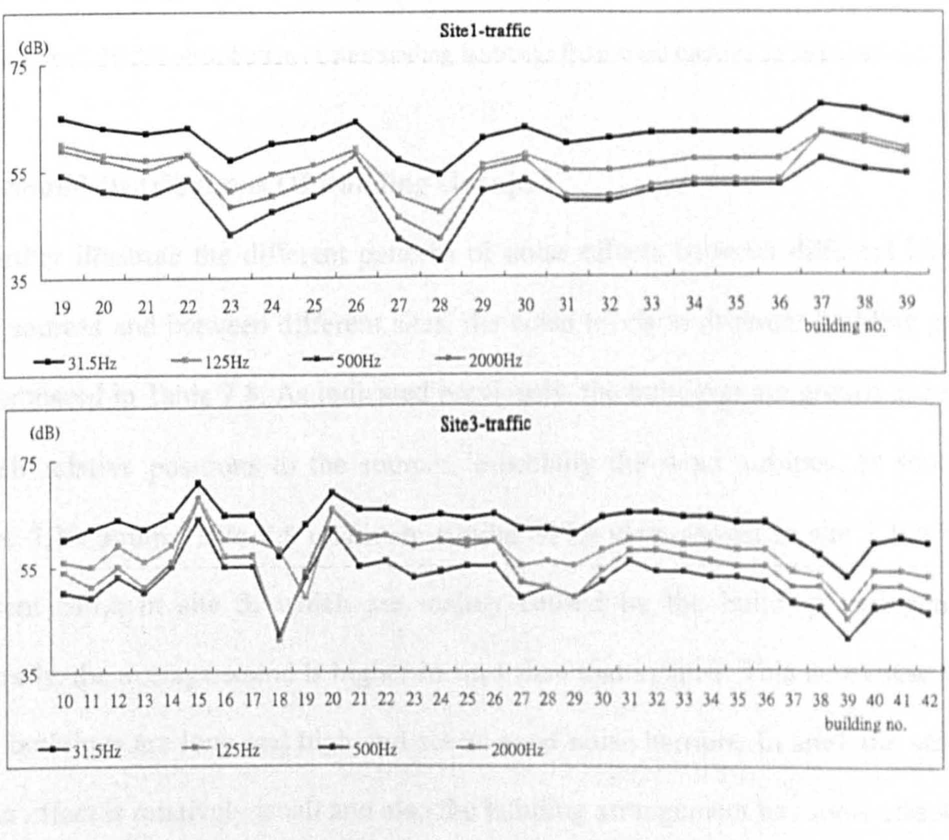
Table 7.7 Highest and lowest SPL of traffic and wind turbine sound in site 1 and site 3.

	Wind turbines mounted on buildings			
	Traffic sound only		Wind turbine sound only	
(SPL)	Highest	Lowest	Highest	Lowest
Site 1	Building 3 (69dBA)	Building 1 (64dBA)	Building 9 (79dBA)	Building 3 (73dBA)
Site 3	Building 1 (61dBA)	Building 3 (55dBA)	Building 1 (68dBA)	Building 6,7 (65dBA)

Overall, it is clear to say that wind turbines can cause very different sound distributions. From the viewpoint of environmentally sustainable acoustics, different sound tendencies should always be examined as well as various environmental arrangements. The implementation of this is that, when wind turbines are installed, the potential compliant patterns would be very different and this must be taken into account in the planning process.

7.3.4 The SPL Distributions Of Surrounding Buildings

A number of existing wind turbine cases showed different sound effects in surrounding areas. In order to know the different sound distributions in two sites, further simulation was made on surrounding buildings, namely, the buildings near the wind turbines. This is an attempt to understand the sound effects in the wind farms' immediate surrounding area. Figure 7.19 illustrates SPLs of surrounding buildings with traffic sound and wind turbine sound respectively. Comparison of traffic sound distribution between site 1 and site 3 (as shown in Figure 7.17a.), shows different tendencies of sound distributions, this is because of different building types as well as building densities. Comparisons between wind turbine sounds of site 1 and site 3 (as shown in Figure 7.17b.) show somewhat different tendencies between the two sites: the SPLs at different frequencies of site 1 are rather close, whereas the SPLs of site 3 at different frequencies differed. This is because the layout of the site is different as well as its building types and densities.



a.

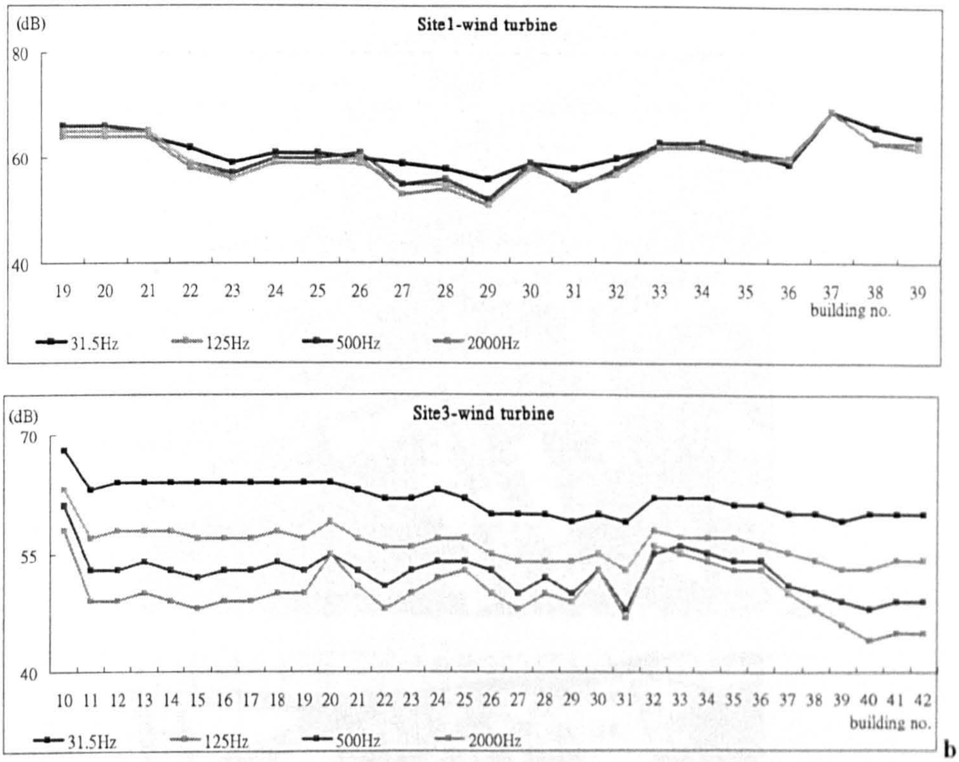
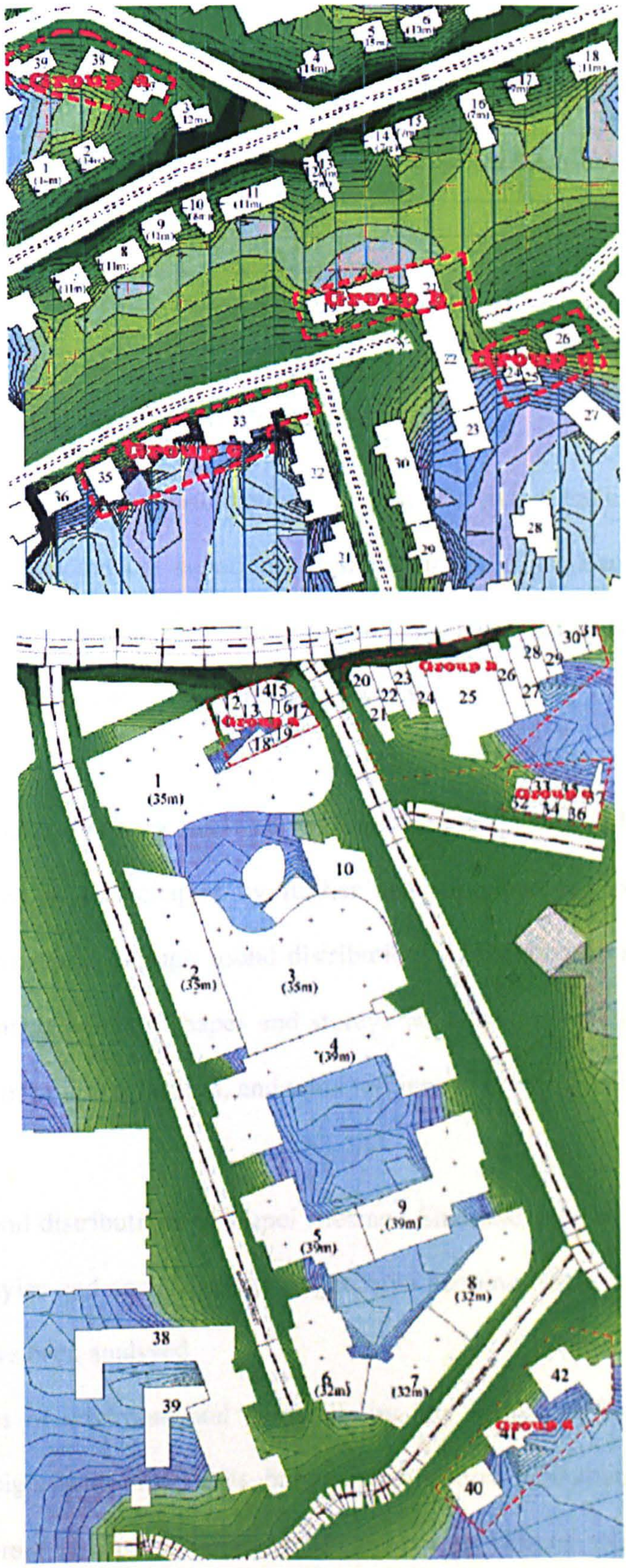


Figure 7.19 SPL distribution of surrounding buildings from wind turbines in site1 and site3.

7.3.5 Sound Distributions Of Building Groups

To further illustrate the different patterns of noise effects between different kinds of noise sources and between different sites, the noise levels in different building groups are compared in Table 7.8. As indicated previously, the buildings are groups according to their relative positions to the sources, especially the wind turbines, as shown in Figure 7.20. From Table 7.8 relatively similar SPLs were shown in site 1 but rather different SPLs in site 3, which are mainly caused by the building arrangements. Generally, the average sound is higher in site1 than that in site3. This is because in site 3 the buildings are long and high and act as good noise barriers. In site1 the effective barrier effect is relatively small and also the building arrangement has some effects.



site1

site3

Figure 7.20 Building groups of site 1 and site 3.

Table 7.8 The average SPL of building groups in site 1 and site 3.

	Site 1		Site 3	
	Traffic sound (dBA)	Wind sound (dBA)	Traffic sound (dBA)	Wind sound (dBA)
Group 1	66	66	64	64
Group 2	63	64	64	61
Group 3	62	62	63	61
Group 4	62	61	59	60

7.4 DISCUSSIONS AND CONCLUSIONS

By means of integrated considerations of people's living environment, residential buildings and hypothetical situations of wind turbine, this chapter examined three aspects. This aim was to link three of essential aspects in order to determine the potential of environmentally sustainable acoustics.

The interactions between acoustic performance and environmental sustainability have been examined in this chapter by further analysing people's perceptions of their acoustic environment through sound distributions of building façades, expanding the study to examine building shapes and storeys with environmental impact and sound distributions of building façades, and wind turbines in existing residential areas. It was shown that:

1. The sound distributions of Taipei sites and Sheffield sites show that the different residential styles and social aspects might have certain effects, and the relationships with SPL have been analysed.
2. In terms of environmental sustainability, the results of building shapes show relatively insignificant differences, but when considered with sound distributions there can be different results. In terms of SPLs between various storeys, when building

height is increased, the SPLs are reduced, compared to some more complex results in terms of Ecopoints in Chapter 5.

3. In terms of additional wind turbines above buildings, the results showed significantly different tendencies caused by sound source types, building arrangements and site conditions.

Overall, it can be suggested that environmentally sustainable acoustics must not only consider typical acoustic aspects, but should also take a number of essential and typical environmental aspects into account. All these aspects might have different impact and a better balance between them must be found. Furthermore, the expanding studies in this chapter environmental sustainability can be described as a self-sustaining circle which contains a number of positive and negative factors. It might not be easy to weight various factors but it is necessary to find the typical and essential factors and to achieve good balance.

Chapter 8

Conclusion

The main aim of this thesis was to examine environmentally sustainable acoustics, considering mainly urban residential areas. The study systematically examined the three essential aspects of environmentally sustainable acoustics, namely, people, buildings and resources. The approach demonstrated that acoustics should be an essential consideration in environmentally sustainable development, particularly in the urban residential areas. It is also important to integrate these three aspects as well as other related factors into the overall planning and improved process. The discussions focused on three aspects: (1) the effects of urban acoustics on people: a systematic field survey on people's perceptions which considered people's living experiences, sound preferences and social factors; (2) a series of buildings' life cycle assessments which examined the environmental impact from cradle to grave of the building's lifespan and tried to further comprehend acoustic sustainability of residential buildings; (3) in the third part, research examined various possibilities concerning the use of wind turbines around and above the residential buildings in an attempt to discover how to regenerate renewable wind energy and to avoid serious noise effects. The study was then further developed and expanded from the three aspects by revealing the full potential of achieving environmentally sustainable acoustics by an examination of their various characteristics. Throughout the discussion, it was stressed that environmentally sustainable acoustics was an essential part of the environmentally sustainability development, particularly in urban residential areas. In these environments, acoustic quality was identified as a major dimension of environmentally sustainable acoustics.

8.1 CONTRIBUTIONS OF THIS THESIS

8.1.1 People's Perceptions Of Their Living Environment

The first section of the research was undertaken through a series of questionnaire surveys in residential areas with various social, cultural and demographic factors. The purpose was to evaluated residents' perceptions of their living environment. The main reason for conducting this survey was to discover which factors should be taken into account in terms of environmentally sustainable acoustics in urban residential areas. This is an important concern of living environments which cannot be evaluated by measuring, monitoring or controlling acoustic factors alone.

In the first part of the study, questionnaire surveys were carried out in three stages: namely, based on samples in six typical residential areas in Sheffield and Taipei; random samples in Sheffield and Taipei; and random samples in the UK and Taiwan, respectively. The questions included social and demographic data, evaluation of environmental pollution and preference for various sound sources, as well as perception of general living environment. The results of this part of the study demonstrated the importance of considering social as well as cultural factors in evaluating environmentally sustainable acoustics. Similar results were found from the first and second stages, namely, that cultural factors, urban texture, building types, living experiences, disturbance of noise sources and sound preference should be considered. Regarding the ranking of various factors when choosing a living environment, it was seen that the factor reflecting the most concern was that of safety in the Stage 1 and 2 studies, whereas in the Stage 3 study the major concern was property price in the UK and convenient transportation in Taiwan. In terms of environmental sounds, the factor 'quiet' was perceived as an important factor in both countries. The correlations between various demographic factors, such as education and age, and current living environments were examined, although no strong tendency was found. The annoyance levels of various sources in the living environment were examined. It was shown that the most noticeable noise sources were caused by various vehicles as well as by neighbours' and respondents' own homes.

The comparative study in the UK and Taiwan revealed the importance of considering cultural factors. This was reflected by the significant difference between the two cultural backgrounds as well as two different densely populated areas in terms of a number of factors. They included choosing a living environment; effects of social and demographic factors; perception/evaluation of current living environment; main activities; noise annoyance and sleep disturbance, and sound preferences. These cultural differences generally corresponded to the different stages. It was emphasised that it was important to consider various social and cultural differences.

8.1.2 Examination Of The Acoustic Sustainability Of Residential Buildings

The second part of the study was aimed at examining the differences in environmental sustainability between various architectural acoustic materials/elements, in various situations, from external envelopes to interior finishing. The software package Envest was used to analyse various aspects of environmental impacts. The results in Envest were shown in terms of overall Ecopoint scores, where the data in 13 impact categories are multiplied by the agreed weight for each category and combined to produce a single score. Both embodied Ecopoints in structure/construction and operational Ecopoints can be considered. The buildings' life cycle analysis was carried out at four levels, in terms of the comparison between five typical house types in the UK (bungalow, detached, semi-detached, terraced, and apartments), comparison between various building elements in a typical apartment building (different building envelope materials, roof types, and number of storeys), comparison between various building openings for each of the five building types, and comparison between various combinations of materials in typical rooms.

The results from the examinations of buildings demonstrated the importance of considering environmental sustainability of various materials which could have similar acoustic performances. The results in this part of the study showed that although individual components may not affect the total Ecopoints greatly, when every acoustics-related component/material in a building is taken into account, significant differences in Ecopoints could be made with a better selection of components/materials from the viewpoint of environmental sustainability. The significance of considering a building's operational sustainability should also be noted.

Creating/developing sustainable living environments is a rather complex process, and it is important to consider various relevant factors and try to achieve a good balance. While this part of the study examined the effects of various building elements, the effects of other factors such as land use, which affect noise source distribution; and quality of open public spaces including soundscape and acoustic comfort, must also be taken into account. With those factors considered, the sustainability rankings derived from this study may change considerably.

8.1.3 Sound Effects Of Wind Farms

The third part of the study, examining the acoustic impact of wind farms, was divided into two parts. Firstly, a number of hypothetical case study sites were considered, with different landforms, number of turbines, turbine locations, hub heights and building arrangements. Secondly, an existing wind farm site, Royd Moor wind farm in the UK was measured and compared with simulation results in terms of the sound distribution patterns. By deriving appropriate sound power levels from the wind turbines, a number of hypothetical scenarios were then examined.

The results from hypothetical cases showed that a wind farm could have significant noise effects over a large area. The effect of landform is insignificant in terms of the differences caused by the source-receiver distance, but various landforms can bring considerable SPL differences in terms of noise barrier effects of buildings and ground profile. With a typical configuration, the buildings within 200m from the source bring a considerable extra SPL attenuation, typically over 5-15dB, especially in the region of about 80-200m from the source. In terms of turbine height: when it is increased from 10m to 46m, the SPL increase could be 10-20dB far a field.

The survey results at the Royd Moor wind farm showed that the SPLs at low frequencies were significantly higher than at high frequencies, which was as expected. This again demonstrated that great attention should be paid to the low frequency effects around a wind farm. With the derived sound power level of wind turbines, further parametric studies showed that the effects of landforms are generally insignificant, while change of source number could typically cause about 2-23dB difference, depending on source-receiver distances.

8.1.4 Integrated Study

In the final part of this thesis, the study was expanded to examine the interactions between the three aspects discussed above and results show that different residential styles, site layouts and social factors have different sound effects. The further analyses and calculation of the sound distributions of Taipei sites and Sheffield sites showed that the different residential styles and social aspects might have certain effects, and the relationships with SPL were analysed. In terms of environmental sustainability, the results of building shapes exhibited insignificant differences, but when considered with sound distributions there were different results. In terms of SPLs between various storeys, when building height is increased, the SPLs are less, comparing to some more complex results in terms of Ecopoints. In terms of additional wind turbines above buildings, results showed significantly different tendencies caused by sound source types, building arrangements and site conditions.

8.2 FURTHER RESEARCH

The context of the research in this thesis was wide-ranging and the focus offered many possibilities to discover environmentally sustainable acoustics in advance. However, it was beyond the scope of this research to achieve a fully comprehensive and detailed framework of environmentally sustainable acoustics. This is because a wide range of complex variables and factors are often involved in this field of research. Further potential research opportunities are listed below:

1. The study of people's perceptions provided a viewpoint to see different social effects from different regions. The examinations of different cultures, in particular, emphasised that social effects can be very different according to different social backgrounds, the size of the city, the population density and the living style. It would be very interesting to examine these social factors further, by investigating the proposed sound perceptions of an area as well as measuring environmental sound to evaluate whether environmentally sustainable acoustics is perceived in a high or low density population urban area.
2. It would be very beneficial to examine in more depth the sound preferences of an area, through surveys. This could then contribute to further creation of pleasing sounds in each area. Consequently, it would be very useful to develop a method for making overall examination of an area's sounds and to find a way of achieving environmentally sustainable acoustics.
3. Within the context of building sustainability, it is important to gain more knowledge as to, whether the acoustics can have more environmental sustainability in terms of similar acoustic performances. For example, an acoustic material would be selected on the basis of environmental friendliness as well as good acoustic performance.

Acoustics and sustainability is a rather new field this study only reveals some key issues, by considering some key factors from three aspects, people, environment and resources. More systematic and in-depth studies in other aspects are still needed.

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Appendix

Field survey questionnaires

A1.

University of Sheffield, United Kingdom

URBAN ENVIRONMENTAL SUSTAINABILITY SURVEY

1. Occupation Student Working person Pensioner Housekeeper Other ____________
2. Educational O level A level University
3. Male Female
4. Age Group 11-17 18-24 25-34 35-44 45-54 55-64 >65
5. Are you a tenant owner
6. How many people live in your house? Living along Number of people ________
7. Are you a local inhabitant? Yes, (please specify how many years) No, (your previous living place)
8. Which area do you live, please specify post code ______________, floor of your home _________ and approximate distance between main opening (such as door, window) of your house and road _________
9. How many years have you been living in this area? ________________
10. How long have you been living in the current house? ________________
11. What kind of transport do you use generally? Public transport Self car Motorbike Bike Walk
12. How many rooms (including living and dining) are there in your house? 1 2 3 4 5 6 Other ___
13. Please give your evaluation for the following factors when choosing a living environment:

Factors \ Ranking	Do not mind ◄ -2	-1	0	1	► very important 2
Convenient for work					
Convenient transportation					
Convenient school, shopping area, etc					
Recreational space (e.g. park, open space)					
Social with neighborhoods/ friends/					
Safety					
Property price					
Quiet					
Views					
Size of the house					
Interior decoration					
Others, please specify					

14. How do you think your living environment? Very well Well Neither well nor bad Bad Very bad
15. How is your health? Very well Well Neither well nor bad Bad Very bad
16. Personal evaluation for sound quality of your living area.
 Very comfortable Comfortable Neither comfortable nor uncomfortable Uncomfortable Very uncomfortable
17. Personal evaluation for sound quality of your home.
 Very comfortable Comfortable Neither comfortable nor uncomfortable Uncomfortable Very uncomfortable
18. Please rank the following environmental pollution factor. Water Air Noise Waste Other, ________
19. Are there any pollution affect your living quality? Yes, please specify ____________ No

20. Do you think any of the pollution in your area will affect your health? ☐ Yes, please specify ____________ ☐ No

21. Are there any noise insulation measures in your house such as double glazing or sound absorption louvers?

☐ Yes, please specify ______________________ ☐ No

22. Do you think it is necessary to add such noise insulation in your house?

☐ Yes, if it is free of charge ☐ Yes, if it is within £ ____________ ☐ No, it is not necessary

23. Are there any noise insulation measures outside your house, such as noise barriers?

☐ Yes, please specify ______________________ ☐ No

24. Do you think it is necessary to add such noise insulation outside your house?

☐ Yes, if it is free of charge ☐ Yes, if it is within £ ____________ ☐ No, it is not necessary

25. How is your sleeping quality? ☐ Very satisfied ☐ Satisfied ☐ Medium ☐ Annoyed ☐ Very annoyed

26. How often do you use sleeping pills or tranquilizers? ☐ Everyday ☐ Frequent ☐ Sometimes ☐ Never

27. Personal evaluation for the natural ventilation of your house.

☐ Very comfortable ☐ Comfortable ☐ Neither comfortable nor uncomfortable ☐ Uncomfortable ☐ Very uncomfortable

28. Situation of using ventilation/heating:

Time	Go out					Stay at home					Sleeping				
Scale	Always close/off	←		→	Always open/on	Always close/off	←		→	Always open/on	Always close/off	←		→	Always open/on
	-2	-1	0	1	2	-2	-1	0	1	2	-2	-1	0	1	2
Windows															
Ventilator															
Louver															
Air-condition															
Heater															
Other,															

29. Please specify below the hours you stay at home on **weekdays**.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

30. Please specify below the hours you sleep at home on **weekdays**.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

31. Please specify below the hours you stay at home on **weekends**.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

32. Please specify below the hours you sleep at home on **weekends**.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

33. What are the main activities when you stay at home? ☐ Reading ☐ TV ☐ Music ☐ Others, please specify ____________

34. What are the personal preferable sounds in your living area?

☐ Bird songs, ☐ Bells of church, ☐ Water, ☐ Music from outside, ☐ Insect sounds, ☐ Others, please specify ____________

35. What are the personal preferable sounds in your house?

☐ Bird songs, ☐ Bells of church, ☐ Water, ☐ Music from outside, ☐ Insect sounds, ☐ Others, please specify ____________

36. Personal evaluation for noise sources disturbs when stay at home?

Situation		Source effect					Annoyance					Sleep disturbance				
Scale		None -2	◄······ -1	······ 0	······► 1	Very significan 2	Not annoyed -2	◄······ -1	······ 0	······► 1	Very annoyed 2	Not disturbed -2	◄······ -1	······ 0	······► 1	Very disturbed 2
Traffic	light vehicle															
	medium heavy vehicles															
	heavy vehicles															
	two wheelers															
	others, ________															
Nearby	school															
	shop															
	recreation															
	transportation station															
	events															
	others, ________															
Neighbours	talking, music, TV															
	air-condition															
	Others,															
Your home	talking, music, TV															
	air-condition															
	others,															

37. Family average income (per/month)? ☐ Under£1000 ☐ £1001-2000 ☐ £2001-£3000 ☐ £3001 and above

38. Personal income (per/month)? ☐ Under£1000 ☐ £1001-2000 ☐ £2001-£3000 ☐ £3001 and above

39. Do you have any comment or suggestion for improve living quality in your residential area?

____

____

____

____

____

____

____

A2.

1. 職業 □學生 □上班族 □退休 □家庭主婦 □其他________

2. 教育 □國中 □高中 □大專

3. □男 □女

4. 年齡 □11-17 □18-24 □25-34 □35-44 □45-54 □55-64 □>65

5. 請問您是 □房客 □房主

6. 有幾位家處有幾位成員與您同住? □獨居 □______位成員

7. 您是本地居民嗎? □是,（居住於本地多長時間） □不是,（原居住較長時間的縣、市、區）

8. 請問您居住的__________區__________街/路______里______鄰______巷________弄________樓；住家主要開窗面至面前道路的大約距離________公尺

9. 請問您居住在此區多少年了? ______________

10. 請問您居住在現居的房子多久了? ____________

11. 請問您日常交通工具? □大眾運輸工具 □自家車 □機車 □自行車 □走路

12. 請問您現居的房子有幾房幾廳? ____________________

13. 請評估您個人對選擇居住環境的考量因子?

因子＼評估	非常不重要 -2	-1	0	1	非常重要 2
鄰近工作、交通便利					
鄰近學校、購物方便					
有許多休閒娛樂設施（公園、綠地等）					
許多熟識的鄰居、朋友、親戚					
安全性					
房價					
安靜					
視野佳					
房屋大小					
內裝					
其他, 請具體說明您所考量的因子					

14. 請問您覺得您現在的居住環境如何? □非常好 □好 □一般 □不好 □非常不好

15. 請問您的健康狀況如何? □非常好 □好 □一般 □不好 □非常不好

16. 請評估您居住環境的聲音品質 □非常舒適 □舒適 □一般 □不舒適 □非常不舒適

17. 請評估您住家的聲音品質 □非常舒適 □舒適 □一般 □不舒適 □非常不舒適

18. 請排序居住環境中的各項污染因子重要性 □水 □空氣 □噪音 □廢棄物 □其他, 請具體說明

19. 請問您覺得您的居住環境中有任何污染影響您的生活品質嗎? □有, __________ □無

20. 請問您覺得您的居住環境中有任何環境污染影響您的健康狀況嗎? □有, 請具體說明 □無

21. 請問您住家中有任何擋音設施(例如雙層窗、消聲百葉等)嗎? □有, 請具體說明設施種類 □無

22. 請問您認為住家中有需要加裝擋音設施嗎?

□需要, 若是免費的 □需要, 若自行負擔金額在新台幣__________元內 □不需要

23. 請問您住家附近有任何擋音設施(例如隔音牆)嗎? □有, 請具體說明 □無

24. 請問您認為住家附近有需要加裝擋音設施嗎?

□需要, 若是免費的 □需要, 若自行負擔金額在新台幣__________元內 □不需要

25. 請問您的睡眠品質如何? □非常好 □很好 □一般 □不好 □非常不好, 常被干擾（請說明干擾主要因素）

26. 請問您常服用安眠藥或鎮定劑幫助睡眠嗎? □每天服用 □經常 □偶爾 □從不服用

27. 請評估您住家中的自然通風. □非常舒適 □舒適 □一般 □不舒適 □非常不舒適

28. 請評估您家中常使用的通風方式?

時間	外出					在家					睡覺				
評估	不使用	◄······►			持續使用	不使用	◄······►			持續使用	不使用	◄······►			持續使用
	-2	-1	0	1	2	-2	-1	0	1	2	-2	-1	0	1	2
開窗															
通風機															
百葉															
冷氣															
暖氣															
其他															

29. 請問您平日在家的時段?(請在下列表格中畫出約幾點到幾點)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

30. 請問您平日在家睡眠時間?(請在下列表格中畫出約幾點到幾點)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

31. 請問您假日在家時間?(請在下列表格中畫出約幾點到幾點)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

32. 請問您假日在家睡眠時間?(請在下列表格中畫出約幾點到幾點)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

33. 請問您在家中的主要活動? □看電視 □閱讀 □其他, 請具體說明

34. 請問您最想聽到哪種悅耳聲音在居住環境中?□鳥叫聲 □昆蟲叫聲 □水聲 □音樂聲 □其他, 請具體說明

35. 請評估您居家生活中主要噪音源

情況		聲源情況					煩惱度					睡眠干擾				
評估		不重要	◄······►			非常重要	沒干擾	◄······►			非常干擾	沒干擾	◄······►			非常干擾
		-2	-1	0	1	2	-2	-1	0	1	2	-2	-1	0	1	2
交通	輕型交通工具															
	中型交通工具															
	重型交通工具															
	兩輪交通工具															
	其他															
鄰近	學校															
	商家															
	休閒娛樂空間															
	車站															
	慶典、儀式															
	其他,															
鄰居	說話、音樂、電視															
	空調機															
	其他															
自家	說話、音樂、電視															
	空調機															
	其他															

36. 請問您家庭平均月收入? □15000 以下 □15001-30000 □30001-45000 □45001-60000 □60001 以上

37. 請問您個人月收入? □15000 以下 □15001-30000 □30001-45000 □45001-60000 □60001 以上

38. 請問您對改善現居環境品質有什麼建議嗎?

A3.

1. Occupation ☐ Student ☐ Working person ☐ Pensioner ☐ Housekeeper ☐ Other, specify ________
2. Educational ☐ O level ☐ A level ☐ University
3. ☐ Male ☐ Female
4. Age Group ☐ 11-17 ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ >65
5. Please select the three most import factors when choosing a living environment?

   ☐ Near work ☐ Near transportation ☐ Near school, shopping area ☐ Recreational space ☐ Near friends or relatives

   ☐ Safety ☐ Property price ☐ Quiet ☐ Views ☐ Size of the house ☐ Interior decoration ☐ Others, specify ________
6. Are you living in ☐ City centre ☐ Suburb ☐ Rural area
7. Are you living in a ☐ Detached house, ☐ Semi-detached, ☐ Terraced, ☐ Bungalow, ☐ Flat, ☐ Other, specify ________
8. Please specify approximate distance of the nearest door or large window to the front road ______ m
9. Please tick the following four which you hear road noise? ☐ Motorway, ☐ Busy road, ☐ Small road, ☐ Other, specify ________
10. How many years have you been living in this area? specify ________
11. How long have you been living in the current house? specify ________
12. In general what do you think of your living environment?

    1. Very good — 2. Good — 3. Average acceptable — 4. Bad — 5. Very bad
13. How comfortable are you with the sound levels in your living area?

    1. Very comfortable — 2. Comfortable — 3. Neither comfortable nor uncomfortable — 4. Uncomfortable — 5. Very uncomfortable
14. How comfortable are you with the sound levels at your home?

    1. Very comfortable — 2. Comfortable — 3. Neither comfortable nor uncomfortable — 4. Uncomfortable — 5. Very uncomfortable
15. Please rank the most annoying noise sources when you stay at home? (Using a five linear scale)

    1. Not very annoyed — 2. Occasional — 3. Medium — 4. Annoyed — 5. Very annoyed

    Traffic: ☐ Light vehicle, ☐ Medium, ☐ Heavy vehicles, ☐ Two wheelers, ☐ Other, specify ________

    Nearby facilities: ☐ School, ☐ Shop, ☐ Recreation, ☐ Transportation station, ☐ Events, ☐ Other, specify ________

    Neighbours: ☐ Talking, ☐ Music, TV, ☐ Air-condition, ☐ Other, specify ________

    Own home: ☐ Talking, ☐ Music, TV, ☐ Air-condition, ☐ Other, specify ________
16. Please rank the most annoying noise sources when you sleep? (Using a five linear scale)

    1. Not very annoyed — 2. occasional — 3. Medium — 4. Annoyed — 5. Very annoyed

    Traffic: ☐ Light vehicle, ☐ Medium, ☐ Heavy vehicles, ☐ Two wheelers, ☐ Other, specify ________

    Nearby facilities: ☐ School, ☐ Shop, ☐ Recreation, ☐ Transportation station, ☐ Events, ☐ Other, specify ________

    Neighbours: ☐ Talking, ☐ Music, TV, ☐ Air-condition, ☐ Other, specify ________

    Own home: ☐ Talking, ☐ Music, TV, ☐ Air-condition, ☐ Other, specify ________
17. What are the main activities when you stay at home? ☐ Reading ☐ TV ☐ Music ☐ Other, specify ________
18. What are your personal preferable sounds in your living area?

    Natural sounds: ☐ Bird songs, ☐ Water, ☐ Insect sounds, ☐ Quiet, ☐ Other, specify ________

    Artificial sounds: ☐ Bells of church, ☐ Music, ☐ Traffic, ☐ Other, specify ________
19. What are your personal preferable sounds in your house?

    Natural sounds: ☐ Bird songs, ☐ Water, ☐ Insect sounds, ☐ Quiet, ☐ Other, specify ________

    Artificial sounds: ☐ Bells of church, ☐ Music, ☐ Traffic, ☐ Other, specify ________
20. Family annual income (before tax) ☐ Under £10,000 ☐ £10,001-20,000 ☐ £20,001-£30,000 ☐ £30,001 and above
21. Personal annual income (before tax) ☐ Under £10,000 ☐ £10,001-20,000 ☐ £20,001-£30,000 ☐ £30,001 and above

A4.

1. 職業 □學生 □上班族 □退休 □家庭主婦 □其他，請具體說明 ______

2. 教育 □國中 □高中 □大專

3. □男 □女

4. 年齡 □11-17 □18-24 □25-34 □35-44 □45-54 □55-64 □>65

5. 請勾選三項您最重視的選擇居住環境考慮因素?

   □鄰近工作 □交通便利 □鄰近學校、購物方便 □有許多休閒娛樂設施 □許多熟識的親戚或朋友

   □安全性 □房價 □安靜 □視野佳 □房屋大小 □內裝 □其他，請具體說明 ______

6. 請問您居住在 □市中心 □城市近郊 □郊區

7. 請問您居住的房子是 □獨棟住宅 □雙並連棟住宅 □連棟住宅 □平房 □公寓式住宅 □其他，請具體說明 ______

8. 請問您住家主要門或窗至面前道路的大約距離______公尺

9. 請問您住家附近相鄰近的道路? □高速公路 □交通繁忙的道路 □小路 □其他，請具體說明 ______

10. 請問您居住在此區多少年了? ______

11. 請問您居住在現居的房子多久了? ______

12. 請問您覺得您現在的住家附近環境品質如何?

    1. 非常好 2. 好 3. 一般 4. 不好 5. 非常不好

13. 請評估您住家附近的聲音舒適度

    1. 非常舒適 2. 舒適 3. 一般 4. 不舒適 5. 非常不舒適

14. 請評估您住家中的聲音舒適度

    1. 非常舒適 2. 舒適 3. 一般 4. 不舒適 5. 非常不舒適

15. 請評估在您住家中主要噪音源所造成的干擾?(請將評估分成五個等級)

    1. 完全不干擾 2. 偶爾有干擾 3. 一般 4. 干擾 5. 非常干擾

    交通: □輕型交通工具 □中型交通工具 □重型交通工具 □兩輪交通工具 □其他，請具體說明 ______

    鄰近: □學校 □商家 □休閒娛樂空間 □車站 □慶典、儀式 □其他，請具體說明 ______

    鄰居: □說話 □音樂、電視 □空調機 □其他，請具體說明 ______

    自家: □說話 □音樂、電視 □空調機 □其他，請具體說明 ______

16. 請評估在您住家中主要噪音源對睡眠所造成的干擾?(請將評估分成五個等級)

    1. 完全不干擾 2. 偶爾有干擾 3. 一般 4. 干擾 5. 非常干擾

    交通: □輕型交通工具 □中型交通工具 □重型交通工具 □兩輪交通工具 □其他，請具體說明 ______

    鄰近: □學校 □商家 □休閒娛樂空間 □車站 □慶典、儀式 □其他，請具體說明 ______

    鄰居: □說話 □音樂、電視 □空調機 □其他，請具體說明 ______

    自家: □說話 □音樂、電視 □空調機 □其他，請具體說明 ______

17. 請問您在家中的主要活動? □閱讀 □看電視 □聽音樂 □其他，請具體說明 ______

18. 請問您在住家附近最想聽到哪種悅耳聲音?

    自然: □鳥叫聲 □水聲 □昆蟲叫聲 □安靜 □其他，請具體說明 ______

    非自然: □教堂鐘聲 □音樂聲 □交通 □其他，請具體說明 ______

19. 請問您在住家中最想聽到哪種悅耳聲音?

    自然: □鳥叫聲 □水聲 □昆蟲叫聲 □安靜 □其他，請具體說明 ______

    非自然: □教堂鐘聲 □音樂聲 □交通 □其他，請具體說明 ______

20. 請問您家庭年收入? □600,000 以下 □600,001-1200,000 □1200,001-1800,000 □1800,001 以上

21. 請問您個人年收入? □600,000 以下 □600,001-1200,000 □1200,001-1800,000 □1800,001 以上