YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

SOUND INSULATION: RETROFITTING THE PARTITION WALLS OF HIGH-RISE RESIDENTIAL BUILDINGS IN NIGERIA

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PRESENTATION DATE: 11.10.2017

BORNOVA/IZMIR
OCTOBER 2017

We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

SOUND INSULATION: RETROFITTING THE PARTITION WALLS OF HIGH-RISE RESIDENTIAL BUILDINGS IN NIGERIA.

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Msc in Architecture

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October 2017

The demand for privacy and sound comfort in high-rise or shared residential buildings has become imperative to most dwellers. Sound insulation and comfort level provided by interior partition walls are essential for improving the general well-being of inhabitants. The intention of this research solely focuses on the effects of the existing wall partitioning systems on sound insulation and transmission in high-rise and shared residential buildings. The retrofitting of wall partitions suggested to moderate the rate of sound to a satisfactory limit. The challenge lies in attaining desired sound levels while simultaneously maintaining or enhancing the visual environment. This research aimed at finding the best and possible ways to retrofit high rise residential buildings that have weak performance against noise.

The methodology used in this research was a case study approach whereby two apartments selected in Lagos, Nigeria namely; C & N Luxury Apartments, Ikoyi and 1004 Estate, Victoria Island. First step is to apply a questionnaire to the dwellers in order to obtain their user perception level of noise. The questionnaire survey revealed that 95% of the respondents were disturbed by the level of noise from their neighbours. Second step is to model and simulate the two case studies in Autodesks ECOTECT analysis. Thereafter, five acoustic wall panels which have very good acoustic properties, were chosen and each panel's condition was simulated in the software environment. The results from the simulations indicated that the five panels, acoustic improvements tested on C & N Luxury Apartments and 1004 Estate, Apartments gave a performance result averagely which is 9.46% (1), 20.79%(2), 21.23%(3) 21.27%(4) and 24.9%(5). This research proves that retrofitting residential apartments in order to have quality sound control is possible.

Key Words: Noise, Sound, Acoustics, Building Retrofitting, Wall Panels, High-Rise Residential

ÖZ

NİJERYA'DAKİ YÜKSEK KATLI KONUTLARDA SES İZOLASYONU SAĞLAYAN FARKLI BÖLÜCÜ DUVARLARIN İNCELENMESİ

MAMUD Ayisha Nnaketwa

Mimarlık Yüksek Lisans Programı

Danışman: Yard. Doç. Dr. Eray BOZKURT

Ekim 2017

Yüksek katlı veya ortak konutlarda mahremiyet ve ses konforu talebi çoğu yerleşim yeri için zorunlu hale gelmiştir. İç bölme duvarları tarafından sağlanan ses yalıtımı ve konfor seviyesi, sakinlerin genel refahının iyileştirilmesi için gereklidir. Bu araştırma, yüksek katlı ve paylaşımlı konutlarındaki sadece duvar bölme sistemlerinin ses yalıtımının etkileri üzerine odaklanmaktadır. Farklı duvar bölme tipleri kullanılarak ses hızının tatmin edici bir sınıra indirgenmesini önerilmiştir. Aynı zamanda, görsel ortamı korumak ya da güçlendirmek için arzu edilen ses seviyelerine ulaşmanın yolları değerlendirilmiştir. Bu araştırma, gürültüye karşı zayıf bir performansa sahip olan yüksek katlı konutların yenilenmesi için en iyi ve olası yolların bulunmasını amaçladı.

Bu araştırmada kullanılan metodoloji, Nijerya'nın Lagos kentinde seçilen iki daireyle ilgili bir vaka çalışması yaklaşımı idi; C & N Luxury Apartments, Ikoyi ve 1004 Estate, Victoria Island. İlk adım, kullanıcı algılama seviyesini elde etmek için yaşayanlara bir anket uygulanmıştır. Ankete katılanların% 95'inin komşularından gürültü seviyesinden rahatsız olduğunu ortaya koymaktadır. İkinci adım, Autodesk'teki "ECOTECT analizi" nde iki vaka çalışmasını modellemek ve simüle edilmiştir. Bundan sonra, çok iyi akustik özelliklere sahip beş akustik duvar paneli seçilerek ve her panelin koşulları yazılım ortamında simüle edilmiştir. Simülasyonların sonuçları, C & N Luxury Apartments ve 1004 Estate Apartments'ta test edilen beş panelin akustik iyileştirmelerinin performans sonuç değerleri % 9.46 (1), % 20.79 (2), % 21.23 (3), %21.27 (4) ve % 24.9 (5). Bu çalışma, yüksek katlı konutlarda kaliteli ses kontrolünün yapılabilmesi için konutların iç panellerin yenilenmesinin bina performansın iyileştirdiğini kanıtlamaktadır.

Anahtar Kelimeler: Gürültü, Ses, Akustik, Bina İnşaatı, Duvar Panelleri, Yüksek katlı konutlar

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor Assist. Prof. Dr Eray BOZKURT for his guidance and patience during this study.

I am beyond grateful to Almighty God for His mercy and infinite blessings. Special thanks to my Parents Dr N. A. Mamudu and Hajiya Ayisha Mamudu, my Brothers; Mamudu A. Mamudu, Adamu. Y. Mamudu and Muhammad A. Mamudu. Words can't express how privileged I feel for your support, encouragement, love, prayers and most importantly the positive influence you had throughout my graduate school. I love you beyond words and I appreciate you.

I am also thankful to all my friends and colleagues; Mashood O. Olawumi, Stephen Adeh and Abdullahi Usman for their support in diverse ways to the success of this thesis. God bless you all.

MAMUD Ayisha Nnaketwa

Izmir, 2017

TEXT OF OATH

I declare and honestly confirm that my study, titled "SOUND INSULATION: RETROFITTING THE PARTITION WALLS OF HIGH RISE RESIDENTIAL BUILDINGS IN NIGERIA." and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

MAMUD Ayisha Nnaketwa

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November 23, 2017

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SYMBOLS AND ABBREVATIONS

ABBREVATIONS:

LARES	Large Analysis and Review of European housing and health Status
DB	Decibel
EEA	European Environmental Agency
HVAC	Heating Ventilation Air Conditioning And Cooling
STRBS	Super Tall Residential Building
IEQ	Indoor Environment Quality
WHO	World Health Organisation
UK	United Kingdom
TNR	Tone-Noise-Ratio
PR	Prominence Ratio
NWTW	North West Trade Wind
SWTW	South East Trade Wind
RT	Reverberation Time
EDT	Early Decay Time
E	Echo
EU	European Union

SYMBOLS:

A	Room absorption
$deff$	Design effect
F	Fluctuation strength
F_{max}	Maximum Fluctuation Strength
F_{mean}	Mean Fluctuation Strength
F_{perc}	Percentile Fluctuation Strength
$F_{\_tnr}$	The frequency of the maximum tone to noise ratio (TNR)
$F_{\_tnr}$	The frequency of the maximum prominence
f_{mod}	Modulation frequency
$FSTC$	Field sound transmission class
IIC	Impact Insulation Class
$FIIC$	Field impact Insulation class
K_o	Directivity index
L_{max}	Maximum level of the signal
L_{mean}	Mean Level of the signal
L_{Aeq}	A-weighted equivalent continuous sound pressure level
$L_{Aeq,T}$	A-weighted equivalent continuous SPL for duration T
L_1	One percentile noise level
L_{10}	Ten percentile noise level
L_{50}	Fifty percentile noise level

L_{90}	Ninety percentile noise level
L_{DEN}	Day-evening-night average noise level
L_{DN}	Day-night noise average level
L_D	Day average noise level
L_N	Night average noise level
L_{NP}	Noise pollution level
L'_{nw}	Weighted normalized impact sound pressure level
MRT	Mass Rapid Transit
n	Sample size
NR	Noise Reduction
NIC	Noise Isolation Class
TNI	Traffic noise index
N	Loudness
N'	Specific Loudness
N_{max}	Max Loudness
N_{mean}	Mean Loudness
$NISO532B$	Loudness according to ISO532B (Zwicker) standard
N_5	Five Percentile Loudness
P	Estimated prevalence of annoyance
PR_{max}	Maximum prominence
PR_{mean}	Mean Prominence

CHAPTER 1

INTRODUCTION

1.1. Subject of the Thesis

Noise is identified in various researches as resident's most annoying and disturbing problem in the urban residential environment. Homes are perceived as places for relaxation and means of relieving one from different disturbances in places of works by residents. But so many homes are unfortunately not conducive for relaxation and living. Aural comfort is attained when the silence and perception of privacy is perceived by the occupant of the building. The aim of design is to bring out a building that is structurally stable and conducive environment which is accepted by all the occupants without any means of both thermal and aural discomfort.

Solely focusing on unprejudiced methods does not ensure a well-functioned design and does not always provide for occupant well-being. Therefore a good home is that which can accommodate various functions and enables individuals to meet their personal requirements at the time of need, for example noise in bedrooms at night is detested but well ventilated bedrooms are recommended for better rest. Currently few researchers have specifically examined the effect of noise transmission between apartments in Nigeria and how to check their solutions. This research focused on identifying the level of the noise distribution within apartments and applies various strategies on walling components of the building to reduce the level of noise thereby providing aural comfort to the users.

1.2. Problem Statement

This research aimed at finding the best and possible ways to retrofit High-Rise residential buildings that are suffering from noise disturbance from neighboring apartments or rooms within an apartment. The methodology adopted for this research was a case study method whereby two apartments in Lagos, Nigeria namely; C & N Luxury Apartments, Ikoyi and 1004 Estate, Victoria Island were selected to be retrofitted. A Questionnaire will be administered in order to obtain the user perception level of noise disturbance in the apartments thereafter, the two case studies were modelled and simulated in Autodesk's ECOTECT analysis using 5 acoustic wall panels which have very good acoustic properties.

Noise is an unwanted sound. Reducing or total elimination of noise is of great importance for privacy, comfort and even productivity. Noise can affect speech, proper attention and sleeping, which can cause discomfort to the person and may lead to stress. The importance of noise control can be seen from the codes and regulations given out by various regulatory bodies in different countries. The intention of this research solely focuses on the effects of the existing wall partitioning systems on sound insulation and transmission in High-Rise and shared residential dwellings, and the retrofitting of wall partitions to moderate the rate of sound to a satisfactory limit. The challenge lies in attaining comfortable levels of sound for different activities while simultaneously maintaining or enhancing the visual environment.

Design and construction of large scale residential and shared apartments have become dominant in recent times due to limited land scale and high influx of people into the city. Due to the high ratio of occupants who lived in high-rise shared apartments, noise has attained an unfavourable level, which is generated from several units of occupants spaces these sounds cumulatively attains a large amplitude proportion and as a result affects the serenity of the other occupant who intend to have a quite solitude time.

Ijaiye (2014) stated that noise pollution can induce a temporary or permanent hearing loss, which is called an Auditory disorder. Nigeria as a developing country also experiences social intolerance due to this dilemma. Different literatures have attempted to hypothesize solutions to this problem. Ijaiye (2014) in his article disclosed that attempts have been made to address the issue of noise pollution. This research intends to investigate adaptable measures that can be incorporated into designing partition walls for high-rise residential buildings to control noise and enhance sound privacy amongst the occupants of shared apartments in Nigeria.

The sound insulation in buildings has gradually developed during the last hundred years. New innovations of building technologies, the introduction of new powerful sound sources in homes, and the increased awareness of noise in the society have all contributed to the development of sound insulation design. However, apartments in high-rise buildings experience more noise compared to other housing forms due to more sprawling views and direct contact with sources of noise such as roads, HVAC systems, corridors, and most buildings are frame structures (Naish, Tan & Demirbilek, 2014; Vlek, 2005).

“In present-day, noise is becoming a serious problem, especially in homes, particularly in countries where there is no enforced Government regulation against public disturbance. Sources of noise are now on the increase and they are steadily growing louder. Previously, noise was taken to cause only discomfort to people, but harmless to their health. Nowadays, noise was understood to be not only the source of discomfort, but rather cause life threatening health problems such as stress which affect the well-being of the people. This is why people spend a lot in-order to be in a quiet environment especially, homes which serves as a resting place for people (Ogunbowale, 2012. P.114).

Building structure noise is also a problem in Nigeria, noise as a result of vibrations is transmitted into the building’s structure, especially through walls of the building. Acoustic privacy is highly valued by residents, according to various researchers this will definitely force professionals in providing a space that will have good acoustic quality thereby preventing noise transfer among neighbouring apartments. Eliminating noise is very crucial as it also improves privacy and therefore it is necessary to achieve this for a comfortable living environment. Windows are meant to serve as a means of lighting and ventilation however, they serve as a major source of aural discomfort if the building is not designed properly. Balconies can serve as a noise barrier if they are designed very well to perform the function (Naish, Tan & Demirbilek, 2014).

1.3. Aim and Ojectives

The aim of this work would be achieved through the following objectives:

(1.) Identify various wall panels that have very good acoustic properties.

(2.) Identify the level of sound problems in shared residential apartment buildings.

(3.) Simulate using Autodesk ECOTECT Analysis software, the effect of various acoustic wall panels.

(4.) Generate suggestions for Retrofitting residential apartments with no noise problems for the users.

1.4. Research Questions

The main research questions of this research are:

1.) What are the various wall panels that have very good acoustic properties?

2.) What is the level of sound problems in shared residential apartment buildings?

3.) What is the effect of various acoustic wall panels for sound insulation by using Autodesk ECOTECT Analysis software?

1.5. Methodology

The research methodology of the study is to evaluate the effect of acoustic properties of wall panels in retrofitted High-Rise apartment buildings in Lagos, Nigeria. This research will first identify various High-Rise residential apartments in Lagos, Nigeria and using purposive sampling two case studies. Selected users of these two cases were given a questionnaire form in order to understand the level of noise and aural discomfort they are experiencing in their own apartments. The type and the nature of the aural discomfort was identified. The architectural data of the two case studies building were taken to provide necessary information for the software program. The literature research also identified the various studies on wall panels with good acoustic properties. Acoustic simulation was then carried out using Autodesk ECOTECT Analysis software.

Firstly, the two buildings were simulated and the level of sound transmission between apartments was calculated. Thereon, the other acoustic panels were simulated so that the effect of each acoustic panel on sound transmission was recorded. This research will establish the current situation of aural discomfort in High-rise residential apartments as well as the acoustic panels with good sound resistance properties that can be used in retrofitting buildings that have similar sound transmission properties.

1.6. Thesis Outline

Different approaches have been investigated during the research. The current research has two main approaches. The first approach is to develop an extensive literature review on relevant areas. The second approach is to test the result with computer modelling software called ECOTECT. This thesis has been structured into five (5) chapters, each chapter having a subheading.

In Chapter 1, the focus is to give an introduction to this research, in major a general background and presenting an overview of the research discussed.

In Chapter 2, the literature review was given to describe the noise and its reflections in the research field.

The chapter concludes with some issues such as the role that played by occupants in order to achieve the desirable level of aural comfort, beside some important factors such as the external environment and the materials used for buildings. An extensive literature review of acoustic performance is carried out as theoretical background. It depends on information from researches, conference papers on various relevant studies. Also simulation was carried out using a program such as ECOTECT which provided reasonable results. The results was evaluated in order to optimize the acoustic properties of the models.

Chapter 3, presents the methodology, how the data are carried out and how it's going to be analysed.

The data collected in chapter 3 are then critically analysed using selected methods which have been previously stated, were discussed in Chapter 4. Computer simulations and questionnaire form results are presented here, with the two simulated case study buildings examined from every aspect. Results and findings are included in the last part of this part of the Thesis.

In Chapter 5, discussion and Summary of findings are the main body of this chapter besides stating out the findings from this research.

In Conclusion, a brief summary of the research, recommendation and contribution to knowledge is discussed in this chapter.

1.7. Scope Of The Study

This research will focus on evaluating the effect of building envelope specifically wall sound transmission and absorption to identify the effect of each strategy applied in improving aural comfort of such building component. It will highlight the theoretical framework necessary to achieve environmentally-friendly sound level within buildings. And this would be coupled with the assessment of existing principles and the consideration of the study area. It is also among the scope of this research to highlight the concept of designing for aural comfort. Finally, the research will develop a theoretical solution as well as design solutions for sustainable and efficient buildings in terms of aural comfort in Lagos, Nigeria.

1.8. Limitations Of The Study

This research is limited to assessing acoustic properties of walling materials in high-rise apartment buildings in Lagos, Nigeria. The research then identified the most suitable way in improving the acoustic response of the walling materials through the application of acoustic panels which will be identified from various literature. The acoustic panels were then simulated on the acoustics simulation software package in order to establish the effect of each panel in acoustic enhancement which was therefore recommended for retrofitting of high-rise apartments. The research used two instruments first, the questionnaire survey to establish the existence of noise in high-rise apartment which the information was obtained from the occupants of the buildings. Secondly, the research, improved the acoustic response in the apartments by modifying the walling component of the building.

The following figure 1.1 below shows the relationship of chapters with one another.

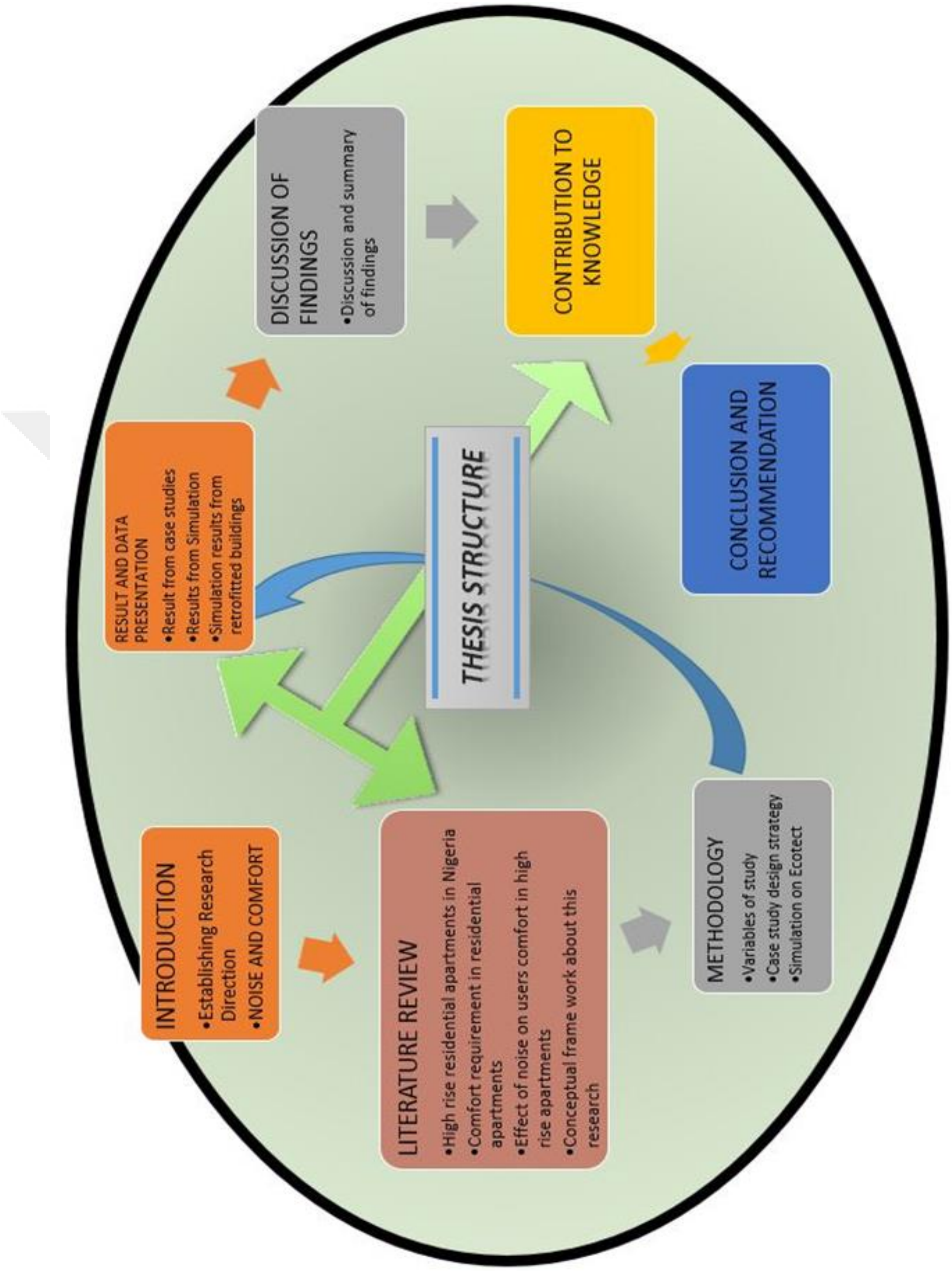

Figure 1.1. Chart Showing Thesis Structure (**Source.** Author 2017).

The blue arrow illustrates the connection between methodology and results & data presentation which implies that the instruments and methods used to collect data were presented and the results were analysed in chapter four. The Green three headed arrow pointing chapters 2 (literature Review), chapter 4 (results and data presentation) and chapter 5 (contribution to knowledge) indicates that after reviewing relevant literature, strategies used in improving aural comfort will be adapted and used as a guide to establish new strategies that might affect the improvement of aural comfort in high-rise residential apartments. The strategies established from the literature review will be tested and their effect will be presented in chapter 4 (result and data presentation), which is why the second arrow is facing chapter 4. The effect established in chapter 4 will serve as the findings of this research which is the contribution to knowledge as it will state the effect of each strategy on aural comfort.

This chapter discusses the intent as well as the direction the research. The following chapter two will discuss the review of relevant literature for aural comfort, noise in high rise apartment and also discuss retrofitting walls for better acoustic panels.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

In this chapter, various relevant studies were reviewed. Firstly, high-rise buildings were explained and why noise is a priority problem in these structures. Secondly, the factors, methodologies and models for evaluation of noise was discussed in order to establish a standard of noise evaluation for this research. Thirdly, various ways for retrofitting walls in order to improve their acoustic performance were discussed. Lastly, conceptual framework for this study was established for proper understanding of the direction of this research.

The word 'skyscraper', as an adjective describing the tall building, first appeared in the United States in 1884, and was used as a noun around the year 1889. Girouard (1985), however, argues that;

"The First known dictionary to include the word 'skyscraper' was Maitland's American Standard Dictionary in 1891." When we turn to Maitland's we find that it defines the 'skyscraper' as "a very tall building such as now those that are being built in Chicago."

As late as 1933, the Oxford English Dictionary included six different definitions of the word 'skyscraper' including, among instances of usage cited, a high-standing horse and a very tall man. Generally speaking, by the advent of World War I, almost everyone had learned what a 'real' skyscraper was: a building having many storeys (Ford, 1994). Today the Oxford English Dictionary devotes seven columns to the term 'skyscraper' and render illustrations as various as "A high building of many storeys especially one of those characteristic of American cities." Two titles, including the word 'skyscraper' appeared in the newspapers, the first one in 1891 and the other two years later in 1893.

Despite the diverse history of the high-rise and given the fact that it is an architectural phenomenon determined equally by technological development, design, conceptual change, social transformation and psychological structure, defining the high-rise is a complex task.

Extant definitions equally engage the facts enumerated above, so that to extricate from this complex body a definition concerning the relationship between the architectural design and the consumer once again requires looking at multi- and interdisciplinary definitions. As a result, the 'high-rise' has various definitions coined by different researchers with sometime having contradicting definitions. The problem is the adjective 'high', how high is high. Thus Taranath, 1988 argued that 'height' is a relative matter (p. 8).

In some countries, seven storey building will be very tall, while in Nigeria a 30 storey structure is one of the few tallest buildings, while in countries like china the tallest buildings range from 80 storeys and above. At the end of the nineteenth century, tall buildings were called 'skyscrapers', which may be described as a name that primarily took into consideration their non-conformity and particular relation to their surroundings and the environment.

2.2. Satisfaction and Perceptions of Aural Comfort by Residents Living in High-rise Apartments.

2.2.1. Resident's Satisfaction

Various studies of residential satisfaction were conducted to find out both social and physical quality of the building structures. For residential satisfaction is based on three crucial factors which are; the occupants, the building and the neighbours as argued by Canter and Rees (1982). Also, Bell, Greene, Fisher and Baum (2001) reviewed various studies conducted in the mid-1990s and came up with a summarized factors that consistently predict housing satisfaction. The four factors described are:

1.) Influence of housing space under the view of privacy or swarming;
2.) Sense of community in terms of Relationships with neighbours.
3.) Neighborhood security perceptions
4.) Physical viewpoints, including quality of construction and spaces to help essential living needs. This identified the aim of this research which is aural comfort.

Notwithstanding, Adriaanse (2007) opined that, the measurements of the housing condition are regularly examined in seclusion from one another, and there is a paucity of knowledge about the common intersection of these parts

Moreover, many studies have concentrated towards the area measurement (Lewicka 2010). Generally, experimental research on skyscraper abiding fulfillment and socio-ecological variables are concerned about the occupant's view of interwoven aspects, from the administration of the building complex of combined qualities of the study location Lagos, Nigeria.

For instance, in Hon Kong Phillips, Siu, Yeh and Cheng (2005) looked for elderly occupant's impression of 10 (ten) indoor qualities that included interior light, light in hallways, ventilation, overcrowding, thermal comfort, security gadgets, stairs, lift, security administration within buildings (for example, an alert framework) e.t.c. But, they didn't determine or separate between the inside natural parts of the private abiding together with general building. Phillips et al. (2005) found that the indoor condition greatly affected occupant fulfillment than the outside condition, despite the fact that these were assessed utilizing diverse assessment measures.

Correspondingly, Lee, Je and Byun (2010) assessed occupant's view of private spaces of exclusive high-storey residential apartments coined as super-tall residential buildings (STRBs), which are higher than 30 storeys in Seoul. Arranged by significance to inhabitants, major residential satisfaction indices are:

i. Health; both physical and psychological;
ii. Safety and security which include
iii. Conveniences and management of building facilities; and
iv. Ecological environment which are (materials and resources and energy efficiency).

Occupants of STRBs for the most part opined that maintenance of buildings; thermal comfort, indoor air quality and ventilation, were pointers of a sound private condition while markers of psychologically healthy homes were day lighting and view, absence of irritating noises, the feeling of openness (instead of a feeling of congestion) and the nature of overall spaces that enable inhabitants to have a control on their interaction with neighbouring occupants (Lee, Je, and Byun 2011).

According to Pacione (1984), he conducted a research on skyscraper social housing separated between the home and the building in which he selected the real parameters of occupant comfort with the quality of the environment of home unit as:

1) External appearance of the residence;
2) Internal plan and standpoint;
3) Measurement of the level of privacy by the measure of the level of noise from outside, from neighbours, and the size of outer spaces for individual use; and
4) Building Standard on the cost and repairs of heating systems

Gifford (2007) has explored and condensed systematically the consequences of research on the impacts of inhabitant's living in high-rise encounters and fulfillment. He concluded that in spite of various complaints and fears, all were not really based on evidence, and yet a couple of scholars estimate that elevated structures will prompt positive results for occupants. Gifford clarifies that the lack of failure to conduct research is an issue itself and the dire requirement for increasingly and carrying out good related studies impacts conditions on tall structures. He contends that studies on residential apartment is unpredictably hard to finish since results are dictated by different components.

Gifford conducted most of the studies that are related to mass housing around 1960s-1970s. These studies majorly involved lower income group of residents and higher population of the occupants were elderly people. These kind of research were not flexible as the occupants cannot be able to leave when they are not satisfied with the apartments (Amerigo and Aragones 1997). 'Choice' is the main critical difference between satisfaction among the resident's housing in private and public type (Gifford 2007). Satisfaction in high-rise apartments living is higher if the buildings are located in conducive areas of the city and the building were selected by occupants themselves. Gifford (2007) also, speculated using the evidence presented that although the problems are multifarious for high-rise living, only very few are as a result of architectural design. The remaining are either from the occupants or from the management of the buildings.

However, according to Urban's (2012) research in mass housing within towns around the world, he pointed out that the subjects were concerned with economic, systemic social, cultural, and other environmental factors that affects housing comforts such as social planning, building management culture and housing policy.

Despite Gifford's (2007) reaching survey of observational discoveries about the social and mental impacts of comfortable life, there was very less knowledge uncovered in the inhabitant's involvement of the home itself, or the qualities or highlights that impact occupant's view of natural quality, or how the occupant's understanding of their private living space might be irritated by or enhanced by the effects of the more extensive setting, specific physiological conditions.

2.2.2. Perceptions Of Comfort

Occupant comfort is arranged at a point in which both their psychological and physiological are met (Amerigo and Aragones 1997), (Lee, Je, and Byun 2011), (Adriaanse 2007). Health, comfort and happiness must be integrated when carrying out evaluation of building performance (Steemers and Manchanda 2010).

Comfort is arranged on the prosperity range where the parameters that include both quantifiable variables (for instance, Noise level, temperature and luminance) and subjective contemplations (for instance, recognition and excellence) were adjusted. During the period of prosperity, happiness overshadows the feelings (Chappells 2010). Logical components make experientially rich indoor conditions and to decipher "well being", solace and contentment attributes of prosperity leads to plan and execution, there is a need for creators to comprehend the intricate connection with tenant's individual discernments whereas accommodating target suitable conditions (Steemers and Manchanda 2010.)

2.2.2.1. Objective Measures of Indoor Quality

How the structure intercedes between the inside and the outside condition is the target ecological execution of structures. The components are connected to consolidated impact affecting the general indoor environmental quality (IEQ) of the abode. Individuals see these ecological factors as far as fulfillments with how agreeable or not they feel, but rather for the most part individuals are not excessively mindful of encompassing physical conditions and endure a scope of variety unless the points of confinement of comfort are beyond tolerable range (Hedge 2000).

- **Illumination**

Daylight is preferred by many people in their home as it relates to psychological and physical health (Baker and Steemers 2002). Lighting nature of inner conditions is basic for the execution of different activities in the residential apartments, however the point of light configuration goes a long way past the arrangement of a given amount of brightening (Tregenza and Wilson 2011). Light is a requirement on the way we perceive colour, beauty, form with many more.

A wealth of manufactured light within the required condition will upset this series, and an absence of introduction to sunlight is connected to wretched ailments (Baker and Steemers 2002). Consciousness of the regular variability of sunshine is fortifying, and imperative for our feeling of association with the fluctuating outside world conditions, the criteria for lighting are gotten from distributed principles; be that as it may, regardless of how mindful the guidelines are taken after, or how broad the criteria are (Tregenza and Wilson 2011). As such it implies the guidelines can't substitute the architect's comprehension of the necessities of the building occupants (Hedge 2000).

- **Quality of Air**

Key inside air quality issues in residences are identified with emanations got from both inside produced sources (for instance, cooking vapor) and to outer contamination (Kotani et al. 2003). Morawska (2009) opposes for normal ventilation to scatter toxins. Also, he described that, more than 60% of poisons that are available outside are additionally discovered inside. As opposed to pushing elective ventilation with the goal that windows can be kept shut.

Air-conditioned interior spaces are not suggested for living healthy because various health problems that may arise, especially on the grounds that the set point temperature of the system is going to be well underneath encompassing conditions in warm atmospheres and add to weakening systems and wall/floor finishes, this cause a lot of health issues.

2.3. Urban Noise Environment And Aural Comfort

With the rapid technological advancement and urban growth to meet residents, housing shortage, superior transport system and improved quality of life, the cities around the world are becoming busy, crowded and dense. The presence of noise beyond an acceptable level and quality is a key concern among the city dwellers since it causes notable annoyance in the daily lives (Morillas et al., 2005). The paucity of knowledge on the level of the effect of noise in Nigeria, which is due to the lack of availability of researches on the issue in Nigeria will direct this research towards reviewing the effect of noise on residents in high-rise apartments in other parts of the world where various researches are available.

A public survey of the citizens in the European Union (EU) shows that the problem of noise in daily lives is often rated as the utmost concern together with issues such as global warming (CALM, 2007). The report (CALM, 2007) revealed that, for the European Union, approximately 80 million people are exposed to unacceptable noise levels and this noise exposure has led to sleep disturbance and other adverse health effects. The report also stated that an estimated 170 million people live in 'grey areas' where noise produces annoyance at a 'serious' level. This demonstrates the severity of noise problem in the EU.

Niemann et al. (2006) reported that in the LARES study (Large Analysis and Review of European housing and health Status), conducted between 2002 and 2003 in eight European cities, neighbour noise is the second major source of noise (followed by road traffic noise) in the residential environment.

The study showed that approximately 39% of the sample was disturbed by road traffic noise. This was followed by 36% of the respondents who were disturbed most by neighbour noise. Neimann et al. (2006) noted that neighbour noise is generally produced by the daily living activities of the residents and it is therefore related to speech, music or impact noise within the residence. Because of such characteristics and information content of the neighbour transmitted noise, attention is drawn much more easily and therefore the potential of becoming annoyed by these noises is higher even at a relatively low noise level.

Langdon et al. (1983) conducted a noise survey among 709 English residents in the UK who lived in multi-storey dwellings. The survey results revealed that approximately 70% of the entire sample population heard noise from their neighbours. The survey also revealed that about 30% of the respondents rated poor sound insulation as the topmost defect in the building due to neighbour transmitted noise, among a number of other building defects such as poor finishes and damp problems. Floor impact noise was found more serious in comparison to airborne noise through party walls.

According to Utley and Buller (1988), noise annoyance due to neighbour noise is the second major source of annoyance followed by the noise annoyance due to road traffic noise, which is the major source of noise in the UK (Fields et al., 1987; Fidell et al., 1988).

2.4. Factors Affecting Evaluation Of Noise

Four factors may affect noise in an environment which are mainly; Environment, Acoustical, Non-acoustical and Psycho-acoustical factors which help to shape living conditions.

2.4.1. Environment

Augoyard (1999) noted that people listen to sound inevitably and they perceive it based on their cognitive attitude towards it. The physical signal (noise) alone does not represent the perceptual quality; rather it depends on the interaction between sound and the listener, resulting in a very complex process of evaluation of the noise environment. This observation holds true for evaluation of the noise environment in a residential setting as well. Research on evaluation of noise environment (the negative evaluation - annoyance) has examined several acoustical and non-acoustical factors (Ouis, 2001). A review of this literature on noise annoyance and its relation to several acoustical and non-acoustical factors are presented below.

2.4.2. Acoustical Factors

Research on noise annoyance has shown that the correlations between global noise annoyance and acoustical factors are generally weak (Marquis et al. 2005). Generally the acoustical factors investigated are A-weighted equivalent sound pressure level

(L_{Aeq}), statistical sound levels ($L_1, L_{10}, L_{50}, L_{90}$), Day-evening-night level (L_{DEN}), Day-night level (L_{DN}), Day level (L_D), Night level (L_N), Traffic noise index (TNI), Noise pollution level (L_{NP}) and Number Index (NNI) etc.

(Juhani, 2007; Marquis et al., 2005; Klaeboe et al. 2004; Ali and Tamura, 2003; Miedema et al., 2001)

The maximum correlations achieved so far on an individual response basis is a Spearman correlation of 0.35 (Marquis et al., 2005). Maarten et al. (2008) also noted that there is no one-on-one relationship between noise annoyance and acoustical factors.

Berglund (1998), Job (1988) and Lercher (1998) noted that with the time average noise exposure level descriptors (L_{Aeq} and L_{DN}), noise annoyance can be explained between 20% and 30% at the most (though the relationships between acoustical factors and annoyance differ depending on the type of noise source, for example, peaks are often useful with aviation noise).

The relationships between noise annoyance and several acoustical factors are shown in Figure 2.1 and Figure 2.2.

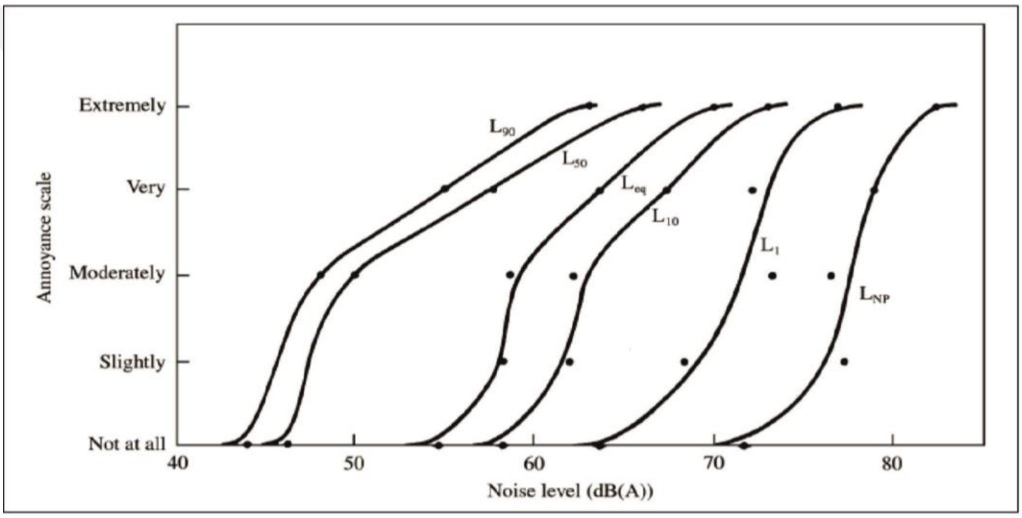

Figure 2.1. Annoyance as a function of noise level. (**Source.** Crocker, 1997)

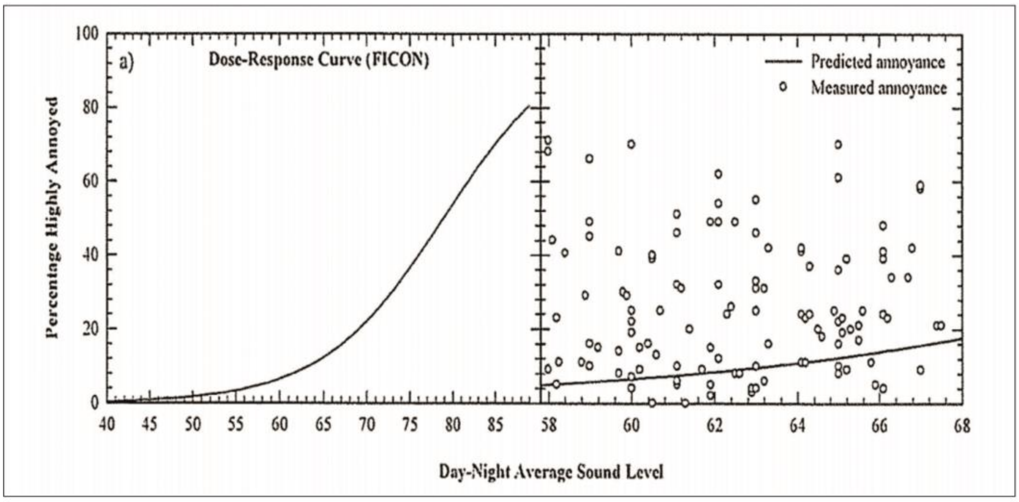

Figure 2.2. Percentage of exposed people highly annoyed by aircraft, road traffic and railway noise. (**Source**. Fidell, 2003).

Lambert et al. (1984) observed that between the time period 8am and 8pm, no noise annoyance is perceived below 55 dBA (L_{Aeq}), whereas more sensitive people start to feel annoyed between 55 dBA and 60 dBA. Finally, definite noise disturbance is exhibited when the noise level exceeds 65 dBA. Contrary to these findings, Fields (1993) noted that for a noise exposure level below 55 dB (L_{DNL}) there could be a correlation between noise annoyance and noise exposure level. However, other than these noise exposure parameters the qualitative aspects of noise have an important role in the development of noise annoyance (Marquis et al. 2005).

Several studies have investigated the influence of the different types of noise sources on an annoyance rating known as the 'mode of transportation effect (Lambert et al., 1998). Since Schultz (1978) published his dose response, controversy has continued over whether all types of transportation noise should be combined under "general transportation noise". In fact, many acousticians agree that aircraft noise is perceived as more annoying when compared to road traffic noise (Kryter, 1982) while road traffic noise was found most annoying when compared to railway noise (Guski, 1998; Hellmann & Broner 1998; Fields and Walker, 1982; Miedema and Vos, 1998). This is, however, found totally opposite in many research studies in the Asian Context (Yano et al., 1996, Lim et al., 2006, Jiyoung et al., 2010).

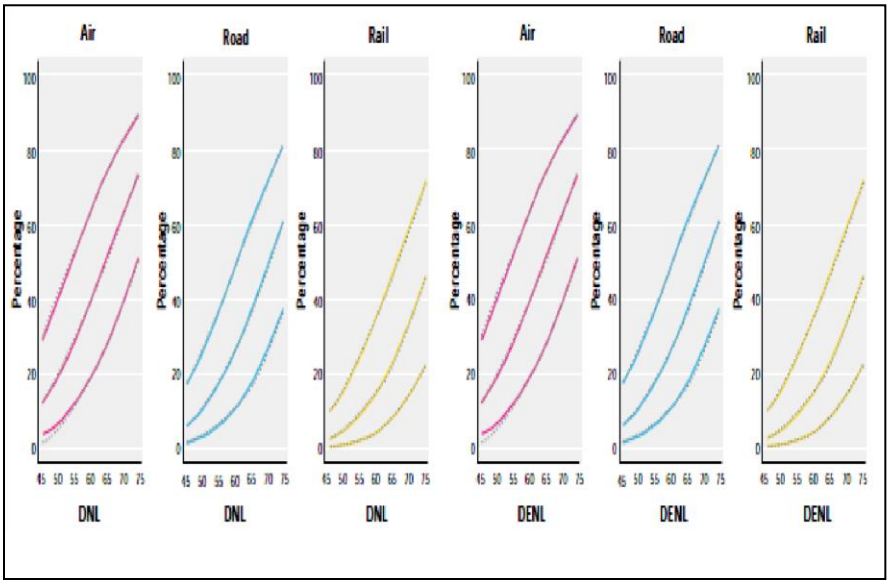

Figure 2.3. The estimated percentage of annoyed individuals as a function of DNL and DENL (annoyance curve: a little annoyed, annoyed and highly annoyed) (**Source.** Miedema et al., 2001)

As shown in Figure 2.3: Miedema et al. (2001) used different polynomial curves to describe different noise sources (aircraft, road traffic, and railway noise).

Table 2.1. Summary of Acoustical Factors Affecting Noise Annoyance (**Source:** Alam, 2014)

Acoustical Factors	**Relationship**	**References**
L_{Aeq}, L_1, L_{10}, L_{50}, L_{90}, L_{DEN}, L_D, L_N	No one–on-one relationship max Spearman correlation 0.35 with noise annoyance.	Maartenetal (2008), Juhani (2007), Marquis (2005), Klaeboe (2004), Ali and Tamura (2003), Lawrence (2002), Miedema and Vos (2001,1998), AranaandGarcia (1998), Fields (1998,1993,1984), Kryter (1982) , Schultz (1978), Griffiths and Langdon (1968)
Mode of transportation (L_{DEN}, L_{DN})	Factors investigated for different modes of transportation effect on noise annoyance. No one-on-one relationship established.	Lambert (1998), Lawrence (2002), Schultz (1978), Miedema (2001)
Noise events number	Once a certain number of events are reached, an increase in that number no longer creates an annoyance increase. The number of noise event is not correlated with noise annoyance alone. Time of the day might also be involved.	Bjorkman and Rylander (1996), Guski (1998)
Ambient noise level	Annoyance is affected very little by the presence of another sound source qualified as ambient noise: a 20 dB increase would have approximately the same impact as a 1 dB drop in the studied annoying noise.	Fields (1998)

Marquis (2005) noted that other quantitative factors that have been used to evaluate noise annoyance include number of noise events, time of the day etc. (Fields et al. 1998, 1997; Vallet et al., 1996; Guski, 1998). A list of acoustical factors influencing noise annoyance (as discussed above) is tabulated in Table 2.1.

Table 2.1 demonstrates that acoustical factors alone are not adequate to elucidate the evaluation of noise environment. Marquis (2005) commented that there is no “miracle” physical acoustical factor that could establish significant correlations between noise and annoyance. Apparently, in addition to the acoustical factors, other non-acoustical factors play an important role in noise annoyance evaluation (Jian Kang, 2006)

2.4.3. Non-Acoustical Factors

Ouis (2001) illustrated that non-acoustical factors are generally person-related and they include physiological, psychological, and social factors that affect a person's perception of noise and impair activities (communication, concentration, sleep, recreation or rest). Numbers of researchers have concluded that there is an unclear relationship between acoustical and non-acoustical factors (Job, 1988).

However, Miedema (2007) concluded that the influences of non-acoustical factors are of great importance for the evaluation of noise annoyance since several mechanisms explain the relationship with noise annoyance. Finally, as noted by Nelson (1987), there are six aspects that researchers agreed influencing noise annoyance. The first aspect is related to the fear related to the noise source - i.e. People are more annoyed if they believe the noise source will affect them (Maarten, 2008; Job, 1988; Hellmann, 1996).

The second aspect is dependent on the noise source - people who are dependent on the noise sources for their living are generally less annoyed (Miedema and Vos, 1999), people may be less annoyed if they are economically dependent on the activities generating the noise. The third aspect is sensitivity to noise, a lot of studies have shown that annoyance evaluation is significantly related to the noise sensitivity (Daniel, 2010; Dirk et al., 2010; Van, 2004; Miedema and Vos, 1999; Vallet, 1996 etc.). The type of activities affected by the intruding noise is the fourth aspect intellectual tasks, rest time and communications are generally more affected by noise (David, 2007; Miedema, 2007; Hellmann, 19960).

Perception of the neighbourhood is the fifth aspect, perception of the neighbourhood in a negative way increases the noise annoyance (Li et al., 2010; Lim et al., 2008; Langdon, 1976; Bertoni et al., 1993). The sixth aspect, as noted by Nelson (1987), is the global perception of the environment the interaction between acoustics and other physical environmental factors that influence the perception of noise (Weber, 2001; Patsouras, 2002; Vallet et al., 1996; Sato, 1993; Yano et al., 1996 etc.).

These factors are interrelated but the implication of the relationships between noise annoyance and these non-acoustical factors remain unclear (Maarten et al., 2008; Job, 1988; Alexandre, 1976; Fields and Walker, 1982). Numerous studies have been made to evaluate noise annoyance with respect to several socio-demographic factors. Nelson (1987) concluded that generally no research has shown a strong and significant relationship between these factors and noise level. Miedema and Vos (1999) also noted that, although results may differ demographic factors do not have any crucial influence on the evaluation of noise annoyance.

A list of non-acoustical factors influencing noise annoyance are presented in Table 2.2 From the above study (Table 2.2), it is apparent that the range of non-acoustical factors are wide and establishing their relationships with noise annoyance is a complex challenge. However, as Guski (1999) noted, only 30% of the variance of noise annoyance can be explained by non-acoustical factors alone. As a result, it is important to consider both acoustical and non-acoustical factors for the evaluation of noise annoyance. There are several Psycho-acoustical factors that are generally used for evaluation of sound quality of specific noise sources. There has been very limited application of these factors in the evaluation of global noise annoyance in a residential context. The following section discusses these factors in relation to noise annoyance.

Table 2.2. Summary Of Non-Acoustical Factors Affecting Noise Annoyance (**Source:** Alam, 2014)

Non-Acoustical Factors	**Relationship**	**References**
Age, Gender, Socioeconomic status, Culture, Education, Home ownership, Dwelling size, Type of dwelling, Family size, Dependency on the source of noise, Length of residence etc.	These factors do not have any significant effect on the evaluation of noise level.	Fields (1993), Nelson (1987), Miedema and Vos (1999), Job (1988), Fields and Walker (1982), Bertoni (1993), Vallet (1996), Tonin (1996), Maurine and Lambert (1990)
Sensitivity to noise	Sensitivity to noise has significant influence on noise annoyance	Fields (1993), Daniel (2010), Dirk (2010), Jakovljevic (2009), Van (2004), Miedema and Vos (1999), Vallet (1996).
Perceived disturbance	Perceived disturbance and control, influence level of noise annoyance	Stallen (1999)
Adaptive behaviours or habits	A couple of studies found a significant influence of adaptive behaviours on noise annoyance.	Bertoni (1993), Lercher (1998)

2.4.4 Psychoacoustical Factors

The evaluation of the 'quality' of a noisy environment (for example 'aural comfort') addresses three factors: Acoustical Factors, Non-acoustical Factors and Psycho-acoustical Factors (related to auditory perceptions) (Genuit, 1996).

Genuit commented that although "noise” is defined in (DIN 1320) as the sound occurring within the human hearing frequency range disturbs silence or an intended sound perception and results in annoyance or endangers health, no such definition can be given to the term 'acoustic quality'.

With the advancement of signal analysis and hardware equipment, various technologies are available in the market for the measurement and evaluation of psychoacoustics magnitudes of a noise. The common method of psychoacoustic evaluation of noise is a recording of a binaural sound either through an artificial manikin or through a binaural headset on a subject and post processing of the noise signal. However, jury testing is an essential part of the psychoacoustical evaluation of noise. Several methods are used for the subjective assessment which are presented in section 2.4 of this chapter.

However, since the perception of sound is dependent on cognitive and emotional factors as well, additional measurements are needed to get the whole picture of sound quality.

- **Loudness**

The loudness of a sound is a perceptual measure of the effect of the energy content of sound on the ear. 'Sone' is the unit of loudness. A tone which is perceived as double the loudness (in sone) indicates that the level of the 1 kHz tone in a plane field has to increase by 10 dB.

Using the reference point the loudness of a 40dB 1kHz tone, corresponding to a loudness of 1 sone, the loudness function is calculated and shown in Figure 2.4

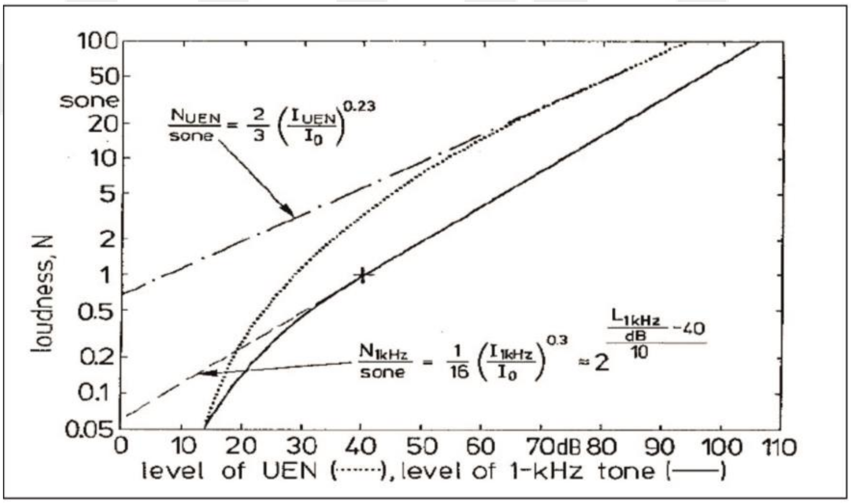

Figure 2.4. Loudness Function Of A 1 Khz Tone (Solid Line) And Uniform Exciting Noise (Dotted); Loudness Is Given As A Function Of The Sound Pressure Level. Approximations using power laws are indicated as broken and dashed, dotted lines together with their correspondings equations **(Source**. Fastl and Zwicker ,2006)**.**

Only for quite large frequency separation, where the two single tones do not influence each other, the loudness value occurs which corresponds to the addition of the loudness of each tone. Therefore, the loudness summation becomes a complicated process for complex sound. So, while it is more usual in acoustics to see the “loudness” of a signal expressed in dB (A), a better measure of the perceived loudness can be found by proper application of the critical bandwidths

The 'Specific Loudness' exhibits the distribution of loudness across the critical bands. A specific loudness is calculated from the dB level for each third octave band using the assumption that a relative change in loudness is proportional to a relative change in intensity (Fastl and Zwicker, 2006). Its unit is “sone/bark”. The total loudness N is the result of the specific loudness’s N' through integration of the critical band rate (refer to Figure 6) and is shown in Eq. 2-1.

$$N = \int_0^{24\,Bark} N'dz \qquad \text{.....................................} \quad \text{[Eq. 2-1]}$$

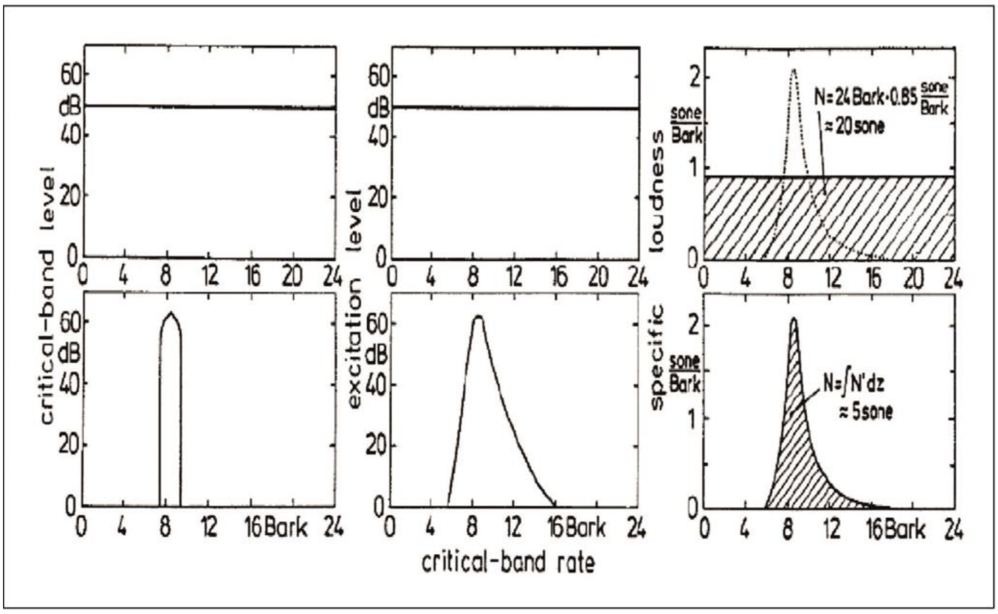

Figure 2.5. Schematic Illustration Of Zwicker Loudness Model**.** (**Source.** Fastl and Zwicker, 2006)

The procedure to evaluate loudness using Zwicker’s method is shown in Figure 2.5. The left diagram shows a narrow band centred at 1000 Hz (corresponds to 8.5 bark). The central diagram in Figure 2.4 presents the narrow band of noise at 1000 Hz, including masking effects caused by spectral broadening in the cochlea due to inner ear mechanics. The rightmost diagram shows the specific loudness/critical band rate pattern (sone/bark), known as the Zwicker diagram. The transition from the masking pattern, shown in the middle diagram in the loudness pattern, shown in the rightmost diagram can be considered to be obtained by taking the square root of the sound pressure or the fourth root of the sound intensity.

The shaded area in the rightmost diagram in Figure 2.5 is directly proportional to the perceived loudness. There are several methods or algorithms for determining loudness. The Zwicker loudness method has been shown to have the highest correlation with human perceived loudness.

Zwicker loudness can be used for both stationary and non-stationary sources. The computation procedure for Zwicker loudness for a stationary source has been standardized and illustrated in both ISO 532B and DIN 45631 standards.

- **Sharpness**

Sharpness is a measure of the high frequency content of a sound. Unit of sharpness is 'acum'. As shown in Figure 2.5, one acum is defined as a narrow band noise one critical band wide at a centre frequency of 1kHz (8.5 Bark) having a level of 60 dB. The formula for computation of sharpness, according to Fastl and Zwicker (2006) is shown in Eq. 2-2.

$$S = 0.11 \frac{\int_0^{24\,Bark} N' g(z) z dz}{\int_0^{24\,Bark} N' dz} \quad \text{....................................... [Eq. 2-2]}$$

In the above equation, the numerator is similar to the first moment of specific loudness over critical-band rate, but uses an additional factor, $g(z)$, that is critical band-rate dependent while the denominator is the total loudness. To account for the increased sharpness of high-frequency sounds, the weighting function $g(z)$ is used. From Figure 2.7 it is obvious that when a low frequency noise is added to a high-pass noise, the centre of gravity shifts downwards.

As a result, a smaller sharpness value is generated compared to dotted and dashed arrows. This implies that sharpness can be reduced by the addition of low frequency components which is useful for sound quality control.

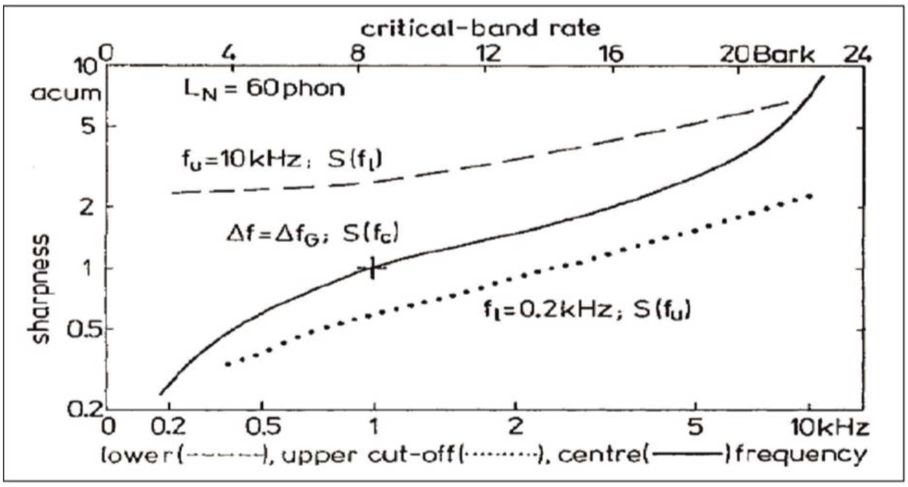

Figure 2.6. Sharpness Of Narrow And Noise (Solid), High Pass Noise (Dashed), Low-Pass Noise (Dotted) (**Source.** Fastl and Zwicker, 2006**).**

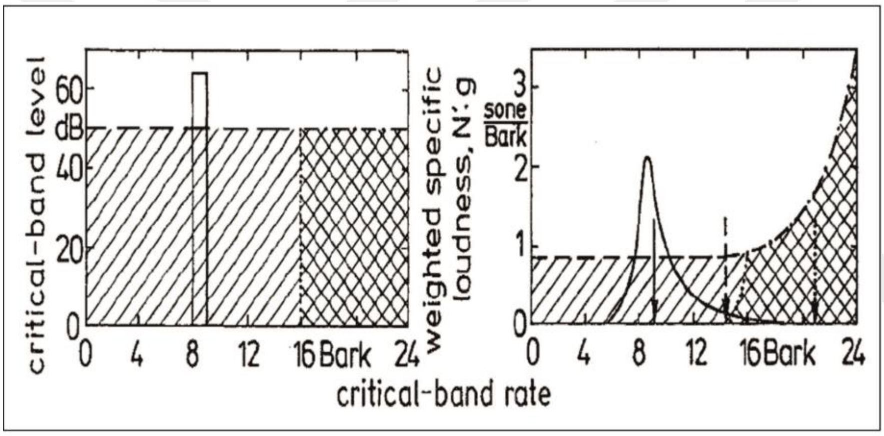

Figure 2.7. Model Of Sharpness Narrow-Band Noise(Solid), Broadband Noise (Dashed), And High-Pass Noise (Cross Hatched) (**Source.** Fastl and Zwicker, 2006)

- **Fluctuation Strength**

Another key psychoacoustic metric is fluctuation strength. A sound which has a strong time-dependent fluctuation in sound pressure level is more annoying than a steady sound (Fastl and Zwicker, 2006). The unit of fluctuation strength is 'vacil'. One vacil is defined as the fluctuation strength generated by a 1000Hz tone of 60dB which is 100% amplitude modulated at 4Hz. According to Fastl and Zwicker (2006), the fluctuation strength (F) is defined as:

$$F \sim \frac{\Delta L}{\left(\frac{f_{mod}}{4Hz}\right)+\left(\frac{4Hz}{f_{mod}}\right)} \text{ .... [Eq. 2-3]}$$

Where, ΔL is the masking depth and f_{mod} is the modulation frequency.

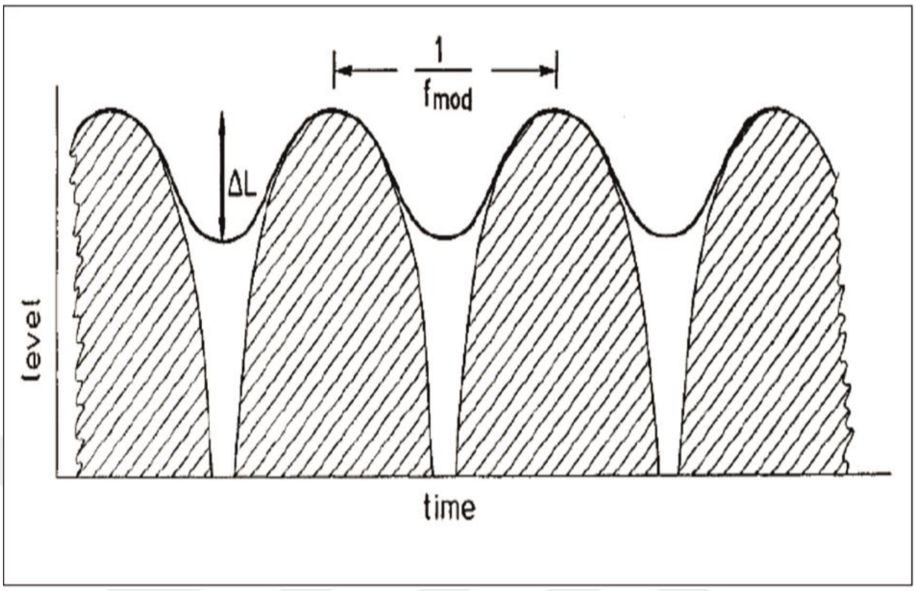

Figure 2.8. Model Fluctuation Strength: Temporal Masking Pattern Of Sinusoidal Amplitude-Modulated Masker Leading To Temporal Masking Depth (**Source.** Fastl and Zwicker, 2006).

Fluctuation strength is used for developing an unbiased annoyance metric (refer to section 2.4). Fluctuation strength is similar to roughness except it quantifies the subjective perception of slower (up to 15Hz) amplitude modulation of a sound. The sensation of fluctuation strength continues up to 15Hz and then the sensation of roughness takes over (Fastl and Zwicker, 2006).

- **Roughness**

Roughness is another important psychoacoustic quantity that quantifies the subjective perception of rapid (15-300 Hz) amplitude modulation of a sound. 'Asper' is the unit of roughness. One asper is defined as the roughness produced by a 1kHz tone of 60dB which is 100% amplitude modulated at 70Hz (Fastl and Zwicker, 2006). Roughness is used for the development of an unbiased annoyance metric (refer to section 2.4). Roughness depends on modulation depth and the sound pressure level. An approximate relationship for roughness is given in Eq. 2-4.

$$R \sim \Delta f_{mod} \text{ .... [Eq. 2-4]}$$

2.5. Methodologies For Evaluation of Noise

There are basically two different approaches to the evaluation of a noisy environment or noise annoyance. They are the Unidimensional Psychophysical Analysis and Multidimensional Psychophysical Analysis evaluation methods. The Unidimensional method establishes relationships between each acoustic factor and perception dimensions. On the other hand the multidimensional method is concerned with various perception dimensions of the noise under investigation. A brief summary of these methods is illustrated in the following sections based on the literature of Marquis et al. (2005) and Kang et al. (2006).

- **Unidimensional Psychophysical Analysis**

According to Marquis et al. (2005), most of the uni-dimensional psychophysical analysis methods are derived from analyses and procedures established in general psychophysics (Stevens, 1951; Torgerson, 1958; Luce and Galanter, 1963; Coombs et al., 1970; Falmagne, 1985). Depending on the measurement methods, there are three classes of Unidimensional psychophysical scale. These are Category Scale, Discrimination Scale and Ratio scales. These are discussed as follows:

Category Scales: This is a classical method of psychophysics in which scaling is universally recognized by scientists for carrying out reliable surveys. This is a relatively quick and reliable approach (Fields, 1996). Verbal or numerical scales are used for the representation of different categories. Fields (1984) concluded that multipoint scales are more dependable when compared to dichotomous measures for evaluation of noise annoyance. Yano et al (1996) demonstrated that the formulation of descriptors ('not at all annoyed', 'a little annoyed'.) is more important compared to the numbers assigned to the descriptor in the category scale. Comparable results were found with category scale having 4, 5, 6 and 7 points. Several studies (have demonstrated that the use of an analog scale, a line with the ends clearly defined is appropriate to collect continuous judgments for unsteady sounds (noise, speech, music, etc.).

Discrimination Scales: The discrimination scale is based on a paired comparison method (Thurstone, 1927b; Baird and Noma, 1978; David, 1988). Two stimuli are compared in pairs in different perception scales in this method. This method generally produces robust results for untrained subjects compared to the category method, given that there is a possibility of confusion generated between scales in the category method (Khan et al., 1996).

Ratio Scales: The ratio estimation method includes the magnitude estimation method and the ratio production method. In the magnitude estimation method, subjects are required to rate a real positive number relative to a reference stimulus such as pink or white noise (Fields, 1996). This method has been used to calibrate different community noises or a combination of several community noises so as to develop a common unit of subjective assessment measurement for comparison of the different noises (Berglund 1981). When no reference is used, the method is known as the absolute magnitude estimation method (Zeitler and Hellbrück, 1999). In the ratio production method a subject adjusts the stimulus (based on his own perception) such that its value is a ratio or a whole part of the reference stimulus.

A combination of different methods has also been used for evaluation of noise annoyance. The Category Partitioning scale method is another kind of uni-dimensional psychophysical scaling method that is a combination of category scales and magnitude estimation methods (Guski, 1997). In this method there are five verbal categories, each of which has ten levels. Subjects are required to give a global evaluation first by choosing a verbal category, followed by a more precise rating - that is choosing one of 10 points in that particular category. Guski (1997) underlines that the method is imprecise on its metric properties.

- Multidimensional Psychophysical Analysis

Multidimensional Analysis***:*** In this method estimation is made of the similarities of pairs of sounds to describe the auditory space of the stimulus (Axelsson et al. 2003, Susini et al. 2001). The dimensions of the space are obtained using a statistical procedure known as multidimensional scaling techniques (Kruskal and Wish, 1978).

2.6. Models For Evaluation Of Noise Annoyance

There are basically three categories of models (specifically used for outdoor; road traffic noise, train noise and aircraft noise) Quantitative Models, Qualitative Models and Psychoacoustics Models. The quantitative models in general, mathematically relate the overall noise annoyance to noise exposure, corresponding annoyance and loudness of each individual noise source. On the other hand, the qualitative models account for the cognitive and perceptual mechanism relating to different noise sources and combine them for an overall annoyance rating. The psychoacoustic models relate the noise perception with different psychoacoustical parameters. A brief summary of these models is found below.

- **Quantitative Models**

As summarized by Marquis et al. (2005), in the Energy Summation Model global noise annoyance is related to the noise levels resulting from the energy summation. In the Independent Effect Model, annoyance is presented as a linear combination of the functions representing the equivalent noise level of each source. The Energy Difference Model presents the overall noise annoyance as the summation of the functions representing the total equivalent noise level and of the difference between the equivalent noise levels of individual sources.

In the Model of Response Summation, a correction factor is added to the equivalent total level (Ollerhead, 1978) to account for the differences in the equivalent noise levels of individual noise sources. In Dominant Source Model, noise annoyance is expressed as the annoyance of the most annoying noise source. In the Summation and Inhibition Model (Powell, 1979), the total annoyance is evaluated according to the total equivalent noise level by a correction factor. The Quantitative Model (Vos, 1992) is in principal very similar to the subjective corrected models, except that the correction factor depends on the equivalent noise level of each individual noise source.

- **Qualitative Models**

As summarized by Marquis et al. (2005), Subjectively Corrected Models use correction factors to approximate the difference in noise perception due to individual noise sources. In the Vector Summation Model, the total annoyance is expressed as the square root of the sum of squares of perceptual variables of an individual noise source (Berglund et al., 1981). In the Structural Equation Model (also known as Path Model), overall noise annoyance is correlated with different non-acoustical factors through simultaneous multiple regression or path analysis.

- **Psycho-acoustical Models**

Sensory Pleasantness Model: This model was developed by Zwicker (please refer to Fastl and Zwicker, 2006) to estimate the pleasantness of a noise by relating perceptual dimension to the relative values of Sharpness (S), Roughness (R), Loudness (N) and Tonality (T). The relative sensory pleasantness, according to Zwicker was defined as:

$$\frac{P}{P_0} = e^{\frac{-0.7R}{R_0}} \; e^{\frac{-10.8S}{S_0}} \left(1.24 - e^{\frac{-2.43T}{T_0}}\right) e^{-\left(0.023\frac{N}{N_0}\right)2} \text{ .... [Eq. 2-5]}$$

Experimental results relating relative pleasantness with relative sharpness, relative roughness, relative loudness and relative tonality are presented in Figure 2.9. As described by Fastl and Zwicker (2006).

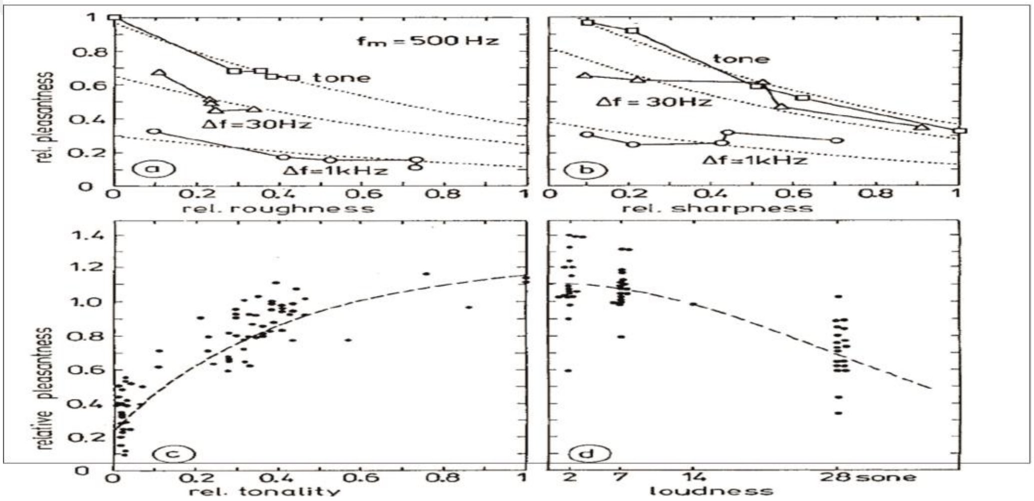

Figure 2.9. Relative Pleasantness As A Function Of Relative Roughness Sharpness Tonality And Loudness (**Source.** Fastl and Zwicker, 2006).

- **Perceived Annoyance Model**

The Psychoacoustics annoyance model was developed by Zwicker (Fastl and Zwicker, 2006) which relates Psychoacoustic Annoyance with five percentile Loudness(N_5), Sharpness(S), Fluctuation Strength (F) and the Roughness (R) of the sound as shown below:

Where, $w_S = \left(\frac{S}{acum} - 1.75\right).0.25lg\left(\frac{N_5}{sone} + 10\right) \; for\, S > 1.75\, acum$ .... [Eq. 2-7]

And $w_{FR} = \frac{2.18}{(N_{5/sone})^{0.4}}\left(0.4\frac{F}{vacil} + 0.6\frac{R}{asper}\right)$ .... [Eq. 2-8]

Eq. 2-6 is used for evaluating psychoacoustic annoyance of synthetic sound as well as sounds like car noise, air conditioner noise, noise from circular saws, drills, etc.

(Fastl and Zwicker, 2006). This model is not widely used, but several examples explain the annoyance behaviour of different transportation noise (Fastl and Zwicker, 2006; More and Davies, 2007).

2.7. Limitations of the Noise Annoyance Evaluation

- **Methods**

From the literature study it is understood that simple energy summation generates poor predictions of noise annoyance while independent effect models and energy difference models provide a better prediction of noise annoyance. Ronnebaum (1996) concluded that the dominant source model provides the best prediction of noise annoyance. However, Izumi (1988) observed that there is no significant difference between these models in predicting overall noise annoyance due to multiple noise sources. The annoyance equivalent model Miedema (2004) has developed (on the basis of energy summation) has resulted in the revision of ISO-1996 which is meant for the measurement and assessment of environmental noise.

However, Jin (2010) noted that it remains unclear about the model's accuracy in predicting global noise annoyance due to multiple noise sources and the suitability of the models for evaluation of the indoor noise environment of residential premises. Maarten (2008) pointed that qualitative research that involves non-acoustical factors are highly inductive and lacks a sound theoretical foundation. Additionally, correlations between noise annoyance and non-acoustical factors might lead to misapprehension as the effect of the factor under consideration is not controlled (Alexandre, 1976).

From the literature review, it was also observed that the inclusion of neighbour noise is missing in the development of overall noise annoyance models. Rather, noise annoyance due to neighbour noise has been investigated in isolation by many authors emphasizing the relationship between noise levels, level of disturbance, audibility, etc. to establish sound isolation requirements (Langdon et al., 1981, 1983; Bodlund, 1985; Rindel et al., 1997, 1999; Jeon et al., 2006).

Jin (2010) found that the neighbour noise annoyance evaluation was not included in the computation of overall indoor noise annoyance in a residential environment. Rather, it was used for the evaluation of individual sound or building elements.

According to Maarten (2008), Stallen's (1999) conceptual model is as of yet the only theory that gives an explanation for noise annoyance. With regards to Psychoacoustical models, Marquis et al. (2005) has pointed out that psycho-acoustical indices have been investigated in laboratory conditions and no research has been made in the psychoacoustical quantities (except loudness) in the field condition or the use of data resulting from field survey. Marquis (2005) emphasized that the evaluation of the indoor aural environment in residential dwellings due to multiple noise source exposure is relatively unstudied and further investigation is required.

2.8. High Rise Living, Tropical Climate And Aural Comfort

While researchers, engineers, planners, architects and politicians have been engaged in the debate on sustainable development, planning of urban areas and green environment, there has been huge interest in initiating high-rise living in the cities (Belinda, 2006). According to city planners, developers and mayors, who took part in the MIPIM 2011 conference, the world's biggest cities are already bursting at the seams but are set to grow even larger. In 1900, around 14% of the world's population lived in cities, by 1950 this had risen to 30% percent and today is about 50%.

Currently, there are more than 400 cities with a population over a million, 19 of which have over 10 million inhabitants. Experts are predicting that about 70% of the world's population will be urban by 2050 (Yahoo News, March 11, 2011). Therefore, the unfolding trend is towards high rise building as the only solution to the housing problems. High-rise housing is being shown in various developed cities (Church and Gale, 2000; Costello, 2005).

In Lagos, Nigeria high-rise housing was constructed to meet the housing shortage due to the land scarcity and increased population growth. A low level of resident satisfaction has been achieved for living in high-rise buildings. The tropical climatic condition in the high-rise urban residential environment demands energy efficient provision of thermal comfort which poses a challenge in the delivery of aural comfort among the high rise dwellers. With the windows left open for natural ventilation, dwellers in the high-rise environment are exposed to relatively high outdoor noise levels in the apartments and aural comfort is compromised. In temperate countries, openings are kept closed for most part of the year to prevent heat loss. In the tropical context, where apartment’s openings in close proximity open for natural ventilation, airborne flanking paths between residential units can significantly compromise sound insulation between apartments.

Owing to the tropical climatic conditions and the high density living in Lagos, and most major tropical cities, achieving high aural comfort and acoustical privacy may be more expensive compared to the temperate zone.

2.9. Theoretical Frame Work

As seen from the literature study, research on the positive evaluation of sound such as aural comfort, is rather limited and nascent. The literature lacks an integrated approach to evaluation of the noise environment. Evaluation of the noise environment, especially noise annoyance is generally based on a subjective or an objective assessment of outdoor transportation noise in isolation. As such, Jin (2010) commented that the suitability of the established noise annoyance models for evaluation of the indoor noise environment of residential premises is in question.

Additionally, the established noise annoyance models did not include neighbour noise in their evaluation framework for the computation of overall noise annoyance. Moreover, psychoacoustical quantities have never been included in the noise annoyance models for defining perceptual dimensions in a residential context.

Based on the above arguments, a holistic approach is required for the integration of the perceptual dimension of noise and its quantitative aspects for assessment of aural comfort in a high-rise residential dwelling. As discussed earlier, Maarten (2008) found that Stallen's (1999) conceptual model is the only theory that gives an explanation for noise annoyance.

The use of such a theoretical framework for the assessment of aural comfort (or discomfort) has never been applied in research. A sound theoretical basis is therefore indispensable for a psychophysical explanation of evaluation of comfort and development of an aural comfort model. The figure below shows different comforts for high-rise apartment buildings in Nigeria.

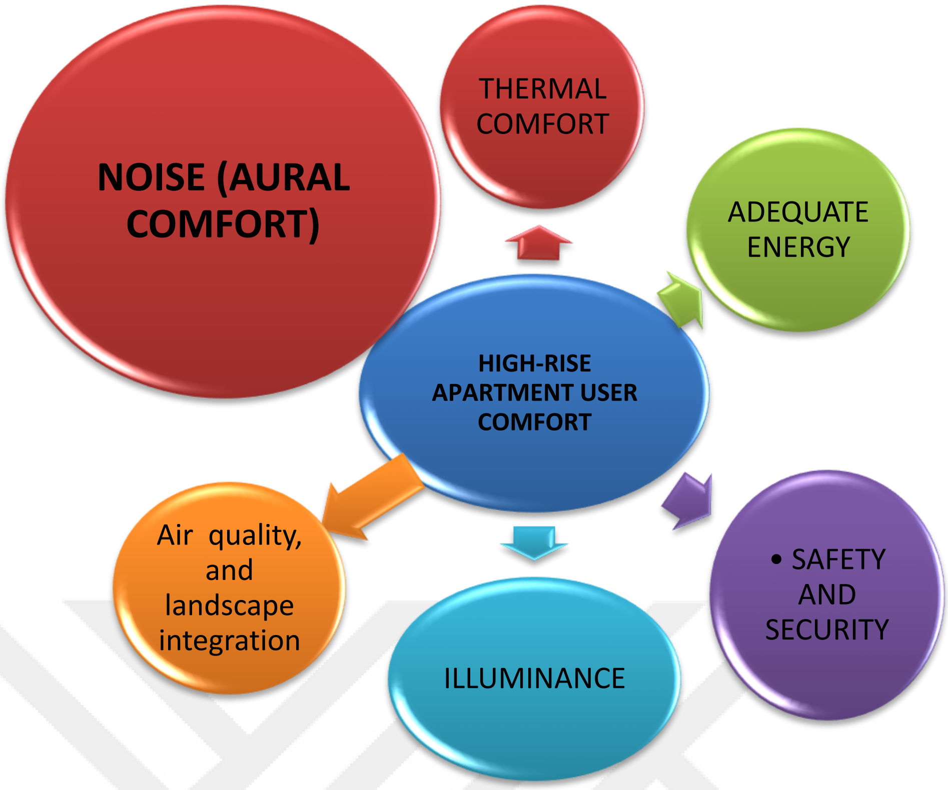

Figure 2.10. Theoretical Frame Work (**Source.** Author, 2017).

Apart from the issues discussed above, indoor noise evaluation in high-rise residential living condition in the tropical climatic environment is absent in the literature on noise annoyance evaluation. The context of this research is Nigeria precisely Lagos, having a tropical climatic condition and more than 82% of the resident population living in the naturally ventilated high-rise public housing apartment. The provision of windows at high-rise building façade is a key bio-climatic building design criterion for natural ventilations in Nigeria, precisely Lagos.

As previously mentioned, these high-rise apartments are located in close proximity (between 5m and 25 m) to different transportation noise sources (e.g. Road and train), community noise sources (playground, foodcentre, etc.) and subjected to neighbour noise due to its high-rise living. As a result the tropical climatic condition and high-rise living condition make the context of the aural comfort study more complicated, which has never been addressed before and must be re-defined.

This study will therefore be useful in expanding knowledge for planning, design and development of new residential estates and high-rise buildings and to ensure aural comfort for occupants of high rise apartments in tropical countries like Nigeria.

2.10. Retrofitting Walls and Partitions to Improve Acoustic Properties

Building components and materials have acoustic properties to some extent in which they absorb, reflect or transmit sound that falls on their surfaces. However, specially designed acoustic materials and components have a higher degree of reflecting, absorbing or transmitting sound because they are purposely designed for such quality. Retrofitting buildings in order to improve the acoustic properties can be done on various building components such as walls, floors, ceilings and so on. There will be no need to make demolitions in order to improve the acoustic properties of a building element, all is needed is the addition of high acoustic layer on the surface. This layer can either reflect, absorb or transmit sound. The figure below shows how an acoustic wall panel reflects sound.

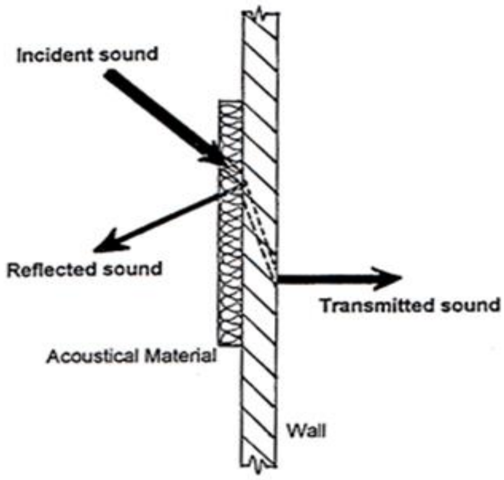

Figure 2.11. Acoustic Wall Panels Reflecting Sound (**Source.** Author, 2017).

2.11. Conceptual Frame Work

From the literature study and preliminary investigation, it is established that several acoustical and non-acoustical factors influence the assessment of the aural environment. For the development of an aural comfort model, acoustical factors are further evaluated through an objective assessment approach, whereas non-acoustical factors are evaluated through 'Attitude' evaluation (explained by both Stallen's (1999) noise annoyance theory and Eagly and Chaiken's (1993) ERM model). The aural comfort evaluation framework is structured based on the fundamental process of controlling environmental disturbance to achieve a level of comfort as demonstrated by Dean (1982) in Figure 2.11.

The 'Subjective assessment' of the aural comfort is fundamentally the assessment of the 'attitude' response of the individuals towards the aural environment they are exposed in their dwellings. According to Eagly and Chaiken (1993), an individual’s attitude towards this noisy environment is an evaluative process which is founded on several psychological and physiological variables that determine the individual's state of aural comfort.

The fundamental components of an individual’s attitude towards the noise environment include cognitive responses (thoughts importance of noise in the living environment) to noise, affective responses (feeling noisiness of the apartment, noisiest time of the day, noise sensitivity, perceived disturbance due to noise) to noise and behavioral responses (adaptive behaviors - likeliness of closing doors, windows, etc.) to noise.

It is only possible to understand the 'experience' of the dweller's aural comfort condition through such an integrated evaluation approach. Once such 'acoustical experience' is defined through acoustical and non-acoustical factors, an aural comfort assessment model can be developed.

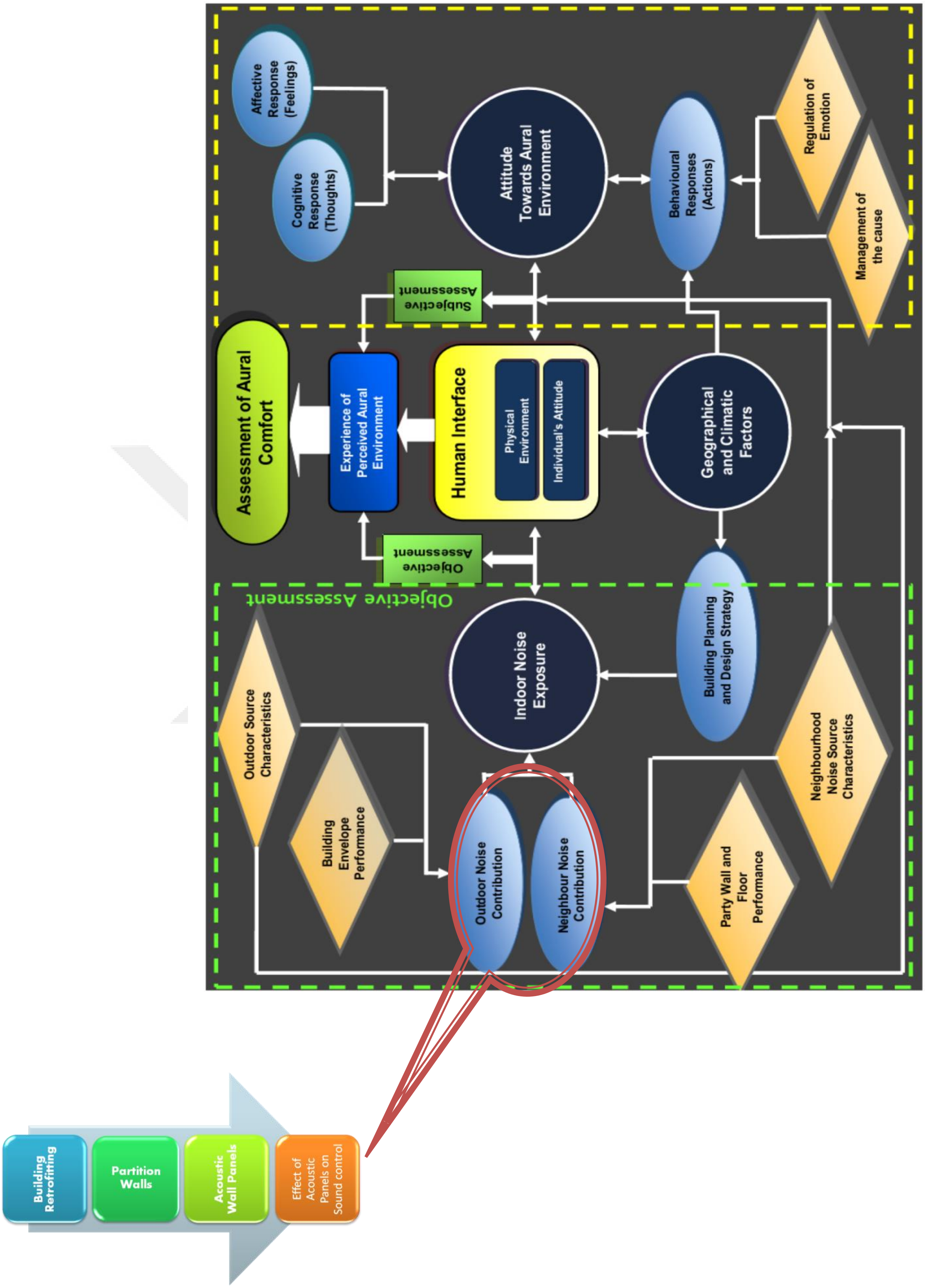

Figure 2.12. Proposed Conceptual Framework For The Aural Comfort Assessment (**Source.** Author, 2017).

In summary the evaluation of a noisy environment, especially noise annoyance is generally based on a subjective or an objective assessment of outdoor transportation noise in isolation. As Jin (2010) pointed out, suitability of the established noise annoyance models for the evaluation of an indoor noise environment of residential premises is in question. Moreover, psychoacoustical quantities have never been included in the noise annoyance models for defining perceptual dimensions in a residential context (Marquis, 2005). Based on the above arguments, a holistic approach is required for the integration of the perceptual dimension of noise and its quantitative aspects for the assessment of aural comfort in a high-rise residential dwelling. Additionally, the use of a theoretical framework for the assessment of aural comfort (or discomfort) has never been studied.

Apart from the issues discussed above, indoor noise evaluation in high-rise residential living condition in the tropical climatic environment is absent in the literature on noise annoyance evaluation. As a result, aural comfort in the tropical climate high-rise living condition which has never been addressed before is in need of investigation. The table below shows the list of acoustical panels that were considered to be very effective in sound absorption.

Table 2.3. Composition Of Simulated Wall Types; (Cibse, 2007)

Frequency (Hz)	**Block walls**	**MDF Panel**	**HDF panel**	**Fibre Glass**	**V-groove**	**KNP mounting Panel**
Frequency (Hz)	**Sound absorption c.**	**Sound absorption c.**	**Sound absorption c.**	**Sound absorption c.**	**Sound absorption c.**	**Sound absorption c.**
125	0.71	0.501	0.370	0.369	0.221	0.155
250	0.90	0.890	0.839	0.705	0.435	0.306
500	1.009	0.999	0.888	0.791	0.502	0.435
750	1.208	0.908	0.839	0.750	0.359	0.346
1000	1.840	0.840	0.816	0.640	0.265	0.137
1500	1.750	0.750	0.705	0.330	0.157	0.050
2000	2.437	0.437	0.305	0.210	0.053	0.020

Summary of Sound Absorption Coefficients of variables 1 to 6

This chapter discussed various relevant studies were reviewed, high-rise buildings were explained and why noise is a priority problem in these structures. Secondly, the factors, methodologies and models for evaluation of noise was discussed in order to establish a standard of noise evaluation for this research. Thirdly, various ways for retrofitting walls in order to improve their acoustic performance were discussed. Lastly, conceptual framework for this study was established for proper understanding of the direction of this research. All these information are based on the previous researches and studies. The next chapter will discuss the process and procedure for gathering data/information for this research.

CHAPTER 3

CASE STUDY: TWO RESIDENTIAL BUILDINGS IN NIGERIA

Having identified the scope and objectives of the study, it is necessary to follow an appropriate research methodology which refers to a set of methods. In this study, various research methods have been chosen to suit the different aspects of the research. This chapter provides information on how the research was conducted in order to achieve the research aim and objectives presented section 1.3. It covers the research strategy, design and method adopted for this dissertation thereby contextualizing the methodology and justifying their use as compared to alternative ones. Other issues discussed in this chapter include reliability, replicability, validity, ethical issues, limitations and a reflection on how the negative effect of these is minimized in the research process.

Figure 3.1 shows the overall research methodology adopted for the research. It shows the context, research aim, research strategy, research design, research methods and analysis adopted for the study. Different methods have different strengths and weakness; however, using a range of methods can produce a more complete picture (Gillham, 2008). Further, a multi-method approach has the potential of enriching, as well as cross validating research findings. The research methods which have been practiced in this study are explained below.

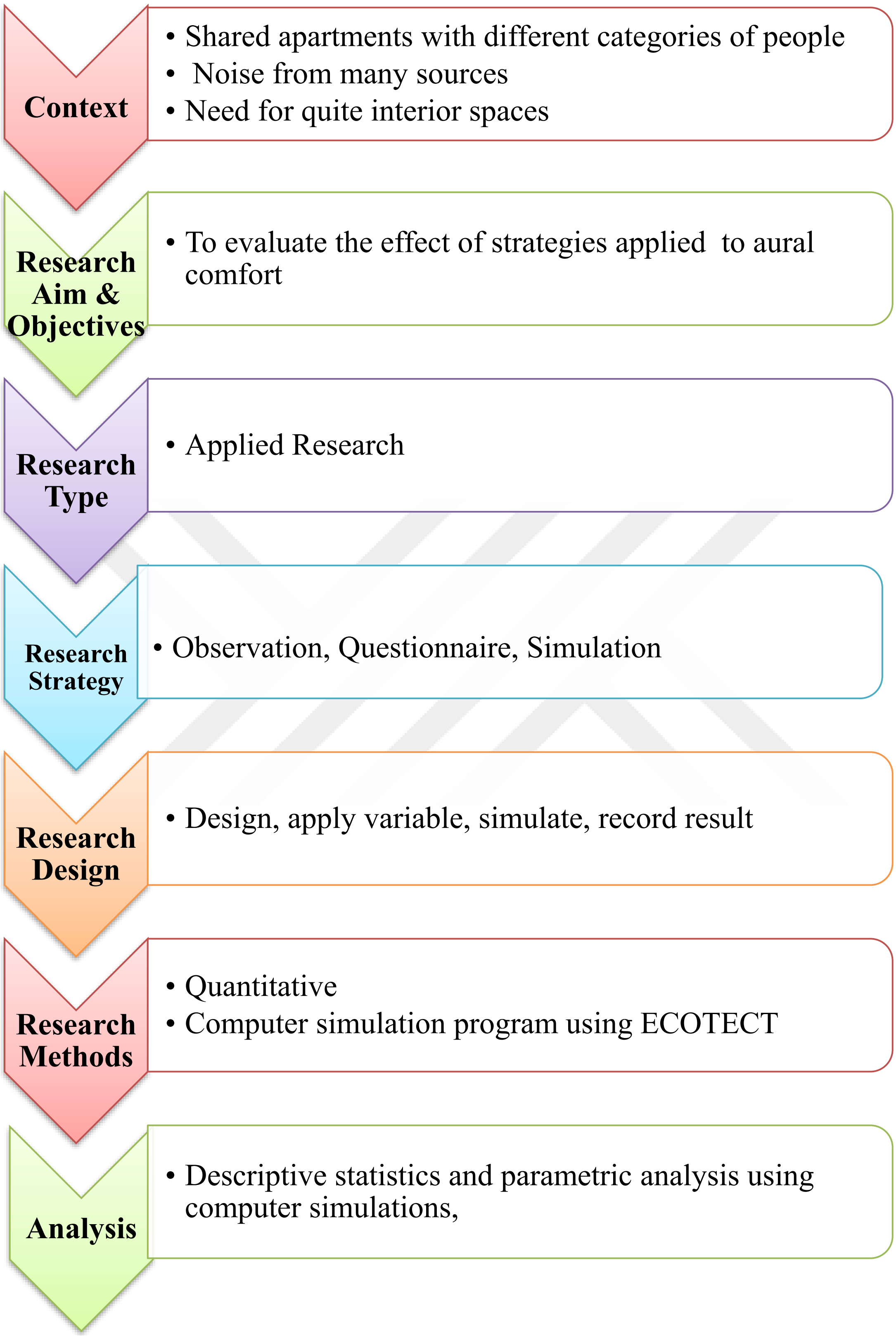

Figure 3.1. Overall Research Methodology Context (**Source.** Author, 2017).

3.1. Research Design

This research adopts an exploratory, and experimental approach to frame the answers to its research aim and objectives. These approaches are classified by (Gliner, Morgan, & Leech, 2000)) who divided research design into:

1.) Exploratory (user perception)

2.) Descriptive (Case studies)

3.) Experimental (Simulation)

Face-to-face and paper methods, questionnaires were practiced as a main tool to examine the indoor environment conditions in the case study selected buildings. Data related to building's locations, their surroundings, and construction materials are gathered through the fieldwork. In addition, indoor observation took place to get close data, such as cooling method used, internal wall colours, e.t.c. which are crucial input data for the computer model. A clear determination for the tasks, the sequence of procedures and the survey materials were essential in order to carry out the field work with the least effort and at the determined time. The importance of the timing of this survey is vital due to the fact that this survey is concerned with indoor conditions. The fieldwork was conducted in two stages discussed below in Figure 3.2.

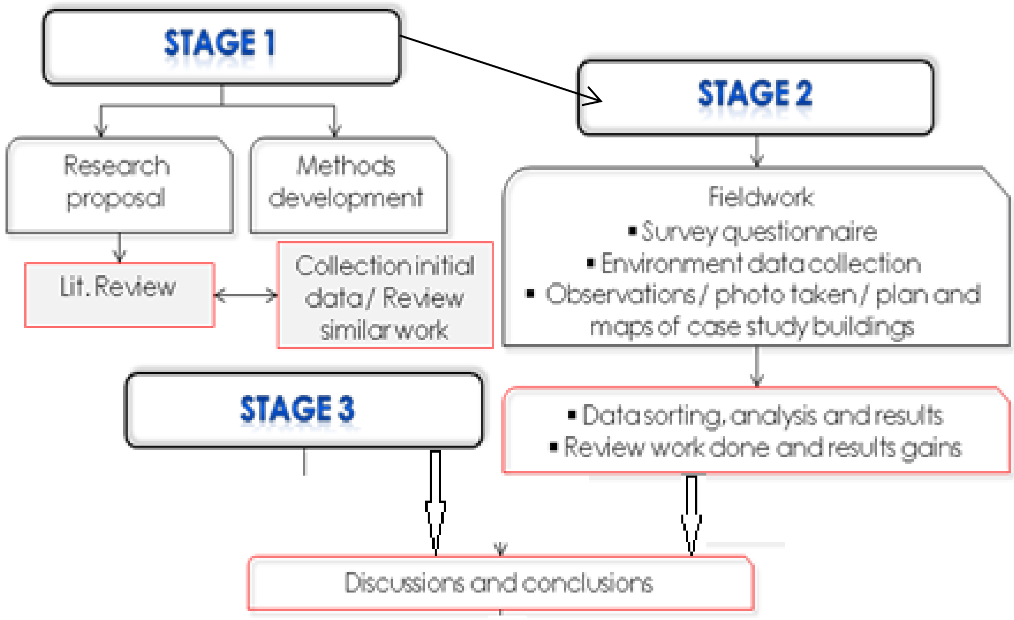

Figure 3.2. Fieldwork Flow Diagram (**Source.** Author, 2017).

3.2. Selection Of Case Study Method

According to Yin (2004), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context using multiple sources of evidences. A case study approach provides a mode of inquiry for an in-depth examination of a phenomenon. The method of study for this research involves a quantitative analysis of cases purposively selected and simulation.

Therefore, this research adapted the use questionnaire survey and archival documentation as a source of data within the case studies, in examining the opinion of the householder about the level of aural comfort in their respective apartments.

3.3. Case Study Data Collection

In order to gather adequate data for analysis and also to avoid biased result, various strategies were applied in order to make effective data gathering from the case study. These data that are presented in Figure 3.3 had a large influence on the results, so in Ecotect simulation when source and position of sound were so essential part in this research. Table 3.1 summarizes the work done and data gathered of the 2 case study buildings while the researcher was in field experimental work. Data was collected through three stages, the 3 stages are physical properties of the case study buildings, aural comfort and user behavior by using the planning questionnaire.

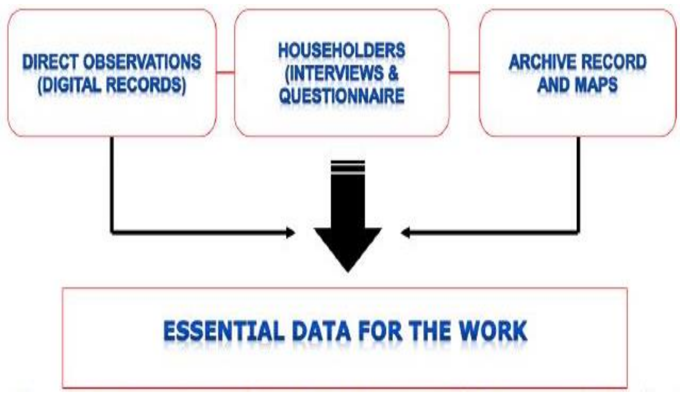

Figure 3.3. The Three Stages Of Data Collection Through A Field Trip (**Source.** Author, 2017).

- **Population of the study**

Population of study comprises the totality of all subjects that have a set of specifications and characteristics that are of interest to the researcher and to whom the research results can be generalised (Polit and Hungler, 1999). The research population for this study involved high-rise apartment buildings selected from Lagos, Nigeria.

- **Sampling**

Sampling is a process of selecting population on which instruments of collecting data will be applied to them (LoBiondo-Wood and Haber, 2006). For the purpose of this research, a non-probability sampling was used and the selection was purposive were two high-rise apartments were selected after careful consideration and due to particular interest for the study. This research involves the use of both qualitative and quantitative research, purposive sampling method is adopted and this will involve the purposive selection of the cases that falls within Lagos, Nigeria. The two case studies selected are:

1.) 1004 ESTATE - VICTORIA ISLAND, LAGOS.

2.) C & N LUXURY APARTMENTS – IKOYI, LAGOS

The reason why the case studies were selected was there are numerous high rise apartments in Lagos, all but a few are mixed used which means that they are residential apartments mixed with commercial institutional or corporate functions. The only two high-rise residential apartments that are purely residence are 1004 Estate - Victoria Island and C & N Luxury Apartments – Ikoyi, Lagos in which data (inputs) could be carried out easily from the building and who granted permission to carry out the survey from facility managers while others didn't permit due to security reasons. This is research is only limited to acoustics in high-rise apartments and hence the selection of the above case studies.

- **Instrument of Data Collection**

Case study for theoretical research in architecture may require the use of general methods of data collection (Oluigbo, 2010). Meanwhile, various sources were selected for this research which were highly harmonising.

For case studies approach, it is important to use as many instruments of data collection. The tools or instrument of data collection to be used are;

1.) Measured drawings

2.) Visual survey

3.) Questionnaires

4.) Simulation of the case studies selected

3.4. Questionnaire Design Process

Prior to the actual evaluation process, a questionnaire was designed and tested for clarity and applicability through a pilot study conducted with some occupants who have experience in survey design. Figure 3.4 shows the steps of developing the questionnaire questions which is clearly a linear plan but is also an iterative process.

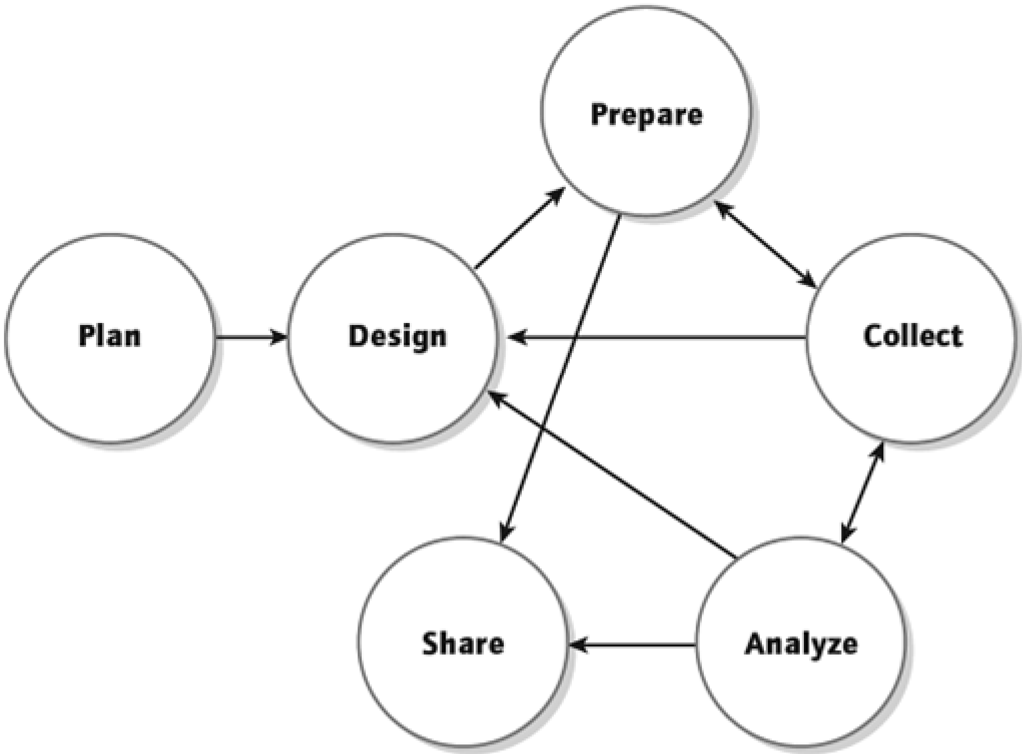

Figure 3.4. Process Of Case Study Questionnaire **(Source.** Author, 2017).

3.5. Questionnaire Layout

First of all, to make it easier for the respondent to understand the general questions, it is classified into a logically coherent section. This will make the questionnaire more readable and easy to observe. In addition to that, grouping the similar questions together will make them easy for the respondent to complete the questionnaire. Furthermore, the transition between questions should be smooth. Such points will have a great impact on response rate (WALONICK 2010).

Taken into account that some aspects could affect questions "arrangements", such as bringing the difficult and more specific questions at the top of the questionnaire might drop the response rate and instead of that an attempt has been made to go through the questions from general to particular and from easy to difficult.

Moreover, even when listing the questions, it would be more convenient for the respondents to fill in closed questions rather than open-ended ones. Considering the points above this questionnaire has been designed with divided sections and sub-headings, starting from the easy and more general questions toward the more specific and deeper questions. The main headings of the sections are as follows:

1.) Introduction (cover letter) includes researcher's information and aims of this survey,

2.) Occupants general information (Demography)

3.) Flat information,

4.) Respondents perception of Aural Comfort,

3.5.1. The Pilot Study

Accordingly, before the survey was carried out, the researcher piloted 15 copies of the questionnaire and the respondents were the occupants living in the chosen residential high-rise buildings.

The aim of the pilot survey was to test the questionnaire and to identify the inevitable problems of converting the questionnaire design into reality. This involved comments about the language, suggested modifications to the questions and additional questions as well as obtaining experience of certain aspects of the survey. The pilot survey sample amounted to 5% - 10% of the actual sample studied later.

The analyses of comments obtained from the reviewers have been very helpful for improving the design of the questionnaire.

The following modifications were made to the field study.

Some important questions had been added after reviewing what else the occupants think is important for their comfort; the design, form and structure of some questions were also changed;

1.) The pilot survey led to changes in the wording of some questions;

2.) The length of some questions was found to be undesirable;

3.) To reveal weaknesses in the questions posed in order to improve their effectiveness;

4.) Order of questions. Useful conclusions were also drawn about the survey procedures and the time needed to conduct the survey.

3.5.2. Procedure For Administration of Questionnaire

The 120 questionnaires were distributed equally in two apartment buildings. The Researcher and two other persons distributed 60 questionnaires at 1004 Apartments and another 60 questionnaires at C & N apartments randomly on 15th march 2017 and 17th March 2017 respectively. Making sure that each floor and each wing of the building got a respondent. This is to eliminate bias in distributing the questionnaire and to also get a full representation of the entire population by 60 samples on both case studies. Two days later, the questionnaires were collected from all the respondents, however 6 respondents were not around. Attempts were made to contact the respondents, but only 2 more questionnaires were gotten back. This makes it that 116 questionnaires were filled and 4 questionnaires were missing.

Among the challenges encountered in the fieldwork was the difficulty of a number of occupants, to respond to the questionnaire, even by making it easy and interesting to answer, and survey team had to make many visits to some flats in order to help the occupants to fill in the questionnaire. Some occupants were not welcoming, the observation process where one of the team members named Ayisha Mamud, had to review the finishes in those apartments, which not everyone allows access into their private rooms because of security and privacy reasons.

Table 3.1. Summarizes Some Basic Characteristics Of The 2 High-Rise Buildings (**Source.** Author, 2017).

Case study buildings	
Number of building	2 blocks
Buildings mode	mixed-mode & natural Ventilation
Avg. occupancy/flat	6 individual
Avg. building age	20 years
Avg. building floor area per storey	410 m²
Avg. floor area per person	30 individual
Number of survey sent out	120
Number of survey respondents	116
Avg. response rate	97%

The average response rate was 77.1%, where it was higher in some cases and normal in some others but never was low at any cases. People's response to the survey was in general good. Furthermore, as stated earlier in this research that this subject of aural comfort is new for people in the case study area so data on 9 copies were incorrect, and people showed misunderstanding of some questions despite they have been given an explanation and answers from the survey team. In the case of collecting the questionnaire, 42 cases were not in their homes and even with many attempts to reach the occupants the survey team had not succeeded to do so.

3.5.3 Visual Observations

Observation is a technique of data collection in which the situation or the behaviour of research subjects is watched and recorded without any direct contact (Bryman, 2005). This method is used in this study as first hand information about the features and site layout, forms, construction materials, and social issues. The information on these features has not been gathered only since the beginning of this research, but also through living in the case study city for many years. All of these data helped in formulating and defining the problem with this study.

In addition, these data drew a clear picture about the studied buildings and also helped in choosing the case studies buildings besides playing an essential role to find the most appropriate and possible solutions from architecture view.

Table 3.2. Information Needed To Be Collected And Their Purpose
(**Source.** Author, 2017).

Information to be collected	Methods of collecting	Aims and purposes
A. Physical properties		
1. Physical size of the building and its flats.	Drawings from the building's management personnel	To find out the building's area and surface area in order to know the amount of exposure on the building
2. Type of building material	Physical observation.	To determine the different types of materials used in order to estimate the building's performance.
3. Building's orientation	Drawings from the building's management personnel	To measure the average of apartments exposure to outside sources of noise.
4. Spaces and zones of the flat	Plans and questionnaire	To measure the average of apartments exposure to outside sources of noise
B. Aural comfort and user behavior		
1. Number of occupants	From the questionnaire.	To measure the noise level with respect to their level of comfort.
2. Level of comfort	From the questionnaire.	To find out the relation between the family size and the noise beside the comfort level.
3. User's behavior towards using windows and balconies	From the questionnaire.	To see the level of using the windows that allow the passage of outside noise
4. Source of noise from the neighboring apartments	From the questionnaire and observation.	To know whether wall partitions are good enough in absorbing sound

3.6. Building Simulation Software

The most popular and advanced simulation software that can be used for this type of analysis for these buildings are the following: DISIA, I-SIMPA and ECOTECT.

3.6.1. Selecting Analysis Computer Programs

In order to select an effective acoustic simulation software three softwares namely, DISIA, I-SIMPA and ECOTECT were selected and compared in the following table 3.3. From the table it can be shown that ECOTECT is more preferable to use for this simulation.

Table 3.3. Comparison Between Various Sound Simulation Softwares

Criteria	**DISIA**	**I-SIMPA**	**ECOTECT**
Developer	Angelo Farina	Nicolas Fortin	Square 1
Inputs	AutoCAD	3DS format	All formats, ability to create a form
Outputs	Counter map DXF	Graphical visualization Image export	1.) Text 2.) Charts 3.) Graphical visualization 4.) Image export
Graphic User interface (GUI)	Sophisticated	Features easily accessible	Self-learning GUI Customizable GUI
Weather data	None	Monthly	Hourly
User customized	None	None	Yes Easily customizable
Cost	Not for sale	Free	$1500
Availability for Academic research	For academic use only	Free	Yes
Language	ITALY	English	English
		Late lateral sound	Visualisation of sound Statistical Reverberation Sprayed Acoustic Rays Animated Sound particles Reflector Coverage

(**Source**: i-simpa, 2017, AcoustiicBulletin, 2017).

- **Advantages Of Ecotect As A Simulation Software**

The ECOTECT is a software that integrates architectural representation of building and simulation inputs for analysis. It is primarily aimed for architects and is intended for use during the early, most conceptual stages of design. ECOTECT has various analysis options from lighting, thermal comfort, acoustics to energy efficiency analysis. ECOTECT's tool related to acoustics can be found under the analysis tab in the interface of the ECOTECT. (Roberts 2014).

3.6.2 Ecotect Acoustic Simulation

Autodesk's ECOTECT is an analysis software for buildings that gives an easy assessment of design and work in 3D which is easier for architects to use. ECOTECT has various analysis options from lighting, thermal comfort, acoustics to energy efficiency analysis. ECOTECT's tool related to acoustics can be found under the analysis tab in the interface of the ECOTECT as shown in Figure 4.28. Since this research deals with improving acoustic response buildings results from this tool will be described in this section.

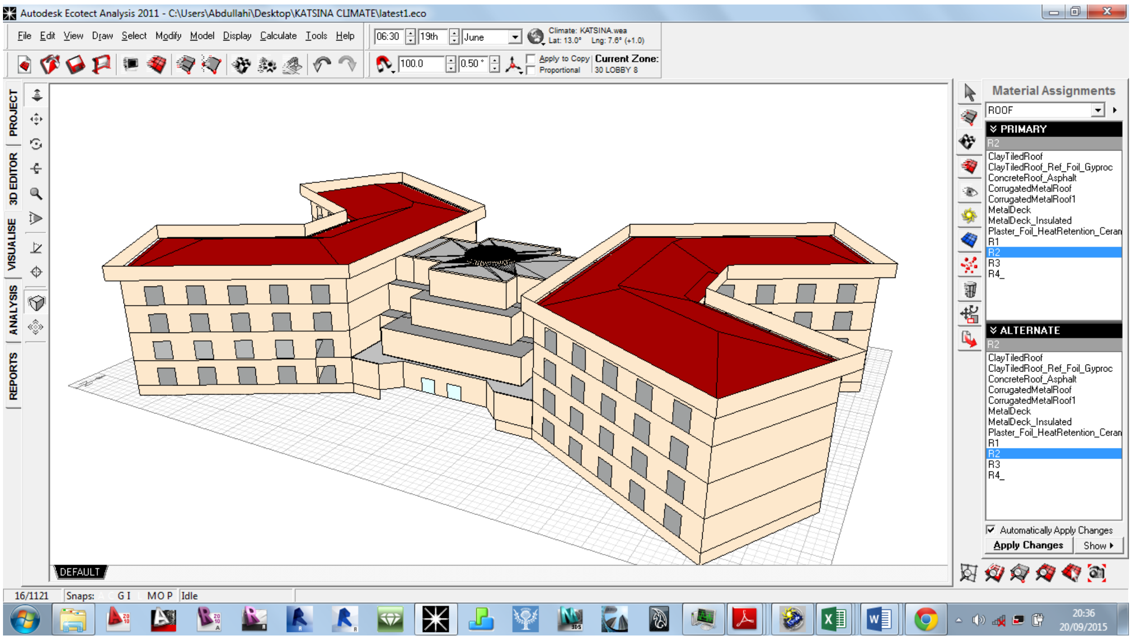

Figure 3.5 Interface Of Autodesk ECOTECT (**Source.** Author, 2017).

- **Dependent and Independent Variables**

The dependent variables predicted are aural comfort which is the level of noise within a room with a source from outside and is measured in Decibel (db). The independent variables examined are various acoustic panels with different sound absorption properties that can be used in retrofitting the high-rise apartment buildings. The details of the components of each Independent variables are in the Appendix of this research dissertation. These variables are examined as part of the process of creating a suitable base-case on which to test the performance of Dependent variables.

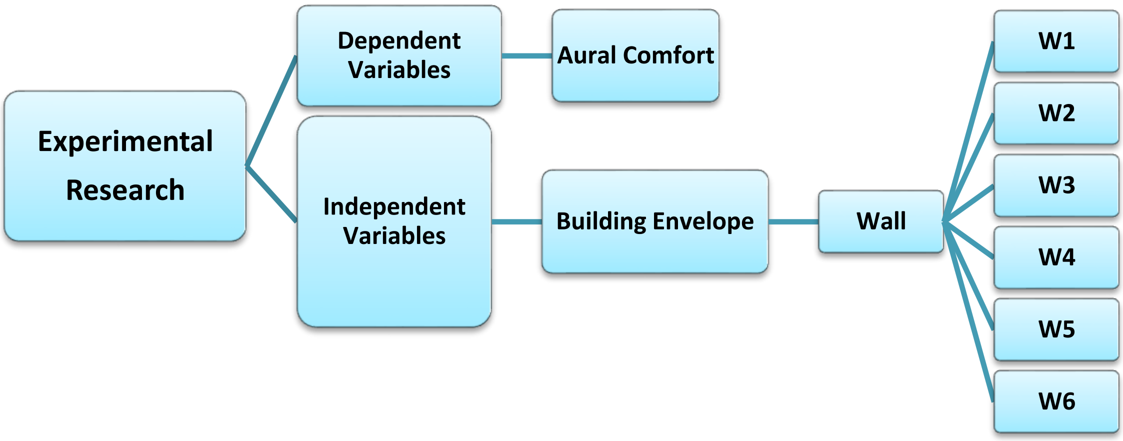

Figure 3.6. Dependent And Independent Variables (**Source.** Author, 2017).

The simulation runs on also, it is important to note that W1 is the common walling materials used building construction in Nigeria and these surfaces are used as a base-case model. The other coded materials are built up in order to get a better material that allows less sound transfer through external and internal layers of one complete surface of the wall. Table (3.4) provides the proposed acoustic panels with different sound absorption properties.

Table 3.4. Composition Of Simulated Wall Types; (CIBSE, 2007) Summary Of Sound Absorption Coefficients Calculations Of Variables 1 To 6

Frequency (Hz)	W1	W 2	W 3	W 4	W 5	W 6
125	0.71	0.501	0.370	0.369	0.221	0.155
250	0.90	0.890	0.839	0.705	0.435	0.306
500	1.009	0.999	0.888	0.791	0.502	0.435
750	1.208	0.908	0.839	0.750	0.359	0.346
1000	1.840	0.840	0.816	0.640	0.265	0.137
1500	1.750	0.750	0.705	0.330	0.157	0.050
2000	2.437	0.437	0.305	0.210	0.053	0.020

3.7. Analysis

- **Parametric analysis with computer simulations**

The aim of the parametric analysis is to observe the response following a modification in a variable. Parametric analyses are conducted in order to determine the effect of various parameters on a research (Hamby, 1994);

The parametric analysis is used to examine the consequence of changing a given independent variable on aural comfort using computer simulations. Figure 3.7 describes the process of parametric analysis conducted. The steps are:

1.) Define the model, its independent and dependent variables. This includes defining the sound properties as discussed in the previous Section.

2.) Vary the values of each independent variable one at a time, in a rational and incremental manner using the whole building acoustic calculation software Ecotect.

3.) Record the corresponding value of the dependent variable

4.) Assess and compare the influences of each input/output relationship through statistical methods

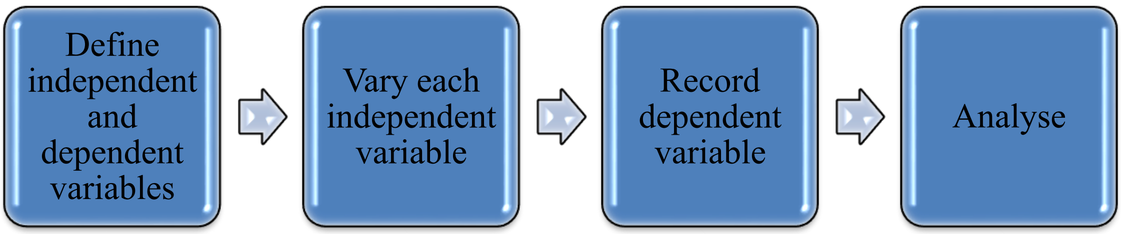

Figure 3.7. Parametric Analysis Procedure (**Source.** Author, 2017).

This chapter discussed the methodology used in this thesis. Firstly the questionnaire survey is used to establish the existence of the noise problem as well as the possible sources of the noise. This was achieved by obtaining response (information) from the occupants of the case study buildings. Secondly, the simulation provided a basis for selecting the most suitable walling component material (acoustic panels) for the solution of the noise problem as this research was limited to the improving the acoustic performance the walls in high-rise residential apartment buildings. These are by first, identifying the method of this research, followed by identifying the variables of this research and finally how the result will be analysed. The next chapter will present the discussion of results from the case studies and simulation conducted.

CHAPTER 4
RESULT AND DATA ANALYSIS

In order to gain actual statistical data of the case study building's a survey was carried out to collect this information. The first survey was used to gather information on the noise in high-rise apartment buildings studied. Secondly, case studies were modelled and the simulation of some acoustic panels was conducted to find the effect panel in improving acoustic response in high-rise apartment buildings. The survey was conducted on 120 samples in 2 buildings located in the city centre of Lagos. Other general information was collected by observation during the survey time, including information such as heights, areas and construction materials, all of which was useful in drawing a clear background about the studied buildings. The data collected during the fieldwork was sorted out in Spearman rank correlation coefficient and Revit Architecture (Ecotect) drawings in order to be used as input data for the acoustic simulation computer modelling.

This information was also used as essential parameters in analyzing indoor environmental conditions and in drawing a sample for acoustic simulation. The first section of the questionnaire was utilized to gather general data which comprised the flat's area, number of rooms and number of occupants and families. Besides, the construction materials used in the flats were observed, along with exploring the integration of partitions in these buildings. The results and findings are provided in the following subsections. The figure 4.1 shows the process of analysis of the 3 instruments of data collection for this research.

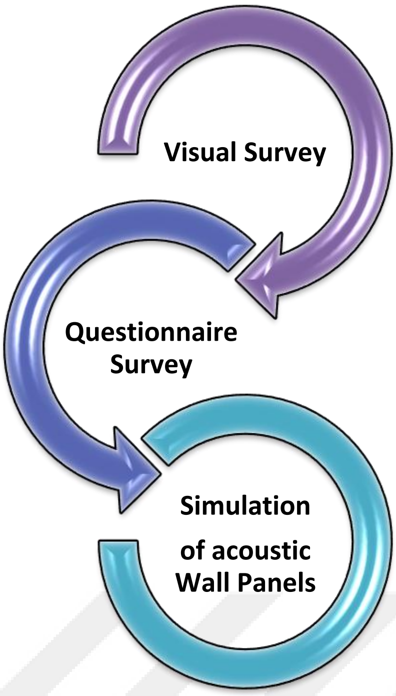

Figure 4.1. Process Of Data Analysis (**Source.** Author, 2017).

4.1. Analysis of Visual Survey

4.1.1. Case Study 1 : 1004 Estate - Victoria Island, Lagos.

The selection of high-rise residential apartment in Lagos is due to the characteristics which the building possess, which correlates with the research topic under review each floor level has apartments, which has separating wall that allows the proper investigation of acoustic level within the building. Other research variables for the choice of selecting the cases includes its number of floors which also enables researchers to determine the extent of the flanking path for sound and the general perception of noise by occupants within the building.

Figure 4.2. Overview Of The High-Rise/ Low-Rise Residential Blocks At 1004 Estate (**Source.** Author, 2017).

The 1004 estate was one of the first typical experiments of high-rise upscale residential building in Lagos, Nigeria, which was commissioned after completion in 1979, during which Lagos was the seat of the Nigerian Government. It was built to accommodate the legislators and personnel from the house of representatives, as time goes by the structure was later possessed by the senior Federal civil servant until a private consortium known as the 1004 Estates Limited in 2007 took over the property and enhanced its status. Immediate stripping and revamp of the Estate commenced after the takeover, a massive update and changes in the facilities was carried out to meet with the requirements of a modern high-rise residential building. The estate has over 1000 flats arranged in four clusters of same prototype. Further breakdown shows that the estate has 6 high-rise buildings and 33 low-rise buildings.

It also has a well defined and dedicated sewage treatment plant, which has a capacity of 250 cubic meters per hour and a central power plant of 10 megawatts capacity. It also has an enclosed neighbourhood centre which consists of a gym, clubhouse and a swimming pool. The lawn tennis/basketball court is situated close to the clubhouse to complement the recreational facilities. There are also landscape verges, common open spaces, and pedestrian walkways across the clusters and parking (see figure below)

Figure 4.3. General Overview Of The High-Rise/ Low-Rise Residential Blocks At 1004 Estate (**Source.** Author, 2017).

The Flat ranges from 2, 3 and 6 bedroom apartments, with dedicated internal spaces which includes the kitchen, main lounge, dining area, bedrooms and a terrace. Other support spaces within the building complex includes two centrally positioned elevators, escape stairs at both ends of the building (see figure 4.3 below)

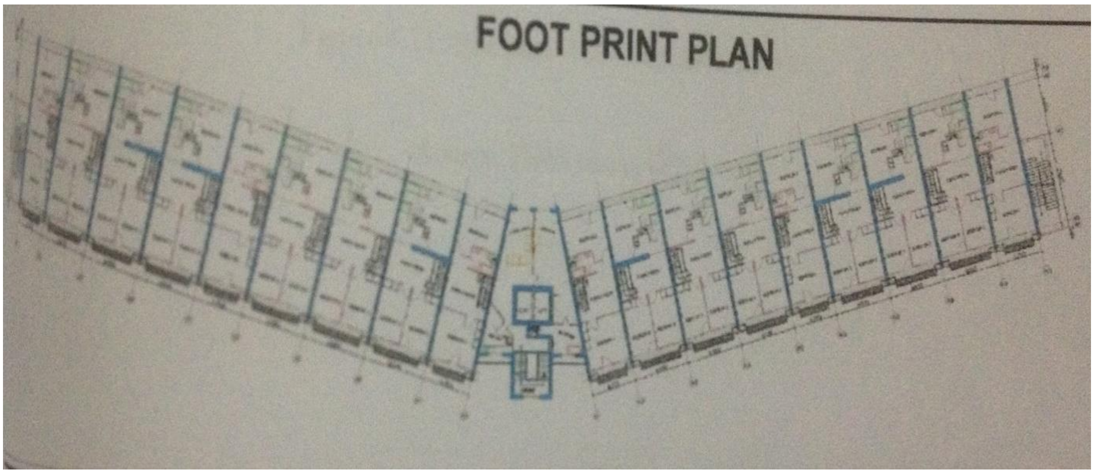

Figure 4.4. Typical Floor Plan Layout Of The High-Rise Complex, 1004 Estate (**Source.** Author, 2017).

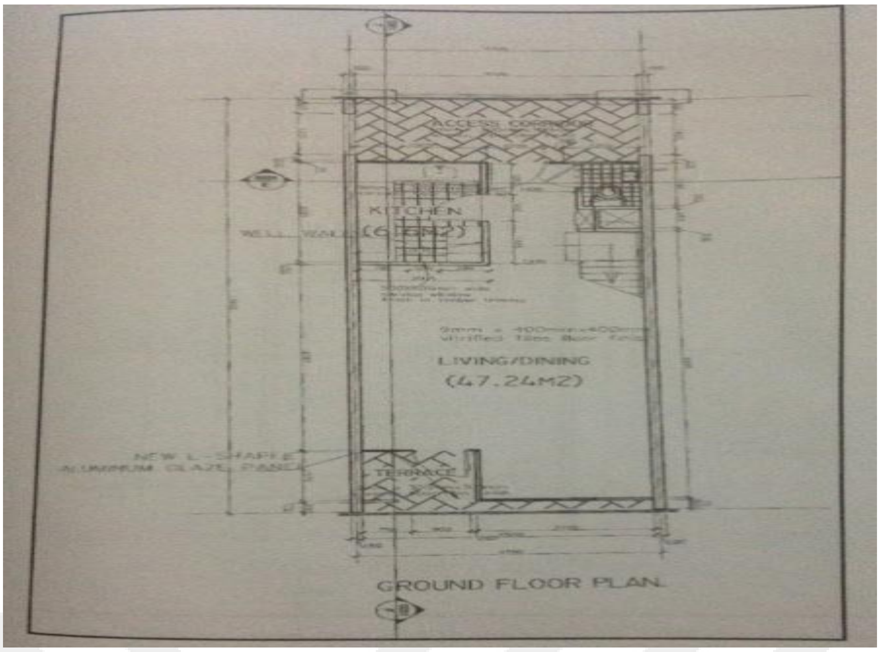

Figure 4.5 Typical Ground Floor Plan Of A 2 Bedroom Flat At 1004 Estate (**Source.** Author, 2017).

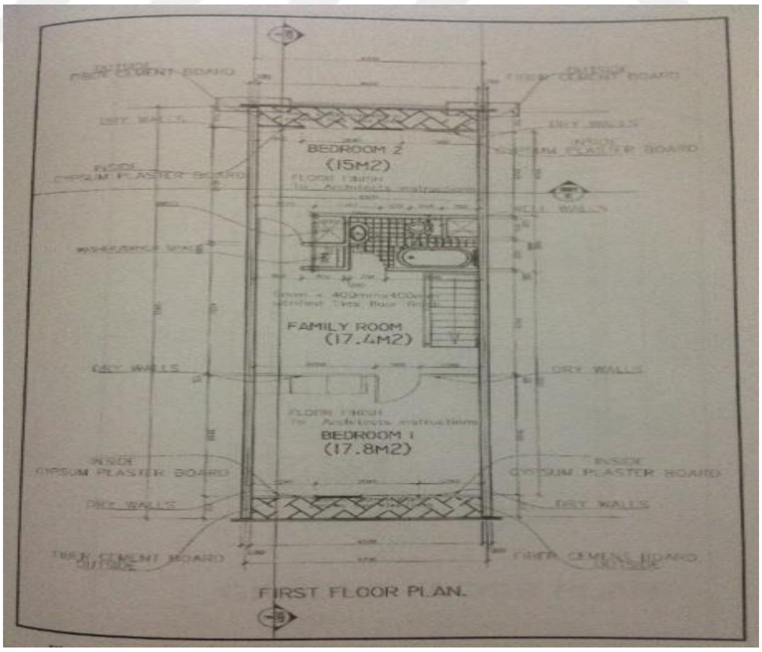

Figure 4.6. Typical First Floor Plan Of The 2 Bedroom Flat At 1004 Estate (**Source.** Author, 2017).

The floor plans as shown above has a minimal amount of internal partitions, thereby enabling an open plan design concept for its occupants. The ground floor consists of the main lounge and dinning combined together with the kitchen as the only enclosed space with an internal partition of the 150mm hollow block which acts as a non-load bearing wall (See figure 4.5). Also, there is a terrace on the exterior rear part of the building after the dinning, which accommodates the outdoors HVAC equipment's. However, the flats share a common veranda towards each individual's entrance this communal space contributes to the increase in sound level around which constitute as noise to other users of the apartments within the building.

The range of spaces on the first floor as shown in figure 4.5 includes the family room, 2 numbers of bedroom, one toilet, which consist of a bath, a closed couple water closet system and shower head. However the bedroom spaces at both ends are cantilevered by 600mm into the terraces, thereby reducing the size of the terraces and making it functional enough to accommodate the outdoor units of the split AC's.

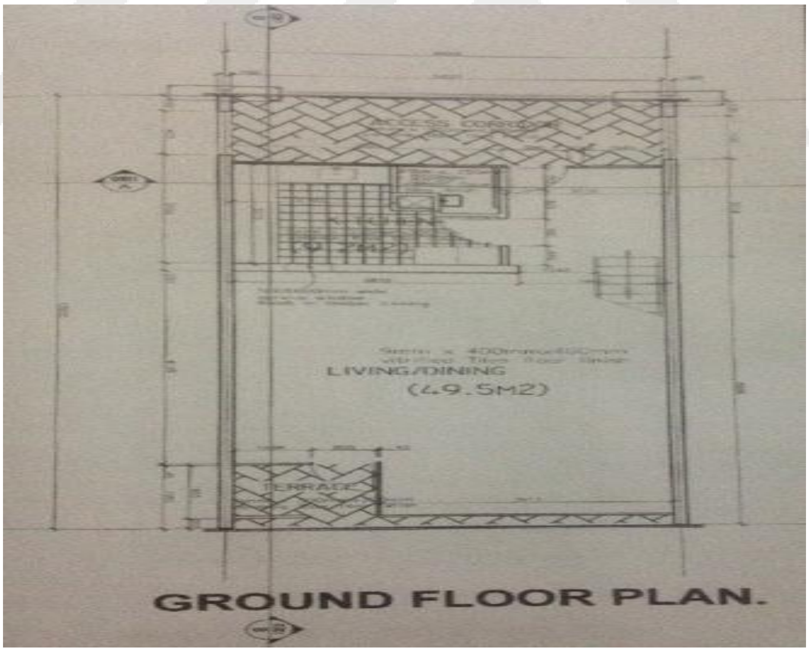

Figure 4.7. Typical Ground Floor Plan Of The 3 Bedroom Flat At 1004 Estate (**Source.** Author, 2017).

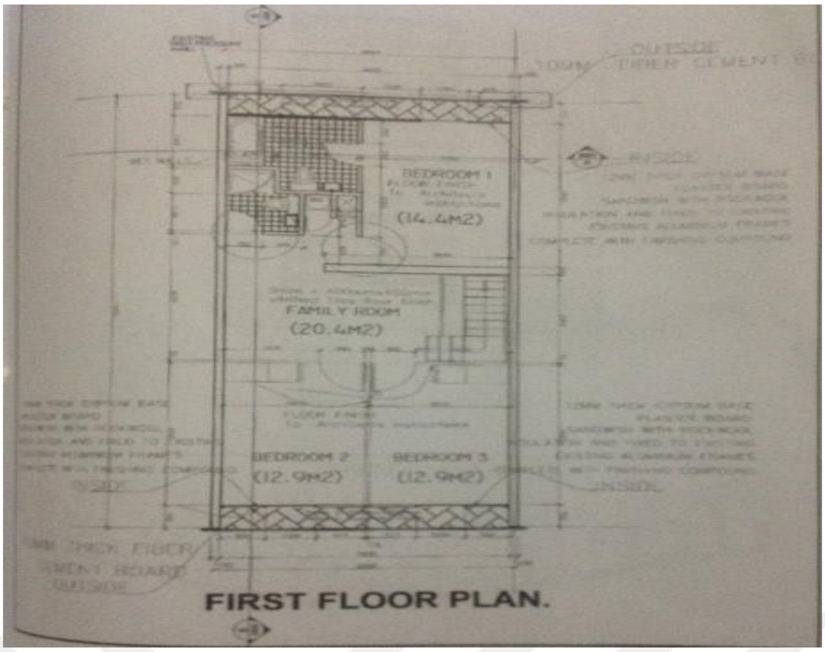

Figure 4.8. Typical First Floor Plan Of The 3 Bedroom Flat At 1004 Estate (**Source.** Author, 2017).

At the ground floor, the 3 bedroom flat has a similar arrangement with to the two bedroom. However, the first floor level has 3 number bedrooms, family room, with 2 numbers of toilet and bathrooms, as one of the bedrooms is en-suite which are cantilevered at 600mm into the adjacent terrace as shown in figure 4.7 & 4.8. The exterior partition system used is the single light glaze panels (see figure below) with the result of the respondent's shows that noise from the verandas filters into the main lounge through the glazed windows. The use of tempered glass material is not sustainable and non-durable since it is fragile the glass panel could easily be shattered on contact with any minor obstacles, hence a better option would be a laminate glazed panel or curtain wall.

Figure 4.9. The Veranda, Which Serves As A Common Circulation To Individual Flats At 1004 Estate (**Source.** Author, 2017).

Figure 4.10. Interior View With The Use of Tempered Glazed System As The External Wall Lining at 1004 Estate (**Source.** Author, 2017).

The service pipes were ducted at the visitors toilet toward the entrance of the main lounge, which goes across all floors, it was observed that the flanking of sound occurs along this path due to cracked open in the wall joints. The lift system is properly designed and no noise was observed during the time of this field survey. However, access to lift is denied on specific floors as a result of the incorporation of Studio Apartment on such floors. In some of the blocks of flats, noise is a serious concern for those living on the 1st, 2nd and 3rd floor respectively due to the on street car parking arrangement. The amount of buffer along these parking route is inadequate, hence cannot curtail the noise amplitude generated from the car parks, (See figure 4.11 below).

Figure 4.11. General Car Park Arrangement At The Low-Rise 1004 Estate Blocks (**Source.** Author, 2017).

The building has two escape stairs, that are both at the extreme side-ends of the high-rise structure this enables ease of escape during emergencies. The escape staircases are rarely utilized as a normal circulation route hence has little contribution to noise level of the estate. Refuse removal is made simple by the utilization of a chute pipe and chute house.

4.1.2. Case Study 2- C & N Luxury Apartments - Ikoyi- Lagos.

The C & N Luxury apartment is a two number multi -level structure, whose design pattern is a solid frame structure. The building has encircled solid segments and beams in lattices and a level concrete slab in fortified post tensioned links. The two-tower structure incorporates eight stories and a penthouse covering a gross floor zone of 18,500m2.

The condominiums are a blend of en-suite 3 and 4 open rooms from the ground to the eight stories and a penthouse on the ninth floor. It has other auxiliary facilities such as a gymnasium unit, an open-air swimming pool, sewage and water treatment plant, borehole, security establishments and standby electricity supply. The high-rise structure is a contemporary design, which serves as a residential complex. The use of curvilinear shape allows the structure to adapt to the flow of wind, which comes from the north-west trade wind (NWTW) or the South East Trade Wind (SETW).

Figure 4.12. Twin Buildings High-Rise Residential C & N Apartments (**Source.** Author, 2017).

The form of the building plays a vital role in its acoustic features, as observed from the literature review. The structure contains two, three and four bedroom flats. Its occupancy usage is at 100 percent. The ground floor is a raised floor of about 2 meters from the natural ground level this gap between the building and the ground level increases the amplitude of sound at the ground floor as observed from the sound meter application during field survey.

The sound meter application subjected under the normal sound source condition at the hallway of the ground floor and first floor, and hence the rate of sound obtained at the ground floor was higher while on the first floor was lower, which suggest that the sound test result reveals the ground floor as having a higher reflectance of sound.

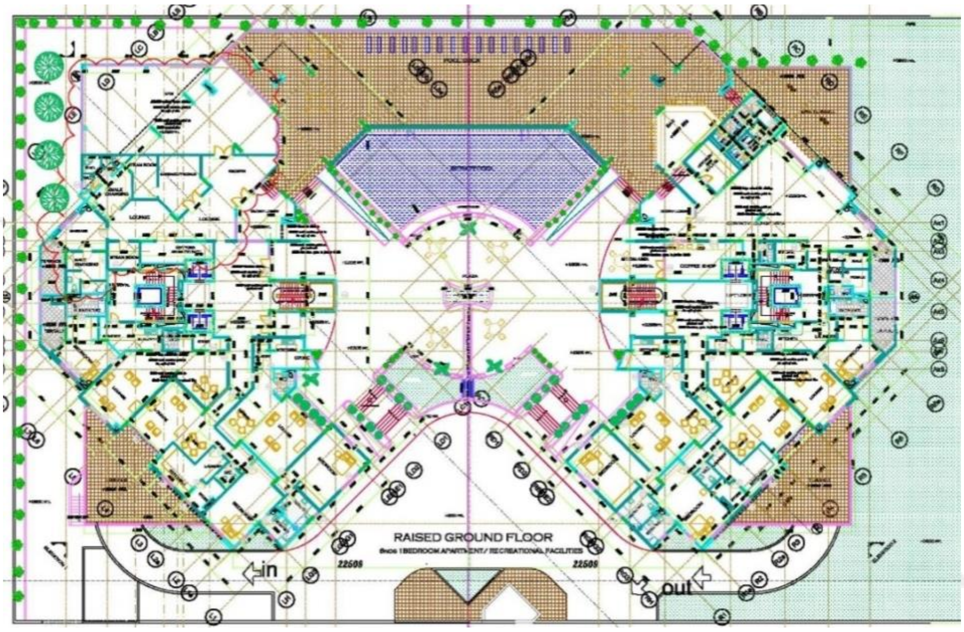

Figure 4.13. Ground Floor Layout C & N Apartments (**Source.** Author, 2017).

The site amount of landscape to hardscape elements is inadequate and hence noise being generated from adjacent roads across the street are not properly insulated due to inadequacy of buffer zones.

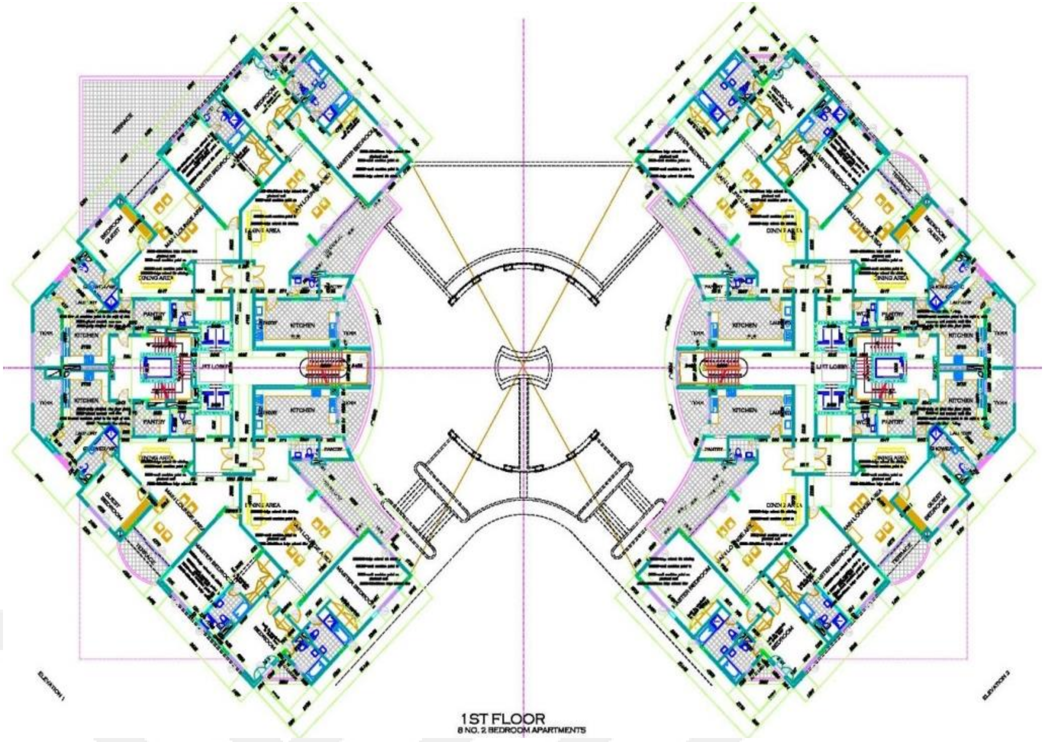

Figure 4.14. Typical First Floor Layout C & N Apartments (**Source.** Author, 2017).

Other sound generating areas within the complex are the verandas, the central core which includes the lifts, stairs, lobbies, chute, drop off, car parking and the power equipment.

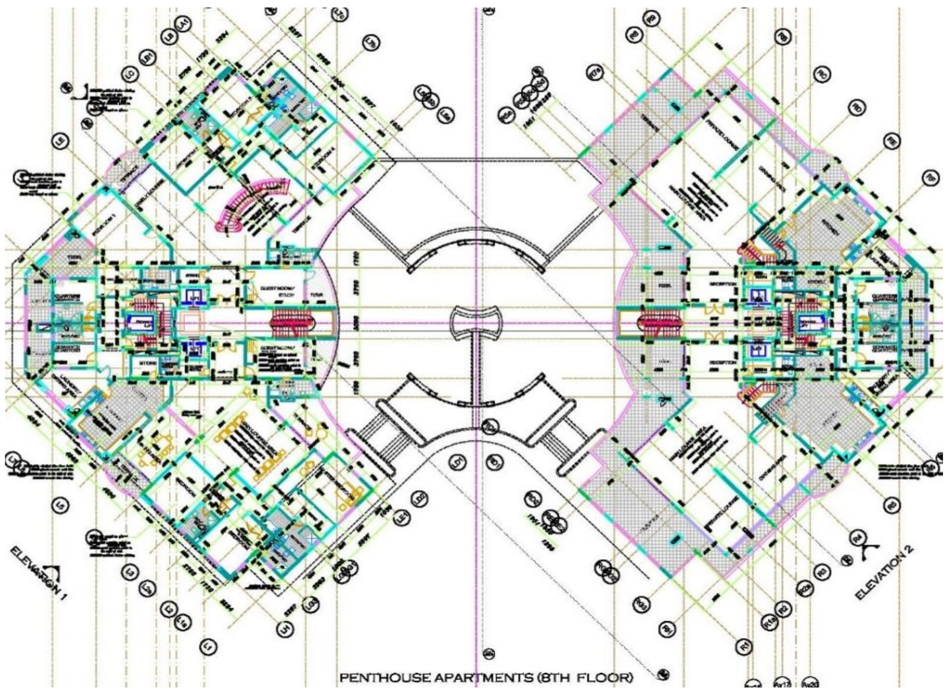

Figure 4.15. Penthouse With Typical Floor Plan (**Source.** Author, 2017).

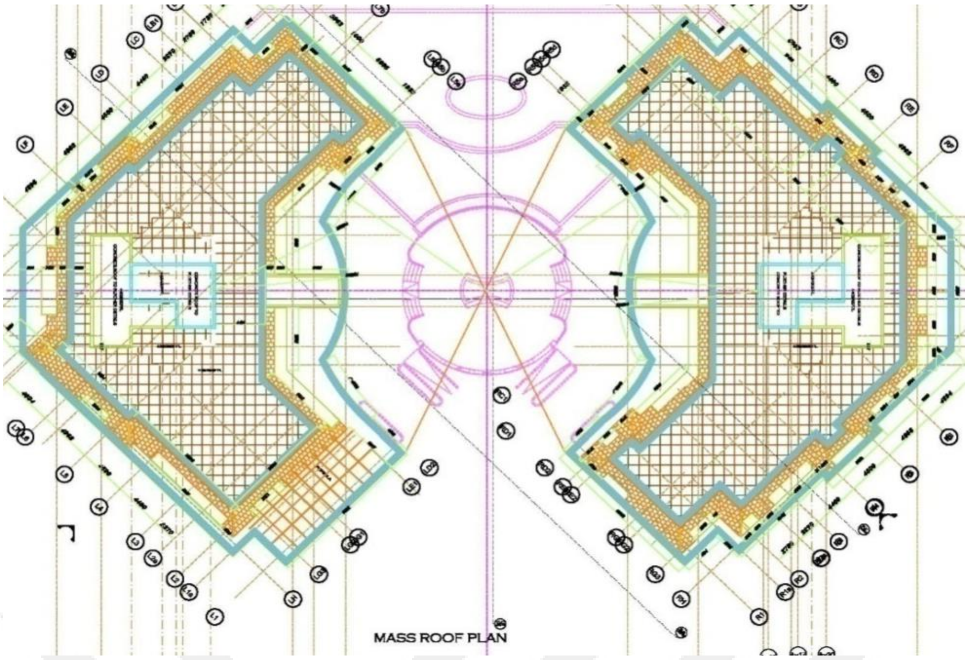

Figure 4.16. Decked Roof Slab Connected With The Service C & N Apartment (**Source.** Author, 2017).

The building's roof is made of concrete slab and neatly felted with double layer of 15mm gauged parolon asphalt. With thick, reflective coating to reflect the sun rays and enhance the durability of the roof cover.

Figure 4.17. Swimming Pool At The Side Of The Building In C & N Apartment (**Source.** Author, 2017).

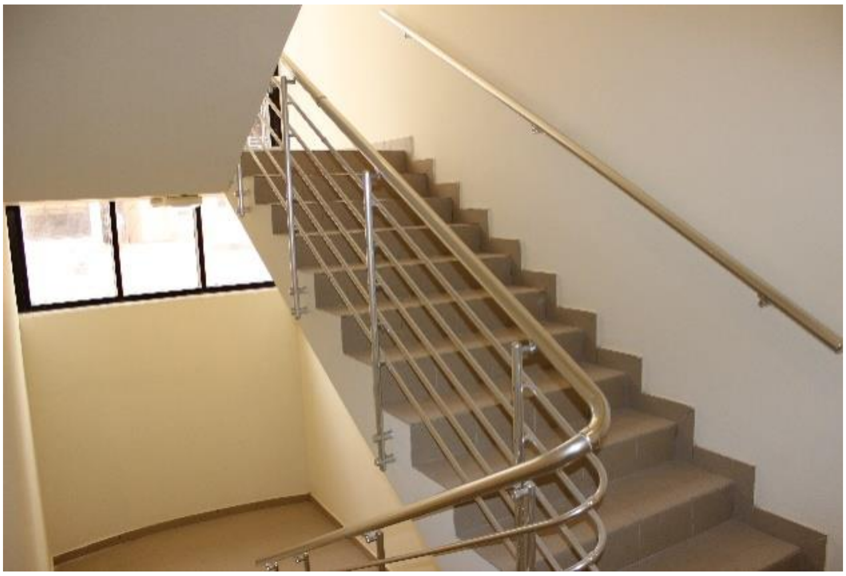

Figure 4.18. Staircase With Ceramic Tiles In C & N Apartment (**Source.** Author, 2017).

The presence of a water body within the building also plays a part in the acoustic control of sound. The basic type of partition system used within the building is the sandcrete hollow block mainly the 150mm, which were utilized as the non-load bearing wall, while the 225mm hollow blocks were considered along the main building grids, each has a vital architectural acoustics feature in the building. The other types of retrofitted building elements used are aluminium slush glazed windows, single panel curtain wall with aluminium frame, laminated timber, glazed wall tiles, and fibreboards.

Figure 4.19. Interior Of Kitchen In C & N Apartments (**Source.** Author, 2017).

Figure 4.20. Corridor Connecting Apartments In C & N Apartments With Ceramic Tiles (**Source.** Author, 2017).

Measuring the speech level of some selected room spaces was conducted, to better understand their influence on the speech delivery of the rooms. The effect of room sizes for occupants on average speech levels, for the occupants with and without sound amplification was investigated. The research considers factors when measuring sound insulation such as the effects of the size of the room, background noise which could come from the activities within the building which influences the noise level of the instrument used.

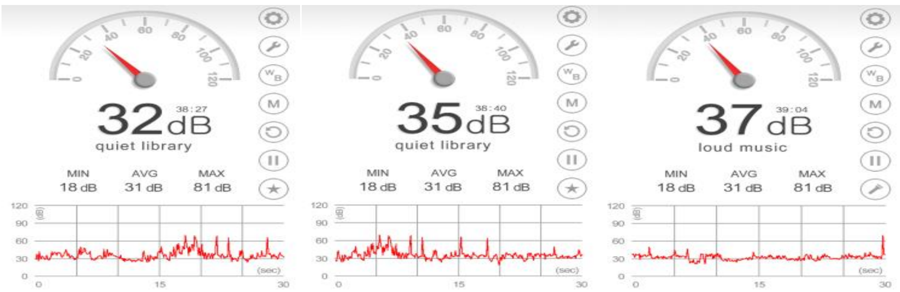

Figure 4.21. Result Of Sound Level Meter At The Main Lounge For 1004 Estate (**Source.** Author, 2017).

The following are three different results obtained from nearly dead sound conditions when most of the apartments within the high-rise complex were accessed under closed fenestrations. These results were obtained using an Android Sound Meter Application, the range of sound decibel noticed was 32Db, 35dB and 37dB (see figure 4.21). However, there was a marginal increase in the result when tested within the same space under a much different condition, the fenestrations were opened and exposed to different sound sources such as human movement and conversations within the hallway and the noise generated from electrical sound systems hence the result obtained is as shown in figure 4.22

Figure 4.22. Result Of Sound Level Meter Within The Main Lounge For C & N Apartments (**Source.** Author, 2017).

The outcome of the result shows that the condition of sound was within the acceptable limit as stipulated in the local building codes STC 60dB to 70dB. This suggests the designer consciously considered sound as an important part of the process.

4.2. Analysis Of Questionnaire

The respondents constituted 61.7% female and 38.3% male all aged above sixteen years in 1004 Estate and C & N Luxury Apartments. Due to the nature of the noise survey during daytime, in both apartments, many working males and females were not included in the survey. This results in a good number of male population away from home each year. Considering the above, the sample size of this composition is considered unbiased. The noise survey also reveals that 46.2% of the respondents were housewives, 24.9% work in quiet office environments, 2.8% were students, 19% were non-working, retired and care takers of apartments, 5.6% people work in a noisy factory environment and 0.4% people work in noisy construction environment.

It is noted that Spearman Rank Correlation test is used in the analysis of noisy data since it is computed on ranks and depicts a monotonic relationship as opposed to Pearson correlation test which is computed on true values and depicts linear relationships. In response to the perception of noisiness in both apartments, 29% of respondents rated their apartments very quiet to accept. 55.5% of the entire cohort of respondents rated their apartment 'Noisy' and 15.5% respondents rated their apartment 'Very Noisy'**.** Figure 4.23 below presents the apartment's rating with regards to the noisiness of the apartment and it generally shows a normal distribution.

Table 4.1. General Rating Of The Apartments With Respect To Indoor Noise Level (**Source.** Author, 2017).

Noise Level	% Respondent
Very Quiet	3.3
Quite	4.4
Acceptable	21.3
Noisy	55.5
Very Noisy	15.5

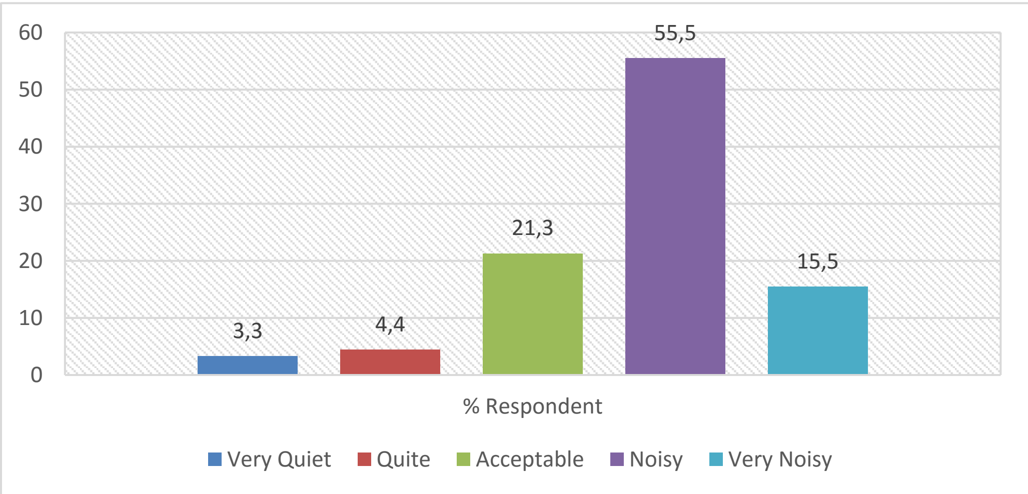

Figure 4.23. General Rating Of The Apartments With Respect To Indoor Noise Level, (**Source.** Author, 2017).

The survey results showed that 71% of respondents felt 'Disturbed' by noise in their living environment while 28% felt 'Not Disturbed' and the remaining 1% of respondents were unsure about their disturbance. About 36% of the respondents considered their ‘Living rooms as the 'noisy' part of their apartment, followed by about 14% respondents who considered this to be their ‘Bedrooms’. The Spearman Rank Correlation test showed that the rating of the noisiness of the apartment is significantly correlated to the disturbance by noise in the living environment with a level of significance of 0.01.

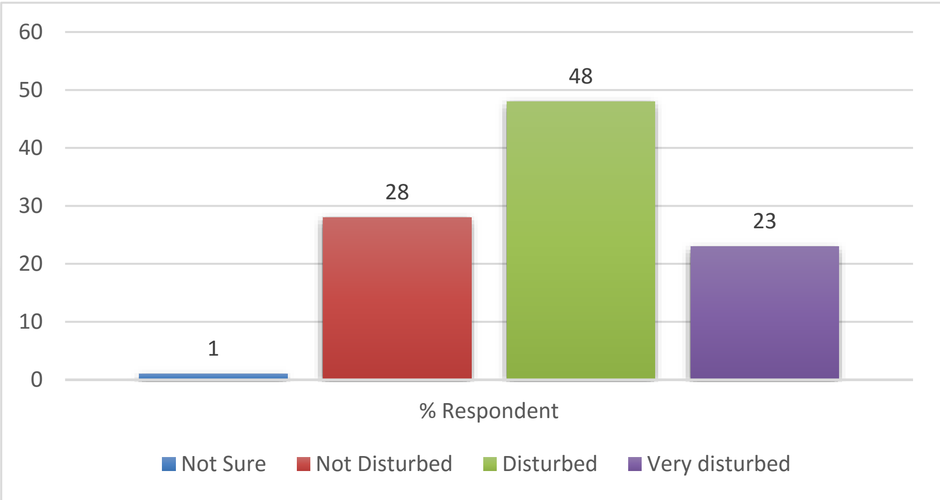

Figure 4.24. Rating Of The Apartments With Respect To Disturbance Level (**Source.** Author, 2017).

The survey results revealed that approximately 68% respondents felt 'the noisiest period' was during the daytime (6 am to 6pm) followed by 16% sample population who felt the noisiest period was during the night (11pm to 6am). Another 9% of the respondents felt the noisiest period was the evening (6pm to 11pm). The rest of the sample population did not feel affected by noise in their living environment.

It was noted from the survey results that 90% of the entire residents generally open windows during their stay at home while the remaining 10% generally leave at least one window closed.

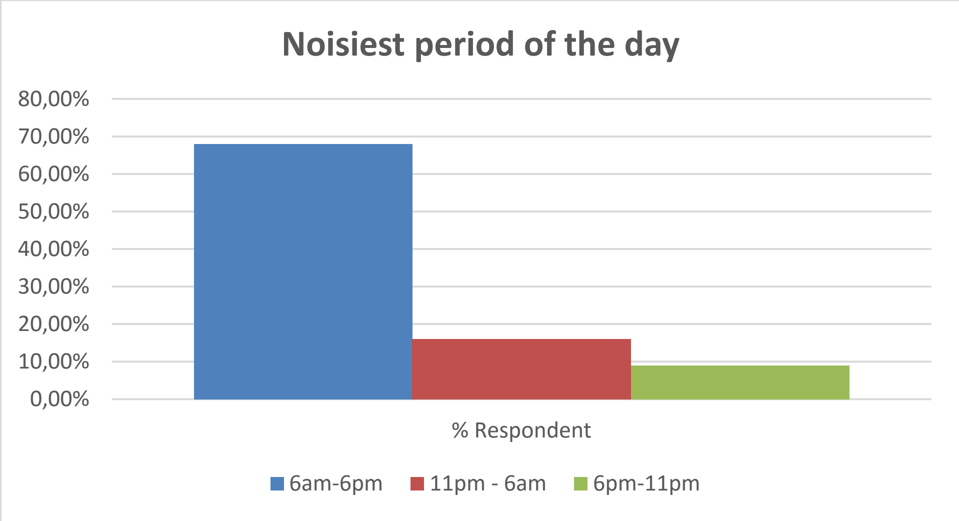

Figure 4.25. Noisiest Period Of The Day (**Source.** Author, 2017).

During the noise survey, a background noise measurement was carried out just outside the entrance of the apartment and the subjective rating of the respondents was recorded. The cumulative data, presented in Figure 4.25 show that an outdoor measured A-weighted noise level of 55 dB is found as an 'acceptable' noise level to 95% of the entire sample size. It is noted that this acceptable noise level is established based on the measured noise data collected between 10am and 6pm during the noise survey.

4.3. Analysis Of The Noise Survey Data

- **Assessment of the Overall 'Noisiness' of the Indoor Aural Environment**

Table 4.2 lists several acoustical and non-acoustical factors that are correlated (tested using a Spearman Rank correlation test) to the overall 'noisiness' of the apartment.

Table 4.2. Factors Correlated To The Overall Noisiness Of The Apartment (**Source.** Author, 2017).

Type of Factor	Factors	Correlation Coefficient	Level of Significance
Non-Acoustical	Sensitivity to noise	0.280	0.01
Non-Acoustical	Consideration of noise as an important aspect in living environment	0.227	0.01
Non-Acoustical	Rating of disturbance by noise in surrounding living environment (outdoor noise)	0.308	0.01
Non-Acoustical	Rating of Disturbance by major noise source	0.290	0.01
Acoustical	Noisiest period for the major source of noise	0.131	0.01
Non-Acoustical	Activities disturbed by the major source of noise	0.211	0.01

From the analysis, it is observed that 'noisiness' of the indoor environment of an apartment is significantly correlated to the sensitivity of the inhabitants. The 'noisiness' perception tends to reduce for people who are less sensitive to noise.

The cognitive response, for example, belief of noise as an important aspect of the living environment, is also found significantly correlated to 'noisiness' of the apartment. It is observed that respondents who rated noise as an important aspect of the living environment showed a higher incidence of finding their apartment noisy. It is also found that the 'noisiness' of the apartment is significantly correlated to the perceived disturbance by noise in the general surrounding living environment. Inhabitants who are disturbed by noise in their general surrounding living environment generally find their apartment noisiest.

A one way Anova test (refer to Table 4.3) shows that the rating of the 'noisiness' of the indoor aural environment is not influenced differ by gender, age, level of the apartment of residence. Length of residence and the belief in the importance of noise as an important aspect. The noisiness of the indoor environment was rated differently by inhabitants with different noise sensitivity and the people who stayed in different types of the apartment (for example, 3 room apartment, 4 room apartment e.tc.).

For the latter, it was observed from a t-test that the mean rating of the indoor noise environment by inhabitants residing in 3 rooms, apartment and 4 rooms apartment significantly differs at an alpha level of 0.05.

A one way Anova test showed that the mean background noise levels across different types of apartments are significantly different ($p<0.05$). The A-weighted mean background noise level of a 3 room apartment (59 dB) was found lower compared to that of the 4 rooms apartments (61 dB).

Test results are presented in Table 4.3. The analysis shows that there are significant differences in rating, noisiness of apartment by different noise sensitive groups, namely 'non sensitive', 'average sensitive' and 'sensitive' group.

Table 4.3. Influence Of Factors To Overall Rating Of Noisiness Of The Apartment (**Source.** Author, 2017).

Type of Factor	Factors	Significance	Remarks
Non-Acoustical	Consideration of noise as an important aspect in living environment	3.535	Significantly important
Non-Acoustical	Rating of apartment by different gender	0.395	Rating of apartment equal across groups
Non-Acoustical	Rating of apartment by different age group	1.877	Rating of apartment equal across groups
Acoustical	Rating of apartment by residents staying at different level of the building	1.156	Rating of apartment equal across groups
Non-Acoustical	Rating of apartment by residents of different length of stay	1.114	Rating of apartment equal across groups
Acoustical	Rating of apartment by residents staying in different types of apartments	2.967	Rating of apartment different across groups
Non-Acoustical	Rating of apartment by residents with different sensitivity to noise	21.653	Rating of apartment different across groups

- **Evaluation of Apartment's Noisiness for Different Categories of Noise Source**

Table 4.4 summarizes the factors that are correlated (tested using Spearman Rank correlations) to the rating of 'noisiness' of the apartments while outdoor environmental noise is considered as the major category of noise source. Apart from the factors that have been discussed in the earlier section relating to the overall noisiness of the apartment, it is observed from Table 4.4 that the rating of noisiness of the apartment is moderately correlated to the disturbance due to the major environmental noise source which in turn strongly correlated to the disturbance by noise in the general surrounding living environment.

It is found that 60 percent, the acceptability of the indoor noise environment (in terms of noisiness of the apartment) reduces with the increase in disturbance by particular major environmental noise source.

Table 4.4. Factors Related To Rating Of 'Noisiness' Of The Apartment When Environmental Noise Is Considered As The Major Category Of Noise Source. (**Source.** Author, 2017).

Dependent Variable	**Type of Factor**	**Factors**	**Correlation Coefficient**	**Significance**
Rating of Apartment (Noisiness)	Non-Acoustical	Sensitivity to noise	0.286	0.01
Rating of Apartment (Noisiness)	Non-Acoustical	Consideration of noise as an important aspect in living environment	0.241	0.01
Rating of Apartment (Noisiness)	Non-Acoustical	Disturbance by noise in surrounding living environment (outdoor noise)	0.303	0.01
Rating of Apartment (Noisiness)	Acoustical	Part of the apartment considered noisy	0.123	0.01
Rating of Apartment (Noisiness)	Acoustical	Type of major noise source	0.214	0.01
Rating of Apartment (Noisiness)	Non-Acoustical	Activities disturbed by the major source of noise	0.220	0.01
Disturbance by major noise source	Non-Acoustical	Sensitivity to noise	0.256	0.01
Disturbance by noise in surrounding living environment	Non-Acoustical	Disturbance by major noise source	0.458	0.01
Activities disturbed by the major source of noise	Non-Acoustical	Disturbance by major noise source	0.497	0.01

Table 4.5 summarizes the factors that are correlated (Tested using Spearman Rank correlations) to the rating of the apartment's noisiness when neighbour noise is considered as the major category of noise source. The type of activity disturbed by the major neighbour noise source is correlated with the disturbance by major neighbour noise source. It was observed that sleep disturbance was mostly affected by the noise from the floor directly above the apartment.

Table 4.5. Factors Related To Rates Of 'Noisiness' Of The Apartment When Neighbour. Noise Is Considered As The Major Category Of Noise Source (**Source.** Author, 2017).

Dependent Variable	**Type of Factor**	**Factors**	**Correlation Coefficient**	**Level of Significance**
Rating of Apartment (Noisiness)	Non-Acoustical	Disturbance by major noise source	0.275	0.01
Rating of Apartment (Noisiness)	Acoustical	Noisiest period for the major source of noise	0.313	0.01
Rating of apartment (noiseness)	Non-Acoustical	Activities disturbed by the major source of noise	0.253	0.01
Activities Disturbed by Major Noise Source	Non-Acoustical	Disturbance by major noise source	0.430	0.01

Table 4.6. Factors Related To Rating Of 'Noisiness' Of The Apartment When External. Noise Is Considered As The Major Category Of Noise Source. (**Source.** Author, 2017).

Dependent Variable	**Factors**	**Type of Factor**	**Correlation Coefficient**	**Level of Significance**
Rating of Apartment (Noisiness)	Sensitivity to noise	Non-Acoustical	0.431	0.01
Rating of Apartment (Noisiness)	Disturbance by major noise source	Non-Acoustical	0.281	0.05
Rating of Apartment (Noisiness)	Level of apartment	Acoustical	0.281	0.05
Activities Disturbed by Major Noise Source	Disturbance by major noise source	Non-Acoustical	0.372	0.01

Table 4.6 Presents the factors that are correlated (Tested using Spearman Rank correlations) to the rating of apartment's noisiness when external noise is considered as the major category of noise source.

Similar to neighbour noise sources, it is observed that the overall acceptability of the indoor noise environment (noisy) is correlated to disturbance due to community noise sources which in turn is correlated to disturbance of activities. It is found that the rating of apartment's noisiness increases with the increase in disturbance by the particular community noise source.

It is also noted that the overall noisiness of the apartment increases for inhabitants who are sensitive to noise and for those who reside in the lower floors (below seventh floor) of the building. The latter may be due to the fact that at lower apartments, the noise exposure levels might be relatively higher.

4.4. Analysis Of Ecotect Simulation And Findings

This section presents in detail how simulation data were collected and analysed. The analysis was done in line with the research questions and it was conducted in a three-stage process. First case studies buildings were modelled with common construction materials in Nigeria (business as usual) as shown in Figure 4.26 and 4.27. The second stage involves applying different independent variables and the results were observed and recorded. The third stage involves interpretation and presentation of results in various tables and charts.

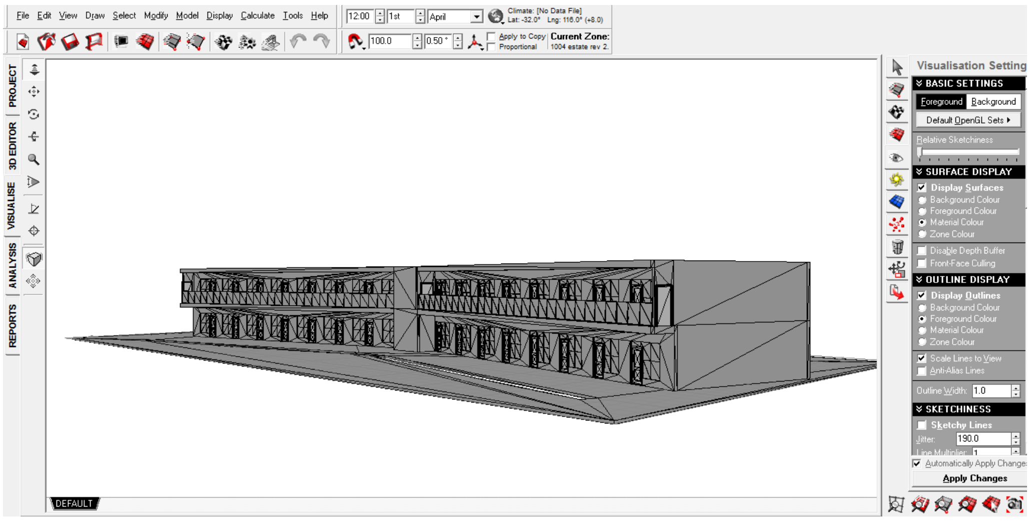

Figure 4.26. 3D View Of The Case Study Model 1004 Estate (**Source.** Author, 2017).

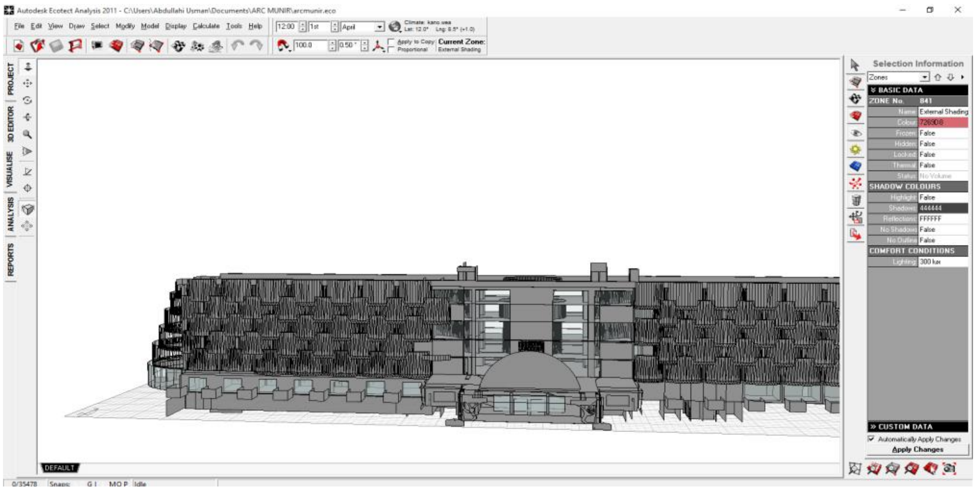

Figure 4.27. 3D View Of The Case Study C & N Apartments (**Source.** Author, 2017).

- **Environment for the Experiment**

Autodesk's ECOTECT is an analysis software for buildings that gives an easy assessment of design and work in 3D which is easier for architects to use. ECOTECT has various analysis options from lighting, thermal comfort, acoustics to energy efficiency analysis. ECOTECT's tool related to acoustics can be found under the analysis tab in the interface of the ECOTECT as shown in Figure 4.28. Since this research deals with improving acoustic response buildings results from this tool will be described in this section.

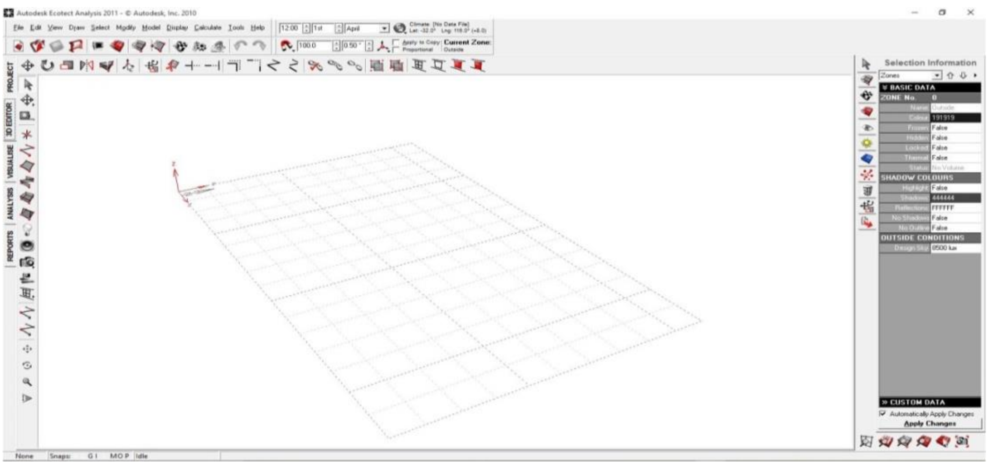

Figure 4.28. Interface Of Autodesk ECOTECT (**Source.** Author, 2017).

- **Process of Case Studies Buildings Simulation**

This simulation tool has potentials for vast analytical analysis. However, for the purpose of this research, the tool will be employed to simulate core acoustic design strategies. Selected case studies at two different locations in an attempt to validate a design notion as common to use of retrofitted materials for high-rise residential apartments. Acoustic analysis study, figures 4.29 and 4.30 below show the result for several stage-by-stage processes in generating the information, with the illustration of graphical indices of the acoustic properties.

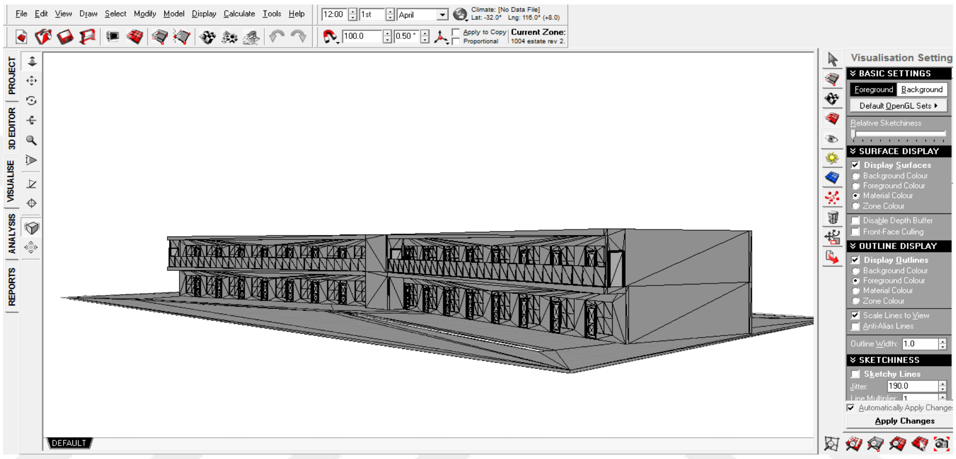

Figure 4.29 Ecotect Analysis Of The Building Block For Acoustic Analysis 1004 Apartments (**Source.** Author, 2017).

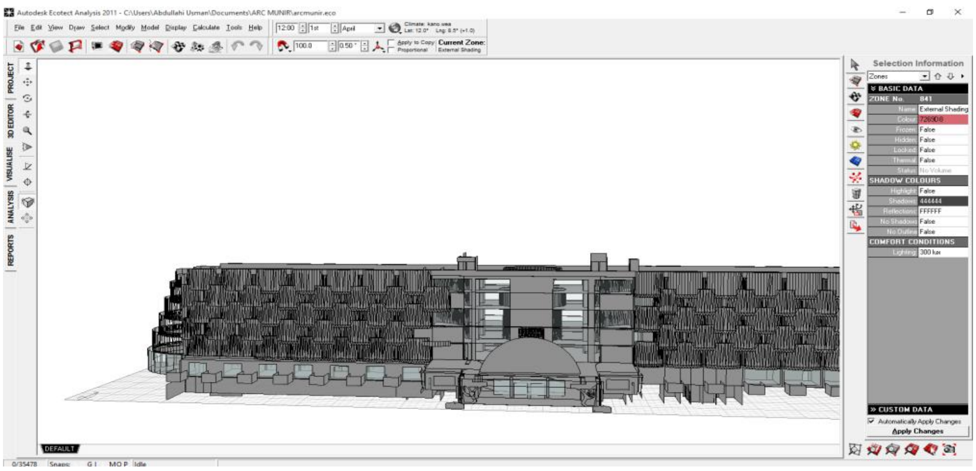

Figure 4.30 Ecotect Analysis Of The Building Block For Acoustic Analysis C & N Apartments (**Source.** Author, 2017).

The drawings and other relevant information were collected from the management of each case study building. These data were used to model the building in Autodesks Revit Architecture. The Model was exported in a Green Building format which is Gbxml for Ecotect Simulation. After the models were imported to Ecotect, the materials which are the variable were added to the global library of the software. The wall panels and their acoustic panels were tabulated and inputted into the software as shown in the figure below.

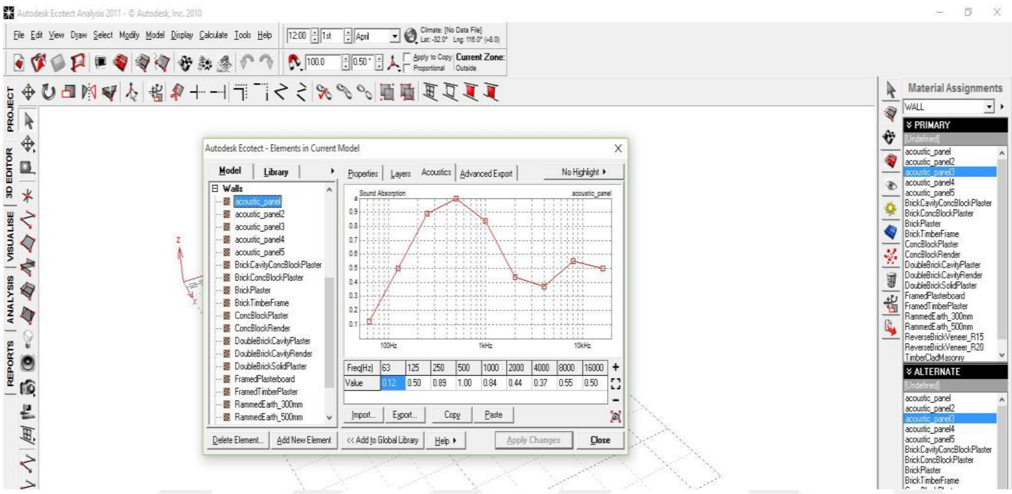

Figure 4.31. Ecotect Analysis Of The Building Block For Acoustic Analysis (**Source.** Author, 2017).

From there on, various simulations were conducted on different wall panels as shown in the following figures and other results were tabulated and charts were drawn out**.**

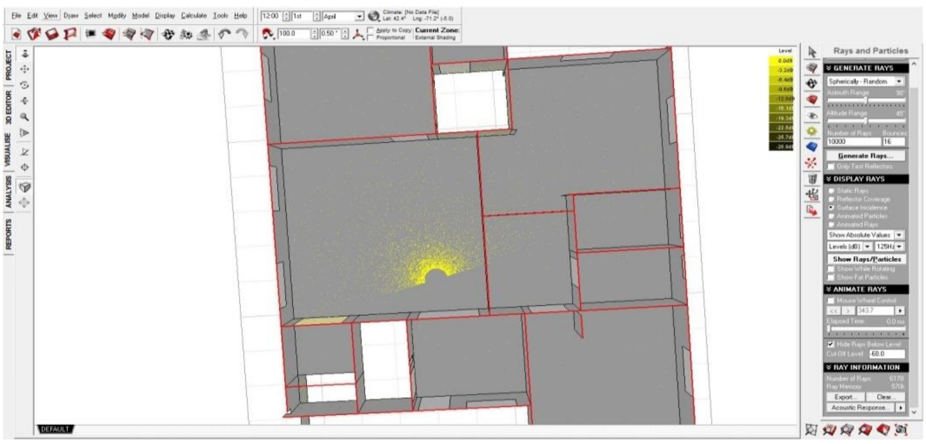

Figure 4.32. Ecotect Analysis Of The Building Block For Acoustic Rays For Sound Absorption (**Source.** Author, 2017).

A prototype of the 1004 estates and C & N residential blocks are modeled in Revit and transferred as a dxf file to Autodesk Ecotect with the building spaces properly tagged before exporting it thereof, the implication is that it enables the simulation of the constituent elements in Ecotect which involves acoustics.

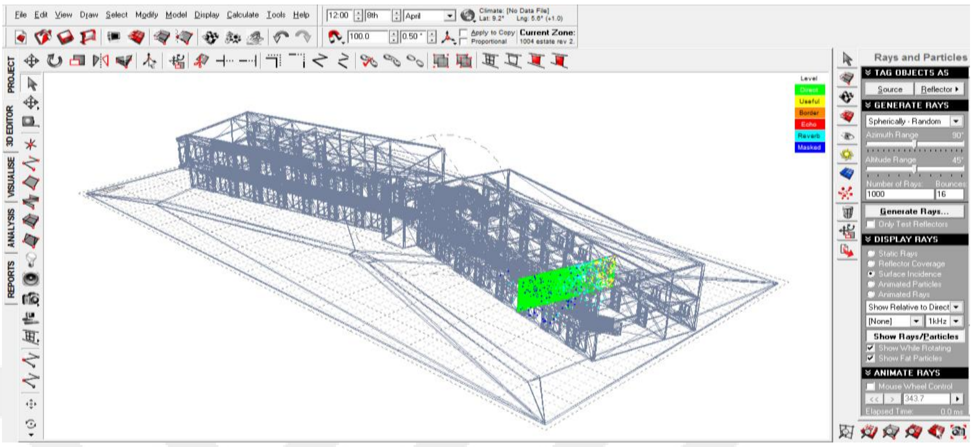

Figure 4.33. Simulating The Estate Blocks For Acoustic Analysis 1004 Estate (**Source.** Author, 2017).

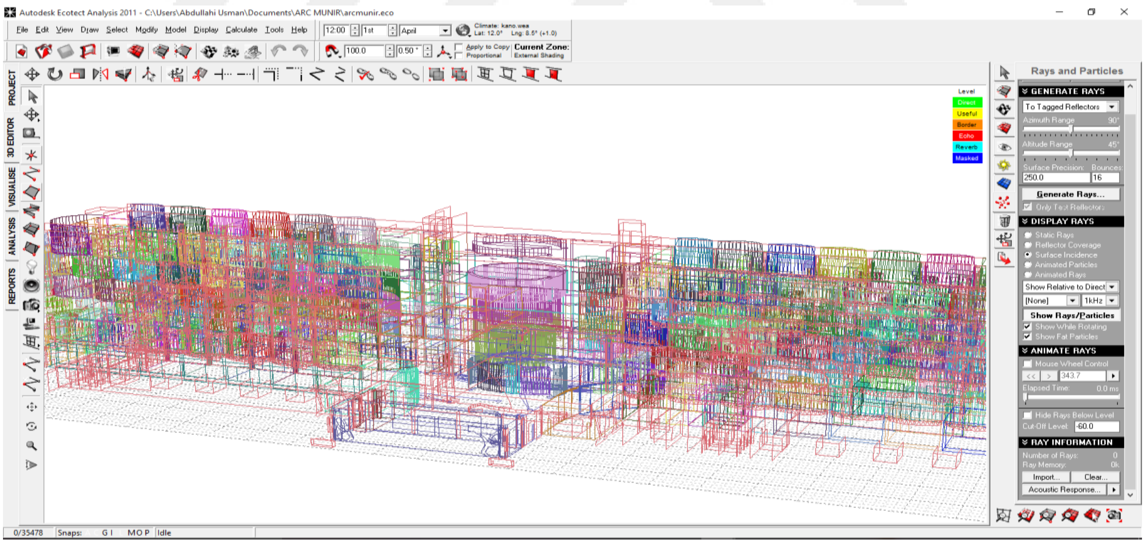

Figure 4.34. Simulating The Estate Blocks For Acoustic Analysis C & N Aparments (**Source.** Author, 2017).

The result of the acoustic simulation and analysis as illustrated in figure 4.33 and 4.34, shows the sound path was positioned at the other end of the verandah which serves as a common circulation amongst the residents at the estates. Hence, tagging the separating wall as the reflector in Ecotect for analysis a baseline material, wall and floor real life properties of the software simulation package to further highlight and enhance the clarity of the acoustic result (see figures 4.35 and 4.36).

This further clarifies the impact and occurrence of sound along the retrofitted material, when simulating the selected portion of the high-rise building block of flat.

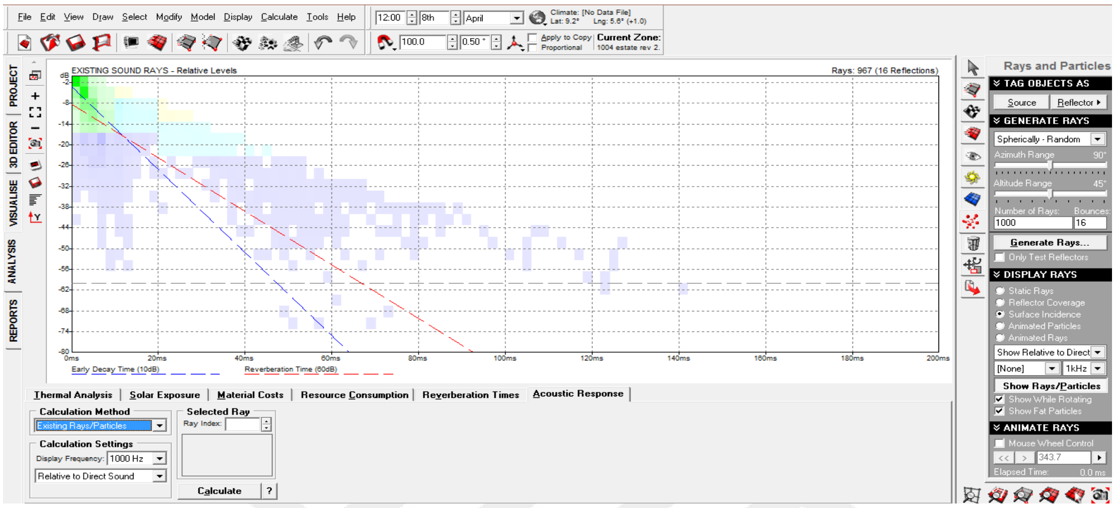

Figure 4.35. Graphical Interpretation Of Acoustic Result At The Estate (**Source.** Author, 2017).

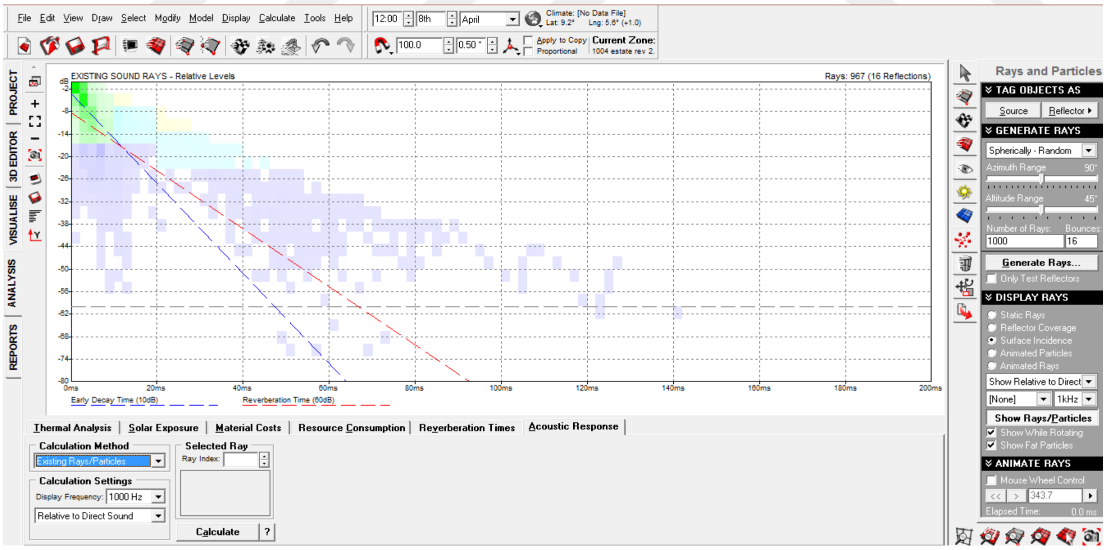

Figure 4.36. Graphical Interpretation Of Acoustic Result At The C & N Aparments (**Source.** Author, 2017).

- **Analysis of Simulation using Ecotect**

The experiment of simulation relies mainly on the separating wall element which makes up to about 80% of the building materials used in the Estate, the use of sandcrete hollow block as observed from case studies was the dominant separating wall types.

However, these wall system comes in two main types: the sandcrete hollow block of 150mm and 225mm thickness both with a 10mm layer of plaster on both sides which tallies with the review in literatures. (Refer to figure 4.35 and 4.36) which clearly indicates the transfer of wall parameters used as separating elements at the high-rise residential buildings at the estate.

The figure below is an indication of the result from the acoustic analysis of the 225mm separating wall used at the 1004 Estates, Lagos. For a better illustration, see figure 4.37, the graph clearly shows a fairly large spread of the ray particles in orange color, this simply means that the rays are most suitable in large open spaces such as auditoriums due to the volume of the building and the quick rate of reverberation time (RT) and early decay time (EDT).

However, this same wall prototype when used does not fit in well with high-rise residential buildings due to its smaller volumes which is design and design with the required specifications of the designer. The highlight of the result from the simulation shows that the rays which is color-coded as border rays (Refer to figure 4.37) generated from the use of such 225mm thick sandcrete hollow walls with associated surface rendering of 10mm thick plastering on both sides releases a large spread of border rays with the line of best fit clearly drawn in red dots are generated via a sound source, whereby other relevant acoustic conditions are kept constant. The implication of this sound is that the borders rays in orange color are rays which, when it attains its threshold, it tends to take quite a long time in speech sound and hence its individual sound components begin to clash and merge with one another thereby creating the potential to reduce intelligibility for the users of such space.

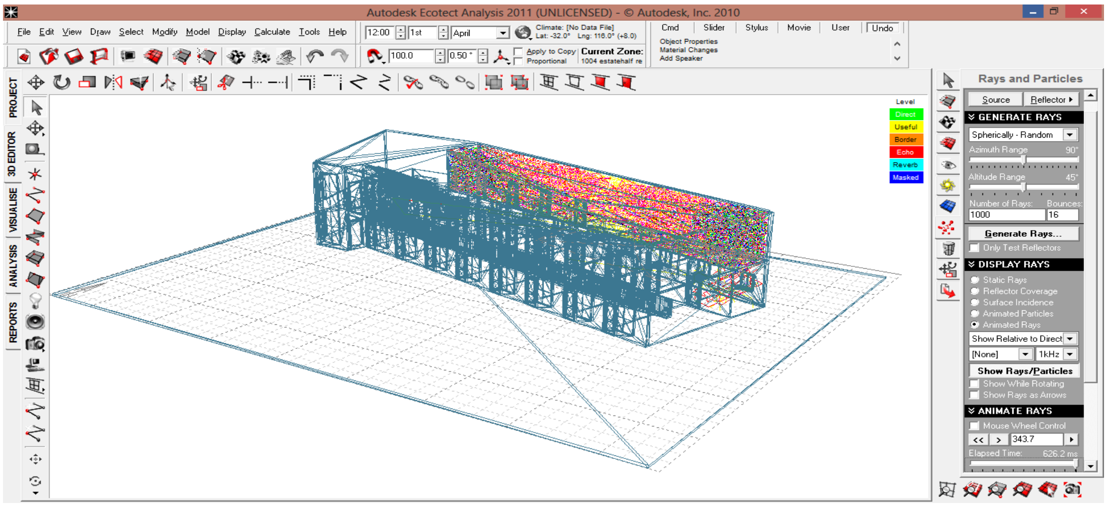

Figure 4.37. Simulating The Estate Blocks For Acoustic Analysis at 1004 apartments (**Source.** Author, 2017).

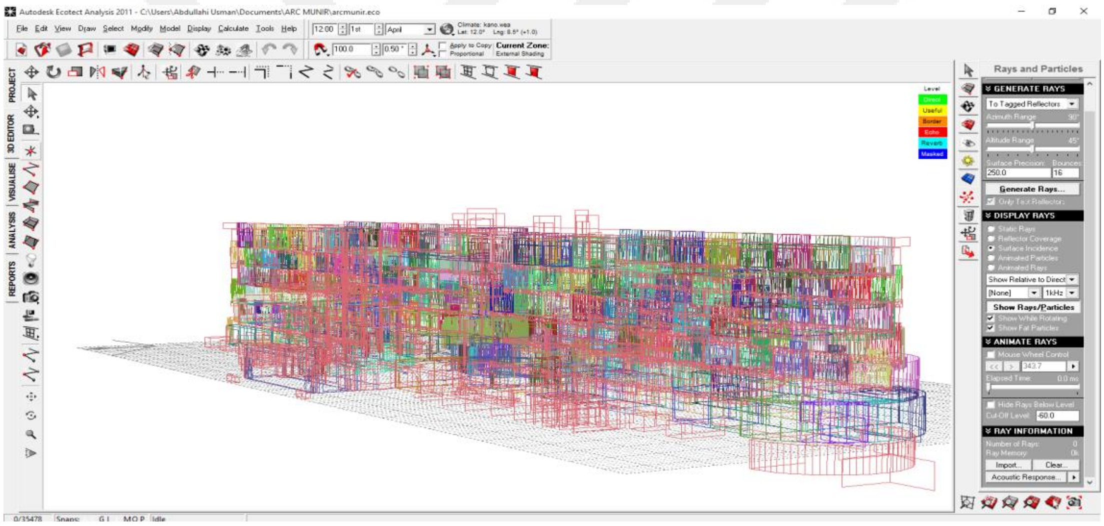

Figure 4.38. Simulating The Estate Blocks For Acoustic Analysis C & N Apartments (**Source.** Author, 2017).

The figures 4.37 & 4.38 are another illustration of simulation results for the 225mm thick separating wall element observed during case study visit to the 1004 estates and C&N apartments. The rays visibly show about 90% of echo rays which is color coded in red, whilst it contains a small tint of useful rays color coded in yellow.

This implies that the properties of the separating wall element as observed during the research case study for the estate has a poor reaction to sound and noise. This kind of rays generates echo which is frustrating to the users of such space and should be avoided. The remedial solution to this type of dilemma is to use proper sound absorbers elements.

Note that the result of this kind of sound occurs when subjected under careful observation with all other experimental conditions kept constant.

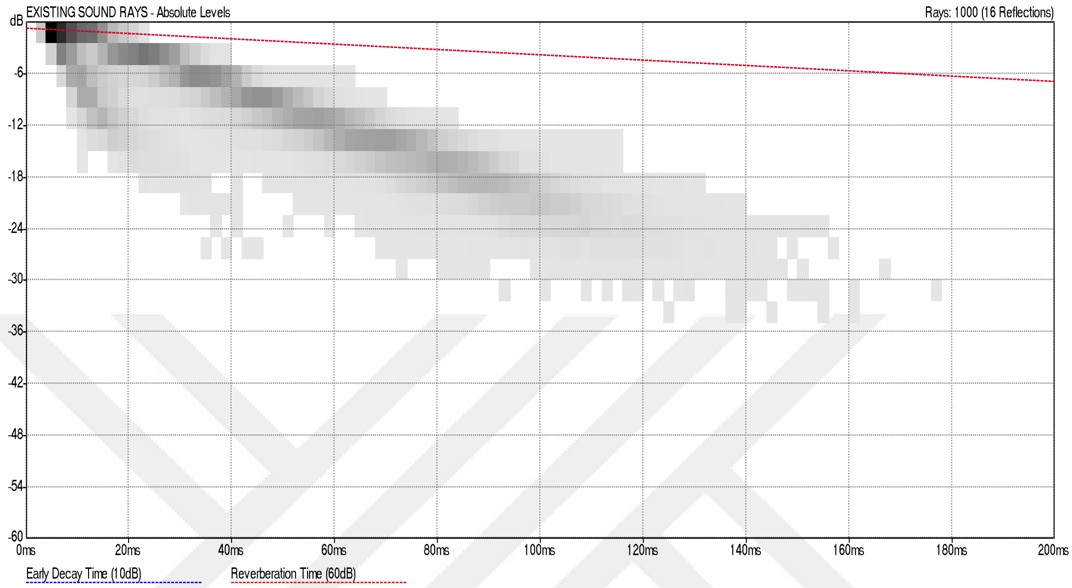

Figure 4.39. Table Of Sandcrete Block Wall Simulation At 1004 Esatate (**Source.** Author, 2017).

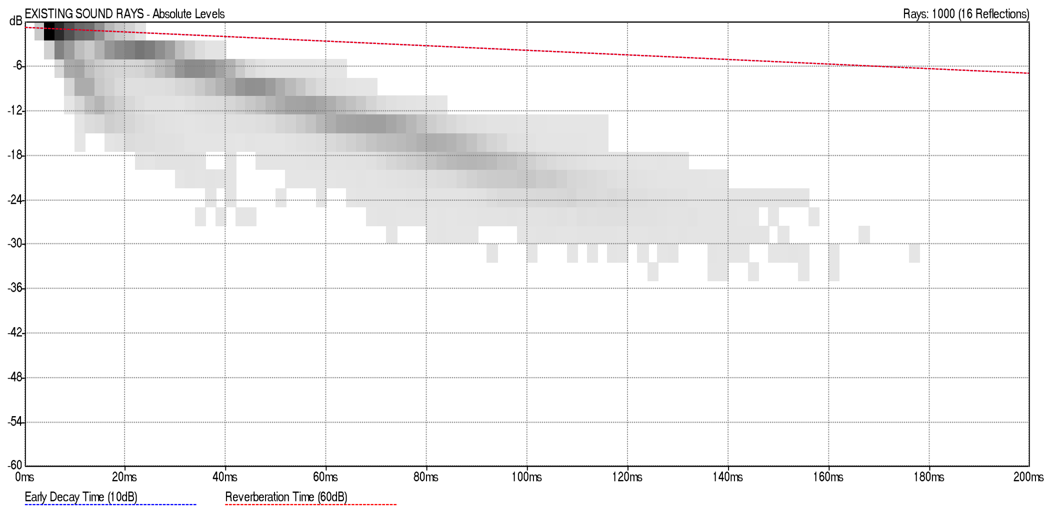

Figure 4.40. Table Of Sandcrete Block Wall Simulation at C & N apartments (**Source.** Author, 2017).

However, it should be noted also that this band of rays occurs due to the type of sound source which has been generated, such as speech or music, for the latter when the sound attains its threshold, it delay time could be up to 80ms (Autodesk Ecotect help menu, 2010) hence such wall material can be suitable for designs of large auditorium. (Refer to figure 4.41 and 4.42)

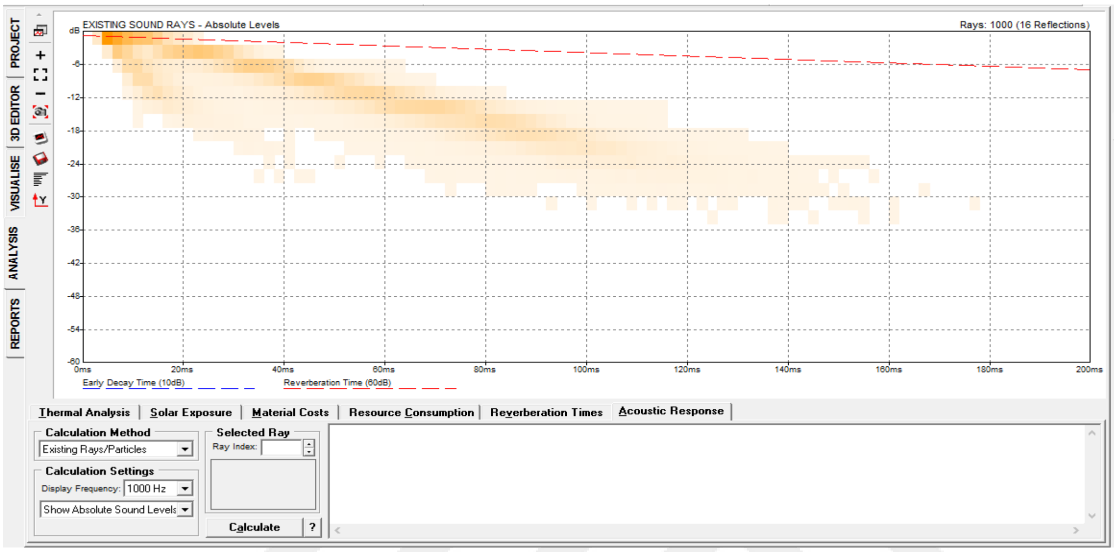

Figure 4.41. Graph Of 150mm Thick Sandcrete Block Wall Simulation at 1004 Estates (**Source.** Author, 2017).

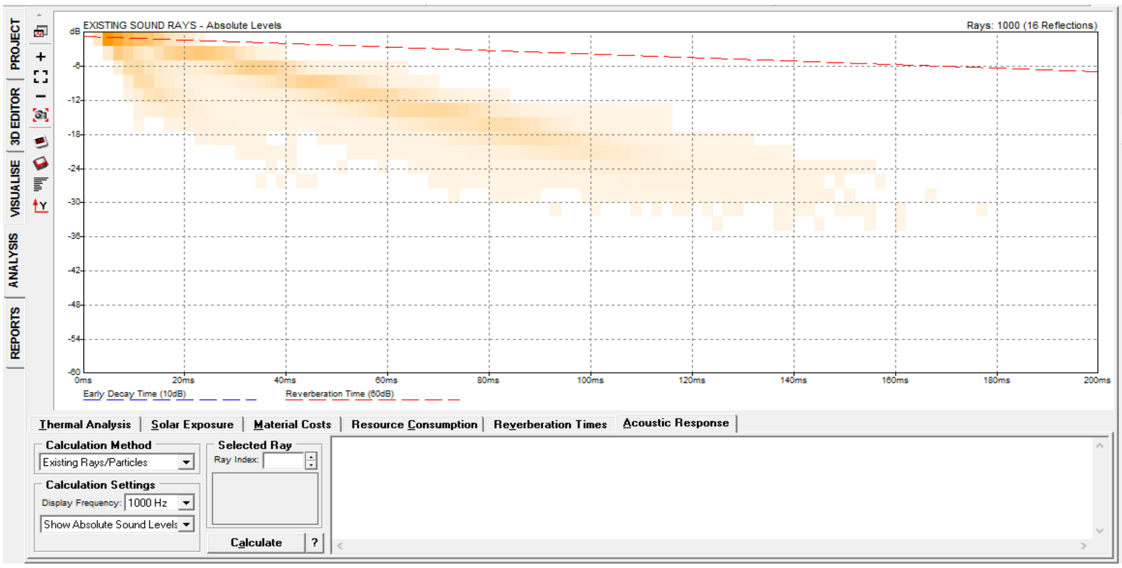

Figure 4.42. Graph Of 150mm Thick Sandcrete Block Wall Simulation at C&N apartments (**Source.** Author, 2017).

- **Simulation of the 150mm thick wall with cavity infills**

The selection of other separating wall elements was considered with the transfer of the actual properties of the element in Autodesk Ecotect software which also further generates other salient information as regards to the acoustic requirements of the wall system for a typical sandcrete hollow block wall of 150mm thickness. Thus, this enables the program to detect the U- Value, admittance, colour, reflection roughness and its emmisivity of the building element (Refer to figure 4.43 and 4.44). This is essential in guiding the program to simulate results for the acoustic indicators such as the Revebration time (RT), Early Decay Time (EDT), and Echo (E), amongst other parameters required for the acoustic and noise analysis which occurs within the Case study as observed during the visit.

The figures 4.43 & 4.44 below clearly disclose the properties in actual cases of the 150mm sandcrete hollow block with light weight infills stuff within the hollow. After the transfer of the properties via Ecotect, the acoustic analysis was conducted.

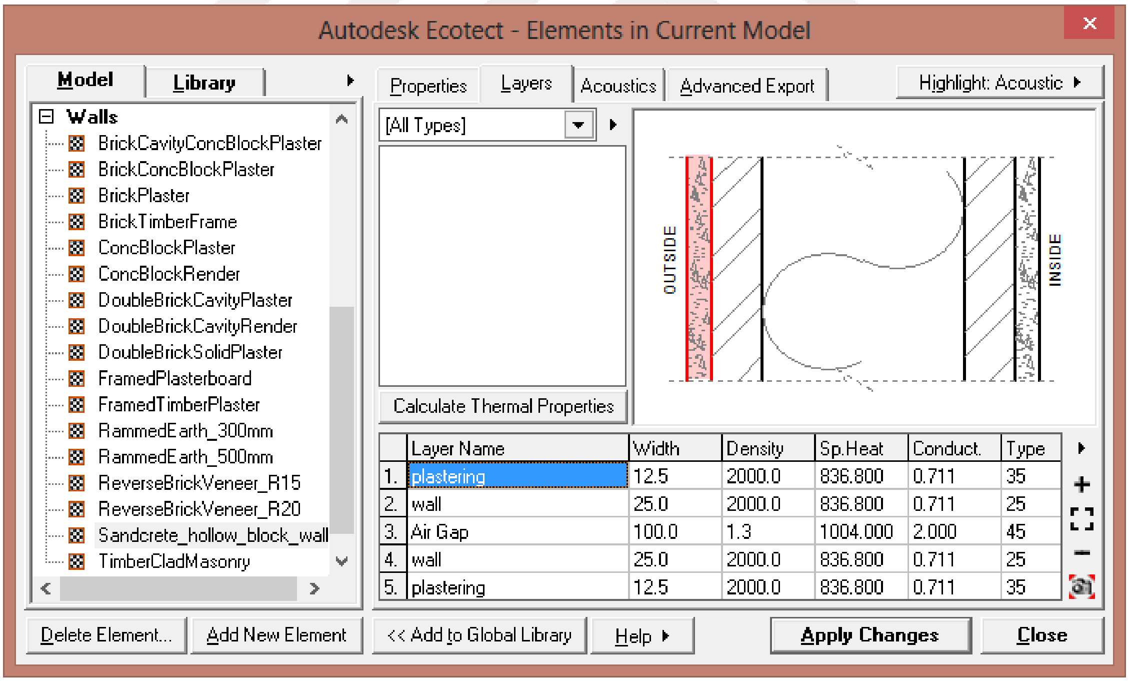

Figure 4.43. Properties Of 150mm Sandcrete Block Wall Simulation (**Source.** Author, 2017).

The Sandcrete hollow block wall has an infill within the hollow section which tends to refer to loose materials such as fibre that it influences the outcome of the result of the rays as simulated. (Refer to figure 4.45,4.46 & 4.47,4.48).

The simulation of the room spaces on the first floor of the high-rise residential building was carried out (see figure 4.45 & 4.46) the result shows three major categories of rays generated. These rays are color coded sky blue, which refers to Reverb deep blue, which refers to masked, green rays which refers to Direct. Sandcrete hollow block of 150mm with weak infills was used to carry out the simulation. The rays generated from the sound after taking note of all other acoustic conditions kept constant would be discussed below. The Direct rays which are color coded green suggests that the reflections from the rays of the main direct source could arrive at some few milliseconds, and the could be slightly higher than < 25dB, which makes it hard for the auditory mechanism to differentiate the two sources.

This thus affects the assumed direction of sound and creates an image shift. This can pose as a threat for speech within rooms as the focus is directly on the speaker (refer to figure 4.45 & 4.46). However, according to (Autodesk Ecotect 2010) humans can usually adapt to this kind of noise from the direct rays, except if such rays occur in large quantity.

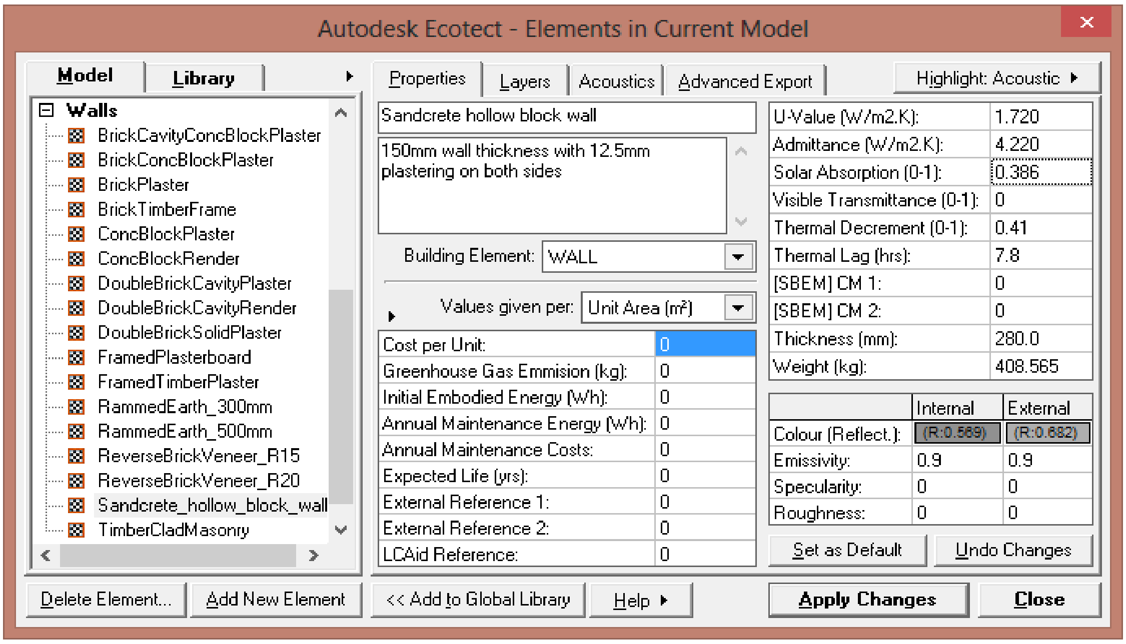

Figure 4.44. Properties Of 150mm Sandcrete Block Wall Simulation (**Source.** Author, 2017).

The simulation also generates another type of ray known as the Masked which is color-coded in deep blue (Refer to Figure 4.45 & 4.46). This type of reflections poses good for human consumption as the poses no threat to the auditory mechanism. The rays when generated at relatively low sound, could become Masked completed by the direct sound and reflections (Autodesk Ecotect 2010). Lastly, the Reverb rays was released from the simulation of the 150mm sandcrete hollow block with weak infill, the color-coding for the reverb is sky blue (Refer to figures 4.45 & 4.46). These rays do not significantly contribute to the perception of the direct sound, but however it present the users of such with a spatial perception of the rooms used as with the case of the 1004 estates and C&N apartments.

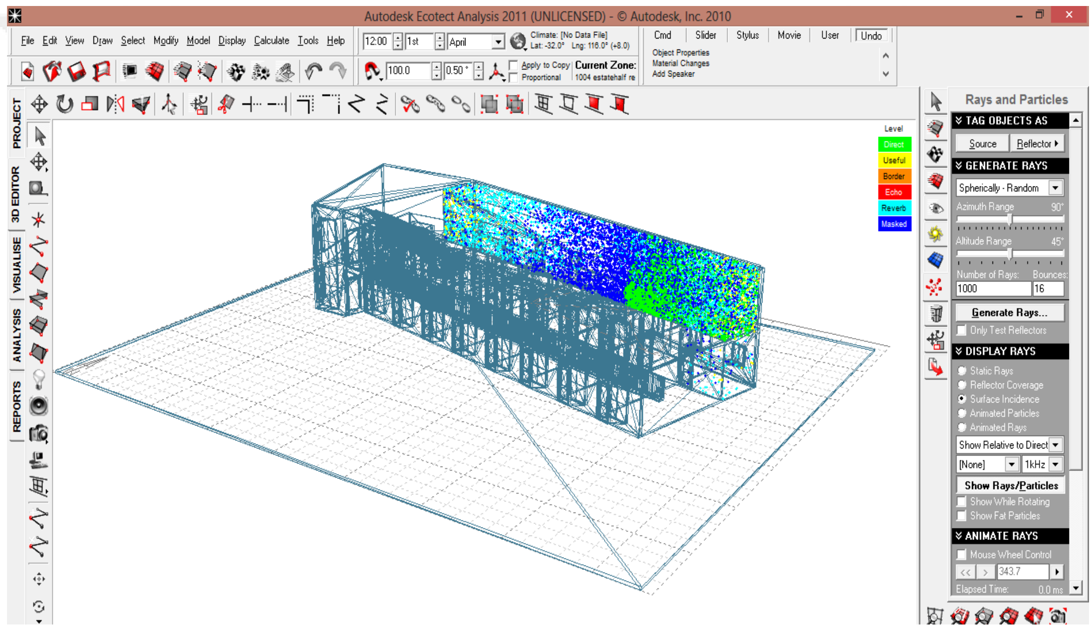

Figure 4.45. Rays Generated From The 150mm Sandcrete Block Wall Simulation At 1004 Estates (**Source.** Author, 2017).

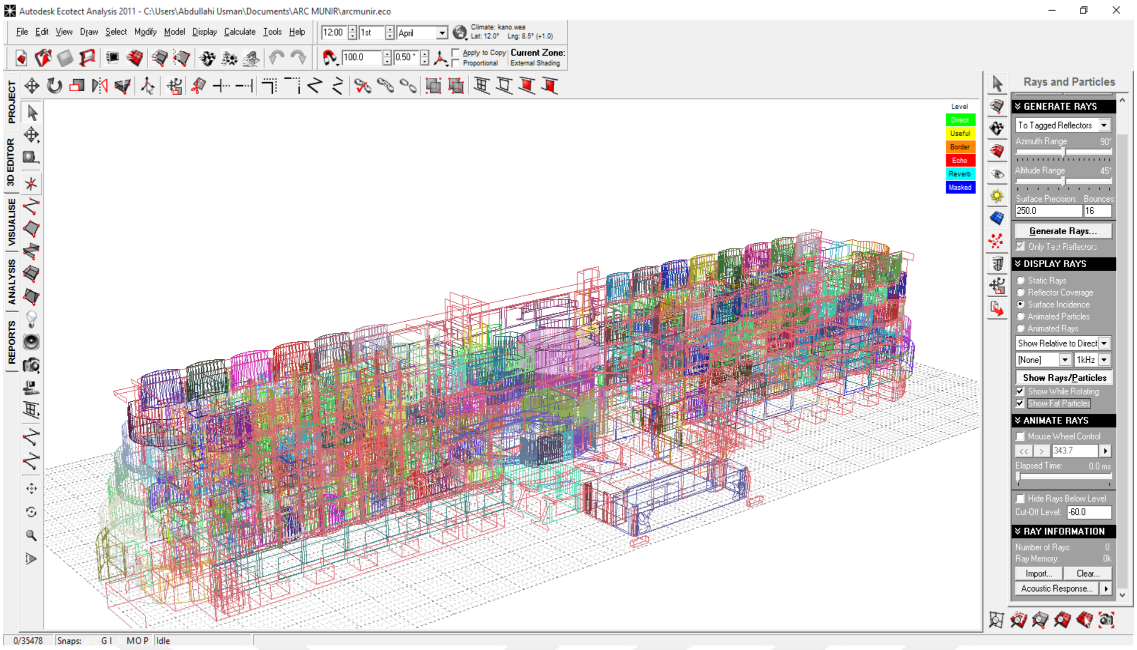

Figure 4.46. Rays Generated From The 150mm Sandcrete Block Wall Simulation at C & N apartments (**Source.** Author, 2017).

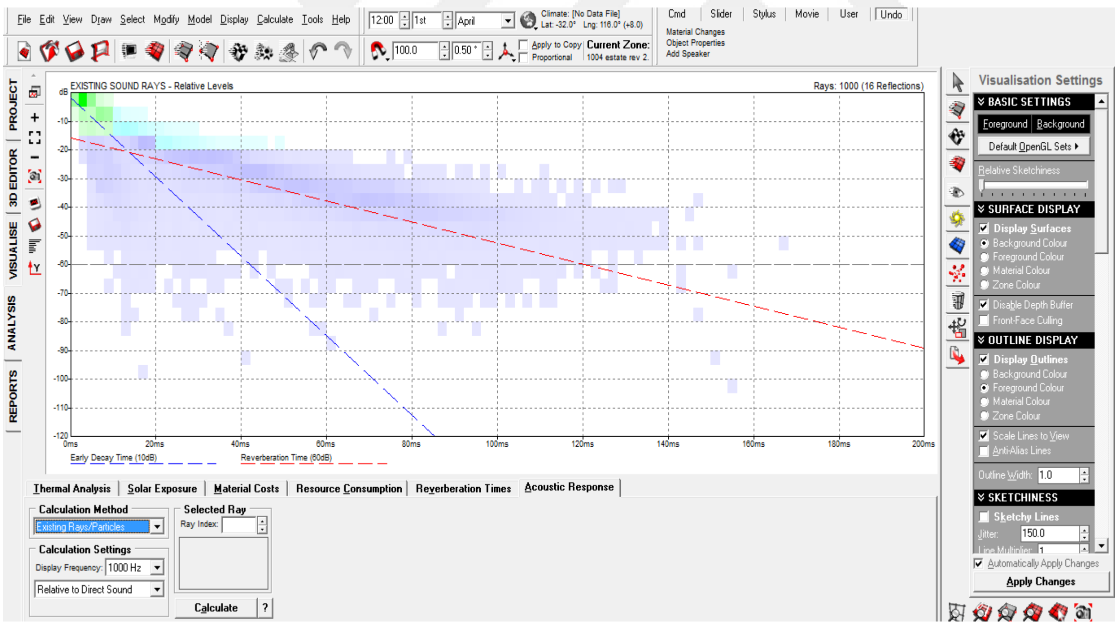

Figure 4.47. Graph For 150mm Sandcrete Block Wall Simulation At 1004 Estates (**Source.** Author, 2017).

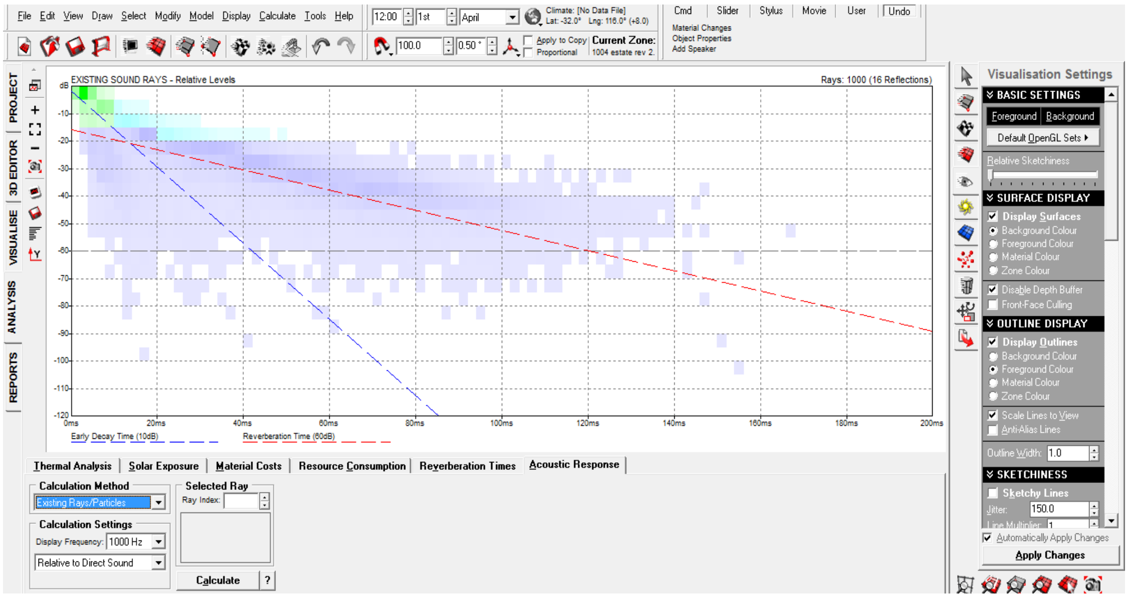

Figure 4.48. Graph For 150mm Sandcrete Block Wall Simulation at C & N apartments (**Source.** Author, 2017).

- **Sound Absorption and Reverberation Time**

In order to identify the best sound level that can be achieved throughout the rooms, various types of wall panels were proposed and simulated. The sound absorption in both floors was estimated with the implementation of the various proposed wall panels and compared with the 225mm hollow block wall in the case of the baseline model wall. Description of the tested walls and the simulation results are provided in the following subsections. Table (4.7 & 4.8) shows selected materials built for Ecotect simulation, that was chosen based on its sound absorption value, as it has been shown in buildings. Five types of construction materials developed or modified were used in this stage and attached each time in a different order to find out if this component has an effect on indoor sound. The coded materials are built up in order to get a better material that allows sound transfer through external and internal layers of one complete surface such as a wall. Table (4.7 & 4.8) provides the proposed walls explaining their simulated sound absorption values.

From the figure below it can be seen that by applying wall P2, an improvement of 9.35% in C & N apartments and 9.56% in 1004 apartments of total sound absorption can be achieved. By applying wall P3 a reduction of 21.30% is achieved in C & N apartments and 19.28% in 1004 apartments. This will however give a clue to the effect of insulation material in the reduction of the sound absorption in the building. Wall panels P4 and P6 show slight improvement in reduction, sound absorption 21.23% and 22.46% in C & N apartments and 20.28% in 1004 apartments respectively, as compared to wall P3 with a value of 0.44% and 0.48% respectively. Also from the result, it can be observed that Wall P5 shows greater improvement in sound absorption with a value of 26.18% in C & N apartments and 27.01% in 1004 apartments. These percentages are based on the average of the sound absorption at various frequencies for both C & N apartments and 1004 apartments as shown in tables 4.7 & 4.8 and figures 4.49 & 4.50 below.

Table 4.7. Sound Absorption At Different Frequencies Of Simulated Wall Panels At 1004 Estates (**Source.** Author, 2017).

FREQ.	Panel 6	Panel 5	Panel 4	Panel 3	Panel 2	Panel 1
63Hz:	182.373	182.373	182.373	182.373	182.373	182.373
125Hz:	606.804	581.435	443.616	442.564	286.861	217.426
250Hz:	1076.525	1051.156	997.501	856.527	572.473	436.759
500Hz:	1456.205	1430.836	1314.058	1212.009	907.967	837.48
1kHz:	1643.811	1618.442	1593.193	1408.032	1013.514	878.851
2kHz:	1251.395	1226.026	1087.155	987.211	822.039	787.321
4kHz:	1085.923	1060.554	986.911	702.858	881.706	1355.128
8kHz:	1244.088	1218.719	924.145	668.497	829.461	1218.719
16kHz:	1136.047	1110.678	805.583	805.583	742.46	1121.198

Table 4.8. Sound Absorption At Different Frequencies Of Simulated Wall Panels At C & N Apartments (**Source.** Author, 2017).

FREQ.	Panel 6	Panel 5	Panel 4	Panel 3	Panel 2	Panel 1
63Hz:	185.233	185.233	185.233	185.233	185.233	185.233
125Hz:	609.664	584.295	446.476	445.424	289.721	220.286
250Hz:	1079.385	1054.016	1000.361	859.387	575.333	439.619
500Hz:	1459.065	1433.696	1316.918	1214.869	910.827	840.34
1kHz:	1646.671	1621.302	1596.053	1410.892	1016.374	881.711
2kHz:	1254.255	1228.886	1090.015	990.071	824.899	790.181
4kHz:	1088.783	1063.414	989.771	705.718	884.566	1357.988
8kHz:	1246.948	1221.579	927.005	671.357	832.321	1221.579
16kHz:	1138.907	1113.538	808.443	808.443	745.32	1124.058

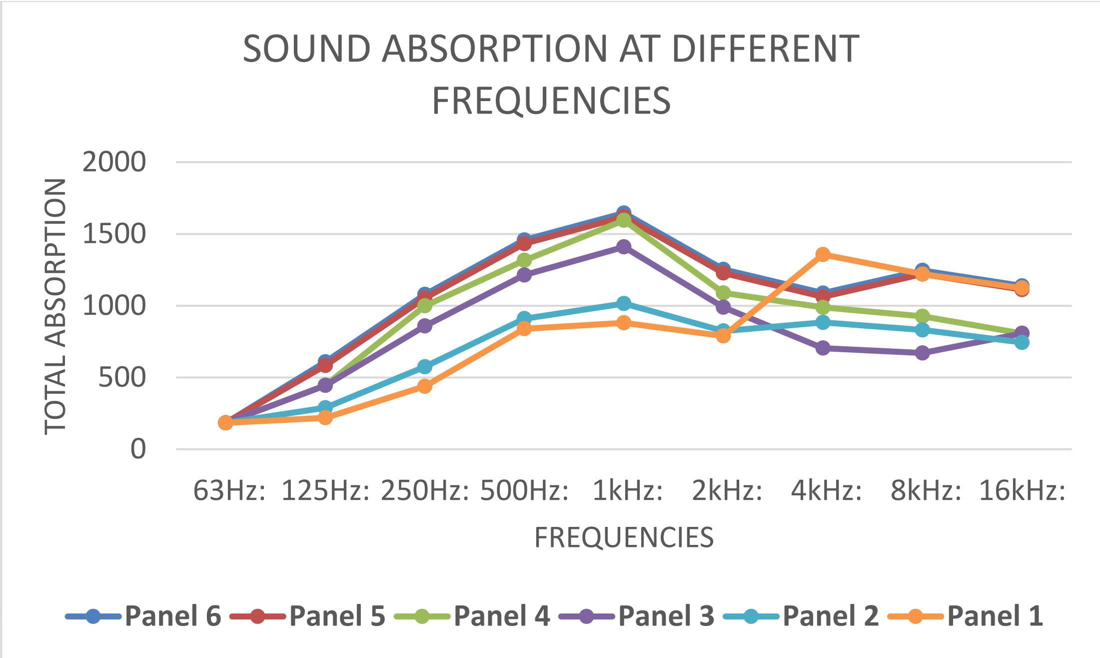

Figure 4.49. Sound Absorption At Different Frequencies Of Simulated Wall Panels At 1004 Estates (**Source.** Author, 2017).

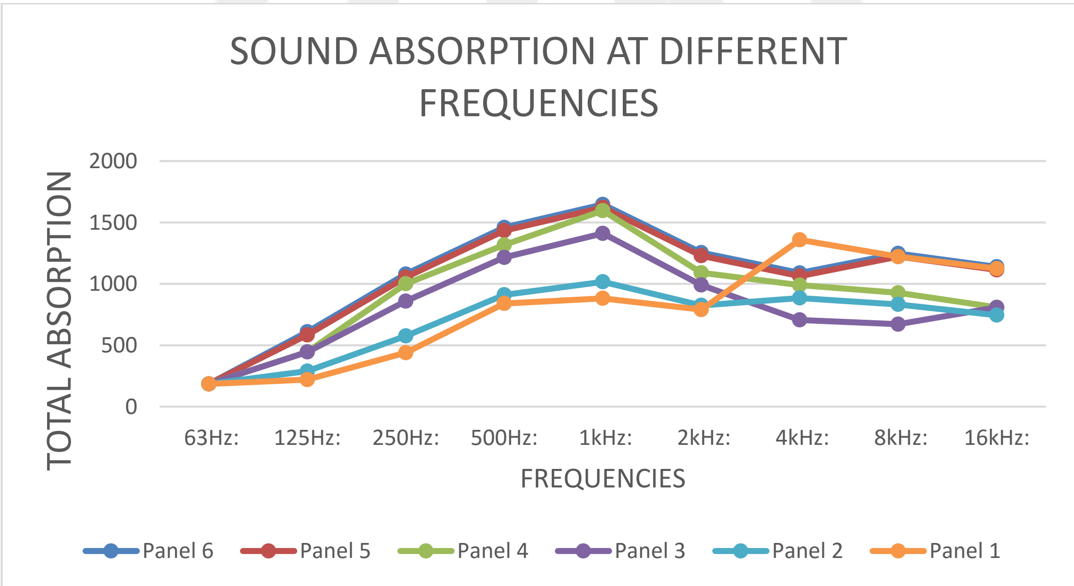

Figure 4.50. Sound Absorption At Different Frequencies Of Simulated Wall Panels At C & N Apartments (**Source.** Author, 2017).

Table 4.9. Reverberation Time At Different Frequencies Of Simulated Wall Panels At 1004 Apartments (**Source.** Author, 2017)

	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
125Hz:	1.393	1.64	2.18	2.18	3.3	4.19
250Hz:	0.463	0.71	0.76	0.91	1.41	1.81
500Hz:	0.203	0.45	0.51	0.58	0.84	0.92
1kHz:	0.113	0.36	0.37	0.46	0.74	0.88
2kHz:	0.303	0.55	0.65	0.74	0.91	0.96

Table 4.10. Reverberation Time At Different Frequencies Of Simulated Wall Panels At C & N apartments (**Source.** Author, 2017)

	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
125Hz:	2.113	2.36	2.9	2.9	4.02	4.91
250Hz:	1.183	1.43	1.48	1.63	2.13	2.53
500Hz:	0.923	1.17	1.23	1.3	1.56	1.64
1kHz:	0.833	1.08	1.09	1.18	1.46	1.6
2kHz:	1.023	1.27	1.37	1.46	1.63	1.68

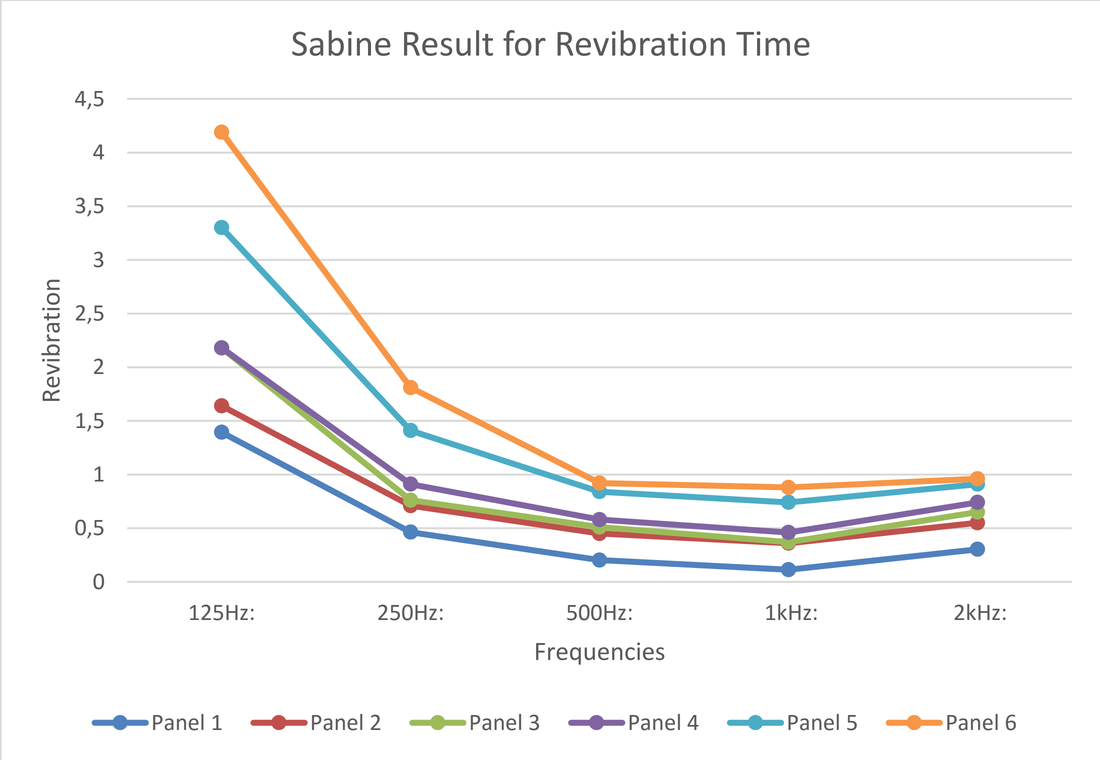

Figure 4.51. Reverberation Time At Different Frequencies Of Simulated Wall Panels At 1004 Apartments (**Source.** Author, 2017)

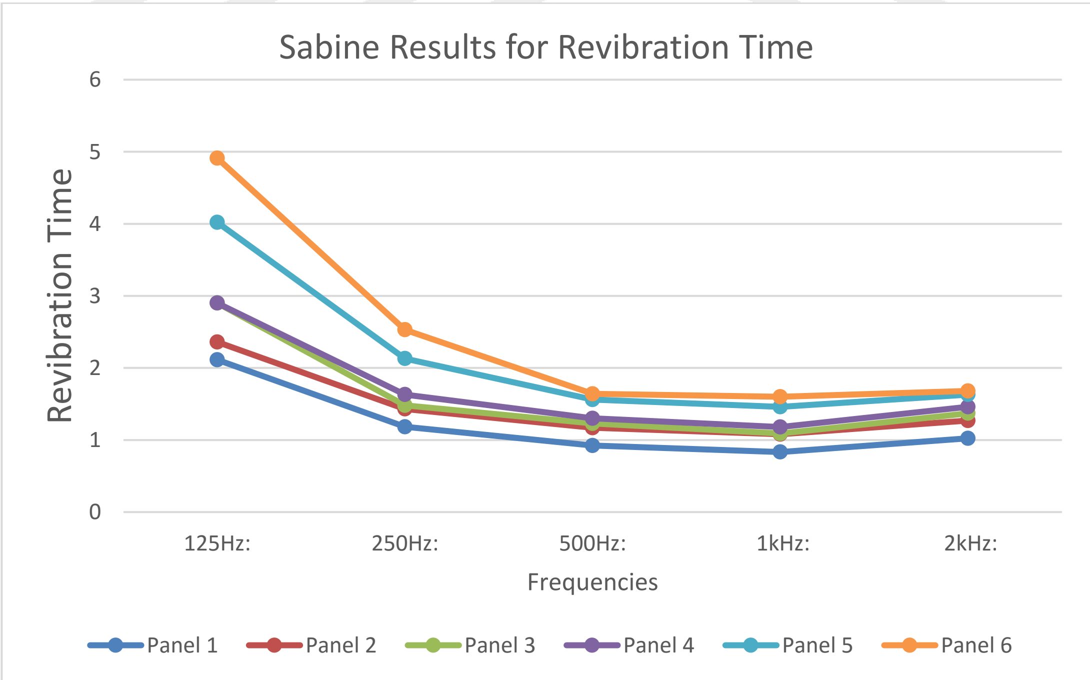

Figure 4.52. Reverberation Time At Different Frequencies Of Simulated Wall Panels At C & N apartments **(Source.** Author, 2017)

This chapter discussed case study results of three instruments. First, visual survey ,which identified the physical properties of the building structures, secondly the questionnaire survey provided data on user response on the level of noise in case study buildings. Lastly, the simulation provided a solution for improving wall acoustic response by applying acoustic panels in order to improve occupant aural comfort. The following chapter will provide a summary and discussion of findings and give a detailed conclusion.

CHAPTER 5

CONCLUSION

This chapter gives a more detailed explanation on issues relating to the data presentation and analysis which helps in articulating those issues emanating from the analysis with respect to their implications on the subject of investigation and a detailed general conclusion of the research.

From the visual survey conducted in two case studies, it can be observed that there are so many sources of noise from the outside buildings which is contributing a lot in noise disturbance during the day. However the noise reduces during the night and this explains that, the source of noise is as a result of human activities in the day. Also, it has been observed that there is low application of building materials and finishes with good acoustic properties. This was further supported from the questionnaire as respondents complained about noise from neighbouring apartments and rooms.

From the questionnaire distributed Firstly, it is observed that the 'noisiness' of the indoor environment of an apartment is significantly correlated to the sensitivity of the inhabitants. The 'noisiness' perception tends to reduce for people who are less sensitive to noise. The cognitive response example, considering noise as a parameter of the living environment, is also found significantly correlated to 'noisiness' of the apartment. It is observed that respondents who rated noise as a parameter of the living environment showed a higher incidence of finding their apartment noisy.

Secondly, observation from this study shows that the inhabitants who found the indoor noise environment noisy felt that the noisiest period of the particular major noise source is mostly during the daytime (6am to 6pm) rather than in the evening and night time. Besides, activity disturbance was found correlate to the 'noisiness' of the apartment. Sleep disturbance was found higher for inhabitants who were disturbed by a particular major noise source.

Futhermore, a one way Anova test shows that the rating of the 'noisiness' of the indoor aural environment is not influenced differ by gender, age, level of the apartment of residence. Length of residence and the belief in the importance of noise as an important aspect. The noisiness of the indoor environment was rated differently by inhabitants with different noise sensitivity and the people who stayed in different types of the apartment (for example, 3 room apartment, 4 room apartment, etc. Later on it was observed from a t-test, that the mean rating of the indoor noise environment by inhabitants residing in a 3 rooms apartment and 4 rooms apartment significantly differs at an alpha level of 0.05. A one way Anova test showed that the mean background noise levels across different types of apartments are significantly different ($p<0.05$). The A-weighted mean background noise level of a 3 room apartment (59 dB) was found lower compared to that of the 4 rooms apartments (61 dB).

While running simulations, it was discovered that a change in walls to improve sound absorption is achievable. Window shading can be used in combination with efficient window systems to further reduce sound from external sources. However, the appropriate window must be selected taking into consideration its material and design. The residential building simulations of the different wall panels offered encouraging good results, even though there is improvement of up to 50% for sound absorption it will also be professional for one to look into cost for each panel simulated. External Noise was taken into consideration and internal blinds; these reduced sound transmission by 19%, However, since the blinds are essentially managed by the building occupants there is the option of not being used for any other reasons such as day lighting and so on.

From the previous chapter, it can be seen that by applying wall P2, an improvement of 9.35% in C & N apartments and 9.56% in 1004 apartments of total sound absorption can be achieved. By applying wall P3 a reduction of 21.30% is achieved in C & N apartments and 19.28% in 1004 apartments. This will however give a clue to the effect of insulation material in the reduction of the sound absorption in the building. Wall panels P4 and P6 show slight improvement in reduction, sound absorption 21.23% and 22.46% in C & N apartments and 20.28% in 1004 apartments respectively, as compared to wall P3 with a value of 0.44% and 0.48% respectively. Also from the result, it can be observed that Wall P5 shows greater improvement in sound absorption with a value of 26.18% in C & N apartments and 27.01% in 1004 apartments. These percentages are based on the average of the sound absorption at various frequencies for both C & N apartments and 1004 apartments

Conclusively, this research assesses the aural comfort of high-rise apartment dwellers in Lagos, Nigeria and endeavoured to propose the solution of noise problems in this apartment.

This research first identified various High-Rise residential apartments in Nigeria and using purposive sampling two case studies. Selected users of these two cases were given a questionnaire form in order to understand the level of noise and aural discomfort they are experiencing in their own apartments. The findings from this research discussed in this chapter proved that noise and aural discomfort exist in these high-rise apartments. This was obtained from visual survey and questionnaire survey. However, the simulation results proved that retrofitting those high-rise apartments with acoustic wall panel will definitely improve the aural comfort of the users. In order to maximize the level of aural comfort in high-rise apartments other building components such as; floors, ceiling, doors and windows material and surface textures need to be considered. Other planning considerations include distance from road traffic or providing buffer such as trees between the buildings and the road. This will definitely contribute a lot in preventing external noise into the apartments.

Building acoustic calculation is especially beneficial at the early stage of design to enable designers to make informed decisions on the type of materials for finishes used in the operational stage of the buildings. This will not only prevent poor building performance due to noise disturbance, but also adapt building users to the mode of interior designs of high-rise apartments in Lagos, Nigeria.

With the current economic challenge facing the world, it is recommended that sustainable methods such as early design stage simulations will be more important for the future buildings. Therefore, building professionals should work together in an integrated approach, focusing on how to improve the aural comfort of buildings, enforcing environmental and Noise regulation policies and encourage the development of more efficient integrated and accessible simulation techniques for predicting and improving the future environment.

1.) Sufficient account must be taken in the regional building materials, especially to the building's form and configuration as the sound transmission is the most important parameter in this residential acoustics.

2.) It is important to eliminate the sound transfer rate between the building envelop and surrounding environment in ways of insulations, blinding and so on for aural comfort.

3.) A high plant coverage, which serves as a buffer on the road side is advocated in order to cut down the interference.

The challenge for this research has been to check the level of noise disturbance in the selected case studies and to propose measures in which such buildings can be retrofitted with better materials for aural comfort. So further research can be;

1.) Study on the effect of each individual building element such as floor and Glazing by modifying various properties of that element to find out the contribution of each property of that element in reducing or increasing noise transfer within a building.

2.) This study as stated earlier is only restricted to Lagos, Nigeria so further research can be done in other cities with different level of building structures and external linings

3.) There is need to replicate this research on another building typology to confirm the effect of the simulated wall strategies in such building

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APPENDIX I - NOISE QUESTIONNAIRE SURVEY

Dear Respondent;

I am doing a Master's degree in Architecture at Yasar University, Turkey. This questionnaire aims to find out your response on Noise in high rise residential buildings in order to retrofit buildings and make them comfortable without any Noise disturbance.

I am hereby asking you to kindly fill all the questions which are very important to my research and ensure you that all the data in this questionnaire will be used in research field only and will be treated privately and confidential.

Please tick the answer that you believe is the most appropriate

SECTION A: PERSONAL PROFILE

1. Which category of age group do you belong to?

0< 20 Yrs { } 20-30 Yrs { } 031-40 Yrs{ } 041-50 Yrs { }

051-60 Yrs { } 61-70 Yrs { } > 70 Yrs { }

2. What is the highest education level you have achieved?

No formal education **{ }** Secondary **{ }** Higher Institution Degree **{ }** Post graduate **{ }**

3. How many years have you been living in this apartment? { } years

4. What is the type of apartment you are living in and what is the total number of occupants?

Total no. of Occupants: **{ }** No. of young Children (Pre/Pri Sch): **{ }**

5. Do you generally work in a noisy environment? Yes **{ }** No **{ }**

6. How would you rate your sensitivity to noise?

(1) Not Sensitive **{ }** (2) A little Sensitive **{ }** (3) Sensitive **{ }** (4) Very Sensitive **{ }** (5) Extremely Sensitive **{ }**

SECTION B: SUBJECTIVE EVALUATION

1. How would you rate noise as an important aspect of your living environment?

1 (Least) { } 2 (Average) { }3 (Most) { }

2. In general, how would you rate the noise level in your living environment (Surrounding area)?

(1) Very Quiet { } (2) Quiet { } (3) Acceptable { } (4) Noisy { } (5) Very Noisy { }

3. In general, how would you rate the noise level in your apartment?

(1) Very Quiet { } (2) Quiet { } (3) Acceptable { } (4) Noisy { } (5) Very Noisy { }

4. In general, what is the extent of comfort with respect to sound/noise In your apartment?

(1) Very Comfortable{ } (2) Comfortable { } (3) Neither comfortable nor uncomfortable{ } (4) Uncomfortable{ } (5) Very Uncomfortable { }

How do you rate the noise in your apartment made by your neighbours?

5. Upstairs:

(1) Not at all loud { } (2) A little loud { } (3) Loud{ } (4) Very loud{ } (5) Extremely loud) { }

6. Downstairs:

(1) Not at all loud{ } (2) A little loud{ } (3) Loud{ } (4) Very loud{ } (5) Extremely loud{ }

7. Adjacent right:

(1) Not at all loud{ } (2) A little loud{ } (3) Loud { } (4) Very loud{ } (5) Extremely loud{ }

8. Adjacent left:

(1) Not at all loud{ } (2) A little loud{ } (3) Loud (4) Very loud (5) Extremely loud

9. What is the nature of noise made by your neighbours?

(1) Low pitched { } (2) Hi pitched { } (3) Impulsive { }

10. Which area in your apartment do you find noisy?

{ } Master bedroom { } Common bedroom { } Living room { } Study room { } Dining room { } All areas { }

11. What is the type of noise made by your neighbours?

(1) Neighbours Speech{ } (2) Music related noise{ } (3) Speech from TV/video{ } (4) Children Playing noise{ } (5) Furniture dragging{ } (6) Footsteps noise { } (7) Dropping objects{ } (8) Renovation { } (9) Appliance noise (state i.e. washing machine) { } (10) Others { } (11) None { }

12. Do you consider this noise as disturbing? Yes { } No { }

APPENDIX II. STATISTICAL ACOUSTICS-RESIDENTIAL APARTMENTS

STATISTICAL ACOUSTICS - RESIDENTIAL APARTMENTS					
STATISTICAL ACOUSTICS - RESIDENTIAL APARTMENTS					
Model: C:\Users\Ayısha Mamud\Documents\ARC ENEH\SIM.eco					
Volume: 8007.770 m3					
Surface Area: 2692.810 m2					
Occupancy: 510 (510 x 100%)					
Optimum RT (500Hz - Spe ch): 1.08 s					
Optimum RT (500Hz - Music): 1.77 s					
Volume per Seat: 15.702 m3					
Minimu (Speech): 5.107 m3					
Minimum (Music): 8.979 m3					
Most Suitable: Millington-Sette (Widely varying)					
Selected: Sabine (Uniformly distributed)					
	TOTAL	**TOTAL**	**TOTAL**	**TOTAL**	**TOTAL**
	ABSPT.1	**ABSPT.2**	**ABSPT.3**	**ABSPT.4**	**ABSPT.5**
FREQ.	**Panel 1**	**Panel 2**	**Panel 3**	**Panel 4**	**Panel 5**
63Hz:	183.803	183.803	183.803	183.803	183.803
125Hz:	582.865	445.046	443.994	288.291	218.856
250Hz:	1052.586	998.931	857.957	573.903	438.189
500Hz:	1432.266	1315.488	1213.439	909.397	838.91
1kHz:	1619.872	1594.623	1409.462	1014.944	880.281
2kHz:	1227.456	1088.585	988.641	823.469	788.751
4kHz:	1061.984	988.341	704.288	883.136	1356.558
8kHz:	1220.149	925.575	669.927	830.891	1220.149
16kHz:	1112.108	807.013	807.013	743.89	1122.628

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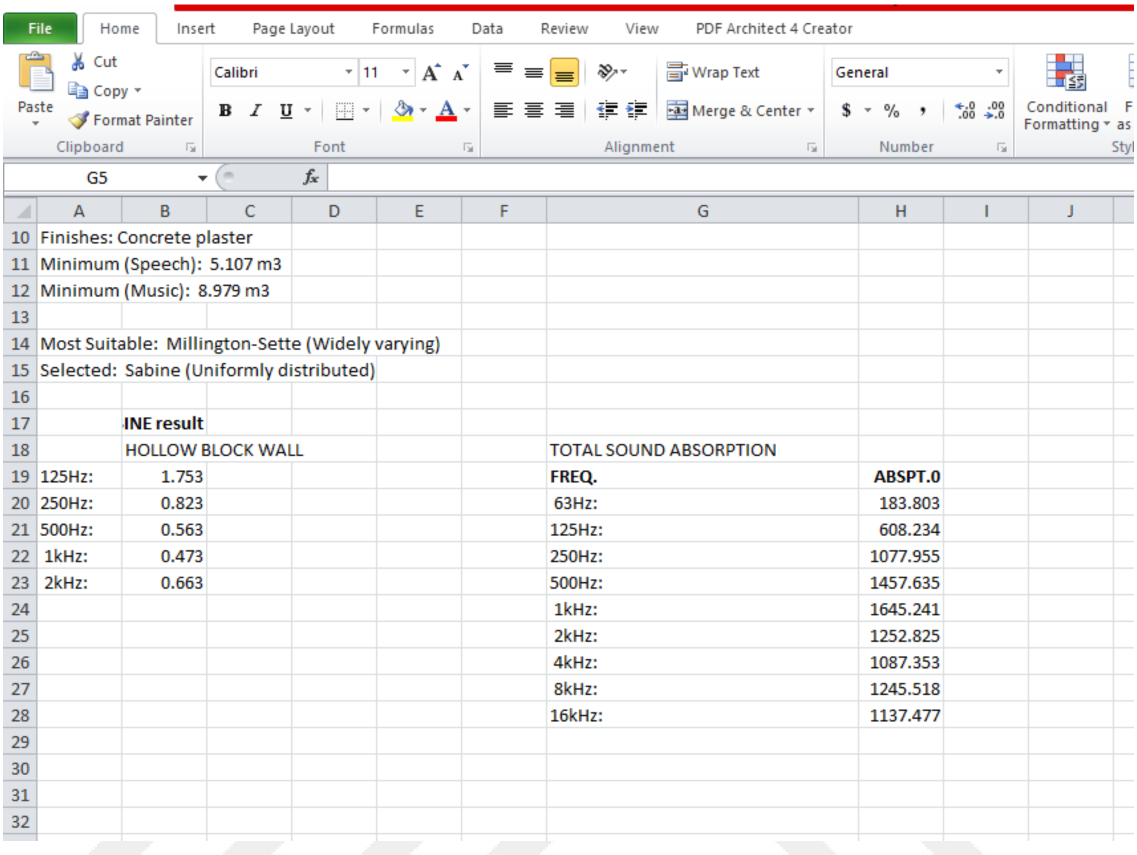
16kHz:	1112.108	807.013	807.013	743.89	1122.628

APPENDIX III. DEFAULT HOLLOW BLOCK SIMULATION.



	A	B	G	H
10	Finishes: Concrete plaster			
11	Minimum (Speech): 5.107 m3			
12	Minimum (Music): 8.979 m3			
13				
14	Most Suitable: Millington-Sette (Widely varying)			
15	Selected: Sabine (Uniformly distributed)			
16				
17		INE result		
18		HOLLOW BLOCK WALL	TOTAL SOUND ABSORPTION	
19	125Hz:	1.753	**FREQ.**	**ABSPT.0**
20	250Hz:	0.823	63Hz:	183.803
21	500Hz:	0.563	125Hz:	608.234
22	1kHz:	0.473	250Hz:	1077.955
23	2kHz:	0.663	500Hz:	1457.635
24			1kHz:	1645.241
25			2kHz:	1252.825
26			4kHz:	1087.353
27			8kHz:	1245.518
28			16kHz:	1137.477
29				
30				
31				
32				