THE NOISE REDUCTION THROUGH LECTURE HALL'S WALL

LEE KWOK SENG

A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons.) Mechanical Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2011

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : *Lee Kwok Seng*

Name : Lee Kwok Seng

ID No. : 07UEB03979

Date : 14th April 2011

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"THE NOISE REDUCTION THROUGH LECTURE HALL'S WALL"** was prepared by **LEE KWOK SENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechanical Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Mr. King Yeong Jin

Date : ___________________________

ACKNOWLEDGEMENTS

My deepest thanks are directed to my final year project (FYP) supervisor, Mr. King Yeong Jin of Universiti Tunku Abdul Rahman(UTAR). Throughout the study, he had giving me many advices and support. Besides that, I would like to thank him for helping me revised my thesis throughout, giving valuable comments on this thesis, and correct me on whichever part that I had made mistake.

Besides that, I would like to thank my course mate, Mr. Lim Koo Ho, Mr. Eric Lim, and Mr. Tee Kit Siang for their contribution in this study. Without their assist, my work will not be that smooth.

In addition, I would also like to express my gratitude to my loving parent for their patience and support. I appreciate help from everyone who had contributed to the successful completion of this project.

THE NOISE REDUCTION THROUGH LECTURE HALL'S WALL

ABSTRACT

The lecture hall is an auditory-verbal environment, however the main problem of it is the noise. The complaint of intrusive noise from outside (corridor) and noise through a wall separating adjoining lecture halls ruin the quiet of the lecture hall, and the lecture is interrupted. Thus, the aim of this study is to identify the degree of sound transmitted through the lecture hall wall, so that we can attenuate the noise from adjacent room, and corridors as well.

With reasonable assumption which our lecture hall wall is built of concrete, which have sound transmission class(STC) value at about 41, which is also mean the sound reduction index. The sound transmission reduction TL of the wall is be then verified by taking sound pressure level reading at various point. 3 cases have been set out for the project, which are case where all door are closed, then middle door is opened, else doors closed, and lastly, case where the backdoor of both room are opened, else doors closed.

After the experiment, the result gathered found that the sound reduction level is at ranged of 30-35dB during 90dB's noise source is turned on. Since the initial assumption of the wall material was not correct, so we have to check for another kind of wall material which have similar sound reduction level to that. Standard Interior Wall with 5/8" drywall on both sides with insulation come into conclusion. The sound distribution map of different case will be shown, so that we are able to see how sound been transmitted under different case. Then recommendations are given on how to improve the sound reduction level of the wall.

The conclusion before I finish the project is that, all the objective of the project have been achieved. Recommendation to the juniors also given at the end of this project part.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

TL	Sound Transmission loss
SPL	Time-weighted Sound Pressure Level (F, S, I)
Lmax	Maximum Time-weighted Sound Pressure Level
Lmin	Minimum Time-weighted Sound Pressure Level
Leq	Time-Average Sound Pressure Level
f	frequency
L	stud spacing
H	separation distance between panels
ASTM E90	*Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions*.
ASTM E413	*Classification for Rating Sound Insulation(1987)*
ASTM C 423	Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method
ASTM E 1414	Airborne Sound Attenuation Between Rooms Sharing a Common Ceiling Plenum
ASTM E 336	Method for measurement of airborne sound insulation in buildings (1990)
ASTM E 497	Installing Sound-Isolating Lightweight Partitions
ISO 11654	Sound absorbers for use in buildings -- Rating of sound absorption(1997)
ISO 140-3	Measurement of sound insulation in buildings and of building elements

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview of the world of acoustic

In today's architectural environment, good acoustic design is no longer a luxury, but a necessity, especially for educational facility. Such an environment must facilitate a wide variety of activities, the most crucial of which is learning. Unfortunately, the acoustics in many educational facilities are less than acceptable. In some cases, the acoustic conditions detract from the educational experience and hinder the learning process. The influence of poor acoustics on the students and teachers can be significant if we do not take good care of it. That is why question of the acoustics in classrooms has been researched internationally in recent years.

A successful acoustical design is based on the understanding of the sound, and knowing how to utilize building materials, system design and technologies Recognizing the trend of sub-par acoustics, the American National Standards Institute (ANSI) recently introduced a standard for the acoustical design of schools, S12.60-2002, "Acoustical Performance Criteria, Design Requirements and Guidelines for Schools." The new standard is in effect and includes several requirements focusing on noise isolation in educational facilities. The standard is broken down into sections outlining guidelines for background noise levels, Reverberation Time, Sound Transmission Class, and Impact Isolation Class.

1.2 The science of sound

In general, sound is an invisible vibration. It originated from the source of the sound such as loudspeakers, speech, etc, then radiates in waves in all directions from a point source until it encounters obstacles like walls or ceilings. Two characteristics of these sound waves are of particular interest to us in architectural acoustics: intensity and frequency. Intensity is a physical measurement of a sound wave that relates to how loud a sound is perceived to be, while the importance of frequency arises when a sound wave encounters a surface, which the sound will react differently at different frequencies. When sound strikes a surface, a number of things can happen, including:

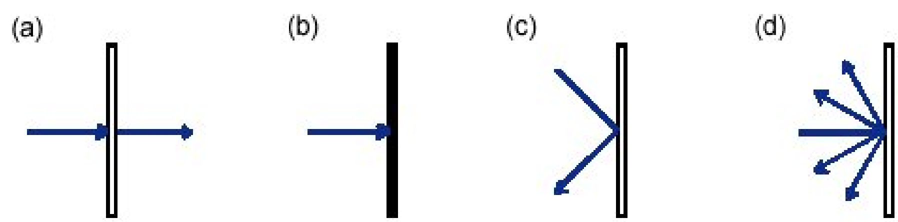


Figure 1-1: Sound/Surface Interaction: (a) transmission, (b) absorption, (c) reflection, (d)diffusion

Table 1-1: The description of sound/surface interaction

Sound/Surface Interaction	**Description**
Transmission	The sound passes through the surface into the space beyond it, like light passing through a window.
Absorption	The surface absorbs the sound like a sponge absorbs water
Reflection	sound strikes the surface and changes direction like a ball bouncing off a wall.
Diffusion	The sound strikes the surface and is scattered in many directions, like pins being hit by a bowling ball.

However, it did not restrict on one form only, several of these actions can occur simultaneously. For instance, a sound wave can, at the same time, reflected by and partially absorbed by a wall.

Basically, sound can be divided into two main nature, which are the airborne sounds such as speech, musical instrument sand loudspeakers (stereos, radios, TVs and home theatre systems) and the impact sounds such as footsteps, furniture moving and some appliances.

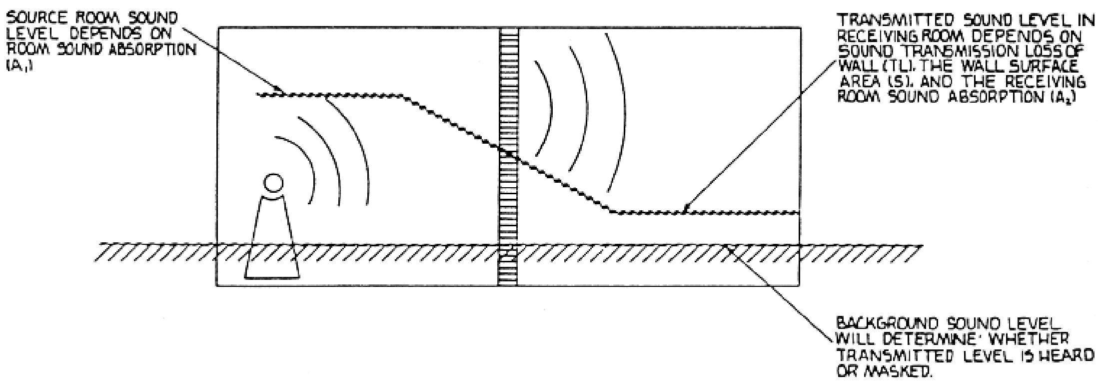


Figure 1-2: Essential elements of the sound transmission through wall

Sound is transmitted through most walls and floors by setting the entire structure into vibration. This vibration generates new sound waves of reduced intensity on the other side. The passage of sound into one room of a building from a source located in another room or outside the building is termed "sound transmission”. Sound can travel through many mediums such as air, liquid and gas states. Each medium represents a different manner in which sound is translated through that medium or between mediums. Basically, the degree of sound transmission (the amount of vibration or noise generation) through a medium is dependent on both frequency (range of sound) and amplitude (amount or degree of loudness).

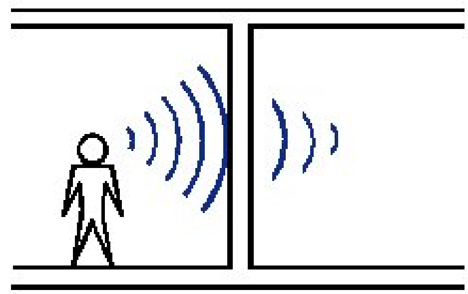


Figure 1-3: noise reduction between two spaces by a dividing wall

When sound comes in contact with a barrier, such as a wall, some of the energy from the vibrations transfers to the wall. The resulting vibrations in the wall itself then set the air in motion on the other side of the wall—creating more sound vibrations.

Usually, the mass, damping and stiffness of the barrier determine its resistance to the passage of sound waves. The greater the mass of the wall or floor, the more difficult it is to set up vibrations in it, and hence more difficult to transfer sound from one side to the other. IN our common life, we can see concrete walls and floors perform well in reducing the transmission of airborne sounds due to their mass.

1.3 Problem statement

Auditoria, music and drama performance halls, conference rooms, sports stadia, classrooms and, for that matter, all spaces large and small where audiences listen to some desired sound source or sources must satisfy certain fundamental acoustical requirements if they are to supply satisfactory listening conditions. So if there are too much noise incur in the lecture hall, it will:

- Affect the concentration of the students, they will be distracted.
- Increase lecturer fatigue, the quality of lecture is then been affected.
- Affect the teaching style of the lecturer.
- Affect speech recognition due to the noise
- Increase tension and discomfort, the lecturer may attempt to end their lecturer soon due to the unpleasant atmosphere.
- Affect on students' health and well being.

The lecture hall is an auditory-verbal environment, however the main problem of it is the noise. The complaint of intrusive noise from outside (corridor) and noise through a wall separating adjoining lecture halls ruin the quiet of the lecture hall, and the lecture is interrupted. Besides that, the sounds from the HVAC systems serving the space also creating undesired noise to the hall.

Thus, to get rid of it, and ensures the lecturer and students enjoy a reasonable degree of noise privacy, we have to control well on the amount of sound transmitted through the wall to the adjacent room. Because we know that once sounds pass through a partition, the actual intensity of the sounds that reach the ear may be less because drapes and furnishings installed in the room will absorb a portion of the sounds.

1.4 The importance of the study

The reason of why the study noise reduction is so important is due to few factors:

- Keep “inside noise in”
- Keep “outside noise out”
- Avoid interrupt the lecture being conducted at adjacent lecture hall.
- To protect privacy
- So that student will not be interrupted by unnecessary noise.
- Interference with communication
- Noise-induced hearing impairment
- Cardiovascular and psycho physiological effects
- Mental health effects
- Effects on performance
- Annoyance responses
- speech interference,
- disturbance of information extraction (e.g. comprehension and reading acquisition)
- message communication and
- annoyance.

1.5 Project Objectives

The objectives of this project have included:

a. To identify and study on the acoustic properties of our lecture hall
b. To study the level of noise which transmitted from adjacent lecture hall.
c. To investigate the degree of sound transmission through the lecture hall’s wall
d. To study sound insulation and absorption performed by the wall.
e. To investigate the effect of door and flanking on the acoustic properties of lecture hall.

1.6 Scope of study

To achieve the objectives stated above, I will have to conduct a few experiment on the lecture hall. For instance, to identify and study on the acoustic properties of our lecture hall, I will look for the Noise Criteria(NC) of the room. The NC obtained should not exceed certain limit, to make sure the speech intelligibility is not affected in the lecture hall.

While, for noise insulation and absorption study, I will calculate the sound transmission loss (TL) from source room to receiving room. From the reading, I will be able to investigate the degree of noise transmission by the wall.

The door is the critical factor in this project, because it will affect the sound transmission through the wall. Thus, I will set few different cases during the experiment, with the door closed or opened, and its affect on the sound transmission level.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, we will look into the sound intensity and decibel, sound transmission level (STC), field transmission level(FSTC), noise criterion (NC), and noise rating (NR).

In the first century B.C., the Roman architect Vitruvius explained in De architectura, his famous 10-volume treatise on architecture, that sound "moves in an endless number of circular rounds, like the innumerably increasing circular waves which appear when a stone is thrown into smooth water … but while in the case of water the circles move horizontally on a plane surface, the voice not only proceeds horizontally, but also ascends vertically by regular stages." While Vitruvius did not understand everything about sound, he was correct about this particular point.

2.2 Sound Intensity and Decibels

2.2.1 The relationship between sound intensities and subjective loudness.

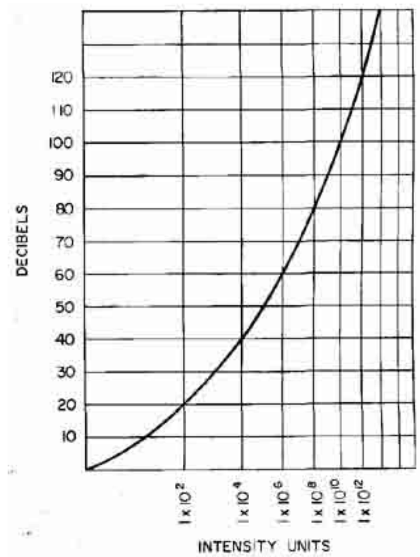


Figure 2-1 :The relationship between actual sound intensities and their subjective loudness

The diagram above is extracted from "Acoustical Materials and Acoustics - The Buildings and Architecture Guide", which compares the logarithmic system of measuring sounds with the decimal system we are all familiar with. Note that the logarithms measure the ratios of sound energy, not the actual values. That is, a 100 percent change in the logarithmic scale is equal to a 10-point change on the decimal scale. A 1000 percent change on the logarithmic scale is equal to a 20-point change on the decimal scale, and so on. So, if sound A is 100 times more intense than sound B, as measured by a sound-level meter, we will think sound B is only twice as loud. And if sound A is 1000 times more intense than sound B, we will think sound B is only three times as loud, and so on. This relationship between the subjective loudness of sounds and their actual sound intensities is true over the entire range of our hearing.

2.2.2 Human sensitivity to sound

Following is the a list of standard of sound level(dB) of our common life activities which extracted from 'Sound transmission properties-light weight concrete-information sheet no.8':

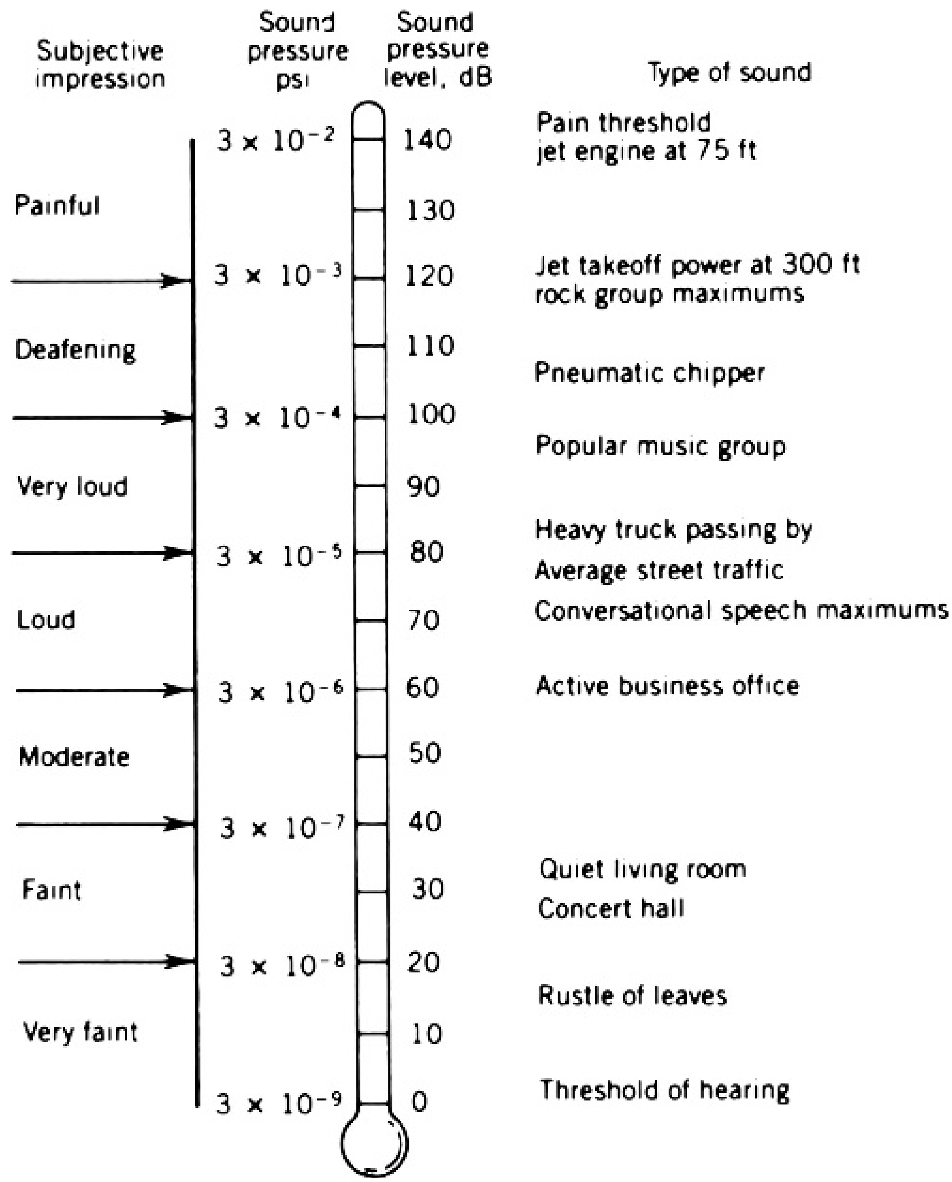


Figure 2-2: Sound level of activities and Human Response

2.2.3 Subjective human response to SPL changes

Table below is provided by National Gypsum in their Gold Bond® BRAND SoundBreak™ Gypsum Board, indicating the subjective human response to sound pressure level changes.

Table 2-1: Subjective human response to sound pressure level changes

Change for sound intensity level (dB)	Human sensitivity
1 dB	Generally not perceptible
3 dB	Just perceptible
5 dB	Clearly Noticeable
10 dB	Twice or Half as Loud
20dB	Four time as loud or ¼ as loud

We learn that humans' ears are very sensible to sound intensity change, for example if there is a change of 3 dB, it would be hardly perceptible, while a change of 5 dB would generally be noticeable to most people. An increase of 10 dB would sound twice as loud while a decrease of 10 dB would sound half as loud.

The following table is extracted from "Acceptable Noise-dBA Levels- The Engineering Toolbox", indicating the Acceptable Equivalent Sound Level-L_{eq} at some common locations in our common life. As you can see, for school classroom, if the equivalent sound level is over 35dBA, it will cause speech interference, communication disturbance.

Table 2-2: Effects of Equivalent Sound Level-Leq on our common life activities

Location	**Effects**	**Equivalent Sound Level - Leq (dBA)**	**Time of day**
Bedroom	sleep disturbance, annoyance	> 30	Night
Living area	annoyance, speech interference	> 50	Day
Outdoor living area	moderate annoyance	> 50	Day
	serious annoyance	> 55	Day
	sleep disturbance, with open windows	> 45	Night
School classroom	speech interference, communication disturbance	> 35	Day
Hospitals patient rooms	sleep disturbance, communication interference	> 30-35	Day and night

2.3 Affect on background noise on nature of speech communication

Background noise is always present, whether the listeners are aware of it or not, and its presence does help to increase the effective transmission loss of any particular wall construction. In any room in which extreme quiet is required, these back ground noise levels may themselves become a nuisance that must be dealt with rather than ignored. Table 6 indicates the nature of speech reception possible in various noise environments, as well as a person's ability to carry on telephone communications in that environment (William J. Cavanaugh, 1988)

Table 2-3: Nature of speech communication possible in various background sound levels

Background Sound Level, dBA	**Voice effort required and Distance**	**Nature of Communication possible**	**Telephone use**
55	Normal voice at 10ft	Relaxed communication	Satisfactory
65	Normal voce at 3ft Raised voice at 6ft Very loud voice at 12ft	Continuous communication	Satisfactory
75	Raised voice at 2ft Very loud voice at 12ft Shouting at 8ft	Intermittent communication	Marginal
85	Very loud voice at 1ft Shouting at 2-3ft	Minimal communication (restricted prearranged vocabulary desirable)	Impossible

As we can see, if the background sound level is within 55-65dBA, the telephone conversation level is considered as satisfactory, which mean that, we can still hear what the caller said. However, if the background sound level exceed 85dBA, the conversation become hardly impossible, and usually we will not be able to listen to the contents.

2.4 Acoustic in Lecture Hall

The study of lecturer hall acoustic is very important because a lecture hall is essential for creating a collaborative environment for learning. Following are the Maximum A-weighted steady background noise levels and maximum reverberation times in unoccupied, furnished learning spaces (Jerry G.Lilly). As you can see, the recommended noise level of a learning space should in range of 35-40dB.

Table 2-4: Maximum A-weighted steady background noise levels and maximum reverberation times in unoccupied, furnished learning space

Learning Space	**Maximum one-hour-average A-weighted steady background noise level, (dB)**	**Maximum reverberation time for sound pressure levels in octave bands, (s)**
Core learning space with enclosed volume <283m^3	35	0.6
Core learning space with enclosed volume >283m^3 and < 566m^3	35	0.7
Core learning space with enclosed volume >566m^3 and all ancillary learning spaces	40	depend

Besides that, according to the Germany Standard DIN 18041:2004-05, (Beuth Verlag GmbH, 2004) lecture halls noise limits should be between 35 dB(A) to 30 dB(A) are recommended.

Table 2-5: Maximum allowable background noise levels in accordance with DIN 18041

Requirements	**Maximum Noise Level**
Low	40 dB(A)
Middle	35 dB(A)
High	30 dB(A)

2.5 STC rating

Sound Transmission Class (STC) is the rating of airborne sound transmission and describes the degree of sound isolation provided by a home construction and materials. STC values are used to define the performance requirements for achieving a specified reduction in sound transmission from a source room to a receiving room.

STC (sound transmission class) is measured in a laboratory according to ASTM E90. Specimens are constructed in the opening between two special reverberation rooms constructed so that the only significant sound path is through the specimen. Transmission losses (TL) are measured at frequencies from 125 Hz to 4000 Hz and STC is calculated according to ASTM E413.

STC	**Performance**	**Description**
50-60	Excellent	Even loud sounds will be muffled.
40-50	Very Good, but not clear	Even a loud conversation is inaudible, but singing, musical instruments (especially brass instruments and the piano), and a radio or television set turned up loud can be heard distinctly enough to be annoying.
35-40	Good	Normal conversation is inaudible. Loud conversations can be heard, but the words are muffled and unintelligible.
30-35	Fair	A loud conversation can be heard through the partition, but much of the conversation will be unintelligible.
25-30	Poor	A conversation conducted in normal tones will be heard through the partition.
20-25	Very Poor	Low speech audible

Table 2-6: Transmission Class(STC) Table

If a wall partition or floor/ceiling assembly manage to reduce the overall incoming sound levels from 80dBA to 20dBA would have an STC rating of approximately 60.

Following is one of the STC testing of a wall, according to ASTM E90 and ASTM E413 (Albert Litvin and Harold W. Belliston, 1978)

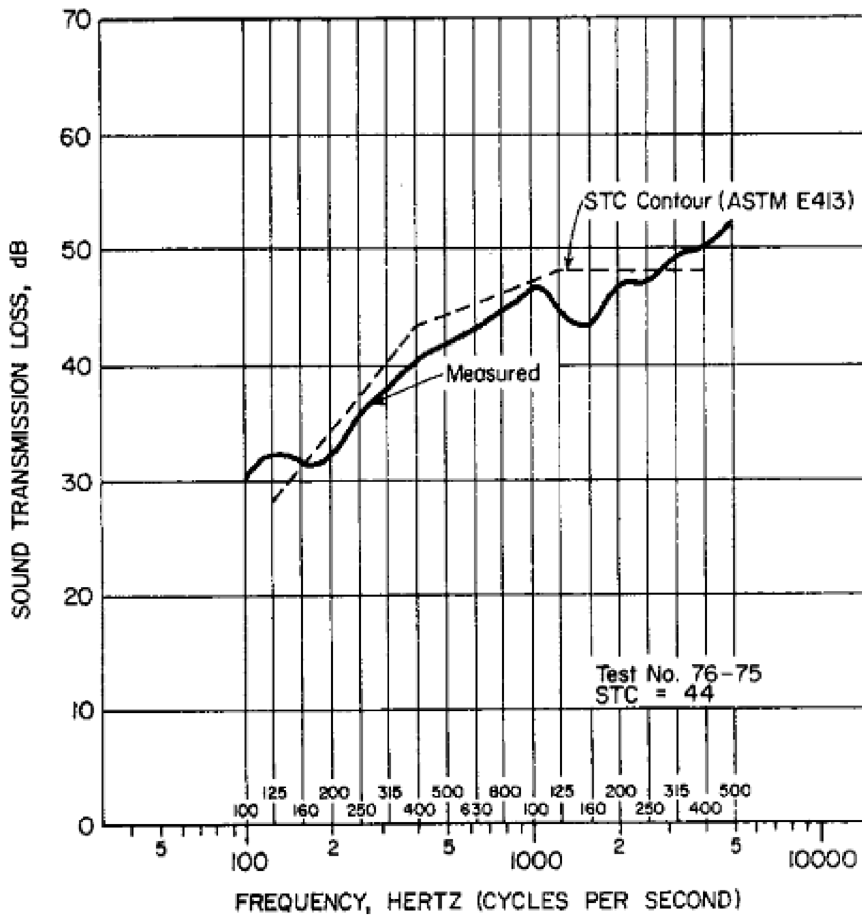


Figure 2-3: the STC testing result of a concrete wall

Following is the STC comparison of two wood stud wall systems, conducted by Stanley D. Gatland II , Manager of Building Science Technology CertainTeed Corporation. The first graph is the transmission loss, TL result of a wood studs which has STC of 29, while the second graph is the transmission loss, TL result of a wood studs which has STC of 46.

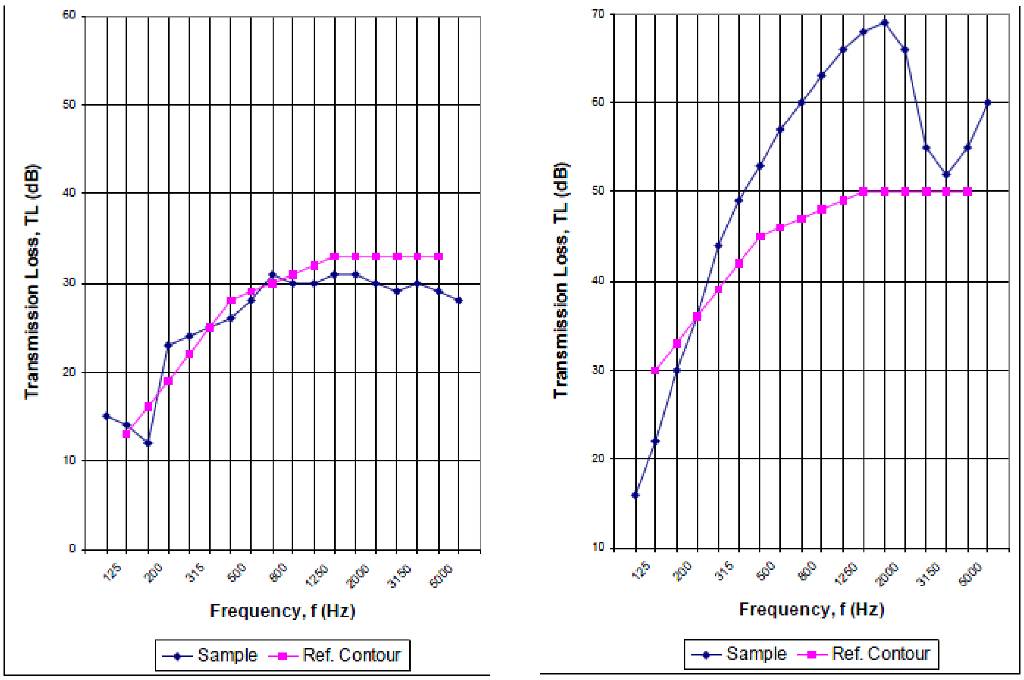


Figure 2-4: The comparison of sound transmission loss between two different STC wood studs

From two of the graph, we can see that the wall partition with higher STC (STC=45), is able to block more sound, therefore it cause more sound transmission loss when the sound pass through the wall.

Table 2-7: The typical sound level and the STC required to produce quiet

Subjective Impression	**Typical Sounds**	**dB**	**STC needed to produce quiet**
Very quiet	Breathing	10	-
	Whispering	20	-
Pleasantly quiet	Quiet library	30	-
	Quiet home	40	0
Normal noise level	General office building interior	50	10
	Normal conversation at 3'-5'	60	20
Loud noise level	Vacuum cleaner Bus idling	70	30
	Noisy office Home theatre, normal operation	80	40
	Male Scream at 6' Home theatre, loud sequences	90	50
	Car going around curve squeal Home theatre, full blast	100	60
Hearing loss if sustained	Rock concert speakers	110	70
	Near a jet engine	120	80
Pain threshold	Cannon explosion	140	100

Based on table above(Charles M.Salter & Associates, 1976), a quality home theatre can produce sounds as loud as 100dB to 110dB. A typical "quiet room" is around 40dB. So to have a quiet room at 40dB adjacent to a loud home theatre with a dB of 100, a wall would have to be rated with an STC of 60 (100 – 40 = 60).

Typical existing wall construction (the most common method is stud construction with drywall on either side) has an STC rating of 30 to 34. A room built with standard construction walls adjacent to the home theatre would have sound levels at 70dB (100 – 30 = 70), which is too loud for conversation. However, with a wall built to an STC of 60, the adjacent room would have sound levels of 40dB, about as quiet as a library.

2.5.1 The Acceptable STC Rating for a Wall Partition

In a prominent study by the National Research Council of Canada (J.S. Bradley), a survey has been conducted as part of the study looked at the attitudes of residents in 600 multifamily dwellings (representing 300 party walls between them). Residents with lower STC- rated walls were more likely to want to move, be awakened by noises, have trouble falling asleep because of noises, and think their neighbours were inconsiderate.

In terms of specific ratings, Bradley concluded from the survey results that an STC rating of 55 was generally a realistic goal for acceptable sound insulation, and that an STC rating of 60 or greater would effectively eliminate negative effects of noises from neighboring dwelling units. Following is one of the experiment conducted by Bradley, and as we can see, when the STC of the wall increase, the music sound intelligence will decrease, and therefore decline in noise complaints.

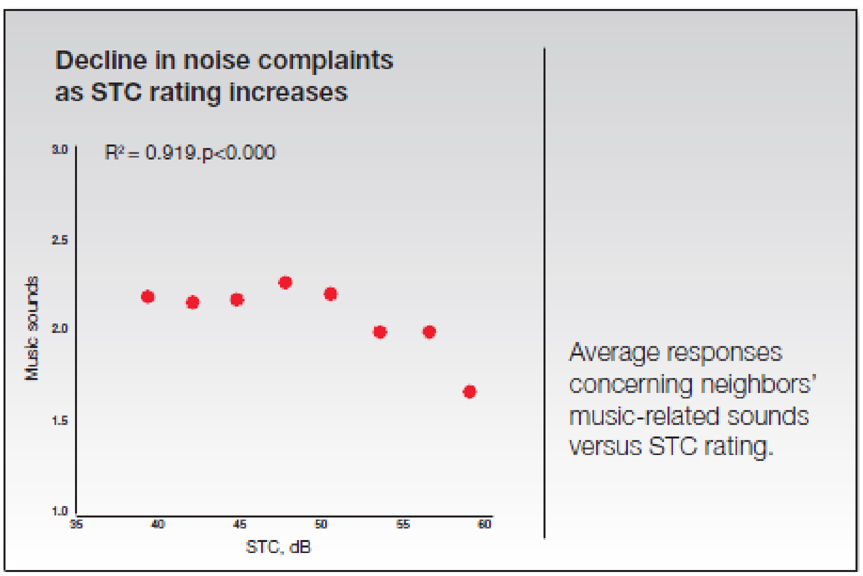


Figure 2-5: The average responses concerning music-related sounds versus STC rating

2.5.2 Sound Insulation

In Sound reduction by simple walls of brick and concrete (Rafael A. C. Laranja and Alberto Tamagna), stated that sound insulation can be difficult to forecast. In most cases it is necessary to take certain precautions in order to avoid degradation in the acoustical performance of walls. Knowing that sound transmission through walls depends on mass per unit area, bending stiffness, damping, mounting conditions, frequencies, etc., the sound transmission can be explained theoretically by several hypotheses

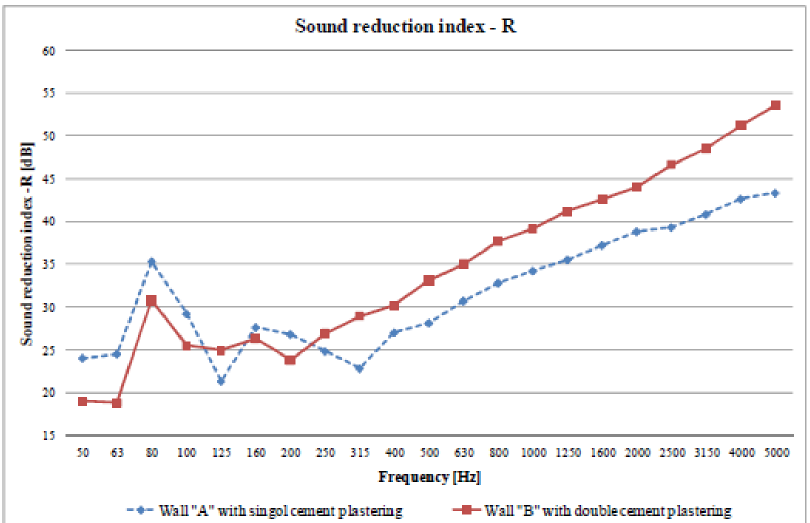


Figure 2-6: The sound reduction index-R of wall A and B

A test had been carried out by G. Semprini and L. Babaresi between single cement plastered wall A, and double cement plastered wall B. The laboratory apparent sound reduction index, Rw, have been calculated to EN ISO 140-3 e EN717-1, giving the value of Rw=33dB for wall A, and Rw=37dB for wall B. The 4dB diffence between two of these wall show the sound reduction index have great dependency with the cement plaster.

What does an STC rating of 55 actually mean in terms of noise reduction? Put simply, a resident in a condominium complex with STC-55 rated partition walls should be able to enjoy the use of the unit without the intrusion of many common sounds, although a partition wall with an STC rating of 60 or above may be needed to reduce loud music coming from next door to an acceptably unobtrusive level. Also, remember that, like decibel ratings, the STC rating system is logarithmic rather than linear, so a difference of 3-5 decibel rating can be significant, depending on the specific point on the rating scale.

The following table indicate the FHA criteria for sound insulation between dwelling units (W. J. Cavanaugh,1981).

Table 2-8: FHA Criteria for Sound Insulation between Dwelling Units

	Quality and Location Grade		
	Grade I	**Grade II**	**Grade III**
Party walls	STC 55	STC 52	STC 48
Party floor/ceilings	STC 55 IIC 55	STC 52 IIC 52	STC 48 IIC 48
Mechanical equipment room to dwelling unit	STC 65	STC 62	STC 58
Commercial space to dwelling unit	STC 60 IIC 65	STC 58 IIC 63	STC 56 IIC 61

2.5.3 STC Value for Standard Wall Construction

The table below lists typical STC values for a variety of STC partition (Cyril M. Harris, 1994). Note that, drywall, also called plasterboard, sheetrock or gypsum board is a construction product commonly used to finish building interiors.

Table 2-9: Effect of plastering one face of lightweight blocks.

STC	Partition type
33	Single layer of 1/2" drywall on each side, wood studs, no insulation (typical interior wall)
45	Double layer of 1/2" drywall on each side, wood studs, batt insulation in wall
46	Single layer of 1/2" drywall, glued to 6" lightweight concrete block wall, painted both sides
54	Single layer of 1/2" drywall, glued to 8" dense concrete block wall, painted both sides
55	Double layer of 1/2" drywall on each side, on staggered wood stud wall, batt insulation in wall
59	Double layer of 1/2" drywall on each side, on wood stud wall, resilient channels on one side, batt insulation
63	Double layer of 1/2" drywall on each side, on double wood/metal stud walls (spaced 1" apart), double batt insulation
72	8" concrete block wall, painted, with 1/2" drywall on independent steel stud walls, each side, insulation in cavities

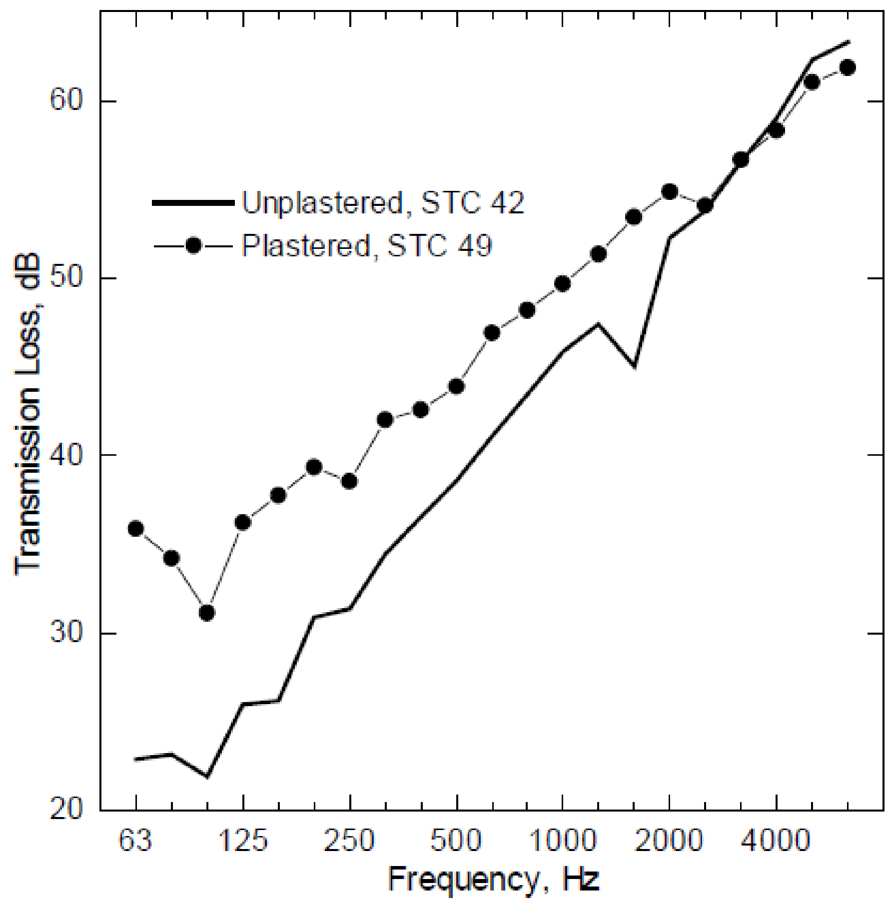


Figure 2-7: Effect of plastering one face of lightweight blocks.

In 'Sound transmission through two kinds of porous concrete blocks with attached drywall.' by A.C.C. Warnock , he did a experiment on testing the effect of plastering one face of lightweight blocks. As the result, the plastering one face of the 190 mm lightweight blocks produced the change in transmission loss shown in Fig. 7. Improvement is most marked at low frequencies and decreases as frequency increases. The dip in the transmission loss curve seen in the bare block result at 1.6 kHz disappeared after plastering. No explanation for this dip has been found. A sound leak or other construction flaw was suspected, but none could be discovered.

Following are a list of common sound insulation construction material and its STC values.

Table 2-10: STC Values Table For Building Materials

Material type	STC
5/16" PLYWOOD	25
24 GAUGE STEEL	26
1/2" Gypsum BOAR 5/8" Gypsum BOARD	26 28
1/8" PLATE GLASS 1/4" PLATE GLASS	28 30
3/16" STEEL PLATE	35
1" THICK WOOD PANEL	36
4" TWO CELL CONCRETE BLOCK	41
8" LIGHTWEIGHT HOLLOW CONCRETE BLOCK	46

2.5.4 The relationship between material mass and sound transmission loss

The diagram below show the average airborne sound transmission loss for single homogeneous partitions. (W. J. Cavanaugh, 1981). The greater the mass of the material, the greater sound it can block.

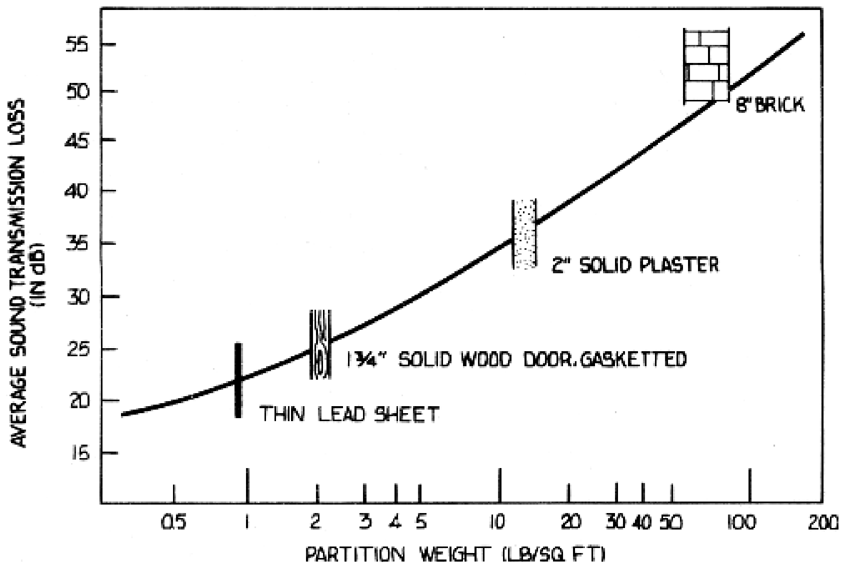


Figure 2-8: The relationship of average sound transmission loss versus the partition weight

Following is the comparison of transmission loss between one layer and two layer of gypsum plasterboard below. This information is taken from the New Zealand Timber Design Guide 2007, published by the Timber Industry Federation and edited by Professor A H Buchanan.

Diagram 1 show transmission loss for a timber stud wall using one layer of gypsum plasterboard (ST C = 35), while diagram 2 show transmission loss for a timber stud wall using two layers of gypsum plasterboard (ST C = 44 dB).

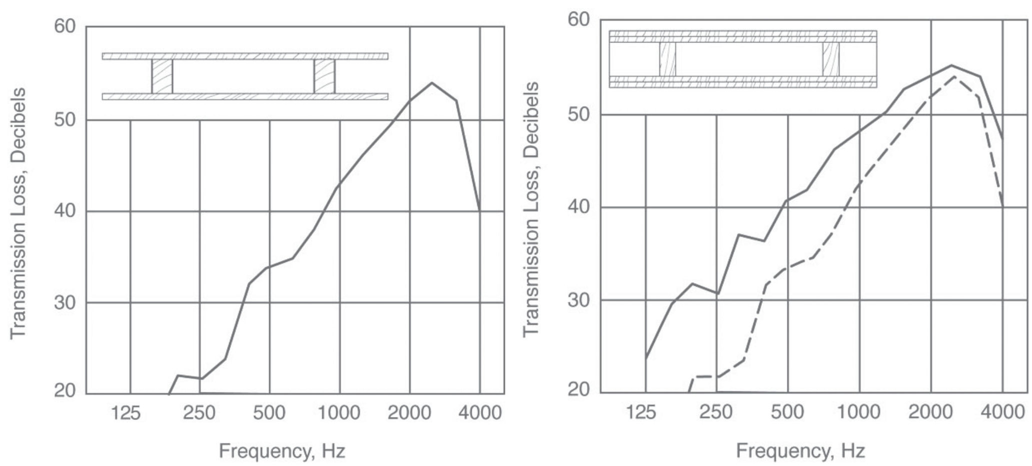


Figure 2-9: The comparison of sound transmission loss between one layer and two layer of gypsum plasterboard

As we can see, the two layer gypsum plasterboard has higher sound transmission loss compared to the single layer gypsum plasterboard, thus we can conclude that if the cavity size is increased, there will be an increase in the STC, although the critical frequency will have a more significant influence on the final STC value.

2.6 Noise Criterion (NC)

Noise Criterion - NC - were established in U.S. for rating indoor noise, noise from air-conditioning equipment etc. The noise in different types of rooms should not exceed the Noise Criterion limits listed below (William J. Cavanaugh, 1981) :

Table 2-11: Recommended Criteria for steady background sound in typical building spaces

Type of Space or activity	Recommended NC Curve	Sound Level, dBA
Workspaces with continuous speech communication and telephone use are not required	60-70	65-75
Shops, garages, contract equipment rooms Kitchen, laundries	45-60	52-65
Light maintenance shops, computer rooms	45-55	52-61
Laboratories, clinic, patient waiting spaces Public lobbies, corridors, circulation spaces	40-50	47-56
Retail shops, stores, restaurants, cafeterias Large offices, secretarial, relaxation areas	35-45	42-52
Residential living, dining rooms General classrooms, libraries Bedrooms, hotels, apartment with air conditioning	30-40	38-47
Bedrooms, private residences, hospitals Executive offices, conference spaces	25-35	34-42
Small general-purpose auditoriums (less than about 500 seats), conference rooms, function rooms	30(max)	40(max)
Radio, TV, recording studios (close microphone pickup)	25(max)	35(max)
Large auditoriums for unamplified music and drama	20(max)	30(max)
Radio, TV, recording studios (remote microphone pickup) Opera performance halls Music performance and recital halls	15(max)	25(max)

The NC rating can be obtained by plotting the octave band levels for a given noise spectrum - the NC curves. The noise spectrum is specified as having a NC rating same as the lowest NC curve which is not exceeded by the spectrum.

Following is the standard NC table and its curve:

Table 2-12: Standard noise criteria table

Noise Criterion	Octave Band Center Frequency *(Hz)*							
	63	125	250	500	1000	2000	4000	8000
	Sound Pressure Levels *(dB)*							
NC-15	47	36	29	22	17	14	12	11
NC-20	51	40	33	26	22	19	17	16
NC-25	54	44	37	31	27	24	22	21
NC-30	57	48	41	35	31	29	28	27
NC-35	60	52	45	40	36	34	33	32
NC-40	64	56	50	45	41	39	38	37
NC-45	67	60	54	49	46	44	43	42
NC-50	71	64	58	54	51	49	48	47
NC-55	74	67	62	58	56	54	53	52
NC-60	77	71	67	63	61	59	58	57
NC-65	80	75	71	68	66	64	63	62

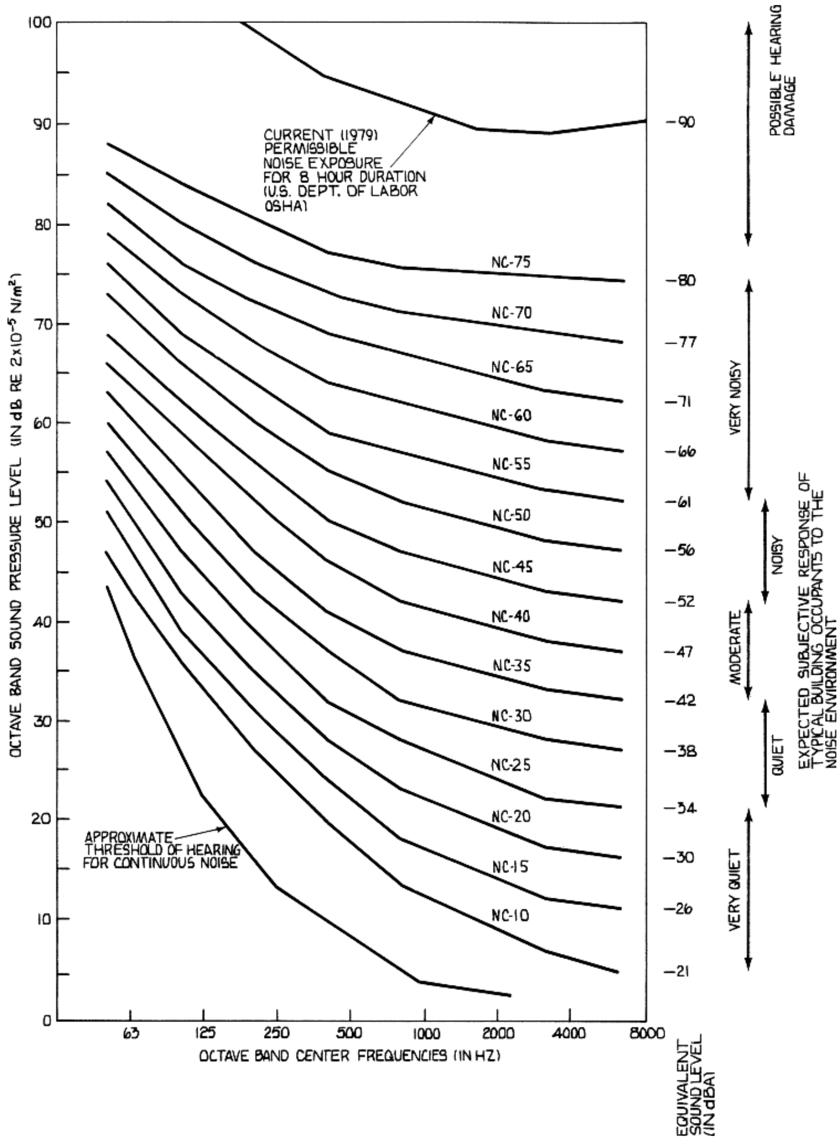


Figure 2-10: The standard NC curves diagram

The NC curves diagram above (William J. Cavanaugh, 1981) specify allowable sound pressure levels in octave bands of frequency over the full audible range. The general objective is *quiet*, that is, a comfortable level of background sound appropriate for the particular space involved.

2.7 Noise Rating (NR)

The noise rating graphs for different sound pressure levels are plotted at acceptable sound pressure levels at different frequencies. Acceptable sound pressure levels vary with the room and the use of it. Different curves are obtained for each type of use, and each of curve is obtained by a NR number. Thus, the Noise Rating level for different uses should not exceed the Recommended Noise Ratings indicated in the table below, which is extracted from "Noise Rating- The Engineering Toolbox":

Table 2-13: The recommended noise rating curve of different application

Noise rating curve	**Application**
NR 25	Concert halls, broadcasting and recording studios, churches
NR 30	Private dwellings, hospitals, theatres, cinemas, conference rooms
NR 35	Libraries, museums, court rooms, schools, hospitals operating theatres and wards, flats, hotels, executive offices
NR 40	Halls, corridors, cloakrooms, restaurants, night clubs, offices, shops
NR 45	Department stores, supermarkets, canteens, general offices
NR 50	Typing pools, offices with business machines
NR 60	Light engineering works
NR 70	Foundries, heavy engineering works

2.7.1 Recommended maximum noise levels for different types of rooms and standards

Choosing an appropriate noise criteria is important when specifying acceptable levels of noise. Most organizations use a particular index based upon practical experience. Recommended maximum noise levels for different types of rooms and standards are indicated in the table below

Table 2-14: The recommended maximum noise levels for different types of rooms and standards

Type of Room	Application	Noise Criterion - NC -	Noise Rating - NR -	db(A)
Very quiet	Concert and opera halls, recording studios, theatres, etc.	10 - 20	20	25 - 30
	Private bedrooms, live theatres, television and radio studios, conference and lecture rooms, libraries, etc.	20 - 25	25	25 - 30
	Private living rooms, board rooms, conference and lecture rooms, hotel bedrooms	30 - 40	30	30 - 35
Quiet	Public rooms in hotels, small offices classrooms, courtrooms	30 - 40	35	40 - 45
Moderate noisy	Drawing offices, toilets, bathrooms, reception areas, lobbies, corridors, department stores, etc.	35 - 45	40	45 - 55
Noisy	Kitchens in hospitals and hotels, laundry rooms, computer rooms, canteens, supermarkets, etc	40 - 50	45	45 - 55

CHAPTER 3

METHODOLOGY

3.1 Experiment facilities and equipment

3.1.1 The plan view of lecture hall and the source of ambient noise

The study area of my project will be concentrated at DK block of UTAR (KL Campus). DK block is constituted of two level, and each level there have three lecturer hall. While my research will be based on lecture hall DK4A, which located at first floor. DK4A is middle hall of the three lecture hall. Outside the lecture hall will be the corridor, where students pass by frequently. So as, the backside of the lecture hall.

Let's take the case of the students engaged in lecture hall activities making noise. And student at outside corridor or at adjacent lecture hall chit chatting noise can be heard inside the lecture halls.

Besides that, high ambient noise from mechanical equipment such as noisy heating from loudspeaker, ventilation and air conditioning (HVAC) systems in the lecture hall itself are all too common in existing lecture halls..

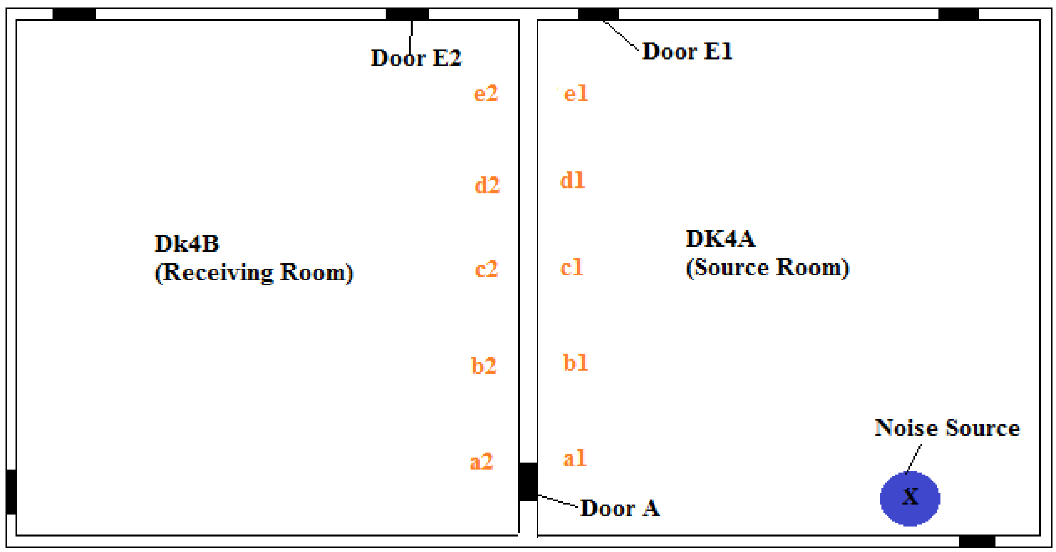
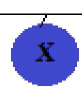


Figure 3-1: The plan view of lecture hall (DK2A and DK2B)

Table 3-1: Symbol and its description

Symbol	**Descriptions**
	The noise source (Loudspeaker)
	The door
a1, b1, c1, d1, e1	Measuring spot for transmission loss experiment
a2, b2, c2, d2, e2	Measuring spot for noise criteria (NC) experiment

3.1.2 The Lecture Hall's Wall

Following is the assumed lecture hall's wall material between DK4A and DK4B, which is constructed by 8 inch lightweight concrete block walls, and its measured STC is about 44. While table indicate its assumed sound pressure level at octave band width ranged from 63 to 8000. Experiment will be conducted later on to prove whether the assumption of the lecture hall wall is right.

Figure3-2: Lecture hall's wall

Table 3-2: Estimated lecture hall wall's material

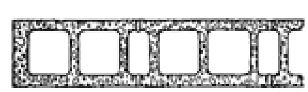
Name	**Image**	**Measured STC**
8 inch lightweight concrete block walls		44

Table 3-3: Estimated sound pressure level of the lecture hall's wall

	Thickness (mm)	Octave Band Centres Frequency *(Hz)*							
		63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Hollow cinder concrete blocks, painted (cement base paint)	**100**	**22**	**30**	**34**	**40**	**50**	**50**	**52**	**53**

3.1.3 Apparatus

Figure 3-3: sound level meter, Pros kit MT-4008

The equipment which used to measure the sound intensity in this project is called the "sound level meter”, modelled Pros kit MT-4008, and this is a type II sound level meter. In this project, it is used to analyze sound level, both in the source and the receiving rooms, measurement of the background noise level as well as measurements of the reverberation time in multiple locations in the receiving room.

Figure 3-4: Loudspeaker

During the experiment, the loudspeaker shown above will be switched on to generate noise to the surrounding. And the sound intensity will be measured by using sound level meter, and adjusted to desire level. The sound pressure level that will be generated for the experiment will be 90dB, 80dB, 70dB, and 60dB.

3.2 Sound reduction Index

The sound reduction of various building constructions can be calculated as the difference between the average sound levels in the two rooms ($L1 - L2$) at any given frequency, so the formula is given by:

$$\mathbf{TL = (L1 - L2)\ dB}$$

where

TL = sound transmission loss

L1= average SPL in the source room

L2 = average SPL in the receiving room

The L1 and L2 is 16 measured values at one third octave intervals between 100Hz and 4000Hz. And this will invariably be found to be similar to the single value measured at 500Hz.

3.2 Process Flow Chart

The process flow chart briefly list out how the experiment going to be taken. It is referred to the appendix 1.

3.3 Measurement Procedure

3.3.1 Calculating transmission loss

The procedure is as below:

1. First, ensure all the door in the lecture hall are closed.
2. The background noise level of location a-e are measured by using sound level meter.
3. Switch on the white noise source and set it at 900Hz by adjusting the volume.
4. The maximum and the minimum sound pressure level of source room(DK4A), *a1- e1* is measured by using sound level meter by every 10s.
5. Then, the maximum and the minimum sound pressure level of receiving room (DK4B), *a2- e2* is measured by using sound level meter by every 10s.
6. The sound pressure level reading is recorded in table below

	1			2			Average
	max	Min	average	max	min	Average	
source							
a1							
b1							
c1							
d1							
e1							
a2							
b2							
c2							
d2							
e2							

7. Step 1-8 is then repeated by adjusting the white noise to 80db, 70db, and 60db
8. The sound transmission loss, TL is calculated by using formula given.

	90db	80db	70db	60db
a				
b				
c				
d				
e				

3.3.2 Sound mapping

The sound distribution of the lecture hall is plotted by using CadNa-A simulation software.

1. First, the dimension of the lecture halls are set.
2. The structure of the lecture hall is plotted.
3. The point source has been located, and the sound pressure level of it is set.
4. The receiving point is located.
5. The map is then generated.
6. The sound distribution map is then inserted into report and discussed.

3.4 Measurement condition

Noise source at sending room

First of all, we have to make sure the loudspeaker is the only noise source in the sending room. Or else, noise from the source is significantly greater than the sound pressure level from all other noise. In this case, the noise source will be generated by the lecture hall loudspeaker, which located at point 'X' in the plan view

Microphone position at receiving room

During the measurement, the microphone will be placed at least 1m from the walls, this is due to at distance shorter than 1m , the intensity of the noise source from sending room tends to change sign very often. Thus, the device will be placed at 1.2m from the wall to let the intensity to be stable before measured. While it is mounted 1.2m above the floor.

Presence of people at a measurement site

The presence of a person near to a measuring microphone may significantly influence the sound pressure levels obtained, for instance the breath exhaled from the observer may dilute the reading of the exact sound level. Thus, for critical measurements, it is recommended that an extension cable or remote control be used to allow the observer to be remote from the microphone. Otherwise, the observer should stand to the side rather than behind the microphone. People, other than those critical to the measurement, should be excluded from the measurement site to avoid any external noise presence during measurement

Noise level readings

The result must be read directly from the meter's display where averaging or statistical analysis is not required. When the output of the meter is steady the displayed value must be taken as the sound pressure level. If the output of an analogue meter indicates a fluctuating sound level the result must be taken as the mid-point of the maximum and minimum swing of the meter's readout.

Measurement tolerance

Tolerance is a very important during data measurement because it will affect the accuracy of the result. For instance, the measurement should be taken within fifteen seconds after the data shown on the screen of sound level meter. While all the linear distances, including the distance from a microphone to the ground and the distance from a microphone to a sound source, can have a tolerance of +/- 10%. For instance, in this project, the microphone is placed 0.2m +/- 0.02m from the wall.

The lecture hall's door

All the door should be enclosed during the experiment. So that the result will not be disturbed. Later on, the effect of the door opened on the degree of sound transmission will be studied.

3.5 Gantt Chart

A Gantt chart allow us to keep track on our project progress, and help us to identify the bottleneck of our project. So, following is the list of activities of my project, and its duration. The total duration taken to complete all the tasks are 15 weeks. Please refer to the Appendix 2 for the Gantt Chart.

Table 3-4: Gantt Chart's activities for phase 1

Activity	Description	Duration	Prerequisite
A	Selecting FYP title	1	nil
B	Gathering relevant information	3	A
C	Consulting supervisor(getting guide and advice)	1	B
D	Draft on chapter 2: Literature review	2	C
E	Send chapter 2 to supervisor for assessment	1	D
F	Amendment on chapter 2	2	E
G	Draft on chapter 1: Introduction	2	E
H	Send chapter 1 and 2 to supervisor for assessment	1	G
I	Amendment on chapter 1 and 2	2	G
J	Draft on chapter 3: Methodology	2	G
K	Send all chapter 1, 2, 3 to supervisor for assessment	1	J
L	Amendment on chapter 1, 2, and 3	1	K
M	Preparing presentation slide	1	K
N	Report submission	1	M
O	FYP phase 1 presentation	1	M

Table 3-5: Gantt Chart's activities for phase II

Activity	Description	Duration (Weeks)	Prerequisite
A	Survey on Sound Level Meter available in market	1	nil
B	Purchase and study the new Sound Level Meter	2	A
C	Conduct experiment and data collection	1	B
D	Data analysis and transmission loss calculation	4	C
E	Consult supervisor	1	D
F	Sound Mapping	1	E
G	Discussion and Conclusion and slide preparation	3	E
H	Consult supervisor	1	F
I	Combining the final thesis	1	G
J	FYP phase II presentation	1	I
	Total Weeks	15	

CHAPTER 4

Results and Discussions

4.1 Introduction

In this chapter, the Sound Pressure Level at specific locations had been obtained by using sound level meter. And the Sound reduction through the lecturer wall at each points will be calculated. The sound mapping of the lecture hall will be shown in this chapter as well. The results will be discussed.

4.2 Calculated Sound Pressure Level

Three different cases have been designed to study the effect of it on the sound pressure level reading obtained. Three of the cases are (1) With All Doors Closed, (2) With Middle Door (Door A) opened, while else doors closed, and (3) With Backdoors (Door E1 and Door E2) opened, while else doors closed. Three of the cases have the same flow of taking reading. First, I will measure the background noise of the room, where no external noise will be generated at this stage. Then I will generate the noise at different level by using speaker, and measure the sound pressure level at the points which I already specified earlier, and record it down into the table I have prepared for it. Each measurement is repeated for two times in order to increase the accuracy of the results. After that only I will calculate the sound reduction of the sounds at every points.

4.3 Case 1: With All Door Closed

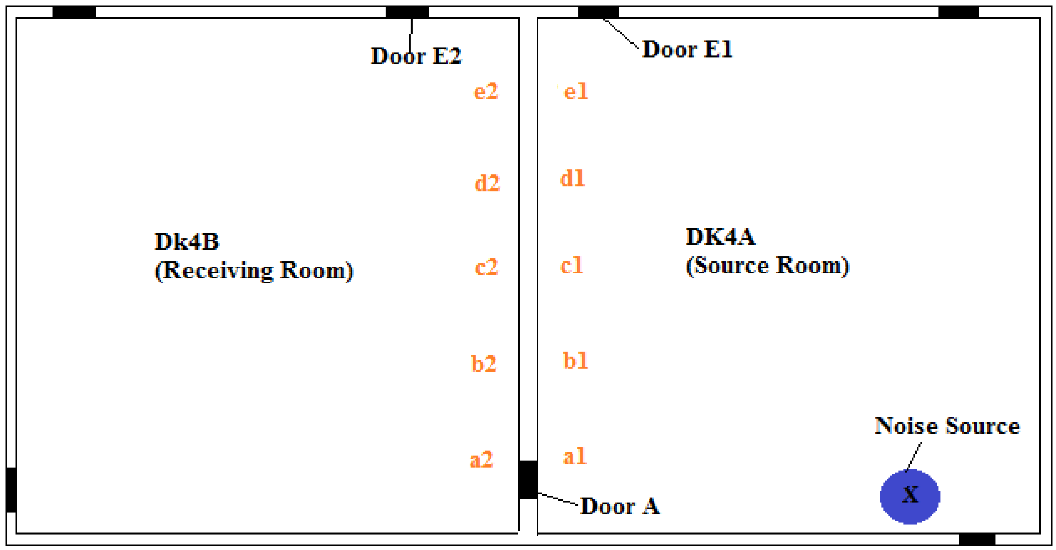


Figure 4-1: Structure of lecture hall in case 1

4.3.1 Results (Case 1)

<u>Background Noise</u>

		MAX	MIN	AVERAGE
DK4A	**a1**	39.00	39.80	**39.40**
	b1	40.20	43.60	**41.90**
	c1	39.40	44.00	**41.70**
	d1	39.90	40.00	**39.95**
	e1	41.00	42.80	**41.90**
DK4B	**a2**	43.80	42.60	**43.20**
	b2	40.00	39.60	**39.80**
	c2	42.10	42.00	**42.05**
	d2	42.80	41.60	**42.20**
	e2	42.50	42.40	**42.45**

<u>Average Background noise</u>

DK4A	**40.97**
DK4B	**41.94**

90dBA

Location	1			2			Average
	max	**min**	**average**	**max**	**min**	**average**	
Source	91.20	88.90	**90.05**	90.30	90.00	90.15	**90.10**
a1	86.60	85.60	86.10	86.30	85.00	85.65	**85.88**
b1	86.20	85.70	85.95	85.90	85.00	85.45	**85.70**
c1	84.20	83.00	83.60	83.80	83.60	83.70	**83.65**
d1	83.70	83.40	83.55	83.60	83.20	83.40	**83.48**
e1	81.50	80.50	81.00	81.70	81.50	81.60	**81.30**
a2	56.80	56.50	56.65	56.40	55.80	56.10	**56.38**
b2	54.70	54.60	54.65	56.00	55.00	55.50	**55.08**
c2	53.50	52.80	53.15	53.30	53.00	53.15	**53.15**
d2	53.90	53.40	53.65	53.40	52.80	53.10	**53.38**
e2	54.00	53.20	53.60	53.90	53.60	53.75	**53.68**

Sound reduction through wall

Location	**Sound Reduction(dBA)**
a	**29.50**
b	**30.63**
c	**30.50**
d	**30.10**
e	**27.63**

Example of calculation:

At point A, sound reduction = a1 – a2

= 85.88 -56.38

= 29.50 (dBA)

80dB

Location	1.00			2.00			Average
	max	min	average	max	min	average	
Source	81.00	78.80	**79.90**	80.80	80.10	80.45	**80.18**
a1	76.80	76.50	76.65	76.20	75.80	76.00	**76.33**
b1	75.60	75.30	75.45	75.00	74.60	74.80	**75.13**
c1	77.00	74.60	75.80	74.60	74.20	74.40	**75.10**
d1	74.10	73.60	73.85	73.80	73.70	73.75	**73.80**
e1	72.20	71.80	72.00	72.00	70.70	71.35	**71.68**
a2	51.80	49.00	50.40	48.20	47.50	47.85	**49.13**
b2	46.60	46.10	46.35	47.00	46.50	46.75	**46.55**
c2	44.50	44.30	44.40	44.90	44.70	44.80	**44.60**
d2	45.40	44.70	45.05	46.00	44.70	45.35	**45.20**
e2	51.40	48.20	49.80	46.20	45.60	45.90	**47.85**

Sound reduction through wall

Location	Sound Reduction (dBA)
a	**27.20**
b	**28.58**
c	**30.50**
d	**28.60**
e	**23.83**

Example of calculation:

At point A, sound reduction = a1 – a2

= 76.33 -49.13

= 27.20(dBA).

70dB

Location	1			Average
	max	min	average	
Source	70.30	69.90	70.10	**70.10**
a1	63.50	63.40	63.45	**63.45**
b1	63.50	63.40	63.45	**63.45**
c1	61.50	61.40	61.45	**61.45**
d1	60.70	60.60	60.65	**60.65**
e1	59.40	58.90	59.15	**59.15**
a2	43.50	43.40	43.45	**43.45**
b2	42.80	41.20	42.00	**42.00**
c2	42.70	41.70	42.20	**42.20**
d2	41.90	41.50	41.70	**41.70**
e2	44.20	43.80	44.00	**44.00**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**20.00**
b	**21.45**
c	**19.25**
d	**18.95**
e	**15.15**

Example of calculation:

At point A, sound reduction = a1 – a2

= 63.45 -43.45

= 20.00(dBA).

60dB

Location	1			Average
	max	min	average	
Source	60.40	59.70	**60.05**	**60.05**
a1	55.00	54.90	54.95	**54.95**
b1	54.60	54.40	54.50	**54.50**
c1	54.10	53.90	54.00	**54.00**
d1	52.80	52.70	52.75	**52.75**
e1	51.40	50.90	51.15	**51.15**
a2	41.70	41.60	41.65	**41.65**
b2	43.00	42.20	42.60	**42.60**
c2	44.00	43.70	43.85	**43.85**
d2	42.40	41.80	42.10	**42.10**
e2	45.40	42.60	44.00	**44.00**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**13.30**
b	**11.90**
c	**10.15**
d	**10.65**
e	**7.15**

Example of calculation:

At point A, sound reduction = a1 – a2

= 54.95 -41.65

= 13.30 (dBA).

4.4 Case 2: With Middle Door (Door A) opened, While Else Doors Closed

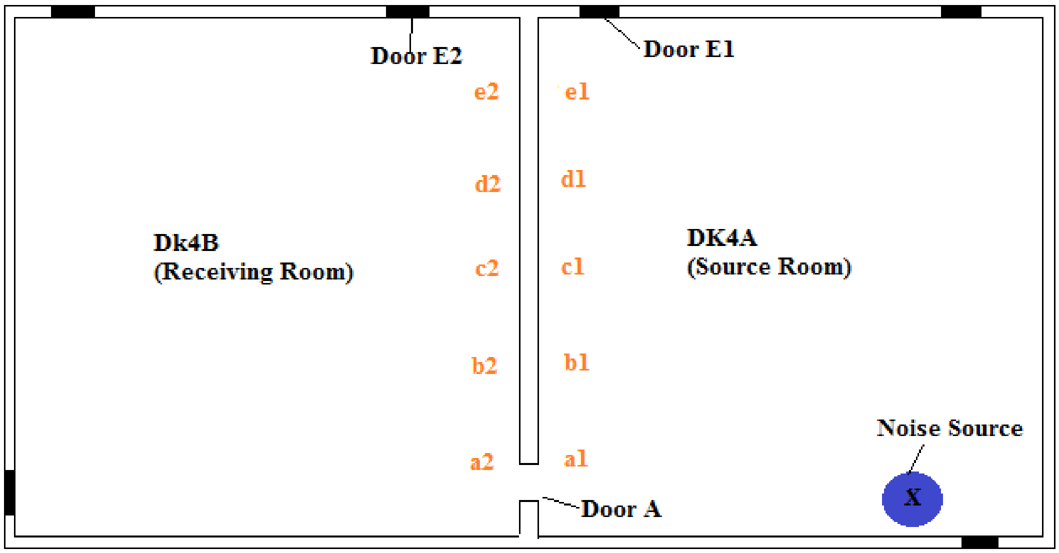


Figure 4-2: Structure of lecture hall in case 2

4.4.1 Result (Case 2)

Background Noise

		MAX	MIN	AVERAGE
DK4A	**a1**	39.00	39.80	**39.40**
	b1	40.20	43.60	**41.90**
	c1	39.40	44.00	**41.70**
	d1	39.90	40.00	**39.95**
	e1	41.00	42.80	**41.90**
DK4B	**a2**	43.80	42.60	**43.20**
	b2	40.00	39.60	**39.80**
	c2	42.10	42.00	**42.05**
	d2	42.80	41.60	**42.20**
	e2	42.50	42.40	**42.45**

Average Background noise:

DK4A	**40.97**
DK4B	**41.94**

90dBA

Location	1			2			Average
	max	min	average	max	min	average	
Source	90.90	90.50	**90.70**	90.20	89.50	89.85	**90.28**
a1	86.40	86.00	86.20	87.00	85.30	86.15	**86.18**
b1	86.20	86.10	86.15	85.60	85.60	85.60	**85.88**
c1	85.00	83.90	84.45	84.20	83.30	83.75	**84.10**
d1	83.90	83.10	83.50	83.40	83.00	83.20	**83.35**
e1	83.00	81.90	82.45	82.60	81.50	82.05	**82.25**
a2	69.30	68.00	68.65	69.20	67.60	68.40	**68.53**
b2	65.40	65.10	65.25	64.70	64.40	64.55	**64.90**
c2	63.90	63.10	63.50	62.90	62.30	62.60	**63.05**
d2	62.70	61.60	62.15	62.30	62.00	62.15	**62.15**
e2	61.80	61.40	61.60	61.50	60.00	60.75	**61.18**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**17.65**
b	**20.98**
c	**21.05**
d	**21.20**
e	**21.08**

Example of calculation:

At point A, sound reduction = a1 – a2

= 86.18 -68.53

= 17.65 (dBA).

80dB

Location	1			2			Average
	max	min	average	max	min	average	
Source	79.80	79.50	**79.65**	80.00	79.40	79.70	**79.68**
a1	75.10	75.00	75.05	75.90	74.40	75.15	**75.10**
b1	74.80	73.80	74.30	74.60	73.90	74.25	**74.28**
c1	73.80	72.60	73.20	73.10	71.50	72.30	**72.75**
d1	72.00	71.60	71.80	72.00	71.40	71.70	**71.75**
e1	70.60	70.00	70.30	70.30	70.10	70.20	**70.25**
a2	57.90	55.80	56.85	57.90	56.40	57.15	**57.00**
b2	54.60	54.50	54.55	53.90	53.50	53.70	**54.13**
c2	52.20	51.80	52.00	51.80	51.60	51.70	**51.85**
d2	51.50	50.80	51.15	51.00	50.80	50.90	**51.03**
e2	49.80	49.80	49.80	50.80	50.20	50.50	**50.15**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**18.10**
b	**20.15**
c	**20.90**
d	**20.73**
e	**20.10**

Example of calculation:

At point A, sound reduction = a1 – a2

= 75.10 – 57.00

= 18.10(dBA).

70dB

Location	1			Average
	max	min	average	
Source	70.30	69.90	**70.10**	**70.10**
A1	63.50	63.40	63.45	63.45
b1	63.50	63.40	63.45	63.45
c1	61.50	61.40	61.45	61.45
d1	60.70	60.60	60.65	60.65
e1	59.40	58.90	59.15	59.15
a2	43.50	43.40	43.45	43.45
b2	42.80	41.20	42.00	42.00
c2	42.70	41.70	42.20	42.20
d2	41.90	41.50	41.70	41.70
e2	44.20	43.80	44.00	44.00

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**20.00**
b	**21.45**
c	**19.25**
d	**18.95**
e	**15.15**

Example of calculation:

At point A, sound reduction = a1 – a2

= 63.45 -43.45

= 20.00(dBA).

60dB

Location	1			Average
	max	min	average	
Source	60.40	59.70	**60.05**	**60.05**
a1	55.00	54.90	54.95	54.95
b1	54.60	54.40	54.50	54.50
c1	54.10	53.90	54.00	54.00
d1	52.80	52.70	52.75	52.75
e1	51.40	50.90	51.15	51.15
a2	41.70	41.60	41.65	41.65
b2	43.00	42.20	42.60	42.60
c2	44.00	43.70	43.85	43.85
d2	42.40	41.80	42.10	42.10
e2	45.40	42.60	44.00	44.00

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**8.90**
b	**13.30**
c	**11.90**
d	**10.15**
e	**10.65**

Example of calculation:

At point A, sound reduction = a1 – a2

= 54.95 -41.65

= 8.90 (dBA).

4.5 Case 3: Backdoors (Door E1 and Door E2) opened, else doors closed

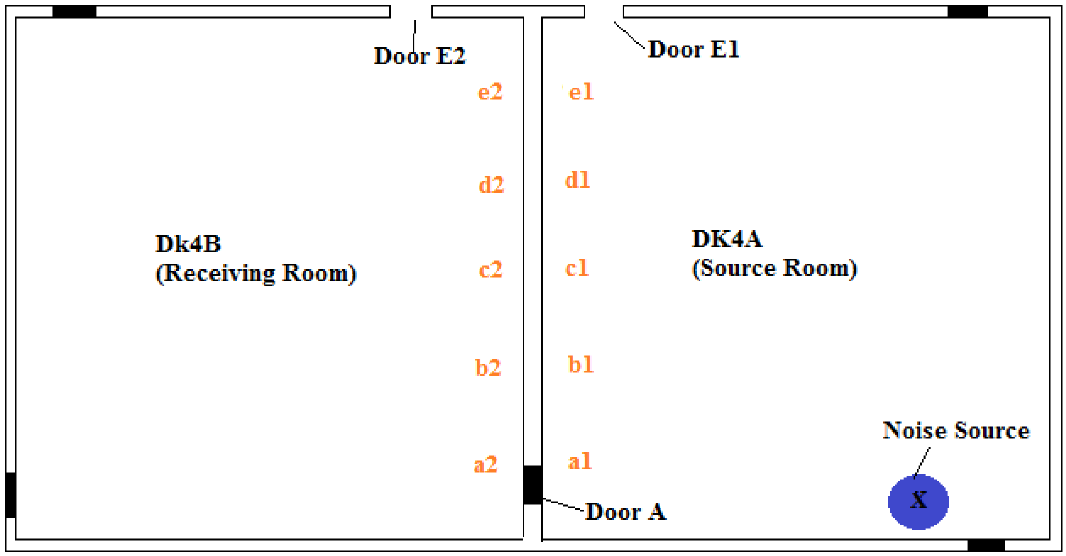


Figure 4-3: Structure of lecture hall in case 3

4.5.1 Results (Case 3)

Background Noise

		MAX	MIN	AVERAGE
DK4A	**a1**	39.00	39.80	**39.40**
	b1	40.20	43.60	**41.90**
	c1	39.40	44.00	**41.70**
	d1	39.90	40.00	**39.95**
	e1	41.00	42.80	**41.90**
DK4B	**a2**	43.80	42.60	**43.20**
	b2	40.00	39.60	**39.80**
	c2	42.10	42.00	**42.05**
	d2	42.80	41.60	**42.20**
	e2	42.50	42.40	**42.45**

Average Background noise:

DK4A	**40.97**
DK4B	**41.94**

90dB

Location	1			2			Average
	max	min	average	max	min	average	
Source	90.60	90.40	**90.50**	90.20	89.90	90.05	**90.28**
a1	88.90	87.80	88.35	87.90	87.40	87.65	**88.00**
b1	87.40	86.80	87.10	87.10	86.80	86.95	**87.03**
c1	86.40	85.70	86.05	85.70	84.60	85.15	**85.60**
d1	84.60	83.90	84.25	83.90	83.60	83.75	**84.00**
e1	83.10	82.40	82.75	82.40	82.00	82.20	**82.48**
a2	55.80	55.50	55.65	56.00	56.00	56.00	**55.83**
b2	54.20	53.80	54.00	53.80	53.50	53.65	**53.83**
c2	53.40	53.10	53.25	52.50	52.40	52.45	**52.85**
d2	52.80	52.00	52.40	51.90	51.20	51.55	**51.98**
e2	54.90	54.60	54.75	54.80	53.80	54.30	**54.53**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**32.18**
b	**33.20**
c	**32.75**
d	**32.03**
e	**27.95**

Example of calculation:

At point A, sound reduction = a1 – a2

= 88.00 – 55.83

= 32.18 (dBA).

80dB

Location	1			2			Average
	max	min	average	max	min	average	
Source	80.20	79.40	**79.80**	80.10	79.30	79.70	**79.75**
a1	75.30	74.60	74.95	76.50	76.40	76.45	**75.70**
b1	74.70	74.70	74.70	75.60	74.90	75.25	**74.98**
c1	74.90	73.80	74.35	75.40	73.70	74.55	**74.45**
d1	70.40	70.10	70.25	73.50	72.10	72.80	**71.53**
e1	68.70	67.60	68.15	71.60	70.70	71.15	**69.65**
a2	44.70	43.70	44.20	44.60	43.50	44.05	**44.13**
b2	43.20	42.40	42.80	46.90	44.50	45.70	**44.25**
c2	46.20	45.40	45.80	47.80	46.40	47.10	**46.45**
d2	49.20	48.30	48.75	49.00	47.60	48.30	**48.53**
e2	51.40	49.50	50.45	51.90	51.00	51.45	**50.95**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**31.58**
b	**30.73**
c	**28.00**
d	**23.00**
e	**18.70**

Example of calculation:

At point A, sound reduction = a1 – a2

= 75.70 -44.13

= 31.58 (dBA).

70dB

Location	1			Average
	max	min	average	
Source	70.30	69.90	**70.10**	**70.10**
a1	63.50	63.40	63.45	**63.45**
b1	63.50	63.40	63.45	**63.45**
c1	61.50	61.40	61.45	**61.45**
d1	60.70	60.60	60.65	**60.65**
e1	59.40	58.90	59.15	**59.15**
a2	43.50	43.40	43.45	**43.45**
b2	42.80	41.20	42.00	**42.00**
c2	42.70	41.70	42.20	**42.20**
d2	41.90	41.50	41.70	**41.70**
e2	44.20	43.80	44.00	**44.00**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**20.00**
b	**21.45**
c	**19.25**
d	**18.95**
e	**15.15**

Example of calculation:

At point A, sound reduction = a1 – a2

= 63.45 -43.45

= 20.00 (dBA).

60dB

Location	1			Average
	max	min	average	
Source	60.40	59.70	**60.05**	**60.05**
a1	55.00	54.90	54.95	**54.95**
b1	54.60	54.40	54.50	**54.50**
c1	54.10	53.90	54.00	**54.00**
d1	52.80	52.70	52.75	**52.75**
e1	51.40	50.90	51.15	**51.15**
a2	41.70	41.60	41.65	**41.65**
b2	43.00	42.20	42.60	**42.60**
c2	44.00	43.70	43.85	**43.85**
d2	42.40	41.80	42.10	**42.10**
e2	45.40	42.60	44.00	**44.00**

Sound reduction through wall

Location	Sound Reduction(dBA)
a	**8.90**
b	**13.30**
c	**11.90**
d	**10.15**
e	**10.65**

Example of calculation:

At point A, sound reduction = a1 – a2

= 54.95 -41.65

= 8.90 (dBA).

4.6 Summary of Sound Reduction Index of Lecture Hall's Wall

For 90dB

	a	b	c	d	e
Case 1	29.50	30.63	30.50	30.10	27.63
Case 2	17.65	20.98	21.05	21.20	21.08
Case 3	32.18	33.20	32.75	32.03	27.95

For 80dB

	a	b	c	d	e
Case 1	27.20	28.58	30.50	28.60	23.83
Case 2	18.10	20.15	20.90	20.73	20.10
Case 3	31.58	30.73	28.00	23.00	18.70

For 70dB

	a	b	c	d	e
Case 1	20.00	21.45	19.25	18.95	15.15
Case 2	20.00	21.45	19.25	18.95	15.15
Case 3	20.00	21.45	19.25	18.95	15.15

For 60dB

	a	b	c	d	e
Case 1	13.30	11.90	10.15	10.65	7.15
Case 2	8.90	13.30	11.90	10.15	10.65
Case 3	8.90	13.30	11.90	10.15	10.65

4.7 Sound Mapping

4.7.1 Case 1- With All Door Closed

<u>90dB</u>

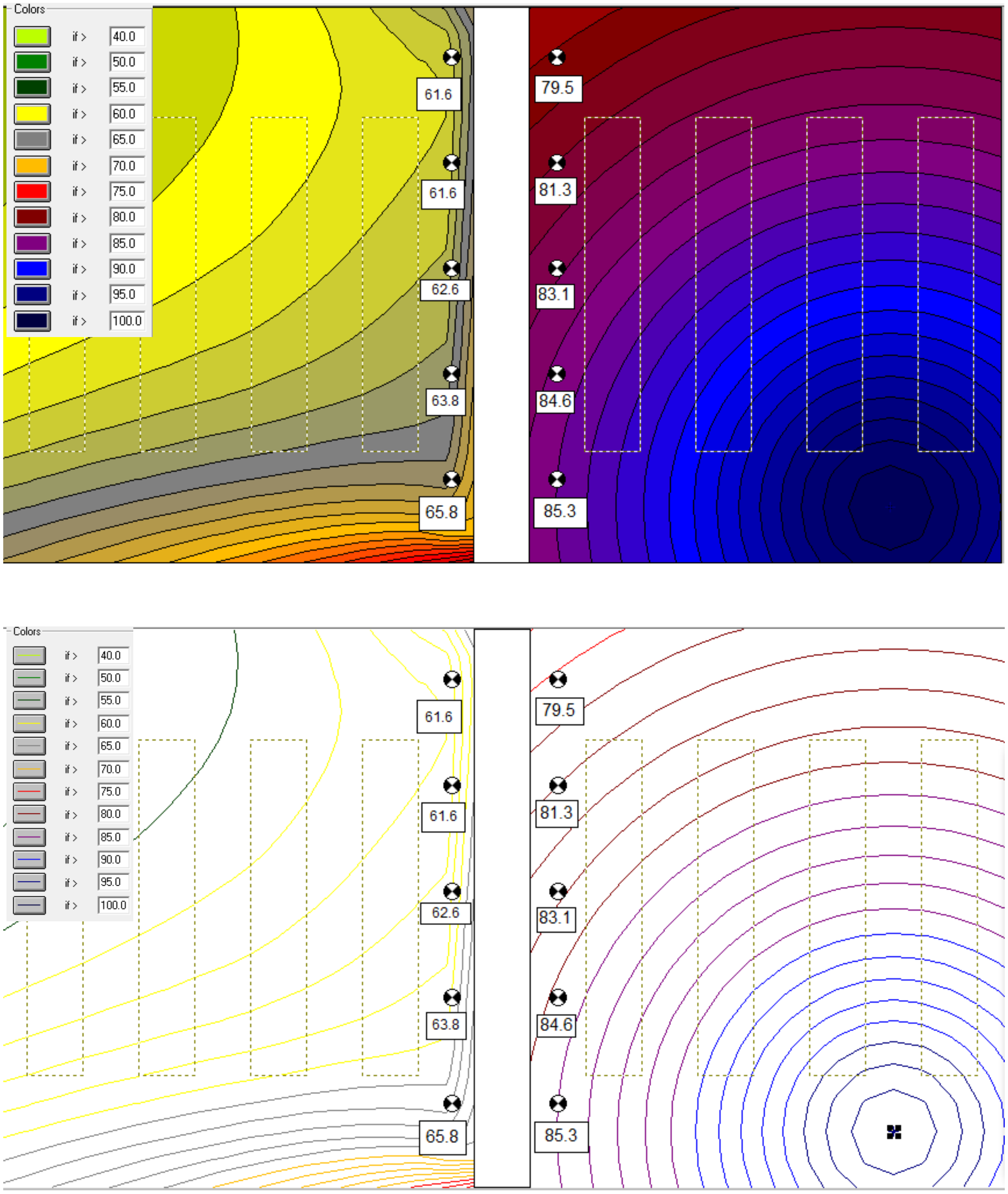


Figure 4-4: Sound distribution of lecture hall in case 1 at 90dB

80dB

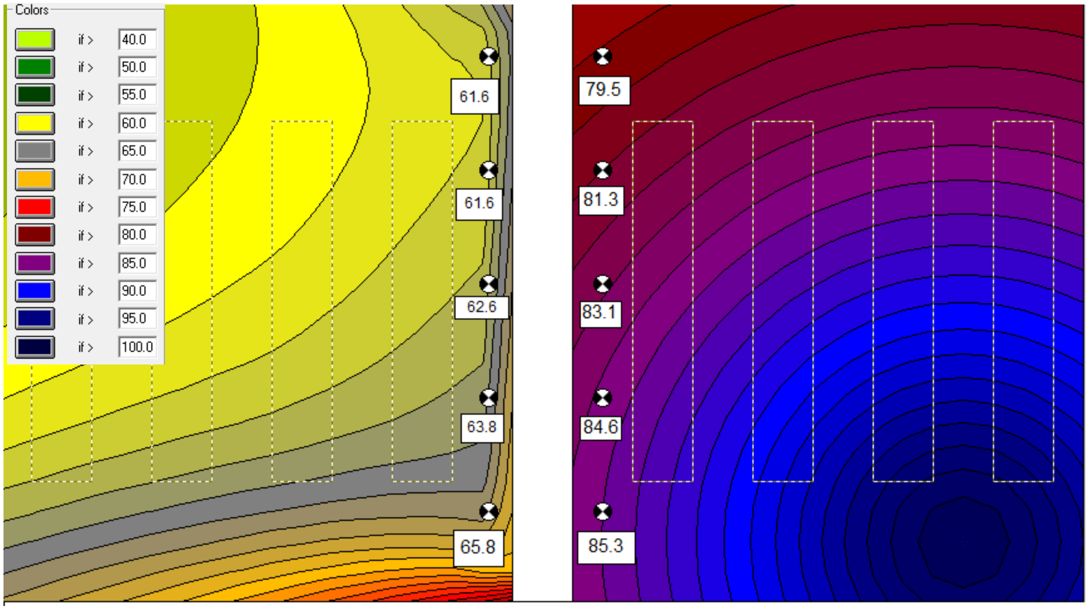


Figure 4-5: Sound distribution of lecture hall in case 1 at 80dB

70dB

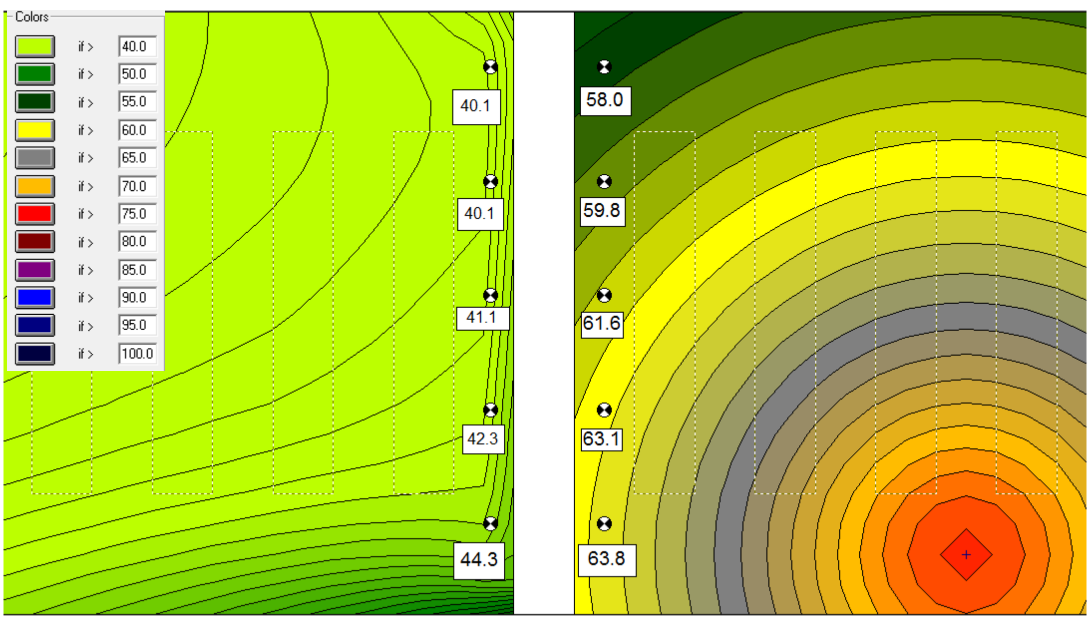


Figure 4-6: Sound distribution of lecture hall in case 1 at 70dB

4.7.2 Case 2 - With Middle Door (Door A) opened, While Else Doors Closed

90dB

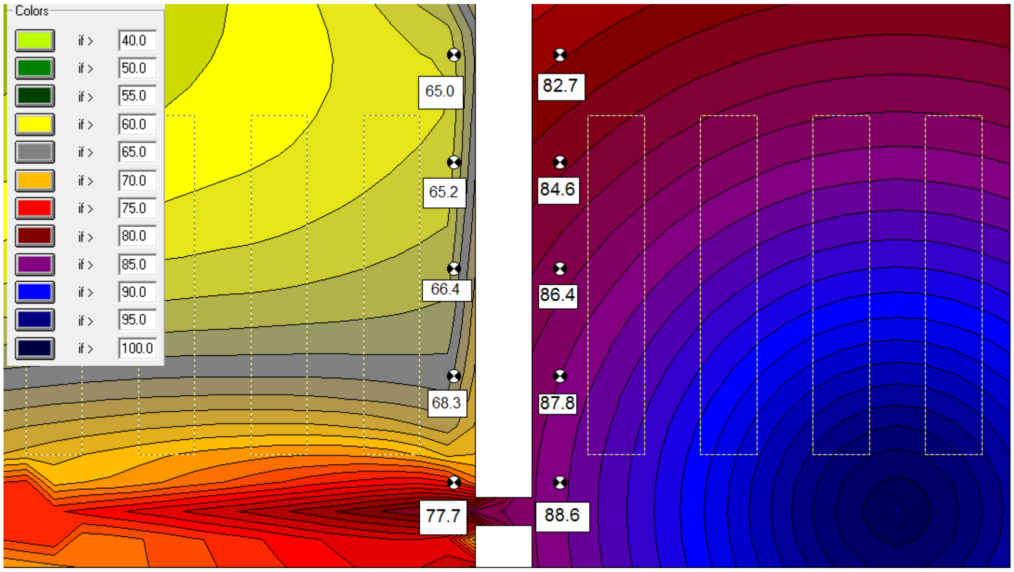


Figure 4-7: Sound distribution of lecture hall in case 2 at 90dB

4.7.3 Case 3 – With backdoors (Door E1 and Door E2) opened, else doors closed

90dB

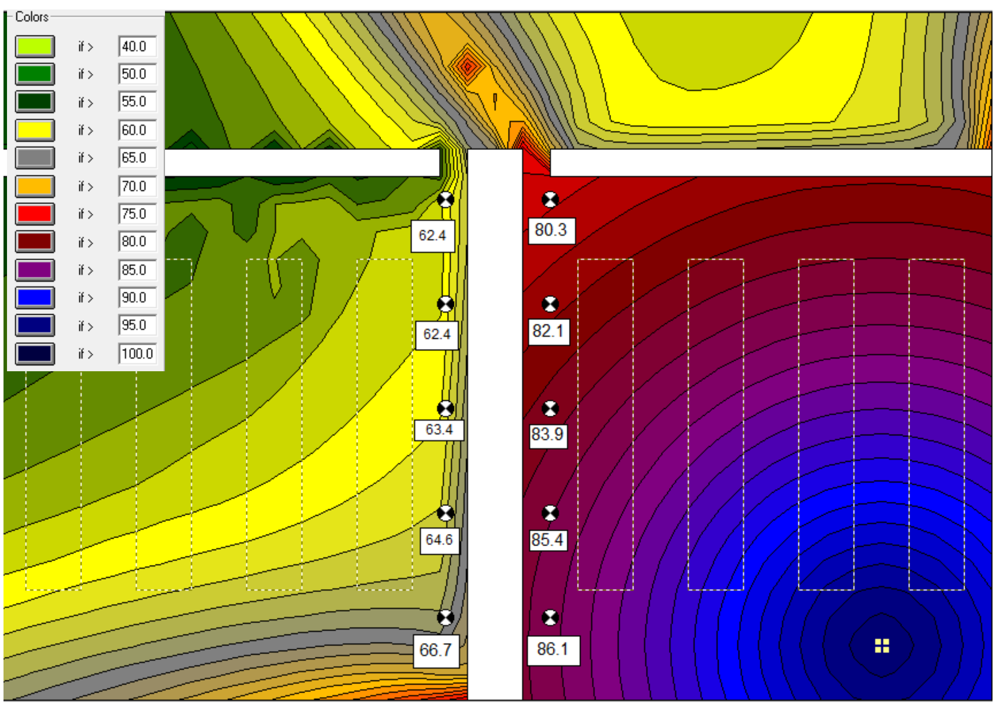
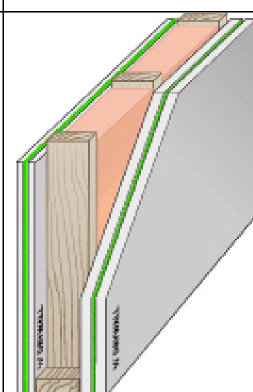


Figure 4-8: Sound distribution of lecture hall in case 3 at 90dB

4.8 Discussions

As I am not able to break apart the wall and study the composition of it, I will assume the wall partition material based on the result I obtained during the experiment. In case 1, when all the doors are closed, the sound reduction is ranged from 27-31dB, from that I checked and found that following material fulfil the above criteria most, which is 'Standard Interior Wall with 5/8" drywall on both sides with insulation (baseline)'. This is the most common kind of material found in wall of many architecture buildings, at both side of the wall is the dry wood, while between the dry wood there are sponge and others sound absorptive materials, and the wood stud is the support of the wall.

Table 4-1: Wall Material

Material Type	STC	Image
Standard Interior Wall with 5/8" drywall on both sides with insulation (baseline)	34	

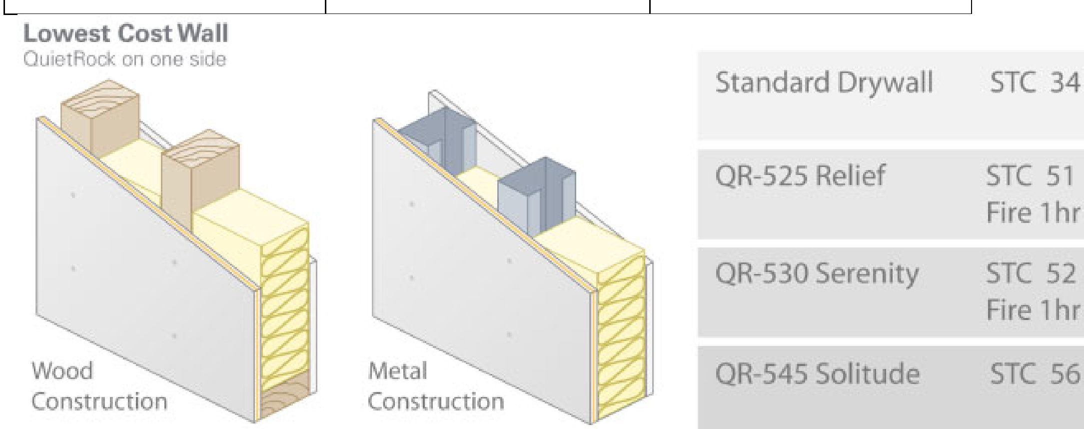


Figure 4-9 : Dry wood Structure

The experiment is conducted during the semester break of the university, it is to ensure minimum factors that can affect the experiment consistency, such as the noises of students pass outside the lecture hall during normal days. Besides that, all the reading have been taken twice, that is due to the external factor which can affect the accuracy of the readings. For example, whenever a heavy vehicles which passed the highway behind the lecture hall, generate loud noise, it will dispute the consistency of the readings.

Other limitation which cause the imperfection of this project, include the type II sound level meter. The experiment supposed to use type I sound level meter, however it was corrupted at the very early stage during the project, thus we had purchased another sound level meter, which is a type II sound level meter. Besides that there is heavy traffic behind the lecture hall, which often caused unwanted noise when I was conducting my experiment, thus sometimes the readings maybe retarded due to that factor. So my solution is that I will re-measure the points which I think is inaccurate, and then I will pick the readings which is more suitable.

Figure 4-10: Opened hole at lecture hall

With little more effort implied, the concrete block walls can provide better sound insulation. The effort can be added through the mass of the wall, the depth of cavity, and the amount of sound absorbing material. Plenty of opened holes have found at the lecture hall's ceilings, this will increase the noise level of the hall, and contribute to the inaccuracy of the readings because the sound of air conditionals, and others external noise will transmitted through the holes. Thus, we should actually seal the roof to improve the acoustic quality of the lecture hall.

Whenever the concrete block is porous, sealing the surface with plaster or block sealer significantly improves the sound insulation, thus we can say that, the more porous the block, the greater the improvement. Thus, to improve the sound insulations, we have to seal all the holes, so that no sound can transmit through.

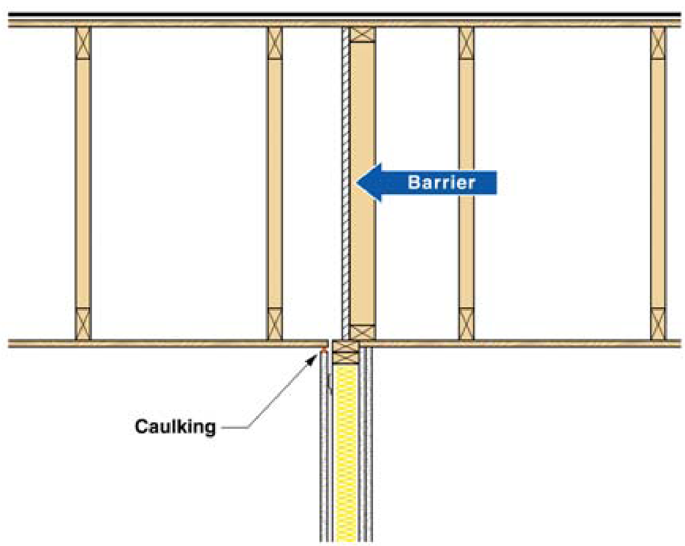


Figure 4-11: Partition wall height extension

For most of the building, the wall only reach the top of the ceiling, and it will not extend to the roof, this allow the noise to pass through from it to the receiving room. Since I am not able to climb up to check whether our wall has the same structure as mentioned, so, I just make assumption that it is. For optimum sound insulation, we should not allow any flanking or gap between two lecture halls. Thus we can extend the wall height to the maximum so that no noise will be able to pass through. Figure above show some idea of it, barrier is added to close the flanking and gap at the walls.

The thickness of the wall greatly affect the sound transmission loss level, the thicker the wall are, the more noises will be filtered as it passed through. Here are some comment extracted from internet, “by adding gypsum board supported on furring or studs at a distance from the surface of the block wall can greatly improve the sound insulation of the wall assembly. If the furring supporting the gypsum board is rigid, sound can travel directly through it from the gypsum board to the blocks. However, if the furring is sufficiently flexible, the sound will be attenuated.”

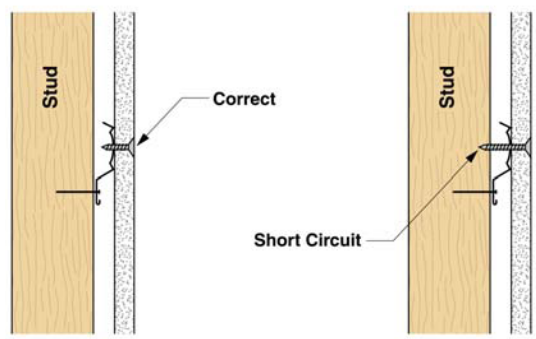


Figure 4-12: Right way of using fasteners over wall

Besides that, when we planning to use fasteners such as nail over the wall, we have to be very careful. As you can see from the figure above, the right way of choosing a nail size is very critical, we should use nail that will not hurt the stud or cavity of the wall so that the acoustic properties of halls is not affected. If the nail is too long and hit the stud, it will then create a crack on the wall, thus affecting the acoustic properties of the hall.

Adding absorptive materials such as furring, sponge at the wall will improve the sound insulation. This is due to the some of the noise which transmitted will be absorbed into the sponge, so only very little amount of noise will be transmitted.

4.8.1 Case 1 - With All Door Closed

As all the door closed, no external noise can come through from the door, thus the noise transmitted is lowest among three case. However it doesn't 100% block all the noise, because the noise still can transmitted through the flanking, for example, from the roof, the door flanking, and others. The background noise of the lecture hall before I generated the noise source had already reach 40-41dBA. The noise is mainly come from the air-cond motor sounds, and the noise came from heavy traffic outside the lecture hall as the highway is just located behind the lecture hall.

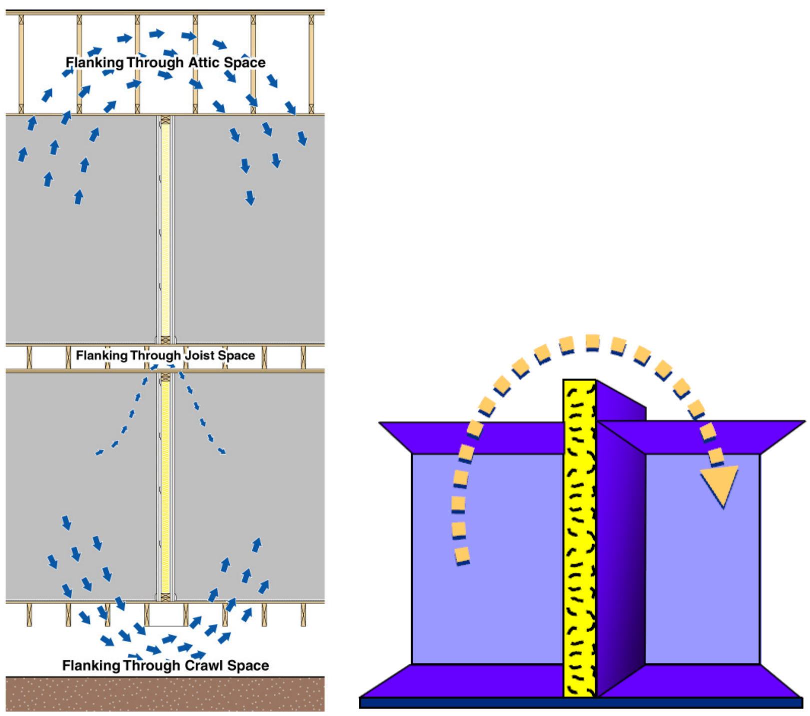


Figure 4-13: Airborne sound transmission through suspension ceiling

From the result, As you can see by using 90dB and 80dB noise source, the sound pressure level nearest to the source, which is A position, record highest sound pressure level. While the reading keeps decreasing as the record point get further from the noise source, which is point ‘b’ to ‘e’ This is because as the sound propagate, its sound pressure level will get weaker as it travel away. The noise reduction through the wall calculated is quite consistent, ranged between 27-31dB, thus it proven that when all the door are closed, the lecture hall’s wall is an effective sound blocker.

As for 70dB and 60dB noise source, the recorded sound pressure level at the receiving room, which is DK4B, is ranged from 40-45dB. The readings cannot be used, because it is mainly affected by the background noise. In the other hand, we can also conclude that any noise lower than 70dB is rarely heard at next room, the noise will be filter.

The sound reduction for 90dB and 80dB is fell inside the acceptance range, as the wall has block more than 30dB of sound from passing through. As discussed in section 2.5 (page 29), the wall has sound transmission of 30-35dB, which its performance is rated as fair, is because loud conversation can be heard through the partition, but much of the conversation will be unintelligible.

4.8.2 Case 2 - With Middle Door (Door A) opened, Else Doors Closed

For case 2, we can see that the overall sound reduction through the wall has been reduced compared to Case 1, that is due to the opened middle door. As the door in between opened, sound able to propagate through it, so more sound will be able to go into receiving room compared to case 1. Another reason is that as the door opened, it will form lower pressure area at the door, thus the sound will be push through there.

The sound reduction reading of 90dB and 80dB for case 2 is lower than the sound reduction reading of case 1, this is because the sound has leak from the opened door at the middle of two rooms. Thus, sound pressure level reading at receiving room for case 2 is higher than in case 1. As you can see, location ‘b-e’ show consistent sound reduction, but for location a, the sound reduction level is slightly lower. That is because point ‘a’ located nearest to the door, thus the sound pressure level of location ‘a’ at the receiving room will be higher than the sound pressure level of others locations in receiving room.

While for 70dB and 60dB, it show same result as the case 1, the sound pressure level recorded at the receiving room is ranged between 41-44dB, but these readings cannot be used because the reading is disputed by the external noises come from background noise.

4.8.3 Case 3 – With backdoors (Door E1 and Door E2) opened, else doors closed

The sound reduction reading of 90dB and 80dB for case 3 are similar to the sound reduction reading of case 1, except for the point ‘e’ reading. This is because both case 1 and case 4 have similar structure, just that the backdoor of the source and receiving room at case 3 is opened, thus the sound reading which affected by this factor only point ‘e’. When the backdoor is opened, more sound able to get into the room through outside, this will affect the Sound pressure level which located at point ‘e’.

However, the sound level at point ‘e’ was lower than expectation, that is because point ‘e’ is actually located at shadow area which the sound will not reach. As you can see from the sound distribution for case3, the sound which go through the open backdoor at source room did not go into the backdoor of the receiving room. If there is a student standing at the backdoor of the source room, he will hear louder noise compared to a student who stand at the backdoor of the receiving room. However the sound pressure level at the backside of the room still higher than in case 1 and case 2 because it affected by the external noises which comes from outside the lecture hall.

While for 70dB and 60dB, it show same result as the case 1 and case 2, the sound pressure level recorded at the receiving room is ranged between 41-44dB, and it cannot be used because the reading mainly come from background noise.

Except for the outliner point ‘e’, the sound reduction for 90dB and 80dB is fell inside the acceptance range, as the wall has block more than 30dB of sound from passing through. As discussed in section 2.5 (page 29), the wall has sound transmission of 30-35dB, which its performance is rated as fair, is because loud conversation can be heard through the partition, but much of the conversation will be unintelligible.

4.9 CadnaA Sound mapping software

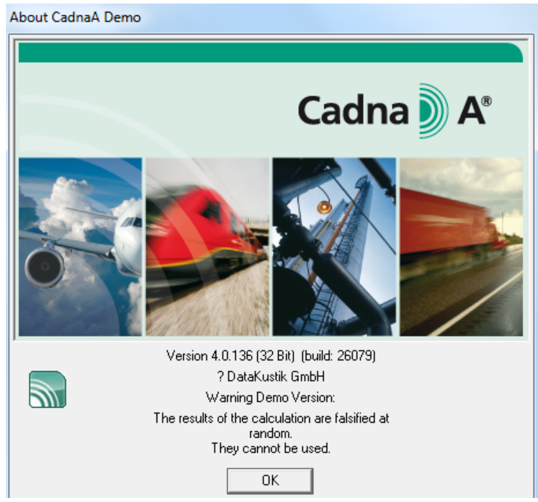


Figure 4-14: CadnA Demo

The CadnA software which used to construct the noise map is a demo version and therefore the value of SPL calculated by the software cannot be used. The main use of the program in our project is actually to plot the sound distribution of two rooms, and from that, we can understand how the sound been propagate.

At case 1, as you can see, the sound is entirely blocked by the wall in between, thus the sound pressure level at the receiving room has been greatly reduced, the sound distribution for the receiving room is weaker than the sound distribution level at the source room. While for case 2, as the door at the middle opened, the sound can pass through the door and go into the receiving room, thus causing the area nearby the doors is higher than the sound pressure level elsewhere at the receiving room. The sound distribution level of receiving room for case 2 is stronger than case 1 as more sound can pass through. For case 3, the sound pressure level distribution of two room still remain almost like in case 1 though two of the back doors are opened during the test. This is because the sound did not pass into receiving room through the back doors as it is blocked by the sound, and it is the shadow area which lesser sound will pass through.

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

The objective of the project has been achieved. The noise level of the both source room and receiving room of lecture hall has been identified by using sound level meter. From the sound mapping which provided at chapter 4 allows us to check the acoustic properties of both source room and receiving room. The sound reduction level across the lecture hall's wall is calculated and shown in chapter 4. From the results shown, I conclude that our lecture hall's wall has work as an effective sound blocker for attenuate the noise which transmitted to the next room. From three of the cases which been conducted in this project, we are able to see the effect of the door works on acoustic properties of lecture hall. Whenever there is a opened door, sound will be able to pass through, thus the sound pressure level of the specific locations will be higher. So, a very important point is, for the lecture hall's wall to work effectively, we have to ensure that all the doors are closed. Flanking such as the holes at the roof, the door gaps also make changes to the reading as the sound can pass through.

5.2 Recommendation

First of all, the results of the experiment can be improved by using the Nor 140 sound level meter, which is a type I sound level meter. This will provide more accurate results compared to the type II sound level meter we used in our project. In section 2, I have include the Sound Transmission Class and Noise Criteria. However I was unable to carry out the test on it due to limitation of equipment. Thus I suggest in future students can carry out the test on STC and NC and study about it after the equipment is available. It is very useful to identify the noise level of a room.

The composition of the wall which I mentioned during discussion was a assumption. It may be very close, but the exact answer can only be known after we study it. So I suggest in future students can try taking piece out from the wall, and recognize what is its composition. This is very useful for us to improve the acoustic properties after we know the composition. In the mean time, juniors are suggested to build a sound insulator for the lecture hall, so that the acoustic properties of the hall can be improved, more noise can be eliminated. For example, add few more layer of gypsum board at both side of the walls to improve the sound reduction.

At discussion, I mentioned of the opened hole found at the roof of lecture hall. So I suggested that my junior can undertake another experiment again after the roof has been fixed, all the hole has been sealed, because I believe that the result will be more accurate, because less flanking exist. Other than the lecture hall, in future students can carry out experiment to study the acoustic properties of others places in university, such as the meeting room, the library, the tutorial room, and others. University is a place to study and gain knowledge, thus I cannot let the noise affect the students from it.

When come to the layout design, noise mapping software is important to illustrate the noise distribution of the workplace. The CadnaA which we used in the project was demo version, although the results generated by it is still use-able, but its accuracy is doubted. Thus I recommend UTAR to purchase a licensed sound mapping software which allow students to use it in future. In additional, UTAR library has not sufficient of acoustic subject reference book when we want to get one for reference. So, I also recommend UTAR to provide more book subject to acoustic in the library for students references in the future.

Last but not least, I hope that UTAR can carry out the maintenance of lecture hall, including the roof and the wall routinely, such as fixing the roof and seal the porous wall. Even minor crack on the wall will affect the acoustic properties of the lecture hall, thus we must take good care of it so that it can remain in good condition all the times.

REFERENCES

A.C.C. Warnock, 'Sound transmission through two kinds of porous concrete blocks with attached drywall'

Acoustical Society of America, ASA. (*2000)*, *'Classroom acoustics. A resource for creating learning environments with desirable listening conditions.'*. Acoustical Society of America, 2 Huntington Quadrangle Melville, NY 11747, 2000

Albert Litvin and Harold W. Belliston (1978), 'Sound Transmission Loss Through Concrete and Concrete Masonry Walls'

Bashar S. Mohammed (2009), 'Papercrete as Infill Materials for Composite Wall System'

Birgit Rasmussen, Jens Holger Rindel(2005), 'Concepts for evaluation of sound insulation of dwellings-from chaos to consensus?'

Birgitta Berglund, Thomas Lindvall, Dietrich H Schwela, 'GUIDELINES FOR COMMUNITY NOISE'

Carol Flexer, 'Classroom Acoustics -The Effects on Standards & Pupils' Learning'

Carol Flexer Ph D, 2006, 'Classroom Acoustics - The Effects on Standards & Pupils' Learning'

CertainTeed Corp (2003), 'Noise Control in Buildings Guidelines for Acoustical Problem-Solving'

Charles M. Salter, P.E. 2002, '*Acoustics for Libraries*'

Charles M.Salter & Associates(1976), 'ACOUSTICS'

Cyril M. Harris (1994), "Noise Control in Buildings: A Practical Guide for Architects and Engineers"

Dennis W. Graber, 'Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls'

DIN 18041 (2004-05), *'Hörsamkeit von kleinen und mittleren Räumen. (Acoustical quality in small to medium-sized rooms.)'*, Beuth Verlag GmbH

D. MacKenzie, S. Airey (1999), *'Classroom Acoustics. A research project. Summary report.'* Heriot-Watt University, Edinburgh

Dr. A.C.C. Warnock and J.D. Quirt, 'Control of Sound Transmission through Gypsum Board Walls'

G. Semprini and L. Babaresi, 'Acoustical proprieties of light brick and its effect on flanking transmission'

James D. Janning, Understanding Acoustics in Architectural Design Norsonic AS (2008), 'nor140 SOUND ANALYSER'

Jerry G.Lilly, P.E. Member ASHRAE, 'Noise in the Classroom'

J. M. Klatte, M. Wegner, J. Hellbrück(*2005)*, 'Noise in the school environment and cognitive performance in elementary school children. Part B - Cognitive psychological studies', *Forum Acusticum 2005*, Budapest

John E.K. Foreman, ‘*Noise Control*’

John E.K. Foreman, ‘*Sound Analysis and Noise Control’*

J. Seidel, L. Weber, P. Leistner (*2005)*, ’Acoustic properties in German class rooms and their effect on the cognitive performance of primary school pupils’, *Forum Acusticum 2005*, Budapest

K. O. Ballagh, 2004, ‘Accuracy of Prediction Methods for Sound Transmission Loss’

Kurt Eggenschwiler(2005), ‘Lecture Halls - Room Acoustics and Sound Reinforcement’

Leo.L. Baranak(1971), ‘Noise and Vibration Control, McGraw Hill’

M. David Egan, ‘*Architectural Acoustics*’

National Gypsum, ‘Gold Bond® BRAND SoundBreak™ Gypsum Board’NRCC, *Deriving Acceptable Values for Party Wall Sound Insulation from Survey Results*, by J.S. Bradley

Quiet Solution Incorp (2004), ‘Soundproofing Home Theaters & Media Rooms’

Russ Lewis , ‘Review of ASHRAE Noise Criteria for Teaching Laboratories Relative to Achieved Speech Intelligibility’

Ronald L. Geren, AIA, CSI, CCS, CCCA, SCIP (2005), ‘ Sound Transmission’

Stanley E. Dunn Jr., 2007, ‘ Meeting the Market’s Growing Need for High-STC Walls: Innovative Solutions for a High-Density World’

Stanley D. Gatland II, 'ACOUSTICAL INSULATION'

Valtteri Hongisto, 2000, 'Airborne sound insulation of wall structures-measurement and prediction methods'

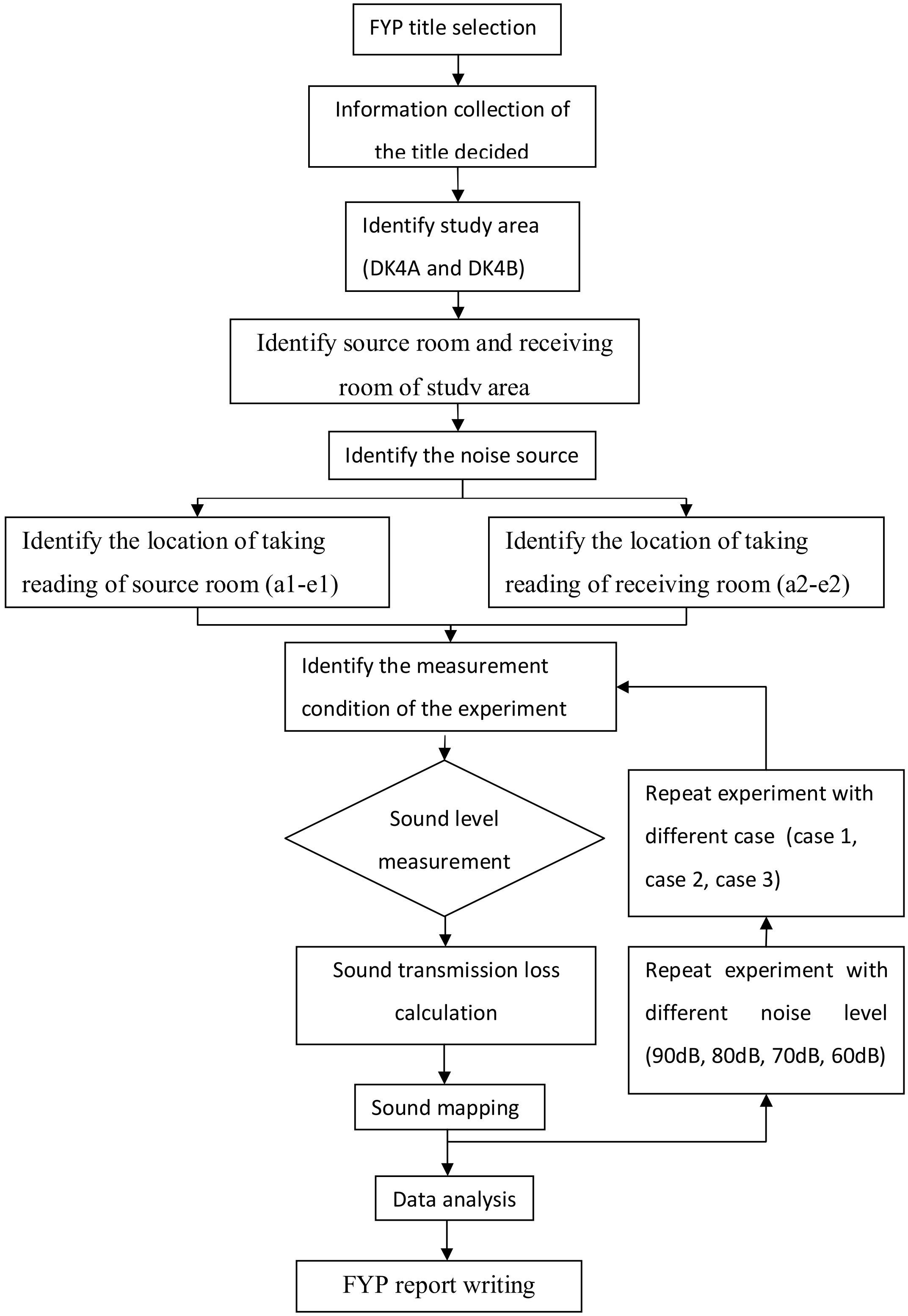
WILLIAM J. CAVANAUGH(2009) 'Introduction to Architectural Acoustics and Basic Principles'

W. J. Cavanaugh, *Building Construction: Materials and Types of Construction*, 5th ed., ed. Whitney Huntington and Robert Mickadeit. Copyright C _ 1981 John Wiley & Sons. Reprinted by permission of John Wiley & Sons.

William J. Cavanaugh, in "Acoustics—General Principles," in Encyclopedia of Architecture: Design, Engineering & Construction, ed. Joseph A. Wilkes. Copyright C _ 1988 John Wiley & Sons. Reprinted by permission of John Wiley & Sons.

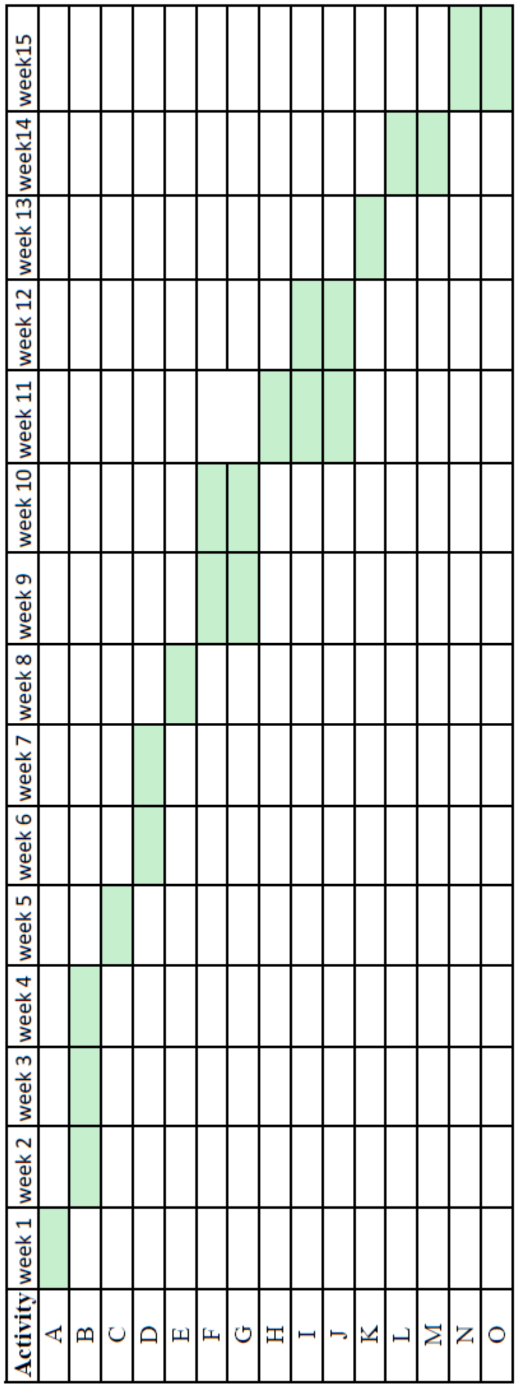
University of Maryland, Baltimore County(2000), 'LECTURE HALL DESIGN STANDARDS'

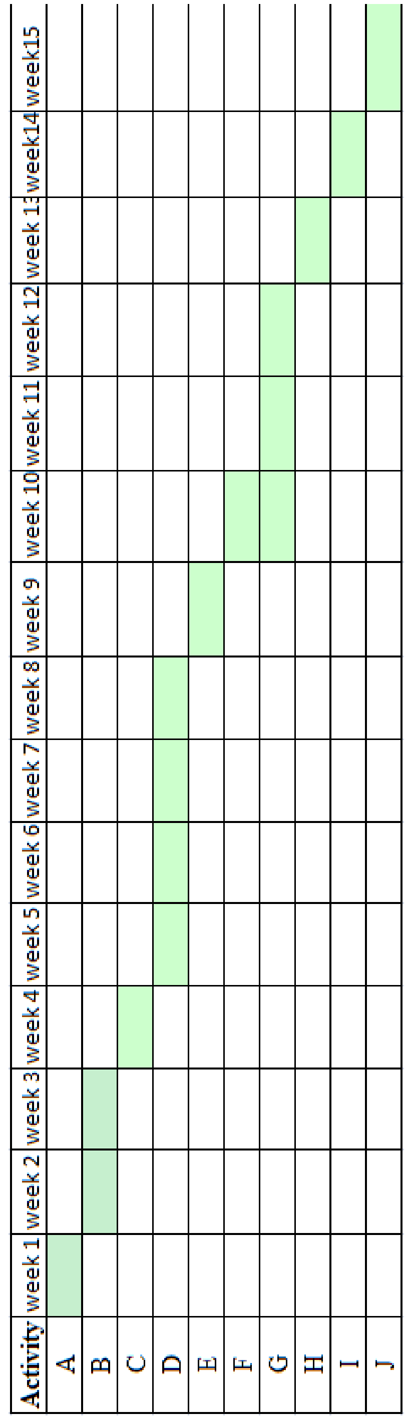
Appendix



Appendix 1: Process Flow Chart

The Gantt Chart





Appendix 2: Gantt Chart for Phase I and Phase II