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Evaluation of Reverberation Time in the Auditorium

(Case of Assembly Hall of Engineering Faculty, Universitas Sebelas Maret)

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Abstract—This research was conducted at the Assembly Hall or auditorium of Engineering Faculty UNS. This study aims to see the acoustic comfort and how to improve it by modifying the room material. The method chosen is the method with the least amount of modification. The method applied was measuring the room condition using laser distance meter and sound level meter, taking notes on the characteristic of the material used, and developing a simulation based on several modifications of the room materials. The result of the simulation was then compared to the standard of reverberation time. The study concludes (1) the acoustic condition in the room is indeed not meeting the standard to ensure users comfort, (2) the reverberation time is better when additional plasterboard ceiling is built. The simulation in this study was done through the help of Ecotect 2011.

Keywords— *acoustic, material, reverberation time*

This research was conducted at the Faculty of Engineering Main Meeting Room with the aim of improving acoustic quality, especially the improvement of reverberation time (RT) of this space to fit the auditorium standards. To achieve this goal, major changes are made to the ceiling material because it has the most impact on space acoustics. Ceiling is also one part of the building whose material is easier to modify. Other parts that are also modified are walls and floors.

I. ACOUSTICS AND REVERBERATION TIME CALCULATION

A. Acoustics

The Oxford Dictionary defines acoustics as "relating to sound or the sense of hearing". In physics, the term *acoustics* is used to explain the properties or qualities of a room or building that determine how sound is transmitted in it (Oxford University Press, 2017). In the classroom, there are three components to consider when studying room acoustics as these components affect users' information reception. The three components are ambient noise, reverberation and signal to noise ratio (SNR).

Ambient noise, or sometimes called background noise, is the prevailing noise level in a specified environment measured in the absence of the noise being studied (Ziobroski and Powers, 2005). Ambient noise may be produced externally, for example the sound of rain, traffic, or operating powerplant outside the room. Internally, the noise may be generated by the noise from PC or laptop used, light blasts or simply users' conversation.

Signal to Noise Ratio (SNR) compares the signal (direct sound or prime sound) to the noise. Basically, SNR is used to understand the quality of the signal transferred to users. Higher ratio is usually considered better specification because it means that the prime sound is louder than the noise (Altunian, 2016). Better level of SNR ensures

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better understanding of the captured audience especially when the audience need to focus on the information. SNR are influenced by several factors, including audience sitting position, room dimension, and room materials.

Reverberation is produced when the boundary surfaces of a room consist of a material which reflects the incident sound, the sound produced by a source inside the room - the direct sound - rebounds from one boundary to another, giving origin to the reflected sound (Hansen, without year). The level of reverberation is measured to ensure that voices (the one that matters to be heard) can be heard clearly by users. There are different levels of ideal reverberation among different functions of the room. Concert halls dan classrooms present two considerably different reverberation levels as the hum of the music may need to stay longer and more satiated in concert halls than in classrooms. The maximum level of reverberation time recommended for auditoriums is 2 seconds, while in classrooms, the ideal condition only allows 1 second. The reverberation time confirms the quality of room acoustics. In this study, it was found that the sound decreases to 60 dB below the original volume of the prime voice.

Reverberation time can be calculated directly using a special equipment installed inside the room. Another way would be calculating the time manually using a Sound Level Meter (SLM) and a stopwatch, but the sound source and the SLM must be positioned in an unobstructed area. The source emits volume higher than 60 dB to simplify the calculation when the sound drops in intensity by as much as 60 dB to prevent experiment failure due to the lack of voice to be identified.

For less active calculation, reverberation time simulation can be done using the Sabin or Eyring formula. Sabin created a formula to calculate reverberation time in a room built using less sound-absorbent materials, while Eyring formula is appropriately used for a room built using more sound-absorbent materials.

Eyring formula is as follows.

$T_R = 0.161\ V/ - \Sigma s.\ Ln(1- \alpha)$…….....1)

T_R Reverberation Time in second

0.161= Constanta

V= Volume (m^3)

Σs= surface area (m^2)

α = absorption coefficient of surface area

The Sabin formula is as follows:
t =0.161V/A……..... (2)

by:

t Reverberation Time in second

V is room volume (m^3)

A = Σs. α = is the total absorption of each boundary surface of the room (m^2)
i.e. Σ (surface area x coefficient of absorption).

For spaces that are more complex and have varying absorption surfaces, the following Mellington Sette formula is used.

$T_R = 0.161\ V/ - \Sigma s_n.\ Ln(1- \alpha_n)$……..... (3)

0.161= Constanta

V= Volume (m^3)

Σs_n = surface area n (m^2)

α_n= sound absorption coefficient of surface area n

B. Echo Control and Reverberation

In certain circumstances, the general expectation is low level of reverberation, although in a room without any material obstruction, reverberation

may still occur. When this appears to be the problem, the only possible intervention is to change the wall surface material forming the room edges from a highly reflective to lowly reflective material. The results showed that when the value of the room total absorption doubled its original value, the undesirable sound reflections or noise (Mediastika, 2006) can be decreased by approximately 3 dB. The rate of noise decline can be calculated using the following formula:

NR=10 log(a2/a1)…….....(4)

With:
NR is a noise reduction obtained (dB)
a2 is the room total absorption after the re-design
a1 is the current room total absorption
One thing to note is that in addition to formula (4), formula (5) can also be used, as formula (5) is the simplified version of formula (1)

NR = 10 (log a2– log a1)…….…… (5)

As the level of absorption of every material is very specific to each frequency, it is important to calculate the NR for every frequency of prime sounds. On paper, NR of 20 dB may be achieved, but actual observation on the room showed that NR 10 dB is the most effective level achieved. This undesirable result may come from the material's quality. Room acoustic design is mainly about material selection when there is a small room for design modification. To achieve higher value of NR, intervention to the ceiling becomes the most possible action to consider. Generally, the ceiling is an element that is free from any other obstruction or divider, so it is a potential reflector of the prime sound. In designing auditoriums, three elements must be considered:

a. The shape and volume of the auditorium

b. Factors that affect hearing,

c. The influence of the geometry of the room views, namely horizontal cover and vertical sight lines.

Reverberation time of the fully occupied auditorium ranges from 0.5 to 0.8 seconds at mid-frequencies, and usually the volume of auditorium noise level is 55 dB (Public Works Department, 2000)

Doelle, Leslie, L., (1993) calculate that at frequency of 500 Hz, the RT of gypsum board (13 mm) is 0.05 s, wood is 0.10 s, and glass is 0.04 s.

The mean RT for auditoriums at 500 Hz is 0.98 s. This value is lower than that proposed by the standard for the acoustic treatment of enclosed spaces (Jedidi, M, Boulila., A. , 2016).

For multi-function auditoriums, Egan (1988) recommend a noise criteria (NC) of 20-30, an equivalence of 30-40 dB.

II. METHODOLOGY

The procedure used in this study consists of the following seven steps:

1 room dimension measurement using laser distance meter and plan and section designing

2 noise measurements at several points in the room with sound level meter

3 auditorium material identification,

4 calculating the existing Reverberation Time

5 simulations using Ecotect 2011 to achieve ideal Reverberation Time

6 redesigning auditorium material

7 noise reduction calculation

(Iswati, T.Y. ,2016)

III. RESULT AND DISCUSSION

The first step before calculating the existing RT is drawing the plan, section, and absorption coefficient of the room material.

TABLE 1. ABSORPTION COEFFICIENT OF SOME BUILDING MATERIALS AT FREQUENCY LEVEL OF **500 HZ ***

Material	Absorption Coefficients
Cement Floor	0.015
Cement Floor covered with ceramics	0.01
Cement Floor covered with thin carpet	0.05
Cement Floor covered with thick carpet	0.14
Cement Floor covered with wood	0.10
Smooth plastered bricks	0.02
Rough plastered bricks	0.01
Expose bricks	0.06
Wooden board	0.10
Painted concrete columns	0.04
Unpainted concrete columns	0.06
Fabric curtain (thin/medium/thick)	0.11/ 0.49/ 0.55
Smooth glass	0.01
Rough or frosted glass	0.04
Concrete floor	0.015
Plasterboard	0.17
Gypsum	0.05
Aluminum	0.01
Fabric chairs	0.60
Plastic chairs	0.01
Furniture, etc.:	0.17
Air	0.007 **
Humans	0.46

*) The frequency of 500 Hz is used as the average absorption coefficient of the material
**) Air is calculated at a frequency of 2000 Hz
Source: www.akustik.ua

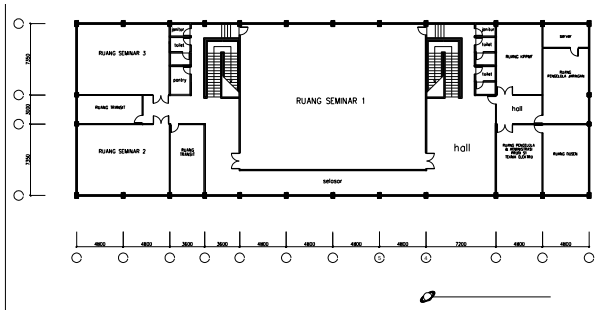

Fig 1.Plan of level 2nd Building 3 Engineering Faculty (source : Engineering Faculty UNS)

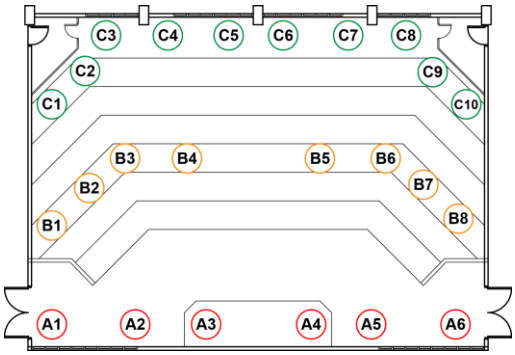

Fig 2. Measurement Points

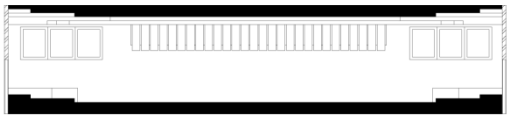

Fig 3 .Section A-A center to front

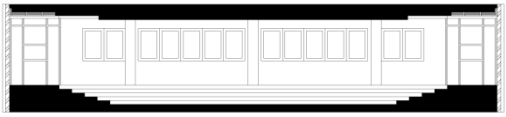

Fig 4.Section A'-A' center to back

Fig 5. Section B-B center to right

Fig 6. Section B'-B' center to left

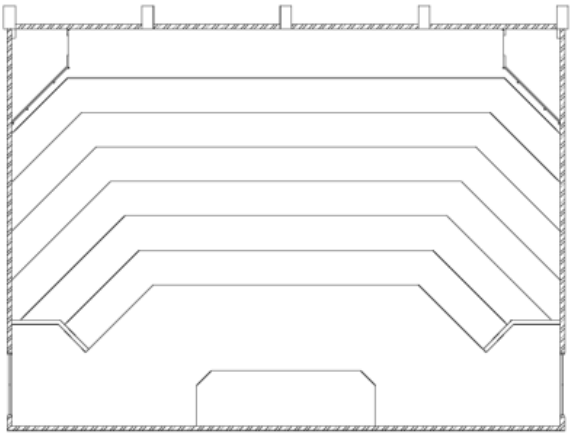

Fig 7. Section C-C center to down

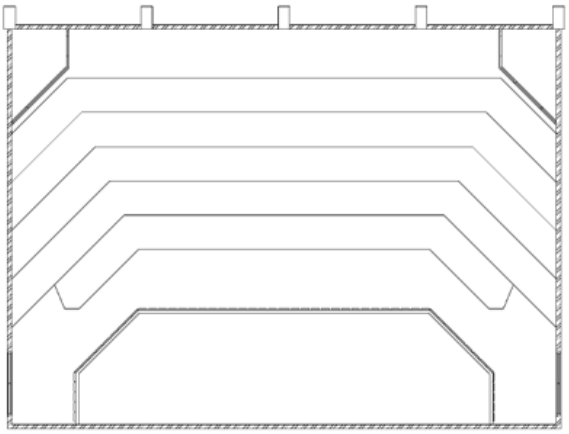

Fig 8. Section C'-C' center to up

Noise level measurement was performed inside the auditorium in three different settings: no user (0%), half capacity (50%), and full capacity (100%)

TABLE 2. MEASUREMENT RESULTS WITH 0% OF USERS (IN dB)

	Min	Max		Min	Max
A1	39.6	43.8	**C1**	39.0	39.9
A2	39.1	41.3	**C2**	39.3	42.4
A3	40.3	44.7	**C3**	40.9	42.8
A4	39.8	47.3	**C4**	40.5	43.9
A5	41.2	44.0	**C5**	40.4	42.6
A6	41.5	44.0	**C6**	39.1	42.7
			C7	40.4	43.3
B1	39.3	48.1	**C8**	38.4	41.6
B2	40.8	48.1	**C9**	39.7	43.7
B3	42.4	45.6	**C10**	38.3	39.4
B4	41.9	48.6			
B5	39.2	48.3			
B6	40.7	43.6			
B7	38.5	48.4			
B8	39.1	44.1			

Source: field measurement 2018

TABLE 3.MEASUREMENT RESULTS WITH 50% OF USERS (IN dB)

	Min	Max		Min	Max
A1	60.6	98.6	**C1**	54.4	98.2
A2	66.4	97.7	**C2**	49.3	75.8
A3	56.2	96.3	**C3**	51.7	77.6
A4	60.2	100.2	**C4**	66.7	81.8
A5	63.9	97.9	**C5**	56.6	98.5
A6	78.5	98.9	**C6**	52.9	75.5
			C7	50.5	74.8
B1	49.0	96.3	**C8**	50.5	78.8
B2	50.7	78.2	**C9**	49.5	79.1
B3	60.5	76.5	**C10**	51.3	100.3
B4	60.8	97.4			
B5	60.6	78.9			
B6	50.3	99.0			
B7	53.9	99.7			
B8	53.2	79.7			

source: field measurement 2018

TABLE 4.MEASUREMENT RESULTS WITH 100% OF USERS (IN dB)

	Min	Max		Min	Max
A1	60.9	74.9	**C1**	57.4	74.5
A2	64.9	94.1	**C2**	60.6	97.4
A3	56.1	97.0	**C3**	67.1	97.9
A4	48.6	98.9	**C4**	57.6	72.3
A5	55.8	99.5	**C5**	59.1	76.4
A6	55.6	99.7	**C6**	60.7	98.1
			C7	54.8	100.3
B1	59.2	75.5	**C8**	62.5	100.0
B2			**C9**	59.2	100.5
B3	59.2	75.9	**C10**	58.0	100.0
B4					
B5					
B6	52.6	97.8			
B7					
B8	54.4	99.9			

source: field measurement 2018

Then, a simulation was done in the existing situation. The results are shown in the following table (according to Sabin, Norman-Eyring, Mellington-Sette):

BEFORE

TABLE 5. ABSORPTION COEFFICIENT OF SOME BUILDING MATERIALS BEFORE DESIGNED

Elements		Wall	Partition	Floor		Ceiling	Doors		Windows
				Podium	Terraced Floor		Main	Partition	
Material		Brick Plaster	Framed Plywood	Conc Slab Timber On Ground	Conc Floor Tiles Suspended	Plaster Joists Suspended	Glass Sliding Door	Hollow Core Plywood	Single Glazed Timber Frame
Absorption Coefficients at Frequency Of	63 Hz	0.10	0.17	0.05	0.02	0.28	0.51	0.44	0.17
	125 Hz	0.07	0.10	0.04	0.02	0.28	0.35	0.41	0.14
	250 Hz	0.03	0.07	0.07	0.02	0.20	0.25	0.35	0.09
	500 Hz	0.02	0.07	0.09	0.02	0.10	0.18	0.25	0.02
	1 KHz	0.02	0.08	0.14	0.03	0.08	0.12	0.20	0.00
	2 KHz	0.02	0.05	0.12	0.04	0.08	0.07	0.15	0.00
	4 KHz	0.03	0.04	0.10	0.07	0.12	0.04	0.14	0.00
	8 KHz	0.02	0.05	0.14	0.07	0.13	0.02	0.13	0.01
	16 KHz	0.03	0.04	0.17	0.09	0.15	0.01	0.12	0.01

TABLE 6. SIMULATION RESULTS WITH 0% USERS BEFORE THE REDESIGN

	Total	**Sabine**	**Nor-Er**	**Mil-Se**
Freq	**Abspt.**	**RT(60)**	**RT(60)**	**RT(60)**
-------	-------	-------	-------	-------
63Hz:	99.385	1.01	0.75	0.89
125Hz:	92.467	1.05	0.91	0.93
250Hz:	64.776	1.23	1.15	1.14
500Hz:	35.951	**1.51**	1.67	1.47
1kHz:	33.105	1.44	1.82	1.41
2kHz:	34.218	1.27	1.68	1.25
4kHz:	55.028	0.94	1.44	0.92
8kHz:	56.928	0.76	1.04	0.75
16kHz:	68.357	0.70	1.03	0.68

TABLE 7. SIMULATION RESULTS WITH 50% USERS BEFORE THE REDESIGN

	Total	**Sabine**	**Nor-Er**	**Mil-Se**
Freq	**Abspt.**	**RT(60)**	**RT(60)**	**RT(60)**
-------	-------	-------	-------	-------
63Hz:	99.385	0.93	0.70	0.83
125Hz:	92.467	0.98	0.86	0.87
250Hz:	64.776	0.95	0.90	0.90
500Hz:	35.951	**1.14**	1.23	1.12
1kHz:	33.105	1.14	1.37	1.12
2kHz:	34.218	1.01	1.25	1.00
4kHz:	55.028	0.85	1.24	0.83
8kHz:	56.928	0.73	0.98	0.71
16kHz:	68.357	0.68	0.98	0.66

TABLE 8. SIMULATION RESULTS WITH 100% USERS BEFORE THE REDESIGN

	Total	**Sabine**	**Nor-Er**	**Mil-Se**
Freq	**Abspt.**	**RT(60)**	**RT(60)**	**RT(60)**
-------	-------	-------	-------	-------
63Hz:	99.385	0.87	0.66	0.77
125Hz:	92.467	0.91	0.81	0.82
250Hz:	64.776	0.77	0.74	0.74
500Hz:	35.951	**0.91**	0.97	0.90
1kHz:	33.105	0.94	1.09	0.93
2kHz:	34.218	0.83	0.99	0.82
4kHz:	55.028	0.77	1.09	0.76
8kHz:	56.928	0.69	0.92	0.68
16kHz:	68.357	0.64	0.93	0.64

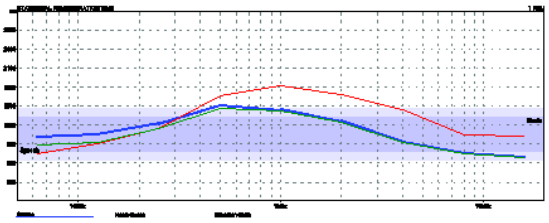

Fig 9. Simulation results with 0% users in the existing design

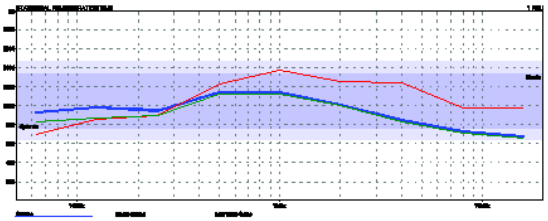

Fig 10. Simulation results with 50% users in the existing desi

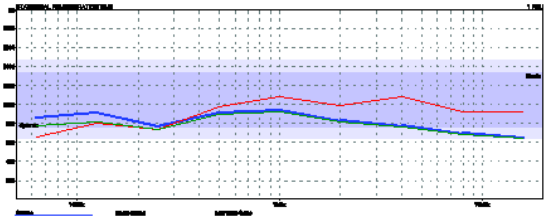

Fig 11. Simulation results with 100% users in the existing design

Then, another simulation was done after the redesign. The results are shown in the following table:

AFTER

TABLE 9. ABSORPTION COEFFICIENT OF SOME BUILDING MATERIALS AFTER DESIGNED

Elements		Wall	Partition	Floor		Ceiling	Doors		Windows
				Podium	Terraced Floor		Main	Partition	
Material		Brick Plaster	Framed Plasterboard	Conc Slab Timber On Ground	Conc Floor Tiles Suspended	Acoustic Tile Suspended	Glass Sliding Door	Hollow Core Plywood	Single Glazed Timber Frame
Absorption Coefficients at Frequency Of	63 Hz	0.10	0.28	0.05	0.02	0.06	0.51	0.44	0.17
	125 Hz	0.07	0.28	0.04	0.02	0.06	0.35	0.41	0.14
	250 Hz	0.03	0.20	0.07	0.02	0.13	0.25	0.35	0.09
	500 Hz	0.02	0.10	0.09	0.02	0.47	0.18	0.25	0.02
	1 KHz	0.02	0.07	0.14	0.03	0.91	0.12	0.20	0.00
	2 KHz	0.02	0.07	0.12	0.04	0.94	0.07	0.15	0.00
	4 KHz	0.03	0.11	0.10	0.07	0.78	0.04	0.14	0.00
	8 KHz	0.02	0.12	0.14	0.07	0.74	0.02	0.13	0.01
	16 KHz	0.03	0.15	0.17	0.09	0.70	0.01	0.12	0.01

TABLE 10 SIMULATION RESULTS WITH 0% USERS AFTER THE REDESIGN

Freq	Total Abspt.	Sabine RT(60)	Nor-Er RT(60)	Mil-Se RT(60)
63Hz:	44.153	1.96	0.74	1.83
125Hz:	38.389	2.04	0.88	1.94
250Hz:	48.769	1.47	1.11	1.41
500Hz:	132.388	**0.67**	1.58	0.54
1kHz:	248.162	0.40	1.71	0.17
2kHz:	257.549	0.38	1.67	0.15
4kHz:	227.324	0.41	1.50	0.24
8kHz:	216.258	0.41	1.25	0.26
16kHz:	212.789	0.40	1.16	0.28

TABLE 11 SIMULATION RESULTS WITH 50% USERS AFTER THE REDESIGN

Freq	Total Abspt.	Sabine RT(60)	Nor-Er RT(60)	Mil-Se RT(60)
63Hz:	44.153	1.69	0.69	1.58
125Hz:	38.389	1.78	0.83	1.71
250Hz:	48.769	1.09	0.88	1.06
500Hz:	132.388	**0.59**	1.18	0.48
1kHz:	248.162	0.37	1.29	0.16
2kHz:	257.549	0.35	1.21	0.14
4kHz:	227.324	0.39	1.26	0.24
8kHz:	216.258	0.39	1.12	0.25
16kHz:	212.789	0.39	1.07	0.27

TABLE 12 SIMULATION RESULTS WITH 100% USERS AFTER THE REDESIGN

Freq	Total Abspt.	Sabine RT(60)	Nor-Er RT(60)	Mil-Se RT(60)
63Hz:	44.153	1.48	0.66	1.40
125Hz:	38.389	1.58	0.78	1.52
250Hz:	48.769	0.86	0.73	0.84
500Hz:	132.388	**0.52**	0.94	0.43
1kHz:	248.162	0.34	1.03	0.16
2kHz:	257.549	0.32	0.95	0.14
4kHz:	227.324	0.37	1.08	0.23
8kHz:	216.258	0.38	1.02	0.25
16kHz:	212.789	0.38	1.00	0.27

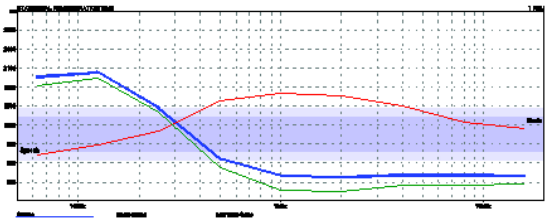

Fig 12. Simulation results with 0% users after the redesign

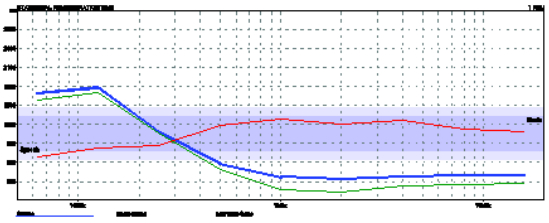

Fig 13. Simulation results with 50% users after the redesign

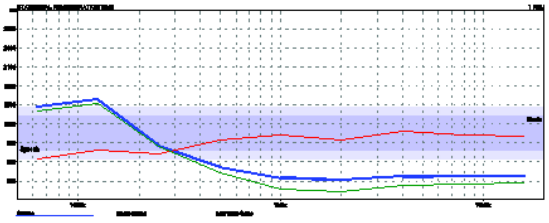

Fig 14. Simulation results with 100% users after the redesign

IV. CONCLUSION

The calculation and simulation produce the following conclusion:

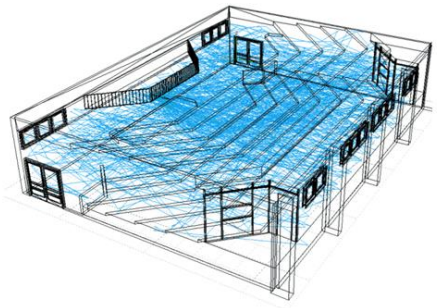

Figure 15. Sound distribution simulation from the stage

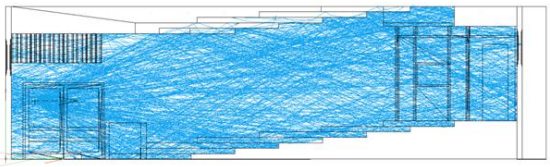

Figure 16. Sound distribution simulation from the stage

After an ideal RT was achieved, noise reduction was measured as shown by the table below.

NR=10
log(a2/a1)……
…….....(

TABLE 13. ABSORPTION COEFFICIENTS OF SOME BUILDING MATERIALS FOR THE SIMULATION

Material	Surface area (s)	Absorption coefficient (α)	s.α	Surface area (s)	Absorption coefficient	s.α
Ceiling	258.2	0.47	121.4	258.2	0.1	25.8
Floor audience	245.8	0.09	22.1	245.8	0.09	22.1
Floor stage	12.4	0.02	0.2	12.4	0.02	0.2
Front wall	13.7	0.02	0.3	13.7	0.02	0.3
Right wall	230.1	0.02	4.6	230.1	0.02	4.6
Right wall board	10.8	0.07	0.8	10.8	0.07	0.8
Left wall	230.1	0.02	4.6	230.1	0.02	4.6
Left wall board	10.8	0.07	0.8	10.8	0.07	0.8
Rear wall	23	0.02	0.5	23	0.02	0.5
Cloth upholstered seats per m2	133.9	0.77	103.1	133.9	0.77	103.1
Adult per person seated	279	0.44	122.8	279	0.44	122.8
Door	10.12	0.18	1.8	10.12	0.18	1.8
window	36.8	0.02	0.7	36.8	0.02	0.7
		Σs.α	392.1		Σs.α	296.5
Total Surface area			383.6			288.1
100%		**Σs1.α1**	**383.6**		Σs2.α2	**288.1**
0%		**Σs1.α1**	**260.8**		Σs2.α2	**165.3**
50%		**Σs1.α1**	**322.2**		Σs2.α2	**226.7**

		NR (dB)	
100%	**(Σs2.α2)/(Σs1.α1)**	**0.75**	1.24
0%		**0.63**	1.98
50%		**0.70**	1.53

Based on data by the Public Works Department (200), an ideal reverberation time (RT) (0.5-0.8) was obtained at all levels of user (0%, 50% and 100%) specifically at 0.63, 0.70, and 0.75 respectively. In addition, Noise Reduction (NR) measurement produced 1.98, 1.53, and 1.24 respectively while the recommended NR value for an auditorium is 30-40 dB.

This research concludes that the auditorium has not met the standards of acoustic space of an auditorium in the Reverberation Time, but it can be solved by modifying the ceiling with Plaster Joists Suspended. The recommended NR value for auditoriums is 30-40 dB, but the measurement result is still far from this standard. The simulation results of the auditorium enclosing materials showed the NR value of less than 1 dB, which is still far from optimal.

This action produces the optimum reverberation time, but the resulting NR (noise reduction) has not been sufficiently optimal to reduce noise.

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