Journal of Physics: Conference Series **776** (2016) 012068 doi:10.1088/1742-6596/776/1/012068

The effect of boundary shape to acoustic parameters

M. S. Prawirasasra*, R. Sampurna and Suwandi
Engineering Physics Department, School of Electrical Engineering, Telkom University, Jl. Telekomunikasi Terusan Buah Batu, Bandung, Jawa Barat, Indonesia

Email: * bibinprawirasasra@telkomuniversity.ac.id

Abstract. To design a room in term of acoustic, many variables need to be considered such as volume, acoustic characteristics & surface area of material and also *boundary shape*. Modifying each variable possibly change the sound field character. To find impact of *boundary shape*, every needed properties is simulated through acoustic prediction software. The simulation is using three models with different geometry (*asymmetry and symmetry*) to produce certain *objective parameters*. By applying *just noticeable difference* (JND), the effect is considered known. Furthermore, individual perception is needed to gain *subjective parameter*. The test is using recorded speech that is convoluted with room impulse of each model. The result indicates that 84% of participants could not recognize the speech which is emit from different geometry properties. In contrast, JND value of T_{30} is exceed 5%. But for D_{50}, every model has JND below 5%.

1. Introduction

Every room should have unique design for specific purpose in acoustic term. The object of this study is audio-visual room. The daily operation is for distance learning-teaching activities with two-way communication: speech and listening and also supported with visual media tools. It is categorized as room for speech. There are criteria need to be fulfilled and certainly many rooms do not meet the requirements. So, the physical properties of boundary (room) need to be re-designed.

The characteristics of acoustic field in enclosures is very complicated due to multiple reflection from boundary (wall, ceiling and floor). The reflected sound creates two specific features: at receiving point, the inverse square law does not apply and reverberation happened after the sound source has stopped [1]. Those phenomenon creates specific sound field which is function of boundary including shape-dependent [2]. The previous research obtained the prediction of Reverberation Time (RT) for several rooms whose geometry boundaries are different but with slightly the same volume and consist of same scattering coefficient [3].

The purpose of research is to identify the effect of geometry shape to human ear. By applying different shape of room, particular sound field is expected to be noticeable by human ear. There are two assessment methods: objective and subjective acoustic parameters. The selective parameters have been chosen related with speech intelligibility: D_{50}, T_{30} and also sound strength (G). The value of it should no less than certain point regarding to Just Noticeable Difference (JND). Subjective test was applied to random health participants by playing recorded voice which is already convoluted by specific room response of different shape of boundary.

Journal of Physics: Conference Series **776** (2016) 012068 doi:10.1088/1742-6596/776/1/012068

2. Methodology and Definition

During research, there are several systematic steps need to be fulfilled. In general, there are two type of method to produce raw data: 1) field measurement and 2) simulation. Below is the brief description of each stage including the description of objective parameters.

The important parameters (D_{50}, T_{30} and G) is investigated in term of simulation and measurement. The differences are discussed and their significance is concluded within the frame of Just Noticeable Difference (JND). Table 1 shows the parameters used with JND. The varies in geometry shape is expected to perceived differently by human ear. Whenever it has value larger than JND, it means human ear could notice the difference and vice versa.

Table 1. Acoustic Parameters and JND value

Parameter	Symbol	JND
Definition	D_{50} (%)	0.05
Sound strength	G(dB)	1 dB
Reverberation Time (30 dB range)	T_{30} (s)	5%

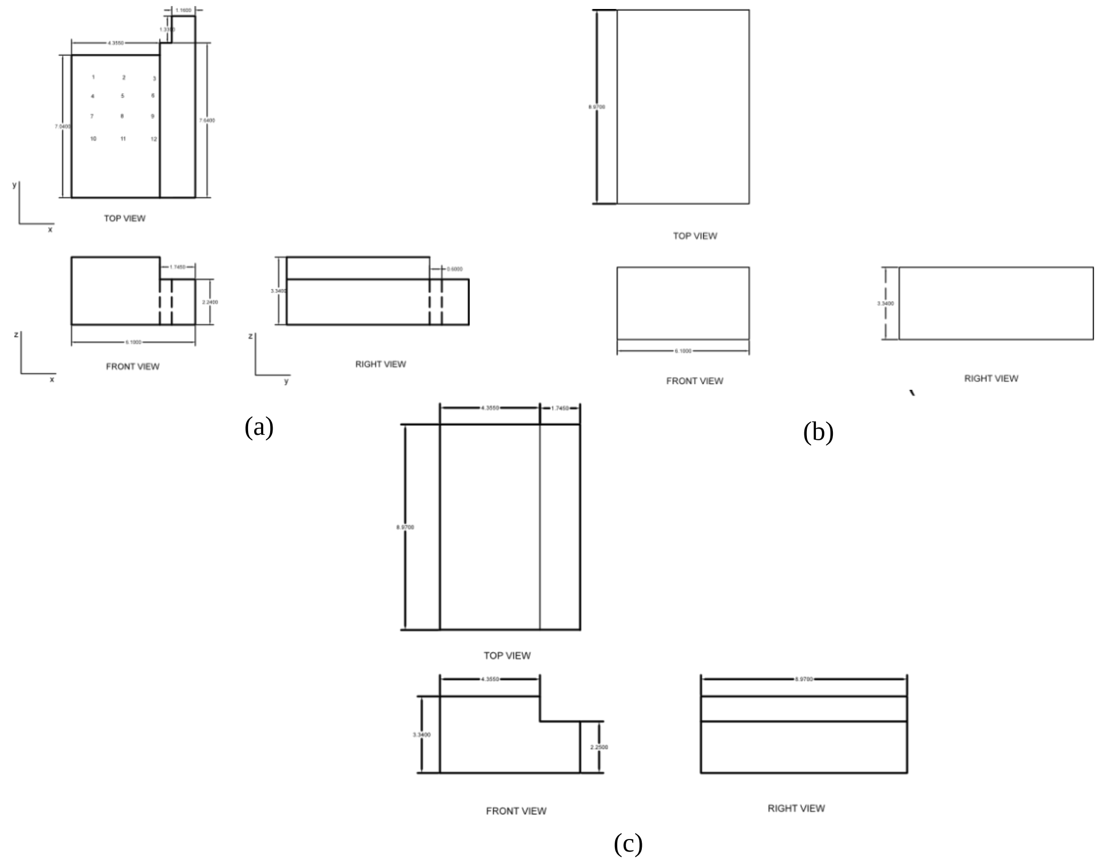

Figure 1 Projection of models (a) Model 1, (b) Model 2 and (c) Model 3.

Measurement is mandatory because the measured variable is used to validate the output of simulation through acoustic prediction software. There are 12 measurement points so simulation requires same point and position to get validated. The simulated model (model 1) is arranged to have identic properties with actual object. Geometry of object has asymmetry cross section refer to xy, xz and yz plane. The projection of model 1 is at Figure 1(a).

To identify the impact of geometry shape to acoustic parameters, it requires evaluation of related objective acoustic parameters represent particular geometry shape with the same acoustic properties. There are two other different shapes of models that will be simulated. Each models have different cross section either asymmetry and symmetry refer to certain planes. Model 2 are considered has symmetry cross section (shoe-box shape) and has the longest length of model 1. Otherwise, model 3 only has symmetry cross section refer to xy and yz plane but asymmetry to xz plane. Similar with model 2, the model 3 has maximum length of model 1. To analyze the impact of geometry shape, the expectation is every models have nearly the same volume. Differently, it is used the comparison of volume and the surface area of models. The projection of last two models and dimension properties are at Figure 1(b) and (c) and Table 2.

Table 2 Comparative of models' dimension

Model	Volume (m^3)	Surface area (m^2)	Volume/Surface area (m)
1	143.306	183.65	0.73
2	212.414	210.1	0.86
3	165.692	196.52	0.84

Procedure of subjective evaluation is different with objective evaluation. However, it requires participants in order to determine the differences of recorded speech. Test voices are convoluted with specific room impulse response of each model. Participants are asked to answer several question related with speech intelligibility and identification whether voices are identic or not. The purpose of assessment is to get individual answer related with ability to differentiate the sound field.

Objective Parameters

D_{50}

At receiving point, the total energy is summation of direct, reflected and noise energy. The reflected energy is potentially either advantage or disadvantage for speech intelligibility. It depends on the amount of energy and receiving time. Useful reflection for speech occurs within early 50 ms after sound source is stopped. The parameters that illustrate the useful energy for speech is definition 50 (D_{50}). In mathematical term it defines as ratio of useful energy (0-50 ms) with total energy (0-∞ ms).

$$D_{50} = \frac{\int_0^{50} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \, [\%] \quad (1)$$

T_{30}

In physical term, reverberation is repetition of reflected sound by boundary after source is stopped. As the boundary has reflective surface the energy will decay in longer time. The parameter that illustrate the phenomena is defines as reverberant time or RT/T_{60}. The definition of T_{60} is the length of time required for sound to decay 60 dB after source stopped. To get the T_{60} value, it needs to discover the relation between decaying energy and time through linear regression. By implement the extrapolation, time to decay energy of 60, 30, or 10 dB is certain.

Source Strength (G)

This parameter measures of the amplification effect of sound produced by the space enclosure with respect to free space. According to ISO 3882, the definition of G is measured sound level is compared with the sound level in open space (no reflection) at distance 10 m from omnidirectional sound source. Below is the formula to find source strength

$$G = 10log \frac{\int_0^{\infty} p^2(t)dt}{\int_0^{\Delta t} p^2(t)dt} \, [\text{dB}] \quad (2)$$

where Δt is emission duration. Based on definition above, there are two possibilities of G, enhanced or diminish of level pressure.

Journal of Physics: Conference Series **776** (2016) 012068 doi:10.1088/1742-6596/776/1/012068

3. Results

Objective Parameters

The sub subchapter 3.1.1-3.1.3 displayed the calculation result of JND value of each assess parameters. The chart in Figure 1, Figure 2, and Figure 3 has two axis where abscissa is measurement point and difference value is plotted in ordinate. The unit in y-axis is similar with JND unit. For D_{50} and T_{30}, the unit is in percentage and it is calculated by normalized difference value of compared models. Differently, JND of G value is subtraction value between models.

3.1.1. D_{50}

This clarity parameter shows that every measurement point of each model have value no less than 92.3% and the largest value is 99.6%. According to the speech criteria of D_{50} parameter, every shape of geometry has 'very good' quality criteria regarding to speech intelligibility. The effect of geometry shape is trying to find out by compare each value of D_{50} for each models. The difference of D_{50} for one model refer to another is illustrate at Figure 1. Based on JND value, there are no difference value is larger than 5% or below JND. It means human ear could not identify either the sound is produced from model 1, 2 or 3.

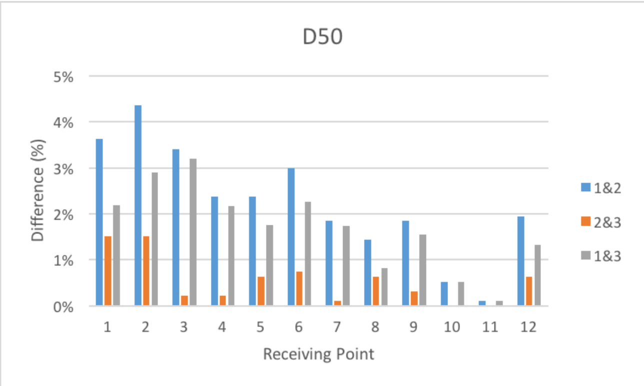

Figure 1 Comparison of D_{50}

3.1.2. T_{30}

In Figure 2, we show that for comparison of every value of T_{30} at measurement point for every models. Almost at every point the JND value fell above the minimum value (5%). Model 1&2 demonstrates that the difference is reach 50%. Only at point 3, the value is below the JND. Similarly, the comparison value of model 2&3 has range of value from 0%-24% and there are 4 measurement point have equal reverberation sound field. Furthermore, the enclosure shape between model 1&3 is clearly has significant effect to the reverberation. Based on the comparison value, there are no point of measurements have difference value less than 5%. The simulation result of this variables are from 11%-25%.

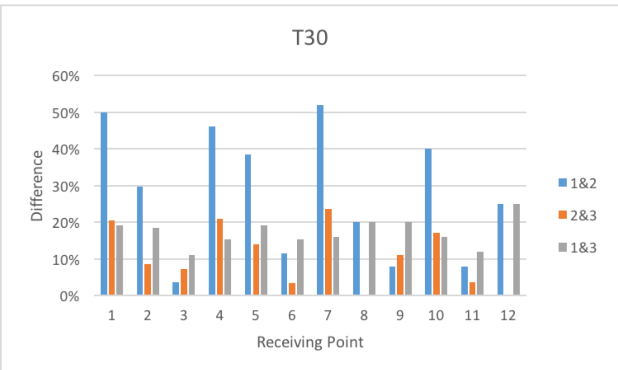

Figure 2 Comparison of T_{30}

3.1.3. Source Strength (G)
In Figure 3, the difference of G value at each measurement point has similar result. The largest difference is located at point 1 for model 1&2. The value is only 0.6 dB while the rest fell between -0.1 - 0.4 dB. Negative mark means that at that point the sound level is decrease and vice versa. According to JND, the source strength at every point does not influenced by geometry shape.

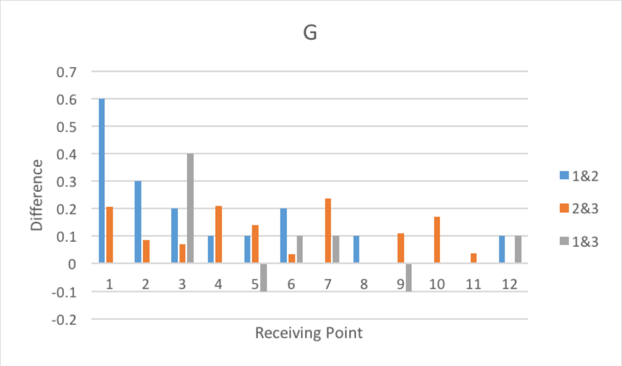

Figure 3 Comparison of G

Subjective parameters
There are 25 participants involved in this questionnaire. Every participant are asked to answer the given questions. The resume of answer related to speech intelligibility are presented in Table 3. The variation of percentage of clarity criteria of each model shows that speech intelligibility in every shape is perceived differently by participants. Only 'fair' criteria has same percentage over the geometry shape.

Table 3 Percentage of chosen criteria

Clarity criteria	Model 1 (%)	Model 2 (%)	Model 3 (%)
Excellent	8	4	8
Good	56	60	20
Fair	36	36	36
Bad	0	0	36

Furthermore, subjective assessment put another question related to hearing ability to differentiate the sound field. After listening the test speech, participants are asked to answer which of sound field were identic or none. The resume of answers is at Table 4. Almost all participants could not recognize the difference of each sound field. According to data, around 84% of participants agreed that the test voice is similar to each other while others say differently.

Table 4 Percentage of sound field recognition

Comparison	Identic (%)	None (%)
Model 1 & 2	72	16
Model 2 & 3	8	
Model 1 & 3	0	
Model 1, 2, 3	4	

4. Conclusion
The conclusion of this research is the geometry shape does not have impact to D_{50} and G because the difference value is lower than JND threshold. There is interesting point related with T_{30} value. The value is equivalent with ratio between volume and surface area. Even though the ratio is alike, it does not

Journal of Physics: Conference Series **776** (2016) 012068 doi:10.1088/1742-6596/776/1/012068

mean it has comparable T_{30} and JND. Apparently, the geometry shape has significant to reverberation time.

For subjective assessment, speech intelligibility among models are perceived differently. Not all participants choose the same category over the models. In contrary, participants could not identify the difference of each audio tests. 84 % of participants answered that there are identic to each other. Only 16% of participants could spot the difference among models.

References

[1] Maekawa, Z, and Peter L. 2004 *Environmental and architectural acoustics*. CRC Press, 2004.
[2] Beranek, L, and Daniel W. M.. 1996 *The Journal of the Acoustical Society of America* 99.5 pp. 2637-2637.
[3] Asta Rønning Fjærli, 2015 *Room Geometries with Non-Classical Reverberation Times*, Ms Thesis, NTNU.
[4] ISO 3382-1: 2009 International Standard ISO/DIS 3382-1: Acoustics – Measurement of room acoustic parameters – Part 1: Performance space.
[5] You, J, and Jin Y. J. 2006 *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. Vol. 2006. No. 1. Institute of Noise Control Engineering.
[6] Pedrielli, F, Eleonora C, and Camilla C. 2008 *Journal of the Acoustical Society of America* 123.5 pp. 3164-3164.
[7] Skålevik, M. 2010 *Proceedings of 20th International Congress on Acoustic, ICA*. Vol. 10.
[8] Haka, C. C. J. M., and Wenmaekersb R. H. C. 2008 *Proceedings of the Internoise*.
[9] Asmoro, W A. 2007. *IPTEK The Journal for Technology and Science*, 18.2.
[10] Araneo, G; Farina, A, Frova, A. 2006 *Saggiatore musicale*, pp 205-220.