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The Influence of Abfusor Configuration to the Speech Privacy and Intelligibility in an Open Plan Office

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ABSTRACT

Open plan office is an office plan which minimizes the use of full room divider such as a private office. Nowadays, open plan office is preferred because it provides many advantages such as working mobility and increasing teamwork between co-worker and managerial. This concept also fulfills today energy management issues. Open plan office provides minimum energy consumption especially in lighting and air conditioning. On the other hand, a problem that usually faced by worker whose work in open office plan, which has correlation in speech comfort, are audial interference caused by another sound or noise, and loss of speech privacy. One way to overcome this problem is by applying absorber – diffuser (abfusor) surfaces. In this paper, simulation of abfusor application in an open plan office model was done by using finite element and ray-tracing method. The simulation was carried out with the reference of ISO 3382-3:2012 for Open Plan Office – measurement of acoustic parameter. Parameters that were varied in this simulation include absorption coefficient, scattering coefficient and the formation of abfusor surfaces. In situ measurements in the real Open Plan Office which was modeled in the simulation were conducted to provide comparison to the based model. The Simulation was used to determine the parameters of abfusor which provides optimum values to increase speech privacy and speech intelligibility for the open plan office model.

Keywords: open plan office, privacy, intelligibility, abfusor, finite element method, ray tracing method.

I-INCE Classification of Subjects Number(s): 25.3 and 51.7

1. INTRODUCTION

Open plan office is known as one of office layouts which commonly used by most of architect these days. This layout uses minimum energy to building needs especially for lighting and air conditioning. This office layout minimizes the number of full room divider that makes this concept has well known as an alternative way to the cost of building construction. Open plan office also known as a layout that may provide and optimize the communication among workers and help them to build a better teamwork (1)(2). Although it could save the building cost, this concept faced a big problem on its acoustic quality. Because it minimizes the number of full room divider, noises and other unwanted sound can be heard by worker and disrupt their concentration.

Another problem that usually faced by the worker is speech privacy and speech intelligibility. There are several causes that may lead to loss of speech privacy such as direct sound that is not well controlled or reflective sound which is not handled properly. To handle this problem, we usually apply absorber surface to absorb most of direct sound energy and reduce reflective sound. Other ways to reduce reflected sound is by using a diffuser. The diffuser can be used to make sound more diffuse so than reflective sounds which come to unwanted area can be handled. The purpose of this study is to see whether combination of absorber and diffuser surface, which called as *abfusor* surface, can become an alternative way to solve speech privacy and speech intelligibility problem in open plan office. There are several abfusor forms that had been tested in this study by using computer modeling and simulation approach based on ISO 3328:3-

2012 for open plan office measurement standard. Acoustical measures which include in this study are $L_{p,A,S,4m}$, distraction distance (r_D), privacy distance (r_p), and sound transmission index (STI). These parameters are used to determine which form gives an optimal condition for speech privacy and intelligibility.

Based on previous study that had been done by Annisa Eska Larasati about The Influence of Workbench Formation to Speech Privacy and Speech Intelligibility in Open Plan Office, the modification of the workbench formation and workbench height gives an impact to the open plan office acoustic condition. The addition of workbench partition height will increase the speech privacy in open plan office (3). Another research about open plan office is also had been done by Wahyu Nur Isnain Novianto. In this study we see that modification of the workbench is also improved the speech privacy and speech intelligibility in open plan office (4). Both of these studies are using ray-tracing method to do the simulation of room acoustic condition. Because this method treat sound as a ray, then sound phenomenon which supposed to be happen in a room such as diffraction is cannot well observed in ray-tracing method. To get more comprehensive result of the simulation, this study is combine two method of simulation. The simulation that had been done in this study is using ray-tracing method for 125 Hz – 4 kHz with 1 octave band filter and by using finite element method for 63 Hz – 125 Hz with 1/3 octave band filter and also for 250 Hz.

2. CASE STUDIED AND MEASUREMENT PROCEDURE

A bank office in Jakarta which uses an open plan office layout was selected as an object studied in this study. The shape and dimension (in meter) of this office are shown in Figure 1.

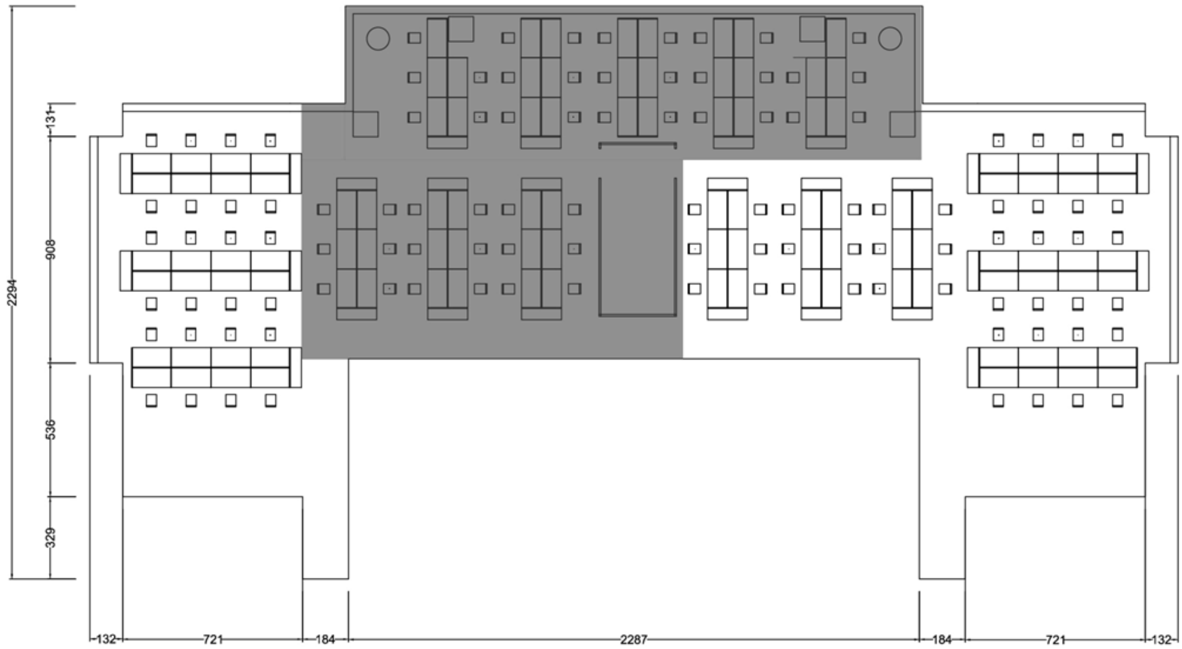


Figure 1 - Office Layout

The height of this room is 3 meters with total volume is about 2880 m^3. The wall of the room is dominated by glass material. This room is using a carpet with 1.5 cm thickness to reduce vibration and noise cause by footsteps. Acoustic tile is used as a ceiling of this room. The absorption coefficient for boundary surfaces that used in the simulation is listed in Table 1. Due to lack of reference for absorption coefficient data, the absorption coefficient value for the frequency below 125 Hz following the absorption coefficient value at 125 Hz.

Table 1 - Absorption Coefficient for Simulation

Material	**α**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Floor (red part)	0,12	0,10	0,28	0,42	0,31	0,33
Floor (white part)	0,11	0,35	0,27	0,40	0,21	0,20
HPL	0,10	0,08	0,05	0,03	0,03	0,03
Column	0,10	0,05	0,06	0,07	0,09	0,08
Sills	0,10	0,08	0,05	0,03	0,03	0,03
Glass (Window and Workstation divider)	0,18	0,06	0,04	0,03	0,02	0,02
Cabinet	0,10	0,08	0,05	0,03	0,03	0,03
Ceiling	0,70	0,66	0,72	0,92	0,88	0,75
Chair	0,04	0,05	0,06	0,07	0,06	0,05
Workstation partition	0,28	0,22	0,17	0,09	0,10	0,11
Table	0,10	0,08	0,05	0,03	0,03	0,03

Acoustic measurements have been carried out of the room before the simulation is done. Measurement of the acoustic quality of the room is had been done in grey area of Figure 1. To obtain the same simulation condition with an existing condition, the calibration should be performed between the simulation results on the initial conditions (before the treatment is given) with the results from acoustic measurements in existing condition. Another part of the room outside the grey area is involved in the simulation without including the furniture such as tables, workstations, chairs, and cabinet. This modification is should be done to simplify the model of the simulated room. Because this modification will give an effect to the simulation results, the absorption coefficient of the floor outside the grey area should have lower value than the one in the grey area. This has to be done in order to obtain same acoustic condition as in existing condition.

Measurement scenario and the location of point of measurement that were used in this simulation based on ISO 3382:3-2012. Based on that standard, a minimum number of measurement points are four with the shortest distance from the wall is 2 meters (5). Based on these requirements, the location of the measuring point is described in Figure 2.

The magnitude of sound pressure level and sound power level that used in this simulation follows the sound pressure level and sound power level required by ISO 3382-3:2012. Based on the SPL and STI results obtained in each measuring point, the quality of the speech privacy and speech intelligibility of the office is determined by reviewing the value of $L_{p,A,S,4m}$, r_D, r_p and STI. Due to finite element limitation, a parameter which can be known from finite element method is only $L_{p,A,S,4m}$. Another parameter like r_D, r_p, and STI only can be analyzed qualitatively based on ray-tracing data.

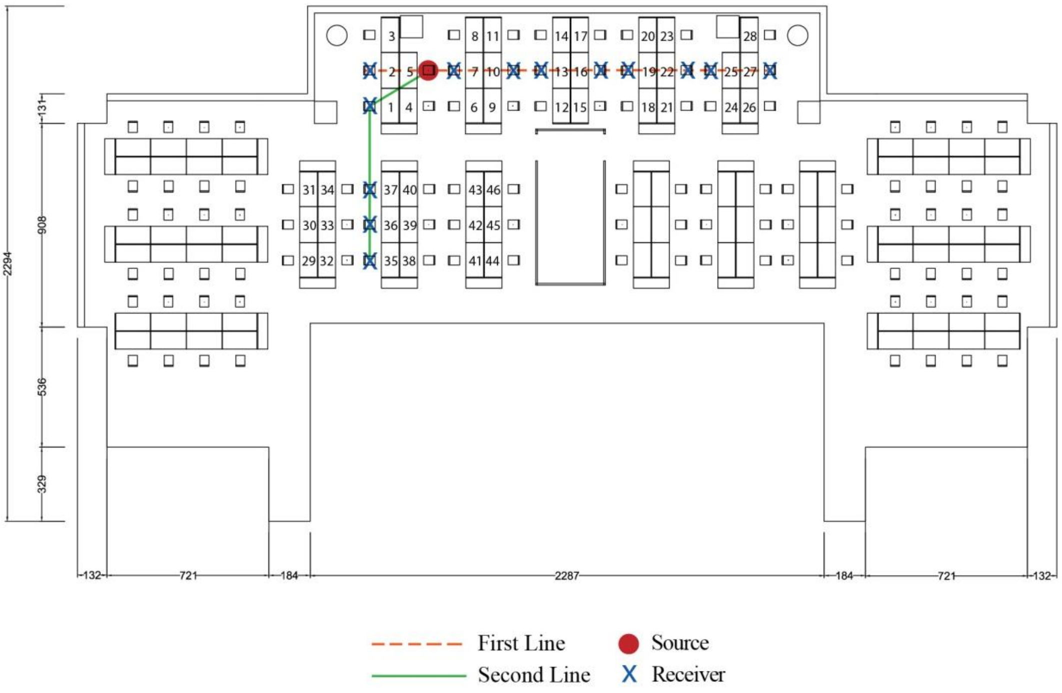


Figure 2 - Layout of Source and Measurement Point

3. ABFUSOR FORMATION

Abfusor can be made by combining surfaces that have different absorption coefficient value. Combination of surfaces that have different absorption coefficient value will make reflected sound become more diffuse. In this study, the combination of two acoustic panels which have different absorption coefficient will be used as an abfusor. The dimension for each panel is 60 cm x 60 cm. In this simulation, abfusor is mounted above the desk area parallel to the ceiling. A grey part of Figure 3 is the area where abfusor is being installed parallel to the ceiling. In figure 4 we can see 4 types of abfusor formations that have been tested in this study. The absorption coefficient value for each panel which used as abfusor is written in Table 2.

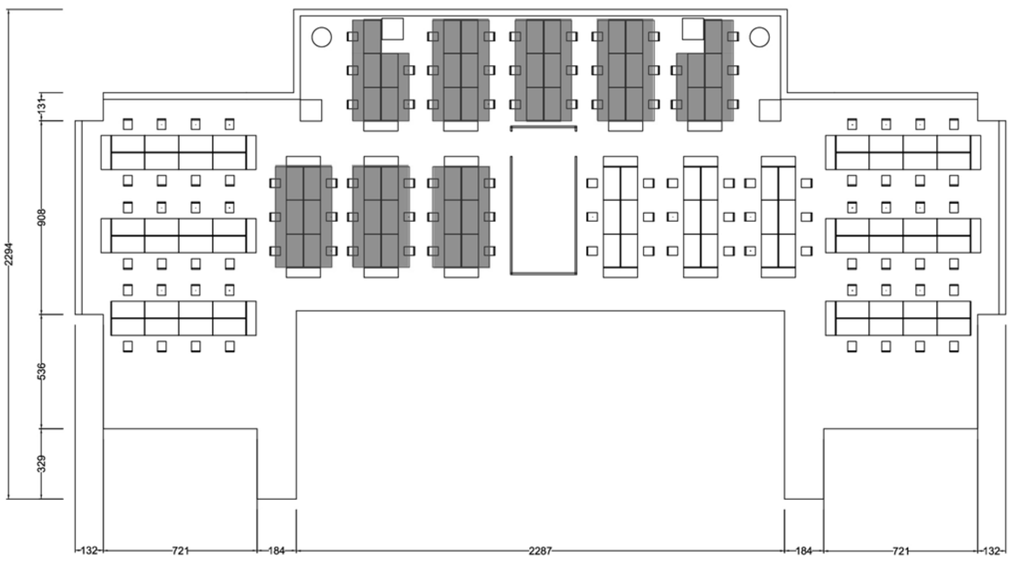


Figure 3 - Installation Area for Abfusor

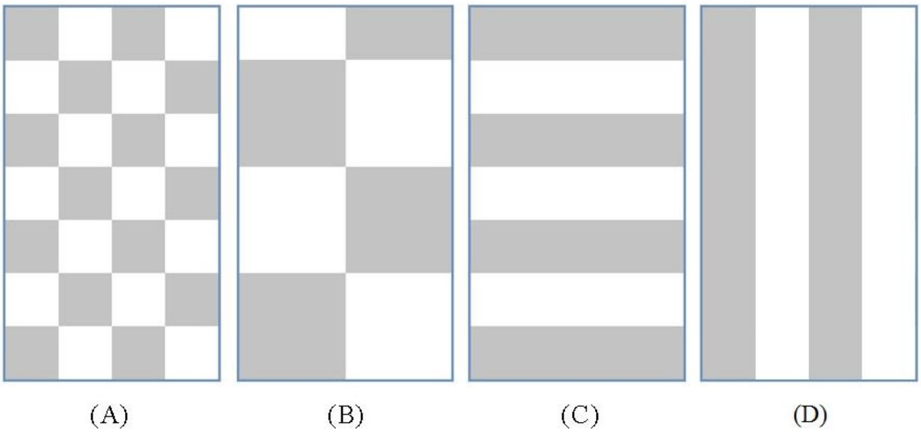


Figure 4 - Abfusor Formations

Table 2 - Absorption Coefficient for each Panel of Abfusor

Material	**α**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Gray part	0,55	0,75	0,75	0,8	0,95	0,99
White part	0,07	0,21	0,66	0,75	0,62	0,49

4. RESULTS AND DISCUSSION

Based on the simulations with a ray-tracing method, the all abfusor formations didn't make a significant influence to the SPL value for each measuring point. Hence, the value of $L_{p, A, S, 4m}$ for each abfusor formation did not have a big difference. Minimum value for $L_{p, A, S, 4m}$ that measured along the 1st line only reached 51.0054 dBA. This happens because ray-tracing method cannot delivers sound scattering phenomena which caused by the differences of absorption coefficient between surfaces. By this method, the abfusor is acted as an absorber surface which will absorb and reflect the incoming sound. Scattering phenomena will only occur if we put a scattering coefficient for each surfaces. Another way to do is by changing the geometry of the surface. Un-flat surface is also can make sound become scattered. However, because this study is examined abfusor which expected has a flat surface, changing the geometry of the ceiling surface cannot be done.

Different result is given from the simulation based on finite element method. Finite element method threats sound as energy so thus all kind of sound phenomena that which occurs in the room will be involved in calculation. Therefore, scattering phenomena that caused by abfusor can be seen on the output of simulation. Sound scattering that occur in the simulation using the finite element method can be seen in Figure 5. Figure 5 is a cross-sectional image of the SPL distribution of the room model along the 1st line. Figure 5.a is a cross-sectional part of the existing condition while Figure 5.b described the SPL distribution of the room after adding abfusor on its ceiling. Based on these figures, it can be noted that scattering phenomena can be seen clearly on the ceiling. This scattering phenomenon is formed due to the impedance difference between the ceiling areas. It can affect the sound field to become more diffuse. If the scattering is formed large enough, then the form of sound field will become more diffuse. Diffuse sound field can reduce the effects of room reverberation.

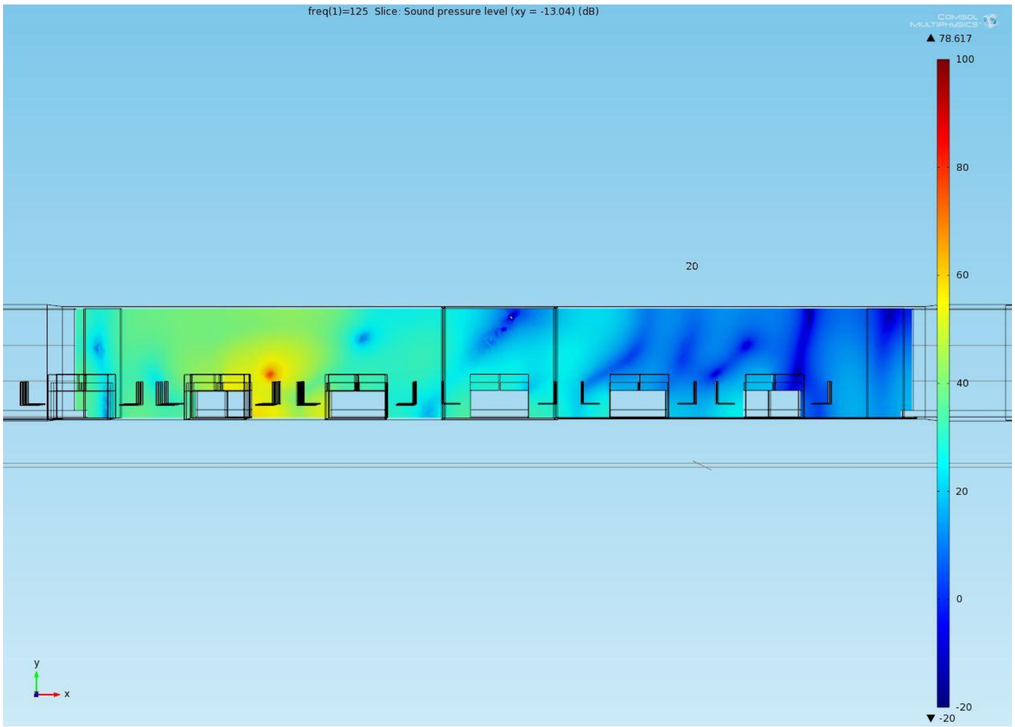
To see the effectiveness of abfusor installation to speech privacy and speech intelligibility of the room model, the simulation of a baseline scene is done to show the the maximum speech privacy improvement that can be achieved by using higher absorption coefficient is applied to all part of ceiling. The absorption coefficient value for ceiling which is used for the baseline scene is described on Table 2 (grey color material). The value of $L_{p, A, S, 4m}$ which is obtained from these baseline scene simulations is 21.50 dBA. From the Table 3 can be seen that abfusor D is giving same $L_{p,A,S,4m}$ value to the baseline scene. By comparing these results, it can be concluded that with smaller surface area, abfusor can produce same value of $L_{p, A, S, 4m}$ to the baseline scene.

Table 3 - $L_{p,A,S,4m}$ Along 1st Line

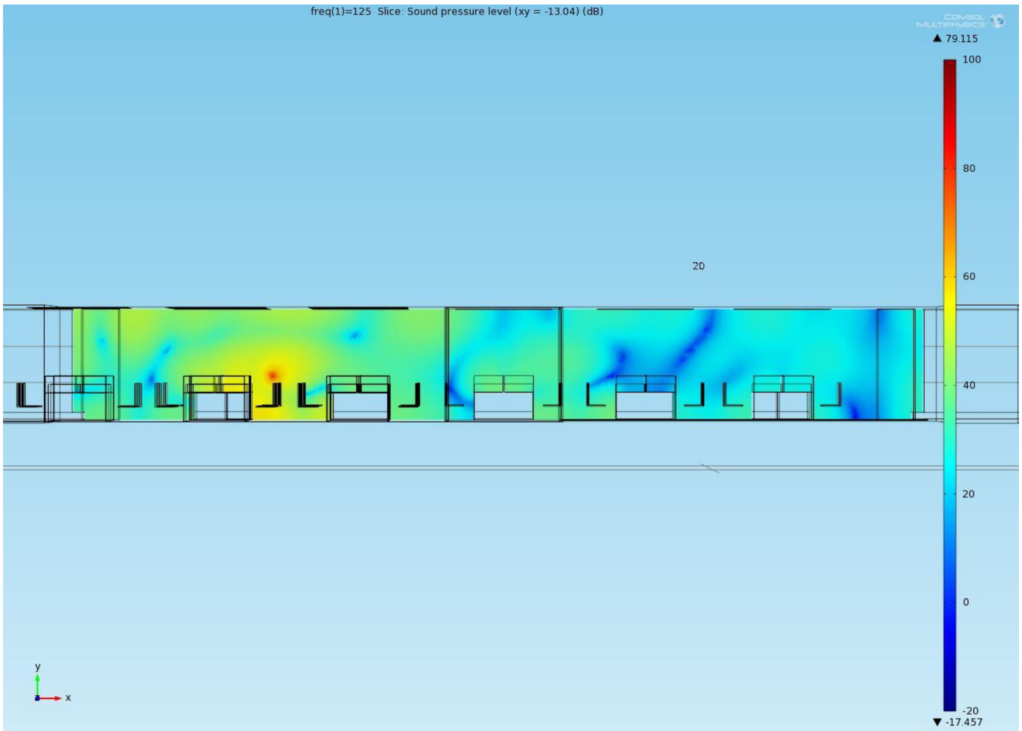
1st Line		Existing Condition	Abfusor A	Abfusor B	Abfusor C	Abfusor D
$L_{p, A, S, 4m}$ (dBA)	Ray-tracing	51.63	51.17	51.00	51.28	51.09
	finite element	21.57	31.20	31.20	21.66	21.53

Table 4 - $L_{p,A,S,4m}$ Along 2nd Line

2nd Line		Existing Condition	Abfusor A	Abfusor B	Abfusor C	Abfusor D
$L_{p, A, S, 4m}$ (dBA)	Ray-tracing	50.81	50.42	50.37	50.31	50.33
	finite element	20.66	24.20	34.60	23.90	23.90



(a)



(b)

Figure 5 - Cross Section Along The 1st Line. (a) The Condition of The Room with Ceiling which Has Homogeneous Absorption Coefficient. (b) The condition of the room with Abfusor.

From the data that had been collected, we can conclude that the value of SPL for finite element simulation method is always less than the value of SPL generated by ray-tracing simulation method. It is caused by there are several sound phenomena that isn't involved in the simulation with ray-tracing method so that the SPL value obtained from this method will be higher than the SPL value obtained by simulation with finite element method. Several sound phenomena, like sound diffraction, will cause interference to sound waves so that the sound pressure will decrease. The reduction of the SPL will certainly occur at each measurement point. The reduction of SPL value is also will decrease the STI value. Therefore, a qualitative analysis can be done to predict the value of distraction distance (r_D) and privacy distance (r_p). This analysis is done by referring STI value that obtained from simulation with ray-tracing method.

Based on qualitative predictions, abfusor D will give less value of r_D and r_p than the value of r_D and r_p (see Figure 6, Figure 7, Table 5, and Table 6 for more detail STI, r_D, and r_p value) which are obtained from simulation with ray-tracing method. Based on this analysis we can conclude that abfusor D give the best quality of privacy among another abfusor formations that had been simulated. However, we cannot conclude whether the room is already has the optimum conditions for speech privacy in accordance with the quality standard ISO 3328-3:2012 or not. The assessment to see the optimum value of the speech privacy and speech intelligibility of open plan office should be calculated quantitatively based on the parameters that comply with these standards.

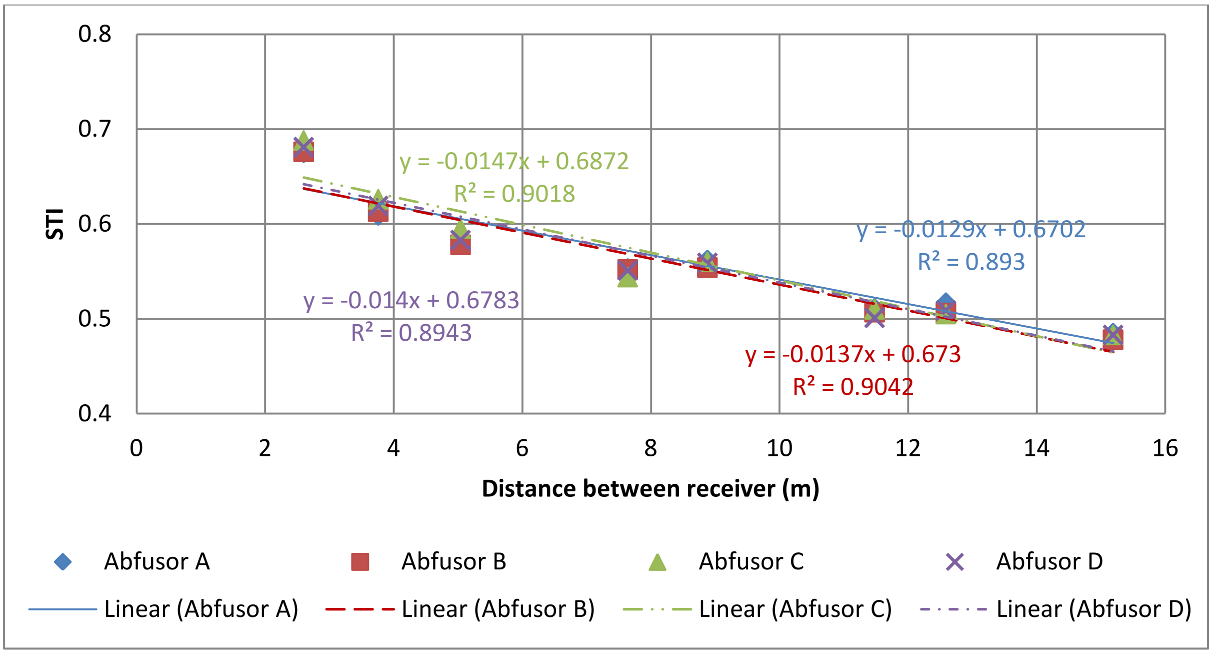


Figure 6 - Graph STI vs. Receiver Distance (1st Line) for Abfusor

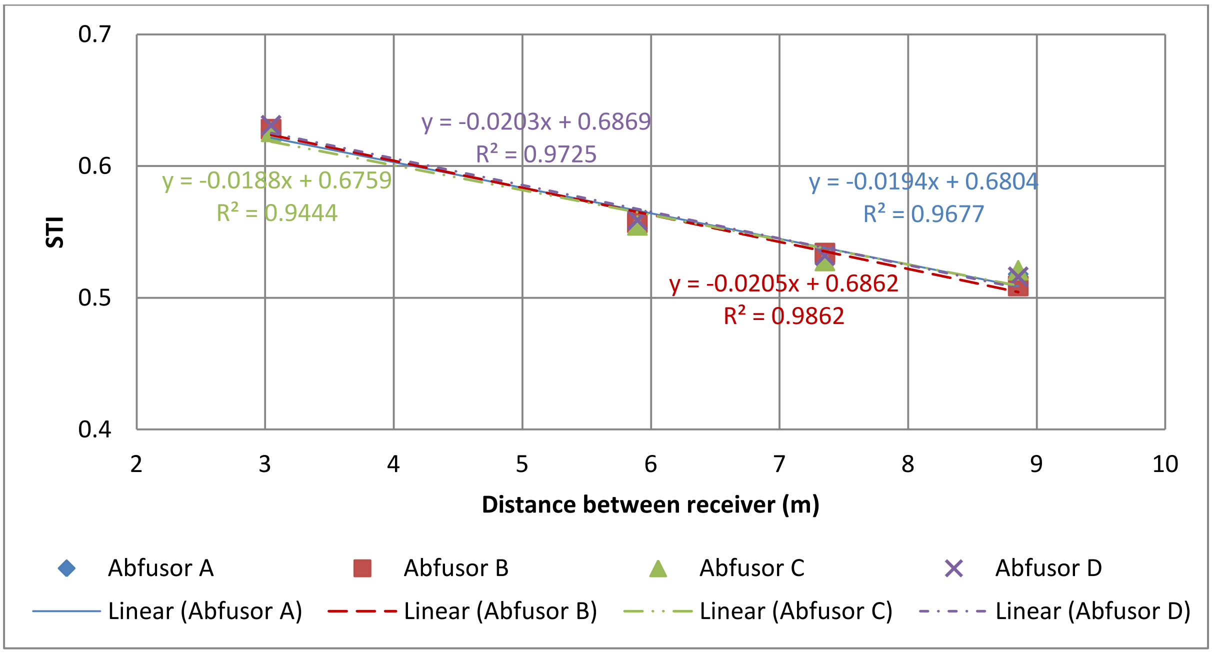


Figure 7 - Graph STI vs. Receiver Distance (2nd Line) for Abfusor

Table 5 - Distraction Distance and privacy Distance for 1st Line

1st Line	Existing Condition	Abfusor			
		A	B	C	D
r_D (m)	13.33	13.19	12.63	12.73	12.74
r_p (m)	36.59	36.45	34.53	33.14	34.16

Table 6 - Distraction Distance and privacy Distance for 2nd Line

2^{nd} Line	Existing Condition	Abfusor			
		A	B	C	D
r_D (m)	10.01	9.30	9.08	9.36	9.21
r_p (m)	27.15	24.76	23.72	25.31	23.99

5. CONCLUSION

Based on simulation results, abfusor D give the best speech privacy and speech intelligibility quality. Based on simulation with ray-tracing method, it gives $L_{p, A, S, 4m}$ = 21.50 dBA, r_D = 12.74 m, and r_p = 36.45 m which are not give many differences to all abfusor formations tested. Value of generated by the simulation range at 12 dBA.

Different results is obtained from the simulation with finite element method. Based on this simulation, abfusor D provide best improvement for speech privacy among other formations. Although it gives $L_{p, A, S, 4m}$ = 21.53 dBA, it is still not meet the standards given in ISO 3328-3:2012.

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