

# Characterizing The Room Acoustics for Speech Privacy in 'Green' Open Plan Offices

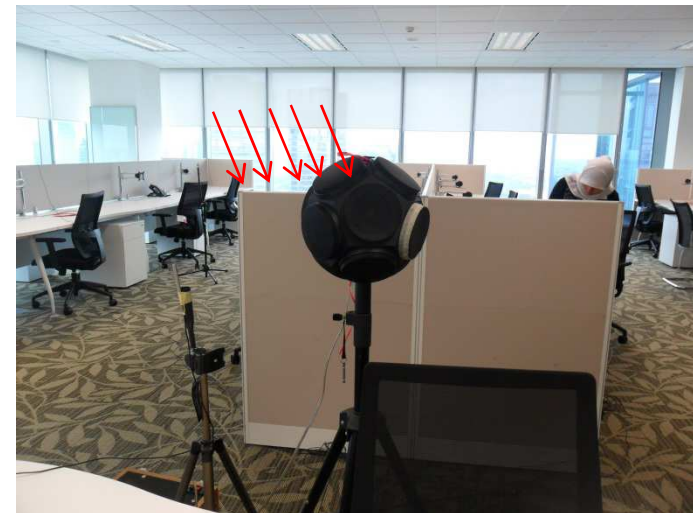
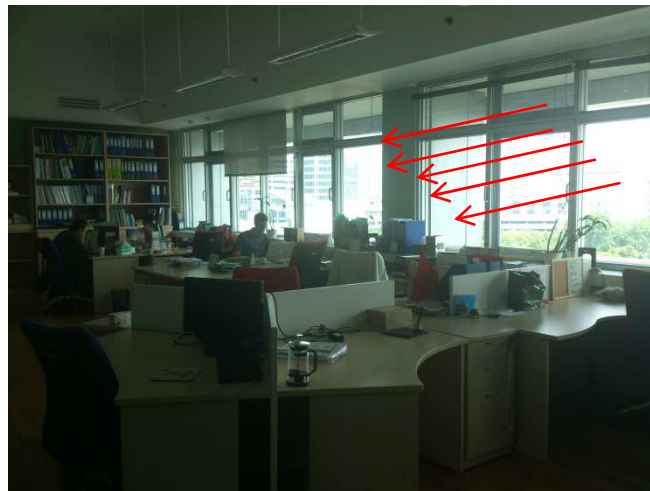


**By**  
**Joko Sarwono**  
**Sentagi Sesotya Utami**



# CHARACTERIZING THE ACOUSTICS OF 'GREEN' OPEN-PLAN OFFICES

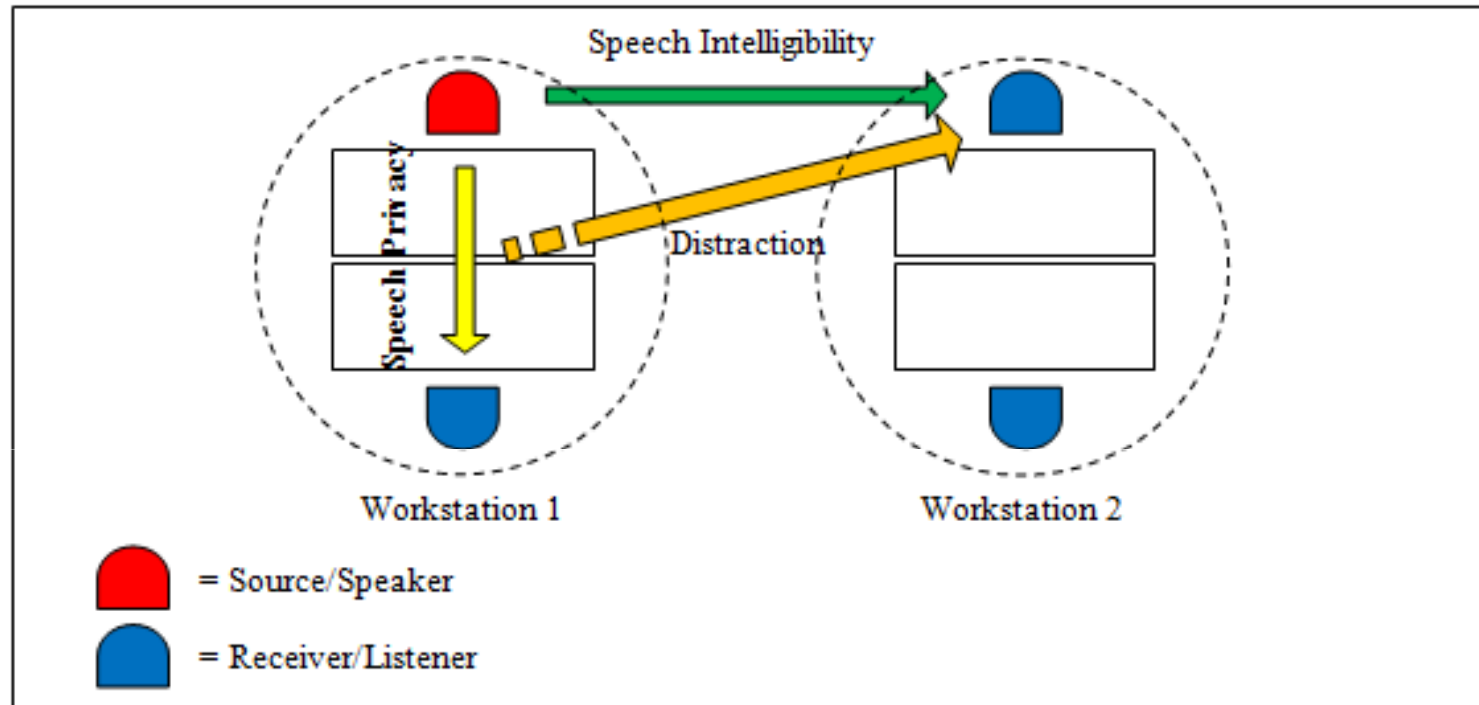
- An open-plan office is generally categorised by offices with the absence of walls and partitions, was first conceived by two West German furniture manufacturers [1].
- The benefits of having an open-plan office layout is the ability to obtain thermal and lighting comfort with less energy use, a goal emphasized by green design. The office space is considered as a single thermal zone with a single air conditioning treatment while daylight are capable to penetrate throughout the entire space.



- Without room barriers, it becomes difficult to avoid unwanted noise from equipment such as copy and printer machines.
- Speech intelligibility improvement has the drawback in speech privacy quality and work distraction
- Optimal distance between the workstations is critical.



# Speech scenarios & acoustical problem in the open-plan office




- Scenario 1, the speaker requires high speech privacy with the listener in workstation 1 and avoids the spread of confidential conversation to listener in workstation 2.
- Scenario 2, the listener in workstation 2 can be distracted by the conversation between speaker and listener in workstation 1.
- Scenario 3, the listener in workstation 2 often requires the ability to clearly understand the speech content from the speaker in workstation 1.



# Research Methods

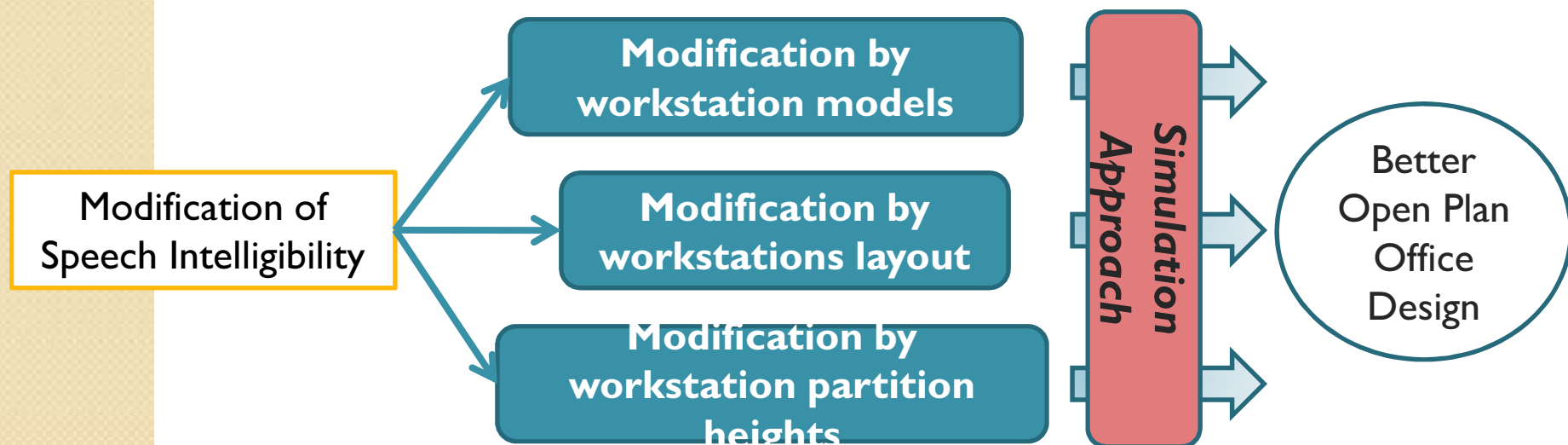
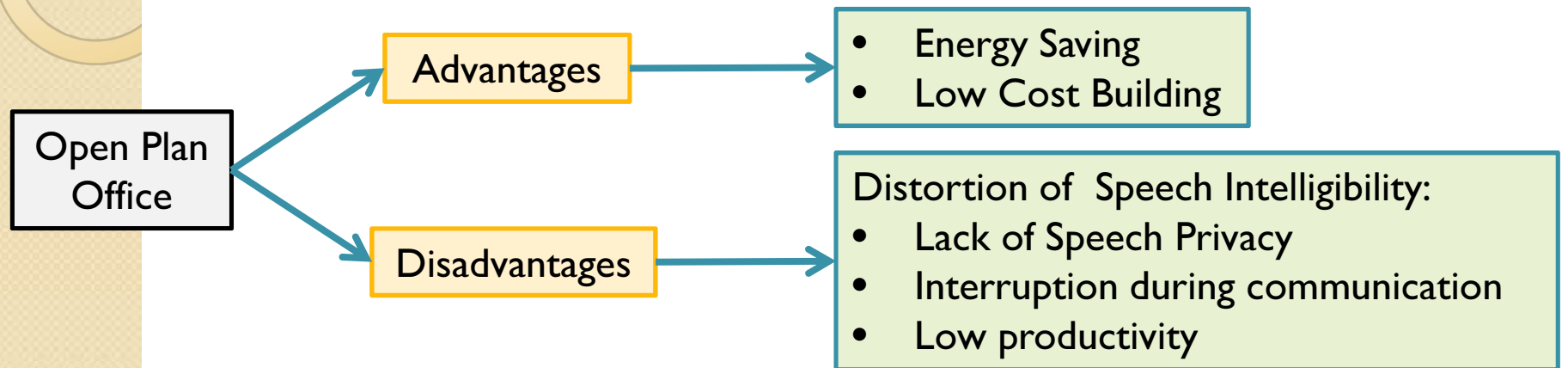
- Simulation
- Field Measurement
- Interview and Questionnaire



# Simulation on Open Plan Office Improvements to Enhance the Speech Intelligibility

## Background

Acoustical problems that occur within open-plan offices are related to communication comfort between co-workers. Problems include distortion of speech intelligibility due to interference by unwanted sound, lack of speech privacy and interruption during the communication by other co-workers.



## Acoustical Problems in the Case Studied

In this research, improved open plan offices are expected to be the output. The improvement is conducted by several open plan office modifications through simulation approach.

- **Modification by workstation models**

The workstation model is modified by the design of the table on the workstation, the constraint of this model is the height that used for all model is the same.

- **Modification by workstations layout**

This modification is applied by changing the arrangement of the workstations position. In these simulation, the number of workstations are the same for each arrangement.

- **Modification by workstation partition heights**

In these simulation, several workstations height are used to improved the acoustic parameters.

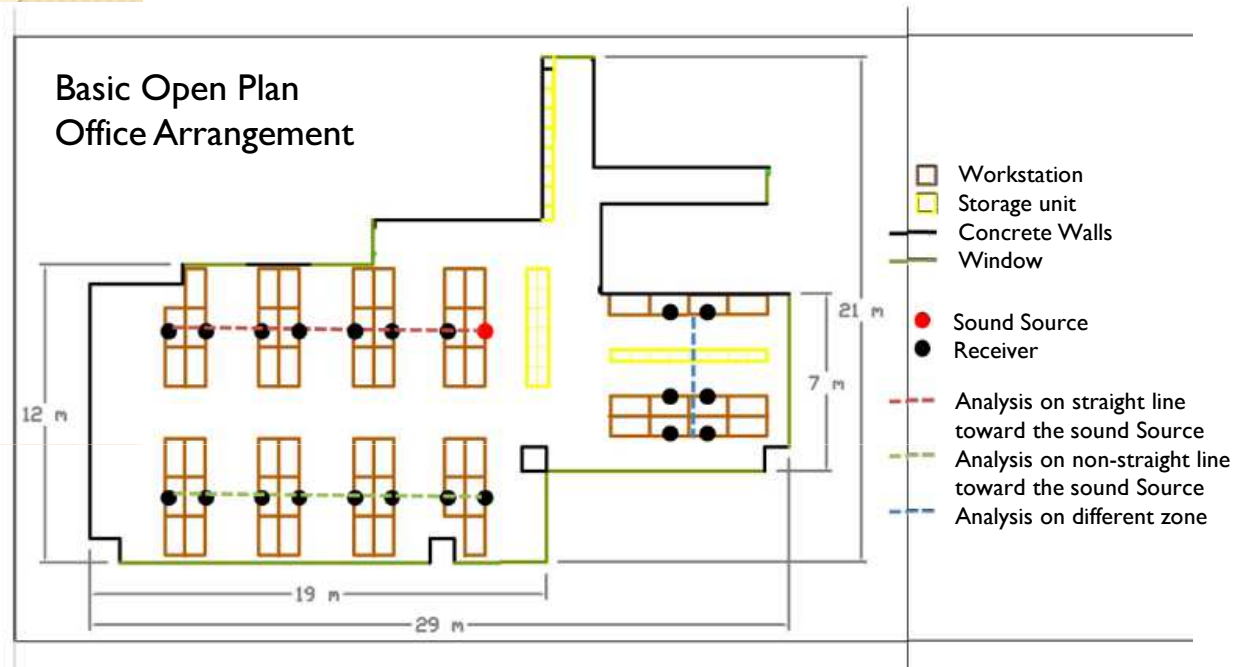
The table model on the workstation is the same.

simulation is based on ray tracing method using commercial software (CATT.9.0), and the parameters are calculated based on ISO 3328-3:2012 for open plan office



# Simulation Condition

## Modification by Workstation Models



### Noise Source:

- 1.2 m heights

### Receiver positions:

- 1.2 m heights
- 0.5 m away from the table (minimum)
- 2 m away from the wall (minimum)

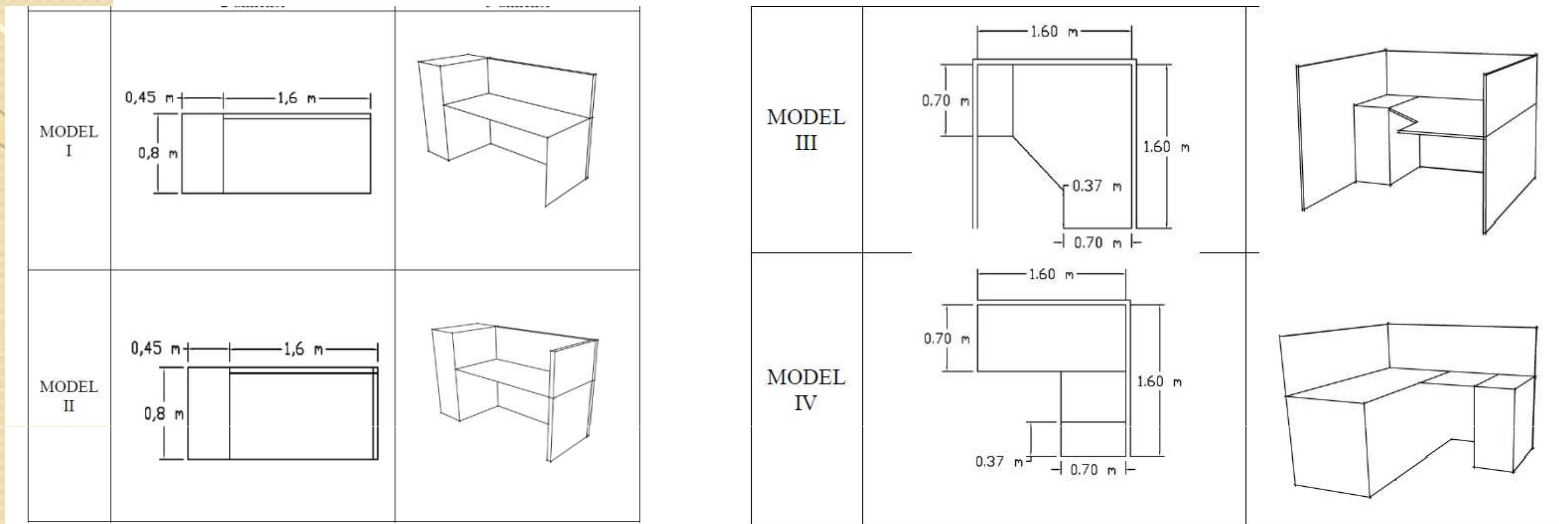
Octave band, $i$	1	2	3	4	5	6
Frekuensi (Hz)	125	250	500	1000	2000	4000
$L_{p,S,1m}$ omnidirectional (dB)	49,9	54	58	52	44,8	38,8
$A_i$ -Weighting	-16	-8,6	-3	0	1,2	1

Sound Source in Simulation for Speech Representation

Octave Band (Hz)	Background Noise (dB)
125	45
250	38
500	32
1000	28
2000	25
4000	23

# Modification by Workstation Models

## Workstation Models



Material / Object	Frekuensi (Hz)					
	125	250	500	1K	2K	4K
<b>Floor</b>						
Thick Carpet	9	8	21	27	27	37
<b>Walls</b>						
Thick Window	18	6	4	3	2	2
Concrete	1	2	2	3	4	5
<b>Ceilings</b>						
Acoustic tile	70	66	72	92	88	75
<b>Furniture</b>						
Workstation : Wood Podium – Karlen]	15	19	22	39	38	30
Storage unit : Metal [Metal Perf – Lauren]	76	76	90	99	85	70

Open Plan Office  
Sabine Area

# Measurement Results

Acoustic parameters comparison between 4 workstation models in straight line path

Parameters	Model I	Model II	Model III	Model IV
STI to the nearest workstation	0,7	0,7	0,6	0,8
Distraction Distance ( $r_D$ , m)	6,1	6,1	5,7	6,1
Privacy Distance ( $r_p$ , m)	14,0	13,6	13,6	11,6
SPLA spatial decay rate ( $D_{2,S}$ , dBA)	-3,6	-3,6	-3,4	-3,9
SPLA at 4 meters ( $L_{p,A,S,4m}$ , dBA)	41,7	41,5	42,6	44,3

Acoustic parameters comparison between 4 workstation models in non-straight line path

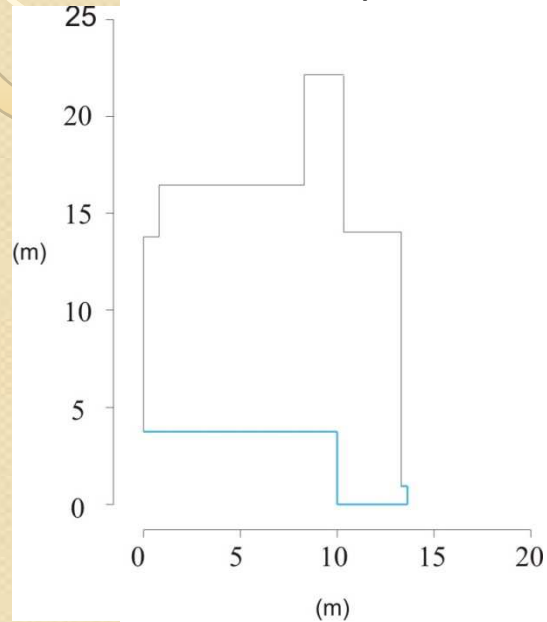
Parameters	Model I	Model II	Model III	Model IV
STI to the nearest workstation	0,7	0,7	0,5	0,5
Distraction Distance ( $r_D$ , m)	8,5	8,4	6,6	6,2
Privacy Distance ( $r_p$ , m)	12,0	12,1	15,2	22,9
SPLA spatial decay rate ( $D_{2,S}$ , dBA)	-4,6	-4,6	-3,0	-3,3
SPLA at 4 meters ( $L_{p,A,S,4m}$ , dBA)	48,9	48,4	41,5	42,7

The overall simulation result shows that each model has unique characteristics of open plan office, for example in straight line path, the model IV has the highest STI to the nearest workstation but in the same time has the shortest privacy distance in general. This means this kind of model is good for type open plan who group between adjacent table based on his work

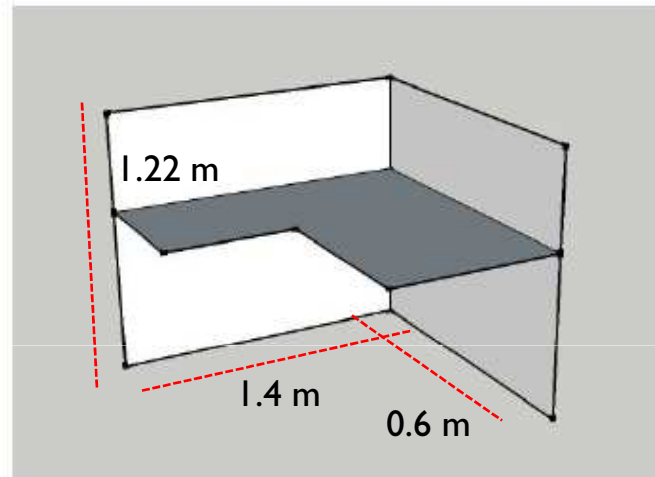
# Simulation Condition

## Modification by Workstations Layout

Basic Scheme of Open Plan Office



Basic Workstation that Used



### Noise Source:

- 1.2 m heights

### Receiver positions:

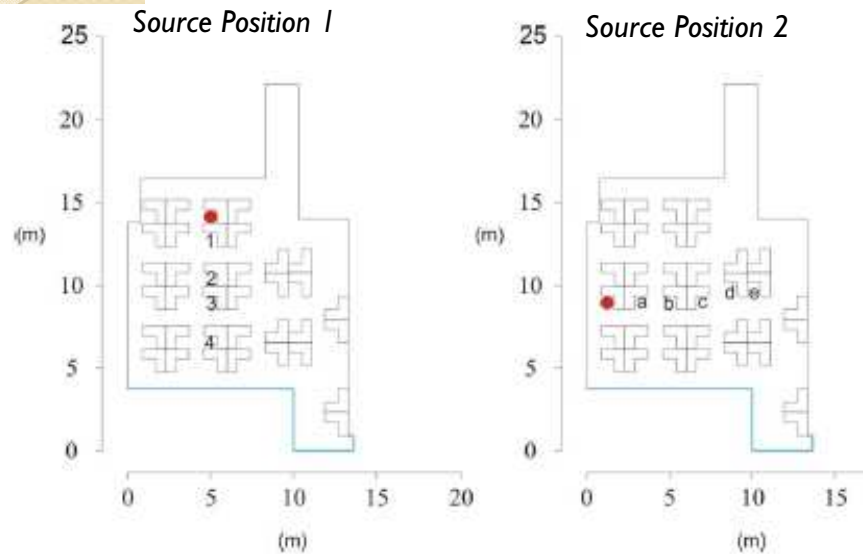
- 1.2 m heights
- 0.5 m away from the table (minimum)
- 2 m away from the wall (minimum)

Octave band, $i$	1	2	3	4	5	6
Frekuensi (Hz)	125	250	500	1000	2000	4000
$L_{p,S,1m}$ omnidirectional (dB)	49,9	54	58	52	44,8	38,8
$A_i$ -Weighting	-16	-8,6	-3	0	1,2	1

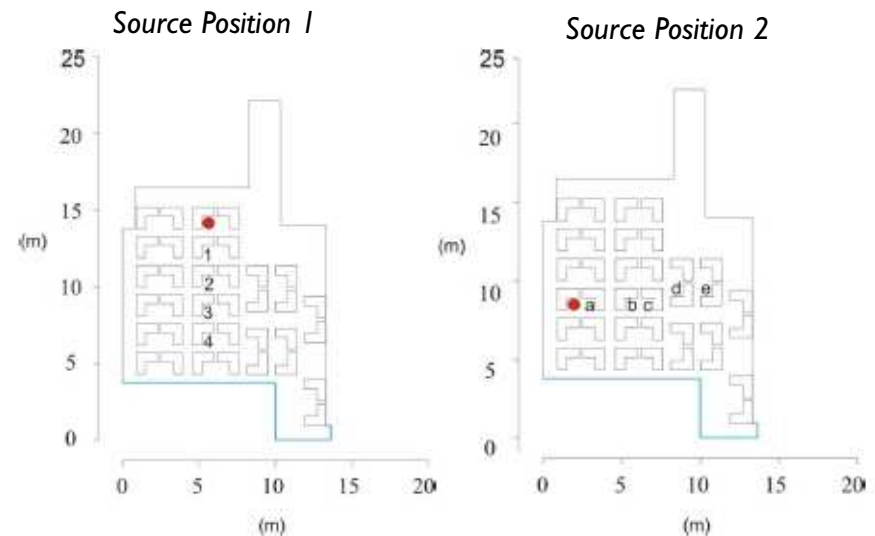
Sound Source in Simulation for  
Speech Representation

Octave Band (Hz)	Background Noise (dB)
125	45
250	38
500	32
1000	28
2000	25
4000	23

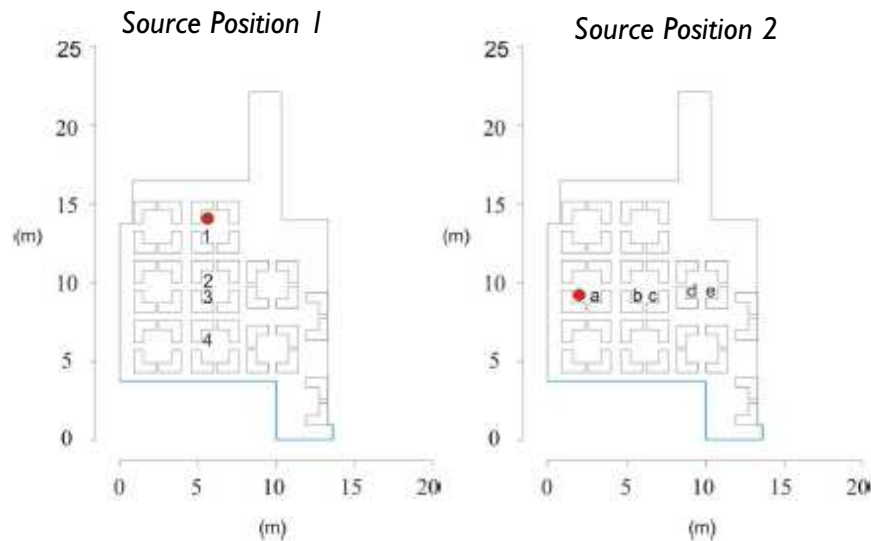
# Modification by Workstations Layout



(a) **Model 1 scheme** (b)



(a) **Model 2 scheme** (b)



(a) **Model 3 scheme** (b)

- *Source Position 1*  
Straight line measurement position
- *Source Position 2*  
Non-Straight line measurement position

# Modification by Workstations Layout

Material / Object	Frekuensi (Hz)					
	125	250	500	1K	2K	4K
<b>Floor</b>						
Thick Carpet	9	8	21	27	27	37
<b>Walls</b>						
Thick Window	18	6	4	3	2	2
Concrete	1	2	2	3	4	5
<b>Ceilings</b>						
Acoustic tile	70	66	72	92	88	75
<b>Furniture</b>						
Workstation : Wood Podium – Karlen]	15	19	22	39	38	30
Storage unit : Metal [Metal Perf – Lauren]	76	76	90	99	85	70

Open Plan Office  
Sabine Area

# Simulation Results

## Modification by Workstations Layout

Model of Workstations Formation	Distraction Distance $r_D$ (m)	Privacy Distance $r_P$ (m)	STI in the Nearest Workstation	Spatial Decay Rate of Speech, $D_{2,S}$ (dBA per doubling distance)	$L_{p,4,S,4m}$ (dBA)
Model I	7,88	21,58	0,66	2,98	47,5
Model II	6,99	22,7	0,61	2,97	46,2
Model III	6,43	11,83	0,88	4,39	50

Open Plan Parameters based on Source Position 1

Model of Workstations Formation	Distraction Distance $r_D$ (m)	Privacy Distance $r_P$ (m)	STI in the Nearest Workstation	Spatial Decay Rate of Speech, $D_{2,S}$ (dBA per doubling distance)	$L_{p,4,S,4m}$ (dBA)
Model I	8,7	15,88	0,76	4,12	50,1
Model II	9,05	15,66	0,93	4,37	51,5
Model III	7,08	13,23	0,91	4,27	50,6

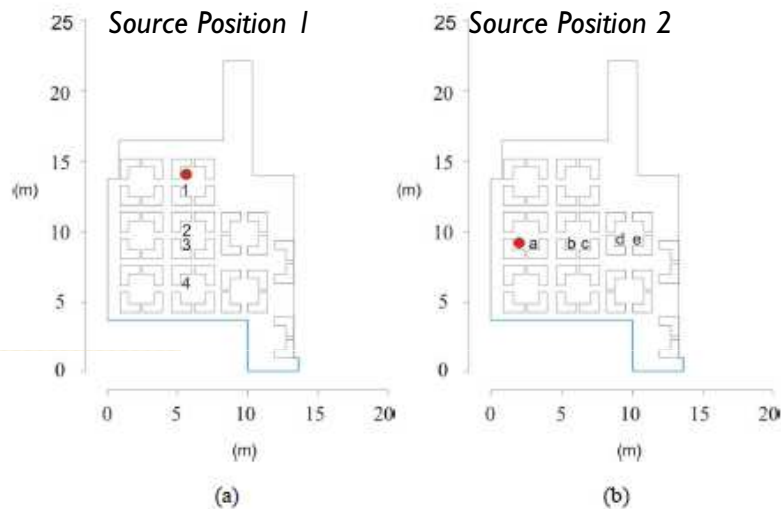
Open Plan Parameters based on Source Position 2

there is a unique difference of speech privacy conditions among 3 types of layout. For example, Layout 3 has STI values the highest compare to other layouts. But on the contrary, it has the shorter privacy and distraction distances among them. It means for short distance from source the communication condition is good but for longer distance it is poor. This kind of type is good for open plan office that utilize group job.

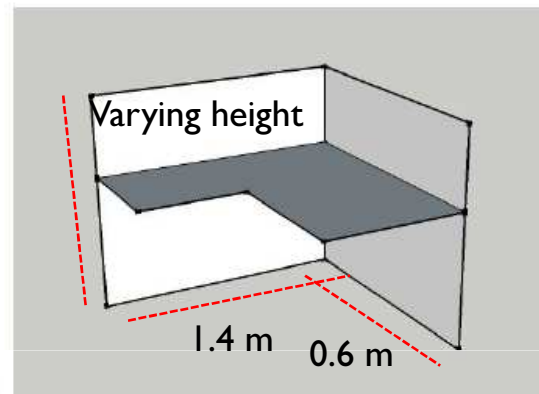
# Simulation Condition

## Modification by Workstation Partition Heights

Basic Scheme of Open Plan Office



Basic Workstation that Used



### Noise Source:

- 1.2 m heights

### Receiver positions:

- 1.2, 1.3, 1.4, 1.5 m heights
- 0.5 m away from the table (minimum)
- 2 m away from the wall (minimum)

Octave band, $i$	1	2	3	4	5	6
Frekuensi (Hz)	125	250	500	1000	2000	4000
$L_{p,S,1m}$ omnidirectional (dB)	49,9	54	58	52	44,8	38,8
$A_i$ -Weighting	-16	-8,6	-3	0	1,2	1

Sound Source in Simulation for Speech Representation

Octave Band (Hz)	Background Noise (dB)
125	45
250	38
500	32
1000	28
2000	25
4000	23

Same Sabine area with the previous is used in this model



# Simulation Results

## Modification by Workstation Partition Heights

Height of Workstation	Distraction Distance $r_D$ (m)	Privacy Distance $r_P$ (m)	STI in the Nearest Workstation	Spatial Decay Rate of Speech, $D_{2,s}$ (dBA per doubling distance)	$L_{p,4,S,4m}$ (dBA)
1,2 m	6,43	11,83	0,88	4,39	50
1,3 m	6,98	12,68	0,88	4,39	50,1
1,4 m	6,69	12,05	0,88	4,52	49,6
1,5 m	6,54	11,65	0,88	4,6	49

Open Plan Parameters based on Source Position 1

Height of Workstation	Distraction Distance $r_D$ (m)	Privacy Distance $r_P$ (m)	STI in the Nearest Workstation	Spatial Decay Rate of Speech, $D_{2,s}$ (dBA per doubling distance)	$L_{p,4,S,4m}$ (dBA)
1,2 m	7,08	13,23	0,91	4,27	50,6
1,3 m	7,06	12,62	0,91	4,35	50,1
1,4 m	6,89	12,26	0,91	4,42	50,3
1,5 m	6,51	11,37	0,9	4,52	49

Open Plan Parameters based on Source Position 2

The overall simulation results show that the higher the workstation partition, the better the communication comfort. But the results also shows that the improvement is not significant, this results may occur due to diffraction phenomena by partition is not treated well in simulation

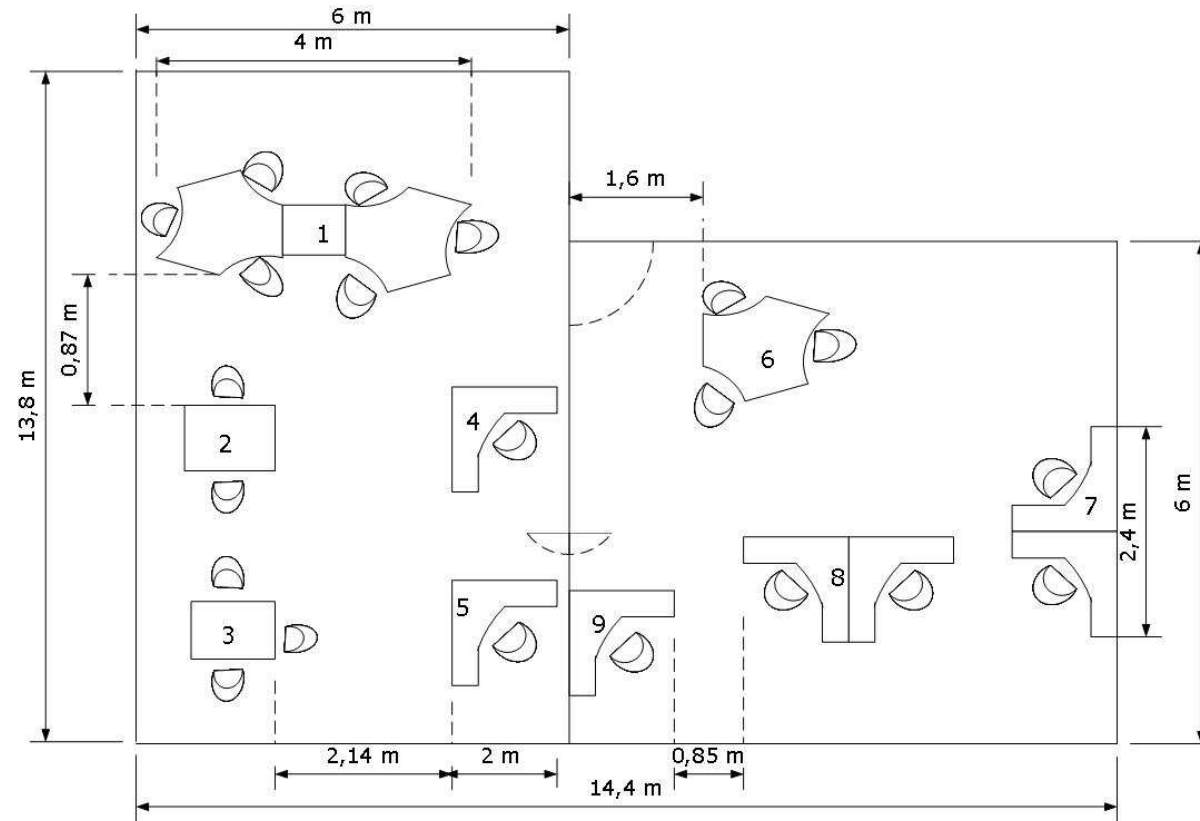


# FIELD MEASUREMENTS



# Acoustical Problems in the Case Studied

## Office I



Acoustical function of the office:

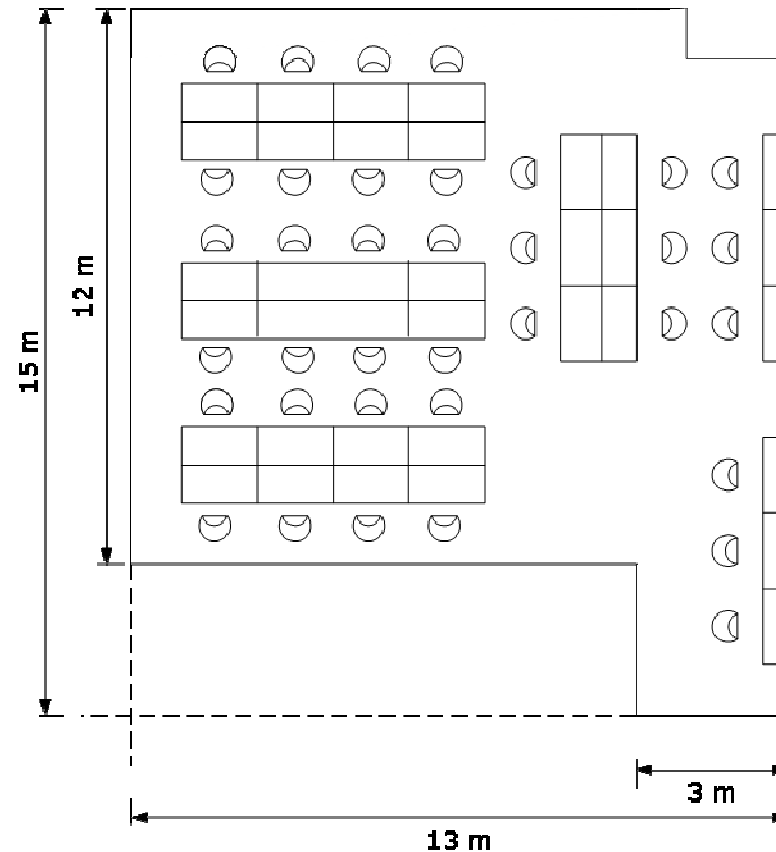
- Held small meeting between workstations.
- Avoid distraction by conversations of nearby co-workers

Acoustical Problems :

- Most prior to scenario 3

# Acoustical Problems in the Case Studied

## Office 2



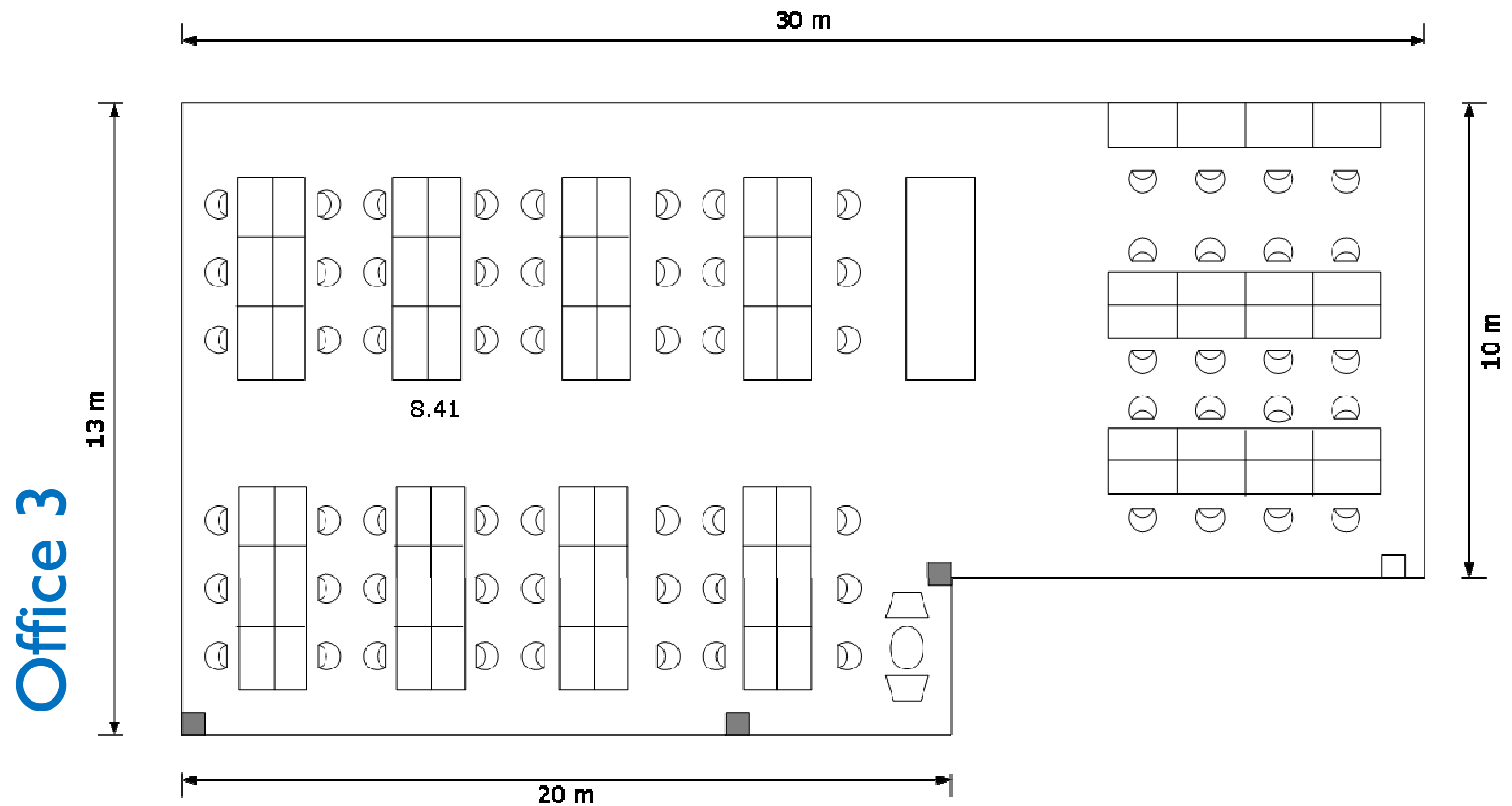
Acoustical function of the office:

- Held private conversation in each workstations.
- Avoid distraction by conversations of nearby co-workers

Acoustical Problems :

- Most prior to scenario I

# Acoustical Problems in the Case Studied



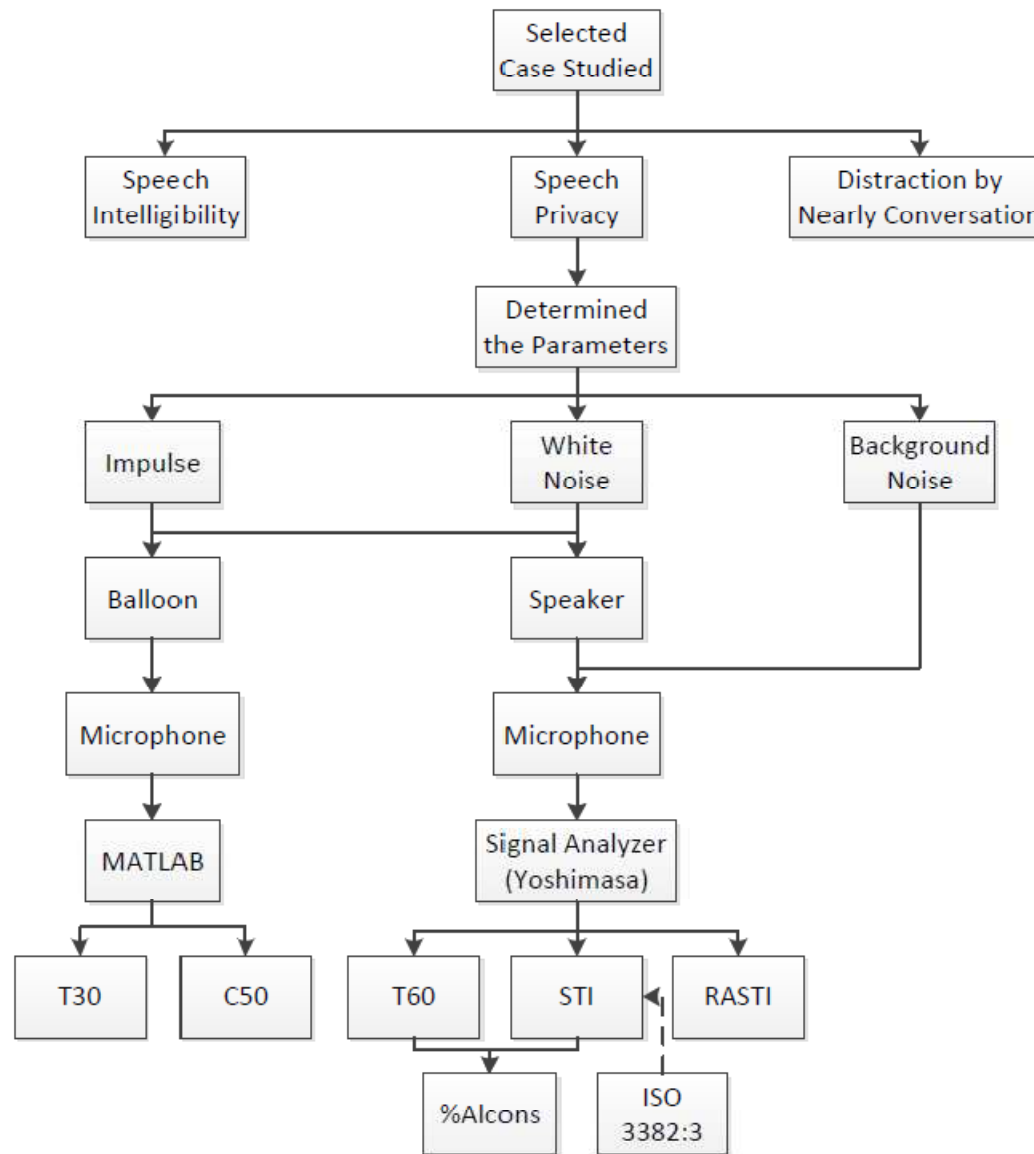
Acoustical function of the office:

- Held private conversation in each workstations.
- Avoid distraction by conversations of nearby co-workers

Acoustical Problems :

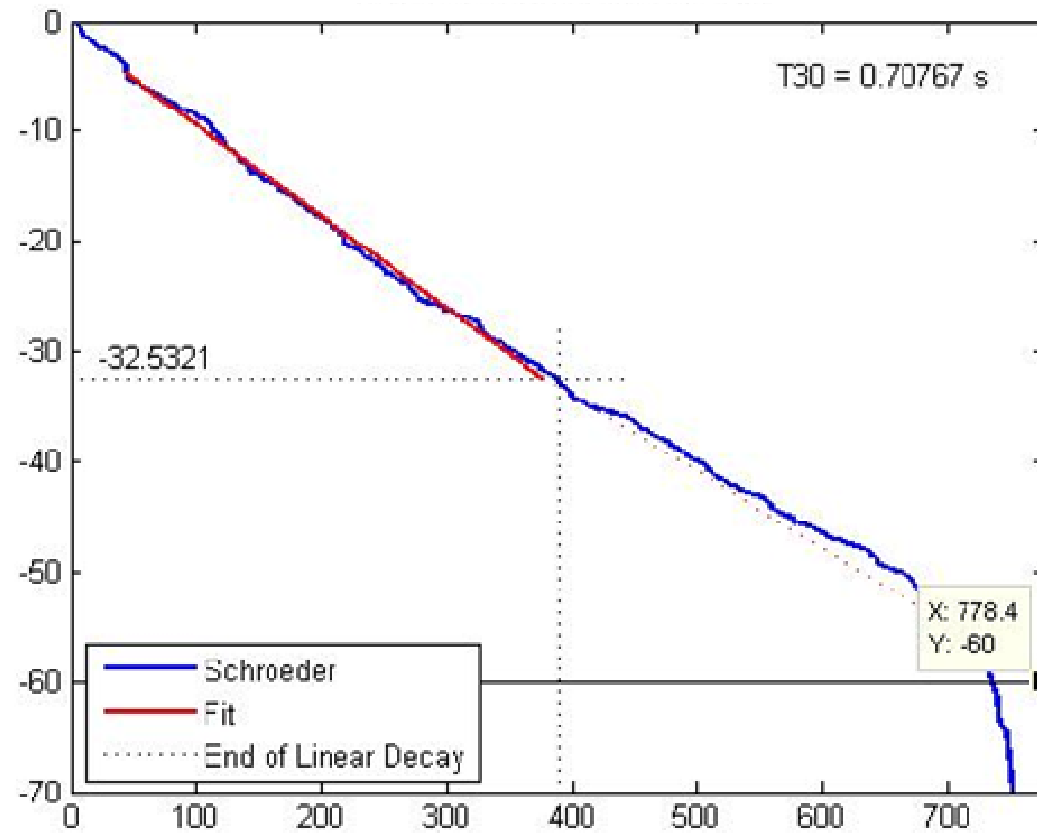
- Most prior to scenario I

# Measurement Procedure



# Acoustic Parameters

## Reverberation Time (T30 and T60)



## Clarity

$$C_{50} = \left\{ \frac{\int_0^{0,05} p^2(t) dt}{\int_{0,05}^{\infty} p^2(t) dt} \right\} \approx 10 \log_{10} \left( \frac{\sum_{n=1}^{N_1} P_n^2}{\sum_{n=N_1+1}^{N_2} P_n^2} \right) \quad [2]$$

## RASTI

RASTI (*Rapid Speech Transmission Index*) adalah prosedur untuk mengukur kualitas transmisi percakapan

$$\overline{(S/N)_{app}} = \sum_{k=1}^2 w_k (S/N)_{app,k}$$
$$\text{RASTI} = \left[ \overline{(S/N)_{app}} + 15 \right] / 30 \quad [3]$$



# $\%Al_{cons}$

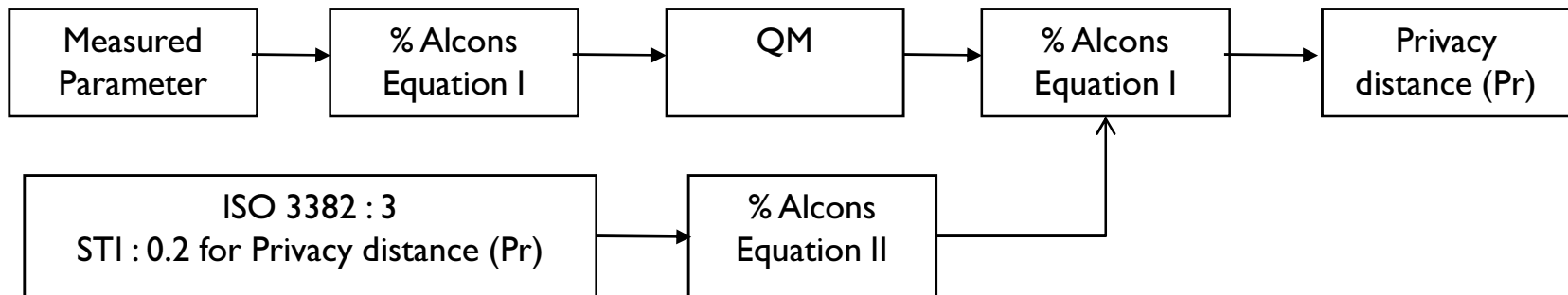
## Articulation Loss of Consonant ( $\%Al_{cons}$ )

$$\text{Equation 1. } (\%Al_{cons}) = \frac{200r^2T_{60}^2(1+n)}{VQM}$$

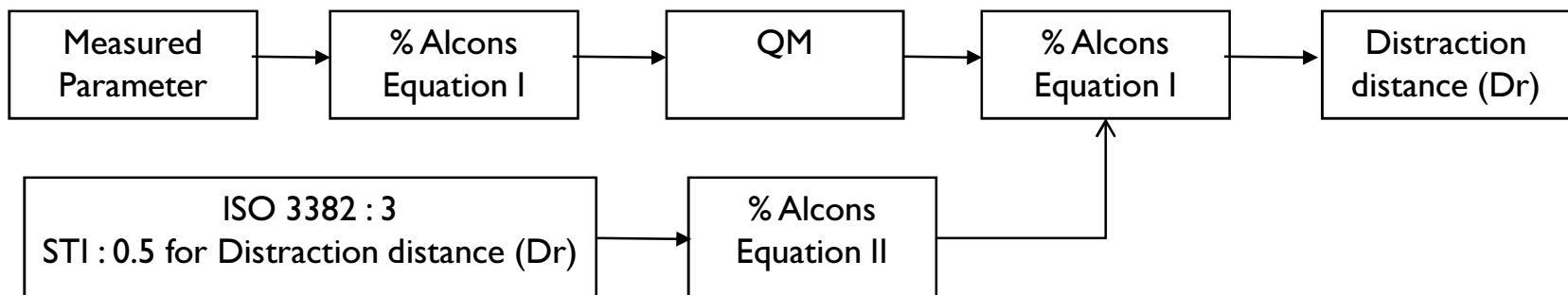
$$\text{Equation 2. } (\%Al_{cons}) = (170,5405) \cdot e^{-(-5,419 \times STI)}$$

STI	0 - 0.30	0.30 - 0.45	0.45 - 0.60	0.60 - 0.75	0.75 - 1.00
	unacceptable	poor	Fair	good	Excellent
$\%Al_{cons}$	100% - 33%	33% - 15%	15% - 7%	7% - 3%	3% - 0%

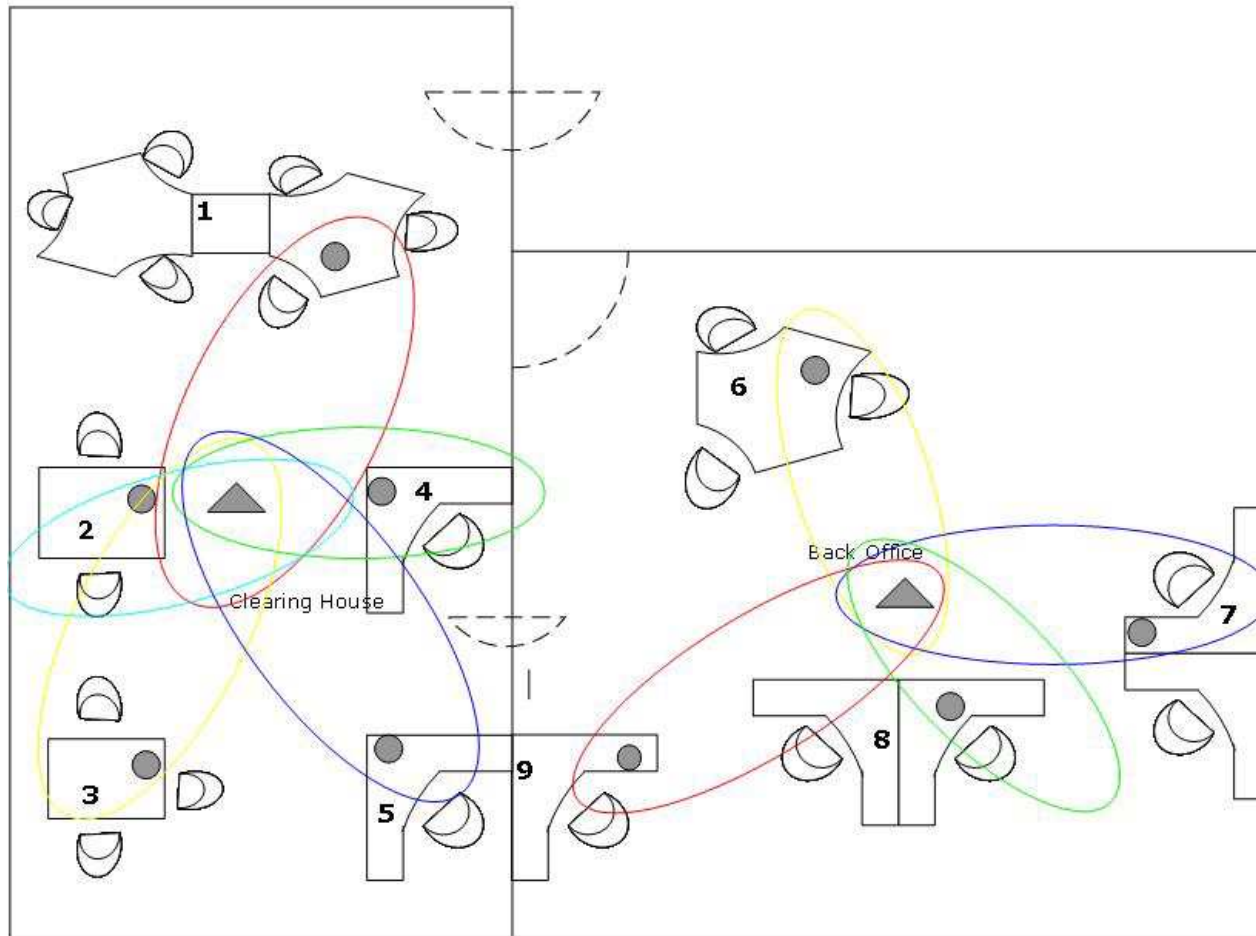
# Speech Privacy Distance (Pr)



# Distraction Distance (Dr)

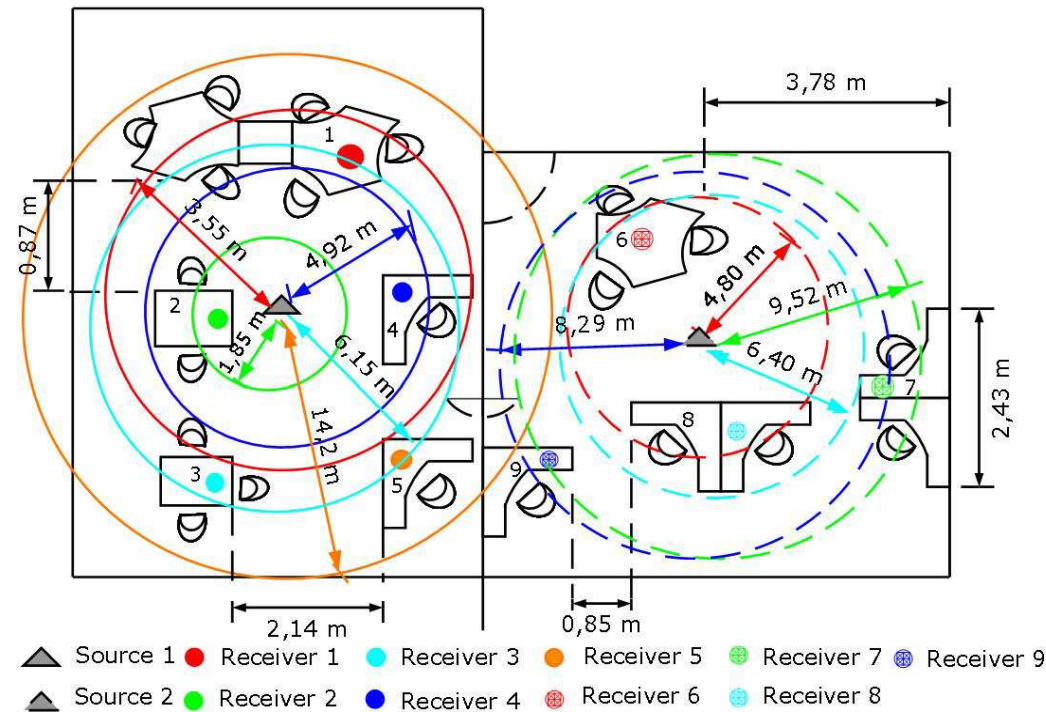


# Eksperimen Layout in Office I



# Measurement Result Office I

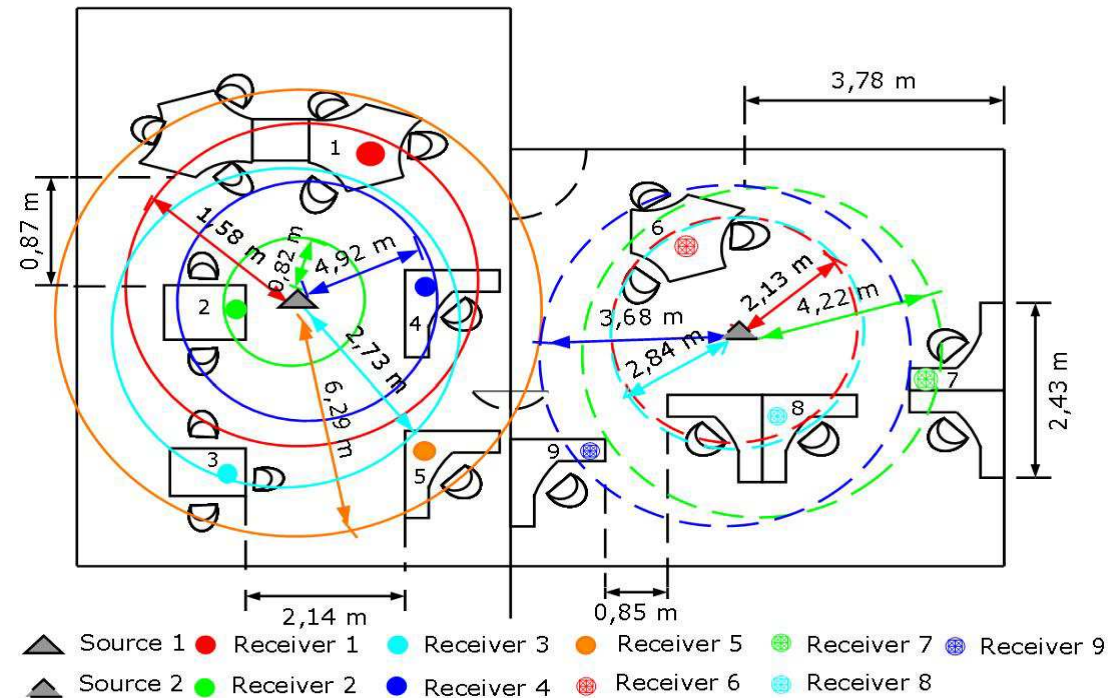
## Speech Privacy distance



The conversation from source 1 to receiver 1 (red colour), or defined as island 1, will be heard by other employees at workstations 2 and 4. However, from employees of workstation 3 and 5, it might not be heard since these positions are outside the speech privacy range.

# Measurement Result Office I

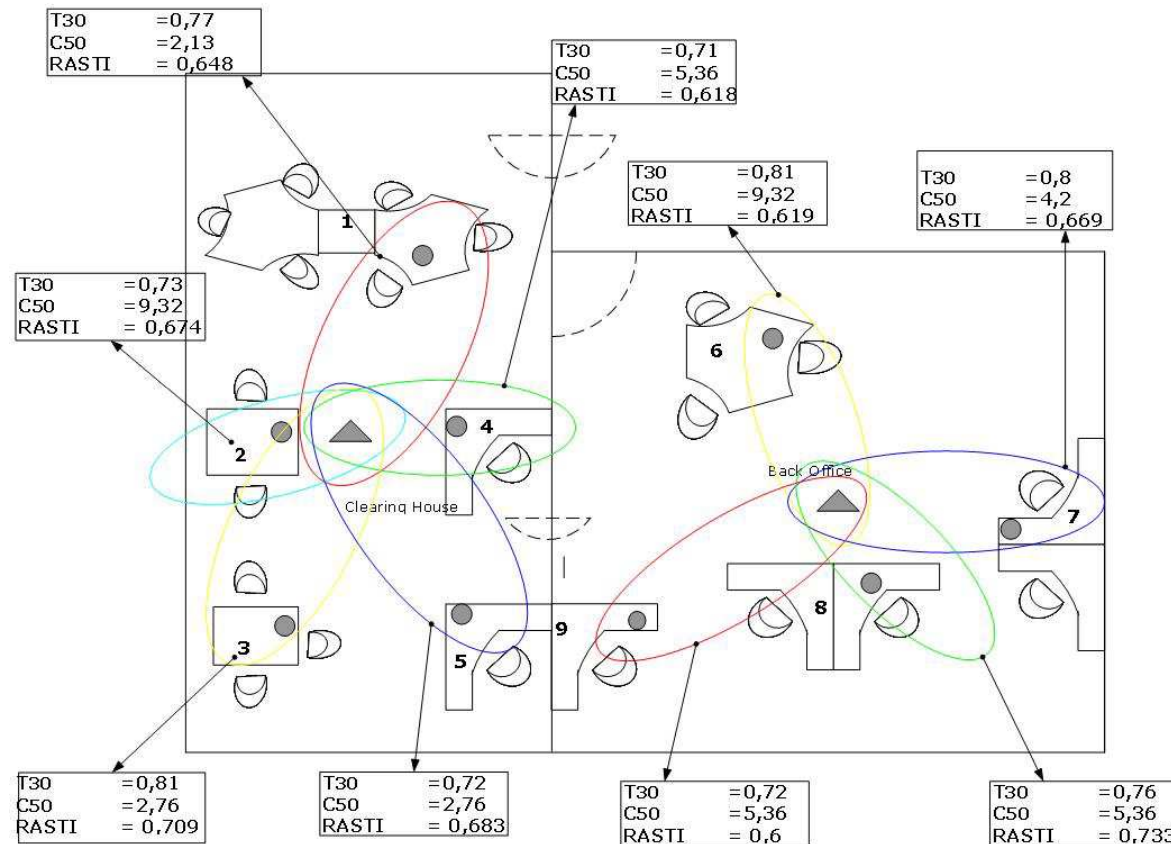
## Distraction distance



The conversation from source 1 to receiver 1 (red colour), or defined as island 1, will create work distraction to other employees at workstations 2 and 4. However, from employees of workstation 3 and 5, it should not influence their concentration since these positions are outside the distraction range.

# Measurement Result Office I

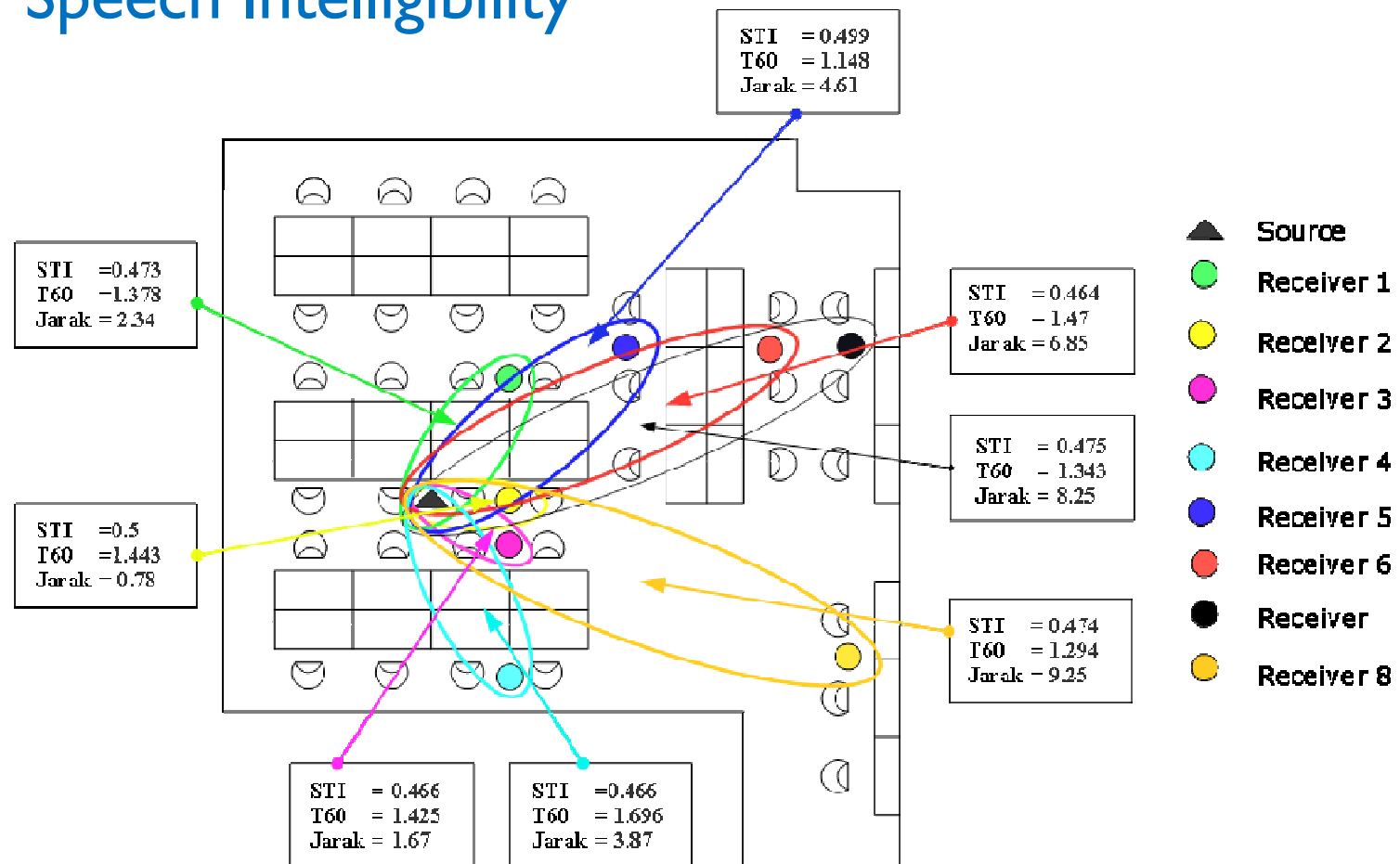
## Speech Intelligibility



Based on the three acoustic parameters, the speech intelligibility in every workstation are considered “very good.”

# Measurement Result Office 2

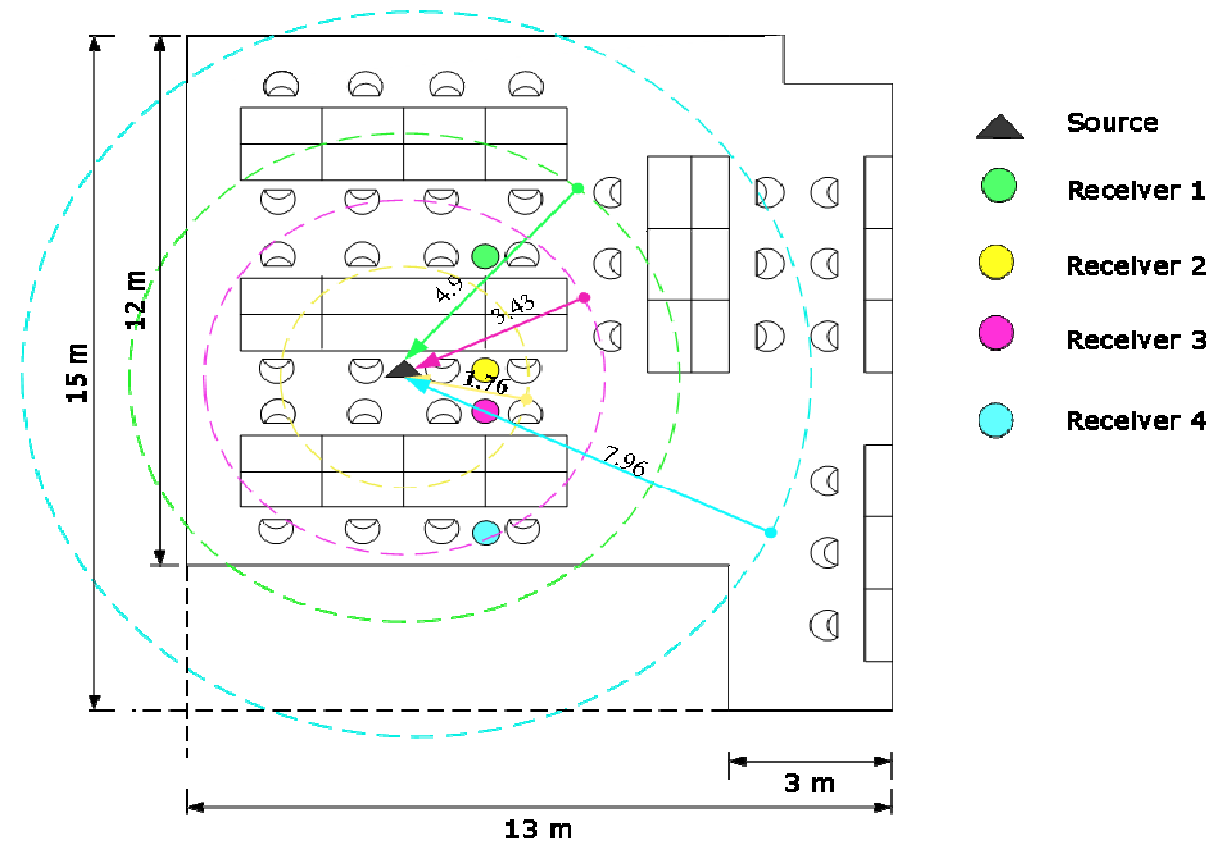
## Speech Intelligibility



Based on the three acoustic parameters, the speech intelligibility in every workstation are considered “poor”.

# Measurement Result Office 2

## Speech Privacy distance with STI 0,2

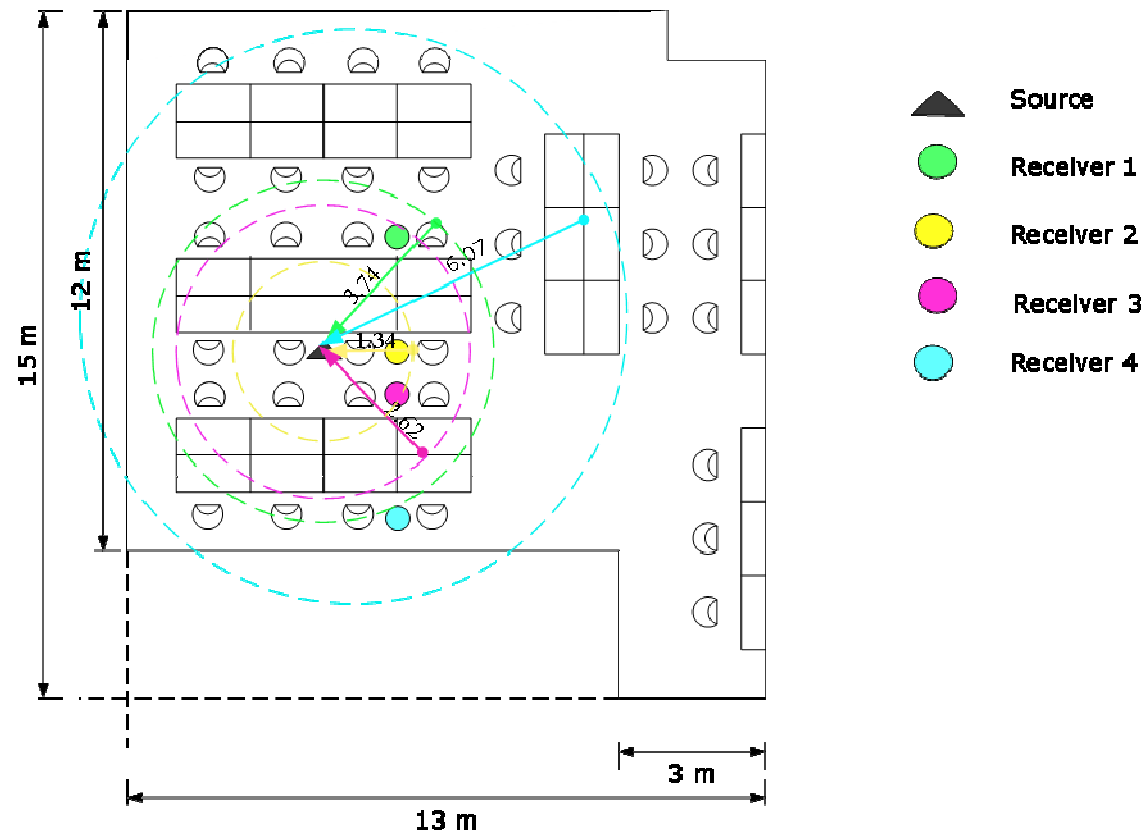


Using STI 0,2 (based on ISO 33282:3) to calculate the speech privacy distance for each workstation with source at the middle of the room, the speech privacy range only occurs for 4 receivers' positions.



# Measurement Result Office 2

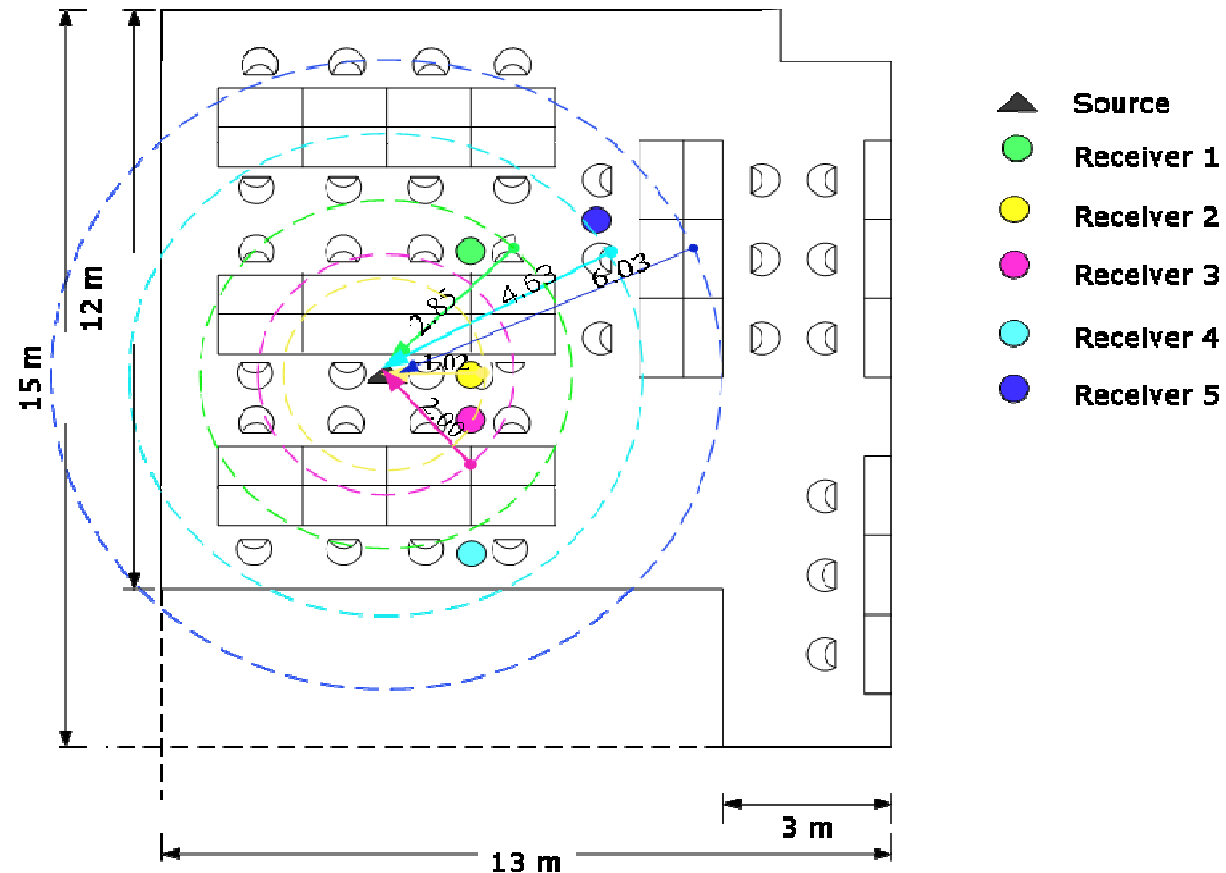
## Speech Privacy distance with STI 0,3



Using STI 0,3 to calculate the speech privacy distance for each workstation with source at the middle of the room, the speech privacy range only occurs for 4 receivers' positions.

# Measurement Result Office 2

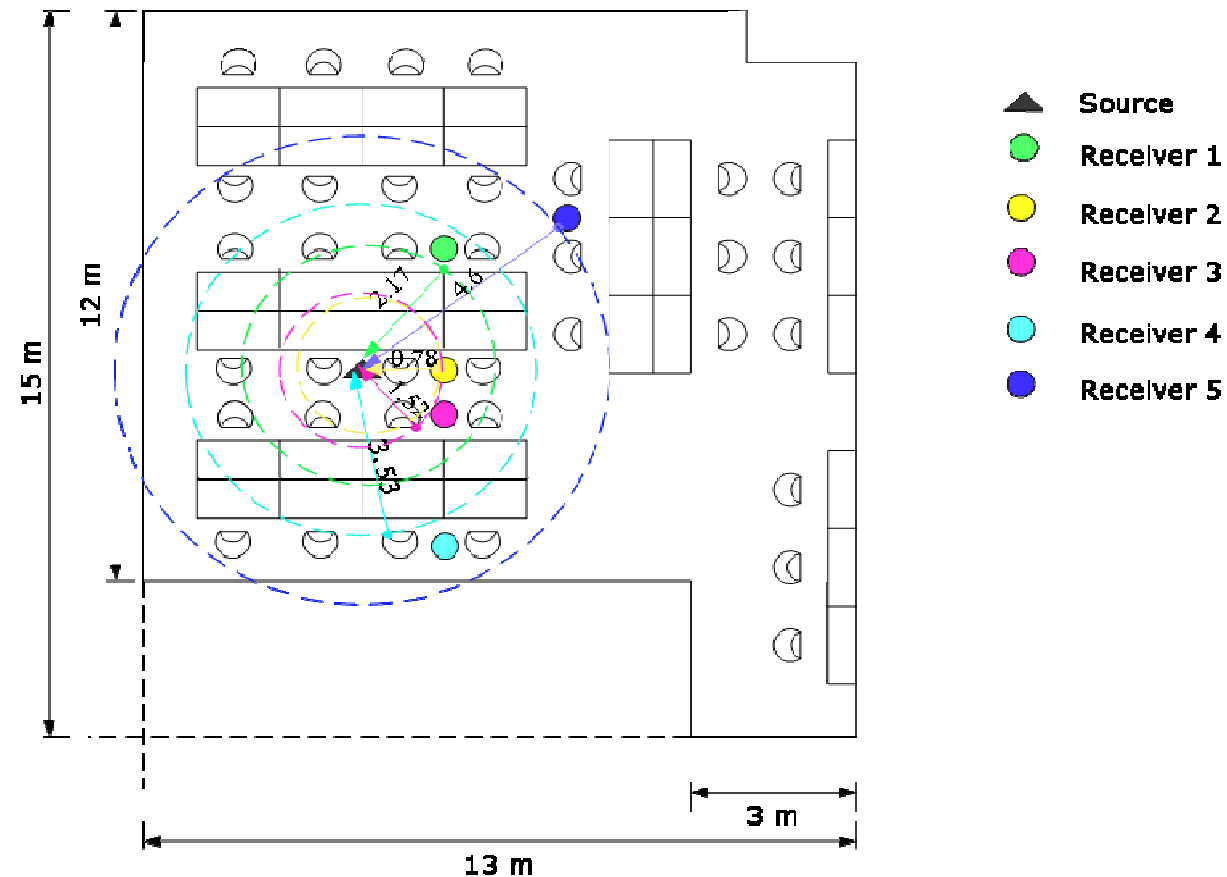
## Speech Privacy distance with STI 0,4



Using STI 0,4 to calculate the speech privacy distance for each workstation with source at the middle of the room, the speech privacy range occurs for 5 receivers' positions.

# Measurement Result Office 2

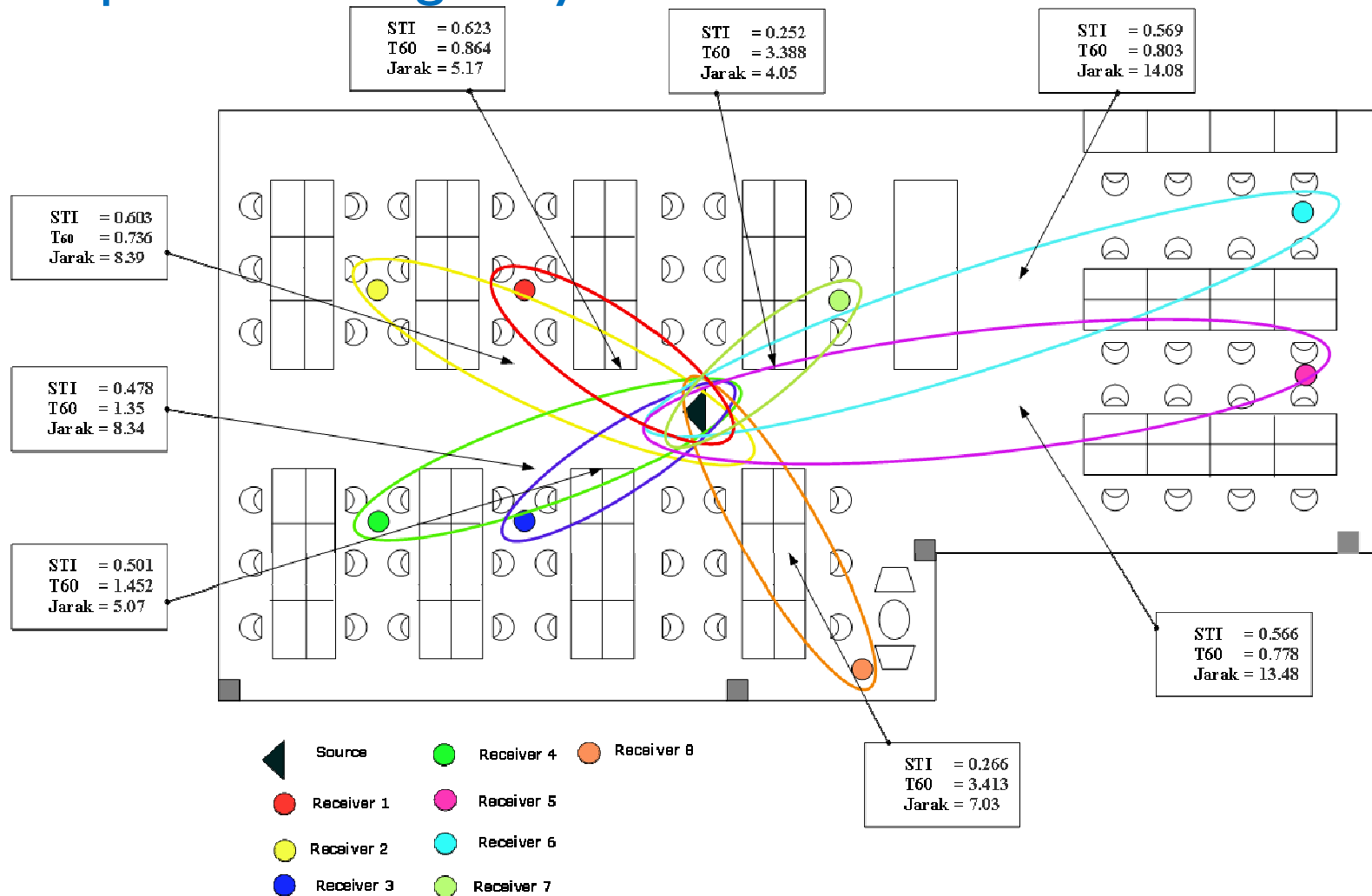
## Speech Privacy distance with STI 0,5



Using STI 0,5 to calculate the speech privacy distance for each workstation with source at the middle of the room, the speech privacy range occurs for 5 receivers' positions.

# Measurement Result Office 3

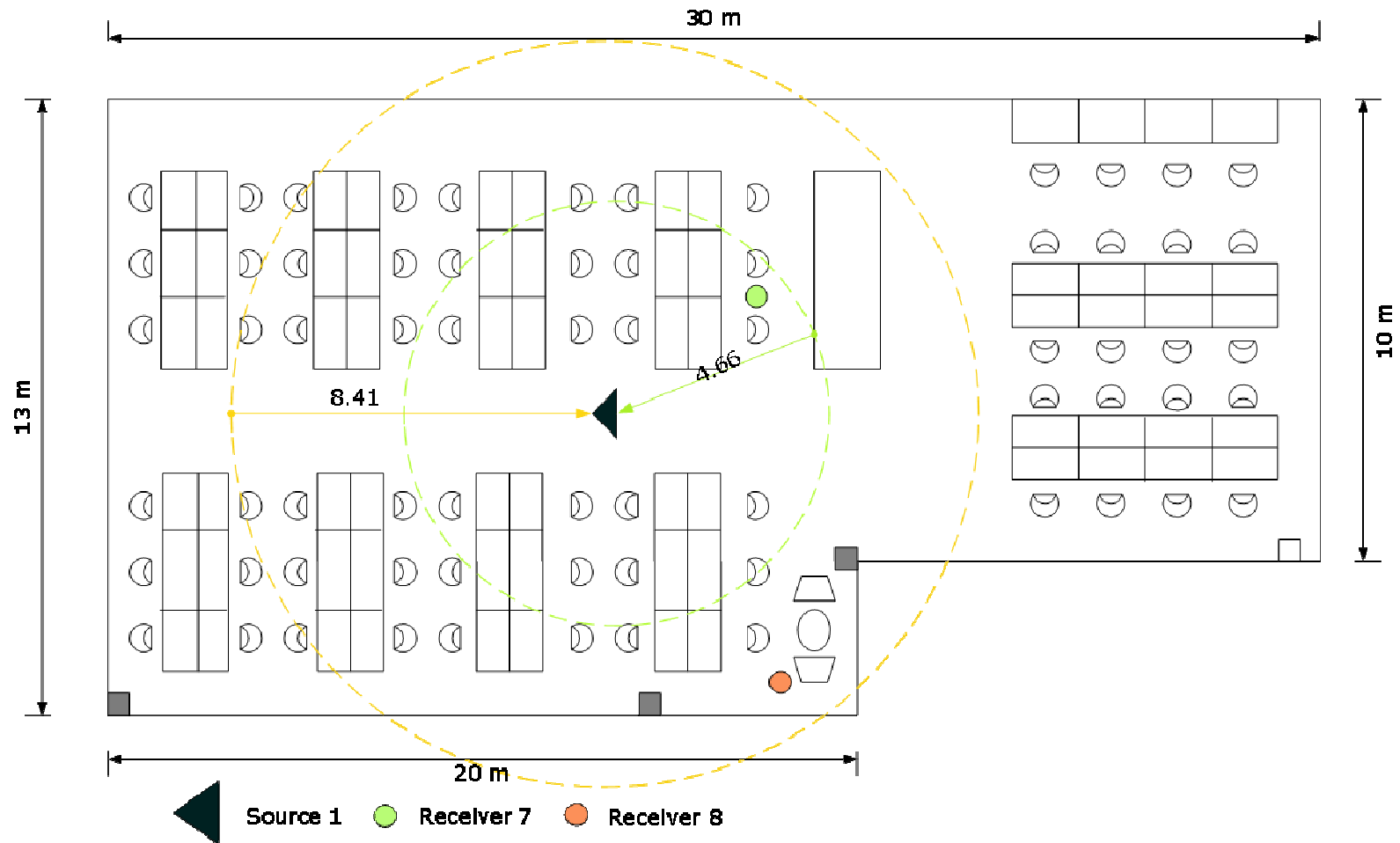
## Speech Intelligibility



The speech intelligibility in every workstation are considered “poor”.

# Measurement Result Office 3

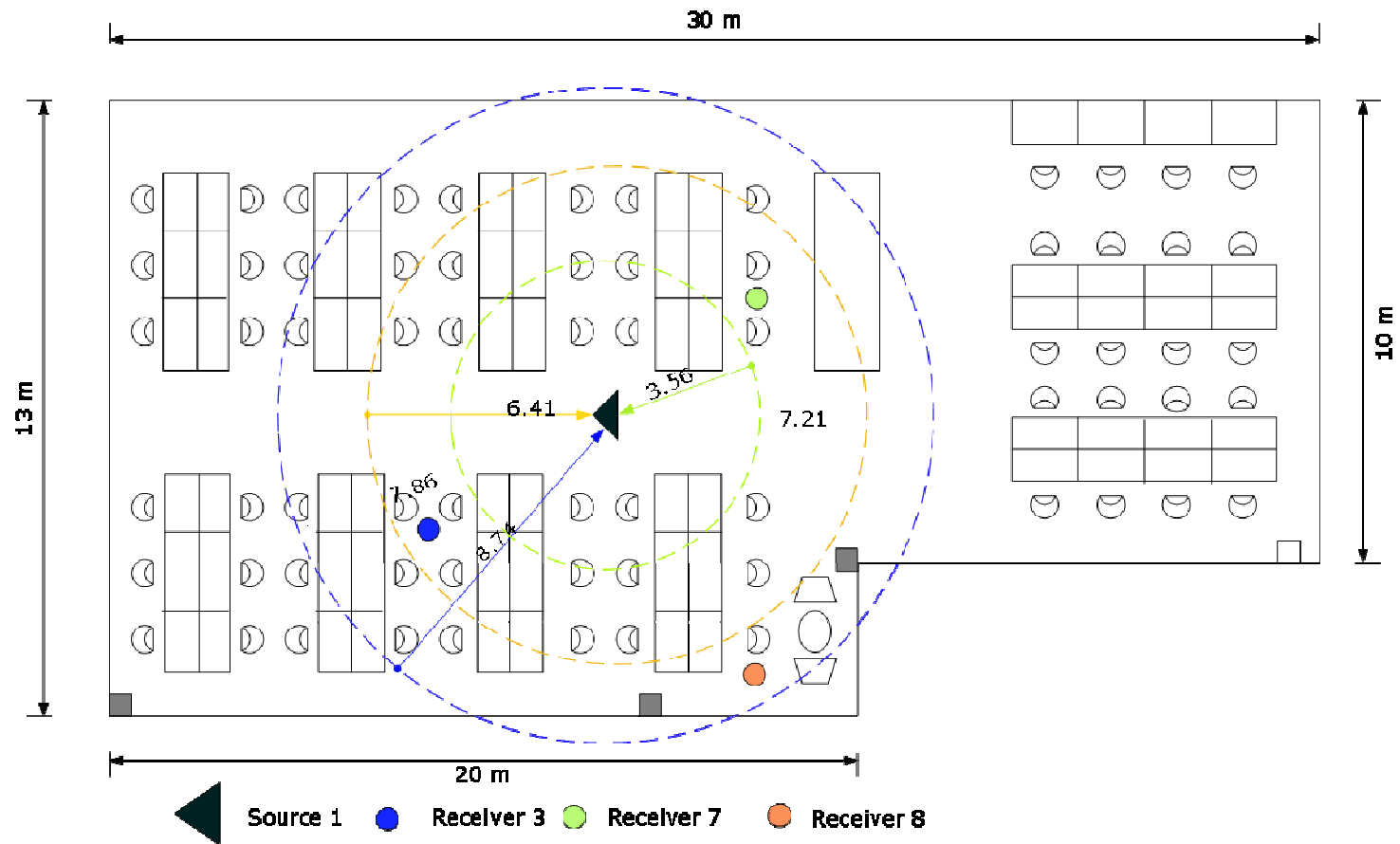
## Speech Privacy distance with STI 0,2



Using STI 0,2, the speech privacy range only occurs for 2 receivers' positions.

# Measurement Result Office 3

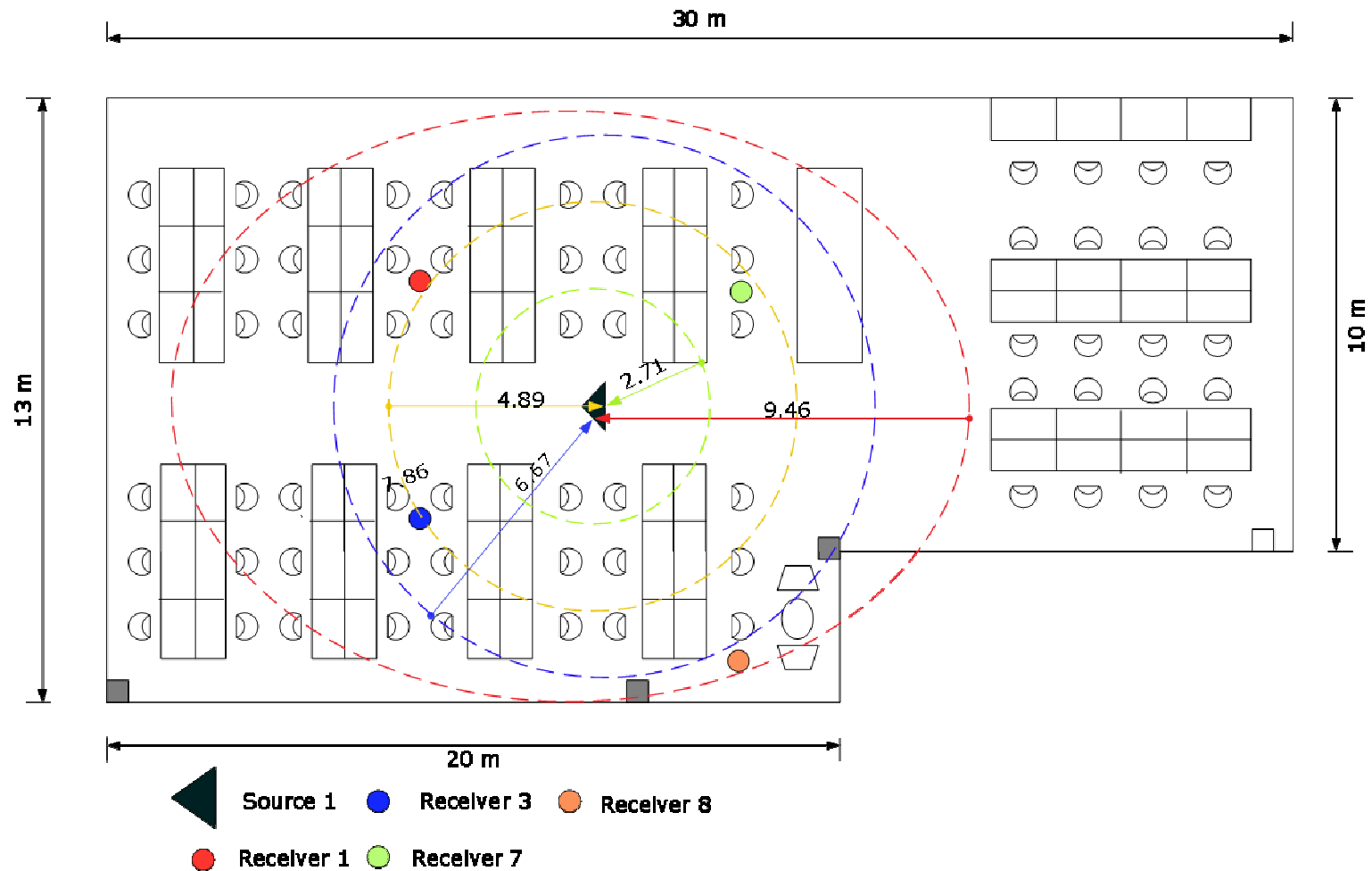
## Speech Privacy distance with STI 0,3



Using STI 0,3, the speech privacy range only occurs for 3 receivers' positions.

# Measurement Result Office 3

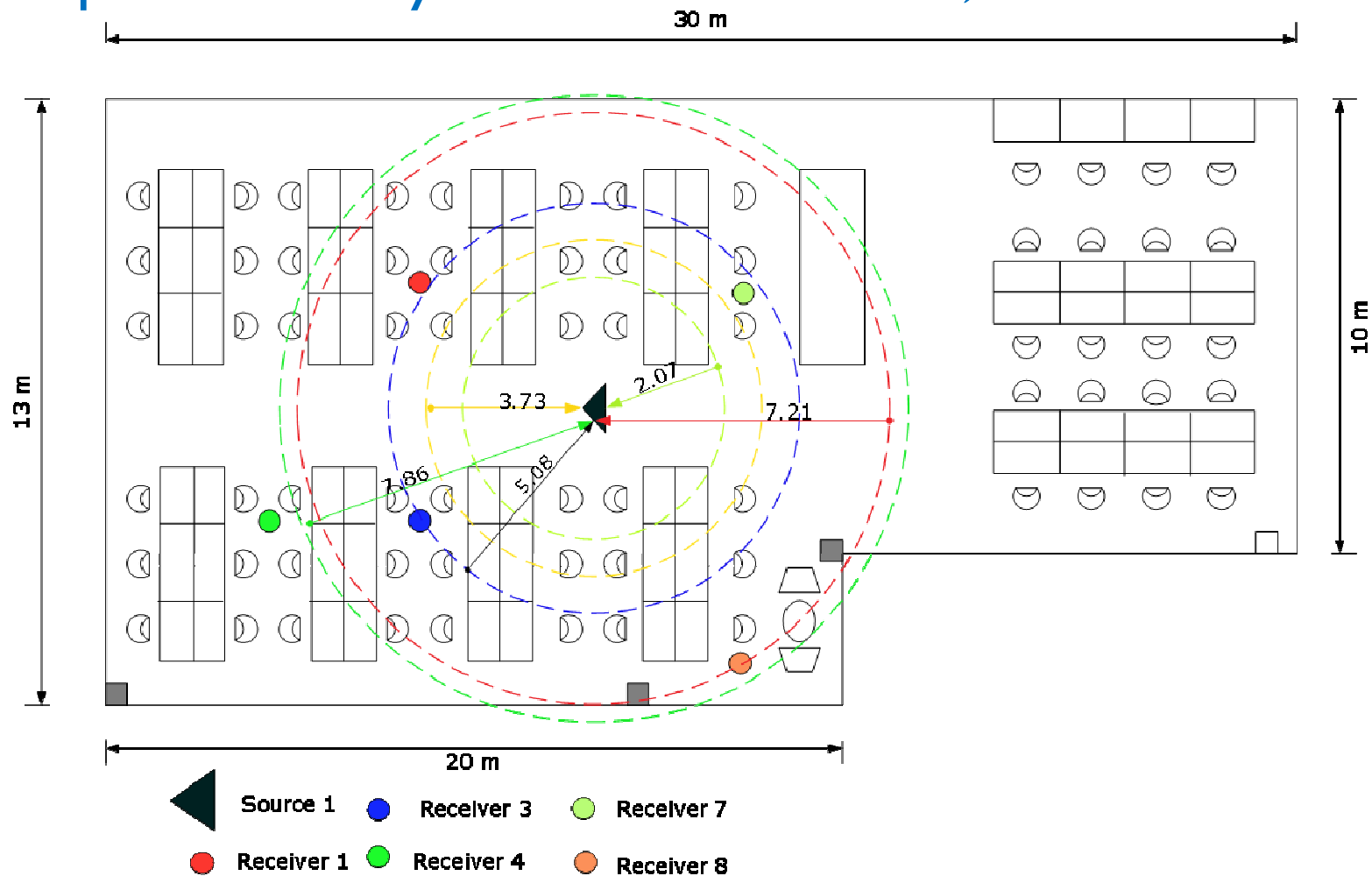
## Speech Privacy distance with STI 0,4



Using STI 0,4, the speech privacy range occurs for 4 receivers' positions.

# Measurement Result Office 3

## Speech Privacy distance with STI 0,5



Using STI 0,5, the speech privacy range occurs for 5 receivers' positions.





## Research Problems

- Difficulties in obtaining permission to enter several offices with an open-plan layout
- Time constraint due to limited eligibility in accessing the offices/case studied.
- Difficulties to obtain data measurement without occupants.
- Subjective evaluation with questionnaires for large sample size is unmanageable and limited to the number of employees/occupants.



# Future Works

- Future research that follows the measurement procedure in ISO 3382:3.
- Extended research using simulation is required to explore possibilities for source's and receiver's positions.
- Further investigation on the impact of partition's height and its material (characteristics of absorption and diffusion).

# OUTPUT

- “Speech Privacy Distance in 3 Open-plan Office Layouts: Computer Modelling and Simulation Approach”, to be appeared in the Proceedings of ICSV20, Bangkok-Thailand, 7-11 July 2013.
- “Characterizing the acoustics of 'green' open-plan offices,” to be appeared in the Proceedings of ICSV20, Bangkok-Thailand, 7-11 July 2013.
- “The Acoustics of ‘Green’ Open-plan Office: Simulation and Measurement approach”, in preparation for International Journal submission (Applied Acoustics)
- “Variation of Speech Privacy Distance in Open Plan Office Model and Layouts: Simulation Approach”, in preparation for National Journal submission.
- 4 Undergraduates Final Projects Report in Engineering Physics, 4 on going Final Projects Works.

# References

1. Hundert, A. T., & Greenfield, N. (1969). Physical space and organizational behavior: A study of an office landscape. Proceedings of the 77th Annual Convention of the American Psychological Association (APA) (pp. 601-602). Washington, D.C.:APA.
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