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Check of alarm impact on human voice communications in control room

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FOREWORD

Scenario

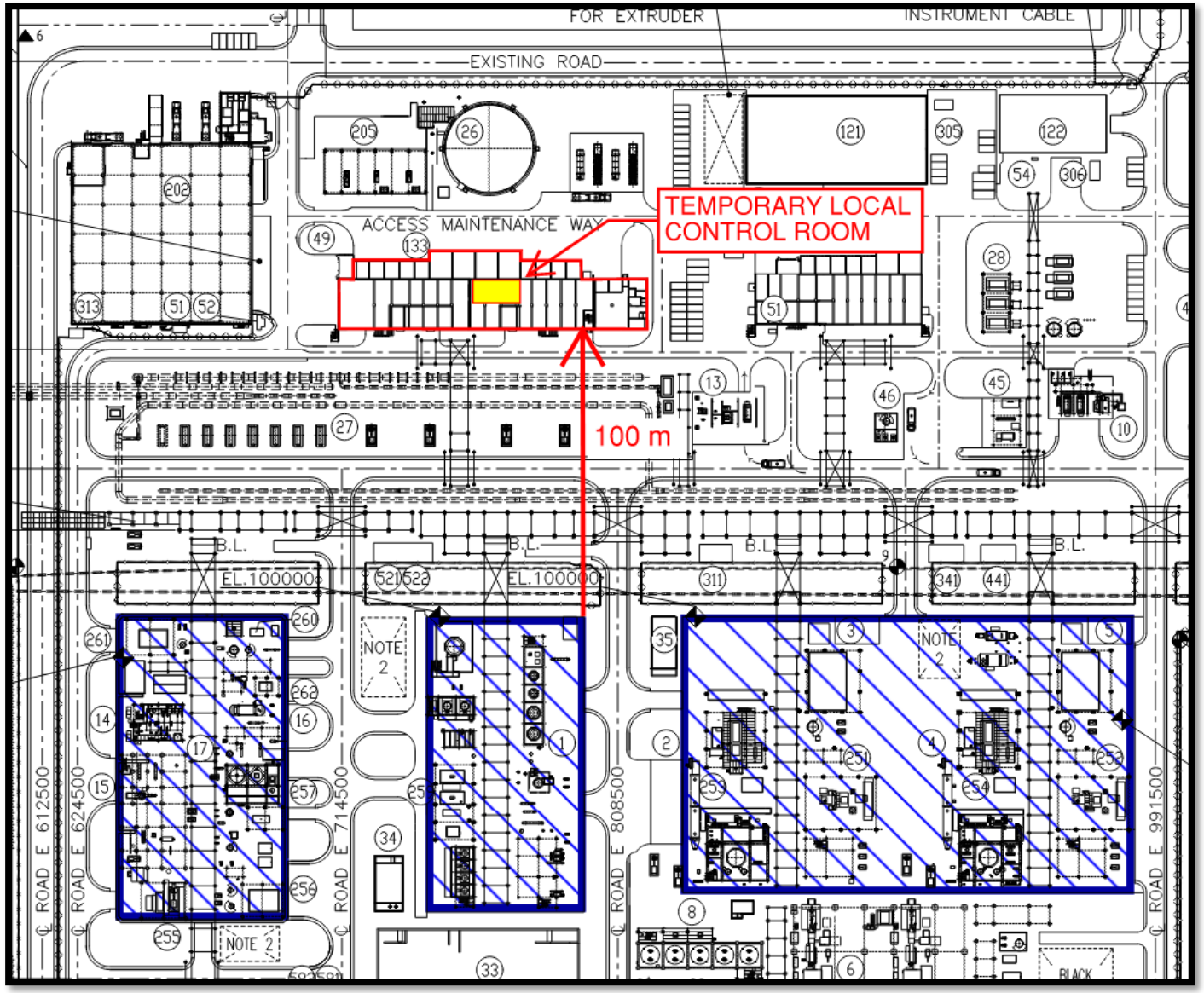
Before completion of the central control room in the administrative buildings area, a temporary local control room (LCR) in substation building (SS) was established for first period of operations.

The temporary LCR was located close to process areas (100m) then it was blast proof and provided with F&G detection and alarming system indoor and outdoor:

- outdoor detection: smoke detectors, hydrocarbons detectors at HVAC intake (in case of detection: closing damper and HVAC in recirculation mode);

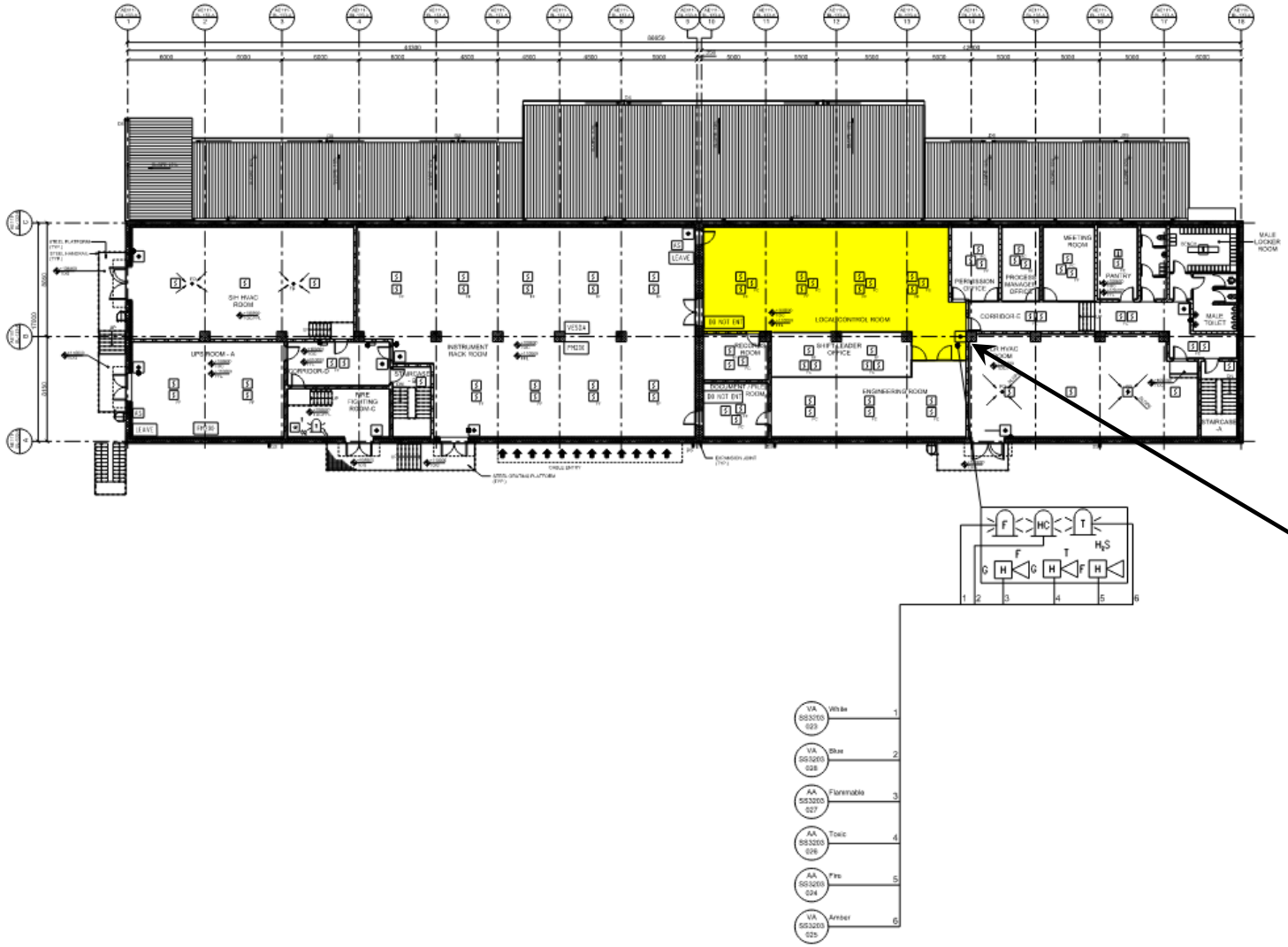
- inside alarming: one set of F&G horns and beacon provided inside the LCR.

Plot Plan



Building Layout

fire and gas system horn and beacon



The Task

The original requirement was:

“Is it ensured that speech communication is not masked by noise sources especially under the noisiest conditions, e.g. emergency preparedness?”

The adoption of ISO 9921:2003(*) was recommended and accepted for testing

(*) ISO 9921:2003 – Ergonomics – Assessment of speech communication (reviewed and confirmed on 2022)

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ACOUSTIC BACKGROUND

Acoustic Alarm Signals

Three main types

1) Warning alarms – potential incoming hazardous situation
2) Emergency alarms – ongoing hazardous situation
3) Evacuation alarm – persisting hazardous situation requiring site evacuation

Alarm properties are the audibility, the distinctiveness and the unambiguity

NOTE: Recorded or live voice alarms are not discussed here

Acoustic Alarm Signal Properties

1) Audibility – mainly depending on Loudness, i.e. Sound Pressure Level SPL
2) Distinctiveness – depending on time pattern (e.g. continuous, intermittent, alternating, sweeping, whooping) and frequency spectrum content (e.g. 340 Hz, 800 Hz and 1000Hz alternating, 800 Hz to 1000 Hz sweeping, 500 Hz to 1200 Hz whooping) (*)
3) Unambiguity – depending on time pattern and frequency spectrum content, as above

Definitions of acoustic alarm signal properties are from reference standard ISO 7731:2003 – Ergonomics – Danger signals for public and work areas – Auditory danger signals

(*) some examples can be heard at the link:
https://www.e2s.com/references-and-guidelines/listen-and-download-alarm-tones

Speech Communication

Effective speech communication properties are the audibility and the intelligibility

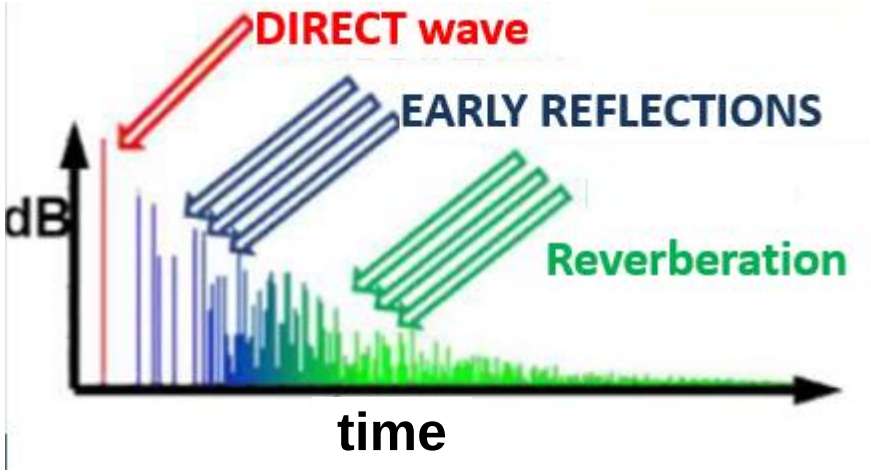
1) Audibility – depending on Sound Pressure Level SPL related to vocal effort (i.e. Relaxed, Normal, Raised, Loud, Very loud) to ensure a difference between signal and ambient noise

2) Intelligibility – depending on message understanding, affected by ambient noise, sound reflections, reverberation and echoes

Intelligibility and sound reflections

In enclosed spaces, that is in any room, the natural speech communication between a speaker and a listener occur by means of direct and reflected waves and reverberation sound queue

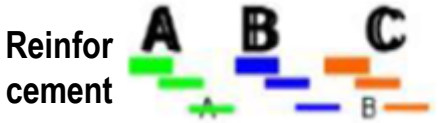
The presence of reflected sound waves is not always detrimental. Early reflections, arriving within a few milliseconds after the direct wave, help the direct wave by reinforcing the latter.



No reverberation
Weak message

Hi how are you

Proper reverberation
Reinforced message



Hi how are you

Too much reverberation
Overlapping

Hi how are you

Reflections that arrive too late overlap direct and early reflected waves, making the word incomprehensible

Reflections shall be controlled to ensure intelligibility especially in environments dedicated to speech communication (schools, conference rooms, etc.)

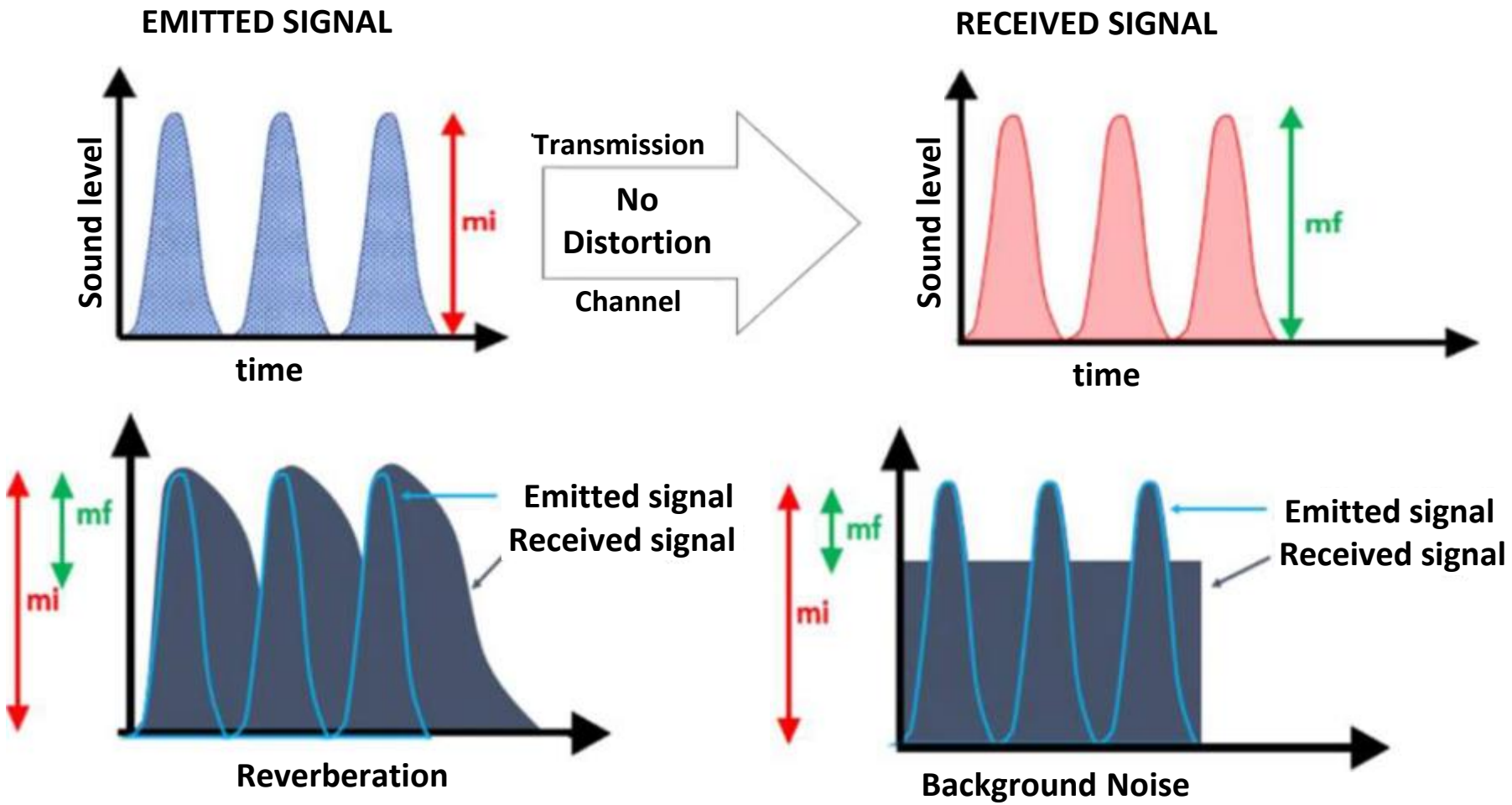
Poor and Good Intelligibility

Example of poor and good speech communication intelligibility

source: [Sound Comfort in Classrooms - Essex Study Experiences (https://www.youtube.com/watch?v=lpfKV_PB3P8)]

Signal analysis approach to Intelligibility

Effects of reverberation and background noise on vocal signal transmission (ref. IEC 60268-16)



mi = modulation depth of emitted signal at source

mf = modulation depth of received signal at listener position

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ACOUSTIC CRITERIA

Requirements for Acoustic Alarm Signals

For present work, the audibility requirements of standard ISO 7731:2003 “Ergonomics – Danger signals for public and work areas – Auditory danger signals” have been applied

1) Minimum Sound Pressure Level SPL of 65 dBA
2) At least one of following criteria:
   A. difference between overall “A” signal and ambient noise greater than 15 dB
   B. difference between octave band signal and ambient noise greater than 10 dB
   C. difference between 1/3 octave band signal and ambient noise greater than 13 dB

NOTE: recorded or live voice alarms requirements for SSEP (Sound System for Emergency Purposes) are covered by standard ISO 7240-19:2003 – Fire detection and alarm systems – Part 19: Design, installation, commissioning and service of sound systems for emergency purposes

Requirements for Natural Speech Communication

For speech intelligibility, the criteria of standard ISO 9921:2003 “Ergonomics – Assessment of speech communication” apply

The acoustic parameters to be checked are:

1) Speech Interference Level SIL

2) Speech Transmission Index STI

INTELLIGIBILITY RATING	SENTENCE SCORE [%]	STI [-]	SIL [dB]
Excellent	100	> 0.75	21
Good	100	0.60 to 0.75	15 to 21
Fair	100	0.45 to 0.60	10 to 15
Poor	70 to 100	0.30 to 0.45	3 to 10
Bad	< 70	< 0.30	< 3

The minimum rating to be complied with was “FAIR”

Acoustic Parameters for Speech Intelligibility

Speech Interference Level SIL (ISO 9921:2003 “Ergonomics – Assessment of speech communication”)

$SIL = L_{S,A,L} – L_{SIL}$

$L_{S,A,L}$ = A-weighted speech level at listener’s position depending on the speaker vocal effort and accounting for the ambient-noise effect, the loud speech effect, the speaker using hearing protector, the non-native speaker or listeners and the distance from speaker to listener

L_{SIL} = arithmetic average of background noise SPL in the octave bands 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz at listener’s position

Speech Transmission Index STI (IEC 60268-16:2020 “Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index”)

STI calculation is rather complex and may be carried out with dedicated instrumentation or software as involves the Modulation Transfer Function MTF of a communication channel from source to listener.

For the 7 octave bands from 125 Hz to 8000 Hz (covering the full range of human voice) a 100% amplitude modulated signal is generated, with 14 modulation frequencies from 0.63 Hz to 12 Hz (to simulate the rhythmic pattern of human speech regardless of language) getting 98 combination in total

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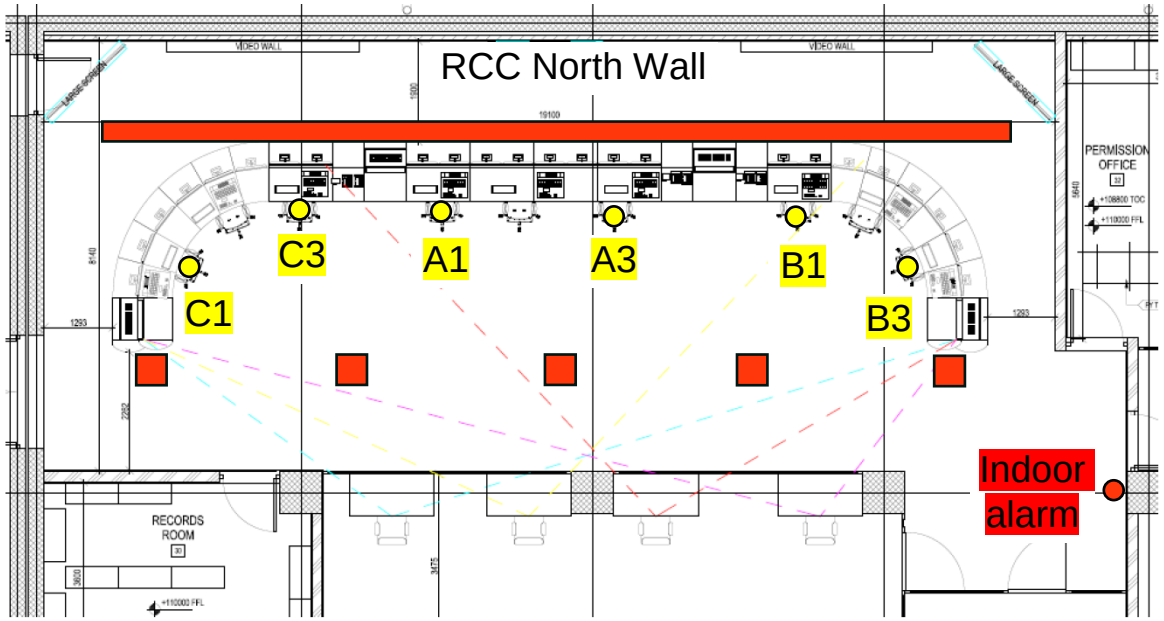
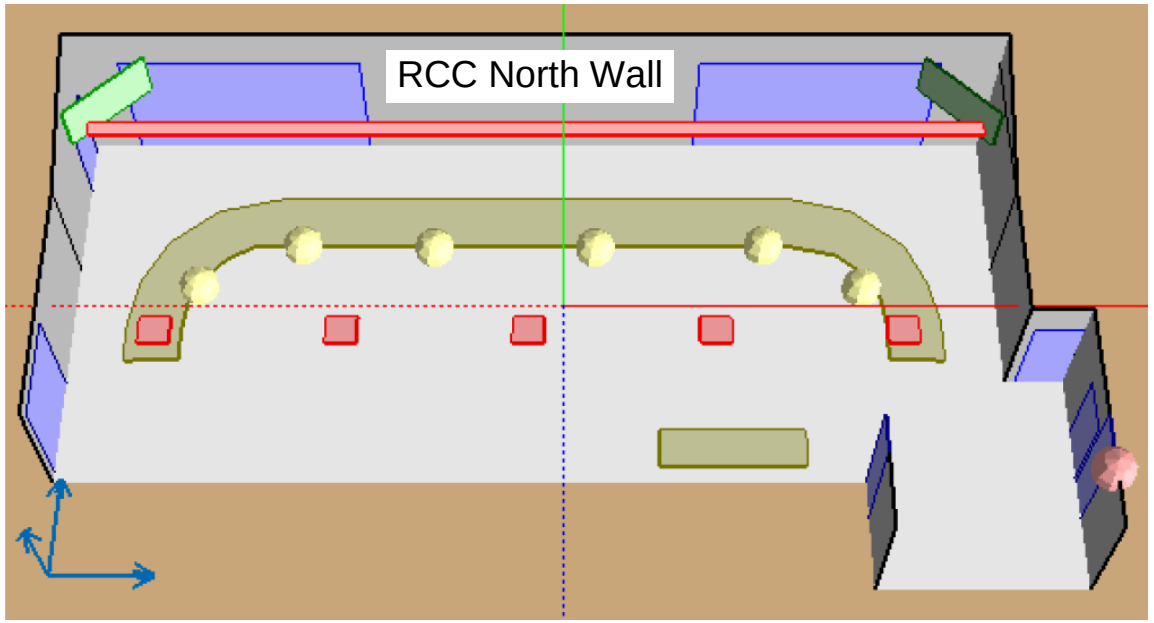
TESTING

Local Control Room (LCR) case study

Layout with furnishing and acoustic model of the same inputted in software SoundPLAN® 8.2





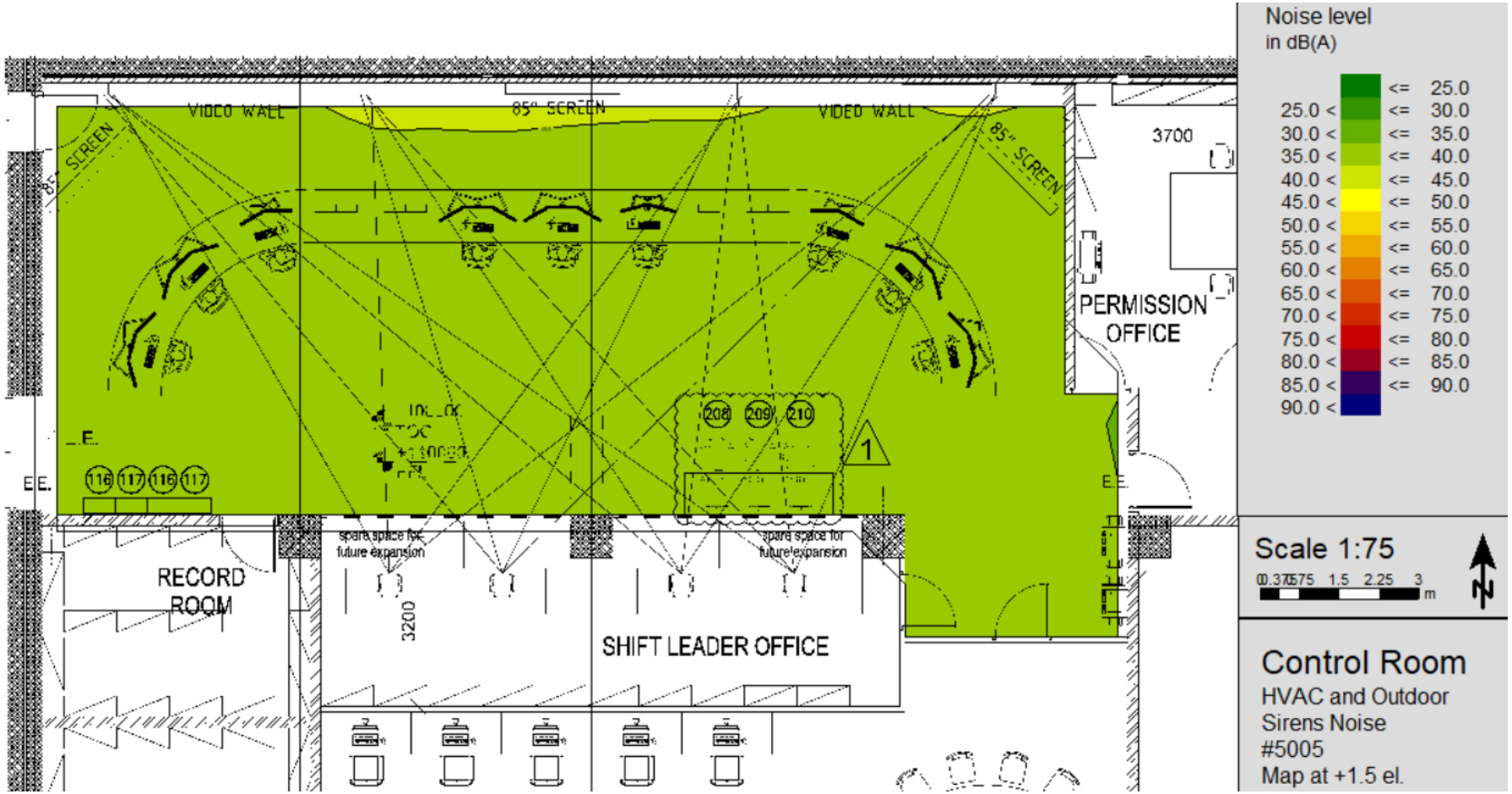
LEGEND: RED = Sound Sources (5 square air supply, 1 narrow air return and 1 indoor alarm)
YELLOW = Receivers (from left to right: C1, C3, A1, A3, B1, B3 at 1.3 m above ground)
GREEN = suspended LCD screens
OLIVE = desks
VIOLET = doors, wall LCD screens

The RCC North Wall also has been included as sound source modelling the outdoor alarms and siren

A) Background Noise in LCR without indoor alarm

During emergency preparedness, the ambient noise is due to HVAC air supply and return along with the outdoor alarms and siren noise entering from the RCC North Wall

Receiver	Background without indoor alarm
A1	38.9
A3	38.9
B1	38.9
B3	38.5
C1	38.5
C3	38.8



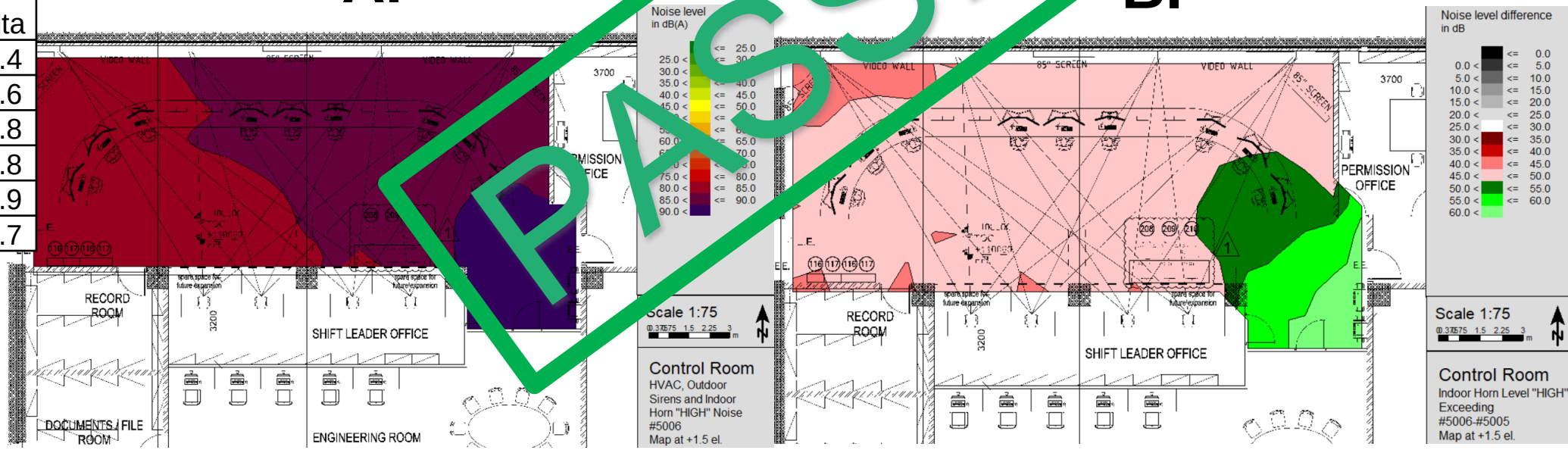
Test #A1: Indoor Acoustic Alarm Signal “HIGH” Audibility

1) Indoor alarm set on “HIGH”, SPL 99 dBA@1m, Tone 500 Hz
2) Audibility requirements:
   A. SPL ≥ 65 dBA
   B. Difference alarm signal SPL and ambient SPL ≥ 15 dB

Receiver	ambient	Alarm	delta
A1	38.9	85.3	46.4
A3	38.9	86.5	47.6
B1	38.9	87.7	48.8
B3	38.5	89.3	50.8
C1	38.5	83.4	44.9
C3	38.8	84.5	45.7

A.

B.

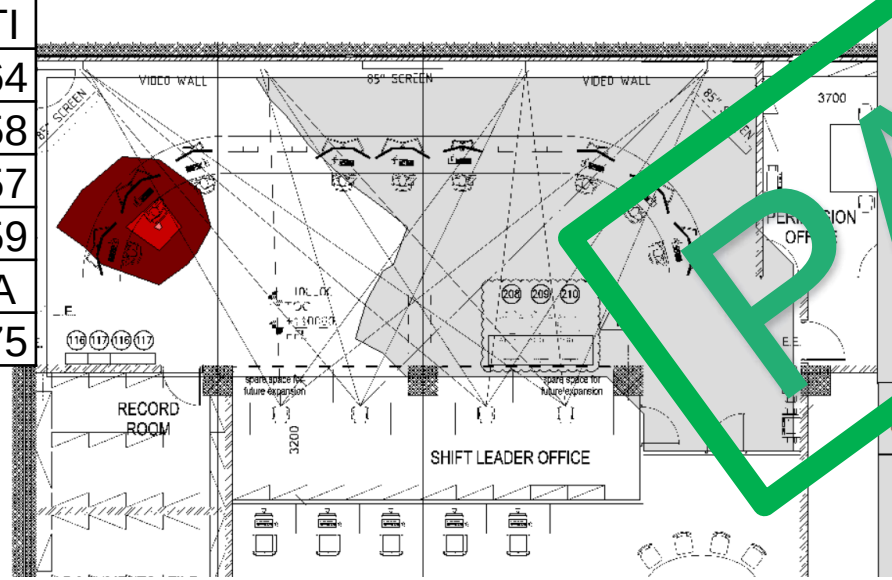


Test #A2: Speech Intelligibility without indoor alarm

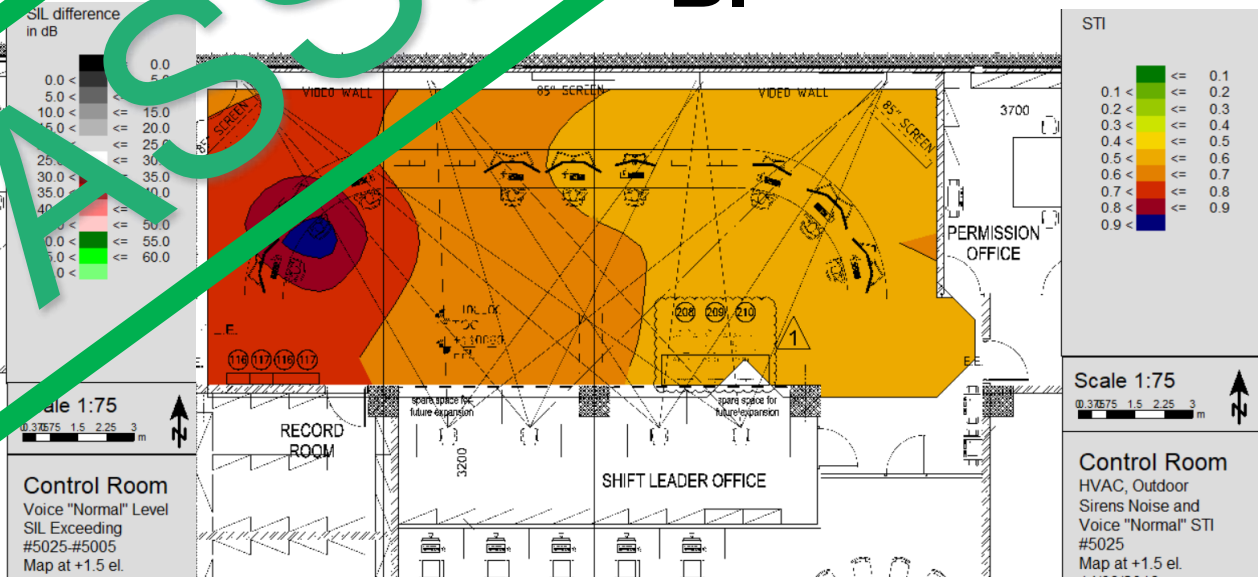
1) Speaker C1, normal voice loudness (60 dBA @ 1m)
2) Intelligibility requirements:
   A. SIL ≥ 10 dB (10 to 15 dB for rating “fair”)
   B. STI ≥ 0.45 (0.45 to 0.60 for rating “fair”)

Receiver	SIL	STI
A1	25.7	0.64
A3	24.0	0.58
B1	23.2	0.57
B3	20.4	0.59
C1 speaker	NA	NA
C3	28.5	0.75

A.



B.

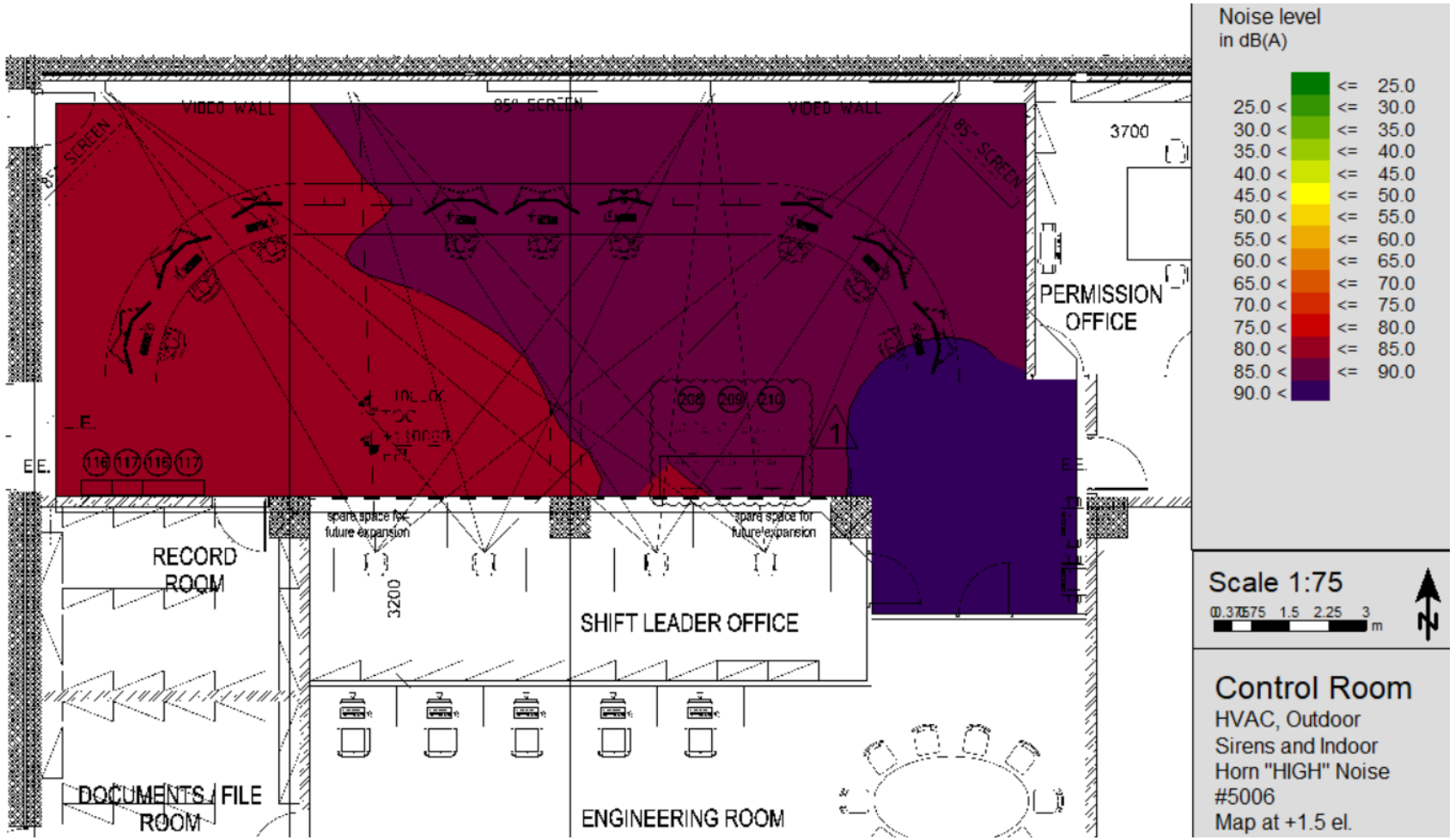


PASSED

B) Ambient Noise in LCR with indoor alarm set on “HIGH”

To test the speech communication during the first stage of emergency preparedness, the ambient noise is due to the indoor alarm set on “HIGH” activated by smoke detection at HVAC fresh air intake before its silencing

Receiver	Background with indoor alarm set on “HIGH”
A1	85.3
A3	86.5
B1	87.7
B3	89.3
C1	83.4
C3	84.5



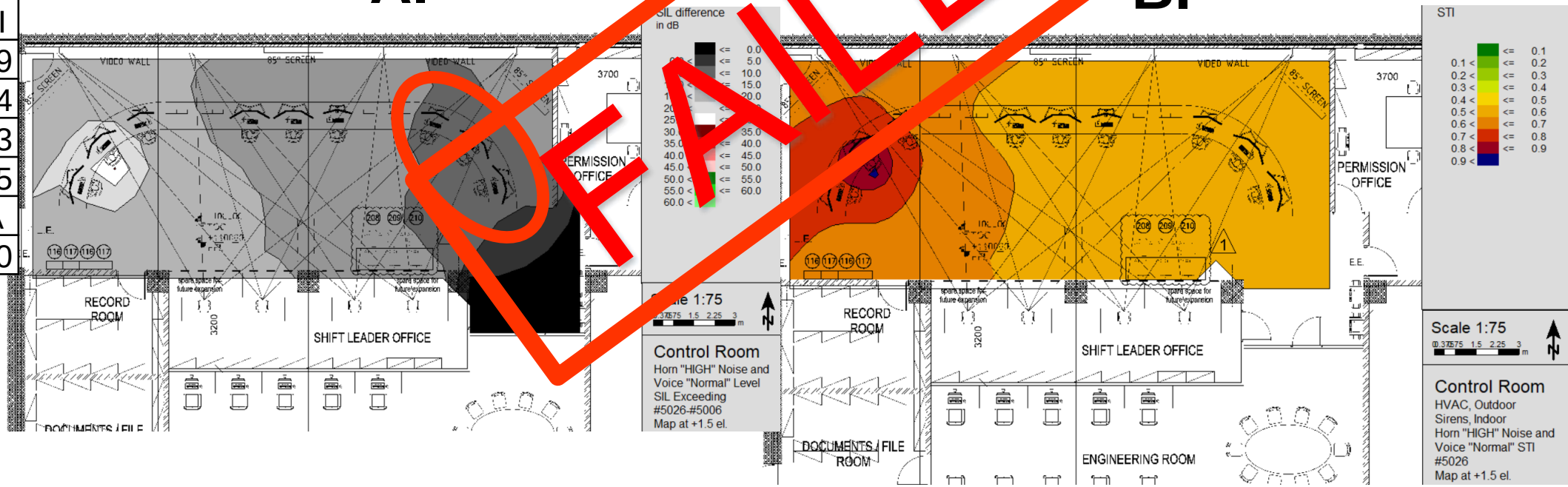
Test #B2: Speech Intelligibility with indoor alarm set on “HIGH”

1) Speaker C1, normal voice loudness (60 dBA @ 1m)
2) Intelligibility requirements:
   A. SIL ≥ 10 dB (10 to 15 dB for rating “fair”)
   B. STI ≥ 0.45 (0.45 to 0.60 for rating “fair”)

Receiver	SIL	STI
A1	12.7	0.59
A3	11.3	0.54
B1	9.73	0.53
B3	9.75	0.55
C1 speaker	NA	NA
C3	16.1	0.70

A.

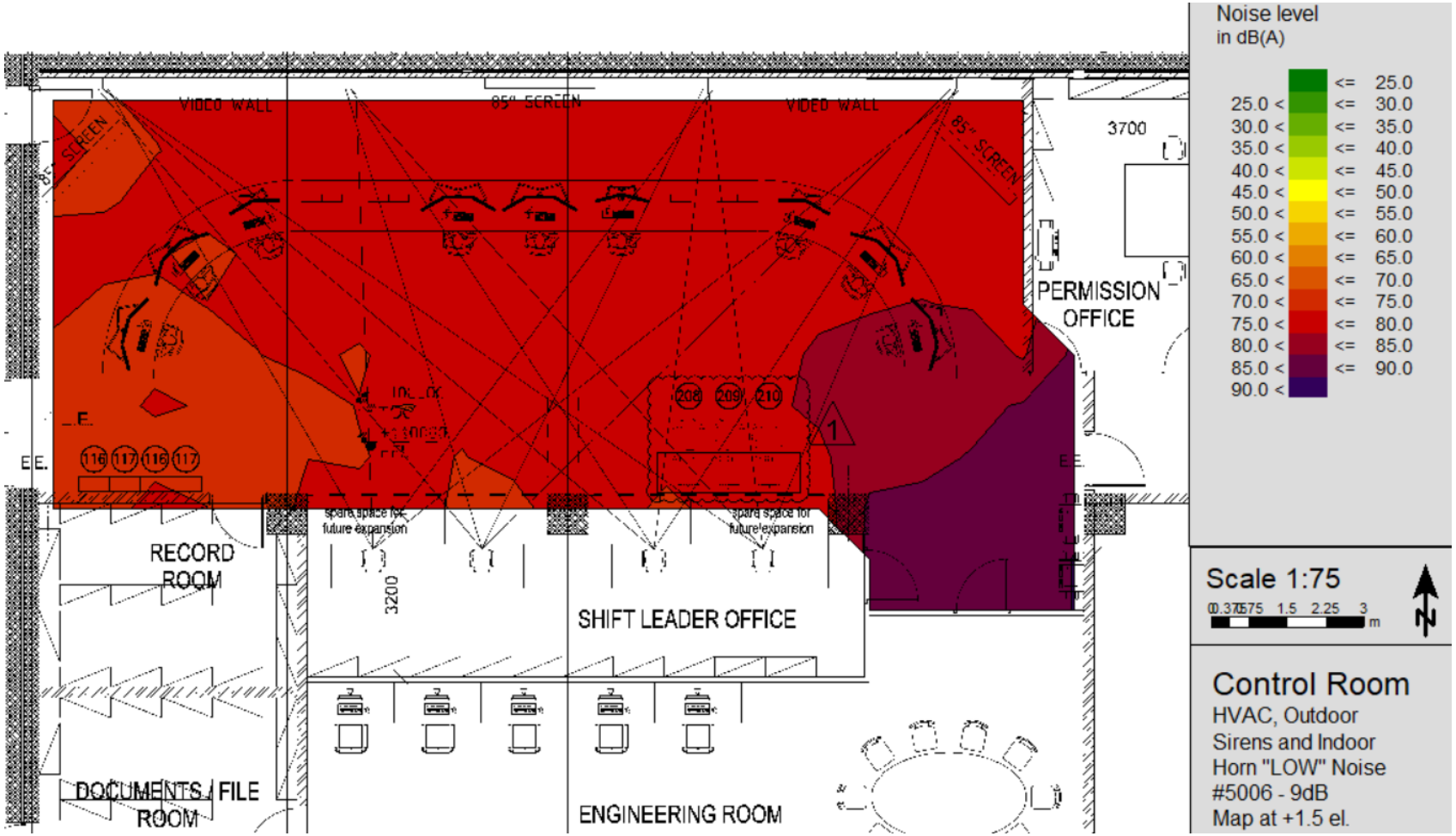
B.



C) Ambient Noise in LCR with indoor alarm set on “LOW”

To improve the speech communication during the first stage of emergency preparedness, the indoor alarm activated by smoke detection was set on “LOW”, reducing the ambient noise by 9 dB, before its silencing

Receiver	Background with indoor alarm set on “LOW”
A1	76.6
A3	76.9
B1	78.9
B3	79.1
C1	74.5
C3	74.9



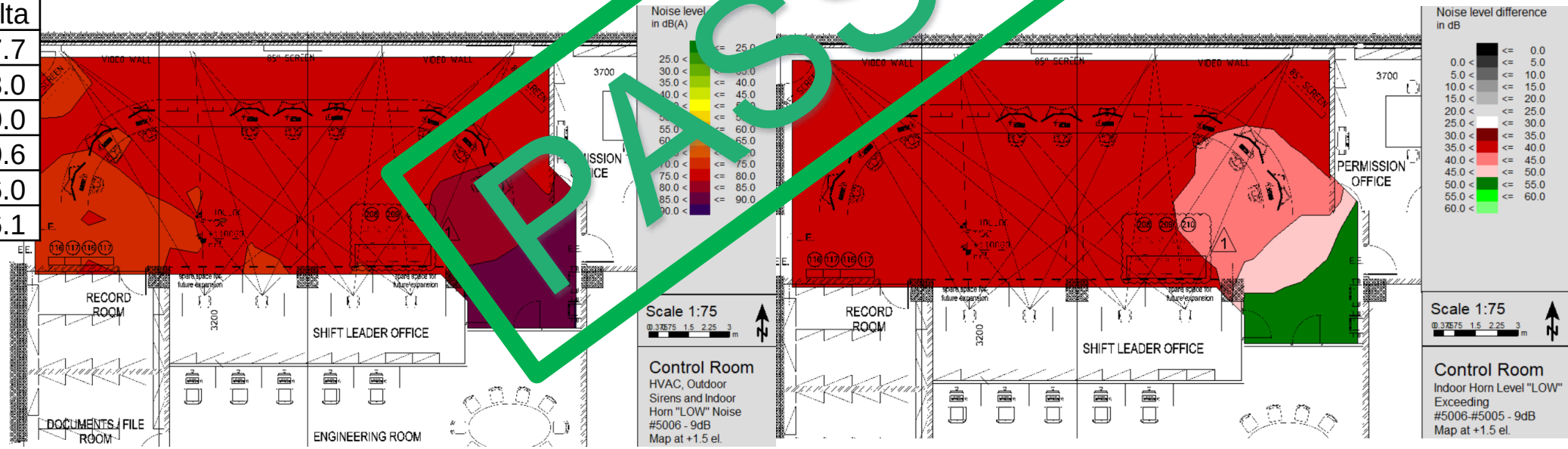
Test #C1: Indoor Acoustic Alarm Signal “LOW” Audibility

1) Indoor alarm set on “LOW”, SPL 90 dBA@1m, Tone 500 Hz
2) Audibility requirements:
   A. SPL ≥ 65 dBA
   B. Difference alarm signal SPL and ambient SPL ≥ 15 dB

Receiver	ambient	Alarm	delta
A1	38.9	76.6	37.7
A3	38.9	76.9	38.0
B1	38.9	78.9	40.0
B3	38.5	79.1	40.6
C1	38.5	74.5	36.0
C3	38.8	74.9	36.1

A.

B.



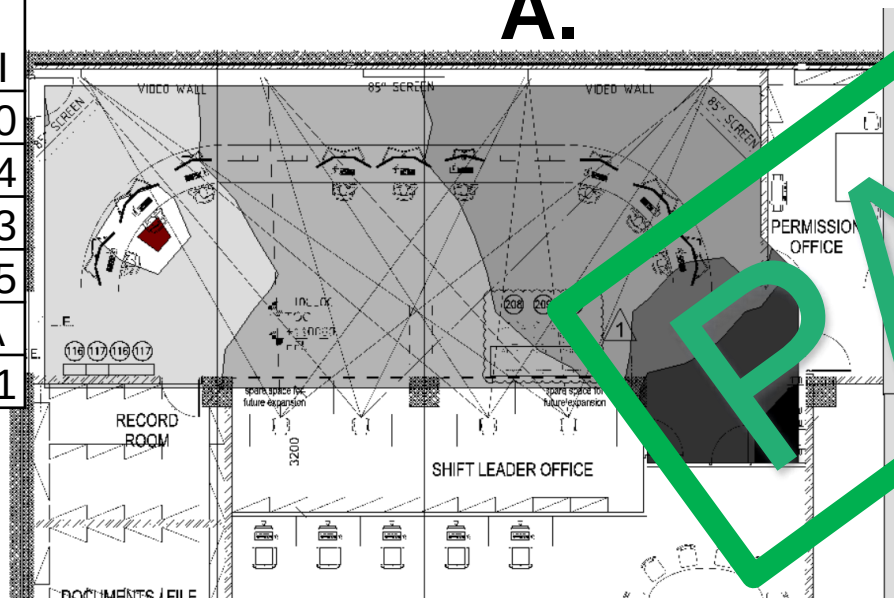
PASSED

Test #C2: Speech Intelligibility with indoor alarm set on “LOW”

1) Speaker C1, normal (*) voice loudness (60 dBA @ 1m)
2) Intelligibility requirements:
   A. SIL ≥ 10 dB (10 to 15 dB for rating “fair”)
   B. STI ≥ 0.45 (0.45 to 0.60 for rating “fair”)

Receiver	SIL	STI
A1	14.9	0.60
A3	13.2	0.54
B1	11.9	0.53
B3	12.3	0.55
C1 speaker	NA	NA
C3	18.3	0.71

A.



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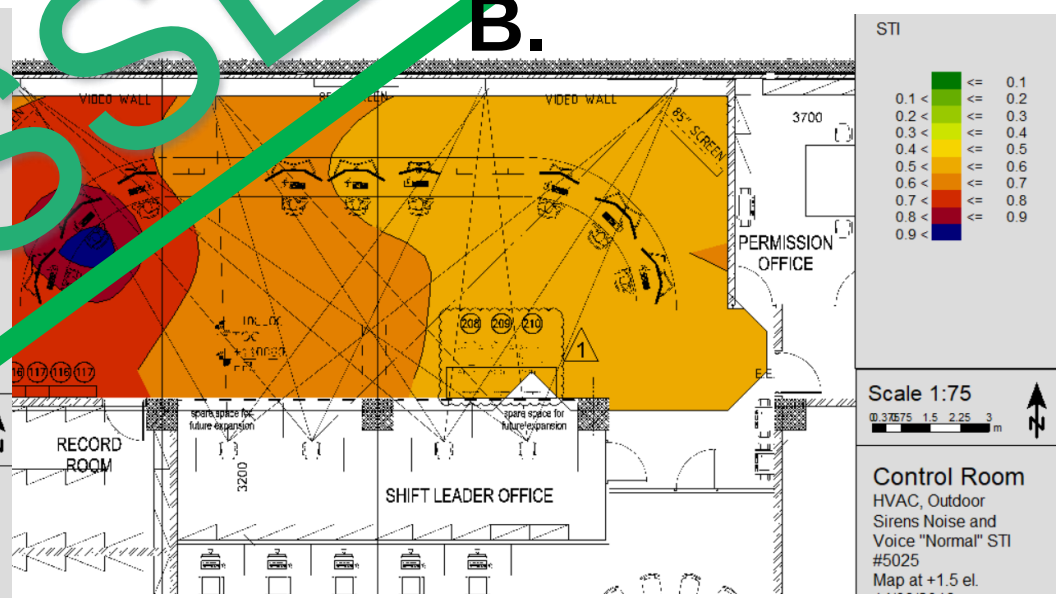

PASSED

(*) NOTE: for raised, loud and very loud vocal efforts the communication rating will increase

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CONCLUSIONS

Conclusion

1) Acoustic parameters are available for design and testing in field:
   A. Audibility is the requirement for emergency alarms
   B. Intelligibility is the requirement for speech communication
2) By means of above criteria defined by standards, a proper tuning of the alarm system will ensure the balance between alarm signals and voice communication, without sacrificing one of the twos

The adoption of technical standards allows to test by means the measurement of acoustic parameters the speech comprehension quality supporting common sense

Recent projects are more demanding and accurate design is needed

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