[TB50172]
[Rev. 00]

CoCo LOCO PROJECT
Thermoacoustic Behaviour

Issued Date:	06/08/2025
Revision Date:	

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Revision History

Rev. No	Revision Info	Date
00	First issue	06/08/2025

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III. ACRONYMS & ABBREVIATIONS

Loco	Locomotive
SI	International System of Units
dB	Decibel
dBA	A-filtered Decibel
HVAC	Heating Ventilation & Air Conditioning
SPL	Sound Pressure Level
SWL	Sound Powel Level
L_pLpAeqT	is the A-weighted equivalent continuous sound pressure level of the unit;
L^ipAeqT	is the A-weighted equivalent continuous sound pressure level at the nearest measuring position I, considering the main air compressor.
RW	Sound Reduction Index

1 INTRODUCTION

1.1 SUBJECT

This document provides the analysis of thermoacoustic behaviour for the CoCo Loco project. The first part defines the materials and stratified layers proposed for the thermo-acoustic insulation of the driver cab and the machine room, while the second part, based on the proposed stratigraphy, analyses the thermoacoustic behaviour of the locomotive, both Electric and Diesel.

1.2 DOCUMENTS AND STANDARDS

In accordance to National Co-Co Type Mainline Locomotive Development Technical Specification (ref. 1 Table 2), the locomotive shall be designed, assembled and tested according to more recently published versions of EN, IEC, UIC, TSI as other international standards required by Table 1, respected in the order of priority.

Table 1 reports the reference standards to the matter of the present document.

#	Standard	Title
1	EN 14813-1/2	Railway applications – Air conditioning for driving cabs
2	TSI 1304-2014 Amended 2023/1694	Technical Specification of Interoperability: Noise - 10August 2023
3	EN 45545:2013-2	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behavior of materials and components
4	EN ISO 354	Acoustics - Measurement of sound absorption in a reverberation room
5	EN ISO 10140 - 1/2	Acoustics - Laboratory measurement of sound insulation of building elements
6	EN 12667	Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods- Products of high and medium thermal resistance
7	EN ISO 6946	Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods
8	UNI EN ISO 3095	Acoustic-Railway application-Measurement of noise emitted by railbound vehicles
9	UNI EN ISO 3381	Acoustic-Railway application-Noise measurement inside railbound vehicles

Table 1 – Reference Standards

Table 2 reports the reference documents to the matter of the present document.

#	Document	Title
1	TŞ 250.900	National Co-Co Type Mainline Locomotive Development Technical Specification
2	TS400048	General Technical Specification of Electric CoCo Loco
3	TS400049	General Technical Specification of Diesel CoCo Loco
4	012GX2000201	CoCo Loco Electric Layout
5	012GX2000301	CoCo Loco Diesel Layout

Table 2 – Reference Documents

2 THERMOACOUSTIC INSULATION DESCRIPTION

2.1 GENERAL INTRODUCTION

In this section material characteristics, requirements and stratigraphy of thermal and noise insulation are provided in order to meet the thermal and noise insulation target. In addition, the bill of insulation material quantities is provided. It is considered that the insulation material shall be ready to be applied on board. All the mounting requirements and surface's treatments, also with the estimation of the necessary pre-treatment materials/tools, if any, are not matter of the design activity. They shall be specified by the materials supplier with the supply. Aluminium adhesive tape shall be also in the supply to close damages during the mounting. The car body structure is made of steel.

2.1.1 GENERAL STRATEGY FOR THERMOACOUSTIC INSULATION

The thermoacoustic insulation material are needed to satisfy two performances:

- Thermal insulation, to reduce energy consumption of the HVAC system and improve interior comfort in the driver cab.
- Acoustic insulation, to reduce the external noise level and the driver cab's internal noise level.

These aspects are addressed with the following general strategies:

- Thermal insulation: due to the very low thermal resistance of the carbody and of most of the interior materials, the greater part of the thermal insulation is performed by the thermal insulation material. Thus, this material is inserted on all the faces of the carbody.
- Noise insulation: it is performed by multiple contribution from all the materials of the vehicle, in particular from the carbody steel and the fiberglass panels. The combined effect of these materials is improved by the presence of the sound absorption material (the same material that is used for thermal insulation). This material is already installed on all the side of the carbody.
  On certain sides of the carbody (such as the driver cab floor), the carbody materials alone are insufficient, thus is inserted a thin layer of noise insulation material to improve the noise insulation performances. Thus, the sound insulation capacity (Rw) target is defined only for these parts.

2.1.2 MATERIAL TECHNICAL DATA

2.1.2.1 DRAINING MATERIAL

Draining material has to ensure a free flow-off condensed water in every direction between the insulation material and the carbody.

Main technical data (as reference):

Working temperature:	-50°C to 100° C
Maximum density:	20 kg/m^3 ± 20%
Thickness Range:	7-10 mm
Flammability	EN 45545-2, R1-HL2

Draining material will be laminated to the thermal insulation material above it. Some examples of draining material can be found in the image below, they are usually composed by metallic net or a dimpled membrane. The first solution is preferred due to lower weight and space.

Figure 1 - Draining material examples: metallic net on the left, dimpled membrane on the right.

2.1.2.2 THERMAL INSULATION

The thermal insulation panel is intended to reduce the heat transfer between two environments at different temperatures. Additionally, it has the ability to absorb noises and a limited ability to propagate the flame, with a strong resistance to flame and limited smoke emission and one face, which is not in touch with carbody, should be covered with an aluminium foil, thickness between 20 to 40 µm.
Main technical data (as reference):

Maximum working temperature:	-50°C to 150° C
Thermal conductivity:	0.035 ± 0.005 W/(m K)
Water absorption:	water repellent treatment
Density:	20 kg/m^3 ± 20% for thickness range 10 ÷ 60 mm
Flammability	EN 45545-2, R1-HL2

Hz	α (40 mm)
100	0.12
125	0.14
160	0.15
200	0.15
250	0.22
315	0.25
400	0.66
500	0.66
630	0.7
800	0.9
1000	0.9
1250	0.8
1600	0.8
2000	0.8
2500	0.66
3150	0.45
4000	0.42
5000	0.4

Table 3 – Sound absorption coefficient α for 40 mm Thermal insulation

2.1.2.3 ACOUSTIC INSULATION

The acoustic insulation panel shall guarantee high opacity of noise in aerial transmission. The material test must comply with EN ISO 10140 or equivalent standard to provide the required acoustic performance.

Main technical data (as reference):

Maximum Density:	2000 kg/m^3
Flammability	EN 45545-2, R1-HL2

Sound insulation capacity for the panel is approx. in the following table.

Hz	Rw [dBA]
31.5	0
40	0
50	4
63	4
80	4
100	11
125	11
160	11
200	17
250	17
315	17
400	23
500	23
630	23
800	29
1000	29
1250	29
1600	35
2000	35
2500	35
3150	41
4000	41
5000	41
6300	41
8000	41
10000	41

Table 4 - Sound insulation capacity for 2mm Acoustic Insulation

2.1.2.4 CLIPS

Clips shall be designed to facilitate the installation of the insulation panels. It shall be able to fix all the different thickness of the insulation panel. On the base, the clips shall be bonded by glue. The temperature of application shall depend by technical specification of glue. The clips shall be made in stainless steel material. The length of the clips must assure the correct application for the type insulation package.

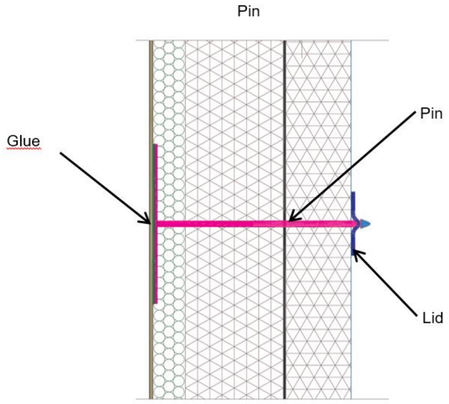

Figure 2 – Example for clip application

Figure 3 – Example of clip

2.1.2.5 TAPE

Aluminium adhesive tape shall be also provided to assure the connection between the different insulation packages and to close open or damages during the mounting. Detail of the aluminium tape width shall be defined after the tender definition phase, during the clause by clause phase. Additionally, tape must fulfil the flammability requirement EN 45545-2 R1-HL2.

Figure 4 – Example of aluminium adhesive tape

2.2 MATERIAL REQUIREMENTS

2.2.1 GENERAL REQUIREMENT

Materials shall be suitable to allow the normal maintenance activities without need to adopt special protections including welding, cuts and so on. They shall be suitable for the waste disposal without need of particular care.

2.2.2 STRUCTURAL REQUIREMENT

All the add on parts and the interfaces on the car body shall be resistant against the loads according to the reference standards.

2.2.3 FIRE RESISTANCE BEHAVIOUR

The system/equipment/components including all their elements therefore shall be compliant to the applicable sections of EN 45545 family norms (-1, -2, -3, -4, -5, -6).

In particular according to EN 45545-1 and -2 the locomotive is ranked as 3N where:

- 3 indicates the operation category
- N indicates the design category

The classification results in an Hazard Level of the vehicle equal to HL2.

2.2.4 SMOKE OPACITY AND TOXICITY

All the materials used do not emit toxic gases in such quantities as to be harmful.
The parameters taken as reference for the selection of materials, and the requirements they must meet, are described in "Table 5" of the EN 45545-2 standard with reference to the classification of the hazard level of the locomotive and the set of requirements R(n) to which the material is associated.

2.3 THERMOACOUSTIC STRATIGRAPHY AND LAYOUT

In this section, the stratigraphy for CoCo Loco project are listed.

2.3.1 THERMO-ACOUSTIC STRATIGRAPHY

2.3.1.1 SIDEWALL, ROOF, FRONT WALL - TYPE “A”

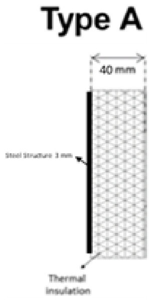

Figure 5 – Sidewall section

The type “A” stratigraphy is composed by thermal insulation material (40mm). It is characterized by a local K value (heat transfer coefficient) of 0.762 W/(m^2 K).

2.3.1.2 FLOOR – TYPE “B”

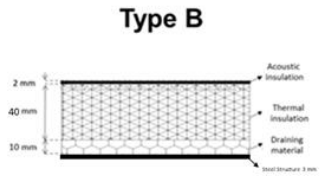

Figure 6 – Floor section

The type “B” stratigraphy is composed by draining material (10mm), thermal insulation material (40mm) and acoustic insulation (2mm). It is characterized by a local K value (heat transfer coefficient) of 0.762 W/(m^2 K).

2.3.1.3 WINDSCREEN – TYPE “C”

The windows are characterized by a local K value (heat transfer coefficient) of 5.0 W/(m^2 K). This value of heat transfer K is supposed and it will be asked to the third-part supplier.

2.3.1.4 WINDOWS – TYPE “D”

The windows are characterized by a local K value (heat transfer coefficient) of 2.4 W/(m^2 K). This value of heat transfer K is supposed and it will be asked to the third-part supplier.

2.3.1.5 DOOR – TYPE “E”

The door is characterized by a local K value (heat transfer coefficient) of 5.0 W/(m^2 K). This value of heat transfer K is supposed and it will be asked to the third-part supplier.

2.3.2 DRIVER-CABS INSULATION LAYOUT

The driver cab of a locomotive is the space where the operator controls the locomotive, and ensuring a comfortable and safe environment within this area is essential. Thermal and acoustic insulation in the driver cab plays a crucial role in maintaining a stable and comfortable internal temperature, protecting the operator from external temperature extremes—whether from the heat generated by the locomotive's machinery or from the external weather conditions.

Effective insulation in the driver cab enhances thermal comfort, reduces the reliance on heating and cooling systems, and minimizes the transfer of noise and vibrations from the engine or surrounding areas, creating a quieter and more focused working environment for the driver.

Type “A” stratigraphy is proposed for the sidewalls, the roof, the partitions between the machine room and the driver’s cabs; Type “B” stratigraphy is proposed for the floor.

2.3.3 ENGINE ROOM INSULATION (DIESEL MODE)

The machine room of a locomotive is a critical area housing engine and various mechanical systems that typically produce high noise levels. To mitigate this, both thermal and acoustic insulation play a vital role — not only by limiting heat transfer between the machine room and adjacent spaces, but more importantly by minimizing noise propagation both toward the exterior and into the driver's cab.

Type “A” stratigraphy is proposed for the Engine Room sidewalls, Roof, Floor, Partition wall between the “Engine Room” and “Engine Cooling Room”, partition wall separating the “Engine Room” from “Air Inlet Room”.

3 THERMAL BEHAVIOUR

3.1 DRIVER-CABS: K-FACTOR CALCULATION

The K-factor is a crucial parameter for evaluating the thermal performance of materials. It indicates the rate at which heat is conducted through a material and plays an important role in determining the efficiency of thermal insulation systems. A lower K-factor signifies better insulating properties, reducing energy losses and helping to maintain the desired internal temperature, thus enhancing both comfort and energy efficiency.
The maximum K-factor value allowed by the EN 14813 standard for a category A cabin in climate zone I is 2.3 W/m²K.

	Type	Area [m²]	Local K-value [W/(m²K)]	Dissipated Heat [W/K]
Sidewall	A	6.1	0.762	4.62
Floor	B	7.5	0.762	5.70
Roof	A	5.7	0.762	4.35
Front	A	3.2	0.762	2.45
Rear	A	5.6	0.762	4.26
Windscreen	C	1.9	5.0	9.35
Windows	D	0.6	2.4	1.42
Doors	E	2.5	5.0	12.72
Total Area [m²]		33.1	**Total Heat [W/K]**	44.9

Table 5 – Driver cab, K-factor calculation

For every difference of one degree the surfaces dissipates 44.9 Watt of heat.

$$K_{DriverCab} = \text{Total Heat/ Total Area} = 44.9\ W/K\ /\ 33.1\ m^2 = 1.35\ W/(m^2K)$$

4 ACOUSTIC BEHAVIOUR

This section presents the acoustic performance for the Coco Loco project. The results are linked both to the thermo-acoustic insulation described in the previous sections and to the noise limits produced by each component

4.1 NOISE REQUIREMENTS

External and internal maximum Noise level are imposed by TSI 1304/2014 Amended 2023/1694 and are listed in the following tables. The noise requirements depend on the mode (Electric/Diesel).

Zone	Condition	Noise Max.Value	Source
External Measured at a distance of 7,5 m from the centre of the track and a height of 1,2 m above top of rail.	Vehicle Standstill in Open Field **LpAeqT**	70 dBA	TSI 1304/2014 Amended 2023/1694
	Vehicle Standstill in Open Field **L^{i}pAeqT**	75 dBA	
	Vehicle Starting to move in Open Field **LpAFmax**	84 dBA	
	Vehicle in Open Field at 80 km/h **LpAeqT**	84 dBA	
	Vehicle in Open Field at 120 km/h **LpAeqT[80km/h]**	84 dBA	
Internal, Driver Cab	Vehicle in Open Field at 120 km/h **LpAeqT**	78 dBA	

Table 6 – Noise requirements for Electric mode

Zone	Condition	Noise Max.Value	Source
External Measured at a distance of 7,5 m from the centre of the track and a height of 1,2 m above top of rail.	Vehicle Standstill in Open Field **LpAeqT**	71 dBA	TSI 1304/2014 Amended 2023/1694
	Vehicle Standstill in Open Field **L^{i}pAeqT**	78 dBA	
	Vehicle Starting to move in Open Field **LpAFmax**	87 dBA	
	Vehicle in Open Field at 80 km/h **LpAeqT**	85 dBA	
	Vehicle in Open Field at 120 km/h **LpAeqT[80km/h]**	85 dBA	
Internal, Driver Cab	Vehicle in Open Field at 120 km/h **LpAeqT**	78 dBA	

Table 7 - Noise requirements for Diesel mode

4.2 NOISE SOURCES LIMITS

The maximum allowable noise sources are reported in Table 8. These values shall be passed as requirements for the component technical specifications. Note that some equipment will have multiple requirements, for different locomotive conditions: Stationary/Starting/Running. Due to lower noise target with the locomotive stopped, the equipment must limit the noise emission in those time periods (e.g. traction converter cooling should reduce fan rpm, or entirely shut off when the locomotive in stopped). Furthermore, in Table 9 are reported additional noise sources used in the calculation that do not translate in a requirement.

#	System	SWL [dBA]	Condition	Notes
1	Traction Motor Cooling	90	Stationary	Target
		100	Starting and Running	Target
2	Diesel Engine Cooling	105	Stationary, Starting and Running	Target
3	Diesel Engine/ After Treatment / Intake Filters	112	Stationary	Target
		118	Starting	Target
		114.8	Running @80 km/h	Target
		114.8	Running @120 km/h	Target
4	Generator	102	Stationary	Target
		105	Starting	Target
		103	Running @80 km/h	Target
		103	Running @120 km/h	Target
5	Main Air Production	92	Stationary and Running	Target
6	Auxiliary Air Production	88	Stationary and Running	Target
7	Battery Charger	85	Stationary and Running	Target
8	Main Transformer	82	Stationary and Running	Target
9	Driver HVAC	84	Stationary and Running	Target
9A	Internal HVAC	62	Stationary and Running	EN 14813
10	Transformer and Converter Cooling	90	Stationary	Target
		100	Starting and Running	Target
11	Traction Motor	0	Stationary	Target
		105.8	Starting (101 dBA per axle)	Target
		105.8	Running @80 km/h (101 dBA per axle)	Target
		110.8	Running @120 km/h (106 dBA per axle)	Target

12	Gear Box	0	Stationary	Target
		97.8	Starting (93 dBA per axle)	Target
		103.8	Running @80 km/h (99 dBA per axle)	Target
		107.8	Running @120 km/h (103 dBA per axle)	Target
13	Braking Rheostat	0	Stationary and Starting	Target
		85	Running	Target
14	Last Mile Module	90	Stationary and Starting	Target
		0	Running	Target

Table 8 – System noise sources

#	Source	SWL [dBA]	Condition	Notes
14	Rolling Noise	0	Stationary	Statistical Data
		91.8	Starting (87 dBA per axle)	Statistical Data
		100.8	Running @80 km/h (96 dBA per axle)	Statistical Data
		106.5	Running @120 km/h (102 dBA per axle)	Statistical Data
15	Aero Noise Side	0	Stationary	Statistical Data
		50	Starting	Statistical Data
		70	Running @80 km/h	Statistical Data
		90	Running @120 km/h	Statistical Data
16	Aero Noise Roof	0	Stationary	Statistical Data
		76	Starting	Statistical Data
		94	Running @80 km/h	Statistical Data
		105	Running @120 km/h	Statistical Data
17	Aero Noise Pantograph	0	Stationary	Statistical Data
		80	Starting	Statistical Data
		98	Running @80 km/h	Statistical Data
		108	Running @120 km/h	Statistical Data

Table 9 – Additional noise sources used in the calculation

4.3 EXTERNAL NOISE

The calculation of the external noise requires to calculate the propagation of the noise from the various sound sources to the measurement point defined by the standard ISO 3095. In reference to section 5.5.1.1 of the ISO 3095, the locomotive should be divided into equally spaced sections, each with an identical horizontal length. The locomotive length is defined as the distance between couplers or buffers, or between the ends of the structure if it encompasses the couplers or buffers. Measurement points should be positioned at the midpoint along each section on both sides of the car.

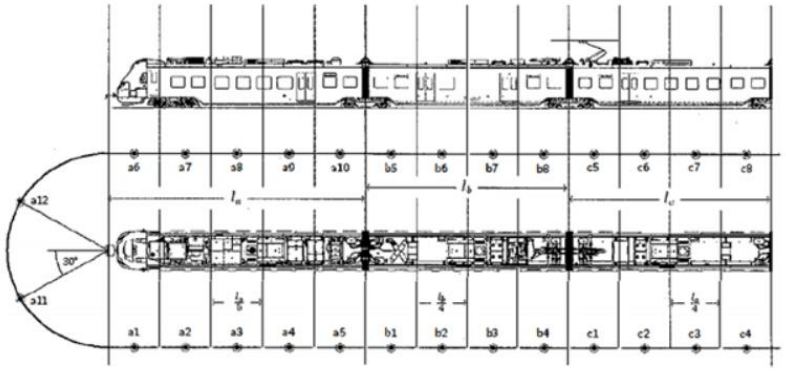

Figure 7 – Example of a mesh of measurement positions for noise level evaluation

Each measurement position in standstill condition shall be located at a distance of 7,5 m from the centreline of the track at a height of 1,2 m above the upper surface of the rail.
Measurement shall be carried out on both sides of the locomotive. If both sides of the unit are acoustically identical (i.e. with a symmetrical distribution of noise sources) then it is permissible to omit the measurement positions on one side of the locomotive.
In reference to section 6.4.1 of the ISO 3095, for the running condition 120 km/h the measurement position is the same of standstill condition, because the operating speed is lower than 200 km/h.

External noise calculation can be done using the propagation formula:

$$SPL = SWL + 10 \log \left[\frac{Q}{4 \pi r^2} \right]$$

Where:

- L_pSPL is the calculated sound pressure level at a certain distance r from the source
- L_wSWL is the noise source sound power level
- QQ is the directivity factor, and is equal to 2 for a half sphere propagation

The overall noise at each measurement point was determined by combining the individual sound pressure level from the noise sources obtained by propagation formula.
The A-weighted equivalent continuous Sound Pressure Level LpAeqT is obtained by spatially averaging the resulting noise at each measurement point, using the following formula:

$$L_{pAeqT} = 10 \log \sum_{i=1}^{N} \frac{l_i}{l_{tot}} 10^{\frac{SPL_i}{10}}$$

Where:

- SPL_i is the sound pressure level measured at the measurement position i
- N is the number of measurement positions
- l_i is the distance between two consecutive measurement point

4.3.1 METHODOLOGY FOR ASSESSING EXTERNAL NOISE OF COMPONENTS

Based on the equipment layouts, four possible types can be identified:

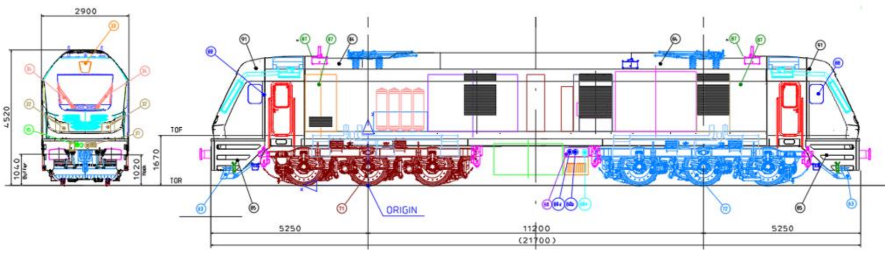

Figure 8 – Electric Mode Layout

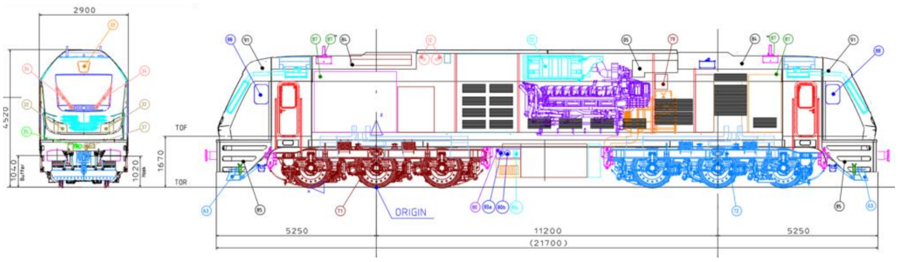

Figure 9 – Diesel Mode Layout

A. **Underbody and Upperbody Equipment**: These are located outside. For this type of equipment, it is sufficient to consider the sound power level (SWL) of Table 8 and the sound propagation formula described in Section EXTERNAL NOISE 4.3. **SWL_{Eff} = SWL**

B. **Engine Room (only for Diesel Mode)**: These are located inside Machine room. For this room, the sound power level (SWL) from Table 8, should be adjusted to account for the noise reduction of 3mm steel and sound absorption of thermal insulation material, after which the sound propagation formula outlined in Section EXTERNAL NOISE 4.3 can be applied.

C. **Internal Equipment with grilles**: These are located inside Machine room. For these components, the sound power level (SWL) from Table 8, should be adjusted to account for the 3mm steel of the car and for the presence of a grilles, after which the sound propagation formula outlined in Section EXTERNAL NOISE 4.3 can be applied.

D. **Internal Equipment without grilles**: These are located inside Machine room. For these components, the sound power level (SWL) from Table 8, should be adjusted to account for the noise reduction and sound absorption coefficient of 3 mm steel, after which the sound propagation formula outlined in Section EXTERNAL NOISE 4.3 can be applied.

#	System	SWL [dBA]	Type	SWL_{Eff} [dBA]	Notes
1	Traction Motor Cooling	90	A	90	Underbody Equipment
		100		100	
2	Diesel Engine Cooling	105	C	97	Air grilles on the sides
3	Diesel Engine/ After Treatment / Intake Filters	112	B	80	Engine Room has been fully insulated, effectively absorbing the majority of the sound energy within the insulation layers.
		118		85	
		114.8		80	
		114.8		80	
4	Generator	102	C	94	Air grilles on the sides
		105		97	
		103		95	
		103		95	
5	Main Air Production	92	D	81	Internal Equipment
6	Auxiliary Air Production	88	D	75	Internal Equipment
7	Battery Charger	85	A	85	Underbody Equipment
8	Main Transformer	82	A	82	Underbody Equipment
9	Driver HVAC	84	A	84	Upperbody Equipment
9A	Internal HVAC	62	-	62	Internal Equipment
10	Transformer and Converter Cooling	90	C	88	Air grilles on the sides
		100		98	
11	Traction Motor	0	A	0	Underbody Equipment
		105.8	A	105.8	
		105.8	A	105.8	
		110.8	A	110.8	
12	Gear Box	0	A	0	Underbody Equipment
		97.8	A	97.7	
		103.8	A	103.8	
		107.8	A	107.8	
13	Braking Rheostat	0	A	0	Upperbody Equipment
		85	A	85	

14	Last Mile Module	90	D	88	Internal Equipment
		0	D	0	Internal Equipment

Table 10 – Equipment SWL_{Eff} calculation

4.3.2 CALCULATION OF EXTERNAL NOISE LEVEL

The results for the Electric mode are:

Zone	Condition	Results [dBA]	Noise Max.Value [dBA]
External Measured at a distance of 7,5 m from the centre of the track and a height of 1,2 m above top of rail.	Vehicle Standstill in Open Field **LpAeqT**	66.0	70
	Vehicle Standstill in Open Field **L'pAeqT**	68.3	75
	Vehicle Starting to move in Open Field **LpAFmax**	83.4	84
	Vehicle in Open Field at 80 km/h **LpAeqT**	83.8	84
	Vehicle in Open Field at 120 km/h **LpAeqT[80km/h]**	83.9	84

Table 11 – Total external noise Electric Mode

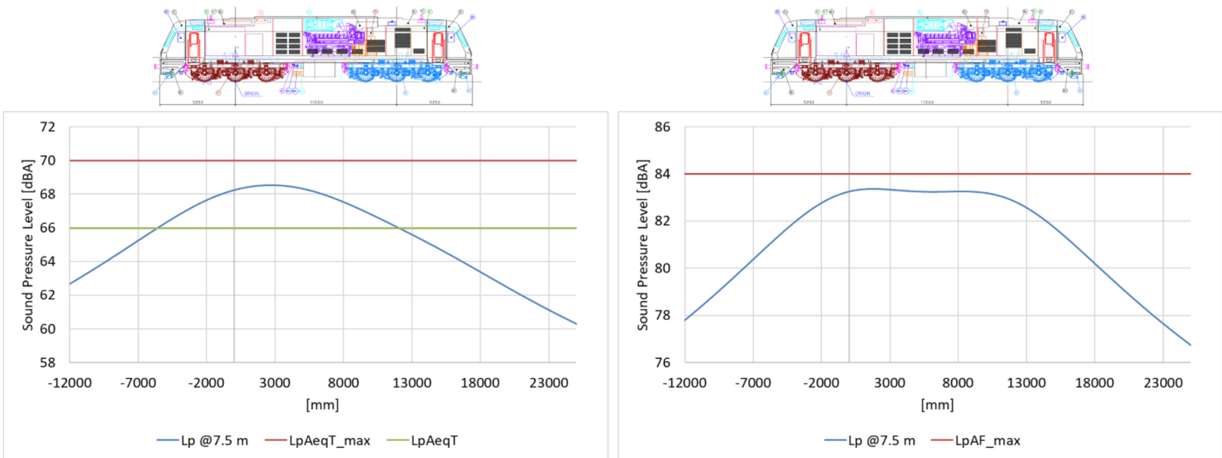

Figure 10 – Total external noise Electric Mode – on the left Standstill, on the right Starting

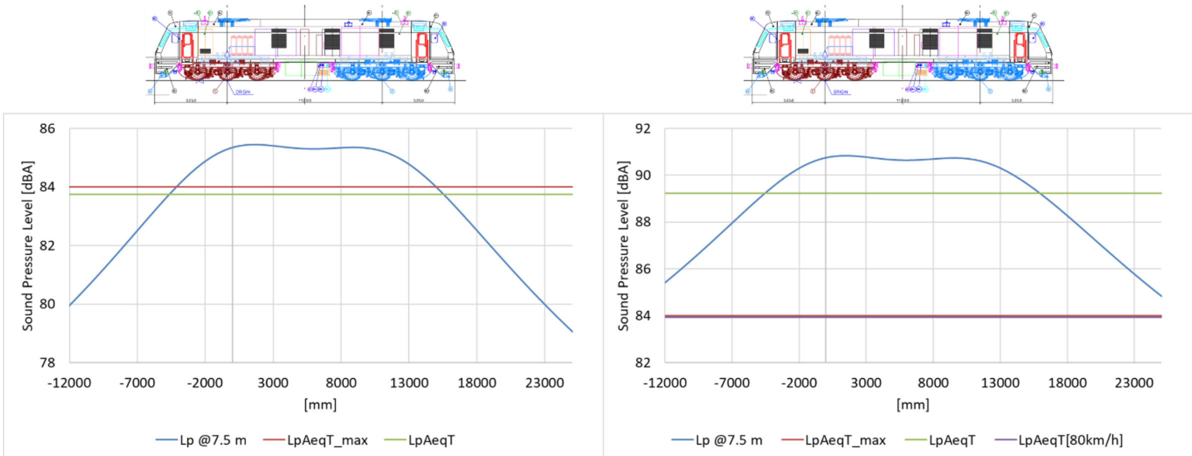

Figure 11 – Total external noise Electric mode - Running: on the left @80km/h, on the right @120km/h

The results for the Diesel Mode are:

Zone	Condition	Results [dBA]	Noise Max.Value [dBA]
External Measured at a distance of 7,5 m from the centre of the track and a height of 1,2 m above top of rail.	Vehicle Standstill in Open Field **LpAeqT**	**70.8**	71
	Vehicle Standstill in Open Field **L'pAeqT**	**72.7**	78
	Vehicle Starting to move in Open Field **LpAFmax**	**83.4**	84
	Vehicle in Open Field at 80 km/h **LpAeqT**	**83.4**	85
	Vehicle in Open Field at 120 km/h **LpAeqT[80km/h]**	**83.0**	85

Table 12 – Total external noise Diesel Mode

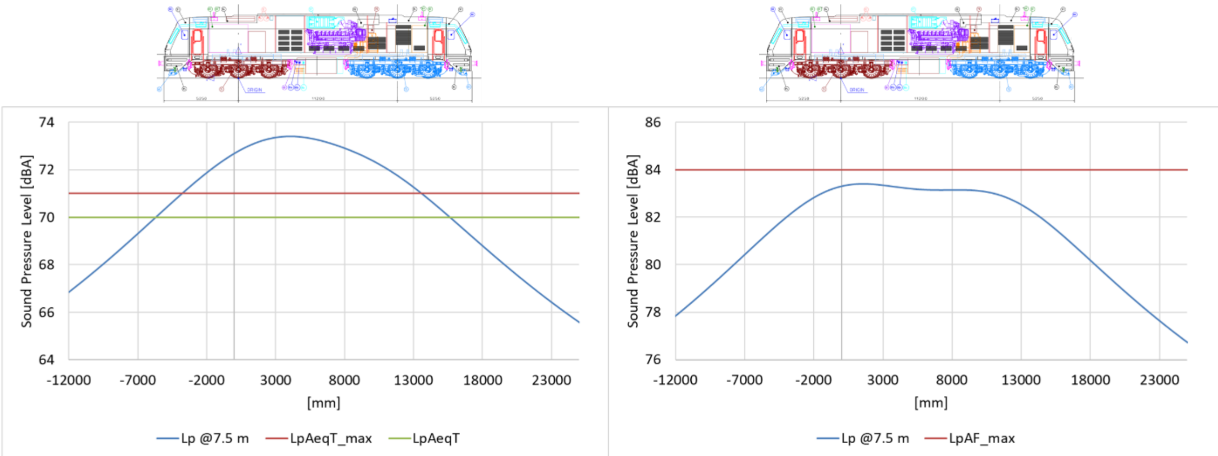

Figure 12 – Total external noise Diesel Mode – on the left Standstill, on the right Starting

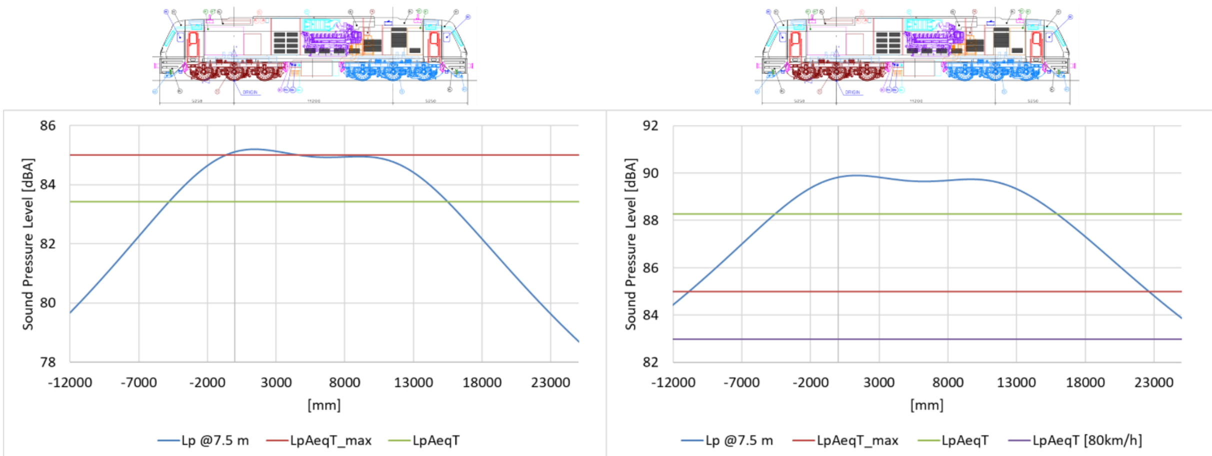

Figure 13 - Total external noise Diesel mode - Running: on the left @80km/h, on the right @120km/h

4.4 INTERNAL NOISE

This chapter describes the evaluation of the noise sources and the typical insulation layout for the section of the side wall, roof and floor for driver cabs. In this evaluation all the noise sources will be considered distributed on the entire car surface, leading to a two-dimensional analysis. In the real case, the noise sources don't add directly because are positioned in different section of the car. Thus, the current analysis is cautionary compared to the real case.

The calculation has been performed only for the driver cabs.

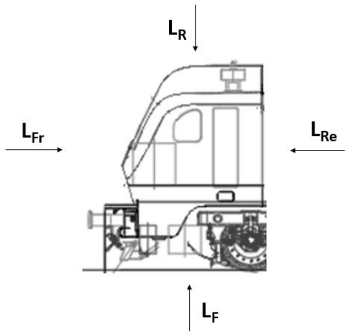

Figure 14 – Noise Source direction

In order to evaluate the total incident noise, the sound power of the various sources is summed:

$$L_i(f) = 10\ Log \sum_j 10^{\frac{SWL_j(f)}{10}}$$

Considering the noise sources defined in Table 8 and Table 9, the total incident noise is evaluated for every side of the car and for every frequency f.

Then, the total noise insulation for every side is considered equal to:

$$R_p(f) = R_s(f) + R_i\,(f) - f(R_s(f), R_i\,(f), R_\alpha(f))$$

Where:

- R_s is the sound insulation of the structural material
- R_i is the sound insulation of the eventual acoustic insulation material
- $f(R_s(f), R_i\,(f), R_\alpha(f))$ is an estimation of the acoustic insulation power of the thermal absorbing material or of the air, depending on the stratigraphy

Finally, the noise entering in driver cab as function of frequency is computed as follows:

$$L_{interior}(f) = L_i(f) - R_{equivalent}\,(f)$$

Where:

- $L_{interior}$ is the total noise entering the driver cab
- L_i is the incident noise
- $R_{equivalent}$ is the equivalent power insulation

4.4.1 TOTAL NOISE INCIDENT OF THE DRIVER CAB

The total noise incident on the various side of the driver cab, for the different Loco mode is shown in the following section.

4.4.1.1 ELECTRIC MODE

In order to evaluate the noise entering from the rear of the cabin, it is necessary to consider two contributions:

- **External noise equipment** entering the machine room, reduced by the RW of 3mm steel.
- **Machinery room noise equipment**

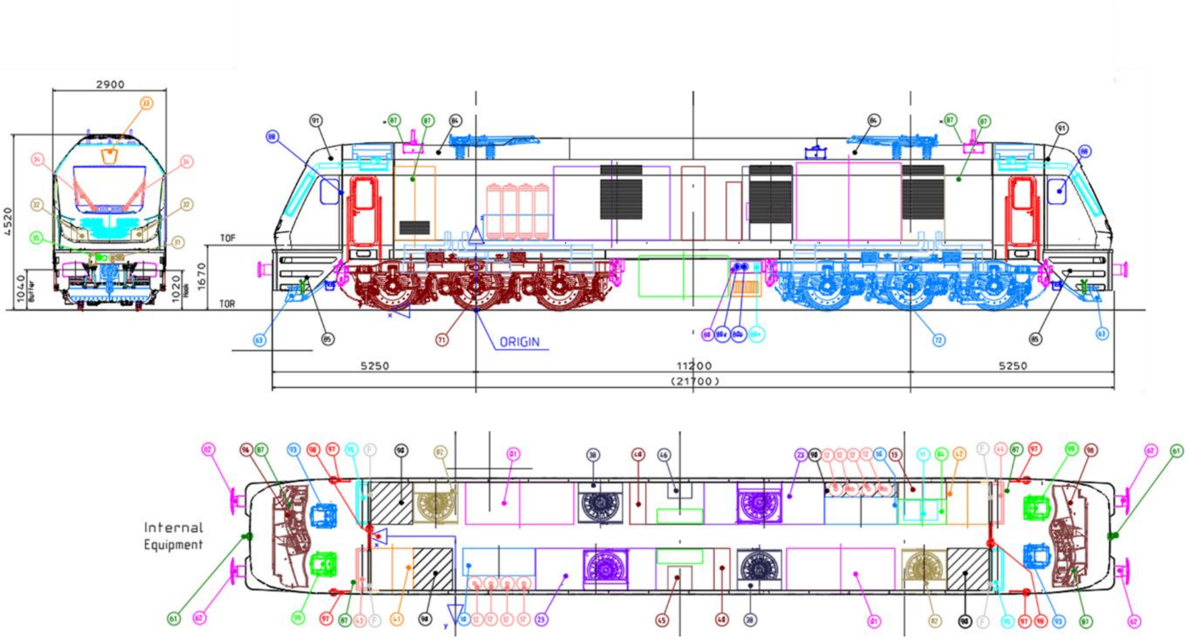

Figure 15 – Electric Mode equipment layout

Mode	Side	Noise	Total Noise [SWL]
Electric	Front	Aerodynamic Noise Front/Roof	104.2 dBA
		HVAC	
	Roof	Aerodynamic Noise Front/Roof	109.7 dBA
		Aerodynamic Noise Pantograph	
		HVAC	
	Side Wall	Aerodynamic Noise Side	90.0 dBA
	Floor	Rolling Noise	113.8 dBA
		Traction Motor	
		GearBox	
	Rear	External	95 dBA
		Machine Room equipment	

Table 13 - Total incident noise for both the driver cab 120 km/h– Electric Mode

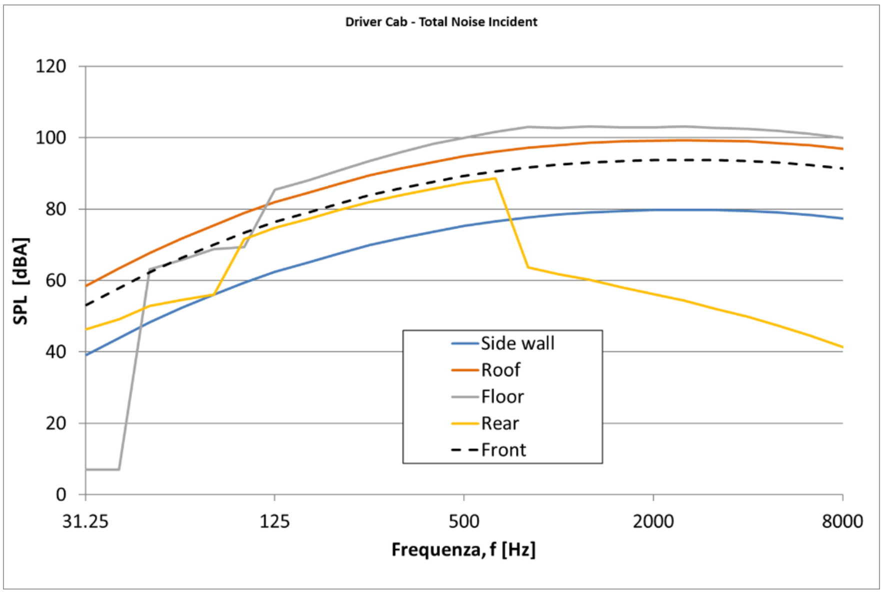

Figure 16 - Total Noise incident in running condition 120 km/h – Electric Mode

4.4.1.2 DIESEL MODE

In order to evaluate the noise entering from the rear of the cabin, it is necessary to consider two contributions:

- **External noise equipment** entering the machine room, reduced by the RW of 3mm steel.
- **Machine room noise equipment**: since it is not a single environment, but there are internal doors separating the rooms, the following procedure must be followed:
  1. Calculate the noise level produced by the equipment in Engine Room.
  2. Calculate the noise level produced by the equipment in Engine Cooling Room, to which the contribution from Engine Room, reduced by the contribution of the thermal insulation, must be added.
  3. Calculate the noise level produced by the equipment in Air Inlet Room, to which the contribution from Engine Room, reduced by the contribution of the thermal insulation, must be added.
  4. Calculate the noise level produced by the equipment in the Machinary Room 1, to which the contribution from Engine Cooling Room, reduced by the internal door effect, must be added.
  5. Calculate the noise level produced by the equipment in the Machinary Room 2, to which the contribution from Air Inlet Room, reduced by the internal door effect, must be added.

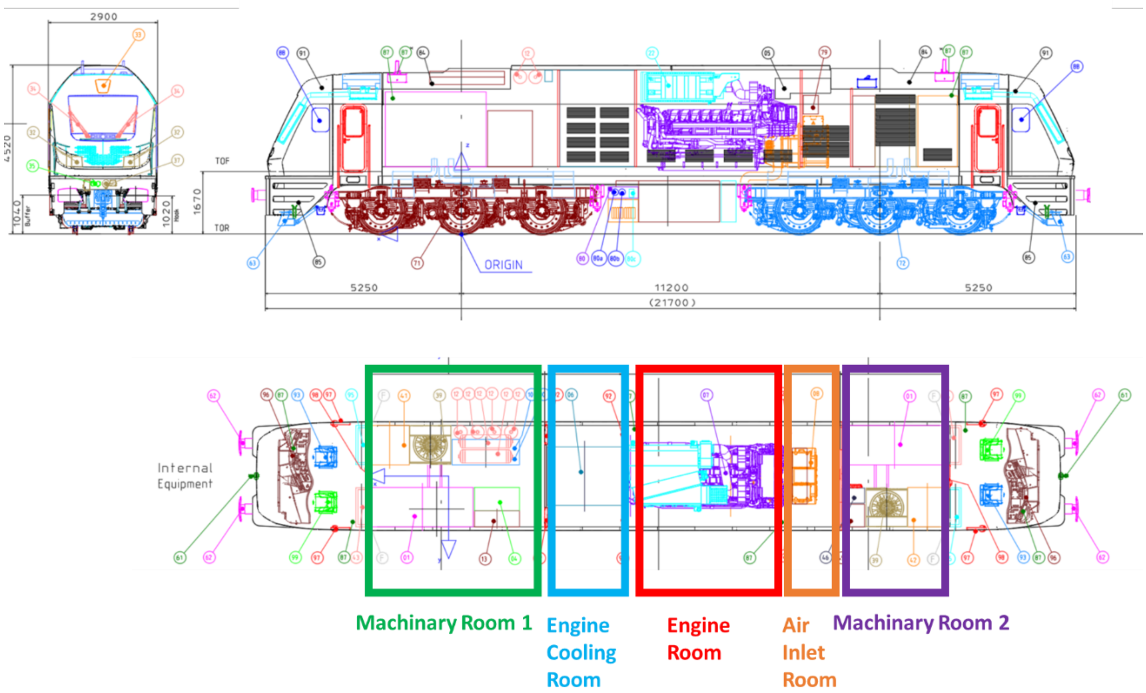

Figure 17 - Diesel Mode equipment layout

Mode	Room	Noise	Noise [SWL]
Diesel	Engine	Internal Equipment	114.8 dBA
	Engine Cooling	Internal Equipment Engine Room Internal Noise reduced	105.0 dBA
	Air Inlet	Internal Equipment Engine Room Internal Noise reduced	103.0 dBA
	Machinery 1	Internal Equipment Engine Cooling Room Internal Noise reduced	102.0 dBA
	Machinery 2	Internal Equipment Air Inlet Room Internal Noise reduced	100.8 dBA

Table 14 – Internal Noise Level in the rooms – Diesel Mode

Mode	Side	Noise	Total Noise [SWL]
Diesel	Front	Aerodynamic Noise Front/Roof	104.9 dBA
		HVAC	
	Roof	Aerodynamic Noise Front/Roof	104.8 dBA
	Side Wall	Aerodynamic Noise Side	90.0 dBA
	Floor	Rolling Noise	113.8 dBA
		Traction Motor	
		GearBox	
	Rear	External	102.0 dBA
		Machine Room equipment	

Table 15 - Total incident noise in running condition 120 km/h, Front Driver Cab– Diesel Mode

Mode	Side	Noise	Total Noise [SWL]
Diesel	Front	Aerodynamic Noise Front/Roof	104.9 dBA
		HVAC	
	Roof	Aerodynamic Noise Front/Roof	104.8 dBA
	Side Wall	Aerodynamic Noise Side	90.0 dBA
	Floor	Rolling Noise	113.8 dBA
		Traction Motor	
		GearBox	
	Rear	External	100.8 dBA
		Machine Room equipment	

Table 16 - Total incident noise in running condition 120 km/h, Back Driver Cab– Diesel Mode

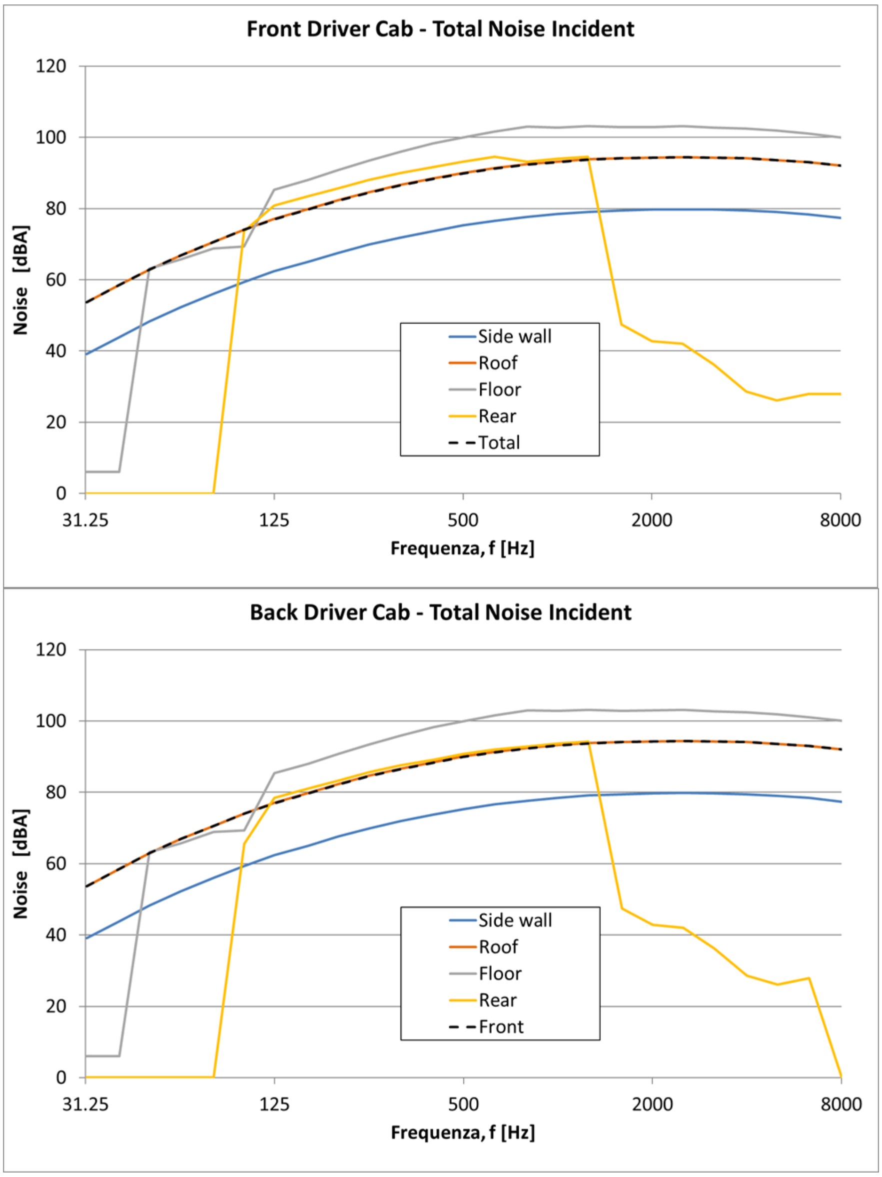

Figure 18 – Total Noise incident in running condition 120 km/h – Diesel Mode

4.4.2 NOISE INSULATION CALCULATION

The sound insulation can be calculated starting from the insulation properties of every material. The following table shows the sound absorbing factor RW for all material considered.

#	Materials	RW [dBA]	Note – ref.
1	Steel plate 3 mm	37	Mass Law
2	Fiberglass 4 mm	29	Mass Law
3	Fiberglass 6 mm	32	Mass Law
4	Noise Insulation 2 mm	27	Datasheet Existing material
5	External Door	24	Datasheet Existing material
6	Windows	32	Datasheet Existing material
7	Thermoacoustic insulation – 40mm	N/A	Datasheet Existing material
8	Internal Door	13	Old project

Table 17 - Sound insulating of materials and components Driver Cab

The material stratigraphy shall also be considered. In the following tables is reported in which section the material is located.

Section\Mat. Ref. Number	1	2	3	4	5	6	7	8
A -Side wall Low	●	●					●	
B - Floor	●			●			●	
C –Roof/Side wall High		●	●				●	
D - Windows						●		
E - Windscreen						●		
F – External Door					●			
G – Internal Door								●
H – Anti Fire Door	●							

Table 18 – Materials stratigraphy Driver cab

4.4.3 CALCULATION OF INTERNAL NOISE LEVEL

The results of Electric Mode are:

Zone	Condition	Results [dBA]	Noise Max.Value [dBA]
Internal, Driver Cab	Vehicle Standstill in Open Field **LpAeqT**	68.3	N/A
	Vehicle in Open Field at 120 km/h **LpAeqT**	73.4	78 dBA

Table 19 - Total Internal noise Electric Mode

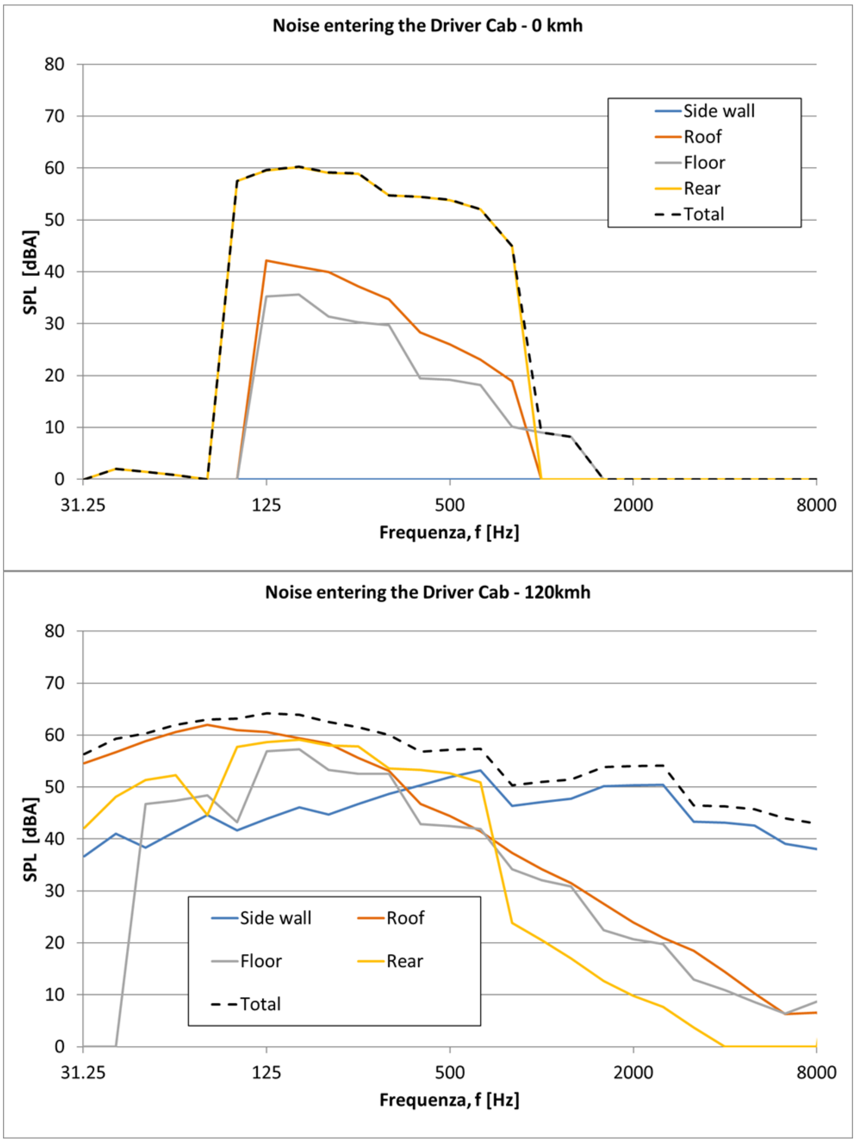

Figure 19 – Internal Noise Level – Electric Mode

The results of Diesel Mode are:

Zone	Condition	Results* [dBA]	Noise Max.Value [dBA]
Internal, Driver Cab	Vehicle Standstill in Open Field **LpAeqT**	71.4	N/A
	Vehicle in Open Field at 120 km/h **LpAeqT**	74.9	78 dBA

Table 20 - Total Internal noise Diesel Mode

* Internal Noise maximum value between Front Driver Cab and Back Driver Cab

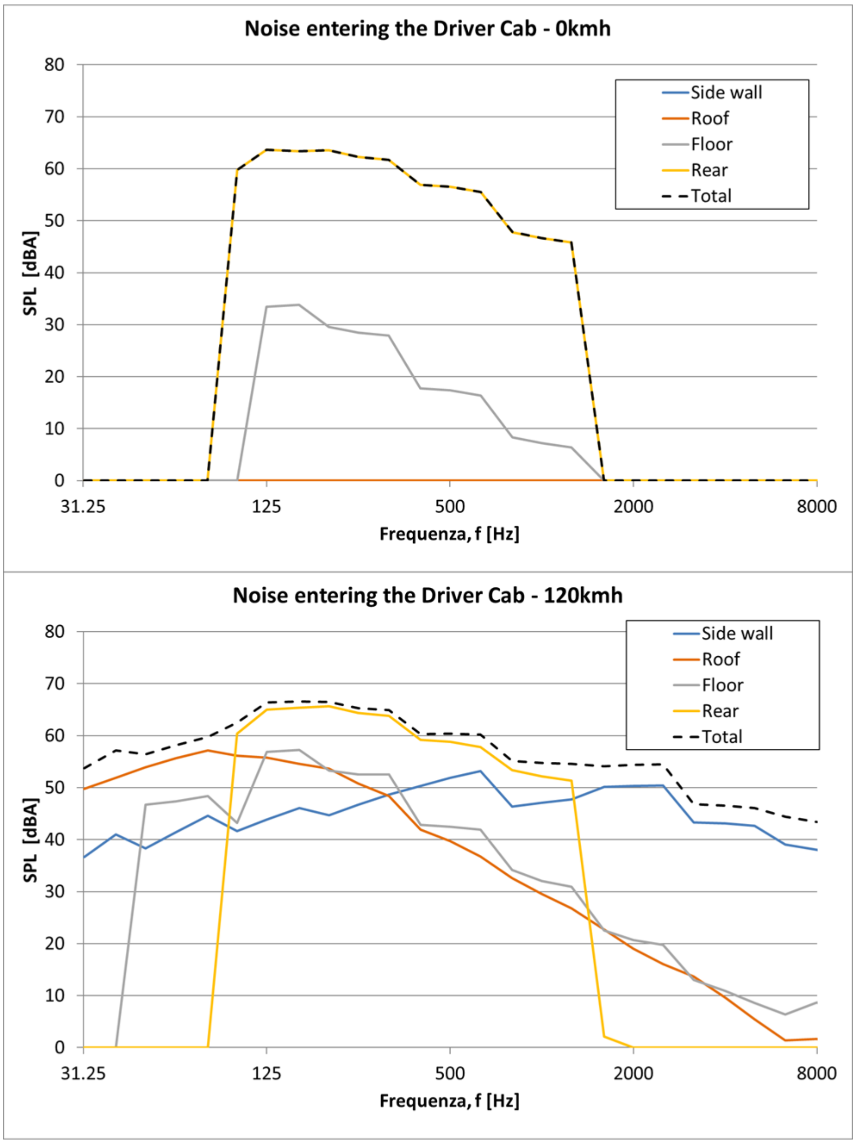

Figure 20 - Internal Noise Level – Diesel Mode

5 CONCLUSIONS

In this document the calculation of the external and internal noise has been performed.
The external and internal noise target can be met if the equipment can satisfy the requirement shown in Table 8, for the equipment noise emissions, and Table 17 for the component noise insulation.

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