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SPATIAL VARIATION OF THE SOUND PRESSURE LEVELS DUE TO HVAC SYSTEMS AND THE ASSESSMENT OF NOISE

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ABSTRACT

Regulations in many countries establish limits on noise produced by building services and equipment and refer to international standards such as ISO 16032 and ISO 10052 or to national procedures for the verification of such requirements.

This study analyses the distribution of sound produced by HVAC equipment in an office building. For that purpose, systematic measurements were conducted at multiple locations within a room to determine spatial variations in sound pressure levels produced by internal units. Factors influencing noise assessments such as room geometry, spatial sampling, HVAC equipment settings and the presence of background noise are also examined. The ultimate aim of this work is to study how variations of sound pressure levels affect the assessment of L_{Aeq} and to propose practical recommendations to assess noise from building services to fulfil regulatory requirements.

Keywords: *noise from building services, noise limit, requirements, ISO 16032, HVAC noise, spatial variation.*

1. INTRODUCTION

This communication aims to study the distribution of sound produced by HVAC (Heating, ventilation, and Air Conditioning) systems in a training room located at the Eduardo Torroja Institute for Construction Sciences, which is part of the Spanish National Research Council (CSIC) in Madrid.

Regulations in many countries establish limits on noise produced by building services and equipment and refer to international standards such as ISO 16032[1] and ISO 10052[2] or to national procedures for the verification of such requirements.

Although weighted descriptors used in regulations such as L_{Aeq}, $L_{\mathrm{Aeq,nT}}$, L_{AFmax}, etc. provide a general sense of acoustic performance, they often fail to capture the spatial non-uniformities of the sound field, in particular in the low frequency range.

This paper studies the spatial variations of sound pressure levels due to service and equipment in a training room in an office building, and its impact on weighted values.

2. SCENARIO DESCRIPTION

The Eduardo Torroja Institute for Construction Sciences is an entity that conducts scientific research and technological development in the field of construction, its materials, and the performance associated with the pursued approaches. It is housed in a distinctive building inaugurated in 1953, originally serving as the new headquarters for the Technical Institute of Construction and Cement, now known as the Eduardo Torroja Institute for Construction Sciences.

A room belonging to the Eduardo Torroja Institute for Construction Sciences was studied, as described below.

The room was originally the archive of the former library of the Institute. This archive was relocated to the basement of the building, creating a space that began to be used as a training room. An absorbent ceiling was installed, along with a movable partition to divide the room into two sections[3]. The absorbent ceiling improves user comfort and ensures compliance with the acoustic conditioning requirements outlined in the current regulations, specifically the Basic Document DB HR Protection Against Noise of the Spanish Technical Building Code[4]. The current layout

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of the training room is rectangular, with a floor area of 69.8 m² and a height of 2.75 m. See Figure 1.

a) b)

Figure 1. a) Photograph of the training room. b) Detail of one of the three indoor units the room is equipped with.

3. MEASUREMENTS PERFORMED

Equivalent sound level (L_{eq}) measurements were conducted over 15-second intervals at 30 points within the room (Figure 2), at two different heights: 1.20 m and 1.50 m, resulting in a total of 60 measurements. These two heights were chosen because they represent typical positions of the occupants in the room, 1.20 m is the ear height used in standards for acoustic measurements[5]. The height of 1.50 m above floor level below the noise source is specified in ISO 16032 procedure [1].

Additionally, sound levels were taken at three room corners, (separated 50 cm from the walls and the floor) and nine background noise measurements were taken in different positions. These measurements were repeated for the V3 and V5 ventilation modes.

The training room is equipped with three ceiling-mounted variable refrigerant flow (VRF) indoor units positioned at the distances marked in Figure 2. These units consisted on four-way ceiling cassettes that operate simultaneously and have three modes of operation: heating, cooling, and ventilation. Each of these modes has five ventilation speed settings.

For this study, measurements were carried out with the "ventilation" mode at two speeds: the highest (V5) and the medium (V3), while the lowest speed was excluded due to its noise levels being close to the background noise. The ventilation mode was selected because it provides a constant fan speed during operation, in contrast to the heating and cooling modes, where the system automatically regulates fan speed and refrigerant flow to maintain the desired room temperature.

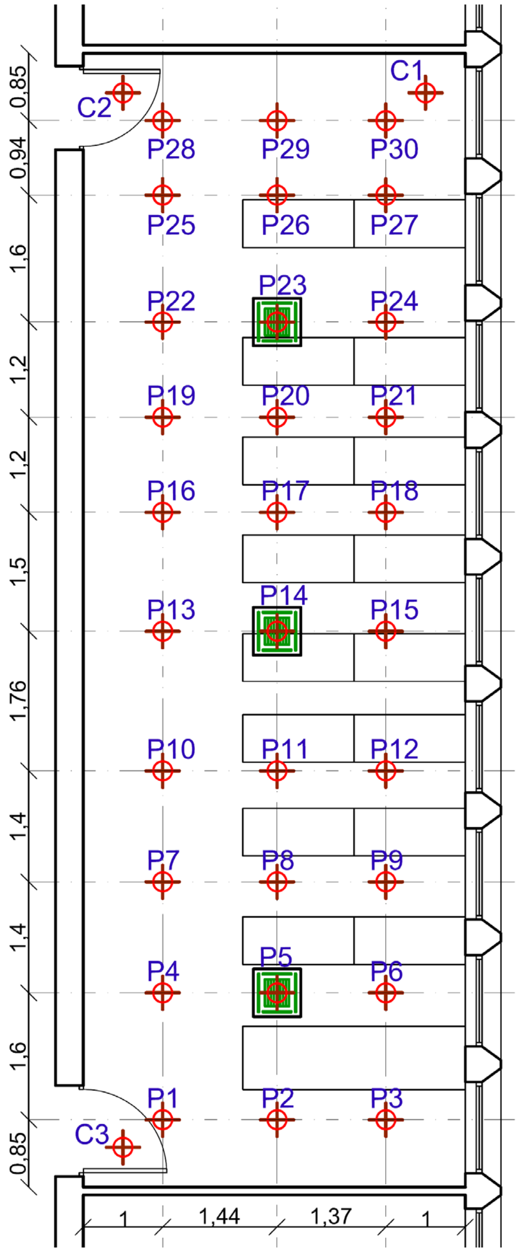

Figure 2. Plan of the room indicating the measurement positions and the location of the VRF cassettes.

The measurements were conducted with two people present in the room, which was furnished with chairs and tables (see test scenario description in Section 2.2). A floor plan of the room with the distribution of the source and microphone positions for the measurements is shown in Figure 2.
The equipment used for the measurements was as follows:

- Environmental sound level meter, Class 1, model CR:171B, by Cirrus Research plc;
- Calibrator model CB006, by Cesva.

Using an acoustic calibrator, sound level checks of the measurement chain were performed before and after the tests, with satisfactory results.
Data processing was carried out using the NoiseTools v1.8.9 software for data downloading, analysis, and reporting, along with Microsoft Excel and MATLAB R2024b update 3.

4. RESULTS

The primary noise sources during the measurements were the fans and the airflow passing through filters, coils and louvers. Refrigerant-related noise was negligible since the compressor was not active, which is why the ventilation mode was chosen for this study.
The sound source remained steady and did not show significant fluctuations over time as the equivalent continuous sound pressure levels (L_{eq}) remained stable throughout the measurement periods.
Table 1 shows the average A-weighted and C-weighted equivalent continuous sound pressure levels obtained for the 30 measurement points, as well as the maximum values and the minimum values of L_{Aeq} and L_{Ceq}, along with the corresponding ranges, for the two fan speed settings and the two measurement heights.

Table 1. L_{Aeq} and L_{Ceq} for the two fan speed settings and the two measurement heights.

Velocity setting		Velocity 3		Velocity 5	
Height (cm)		h=120	h=150	h=120	h=150
$L_{A,eq}$ (dB)	Average	40.1	40.0	44.7	44.8
	Max	41.3	41.9	45.9	47.2
	Min	38.8	38.3	43.5	43.1
	Range	2.4	3.6	2.4	4.1
$L_{C,eq}$ (dB)	Average	52.3	53.4	53.9	54.6
	Max	56.3	59.0	55.4	60.5
	Min	49.4	49.9	52.7	52.3
	Range	6.9	9.1	2.7	8.2

Table 2 shows the values of the equivalent continuous sound pressure level measured at the 3 corner positions. The average background noise levels L_{Aeq} measured at the nine positions were 32.0 dB and 31.4 dB. Two sets of background noise level measurements were obtained, as the measurements for each fan speed setting were conducted different days.

Table 2. L_{Aeq} and L_{Ceq} measured at the 3 corner positions.

Velocity setting	Velocity 3			Velocity 5		
Corner	C1	C2	C3	C1	C2	C3
$L_{A,eq}$ (dB)	39.4	38.2	38.1	43.9	44.9	43.2
$L_{C,eq}$ (dB)	57.1	53.6	56.7	56.2	56.5	57.2

4.1 Spatial distribution of sound

Figure 3 shows the L_{Aeq} at each measurement position, including the corner positions, for each velocity setting and measurement height. The highest values corresponded to the positions located directly beneath the internal VRF units (P5, P14 and P26). The values of corner positions are represented by crosses.

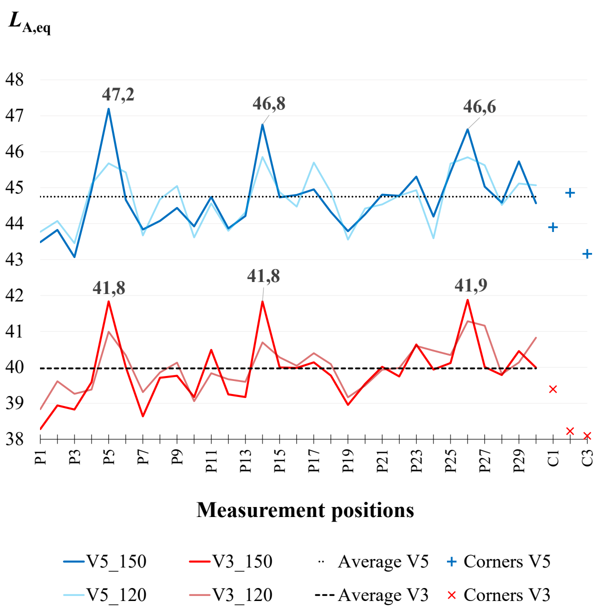

Figure 3. L_{Aeq} at each measurement position.

As seen in Figure 3 and Table 1, the average difference between the measurements performed at 120 cm and 150

cm is 0.4 dB in average. In contrast, the average difference between the measurements performed with V5 and V3 fan speeds is significantly higher 4.7 dB, likely due to the increased air volume and turbulence at V5.
Figure 4 shows the spatial variations of the L_{Aeq} in the room for the fan speed V5 and height 120 cm. It is clearly seen the positions with the highest L_{Aeq}, which are beneath the internal units.

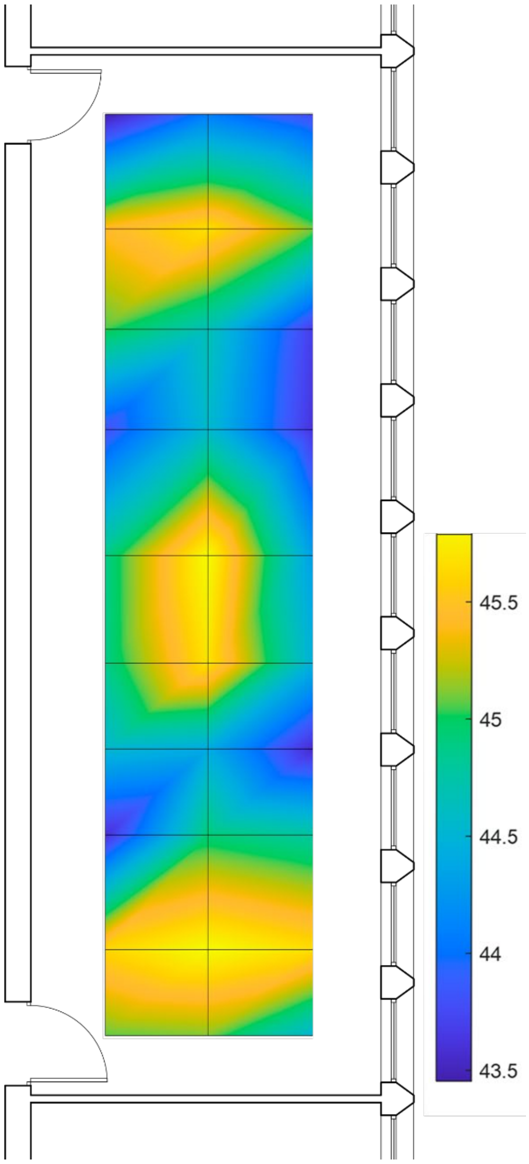

Figure 4. L_{Aeq} spatial variations in the room for the fan speed V5 and height 120 cm. Graph based on measured data. Plan view.

4.2 Frequency spectrum variations

Figure 5 shows the spectra of the average equivalent continuous sound pressure level obtained for the 30 points for the fan speed of V5 and height of 120 cm. The hearing threshold has also been represented, showing that part of the energy in below 50 Hz is below it Similar results were observed for measurements at fan speed V3 and height of 150 cm.

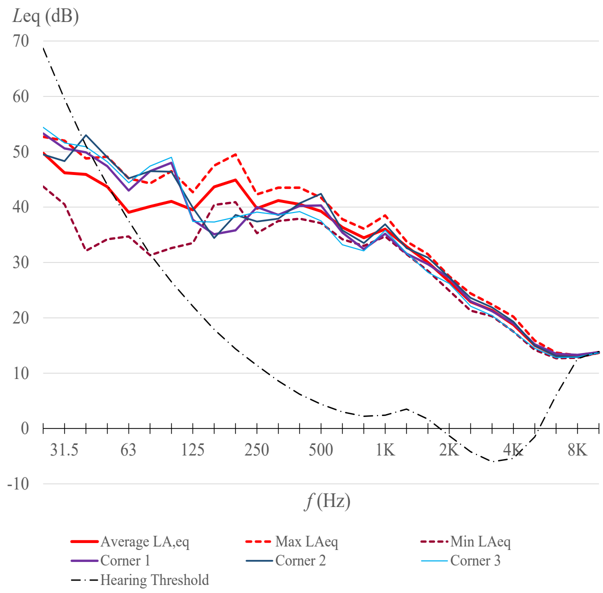

Figure 5. Average L_{Aeq} in the room for the fan speed V5 and height 120 cm.

As seen in Figure 5, most of the acoustic energy emitted by the VRF cassette units is concentrated in the low-mid frequency range.
Even though the A-weighted equivalent sound pressure level differences range from 2.4 to 4.1 dB, a closer look at the spectral results reveals differences of 7 to 15 dB in the low-frequency range (50–250 Hz). See Figure 5, which shows the average equivalent continuous sound pressure level obtained for the 30 points for the fan speed of V5 and height of 120 cm.
The Figure 6 shows the spatial distribution of the sound pressure levels in the room for the frequencies of 50, 125, 250, 500 Hz. The same color scale was used to plot all the graphs, and across the series, it is evident that the largest variations in the sound field occur in the low-frequency range. The Schroeder frequency of the room is 130 Hz, which marks the boundary between the low-frequency

range dominated by discrete room modes and the higher-frequency range where the sound field becomes statistically diffuse. As seen in Figures 5 and 6, the spatial variations become more significant bellow it due to the non- irregular modal behavior. At 50 Hz, the graph may show the influence of background noise coming from outside, caused by traffic.

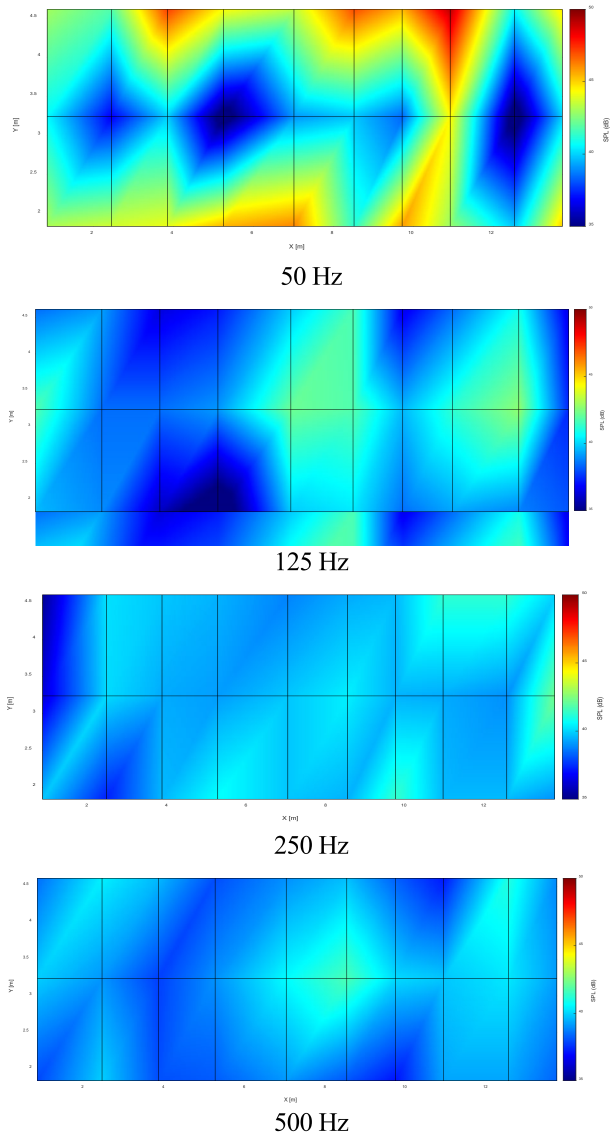

Figure 6. Spatial distribution of the sound pressure levels in the room for the frequencies of 50, 125, 250, 500 Hz. Graph based on measured data. Plan view.

5. THE ASSESSMENT OF SERVICE AND EQUIPMENT NOISE

ISO 16032[1] contains the engineering method for the measurement of sound pressure levels in rooms from service equipment. It is referred in several European regulations[6] to verify compliance with requirements. This section presents the results that have been obtained using the estimation method described in ISO 16032[1] for the calculation of the average sound pressure level in the room, L_{Aeq}.

The sound pressure level is determined for a specified operating condition and duty cycle. Sound pressure levels are measured in three microphone positions, one position in a selected corner of the room and two positions in the reverberant sound field. All values were corrected for background noise.

Table 3 shows the results of the calculations. They were performed to determine the range of the average sound pressure levels, L_{Aeq}, obtainable in the room. The following criteria was used for the calculations:

– Positions with the highest sound pressure level, which are the ones beneath the internal units (P4, P14)
– Positions with the lowest sound pressure levels (P3, P13)
– Two positions chosen at random (P15, P19).

The corner position chosen was Corner C1, which is the corner that has the highest sound pressure level for both velocities (V3 and V5). This section aims to find the highest and the lowest value of the average L_{Aeq} obtainable, so positions below the VRF units are also included in the calculations, even when they are considered additional measurements in ISO 16032[1].

The differences found are 2.1 dB for V3 and 2.5 for V5.

Table 3. Calculated average L_{Aeq} in the room.

Velocity	**Corner**	**Position 1**	**Position 2**	**ISO 16032 L_{Aeq}**
V3	C1	P4	P14	40.5
V3	C1	P15	P19	40.0
V3	C1	P3	P13	38.4
V5	C1	P4	P14	45.8
V5	C1	P15	P19	44.0
V5	C1	P3	P13	43.3

5.1 Background noise levels

Background noise was measured at 9 positions across the room. Figure 7 shows a comparison of the sound pressure level of position 5, which is just beneath the internal unit and the background noise levels measured in the same position. Figure 8 shows the sound pressure levels at position 27, which was randomly selected from among the positions with average sound pressure levels. Background noise levels interfered in the positions that were far from the noise sources at fan speed 3 in the low frequency range and from 800 Hz upwards.

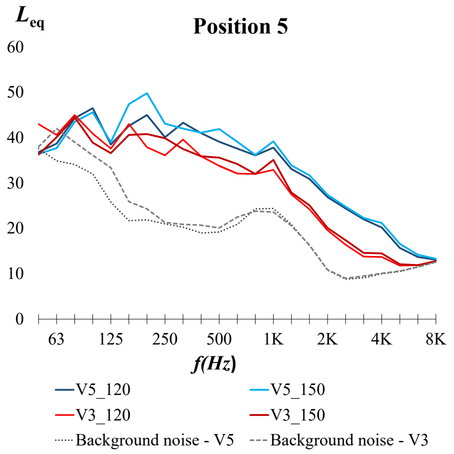

Figure 7. Sound pressure level in position 5 for two fan speed settings (V5 and V3) and two heights in comparison to background noise.

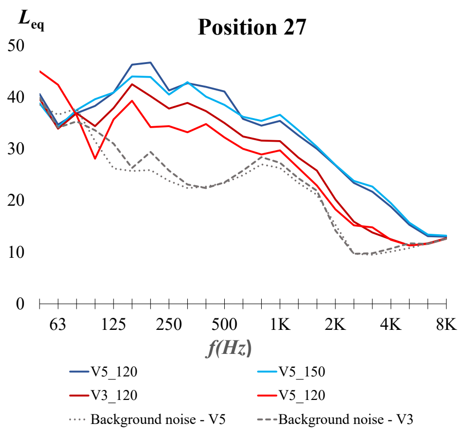

Figure 8. Sound pressure level in position 27 for two fan speed settings (V5 and V3) and two heights in comparison to background noise.

6. CONCLUSIONS

This paper is a study of the variation of the sound pressure levels in a room produced by HVAC equipment and how this affects the values of the average L_{Aeq} defined in ISO 16032.

A room in an office building was selected and measurements were performed in 30 positions, for two fan speed settings and two microphone heights: 120 cm and 150 cm, as these heights are typical occupant positions within this room.

The differences in sound pressure levels have been studied and compared in each position and in each frequency range.

Significant spatial variations of sound pressure levels were observed in the room, particularly in the low-frequency range (50–250 Hz), where differences of up to 15 dB were found between positions.

The average A-weighted differences between the two heights (120 cm and 150 cm) were minimal (~0.4 dB), indicating vertical uniformity at the range 120–150 cm of listener height, whereas fan speed changes (V3 vs. V5) resulted in much greater differences (~4.7 dB), primarily due to increased airflow.

The highest SPL values were consistently measured directly below the internal VRF units, confirming these areas as critical points for acoustic comfort.

When average L_{Aeq} levels were estimated using ISO 16032 method, differences of 2.1 dB and 2.5 dB were found between positions in this room for fan speeds of V3 and V5 respectively. Although the difference is small, it may determine whether the measured values fall within or exceed the limit values specified in national regulations.

In this particular case, it is sensible to take measurements at 1.50 m below the VRF units when assessing noise from building services, as this location represents a typical occupant position during courses and corresponds to a critical point in terms of sound exposure.

This study is part of a broader research carried out at Eduardo Torroja Institute for Construction Sciences, IETcc-CSIC, on service and equipment noise and its assessment. Other critical factors in the assessment of service and equipment noise have also been studied like the reverberation time correction[7].

7. REFERENCES

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