acoustics

Technical Note

Evaluation of the Environmental Noise and Prevention Measures for a Standard Hospital Area from Spain

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Abstract: In this research, a global assessment of the acoustic situation of the Juan Ramón Jiménez University Hospital (Huelva, Spain) was carried out. For this study, measurements were made in situ, both outside and inside the buildings. With the methodology used, long-term exterior and interior measurements were performed, and an acoustic propagation model of exterior environmental noise was also developed, digitising the main sources of noise, thereby obtaining the corresponding noise maps of the study area. This study demonstrates that the indices of the external and internal acoustic environment of the hospital exceed those recommended by the World Health Organization, United States Environmental Protection Agency, and Spanish law itself. It is concluded that the acoustic environments, both outside and inside, should be improved, for which a series of interventions on the external zone, other interventions on the internal zone, and others on management has been proposed.

Keywords: noise pollution; noise measurements; hospital sound environment; hospital noise; awareness preventive measures

Academic Editors: Jian Kang and Francesco Aletta

Received: 4 December 2024
Revised: 25 February 2025
Accepted: 28 February 2025
Published: 19 March 2025

Citation: Sánchez-Sánchez, R.; Barba-Lobo, A.; Isasti Aizpurua, G.; Bolivar, J.P. Evaluation of the Environmental Noise and Prevention Measures for a Standard Hospital Area from Spain. *Acoustics* **2025**, *7*, 16. https://doi.org/10.3390/acoustics7010016

1. Introduction

Numerous studies show that the noise levels that exist inside hospitals are increasing, especially since 1960, due to technological advances in medical equipment and construction processes [1–3], affecting patients, their visitors and hospital staff.

The impact of noise on people's health is widely known, as reported by the large number of studies that have been carried out in different fields of medicine: sleep disorders [4–7], hearing impairment and tinnitus [8–10], cardiovascular disease [11–14], learning disabilities [15,16], ischemic heart disease due to hypertension [17–20], decreased foetal weight at birth [21,22], cognitive impairment [23,24], and stress and mental health [25–28].

The impact of noise on human health has been recognised for many years, as evidenced by a statement in 1859 by Florence Nightingale [29] "...since the unnecessary noise is the absence of care, which can be inflicted either on sick or well...", thereby conditioning the recovery of patients in hospitals and those who work in them [30,31].

Many research studies have been focused on the negative impacts that high noise levels have on hospital patients, demonstrating that, in addition to mood disturbances, noise has been related to sleep disturbances in hospitalised patients [32], mainly in neonatal and adult ICUs [33–35]. Likewise, other studies indicate that noise negatively affects surgical wound healing, requiring more medication [36].

Noise is considered one of the sources of stress of workers in general [37], and for hospital staff in particular, affecting their ability to effectively perform their jobs. Some studies show that professionals were more relaxed and made fewer demands related to their work in environments with better acoustic conditions [38–40], whereas under noise stress, staff were emotionally drained [41].

However, until the last decade, there has been a lack of articles regarding the characterisation and reduction in hospital noise, even though it often ranks among the top complaints of hospital patients, visitors, and staff [42,43].

Based on numerous noise studies, the World Health Organization (WHO) released the Guidelines for Community Noise [44], where they recommend not to exceed 35 dBA inside rooms where patients are cared for or observed, and 30 dBA for wards in hospitals, as guideline values. The United States Environmental Protection Agency (USEPA), in their Report on Environmental Noise Levels Necessary to Protect Public Health and Welfare with an Adequate Safety Margin [45], suggested that the maximum noise level in a hospital should not exceed 45 dBA during the day and 35 dBA at night. In Spain, the Royal Decree-1367, 2007 and Royal Decree-1038, 2012 [46,47], Royal Decrees that are transpositions of Directive 2002/49/EC of the European Parliament and of the Council, regarding acoustic zoning, quality objectives, and acoustic emissions, establishes acoustic quality objectives for outdoor acoustic areas (Type-e, or sectors of the territory with a predominance of land for sanitary, educational, and cultural use) of 60 dBA and 45 dBA in hospital centres. All these recommendations are summarised in Table 1.

Table 1. Guidelines for hospitals regarding maximum noise values (*).

Place	WHO	USEPA	Spain (RD 1367) (**)
Inside	Ld, Le, Ln: 30 LAmax: 40	Ld, Le, Ln: 45	Ld, Le: 45 /Ln: 35 (Living areas) and 40/30 (Bedrooms)
Outside	Ld, Le, Ln: 50	Ld, Le, Ln: 45	Ld, Le: 60 Ln: 50

(*) Index values in dBA; (**) a transposition of Directive 2002/49/EC.

The aim of this study is to analyse both the outdoor and indoor acoustic environment of the main areas of the Juan Ramón Jiménez University Hospital (JRJUH) in Huelva (Spain) using global standards. JRJUH is the main hospital in the province of Huelva and one of the most important in Andalusia. In addition, with the method used, the main sources of external and internal noise are identified and analysed, and, lastly, for the reduction of noise levels in both situations, we propose recommendations to reduce the noise generated by these sources.

2. Materials and Methods

The results of the measurements were compared with the values recommended by the Spanish legislation and those of the most important international guidelines, quantifying the differences between them.

2.1. Study Area

The province of Huelva is in the southwest of the Iberian Peninsula. The parcel where the hospital is located has approximately 12.5 ha, and its distribution is shown in Figure 1. In this figure, it can be observed that the hospital area is surrounded by the H-30 ring freeway (with high traffic density) to the north, by Flores Avenue to the west, by internal vehicle parking to the east, and by external vehicle parking to the south. The distribution of the different areas and buildings of the hospital can also be seen as well as a general view of the hospital, indicating its main modules differentiated by letters. The complex is made up of a main building and other adjacent buildings connected by corridors or galleries. The letter E with different numbers, that appear in this figure, represent the different entrances to the hospital:

- E1: Main entrance.
- E2: Paediatrics and emergency.
- E3: Outpatient.
- E4: Staff entrance.

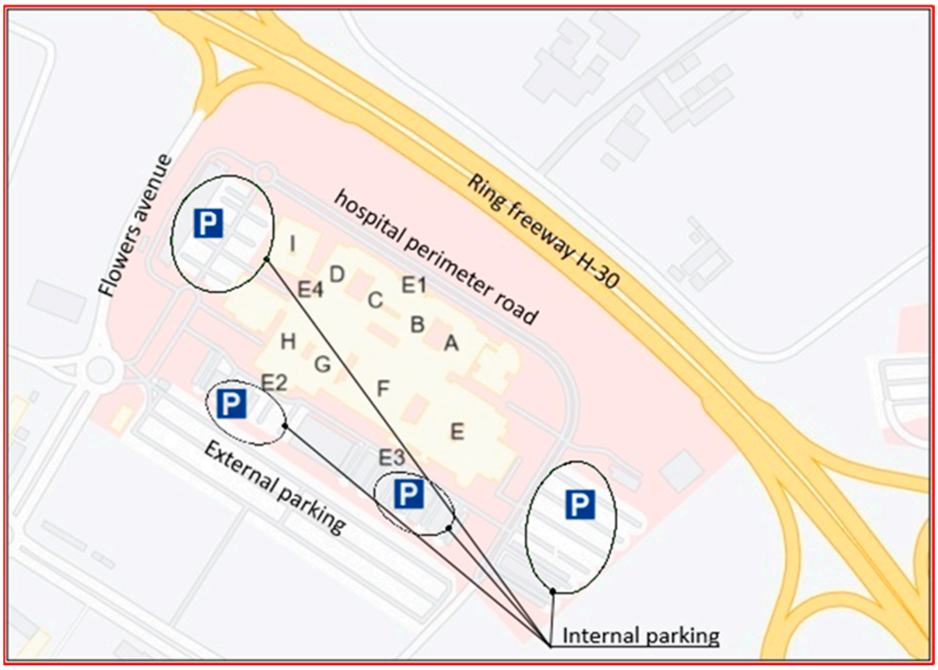

Figure 1. Locations of the Juan Ramón Jiménez University Hospital.

The subsequent modules that make up the hospital are organised as follows:

- Modules A, B, C, and D (Hospitalisation): nine wings available to the hospital.
- Module E (General Services): laboratories, outpatient consultations, special examinations, rehabilitation, day hospital.
- Module F (Surgical): sterilisation, RX, operating rooms, obstetrics, and gynaecology (delivery room).
- Modules G and H (Critical): ER, paediatrics, and ICU.
- Module I (Psychiatry).

2.2. Instruments

The equipment used for continuous (long-term) measurements included four RION brand NL-31 sound level metres (Class 1), in accordance with IEC/CDV 61672-1 and adjusted to fast time weighting, with an integration time of 10 s. The sound level metres in continuous outdoor monitoring were placed in environmental cases, purpose-designed for this experiment, with two high-resistance batteries, to ensure that data could be collected for 1 week at each measurement position before the batteries needed to be replaced.

To test the sound level metre before and after each measurement, a Sound Level Calibrator (SLC, RION model NC 74) was used, which can generate sound pressure levels of 94 $\pm$ 0.3 dBA (standard uncertainty to 1 sigma level).

For the acoustic simulations, in the external part of the hospital, the acoustic prediction software CadnaA version 4.6 from DataKustik GmbH was used, obtaining the corresponding noise maps.

2.3. Measurement Methods

With the four sound level metres, long-term follow-up measurements were made for one week, with records of 10 s, both outside and inside the hospital (Figure 2). From the 8640 10 s records of each day of the week, the equivalent level of 24 h (L24h) was calculated. Moreover, integrating, in turn, the 360 records of 10 s carried out per each hour of the day, the equivalent levels of one hour (LAeq,1h) were calculated for the different external and internal long-term measurement points. Likewise, considering only the records for the intervals of 7:00–19:00, 19:00–23:00, or 23:00–7:00, the indexes Ld, Le, Ln, and Lden (defined in Annex-1 of Directive 2002/49/EC) were determined. These indexes were adjusted only to the weekly monitoring of the study, and not to a full year, as defined in Directive 2002/49/CE. The locations of the outdoor (long-term) monitoring points are detailed in Tables 2 and 3, while Tables 4 and 5 detail the locations of the indoor monitoring points within the JRJUH building. Figure 2 shows the locations of the monitoring points outside (points 1, 2, 3, 4, 5, 6 and 7) and inside (points 1′, 4′ and 5′). During the week of measurement, the average outside temperature was (16.00–18.3) °C; the maximum wind speed was (19–34) km/h; the precipitation was (0.0–0.4) mm.

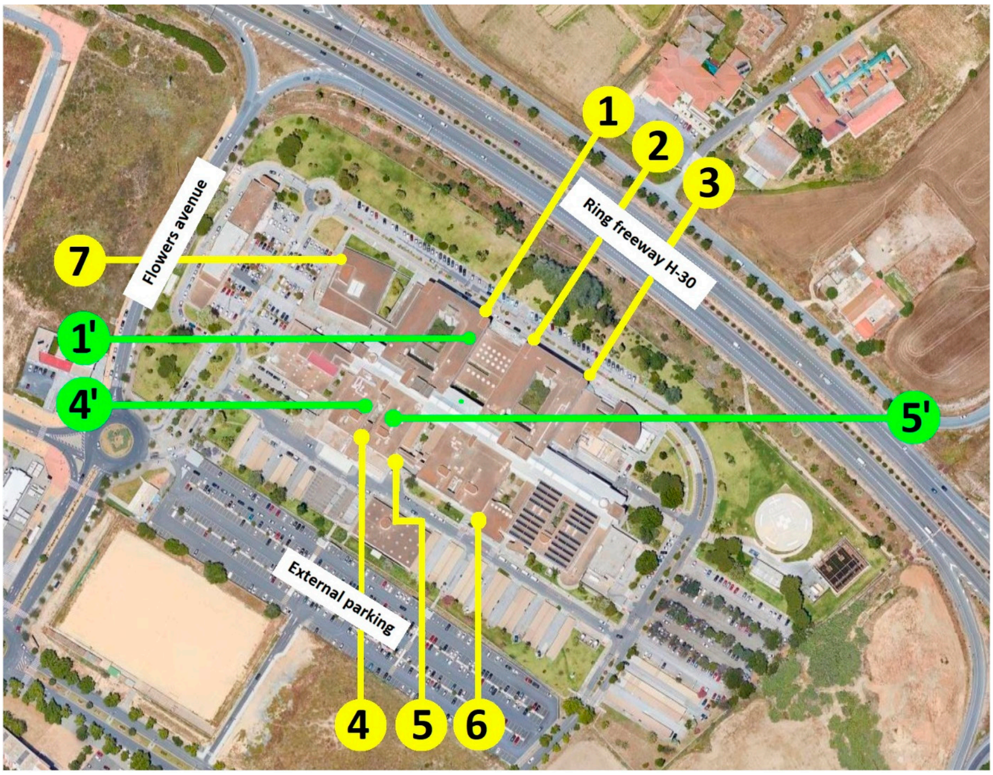

Figure 2. Locations of long-term measurement points. Outside: 1—Surgery Hospitalisation (1st floor, terrace); 2—Obstetric Hospitalisation (1st floor–terrace); 3—Cafeteria Area (1st floor, terrace); 4—Critical Care (3rd floor, covered); 5—Adult ICU Area (3rd floor, covered); 6—Laboratory Area (3rd floor, covered); 7—Psychiatry Area (1st floor, terrace). Inside: 1′—Surgery Hospitalisation (nursing control, false ceiling); 4′—Critical Care (nursing control, false ceiling); 5′—Adult ICU (nursing control, centre column).

Table 2. Location of measurement points outside the JRJUH building.

Point	Area	Location	Main Sources
1	Surgery Hospitalisation	1st floor (*) (terrace)	H-30 and PR (***)
2	Obstetrics Hospitalisation	1st floor (terrace)	H-30 and PR
3	Cafeteria	1st floor (terrace)	H-30 and PR
4	Critical Care	3rd floor (**) (covered)	Ambulances and traffic PR
5	Adult ICU	3rd floor (covered)	Ambulances and traffic PR
6	Laboratory	3rd floor (covered)	Ambulances and traffic PR
7	Psychiatry	1st floor (terrace)	H-30 and PR

(*) The 1st floor: 4.5 m from the ground. (**) The 3rd floor: 11.0 m from the ground. PR (***): perimeter road.

Table 3. Distances from the measurement points outside, to the nearest roads to JRJUH.

Point	Distance (m) to:		
	H-30 Ring Freeway	Perimeter Road	Flower's Avenue
1	94	10	151
2	90	9	220
3	87	9	263
4	-	3	155
5	-	12	182
6	-	14	247
7	134	36	104

Table 4. Location of measurement points inside the JRJUH building.

Point	Area	Module	Zone	Location
1′	Surgery Hospitalisation	C	Nursing control	False ceiling (*)
4′	Critical Care	G	Nursing control	False ceiling (*)
5′	Adult ICU	H	Nursing control	Centre column (**)

(*) False ceiling: microphone 3.5 m from the ground. (**) C. column: microphone 35 cm from the wall.

Table 5. Distances from the SLM microphone to the nearest walls of the different areas of the JRJUH.

Point	Distance (m) to Nearest Walls:			
	Wall 1	Wall 2	Wall 3	Wall 4
1′	0.52	0.82	1.83	4.46
4′	1.70	2.23	4.72	3.91
5′	0.35	3.27	5.16	4.20

2.4. Acoustic Modelling by Software

For the calculation, presentation, assessment, and prediction of environmental noise of the study area, the commercial software CadnaA (DataKustik GmbH, Gilching, Germany), having been calibrated and validated by the manufacturer itself, was used but greater accuracy at higher traffic exposures was reported by other researchers [48–50]. The main noise sources, H-30 and the perimeter road (PR), were digitised by introducing their average daily traffic densities (ADTD), obtained from the administrator of the H-30 (Transport Department of the Andalusia Government) and by sampling for the RP. Table 6 shows the ADTD data for both roads, and their breakdown by daily periods.

Table 6. Average daily traffic density (ADTD) in vehicles/day of the main roads (linear noise sources).

Road	ADTD	ADTD (d)	ADTD (e)	ADTD (n)
H-30	36,599	26,800	5997	3802
PR	1798	1339	301	158

To build the CadnaA model, it was also necessary to obtain and adapt cartography/topography, determine the heights of the buildings, determine the type of road pavement, and carry out field work to determine the width and profile of the roads, the existence of pedestrian crossings, location of possible traffic lights, material of the façades, existence of vegetation and gardens, etc.

3. Results and Discussion

3.1. Long-Term Outdoor Measurements

3.1.1. Main Façade

For the measurement points 1, 2, and 3, corresponding to the main façade, the graph of the daily pattern of the equivalent levels of one hour (LAeq,1h) was obtained (Figure 3). The first conclusion that can be drawn is that points 1, 2, and 3 follow the same pattern of daily evolution. This confirms that the full main façade is affected by the same noise sources, which, in this case, are the H-30 ring freeway and the perimeter road inside the hospital. All of them range between the minimum levels, (53–54 dBA) between 2:00 and 4:00 a.m., and the maximum levels (67–68 dBA) at 08:00 a.m., a typical evolution of sound footprint for a working day [51]. In addition, the rest of the hourly evolutions are very similar for the three measurements points. Appendix A includes the graphs of the daily evolution of LAeq/10s of the three points for the main façade.

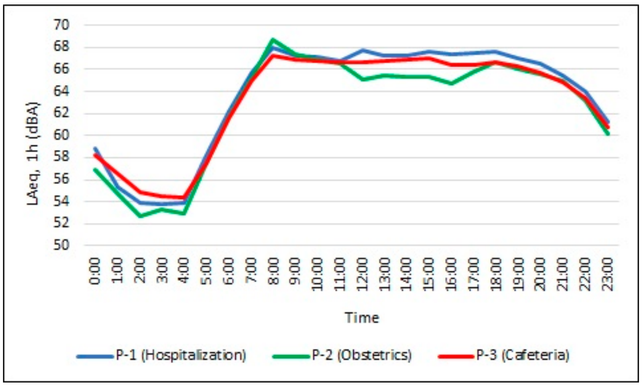

Figure 3. Daily evolution of LAeq,1h in the main façade of the JRJUH (points 1, 2, and 3).

Figure 4 shows very similar values for all five indices (L24h, Ld, Le, Ln, and Lden) at the three points. By performing three comparative regressions, two by two, between the values of these indices, three R^2 (coefficient of determination) of 0.9993 (Hospitalisation vs. Obstetrics), 0.9994 (Hospitalisation vs. Cafeteria), and 0.998 (Obstetrics vs. Cafeteria) were obtained. This means that there are no differences between the values of the indices and, therefore, that the three points of the main façade are subject to the same sources of noise. The software used for the statistical calculations were the EXCEL and the XLSTAT 2014 software, which work under Excel.

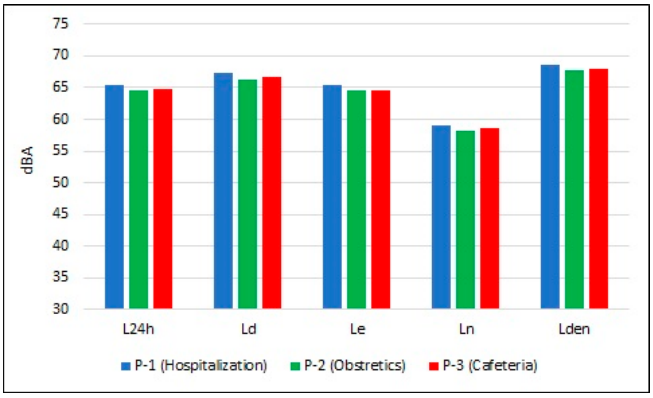

Figure 4. Sound levels by period for the main façade of JRJUH (points 1, 2, and 3).

From the analysis of the frequency diagrams of points 1, 2, and 3 located in the main façade (Figure 5), it is observed that there is practically only one distribution function for each point, which follow identical patterns, with some very prominent peaks at 66–67 dBA, which correspond to the main source of noise, that is, the traffic on the H-30 ring road. These peaks collect between 56% and 59% of the 10 s records. Several peaks, much more attenuated and diffuse, can also be observed at 54–58 dBA, collecting only 5–6% of the records, which correspond to the background noise and small traffic on the perimeter road (PR).

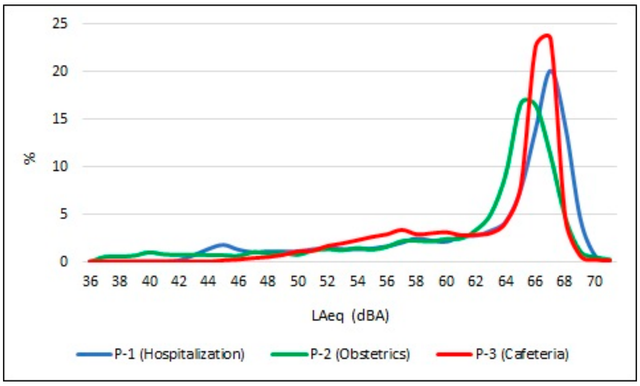

Figure 5. Frequency percentage diagram in the main façade of JRJUH (points 1, 2, and 3).

3.1.2. Back Façade

Measurement points 4, 5, and 6 correspond to the back façade. As in the main façade, the graph of the daily pattern of the equivalent levels of one hour (LAeq/1h) was obtained (Figure 6). From this graph, the first conclusion that can be drawn is that points 4, 5, and 6 follow the same pattern of daily evolution. This confirms that the whole back façade is affected by the same noise sources. Due to the shape of the rear façade of JRJHU, i.e., not continuous but rather scattered, the Laboratory façade is further away (16 m) from the perimeter road, which would cause an attenuation of approximately 5 dBA compared with the Adult ICU. This proves that the Laboratory graph is parallel to that of Adult ICU but about 5 dBA below it. In all of them, the minimum levels occur between 03:00 and 05:00, and the maximum levels at 12:00, with relative peaks at 07:00 and 18:00. Appendix A includes the graphs of the Daily evolution of LAeq/10s of the three points for the back façade.

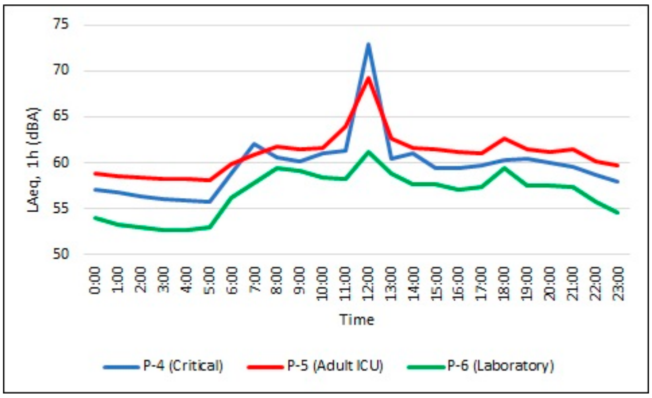

Figure 6. Daily evolution of LAeq/1h in the back façade of JRJUH (points 4, 5, and 6).

Figure 7 represents the L24h index for points 4, 5, and 6, as well as the values of Ld, Le, Ln, and Lden.

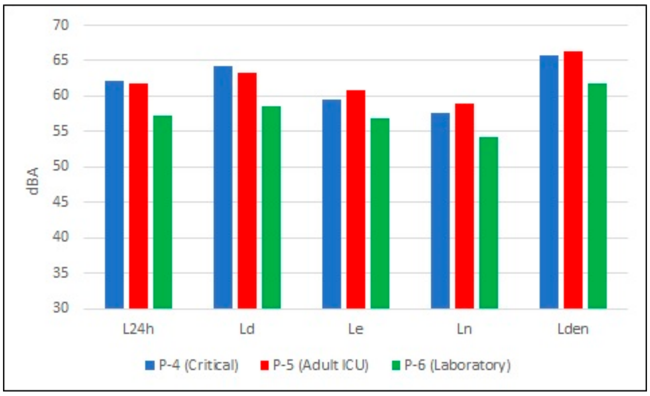

Figure 7. Sound levels by period for the back façade of JRJUH (points 4, 5, and 6).

In Figure 7, the five indices (L24h, Ld, Le, Ln, and Lden) of point 4 (Critical care) and point 5 (Adult ICU) obtained practically the same values, with a coefficient of determination R^2 of 0.91 from their linear regression, while the indices of point 6 (Laboratory) were between 5 and 6 dBA below the indices of points 4 and 5, with the coefficients of determination R^2 of comparative regressions (Critical vs. Laboratory) and (Adults ICU vs. Laboratory) being 0.6454 and 0.7478, respectively. This indicates that the Laboratory indices are very different from those of the Critical and Adult ICU.

From the analysis of the frequency diagrams of points 4, 5, and 6 of the back façade (Figure 8), it can be clearly distinguished that there were different distribution functions for each point, although they followed similar patterns, consisting of two large peaks. The first peak would correspond to the noise source of the traffic on the perimeter road inside the hospital area, including the acoustic signals from the sirens of ambulances and mobile UVIS that access the Critical Emergencies. The second peak corresponds to the background noise from the back of the hospital, which would be made up of the conversations of hospital workers and visitors, the noise of ambulance doors, the noise of pulling out/putting in stretchers, people waiting at the access doors, etc. The three distribution functions are displaced instead of being very similar to each other, which could be due to the fact that the sound level metre of point 4 (Critical Care) is screened by the canopy of the access door to ER. This would attenuate by 2 dBA both sources compared to the diagram in point 5 (Adult ICU), whose sound level metre would not be shielded by anything. Finally, the sound level metre of point 6 (Laboratory), due to the shape of the back façade of JRJHU, is set back 16 m with respect to the perimeter road, which would cause an attenuation of 5 dBA on both noise sources. It can also be observed that the 10 s records are collected between both peaks of the distributions at 92–96%.

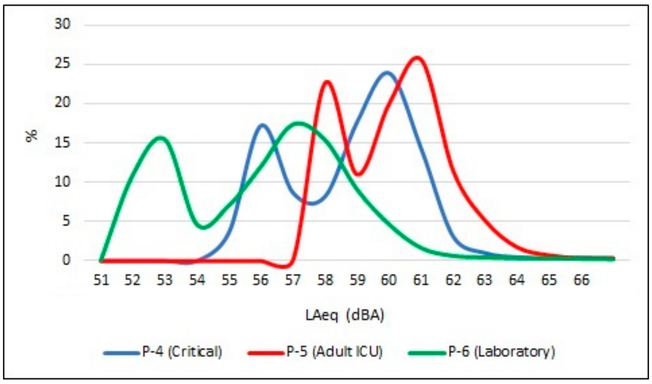

Figure 8. Frequency percentage diagram in the back façade of JRJUH (points 4, 5, and 6).

3.1.3. Side Façade

Measurement point 7 (Psychiatry Area) corresponds to the side façade of JRJUH, and its analysis is shown in Figures 9–11.

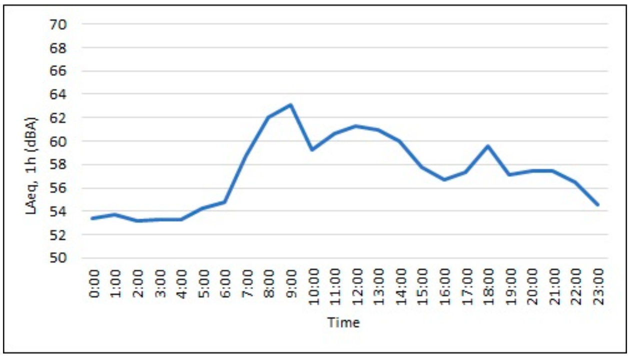

Figure 9. Daily evolution of LAeq/1h in the side façade of JRJUH (point 7).

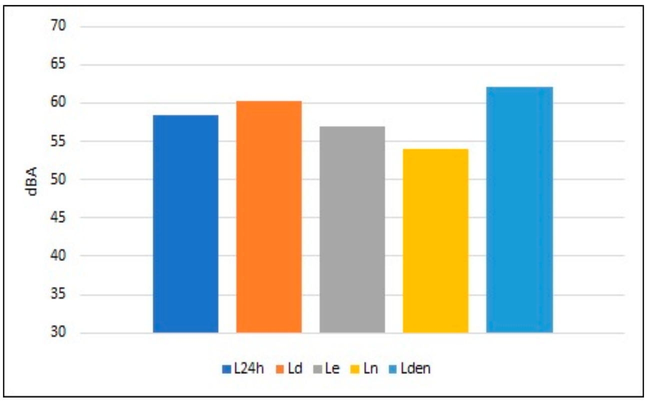

Figure 10. Sound levels by period in the side façade of JRJUH (point 7).

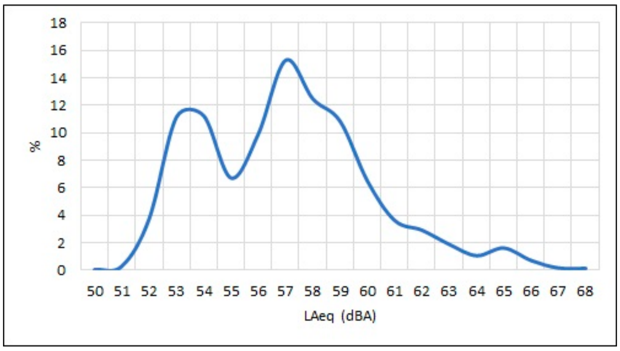

Figure 11. Frequency percentage diagram in the side façade of JRJUH (point 7).

The graph of the evolution of LAeq/1h (Figure 9) shows a pattern like those on the main façade. This is due to its location on the side façade, where the H-30 ring road also exerts an influence, although at a longer distance, and, therefore, it is more attenuated; however, it is also influenced by the noise coming from the courtyard of the Psychiatry building, which is the place where the admitted patients of this specialty walk. Analysing the daily evolution of the equivalent levels of one hour (LAeq/1h), a much flatter graph is observed, with a less significant difference between the maximum level (63 dBA at 09:00) and the minimum level (53 dBA at 02:00–04:00 h). The Appendix A includes the graph of the daily evolution of LAeq,10s of the point for the side façade.

In Figure 10, the five indices of the side façade are ranged between 5 and 7 dBA below those of the main façade. This corroborates that the traffic of the H-30 ring road is the main source of noise on this façade, but with more attenuation due to the distance.

From the analysis of the graph of the frequency diagram in point 7 (Figure 11), a pattern with two prominent peaks at 53 and 57 dBA is observed. This indicates the existence of two main sources of noise. The highest peak corresponds to the traffic on the H-30 ring road, and the second peak corresponds to background noise.

3.1.4. Comparison Between Points

Comparing the sound levels of the seven measurement points by period, the graphs in Figure 12 were obtained. In these graphs, in the three points (1, 2, and 3) of the main façade the levels were very similar. On the other hand, on the back façade (points 4, 5, and 6), although they were also very similar, in the night period in point 4 (Critical Care), there was a more pronounced drop, which could be due to the fact that ambulances use optical signals rather than acoustic signals during the night period. It is also observed that points 6 and 7 had lower levels, as they are further away from the perimeter road (PR) and the acoustic signals of the ambulance sirens.

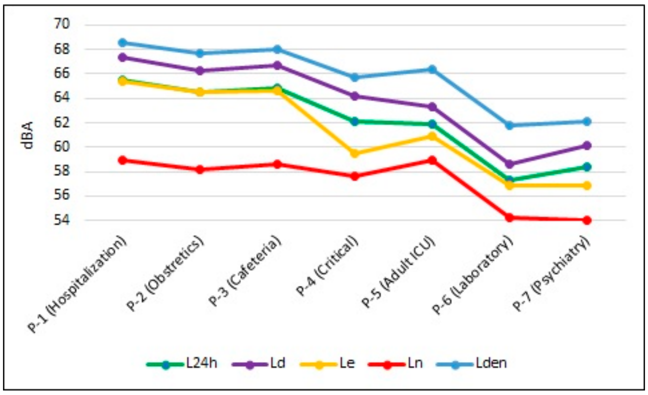

Figure 12. Comparison of noise levels by period at the seven measurement points.

3.2. Acoustic Simulations Outside the Hospital Using the CadnaA Acoustic Software Prediction

After digitising in CadnaA, all the buildings of the JRJUH area and the main noise sources (H-30 and PRs) with the data of Table 4, also considering the type of road pavement as well as its slopes and atmospheric conditions, and using a 1 × 1 m grid, the exterior noise maps were obtained at 4 m above the ground for the periods of day, afternoon, night, and Lden, such as the one shown for Lden in Figure 13. The maps obtained with CadnaA were previously calibrated with the results of the measurements before being considered final. The remaining noise maps are included as Material in Appendix A.

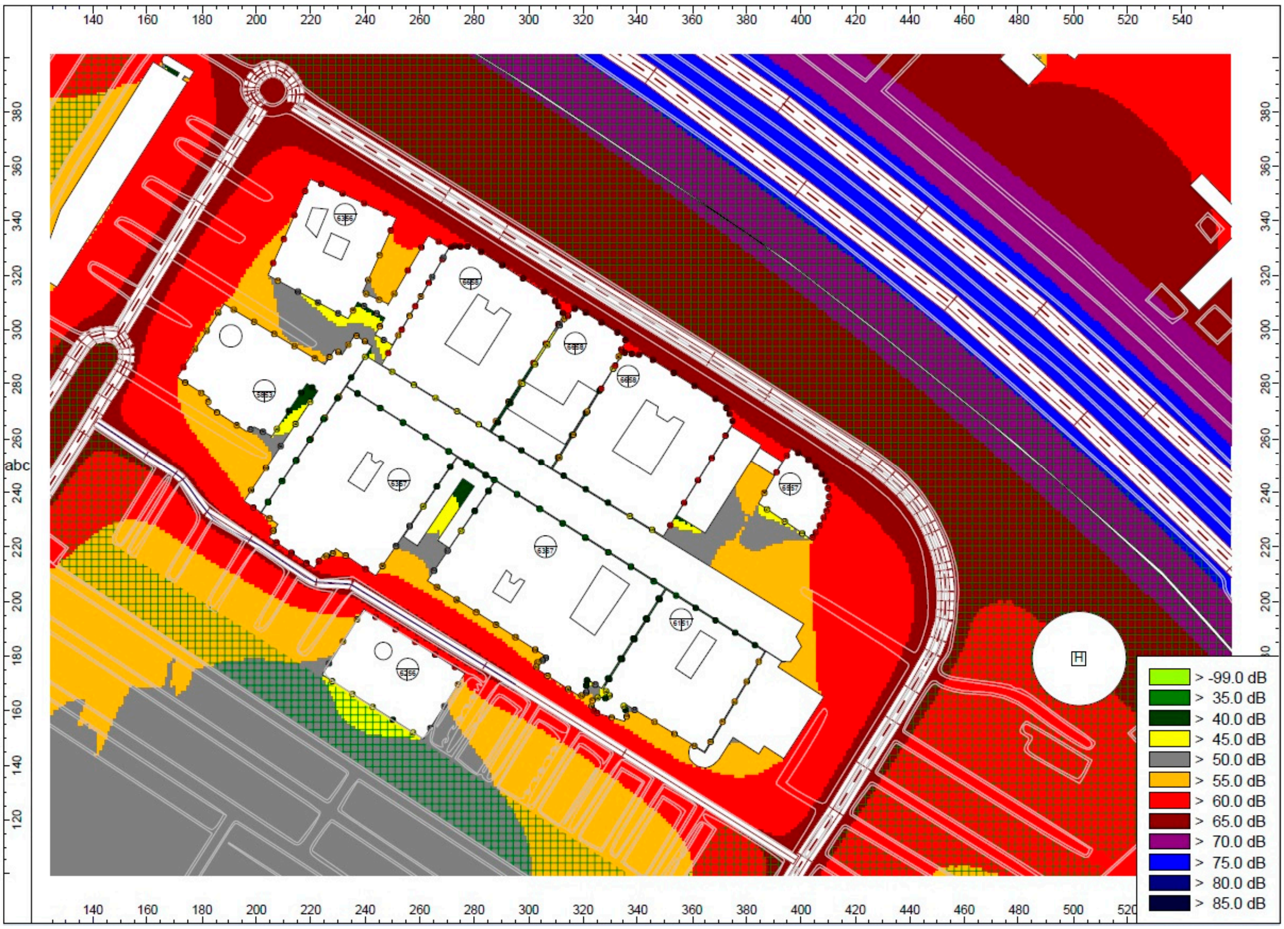

Figure 13. JRJUH outdoor noise map, day–evening–night period (Lden), at 4 m above the ground.

In Appendix A, Table A1 is included, with the values of the levels by period at the seven points, obtained from the measurements, and those obtained from the CadnaA model (without acoustic screen and with acoustic screen).

Comparing the values of the measurements with those of the model (without acoustic screen), the graphs shown in Figure 14 were obtained.

In all measurements, it is observed that the values provided by the model are always below the values measured at the seven monitoring points. This is due to the fact that there is background noise (people talking, doors opening and closing, noises from luminaires, etc.), in addition to the main noise sources that were modelled in CadnaA, where the background noise cannot be modelled. However, while on the main façade (points 1, 2, 3) the measured/model differences ranged between 0.6 and 2.4 dBA, on the back façade (points 4, 5, 6) these differences were higher than the previous ones, which were between 0.5 and 4.9 dBA. As can be observed in Figure 5, this is explained by the fact that there is only one noise source on the main façade with the background noise masked by the slight ramps in the frequency diagrams, whereas on the back façade, two noise sources were clearly distinguished in Figure 8: the PR traffic and the background noise. The former was perfectly modelled, but not the latter, hence the differences of over 4 dBA.

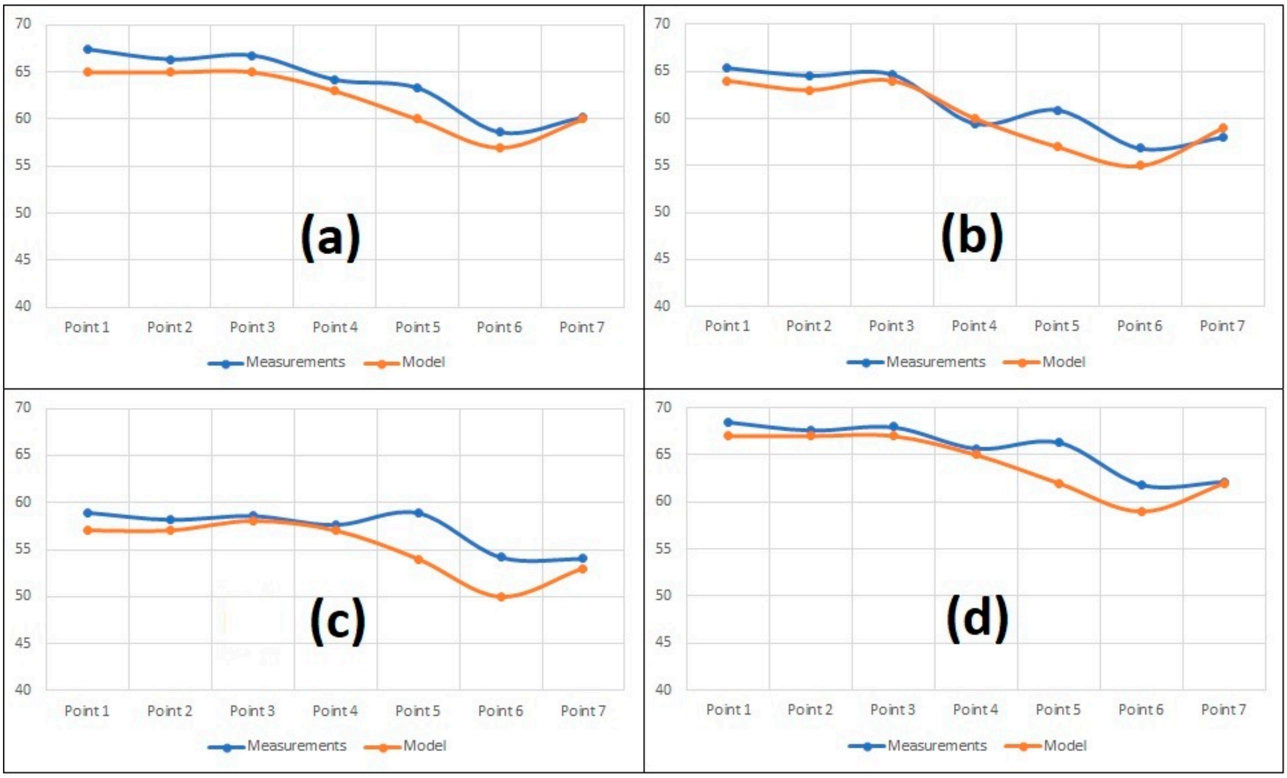

Figure 14. Comparison of measurements against the CadnaA model (without acoustic screen): (**a**) Ld, (**b**) Le, (**c**) Ln, (**d**) Lden.

To validate the noise maps obtained with the CadnaA model, the data from the external measurements were compared with those obtained from the noise maps at the same points. The comparisons, point by point, were carried out by means of statistical analysis based on the non-parametric Mann–Whitney–Wilcoxon test [52] with a significance level (alpha) of 0.05, at each of the seven sampling points, comparing the values of the measurements (Ld, Le, Ln, Lden) with the levels from the noise maps. The results of these tests are shown in Table 7.

Table 7. Results of Mann–Whitney–Wilcoxon test (Measurements vs. CadnaA model).

Point	Area	U	*p*-Value (Two-Tailed)	Alpha
1	Surgery Hospitalisation	12	0.3123	0.05
2	Obstetrics Hospitalisation	10	0.6650	0.05
3	Cafeteria	10	0.6650	0.05
4	Critical Care	9	0.8852	0.05
5	Adult ICU	13	0.1939	0.05
6	Laboratory	10	0.6650	0.05
7	Psychiatry	9	0.8852	0.05

As can be observed in Table 7, in all points, the calculated *p*-value is greater than the significance level (alpha = 0.05), i.e., the null hypothesis, H0, cannot be rejected, where H0 is "The difference in location between the samples is equal to 0".

An acoustic screen surrounding the ring freeway H-30 was subsequently digitised to simulate its potential impact on the acoustic landscape of the JRJUH, should the decision be made to install this type of protection to enhance the external acoustic environment of the hospital. The acoustic map for the Lden period is presented in Figure 15, while the maps for the other periods are included in the Appendix A, along with the index values at the various measurement points in Table A1. From this analysis, it can be inferred that there is an average improvement of 3 dBA on the main façade of the JRJUH, achieving values that are somewhat closer to the limits of RD.-1367.

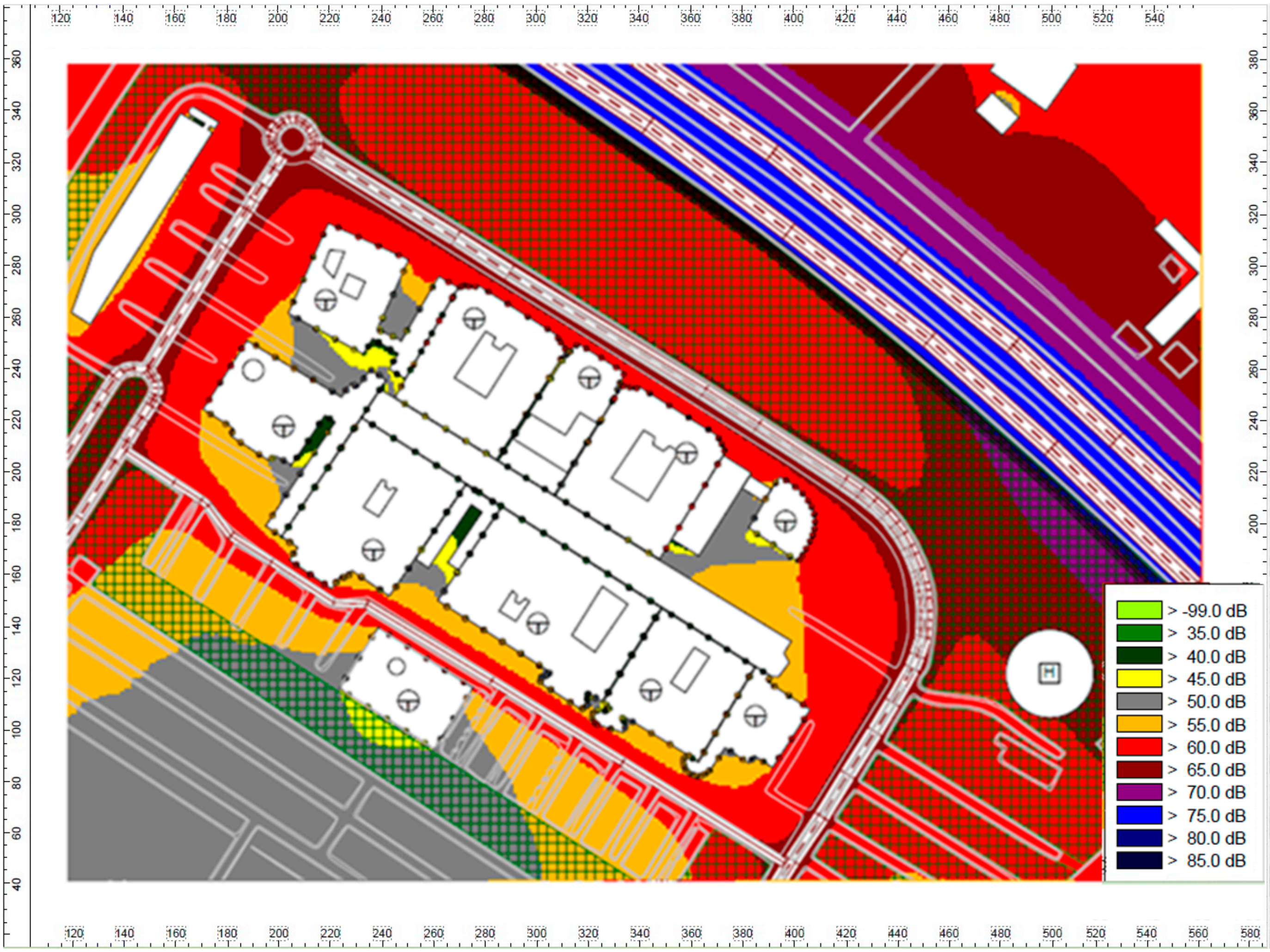

Figure 15. JRJUH outdoor noise map (with acoustic screen), day–evening–night period (Lden), at 4 m above the ground.

3.3. Long-Term Indoor Measurements

Figure 16 shows the patterns of the temporal evolutions of the LAeq,1h levels corresponding to the measurement points inside the JRJUH building: 1′ (Hospitalisation), 4′ (Critical), and 5′ (Adults ICU).

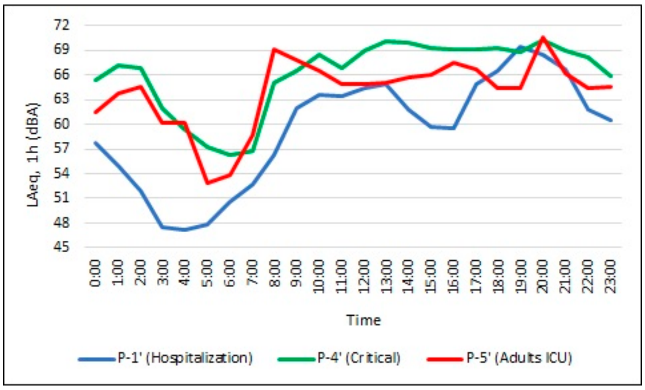

Figure 16. Daily evolution of LAeq,1h inside JRJUH (points 1′, 4′, and 5′).

From the observation and analysis of Figure 16, it can be deduced that in Hospitalisation (point 1′), the minimum sound level values (47 dBA) occur between 03:00 and 06:00, that is, during the hours of night-time sleep, and a relative minimum (59 dBA) between 15:00 and 16:00, which coincides with nap time, while the maximum values occur at 13:00 and 20:00 h, with 65 and 70 dBA, respectively, which coincide with lunch and dinner hours.

However, the Critical area pattern shows a minimum at 57 dBA at 6:00, but with a duration of less than one hour, although it should also be noted that this minimum is 6 dBA higher than that recorded in point 1′ (Hospitalisation), while the maximum at 70 dBA occurs at 13:00 and 20:00 h. It is significant in this pattern to observe a great deal of stability, in high values, between 13:00 and 20:00; this is justified by the type of activity that takes place in this service, which is subjected to abundant activity, attending to the emergencies that occur.

Finally, the pattern of the Adult ICU shows a minimum between 05:00 and 06:00, with a value of 53 dBA, and the maximums occur at 8:00 and 20:00, coinciding with shift changes in this service.

From the analysis of the graphs of sound levels by period in Figure 17, it can be deduced that all the sound levels of the Ld and Le indices range between 66 and 68 dBA, while Ln decreases until 55 dBA in P-1′ (Hospitalisation), which is consistent, as it corresponds to the hours of night-time sleep, where activity decreases considerably during this period. At points P-4′ and P-5′, the Ln value only decreases until 63 and 61 dBA, respectively, corresponding to the night-time noise in these Critical Care and Adult ICU areas, due to the activity that takes place there.

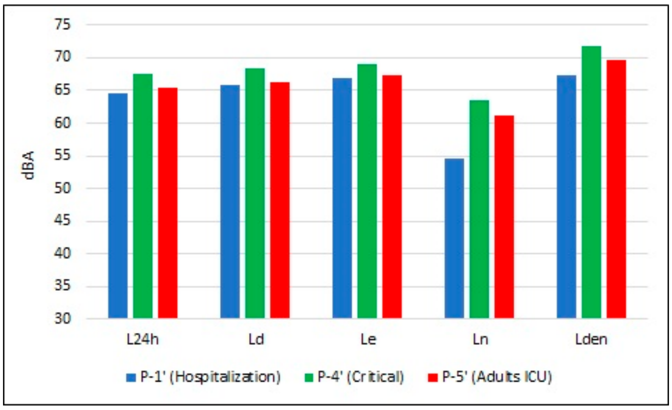

Figure 17. Sound levels by period inside JRJUH (points 1′, 4′, and 5′).

Figure 18 clearly indicates that in P-1′ (Hospitalisation), there are two sources of noise: the first source at 67 dBA, which corresponds to the noisiest activities in the area (meals, dinners, visits, etc.); and the second source at 48 dBA, corresponding to the background noise of the area, which would include staff conversations, monitoring equipment, oxygen supply, lifts, lighting, etc. At points P-4′ (Critical Care) and P-5′ (Adults ICU), there is only one source of noise at 65 and 68 dBA, which correspond to the noisiest activities in both areas: admissions, resuscitation, patient stabilisation, examinations, tests, etc., in the former, and monitoring, alarms, treatment, follow-ups, dinners, etc., in the latter.

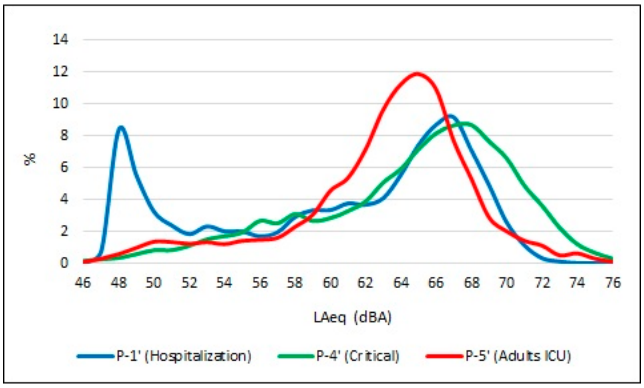

Figure 18. Frequency percentage diagram inside JRJUH (points 1′, 4′, and 5′).

3.4. Comparison with Regulatory Guidelines

Figure 19 presents the data resulting from the long-term outdoor measurements, and the acoustic quality objectives recommended by the WHO, the USEPA, and Spanish legislation through Royal Decree 1367/2007, which includes Law 37/2003, on noise, in relation to acoustic zoning, quality objectives, and acoustic emissions (RD.-1367).

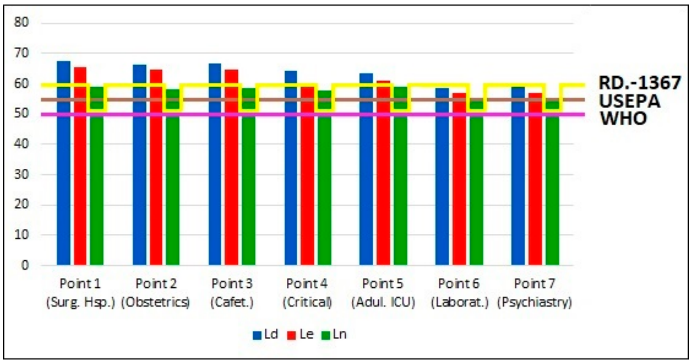

Figure 19. Histograms of the acoustic indices, by period, of the long-term outdoor measurements in JRJUH, and comparison with the maximum levels recommended by the guidelines.

From the analysis of Figure 19, it can be deduced that the acoustic environment at the exterior (points 1, 2, and 3) of JRJUH far exceeds all the recommended values of the WHO, USEPA, and RD.-1367. This means that around the main façade of JRJUH, not all regulations are complied with, where the source responsible for that breach is the H-30 ring freeway.

In points 6 and 7, the WHO and USEPA acoustic quality objectives are exceeded, but not those of RD.-1367, except for Ln, which is also exceeded. These two points are subjected to the perimeter road, as the main source of noise. Analogously to point 6, points 4 and 5 are on the back façade of JRJUH, with both exceeding the objectives of the three regulations, except for Le of RD.-1367, which practically meets them.

Table 8 shows the differences between the maximum levels recommended by the guidelines and the average noise levels by period, for areas with a predominance of land for healthcare. Similar findings can be seen in other research articles [53,54].

Table 8. Differences between measurement levels and the maximum outdoor levels recommended by the guidelines.

		WHO (Ld = Le = Ln = 50) dBA			USEPA (Ld = Le = Ln = 55) dBA			RD.-1367 (Ld = Le = 60, Ln = 50) dBA		
Point	**Area**	**Ld**	**Le**	**Ln**	**Ld**	**Le**	**Ln**	**Ld**	**Le**	**Ln**
1	Surgery Hospitalisation	17.3	15.3	8.9	12.3	10.3	3.9	7.3	5.3	8.9
2	Obstetrics	16.3	14.5	8.2	11.3	9.5	3.2	6.3	4.5	8.2
3	Cafeteria	16.7	14.6	8.6	11.7	9.6	3.6	6.7	4.6	8.6
4	Critical Care	14.1	9.5	7.6	9.1	4.5	2.6	4.1	−0.5	7.6
5	Adults ICU	13.3	10.9	8.9	8.3	5.9	3.9	3.3	0.9	8.9
6	Laboratory	8.6	6.8	4.2	3.6	1.8	−0.8	−1.4	−3.2	4.2
7	Psychiatry	10.2	6.9	4.0	5.2	1.9	−1.0	0.2	−3.1	4.0

Positive numbers: indices above the limits. Negative numbers: indices below the limits.

The histogram of Figure 20 was obtained considering the data of the long-term indoor measurements, and the objectives of acoustic quality in the interior space of the hospital facilities recommended by the WHO, USEPA, and RD.-1367.

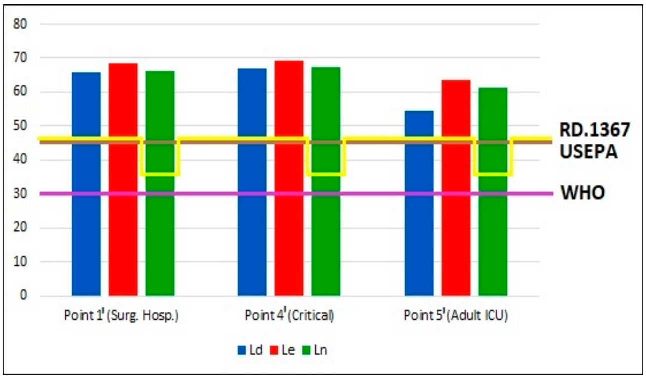

Figure 20. Histograms of the acoustic indices, by period, of the long-term indoor measurements in JRJUH and comparison with the maximum levels recommended by the guidelines.

Table 9 shows the differences between the maximum levels recommended by the guidelines for the interior space of hospitals and the average noise levels measured by period in the Hospitalisation, Critical, and Adult ICU areas.

From the analysis of the histogram and data shown in Figure 20 and Table 9, respectively, it can be deduced that, for the indoor acoustic environment of the three interior areas studied at JRJUH (Surgery Hospitalisation, Critical Care and Adult ICU: points 1′, 4′ and 5′, respectively), the maximum values recommended by all the guidelines for the inside of the different hospital areas are widely exceeded in all periods and facilities. Therefore, inside all the analysed areas, the generated noise levels exceed those recommended by more than 38 dBA, that is, there are acoustic powers 6000 times higher than those recommended. Similar findings can be seen in other research articles [55,56].

Table 9. Differences between measurement levels and the maximum indoor levels recommended by the guidelines.

		WHO (Ld = Le = Ln = 30) dBA			USEPA (Ld = Le = Ln = 45) dBA			RD.-1367 (Ld = Le = 45, Ln = 35) dBA		
Point	**Area**	**Ld**	**Le**	**Ln**	**Ld**	**Le**	**Ln**	**Ld**	**Le**	**Ln**
1′	Surgery Hospitalisation	35.8	36.8	24.7	20.8	21.8	9.7	20.8	21.8	19.7
4′	Critical Care	38.4	39.0	33.5	23.4	24.0	18.5	23.4	24.0	28.5
5′	Adults ICU	36.2	37.3	31.1	21.2	22.3	16.1	21.2	22.3	26.1

Positive numbers: indices above the limits. Negative numbers: indices below the limits.

3.5. Comparison Between Outdoor and Indoor Acoustic Environments

Comparative analyses have been carried out with linear regression adjustments between the results of the measurements outside and inside the "emergency", "ICU", and "Surgery Hospitalisation" areas, proving that the external noise of the JRJUH does not condition the internal acoustic environment of the different interior areas of the hospital.

These comparative analyses are included in the "Analysis of comparison of the external-internal measurements" section of Appendix A.

4. Conclusions

By analysing the frequency diagrams, it has been possible to distinguish the main sources of noise that act at each measurement point. Outside sources—traffic on the H-30, traffic on the perimeter road, sirens of ambulances, and background noise. Inside sources—noises specific to each area (meals, dinners, visits, etc.), and the background noise of the area (staff conversations, monitoring equipment, oxygen supply, lifts, luminaires, etc.).

It has also been proven that the external noise of the JRJUH does not affect the internal acoustic environment of the different interior areas of the hospital.

The acoustic indices proved that the acoustic environment, both inside and outside the hospital, does not comply with all the recommendations of national and international standards.

From the analysis of the results of the 21 measured indices of the external acoustic environment of JRJUH, all 21 indices exceeded the maximum levels recommended by the WHO, 19 of them exceed the recommendations of the USEPA, and 17 indices exceeded the Spanish law (RD.-1367), exceeding by 8.9 dBA in some cases, with the main façade being the most affected and the H-30 being the main source of noise. While inside the JRJUH, the nine indices analysed exceed the recommendations of WHO, USEPA, and RD.-1367, exceeding by 28.5 dBA in some cases.

Therefore, it is recommended to implement several strategies to mitigate external noise such as installing acoustic screens around the H-30 ring road, which could enhance the acoustics indices values of the main façade by approximately 3 dBA, and adopting protocols to ensure that ambulances turn off their sirens upon entering the JRJUH premises, thereby improving the acoustic indices of the back façade.

Similarly, we also recommend strategies to be implemented inside the hospital: hiring acoustic consultants with experience in evidence-based hospital design; installing a sound level metre in all staff facilities with light signal warnings of elevated noise levels; and identifying sources of excessive noise, such as food carts, linen and towel delivery carts, automatic doors, telephones, televisions, clipboards, ice machines, beds, patient monitoring equipment alarms, pagers, etc. Thus, the aim is to change the location of the noise sources or replace them with other devices and instruments that perform the same functions in a quieter manner; to cover walls and ceilings of staff centres and corridors, with acoustic, sound-absorbing panels that are washable and feasible to disinfect; and to recommend that health professionals to try to make less noise in their daily activities.

Author Contributions: Conceptualization: R.S.-S., A.B.-L. and J.P.B.; methodology: R.S.-S. and J.P.B.; software: R.S.-S.; validation: G.I.A. and J.P.B.; formal analysis: R.S.-S. and J.P.B.; investigation: R.S.-S. and G.I.A.; resources: J.P.B. and A.B.-L.; data curation: R.S.-S. and J.P.B.; writing—original draft preparation: R.S.-S.; writing—review and editing: R.S.-S.; visualisation: A.B.-L.; supervision: J.P.B. and G.I.A.; project administration: R.S.-S.; funding acquisition: J.P.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been partially funded by the Research State Agency project with Ref.: PID2020-116461RB-C21, and the CSN (Nuclear Safety Council) projects with Refs.: SUBV-4/2021 (EXRADON).

Data Availability Statement: Data available on request due to privacy restrictions. The data presented in this study are available on request from the corresponding author.

Acknowledgments: We thank those responsible for the JRJUH for allowing us to access and install the equipment, as well as their help in monitoring them. Also, we extend our gratitude to Antonio Padilla Ollero, for his technical support in the design, development, and assembly of the equipment used to carry out this research.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

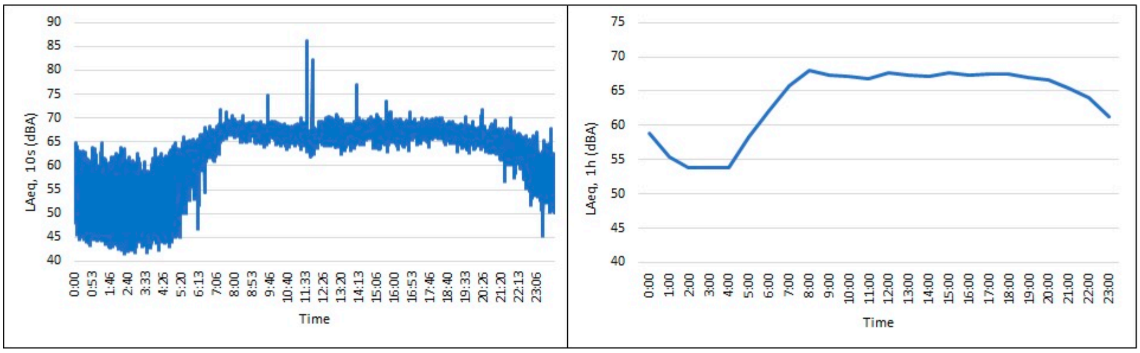

Figure A1. Daily evolution of LAeq,10s and LAeq,1h outside the Surgery Hospitalisation (Point-1).

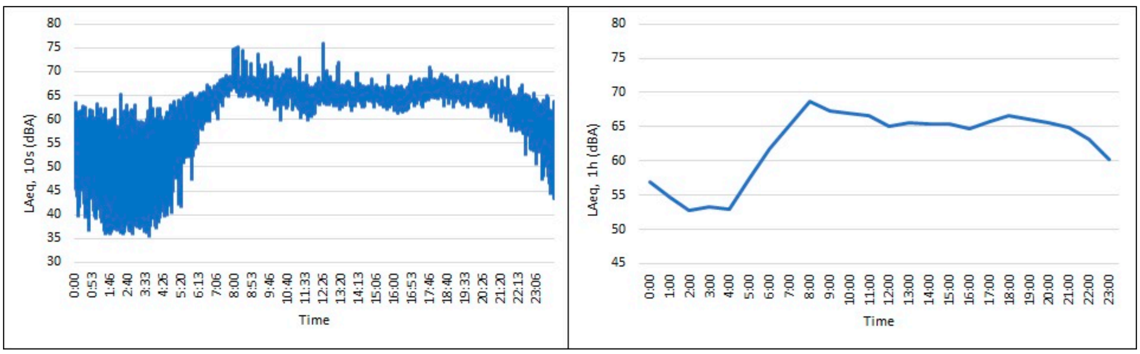

Figure A2. Daily evolution of LAeq,10s and LAeq,1h outside Obstetric Hospitalisation (Point-2).

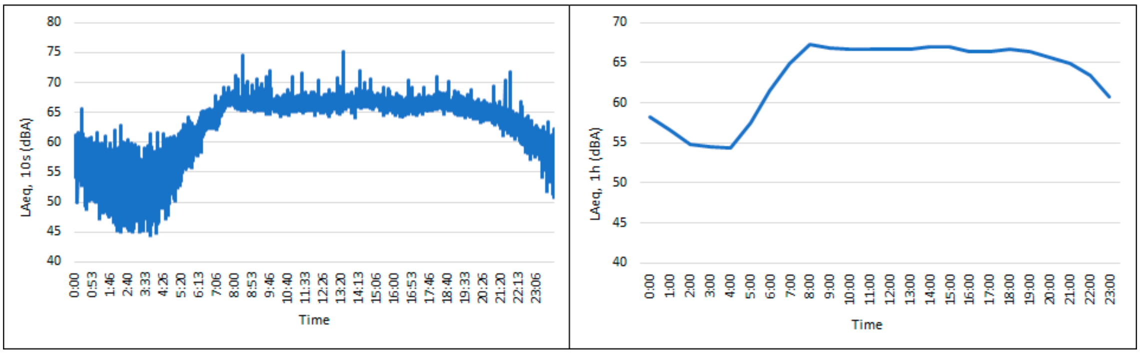

Figure A3. Daily evolution of LAeq,10s and LAeq,1h outside Cafeteria (Point-3).

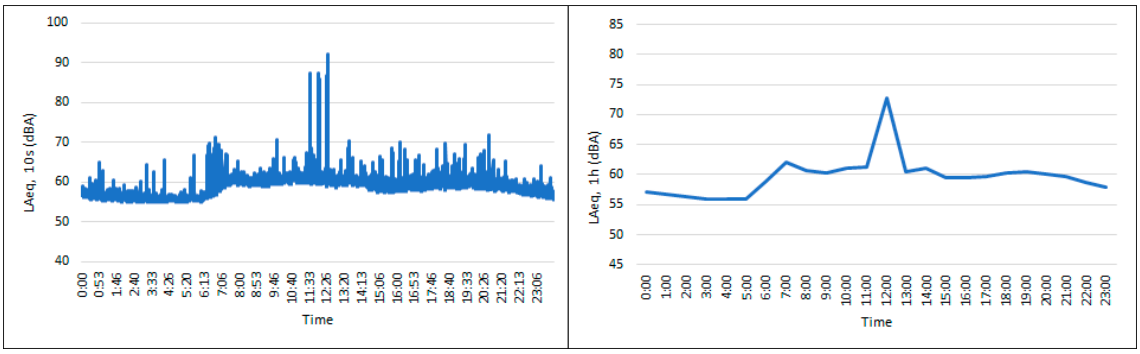

Figure A4. Daily evolution of LAeq,10s and LAeq,1h outside Critical Care (Point-4).

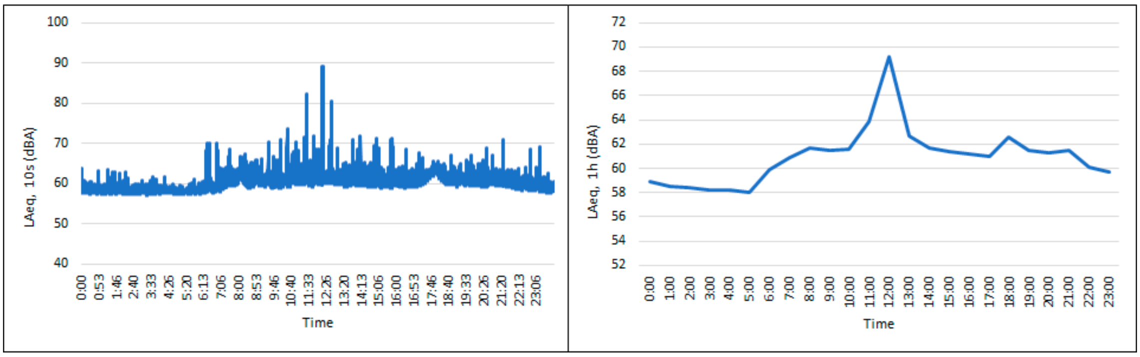

Figure A5. Daily evolution of LAeq,10s and LAeq,1h outside Adults ICU (Point-5).

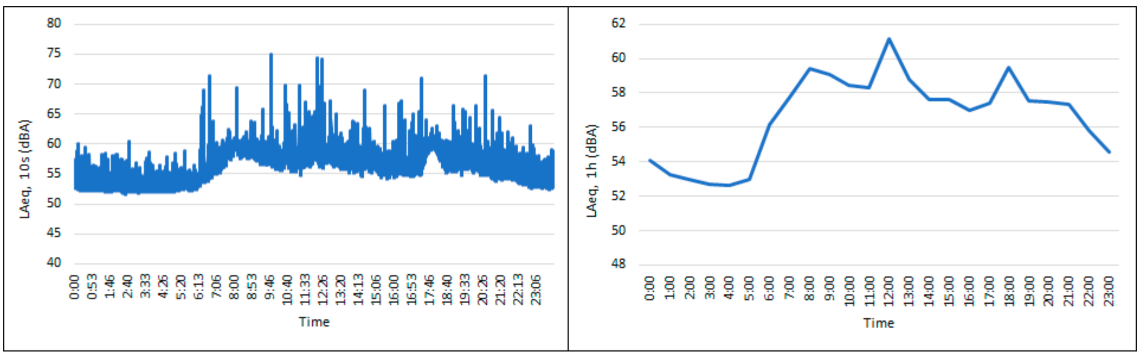

Figure A6. Daily evolution of LAeq,10s and LAeq,1h outside Laboratory (Point-6).

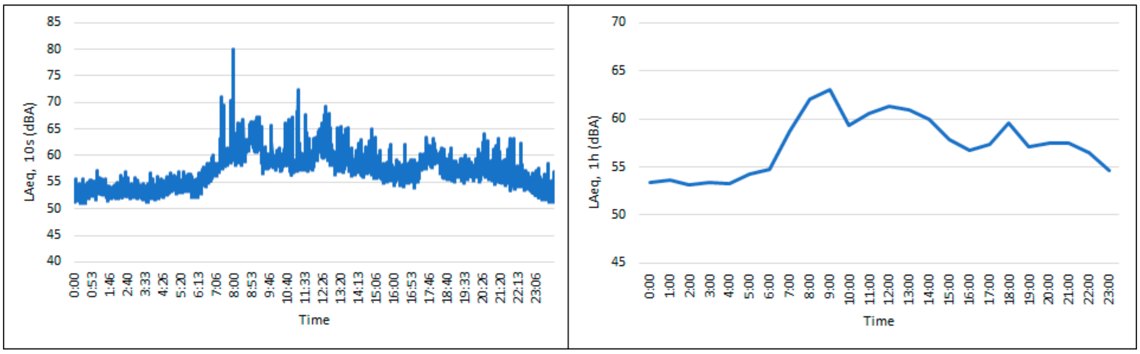

Figure A7. Daily evolution of LAeq,10s and LAeq,1h outside Psychiatry (Point-7).

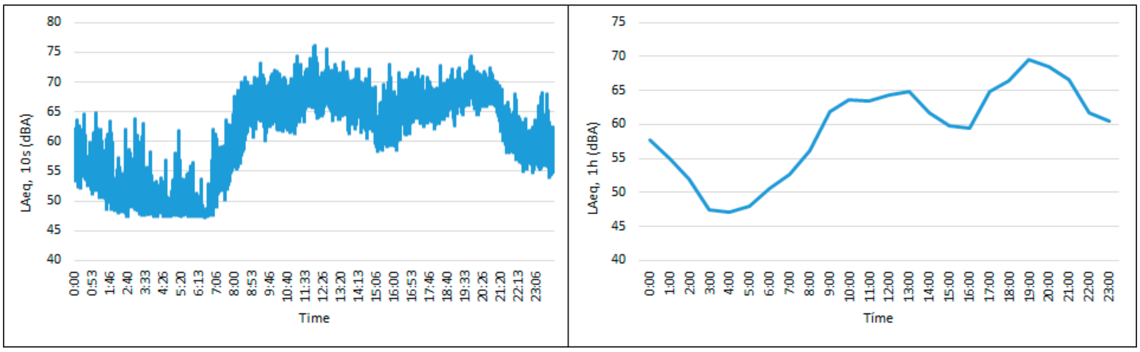

Figure A8. Daily evolution of LAeq,10s and LAeq,1h inside Surgery Hospitalisation (Point-1′).

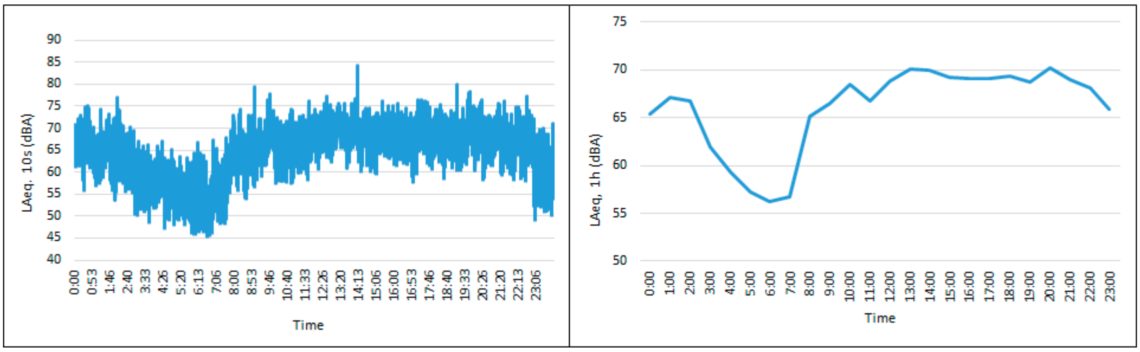

Figure A9. Daily evolution of LAeq,10s and LAeq,1h inside Critical Care (Point-4′).

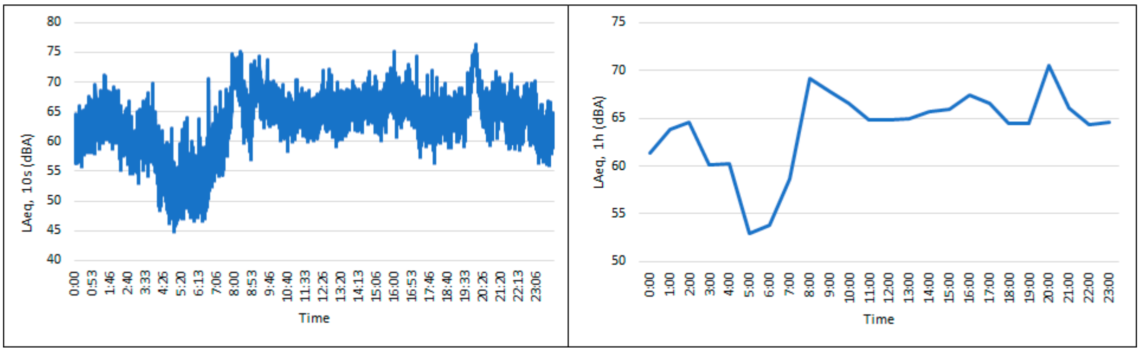

Figure A10. Daily evolution of LAeq,10s and LAeq,1h inside Adults ICU (Point-5′).

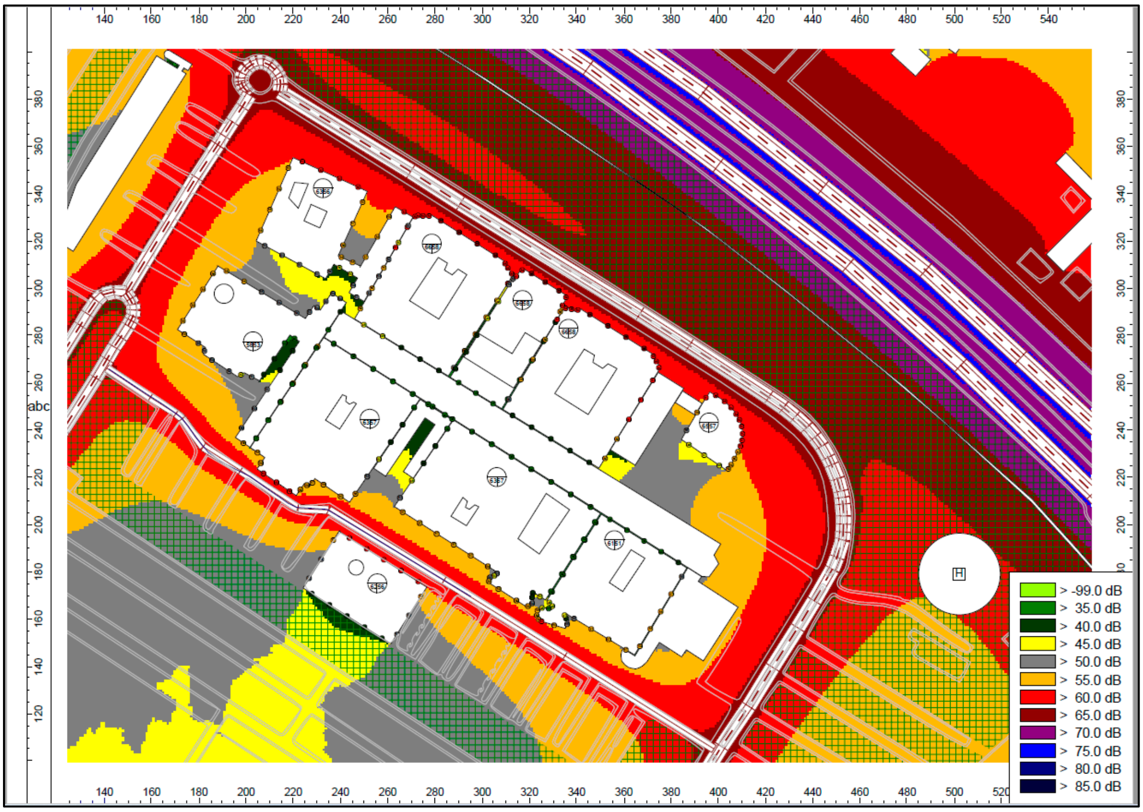

Figure A11. JRJUH outdoor noise map, day period (Ld), at 4 m above the ground.

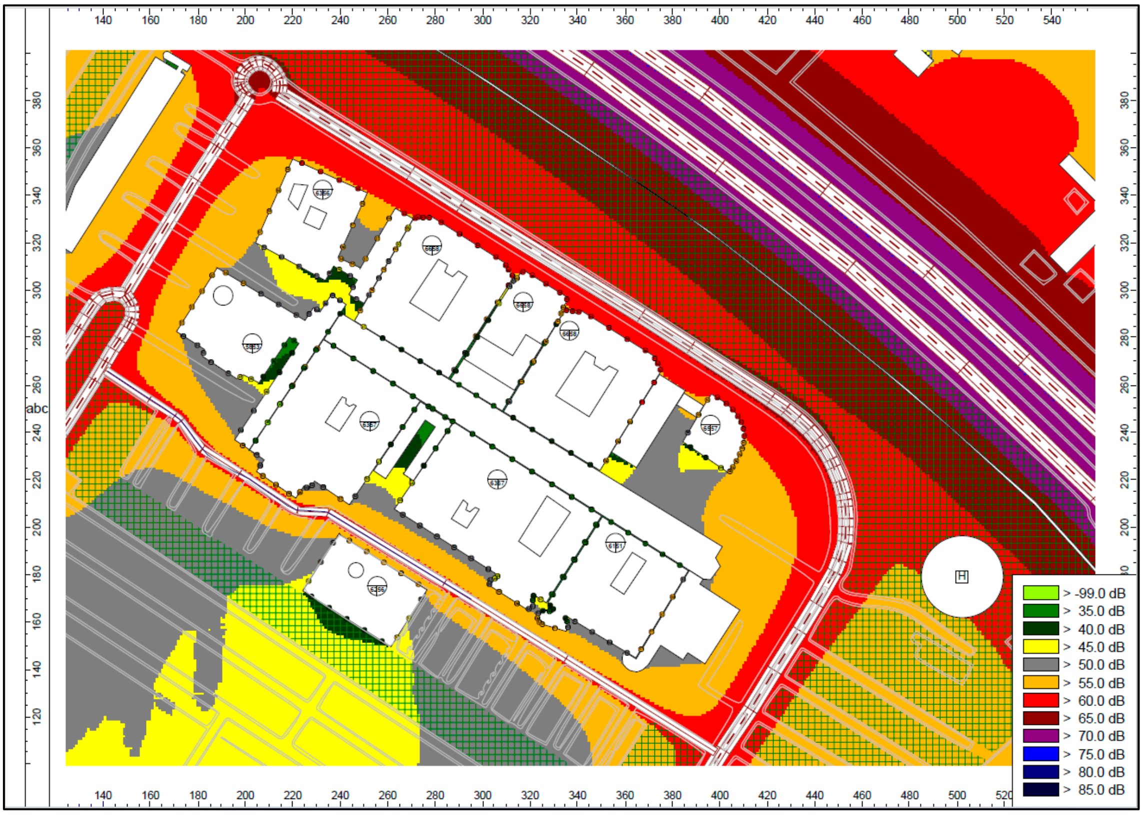

Figure A12. JRJUH outdoor noise map, evening period (Le), at 4 m above the ground.

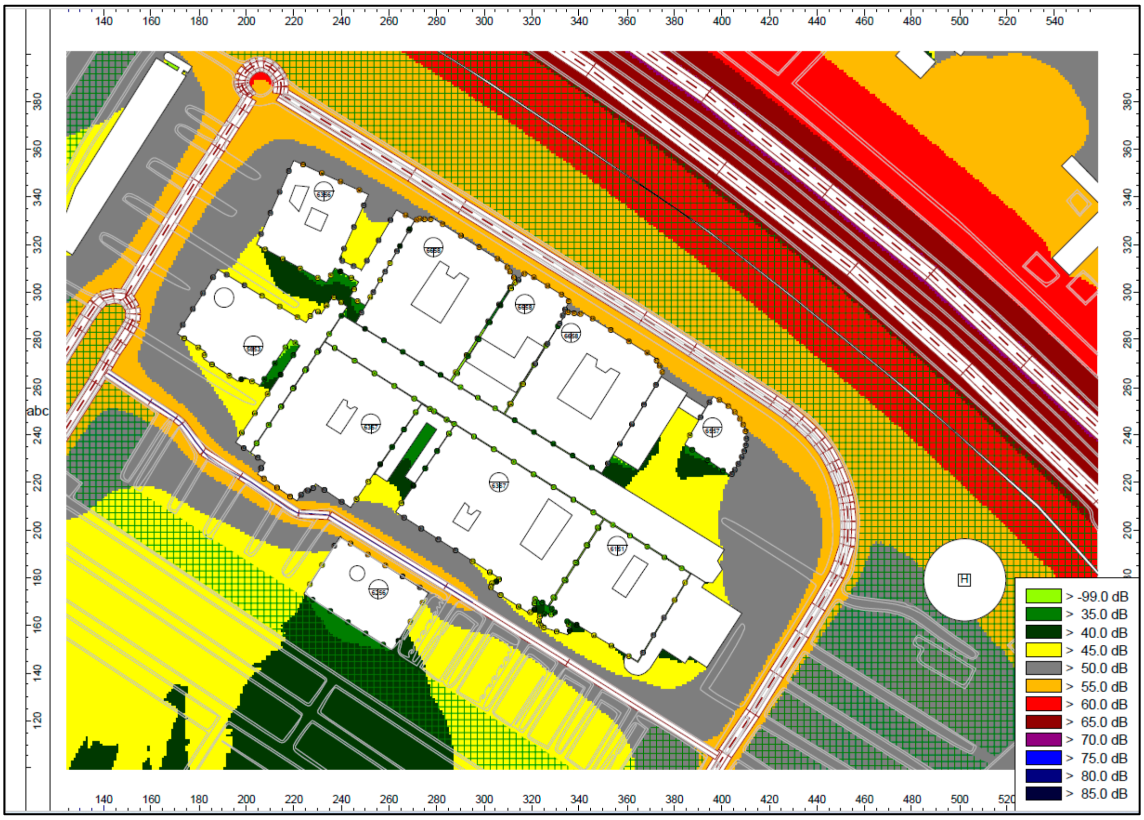

Figure A13. JRJUH outdoor noise map, night period (Ln), at 4 m above the ground.

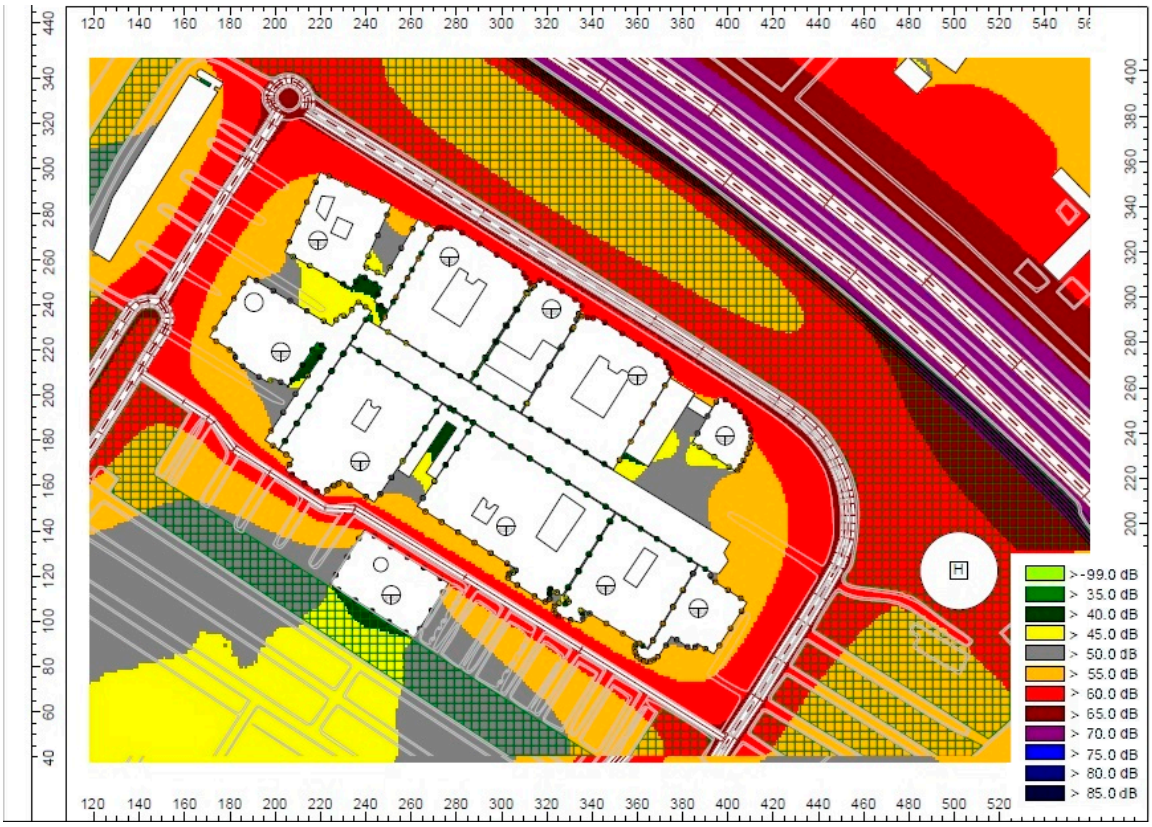

Figure A14. JRJUH outdoor noise map (with screen), day period (Ld), at 4 m above the ground.

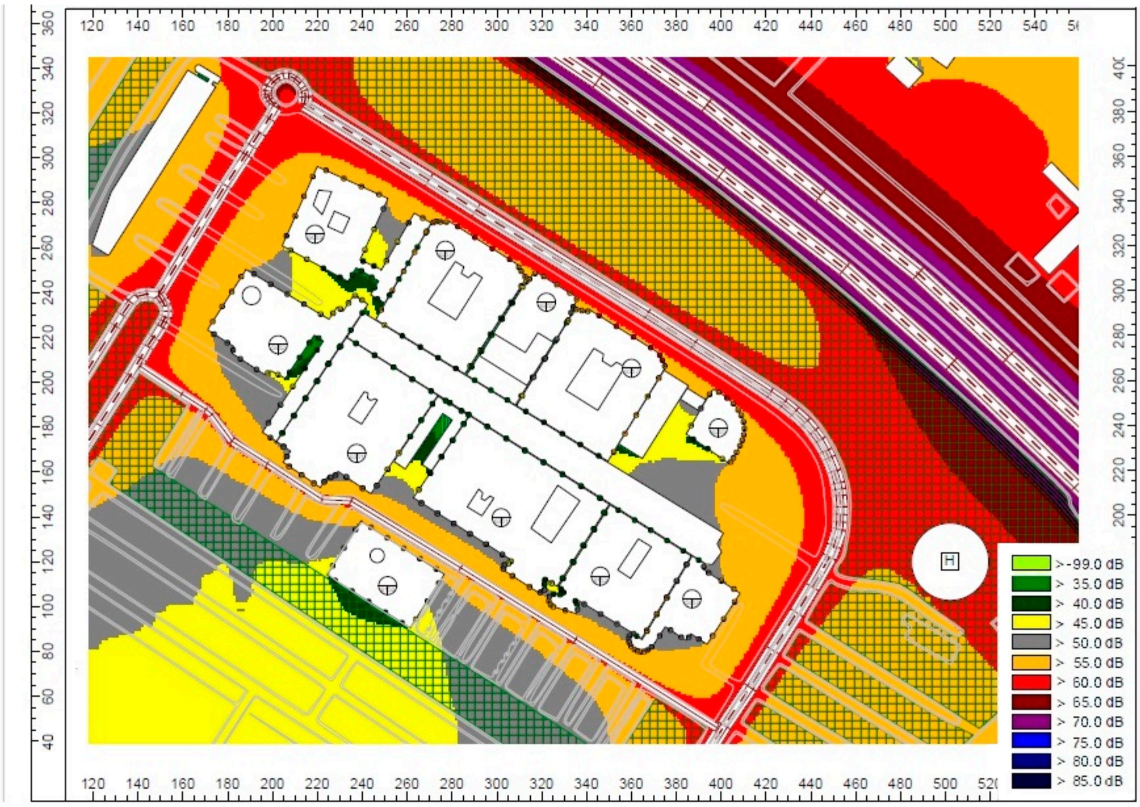

Figure A15. JRJUH outdoor noise map (with screen), evening period (Le), at 4 m above the ground.

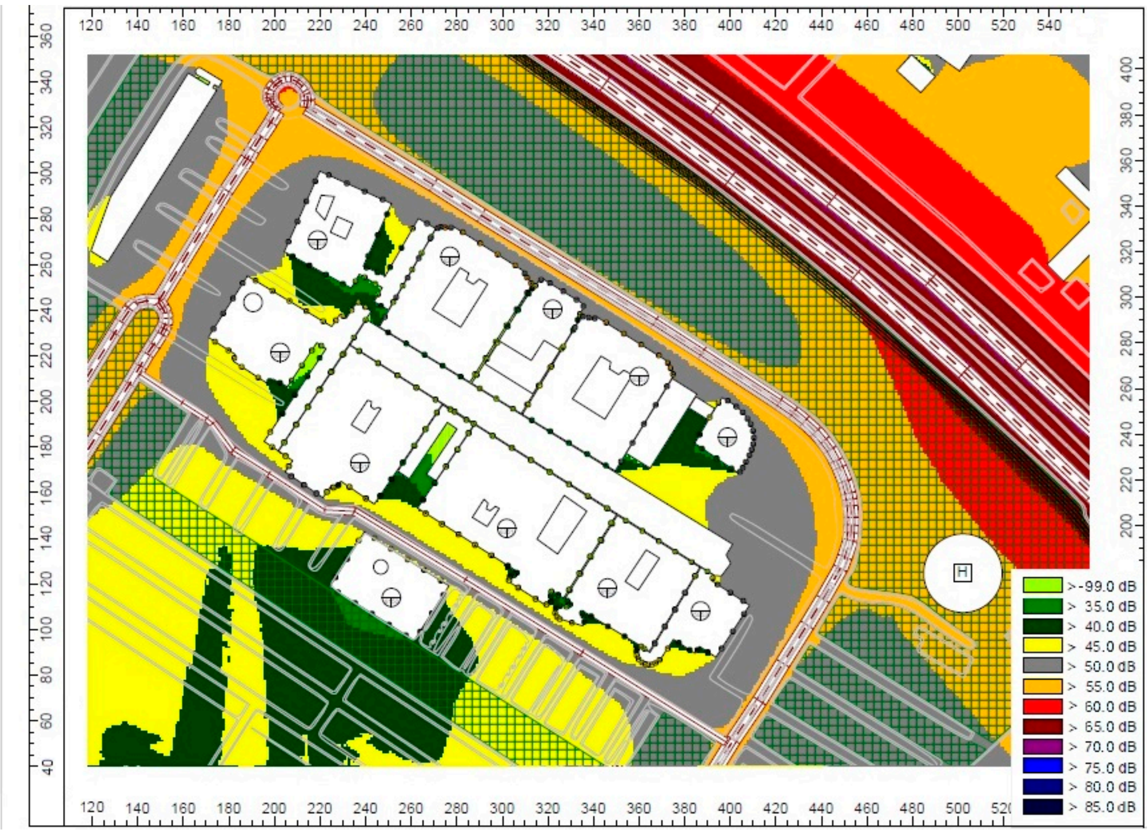

Figure A16. JRJUH outdoor noise map (with screen), night period (Ln), at 4 m above the ground.

Table A1. Noise level values per period in measurements (M): CadnaA model (C), and CadnaA with acoustic screens (S).

Level	Point 1	Point 2	Point 3	Point4	Point 5	Point 6	Point 7
Ld (M)	67.4	66.3	66.7	64.1	63.3	58.6	60.2
Ld (C)	65.0	65.0	65.0	63.0	60.0	57.0	60.0
Ld (S)	61.0	61.0	62.0	58.0	53.0	56.0	58.0
Le (M)	65.3	64.5	64.6	59.5	60.9	56.8	58.0
Le (C)	64.0	63.0	64.0	60.0	57.0	55.0	59.0
Le (S)	60.0	59.0	61.0	54.0	52.0	53.0	57.0
Ln (M)	58.9	58.2	58.6	57.6	58.9	54.2	54.0
Ln (C)	57.0	57.0	58.0	57.0	54.0	50.0	53.0
Ln (S)	56.0	55.0	57.0	47.0	48.0	47.0	52.0
Lden (M)	68.5	67.7	68.0	65.7	66.3	61.8	62.1
Lden (C)	67.0	67.0	67.0	65.0	62.0	59.0	62.0
Lden (S)	64.0	64.0	65.0	61.0	56.0	58.0	61.0

Analysis of Comparison of the Exterior–Interior Measurements

To quantify the differences between the equivalent indices 1 h between the inside and outside of the "Emergency" area, a linear regression fit has been performed, as shown in Figure A17.

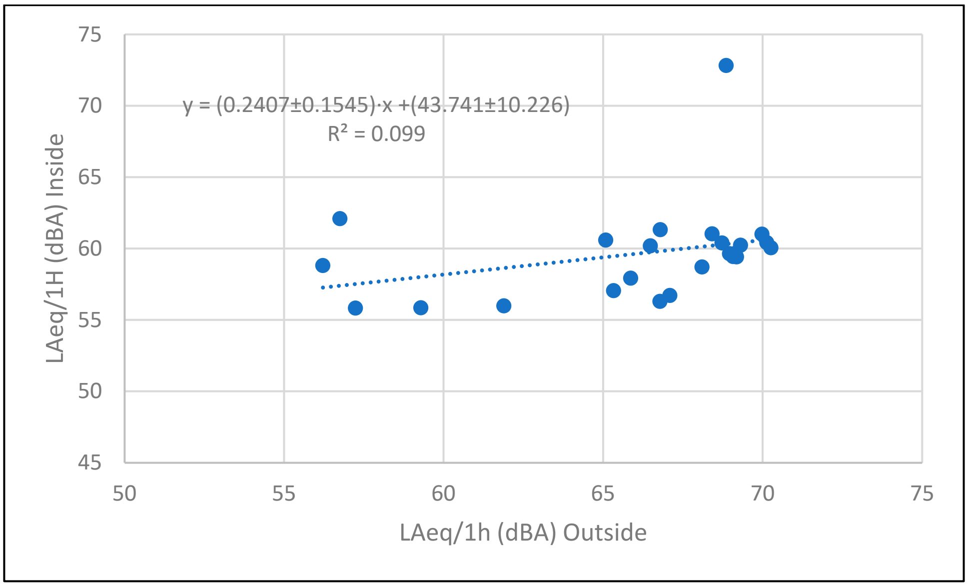

Figure A17. Comparison inside–outside LAeq/1h levels in "Critical Care" area.

The fit, with its uncertainties, is given by the following equation:

$$LAeq.1h(inside) = (0.2407 \pm 0.1545) \cdot LAeq.1h(outside) + (43.741 \pm 10.226)$$

and the coefficient of determination: $R^2 = 0.099$.

If the same fit is made to quantify the differences between the equivalent 1-hour indices between the inside and outside of the "UCI" area. Figure A18 is obtained:

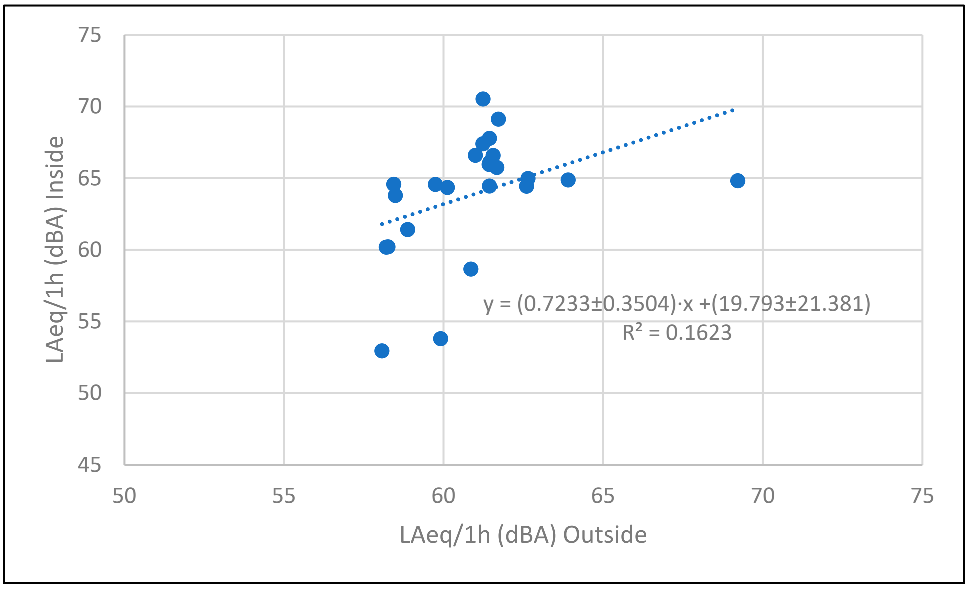

Figure A18. Comparison inside–outside LAeq/1h levels in "UCI" area.

The fit. with its uncertainties. is given by the equation:

$$LAeq.1h(inside) = (0.7233 \pm 0.3504) \cdot LAeq.1h(outside) + (19.793 \pm 21.381)$$

And coefficient of determination: $R^2 = 0.1623$.

This again indicates that the noise outside the hospital in the "ICU" area has no impact on the noise inside the hospital.

Likewise, to quantify the differences between the equivalent indices 1 h between the inside and outside of the "Surgery Hospitalisation" area, a linear regression fit has been performed, as shown in Figure A19.

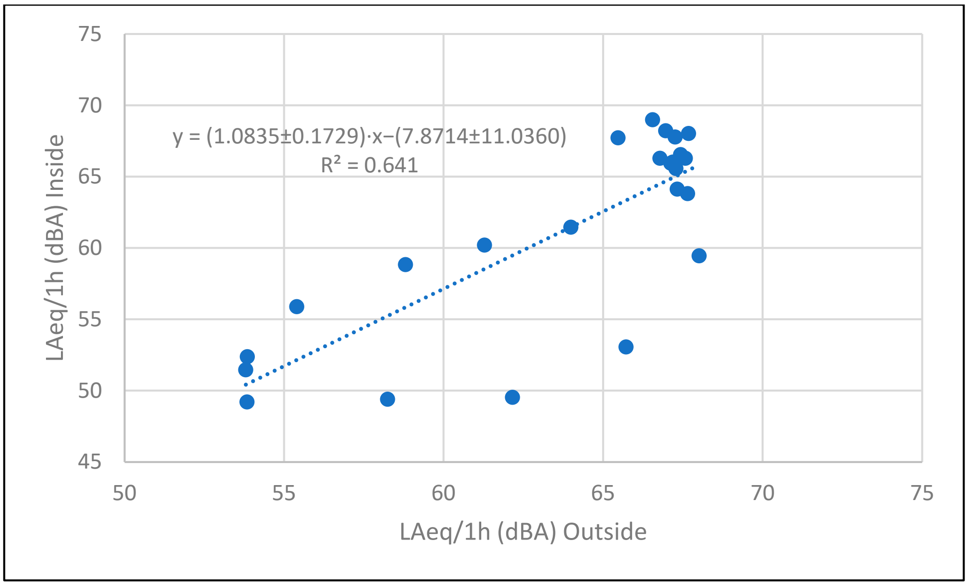

Figure A19. Comparison inside–outside LAeq/1h levels in "Surgery Hospitalisation" area.

The fit, with its uncertainties, is given by the equation:

$$LAeq.1h(inside) = (1.0835 \pm 0.1729) \cdot LAeq.1h(outside) - (7.8714 \pm 11.0360)$$

Since the slope of the regression line may be compatible with the unit, this may suggest that there may be a small correlation between the exterior and interior acoustic environment of this area. The coefficient of determination of $R^2 = 0.641$ indicates that if it exists, it is very slight.

There is a mean difference of $\overline{x} = (-2.56 \pm 0.85)$ dBA and a standard deviation $\sigma = 4.16$, which has been determined as $\sigma = \sqrt{(x_i - \overline{x})^2/(n-1)}$:

As a third test, if the *t* statistic is applied to the means of two paired samples, using the Excel programme, the results in Table A2 are obtained.

Since $t_{exp} > t_{0.975}$, it cannot be concluded that there are no significant differences between LAeq. 1h (outside) and LAeq. 1h (inside).

These three checks indicate that the noise outside the hospital in the "Surgery Hospitalisation" area has no impact on the noise inside. This is perfectly justified, since the location of the interior measurement points in the "Surgery Hospitalisation" area of the JRJUH in Huelva (Spain) was in the nursing control area. As in most hospitals, these controls are in a central location in the area, away from the façades of the buildings.

Thus, for example in the JRJUH, as can be seen in Figure A20, the measurement point (in the nursing control area) is isolated from the main façade (NE orientation of the building) by a row of double patient rooms, from the façade of the inner courtyard (NW orientation) by the visitors' living room, and from the left side façade of the courtyard (SE orientation) by another row of individual patient rooms.

Table A2. Results of the t statistic applied to the means of two paired samples: outside/inside (Surgery Hospitalisation).

	LAeq. 1h (Outside)	**LAeq. 1h (Inside)**
Mean	63.6	61.1
Variance	26.1	47.8
Observations	24	24
Pearson correlation coefficient	0.80062111	
Hypothesised difference in means	0	
Degrees of freedom	23	
t statistic	3.009291211	
P(T $\leq t$) one-tailed	0.003126195	
Critical value of *t* (one-tailed)	1.713871528	
P(T $\leq t$) two-tailed	0.00625239	
Critical value of *t* (two-tailed)	2.06865761	

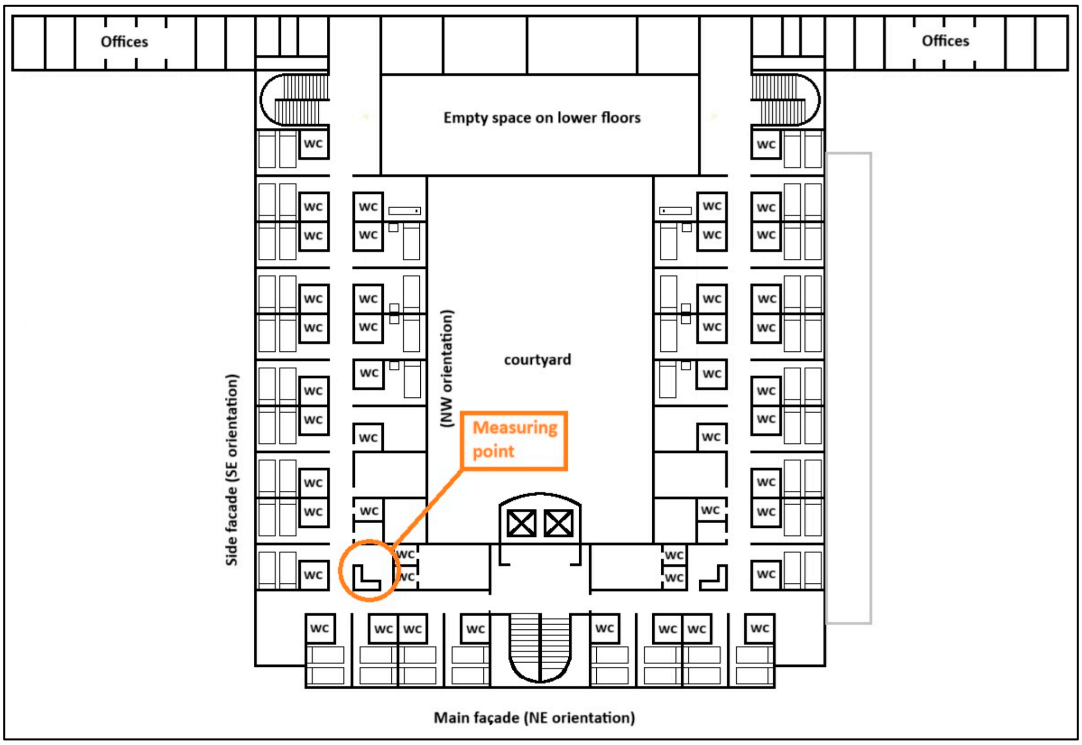

Figure A20. Measuring point in "Surgery Hospitalisation".

From this, it is concluded that the outside noise of the JRJUH does not condition the interior acoustic environment of the different interior areas of the hospital.

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