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Acoustics of Modern and Old Museums

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ABSTRACT

The goal of this study is to acoustically characterize typical modern and old museums. Modern museums can easily have a bad acoustic behavior due to the widespread use of very smooth and reflective coatings, hard floors, high-ceilings and very expressive volumes. This situation is not usually seen in "old" museums. Acoustic analyses of two case-studies (the 1999 Contemporary Art Museum of Serralves and the National Museum of Soares dos Reis, in Porto, Portugal) are held using objective parameters measured *in situ* in their largest showrooms (RT, RASTI, LAeq background noise HVAC and NC/NR). This work studies the generic acoustic requirements of these buildings and recommends optimal values for those parameters. Some proposals for the acoustical improvement in the main rooms are suggested. A short comparison of results with other museums is shown.

1. INTRODUCTION

The museums have evolved in the last centuries. The ones of a "traditional" typology (or "old" in the terminology used here) are installed in historic buildings, where its past or architectural features are also documents to be preserved. In this context of valuing a historic reference certain aspects of the visitors' environmental comfort are sometimes neglected, such as the acoustics.

Museums here called "modern" are those characterized by having a building typology later than the mid-twentieth century, considered the generation of reinforced concrete, buildings framed in the *modern* and *post-modern* architectural styles. They are often installed in buildings specifically constructed for this purpose.

The architecture in museums is often a goal but the acoustics also has a special value because these buildings are busy areas, but where silence should prevail, particularly in exhibitions rooms. The connection between both arts is in the relationship between geometry and materials. Therefore, the architectural changes that museums have suffered throughout history have also had major repercussions on their acoustic characteristics.

The acoustics of "modern" museums suffers from major weaknesses arising from the characteristics of the architecture of recent decades, in the desire for smooth surfaces, highly reflective, large spans and glazing areas, high ceilings and the large use of stone materials and/or glazed ceramic. The situation is aggravated with the usual large number of visitors that easily generates high levels of background noise. The geometric characteristics of the exhibition halls, their materials and the very terms of use of these spaces, easily allow to high reverberation and associated problems, such as lack of speech intelligibility (important in guided tours), echoes, or high background noise, motivated by a sound field dominated by the reverberated component.

2. SAMPLE

This work uses two museums as typical examples: an "old" art museum (National Museum of Soares dos Reis) and a "modern" museum (Contemporary Art Museum of Serralves). The goals are to acoustically characterize these museums by objective parameters measured *in situ*, to suggest corrective measures and to make a comparison with other museums.

The National Museum Soares dos Reis (NMSR) is installed in the *Palace of the Carrancas* (Porto, Portugal) in a neoclassical building built in 1800 (Figures 1 to 3). In 1934 works begin to adapt it to a museum. In 1992 it is again renovated, by architect Fernando Távora.



Figures 1 to 3: National Museum of Soares dos Reis (exterior view and tested rooms nº 2 and 16).[1]


Figures 4 and 5: Museum of Contemporary Art (Serralves), Exterior view and tested room n. 11.[2]

The Contemporary Art Museum of Serralves (CAMS), also located in Porto, is a typical example of a "modern" museum. The building (1999) designed by the architect Siza Vieira, has three floors (total area 12,670 m^2) with 14 exhibition rooms (occupying 4,485 m^2), almost entirely with double floor height (Figures 4 and 5). The exhibition halls are wide and free of partitions inside. The walls are lined with plasterboard; floors are in hardwood except for two rooms (# 12 and 13) with a marble floor. The ceilings are mostly plasterboard coated, having some areas with the acoustic material *Wilhelmi Alvaro,* both with a reduced air space (≈ 5 cm).

3. IDEAL VALUES

Some of the parameters that can characterize a good acoustic behavior of a museum room are: Reverberation Time (RT), STI or RASTI, the sound level of HVAC background noise and the corresponding noise criteria curves and the background noise with visitors. In Table 1 are the values that can be considered ideal for these parameters in exhibition rooms.

These ideal RT ranges of values attempt to fit the acoustic needs of different museums, which may, in case of existence of multimedia systems, to choose the value of 0.8 s and in other circumstances, go to 1.4 s. It is further recommended that the RT values, even if framed in those ideal values, should be within the expectations of visitors, i.e., larger rooms shall have a slightly higher reverberation than smaller rooms, because this is the feeling that visitors subjectively expect.

The study of the requirements for the levels of background noise made in this work led to recommend a 45 dB(A) maximum value, which should correspond to maximum levels of NC-35 and NR-37.

As regards RASTI or STI values they should be within the range of 0.45 to 0.65 to create good speech intelligibility conditions for near field but not for remote field intelligibility. Trying to balance those criteria of speech intelligibility and privacy, the value 0.45 prioritizes privacy, while the 0.65 privileges intelligibility.

Table 1: Ideal values for museums exhibition rooms and for several acoustical parameters.

Parameter	RT (s) [500, 1k Hz]	RASTI	$L_{A\,eq}$ - background noise level with HVAC (dB)	NC	NR
Ideal values	[0.8 ; 1.4]	[0.45 ; 0.65[	≤ 45	≤ 35	≤ 37

4. MEASUREMENTS

A. Methodology

The objective acoustic characterization of the exhibition rooms of the two museums was done (April 2012) by *in situ* measurements of Reverberation Time (RT), equivalent continuous sound pressure level of the background noise (*LAeq HVAC off*); equivalent continuous sound level of noise with HVAC (*LAeq HVAC on*)*;* equivalent continuous sound pressure level of background noise with visitors (*LAeq visitors*), and Rapid Speech Transmission Index (*RASTI*), using a sound level meter *B&K 2260*, a sound source *B&K 4224* and a RASTI analyzer *B&K 3361*.

Three representative rooms were selected in each museum (n. 11, 12 and 14 in CAMS and n. 2, 5 and 16 in NMSR) whose dimensions are shown in Table 2. In the NMSR only the rooms in the old palace (not in the new annex) are used to represent typical situations of an "old" museum (Figures 2 and 3).

Table 2: Dimensions of the rooms tested at both museums.[1,2]

Museum	National Museum of Soares dos Reis			Contemporary Art Museum of Serralves		
Room #	2	5	16	11	12	14
Volume (m^3)	350	510	710	1,760	1,350	1,070
Maximum height (m)	3.00	4.85	6.70	8.73	5.16	6.77

B. Reverberation Time

The Reverberation Time values were measured at three positions in each room, per octave band from 125 to 4k Hz and resulted in the values seen in Figure 6 and Table 3.

The CAMS has the rooms with the highest RT values, nearly 1.5 s superior to the traditional NMSR rooms. Room 11 showed the worse reverberation. Those high reverberation time values are justified by the characteristics of the CAMS rooms (large volumes, very high ceilings and very reflective surfaces).

In NMSR is room 16 that has the largest RT value (3.0 s) almost doubles room 2 values due to the large difference in volumes.

Analyzing the average RT values with the ideal range for museums (0.8 to 1.4 s) only room n. 2 of NMSR approaches this recommendation.

The figure 7 compares the evolution of average RT values concerning the room volumes in both museums. The "old" museum RTs show a step increase with volume as the "modern" museum has it more softly (but much higher values).

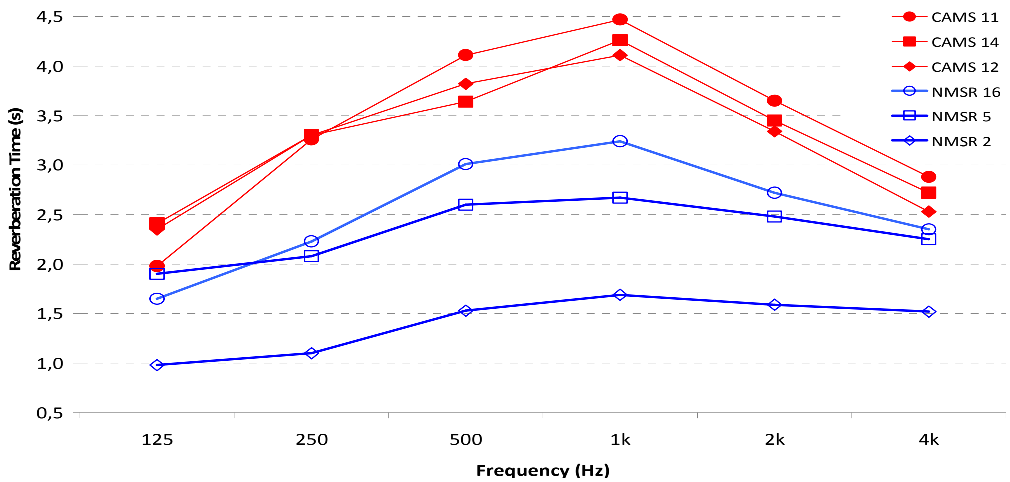

Figure 6: Reverberation Times at the six rooms at both museums (above red CAMS, below blue NMSR).[1,2]

Table 3: Average Reverberation Time and RASTI values at six rooms of both museums.[1,2]

Museum	National Museum Soares dos Reis			Contemporary Art Museum of Serralves		
Room #	2	5	16	11	12	14
RT avg. [500, 1k, 2k Hz]	1.6	2.6	3.0	4.1	3.8	3.8
RASTI room avg.	0.53	0.47	0.47	0.40	0.42	0.45

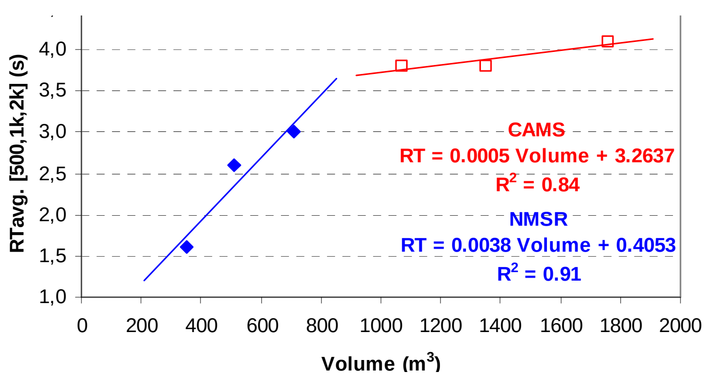

Figure 7: Average RT values related with room volumes, in both museums (above red CAMS, left blue NMSR).

C. RASTI (*RApid Speech Transmission Index*)

The RASTI measurements were held at six positions in each room (three readings in each). The results (Table 3) show that the intelligibility in rooms 11 and 12 (CAMS) is *poor* (0.30-0.45) and in the other rooms is at the low end of the *fair* grade (0.45-0.60). Overall, the values in the "old" NMSR (average of 0.49) are better than the ones in the "modern" CAMS (average of 0.42).

The explanation for the presence of these low values is the lack of sound absorption in the rooms, and as a result, when a sound is made (as the human voice) it tends to delay to fade away. In a museum the lack of speech intelligibility can be understood with a double meaning, on the one hand, in these spaces there is a great need to create good conditions for the guides speech intelligibility and on the other hand, when people are not accompanied by guides it should be a certain speech privacy (the opposite of intelligibility) so that people feel comfortable in their space and are not disturbed by the conversations of others.

The variation of the RASTI values in rooms was 0.49 ± 0.04 (in "old" NMSR) and 0.42 ± 0.03 (in "modern" CAMS). Analyzing these values with the ideal range (0.45-0.65) all rooms in the NMSR meet that requirement but just one in the CAMS (and barely).

D. Background Noise

1. Method

The measurement of the sound level of the background noise in the museums' rooms was done in two phases: Museum without visitors (closed to the public), with HVAC equipment off and then activated; Museum with visitors (open to the public) and the HVAC equipment activated.
The measurements were done at one position in each room, by octave bands from 16 to 8k Hz, each measurement in 10 minutes, with only two persons present in the first stage and with about 5 to 20 people in every room during the second phase.

2. Background noise without visitors

In CAMS the measured values of the A weighted sound pressure levels of background noise without visitors (with and without HVAC) show that the noise in the rooms is very variable in frequency, with a major importance in the middle frequencies (Figure 8). The HVAC operation revealed a noise increase in rooms 11, 12 and 14 (CAMS) respectively for 9.0 / 2.2 / 1.3 dB(A), presenting room 11 the maximum background noise.

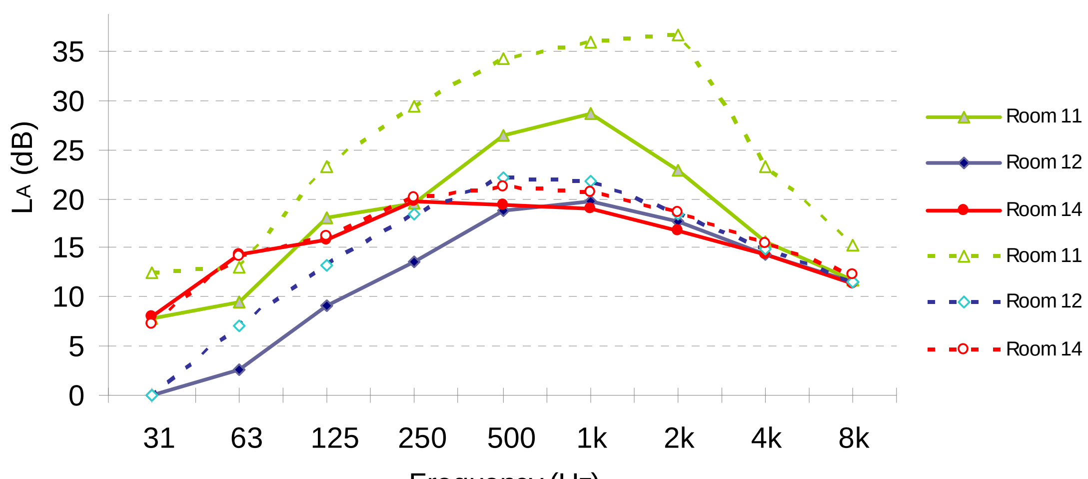

Figure 8: Background sound pressure levels (A weighted), with (-) and without (---) HVAC at CAMS.[2]

In NMSR the values of the sound pressure levels (A weighted) with and without HVAC are shown in Table 4 (room 16 did not have an operating HVAC).

Without the HVAC, rooms 2 and 16 have the largest noise levels (42 dBA) while room 5 has noise levels of 29 dB(A). That higher result is due to the fact that such rooms are in the front facade of the building, facing a major urban street. This traffic increases in 13 dB(A) the sound levels of the rooms exposed to it.

With the HVAC on, room 2 has the higher noise levels (47 dBA) motivated by its proximity to the street and by the exterior noise, although the noise from the HVAC system looks similar. Room 5 has the lowest noise level of (40 dBA).

A comparison of the sound levels with the HVAC on and off in both museums (Table 4) show that the HVAC produces an increases up to 11 dB(A) in relation to existing background noise (in room 5 NMSR). The all rooms' noise level average, in each museum, indicates that is in the NMSR that the HVAC causes a greater increase in sound level over the background noise.

Noise criteria curves (Noise Criterion NC and Noise Rating NR) with the noise of HVAC were also calculated (Table 4). Significant differences in the CAMS results were found that show the disparity between the levels of background noise in room 11 and rooms 12 and 14, being the 11 significantly more oppressive and causing discomfort. In NMSR room 2 does not respect the ideal conditions (NC ≤ 35) indicating a possible nuisance by operating the HVAC.

Table 4: Noise levels (HVAC *off* and *on*, and with visitors), their differences, and NC/NR at both museums.[1,2]

Museum	NMSR			CAMS		
Parameter — Room #	2	5	16	11	12	14
L_{Aeq} HVAC off (dB)	42	29	42	32	25	26
L_{Aeq} HVAC on (dB)	47	40	*	41	27	27
ΔL_{Aeq} (= L_{Aeq} HVAC on - L_{Aeq} HVAC off) (dB)	5	11	*	9	2	1
L_{Aeq} visitors (dB)	60	62	58	66	63	61
ΔL_{Aeq} (= L_A visitors - L_A HVAC on) (dB)	13	23	*	25	36	34
ΔL_{Aeq} (= L_A visitors - L_A HVAc off) (dB)	19	34	16	34	38	35
Noise Criteria (NC) with HVAC on	42	33	*	37	20	19
Noise Rating (NR) with HVAV on	43	34	*	39	22	21

* HVAC not available

3. Background noise with visitors

The measurements of the background noise with the museum open to the public, that is, visitors and HVAC noise (Table 4) show, in CAMS, that the equivalent continuous sound level resulted in significantly higher values (61 to 66 dBA) than without visitors (27 to 41 dBA). An increase between 25 and 36 dB(A) in the sound level was found between the situations with and without visitors (with HVAC on).

For NMSR Table 4 shows the results of the room average noise levels of visitors with guided tours (L_A *visitors*). These results (58-62 dBA) are 13 to 23 dB(A) greater than the background noise only with HVAC, which means that the visitors' noise masks the HVAC noise, making it almost unnoticeable. The room dominant noise becomes the visitors, which makes the number of persons the prevailing factor for the overall acoustical conditions within the rooms. So, on a given day when there are few people, the dominant noise is the HVAC. On days when there are many visitors, visitor noise becomes dominant.

The room noise levels with visitors are 16 to 33 dB(A) higher than without visitors and without HVAC, which also makes it almost imperceptible any noise from outside.

5. COMPARATIVE ANALYSIS WITH OTHER MUSEUMS

To analyze the CAMS acoustic behavior compared to other "modern" museums, its measured values were compared with those in the National Museum of Iceland (NMI) and in the New Acropolis Museum (Athens) (Table 5).

In these museums the RT [500, 1k, 2k Hz] values vary between 1.5 and 4.1 s, what is a broad divergence. Of the three, the CAMS presents the higher RT and to a large extent.

The lower values for the Museum of Iceland are due to a great concern for its soundscape taken into account in the rehabilitation works done in 2004. The Greek museum, built from scratch (in 2007) having very high volumes and many concrete and glazing surfaces, and anticipating a bad acoustic behavior that was solved in the design stage.

Also compared were CAMS background noise levels with the NMI when they are closed to the public but with the HVAC connected (Table 5). The *LAeq* at both museums were between 27 and 44 dB, representing a wide margin for these values but it is the CAMS that presents, in general, lower sound levels.

Table 5: Comparison of several "modern" museums.[2,3,4]

Museum	Room Volume (m^3)	RT [500, 1k, 2k Hz] (s)	L_A *HVAC without visitors* (dB)
National Museum of Iceland (Reykjavik)	115 to 1,450	1.5 to 1.7	36 to 44
New Acropolis Museum (Athens, Greece)	4,750 to 10,115	1.7 to 2.1	-
Contemporary Art Museum of Serralves (Porto, PT)	1,070 to 1,760	3.8 to 4.1	27 to 41

6. SUGGESTIONS FOR ACOUSTIC CORRECTION

The study of CAMS' rooms revealed as major acoustic pathologies the high RT values that contribute to raise the background noise to unacceptable values and influence speech intelligibility. This is due to the high ceilings, long corridors, very large volumes and halls contactable with each other through large openings. These rooms are further characterized by very smooth and reflective surfaces with a low sound absorption coefficient and without any significant absorbent elements.

Based on those problems, some suggestions are presented to reduce the RT values closer to the ideal, by an increase of sound absorption. The ceiling systems selected were: *BASWAphon Classic*, *Sonacoustic*, *Fellert Ultra*, *Rockfon Mono Acoustic TE*, *StoSilent Top Finish* and *Wilhelmi Álvaro* (Figure 9).

Only the conclusions for room 11 are presented because it has the worst conditions (see others in [2]). It was chosen only to intervene on the ceiling (268 m^2) by replacing the existing plasterboard by the various proposals achieving a significant RT reduction (Figure 9). Most materials present a worse performance at the 125 Hz frequency band than the existing material. In the remaining frequencies there is only a slight variation of RT values among proposals.

Two additional proposals are also presented that jointly use *BASWAphon* and *Jocavi* panels for a correction in the 125 Hz band to fix a *BASWAphon* deficit absorption at that frequency.

The best solutions for room 11 are *Sonacoustic* or *StoSilent A-Tec Top Finish*, with a predicted RT [500, 1k, 2k Hz] reduction of about 3 s for about 25,000 € ($33,000) but it can double with a correction at low frequencies.

Table 6: Acoustical problems at the NMSR and corrective proposals.

Acoustical problems	Proposals
RT and RASTI	Add sound absorptive materials/systems (for example on ceilings)
HVAC noise	Change HVAC and/or improve duct isolation
Exterior noise	Change window frames and/or include double windows
Step noise	Include underlays and/or carpets

For the NMSR, Table 6 identifies its typical main problems and possible solutions. In room 2 the correction would include new interior double windows (to reduce exterior noise) and the placement of a walkway carpet surrounding the room (to minimize step noise) at a total cost around 1,500 € ($2,000); In room 5 the solution would be to put absorptive material on the ceiling and a walkway carpet surrounding the room, with a total cost of about 2,300 € ($3,000); In room 16 new interior double windows and carpet on the floor (to reduce RT) with a total cost of 5,000 to 7,500 € ($6,600-$9,800). With the restriction of not being able to change the walls, ceiling and the positioning of the exhibition, the solutions to this room are limited.

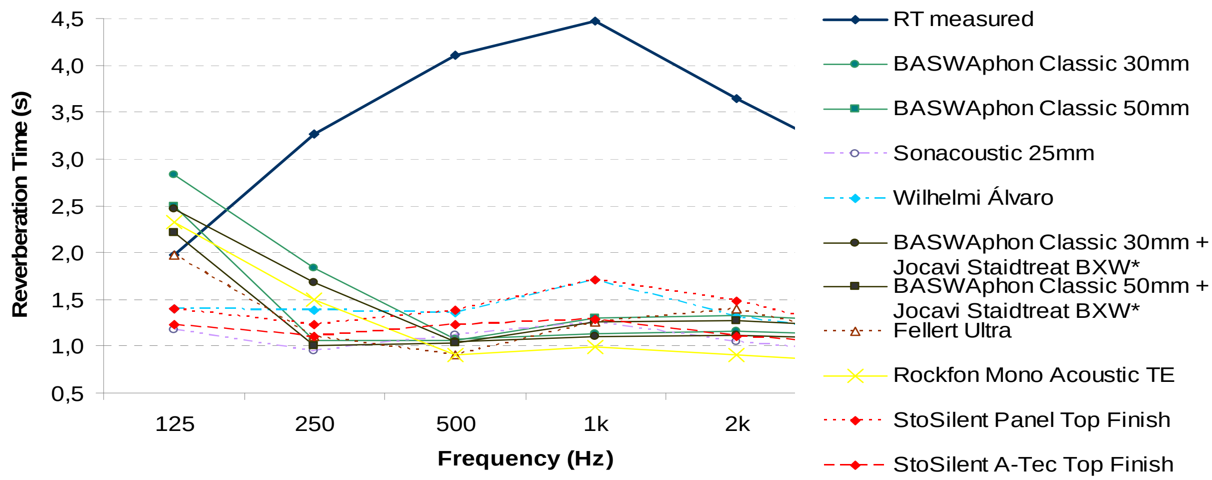

Figure 9: Measured and predicted RT in Room 11 (CAMS) for the suggested acoustical corrections.[2]

7. CONCLUSIONS

Table 7 summarizes the measured values in the museums and compares them with the ideal values. The average RT values are higher in CAMS (≈ 4 s) compared to the ideals and to other modern museums, due to the large room volumes, high ceilings and the existence of highly reflective surfaces.

The measured background noise values show a mismatch for the target levels. Also RASTI values show inadequate conditions of speech intelligibility but show good conditions of privacy in conversations among visitors.

Improvement at CAMS can be achieved by increasing sound absorption at the exhibition halls' ceilings with a minimum cost of approximately 25,000 € ($33,000) per room, which would reduce the average RT of about 3 s.

In the "old" museum (NMSR) measures to improve its acoustics were also suggested by using double interior windows (to reduce background noise from outside), carpet walkway circling the rooms (to minimize step noise and decrease RT) and, where aesthetically possible (a major but usual restriction in this type of museum) an increase of ceiling absorption, with a total cost per room, between 1,500 and 6,300 € ($2,000 to $8,300).

Table 7: Measured in both museums and ideal values for several acoustical parameters (* HVAC not available).[1,2]

Museum	"old" NMSR			"modern" CAMS			Ideal values
Parameter Room #	2	5	16	11	12	14	
Reverberation Time (s) RT avg. [500, 1k Hz]	1.6	2.6	3.1	4.3	4.0	4.0	0.8 - 1.4
Background noise level (dB)							
L_{Aeq} (without HVAC and without visitors)	42	29	42	32	25	26	≤ 35
L_{Aeq} (with HVAC and without visitors)	47	40	*	41	27	27	≤ 45
L_{Aeq} (with HVAC and with visitors)	60	62	58	66	63	61	≤ 55
Noise Criteria (NC) / Noise Rating (NR)	42/43	33/34	*	37/39	20/22	19/21	≤ 35/37
RASTI	0.53	0.47	0.47	0.40	0.42	0.45	0.45 - 0.65

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