CONTEMPORARY SPORTS ARENA ROOM ACOUSTICS DESIGN

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In this study, the room acoustics design of sports facilities is discussed over a long-term experience on contemporary sports arenas designed and/or built-in recent years. These arenas are serving as spaces accommodating entertainment facilities from sports events to pop concerts. Acoustic design considerations vary from providing the intelligibility of the instructor to creating the required lively ambiance in these halls. Acoustical comfort conditions need to be arranged in sports arenas considering volume, function, and designated atmosphere together. The challenge of taming the reverberation time in a large arena volume increase when there is no sufficient area - approved by the design team or client- to apply sound absorptive materials. The absence of the audience after the Covid-19 pandemic has caused even a greater problem due to the lack of main sound absorptive areas in sports halls. In this study room acoustics design parameters and design limitations in sports arena projects are discussed through the available literature and in-house experience of the authors. Current practices and multi-function uses of recent sports arena designs are discussed from acoustical point of view. Comparative analysis of acoustical conditions in different cases is shared to guide future arena designs and to contribute to room acoustics studies in the field.

Keywords: sports arena, room acoustics, acoustical design, reverberation time

1. Introduction

Sports Arena structures are built with remarkable budgets and bring economic and social value to the cities. Hence, they generally tend to be used for more than a singular purpose. The activities accommodated by these structures require acoustical precision. The acoustical design of these buildings necessitates a comprehensive work including room & building acoustics design, sound isolation, environmental noise control and vibration isolation issues. This paper is focusing on the room acoustics design in the contemporary sports arenas. In this study, the state-of-the-art sports arena acoustics design is reviewed and the room acoustics design concerns are assessed over 10 Sports Arenas from 5 different countries. The main purpose is to provide a foundation for the benefit of praxis in the design of Sports Arenas.

Arena structures accommodate pop and rock events [1]. The music performances in large arena volumes are distinguished from the other music halls. In these spaces, rather than listening to the response of the architectural space, the electro-acoustic system gain significance. The reverberance is designated to be provided artificially [2]. Therefore, the hall designs aimed to be dry as much as possible by designers. Acoustically dry space is not so likely in these large volumes, in addition, this approach is contradictory to the aim of designing a lively environment for sports events [3]. Architectural room acoustics and active system design need to be considered together to create the desired lively ambiance for spectators.

While the one edge of the spectrum is about creating a lively ambiance the other is the control of the crowd noise and increasing the intelligibility of announces. The reverberation time of the hall is the primary parameter for the control of the crowd noise. Despite the noise, speech intelligibility should be high enough for the players to understand the natural voice of the coach on the field. Noise exposure of the staff, and instructors' voice difficulty during the sports game need to be considered [4]. All these concerns are related to the reverberation time parameter which is difficult to tame due to large hall volumes. Listeners expect a longer reverberation time for the larger halls [5]. Nevertheless, the reverberation time is always an issue that needs to be controlled. The main tool to control the reverberation is the application of sound absorptive materials. However, the number of suitable areas for these applications is limited in sports halls [6]. Hard and smooth surfaces are preferred for maintenance and against vandalism. Hence, discussion and determination of criteria at the beginning of the design process gain importance by pushing the limits to reach recommended values despite the challenges during the design process. Reducing reverberation time further brings material and cost concerns to these large spaces [7]. The answer to the determination of criteria for the large sports halls is searched in the literature in the scope of this paper together with the contributions from the praxis.

2. Literature review

This section compiles the reverberation time and room acoustic design discussions for different sports facilities (basketball, football, badminton, skating, swimming), multi-function arenas, and by comparing different arena volumes. The systematic review is made in the database of Scopus at the intersection of relevant keywords (Sports AND Hall AND Acoustics) and supported by non-systematic research to enlarge the review. Findings distilled by the review of seventeen resources are shared in the following Table 1.

Although the adequacy of reverberation time (RT, T20, T30, T60) as a room acoustics parameter in assessments of the sports halls is debatable, it is still the most mentioned parameter in the literature. Besides the reverberation time, bass ratio, clarity, strength, and speech transmission index are other parameters proposed to be used in the room acoustics design of large sports halls. Elimination of adverse echo by application of broadband sound absorptive materials at walls and ceilings improves the acoustical conditions [1, 8].Adaptation of bass ratio (BR) as the ratio of 125Hz-250Hz average T60/ 500Hz-1000Hz T60 is shared in literature and 1.1, 1.2 values are stated as recommended values [9]. The criteria for speech intelligibility are suggested to be in between 0.50 - 0.55 [10]. These two parameters (BR and STI) indicate a strong relationship with RT. Therefore, RT is the main tool to be used to draw the outline of the room acoustic design for sports arenas.

The mean RT value for the halls having volumes between 40,000 - 440,000m^3 is stated as 2.6 s for the average of 125 Hz, 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz (Figure 1, above). RT values can reach 6 s - 8 s levels in unoccupied halls [9, 10]. The target values regardless of the sports facility (basketball, badminton, swimming) come to a consensus around 2 s in different sources. The question raised at that point is about signifying a single target value for sports hall function. Especially regardless of the volume of the space, a single number criterion may not be reasonable. In one of the previous studies a volume-based function to define the preferable RT for the pop avenues is proposed ($T60=0{,}038*V^{0{,}325}$) [1]. Using this formula, the scattering of RTs for the assessed halls in the literature according is presented in Figure 1.

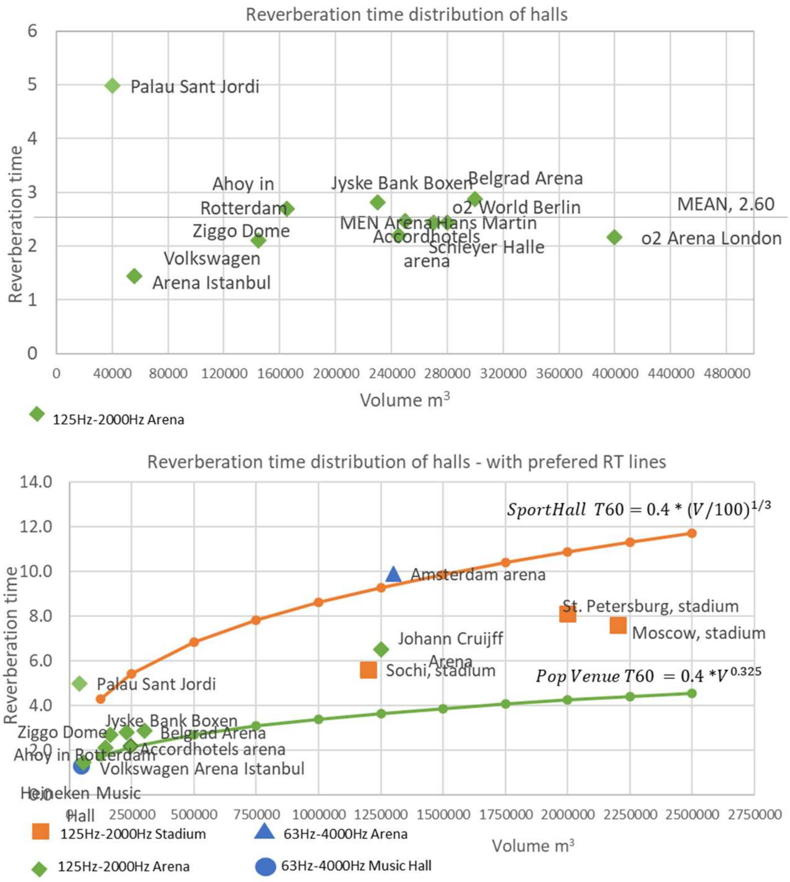

Figure 1: RT distribution of sports halls from the literature: arenas (40000-440000m^3) (above), distribution with preferred RT values (below) *(Source: produced by the author)*

Table 1: Reviewed sources for different sports functions, indicated criteria, estimated or measured RTs and the capacity of the halls

Source	**Room Function**	**Volume (m^3) or Floor area (m^2) – Audience capacity**	**RT- Criteria and Notes**	**RT- Observed (by measurement & estimations)**
[11]	Badminton court	Single court (17.40 x 9.10 x 6.70 m) 1060 m^3 Five courts (42.50 x 17.40 x 9.00) 6655 m^3	1.5 – 2.0 s at mid frequencies	NA
[12]	Basketball facilities	From 4000 seats to 15000 seats (World Championship for Women to	“To avoid excessive delay back walls and ceiling should be treated with sound absorbing elements.”	NA

<table>
<tr><td></td><td></td><td>Continental or Zone Championship stadiums)</td><td colspan="2"></td><td></td></tr>
<tr><td>[3]</td><td>Bowl acoustics</td><td>-</td><td colspan="2">“In general, for sporting events the acoustics need to be as reverberant (‘live’) as possible to provide atmosphere” speech intelligibility index (SII) of not less than 0.5 (by sound system in reference to BS EN 60268 - Sound system equipment)</td><td>NA</td></tr>
<tr><td>[9]</td><td>Stadiums with closed and open roof</td><td>Seat capacity: 47929 - 80311 (open \closed\partial roof)</td><td colspan="2">Bass ratio 1.1 - 1.2
BR based on average RT rather than EDT in consider the large space volume</td><td>4.41 s – 9.05 s (500 Hz- 1000 Hz average) T60 (s)</td></tr>
<tr><td rowspan="3">[2]</td><td rowspan="3">Indoor large pop avenues</td><td>1,300,000m^3
50,000-70,000 audience in concert organization</td><td rowspan="3">Preferred average reverberation time: T60= 0,038*V^{0,325} “for maximum control over the reproduced music, a minimum influence of the hall is wanted. (If reverberation is wanted, it can be managed electronically). More important than the actual reverberation time, is a flat reverberation spectrum from 63 up to 4000 Hz”</td><td>3.7 s</td><td>9.9 s 63 Hz-4000 Hz (without treatment and audience) 4.3 s 63 Hz-4000 Hz (with audience) Amsterdam arena</td></tr>
<tr><td>Up to 7200 audience standing</td><td>-</td><td>2.1s 63 Hz-4000 Hz …is found as “too long for the sound check in the hall without audience” (Zeniths Dijon Hall)
1.7s 63 Hz-4000 Hz …is found as “adequate” Zeniths Nantes Hall</td></tr>
<tr><td>4,8000 m^3
3200 seated 5500 standing audience</td><td>1.3 s</td><td>1.3s 63 Hz-4000 Hz
Heineken Music Hall</td></tr>
<tr><td rowspan="2">[10]</td><td rowspan="2">Football stadium (partially closed: roof over the stands & open sky above the football field)</td><td>700,000 m^3 – 2,200,000 m^3</td><td colspan="2"><4 s (125H-4000Hz) for FIFA stadiums[1] used for multi-purpose events
STI > 0,55 (with Public Announce Stystem)</td><td rowspan="2">4.1 s -8,94 s 125 Hz – 4000 Hz (Unoccupied)</td></tr>
<tr><td>>50,000 m^3</td><td colspan="2">< 2s according to Russian standard[2] for electroacoustics hall</td></tr>
<tr><td rowspan="2">[13]</td><td rowspan="2">Sport hall</td><td>10,800 m^3</td><td colspan="2" rowspan="2">1.8s for sport halls having volume around 10.000m^3
α_{mean} = 0.25, for any volume
α_{mean} < 0.20 is never recommended.
T = 0.4*(V/100)$^{(1/3)}$
based on assumption of α_{mean} = 0.25
V in Cubic meter, T in Seconds</td><td>1.79s T_{sab}</td></tr>
<tr><td>28,000 m3</td><td>2.3s T_{sab}</td></tr>
<tr><td rowspan="4">[1]</td><td rowspan="4">Indoor pop venues</td><td>165,000 m^3</td><td rowspan="4">T60=0.038*V^{0,325}</td><td>1.9 s</td><td>2.7 s average 125Hz-2000Hz (empty hall\unoccupied)
Ahoy in Rotterdam, The Netherlands</td></tr>
<tr><td>1,250,000 m^3</td><td>3.6 s</td><td>6.5s average 125Hz-2000Hz (empty), 4,3s average 125Hz-2000Hz full audience (Johann Cruijff Arena, Amsterdam)</td></tr>
<tr><td>145,000 m^3</td><td>1.8 s</td><td>2.1s (125-2000Hz)
Ziggo Dome, Amsterdam</td></tr>
<tr><td>56,000m^3</td><td>1.3 s</td><td>1.45 s
Volkswagen Arena Istanbul, Turkey</td></tr>
<tr><td>[6]</td><td>Amman sport arena</td><td>50,000 m^3</td><td colspan="2">< 2s mid frequencies unoccupied hall
< 1.5 s mid frequencies occupied hall</td><td>2.2-2.5 s (Unoccupied)
1.2-2.0 s (Occupied)</td></tr>
<tr><td rowspan="2">[14]</td><td rowspan="2">Chinese national olympic sport center</td><td>100,000 m^3</td><td colspan="2">Initial target: Gymnasium (Sport event and performances) 1.6 s (500 Hz, occupied)

Final comment at conclusion : 1.8 s – 2.0 s is proposed for large size gymnasium with 100,000 m^3</td><td>2.65 s (500 Hz , Unoccupied, measured) 1.6 s (500 Hz , Occupied, calculated according to measurement)</td></tr>
<tr><td>162,000 m^3</td><td colspan="2">Initial target: Natatorium 2.5 s (500 Hz, Occupied)

Final comment: 2.5 s – 3.0 s for speech intelligibility by loudspeaker</td><td>3.55 s (500 Hz , Unoccupied, measured) 2.42 s (500 Hz , Occupied, calculated according to measurement)</td></tr>
<tr><td>[15]</td><td>Ice Arena (skating, concert, conference and other sport activities)</td><td>53,000 m3</td><td colspan="2">“minimum objective is set as” 2.5 - 3 s to create “involving climate for sports fans”</td><td>Without treatment 6.2 s (average 125Hz-4000 Hz) > 9 s at 500 Hz
With treatment 2.2 s (average 250Hz – 2000Hz)</td></tr>
</table>

[1] FIFA World Cup Handbooks Stadium Requirements Handbook (Stadium Infrastructure & Stadium Operations) Version 2018 FIFA World Cup / 01.11.2014.

[2] Russian standard 51.13330.2011 Sound protection updated edition 23-03-2003 (Moscow, 2011).

[16]	Belgrad Arena	300,000m3	< 2.7 s (for each frequency)		Without treatment 9 s (average 500 Hz-2000 Hz) With treatment 3 s (average 500 Hz-2000 Hz)
[17]	Sports Halls	13,800 m3	Ivan Benković sports hall	2 s	4.57 (500Hz- 1000Hz)
		18,600 m3	Ljudevit Modec sports hall		5.41 (500Hz- 1000Hz)
[7]	Palais des Sports Paris-Bercy (later AccorHotels Arena)	245,000 m3 Seating capacity 17000	Purpose of use “concerts, sports events (tennis, motocross, ice skating, basketball, etc.), and political rallies.”	$T60=0.038*V^{0.325}$ 2.1 s	2.7 s (125Hz- 2000Hz) (unseated-concert set-up)
[18]	Gymnasium	≤ 5000m3	≤ 1.5 s	Tmax (s)	NA
		> 5000m3	≤ 1.8 s		
	Indoor swimming pool	≤ 5000m3	≤ 1.8 s		
		> 5000m3	≤ 2.2 s		
[19]	Natatorium	≤ 25 (capacity/m^3)	< 2.0 s	(500 Hz-1000 Hz)	NA
		>25 (capacity/m^3)	< 2.5 s		
[20]	Sports hall (band music, short dramas, and guitar performances)	55000 m^3 10000 audience	2 s		5.5 s (500Hz-1000Hz)

3. Contribution from the practice

In this section, ten arenas from five countries are presented according to the professional experience of the authors in MEZZO Stüdyo. In Table 2 aimed RT limits are presented for the designed arenas with before and after acoustical treatments. Additionally, the sound absorptive material positions are described. The arena structures are evaluated generally both in unoccupied and occupied conditions. In the era of Covid- 19 and after, the requirement of assessing the halls with different occupancy ratios arose as depicted for Abdi Ipekçi Sports Hall of Basketball Federation and Lagos Arena. RT values in Table 2 are estimated by geometrical room acoustics models. Studies in literature indicate that hybrid ray-tracing simulations shows the same distribution tendency with field measurements and geometrical acoustics is accurate method for estimations [20] however, they may result with rather an overestimation according to the field measurements [21].

The acoustical performance of these ten sports halls from practice are compared to selected cases from the European region in literature [22] as represented in Figure 2. RT values for the selected arenas in literature are presented in Figure 2 by grey area. RT values for arenas selected from literature are presented in Table 3 in 1/1 octave bands.

Table 2: Sports Arena room acoustics design parameters and materials

Project / Location / Year	**Function/ Scenarios**	**Volume (m^3)**	**RTmid Design Goal (s)**	**RTmid (s) Without Treatment**	**Acoustical Intervention**	**Final RTmid (s)**
Sinan Erdem Arena, İstanbul, 2009 Designer: ARIMA Architects Contractor: Istanbul Municipality	Arena	321,000 m^3	2 s – 3 s ** 1.6 s - 2.4 s *	-	Ceiling surfaces: 52kg/m^3, 50mm thick mineral wool layer (covered with acoustically transparent fabric) placed in chessboard pattern	2.27s *
Ankara Arena, 2010 Designer: Yazgan Design Contractor: Turkish Basketball Federation	Arena	164,077 m^3	< 3s*	-	Hall roof and VIP ceiling: perforated gypsum with mineral backing	2.5s *
Konya Velodrome, 2013 Designer: Artı Architecture Contractor: Konya Greater Metropolitan Municipality	Arena		< 2.5 s	9.66 s	Alt. 1. Back isle ceiling surfaces: perforated gypsum with mineral backing Side surfaces of suspended ceiling, façade window, parapet and side wall surfaces: perforated metal with non-woven textile and mineral backing Alt.2. (In addition to Alt.1.) 13mm stabilized aluminum foam with mineral backing	(A1) 7.57s* (A2) 2.67s*

Baku Olympic Stadium, 2012 Designer: Contractor:	Arena	64,000 m^3	< 2.5s (fully occupied)	5.28s	Roof surfaces: 1305 g/m^2 PFTE	3.98s
Fenerbahçe Şükrü Saraçoğlu Stadium, İstanbul, 2017 Contractor: MÖN Construction	Arena	411,768 m^3	-	4.31s - 4.37s (500Hz)	Roof surfaces above behind-goal tribune: 1550 g/m^2 PFTE Reflective billboards inclined to game field: Metal plates Main target: to enhance the direct sound from spectator area to the field	4.36s - 4.5s (500Hz)
Chisinau Arena, Moldova, 2018 Designer:Yazgan Design Contractor: ICS Summa SRL	Multipurpose Sport facility	53,951 m^3	< 3s	-	Around roof trusses: Pyramid-like application of molton fabric, Lodge ceiling and wall surfaces: perforated gypsum with mineral backing	2.4s*
Chisinau Arena Aquacenter, Moldova 2018 Designer:Yazgan Design Contractor: ICS Summa SRL	Olympic Swimming Pool	13,603m^3	< 3s	-	Ceiling surfaces above pool & wall surfaces behind starting block: Mineral wool tile with airgap behind	2.45s
Kigali Arena, Rwanda, 2018 Designer:Yazgan Design Contractor: ICS Summa SRL	Multipurpose Sport facility	125,000 m^3	< 3s	-	A1. perforated trapeze ceiling on whole upper roof surface area with mineral backing A2. perforated trapeze ceiling on upper roof surface above main game field with mineral backing	(A1) 2.5s * (A2) 3.46s*
Lagos Arena, 2019 Designer:Yazgan Design Contractor: Sinerji Construction	Multipurpose Sports facility S1.basketball S2.pop/rock concert S3.congress	280,000 m^3	< 2.5s	-	Inner finish layer of roof: perforated trapeze with mineral wool corrugated core infill Lodge ceiling surfaces, wall surfaces over 3 m facing the game field: perforated gypsum with mineral backing	(S1) 2.33s* (S2) 2.14* (S3) 2.28s*
Abdi İpekçi Sports Complex, İstanbul, 2021 Designer: Teğet Architecture Contractor: Turkish Basketball Federation	S1. fully occupied S2. 50% occupied S3 25% occupied	200,000 m^3	2s – 2.2s	3.49s	Roof surfaces: 45mm mineral wool panels (with acoustically transparent fabric facing) Wall surfaces facing the game field: perforated gypsum with mineral backing Dividing curtains: 470 kg/m^2 serge wool	(S1) 1.84s (S2) 2.02s (S3) 2.13s
* fully occupied, ** without audience						

Table 3: Selected sports arena within EU, T30 (s)

Arena	Volume (m^3)	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Jyske Bank Boxen	230,000 m^3	2.77	2.87	2.75	2.86	2.82	2.18
MEN Arena	250,000 m^3	3.09	2.6	2.3	2.32	2.06	1.53
o2 World Berlin	280,000 m^3	2.74	2.6	2.32	2.31	2.23	1.76
Hans Martin Schleyer Halle	270,000 m^3	2.64	2.55	2.27	2.49	2.21	1.57
o2 Arena London	400,000 m^3	2.77	2.15	2.01	2	1.92	1.62
Palau Sant Jordi	40,000 m^3	5.3	5.56	5.57	4.75	3.73	2.85

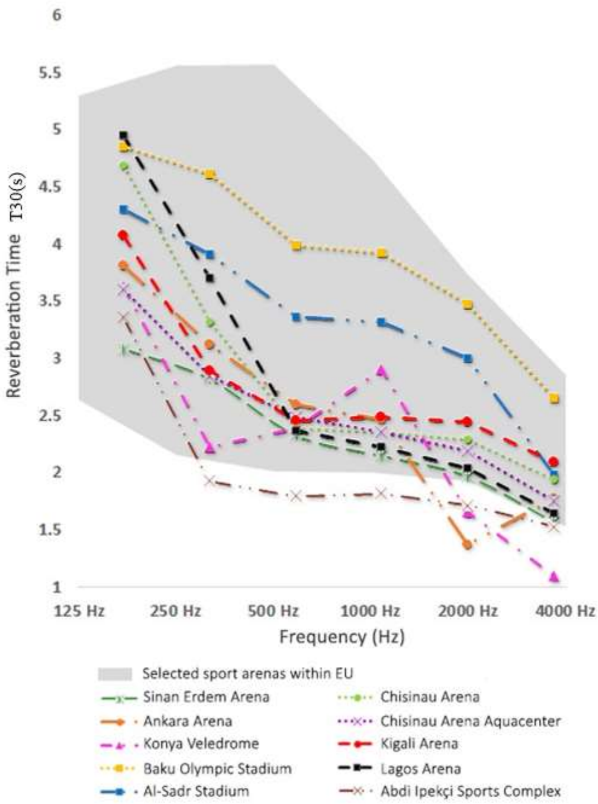

Figure 2: Reverberation time distribution of sport arenas

4. Conclusion

This study exhibits the challenges of room acoustics design for sports arenas with large volumes and varying functions. Despite the general statement about the reverberation time criteria for the sports halls is around 2 s, the shared reverberation time values in the literature emphasize the difficulty of depending on a single value regardless of the volume. The mean reverberation time for the arenas shared in the literature (40,000 – 440,000 m^3) is 2,6 s (125Hz-2000Hz average). 2.5 s – 3.0 s limit values in mid frequencies are aimed for the recently built ten sports arenas which have acoustically effective volumes from 13.603 m^3 to 827,900 m^3. The limits are specified in consideration of desired lively atmosphere and requirements of the electro-acoustical system together. The reasonable limit values are achieved for these halls within the limits of the architectural design by avoiding the unnecessary precautions and overuse of sound absorptive materials. Durability, long-term maintenance, and structural stability are effective factors in the material decision process besides their sound absorption and scattering characteristics. Considering the real-life concerns and conditions, with this study an acoustical criteria guide is aimed to be provided for future sports facility designs.

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