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Acoustics features of sports facilities on the example of FIFA 2018 football stadiums in Russia

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ABSTRACT

The FIFA World Cup 2018 an international football tournament took place in Russia at 12 stadiums in 11 cities: Kazan, Kaliningrad, Moscow, Nizhny Novgorod, Rostov-on-Don, Saint Petersburg, Samara, Saransk, Sochi, Volgograd and Yekaterinburg. Some stadiums were «greenfield projects», others were adapted to FIFA requirements. Acoustic parameters as reverberation time and speech transmission are standardized for FIFA stadiums. After the tournament is finished, the stadiums are to be used both for football games and commercial purposes: concerts and shows with the use of PA Systems. If stadiums are used as concert venues, their acoustics should be high. An acoustic survey of the stadiums was carried out. Acoustic parameters were measured in unoccupied stadiums. Recalculation of occupied stadiums was made in computer simulation models. The measured values of acoustic parameters were analyzed and compared with FIFA acoustic requirements. Positive and negative acoustic characteristics of the stadiums were determined. Acoustic characteristics were compared with architectural features.

Keywords: stadium's acoustics, acoustic measurement, reverberation time

1. INTRODUCTION

World Cup of 2018 took place in 12 stadiums in 11 Russian cities: in Kazan, Kaliningrad, Moscow, Nizhny Novgorod, Rostov-on-Don, St. Petersburg, Samara, Saransk, Sochi, Volgograd and Yekaterinburg. Some stadiums were built, other were reconstructed to comply with FIFA World Cup requirements. After the World Cup, the stadiums would chiefly be used for football matches: tournaments of Russian football leagues and international tournaments. In addition, the stadiums are planned to be used for commercial events: electronic music concerts, shows, etc.

The main element of the football stadium is the stadium bowl with 35,000 to 80,000 spectators capacity, with football field, stands around the field (in 2 circles), a roof over the stands and an open sky above the football field. When conducting international competitions and concerts using the sound amplification system when spectators are in the stands, the acoustics of the stadiums has to meet high standards. During a football match, fans should perceive the announcer's information messages transmitted by the standard sound amplification system with high background noise in the stadium. During concerts, viewers should perceive the media content played by the sound amplification system with fair intelligibility. In addition, in the football mode, in accordance with work [4], the stadium response to fans emotions is also very important: the volume level of fan support sets the emotional background and atmosphere of a sports event. Thus, the task of researching and evaluating the acoustics of stadiums is relevant, since the stadium is used both for sports events and for concerts and music shows, the acoustic requirements for the stadium bowl are of different nature: high intelligibility, low reverberation and high volume level.

In the framework of this work, an acoustic survey of stadiums was carried out, and acoustic parameters were measured with empty stands. A recalculation was made for filled stands based on computer modeling. The measured values of acoustic parameters were correlated with FIFA acoustic requirements [1]. Acoustic parameters measured at 11 stadiums were compared and analyzed. Positive and negative architectural and acoustic features of stadiums were analyzed. The effect of stadium geometry on the level of fan support was evaluated.

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2. ACOUSTIC REQUIREMENTS FOR STADIUMS

According to the specification [1] requirements, the following parameters of architectural acoustic and electroacoustic are regulated at international FIFA competitions: STI speech transmission index, RT reverberation time, sound field unevenness and maximum sound level reproduced by the standard stadium amplification system. In this study, the reverberation RT time was measured, the STI index, and the unevenness of the sound field in the stands.

Criteria of specified parameters for FIFA stadiums:

– RT is not more than 4 s in the frequency range 125 – 4000 Hz when the stadium is used for multi-purpose events;

– STI (speech transmission index for PA system) for a full stadium > 0,55 (recommended value – 0,75);

– The non-uniformity of the sound field frequency response produced by the sound amplification system, should be ± 3 dB in the frequency range 125 – 4000 Hz (at STI being at least 0,5).

Based on international experience, the main specified parameter for an electro-acoustic concert hall is the RT. According to the Russian standard [2], the reverberation time for an electroacoustic hall with an air volume > 50,000 m^3 should be no more than 2 s. In addition, for the electroacoustic hall, the parameters of speech intelligibility, the uniform distribution of the sound field among spectator seats, are important along with other characteristics. However, these parameters are associated with sound amplification characteristics: radiators arrangement, radiators orientation, etc. When using a stadium for concerts, an imported (hired) set of equipment is chiefly used, therefore, these parameters are not evaluated in this work.

3. ACOUSTICAL SURVEY OF THE STADIUMS

Acoustical survey of the stadiums was carried out in compliance with standard [3]. The reverberation RT time, the STI index, and the unevenness of the sound field in the stands were measured at the stadiums without spectators. A standard sound amplification system – linear arrays and clusters installed above the seats were used as a source of the test signal. The sound receiver – the test microphone – was installed on the spectator's places in several points (at least 18 – 20 points, evenly distributed over the spectators seats). Since the stadium has a symmetrical shape, the impulse response was measured only for 1/4 of the stadium area.

3.1 Stadiums characteristics

Table 1 provides the stadiums characteristics: capacity and air volume.

Table 1 – Characteristics of stadiums

Stadium	Capacity	Volume, m^3	Stadium	Capacity	Volume, m^3
Kazan (KZ)	45 379	$1,1\times10^6$	Samara (SM)	41 970	$1,2\times10^6$
Kaliningrad (KL)	35 016	$0,8\times10^6$	Saransk (SR)	43 958	$1,1\times10^6$
Moscow (MSC)	78 011	$2,2\times10^6$	Sochi (SCH)	44 287	$1,2\times10^6$
Nizhny Novgorod (NN)	45 000	$1,1\times10^6$	Volgograd (VL)	45 568	10^6
Rostov-on-Don (RD)	43 472	10^6	Yekaterinburg (YEK)	35 696	$0,7\times10^6$
St. Petersburg (SP)	64 468	2×10^6			

3.2 Measuring RT reverberation time

The RT values, measured at stadiums in the frequency range 125 – 4000 Hz, are averaged over all measurement points and are given in Table 2.

As we can see from the measurement results, stadiums without spectators produce higher the RT value than the recommended values [1]. The RT values measured at different stadiums vary from 4,1 s to 8,94 s at medium frequencies. This difference can be explained by different geometry, air volume and finishing materials. The Yekaterinburg stadium has perforated wall cladding, the Sochi stadium does not have a roof over the transverse stands, the stadiums in Moscow and St. Petersburg have the largest roof area above the stands.

Table 2 – Measured values of RT in unoccupied stadiums

Stadium	RT, s, in the frequency range 125 – 4000 Hz					
	125	250	500	1000	2000	4000
Kazan (KZ)	5,08	5,47	5,46	5,38	4,92	3,75
Kaliningrad (KL)	3,79	4,59	5,18	5,34	4,63	3,32
Moscow (MSC)	7,91	7,52	8,24	8,18	6,12	3,44
Nizhny Novgorod (NN)	6,09	6,70	6,92	6,56	5,82	3,56
Rostov-on-Don (RD)	3,74	5,11	5,99	5,95	5,09	3,29
St. Petersburg (SP)	8,68	8,28	8,94	8,32	6,02	2,88
Samara (SM)	7,78	7,83	7,58	7,85	6,64	4,59
Saransk (SR)	5,84	6,18	6,31	6,10	4,86	3,06
Sochi (SCH)	4,48	5,29	6,05	6,20	5,75	4,28
Volgograd (VL)	4,42	5,09	5,94	5,90	4,92	3,00
Yekaterinburg (YEK)	3,85	3,89	4,10	4,35	4,12	3,21

3.3 Measuring STI speech transmission index

The values of the STI, measured at the stadiums, are averaged by first circle, second circle, and throughout the stadium and are provided in Table 3.

As we can see from the measurement results, the STI does not always correspond to ≥ 0,55, according to [1], at stadiums without spectators. Since STI depends both on the premises geometry, on the characteristics of the sound amplification system, and on the noise level in the premises, one can be assume that the tuning or correction of the PA system will allow to comply with the requirements [1].

Table 3 – Measured values of STI in unoccupied stadiums

Stadium	STI		
	First circle	Second circle	Throughout the stadium
Kazan (KZ)	0,56	0,40	0,47
Kaliningrad (KL)	0,48	0,51	0,50
Moscow (MSC)	0,47	0,40	0,43
Nizhny Novgorod (NN)	0,54	0,51	0,53
Rostov-on-Don (RD)	0,49	0,44	0,46
St. Petersburg (SP)	0,53	0,54	0,53
Samara (SM)	0,44	0,37	0,40
Saransk (SR)	0,44	0,62	0,53
Sochi (SCH)	0,52	0,48	0,50
Volgograd (VL)	0,57	0,59	0,58
Yekaterinburg (YEK)	0,57	0,52	0,54

3.4 Measuring the sound field unevenness

The values of sound field unevenness, measured at the stadiums in the frequency range 125 – 4,000 Hz, are assessed over all measurement points and are provided in Table 4. The table shows the difference between the maximum and minimum deviation of sound pressure levels from the reference value measured in each frequency band.

Table 4 – Measured values of sound field unevenness in unoccupied stadiums

Stadium	Sound field unevenness, dB, in the frequency range 125 – 4000 Hz					
	125	250	500	1000	2000	4000
Kazan (KZ)	-1,8	-2,9	-2,9	-1,8	-3,0	-4,0
	+4,2	+4,4	+3,4	+4,7	+4,7	+5,7
Kaliningrad (KL)	-3,5	-2,8	-0,7	-0,1	-0,6	-0,7
	+2,9	+4,1	+5,8	+8,2	+8,8	+9,1
Moscow (MSC)	-2,8	-4,6	-2,1	-0,6	-1,4	-6,2
	+7,6	+5,2	+4,0	+4,5	+4,1	+4,3
Nizhny Novgorod (NN)	-2,4	-2,1	-1,7	-0,2	-2,3	-2,3
	+0,4	+0,4	+1,6	+2,7	+1,0	+3,7
Rostov-on-Don (RD)	-6,4	-5,0	-5,8	-4,2	-2,9	-7,4
	+0,1	+0,7	+0,2	+0,4	+3,4	+1,8
St. Petersburg (SP)	-2,5	-2,1	-2,5	-2,6	-2,9	-3,4
	+4,3	+2,8	+3,1	+3,6	+2,5	+3,1
Samara (SM)	-1,8	-1,3	-0,4	-2,1	-3,9	-4,3
	+4,2	+4,6	+4,0	+0,7	+0,1	+0,1
Saransk (SR)	-2,3	-2,6	-1,0	-0,1	-0,6	-0,4
	+4,3	+3,1	+4,2	+4,3	+3,8	+7,2

Table 4 – Measured values of sound field unevenness in unoccupied stadiums

Stadium	Sound field unevenness, dB, in the frequency range 125 – 4000 Hz					
	125	250	500	1000	2000	4000
Sochi (SCH)	-2,1	-1,8	-0,8	-1,3	-1,1	-1,5
	+2,4	+2,5	+1,8	+2,8	+3,8	+1,7
Volgograd (VL)	-2,6	-2,2	-2,0	-1,8	-4,5	-4,1
	+3,3	+2,2	+1,2	+1,8	+2,3	+2,7
Yekaterinburg (YEK)	-2,7	-1,3	-4,5	-4,4	-3,7	-4,9
	+5,7	+5,1	+2,8	+3,2	+3,7	+1,8

As we can see from the measurement results, in some stadiums, there is unevenness of the sound field in the stands, which does not comply with the requirements [1]. Probably an additional tuning of the PA system is required.

4. ANALYSIS OF THE STADIUMS ACOUSTIC CHARACTERISTICS

4.1 Spectators effect on the stadiums acoustic characteristics

Assessment of spectator's effect on the stadiums acoustic parameters is exemplified by the St. Petersburg stadium.

To assess the spectator's effect, an acoustic model of the stadium was built in ODEON 12.15 software application. The sound absorption coefficients of stadium materials (field, walls, stands) are assumed in accordance with the sound absorption coefficients from the reference literature. The RT values obtained during the modeling correspond to the measured values with an accuracy of ~ 5%.

Table 5 shows the calculated values of the RT at the stadium with spectators (70% of the stands are filled with spectators), which are compared with the measured reverberation time values with empty stands.

Table 5 – Calculated and measured values of RT in occupied and unoccupied stadiums

Condition	RT, s, in the frequency range 125 – 4000 Hz					
	125	250	500	1000	2000	4000
Unoccupied (measured), s	8,7	8,3	8,9	8,3	6,0	2,9
Occupied (calculated), s	7,4	6,7	6,4	6,1	4,9	2,8
Difference, s (%)	1,3 (15%)	1,6 (19%)	2,5 (28%)	2,2 (26%)	1,1 (18%)	0,1 (4%)

Table 6 provides the calculated values of the STI at the stadium with the spectators, which are compared with the STI measured values with empty stands values.

Table 6 – Calculated and measured values of STI in occupied and unoccupied stadiums

Condition	STI
Unoccupied (measured, background noise 45 dBA)	0,53
Occupied (calculated, background noise 45 dBA)	0,57 (+ 4%)
Occupied (calculated, background noise 90 dBA)	0,56 (+ 3%)

Based on the results of computer modeling, the inference can be made on the spectator's positive influence on the acoustic characteristics: the reverberation time for full stands decreases at medium frequencies by up to 28%, the STI increases by 3 – 4%.

4.2 Geometry effect on the acoustics

This work presents assessment of the stadiums geometric characteristics effect on acoustics. Figure 1 shows the dependence of the RT on the specific air volume.

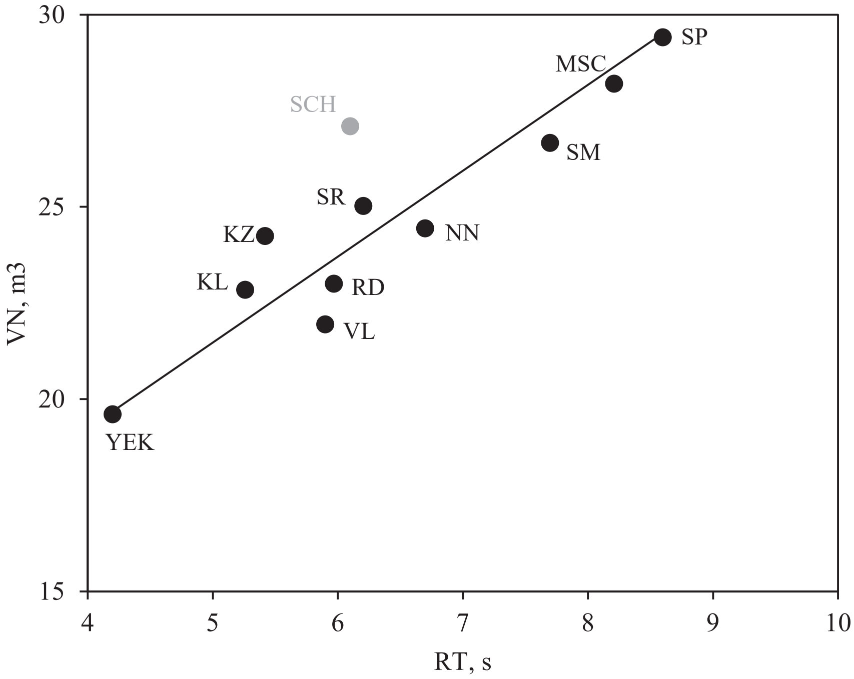

Figure 1 – RT and V_N dependence

Specific air volume per viewer V_N is determined using the formula:

$$V_N = V/N,$$

Where V – the stadium air volume, m^3, N – stadium capacity, people.
Figure 2 shows the dependence of the RT on the specific area of the stadium roofing

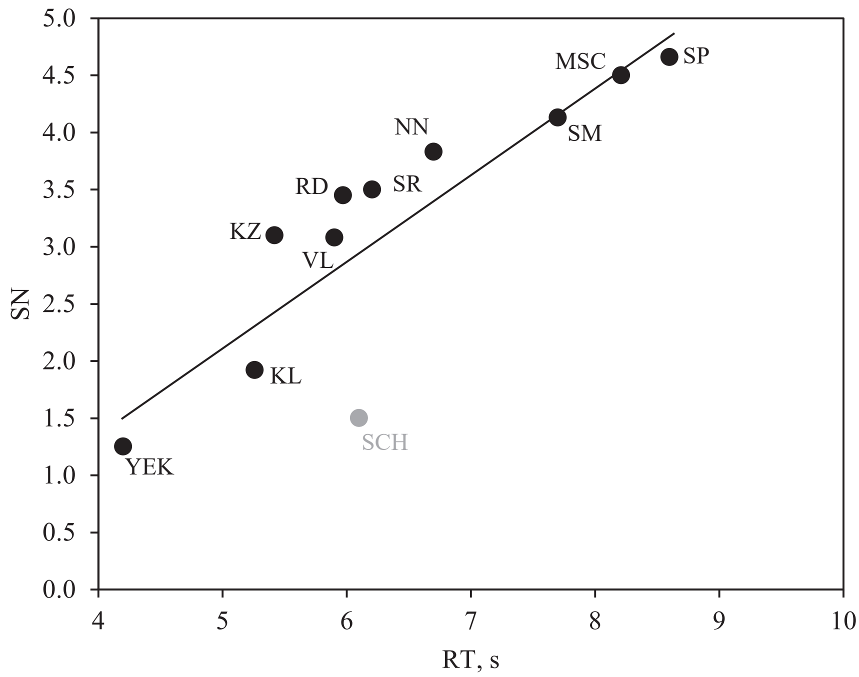

Figure 2 – RT and S_N dependence

. Specific area of roofing S_N is determined using the formula:

$$S_N = S_R/S_E,$$

Where S_R – the roofing area above the stands, m^2, S_E – the area of the glade above the field, m^2.
Based on the analysis performed, we can make inference on the RT being directly proportional to the stadiums air volume.

The roofing area above the stands is a reflective surface, therefore, an increase in the roofing area above the stands increases the RT. The Sochi stadium has roofing only above the longitudinal stands, which accounts for S_N low ratio.

4.3 Effect of the stadiums acoustics on fans support

Modeling was performed in ODEON 12.15 software application. 3 stadiums with the following forms in the plane were studied: Kaliningrad (rectangular shape), Volgograd (oval shape), Samara (circle shape).

To estimate the fan support index, the FSI was introduced, which was calculated along the stands.

$$FSI = 6 – DL2, dB,$$

Where DL2 is the rate of spatial decay of sound pressure levels per distance doubling. For a free field DL2= 6 dB. The objective of this study was to assess the impact of the stadium shape on the fan support level. The smaller the DL2 value, the lower the sound attenuation along the stands and the higher the stands fan support and consequently, the higher the FSI is.

The omnidirectional sound source was located at 2 points of the stands behind the gates (along the central axis of the stand): in the upper part of the stand (source P_1) and in the lower part of the stands at a height of approximately 5 m from the field level (source P_2). The sound source was placed at a height of 1,2 m from the floor level at the stadium (sitting fan imitation). The sound receivers were located along the stands at a distance of 20 – 30 m from each other. Up to 10 sound receivers were installed along the upper circle and up to 7 receivers – along the lower circle at a height of 1.2 m from the floor level. These receivers simulate behavior of the other fans sitting in stands.

The sound sources power level was chosen to be equal to 117 dBA (or 110 dB in octave-frequency bands 63 – 8000 Hz).

The sound absorption coefficients of stadium materials (field grass, walls, stands) are assumed in accordance with the sound absorption coefficients from the reference literature. The RT values obtained during the modeling correspond to the measured values with an accuracy of ~ 5%.

Fig.3, Fig.4 and Fig.5 provide computer models of Kaliningrad (rectangle shape), Volgograd (oval shape) and Samara stadiums (circle shape) with indication of sound sources and receivers positions.

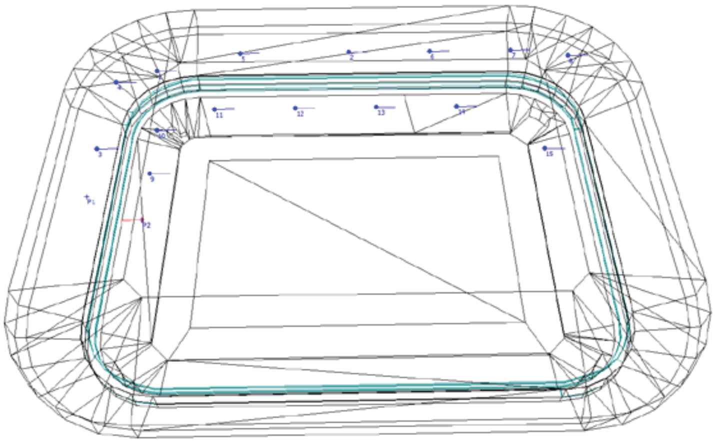

Figure 3 – KL Odeon model (rectangle shape)

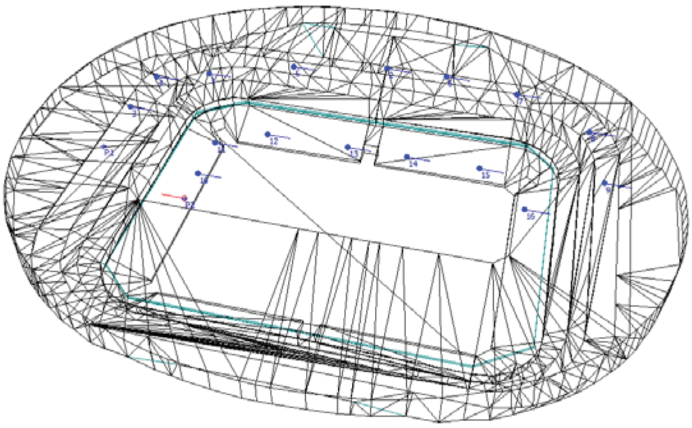

Figure 4 – VL Odeon model (oval shape)

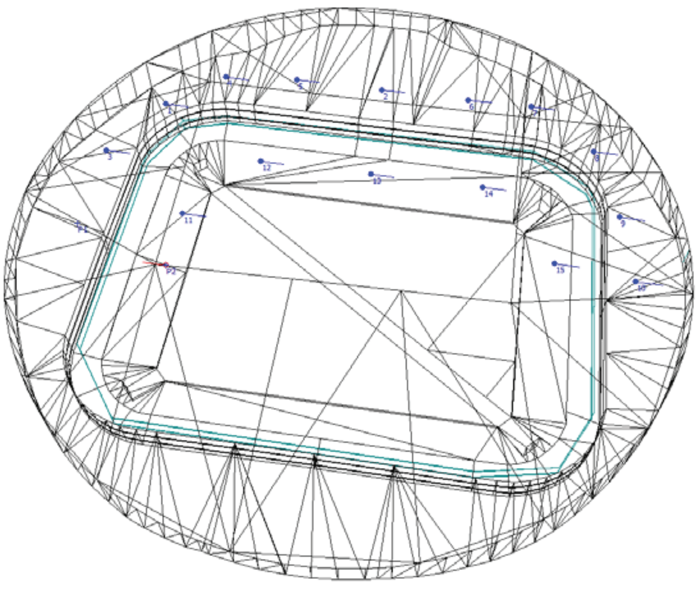

Figure 5 – SM Odeon model (circle shape)

Table 7 provides FSI values for stadiums. The lowest FSI value corresponds to the fastest sound attenuation and is determined for the Kaliningrad stadium (rectangular shape). The highest value of the FSI corresponds to the slowest sound attenuation, and thus – to high fan support, and is determined for the Samara stadium (circle shape). The Volgograd stadium (oval shape) has an average value of the FSI. The difference is most noticeable in the upper stands, while in the lower stands it is noticeable to a lesser extent, since the stadiums have similar geometry on the first circle and unique geometry on the second circle.

Thus, it is shown that the stadium shape affects the sound propagation along the stands (fan support index). The higher the FSI, the higher fan support index value is, the football fans chanting better propagates along the round stadiums stands.

Table 7 – Calculated values of FSI

Stadium	FSI, dB	
	Second circle	First circle
KL (rectangle shape)	1,9	2,0
VL (oval shape)	2,5	2,1
SM (circle spahe)	3,7	2,2

5. CONCLUSIONS

11 football stadiums in Russia were studied for the World Cup. RT values at stadiums without spectators varies from 4,1 to 8,9 s in medium frequencies. STI corresponds to values from 0,40 to 0,58. The spectator's effect on the changes in the acoustic parameters of the stadiums was assessed based on computer modeling: the RT at the stadium with spectator's decreases by up to 28% at medium frequencies, the STI for a stadium with spectator's increases by up to 4%.

The geometry of stadiums and acoustic characteristics ratio was analyzed: with an increase in the roofing area above the stadiums stand, as well as the air volume of the stadiums, increase in the RT is observed.

The effect of stadium shape on fan support was analyzed. The FSI (fan support index) was introduced, which was calculated for the stadiums Kaliningrad (rectangular shape), Volgograd (oval shape) and Samara (circle shape) based on the computer model. The FSI is higher in round stadiums.

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