Soundscape quality analysis by fuzzy logic: A field study in Cordoba, Argentina

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ABSTRACT

This research studies urban soundscapes through the comparative analysis of twelve public open spaces in the city of Córdoba (Argentina), taken as case studies. The work aims to examine selection of indicators and assessment tools intended to characterize soundscape quality. The field study was carried out through surveys and acoustic and psychoacoustic indicators, that are used together to objectively describe the sound quality of urban spaces.

The study shows that, while there is a relationship of these indicators with the sound quality of the spaces, this is not linear. Their relative importance or influence depends on the interrelations occurring between the parameters studied. A model analyzing and correlating the parameters with the sound quality, based on the postulates of fuzzy logic, was applied as a tool of analysis, and it was seen to achieve a very close approximation to the subjective or perceptual response of the inhabitants. This close match between the model results and the perceptual response of the users confirms the fuzzy model as an effective tool for the study, not only of soundscapes, but also for those situations in which objective parameters must be related to the perceptual response of users.

1. Introduction

The evaluation of sound is a complex system that relates various disciplines: acoustics, physiology, sociology, psychology, anthropology and statistics [1,2]. Research concerning the problem of urban noise has focused on two main areas considered priority for their impact on city populations: quantitative analysis of acoustic conditions (3,4) and subjective evaluation of the response of the inhabitants [5-9].

In recent times, there is a tendency to pay attention not only to the negative aspects of sound, mainly discomfort, but also to the sound quality of the space (10-12). This approach involves the concept of "sound environment design" as a stage beyond the control or reduction of noise to acceptable limits. It involves a comprehensive methodological development that takes the interaction between people, sound and context into account (13-17).

The urban soundscape normally consists of a mixture of various sounds with varying intensities, directions and durations, which makes its assessment more difficult (18). Sound sources are analyzed not only from the physical point of view, by means of acoustic indicators, but semantically, looking for the meanings that sound has for the population and the specific users (19-23). This analysis is usually conducted through a study based on the application of opinion polls on site simultaneously with measurements.

Ambient sound can cause subjective reactions, and may be appropriate, pleasant, familiar, useful for orientation, irritating, among others. Such attributes, and their meanings, respectively have a great impact on the assessment of the soundscape (28-31). The soundscape cannot be studied independently. The condition of comfort of an environment is the result of the integration of several factors, one of which is the acoustic. It is evident that the response of tolerance or discomfort to a sound stimulus is conditioned by other visual, thermal and/or multisensory factors (32-39).

Different authors have begun recently to apply the psychoacoustic descriptors, originally developed to define the sound quality of products (40-44), to the assessment of environmental situations such as soundscapes (45-47). Psychoacoustics studies sound from the point of view of its subjective perception, looking for relationships between the physical stimulus and the psychological response that it causes in people. Applying this type of descriptors can help in the evaluation of soundscape quality, relating ambient sound with the level of anticipated discomfort.

This study analyzes a set of urban public spaces located in the central area of the city of Córdoba, in Argentina. The study of the sound quality of public spaces in the city center enables the analysis of the different reactions and degree of acceptance of the users of urban open spaces in which the objective sound conditions are similar. A methodological approach is proposed for the analysis of the soundscape, based on a mechanical practice for objective evaluation, integrating and interrelating the acoustic descriptors selected through a system of fuzzy logic. The importance of fuzzy logic [48] is based on its similarity with human reasoning, tending to obtain results that are not necessarily exact but are rather perfectible. Fuzzy logic has been used successfully in several studies related to the problem of noise in relation to aspects such as the modelling of working efficiency in noisy environments [49]; definition of discomfort from noise [50,51]; prediction of train noise [52]; and interference in communication [53].

2. Methodology

2.1. Field of study

Fig. 1 shows the location of the twelve public spaces, squares and promenades analyzed, which make up the main network of public spaces in the city center. All of the spaces have common character

istics that were taken as a starting point for their selection: they are in areas of high population and building density, are bordered with avenues and streets with high traffic levels, and together make up the main network of urban spaces corresponding to the central area of the city. The differences between the mentioned cases can be seen in their shape, the ratio of green areas to paved areas and especially in their function. Urban spaces can be arranged according to their main purpose, as squares, suitable for relaxation (Pa Sb, PI Es), meeting or strolling (PI VS, PI SM, PI Co, PI It); pedestrian areas intended for circulation with a significant presence of bars (Plz F) and shops (Pt CJ, Pt SC); markets (Pa BP, Pa Ar), and recreation spaces used for informal sports activities (PI In).

2.2. Acoustic measurements

Objective acoustic assessment of the urban spaces in this study was performed by means of noise measurements followed by statistical noise analysis in the inner areas of the spaces and at their perimeters, coinciding with vehicle traffic routes. The parameters measured were L_{Aeq} , L_{Ceq} , percentiles L_N ($N = 1, 5, 10, 50, 90, 95, 99$) and L_{Zeq} in third octave bands from 12.5 Hz to 20 kHz. The measurements were performed with a Brüel & Kjær type 2250 sound level meter equipped with software for analysis in frequency BZ 7223.

Fig. 1. Location of the spaces analyzed.

The number and location of the measurement points were determined with the criterion of surveying the general behavior of the area: the edge situation of each of the areas analyzed, and the specific behavior of each space in the interior of the squares, simultaneously with the subjective survey. The times chosen were those of greatest activity and greatest traffic flow in the central area, on weekdays between 10 am and 5 pm.

The number of internal or external points of each sector analyzed was defined on the basis of the formal characteristics of each space and the number of surrounding high traffic routes. Considering the necessity of simultaneous subject and noise level surveys, the duration of the measurements was set according to the duration of the opinion polls, with a period from 5 to 15 min. For the minimum period of 5 min adopted, it is known [54] that the margins of error in urban noise measurements remain within permissible values and similar to greater periods of up to 15 min, always following the indications of ISO 1996 2, which recommends the adoption of a time range for measurement that covers all the significant variations in the emission and propagation of noise.

2.3. Psychoacoustic descriptors

Simultaneously with the measurements of the physical parameters and the subject surveys, a recording was made of each sound scene for subsequent analysis. The recordings were made with a Zoom digital recorder model H4n, with two XY stereo condenser microphones and audio recording up to 24 bit/96 kHz, with a sampling frequency of 44.1 kHz. PsySound3 software, intended for the analysis of sound recordings based on physical and psychoacoustic algorithms, developed under the Matlab environment, was used for calculating the acoustic descriptors [55].

The psychoacoustic descriptors calculated by PsySound3 were: loudness, sharpness and roughness. The PsySound3 analysis modules used under Matlab environment also enables the spectrum to be calculated by one third band, the respective levels and the specific loudness pattern. For loudness calculation this analyzer implements the dynamic loudness model of Chalupper and Fastl. This model uses the Bark critical band rate scale to model auditory filters. An auditory temporal integration is included in the loudness model. For sharpness calculation, it uses the Aures model and for the roughness, implements the roughness algorithm of Daniel and Weber [48]. The 1/3 octave spectrum, the equivalent continuous sound level and the loudness calculated by software were compared with those measured simultaneously with the BK2250 sound level meter. The variations and errors detected were low, and they were seen not to influence the type of analysis in process.

2.4. On site survey

Simultaneously with the acoustic measurements, user opinion polls were conducted in each of the urban spaces under study. The questionnaire examines general sociological and particular aspects in relation to the physical space to evaluate and the characterization of its soundscape. The survey responds to practical application criteria based on other experiences of this kind taken as a model [56]. A total of 416 surveys, consisting of 8 questions, were applied in the twelve spaces, taking from 5 to 10 min each.

The first four questions referred to the age, sex and activity of the people: motivations for the use of the space, distance from the area where they live, and the average time they remain there. Questions 5 and 6 evaluate the soundscape quality in particular and the environment in general, with a bipolar scale of five points with the response alternatives: "very good", "good", "fair", "bad" and "very bad". Question 7 focuses specifically on identifying types of sounds, split into three categories: (1) human sounds, (2) natural sounds, and (3) technological sounds. For each of the three cate-

gories, the degree of perception was indicated and the level of pleasure or discomfort of it during a visit to the area. Responses were given on a five point category scale, with the response alternatives "not heard", "heard a little", "sometimes heard", "heard a lot" and "completely dominant". The aim of the scale is to represent the degree of presence of each sound perceived by each user individually. The level of satisfaction is also evaluated on a five point scale, with response alternatives: "pleasant", "quite pleasant", "fair", "quite annoying" and "annoying".

2.5. Fuzzy logic analysis

The use of a system is proposed that aims to qualify urban spaces through analysis by fuzzy logic of the acoustic and psychoacoustic indicators or descriptors that are identified as traits of the sound quality of the soundscape.

A diffuse or fuzzy system is structured in three fundamental stages: fuzzification or diffusion of the input variables, inference through assessment and formulation of control rules, and defuzzification or de diffusion to calculate the output results (Fig. 2). For practical calculation purposes, we used the Matlab® fuzzy logic toolbox. The inference process used corresponds to the Mamdani criterion and the technique adopted for defuzzification is the centroid method.

At the fuzzification or diffusion stage, the inputs are selected and the degree of belonging of each of the fuzzy sets from membership functions related to each descriptor. For each input variable, the range and the degree of belonging to a fuzzy linguistic set was defined (0 100%). In this work, membership or belonging functions used are trapezoidal.

The rules are a list of "if then" type statements. The part corresponding to the "if" is the antecedent and lists the condition(s) related to the inputs belonging to a particular fuzzy set. The second part is the consequent and indicates the set to which the outputs of the system must belong to the extent that it complies with the corresponding antecedent. In defuzzification, the fuzzy sets that represent the results of each rule are combined into a single final fuzzy set.

3. On site survey results and discussion

3.1. Qualitative survey

Table 1 shows the number of respondents in each space, together with the data resulting from the initial questions: age, sex and activity. It can be seen that the respondents are distributed almost equally by gender: men (57%) and women (43%). More than half of those surveyed live in the area (25%) or in a nearby neighborhood (32%) and the predominant activity is walking or relaxing.

Table 2 lists, for each space studied, the percentage of interviewees who consider that the sound quality of the place is very good to very bad. Taking a value of 5 as "very good" and a value of 1 as "very bad", the weighted average of the percentages was calculated to give the final value.

Fig. 3 summarizes all the responses for the overall analysis of the quality of the space, representing the quality level by the weighted average.

The graphs of Figs. 4 and 5 show the percentages of interviewees who considered as high the levels of presence and acceptance for the urban zones classified as squares, pedestrian, market and recreational spaces.

A strong presence of technological sounds is found, mainly the noise of vehicle traffic, followed by the presence of sounds of human origin and finally natural sounds. Acceptance levels are variable, showing a tendency toward greater acceptance of natural

Fig. 2. Basic structure of the proposed system.

Table 1
Data resulting from the initial questions.

		Total	Percent
Gender	male	229	57
	female	175	43
Age	18–30	195	48
	31–50	177	44
	over 50	32	8
Lived in	the area	101	25
	a nearby neighborhood	130	32
	a distant neighborhood	137	34
	another city	36	9
Activity	in passing	70	17
	for a walk	84	20
	to read a book	15	4
	to relax	180	42
	to do sport	25	6
	others	50	12
Time spent in the place	less than one hour	188	47
	about one hour	55	14
	up to two hours	27	7
	over two hours	27	7
	it depends	104	26

and human sounds rather than technological. The acceptance or discomfort level depends in all cases on the type of activity, with market or recreational activity spaces having a higher acceptance level for sounds of human origin such as conversations or music. Spaces for strolling and resting are seen as positive when the level of presence of natural sounds increases, and so sounds of human origin are rated as discomfort when their level of presence tends to mask natural sounds.

Recreational areas are seen to generally have a higher level of acceptance of technological sounds than the others. The responses of acceptance or pleasure produced in the user by the urban space are related not only with urban space quality environment indicators, but also with their use. When natural or human sounds have a level of presence sufficient to stand out above technological sounds, the latter are not definitive in the overall acoustic rating.

3.2. Acoustic measurements

Tables 3 and 4 list the average values for the L_{Aeq} and L_N parameters resulting from the measurements at inner and outer points of the urban spaces. The results of measurements at outer perimeter points reflect the strong incidence of traffic noise in all the environ-

ment of the areas studied. In all cases, these mark over 72 dBA of continuous equivalent sound level, while toward the interior of the spaces they are between 65 and 70 dBA. The reduction of sound level toward the interior of the squares is about 5–10 dB. The very marked difference of about 10 dB between L_{10} and L_{90} shows the great variation in traffic flow during the measurement period. The reduction of sound level depends, among other aspects, on the distance between the inner and outer points. The spaces with higher propagation attenuation have a total width between 100 and 110 m, while the small squares and pedestrian areas aren't exceeding 50 m. In all cases they are completely surrounded by buildings from 10 to 15 m high that characterizes the central area.

The graph in Fig. 6 shows the low correlation between the sound levels surveyed and the acoustic rating of each space. The sound quality of open urban spaces can be good or very good despite sound levels being higher than 60 dBA. It can also be noted that in spaces for resting or strolling, quality increases with the reduction of sound level, while in spaces for recreation, craft markets, pedestrian or commercial areas, the relation is not in accordance and visitors accept higher sound levels, but never above 65 dBA. Generally, nearly all the studies made agree that the strength of the sound is recognized as one of the important factors. The classic indicators of sound level seem useful for describing this first factor of the soundscape, although this does not mean that the indicator must necessarily be the L_{Aeq} [11].

The L_{Ceq} L_{Aeq} difference is seen to be a good descriptor of the low frequency content of the urban sound scene. In general, urban spaces with low sound levels and normal sound quality have a high L_{Ceq} L_{Aeq} , derived from the exclusive presence of low frequency sound from traffic.

The L_{10} L_{90} difference is also an important indicator, but difficult to classify, for characterizing a soundscape. A high value is related with the possibility of perceiving the main sounds of the space above the background sound. The spaces are rated as good as long as the difference means that the characteristic sounds of the space stand out above the background noise and it is not the result of temporary variations of intrusive noise. In some cases there is a significant difference of L_{10} L_{90} produced by the temporary fluctuation of sounds of technological origin and the environment in this case is considered negative.

3.3. Psychoacoustic descriptors

The graphs in Figs. 7 and 8 compare the values of sharpness and loudness with the resulting perceptual sound quality. A significant

Table 2
Sound quality of each particular space.

	Pa Sb	Pl In	Pa BP	Pt SC	Pa Ar	Pl It	Pl SM	Pt Cj	Pl Co	Pl Es	Pl VS	Plz F
Very good (5)	26%	5%	9%	20%	6%	2%	0%	7%	3%	0%	0%	0%
Good (4)	42%	57%	30%	20%	26%	32%	17%	10%	9%	5%	0%	0%
Neutral (3)	19%	24%	46%	40%	35%	27%	47%	37%	28%	34%	27%	0%
Bad (2)	10%	7%	13%	10%	24%	37%	30%	37%	38%	45%	53%	60%
Very bad (1)	3%	7%	2%	10%	9%	2%	6%	10%	22%	16%	20%	40%
Weighted average	(3.8)	(3.5)	(3.3)	(3.3)	(3.0)	(3.0)	(2.8)	(2.7)	(2.3)	(2.3)	(2.1)	(1.6)

Fig. 3. Overall environmental rating of urban spaces.

Fig. 4. Levels of presence for urban areas classified as squares, pedestrian, markets and recreational spaces.

Fig. 5. Levels of acceptance for urban areas classified as squares, pedestrian, markets and recreational spaces.

Table 3
Average interior sound levels: L_N and L_{Aeq} (dBA).

	Pa Sb	Pl In	Pl It	Pl SM	Plz F	Pt SC	Pt CJ	Pa Ar	Pa BP	Pl Es	Pl Vs	Pl Co
L_1	71.0	77.1	74.9	74.3	71.0	66.5	71.5	73.3	77.1	72.2	76.1	76.2
L_{10}	67.2	68.4	68.6	71.4	67.1	63.9	65.8	68.6	70.6	68.3	73.5	71.2
L_{50}	62.5	61.8	63.6	65.9	62.8	61.2	61.4	62.6	67.4	65.5	71.9	67.1
L_{90}	59.4	57.8	61.1	61.8	59.6	59.6	58.9	59.1	65.5	63.2	70.5	63.5
L_{99}	57.9	56.1	59.5	60.3	57.9	58.7	57.8	56.8	64.2	61.7	69.8	60.8
Mean L_{Aeq}	64.6	67.3	66.2	67.8	64.7	62.0	64.0	65.1	68.5	66.3	72.2	68.6
$L_{10}-L_{90}$	7.8	10.7	7.5	9.6	7.6	4.3	6.9	9.5	5.1	5.1	3.0	7.7

Table 4

Average external sound levels: L_N and L_{Aeq} (dBA).

	Pa Sb	Pl In	Pl It	Pl SM	Plz F	Pt SC	Pt CJ	Pa Ar	Pa BP	Pl Es	Pl Vs	Pl Co
L_1	85.9	83.2	84.5	85.1	79.0	83.0	81.9	80.1	84.0	84.9	80.2	82.8
L_{10}	76.9	74.5	78.0	78.8	73.8	77.7	77.1	73.7	76.2	77.2	76.9	77.2
L_{50}	69.1	68.3	72.3	71.5	68.2	71.9	72.2	66.5	70.1	71.6	73.3	72.0
L_{90}	63.6	63.4	68.0	64.9	63.1	66.9	66.6	58.7	65.5	68.2	70.9	66.6
L_{99}	60.2	60.3	65.0	62.9	61.3	63.8	63.3	55.5	63.9	66.6	69.9	62.1
Mean L_{Aeq}	74.7	72.1	75.0	75.5	70.5	74.3	74.2	70.4	73.2	74.2	74.3	73.9
$L_{10}-L_{90}$	13.3	11.1	10.0	13.9	10.7	10.8	10.5	15.0	10.7	9.1	6.0	10.6

Fig. 6. Relation between sound quality and equivalent continuous sound level L_{Aeq} within urban spaces.

Pearson correlation ($r = 0.81$) is noted between the trend lines of sound quality of the space and sharpness. The distancing of the trend line in some specific cases is related to other parameters analyzed: high level of loudness, high content of low frequencies (represented by L_{Ceq} , L_{Aeq} or C_{0G}) or a low figure background ratio (saturated soundscape). In the case of loudness, there is no direct ratio with perceptual sound quality (Pearson Correlation $r = 0.19$). Loudness is seen to be related to discomfort from noise but not with the level of pleasure or acceptance of an urban scene or soundscape. In some of the twelve public spaces, up to three scenes were analyzed, thus achieving a total of 22 different sound scenarios.

Sound scenes with high sharpness values are characterized by the presence of music, active fountains of water, and people's conversations and voices. For assessing sound environments, the two basic psychoacoustic measurements, loudness and sharpness, proved to be effective for evaluating the volume and tone color of the sounds.

4. Applying a fuzzy logic system

4.1. Description of the proposed system

Following the analysis made, the descriptors or input data adopted are sharpness, loudness, L_{Ceq} , L_{Aeq} and $L_{10}-L_{90}$. The ranges of input variables are set according to the values emerging from the survey of objective and psychoacoustic descriptors: sharpness (0–5 acum), L_{Ceq} , L_{Aeq} (4–20 dB), $L_{10}-L_{90}$ (2–15 dB) and loudness (0–40 sones). The membership rules are made up in function of the quality associated with the range of the variable considered (e.g., Sharpness 1–5 acum; low, medium, high quality).

In the case of sharpness, loudness and the L_{Ceq} , L_{Aeq} difference, the linguistic sets chosen were “low”, “medium” and “high”, while for the difference of percentiles $L_{10}-L_{90}$ they were only “low” and “high”. Figs. 9 and 10 show the functions of belonging to the fuzzy set defined for each range.

The list of sentences or rules is defined indicating the action to be performed with each of the fuzzy sets analyzed at the previous stage. Fig. 11 shows a breakdown of the 11 rules adopted for the inference process.

The graph of Fig. 12 shows the membership function of the output variable (sound quality). The function used is triangular in type.

Fig. 7. Relationship between sharpness and sound quality.

Fig. 8. Relationship between loudness and sound quality.

Fig. 9. Functions of belonging for sharpness and $L_{Ceq}-L_{Aeq}$.

Fig. 10. Functions of belonging for $L_{10}-L_{90}$ and loudness.

Fig. 11. Schedule of input, output variables and rules of the proposed system.

Fig. 12. Functions of belonging for sound quality.

4.2. Results obtained

The proposed fuzzy inference model was applied to the exterior urban spaces studied in the course of this work. Table 5 shows the sound quality results and the graph in Fig. 13 shows the relation with the values emerging from the subjective polls. A close relation can be seen (Pearson coefficient $r = 0.94$) between the quality value found in the polling and that calculated by the fuzzy inference technique. In some spaces, up to three different sound scenarios were analyzed.

The fuzzy inference methodology used also makes it possible to visualize the relationships that are established between the descriptors adopted and to interpret the degree of influence they have in the subjective definition of the soundscape. It is thus noted, for example, that high sharpness values imply high sound quality (Fig. 14) almost independently of the other variables.

High sound quality, directly related to increasing sharpness, is caused by the dominant presence of masking sounds, such as active fountains of water and voices. However, vehicle noises with

high sharpness can also create higher annoyance. In this case the low sound quality is determined by the excessive low frequency content (L_{Ceq} L_{Aeq}). As sharpness diminishes, the low frequency content represented by the L_{Ceq} L_{Aeq} difference begins to gain importance. For low sharpness values, a relation with low content of low frequencies helps to increase the sound quality of the space. As sharpness increases, the influence of spectrum composition on quality reduces. A similar relationship is seen between sharpness and loudness. Loudness is important in the middle range of sharpness values. Lower loudness enables an increase in the sound quality of a space. In this case, loudness has a greater influence in spaces where sharpness is low.

5. Conclusions

The analysis makes it clear that the evaluation of the sound scape of an open urban space must be tackled keeping in mind the interaction between acoustic parameters and other elements

Table 5
Inferred sound quality and by subjective study.

	Sound quality	
	Calculated by fuzzy inference	From subjective study
Plaza San Martin	2.46	2.50
	2.90	3.50
Fundador	2.63	2.50
	2.73	3.00
Santa Catalina	2.55	3.00
	3.39	3.20
Compañía	2.69	2.50
	2.96	3.00
	3.21	3.50
Vélez Sarsfield	2.40	2.40
Plaza Colón	2.30	2.40
Plaza Italia	2.45	2.00
	2.69	2.50
Paseo Sobremonte	2.66	2.60
	4.67	4.60
Plaza de la Intendencia	2.43	1.20
	2.44	1.60
Paseo del Buen Pastor	4.68	4.20
Plaza España	2.00	1.80
	2.67	2.50
Paseo de las Artes	2.89	2.70
	3.80	4.00
Pearson correlation coefficient $r = 0.94$

Fig. 13. Comparison of inferred and surveyed quality levels.

characteristic of the environment. The level of sound pressure is an important parameter in evaluating a sound environment, but the studies clearly show that there is no direct correlation between discomfort from noise and the physical sound parameters. The

analysis confirms that the continuous equivalent sound level can not be the only objective parameter characterizing the soundscape of outdoor spaces. Noise levels below 65–70 dBA are more influenced by the character of the sound source than by the general sound level. In soundscapes, it is proposed to use the concept of displeasure for situations in which sound levels are below this range.

The sound quality of urban spaces, within the range of acceptable sound levels in which no discomfort is caused, has been shown to depend on factors related to the subjective response of users, conditioned by cultural and social patterns. Therefore, in parallel with the analysis of the levels of presence and/or discomfort of sounds of a soundscape and of the sound level of the environment in general, variables related with the users' perceptions should be taken into account, for which the urban soundscape analysis is complemented with psychoacoustic indicators used in sound quality studies. The perceived sound quality of a soundscape depends, in accordance with the ISO 12913-1 [57], on the context, on the auditory sensations, on the expectation and even on the cultural background.

We conclude that, when the L_{Aeq} sound pressure level is not above 65–70 dBA, the sound quality of a soundscape can be studied based on four combined descriptors: sharpness, loudness, L_{10} – L_{90} and C_{0G} or L_{Ceq} – L_{Aeq} . The sound rating for each descriptor separately cannot be applied or generalized to the sound environment. The latter is the set of descriptors that interact to define the sound quality of the urban space. The influence of each indicator on quality depends on the interrelation with the other parameters considered.

Fuzzy logic postulates are adopted as suitable for studying soundscapes in which the limits of acceptability or quality for each of the acoustic and psychoacoustic descriptors involved in the soundscape rating are not precise. This non linear interrelation between the descriptors approximates to the postulates of fuzzy logic, which justifies adopting this methodology as a tool for the analysis of sound quality in outdoor spaces, based on the interrelation of the acoustic descriptors with the subjective response.

The fuzzy logic model proposed aims at defining a mechanism to enable soundscape rating by analyzing the acoustic and psychoacoustic indicators and descriptors identified as characterizing the sound quality of the space. The rules for the model were defined using the conclusions of the cross analysis of physical, psychophysical and perceptual sound quality variables resulting from the study made and are thus valid for the sociocultural situation proper to the spaces studied. A very accurate relation is achieved between the rating reached in the survey with the value calculated with the fuzzy logic technique.

Fig. 14. Sharpness-loudness (a) and sharpness L_{Ceq} – L_{Aeq} relationships with sound quality.

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