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SOUNDSCAPE EVALUATION OF RESIDENTIAL OUTDOOR SPACES BASED ON A SUBJECTIVE QUESTIONNAIRE AND OBJECTIVE ACOUSTICAL MEASURES

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ABSTRACT

With the increasing attention to soundscape concepts in noise policy discussions and the recent integration into legislation in some regions, there is a growing need for objective measures to assess soundscape quality. In a project funded by the Swiss Federal Office for the Environment, various acoustical, room-acoustical, and psychoacoustical parameters identified through acoustic literature, as well as preliminary research and measurements, were used to evaluate soundscape quality. These parameters include, among others, L_{Aeq}, RT60, STIPA, sharpness, loudness, tonality, and fluctuation strength. Additionally, environmental factors such as nearby noise sources, greenery, and spatial morphology were documented. Measurements were conducted in four residential outdoor spaces in Switzerland and compared to subjective evaluations obtained from a small group of participants at the same locations. This paper presents the measurement results and subjective evaluations, along with a statistical analysis comparing the two datasets. Based on the findings, a method for the objective assessment of soundscapes is proposed, and recommendations for improving soundscape quality are discussed.

Keywords: *Soundscape quality, Soundscape Evaluation, Soundscape indices, ISO 12913*

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1. INTRODUCTION

According to the ISO 12913-1 standard, a soundscape is an ”acoustic environment as perceived or experienced and/or understood by a person or people, in context” [1]. This definition entails the inclusion of holistic principles and subjective views of the people experiencing the soundscape [2, 3]. For legislative purposes, objective, simple and reproducible methods to assess the quality of soundscapes are needed, however. Different researchers have thus proposed objective evaluation methods, a review of which can be found in [4]. The ISO/TS 12913-2 and 12913-3 standards [5, 6] propose a number of methods for the collection and analysis of soundscape studies, investigations and applications. Different, more recent efforts aim for a simplification of soundscape evaluation by providing single number indices [7, 8].

The Swiss Federal Council proposed an amendment to the Environmental Protection Act (EPA), according to which, among other things, the planning of additional residential housing in noise-polluted areas should also include the provision of open spaces/quiet areas for recreation and measures to ensure an acoustically appropriate quality of living. These requirements need to be specified and objectified. As part of a study for the Swiss Federal Office for the Environment FOEN, the physical and perceived soundscape qualities of urban residential courtyards at four locations in Switzerland were investigated by the authors. The goal of the study is to provide insights for the as of yet not clearly defined minimum requirements and guideline values in the context of soundscape design in view of aforementioned changes to the Environmental Protection Act. This interdisciplinary project aimed to de-

velop an objective evaluation method for soundscape assessment and classification. Both acoustic measurement methods and qualitative survey methods of soundscape perception were tested and compiled into suitable sets of methods. These were tested on four case studies - different residential courtyards in four Swiss cities. Subsequently, the acoustic and qualitative results were checked for consistency and initial findings were derived.

2. METHODS

2.1 Selection of objects

The aim of the object selection was to achieve heterogeneity in the survey of the soundscape quality of different recreational spaces in housing areas. The main parameters for the selection were their noise situation, proportion of greenery, and character as a publicly used space. All objects are surrounded by residential buildings. The soundscapes are located in four different cities in Switzerland (see Tab. 1).

Table 1: Selection of soundscapes

No.	Object	City
1	Erlenmatt Ost	Basel
2	Park Humboldtstrasse	Bern
3	Himmelrich 3	Luzern
4	Zwicky-Areal	Zürich

2.2 Acoustical measurements

Measurement variables were chosen according to results found in the scientific and normative literature, linking them to subjectively perceived soundscape quality [4, 5, 9, 10]. The main data acquisition methods included the measurement of sound pressure level (*SPL*), reverberation time (*RT60*), speech transmission index (*STI*) and room impulse responses (RIR). Binaural audio recordings were made and used for the extraction of psychoacoustic metrics. Additional metrics were extracted from the RIRs and audio files, recorded by the sound level measurement device. Measurement methods were adapted according to the findings of a preliminary study [11]. This includes the measurement of sound pressure level during different times of the day, a high number of measurement repetitions for reverberation time measurements and the possible division of the soundscape into sub-spaces with different acoustical characteristics. A complete list of the measured and calculated variables can be found in Tab. 2.

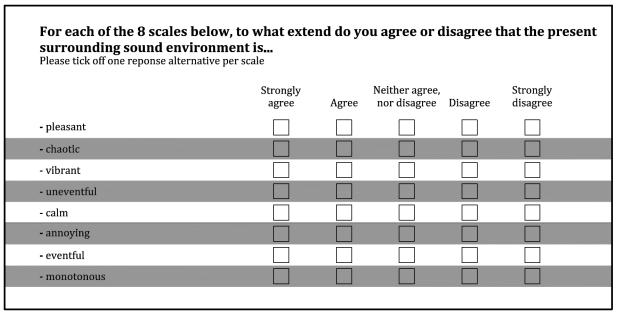

Figure 1: Questionnaire related to the perceived soundscape quality according to ISO/TS 12913-2 [5]

2.3 Subjective Survey

Soundscapes are inextricably linked to their uses and users. However, a mere description of uses and users is not sufficient for describing how soundscapes are perceived. It is the meaning which respondents (users) attribute to uses and other users that provides clues to how the soundscape is perceived.

Based on results of previous research ([25] and ISO/TS 12913-2 [5]), the following procedure was designed for the survey in the four soundscapes.

1. Questionnaire survey on the perception of the soundscape with the following questions:
   - Opening question: what do you hear? (Please indicate in descending order of clarity) the various sound sources that you can identify (e.g., “children,” “airplane,” “birds,” ... maximum of 8).
   - Three statements regarding the perception of sounds and soundscape, rated on a 5-point scale: It’s loud here / it’s acoustically pleasant here / the sounds fit the surroundings.
   - How do you perceive the soundscape? (ISO/TS 12913-2 dimensions [5]; see Fig. 1).
2. On-site focus group discussion on perception of the soundscape, guided by the following questions:
   - What do you like about this place? Why?
   - What is the quality of stay of this place? What defines it?
   - How would you rate the ”room acoustics” of this courtyard?

Table 2: Acoustical measurement variables with measurement/calculation method

Variable	Method	Ref.
SPL with different time and frequency-weightings, as well as percentiles	4 measurements of 15 minutes between 08:00 and 18:30 hours per area	[12]
RT60 (T30)	1 measurement with 10-12 repetitions per area	[13]
STI	1 measurement distances 1m/4m 8 repetitions per measurement	[14]
RIR	1 measurement distances 1m/4m	[15]
Sharpness	Evaluation of 4 binaural audio recordings of 15 minutes between 08:00 and 18:30 hours	[16] [17]
Loudness	See *Sharpness*	[18]
Harshness	See *Sharpness*	[19]
Tonality	See *Sharpness*	[20]
Mel Frequency Cepstral Coefficients (*MFCC*)	Evaluation of the audio recordings from the *SPL* measurements	[21]
Spectral Slope	See (*MFCC*)	[22]
Time Frequency Second Derivative (*TFSD*)	See (*MFCC*)	[4]
Echo criterion	Evaluation with RIR-measurements	[23]
Percentage of green/blue	Calculation of green/blue from views of typical seating locations	[24]

- What sounds/soundscape would you typically expect in this place?
- Would you want to live here? Why/why not?

3. Questions regarding additional assessment positions:

   - What has changed in the sounds/soundscape compared to the center of the courtyard?

Note: Evaluating audio recordings without direct spatial reference at other times of day has not proven effective. For spaces characterized by different areas, this survey should be conducted separately for each area.

3. RESULTS

3.1 Acoustical measurements

Tab. 3 shows average values across all measurements, positions and measurement repetitions of the four soundscapes. The averaged L_{Aeq} values are significantly lower in Basel and Bern, while the *RT60* measurement shows similar values across objects. The median values of the *STI* measurements at a distance of 1 meter are above limit A (high speech intelligibility, complex messages, unfamiliar words) for 3 objects. Depending on the room and measurement position, the values fluctuate between the F (Good quality PA systems, complex messages, familiar context) and A ratings (see Fig.2). At a distance of 4 meters, the median value in Basel remains at level D, while the values of the other objects drop to level H (normal lower limit for VA systems, simple messages, familiar context).

Table 3: Averaged results of the measurements

Parameter	Basel	Bern	Luzern	Zürich
L_{Aeq} [dB]	50.02	53.39	61.90	58.51
RT60 [s]	1.29	1.44	1.35	1.24
STI 1m	0.88	0.77	0.73	0.71
STI 4m	0.65	0.47	0.51	0.45
Percentage of Green	21.9%	64.9%	14.6%	15.8%

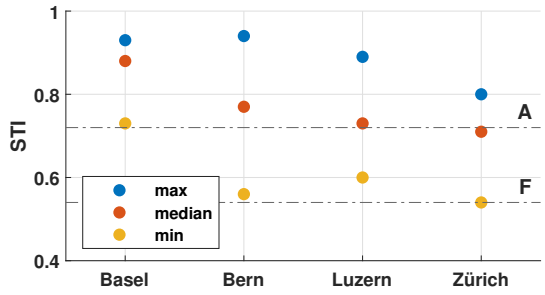

Figure 2: Measured *STI* values at 1 m distance

3.2 Subjective Survey

Mean ratings of the ISO items are shown in Fig. 3 for the four locations investigated in this study.

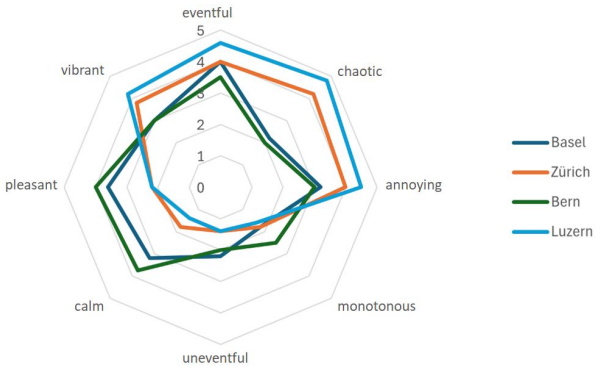

Figure 3: Survey results of soundscape perception according to ISO/TS 12913-2.

The following indications for the planning of soundscapes can be derived from the case studies:

- Greenery and proximity to nature (also sounds of nature) is associated with a more positive perception of the soundscape.
- Attractive utilization options and high-quality design can improve the quality of stay.
- The above positive criteria can only partially compensate for high-level noise pollution.
- A variety of possible uses and the presence of other people play a decisive role in whether people feel comfortable or not.
- Identification with the space, its uses, and people present fosters a positive soundscape perception.

3.3 Comparison of acoustical and subjective data

A post hoc correlational analysis was conducted to investigate the extent of the association between quantifiable subjective perception indications and objective data. A few examples are shown in the following.

3.3.1 Percentage of green

Tab. 4 shows correlations between *Percentage of green* and the subjective quantitative items (translated from German). Strong associations are observable: courtyards with more greenery were perceived as more pleasant, calming, and less noisy or annoying. A saturation of the positive greenery effect can be observed in Fig. 4.

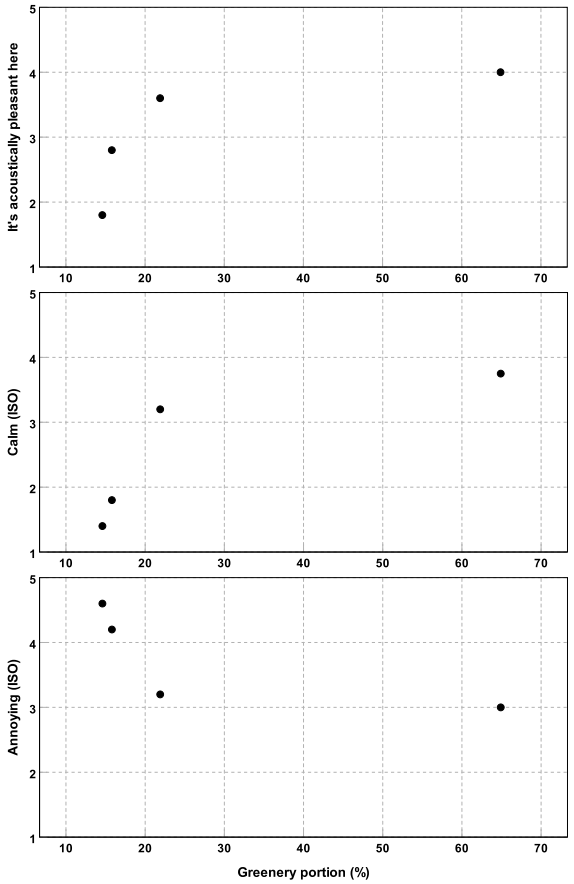

Figure 4: Mean subjective ratings for the items *It's acoustically pleasant here*, *Calm (ISO)*, and *Annoying (ISO)* as a function of *Percentage of green*.

Table 4: Correlations between *Percentage of green* and *STI* and the subjective ratings. Significant ($p < 0.05$) and highly significant correlations ($p < 0.01$) are marked with * and **, respectively.

	Green (%)		*STI*	
	r	p	r	p
It's loud here	-.585**	.008	-.863**	.000
It's acoustically pleasent here	.555*	.014	.741**	.000
The sounds fit the surroundings	.253	.295	.090	.714
eventful (ISO)	-.303	.208	-.578**	.010
chaotic (ISO)	-.626**	.004	-.884**	.000
annoying (ISO)	-.575**	.010	-.786**	.000
monotonous (ISO)	.495*	.031	.420	.074
uneventful (ISO)	.233	.338	.409	.082
calm (ISO)	.611**	.005	.772**	.000
pleasent (ISO)	.522*	.022	.660**	.002
vibrant (ISO)	-.335	.162	-.503*	.028

3.3.2 STI

Correlations between the *STI* and the subjective quantitative items are presented in Tab. 4. Courtyards with high *STI* values (at 1 m) were rated more positively (see also Fig. 5). This was also the case for *STI* values measured at a distance of 4 m (not shown here).

3.3.3 RT60

The potential correlation between *RT60* and the subjective ratings was examined, but no such relationship was observed in the cases investigated in this study. Instead, the subjective evaluations appeared to be more strongly influenced by the *Percentage of green*, *STI*, and *SPL* than by *RT60*. This finding warrants further investigation, as it contrasts with previous results and recommendations reported in the literature [7, 10, 11].

3.3.4 Subjective methods

It was investigated whether the first three quantitative items (*It's loud here*, *It's acoustically pleasant here*, and *The sounds fit the surroundings*) are correlated with the ISO items. Tab. 5 shows that most items were significantly correlated, and in a reasonable and interpretable direction. Several items exhibited significant and strong correlations. Notably, this was not the case for the item *The sounds fit the surroundings*. The authors suggest that this item may represent a distinct dimension in soundscape assessment or may capture a novel factor in the context of factor analysis.

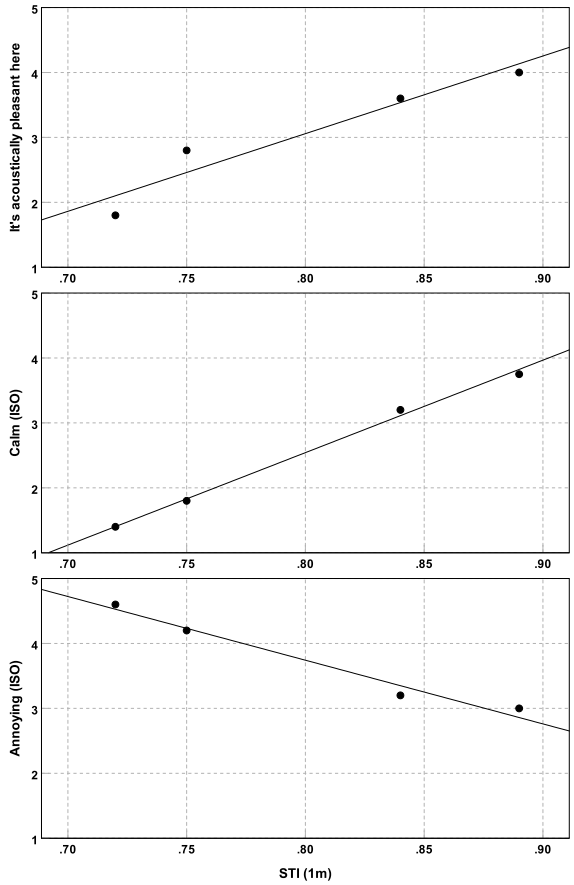

Figure 5: Mean subjective ratings for the items *It's acoustically pleasant here*, *Calm (ISO)*, and *Annoying (ISO)* as a function of *STI*.

Table 5: Correlations between the subjective items *It's loud here*, *It's acoustically pleasant here*, and *The sounds fit the surroundings*, and the ISO items. Significant ($p < 0.05$) and highly significant correlations ($p < 0.01$) are marked with * and **, respectively.

	It's loud		Acoustically pleasant		Sounds fit	
	r	p	r	p	r	p
It's loud here	1					
It's acoustically pleasant here	-.737**	.000	1			
The sounds fit the surrounding	-.011	.965	.323	.177	1	
eventful (ISO)	.658**	.002	-.663**	.002	-.158	.519
chaotic (ISO)	.803**	.000	-.763**	.000	-.208	.392
annoying (ISO)	.735**	.000	-.823**	.000	-.414	.078
monotonous (ISO)	-.230	.344	.153	.532	-.043	.862
uneventful (ISO)	-.420	.073	.374	.114	.171	.484
calm (ISO)	-.720**	.001	.875**	.000	.312	.193
pleasent (ISO)	-.696**	.001	.821**	.000	.402	.088
vibrant (ISO)	.588**	.008	-.394	.095	-.037	.881

4. DISCUSSION

4.1 Proposal for new evaluation method

Research into the perception of soundscapes requires the human perspective. The survey by a selected group of test subjects, who adopted the perspective of users, has provided results that, together with the measurement results, provide comprehensible interpretations. In particular, the separation into individual perception of the sound situation and a dialogue-based consideration in the group led to differentiated results and the integration of different perspectives. A strong agreement was observed between the objective measurement results and the subjective quantitative ratings across the different methods and items.

4.2 Limitations and further research

The sample size of objects (4) and participants (a maximum of 5 per room) in this study's subjective survey is limited. A larger sample size would enable more reliable statistical analyses, allowing the tendencies observed in this study to be verified.

5. CONCLUSIONS

This study investigated a combination of objective (acoustical) measurement methods and a subjective evaluation (including qualitative and quantitative items and focus group discussion) to assess soundscape quality in the vicinity of residential housing complexes. Four objects were investigated in this case study, representing various courtyards. The results emphasize the need for both objective and subjective evaluations. Acoustical data (e.g. *SPL*, *STI*) combined with non-acoustical parameters (e.g. *percentage of green*, natural elements) and qualitative descriptions (e.g., usage, design) were shown to provide provide a multi-disciplinary description of soundscapes, enabling evaluation. The quantitative survey data showed statistical correlations with the acoustical data to some degree. It was not possible to further simplify the evaluation using e.g. a point-based or traffic light system. Developing such a system would require a systematic investigation of all relevant factors, based on a substantially larger dataset and analysis using multi-factorial models. Furthermore, it remains uncertain whether an objective evaluation of soundscapes is achievable, as subjective, holistic and descriptive factors appear essential for a comprehensive assessment.

6. ACKNOWLEDGMENTS

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