# Full Scale Simulation of Soundscapes

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**Abstract**

Full-scale simulations of soundscapes in actual neighborhoods offer the possibility for people living in a community to experience and evaluate the soundscape while going about their normal daily routines. The current soundscape exists as a real, base line condition. Computer models are used to determine the time, sound level and frequency spectrum of proposed changes to the soundscape. Sound recordings of the actual events that will occur in the proposed soundscape are made at an existing location with a similar activity or during mock-ups of the activity. Loudspeaker arrays are set up in the community to propagate the sounds from the area where the sound sources are located to the areas where receivers are located. The sound levels and frequency spectrum from the computer models are used to calibrate the playback levels and equalization.

Juries of listeners are assembled from the community at large or from representative stakeholder groups to evaluate the existing and proposed soundscapes. Sometimes computer models and recordings are made of several different design proposals that are played back and evaluated. A case study of the soundscape design and evaluation of a proposed central plant adjacent to a quiet residential neighborhood by a jury comprised of various stakeholders is used to describe the process and results of the research. The evaluation included focus group discussions and interviews with information exchanged among the jury in narrative form.

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## 1. Introduction

A soundscape is any portion of a sound environment regarded as a field of study according to R. Murray Schafer. This can include actual environments, or abstract constructions such as musical compositions or electronic montages particularly when considered as an environment. Schafer elaborates on this concept in his seminal work *The Soundscape: Our Sonic Environment and the Tuning of the World* (Schaffer, 1977) although neither he nor Barry Truax (Truax, 2001) really develop a concise definition of the concept. Rather, they leave the concept somewhat open-ended to be interpreted and explored creatively by those who work in the field. Social interchange via acoustical communication in many forms from direct speech between people to discussions over cell phones, to listening to media of various types form one of the bases of urban culture. Cities, towns, buildings and natural areas where people congregate for work, social interaction, civic functions, recreation and other activities all form rooms for acoustical activities of various types whether they are designed to optimize that function or not (Siebein et al, 2013b). Soundscape planning and design methods have been developed to carefully design urban spaces, natural areas and buildings to optimize the acoustical qualities of these spaces (Siebein et al, 2012). Recent advances in visual and aural simulation technology allow the qualities of the spaces to be consciously designed and evaluated by an engaged citizenry as part of the design and development process (Siebein et al, 2006).

The ambient sound in a soundscape is composed of a series of specific acoustic events that form a multi-modal communication system that underlies the structure of the acoustic community. The soundscape design and analysis system incorporates new methods to measure, map, predict simulate, design and evaluate the soundscape. The concept of identifying acoustical rooms within the soundscape linked by acoustical itineraries that vary over acoustical calendars allows one to understand the cyclical rhthyms of the sounds that function within the urban ecosystem so the need in time, place and sequence for sound and relative quiet can be determined as a unique attribute of a specifically designed urban system (Siebein and Skelton, 2009).

## 2. Methods

Soundwalks are taken at representative times of the day including early morning, mid day, afternoon evening, night and late at night to understand how activities and sounds vary over the course of a typical day. The acoustical communities that comprise the soundscape are identified. The participants in each acoustical community are identified in a taxonomy of sound sources. The sonic flows between and among sound sources are mapped and modeled in ecological flow diagrams to describe the structural ecological relationships that underlie the soundscape. Primary and secondary acoustic zones or rooms and itineraries are identified within the soundscape for each of the participants. The variation of these sounds is mapped on an acoustic calendar. Qualitative observations are made of the type, level, duration and calendar of specific acoustic events within the soundscape (Siebein et al, 2010).

The specific acoustic events within the soundscape are identified by direct observation, calibrated video and audio recordings of the observations and short term, detailed acoustical measurements of various types. Long term average acoustical measurements of typical ambient sound levels at various locations in acoustical rooms or along acoustical itineraries are made to document general acoustical conditions in each zone using metrics such as continuous equivalent sound levels (Leq's, Lmax's, Lmin's), day-night average sound levels (LDN's), and a number of statistical metrics (L10, L50, etc) (Siebein et al, 2013a).

Calibrated audio recordings of specific acoustic events are also used to document the aural complexities of soundscapes and to identify the specific source sounds included in the ambient. Short term measurements of specific acoustic events are made using overall A-weighted and octave, 1/3 octave or narrow band measures. The short term measurements are used in conjunction with the taxonomy and ecological systems diagrams to identify the sounds that comprise the ambient in each acoustical room or zone, identify the combinations of sounds that comprise the ambient at each selected location made during each sound walk and to develop an acoustical calendar or profile of the specific acoustic events that contribute to the ambient at different times of day in different locations (Siebein et al, 2006).

Focus group discussions to discern issues of importance are held with participants in the soundscape in an open process to allow stakeholders' views to be incorporated within the study. This is part of the identifying and building of an acoustical community through the soundscape evaluation, planning and design process (Siebein et al, 2013a).

Acoustical mapping of soundscapes in several modes is done to graphically depict the findings over the project area. The identity of the acoustical community and its constituents is shown in abstract and in concrete forms. Values and meanings associated with attributes of the soundscape by each stakeholder are also mapped. Sonic flows are mapped in location in both horizontal and vertical dimensions; in time in an acoustical calendar; as social events that comprise the acoustical community in acoustical rooms or zones; and sonic flows that give structure to the acoustical components of the ecosystem (Siebein et al, 2006).

Acoustical modeling of proposed interventions to evaluate elements in the acoustical palette to understand where and how each can be used in the project is important in the analysis and design process. The mapping is of both quantitative and qualitative attributes of the soundscape with values and meanings associated with each of the participants included in the modeling process (Siebein et al, 2006). Stakeholders or juries are asked to evaluate the soundscapes using questionnaires, narrative descriptions, focus groups or on-line surveys of various types (Siebein, 2012).

The method leads to the design of ecological niches for the specific acoustic events of interventions proposed for the soundscape that allow participants to evaluate existing and proposed sonic qualities in an iterative, interactive process to preserve and enhance the sonic character of the environment. This can result in quiet communities whose soundscapes are tuned to the unique attributes of local sonic character; improve quality of life for people and wildlife in natural, suburban and urban settings as well as within buildings; and to engage the community in an active, participatory acoustical planning process to create healthful environments by design.

## 3. Case Study

The case study is the acoustical simulation of sounds from alternate designs for a chiller plant at a college in a medium-sized city. The college is situated on the border between a commercial corridor that extends along a busy four lane roadway and a quiet residential neighborhood of traditional homes nestled in tropical foliage. Many of the homes are more than 50 years old. Most have central air-conditioning systems, although some of the homes have window unit air-conditioners. Some have jalousie windows which are opened during moderate times of the year. The college considered four alternate sites for the chiller plant.

Site 1 is located on the eastern edge of the college campus and adjoins the residential neighborhood. The existing ambient sound levels measured at Site 1 varied between 32 and 55 dBA with the lower levels occurring at night and in the early morning until approximately 5:00 a.m. The sounds consisted of light traffic on local streets, distant traffic on a major road, wind rustling through the trees, sounds from air-conditioners at the homes, bird calls from time to time and insects. Site 2 was located at the intersection of a major road and a neighborhood street on the north corner of the campus. There is an existing building on the site that houses some college functions and mechanical equipment. The existing ambient sound levels measured at Site 2 varied between 45 and 60 dBA and consisted of pulses of traffic on the major road when the traffic signals were green, pauses in the traffic when the background sounds of insects, the breeze blowing through the trees and light traffic sounds on secondary streets could be heard. Site 3 was located adjacent to Site 2 and had sound levels and sounds similar to Site 2. Site 4 was located at the rear (east) edge of a parking lot near a dormitory building on campus. The existing ambient sound levels measured at Site 4 varied between 40 and 58 dBA and consisted of light traffic on local streets, distant traffic on a major road, wind rustling through the trees, bird calls from time to time and insects. Figure 1is an aerial map showing long term and short term ambient measurement locations and sound levels for all four proposed sites.


Figure 1. Aerial map showing long term and short term ambient measurements taken in the vicinity of all four proposed sites.

Computer model studies showed that there were residential receiving properties in close proximity to all four potential sites. Therefore, noise mitigation design would be required for the chiller plant at all four sites. A combination of acoustical, site, cost and other considerations were evaluated to select Site 1 as the final site. The local noise ordinance allows sounds at residential receiving property lines to be up to 75 dBA and 75 dBC during night time hours and 75 dBA and 80 dBC during day time hours, however, the sound walks and the long term acoustical measurements made in the neighborhoods around all four sites showed that the existing ambient sound levels were far below the maximum allowable sound level limits stated in the ordinance. Figure 2 shows a graph of average and maximum ambient sound levels with activities on site that produce the sounds labeled.

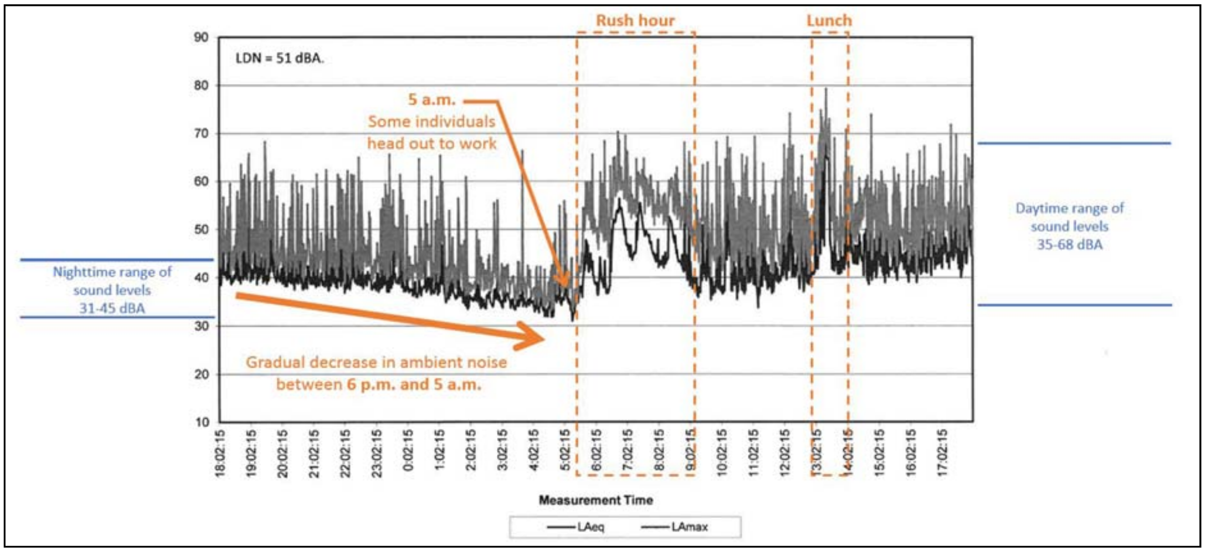


Figure 2. Graph of ambient sound levels with activities on site that produced the sounds labelled.

The chiller plant building was designed as a "green" building as shown in Figure 3 with integral noise mitigating features including masonry walls, concrete roof, large sound reducing doors, acoustical louvers on ventilation openings and large walls to enclose the cooling towers.

Figure 3. Rendering of the proposed chiller plant building.

Three design proposals were evaluated in the full-scale soundscape simulation. Scheme 1 had the basis of design cooling towers with quiet fans. Scheme 2 had ultra-quiet fans on the cooling towers and Scheme 3 had the quiet fans and silencers on the discharge of the cooling towers. Noise contour plots were produced in CadnaA software for the 3 schemes to show the reduction in sound levels at off-site locations for the 3 schemes.

The client and design team could read the noise contour plots and visually see the difference in sound levels for the 3 different schemes as shown in Figure 4. However, they could not determine the perceptual aspects of the sounds that would be heard in the neighborhood for the schemes.

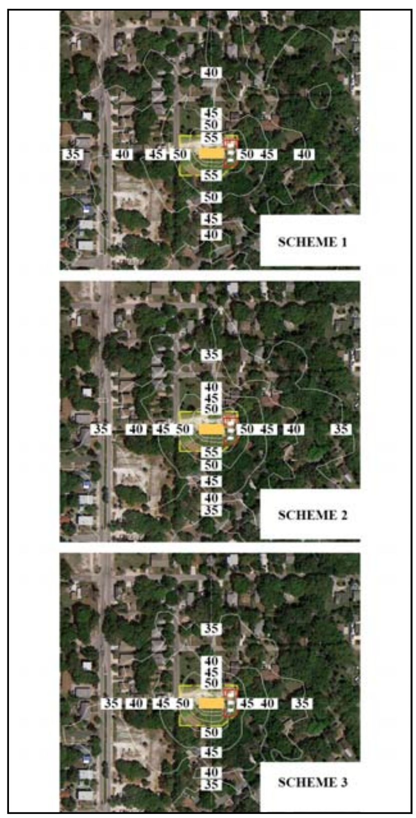


Figure 4. Aerial photographs of the site showing noise contours for the 3 alternate cooling tower selections. Cooling towers with quiet fans (top). Cooling towers with an ultra-quiet fan (middle). Cooling towers with quiet fans and silencers (bottom).

A calibrated simulation of the sounds that would propagate through the neighborhood was developed for use in a loudspeaker system so that the team could walk through the neighborhood and hear the sounds as they would be heard after completion of the chiller plant. There were several challenges that had to be dealt with in developing the simulation. First, wave file recordings of the source sounds had to be made at a chiller plant with similar equipment to that proposed for this project. The local equipment vendor assisted in finding a similar existing facility. Acoustical measurements and wave file recordings were made at the existing chiller plant facility for sounds from the top of the cooling towers where the fan noise predominates, at the sides of the towers where water noise dominates and outside the large doors of the enclosed chiller plant where the sounds of the chillers and pumps with their associated tones propagate.

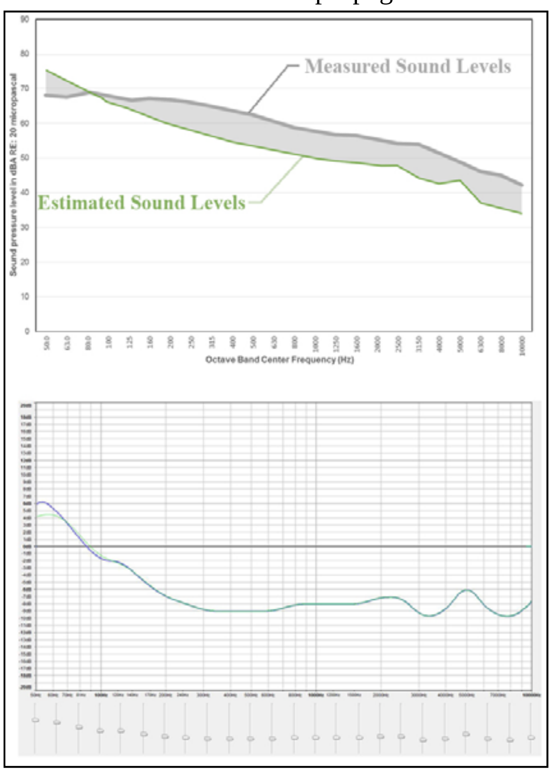


Figure 5. Graph comparing measured sound levels of the cooling towers at the existing chiller plant facility with the sound levels derived from the computer model studies of the cooling towers (top). Filter used in the equalization process to adjust the frequency spectrum of the audio recording of the existing cooling towers to the calculated spectrum for the audio content used in the simulation (bottom).

The wave files were combined for each of the primary sound sources and the frequency content or pitch of the sounds were adjusted using Audacity software so that the spectrum and loudness of the sounds matched those predicted by the computer model. Figure 5 shows a graph comparing measured sound levels of the cooling towers at the existing chiller plant facility with the sound levels derived from the computer model studies of the cooling towers (top) and the equalization process to adjust the frequency spectrum of the audio recording of the existing cooling towers to the calculated spectrum for the audio content used in the simulation (bottom).

The second challenge was to design a set of loudspeakers that could be located on grade at the proposed site that could simulate sound propagation from a combination of sound sources propagating from different heights and locations on the site through the neighborhood. The sounds from the fans and water flow from the cooling towers will propagate over the top of the surrounding barrier wall. Sounds from the chillers and pumps inside the building will propagate through large metal doors and ventilation openings located at the face of the building near the ground.

At the time of the simulation, buildings existed at locations on the site that would be demolished as part of the construction process. Sounds from the loudspeakers had to propagate into the neighborhood as though the buildings were not located there and sounds could freely propagate into the neighboring lots. The design of the loudspeaker system that was used to play the simulated sounds was developed using the EASE and CadnaA computer model programs so that the sound level contours for the simulated sounds that would be played through loudspeakers mounted on stands located approximately 5 ft. 6 in. above grade would be similar to the way that sounds from the actual chiller plant with the sound sources located near grade level and at the top of the 25 ft. tall barrier wall that surrounded the cooling towers would propagate at locations away from the chiller plant. Figure 6 shows a graph comparing the sound levels for the chiller plant predicted using the CadnaA software program and for the proposed loudspeaker array developed using the EASE computer program.

The third challenge was to calibrate the playback system on site so that the sounds from the loudspeakers represented the sounds modeled in the computer. This involved narrow band equalization of sounds at multiple locations around the chiller plant site so that the actual response of the loudspeakers and amplifiers reproduced sounds of similar levels and frequencies (measured in 1/3 octave bands) at multiple locations in the presence of the sound reflections from the buildings and other obstacles on the site. Figure 6 shows a graph of measured sound levels to the north of the site compared to the computer predicted sound levels at the same location: Scheme 1- Cooling towers with quiet fans (top); Scheme 2-Cooling towers with an ultra-quiet fan (middle); Scheme 3-Cooling towers with quiet fans and silencers (bottom).

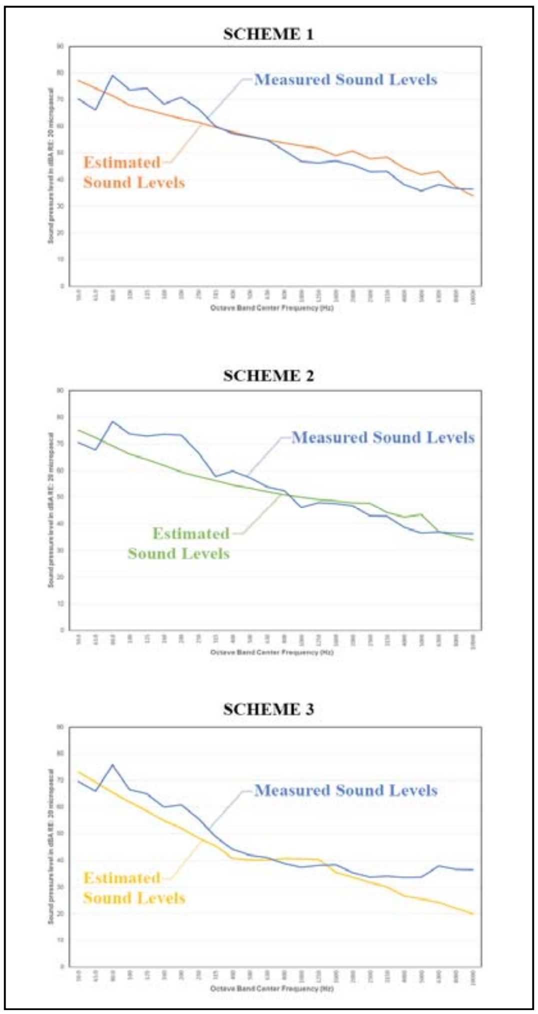


Figure 6. Graph of measured sound levels to the north of the site compared to the computer predicted sound levels at the same location. Scheme 1: Cooling towers with quiet fans (top). Scheme 2: Cooling towers with an ultra-quiet fan (middle). Scheme 3: Cooling towers with quiet fans and silencers (bottom).

## 4. Results

The sound system was set up and calibrated on site so that sound levels and spectra at several locations matched those predicted for the chiller plant in the computer model. A listening jury consisting of the Trustees and the Vice President of Facilities for the college, college staff, the Architect, Mechanical Engineer, Cooling Tower vendor and the acoustical consultants met to listen to the simulated sounds once the sound system was set up and calibrated. This was done as a soundwalk along an itinerary selected so that the variation in sound levels throughout the neighborhood could be heard. Fourteen specific locations were established at which the jury would stop and listen for a period of time. Sounds for each of the 3 schemes were played for several minutes each so the jury could listen. Jury members could communicate with the sound system operator to replay tracks if desired, play them longer or play them so A/B or A/B/C comparisons could be made at each location. The jury discussed what they heard at each point. The jury decided that they preferred a narrative debriefing as the method to evaluate the sounds rather than a questionnaire or a numerical scale. Two of the acoustical consultants took measurements of the sound levels and frequency content of the sounds simultaneously with the evaluations. The first sound walk occurred at approximately 3:00 p.m. A second sound walk was held at approximately 8:00 p.m. and again at 3:00 a.m. the following morning. The reason for the late night and early morning sound walks was that as the background sounds from traffic and insects decrease in the late night and early morning, it was important to experience the soundscape of the neighborhood with and without the simulated sounds from the proposed chiller plant. Figure 7 shows listening groups at locations around the proposed chiller plant during the afternoon (top), evening (middle) and early morning (bottom).

The listening jury decided that the loudness of the schemes was clearly heard to decrease from Scheme 1 to Scheme 3 as more noise mitigation was added to the chiller plant. It was also decided that Scheme 2 could meet the project goals of being significantly quieter than the 75 dBA allowed by the noise ordinance and approaching the vicinity of the existing background sounds at the site at most locations, especially those more than 1/2 block away from the chiller plant. The college actually purchased several of the homes close to the site for use as buffer spaces. The consensus of the jury was that the simulation was much easier to understand than the numerical sound contours produced in the report given the subtleties of the different frequency content or pitch of the different fan selections and the presence of other complex environmental sounds in the area.

Figure 7. Photographs of listening groups at locations around the proposed chiller plant during the afternoon (top), evening (middle) and early morning (bottom).

## 5. Discussion

The jury agreed that the full-scale simulation enabled them to aurally experience the effects of the various chiller plant designs in a way that was more helpful than seeing noise contours on a site plan. They felt informed enough to make the decisions about plant location, equipment selection and noise mitigation features for the project. The narrative format for the jury evaluation and discussion among the jury members allowed consensus to be reached so that the project could move forward. The radio contact with the sound system operator allowed jury members to request replaying of specific tracks so they could hear or not hear them again. This was especially useful during the 3:00 p.m. and 8:00 p.m. soundwalks when other background sounds made it difficult to hear Scheme 2 and Scheme 3 sounds at some locations.

## 6. Conclusions

The case study demonstrates that full scale simulations of soundscapes in the actual environments where they will occur enables participants in the soundscape to experientially preview the aural consequences of planned interventions in the community before they actually occur. This provides sensory information to stakeholders that can illuminate the decision-making process. Decisions can be made about alternative design opportunities based on aural simulations that are executed in technically accurate ways so that the simulation is a reasonable reproduction of what the actual event will be. The process allows non-technical people to evaluate the acoustical consequences of design decisions involving architectural, urban, rural and natural spaces. Narrative interviews and focus group discussions were used to elicit feedback from participants in the case study about attributes of the simulated environment. Some of the responses were related to the level of the sounds heard. Other responses were related to the opinions people held about the sounds, i.e., whether they liked them or not, rather than how loud or disturbing the sounds were. The process described for the chiller plant could also be applied to a wide range of situations where people are having difficulties relating numerical evaluations of the acoustical environment to the qualities of the environment that will be perceived by the users of the spaces.

There are a number of case studies presented in the literature that report on simulated sounds being used to evaluate the acoustical consequences of design decisions in religious and performing arts buildings. These often have the listeners evaluate the space in a special acoustical environment. In this study the evaluations all occurred in the full scale, actual space where the interventions will be built. This method allows people to experience the sounds of a proposed intervention in the course of their everyday lives with the complete physical and sonic context of the totality of their environment in place so that the sonic changes can be heard in a complete experiential context. The method offers promise as a way to aurally preview the acoustical effects of alternative designs for other types of projects so that stakeholders can fully participate in an inclusive, participatory design process.

## Acknowledgement

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