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Acoustical evaluation of non-classroom university learning spaces

Murray Hodgson and Jorge Garcia Moreno

School of Occupational and Environmental Hygiene & Department of Mechanical Engineering, The University of British Columbia, 2206 East Mall, Vancouver, BC, Canada V6T 1Z3
mhodgson@interchange.ubc.ca

An acoustical evaluation was done of non-classroom learning spaces (NCLS) at the University of British Columbia. In eleven buildings, twenty-three indoor spaces—a restaurant, a cafeteria, libraries, dedicated study spaces, building lobbies and atria, etc.—used for learning activities by at least 40 students were studied. The evaluation involved physical and acoustical (noise level, reverberation time, Speech Intelligibility Index) measurements, and occupant demographics and satisfaction questionnaires. Questionnaires were administered three times (morning, lunchtime, afternoon) in each space. The questionnaires asked about satisfaction with, and the effects on learning of, the acoustical and non-acoustical environments. The physical-acoustical measurement results were compared with acceptability criteria. The questionnaire responses and acoustical-measurement results were correlated and their implications considered. Using both as possible predictors, multivariable regression models for predicting and explaining occupant satisfaction with, and the effects of, the acoustical environment were developed. The implications of the study results for optimal NCLS design were considered.

1. Introduction

At the University of British Columbia (UBC), students learn in many different spaces, including classrooms. These are where students and teachers interact, in lectures and seminars. However, there are more suitable spaces for sharing ideas, doing homework, concentrating, reading, writing, studying, computing, discussing classroom topics, or simply interacting with fellow students to the benefit of learning. Such spaces include lobbies, hallways, lunch rooms, cafés, labs, libraries and common rooms. These areas are non-classroom learning spaces (NCLS).

A good acoustical environment in a learning space is essential for a positive learning outcome. Areas where verbal communication (speech intelligibility and/or speech privacy) is integral to the learning process require very specific acoustical characteristics. If there is too much reverberation, not only will the area feel noisy, but the reverberation will interfere with the communication process, thus interfering with learning. Too little background noise can make even the slightest sound noticeable, intensifying distraction and contributing to broken concentration, but enhancing verbal communication and providing limited speech privacy. Too much noise can be annoying, and can make verbal communication difficult, but can enhance speech privacy.

2. Methodology

2.1 Objectives

The main objective of this research project was to evaluate non-classroom learning spaces located in buildings at UBC, to determine the quality of their acoustical environments and how to improve their designs. Spaces were chosen for study based on the following criteria: be used by students for learning purposes; have capacity for at least 40 users; have a constant flow of users.

In the end, 23 spaces in 11 buildings were studied. Among them were libraries, academic common areas, coffee shops, eateries and dedicated study spaces. The evaluation assessed the spaces by questionnaire survey and physical-acoustical measurement.

2.2 Questionnaire

A questionnaire was developed for the study. Its length had to give a response time of 5-7 minutes. Both acoustical and non-acoustical questions were included, as follows:

Non-acoustical:

- respondent demographics (sex, number in group, wearing of earplugs or headphones, current learning activities)
- perceived overall quality of the NCLS learning environment
- perceived quality of non-acoustical aspects of the environment (lighting, air, temperature, furniture).

Acoustical:

- perceived overall quality of the acoustical environment
- effects of aspects of the acoustical environment
- awareness of the acoustical environment
- positive and negative consequences of the acoustical environment

The questionnaire was evaluated by acoustical professionals, a psychologist, and an ethics committee. Informal testing sessions were organized, and the questionnaire refined until a final version was obtained.

2.3 Physical-Acoustical Parameters

The following physical-acoustical parameters were measured:

Noise levels. Equivalent-continuous noise levels in the 63-8000 Hz octave bands were measured. In the unoccupied spaces total, A-weighted and NC levels were determined. In the occupied spaces, total, A-weighted and NC(B) levels were determined;

Reverberation time at mid-frequencies (**RT_{mid}**);

Speech Intelligibility Index (**SII_n**), calculated at a receiver position from the speech level, occupied noise levels and unoccupied RT_{mid}'s. Actual speech levels were not measured. Instead, levels corresponding to an average adult talking in a normal voice were determined from the corresponding sound-power levels and the sound levels generated by a source of known output sound-power levels (a calibrated omni-directional loudspeaker array), at standard distances (1, 2, 4…32 m). SII_n at 1 m (SII_n1) was used to assess speech intelligibility. SII_n at 4 m (SII_n4) was used to assess speech privacy.

2.4 Acceptability Criteria

The evaluation criteria chosen for this study were adopted from the ANSI classroom standard [1] and other sources [2, 3, 4].

RT_{mid}. For rooms of up to 566 m^3 (20 000 ft^3), the recommended unoccupied RT ranges from 0.5-0.7s for acceptable quality, and is less than 0.5 for excellent quality. Many spaces evaluated for the purpose of this project are larger than those considered in the standard, sometimes considerably larger. Moreover, students actually experience the occupied space, and occupant absorption reduces the RT of the unoccupied space. Thus, for such spaces, an RT < 1.0 s was considered acceptable, and values less than 0.7 s were considered excellent.

SII_n. Both speech intelligibility and speech privacy were evaluated by SII_n. Speech Intelligibility was considered acceptable for SII_n1 values of 0.5-0.75; above 0.75, it was considered excellent. For Speech Privacy, SII_n4 values ranging from 0.10-0.20 were acceptable; values below 0.1 were considered excellent.

NC_u. Continuous noise (mainly generated by mechanical services) in an unoccupied learning space should be in the range NC 25-30. Values below NC 25 were considered excellent.

NCB_o. Continuous noise in an occupied learning space should not exceed NC(B) 40; values below NC(B) 35 were considered excellent.

$dBA_{u,o}$. Values of total, A-weighted level up to 40 dBA were acceptable for unoccupied learning spaces, and up to 47 dBA for occupied learning spaces.

2.5 Measurement Equipment

The physical-acoustical measurements were made using a laptop computer with the WinMLS 2000 software. A dodecahedral loudspeaker array, calibrated for its sound-power-level output, was used as the speech source. Sound-pressure levels were measured using a Rion NA-29E Octave Band Analyzer.

2.6 Test Protocol

Four visits were made to each space. For visits 1, 2 and 3 (occupied NCLS), noise levels were measured and the questionnaire administered in the periods 9:30-11:00, 12:00-14:00 and 14:00-16:00. For visit 4 (unoccupied NCLS), all physical measurements were performed. Questionnaire administration was spread over several days to avoid approaching the same people in the same area.

Area	Space	unoccupied		occupied		RT_{mid}	SII_n	
		dBA_u	NC_u	dBA_o	$NC(B)_o$		at 1m	at 4m
1	1	39.2	41	61.9	55	0.76	0.18	0.02
	2	32.6	34	55.2	50	0.96	0.36	0.14
	3	44.5	46	48.5	43	0.52	0.55	0.36
2	1	50.3	41	63.5	59	0.96	0.17	0.03
	2	41.9	31	45.6	40	1.78	0.43	0.32
3	1	48.2	40	63.3	59	0.37	0.23	0.07
	2	46.8	34	53.8	48	0.31	0.51	0.39
4	1	34.3	25	45.4	43	0.46	0.60	0.40
	2	35.7	25	42.4	39	0.37	0.70	0.54
	3	32.2	15	41.6	38	1.09	0.52	0.43
5	1	43.5	33	54.5	48	1.58	0.33	0.12
6	1	41.1	30	61.5	55	1.00	0.21	0.06
	2	38.8	26	65.1	59	0.65	0.14	0.04
7	1	54.4	45	67.6	62	0.96	0.06	0.00
8	1	44.1	31	54.6	48	2.77	0.26	0.05
9	2	42.3	34	58.4	53	0.79	0.32	0.16
	3	39.5	30	51.9	50	1.12	0.40	0.35
10	1	50.1	40	56.4	51	0.74	0.40	0.17
11	1	43.7	33	67.1	62	0.54	0.10	0.01
	2	46.0	35	73.5	69	0.93	0.02	0.00
	3	54.9	45	64.2	60	1.56	0.13	0.05
	4	45.9	33	60.7	55	1.00	0.24	0.11
	5	47.6	35	62.4	57	0.97	0.18	0.06

Table 3. Measured and calculated physical-acoustical parameters, and their acceptability (u=unoccupied, o=occupied; white=unacceptable quality, yellow=acceptable quality, green=excellent quality).

3. Results

3.1 Questionnaires

850 completed questionnaires were collected. The average results for each space were calculated and spaces with better or worse quality identified. Average responses for each question were also calculated. Following are the main results:

- the learning activities reported most often were thinking and reading
- lighting, air, temperature and furniture comfort generally enhanced learning; the acoustic environment interfered with it
- people moving and talking was the aspect of the acoustical environment that most impaired learning, followed by intermittent noise
- distraction was the most reported negative consequence of the acoustical environment, followed by annoyance; difficulty hearing and talking were reported least
- feeling relaxed was the most reported positive consequence of the acoustical environment, followed by feeling productive; conversational privacy was reported least
- 22% of respondents reported that they chose their study location because of the acoustical environment; in most cases they chose a quiet location.

3.2 Physical-Acoustical Measurements

Table 3 shows the results of the physical measurements, and their acceptability in comparison with the study criteria.

3.3 Statistical Analysis

Correlation

In order to observe if there was any apparent relationship between the questionnaire responses and the measured physical-acoustical parameters, and in preparation for a regression analysis, Pearson's correlation coefficients between all data pairs were calculated. Values >0.2 in absolute value were considered significant and their apparent implications deduced, as described below.

First, considering only the questionnaire responses (note: 'satisfaction' refers to the perceived extent to which learning was interfered with or enhanced):

- no responses were correlated with the time of day or respondent sex
- overall satisfaction with the learning environment was associated with increased satisfaction with people talking and moving, continuous noise and intermittent noise
- overall satisfaction with the learning environment was associated with increased experiencing relaxed, energized and productive
- overall satisfaction with the learning environment was associated with decreased distraction
- satisfaction with lighting was associated with feeling productive
- satisfaction with air quality was associated with feeling relaxed
- satisfaction with furniture comfort was associated with feeling relaxed and productive
- satisfaction with the acoustical environment was associated with increased satisfaction with people talking and moving, continuous and intermittent noise and reverberation
- satisfaction with the acoustical environment was associated with decreased annoyance, distraction, stress and difficulty hearing
- satisfaction with people talking and moving, continuous and intermittent noise and reverberation were mutually correlated
- satisfaction with people talking and moving, continuous and intermittent noise and reverberation were associated with decreased annoyance, distraction and stress
- experiences of annoyance, distraction, stress, fatigue, difficulty hearing and difficulty talking were correlated
- experiences of conversational privacy, and of feeling relaxed, energized and productive were correlated.

Second, considering only the physical-acoustical parameters:

- all noise levels and SII_n values were correlated
- RT_{mid} was only correlated with SII_n4.

Finally, considering both the questionnaire responses and the physical-acoustical parameters:

- when noise levels were lower, students were more likely to be involved in reading
- when noise levels were higher and SII_n's lower, people were less satisfied with the overall learning environment and with furniture comfort, were more likely to be involved in discussion, to work in groups, to report more difficulty hearing, slightly more difficulty talking, and to feel less productive, and were more likely to choose their study location because of the acoustical environment.

Regression analysis

Based on the correlation analysis, various multivariable linear-regression models were developed to predict the response to the question, "How well does the environment *in general* in this learning space interfere with or enhance your ability to use this space for your activities?" on a scale from -3 (interferes a lot) to +3 (enhances a lot) (variable *env_gen*).

First, using only the other questionnaire responses as predictors, an optimal model which had an adjusted-R^2 of 0.48 was found. Second, using only the physical parameters as predictors, an optimal model which had an adjusted-R^2 of 0.19 was found. The best model, with an adjusted-R^2 of 0.53, was developed using both the questionnaire responses and the physical-acoustical parameters, as follows:

$$\begin{aligned} env\_gen = {} & 0.151\,light + 0.126\,furn + 0.264\,people \\ & + 0.174\,prod + 0.401\,acoust - 0.014\,\mathrm{BNA_u} \\ & + 0.348\,\mathrm{RT_{mid}} + 2.188\,\mathrm{SII_n4} \end{aligned} \quad (1)$$

in which: *light* quantifies the perceived quality of the lighting, *furn* quantifies the perceived comfort of the furniture and *people* quantifies satisfaction with people talking and moving (on the same scales as *env_gen*); *prod* quantifies the reported feeling of productivity on a scale from 0 (not at all) to 5 (a lot), *acoust* = 1 if respondents chose their study location because of the acoustical environment and 0 if not. BNA_u is the total, A-weighted unoccupied noise level, RT_{mid} is the unoccupied mid-frequency RT, and SII_n4 is the normal-voice SII at 4 m.

4. Discussion

Without exception, no NCLS met all of the criteria established for an acceptable acoustical learning environment. This was seen in both the physical-acoustical measurement results, and in the questionnaire responses.

According to the questionnaire results, greatest perceived learning-environment quality was in spaces 2-2, 4-2 and 4-3; these are three library study areas. The worst quality was in spaces 7-1 and 11-5, an eatery and a study space in the basement of a student-services building. According to Table 3, the best spaces had acceptable noise levels (especially when occupied) and/or low RTs. The worst had unacceptable unoccupied and occupied noise levels, RT and speech intelligibility, but high speech privacy.

According to the regression model of Eq. (1), occupant satisfaction with overall environmental quality can be improved by improving the lighting and furniture comfort, ensuring that people talking and moving are not a problem, decreasing noise levels and increasing speech privacy. The positive coefficient of the RT_{mid} term suggests that environmental quality can be increased by increasing the mid-frequency RT; however, it also increases with SIIn4 which decreases with increase RT, so the effect of reverberation is not simple.

All of the average acoustical ratings given by the questionnaire respondents to all the NCLSs evaluated were negative. It was the only aspect of the environment that received negative scores from the respondents; non-acoustical aspects received positive scores.

The average unoccupied noise level satisfied the criteria in less than one third of the spaces. This shows that, in 70% of the cases, there is an unacceptable amount of noise being generated by equipment and mechanical services and, possibly, that this is being amplified by strong reverberant fields due to insufficient sound absorption.

The average occupied noise level was higher than recommended in 83% of the spaces, and a lot higher in most of the cases. Although this can readily be explained by the large number of people studying in groups, it results in compromised speech intelligibility, requiring talkers to raise their voices or move closer together than 1 m to talk.

RT values were not acceptable in 70% of the cases. Retrofitting the NCLS's to have lower RT_{mid}s by a reduction in room volume and an increase in sound absorption would be a first step in enhancing the acoustical environments of these spaces. This would make the spaces feel less noisy, lower reverberant noise levels and increase speech intelligibility.

Speech intelligibility was only acceptable in five of the spaces, four of which are library spaces in which little to no group study takes place and students are expected to be quiet.

Conversational privacy was, by far, the most acceptable physical parameter measured in all NCLSs. Out of the 23 spaces, 16 had acceptable values, with 11 of those providing excellent speech privacy. This was, of course, due to the elevated noise levels present in most of the occupied spaces.

SII was never found to be acceptable for both speech intelligibility and speech privacy in the same NCLS. Even if the speech intelligibility is sufficiently high at 1 m from a talker, speech sounds do not decrease rapidly enough with distance in these spaces to result in sufficiently high speech privacy (sufficiently low speech intelligibility) at 4 m. Increased sound absorption and acoustical screens are two possible solutions.

References

[1] ANSI S12.60-2002. American National Standard Acoustical Performance Criteria, Design Requirements and Guidelines for Schools. Acoustical Society of America, New York, 2002.

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[4] Noise and Vibration Control Engineering – 2nd edition, I. Ver, ed. (John Wiley & Sons, New York, 2005).