Occupant Satisfaction with the Acoustical Environment:

'Green' Office buildings before and after treatment

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ABSTRACT: This paper reports the results of two studies of the acoustical environments in 'green' office buildings before and after acoustical-control measures were installed. Acoustical quality was evaluated by occupant-satisfaction surveys and acoustical-parameter measurements. Occupants rated various aspects of the building and its built environment, including acoustical quality. The first study involved six 'green' office buildings. The acoustical environments were rated as the worst aspect, and as poor, in all buildings. The results show that the various aspects of a building's design are intimately interconnected; no aspect can be successfully designed in isolation. Buildings designed to obtain LEED ratings are unlikely to have satisfactory acoustical environments. In the second study, a naturally-ventilated, 'green', university building was studied before and after treatment. To promote natural ventilation, the floors are inter-connected by ventilation openings/shafts; the partitions separating the offices from the corridors have openings. Pre-treatment surveys rated the acoustical environment as its worst aspect, and as very poor. Occupants were particularly dissatisfied with speech privacy. Noise-control measures were designed, installed and tested. The ventilation shafts connecting the floor openings were lined acoustically and had acoustical baffles suspended in them. The results show that poor acoustical environments can be improved using engineering-control measures, but that these must be optimized.
Keywords: 'green' buildings, acoustical environment, offices, occupant satisfaction, acoustical parameters

INTRODUCTION

The aim of sustainable ('green') architecture is to create buildings that preserve the environment and conserve natural resources, as well as provide a 'healthy' environment for their occupants. A 'healthy' environment is one that does not cause disease, that promotes well-being and, in the case of workplaces, that enhances productivity. An important aspect of the built environment—often overlooked or undervalued in design—is the acoustical environment. Recent papers have pointed out that 'green' buildings are often less than satisfactory acoustically, and have reported work devoted to the design, control and/or optimization of their acoustical environments [1-4]. The work discussed here was an attempt to investigate this issue more fully, with a focus on 'green' office buildings, and to increase awareness of 'green'-building acoustical issues in the non-acoustical design community.

This paper reports the results of two studies that evaluated the acoustical environments in 'green' office buildings: Study 1 involved six buildings; Study 2 involved the UBC Liu Institute before and after acoustical-control measures were installed to improve the environment. The buildings were 5-15 years old, and had been designed to the sustainable-design principles in place when they were designed; several were designed to the specifications of LEED. The building acoustical quality was evaluated by occupant-satisfaction surveys and physical/acoustical-parameter measurements. Occupant satisfaction was assessed using the web-based survey developed by the Centre for the Built Environment at the University of California at Berkeley [5]. The Berkeley survey asks occupants to rate their general satisfaction with the building and with their workspace, with the office layout, with the office furnishings, with thermal comfort, air quality, lighting, acoustic quality and with the washrooms. In this study, it also asked about cleanliness/maintenance. Occupants rate quality on a scale of -3 (maximum dissatisfaction) to +3 (maximum satisfaction).

Regarding the acoustical environment, it asks occupants to rate their satisfaction with noise levels, acoustical privacy, and the extent to which the acoustical environment promotes productivity, as well as to specify the sources of dissatisfaction. The acoustical measurements involved measuring four parameters—reverberation time, continuous noise level, Speech Intelligibility Index and noise isolation—at appropriate work positions in the buildings, under different conditions (unoccupied and occupied, near to or far from external walls, external windows and office doors closed and open, quiet and noisy external environment, etc.). Table 1 shows the four acoustical parameters that were measured. Also shown are the acceptability criteria used to evaluate each aspect of the acoustical environments in these office buildings chosen from information in various sources [6-10].

Table 1: Acoustical measurement parameters and acceptability criteria.

Measurement parameter	Acceptability criterion
Background noise level, NC in dB	NC 30-35 in meeting, conference rooms NC 35-40 in workspaces
Reverberation time (mid-frequency), RT_{mid} in s	< 0.75 s for comfort, verbal communication
Speech Intelligibility Index, SII	> 0.75 for high speech intelligibility < 0.2 for high speech privacy
Noise Isolation, NIC in dB	NIC 35-40 for executive offices, conference rooms NIC 30-35 for general offices, meeting rooms

STUDY 1

Objectives and Methodology The objective of this work was to evaluate six 'green' office buildings acoustically, to learn design lessons. It involved a meeting with designers (usually an architect and a mechanical engineer), performing an occupant-satisfaction survey, analyzing the acoustical responses, walking through the building, planning acoustical measurements, performing and analyzing the acoustical measurements and considering the design implications.

The study involved six very different nominally-'green' office buildings, evaluated 1-5 years after occupancy. Descriptions can be found at www.sbtc.ca/index.cfm?bd=KBDet.cfm&id=60. All buildings had mainly glass façades for day-lighting, with sun shades and operable windows, and contained a mix of private and shared offices, and open-office cubicles.

Acoustical-Parameter Measurements Acoustical-parameters measurements were done to characterize and evaluate the acoustical environment, situations (workplaces and building conditions) of high and to explain the survey results, which had identified and low occupant satisfaction. Workplaces at which measurements were performed were chosen to correspond to high and low occupant satisfaction. In general, these included desks in open-plan, shared and private offices, located in quiet and noisy areas, near and far from operable windows. Furthermore, measurements were made under building conditions expected to correspond to high and low satisfaction (windows or doors closed or open, quiet or noisy external source).

Results *Designer meetings* Following are the main points relevant to acoustics learned from the designers at the meetings with them: LEED certification is often a goal that influences design; design often does not involve specialized acoustical expertise—acoustical consultants deal with 'special cases'; quantitative acoustical design targets are never set; designers are aware of acoustical issues; external noise (and pollution) concerns may rule out a fully-natural ventilation concept; 'green' buildings often have operable windows, which causes noise concerns if there's an external noise source; low noise levels resulting from the absence of a mechanical system result in low speech privacy; client's wishes (e.g. for open-office design) may affect design; budget short-falls at the end of the project may affect acoustical quality; obtaining good noise isolation may involve lined return-air ducts, upholstered furniture, acoustical ceilings, carpet, open-office partitions; some buildings are designed for any occupant; the internal 'fit-up' (e.g. acoustical treatments) is done later by contractors for tenants (on limited budgets); designers often believe their building is well designed, and is successful with the occupants.

Occupant-satisfaction surveys Figure 1 shows the results of the occupant-satisfaction surveys done in five of the six buildings. Also shown (Ref) are the average scores from all buildings ('green' and non-'green') surveyed using the CBE survey at the time. In general, satisfaction ratings were positive, indicating satisfaction. Occupants were very satisfied with their buildings and workspaces, with the furnishings, office layouts, cleanliness and maintenance and with the washrooms. They were generally very satisfied with the lighting, and some-what satisfied with air quality. Satisfaction with thermal comfort varied from somewhat satisfied to somewhat dissatisfied.

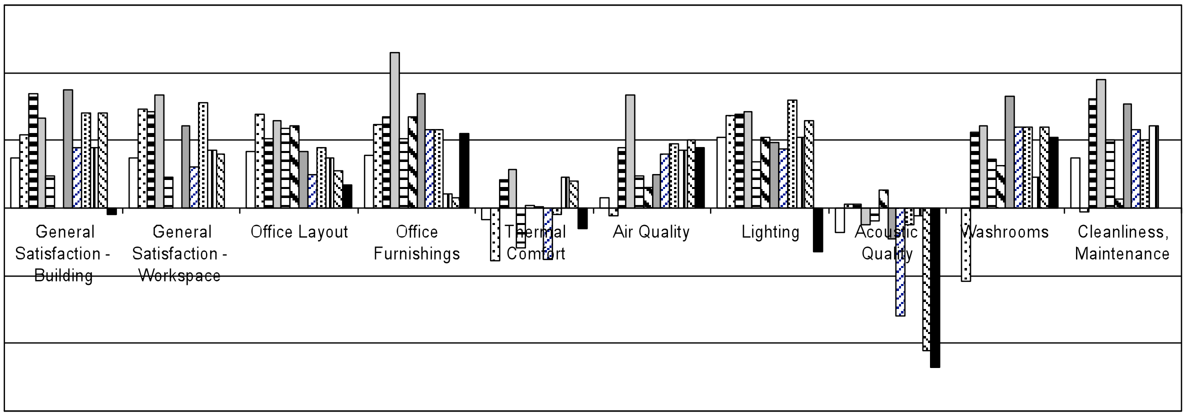

Figure 1: Occupant-satisfaction-survey results for five 'green' office buildings (A to E) in the six-building study, and in the UBC Liu Institute (K), and in other buildings surveyed.

Occupants were generally dissatisfied with the acoustical environment, which often received the lowest rating. Speech privacy is the biggest acoustical issue.

Acoustical-parameter measurements Following are the main results of the acoustical-parameter measurements:

- Background Noise Level: NC 26-34 (unoccupied, natural ventilation); NC 35-42 (unoccupied, forced-air ventilation); NC 45-60 (external noise, windows open); NC 40-60 (occupied);
- Reverberation Time: open-office areas: 0.6-1.0 s (low absorption); 0.2-0.4 s (high absorption); private offices: 0.4-0.7 s (low absorption); 0.2-0.4 s (high absorption); hallways, atriums: 0.9-2.4 s;
- Speech Intelligibility (private office, across desk, casual voice): 0.3-0.6 (forced-air ventilation, low absorption); 0.7 to 0.8 (natural ventilation, high absorption);
- Speech Privacy. Between open-office cubicles, casual voice): 0.3-0.6 (forced-air ventilation, low absorption); 0.7-0.8 (natural ventilation, high absorption). Outside-inside private office (door open, casual voice) = 0.7;
- Noise Isolation: into closed offices = NIC 25-30 (door closed); = NIC 9-15 (door open); between work areas = NIC 7-20.

Design implications The main acoustical design implications of the results relate to low background-noise levels, inadequate speech privacy, excessive reverberation, inadequate noise isolation between workplaces in open and shared work areas, and inadequate internal and external wall isolation. Following are details as they relate to 'green'-building issues:

- since LEED virtually ignores acoustics, a building designed to obtain LEED certification is unlikely to have adequate attention paid to the acoustical environment;
- 'green' buildings often are designed to have natural/displacement ventilation systems; these can affect the acoustical environment beneficially or detrimentally, resulting in low background-noise levels and low noise isolation; however, forced-air ventilation *can* figure in 'green'-building design;
- many 'green' buildings have little sound-absorption; this affects the acoustical environment detrimentally, resulting in excessive reverberation, low acoustical privacy and inadequate attenuation of sound propagating through the building; however, beneficial sound-absorbing materials *can* figure in 'green'-building design;
- if a 'green' building, designed with a ventilation system relying on operable windows, is located next to a significant noise source, noise problems are likely, especially if the windows open on the source side;
- a 'green' building designed to rely on a natural/ displacement ventilation system, and with transparent envelope for day-lighting, may overheat on hot, sunny days, forcing occupants to open windows and office doors, resulting in excessive noise and low speech privacy;
- background-noise levels in a 'green' building with full or partial natural-ventilation system may be lower than as expected in a conventional building with a forced-air system. These low levels may make it more difficult to achieve adequate speech privacy;
- a 'green' building designed to rely on a displacement ventilation system usually involves air-transfer

openings and/or ducts in partitions. These significantly reduce noise isolation between areas, even when treated acoustically.

Discussion The acoustical environment is often judged the least satisfactory aspect of 'green' office buildings by the occupants. They are dissatisfied with excessive noise and poor speech privacy, and consider that the acoustical environment does not enhance their ability to work (i.e. productivity). Speech privacy is often the biggest concern.

The results of this study suggest that improving acoustical environments in 'green' buildings fundamentally requires good acoustical design—that is, the application in design of existing knowledge, with input from an acoustical specialist from the beginning of the design process. This knowledge relates to site selection and building orientation, to the design of the external envelope and penetrations in it, to the building layout and internal partitions, to the design of the HVAC system, to the appropriate dimensioning of spaces, and to the amount and location of sound-absorbing treatments. For a satisfactory acoustical environment, the advice of the acoustical specialist must be followed, and the budgetary resources made available for it to be implemented.

STUDY 2

In the second study, the naturally-ventilated, 'green', UBC Liu Institute was studied before and after acoustical treatment. It was a multi-storey building, with operable windows, but a quiet external environment, and with private and shared offices along both sides of corridors. To promote natural ventilation, the floors are inter-connected by atria or ventilation openings/shafts; the partitions separating the offices from the corridors also have openings. Pre-treatment occupant-satisfaction surveys rated the acoustical environments in both buildings as the worst aspect of the buildings, and as very poor (ratings around -2.1 on a -3 to +3 scale, see Figure 1). Occupants were particularly dissatisfied with speech privacy between offices on the same and different floors, and in shared offices. Acoustical measurements found that the noise isolation between floors was an inadequate NC 15-25; with casual voice, SII varied from 0.03 (confidential privacy) into closed offices, to 0.43 (no privacy) to the corridor. Between offices and corridors on a floor, the noise isolation was a very poor NC 10; the casual-voice SII averaged 0.63 (no privacy).

To improve the noise isolation between floors, and between offices and corridors in the building, noise-control measures were designed, subject to minimum air-flow constraints, installed and tested. Design involved predicting the noise isolation of various treatment configurations using an acoustical ray-tracing model, in order to identify the optimal design. To improve inter-floor noise isolation, the ventilation shafts connecting the floor openings were lined acoustically and had acoustical baffles suspended in them. They increased the noise isolation by NC 15-25, to a generally excessive NC 35-55; casual-voice SII decreased to between 0 and 0.06 (confidential privacy) everywhere. Noise isolation between offices and corridors was improved using an acoustically-lined Z-shaped duct installed in the ventilation openings. This increased the noise isolation by about NC 15 to NC 25, which is still inadequate; casual-voice SII decreased to an average of 0.29 (inadequate privacy). Limited air-flow monitoring was done between offices and the corridor before and after treatment to determine if the Z-duct silencer affected ventilation; they caused no change in air-flows, but the results were inconclusive since there was little airflow before treatment. The results of this study show that poor acoustical environments can be improved using appropriate engineered acoustical-control measures, but that these must be optimized.

Limited air-flow monitoring was done between offices and the corridor before and after treatment to determine if the Z-duct silencer affected the ventilation quality. The results suggest that the silencer caused no change in air-flows, but the results were inconclusive since there was little airflow measured before treatment.

Unfortunately, it was not possible to repeat the occupant-satisfaction survey after treatment. However, discussion with the occupants of offices fitted with the Z-ducts suggested that they were happy with their acoustical performance; they also reported that the rooms became 'stuffy' after treatment.

CONCLUSION

The aim of sustainable ('green') building is to create buildings that preserve the environment and conserve natural resources, as well as to provide a 'healthy' environment for its occupants. Designing a building to preserve the environment and conserve resources is admirable and essential, but it must not be done to the detriment of the occupants, who will live and work in the building. The acoustical environment is often judged the least satisfactory aspect of 'green' office buildings by the occupants. They are dissatisfied with excessive noise and poor speech privacy, and consider that the acoustical environment does not enhance their ability to work (i.e. productivity). Speech privacy is often the biggest concern.

The results of this work suggest that improving acoustical environments in 'green' buildings fundamentally requires good acoustical design – that is, the application in design of existing knowledge, with input from an acoustical specialist from the beginning of the design process. This knowledge relates to site selection and building orientation, to the design of the external envelope and penetrations in it, to the building layout and internal partitions, to the design of the HVAC system, to the appropriate dimensioning of spaces, and to the amount and location of sound-absorbing treatments. For a satisfactory acoustical environment, the advice of the acoustical specialist must be followed, and the budgetary resources made available for it to be realized.

The results of the studies also show that the various aspects of a building's design (e.g., energy efficiency, lighting, ventilation, air-quality, acoustics) are intimately interconnected, and that no aspect (e.g. the ventilation system) can be successfully designed in isolation. A recent pilot study [11] investigated the relationship between ventilation, air and acoustical qualities in 'green' and non-'green' buildings, finding that forced-air ventilation gives better indoor air quality (IAQ), but higher ventilation-system noise levels, that IAQ and noise level are directly related, that in naturally-ventilated spaces with radiant ceiling slabs, lack of acoustical treatment gives lower fibre concentrations, but worse acoustical conditions, that naturally-ventilated spaces have unsatisfactory ventilation quality but acceptable noise levels with the windows closed, and satisfactory ventilation quality but excessive noise levels with the windows open, even without significant external noise sources, that naturally-ventilated spaces with few furnishings or sound-absorbing materials have higher IAQ, and that acoustical treatment can enhance acoustical quality, but worsens IAQ. 'Green'-building design must take an integrated, holistic approach.

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