ACOUSTICAL IMPROVEMENTS WITH NATURAL AIR VENTILATION IN THE LIU INSTITUTE FOR GLOBAL ISSUES AT THE UNIVERSITY OF BRITISH COLUMBIA

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ABSTRACT

Low speech privacy in shared and private offices in one of the early generation of a "green" building resulted in occupants' dissatisfaction. This problem is experienced in Liu institute with a natural-ventilation system. Such a system requires low air-flow resistance which is achieved by large openings which will result in noise transmission between various spaces within the building. The poor acoustical quality in this building resulted in occupants' noise complaints which were further investigated by way of relevant acoustical measurements. CATT-Acoustic software was utilized to modify the acoustical quality of the building without any disturbance to the occupants. The optimized design of the transfer box above the office door was selected based on CATT-Acoustic predictions. The acoustical measurements were conducted after installation of the transfer box above the office door. The measurements' results agreed with the predictions which led to improved speech privacy to an acceptable level between the office and the corridor in Liu Institute. More work should be done to improve the acoustical quality of natural-ventilated building to conform to ANSI standards.[1] *The results of this study strongly support including acoustics in "green" building designs with natural ventilation to avoid users' complaints.*

KEYWORDS

"green" building, natural ventilation, acoustical environment, noise control

INTRODUCTION

One of the most important benefits of "greening" a building, aside from reduced environmental impacts, is to provide an environment in which the occupants can perform at their optimum level. Any gain in occupant productivity translates into enhanced building sustainability. However, widespread dissatisfaction with the acoustical quality in workplaces can lead to costly errors in communication and reduced productivity due to distraction.

The University of British Columbia (UBC) Liu Institute for Global Issues was constructed in the late 1990s. This building is nestled in a giant stand of trees. The building site created a suitable microclimate for natural ventilation, which became a critical component of its design. As designed, the Liu Institute includes considerable thermal mass and permits airflow into the interior of the building. Perimeter windows are fitted with "trickle" ventilators (small 50 mm high openings integrated into the length of the window units) that can be opened and closed to permit air intake. As can be seen in Figures 1, hopper windows are included for larger air intakes in the offices as needed and as controlled by the users. As air flows into perimeter spaces, it is vented into interior hallways through large openings located above doorways and corridor partitions. These large openings are paths for air as well as noise to travel between spaces.

The Liu Institute is an early-generation "green" building, designed with a natural-ventilation system. The spaces at the two ends of the building are ventilated by a natural-ventilation system, working on the basis of temperature and moisture differences between the inside and outside air (the stack effect).

Depending on indoor/outdoor temperatures, the air inside office spaces is drawn by the stack effect through ventilation shafts and exhausted out of upper openings (in the roof) or drawn out of lower openings, and fresh air from windows or trickle vents replaces it.

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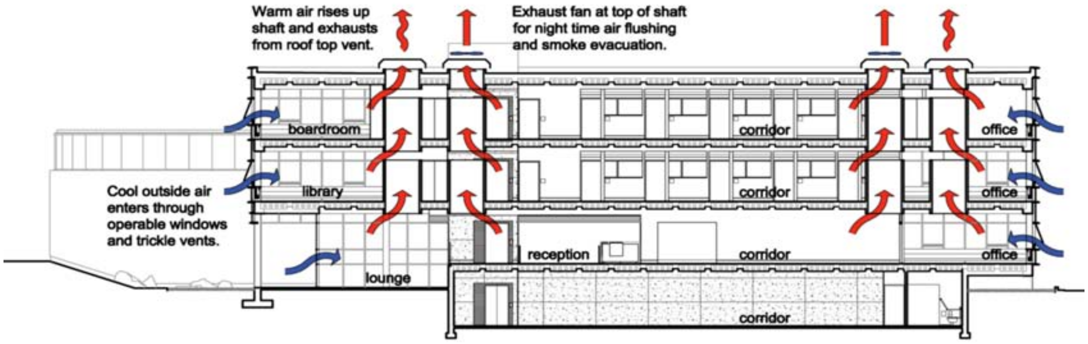
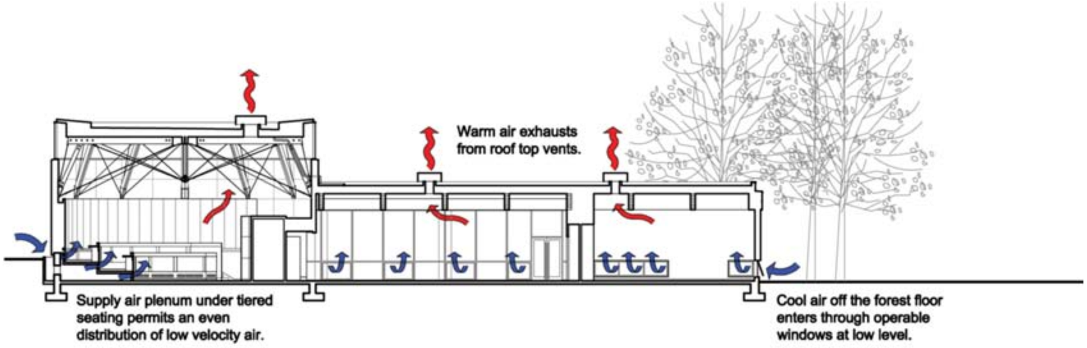
FIGURE 1. Natural air ventilation in the Liu Institute through ventilation shafts and operable windows between floors. Air intakes and exhausts are shown in blue and red, respectively.



Research Wing



Seminar Wing

This process provides fresh-air infiltration and air circulation but, in addition, can provide paths for noise transmission.

Large open spaces between offices and shafts, and between shafts and corridors, facilitate air movement between ventilation shafts in these areas, but this can be a drawback since, on the other hand, these open areas can also be noise-transmission paths.

Noise complaints from employees resulting from noise traveling from offices to the corridor and vice versa led to this study.

This was a collaborative project between Stantec Consulting Ltd. and the UBC Acoustics and Noise Research Group, funded by the UBC Sustainability Office and Stantec Consulting Ltd. The design of a transfer box in an office was performed by Stantec Consulting Ltd and the design of noise isolation for ventilation shaft has been undertaken by UBC. The former work will be discussed here; the latter work is reported elsewhere[2].

This paper documents steps taken from problem assessment to post-implementation evaluation measurement done on acoustical improvements to offices. The air-quality effect due to this treatment was also assessed, and is discussed here.

LITERATURE REVIEW

In 2002, M.H. F. De Salis et al.[3] studied a method to minimize road traffic noise intrusion into a natural ventilated building. The Sound Reduction Index (SRI) was used to describe façade acoustical insulation in the field. The objective of the study was to achieve 35–40 dBA façade sound insulation in areas of high road traffic noise of equal to 70–80 dBA. This level of attenuation would be difficult to achieve when an adequate rate of natural ventilation is required. Some of the general solutions were to locate apertures away from direct noise paths and screening, using internal or external barriers or alternatively less noise sensitive areas of a building to be used as a noise barrier. It is found that the barriers show a limited attenuation at low frequencies and that in turn limits the total noise attenuation. They found the low attenuation at low frequencies with acoustical louvers will result in their poor acoustical performance. Incorporating of reactive silencers didn't work due to need for a large space to achieve the required attenuations at low frequencies. They studied active noise cancellation which was found to be more effective at low frequencies. They came up with the optimal solution of a hybrid passive/active system to achieve noise attenuation of

30 dB in frequency band of interest. However they suggested further research into use of hybrid treatment since a number of promising strategies have been identified where information on both the acoustical and airflow characteristics was limited.

In 2005, D. J. Oldham et al.[4] studied different configurations of a lined aperture on the acoustical and ventilation performance of an aperture to establish the optimum configurations. The paper dealt with the simplest form of natural ventilation inlet and outlet device which is a simple aperture in a façade. The technique employed was the Finite Element Method (FEM) using the SYSNOISE software package. A commercially available Computational Fluid Dynamics (CFD) software was used to model the airflow chrematistics of the aperture. They suggested two mechanisms whereby the performance of a ventilator can be enhanced. They included geometrical configuration of designs (e.g. length and height) and use of absorptive lining. It is found that porous lining are most effective for frequencies above 500 Hz. It is also found that the length of aperture has a significant effect on its acoustical performance. They suggested a possible means to improve the acoustical performance of aperture was to increase its length. The challenge was the thickness of the containing wall. Thus, they suggested a convoluted geometry might be employed to increase the acoustic path which warrants further study.

In 2009, Hodgson et al.[2] studied noise transmission between various floors through natural-ventilation shafts, as noted before. A ray-tracing model was used to predict the performance and refine the designs. The physical-acoustical measurements were conducted before and after changes to the ventilation shafts to evaluate the performance of changes. In the ventilation shafts, the acoustical treatments comprised a sound-absorptive lining and suspended sound-absorptive baffles. They found that lining the ventilation shafts alone was insufficient, that lining and baffles provided more noise isolation than required. The air-quality tests before and after treatment showed that the changes after treatment were insignificant, suggesting the treatment had little effect on ventilation and air quality.

FIGURE 2. Large openings above doorways and corridor partitions.

ACOUSTICAL ENVIRONMENT

Because of the large openings between offices and corridors, shown in Figure 2, speech privacy was negatively affected. Through an acoustical walk-through survey conducted in the building, it was found that any conversation generated in the corridors could be heard in the offices, and vice versa. The acoustical quality in office 310 without and with acoustical treatment in the openings above the doorway is discussed in this paper.

Pre-Treatment Measurements

Acoustical measurements were conducted to evaluate the working conditions for the occupants. These measurements were taken when the building was unoccupied to avoid any occupant's disturbances. Following are details of the measurements:

- Reverberation Time (RT): Reverberation Time is the time in seconds that it takes for a sound to decay by 60 dB (or reach inaudibility) after the sound source is stopped. Reverberation time depends on both the size (volume) of the space, and on the sound-absorptive properties of the interior finishes. Larger spaces (with more volume) usually have longer reverberation times.
- Noise Isolation Class (NIC): NIC is a partition's ability to attenuate sound. The sound-pressure level on both sides of a partition is measured at octave-band frequencies; the difference in the measured data on the two sides of the partition indicates the octave-band Noise Isolation[5]. NIC is determined in dB.
- Speech Intelligibility Index (SII): Speech Intelligibility Index is a measure that is highly correlated with speech intelligibility and speech privacy, which depend on the background noise, talker voice level and RT. It varies from 0 to 1, where 0 indicates low speech intelligibility/high speech privacy and 1 corresponds to high speech intelligibility/low speech privacy[6]. The various values of SII and the corresponding Speech Intelligibilities (SI) are tabulated in Table 1, where Speech Privacy (SP) is essentially the opposite of SI.

Pre-Treatment Measurement Results

- RT: The average measured RT at the octave-band frequencies in office 310 was 0.39 s, where RT should not exceed 0.75 s for a comfortable environment and easy verbal communication[7]. Thus, RTs were acceptable in office areas.

TABLE 1. Speech Intelligibility Index (SII) values and corresponding Speech Intelligibility (SI) and Speech Privacy (SP) quality ratings.

SII	<0.20	0.2 – 0.45	0.45 – 0.60	0.60 – 0.75	>0.75
SI / SP	Bad/Excellent	Poor/Good	Fair/Fair	Good/Poor	Excellent/Bad

TABLE 2. Noise Isolation between office 310 and the corridor, before treatment.

		Noise Isolation (dB)							
		Frequency (Hz)							
Source	**Receiver**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**NIC**
Office 310	Corridor	12.0	8.3	8.8	9.7	10.0	9.4	11.1	10

TABLE 3. Speech Intelligibility Index between office 310 and the corridor, for three voice levels, before treatment.

Speech Intelligibility Index (SII)				
Source	**Receiver**	**Casual Voice**	**Normal Voice**	**Raised Voice**
Office 310	Corridor	0.50	0.59	0.66
Corridor	Office 310	0.77	0.80	0.81

- NIC: The Noise Isolation between office 310 on the third floor and the corridor was measured and is tabulated in Table 2. As can be seen, the NIC was calculated to be 10, whereas the recommended NIC for general offices is NIC 30–35[8].
- SII: Speech Intelligibility Index from the corridor to the office 310, with casual, normal and raised talker voice levels, for two source and receiver locations were measured, and are tabulated in Table 3. The recommended SII for acceptable speech intelligibility is SII>0.6, and for normal speech privacy is SII<0.2. As can be seen in Table 3, values correspond to acceptable speech intelligibility and no speech privacy.

Acoustical-Treatment Designs

The CATT-Acoustic software[9] was used to find the best way to optimize the acoustical environment in the Liu Institute. This software was utilized to design acoustical treatments, and predict RT and SI before and after treatment, before any changes were made on site.

CATT-Acoustic Software

CATT-Acoustic is room-acoustical prediction software which requires the absorption coefficients of the different room surfaces, the locations and powers of the noise source(s), and the number and location of the receivers. This is a room-acoustic prediction model based on ray-tracing and the Image Source Model (ISM). Creating an AutoCAD file of the space and importing it into CATT-Acoustic with information about absorption and diffusion coefficients and background noise level defined in octave bands, impulse responses are predicted. From the impulse responses relevant acoustic parameters (e.g. *Reverberation Time and Speech Transmission Index*) characterizing the acoustical environment are predicted. STI values were calculated with CATT-Acoustic based on the Houtgast and Steeneken method[10]. To improve speech privacy between offices and adjacent corridors, an acoustically-lined Z-shaped transfer box was designed, drawn in AutoCAD and exported into CATT-Acoustic. The proposed size of the openings in the transfer box was based on the air-flow prediction results, to avoid excessive resistance to air flow.

TRANSFER-BOX DESIGN

Air-flow modeling

Thermal Analysis Software-TAS was used to predict the opening size on the transfer box. The software package is for the thermal analysis of buildings. TAS includes a 3D modeller, a thermal/energy analysis module, a systems/controls simulator and a 2D CFD package. It is a complete solution for the thermal simulation of a building, and a powerful design tool in the optimization of a buildings environmental, energy and comfort performance. The existing openings above the doorways and the corridor partitions were 457 mm tall and 2540 mm wide, whereas the proposed minimum opening was to be 127 mm tall and 2540 mm wide. This opening size was proposed based on UBC indoor-temperature guidelines and LEED® Bounding Comfort Parameters. The UBC indoor-temperature target for non-air-conditioned spaces is 28 °C, whereas LEED® Bounding Comfort Parameters allow 220 hours above 24 °C. The proposed design air temperature was compared with the existing situation and is tabulated in Table 4; both conditions are within the guidelines.

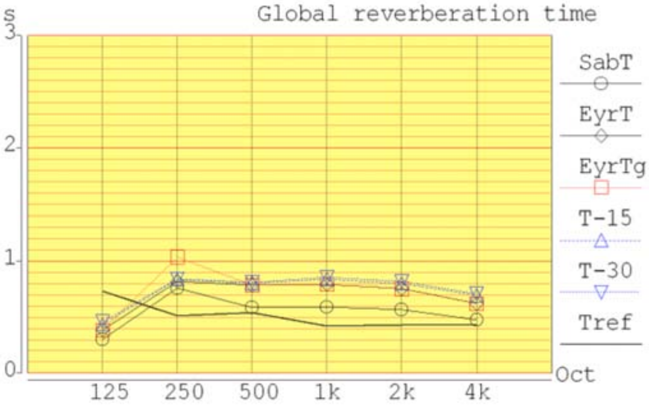
Acoustical Modeling

The CATT-Acoustic software was utilized to predict the RT and Sound Transmission Index (STI) in the original condition (e.g. before transfer-box installation) and compare this

TABLE 4. The temperature conditions in the Liu Institute before and after transfer-box installation.

Conditions	Annual # of hours above 28 °C	Annual # of hours above 24 °C
Existing	1	79
Proposed Design	3	98

FIGURE 3. Predicted octave-band RTs in the model office 310 when untreated. Tref is the measured RT and SabT is the predicted RT based on Sabine diffuse-field theory. The other curves are the RTs predicted by CATT-Acoustic. The X axis represents octave band frequencies in Hz and Y axis represents RTs in seconds.



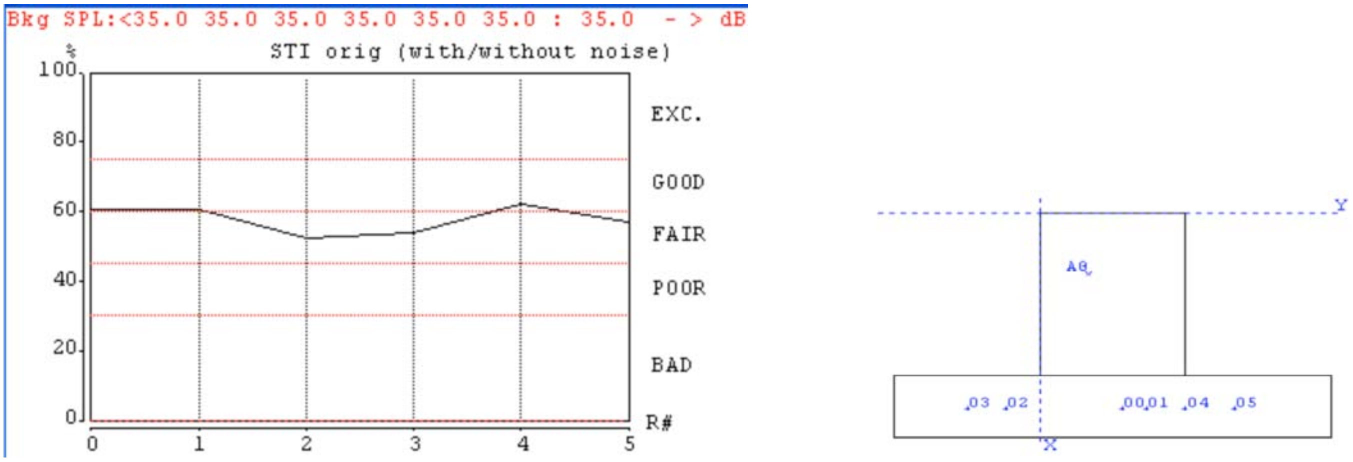
with the measurement data in order to evaluate the accuracy of the building model. The STI is a measure of speech intelligibility that has been included in the CATT-Acoustic software, and which varies from 0% to 100%, meaning high speech privacy and high speech intelligibility, respectively.

The STI is frequency weighted signal-to-noise ratios similar to SII. The difference between the STI and SII is including the effect of reverberant speech as a contribution to the noise component in the former. In acoustically dead conditions STI values would expect to be similar to SII values but when there is significant reverberant speech sound, STI values would be systematically reduced relative to the corresponding SII values. The difference between measured SII and STI is in the range of 0.05[11].

In the prediction, a model with the same dimensions as the Liu Institute's third-floor office and corridor was plotted. Materials for the floor, wall and ceiling were reference from the CATT-Acoustic database, which is based on the actual materials in the Liu building: painted plaster surfaces for the walls, carpeted floor and hard ceiling in the office, and hard floor and ceiling in the corridor. Predictions were made in different conditions. This started with the original configuration and then considered different configurations of the transfer-box. As can be seen in Figure 3, there was a good agreement between the trend of changes in the predicted and measured RT values in the original condition. In this study, Sabine diffuse-field theory (it is shown as SabT in Figure 3) was the reference from the software for RTs. The Tref in the figure represents the measured RT values. The average RTs at the octave-band frequencies from prediction and measurement were similar. It was an indication that the computer model is a good representation of the actual office area.

As can be seen in Figure 4, the STI prediction confirmed this claim, as the average STI obtained with the computer model was found to be 57%, the same value as the corresponding measured SII value of 0.57. In the STI prediction, a normal voice level for the human talker at a typical seating location in the office was considered. The background-noise level included in the prediction was based on measured background-noise levels in the lobby area, where the receivers are. Five different

FIGURE 4. STI prediction with CATT-Acoustic. The typical receiver locations are numbered as 00 to 05 (e.g. along the corridor) and the talker is shown as A0 (e.g. office desk location). The X and Y axis in the plot represents receiver locations and STIs in %, respectively. The corresponding ranges of STI from BAD to Excellent are shown.



receiver locations along the corridor and one speaker at a typical seating location in the office was considered, as shown in Figure 4. The STI was predicted along the corridor, as shown by numbers from 1 to 5. The X axis represents receiver locations and Y axis represents STIs in %. As can be seen in Figure 4, the various ranges of STI in % (e.g. <30, 30–45, 45–60, 60–75, >75), correspond to different speech intelligibility levels (e.g. BAD, POOR, FAIR, GOOD and EXCELLENT) respectively.

Transfer Box

Based on the required openings for air flow, different acoustical approaches were taken. The first attempt was a horizontal transfer box made out of plywood, with 25 mm lining on all internal surfaces. As can be seen in Figure 5, the air in the room enters the transfer box in the right hand side, passes through the transfer box and exits the box from the other side. The entry and exit of the air in the transfer box are shown in the figure, by noting inside and outside.

As can be seen in Figure 6, the acoustical predictions were made and found that STI improved from 0.56 to 0.39, whereas the recommended STI for speech privacy is 0.20. The second design was a vertical transfer-box, shown in Figure 7. In all of the designs, the opening was 0.39 m^2 at all intersections along the box. The air exits the office from opening at the bottom of the transfer box passing through the transfer box and entering the corridor from the top of the box.

As can be seen in Figure 8, the same predictions with vertical transfer box were made, and found that the STI improved to 0.21, which met the recommended STI between offices and corridors.

FIGURE 5. Horizontal transfer-box sections with views from inside and outside the office. The section of the transfer box is shown in the right side of the figure. The air enters the transfer box in the right hand side, passes through the transfer box and exits the box from the other side.

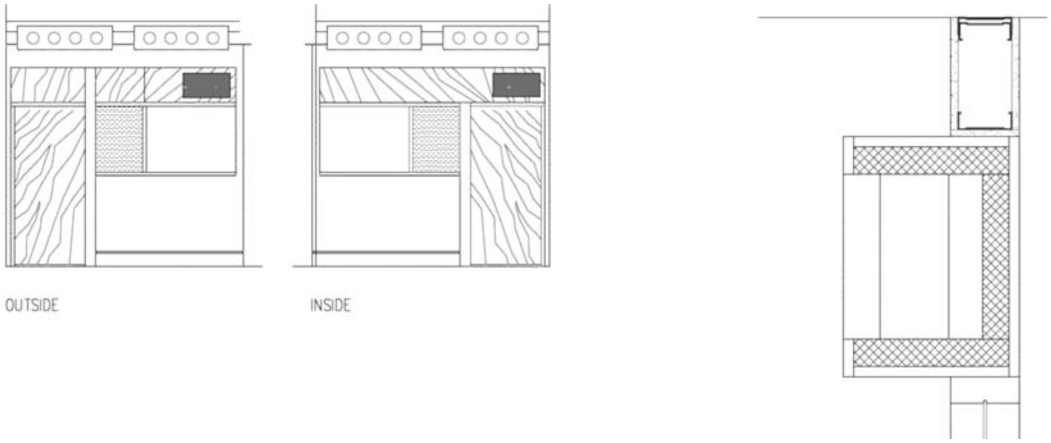


FIGURE 6. 3D view of the office and the corridor in the right side and STI predicted with CATT-Acoustic, with horizontal transfer-box in the left side. The X axis represents the location of the receiver (e.g. 0 to 5) and Y axis represents the STI in %. The corresponding ranges of STI from BAD to EXCELLENT are shown. The octave band frequency background noise level considered in the prediction is shown at the top of the plot.

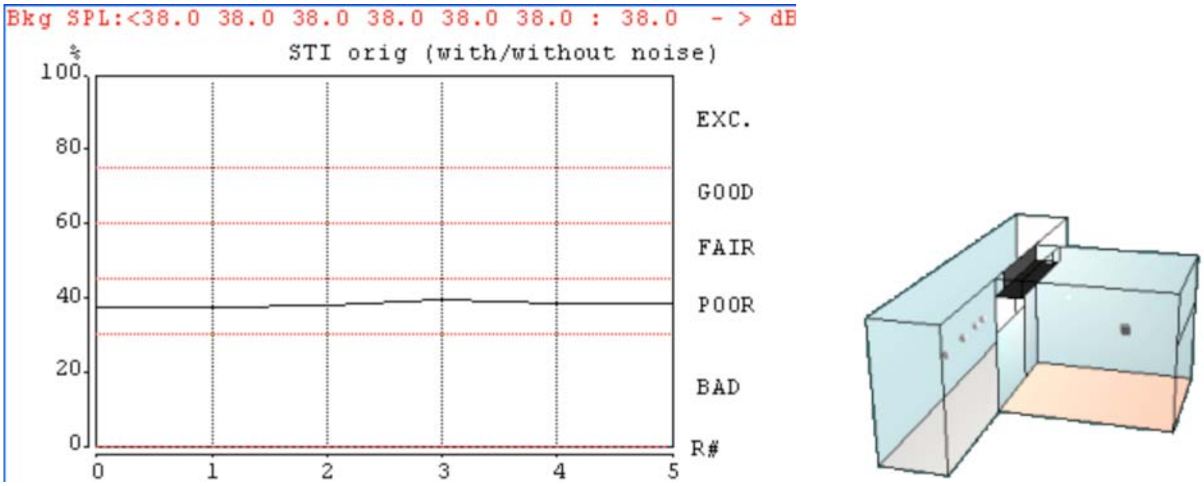


FIGURE 7. Vertical transfer-box sections with views from inside and outside of the office. The section of the transfer box is in the right side of the figure. The air exits the office from opening at the bottom of the transfer box (shown as inside) passing through the transfer box and entering the corridor from the top of the box (shown as outside).

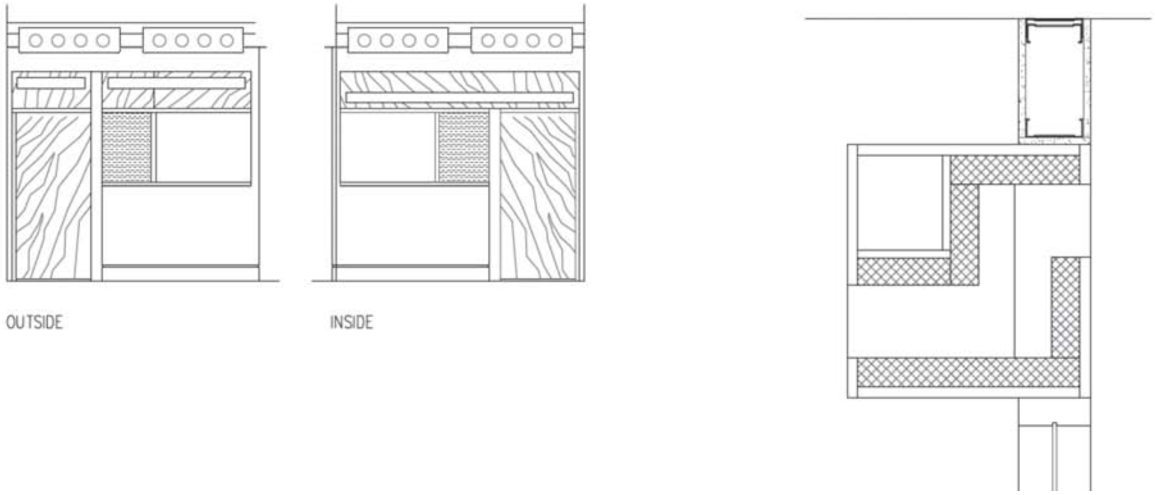
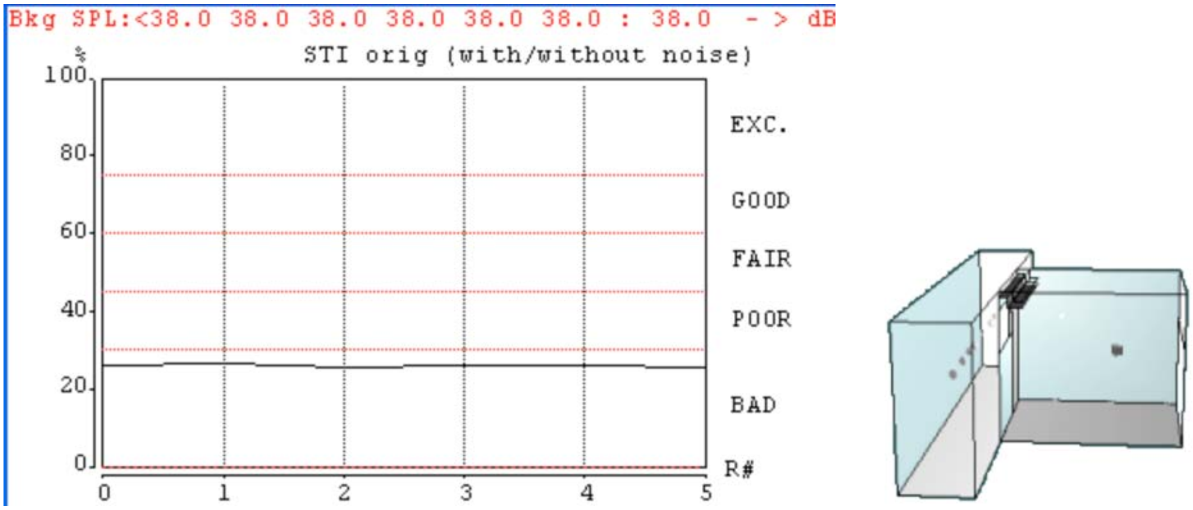


FIGURE 8. 3D view and STI predicted with CATT-Acoustic, with vertical transfer-box. The X axis represents the location of the receiver and Y axis represents the STI in %. The X axis represents the location of the receiver (e.g. 0 to 5) and Y axis represents the STI in %. The corresponding ranges of STI from BAD to EXCELLENT are shown. The octave band frequency background noise level considered in the prediction is shown at the top of the plot.



Transfer box construction

A transfer box out of plywood with 50 mm lining according to the prediction results was made and installed in the opening on top of the demising wall between office and the corridor. After the transfer box installation, the site was inspected for any gaps around the box which can compromise its performance. All gaps where noise might leak around the transfer box were sealed. The bottom door sweeps was added to the bottom of the office door to avoid any leaking noise transmission through any openings.

Post-Treatment Measurements

After the installation of the transfer box was complete, the same acoustical measurements were conducted to evaluate the acoustical quality of the space. These measurements were taken at the same time of day as before and at the same locations. Following are details of the measurements:

- Reverberation Time (RT): Since the RT was acceptable for all office areas, this measurement wasn't included at this stage;

- Noise Isolation Class (NIC): The measured octave-band Noise Isolation between office 310 and the corridor, and the corresponding calculated NIC, are tabulated in Table 5. At the time of the measurements, it was determined that there were some paths for noise to 'leak' around the transfer box and underneath the door. The gaps around the door were sealed with caulking, and bottom door sweeps were used to seal the door gap. The same measurements were conducted to investigate the effects of these flanking paths on the performance of the transfer box; the results are included in Table 5. The last column in the table shows that the NIC increased due to the transfer box;
- Speech Intelligibility Index (SII): Speech Intelligibility Index was measured in two conditions, before sealing the noise flanking path and after. The voice levels and measurement conditions were the same as before the acoustical treatment. The results of measurements, along with the changes, are included in Table 6.

Air Quality and Acoustical Treatments

The air-quality tests were performed before and after the transfer-box installation in order to investigate any adverse changes on the ventilation and air quality. The tests were performed by Dr. Karen Bartlett, Associate Professor at the School of Occupational and Environmental Hygiene (SOEH) at UBC. She measured temperature, relative humidity, carbon dioxide, and fungal-spore concentrations in Colony Forming Units (CFU) per m^3 as indoor-to-outdoor ratios. The numbers of Air Changes per Hour (ACH) in offices with open and closed doors were determined. Ventilation was more adequate in office 310 than in some of the offices without transfer boxes[12].

DISCUSSION AND CONCLUSION

Due to complaints about the acoustical environment in the Liu Institute at UBC, the acoustical quality in that building was studied. By way of a walk-through survey and acoustical measurements, it was found that, due to the large openings above the doorways and the corridor partitions, speech privacy was not adequate. CATT-Acoustic software was utilized to modify the acoustical quality of the building without any disturbance to the occupants. The optimized design of the transfer box above the office door was selected based on CATT-Acoustic predictions. The measurement results after installation of the transfer box agreed with the results of the predictions and improved speech privacy between the office and the corridor in the Liu Institute to an acceptable level. However there is still more research is needed to build natural ventilated building in compliance with ANSI acoustical standards.

TABLE 5. NIC between office 310 and the corridor after transfer-box installation, along with the corresponding changes in the two conditions of gap unsealed (US) and sealed (S).

		Noise Isolation (dB)								
		Frequency (Hz)								
Source	Receiver	125	250	500	1k	2k	4k	8k	NIC	Δ NIC
Office 310	Corridor - US	15.7	16.1	19.4	23.1	22.4	23.8	26.0	22	+12
	Corridor - S	16.3	17.1	20.3	27.8	24.8	24.4	26.1	24	+14
Corridor	Office 310 - US	10.4	17.2	19.6	24.7	23.5	25.8	29.0	23	+13
	Office 310 - S	12.7	18.6	24.0	29.3	26.9	26.7	28.9	26	+16

TABLE 6. SII between office 310 and the corridor after transfer-box installation, along with the corresponding changes at different talker voice levels, for two conditions of gap unsealed (US) and sealed (S).

Speech Intelligibility Index (SII)							
Source	Receiver	Casual Voice	Δ SII	Normal Voice	Δ SII	Raised Voice	Δ SII
Office 310	Corridor - US	0.18	–0.32	0.36	–0.23	0.62	0.04
	Corridor - S	0.12	–0.38	0.29	–0.30	0.60	–0.06
Corridor	Office 310 - US	0.54	–0.23	0.67	–0.13	0.79	–0.02
	Office 310 - S	0.46	–0.31	0.62	–0.18	0.79	–0.02

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