UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Post Occupancy Evaluation of Aquatic Ecosystem Research Laboratory

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University of British Columbia

CIVL 589C, MECH 550G

April 30, 2012

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Greg Johnson, SBSP Course 2012 Instructor
University of British Columbia
2329 West Mall
Vancouver, BC, V6T 1Z4

Dear Dr. Johnson:

We, students of the SBSP course for winter 2012 semester, respectfully submit our final report.

From January until March 2012, we performed a Post Occupancy Evaluation on the UBC Aquatic Ecosystems Research Laboratory (AERL) in order to find ways to improve the general building efficiency and occupancy comfort and to provide guidance to the UBC Sustainability Initiatives. We maintained an ambitious schedule to complete this report by the April 30, 2012 deadline.

In an effort to fully understand the current performance of AERL in providing occupancy comfort, we sent surveys to occupants, completed a one day morning and afternoon field measurements, obtained trend logged data from the campus Building Management and Control Systems, and interviewed maintenance staffs.

We have made numerous recommendations in these areas that are listed in the *Conclusions and Recommendations*. A more detailed discussion is provided in the body of the report. Recommendations for improving the building's visual and acoustic comfort can be implemented without much additional resources; however, to improve the building thermal comfort, additional resources may be needed.

We wish to express our appreciation for the guidance that you and Dr. Murray Hodgson provided in completing this POE. Although this report is the most obvious product of our efforts, we believe this intensive four-month process of review will yield benefits both now and in the future.

It was a pleasure for us to participate in this project. Thank you for the opportunity.

Sincerely,

SBSP 2012 Course – POE Team Members

Shen Tan, Civil M.Eng ([redacted])
Yi Zhong Lei, Mechanical M.Eng([redacted])
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Post Occupancy Evaluation of

Aquatic Ecosystem Research Laboratory

University of British Columbia, Vancouver Campus

Performed by:

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Executive Summary

This Post Occupancy Evaluation was performed as a requirement for the completion of MECH 550G/CIVL 598C. The purpose of this POE is to deliver a detailed report in order to provide UBC Campus Sustainability Initiatives with recommendations for improving the performance of the Aquatic Ecosystem Research Laboratory. Based on AERL's trouble log history, we focused on evaluating the open-plan and private offices. The data collected consisted of measurements of the physical environment (thermal, acoustic, air quality, and lighting) at representative locations, a questionnaire administered to all occupants about satisfaction to current indoor environment, and monthly utility data supplied by the building owners. Physical and questionnaire data were collected in March, 2012. Key findings and recommendations are as follows:

- Water consumption has always been above the design goal and MNECB baseline.
- Energy consumption is below the MNECB baseline but further improvements are still needed to get closer to the design goal. Windows glazing can be replaced with ones that have higher R value.
- The open-plan offices have excellent speech intelligibility but poor speech privacy. Furthermore, noises from the atrium propagate easily into the offices. Installing more acoustic baffles within the atrium and open-plan offices can minimize the discomfort.
- The CO2 level within the open-plan and private offices were well below the 1075 ppm limit set by ASHRAE 62 – 2007
- There is insufficient illumination within the open-plan offices. Higher wattage light bulbs or LED lights may be used on replace existing light bulbs.
- The current control algorithm for space heating does not promote optimum heat transfer rate into the offices. Flow rate of hot water need to be controlled by automatic flow control valves instead of by manually controlled valves.

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Glossary

Thermal stack effect

The movement of air into and out of buildings which is driven by buoyancy effect. Buoyancy effect occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences.

Energy intensity

A measure of energy efficiency as in energy input required per unit area

Foot candle

A unit of luminance or light intensity widely used in the lighting industry

Reverberation time

The time required for reflections of a direct sound to decay by 60 dB below the level of the direct sound. Reverberation time is frequently stated as a single value however it can be measured as a wide band signal (20 Hz to 20kHz) or more precisely in narrow bands (one octave, 1/3 octave, 1/6 octave, etc.)

Sound pressure level (SPL)

A logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The commonly used "zero" reference sound pressure in air is 20 µPa RMS, which is usually considered the threshold of human hearing (at 1 kHz).

1. Introduction

Building operation is the largest component of UBC's environmental footprint. Thus, UBC Sustainability Initiatives (USI) has been transforming UBC campus buildings to become visible and enduring elements of the university's commitment to sustainability. To realize this goal, UBC has completed the construction of multiple green buildings on campus starting with the C.K. Choi Building in 1996, the Liu Institute for Global Issues in 2000, Life Sciences Centre in 2004, and the Aquatic Ecosystems Research Lab (AERL) in 2006; however, designing and constructing green buildings are just the first steps of a sustainable development process. To verify that buildings are operating as intended, UBC has established Post Occupancy Evaluation (POE) program, customized for campus buildings, to regularly evaluate occupancy satisfaction within UBC's facilities, and to verify energy and water use performance. Ultimately, the purpose of POE is to provide suggestions for continuous improvements on existing facilities.

Currently, the Aquatic Ecosystems Research Lab (AERL) is one of the top priorities on the UBC Sustainability agenda for continuous improvements. In 2011, National Research Council – Institute for Research in Construction (NRC-IRC) performed POE on six UBC facilities, including AERL. The evaluation, however, was only to provide a quick estimate on the occupancy comfort level within the building. The evaluation was not intended to identify or diagnose specific building performance issues, or to remedy any emerging issue.

To help UBC Sustainability Initiatives devising tangible improvements for AERL, we have undertaken the opportunity to perform a more comprehensive POE. Our goal is to identify and address specific issues and to recommend feasible solutions. The scope of this POE is to evaluate and analyze the following aspects of AERL:

- Water and energy consumption
- Occupancy comfort and safety within specific area of concern (air quality, thermal comfort, acoustical comfort, and visual comfort)

1.1 Building Systems

AERL is a four story, 6000 m^2 facility that accommodates approximately 220 occupants from three distinct research units: the UBC Fisheries Centre (FC), the Institute for Resources, Environment and Sustainability (IRES), and the BC Fisheries Research unit (BCFU). AERL is organized around a central atrium that connects all four levels providing visual interest and space for natural ventilation via ***thermal stack effect*** (see Figure 1). The building is designed to consume 301.3 Megawatt hour (MWh) less energy than the Model National Energy Code for Buildings (MNECB) baseline and effectively reduces the amount of equivalent carbon dioxide (CO2) by 40.5% per year. For its construction, AERL made extensive use of low Volatile Organic Compound (VOC) products. AERL is also designed to maximize the daylight that enters the building by installing double-glazed windows. The top of the atrium has windows that allow daylight to enter deep into the building. As a result, the Canada Green Building Council has awarded LEED-BC Gold Certification to UBC-AERL.

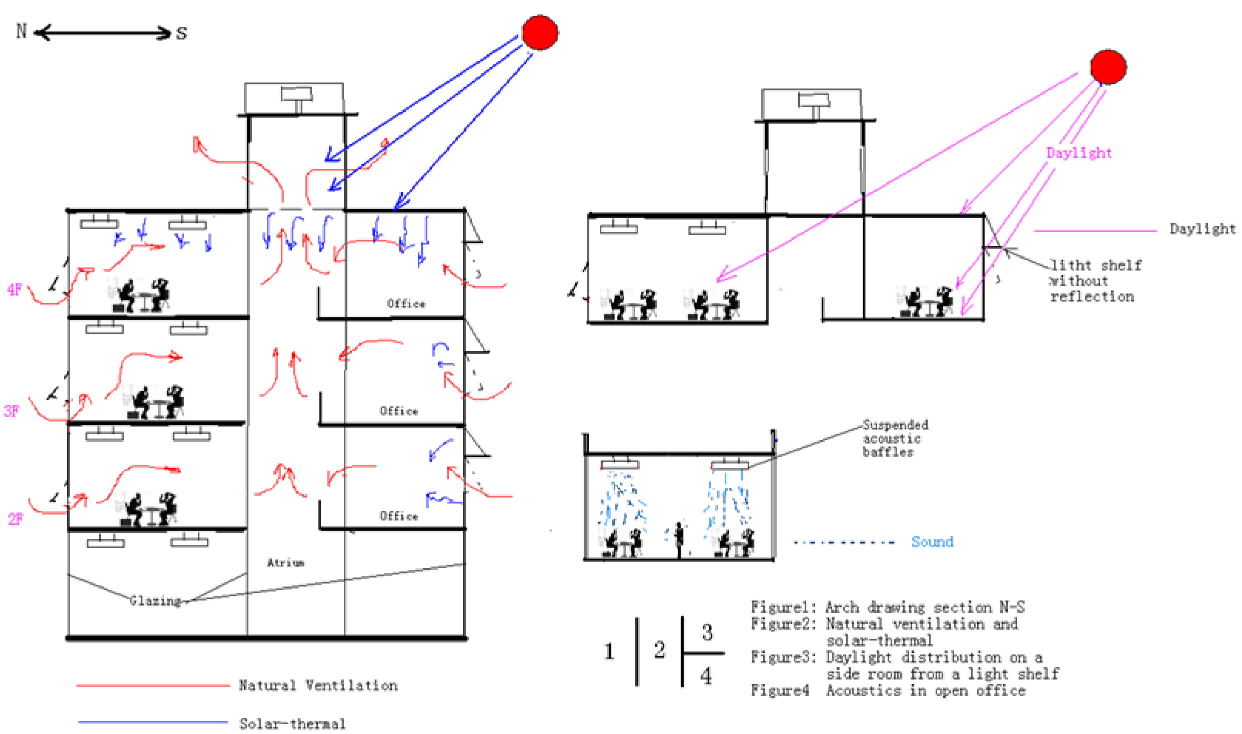


Figure 1.

Detailed AERL's cross-sectional view. Source: *UBC Campus Sustainability*

To passively control the indoor temperature and the level of carbon dioxide (CO2) inside the building, the central atrium, office area and research laboratories have dampers, located along the building perimeter, that open and close according to certain set points of indoor temperature and CO2 level (see Figure 2). When indoor temperature falls from a relatively higher temperature (i.e. outdoor temperature is lower than indoor temperature), the dampers will not close until the indoor temperature reaches 21°C. Conversely, when indoor temperature rises from a relatively lower temperature (i.e. outdoor temperature is higher than indoor temperature), the dampers will not open until indoor temperature reaches 23°C. This control algorithm prevents the dampers from opening and closing erratically.

The dampers within the offices, labs, and the atrium open progressively between 0 to 100% when the CO2 level reaches 600 ppm set point. When CO2 level reaches 1000 ppm, the dampers will open 100%. This control algorithm is to ensure that the CO2 level inside the building stays below 1075 ppm, which is the acceptable limit according to ASHRAE 62-2007.

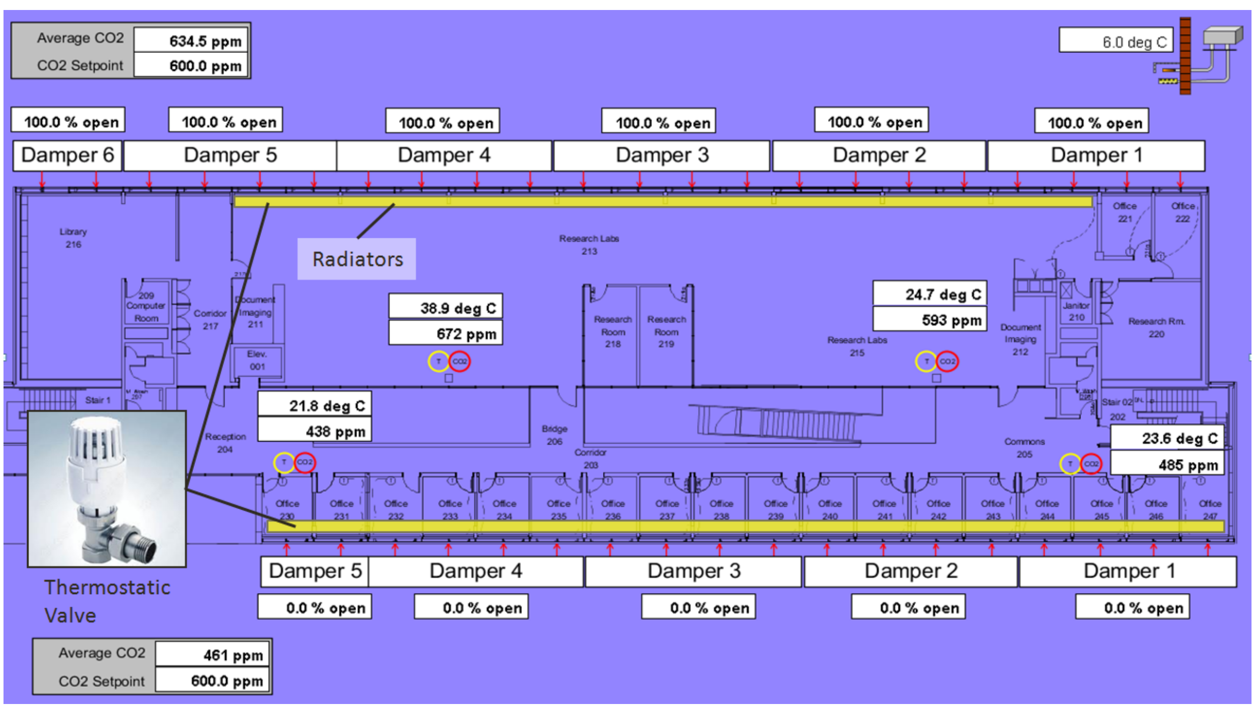


Figure 2.

AERL's typical office floor plan. Source: *UBC Building Management and Control System Department*

For space heating, AERL has a central hot water system that supplies hot water to individually operated radiators inside the laboratories and office spaces. Inside the open-plan and private office spaces on the second floor up, hot water radiators are installed along the building perimeters (see Figure 2 and Appendix A for more details). The radiators are placed along the building perimeters, just under the windows, each with adjustable thermostatic valves. The idea behind perimeter heating setup is to counteract cold drafts that occur by the exterior window during cold seasons. The density gradient between the warm room temperature and the cold window glazing surface causes local air movements. As part of AERL's energy saving control algorithm, the hot water temperature supplied to the radiators is set to be a function of outdoor temperature ($\mathrm{T}_{\text{hot water}} = -2.13\mathrm{T}_{\text{outdoor}} + 82.2°\mathrm{C}$).

1.2 Other Building Features

AERL's acoustic design utilizes acoustic baffles in office spaces, corridors, and lecture halls. Depending on the purpose, some area has more noise absorbing materials than others. For example, AERL's lecture hall on the ground floor is surrounded with sound absorbing materials; meanwhile, the open-plan offices only have acoustic baffles installed in the ceiling in order to provide a descent amount of glazing area. The justification for this arrangement is that the cubicle walls within the office also act as sound barriers.

Figure 3

Acoustic design of AERL's open plan office (left) and lecture hall (right).

1.3 Specific Area of Concern

Regardless of AERL's initial LEED-Gold award, there have been continued concerns regarding poor occupancy thermal, acoustical, and visual comfort. In April 2011, a team from the National Research Council – Institute for Research in Construction (NRC-IRC) conducted a Post Occupancy Evaluation (POE) on AERL along with other five similar on-campus buildings. The team performed physical measurements (thermal, acoustic, air quality, and lighting) and sent occupancy surveys for feedback. The physical measurement data was within recommended values by ASHRAE; however, the occupancy survey for AERL failed to yield statistical significance due to insufficient number of feedbacks. Thus, NRC-IRC combined the survey results for AERL with survey responses from the other five on-campus buildings. Overall, the occupancy surveys indicated the buildings being on the cold side of neutral in winter, and the warm side of neutral in summer. The finding is consistent with the occupants' complaint log recorded between April 2010 and August 2011 shown in table 1.

Table 1

AERL's Trouble Log up to December 2011

DATE	LOCATION	COMPLAINT	OUTD. TEMP.	REQUESTED ACTION
Aug. 2011	RM 323	Hot	16.9	Valve Replacement
May 2011	RM 318	Hot	11.9	N/A
April 2011	RM 301 (Server Room)	Hot	8.3	N/A
Jan. 2011	General Building Area	Cold	7.2	Close Roof Vents
Nov. 2010	RM 315 & 323	Cold	-4.6	N/A
Nov. 2010	RM 107 (Lecture Hall)	Cold	-1.7	N/A
Nov. 2010	General Building Area	Cold	8.4	Close Roof Vents
Nov. 2010	RM 411	Cold	8.7	Heater Check
Nov. 2010	General Building Area	Cold	11.2	Close Roof Vents
Oct. 2010	General Building Area	Cold	12.4	Close Roof Vents
Aug. 2010	General Building Area	Hot	19.2	Open Roof Vents
June 2010	RM 417 & 418	Hot	14.8	N/A
June 2010	General Building Area	Hot	14.7	Open Roof Vents
May 2010	General Building Area	Cold	11.7	Close Roof Vents
April 2010	RM 213.3	Hot	13.6	N/A
April 2010	General Building Area	Cold	6.7	Close Roof Vents

On top of the reported complaints in Table 1, there have been unofficial verbal complaints regarding the high noise level within the open-plan office when large number of students come out from classrooms on the ground floor and start conversing in the atrium lobby. From this initial investigation, we conclude that the open-plan and private offices on the third and fourth floors need to be closely investigated.

2. Building Performance Evaluation

We evaluated AERL's performance through quantitative and qualitative methods. For the evaluation of building energy efficiency and comfort level, utility data and field measurement data was acquired for comparison with design goal and building code standard. For qualitative data, we sent out survey forms to occupants working in within the office spaces for feedbacks (see appendix A). We also interviewed the maintenance staffs and the Building Management and Control System (BMS) specialist for any technical adjustments in the past which might explain abnormality within the historical data.

2.1 Water and Energy Consumption

Water and energy consumptions are the main environmental footprints for any building. Therefore, reduced water and energy consumptions are always the main focus for green buildings. Reduction in water and energy consumption also leads to other benefits such as:

- **Reduced building operational cost**
- **Reduced CO2 footprint and increased public relations values** (i.e. protecting the environment is looked upon favorably by the general public).

Potable water system, which consists of kitchen sink, shower, and lavatory, takes a major portion of AERL's water consumption. Meanwhile a very small portion is used for make-up water for radiator. In terms of energy consumption, AERL utilizes steam energy for hot water heating and electrical energy for auxiliaries, interior lighting and receptacle and process loads system (see Appendix B for details).

To evaluate AERL's water and energy consumption efficiency, we utilize three sources of reference data for comparison: MNECB, AERL design specification, and the NRC Commercial and Institutional Building Energy Survey 2000. From the NRC survey, we use average ***energy intensity*** for buildings in the education sector and for buildings with floor area between 4645 m^2 and 9290 m^2 as comparisons. Based on the utility data from 2009 to 2011, AERL's annual energy intensity is below the MNECB and NRC baseline, but still quite above the design specification (Figure 4, top). The monthly energy consumption breakdown also shows normal peak consumption during winter for space heating and lighting (Figure 4, bottom).

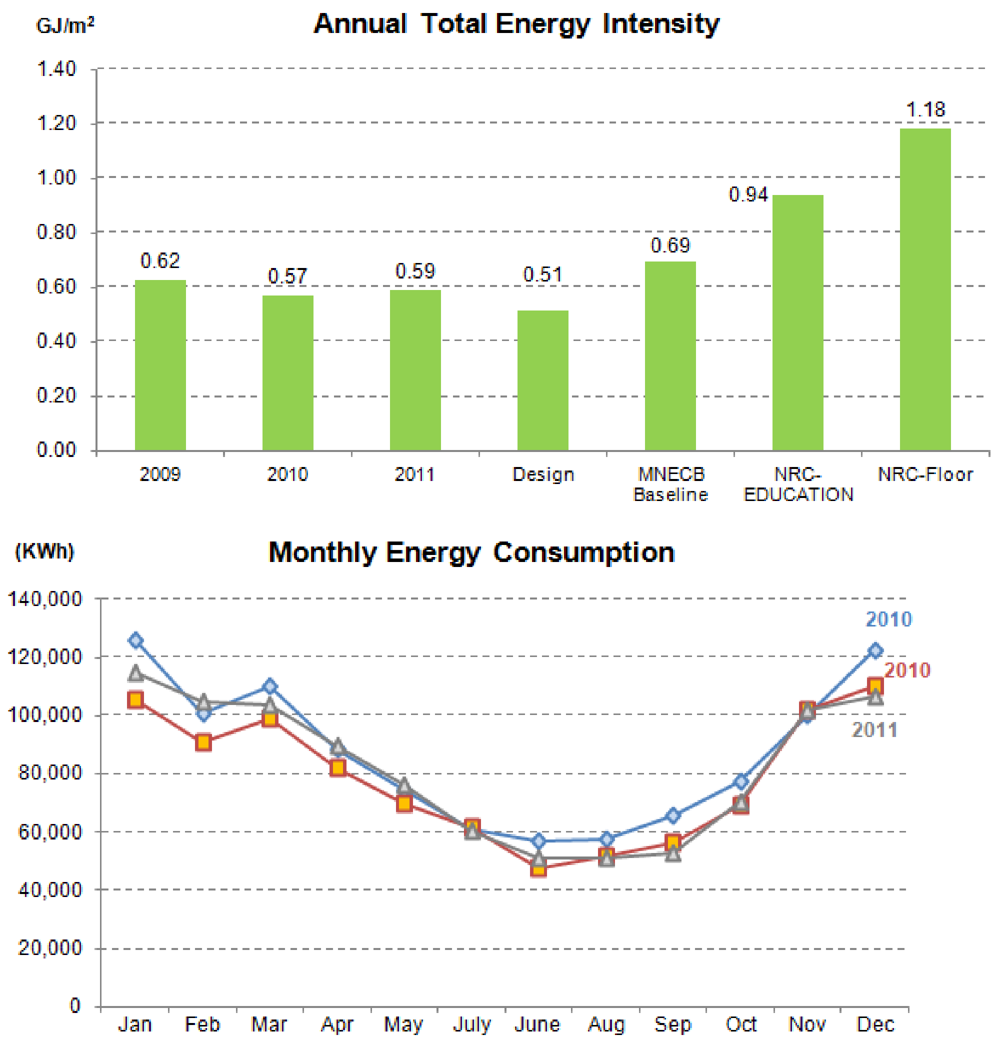


Figure 4

AERL's annual (top) and monthly energy consumption (bottom). Source: *UBC Campus Sustainability*

In terms of water consumption, AERL has been consuming amounts that are above the MNECB baseline, with the highest consumption in 2009 (see Figure 5, top). Even after interviewing AERL's maintenance staffs, there was no reported leakage or building mechanical modifications that might have affected the water consumption. The only plausible reason behind this phenomenon is the heat wave that engulfed Vancouver during the summer of 2009 which might have led to increased water consumption for shower or kitchen use.

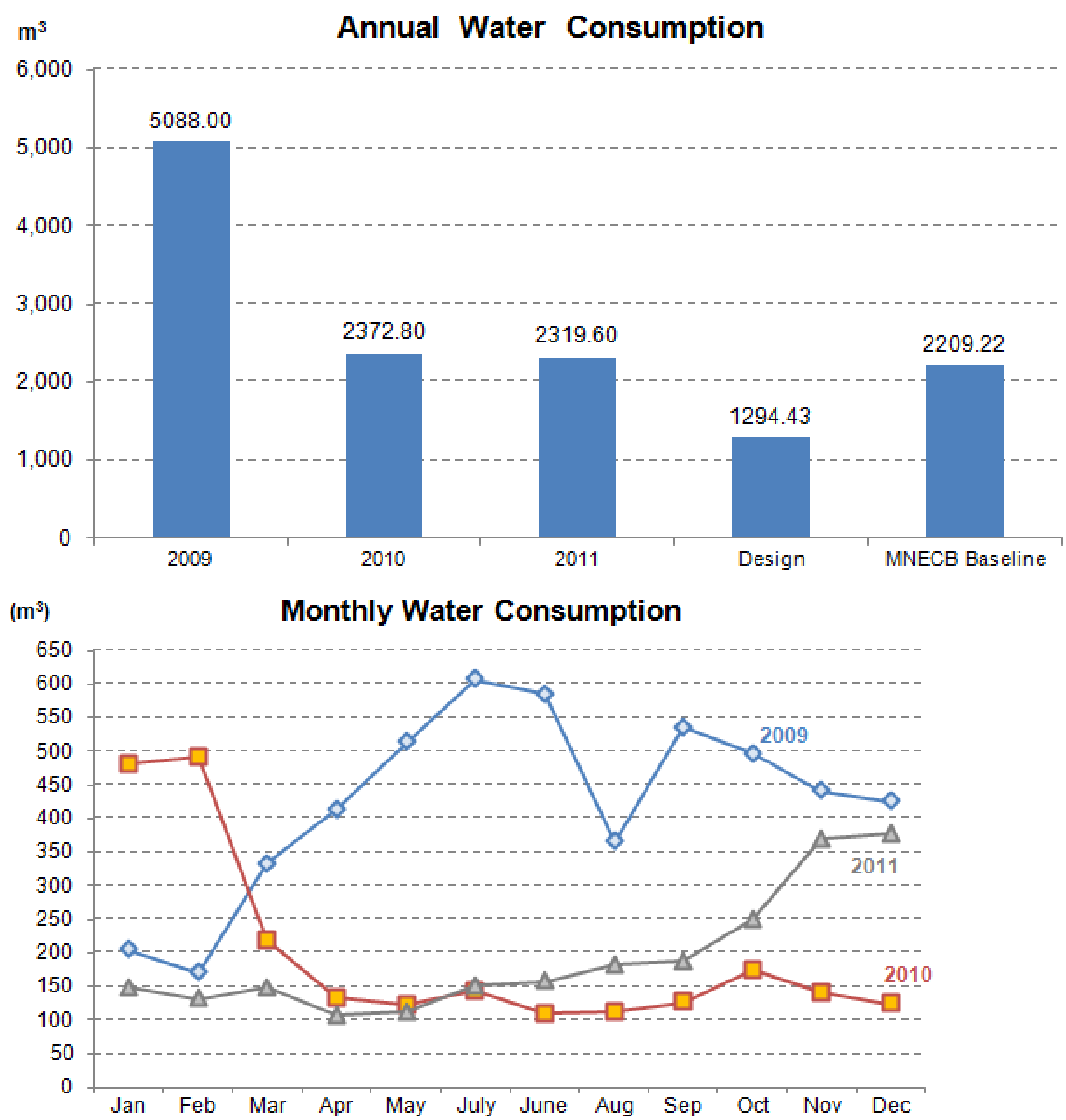


Figure 5.

AERL's annual (top) and monthly (bottom) water consumption. Source: *UBC Campus Sustainability*

2.2 *Acoustical Comfort Evaluation*

Parameters that characterize the acoustic comfort of a given space are Background Noise Level (BNL), Reverberation Time (RT), and Speech Intelligibility Index (SII). Following the industrial standard ANSI S12.2-1995, in order to have an acoustically comfortable space, the BNL should be between NC-35 and NC-40, RT less than 0.5 second, and SII less than 0.2. For this POE, we have decided to investigate the acoustic characteristic within the open plan office, private space office, and atrium.

Field Measurements

Since the open-plan offices in AERL have more or less similar construction and furniture arrangements, we took the open-plan office on the third floor as a representative area. To measure the speech intelligibility, we placed a directional speech simulating loudspeaker, SSARAH (see Appendix C). The speech intelligibility was measured at one, two, four, six and eight meters away from the "talker" along a receiver line (see Figure. 7). The reverberation time was averaged using data measured at six locations marked red in Figure 7.

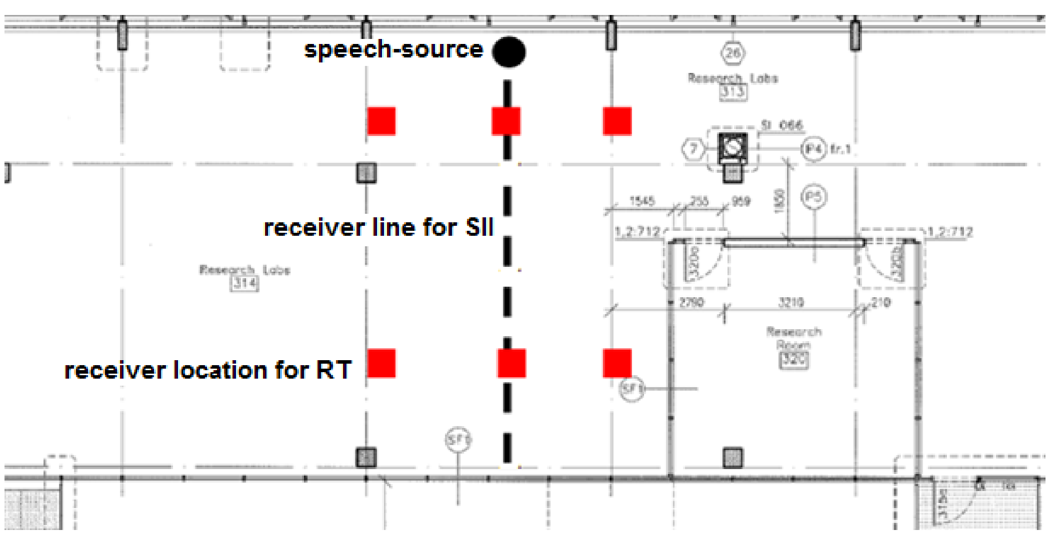


Figure 6

Field measurement arrangements, showing the speech-source position, receiver line for SII measurements, and receiver positions for RT measurements.

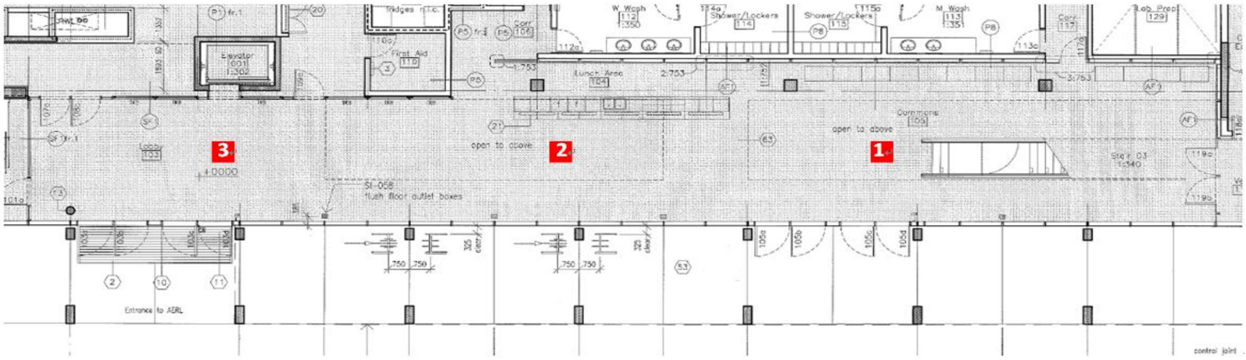


Figure 7

Measurement points in the atrium

In the atrium, the noise levels were measured at various points marked red in Figure 8 during normal working hours and at the end of a class when students come out from the classrooms. Staff and students working in AERL have been complaining on the high noise level when students come out of classes, but no investigation has been done before whether the acoustic environment in the atrium is acceptable. Also, we measured one private office, room 232, as a representative area for the rest of the private offices in the building. Measurements were done when doors were opened and closed.

Results

Figure 9a shows the BNL distribution across the octave band frequencies for the open-plan office. The equivalent NC level is NC-35, and is on the lower border line of NC35-40 recommended for offices in the acceptability criteria. Looking at Figure 9b, RT ranges from 0.29 second at 8000 Hz to 0.52 second at 250 Hz. The average RT at 500 and 1000 Hz is 0.45 second, which is lower than the recommended 0.5 second. In Figure 9c, the SII varies from 0.72 at close distances to 0.29 at longer distances. All of them are higher than 0.2, which is for good speech privacy. These values demonstrate that, in the open-plan office, high speech intelligibility exists within the whole space, but limited speech privacy exists, even when the talker and listener both stand at opposite ends of the open-plan office.

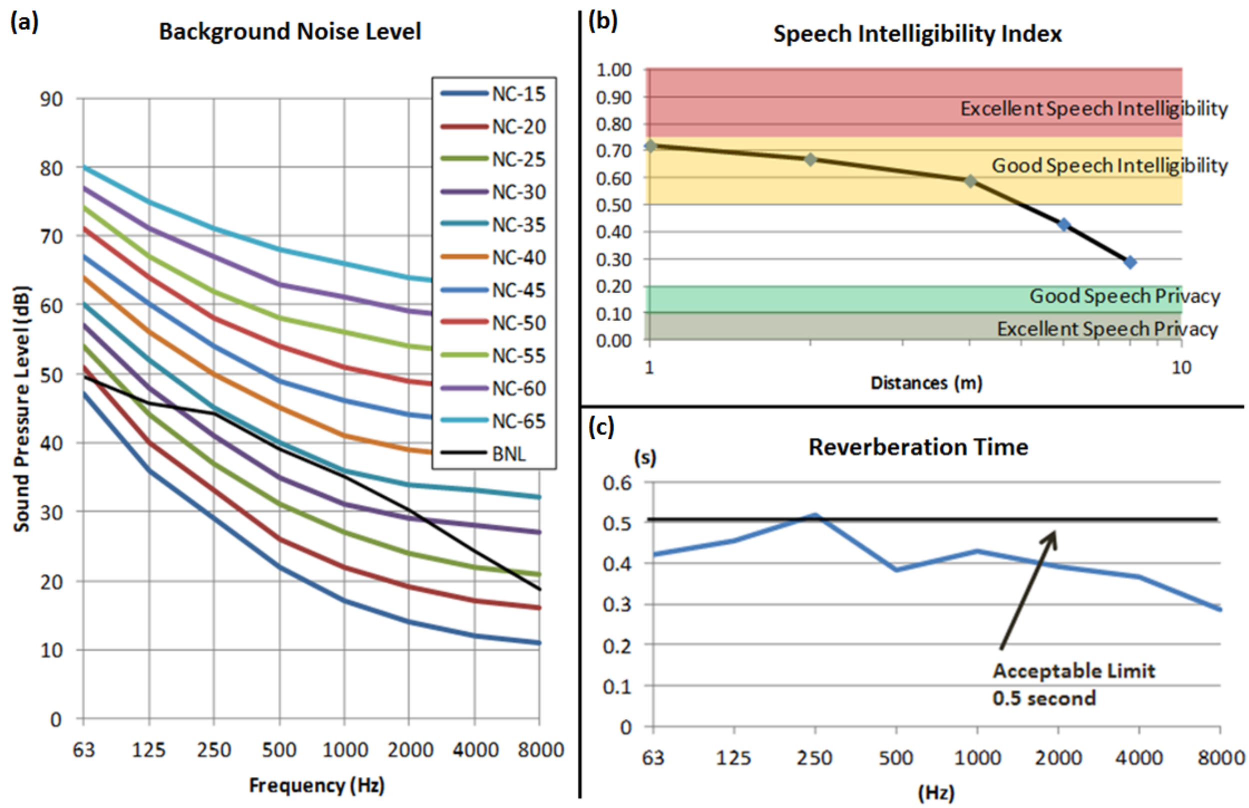


Figure 8

(a) Background noise level, (b) speech intelligibility index, and (c) reverberation time for open-plan office

The BNL in the private office space reaches nearly 50 dB (43 dBA), equivalent to NC-37, which is within the NC-35 to NC-40 recommended acceptable range. Meanwhile, when the door is open, the BNL of the private office increased to 52.5 dB (47 dBA), equivalent to NC-40, and was the upper borderline of NC35-40 recommended for offices in the acceptability criteria (Figure 10a).

The averaged total un-weighted Sound Pressure Level (SPL) within the atrium before and after class ends differed quite significantly. Figure 10b shows that the SPL increased approximately by eight decibels after the class ended. Since no design criteria has been found for atrium's acoustical environment, the analysis could not be done. However, the result shows that the students coming out of a class would increase the noise level a lot, and make the acoustical environment much worse.

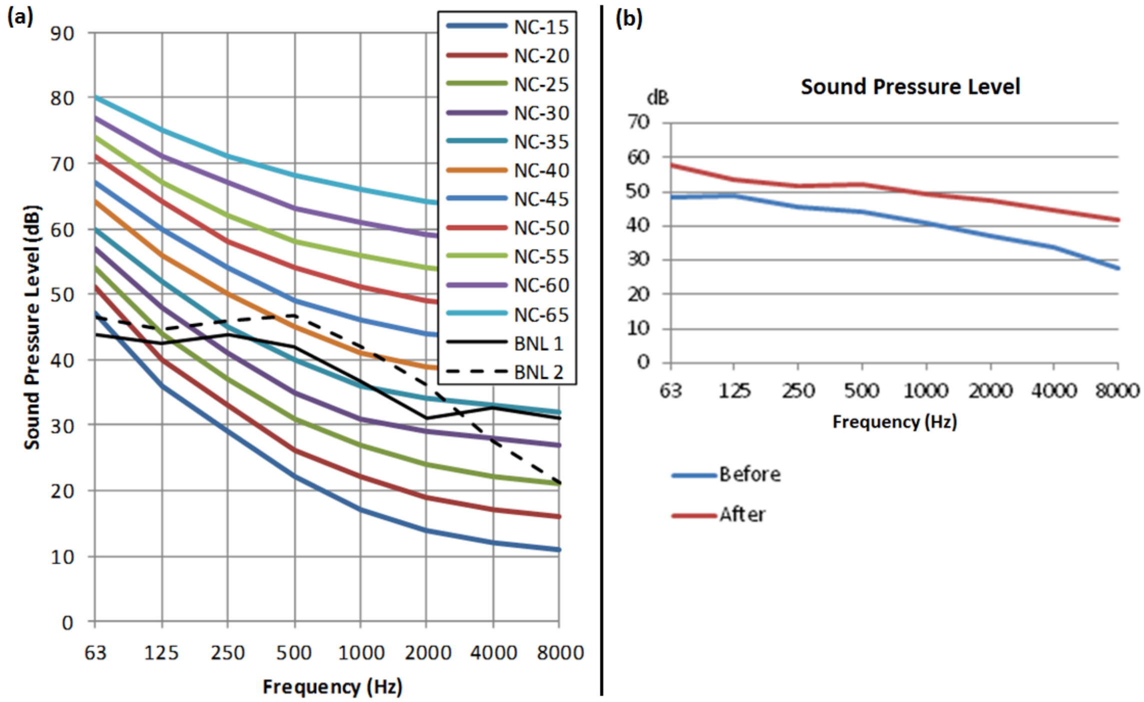


Figure 9

(a) BNL of a private office in AERL; (b) averaged total un-weighted SPL of each point in the atrium

According to survey feedbacks, employees in AERL have different complaints on acoustic environment (see Appendix B for survey form). Some of the major comments were highlighted below. For each major factor, there is also a specific comment stated behind written in italics.

1. The Atrium is too noisy: 28.6% of employees have this problem.
2. Poor Speech Privacy within workstations: 33.3% of employees have this problem.
3. Else: Printing machines, coffee/cooking areas, people go in and out: 14.3% of employees have this problem.

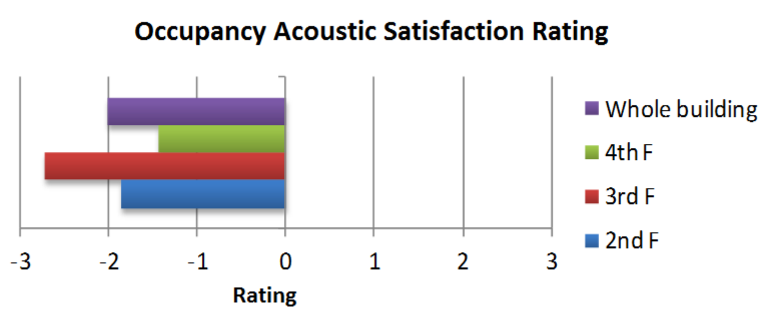


Figure 10

Averaged satisfaction levels of each floor and the whole building according to survey feedbacks

2.3 Indoor Air Quality Evaluation

In this POE, only CO2 concentration within the building was verified as there was no problem reported with the indoor air quality. Our objective is to verify that the current ventilation rate is sufficient to keep a safe level of CO2 concentration within the open-plan office. The guideline used for IAQ evaluation is ASHRAE 62-2001, "*Ventilation for Acceptable Indoor Air Quality.*" ASHRAE 62-2001 outlines that the critical level of acceptable indoor CO2 concentration is 1000 ppm. Figure 12 shows the CO2 concentration data varying with time measured by sensors on third and fourth floor in open-plan offices over the span of five day period. From the trend data logged, we can see that the CO2 concentration never reaches 1000 ppm which means that the ventilation rate within the open-plan office is sufficient.

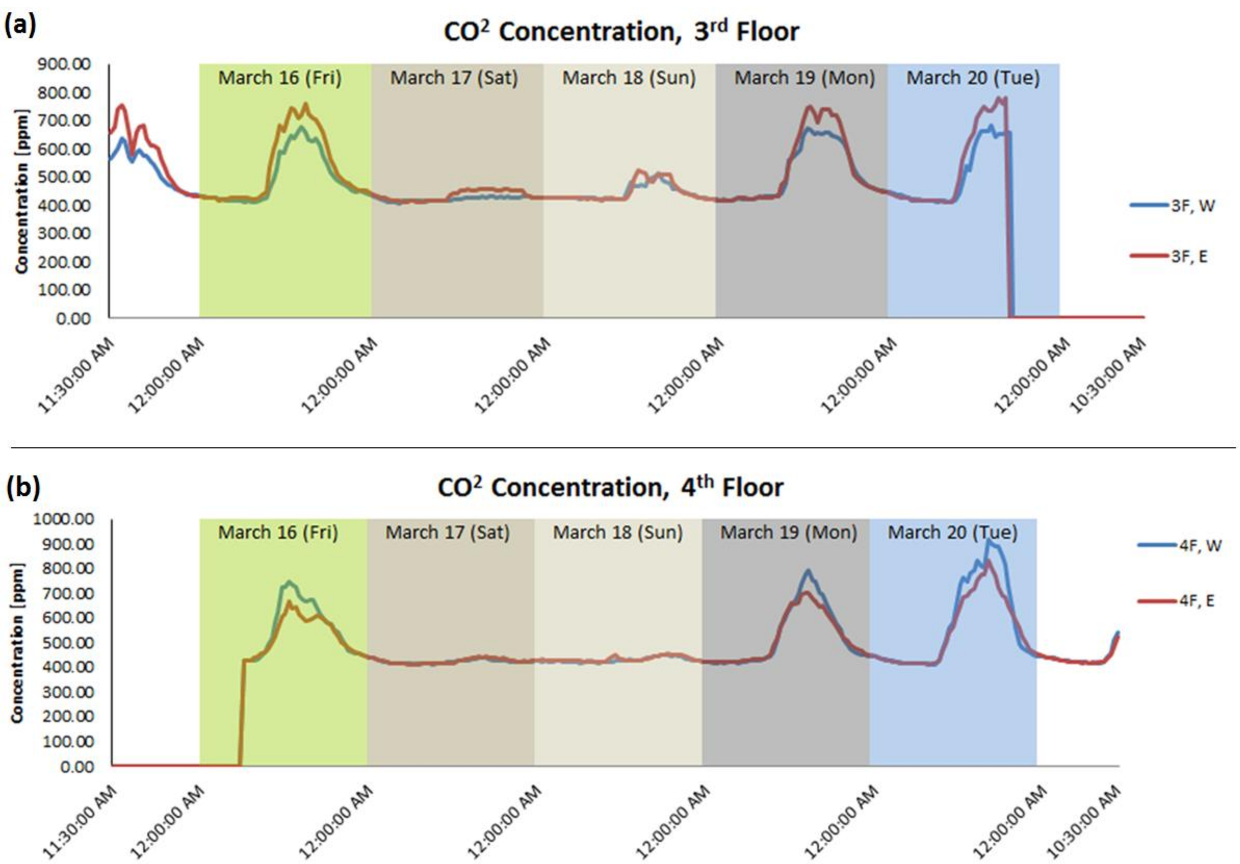


Figure 11

CO2 concentration data recorded by sensors on third floor (a), and fourth floor (b)

2.4 Visual Comfort Evaluation

For visual comfort evaluation, we use the recommended illumination level in the unit of Foot-Candle (FC) by ***NRCC-45620***, ***Advanced Energy Design Guide (AEDG)* and Illuminating Engineering Society of North America (*IESNA*).** These standards recommend that for desk activities, the minimum and average maintained illumination should be 50 FC and 30 FC respectively by a combination of natural and supplemental lighting; however, there should not be any desk that is illuminated at more than 70 FC to avoid over-exposure or glare.

Field Measurements

During field measurement day, on March 16, 2012, illumination levels within the open-plan office on the third and fourth floors were measured once in the morning and once in the afternoon. Illumination levels were measured at every cubicle within the open-plan office, totaling to 18 locations as described in Figure 12 below.

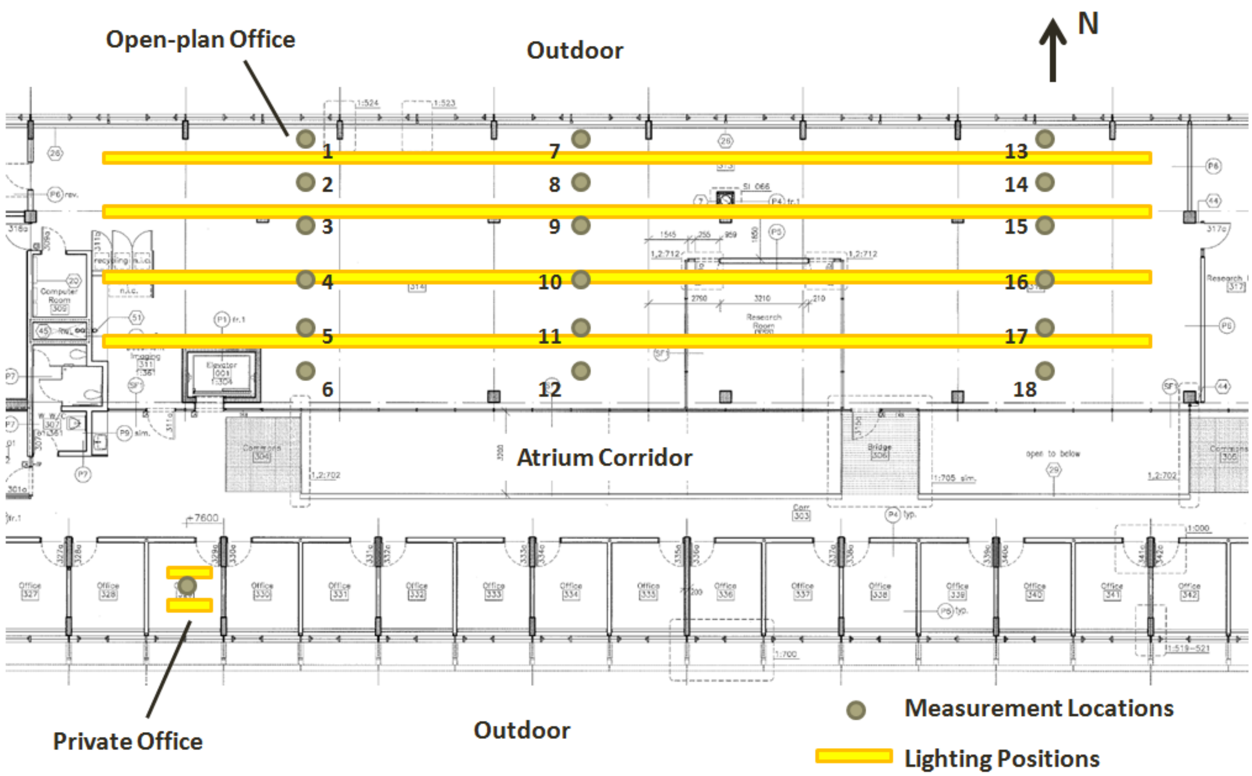


Figure 12

Illumination level measurement positions at the private and open-plan offices

Results

The measurement results at every location described in Figure 12 are tabulated in Table 2 below. During the measurement day, the weather was partly cloudy with sporadic showers. We noted that on the third floor open-plan office, the auxiliary lights were all turned on with most of the blinds shut. Meanwhile, on the fourth floor, the lights were turned off with the blinds opened.

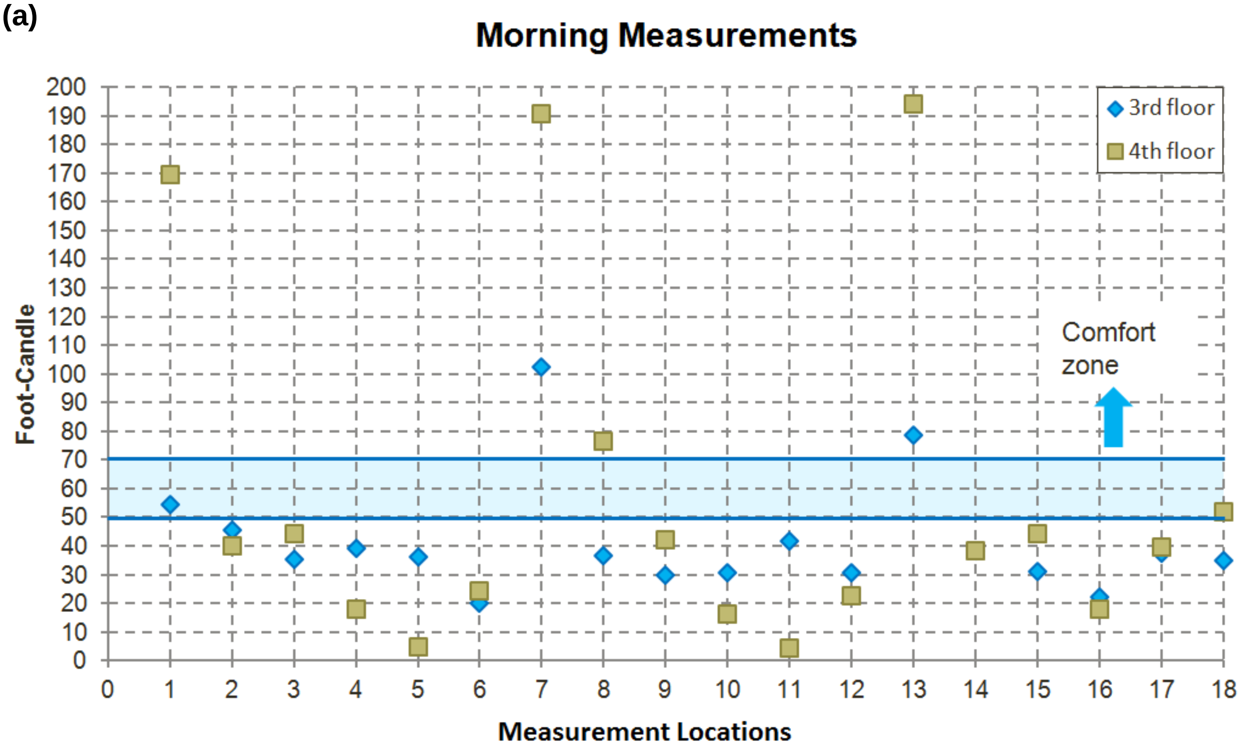
The resultant average maintained illumination levels are all well above 30 FC for both third and fourth floors during the morning and afternoon measurements. These data are graphed into simple XY scatter charts shown in Figure 13a and 13b on page 21. We may clearly see that even though the average maintained illumination is sufficient, most of the spot measurements are well below the minimum 50 FC requirement. Meanwhile, all of the locations measured next to the exterior windows are well above the 70 FC limit (location 1, 7, and 13).

Table 2

Measurement results for visual comfort evaluation in open-plan offices on third and fourth floor

Measurement Location	**Morning**		**Afternoon**	
	Third Floor (FC)	**Fourth Floor (FC)**	**Third Floor (FC)**	**Fourth Floor (FC)**
1	54.3	169.5	64.5	121.3
2	45.6	40	43.6	46.3
3	35.2	44.2	37.6	25
4	39.1	18	40.6	15.5
5	36.2	4.9	36.4	5.1
6	20.1	24.4	19.2	24.4
7	102.3	190.7	69.5	99.5
8	36.8	76.7	42.4	31.7
9	29.7	42	34.2	22.9
10	30.7	16.2	34.5	9.3
11	41.7	4.3	49.2	4.5
12	30.7	22.5	70.3	20.6
13	78.6	194.2	42.4	112.7
14	38.3	38.2	41.6	46.3
15	31.2	44.4	29.9	25.1
16	22.3	17.9	37.7	13.6
17	37.5	39.8	42.4	33
18	35	51.8	78.6	46.8
Average	**41.41**	**57.76**	**45**	**39**

(a)



(b)

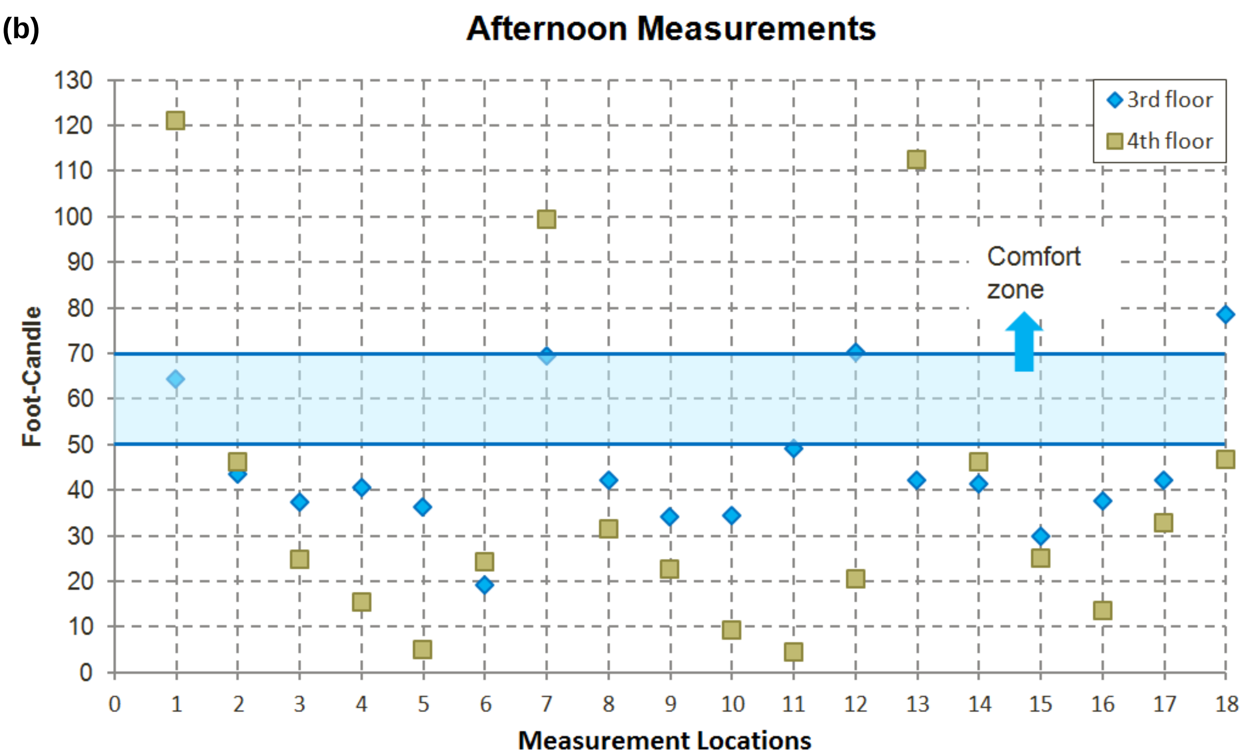


Figure 13

Illumination level measured in the open-plan offices in the morning and afternoon of March 16, 2012

Since the blinds on the third floor were shut, while the blinds on the fourth were open, we can clearly see the effectiveness of the blinds. The locations that were visually comfortable were the ones located next to the exterior windows with the blinds shut. When the blinds are open, the desks located by the exterior windows become overly exposed to sunlight. More importantly, the work desks that are located closer to the atrium corridor receive insufficient lighting even with the auxiliary lights turned on. From survey questionnaire that we sent to occupants of the open-plan offices, 25% of the replies reported that the open-plan offices were too dark. These findings suggest that the auxiliary lighting need higher wattage light bulbs.

2.5 Thermal Comfort Evaluation

The current thermal comfort model is a correlation, derived from experimental studies using test subjects placed in a climate controlled chamber, between thermal sensation and seven parameters: relative humidity, clothing, metabolic rate, operative temperature, mean radiant temperature, and air velocity. The resulting correlation, published in ASHRAE 55 – 2010, utilizes the seven parameters as inputs to predict the thermal sensation of a large population of people exposed to the same environment. This prediction is called Predicted Mean Vote (PMV) which utilizes a seven point thermal sensation scale from -3 to 3 (Figure 14).

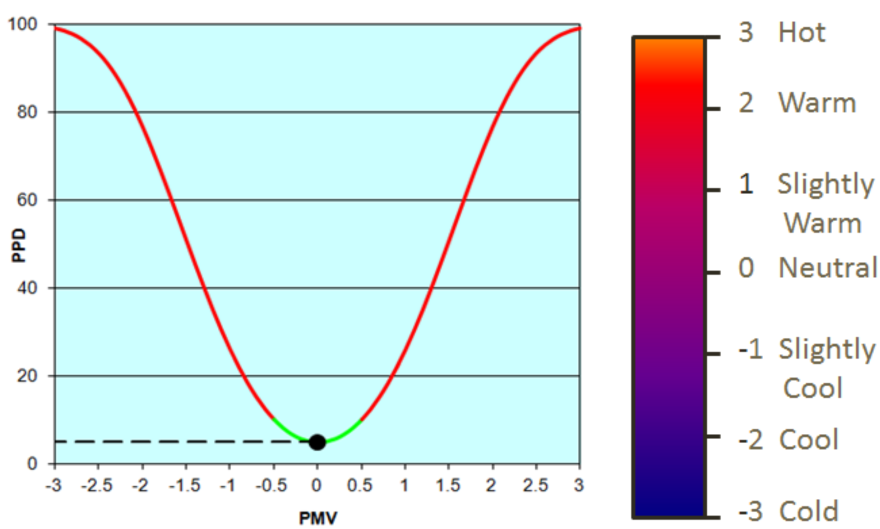


Figure 14

Correlation between Predicted Percentage Dissatisfied (PPD) and Predicted Mean Vote (PMV)

Since thermally comfortable environment for every person is different, PMV model estimates that in order for at least 90% of the people at a given environment to be thermally comfortable, the PMV rating should be between -0.5 and 0.5. This prediction of the percentage of people who are dissatisfied is called Predicted Percentage Dissatisfied (PPD) (Figure 14).

Field Measurements

To evaluate the thermal comfort of the open-plan offices on the third and fourth floors, the measured parameters were relative humidity, operative temperature, mean radiant temperature, and air velocity. Meanwhile, we estimated clothing and metabolic rate from standard tabulated values for specific activities in ASHRAE 55 – 2010. Seven locations were chosen for field measurements: two by the exterior windows, two by the atrium side windows, one inside the meeting room, and two by the west and east exits (see Figure 15).

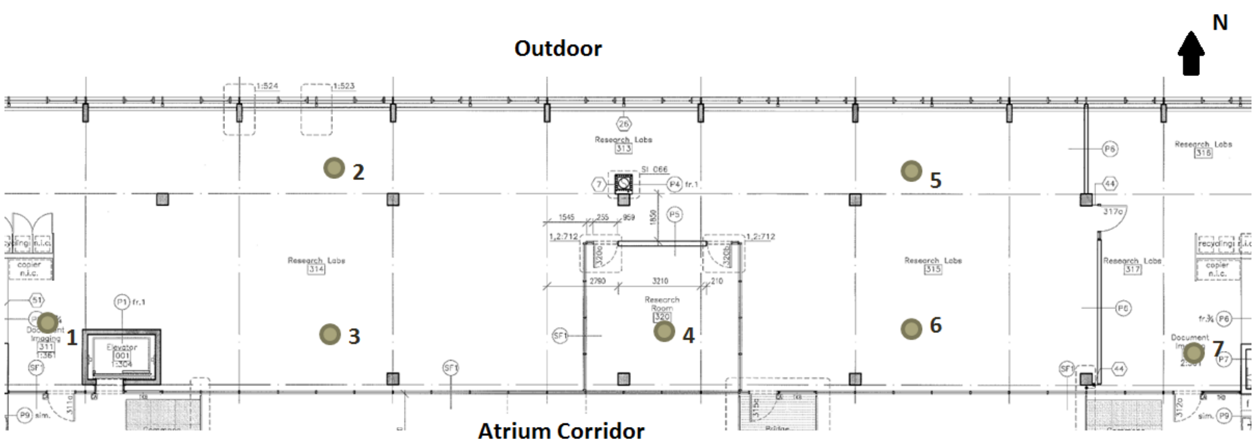


Figure 15

Measurement locations within the open-plan offices on the third and fourth floors.

Results

For easy computation, we generated a PMV calculator by coding the correlation between the aforementioned seven input parameters and the PMV scale using VBA code in Microsoft Excel. The resulting values are presented in Figure 16.

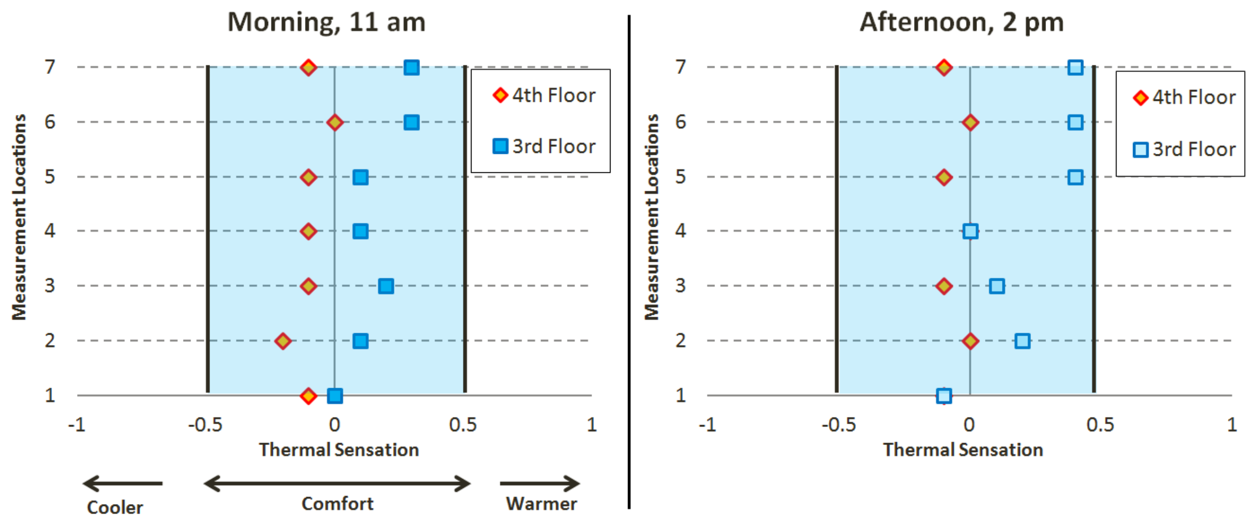


Figure 16

PMV rating at the measurement locations for open-plan offices in the morning and afternoon of March 16

As seen in Figure 16, the PMV rating for the open-plan offices on the third and fourth floors were generally within the comfort zone. Room 432 and 231 were also evaluated to estimate thermal comfort within private offices which resulted to PMV ratings of zero and -0.2. By inspection of Figure 16, the open-plan office on the third floor was a little warmer than the open-plan office on the fourth floor. The building administrators also confirmed that there are more people working on the third floor than on the fourth floor.

From the survey responses received, building occupants agreed that the indoor environment was comfortable during spring and fall when outdoor temperature was generally milder; however, the open-plan and private offices become too cold in winter and too warm in summer. Furthermore, people also commented that when more space heating was needed, the radiators were not hot enough even though the individually operated thermostatic valves were opened to 100%. We also verified that there was no discrepancy between the surface temperature of the radiator hot water pipes and the hot water supply temperature. Figure 17 shows the trend data for the hot water supply as a function of outdoor temperature.

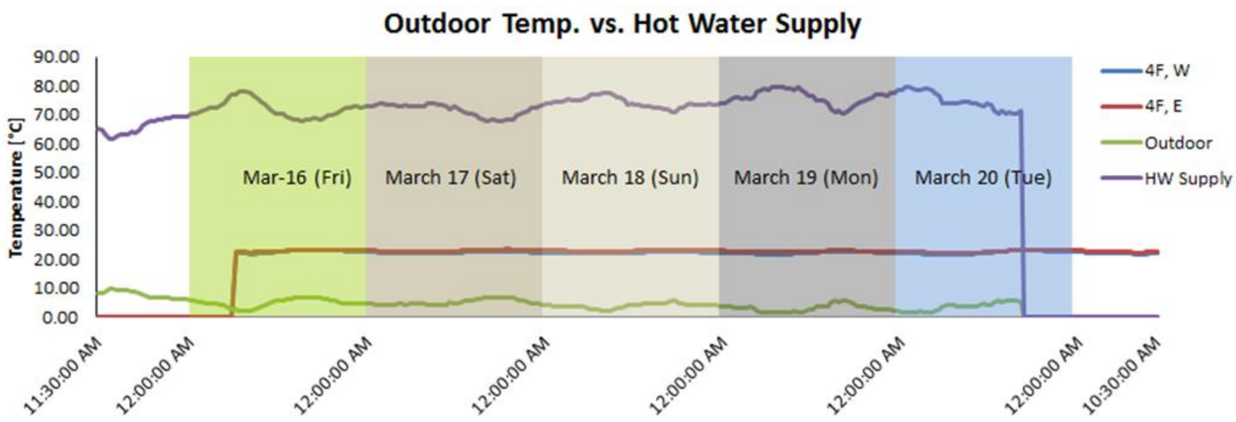


Figure 17

Outdoor temperature versus hot water supply for space heating

3. Conclusions and Recommendations

From the occupancy surveys and the analytical evaluation results, we conclude that significant improvements are still needed in the area of thermal, visual, and acoustic comforts within the open-plan offices. Furthermore, fine tunings are still possible to improve AERL's water and energy efficiency. Our recommendations for improvements are outlined as follows:

3.1. Thermal Comfort Improvement

As of now, there are two systems controlling the temperature within the open-plan offices: the radiators and the dampers. The dampers control algorithm prioritizes controlling the level of CO2 within the open-plan offices and therefore should not be modified. The only adjustments can be made is on the space heating system. As of now, the heat transfer rate between the radiators and the open-plan offices is controlled by varying the hot water supply temperature as a function of outdoor temperature. However, the manually controlled valves located by the exterior windows are currently counter-productive to delivering optimum heat. One way to improve the system is by opening all of the manual thermostatic valves to 100% and install an automatic flow controller for each branch of pipeline that supply hot water to the radiators on each open-plan offices.

Assuming that the heat losses in the open-plan offices are through the windows, a control algorithm can be set to vary the hot water flow rate as a function of the instantaneous heating load. The heating load is a function of outdoor temperature, indoor temperature in the atrium, and indoor temperature in the open-plan offices (see Figure 18). Furthermore, the current window blinds may be replaced with thermal blinds to further reduce heat losses during cold weather.

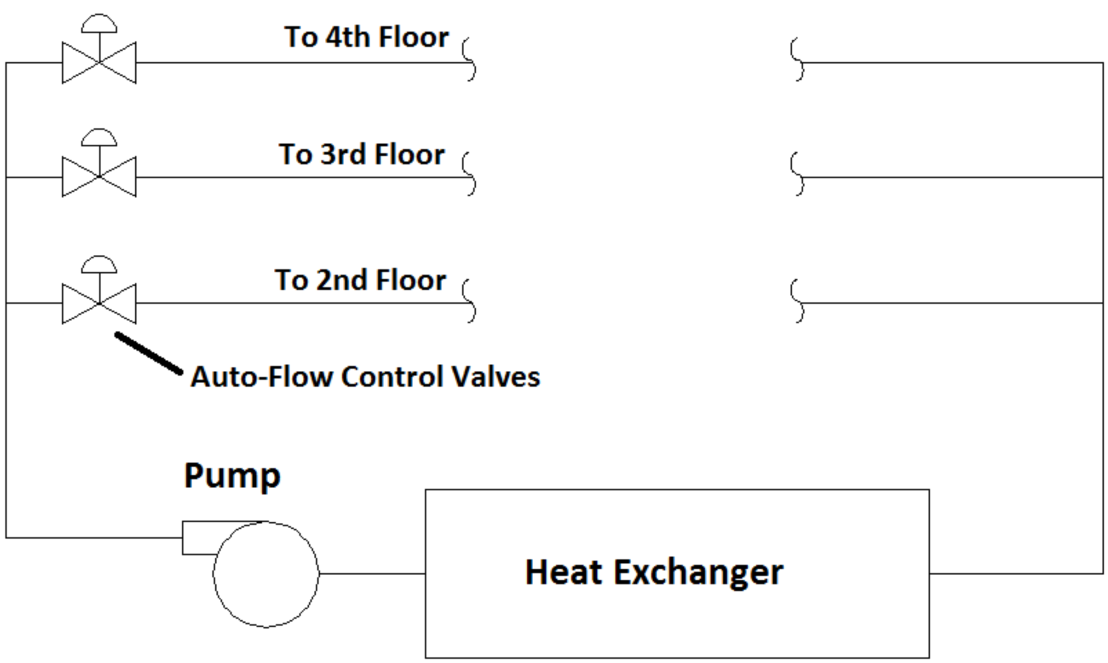


Figure 18

Schematic Diagram of proposed solution

3.2. *Energy Efficiency Improvement*

One of the energy saving strategies in AERL is maximization of natural lighting. In effort to achieve this goal, up to 47.82% of AERL's total building envelope is made up of high performance double-glazed windows (insulation performance, R=2.64); however, based on the study by White, M, on the correlation between required insulation performance for a given percentages of window area, the R value of 2.64 is insufficient (see Figure 19). Therefore, our recommendation is to replace all of the window glazing with R value of higher than five

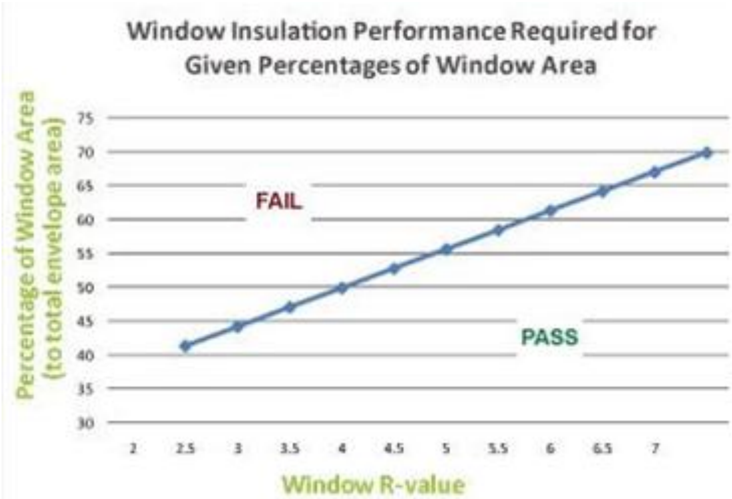


Figure 19

Window Insulation Performance Required for Glazing Area. *Source: Effective Early Collaboration between Engineers and Architects for Successful Energy-Efficient Design*

3.3. *Acoustic Comfort Improvement*

In AERL's open-plan offices, the speech intelligibility index is too high for good speech privacy. Furthermore, the noise level within the private and open-plan office spaces will be unacceptably high when the noise level in the atrium increases because of students conversing at the end of classes. There are a few possible solutions to solve these problems:

- Installing horizontal acoustic panels in the open-plan offices to improve the acoustic comfort within the open-plan offices. As of now, there are horizontal panels inside the private offices and lecture halls, but not in the open-plan offices.
- As of now, all of the floor finishing is made of concrete. Installing carpet inside the office spaces can effectively improve the speech privacy.
- More acoustic baffles may be installed within the atrium to dampen the noise within the atrium before it can propagate into the office spaces.
- As suggested in previous section, in order to reduce energy losses, the window glazing may be replaced with ones that have higher R value. If possible, the new glazing should have better sound damping performance.

3.4. Visual Comfort Improvement

As of now, even with auxiliary lighting, the illumination level within the open-plan offices are only sufficient for the desks located by the exterior windows. Higher wattage light bulbs are required to improve illumination level within the open-plan offices in general. Furthermore, high efficiency LED lights may also be used if budget is not an issue.

Acknowledgements

The Post Occupancy Evaluation of AERL is supported by the UBC Sustainability Initiatives and the UBC Campus Building Management and Control Systems

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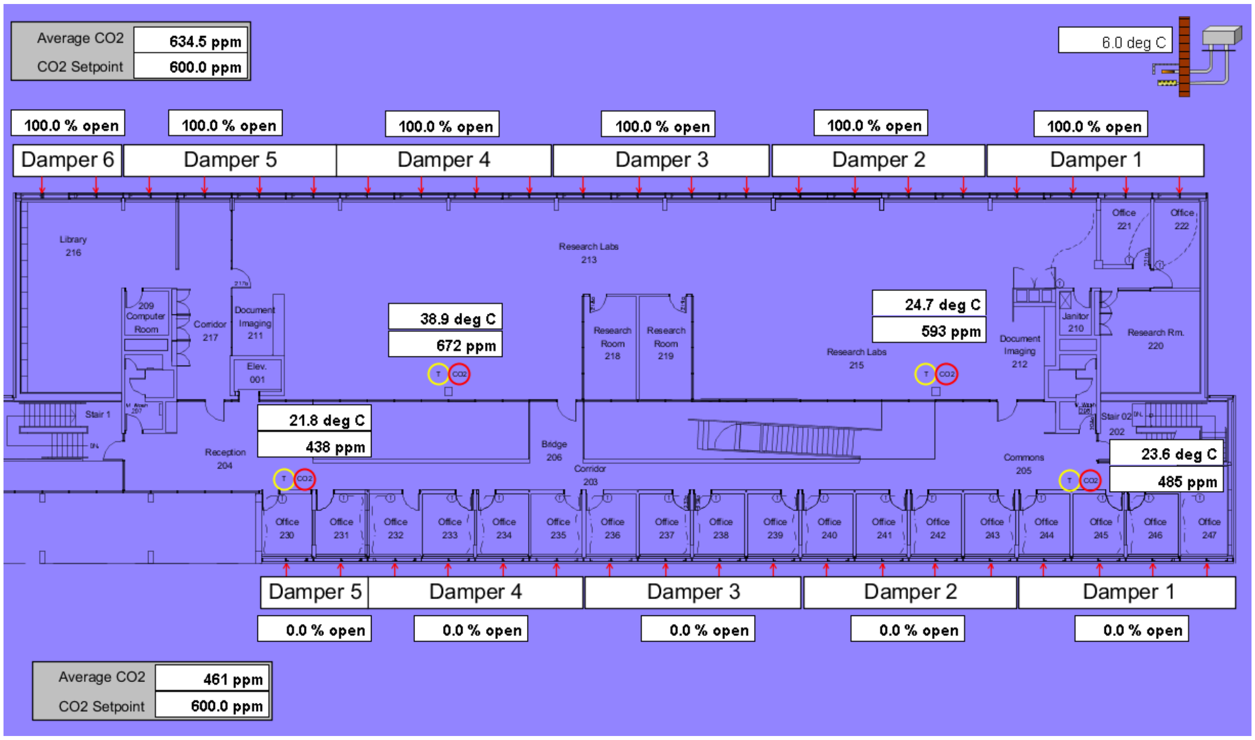
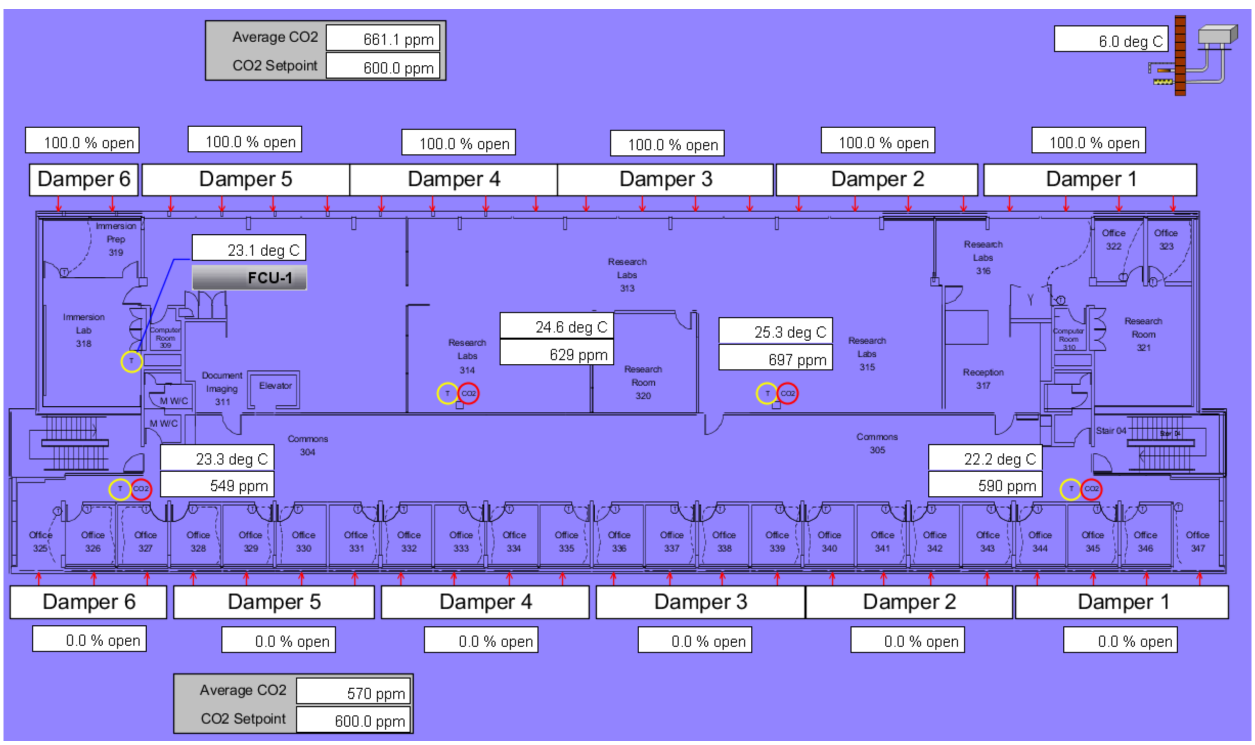
APPENDIX A – Indoor Monitoring Sensors

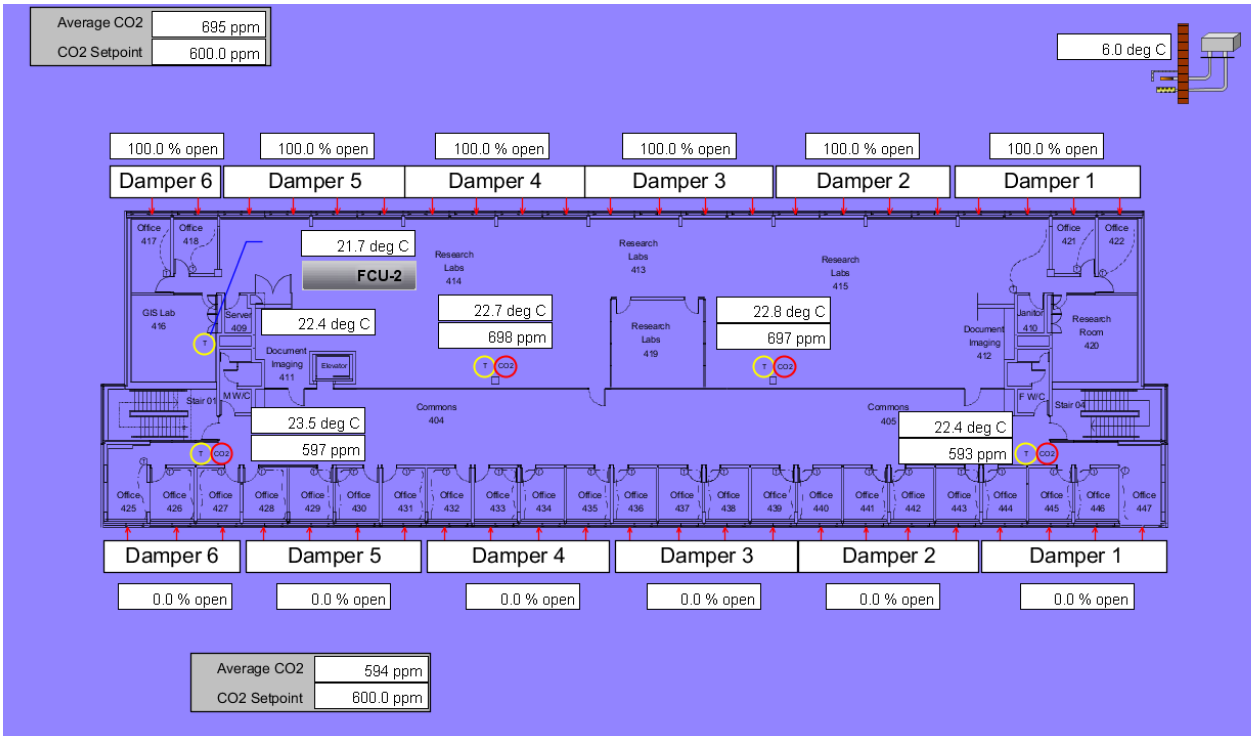
AERL Second Floor



AERL Third Floor



AERL Fourth Floor



APPENDIX B – Survey

Post Occupancy Evaluation Project - Indoor Environment Quality Survey of AERL in UBC

Room Number: ________________________________ Date and Time: _________________________________

Thermal comfort:

1. Are you satisfied with the room temperature right now? (Circle your answer)

Very Unsatisfied	Quite Unsatisfied	Neutral	Quite Satisfied	Very Satisfied
-2	-1	0	1	2

2. Please choose one that best describes your thermal sensation. (Circle one)

Cold	Cool	Slightly Cool	Comfortable	Slightly Warm	Warm	Hot
-3	-2	-1	0	1	2	3

3. If the temperature is too cold or too hot, please state the possible reason for the discomfort (i.e. cold draft, uncontrollable heater, etc.)

Visual comfort (In terms of indoor lighting):

1. Please choose one that best describes your visual sensation. (Circle one)

Too dark	Dark	Comfortable	Bright	Too bright
-2	-1	0	1	2

2. IF the visual environment is uncomfortable, please explain the issue (i.e. direct sunlight, lighting is inadequate, glare, etc) and point out the solution which you selected or would like to choose to avoid that (i.e. barriers, personal lighting equipment).

3. How many hours approximately do you use the indoor lighting in a whole day? (If the time equals to your office hours, please tell us the approximately length)

4. Do you think the indoor lighting needs to be turned on during the day even the weather is sunny? (Yes or No)

(Please turn the page back)

Acoustical comfort

1. Please rate your feeling about the **acoustical environment** of the space around. (Circle on the score bar below)

-3	-2	-1	0	1	2	3
Completely unsatisfied			Acceptable			Completely satisfied

2. If there is one (or some) **acoustical issue** that has troubled you when you're working on your place, what is it? (You can select the issues below, or write it down if there is more).

A. People talking or activities (e.g. cooking, keyboarding, walking).
B. Ventilation noise (e.g. wind, diffusers).
C. Building facilities (e.g. lift)
D. Traffic noise from streets outside.
E. What else? ____

Please write down your selection ____________________ (Please **rank** them if more than 1 selection)

3. Please add your comments below about the acoustical environment if you have any. Suggestions on possible improvements are welcome.

Indoor Air Quality

1. Please rate your feeling about the **air quality** of the space around. (Circle on the score bar below)

-3	-2	-1	0	1	2	3
Completely unsatisfied			Acceptable			Completely satisfied

2. If there is one (or some) **indoor air quality issue** that has troubled you when you're working on your place, what is it? (You can select the issues below, or write it down if there is more).

A. Cooking in offices (e.g. microwave, sink)
B. Ventilation (e.g. air velocity is inadequate, diffusers is dirty)
C. Office equipment and materials (e.g. carpet, printer emission, dustbin)
D. Air pollution outside (e.g. traffic)
E. What else? ____

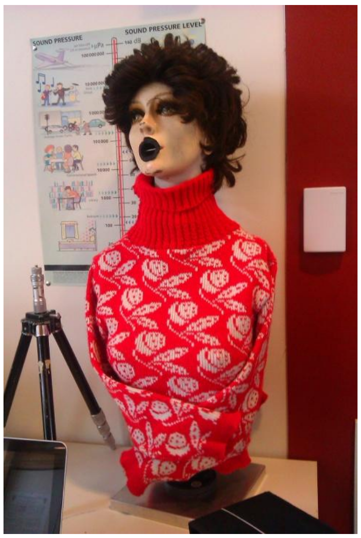
Please write down your selection ____________________ (Please **rank** them if more than 1 selection)

3. Please add your comments below about the indoor air quality if you have any. Suggestions on possible improvements are welcome.

APPENDIX C – Field Measurement Equipments

Instrument/Sensor	Measured Parameters	Range	Accuracy	Measurement Height
Omega HHM25	Air Temperature	-200 ~ 1370 °C	±(0.1+0.7°)	0.9 m
Omega HHM25	Relative Humidity	5 ~ 95%	±5% (15~90%) ±7% (5 ~ 15%) ±7% (90 ~ 95%)	0.9 m
EXTECH Instrument Model AN100	Air Velocity	0.40 ~ 30.00 m/s	±0.01 m/s	0.9 m
Heat Gun	Surface Temperature			0.9 m
Q-trak Model 8551	CO2	0~5,000 ppm	±50 ppm	1.5 m
DLM2	Luminance	0~5,000 fc	±5%	0.9~1.2 m
RION NA-28	Sound Level	20~130dB	±2dB	0.9~1.2 m

Directional talker simulated loudspeaker – SSARAH



Omni-directional loudspeaker used in reverberation time measurements