Do our green buildings perform as intended?

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Abstract:

This paper summarizes the lessons learned from carrying out building performance evaluations of nine Canadian green buildings using a standardised framework and key performance indicators. The aim was to better understand the operational performance of the buildings, compare it to predicted performance and identify lessons for their owners, design teams and the construction industry. A summary of the findings and lessons for each building are presented. The project was initiated by iiSBE Canada[5] with development of an assessment protocol and building performance evaluations conducted by researchers from the University of British Columbia, University of Manitoba and Ryerson University, and sponsored by Stantec and NSERC[6]. More information about the project is available on the iiSBE Canada web site: http://iisbecanada.ca

Keywords: post occupancy evaluation, building performance, energy efficiency, indoor environment quality.

Introduction

Green building rating systems such as LEED[R], Green Globes and BREEAM have traditionally focused on predicted performance at the design stage, but there are many lessons to be learned from understanding how buildings actually perform once occupied. There can be significant gaps between predicted (or expected) performance and measured performance in areas such as energy use, carbon emissions, water use, indoor environment and comfort. This can lead to additional costs to building owners, reduced occupant productivity and buildings that fail to live up to their potential. These discrepancies arise from a variety of reasons such as modelling inaccuracies, envelope and systems integration problems, construction quality issues, occupancy changes, commissioning and handover processes, operational issues, motivation of occupants, and understanding of comfort. An investigation of these variations and discrepancies can help building owners improve the performance of their buildings by better understanding how to optimise performance and prioritise upgrades, and can help designers integrate lessons from existing buildings into future projects.

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[1] Further assistance was provided by University of British Columbia researchers Sylvia Coleman, Juliette Rauscher, Paul Save and Jinying Sun, and Ryerson university researcher Moe Otsubo
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[5] International Initiative for a Sustainable Built Environment – Canada is an independent, non-profit group committed to advancing the sustainable building agenda. See http://iisbecanada.ca
[6] Natural Sciences and Engineering Research Council

This project was initiated by iiSBE Canada and undertaken by researchers from the University of British Columbia, University of Manitoba and Ryerson University with support from Stantec and Canada's Natural Sciences and Engineering Research Council (NSERC). The aim was to investigate the "performance gap" by documenting the differences between predicted and measured performance; compare with benchmarks for "typical" performance of similar buildings; expand the knowledge base about the actual performance of Canadian green buildings; and identify lessons for their owners, design teams, and the industry in general. Nine buildings from across Canada were evaluated with the key findings and lessons for each reported separately in the appendix below.

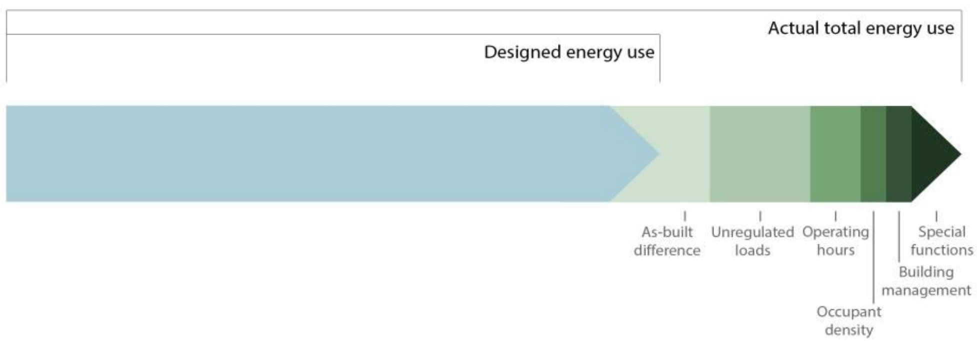

Figure 1: *Conceptual diagram of the "performance gap" (based on Carbon Buzz graphic[7]).*

Research Methodology

Building performance evaluation (BPE) is a process to investigate and analyse how a building is operating, compare it to benchmarks, and identify problems or concerns that need to be addressed. This research involved developing a standardised BPE protocol and applying it to the nine buildings in this study (see http://iisbecanada.ca for more information).

The protocol focused on assessing the following categories of performance: occupancy issues, energy use, water use, economic factors, indoor environment, site issues, and materials issues. Key performance indicators (KPIs) were defined and collected for:

- actual building performance over a minimum of two years of operation;
- predicted performance at the design stage (based on design stage modeling and green rating submissions); and
- reference values for typical buildings of similar use in the region.

This was used to identify the difference between actual and predicted performance. The work required the research teams to collect both quantitative and qualitative data from several sources:

- Metered data for energy and water use was collected for each building from utility bills or sub-meters. Energy use intensity (EUI) in kWh/m^2.yr was calculated and weather normalised using

[7] Based on Carbon Buzz graphic - http://www.carbonbuzz.org/

heating degree days (HDD) and cooling degree days (CDD). Water use intensity (WUI) was calculated in m^3/m^2.yr (of occupied space) and, where an accurate occupancy number was available, in m^3/occupant.yr. This was compared to predicted energy and water use modelled at the design stage (the models were not verified by the research team) and to the energy use of "typical" buildings of that type for their region in Canada based on the Comprehensive Energy Use Database[8] published by Natural Resources Canada. Greenhouse gas (GHG) emissions were calculated using provincial carbon intensity factors[9].

- Spot measurements for indoor environment conditions were taken in a selection of typical work spaces in each building when occupied. These mesurements included: light levels, temperature range, relative humidity, background noise levels (using Balanced Noise Criteria values, NC(B)), CO_2 levels, and particulate concentrations.
- A standard survey of occupants[10] was carried out to investigate the occupants' experiences and their levels of satisfaction with the building in general and the indoor environment in particular. Occupants provided scores of 1 to 7 for their perception of a range of building characteristics, including lighting, thermal, acoustic and air quality issues. They were also able to provide comments on specific concerns. The statistical validity of these varies with response rate.
- Interviews were carried out with representatives from the design team, the building manager/owner, and, where possible, occupants.
- Observations were made during building visits to provide supporting information.
- Design documents including drawings and specifications, green building rating submissions (such as LEED[R] or Green Globes) and energy models were used to identify predicted performance at the design stage.
- Standardised calculation methodologies were used for weather normalisation of energy data, conversion of energy into carbon emissions using the Common Carbon Metrics process with provincial greenhouse gas conversion factors, and local utility rates for economic analysis.

This diverse data enabled the research teams to document the achieved performance of each building and identify performance issues. Qualitative and anecdotal data from interviews, observation and spot measurements were used to support the metered data and occupant survey.

Buildings

Nine buildings across Canada that had data available for both the design stage predictions of performance and operational data were selected for this study (Table 1). Five are academic buildings at universities or colleges, three are private or public office buildings, and one is a community building. All were built or had undergone a major renovation in the last ten years. In each case the client had set "green" objectives and targets for better than typical level of performance in areas such as energy use, water use and indoor environment.

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[8] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_egen_ca.cfm

[9] Envionment Canada. (2013). National Inventory Report 1990-2011 Part 3. Minister of the Environment.

[10] This was based on a survey developed by Dr Guy Newsham at IRC-NRC Canada, (see Newsham et al, 2012).

Building	Location	Type	Net floor area (m^2)	ASHRAE Climate Zone	Construction cost ($\$/m^2$) [11]	Type
MMM Group office	Kitchener Ontario	Small Office	1,900	6	$2,900	New build
Manitoba Hydro Place	Winnipeg Manitoba	Large Office	64,590	7	$3,550	New build
Surrey District Education Centre	SurreyBritish Columbia	Medium Office	11,420	5	$2,500	New build
Canal Building	Ottawa, Ontario	Medium Academic	7,310	6	$4,160	New build
Ron Joyce Center	Burlington, Ontario	Medium Academic	9,340	5	$1,980	New build
Roblin Centre	Winnipeg Manitoba	Large Academic	19,210	7	$1,950	Adaptive re-use & new build
Jim Pattison Centre of Sustainable Building Technologies	Okanagen, British Columbia	Medium Academic	6,780	5	$4,150	New build
Centre for Interactive Research on Sustainability	Vancouver British Columbia	Medium Academic	5,500	5	$6,150	New build
Alice Turner Library	Saskatoon, Saskatchewan	Small Community	2,070	7	$3,200	New build & addition

***Table 1**: Buildings in the study*

The buildings range in size from 1,900 m^2 to 64,500 m^2 of net conditioned floor area. Construction costs vary from $1,950 to $3,200 per m^2 for the new build/addition and adaptive reuse/new build projects, and $2,500 to $6,150 per m^2 for the new build projects.

A variety of established, new and innovative technologies were used in these buildings. Many focused on natural daylighting and natural or mixed-mode ventilation strategies, passive solar strategies including improved thermal insulation and the use of thermal mass. A wide range of HVAC systems from simple to complex were used. Four buildings included renewable energy systems and three included water collection or recycling systems.

Discussion

Though this project was designed to identify performance gaps in high-performance buildings, this goal is often difficult to achieve. The scope of this study did not allow for the rigorous reconciliation between projected and actual performance. Reconciliation would include methodologies such as revising performance projections made at the design stage to reflect actual building use and occupancy,

[11] All costs are in Canadian Dollars

as well as resolving energy and water use to a greater degree of granularity (e.g., specific end-uses). Indeed, only one of the nine buildings had an energy model that had been recalibrated.

Without these recalibrated models, evaluating performance gaps relies on comparing actual performance to models that may not be effective at predicting actual performance, or were never designed with this explicit purpose. Models often exist simply to compare the relative impact of different design options. At the very least, designers should be aware that energy and water models are often not ideal for predicting of future consumption, but a good way of comparing the relative efficiency of design options.

Providing slightly more context are the reference values for each KPI although even these do not always give an appropriate point of comparison. In other words, it is difficult to determine which standard a high-performance building should be compared to. Despite these concerns the high-level analysis in this study did uncover several trends and relationships that will prove useful in improving building design, construction, and operation, as well as contributing to the further development and implementation of Building Performance Evaluation (BPE) methodology.

When considering building performance it is important to look at the bigger picture. For example, a building may not meet its energy or water targets because it is being used more intensively. This may be a good thing as it avoids the construction and operation of additional space. In contrast a building may meet its energy targets, however the building's location may result in increased travel distance and lower use of public transportation by its occupants leading to increased carbon emissions.

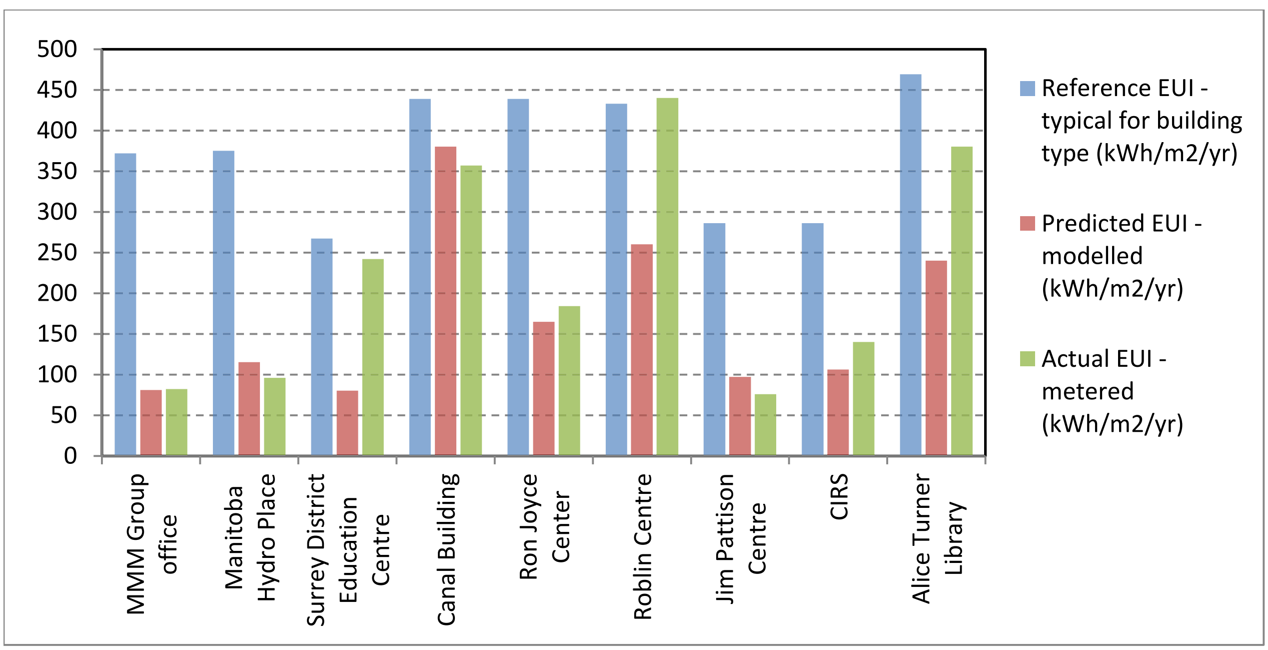

Figure 2: *Comparison of building EUI predicted, actual and reference*

Conclusions - Initial Findings

Below is a summary of some key lessons identified from the nine building performance evaluations. This project is not complete and these are initial findings. These results will be explored further in other papers and at the SB14 Conference panel session:

1. Actual building occupancy (i.e., hours of operation and occupant load) can be very difficult to determine if not monitored and recorded on an ongoing basis. This is a key aspect that must be addressed in BPEs going forward.
2. Building occupancy often changes significantly from the original design assumptions, which can have significant impact on actual energy and water use.
3. The most pervasive building performance issue in the buildings evaluated was acoustic quality, with speech privacy being the main concern. Acoustic intrusion from external sources did not appear to be an issue.
4. There does not appear to be a correlation between conventional lighting level metrics or standards and occupant satisfaction with lighting. More specifically, high levels of daylight well beyond accepted lighting level standards did not appear to detrimentally affect lighting satisfaction, and may in fact have contributed to it. Definitive conclusions in this regard require further study.
5. All buildings evaluated for this project claimed to utilize an Integrated Design Process (IDP). However, there was no evident correlation between implementation of an IDP and performance outcomes other than if gaps were reported in the IDP, building performance issues were observed that arguably were related to the gaps in the design process.
6. The exemplary actual performance of several projects appeared to be directly related to the building management and operational staff. Those projects generally correlated with higher management and operational capabilities and capacities.
7. A number of building performance issues could be directly attributed to commissioning gaps. Ongoing commissioning was also instrumental in sustaining or improving the performance of several projects.
8. A lack of sub-metering and/or data acquisition was a significant obstacle in the assessment of a number of projects, as well as clearly handicapping the building operators in terms of monitoring, maintaining and improving the performance of their buildings.
9. Occupant surveys were useful to identify trends and provide a perspective on building performance that is not readily identifiable by direct measurement.
10. Our occasional but considerable difficulty collecting data indicates that if the industry is to carry out effective BPEs on a wider scale, it is important that better documentation of design assumptions and provision for collecting performance data for later use be considered at the design stage.

APPENDIX – BUILDING SUMMARIES

MMM Group Office, Kitchener, Ontario

ASHRAE Climate Zone 6 - Humid continental, cold winters (4,194 HDD, 201 CDD)

Building Summary

- Owner: MMM Group (formerly Enermodal)
- Project type: New build, small office building
- Construction completed in 2009
- Construction cost: \$2,900 /m^2
- Net conditioned area: 1,900m^2
- Facilities: Offices, kitchen
- Green building rating: LEED^R Platinum
- Mechanical: Variable refrigerant flow (VRF) multi-split air source heat pumps
- Ventilation: Separately zoned HRVs with CO_2 sensors; earth tube en route
- Controls: Space heating and cooling controlled by occupant sensors in multiple zones; corner offices and meeting rooms have local set point override for occupants.
- Occupant operable windows in shared and private offices
- Lighing: Efficient lighting design; daylighting and occupant sensors
- Water: Rainwater collection; no irrigation system for landscape.

This LEED^R Platinum building demonstrates how with careful design and management a small office building can achieve very high levels of energy performance and indoor quality within a typical construction budget. The building features a relatively narrow footprint that enables maximum daylighting and access to views from all work spaces, simple HVAC systems, re-naturalization of the surrounding environment, and extremely low water use fittings and appliances.

Highlighted Key Performance Indicators – Energy and Water

As seen in Figure 3, the EUI of 82 kWh/m^2/year is considerably below a typical building of this type in this location, which consumes 372 kWh/m^2/year (Natural Resources Canada, 2014). This reflects the careful design process and subsequent care over commissioning and understanding how the building operates. Its performance has been refined over several years to now almost meet the predicted performance (1% difference).

A photovoltaic array has only recently started generating electricity for use in the building and to offset grid-purchased electricity. This is not reflected in the analysis. This delay was caused by inspections from the local utility and now that it has been resolved will reduce net delivered energy for this building.

Figure 3 also shows the actual gross water use per occupant is 3.6 m^3/yr, which is 12% higher than predicted. However, 1.4 m^3/yr of this comes from collected rainwater on site. Thus, municipal water use in the building is a low 2.2 m^3/yr per occupant. This figure is 69% higher than predicted as less collected rainwater water was used due to occupancy patterns.

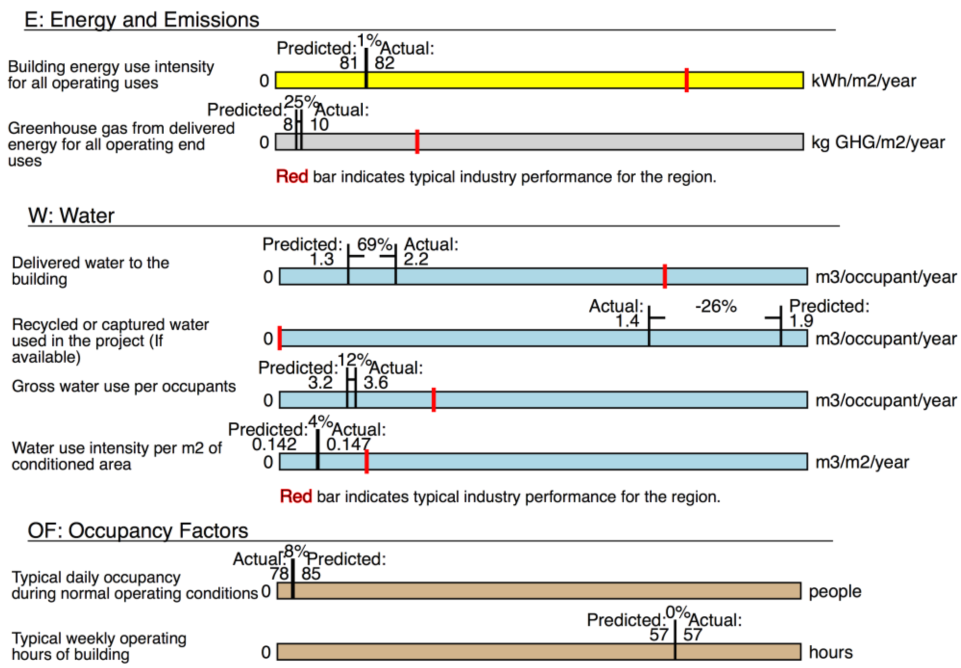

Figure 3: *MMM Group Office key performance indicators for energy and water - predicted vs. actual*

Indoor Environmental Quality

An indoor air quality (IAQ) evaluation was carried out in July 2014 during a largely overcast period, when employees were encouraged to open their windows ("free cooling day"). It should also be noted that the building had recently undergone an increase in occupancy as a result of changes in company structure.

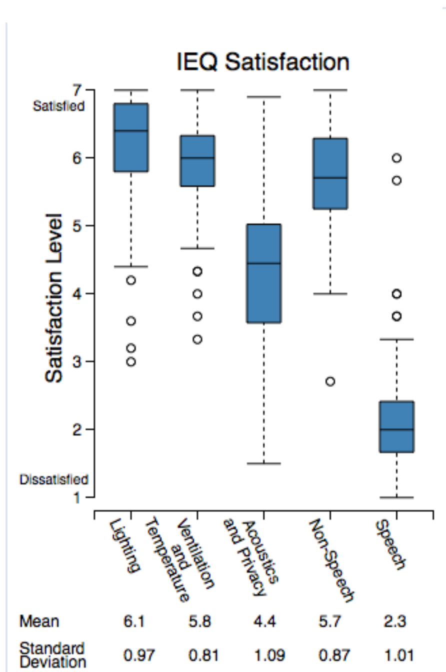

Figure 4: *MMM Office occupant survey results (Boxplots display quartiles & median)*

The lighting measurements from spot daylight factor and luminance data collection suggest this building is not meeting the reference target for both lighting levels. The daylight factor results were below the target values for 77% of the spaces measured and light levels above the target values for 64% of the spaces measured. However, this is contradicted by occupant survey score (with a mean of 6.1 out of 7) which show that lighting is the environmental variable that employees expressed the greatest satisfaction. Overall, the absence of questionnaire complaints about over-lighting, and the fact that not all electric overhead lights were in use on an overcast day suggest some success in this area, despite the indications of the spot physical measurements. The only recommendation would be to wire lighting zones such that individual workers have greater control over their immediate lighting conditions.

Acoustics generally received the lowest scores in the occupant survey. It is clear in Figure 4 that speech privacy (with a mean of 2.3 out of 7) is the greatest source of acoustic dissatisfaction for employees, and that it is likely the reason that the general factor 'acoustics and privacy' was rated lower than the other IEQ factors. Comments from occupants support this: of 51 comments received, 35% expressed concern about the lack of speech privacy in the office environment. It is reasonable to assert that speech noise and a lack of speech privacy is a source of concern for some employees.

Interestingly, when first occupied it was noted that the work environment that was too quiet and in the manager's opinions negatively affected productivity. After initial occupation it was noticed that employees were speaking to one another using whispers instead of normal speaking voices, something which could inhibit the collaborative atmosphere that was desired. White noise speakers were installed in an effort to raise the background noise in the building to a level at which employees could speak more normally.

Figure 5 shows that for thermal comfort 92% of spaces (24 of 26, feet and head height spot measurements included) were in the acceptable range for summer, with the remaining being too cool. Occupant survey scores offer some corroboration with a relatively high mean score of 5.8 out of 7 indicated in Figure 4. If scores of 4 and above are taken to indicate thermal satisfaction, then questionnaire results show that 96.2% (50 of 52) are satisfied. If scores of 5 and above are used, then 88.5% are satisfied.

Questionnaire comments confirm the physical observation that occasionally spaces are overcooled during summer. Twenty-two percent of comments indicated being too cold, with most mentioning cold air being blown on their workstation. Raising the set point may increase satisfaction, and further reduce energy consumption.

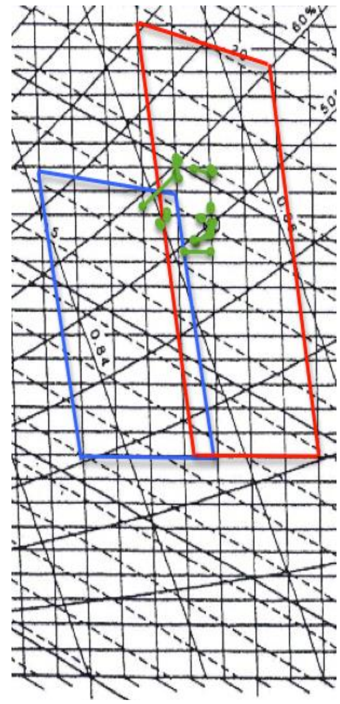

Figure 5: *MMM Office thermal measurements (July 2014) mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zone; Red box indicates Summer Comfort Zone)*

Discussion

This building comes close to meeting its KPI targets for energy and water use, and performs much better than a typical Canadian office building of this type. It provides a high quality indoor environment that allows natural ventilation and daylighting for much of the occupied period. The building is experiencing some relatively typical IEQ problems namely overcooling during warm weather and some acoustic dissatisfaction with speech noise. Overall, occupants reported a high level of satisfaction with the building, and problems that were anticipated are being addressed. In addition, factors such as preservation of the landscape and use of low carbon materials are addressed. One issue raised in the occupant survey was that due to the out-of-town location, 80% of employees traveled to the building by car. This is now being mitigated by policies to reduce the impact of transport from company activities and its associated carbon footprint.

Manitoba Hydro Place, Winnipeg, Manitoba

ASHRAE Climate Zone 7 - Continental, very cold winters, warm summers
(5,557 HDD, 310 CDD)

Building Summary

- Owner: Manitoba Hydro
- Project type: New construction
- Construction completed in 2009
- Analysis completed for 2012/2013
- Construction cost: \$3,550/m^2
- Net conditioned area: 64,590m^2
- Facilities: Office building, public gallery, retail and food outlets
- Green building rating: LEED^R Platinum
- Mechanical: Geothermal heat pumps provides radiant space heating /cooling through building structure; back-up natural gas boilers; advanced building management system.
- Ventilation: Hybrid mechanical/natural ventilation filtered through winter gardens and using orientation of interior atria to prevailing wind and solar chimney; occupant-operable windows.
- Envelope: Double façade envelope on east and west. High fenestration to wall area ratio. High performance curtain wall. Green roof.
- Water: Low flow fixtures; rainwater harvesting; storm water control.
- Materials: Materials from existing buildings on-site were reused or sold to other projects; locally-sourced materials were also used.
- IEQ: Shallow depth floor plate with open plan workstations plus low/transparent interior partitions and floor-to-ceiling perimeter glazing to maximize daylight and view; desktop software gives occupant individual control over operable windows, and lighting at workstation; raised floor provides displacement ventilation and sound-masking systems; low VOC furnishings and carpeting.

This building's design and construction took five years to complete. According to the designer, the successful realization of the project was due to precedent research, establishment of clear design goals, and a strong integrated design process with experienced consultants. This building featured several innovative strategies that contribute to its low energy use. Although the building consumed more energy than modeled in its first few years of occupancy, on-going commissioning and modifications have signifciantly decreased its energy consumption in later years, so it is now close to predicted performance.

Highlighted Key Performance Indicators – Energy and Water

Figure 6 summarizes the building's energy and water KPIs. The building's actual electricity and gas consumption during 2012-2013 was nearly 75% less than a typical building of similar size and function. Its actual EUI for 2012-2013 fell within the range of model predictions after adjusting for "non-regulated" energy use which was not modeled. It is important to note that the building houses several non-office uses such as restaurants, cafes, and a large data centre which significantly contributed to its "non-regulated" energy use. Additionally, the building's actual wáter consumption for 2012-2013 exceeded both its predicted and reference consumption possibly due to the consumption of restaurants and cafes in the lower floors which are not part of the “office building” wáter use calculations.

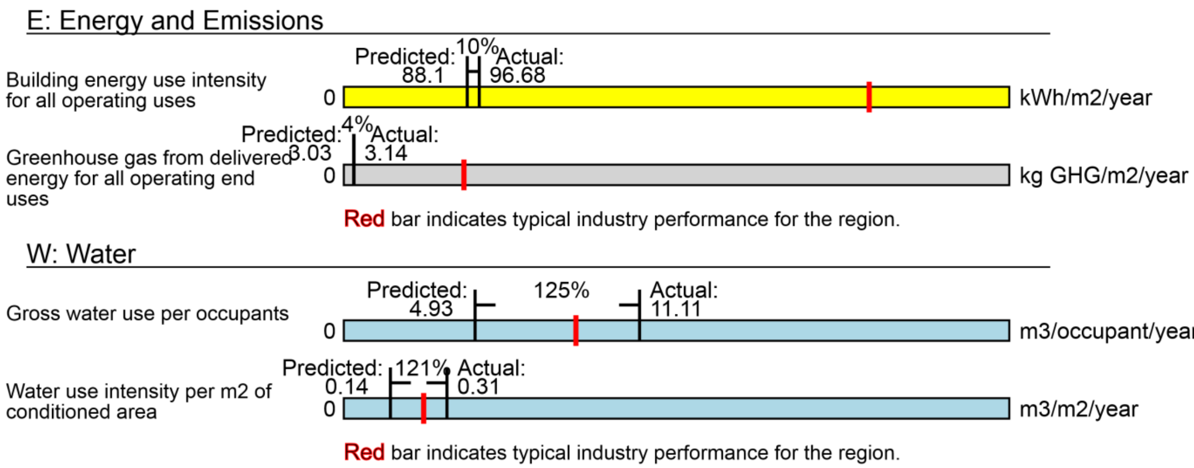

***Figure 6:**– Manitoba Hydro Place key performance indicators for energy and water - predicted vs. actual*

Indoor Environmental Quality

The evaluation of IEQ in the building was based on physical measurement of environmental conditions during Summer 2014 and interviews with design and operational and management staff. According to the measurements, the natural ventilation system appears to provide excellent indoor air quality with CO_2 concentration averaging 540 ppm in the open office areas. An occupant reported feeling the air quality was significantly better in their new workplace than their previous building. Enclosed conference rooms located at the interior core of the building had slightly higher concentrations of CO_2 (687 ppm) but still well below the recommended maximum of 1000 ppm.

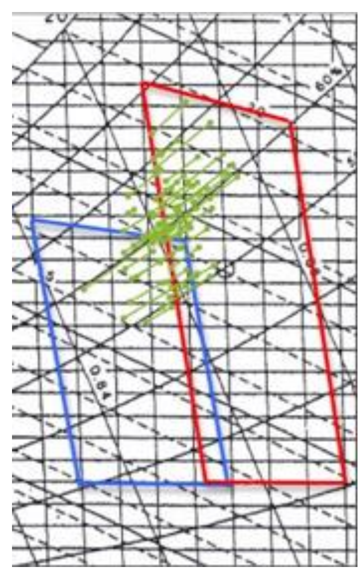

***Figure 7:** Manitoba Hydro Place paired foot & head height thermal measurements mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zone; Red Box indicates Summer Comfort Zone)*

Measured temperature and relative humidity in the building are all well within comfortable levels (82% compliance with ASHRAE 55 – see Figure 7). Some stratification was noted between foot and head temperatures (+/- 1°C), which is not uncommon with displacement ventilation where air is introduced at the floor level.

The luminous measurement results indicate that 49% spaces fall within recommended lighting levels. The remainder (51%) of vertical and horizontal surfaces in the workplace are overlit, which, as a design optimized for daylight penetration, is not surprising. However, a facility manager also noted that some of the controls for automated blinds and dimmable lighting are undergoing further fine-tuning. A facility manager commented that occupant complaints of glare and overheating mainly occur in the south-facing offices. Here the envelope consists of a triple-pane fritted glass façade that, unlike the innovative façades on the west and east elevations, provides less of a barrier to solar heat gain. According to one of the designers, these areas of the building were converted to private, enclosed offices that are more difficult to condition than the original open plan workspaces.

The designer also indicated that achieving speech privacy in the building was particularly challenging due to the need for low interior partitions (for daylighting), an absence of acoustical ceiling tile (would obstruct the radiant ceiling) and the lack of mechanical ventilation fans that typically provide a certain level of noise masking background sound. Although baffles and other solutions were considered, this issue was addressed by introducing artificial background noise with a sound masking system located in the raised floor. An occupant survey is planned to further measure occupant satisfaction in relation to IEQ.

Discussion

In terms of measured IEQ parameters, overall the building performed well. Higher than recommended lighting levels and reduced speech privacy were noted and attributed, in part, to trade-offs in achieving a high level of natural lighting, passive ventilation and heating. As a result, designers should be aware that additional solutions, such as sound masking in this case, may be required.

The largest performance gap noted was between modeled and actual metered energy and water consumption. Although the building's operating hours were longer than the model assumptions, the actual number of occupants was approximately 10% less than the building's design capacity. The building manager also explained the radiant floor heating, coupled with the innovative façade, has significantly decreased the heating demand compared to similar buildings. According to a facility manager, however, the leased-space tenants of the building were unknown at the time of design, so their consumption of energy and water was not accounted for in the original energy model and water calculations. This would account for a large portion of the difference and further suggests that it would be useful to validate energy models with as-built information.

Overall, this building consumed significantly less energy compared to that of a similar building of conventional design. A facility manager did note that there was higher energy demand during the first years of occupancy due to the complexity of the systems and the unfamiliarity of the building management staff with these innovative systems. Lighting sensors, for example, that were installed to decrease artificial lighting based on available daylight did not function as planned, resulting in a slight increase in electricity consumption. This suggests that building operators will require time to learn, fine-tune and optimize the actual performance of high-performance buildings with climate responsive and/or innovative systems.

Surrey District Education Centre, Surrey, British Columbia
ASHRAE Climate Zone 5A - Coastal climate with wet winters and mild, sunny summers (3,100 HDD, 218 CDD)

Building Summary

- Surrey Board of Education
- Project type: New construction, medium size office building
- Construction completed in 2011
- Net Conditioned Area: 11,420 m^2
- Construction cost: $\$2,500/m^2$
- Facilities: Offices, meeting rooms, boardroom, cafeteria
- Green building rating: LEED[R] Gold
- Modeling Software: EE4 (for CBIP)
- Analysis completed for 3/2012 to 2/2014
- Mechanical: Primary HVAC system is a geoexchange with a central variable-speed drive heat pump for heating (avg. COP=5.0) and one for cooling (avg. EER=13.7); two constant volume ground loop pumps were installed with a 60% combined efficiency; secondary HVAC system is based on chilled beams and air handling units, with a heat recovery effectiveness of 57%; when cooling load exceed capacity of chilled beams, air handling units ramp up to meet additional load.
- Water: Low flow fixtures; ground water use for irrigation and 50% irrigation reduction.
- Materials: Increased roof insulation; spectrally-selective double pane low-E glazing.
- Additional indoor systems: Automated occupancy sensors and daylight sensors for lighting and skylight; radiant floor heating and cooling; operable windows.

This is principally an office building with private and open plan offices, small meeting rooms and a cafeteria on 5 floors (including the basement). It also provides a lounge area in the atrium, training rooms, and a boardroom. Since opening, the building has been used extensively for daily workshops and extra-curricular events that could not be accounted for in the actual occupancy. According to the Associate Director, Business Management Services and the energy manager, the integration of innovative design features has been a challenge for both the design team and operations due to the novelty and complexity of those features.

Highlighted Key Performance Indicators – Energy and Water

The actual energy use intensity of the building was considerably higher than predicted (see Figure 8). However, the building consumed 9% less than a typical office building in this location. The energy model predicted that 96% of the delivered energy would be electricity and the remaining 4% would be natural gas. Energy bills revealed that the natural gas consumption was 15 times higher than estimated and was responsible for 30% of the building's energy consumption. Natural gas was expected to be used mainly for domestic hot water heating and for emergency air heating during extreme weather conditions in the winter. However, in reality the back-up air heating system turned on even under less extreme weather conditions.

Figure 8 also shows that the building consumed three times more water than was predicted (per m² of floor area), and double the predicted water use per occupant, The official occupancy of the building was only slightly higher (17%) than predicted. Since the green roof was removed after construction due to a lack of maintenance staff, and no additional water is needed for irrigation purposes, the higher consumption is likely due to higher occupancies and higher amounts of water use per occupant. Due to a lack of sub-metering the higher water consumption cannot be further explained.

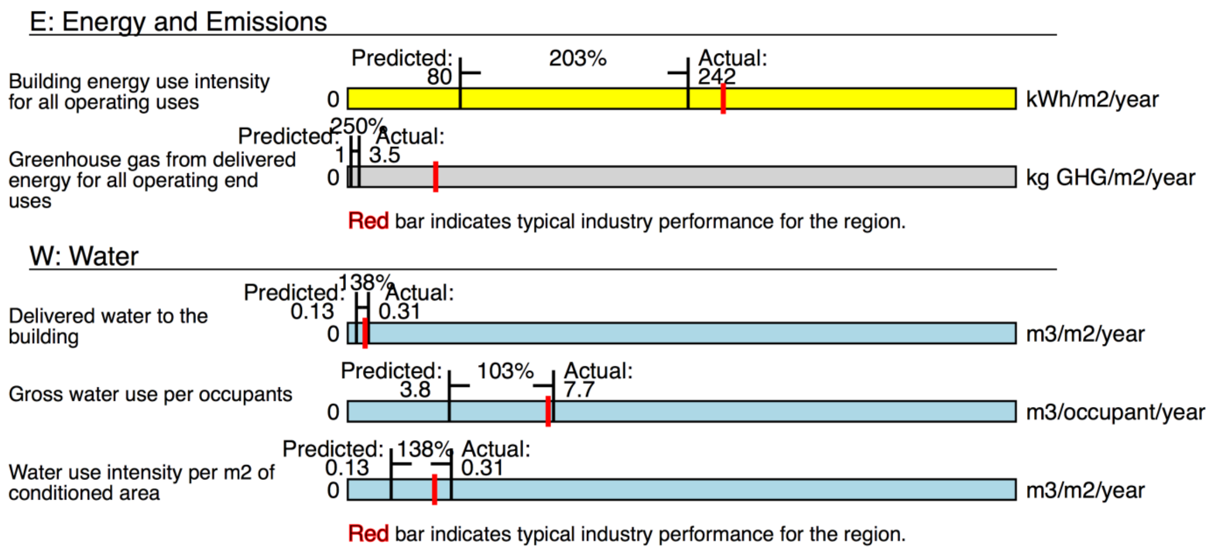

Figure 8: *Surrey Education Centre key performance indicators for energy and water - predicted vs. actual*

Indoor Environmental Quality

The physical spot measures of IEQ in this building on the day of testing (in June) varied in terms of degree of compliance with reference standards, and occupant dissatisfaction with some features was noted; 35% of respondents were less-than-satisfied with the environment as a whole.

Figure 9 shows that acoustics and privacy satisfaction ratings were lower than ratings of the other aspects of IEQ. In support of this, more of the negative comments (i.e., 39%) were about acoustics than any other attribute. Non-speech sounds were generally acceptable; speech sounds received lower ratings. Specific comments revealed the sources to be noise from other people, distraction from speech in open-plan offices, and an inability to obtain speech privacy. Sound levels were measured across room types, and generally exceeded guidelines.

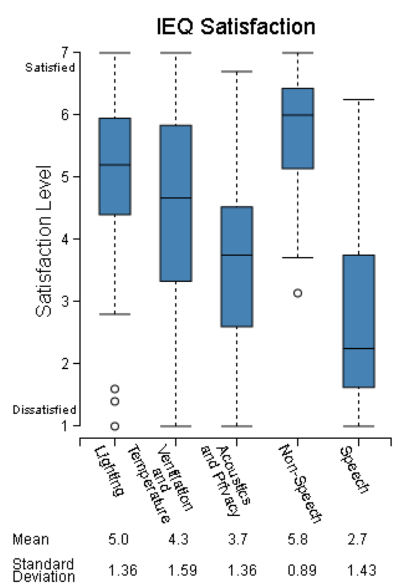

Figure 9: *Surrey Education Centre occupant survey results (Boxplots displaying quartiles and median)*

Of the occupant survey responses, satisfaction with temperature and ventilation varied the most (see Figure 9); 17% of the occupant concerns about thermal comfort related to faulty thermostats and fluctuations between temperatures that were too cold and too hot. In agreement with this, the thermal comfort chart (see Figure 10) shows that 59% of the spot thermal measurements were below the acceptable summer range, and the other 41% of the measurements are near the border of the comfort zone.

Indoor CO_2 concentrations (512-589 ppm) met ASHRAE 62.1 guidelines, although actual occupancy on the measurement day was lower than predicted. The ratios of indoor-outdoor particulate matter and ultrafine particulates indicated that the ventilation system in this building worked well to filter outdoor particulate matter. One exception was a copy room, where high levels of ultrafine particulates were measured.

The lighting levels on the desks and computer screens were both above and below the 300-750 lux guidance levels, and some of the negative comments about the building were about excessive brightness and glare. Despite this, however, most respondents were satisfied with lighting levels; positive comments described access to natural light and views of the outdoors. Additional comments related to a lack of visual privacy (i.e., working in spaces with untextured glass walls) as well as a lack of private areas for retreat or holding private conversations.

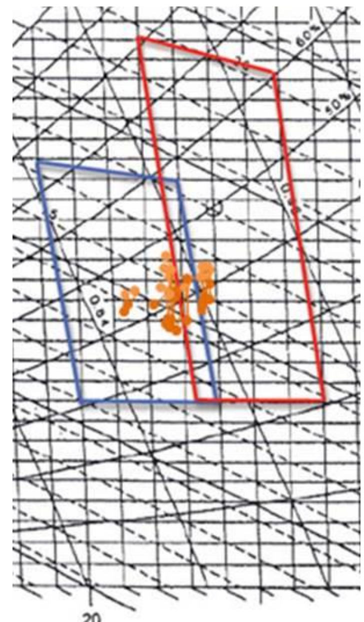

Figure 10: *Surrey Education Centre thermal measurements (June 2014) mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zones; Red box indicates Summer Comfort Zone)*

Discussion

Performance gaps in this building were revealed for the energy and water systems, as well as for occupant satisfaction. The extensive electricity consumption could not be further explained by operating end uses, since the building is not equipped with sub-metering systems. Interviews with building designers and facility managers revealed that there have been operational issues with the geothermal system regarding the automated functioning of valves and pumps, and uneven distribution of heated/cooled air in the building since it opened. The system has required a lot of maintenance for a small team of operators that are responsible for a large number of buildings, were fairly new to the geothermal system and chilled beams, and did not receive extra training in its operation.

Occupant concerns with various aspects of indoor environmental quality represent an important gap in this building's performance. Primarily, speech sounds and a lack of speech privacy interfered with occupants' satisfaction and productivity – a result that is reported in several buildings in this and other studies[12] but holds opportunities for improvement. Noise levels generally exceeded applicable guidelines. Air quality was generally acceptable, with the exception of higher levels of ultrafine particulate matter in one copy room.

[12] Baird, G., & Dykes, C.M. (2013), Newsham, G., et al. (2012).

Canal Building, Ottawa, Ontario
ASHRAE Climate Zone 6 - Cold, humid continental (4477 HDD, 260 CDD)

Building Summary

- Owner: Carleton University
- Project type: New build
- Construction completed in 2011
- Analysis completed for 2012/2013
- Net conditioned Area: 7,340 m^2
- Construction cost: $4,160 per m^2
- Facilities: Offices, lecture halls, computer labs, engineering research labs
- Green building rating: Green Globes
- Mechanical: District steam supporting ceiling mounted radiant Panels. Cooling is provided by chillers dispersed through a VAV box system.
- Ventilation: ERV
- Water: Low flow fixtures
- Lighting: Day-lighting provided to 80% of primary spaces, occupancy controlled dimmable lighting

Since completion of the building, faculty and students have slowly moved their labs and offices into the building. The building is currently only partially occupied. Due to this and to the building's nature as an academic building, it has been difficult to assess and calculate a typical occupancy for the building. This in turn has had implications on many of the KPIs as the building is not operating at full capacity. It has also made it impossible to calculate KPIs such as an alternative water KPI measured in m^3/occupant.

Highlighted Key Performance Indicators – Energy and Water

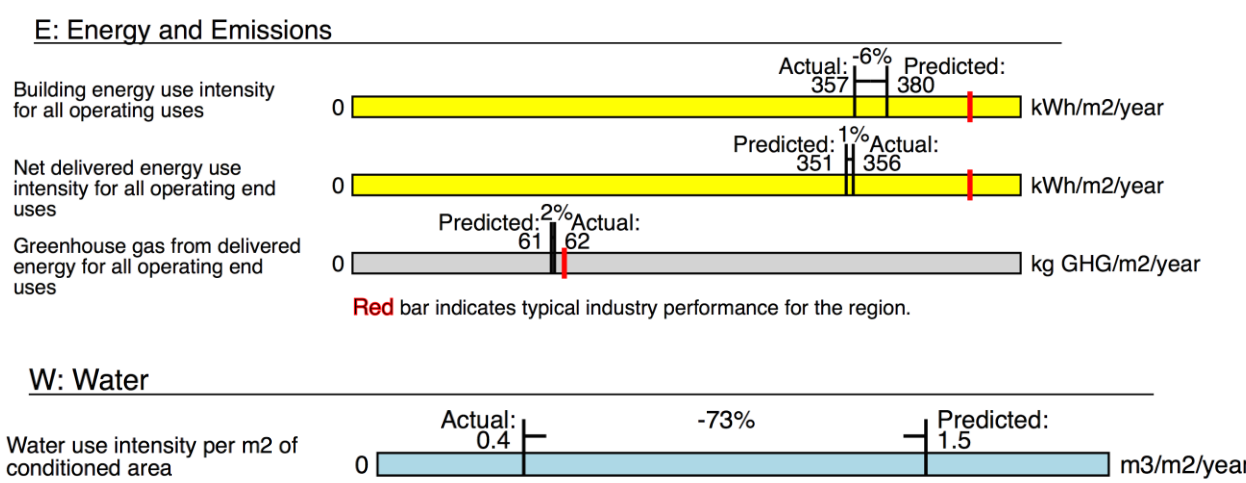

Figure 11: *Building D key performance indicators for energy and water - predicted vs. actual*

The metered energy consumption for the 2012/13 assessment period (see Figure 11) shows that the building was performing 6% better than predicted by modelling and 19% better than a typical academic building in this location. However, at this stage the building was only partially occupied, and it is not clear how this has affected energy use. Net delivered energy does not show this same 6% better performance because the design intention to include 5-10% (of total energy use) renewable energy systems was not fully realized in the actual building which means less energy generated on site.

The large gap between actual and predicted water use (see Figure 11) is likely tied to the ongoing partial occupancy of the building. The water use pattern shows a slow process of growth over several years as faculty and labs move into the building. However, academic buildings have a large variation in water use between fully occupied periods and periods during the academic year where less students use the building at vacation times.

This same phenomenon should not affect energy to the same extent, because while plug loads are largely driven by occupancy and lighting to a certain extent, space conditioning is less affected.

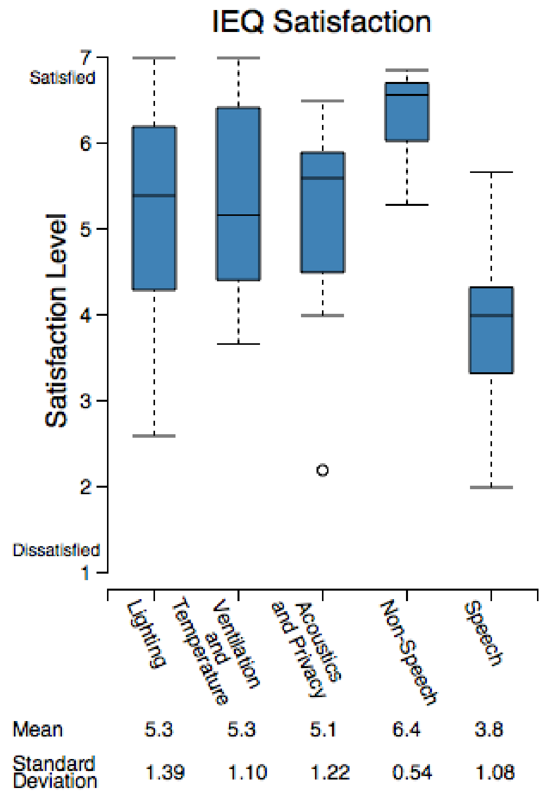

Figure 12: *Canal Building occupant survey results (Boxplots display quartiles and median)*

Indoor Environmental Quality

The occupant survey received a limited number of respondents due to low use of the building in summer when the survey was conducted. Nevertheless, the results indicate a generally good level of satisfaction with the IEQ in the building. The three areas that were identified as having some issues were lighting, thermal comfort, and acoustic issues due to speech (see Figure 12).

Acoustic speech environments received a mean score of 3.8 out of 7 and scored worst of the IEQ issues addressed. This appears to be are a recurring problem amongst many of the buildings within this study, and within green buildings in general. More information would be required to determine exactly which floor plans and spaces within the building have the largest issue with acoustic comfort.

Lighting received a mean score of 5.3 out of 7, and while it was not reflected in the comments that accompanied the survey, the issue was brought up in several of the interviews. The building manager perceived some dissatisfaction with the capacity of the automated light level controls, and witnessed occupants unscrewing their light bulbs or taping over their sensors because the electric lighting would come on when light levels were already adequate in a space. An occupant interview highlighted concerns about windows on the south-west side receiving significant afternoon glare. The building was designed with a saw-tooth façade that was to accommodate BIPV panels facing due south in addition to the office windows facing west. Ultimately the BIPV were not included due to budget constraints, yet unfortunately at this point in the design process no adjustments could be made to the buildings geometry, and the west facing windows remain.

Thermal comfort is the other topic which received some attention from interviewers and occupants. Some of the comments indicate that there is a problem with the thermal conditioning in the space. The building manager noted that the building has experienced teething problems and that initial set points created in some unacceptable conditions. However, an ongoing process of adjustments to the building automation system has addressed many of the initial thermal comfort issues. On-site spot temperature measurements taken in May, (see Figure 13), show thermal conditions as slightly cool for summer conditions but within acceptable ranges for winter.

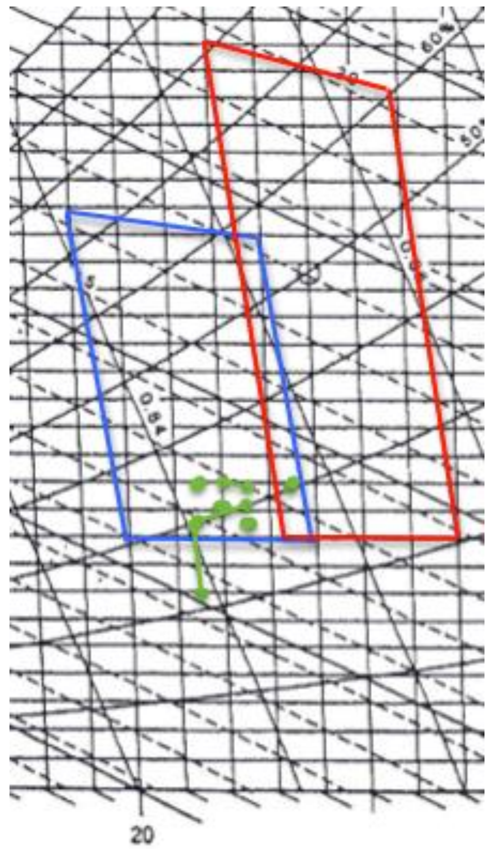

Figure 13: *Canal Building thermal measurements (May 2014), mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zone; Red box indicates Summer Comfort Zone)*

Discussion

The evaluation of this building showed some of the difficulties of assessing a building that is still not fully occupied, thus making it difficult to compare actual to predicted performance. Furthermore, the changing nature of occupancy in academic buildings (with large numbers of students occupying the building during term time, but sometimes only for the length of a class, and not necessarily for a whole working day), make it difficult to predict KPIs such as water use intensity. Also the evaluation highlights that when building features such as facades designed around PV systems are changed at a late stage, problems in performance can occur.

Besides this methodological point the building appears to be operating up to all expectations, however its exact performance is difficult to judge in a partially occupied state.

Ron Joyce Centre, Burlington, Ontario
ASHRAE Climate Zone 5 - Humid continental, cold (3,924 HDD, 259 CDD)

Building Summary

- Owner: McMaster University
- Project type: New build, medium-sized academic building
- Construction completed 2009
- Construction cost: $1,980 per m^2
- Net conditioned area: 9,340 m^2
- Facilities: Offices, classrooms, lecture theatre, cafeteria
- Green building rating: LEED^R Gold
- Controls: Building automation system to control mechanical and electrical systems
- Mechanical: Approx. 100 water source heat pump units, tied into a 250-ton boiler/tower loop system
- Lighting: Efficient lighting design including occupancy sensors
- Ventilation: Demand-controlled ventilation with CO_2 control and heat recovery (enthalpy wheel) on exhaust air
- Envelope: Well-insulated walls and roof
- Water: No irrigation system and drought resistant plants

This multi-use academic building is home to a university department, housing students, faculty, and support staff. The building has a main floor cafeteria, computer lab, and lecture hall, accessed from an atrium space, with the second and third floors being composed of smaller classrooms, study spaces, and both open plan and private offices. The fourth floor is currently unfinished, though it is partially conditioned. The building hosts special events on many evening and weekends, an expected occupancy load of the building, but one that is difficult to measure accurately, as will be discussed.

Highlighted Key Performance Indicators – Energy and Water Use

Data corresponding to a number of KPIs was collected in early 2014; salient results are presented in Figure 14. Actual energy use is close to that predicted (8% over), but it is 58% better than a typical building of this type. Greenhouse gas emissions are 30% higher than predicted since the building is using a different energy mix than expected – less electricity, and more natural gas (which in Ontario has a higher carbon emission factor than electricity).

Actual water use is 10% less than predicted, and also far less than is the norm for this building type. The facility manager has pointed out that not having a centralized irrigation system is one of the reasons for this success as staff have to manually water the limited landscaping as needed. However, it is unclear how energy and water use will change when the 4th floor is fully occupied (at present it is heated to a lower temperature in winter). Ideally, water would be reported as water use per occupant, however a realistic value for occupancy could not be calculated with any accuracy because of the unpredictable scheduling for the building.

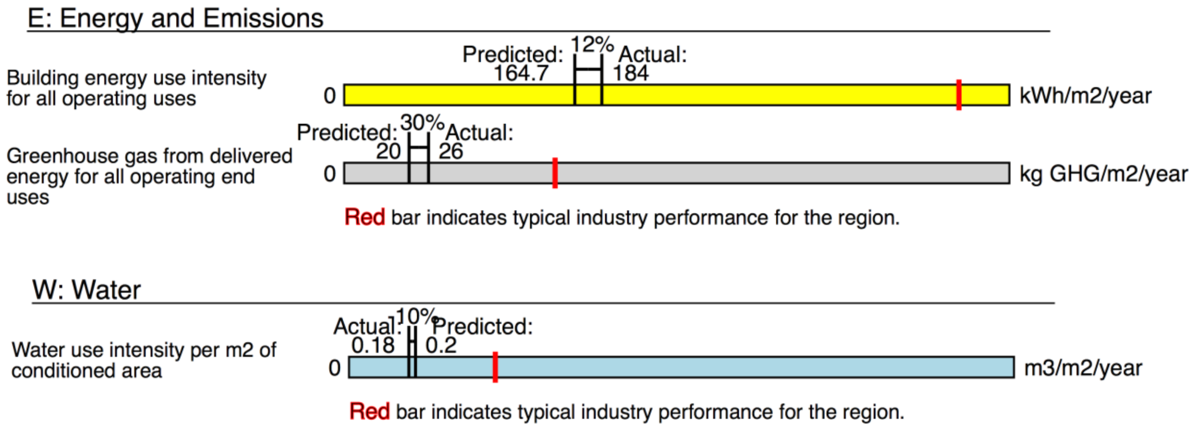

Figure 14: *Ron Joyce Centre key performance indicators for energy and water - predicted vs. actual*

Indoor Environmental Quality

The indoor air quality (IAQ) evaluation in this building involved carbon dioxide, temperature, and humidity measurements. The fifteen carbon dioxide measurements ranged from 547-853 ppm; this is below the building set point of 880 ppm and may be due to low occupancy at the time of measurement. It is well below the industry standard of 1000 ppm.

Figure 15 shows a psychometric chart containing a scatterplot of temperature and humidity spot measurements taken in March at fifteen locations in the building (mostly workstations). It shows that 80% of the spaces measured are within the winter range of acceptability (blue box). Scores from fifteen questionnaires completed by full-time employees revealed a mean score of 5.4 (out of 7), with a standard deviation of 1.06 for temperature and ventilation (see Figure 16). Though these scores and physical measurements suggest general satisfaction with the thermal environment, there were three complaints received on the questionnaire about dissatisfaction with thermal comfort and two about a perceived lack of control over thermal conditions. Using questionnaire scores, of 4 and higher (out of 7) as indicating a respondent's satisfaction (or at least the absence of dissatisfaction), [redacted] are satisfied. This means that the comments received are not likely representative of conditions overall, but may point at specific areas that could be improved.

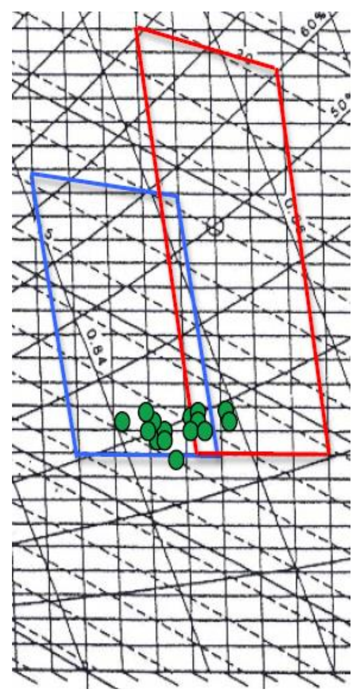

Figure 15: *Ron Joyce Centre thermal measurements (March 2014) mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zone; Red box indicates Summer Comfort Zone)*

Questionnaire scores for acoustics in general and non-speech disturbances were good (mean of 5.2 to 5.3 out of 7). This is in part because designers made an effort to locate noisy heat pumps away from teaching and work spaces.

Also, some sound proofing was included in partition walls in an effort to reduce disturbances. However, as is common in green office buildings, respondents indicated concerns with speech privacy which had the lowest score (a mean score of 3.9 out of 7), and was the greatest source of complaint-focused comments on the questionnaire. It must also be noted that the limited sample noise measurements taken in the building showed that 50% of spaces measured under the ANSI prescribed threshold. This is an area that needs further investigation to understand the concerns of certain users.

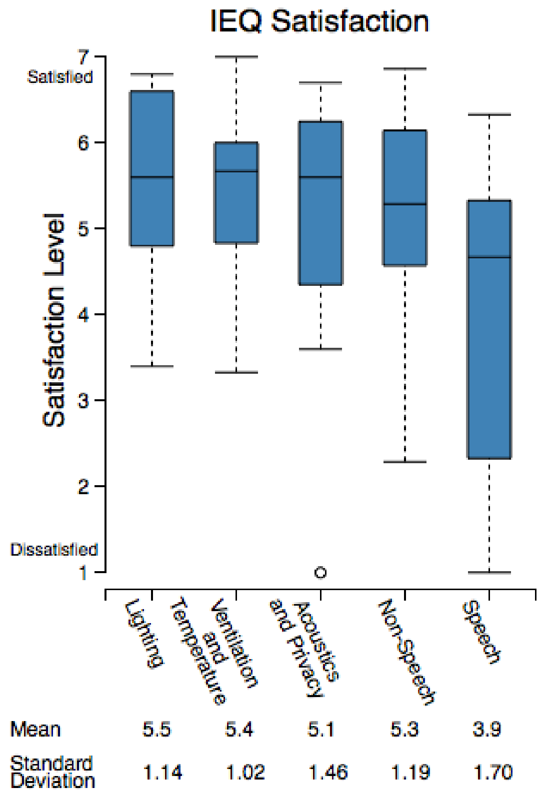

Figure 16: *Ron Joyce Centre occupant survey results (Boxplots displaying quartiles and median)*

Discussion

This building appears to be generally meeting expectations and is functioning as designed in most areas. Although an 8% performance gap can be observed in the energy use intensity compared to expected performance, it is below typical buildings of this type. This is despite the presence of a full catering kitchen and cafeteria, which is certainly a driver for additional energy use (though sub-metering was not available to confirm this). This is in part due to the design features outlined above, but is also the result of an effective management staff. This building illustrates the value of a well informed building manager who works in the building full-time and has demonstrated an interested in improving building performance. The building automation system (BAS) is used effectively to control and monitor spaces carefully, which certainly plays a role in the level of performance achieved.It should also be noted that it is not clear how the measured EUI will be affected when the building is fully occupied (i.e., when the fourth floor is completed).

This project also featured an integrated design process (IDP), which was described during interviews as effective because of early buy-in from the client and the familiarity of the various design team members with each other.

The site for this building was previously industrial land far away from the city centre and not easily accessible by public transit, or bicycle. Students and staff must be entirely reliant on cars or the shuttle service provided by the school, something which impacts the overall carbon footprint due to generation of additional road transport (though this was not measured directly).

Roblin Centre, Winnipeg, Manitoba
ASHRAE Climate Zone 7 - Continental, very cold (5,557 HDD, 310 CDD)

Building Summary

- Owner: Red River College
- Project type: Adaptive re-use/new construction
- Construction completed in 2004
- Analysis completed for 2012/2013
- Construction cost: $1,950/m^2$
- Net floor area: 19,210 m^2
- Facilities: Academic building, food outlets
- Mechanical: Five high efficiency gas-fired boilers and two air-cooled screw chillers with 180 fan coils terminal units; building management system (BMS) provide high level of local control.
- Ventilation: Four make-up air handling units; occupants do not have access to operable windows.
- Envelope: Historic parts of façade are uninsulated; green roof.
- Renewables: Building integrated photovoltaics
- Water: Low flow fixtures; twenty-seven point-of-use hot water tanks; stormwater management on roof.
- Materials: Parts of existing masonry facades and one building on-site were retained; materials recovered from deconstruction of remaining buildings on-site were extensively integrated in new construction or sold to other projects; rapidly renewable (strawboard) and "raw" materials (e.g., polished concrete floor, brick, exposed steel ceilings).
- IEQ: Open plan workplaces; daylighting; CO_2 and occupancy sensor controls in classrooms.

This project was one of the first green projects to be built in the region. Designed to fulfill the need for a new multi-media campus, the project consists of three structures connected by a central enclosed atrium. Construction was phased to allow occupancy of parts it within two years. Located downtown, the campus location has significantly increased the use of public transit by both staff and students compared to the institition's main suburban campus. High efficiency HVAC equipment along with an advanced multi-unit fan-coil system and CFL lighting were central to increasing energy efficiency. In addition, a 12.5 kW building integrated photovoltaic facade on the building's south elevation was added to generate additional on-site electricity.

Highlighted Key Performance Indicators – Energy and Water

Figure 17 shows a summary of the building's energy, water and occupancy KPIs. The building's operations were considerably impacted by a change in the building's operating hours, which increased by 43% due to the addition of nighttime classes that were not anticipated in the original building energy model. The number of occupants also increased with more students joining the night classes, adding 17% to the design occupant capacity of the building. As a result, the building's electricity and gas consumption were 41% higher in comparison to design model predictions. However, even with much higher occupancy than expected, and the heritage features of parts of the building, the EUI is approximately the same as typical academic buildings in this location. Although occupancy changes have resulted in an increase in the building's energy consumption, it can be argued that the building was used more effectively. Instead of adding a new building that would have consumed a lot more energy, adapting the existing building to meet new demand for classes may have actually resulted in energy savings for the whole campus.

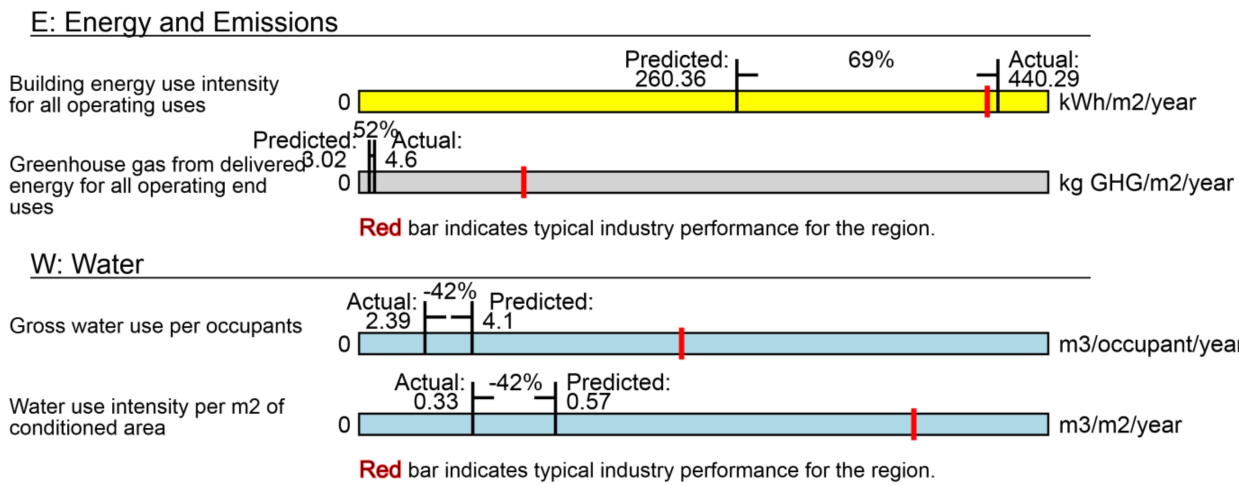

***Figure 17**: Roblin Centre key performance indicators for energy, water and occupancy – predicted vs. actual*

Surprisingly, water consumption was unaffected by the increased occupancy levels. Actual consumption was less than predicted and significantly less than a typical building of similar type. This may, in part, be due to the replacement of original residential grade fixtures with high efficiency, sensor controlled commercial grade toilets and faucets.

Indoor Environmental Quality

Survey results indicate that occupants are generally satisfied with their indoor environment (see Figure 19). One issue raised is with thermal comfort, where occupants say they feel too cold in the building during the summertime. This finding is supported by physical spot measurements of the indoor environment in the summertime that show measured thermal comfort indicators (e.g. temperature and relative humidity) fit mainly within the ASHRAE 55's comfort zone for wintertime (see Figure 18). A facility manager noted that humidification is not provided in the building in order to protect the uninsulated portions of the historic masonry facades from damage, particularly in winter, which may be a factor in the occupants' perception of thermal comfort. Occupants also expressed a desire for more control over windows, ventilation, and temperature. This result may also be related in part to an operational decision to seal all of the formerly operable windows following a serious frozen water line break and flood when a window was left open in the wintertime.

Of the IEQ parameters investigated (see Figure 19), occupants are most concerned with issues of acoustics and privacy, particularly speech sounds (non-speech sounds were not identified to be particularly problematic). The design's "raw" minimalist material use means that there are hard acoustically reflective surfaces. One of the designers noted that several classrooms had been retrofitted with special eco-absorbent panels to help mitigate this problem. Open office areas and partitions that do not continue to underside of structure allow for flanking sound from conversations in adjacent spaces. Like many green buildings, some of these strategies are intended to help increase daylighting and view, and collaboration between workers, but can also increase speech noise. In some locations in this facility there are several smaller, breakout or conference rooms for tasks requiring more concentration.

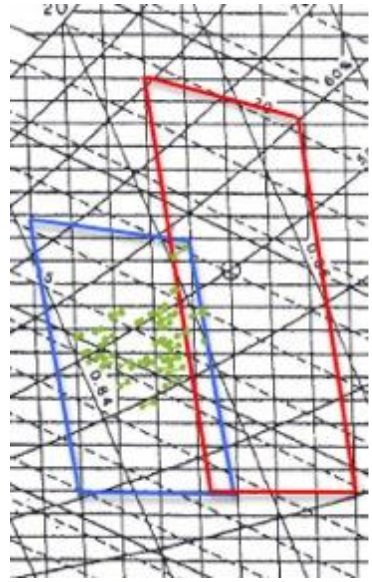

Figure 18: *Roblin Centre thermal measurements (July 2014) mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates winter comfort zone; Red box indicates Summer Comfort Zone)*

Discussion

This building highlights the role that occupancy can have on energy use, and how misleading it can be to look at single figure numbers such as energy use intensity independently of other factors. The increased occupancy and hours of building operation over what was anticipated in the original design phase are the most likely reasons for the greater energy use. The extended operating hours have delayed the building's automatic setback temperature until later in the night. The building manager also explained that the desire to reuse the existing building's materials where possible decreased the efficiency of parts of the building's envelope which in turn increased its energy demand. While the BIPV contributed only a small amount of the building's electricity needs, it produced the most electricity in the middle of the winter, when the low sun shines directly on the vertical panels. Despite apparent shortcomings, the building's energy consumption was still less than that of reference buildings of similar functions and size.

Water consumption was significantly lower than predicted, which is laudable for a semi-public downtown building of this size. One of the reasons highlighted by the building manger was that large-scale retrofitting was completed seven years after construction for all water fixtures. The new low-flow fixtures and sensor activated faucets possibly decreased overall water consumption to levels that were not possible at the time of the building's construction.

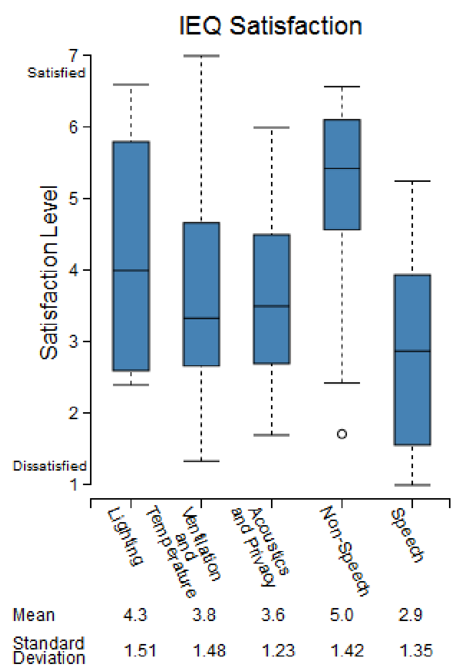

Figure 19: *Roblin Centre occupant survey results (Boxplots display quartiles and median)*

Overall, indoor environmental quality was perceived by occupants to be satisfactory. Survey and field measured results indicate the building was cooler than desirable in the summertime. The majority of respondents were unsatisfied with speech noise, which is a likely trade-off in order to achieve high level of material reuse and daylighting. Measured CO_2 levels were very good in classrooms and office areas, likely because of the use of CO_2 sensor controls for increasing ventilation when in use.

Jim Pattison Centre of Excellence in Sustainable Building Technologies & Renewable Energy Conservation, Penticton, British Columbia
ASHRAE Climate Zone 5A - Semi-arid climate with dry and hot summers, and moderately cool, mostly cloudy winters (3,341 HDD, 239 CDD)

Building Summary

- Owner: Okanagen College
- Project type: New construction
- Construction completed in 2009
- Net conditioned area: 6,780 m^2
- Construction cost: $4,150/$m^2$
- Facilities: Classrooms, laboratories, trade shops, common tool crib, meeting rooms, offices, gymnasium
- Green building rating: LEED[R] Platinum
- Modeling software: IES VE 6.1
- Analysis completed for 2012/2013
- Mechanical: Open-loop geoexchange system with heat pumps for heating and cooling, drawing groundwater from drilled wells (electrical pumps). Hot water is produced for in-slab heating. To balance the heat flow, the building uses solar thermal hot water heating as a supplement.
- Ventilation: Combination of a natural ventilation system (with operable windows, trickle vents, and solar chimneys) and mechanical ventilation systems (based on a dedicated outdoor air system with heat pumps and displacement diffusers).
- Renewables: Large PV array located on roof
- Water: Low flow fixtures; treated grey effluent water for irrigation and toilet flushing (summer), and well water for mechanical system (and toilet flushing in winter).
- Materials: Primary local pine-beetle-kill and FSC wood; composite concrete/ glulam wall panels for the gymnasium; high efficiency glazing; glare reduction through Brise Soleil; extensive green roof.
- Additional indoor systems: Occupancy and daylight sensors; temperature sensors for operable windows; sun-tracking light pipes; radiant hydronic heating; cooling active slab.

The Jim Pattison Centre of Excellence is an post-secondary facility that aims to be highly adapted to its site, climate, and context. It provides space for courses on sustainable building technologies and processes, as well as research on alternative and renewable sources of energy. As such, the innovative design features of the building itself are intended to be used as a teaching tool.The two-story building features a cafeteria, classrooms, laboratories, trade shops and a gymnasium on the first floor, and open plan and private offices, meeting rooms, computer labs, study spaces, and classrooms on the second floor.

Highlighted Key Performance Indicators – Energy and Water

As seen in Figure 20, the actual energy use intensity (EUI) of the building is 76 kWh/m^2 per year, which is 74% below that of a typical academic building in this location, and 22% lower than was predicted by energy modeling at design stage for this building. The lower consumption is partly due to the fact that the building consumed less electricity during winter and spring than predicted, possibly because occupancy patterns differed from what was expected. In the summer, the building required less energy than was produced by the PV panels, even though the electricity generated by the PV array was 20% below the predictions. Thus, almost half of the yearly-generated electricity could be exported to adjacent buildings. A breakdown of the energy consumption from May to July 2014[13] revealed that the building consumed less electricity for lighting and plug-loads that make up over 65% of the total EUI.

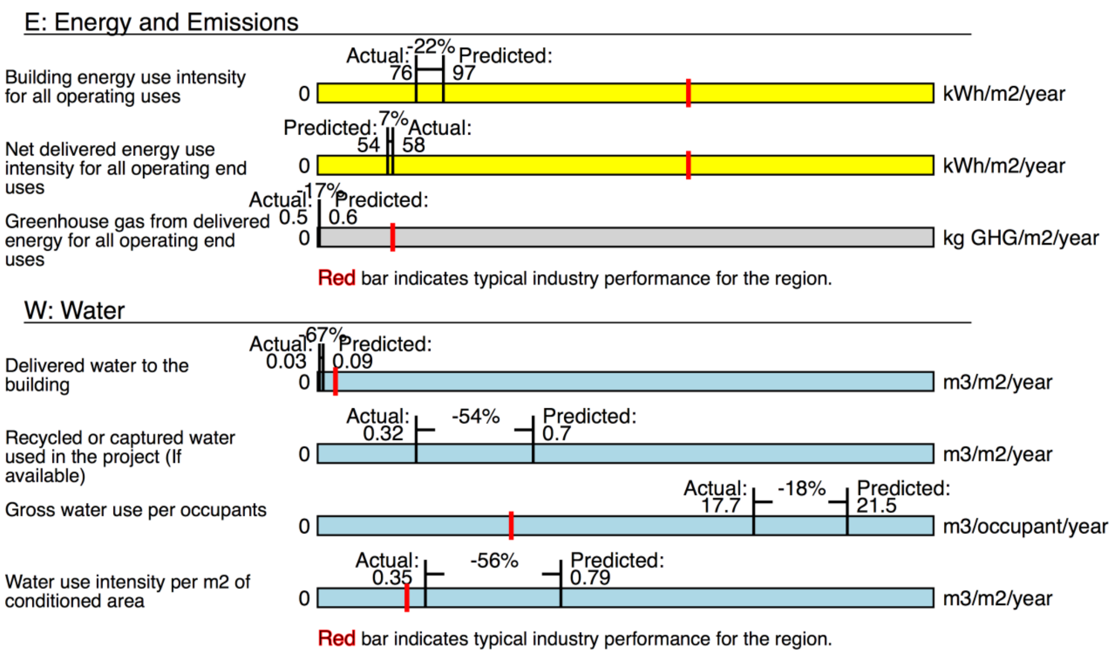

Figure 20: *Jim Pattison Centre key performance indicators for energy and water - predicted vs. actual*

The delivered to the building is only 0.03 m^3/m^2/year (Figure 20), since the building only requires potable water for sinks, showers, and kitchen uses. Water for toilet flushing, the mechanical system, and irrigation comes from well ground water and treated effluent water provided by the City's wastewater treatment plant. The actual potable water use intensity per occupant was 67% lower than predicted which can be partially explained by lower occupancy of the building in practice compared to the predicted values. However, there is uncertainty related to the occupancy number since the building was nearly unoccupied during the measurement period in the summer months. The water use intensity includes water for occupant usage and irrigation, not the amount of mechanical process water since the building was not equipped with sub-meters for the water system. The actual water use intensity, excluding the process water, was higher than for a typical building in the region, because the predicted and actual values for irrigation water was relatively high compared to other water uses in the building.

[13] The electricity consumption of the sub-systems (i.e. lighting, HVAC, DHW, plugloads) has only been logged since May 2014 even though the meters were installed during the construction of the building.

Indoor Environmental Quality and Occupant Survey

The successful performance of this building was reflected in satisfaction ratings by occupants; 85% of survey respondents were satisfied with the building as a whole (M = 5.86, SD = 1.46), as well as most of its indoor attributes, as shown in Figure 21. Furthermore, all measured aspects of indoor environmental quality were found to be acceptable, although these data were limited by atypical weather and low levels of occupancy in the building on the measurement day. CO_2 levels in the work spaces met ASHRAE 62.1 guidelines (403-543 ppm). Although this may reflect low levels of occupancy on the testing day than design values, air quality was still rated very positively by respondents several weeks later.

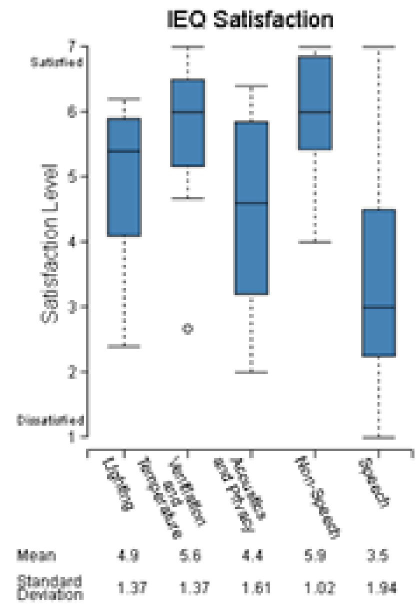

Figure 21: Jim Pattison Centre occupant survey results (Boxplots display quartiles and median)

Ultrafine particulate (UFP) levels ranged from 721-1285 pt/cm^3, in most areas, except the kitchen (from cooking) and the trade shop (from an open door), where levels were up to 3216 pt/cm^3 and 3519 pt/cm^3, respectively. Temperatures in most of the open plan offices, private offices and shared offices were within the comfort zone (see Figure 22). A few morning measurements were cooler than summer comfort levels; this likely reflects the cooler-than-average weather conditions on the measurement day. Survey results suggest occupants are generally satisfied with temperature, but those who were dissatisfied found the space to be slightly too warm. Compared to the other aspects of the indoor environment, occupants showed lower levels of satisfaction with acoustics and privacy, and were especially dissatisfied with speech noise. Sound levels in all areas exceeded applicable standards, despite the low levels of occupancy on the measurement day. Most respondents (71%) rated lighting favourably. Despite this, the minimum and maximum lighting levels on desk surfaces ranged considerably, from 136 to 2130 lux. Respondents who were dissatisfied commented on inadequate lighting on overcast days and excessive glare in the summer months. Finally, respondents indicated having little control over lighting, ventilation, noise and temperature, and 60% indicated a desire for more control.

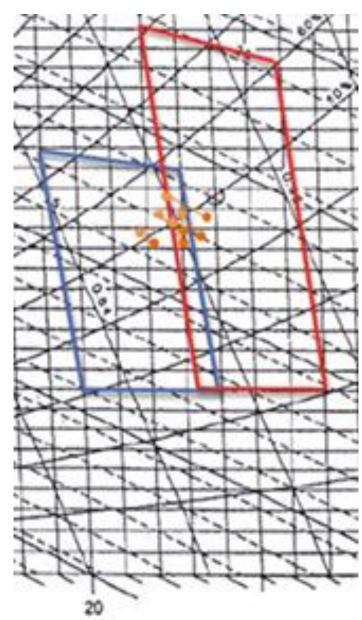

***Figure 22:** Jim Pattison Centre thermal measurements (June 2014) mapped onto ASHRAE 55 Thermal Comfort Zones. (Blue box indicates Winter Comfort Zone; Red box*

Discussion

This building outperforms its predicted design in most areas, and performs generally much better than a typical building of this type. It consumes 22% less energy than predicted, but whether this is due to an outstanding performance or inaccurate predictions remains unclear. The building also outperformed the predictions for water consumption, but the mechanical process load was not included in the calculations due to a lack of sub-meters. The high performance of the building might relate to uncertainties in the occupancy number, which varies throughout the year. Interview results with the facility manager revealed that there are still opportunities for improvement in the building's performance. For example, the pump water flows could be significantly reduced on weekends and holidays. Further, there is an extensive exterior lighting system that could not be accounted for in the energy calculations since it was not part of the zoning of the building.The indoor environmental quality contributed to the success of this building. The gaps that persisted include noise levels, dissatisfaction with speech noise, and lighting levels above. The low occupancy levels and atypical weather on the day of IEQ measurements limit the generalizability of the data.

Centre for Interactive Research on Sustainability (CIRS), Vancouver, BC
ASHRAE Climate Zone 5A - Moderate oceanic climate with dry summer months and rainy, humid, and cool winters (2,817 HDD, 56 CDD)

Building Summary

- Owner: University of British Columbia
- Project type: New construction
- Construction completed in 2011.
- Approximate size: 5,500 m^2
- Construction cost: $6,888/$m^2$
- Facilities: Meeting rooms, private and open plan offices, auditorium, theatre room and cafeteria.
- Green building rating: LEED^R Platinum
- Modeling Software: eQUEST v3.61
- Analysis completed for 3/2012 to 2/2014
- Mechanical: Ground-coupled heat pumps with extensive heat recovery from air-handling units and washroom exhaust and exhaust fume hoods of an adjacent building. All recovered heat is collected in main heat recovery header connected to the source side of two water-to-water heat pumps. Heat pumps provide heating (and cooling for some places of the building) through radiant slabs and displacement ventilation. In addition, heat recovery system preheats 30% of the domestic hot water.
- Ventilation: Mixed-mode system with two air-handling units, a mixing damper, supply fans, operable windows and CO_2 sensors.
- Water: Low flow fixtures; rainwater harvesting system; on-site water treatment system; and storm-water runoff system.
- Materials: Wooden structure; combination of pre-fabricated glulam members, dimensional lumber, plywood, local non-FSC certified wood; low-e glazing; living green wall and roof; increased roof and wall insulation.
- Additional indoor systems: Occupancy and day-lighting sensors; CO_2 sensors, radiant floor heating; operable windows.

The Centre of Interactive Research on Sustainability (CIRS) strived to achieve *regenerativity* at all levels ranging from energy and water use to inhabitant comfort, and social sustainability. It also serves as "living lab" wherein human behaviour, landscape planning, building science, and other key facets of sustainability are researched and tested within the context of the building. This four-storey building is a multidisciplinary education and research facility. University students, faculty and support staff are the primary occupants of the building, while different social events, conferences and seminars take place in the auditorium, amphitheatre and atrium.

Highlighted Key Performance Indicators – Energy and Water

The building was originally designed to use a waste-heat transfer system with a neighbouring building. The system was intended to reduce or eliminate the thermal heat requirements for the building itself and the natural gas consumption of the adjacent building. As seen in Figure 23, the building uses 29% more energy than predicted. This performance gap is mainly due to the fact that the building consumed far more electricity for lighting (61%) and plug-loads (85%) even though the building occupancy was officially only slightly higher than predicted (10%). The high use of plugloads in the building resulted in additional electricity losses in power transformers and the uninterruptable power supply (UPS) system. Furthermore, the waste-heat system of the adjacent building did not function as expected. The actual heat that was harvested and sent back to the adjacent building was far below the predicted values (-70% or -86%). Since the heat transfer system was operating only in part-load, the ground source heat pumps required substantially more energy than predicted. Nevertheless the building performs 50% better than a typical academic building.

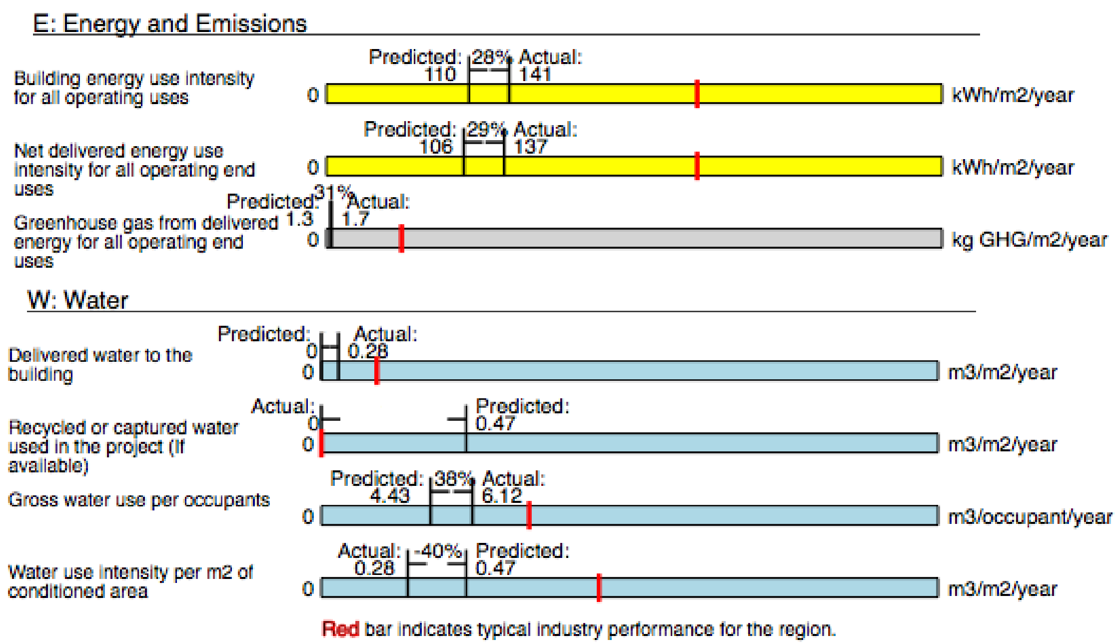

Figure 23: *CIRS key Performance Indicators for energy and water - predicted vs. actual*

The building was designed to be net positive in water performance, by relying entirely on rainwater for all water uses in the building through an on-site wastewater treatment system. Although the water use intensity per square meter was 40% lower than predicted, the gross water use per occupant was 38% higher than predicted since the occupancy values were lower than the design intent (Figure 23). Furthermore, rainwater and wastewater systems of the building have not been used on a sustained basis. Since shortly after its opening, the building has been using potable water instead (Figure 23). There have been a number of challenges in implementing the wastewater system, from the design through to construction and operation stage, since the development process followed a design-build approach or “turn-key” delivery (instead of more conventional design process for rainwater treatment systems). For example, due to a lack of experience, the turn-key process resulted in communication challenges between the technology provider and the mechanical engineers.

Indoor Environmental Quality

Survey responses indicated that 88% of respondents were generally satisfied with the environmental quality of their building, and they were particularly pleased with its aesthetics. However, assessments of the different indoor features varied somewhat (Figure 24). Lighting received high satisfaction ratings, ($M = 5.67$, $SD = 0.95$), and was praised by 33% of those with positive comments. Despite this, however, physical spot measurements of desk lighting varied well above and below the reference standards of 300-750 lux. Of those individuals who were not satisfied, some commented on excessive darkness from partitions and blinds, and being situated away from the window. In addition, some occupants were displeased with the automated lighting in their workplaces.

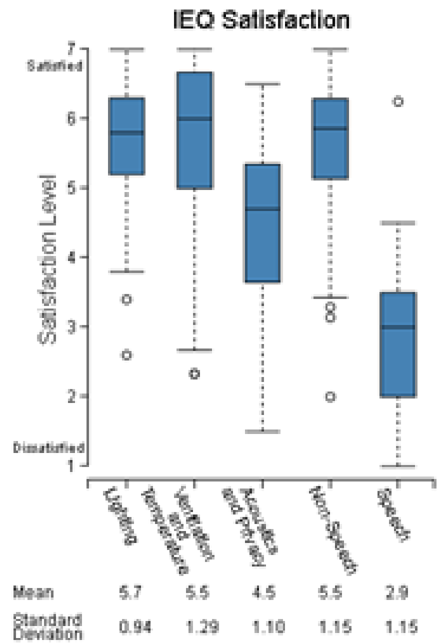

Figure 24: *CIRS occupant survey results (Boxplots display quartiles and median)*

Acoustic measurements revealed that average sound levels differed little among private offices, shared offices, and open-plan office spaces, presumably because the sound is transmitted between private offices and other areas through natural ventilation openings between the tops of the walls and the ceiling. Noise levels generally exceeded standard guidelines. In the comment section, occupants were mostly dissatisfied with acoustics, more with speech noise and lack of speech privacy than with noise from mechanical systems or other sources.

Physical measures of air quality were acceptable; CO_2 levels and indoor particulate matter (PM 2.5) did not exceed the reference guidelines, although it should be noted that the actual occupancy on the measurement day was lower than predicted. Occupants were generally satisfied with temperature and ventilation, but responses varied throughout the building. Winter months were perceived to be slightly cooler than desired, and summer months were perceived to be warmer. Figure 25 shows afternoon dry bulb temperature and relative humidity spot readings were within the summer range of acceptability. Morning measurements were cooler, but not beyond that which could be addressed by clothing adjustments.

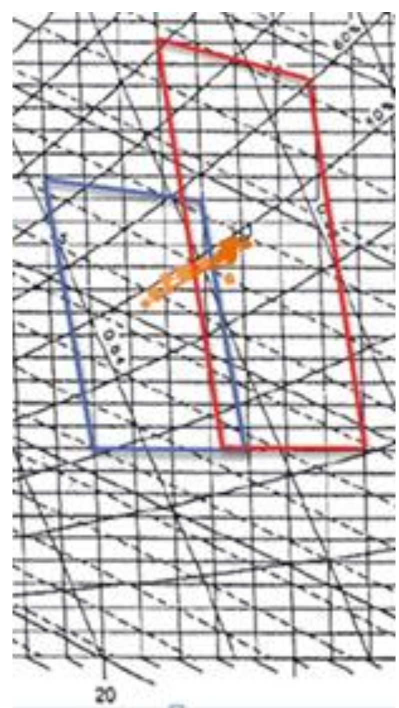

Figure 25: *CIRS thermal measurements (May 2014), mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates Winter Comfort Zone; Red box indicates Summer Comfort Zone)*

Discussion

The building had difficulties achieving its net positive concept for energy and water since the waste-heat transfer system and the wastewater treatment systems did not function as intended in the design. The energy performance gap is mainly due to higher electricity consumption for lighting and plug-loads. This leads to higher process loads of transformers and UPS and thus to additional efficiency losses in the building system. The performance issues related to the waste-heat system and the wastewater systems were only discovered after the building started operating. There might have been opportunities to prevent the performance gap earlier during the lifecycle of the project. For example, better communication or more thorough site visits would have helped to discover system compatibility issues at the design stage. A recurring lesson learned from this and previous research is that considering all modes of operation and potential flows of the heat transfer system is necessary.

Occupants' assessment of this building was largely positive, but some of the complaints indicate that a lack of control still remains as an occupant-relevant performance gap. One designer noted that mechanical blinds (which are both automatic and occupant-controlled) would have partly helped to address lighting and thermal comfort issues; however, they were value-engineered out. Another salient gap was in noise levels, occupants' concerns of speech sounds in open-plan areas, and a lack of speech privacy, stemming from natural ventilation openings in private offices.

Alice Turner Branch Library
ASHRAE Climate Zone 7 - Very cold, continental (5742 HDD, 125 CDD)

Building Summary

- Owner: City of Saskatoon
- Project type: New construction addition
- Year of original construction:1998s. Year of addition: 2012
- Analysis completed for 2012/2013
- Net conditioned area: 2,070 m^2
- Construction cost: $3,200/$m^2$
- Facilities: Library, public meeting rooms, offices
- Mechanical: Natural gas boilers and chiller supporting radiant floor heating in combination with overhead distribution 4-pipe FCU secondary system; ventilation is provided by a multi-speed central supply and exhaust system along with an ERV.

Water: Low flow fixtures

- Envelope: Wood frame construction for reduced thermal bridging and embodied energy; nominal 3.5 RSI walls and 5.3 RSI roof; spectrally selective double-pane argon-filled clear low-e glazing fenestration with high performance thermally-broken frames.
- Lighting: Optimized daylighting with a predominance of north and south fenestration; automated lighting controls including daylight sensor controlled blinds; operable windows throughout workspaces.

This library was first constructed in the 1990s. Upon completion it was widely heralded as a success achieving 65% lower energy and 48% lower energy cost compared to Canada's *1997 Model National Energy Code for Buildings* while achieving similar construction costs per m^2 to typical commercial buildings. These values were confirmed through a post-occupancy evaluation (POE) after the building's original completion. In 2012, an addition designed to the same performance standards as the original building increased the floor area by 15% and was incorporated into the existing HVAC system. This current evaluation considers the performance of the building since 2012.

Highlighted Key Performance Indicators – Energy and Water

At the time Alice Turner Library was first built, green building standards were not in common usage and did not consider many of the aspects of building performance that we are now interested in. As such for water use we do not have a predicted value for which to compare current water use figures. Nevertheless water use seems to be extremely low. This may be due to the transient nature of most of the users.

For energy, the library performed close to predictions when originally constructed in 1998, and progressively energy use increased to the extent that Figure 26 shows there is a 58% performance gap between predicted and actual energy use for 2012/13. The current performance issues appear to be associated with the new addition, aeging mechanical equipment and operational difficulties encountered with the mechanical systems. The exact nature of these issues will be further explored in the discussion section. Nevertheless, the EUI is still 19% better than a typical community building at this location.

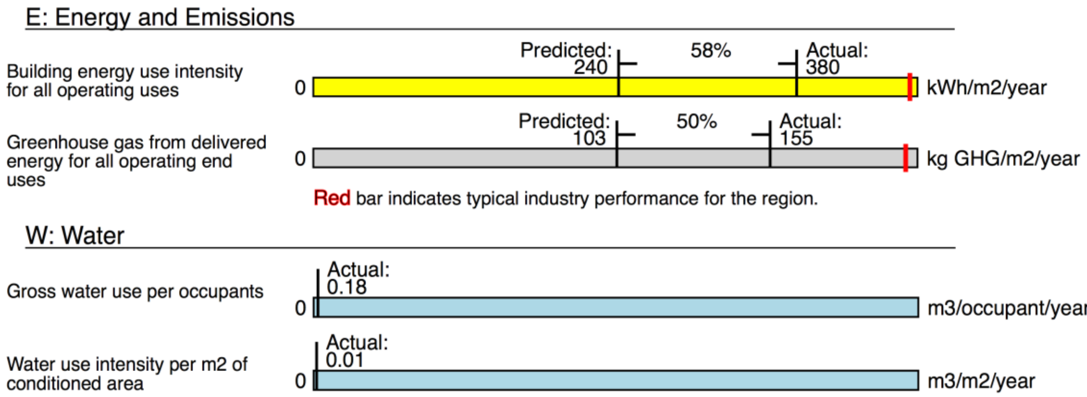

Figure 26: *Alice Turner Library key performance indicators for energy and water - predicted vs. actual*

It should also be noted that the EUI used for the predicted value comes from the initial energy modeling for the building. No new modeling was conducted for the building incorporating the addition. This number was deemed as a best guess for predicted EUI as the addition was constructed to similar performance standards as the original building.

Indoor Environmental Quality

The occupant survey, distributed to staff working in the building, indicated general satisfaction with the workplace with some notable exceptions. Most significant were concerns expressed about thermal comfort. Figure 28 indicates that ventilation and temperature achieved a mean score of 4.5 out of 7, suggesting some dissatisfaction. Comments indicated that the workstations were too cold throughout the entire year, some indicating that this problem had lasted for the entire time they had worked at the library. Mapping the spot temperatures measurements taken in the building during May onto the thermal comfort zones set out by ASHRAE 55 (see Figure 27) indicates that temperatures within the workspaces tend towards the lower end of an acceptable range for summer conditions. Other concerns from occupants included insufficient control over lighting, and indoor air quality (IAQ) issues, although lighting satisfaction was

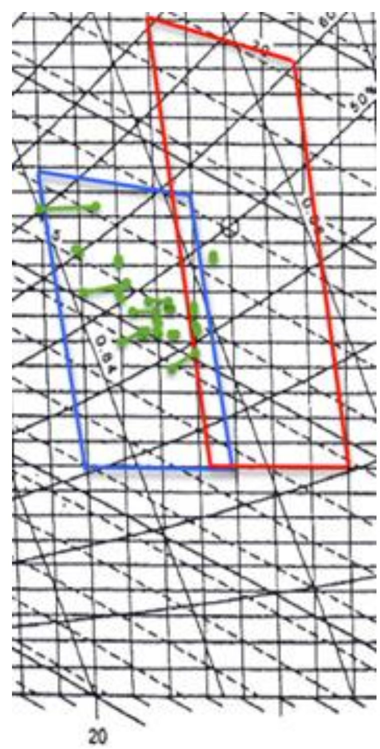

Figure 27: *Alice Turner Library thermal measurements (May 2014) mapped onto ASHRAE 55 Thermal Comfort Zones (Blue box indicates winter comfort zone; Red box indicates Summer Comfort Zone)*

generally high (mean of 5.6 out of 7). The comments about lighting generally centered around specific technology (e.g., light switches that are too complicated; automatic blinds that don't work; blinds on large windows that aren't selective enough; blinds that are too shear and not effective against glare although a number are also in response to the few east or west facing windows that receive low angle sun).

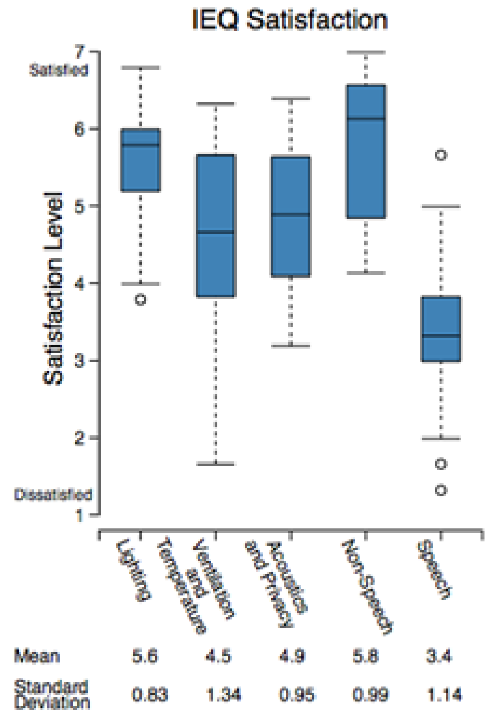

Figure 28: *Alice Turner Library occupant survey results (Boxplots display quartiles and median)*

Discussion

This building demonstrates some issues related to both energy use and thermal comfort. There is sufficient evidence to suggest that the underperformance of the building is related to the age of the building compounded by a lack of operational information and resources. As equipment comes to its normal end-of-life the complexity in building systems can exacerbate operational challenges, particularly in smaller projects where the resources to operate them effectively may not be available. For example, several valves controlling the radiant floor heating failed open disabling the BAS ability to control the heat delivered to the space. This resulted in both overheating and the chillers being run year round, which besides contributing to increased energy use, also caused cold drafts for individuals located near the FCUs. This problem has since been fixed after the difficult process of diagnosing which valves had failed. In one of the designer interviews, the radiant floor heating was identified as principally an amenity for the library and not central to the energy efficiency strategy. In cases like these it should be evaluated if the added complexity is worth added amenity.

Construction issues have also been a problem in the building. The building manager indicated that some IAQ issues are linked to inappropriately installed flashing that has led to severe mold problems in one wall of the building. This entire wall is set to be replaced. As well changes in the intended layout of the building (certain internal partition walls were excluded to increase the size of the open plan office). As such the conditioning zones do not match the rooms within the building; this has led to difficulty controlling thermal comfort. In addition The BAS systems has been not been satisfactorily commissioned in order to address these issues. This building highlights that informational and operational resources for building managers, as well as continuity of institutional operational knowledge, are key to ensuring persistent building performance.