Hood River Middle School Music & Science Building Post Occupancy Evaluation

prepared for:
Energy Trust of Oregon
& Hood River County School District

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May 31, 2013

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Introduction

The Hood River Middle School Music & Science Building was opened in the fall of 2010 on the campus of Hood River Middle School. The building was constructed by Hood River County School District using funding from the May, 2008 Construction Bond. The building also used incentive funding from Energy Trust of Oregon as part of the 'Path to Net Zero' pilot program.

The building houses a music classroom, music practice rooms, a new science lab with an attached greenhouse and associated offices and support space. It includes 5,331 of conditioned space and a total of 6,887 of new construction. See Appendix C for a list of building statistics and features.

This Post Occupancy Evaluation was conducted for Energy Trust of Oregon using an occupant survey conducted by Opsis Architecture, analysis of metered energy and water use and recalibration of the design energy model by Interface Engineering, and faculty and facilities staff interviews conducted by both Opsis Architecture and Interface Engineering.

Students sit in the amphitheater outside the greenhouse.

Occupant Feedback

Summary

The occupant feedback included in this section was collected by Opsis Architecture using a post occupancy evaluation survey of students and faculty/staff and interviews with faculty, administrators and facilities staff.

The survey was created in SurveyMonkey and distributed in June, 2012. It was filled out online by faculty and staff, while students filled out the survey out by hand on hard copies distributed by teachers in the classroom. There were a total of 36 respondents, 30 of whom were students. One initial concern about the data was that middle school students might not take the survey seriously, but in general the survey was filled out as completely and thoughtfully as we have seen in similar surveys taken by adults, with a far greater percentage of respondents providing comments in the optional comment boxes. Another concern with the survey outcome is the relatively small sample size of data that we were able to collect, and the results should be interpreted accordingly. Full survey results are included in Appendix A.

The authors conducted two interviews in November, 2012. One interview included school principal Brent Emmons, science teacher Michael Becker, and music teacher Rebecca Nederhiser. Both teachers work full time in the Music and Science building. The second interview included Hood River County School District Facilities Director Randall Johnston and Hood River Middle School head custodian Gary Schilling. Brent Emmons and Randall Johnston were intimately involved in the design and construction process, and all of the interviewees represent the people who are most familiar with the building and its operation.

The music classroom.

Thermal Comfort

Overall, thermal comfort in the building was perceived as good, with 87% percent of building occupants reporting being satisfied with the building temperatures (See figure 1). On occasions when temperatures were not optimal, more survey respondents reported being too warm, but there were respondents who felt the building was sometimes too cold (See figure 2). Survey comments on the subject included a desire for 'a way to cool down the building', and 'It gets too hot.' Staff also reported in the interviews that the building was often too warm, particularly in the spring and fall when outside temperature swings occur quickly, making it difficult for the building's thermal mass to keep up. This anecdotal evidence reinforces what was found in the energy model calibration process outlined in the following section, where reducing the thermostat set points is recommended.

Figure 1

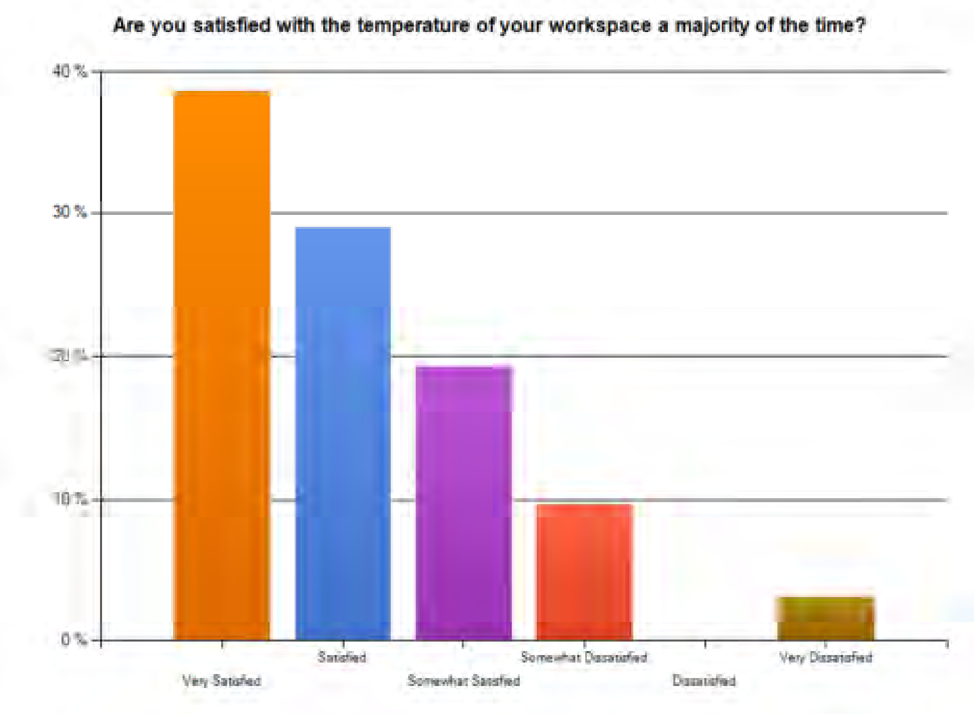
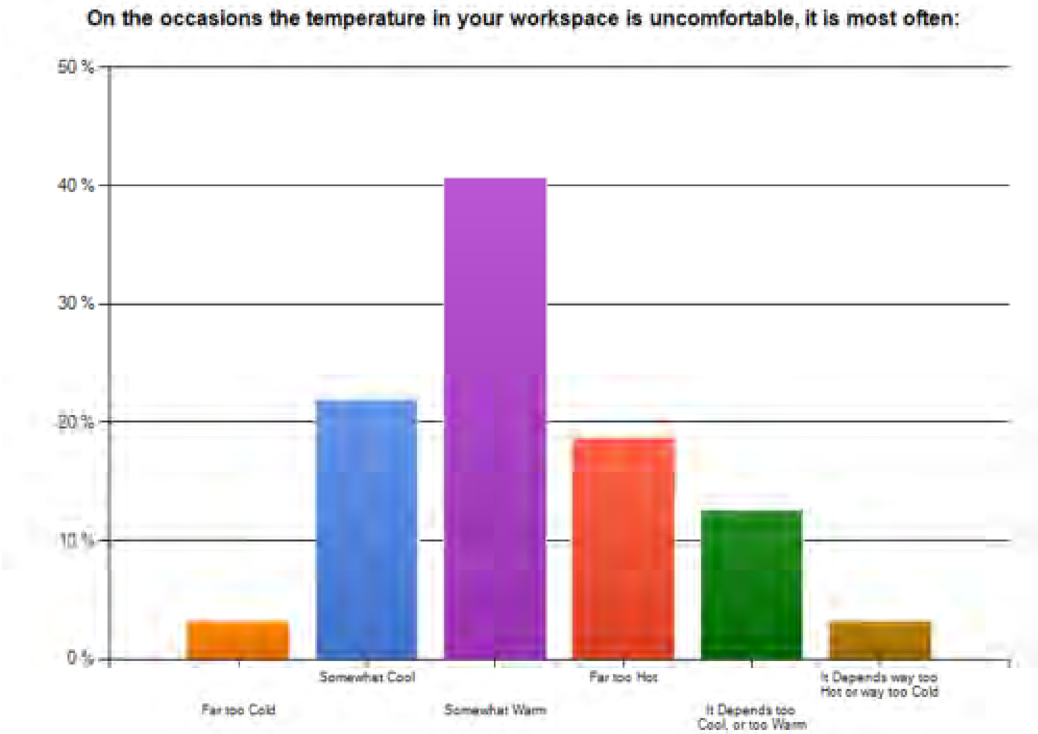


Figure 2

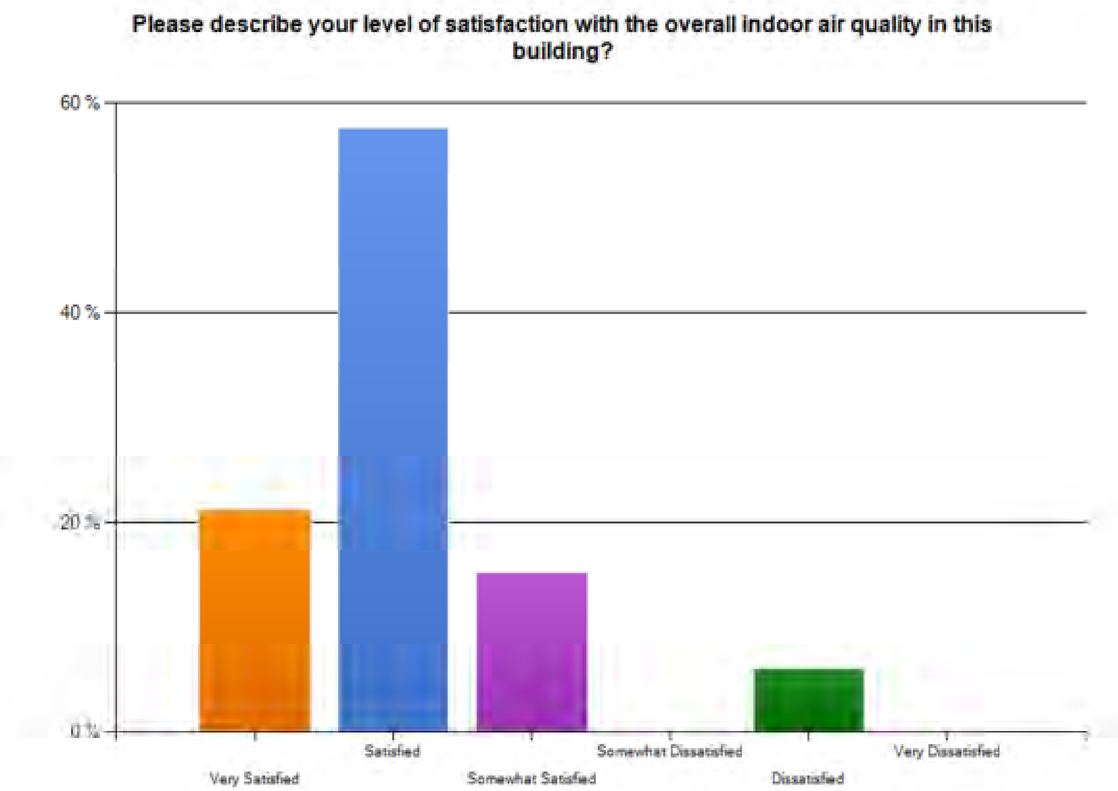


Mechanical system pumps and pipes fill the mezzanine space and can be seen through a window from the science classroom below.

Air Quality

94% percent of survey respondents reported being satisfied with the indoor air quality of the building (See figure 3). The lead custodian suggested better air circulation in the restrooms would be beneficial, where he says the waterless urinal in the boys bathroom gave of odors even after a filter replacement; however faculty thought that the waterless urinal was working well. No other air quality issues were mentioned.

Figure 3



Lighting and Views

Careful attention was paid to the building's daylighting and artificial lighting system design. Daylight modeling was done on several skylight and clearstory window configurations, and the same options were run on the energy model so that the needs of daylighting, energy, and solar access for photovoltaic panels could all be taken into consideration. A greater emphasis was placed on ensuring balanced lighting than on lighting level to avoid high levels of contrast that might prompt building occupants to use artificial lighting even when it was bright outside. 97% of respondents were satisfied with the views from the building, 93% were satisfied with the daylighting (See figure 4), 100% were satisfied with the artificial lighting (See figure 5), and 90% were satisfied with the glare control (See figure 6). Both teachers confirmed that the artificial lights were rarely used in the classrooms during daylight hours. The music teacher had the following comment about glare: "We need a way during fall/winter to have blinds or curtains to block the sun from shining into student eyes." Presumably this is an issue with direct light through the south windows that is not blocked by the trellis during the fall and winter. This sunlight is welcome for winter heat gain from an energy perspective, but would shine into student eyes during the afternoon hours. The design team did propose the addition of roller shades on south facing windows, but the District opted to postpone the decision to purchase these until they confirmed if they were needed. We would suggest that it would be a good idea to revisit this discussion at this time.

Figure 4

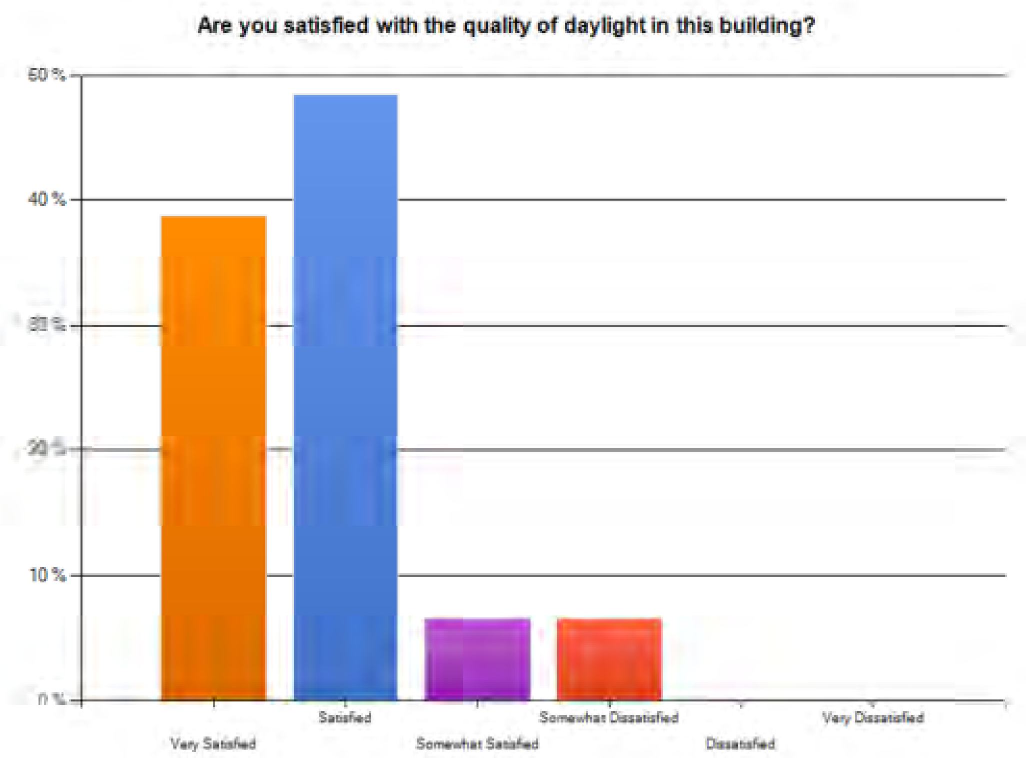


Figure 5

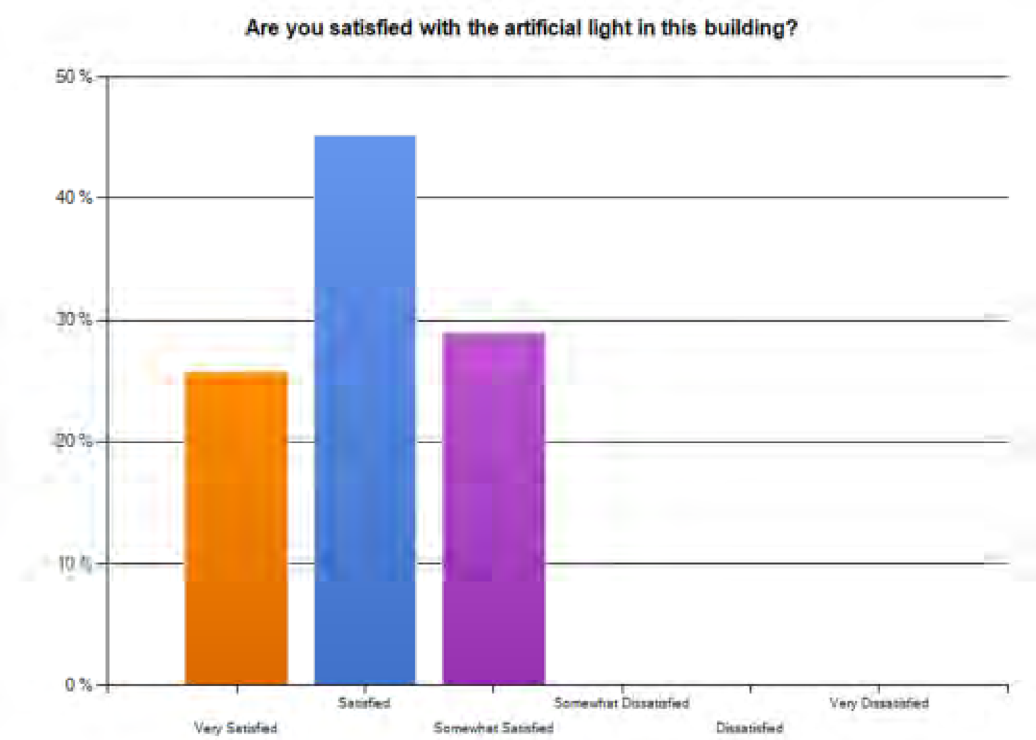
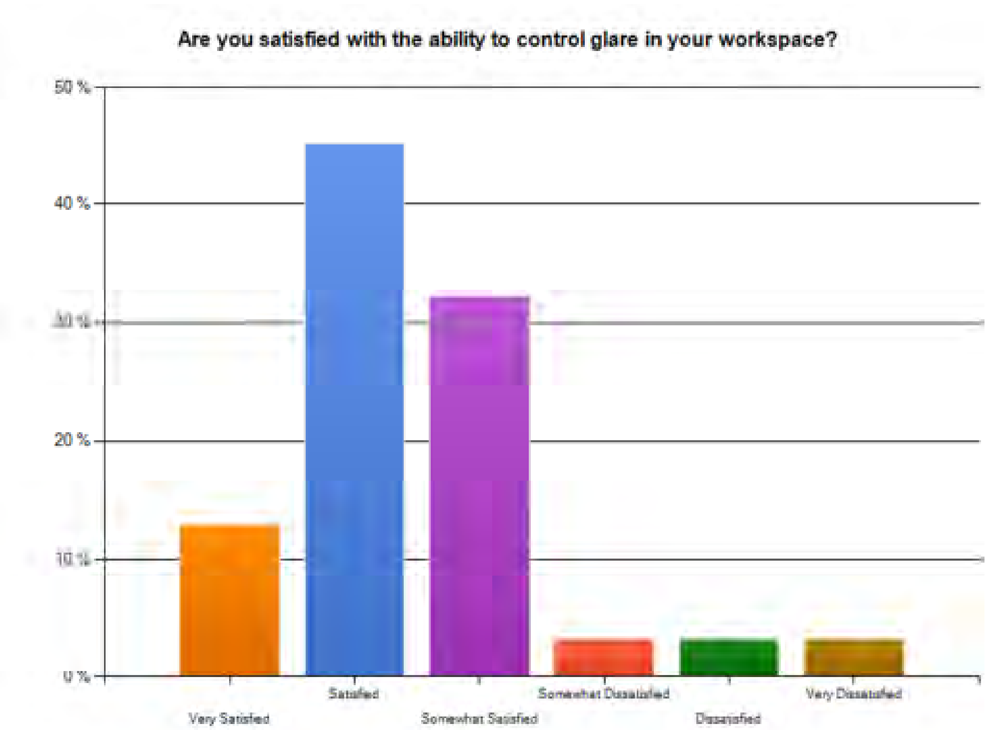


Figure 6



Acoustics

The program combination of a music room, practice rooms and science classroom presented some tricky acoustical separation issues in the building. Also, the desire to use radiant slab heating and minimize non-essential finish materials led the design team to expose highly sound-reflective floor and roof materials. Sound absorbing panels were used in both the science and music classrooms to improve voice recognition, these panels doubled as light reflectors in some locations do improve the diffusion of daylighting. Sound diffuser panels were used in the music room to scatter sound reflections and improve the quality of sound for music. Insulated concrete formwork (ICF) walls and insulated frame walls with extra gypsum board hung on resilient clips help to isolate spaces acoustically from one another. According to teacher interviews, the music room acoustics are 'outstanding', and there are no complaints about inability to hear spoken words in either room (See figure 7). It is reportedly sometimes possible to hear sound transfer from the music and practice rooms and from the equipment in the mechanical room in the science classroom, but it is not to a level where it is distracting. 100% satisfaction was reported for both ability to hear spoken communication and overall sound in the music room (See figures 7 and 8).

Figure 7

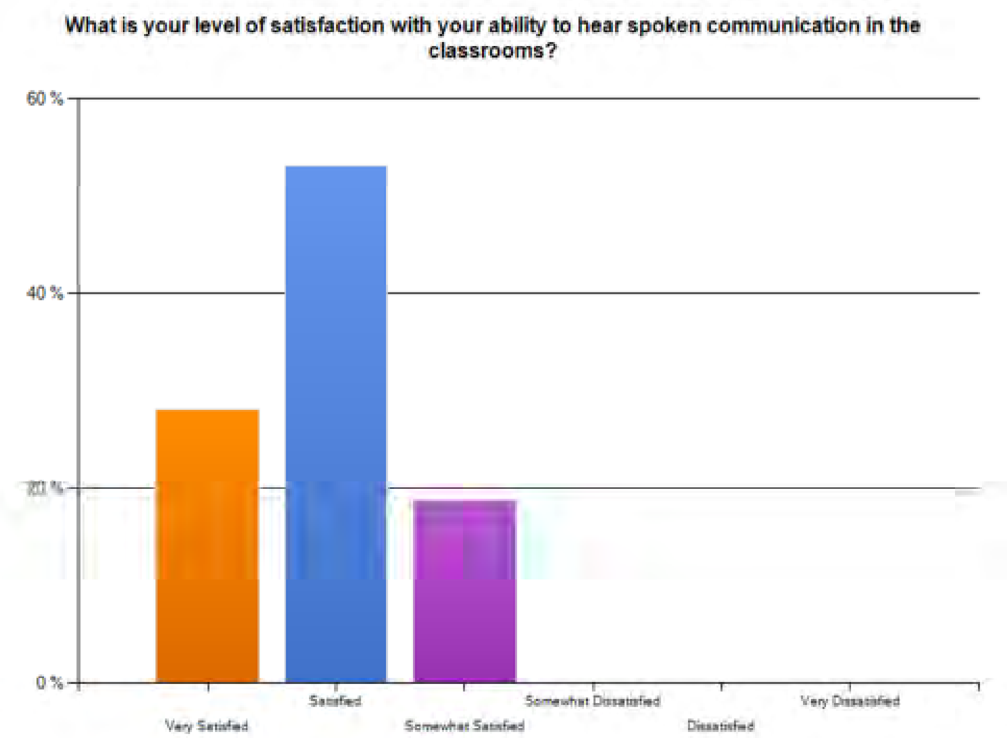
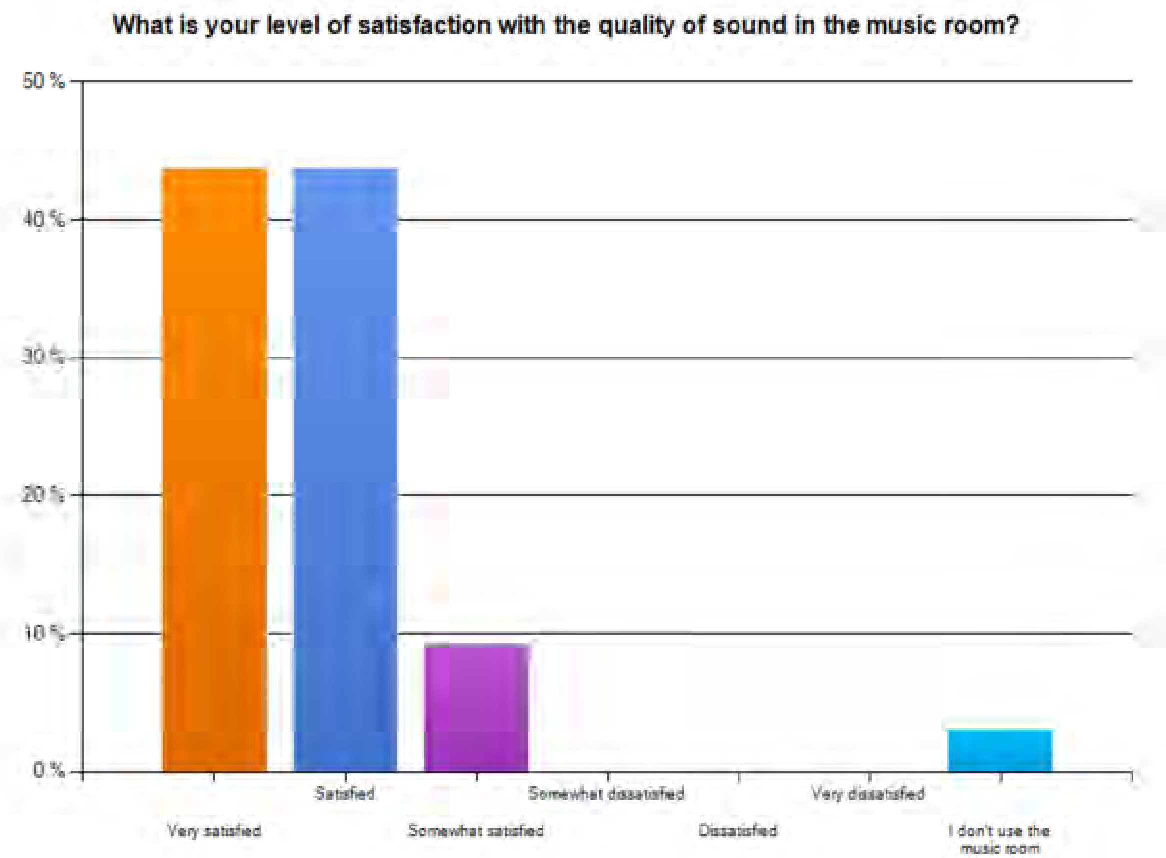


Figure 8




Diffuser panels in the music classroom.

Health and Wellness

It is notoriously hard to come by rigorous scientific studies of the potential for elements such as daylighting and ventilation to improve the overall health, attendance, and performance of building occupants. The Center for Green Schools 2012 White Paper, "The Impact of School Buildings on Health and Performance" is a good starting point for understanding the evidence that exists and what types of studies need to be done. The questions below (see figures 9 and 10) add to the anecdotal body of evidence that suggest that where we learn matters.

Figure 9

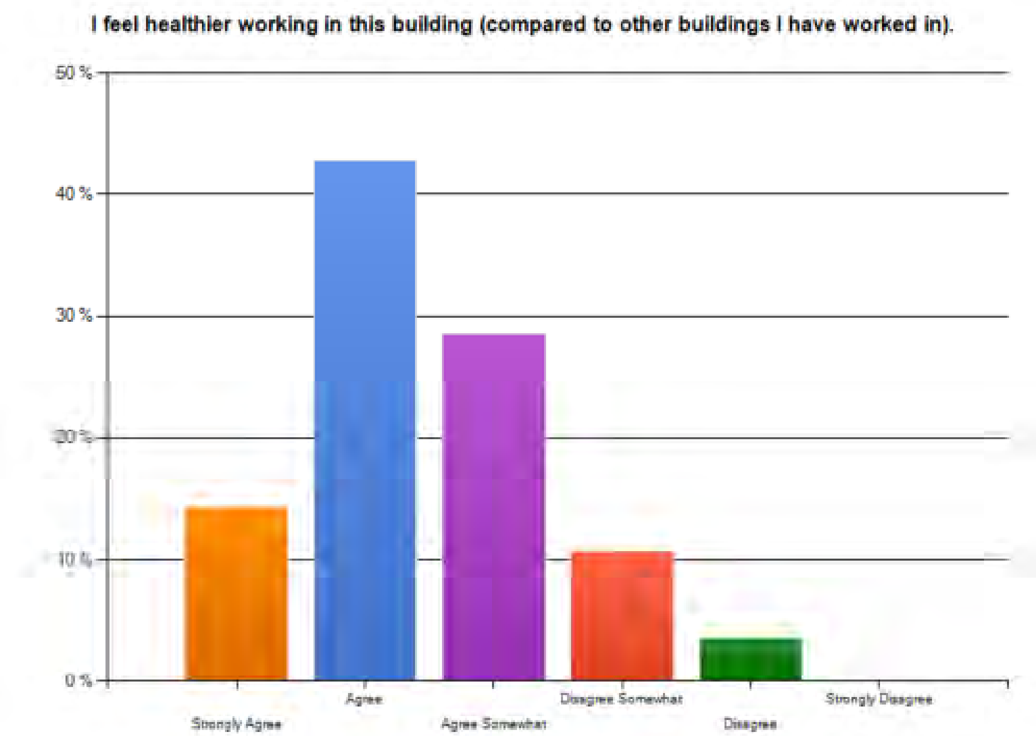
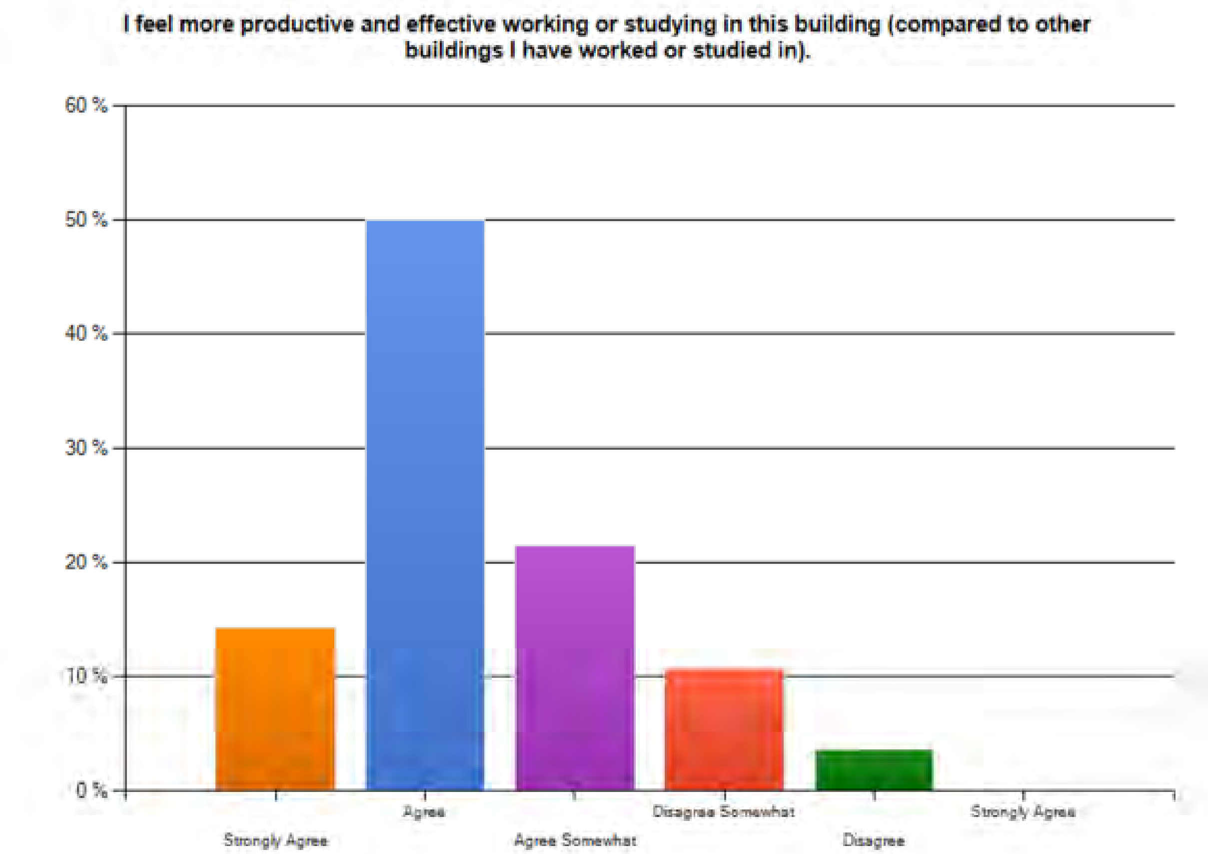


Figure 10



Students in the science classroom.

Materials

The interviews with facilities staff and teachers included a review of most of the building's materials. Some comments are as follows:

- Ceramic floor tile was apparently walked on prior to being sealed, and now it looks dirty and difficult to clean. Randall Johnston suggested steam cleaning.
- A small concrete portion of pathway was added to accommodate a 'desire line' to the building's south entry.
- Some linoleum weld joints have been replaced. The outside corners of linoleum trim at music room risers show wear and are peeling.
- Maintenance staff suggest a glossier paint should have been used in the hallways for ease of cleaning.
- Most finishes such as entrance floor mats, ceramic wall tile, acoustical ceilings, FRP, acoustical panels, displays surfaces, etc. have been satisfactory.
- The interior casework is holding up well, but the cabinet inside the greenhouse is often wet and is not holding up well.
- The latches for the musical instrument storage in the hallway have had occasional problems and a heavier duty option would have been preferred by maintenance staff. Other hardware has been 'great'.
- Opening the clearstory windows using the wand is difficult, faculty suggests motorized operators could have been used at that location.
- The skylights have had no problems.
- The infrared plumbing fixture sensors have worked well.
- There is a puddle at some of the pavers near the greenhouse.
- The specified planting in between the pavers has not taken well, and weeds are now growing in between some of the pavers.
- The irrigation heads are not tall enough to water the 'meadow' grasses. Suggest installing head extenders.
- The suggested plant mix for the swale has not yet been installed. The design team suggests adding more plants to improve drainage time. Suggested species are: 50% Juncus Patens (Spreading Rush), 30% Carex Opbnupta (Slough Sedge) and 20% Iris Tenax (Oregon Iris).
- The space that was set aside to replace the old campus recycling collection center is being used as storage instead.
- The ceiling exhaust vents that have manually switched dampers are rarely used. Currently the manual switch only works when outside temperatures are in a range deemed appropriate by the controls system. One teacher suggests modifying controls so they can be opened manually, but automatically shut after a brief period.

The School as a Teaching Tool

One of the main goals for the building was that it could serve as a 'teaching tool' for the students as they learned about the concepts of sustainability in the science classroom. Some of the building features used in this effort included Plexiglas 'windows' into the wall and floor to expose how these were assembled, windows from the science classroom into the pump room, a sundial to emphasize the relationship of the building to its solar orientation, interpretive signage on a kiosk in the buildings entry lobby, and 8 ½" x 11" signage inserts around the building that can be used to explain how systems work or to post student science experiments or other content. Copies of both the interpretive signage and 8 ½" x 11" systems insert signage are included in Appendix D of this document. Another aspect of using the school as a teaching tool involves leaving space in the design for students to create projects and develop a continuing sense of investment in the school and in their work.

A 'building dashboard' computer screen was provided on the interpretive signage kiosk to display the real time energy and water use and production information. A web page was set up to view real time information, but historical data is not accessible through this site. The science teacher still plans to use this system as part of the curriculum, however to date there have been problems setting up access to the controls system data for student use in the classroom. Further effort will be needed and coordination between the Districts controls contractor and the faculty to complete the setup in a satisfactory manner. As part of this post occupancy study the authors have had to find ways to access data from the controls system, and plan to share this with the science teacher.

While more remains to be done, the answers to the following survey questions are encouraging in the sense that according to the author's experience, a far smaller portion of adults would typically express a willingness to modify their habits or learn more about what they can do to control their environment. This suggests that teaching students the lessons of sustainability at this age a good opportunity to affect their habits and priorities for a lifetime.

Figure 11

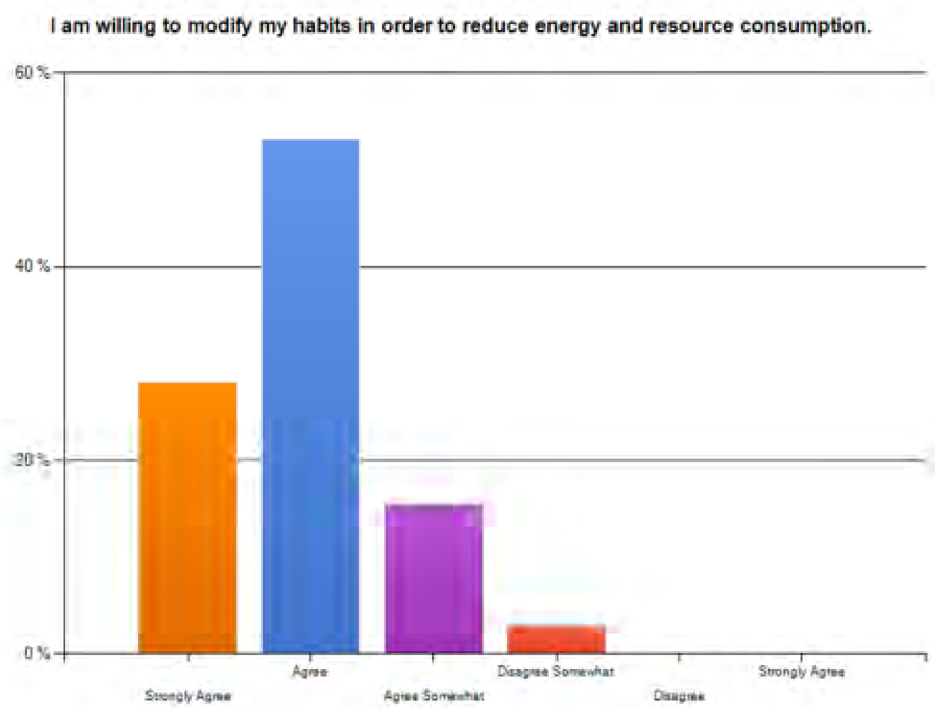
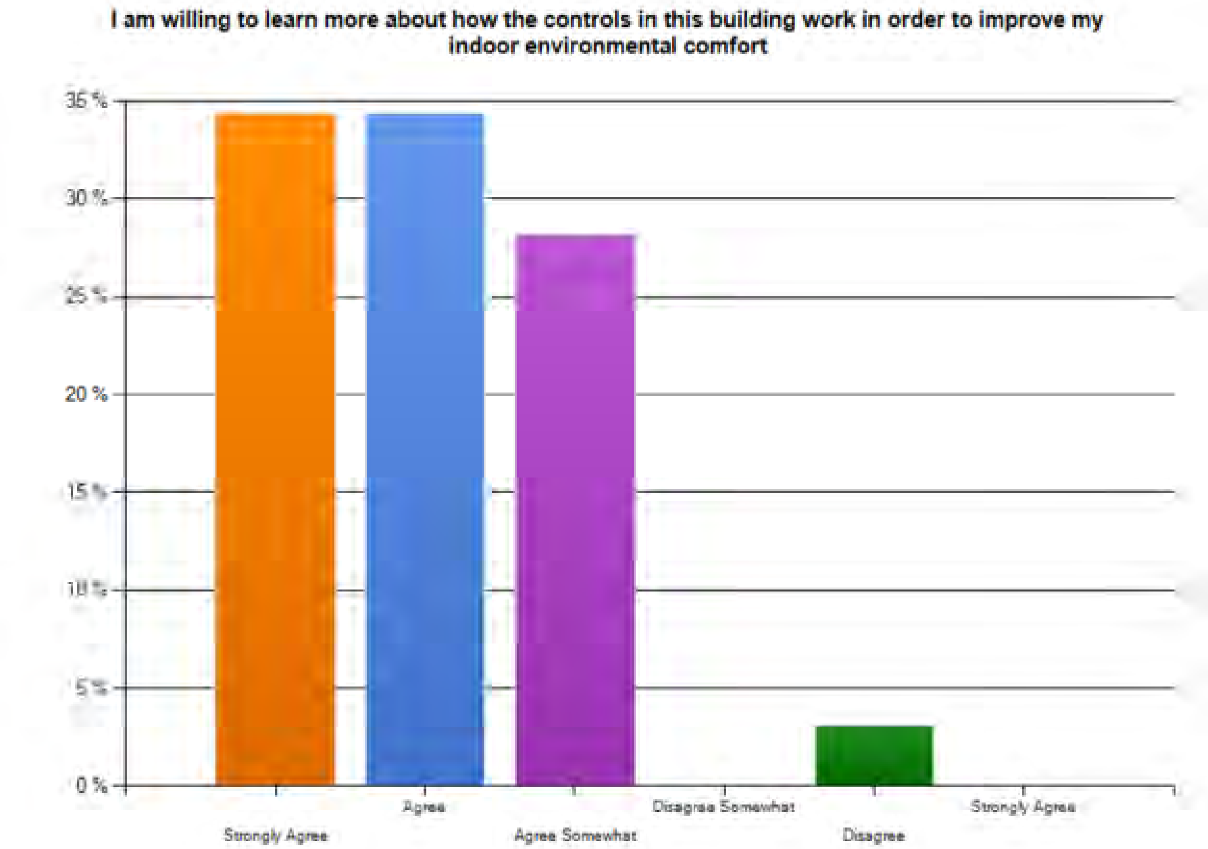


Figure 12

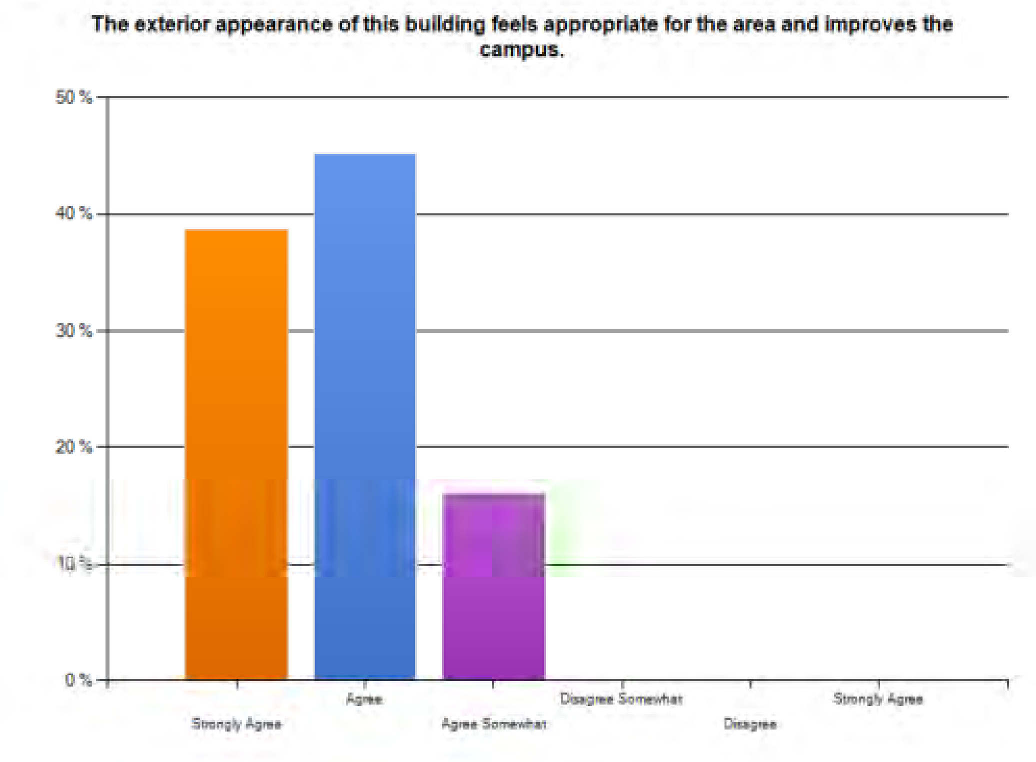


A biofiltration system that uses fish waste to fertilize plants in the greenhouse is an example of a student designed project.

Aesthetics

The building sits on a campus that is listed on the National Register of Historic Places because of the school's main building which was constructed in the 1920's, and was required to be approved by a Historic Design Review. The building was designed to both accommodate many sustainable systems while still appearing appropriate to its historic surroundings. We are happy to report that there is 100% agreement among those surveyed that the building's appearance is appropriate and improves the campus.

Figure 13



Energy Model Calibration

Summary

The 6,900 sf Hood River Middle School Music and Science building was completed in 2011 and has achieved LEED Platinum certification as well as net-zero annual energy usage. The building contains a litany of energy efficient measures including a high performance envelope, geothermal heating, cooling using heat exchange with water from an adjacent stream, radiant slabs, displacement ventilation via heat recovery ventilators, natural ventilation when available, daylighting and a 35 kW photovoltaic array.

The original energy model submitted for LEED certification showed the building consuming 37,061 kWh/yr and producing 36,584 kWh/yr for a net EUI of 0.23 kBTU/sf/yr. It should be noted that the original LEED submitted model did not take any credit for the "free" cooling provided by the existing irrigation line on the site to avoid unnecessary complications in the review process.

This study looks at the predicted energy usage and production for the building and compares it to a year's worth of measured data from May 2011-April 2012. During that period, the building consumed 41,815 kWh and produced 42,418 kWh for a net EUI of -0.36 kBTU/sf/yr. The intention of this report is to present the areas in which the model accurately predicted the performance of the building systems and where and why there were discrepancies. It is also expected that the calibrated energy model could be used for future energy retrofits or studies to determine a more accurate estimate of potential energy usage and/or savings.

Comparison of Predicted vs. Measured Energy

The HRMS Music and Science Building was designed with two separate submeters on the building usage side: 1. Mechanical and plumbing loads (ground source heat pumps, circulation pumps, heat recovery ventilators), and; 2. Lighting and receptacle loads. Along with the building submeters there were also four separate submeters installed on the photovoltaic arrays to measure the energy production side.

The following set of bar graphs shows the predicted vs. measured energy production and consumption over the year of analysis:

Figure 14 shows the monthly energy consumption of the original modeled vs. actual mechanical and plumbing equipment. From the graph the following conclusions can be made:

- There is very little difference in the summer/cooling months but a large discrepancy in the winter months. It can be assumed that the energy model under predicted the energy usage of the ground source heat pumps that serve the radiant slabs.

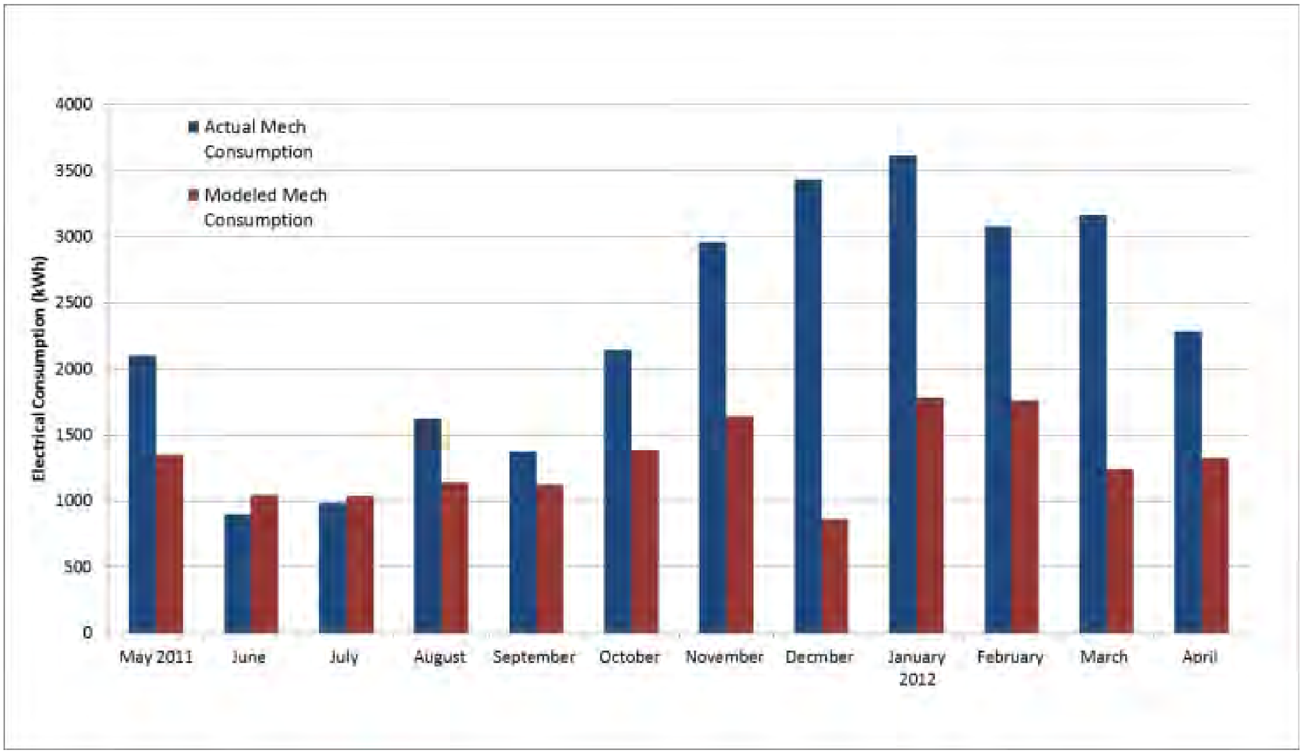


Figure 14: Modeled vs. Actual Mechanical Energy Usage (kWh)

Figure 15 shows the monthly energy consumption of the original modeled vs. actual lighting and receptacle loads. The following conclusions can be made:

- The energy model consistently over predicted the lighting and plug load energy every month except

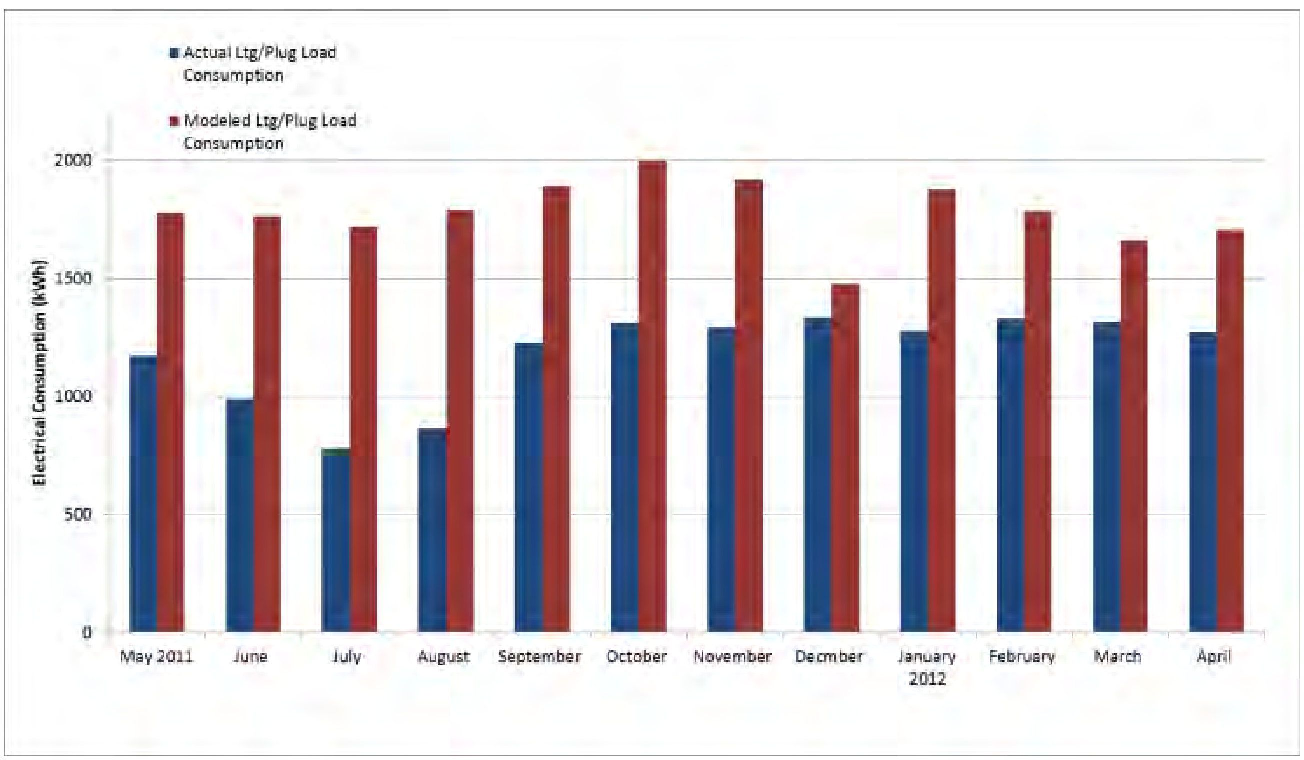


Figure 15:Original Modeled vs. Actual Lighting/Plug Load Energy Usage (kWh)

for December. This suggests that across the board, either the plug loads or lighting power densities or their associated schedules were input into the model at a higher rate than actual. It can also be concluded that the modeled schedule of usage for the month of December might have been less than the building actually saw. This is confirmed by the Mechanical graph above which shows a significant dip in the modeled energy for the month of December.

Figure 16 shows the predicted vs. actual Photovoltaic production and the following conclusions can be made:

- The PV arrays produced more energy than predicted for the months of April-August while the rest of year had a fairly close match. One possible explanation is that the nearest weather file for the PV estimation software was Portland which doesn't have as many clear sunny days through the summer months as Hood River.

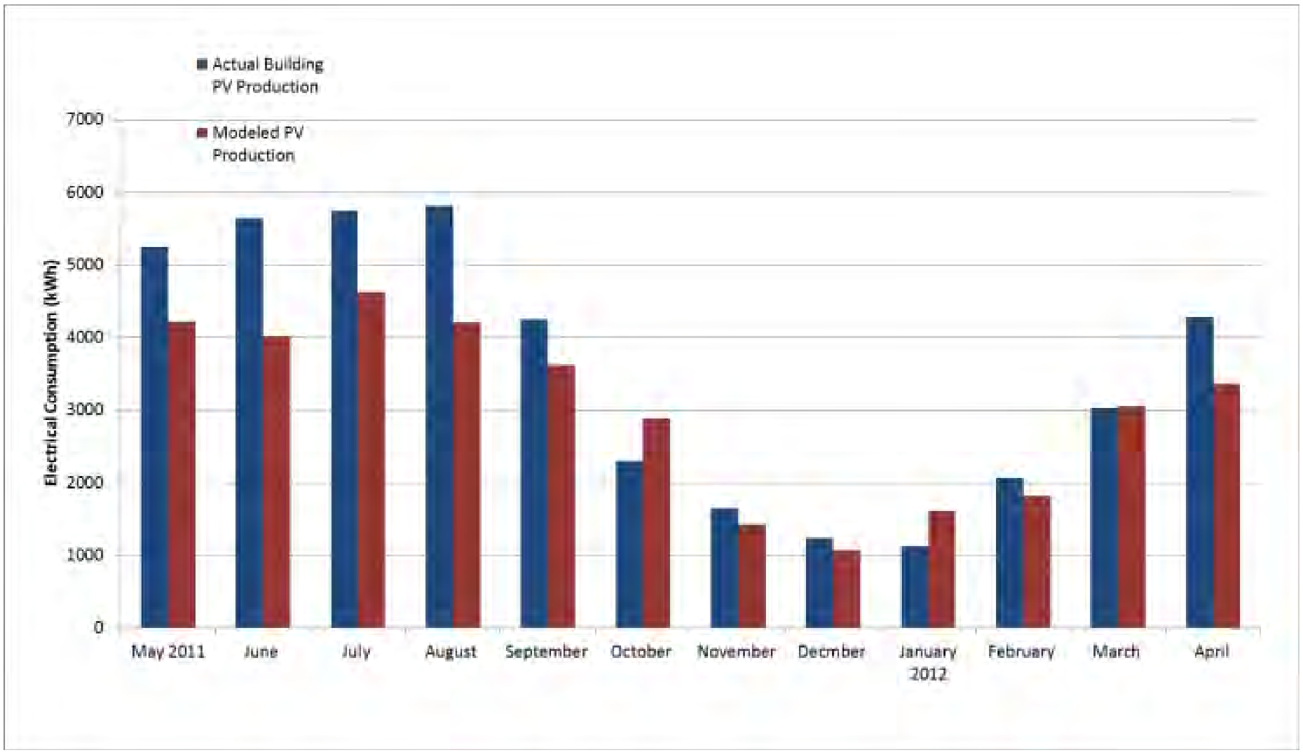


Figure 16: Original Modeled vs. Actual PV Production (kWh)

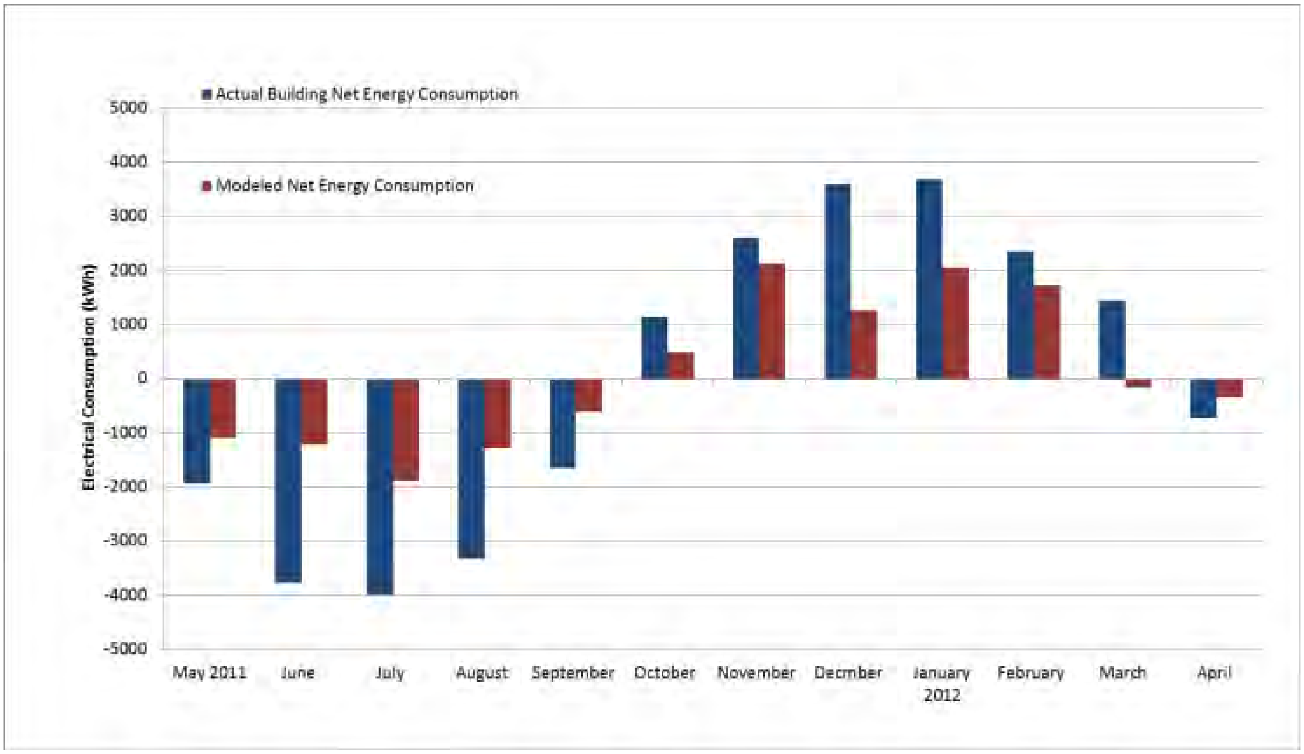


Figure 17: Original vs. Modeled Net Energy Usage (kWh)

Figure 17 shows the Net Energy Consumption modeled vs. actual energy and the following conclusions can be made:

- The balance of photovoltaic production through the summer months was enough to offset the increased energy consumption through the winter months while the increased heating energy in the actual building is apparent.

The primary goals of the energy model calibration were to:

1. Survey the receptacle loads and lighting in the actual building and their estimated schedule of operation;
2. Compare the thermal setpoints and schedule of operation of the radiant slab system;
3. Examine the temperatures and power draw of the ground loop heat pump system as compared to the modeled data specifically in heating mode;
4. Modify the estimated PV production to more accurately reflect the increased production in the summer;

Walkthrough of Building and Calibration of Existing Model

Lighting and Receptacle Loads

After examining the monthly energy usage of the actual building's lighting and receptacle loads (Figure 14), it was necessary to walk through the building and do a tally of installed lighting and receptacle loads to see where the discrepancy lie. The lighting fixtures matched up with the design drawings and the installed lighting power density checked out. As well, the daylighting controls seemed to be working appropriately as verified by the teachers. They commented that there are many hours when the lighting fixtures are not needed in the classrooms. However, it was quickly evident that the modeled plug load density was much higher than what was actually used in the spaces. This observation solidified the trend seen in the monthly energy usage profiles showing the model having much higher receptacle/lighting values. The chart below shows the various spaces with their modeled receptacle load density and actual tallied values.

Table 1: Actual vs Modeled Receptacle Load Density

Space	Area (sf)	Modeled Receptacle Load Density (W/sf)	Modeled Equipment Power Input (W)	Actual Receptacle Load Density (W/sf)	Actual Equipment Power Input (W)
Music Room	1963	1.5	2945	0.85	1670
Practice Room 106	93	1.25	116	0.1	10
Practice Room 107	96	1	96	0.1	10
Boys Restroom	140	0.75	105	0	0
Music Office	116	1.5	174	1.25	150
Janitor's Room	48	0.5	24	0.1	10
Girls Restroom	118	0.75	89	0	0
Science Classroom	1016	2.5	2540	1.35	1380
Science Office	104	1.5	156	1.5	150
Greenhouse	956	0.5	478	0.15	150
Storage	384	0.2	77	0	0
Total	5034	1.35	6799	0.70	3530

The tallied load density in the building turned out to be almost half of what was originally modeled. These values were input into the calibrated model. The last discrepancy noted was for the month of December where the actual vs. modeled data was almost identical as seen in Figure 15. This was atypical in that every

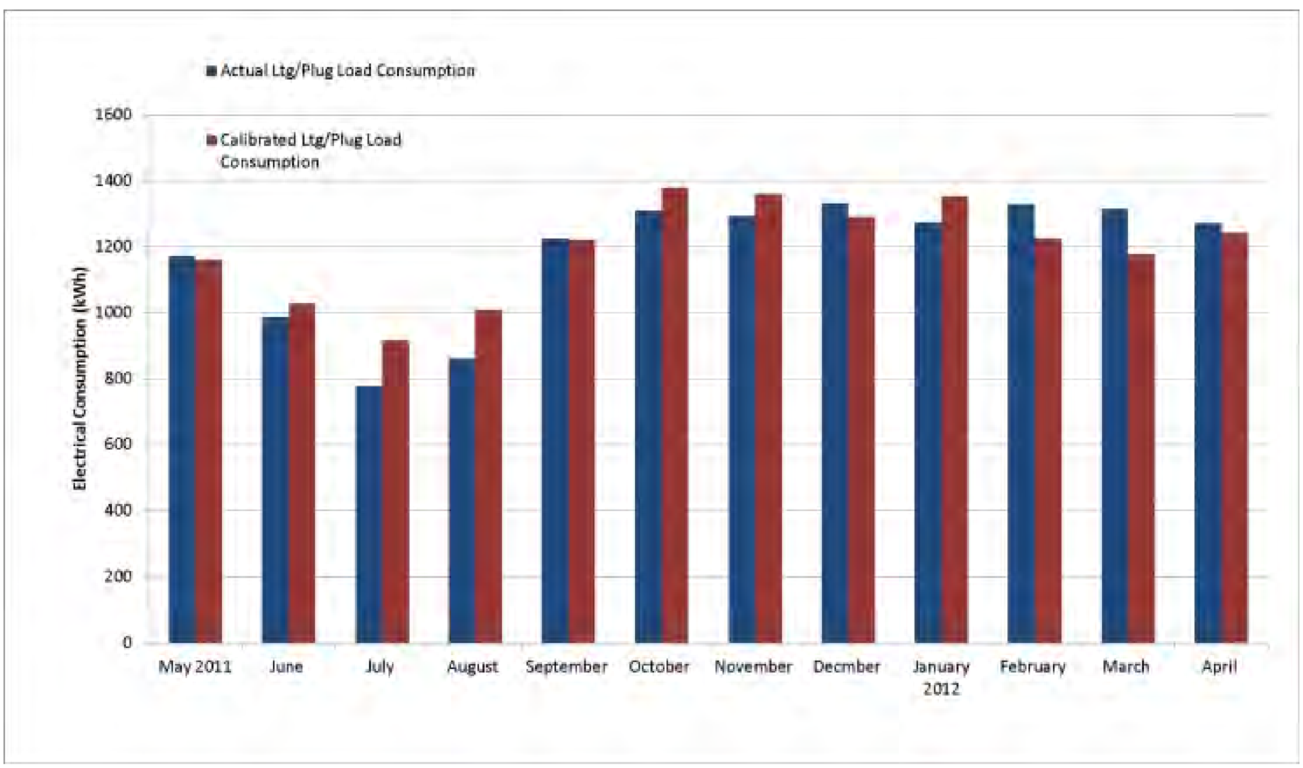


Figure 18: Calibrated Model vs. Actual Lighting/Plug Load Energy Usage (kWh)

other month showed much higher modeled numbers. In looking back at the annual schedule of operation, it was seen that school was in session a week longer than modeled. This was corrected across the board for lighting/plug load/fan, etc. schedules. Once the calibration was completed for the lighting/plug loads, the annual difference in energy between the model and actual building was 1.5% while monthly variation averaged 6.4%. Figure 18 shows the actual building lighting and plug load energy usage vs. the calibrated energy model.

Mechanical/Plumbing

The Hood River Music/Science building is served by a hybrid HVAC system consisting of two water-to-water heat pumps paired to a vertical geothermal field on the source side and radiant heated and cooled slabs on the load side as well as rooftop heat recovery ventilators that provide ventilation air via displacement ventilation grilles installed at the floor level. As seen in Figure 14 above, the energy model consistently under-predicted the mechanical and plumbing energy. Looking closer, it is clear that the discrepancy grows in the winter months indicating that the system in heating mode is less efficient than estimated.

The first step in the HVAC calibration was obtaining an Actual Meteorological Year (AMY) weather file taken from Hood River via the company Weather Analytics (http://www.weatheranalytics.com). The original energy model used a Typical Meteorological Year (TMY) weather file from Portland, OR as this was geographically the closest site. Its immediate effect was to actually lower the annual heating energy and drastically increase the annual cooling energy. This indicated that the discrepancies in the energy model were more due to equipment efficiencies, set point discrepancies, operational schedules and/or general setup.

The next step was interviewing both the teachers and maintenance staff to determine typical thermostat set points and hours of operation. In talking with the lead janitor who works closest with the system, it was determined that the radiant slab system never completely shuts off through the night but merely goes into a setback temperature mode. When they first opened the building they quickly realized that if they shut the system off completely overnight, or particularly over the weekend, there wasn't enough time for it to come back up to temperature before school started. Due to this, the system pumps run 24/7 with the heat pumps cycling on as necessary to maintain setback temperatures. The first thing to do in the calibrated energy model was to change the radiant slab pump schedules to 24/7.

In talking with the staff and examining the DDC system trendlogs, it was discovered that both the occupied setpoint of the radiant slab and the setback temperatures were higher than modeled. The model had 55°F/70°F setback/occupied setpoints for the radiant slab while in reality they were operating at 65°F/75°F as shown in Table 2. This was updated in the calibrated model to match actual operation. In interviewing the teachers, they both mentioned that the temperature in the room always felt sufficiently warm and at times too warm. In going forward the heating setpoint of the slabs might be able to be depressed slightly with no thermal comfort complaints. This would improve the efficiency of the ground source heat pumps.

Table 2: Calibrated vs Original Enegy Model Radiant Slab Htg Setpoints

Hour	1AM - 6AM	7AM	8AM - 5PM	6PM	7PM-12AM
Original Model	55°F	55°F	70°F	55°F	55°F
Calibrated Model	65°F	72°F	75°F	72°F	65°F

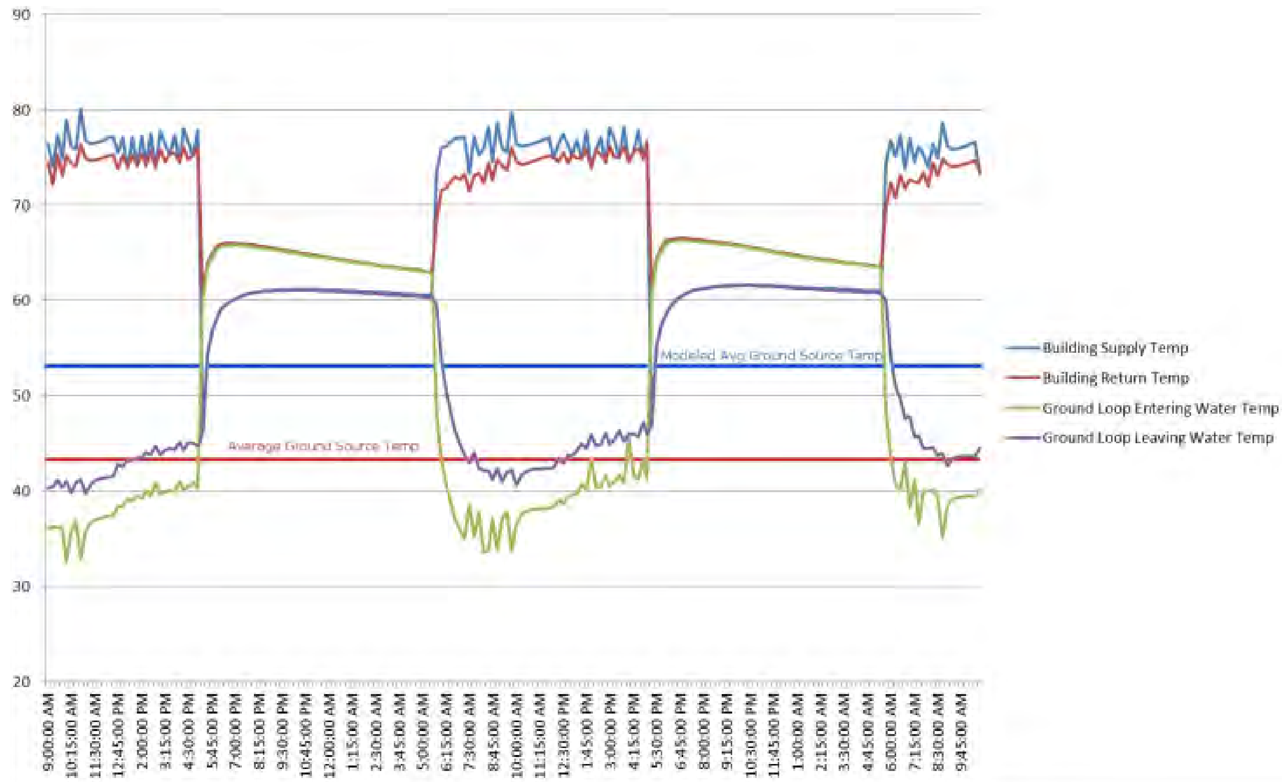


Figure 19: Trendlog of Building Ground Source Temperatures

After updating the model with the pump schedule and setpoint changes there were still significant discrepancies between the model and actual operation in the winter months. Therefore the next step in the HVAC calibration was determining how the ground source heat pumps were operating in reality and why they were using more energy than the model. A trendlog was created (Figure 19, above) which examined the source and load side temperatures of the ground source heat pump system. The red line across the graph shows the average source side temperature that the system sees during occupied hours which ends up being about 42°F. In examining the energy model, the average ground temperature was nearly 10°F higher as represented by the blue line in Figure 19. The original energy model defaulted to an undisturbed ground temperature of 55°F which was assumed to fluctuate somewhat with the seasons. However, as witnessed in the trendlogs, the ground temperature has been depressed over time due to the imbalance of heating vs. cooling loads. In retrospect, the ground temperature in the original model should have been lowered based on projections obtained from the ground loop design software used to size the system. The undisturbed average ground temperature in the energy model was updated to more accurately reflect actual operating conditions and the impact was immediately noticed. The annual discrepancy between the HVAC energy of the model and actual building went from 32% down to 8% with an average monthly discrepancy of 21%.

The calibrated heating energy was now very much in line with the actual building but the cooling energy was still averaging a monthly discrepancy of 51% compared to actual. For comparison the monthly heating energy discrepancy had been brought down to an average of only 6%. The water meter that was installed in line with the irrigation system designed to provide free cooling to the radiant slab recorded 134,000 gallons of flow for the duration of the post occupancy study, almost all during the summer months. Although only a portion of this water goes into the heat exchanger, it appears that the irrigation system was able to provide the entire radiant slab cooling load through the summer months which would eliminate the DX cooling energy from the ground source heat pumps. With the mechanical cooling energy subtracted out of the calibrated model, the overall mechanical difference between calibrated and actual dropped to only 1.4% annually with a monthly average difference of 9%.

The ventilation for the building is provided via two rooftop heat recovery ventilators which serve displacement ventilation grilles in the classrooms. During appropriate outdoor conditions, operable windows can be used in the classrooms to provide natural ventilation with relief being provided via a roof mounted hood. In heating mode, the HRVs operate in a minimum ventilation mode only modulating up if space CO2 levels climb above 1000ppm. Initially it was a concern that the ventilation system wasn't working appropriately because the HRVs were off during the post-occupancy walkthrough of the building. However the janitor said that the unit had just recently tripped off and hadn't been reset yet. During all subsequent log-ins to the DDC system it appeared that the HRVs were operating correctly and modulating based on space CO2 concentrations. The HRVs are also connected to a 500 sf SolarWall array which acts to preheat the incoming ventilation air during the colder months. In warmer months there is a damper which bypasses the array. SolarWall is merely an angled plenum on the roof with a black perforated panel facing south. This panel serves to heat up the plenum and thus preheat the incoming air. At Hood River MS, PV panels are also installed on the SolarWall plenum due to space constraints. Unfortunately there weren't separate temperature sensors or submeters installed on the SolarWall array so we are unsure of its actual benefit. Infiltration was modeled at an average of 0.05 CFM/sf in the original energy model. There was no whole building pressurization test performed for the post-occupancy evaluation so the base infiltration rate remained unchanged in the calibrated model. While we are not able to verify infiltration rates, the monolithic nature of the insulated concrete formwork and careful attention that was paid to window detailing may outperform the estimates used in the model.

Figure 20 shows the monthly mechanical/plumbing energy comparison between the calibrated model and the actual building.

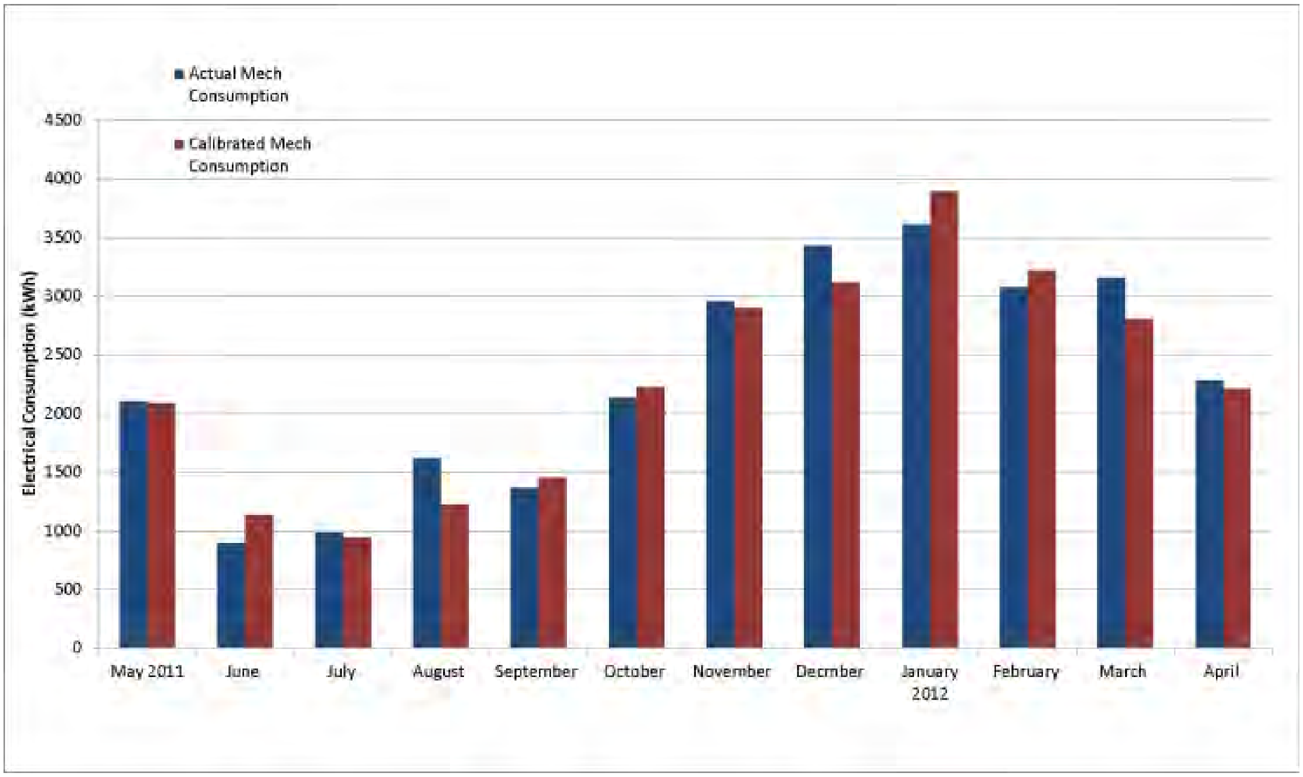


Figure 20: Calibrated vs. Actual Mechanical Energy Consumption (kWh)

PV Array

The PV array was originally simulated using the PV Watts v1.0 system available online (http://rredc.nrel.gov/solar/calculators/pvwatts/version1/). This is a very convenient and oft-used tool but pulls from the same list of available weather files as most energy models meaning that one was not available for Hood River, OR. As in the base energy model, the closet geographical weather file in PV Watts was Portland, OR. As a comparison, the average annual total horizontal solar radiation variable was taken out of the Hood River AMY weather file and compared to the Portland TMY weather file and was 16% higher (102.1 Btu/hr/ft2 vs. 88.1 Btu/hr/ft2). Applying this 16% increase to the original predicted PV production of 35,952 kWh would make it 41,704 kWh which is a discrepancy of only 1.7%. Figure 21 below shows the calibrated PV production:

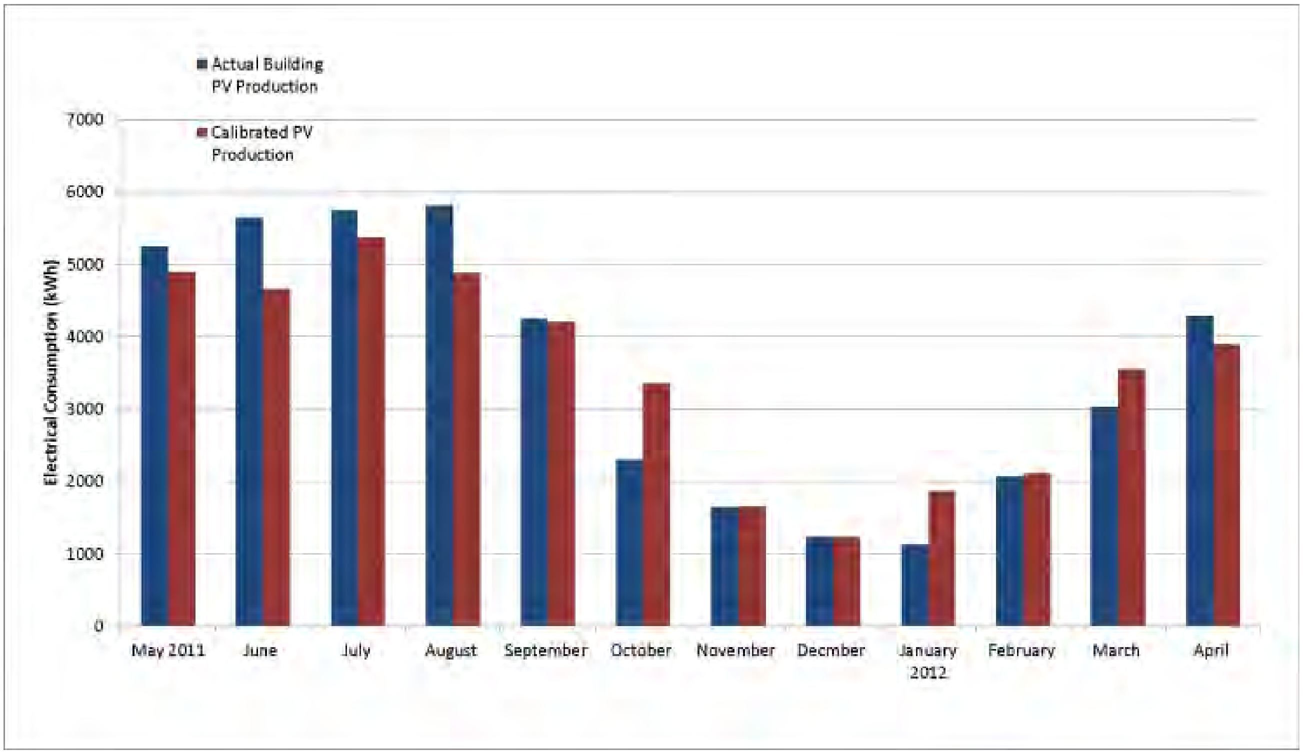


Figure 21: Calibrated vs. Actual PV Energy Production

Water Use

The water flow schematic in Appendix B depicts how water flows through the site and building and the various sources and end uses. Four water meters were installed in the system (labeled as WM-# in the schematic). Water is collected on the roof of the building through the year and is diverted and filtered to a 14,000 gallon underground cistern. The cistern is divided into two separate sections that independently serve either the building's water needs or the greenhouse/garden irrigation needs (WM-1). The section of the cistern that serves the building's toilets is 11,000 gallons while the irrigation system is 3,000 gallons. Water is allowed to pass from the building/rainwater side to the irrigation side but not vice versa. Water pumped into the building is used to either supply water to the toilets (WM-3) or makeup water to the HVAC system (WM-4). An existing irrigation line on the site is connected to the irrigation division of the cistern and is used for the greenhouse and building irrigation needs when there isn't enough rainwater to fill both sides. This irrigation line is supplied by a stream that runs through the middle school property. In the warmer months, this water can be diverted into a plate and frame heat exchanger that provides free cooling into the building's radiant slabs. After going through the heat exchanger it can either be used to irrigate the playfields or can be diverted to the irrigation portion of the underground cistern to be used in the greenhouse (WM-2). Lastly potable water from the local water utility is piped into the building to serve the sinks and drinking fountains. Unfortunately a sub-meter wasn't installed on the potable water line fed from the existing building to the new Music and Science building so there is no accurate way of determining how much potable water is being used annually. It is assumed to be a relatively small amount, since little change was seen on the water meter that serves the building (which also serves the existing library building), and there is reportedly little water use for the science lab sinks, which along with restroom sinks, music office sink and the drinking fountains are the only fixtures served by potable utility provided water.

For the period of analysis, no flow was recorded through WM-1 which seems erroneous. It is recommended that this meter be inspected to see if it is functioning properly. It is known that plants were raised throughout the school year in the greenhouse so there should have been some flow recorded through WM-1. WM-2 however recorded an annual flow of 134,000 gallons, almost all at the end of the summer (August/September), indicating that the existing stream is utilized to fill the irrigation side of the cistern in months when there is little to no rainfall. This volume of water far exceeded the original LEED irrigation estimate of ~28,000 gallons and is more in line with the calculated baseline volume of 124,000 gallons. This indicates that the actual irrigation demand for the greenhouse and site is much more intensive then the assumptions made in the original LEED template. A portion of this water is assumed to have flowed through the plate and frame heat exchanger providing free cooling to the building as noted above due to the very small amount of mechanical energy seen in the summer months. WM-3 recorded an annual building usage of 10,900 gallons to flush toilets which was about one-third of what was predicted in the original LEED submission. This suggests that the toilets weren't used as often as assumed or there was a larger ratio of boys to girls. The LEED guidelines require the user to assume a 50/50 split between males and females with females using the toilet three times a day and male's only one. It is theorized that the average female student isn't using the building's toilets three times per day. Lastly no data was recorded for WM-4 which isn't completely unexpected. This meter serves to monitor makeup water to the HVAC system which wouldn't change much in a closed loop system unless there was a leak in the system or it had to be refilled.

Summary of Findings/Recommendations

The Hood River Music and Science building achieved net zero energy through the year analyzed although it accomplished it in a manner that didn't align with the modeled results. In general, the model over-predicted the plug load/receptacle energy usage of the building while under-predicting the amount of heating energy needed in the building. The 24/7 runtime of the radiant slab pumps coupled with the colder ground loop temperatures/lower heat pump efficiency were the main drivers of the increased heating energy. Conversely on the cooling side it appears that the free cooling provided by the irrigation water on the site was able to essentially eliminate the need for any mechanical cooling. On the energy production side, the photovoltaic array generated 16% more energy than predicted showing that Hood River appears to have a higher solar income than the Portland, OR weather file used in the original renewable energy calculation.

The project has been able to utilize both collected rainwater and site water for the needs of both the greenhouse and the flush fixtures in the building. However without the correct operation of WM-1, it is impossible to calculate the ratio of stream water to rainwater (WM-2/WM-1+WM-3). It is strongly recommended that the operation of WM-1 be verified going forward to ensure that an accurate representation of the building's water usage can be made.

After all adjustments had been made to the calibrated energy model, the difference on the consumption side was brought down to 3.8% and only 1.7% on the production side. Figure 22 below shows the comparison between the net energy of the actual building and calibrated model. Going forward, it is recommended that minor adjustments be made to the operation of the building's HVAC system which would drop the overall energy consumption and provide more of a buffer for the PV energy production.

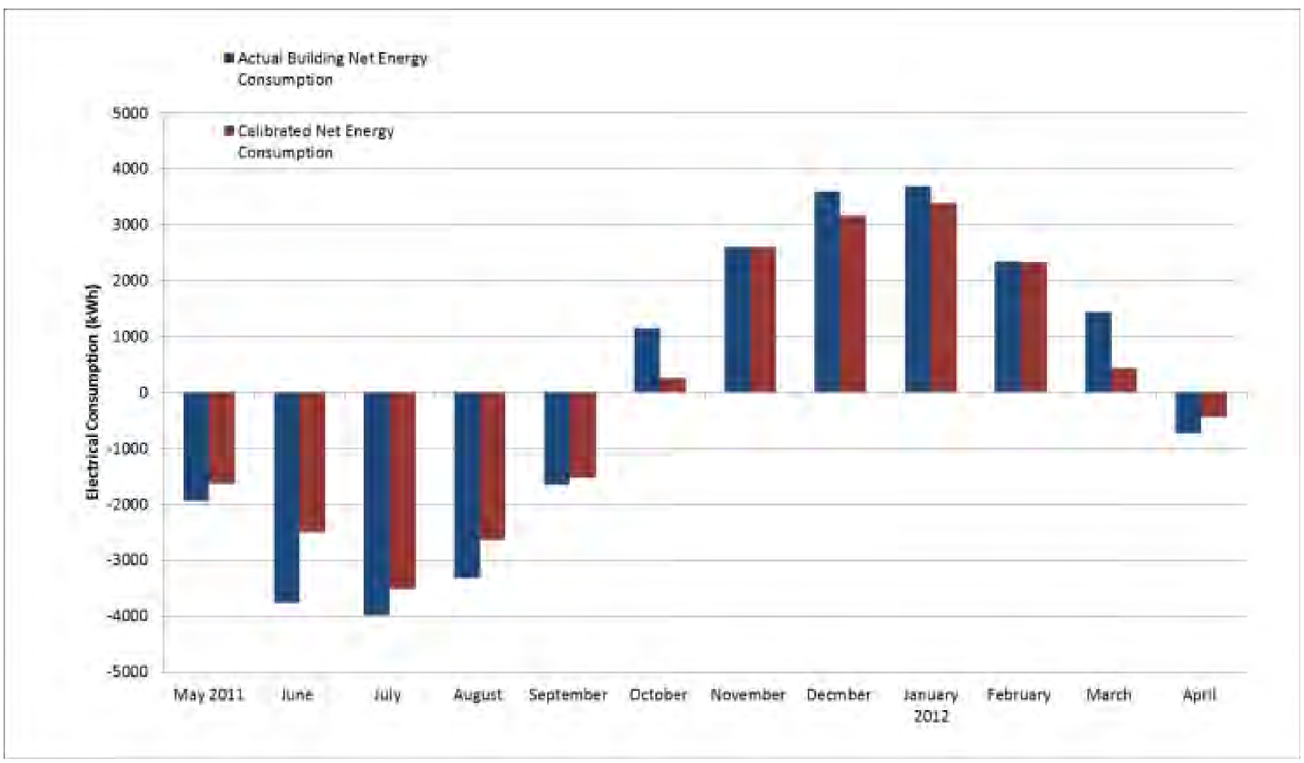


Figure 22: Net Energy Comparison of Actual vs. Calibrated Model

Interviews with the staff indicated that the largest complaint was that it was too warm at times in the classrooms. It is theorized that the heating setpoint for the radiant slab could be lowered. This measure would slightly improve the efficiency of the ground source heat pumps when they are operating in heating mode. Another potential improvement could be shutting off the radiant slab pumps during a block of hours when the building is unoccupied. If the thermal lag could be determined in the system than the radiant slab pumps could be shutoff at the end of occupancy on say a Friday afternoon and enabled again Sunday evening or early Monday morning to bring the building back up to temperature. However, the fine-tuning of this loop and operator interaction would require additional time which might not be practical for the end-users. In talking with the head custodian, there didn't seem to be a clear understanding of how the system could be shut down or turned back for summer operation when the building is not being used. An area of improvement going forward would be to construct a summer setback procedure for the building HVAC system to ensure that the ground source heat pumps, associated pumps and HRVs are only running when absolutely necessary. This will help bring down the building's annual energy usage and help offset the more energy intensive consumption during the winter.

A summary list of recommendations from the above investigations include the following:

- Investigate resetting the heating setpoints to avoid overheating the space.
- Investigate if the system can be shut down during non-operational hours, at least during some seasons.
- Investigate summer system procedures if the building is not used over the summer.
- Investigate if water meter WM-1 can be fixed to provide data.
- Review the manufacturer's recommended maintenance procedures for the waterless urinal and modify procedures if needed.
- Consider installing roller shades with approximately 5% transmittance on the the south facing music room windows to mitigate glare issues.
- Consider steam cleaning ceramic tile floors.
- Consider additional planting of the following species at the swale
    - 50% Juncus Patens (Spreading Rush)
    - 30% Carex Opbnupta (Slough Sedge)
    - 20% Iris Tenax (Oregon Iris)
- Consider re-programming the controls settings for the dampers at the passive exhaust vents to manually operate on demand, then shut after a 20 to 60 minute duration.
- The design team and controls contractor should work with the science teacher so that he and his students can gain access to view and create trendlogs of data from the controls system.

In conclusion, by and large building users are very happy with the building and it was able to reach the net-zero energy goal for the year studied. However there are a number of ways to improve the function of the building and systems without substantial upfront cost which should be investigated and implemented if desired.

Appendix A:

Complete Survey Results

Hood River Middle School Music and Science Building

SurveyMonkey

1. Which of the following best describes you:

	Response Percent	Response Count
Student	**85.7%**	**30**
Faculty	2.9%	1
Admin/Staff	5.7%	2
Visitor	0.0%	0
Other	5.7%	2
	answered question	**35**
	skipped question	**1**

2. In an average week, I typically use this building....

	Response Percent	Response Count
0-4 Hours	31.4%	11
5-8 Hours	**40.0%**	**14**
9-16 Hours	14.3%	5
17-40 Hours	8.6%	3
41 or More Hours	5.7%	2
	answered question	**35**
	skipped question	**1**

3. Which of the following areas of the building do you use (please check all that apply)

	Response Percent	Response Count
Classrooms	**97.1%**	**34**
Offices	17.1%	6
Greenhouse	71.4%	25
	answered question	**35**
	skipped question	**1**

4. How satisfied are you with this building's support of your needs to complete your work/studies effectively?

	Response Percent	Response Count
Very Satisfied	**48.5%**	**16**
Satisfied	**48.5%**	**16**
Somewhat Satisfied	0.0%	0
Somewhat Dissatisfied	3.0%	1
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
	answered question	**33**
	skipped question	**3**

5. This building reinforces my connection to my work or studies and those who work with me.

	Response Percent	Response Count
Strongly Agree	**39.4%**	**13**
Agree	36.4%	12
Agree Somewhat	15.2%	5
Disagree Somewhat	9.1%	3
Disagree	0.0%	0
Strongly Disagree	0.0%	0
	answered question	**33**
	skipped question	**3**

6. This building inspires my work or studies and I am more productive as a result.

	Response Percent	Response Count
Strongly Agree	21.2%	7
Agree	36.4%	12
Agree Somewhat	**39.4%**	**13**
Disagree Somewhat	0.0%	0
Disagree	3.0%	1
Strongly Agree	0.0%	0
	answered question	**33**
	skipped question	**3**

7. I look forward to coming to work/study in this building.

	Response Percent	Response Count
Strongly Agree	**42.4%**	**14**
Agree	36.4%	12
Agree Somewhat	18.2%	6
Disagree Somewhat	3.0%	1
Disagree	0.0%	0
Strongly Agree	0.0%	0
	answered question	**33**
	skipped question	**3**

8. I am willing to modify my habits in order to reduce energy and resource consumption.

	Response Percent	Response Count
Strongly Agree	28.1%	9
Agree	**53.1%**	**17**
Agree Somewhat	15.6%	5
Disagree Somewhat	3.1%	1
Disagree	0.0%	0
Strongly Agree	0.0%	0
	answered question	**32**
	skipped question	**4**

9. I am willing to learn more about how the controls in this building work in order to improve my indoor environmental comfort

	Response Percent	Response Count
Strongly Agree	**34.4%**	**11**
Agree	**34.4%**	**11**
Agree Somewhat	28.1%	9
Disagree Somewhat	0.0%	0
Disagree	3.1%	1
Strongly Agree	0.0%	0
	answered question	**32**
	skipped question	**4**

10. Do you have any additional comments about your overall experience of the building?

	Response Count
	19
answered question	**19**
skipped question	**17**

11. What is the exterior temperature today?

	Response Percent	Response Count
Very Hot	0.0%	0
Hot	3.1%	1
Warm	43.8%	14
Cool	**46.9%**	**15**
Cold	6.3%	2
Very Cold	0.0%	0
	answered question	**32**
	skipped question	**4**

12. The weather outside today, compared to a 'typical' day this time of year, is...

	Response Percent	Response Count
Warmer Than Usual	3.2%	1
Typical	**67.7%**	**21**
Cooler Than Unusual	29.0%	9
	answered question	**31**
	skipped question	**5**

13. How would you describe the clothing you are wearing today?

	Response Percent	Response Count
Very Heavily Dressed	0.0%	0
Heavily Dressed	9.4%	3
Typical For This Time Of Year	**65.6%**	**21**
Lightly Dressed	25.0%	8
Very Lightly Dressed	0.0%	0
	answered question	**32**
	skipped question	**4**

14. If you are in the Music and Science building now, is the temperature...

	Response Percent	Response Count
Much Too Hot	9.4%	3
A Bit Warm	28.1%	9
About Right	**59.4%**	**19**
A Bit Cool	0.0%	0
Much Too Cold	0.0%	0
I Am Not In the Building	3.1%	1
	answered question	**32**
	skipped question	**4**

15. Are you satisfied with the temperature of your workspace a majority of the time?

	Response Percent	Response Count
Very Satisfied	**38.7%**	**12**
Satisfied	29.0%	9
Somewhat Satisfied	19.4%	6
Somewhat Dissatisfied	9.7%	3
Dissatisfied	0.0%	0
Very Dissatisfied	3.2%	1
	answered question	**31**
	skipped question	**5**

16. On the occasions the temperature in your workspace is uncomfortable, it is most often:

	Response Percent	Response Count
Far too Cold	3.1%	1
Somewhat Cool	21.9%	7
Somewhat Warm	**40.6%**	**13**
Far too Hot	18.8%	6
It Depends too Cool, or too Warm	12.5%	4
It Depends way too Hot or way too Cold	3.1%	1
	answered question	**32**
	skipped question	**4**

17. Are you willing to accept slightly wider temperature swings in a building in order to reduce energy consumption?

	Response Percent	Response Count
Yes	28.1%	9
Yes, within reason	**59.4%**	**19**
I'd Rather Not	12.5%	4
No	0.0%	0
	answered question	**32**
	skipped question	**4**

18. Which of the following are you able to control in your individual work space, and to what extent?

	I have total control over this	I have some control	I have no control over this	Response Count
Heating	3.1% (1)	25.0% (8)	**71.9% (23)**	32
Cooling	3.1% (1)	31.3% (10)	**65.6% (21)**	32
Window Opening	28.1% (9)	**46.9% (15)**	25.0% (8)	32
Blinds	3.1% (1)	31.3% (10)	**65.6% (21)**	32
Lighting	9.4% (3)	43.8% (14)	**46.9% (15)**	32
			answered question	**32**
			skipped question	**4**

19. Do you have any additional comments about the indoor thermal comfort of this building?

	Response Count
	16
answered question	**16**
skipped question	**20**

20. Please describe your level of satisfaction with the overall indoor air quality in this building?

	Response Percent	Response Count
Very Satisfied	21.2%	7
Satisfied	**57.6%**	**19**
Somewhat Satisfied	15.2%	5
Somewhat Dissatisfied	0.0%	0
Dissatisfied	6.1%	2
Very Dissatisfied	0.0%	0
If you answered "Somewhat dissatisfied," "Disatisfied" or "Very dissatisfied," please describe the problem:		3
answered question		**33**
skipped question		**3**

21. The air in my workspace is stuffy...

	Response Percent	Response Count
Never	12.1%	4
Rarely	**42.4%**	**14**
Occasionally	36.4%	12
Usually	6.1%	2
Always	3.0%	1
	answered question	**33**
	skipped question	**3**

22. Do you have any additional comments about the air quality in this building?

	Response Count
	15
answered question	**15**
skipped question	**21**

23. Are you satisfied with the opportunities for views to the outdoors from within this building?

	Response Percent	Response Count
Very Satisfied	34.4%	11
Satisfied	**46.9%**	**15**
Somewhat Satisfied	15.6%	5
Somewhat Dissatisfied	3.1%	1
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
answered question		**32**
skipped question		**4**

24. Do you have any additional comments about the views from this building?

	Response Count
	12
answered question	**12**
skipped question	**24**

25. Are you satisfied with the quality of daylight in this building?

	Response Percent	Response Count
Very Satisfied	38.7%	12
Satisfied	**48.4%**	**15**
Somewhat Satisfied	6.5%	2
Somewhat Dissatisfied	6.5%	2
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
	answered question	**31**
	skipped question	**5**

26. Are you satisfied with the artificial light in this building?

	Response Percent	Response Count
Very Satisfied	25.8%	8
Satisfied	**45.2%**	**14**
Somewhat Satisfied	29.0%	9
Somewhat Dissatisfied	0.0%	0
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
	answered question	**31**
	skipped question	**5**

27. Are you satisfied with the ability to control glare in your workspace?

	Response Percent	Response Count
Very Satisfied	12.9%	4
Satisfied	**45.2%**	**14**
Somewhat Satisfied	32.3%	10
Somewhat Dissatisfied	3.2%	1
Dissatisfied	3.2%	1
Very Dissatisfied	3.2%	1
	answered question	**31**
	skipped question	**5**

28. Overall, the quality of light and the control that I have support my ability to complete my work or studies effectively:

	Response Percent	Response Count
Strongly Agree	29.0%	9
Agree	**38.7%**	**12**
Agree Somewhat	29.0%	9
Disagree Somewhat	0.0%	0
Disagree	3.2%	1
Strongly Disagree	0.0%	0
If you answered "Disagree somewhat," "Disagree," or "Strongly disagree," please describe the problem:		3
	answered question	**31**
	skipped question	**5**

29. What is your level of satisfaction with the noise level in the building overall?

	Response Percent	Response Count
Very Satisfied	15.6%	5
Satisfied	**62.5%**	**20**
Somewhat Satisfied	18.8%	6
Somewhat Dissatisfied	3.1%	1
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
	answered question	**32**
	skipped question	**4**

30. What is your level of satisfaction with the quality of sound in the music room?

	Response Percent	Response Count
Very satisfied	**43.8%**	**14**
Satisfied	**43.8%**	**14**
Somewhat satisfied	9.4%	3
Somewhat dissatisfied	0.0%	0
Dissatisfied	0.0%	0
Very dissatisfied	0.0%	0
I don't use the music room	3.1%	1
	answered question	**32**
	skipped question	**4**

31. What is your level of satisfaction with your ability to hear spoken communication in the classrooms?

	Response Percent	Response Count
Very Satisfied	28.1%	9
Satisfied	**53.1%**	**17**
Somewhat Satisfied	18.8%	6
Somewhat Dissatisfied	0.0%	0
Dissatisfied	0.0%	0
Very Dissatisfied	0.0%	0
	answered question	**32**
	skipped question	**4**

32. Do you have any additional comments about the acoustics in this building?

	Response Count
	13
answered question	**13**
skipped question	**23**

33. I feel healthier working in this building (compared to other buildings I have worked in).

	Response Percent	Response Count
Strongly Agree	14.3%	4
Agree	**42.9%**	**12**
Agree Somewhat	28.6%	8
Disagree Somewhat	10.7%	3
Disagree	3.6%	1
Strongly Disagree	0.0%	0
	answered question	**28**
	skipped question	**8**

34. I feel happier working or studying in this building (compared to other buildings I have worked or studied in).

	Response Percent	Response Count
Strongly Agree	21.4%	6
Agree	**35.7%**	**10**
Agree Somewhat	25.0%	7
Disagree Somewhat	14.3%	4
Disagree	3.6%	1
Strongly Agree	0.0%	0
	answered question	**28**
	skipped question	**8**

35. I feel more productive and effective working or studying in this building (compared to other buildings I have worked or studied in).

	Response Percent	Response Count
Strongly Agree	14.3%	4
Agree	**50.0%**	**14**
Agree Somewhat	21.4%	6
Disagree Somewhat	10.7%	3
Disagree	3.6%	1
Strongly Agree	0.0%	0
	answered question	**28**
	skipped question	**8**

36. Do you have any additional comments about the how healthy this building is?

	Response Count
	11
answered question	**11**
skipped question	**25**

37. Working in a more sustainable building which uses less energy makes me feel good.

	Response Percent	Response Count
Strongly Agree	**41.9%**	**13**
Agree	38.7%	12
Agree Somewhat	16.1%	5
Disagree Somewhat	0.0%	0
Disagree	3.2%	1
Strongly Agree	0.0%	0
	answered question	**31**
	skipped question	**5**

38. I am proud to show this building to visitors.

	Response Percent	Response Count
Strongly Agree	**41.9%**	**13**
Agree	38.7%	12
Agree Somewhat	19.4%	6
Disagree Somewhat	0.0%	0
Disagree	0.0%	0
Strongly Disagree	0.0%	0
	answered question	**31**
	skipped question	**5**

39. When I show this building to visitors, I make an effort to point out some of the 'green' features of the building.

	Response Percent	Response Count
Strongly Agree	23.3%	7
Agree	**36.7%**	**11**
Agree Somewhat	30.0%	9
Disagree Somewhat	3.3%	1
Disagree	6.7%	2
Strongly Agree	0.0%	0
	answered question	**30**
	skipped question	**6**

40. The exterior of this building creates positive outdoor space people can use and appreciate

	Response Percent	Response Count
Strongly Agree	**46.7%**	**14**
Agree	**46.7%**	**14**
Agree Somewhat	6.7%	2
Disagree Somewhat	0.0%	0
Disagree	0.0%	0
Strongly Agree	0.0%	0
	answered question	**30**
	skipped question	**6**

41. The exterior appearance of this building feels appropriate for the area and improves the campus.

	Response Percent	Response Count
Strongly Agree	38.7%	12
Agree	**45.2%**	**14**
Agree Somewhat	16.1%	5
Disagree Somewhat	0.0%	0
Disagree	0.0%	0
Strongly Agree	0.0%	0
answered question		**31**
skipped question		**5**

42. How satisfied are you with the interior colors and textures of surface finishes?

	Response Percent	Response Count
Very Satisfied	**38.7%**	**12**
Somewhat Satisfied	29.0%	9
Satisfied	16.1%	5
Dissatisfied	12.9%	4
Somewhat Dissatisfied	3.2%	1
Very Dissatisfied	0.0%	0
answered question		**31**
skipped question		**5**

43. Do you have any additional comments about your impressions or the appearance of this building?

	Response Count
	11
answered question	**11**
skipped question	**25**

44. Comments: What else can you tell us about your impressions of this building and its features?

	Response Count
	15
answered question	**15**
skipped question	**21**