

# Student learning through monitoring and simulating buildings' energy use and comfort

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**ABSTRACT:** This paper shares the methods, selected projects, and reflections on the effectiveness of extracurricular student learning through monitoring and simulating buildings' energy use and occupant thermal comfort. The following applied research features occur sporadically in architecture schools and it is notable to see a research laboratory consistently maintain them over many years. The atypical method uses a research lab to simultaneously combine: extracurricular in-depth, hands-on environmental systems education; community engagement on "real world" buildings; paid student research positions in multiple disciplines; gradual acquisition of an environmental systems tool kit; and sustained consistent funding from research grants. While the previous qualities exist in architectural education, studies show they are the exception and not the norm (Carraher et al., 2017). The University of Hawaii at Manoa School of Architecture Environmental Research and Design Lab consistently goes beyond the typical professional architecture curriculum to deepen students' knowledge in and affinity for designing and operating energy efficient, comfortable buildings. The pedagogical approach and hypothesis proposes that student researchers who work in these extracurricular research positions gain a deeper understanding of building physics and are enriched by interdisciplinary student interactions, which will positively benefit their future studies and careers in a way that is not possible through curricular work only. Finally, the evidence of the student learning and positive influence on students' future careers are benchmarked against Bloom's Taxonomy, a framework for categorizing educational objectives (Bloom, 1956).

**KEYWORDS:** student learning, pedagogy, architecture research laboratory, energy efficiency, thermal comfort

## INTRODUCTION

Fossil-fuel energy use in the operation of buildings accounts for nearly 30% of global greenhouse gas emissions (Architecture, 2030, 2018). The American Institute of Architects (AIA) updated the AIA Code of Ethics and Professional Conduct in 2018 to "require architects to consider environmental impacts, and... recommend addressing specific environmental priorities like energy... conservation" (Melton, 2018). As educators, we have a responsibility to help students understand how their design decisions affect energy consumption and occupant well being in buildings.

Per the conference prompt, this paper contemplates how we, as instructors and architectural designers, can teach students to make decisions that result in a sustainable future seven generations away, without resorting to checklists. One alternative to prescriptive checklists or minimal code requirements is to provide students in professional architecture degree programs the opportunity to learn about energy efficiency and thermal comfort through hands-on monitoring of existing buildings and practice with computer simulation programs.

The uncommon pedagogical quality of the University of Hawaii School of Architecture (UH SoA) Environmental Research and Design Lab (Lab) is that it simultaneously meets the following multiple objectives through one delivery method: extracurricular student research positions in building science.

- Provide extracurricular learning opportunities rather than squeezing more building science content into an already packed architecture curriculum.
- Provide paid building science positions, acknowledging that most of the student body must work to support themselves through school.
- Develop students' ability to use equipment to monitor existing building energy use and thermal comfort.
- Build up a tool kit for use in curricular and extracurricular activities.
- Enable students to use computer simulations to compare to existing building measurements.
- Understand and reference energy and thermal comfort standards to benchmark monitored and simulated energy data.
- Communicate benchmarked data for the benefit of building occupants and developers.
- Motivate students to reduce greenhouse gas emissions by using building science content delivery methods other than lecture.
- Attract student researchers from fields outside of architecture (e.g., computer science, mechanical engineering, urban planning).
- Learn skills and problem-solving approaches from students in other disciplines.
- Conduct community engagement that meets needs of underserved populations (e.g., Department of Hawaiian Homelands).

The pedagogical approach and hypothesis proposes that the student researchers who are hired in these extracurricular research positions gain a deeper understanding of building physics and are enriched by interdisciplinary student interactions, which will positively benefit their future studies and careers in a way that is not possible through curricular work only. The effectiveness of the student learning is benchmarked against Bloom's Taxonomy, a framework for categorizing educational objectives (Bloom, 1956).

First, we describe student learning on a variety of equipment and computer simulation, benchmarking, and communication techniques. Second, we reflect upon the extracurricular student research successes, challenges, and opportunities for improvement. Finally, we consider the long-term student impact through the Lab's alumni job placement and feedback.

The processes and lessons learned should be useful to researchers and professors at other schools of architecture. This paper provides replicable examples of enhanced education that enables students to go beyond checklists by monitoring and simulating buildings' energy use and occupant comfort. The paper describes the structure of the laboratory staff, criteria for project selection, student activities and learning, and assessment of student learning

## 2.0 MOTIVATION

This section discusses the motivation for extracurricular opportunities for students to enhance knowledge in environmental systems, including lack of time in the architecture curriculum; need for student employment; and the dual benefit of community engagement projects for under-represented communities and students. Several forces shape the ongoing demand for the Lab to hire students for extracurricular work on "real-life" projects to build environmental systems knowledge. Given that 86% of A/E firms report difficulty finding employees equipped with the knowledge and skills needed to achieve the AIA's 2030 Challenge (Kwok et.al., 2014), one would think that extensive use of hands on tools and simulation programs would be a NAAB requirement for professional degree programs. At the UH SoA, the NAAB student performance criteria "Environmental Systems" is addressed in a 3-credit required course with only a brief introduction to hands on tools or building performance simulation. In depth coverage of hands on tools and simulation is likely a challenge at other schools, as architecture curricula are already "packed" (Kwok et al., 2015) and oversubscribed with important content (Nicol et. al., 2000 and Smith, 2017).

A 2017 national survey of over sixty building technology educators provides insight into other schools' practices. Integration of building technology courses with studio courses is possible but a survey shows that this is atypical (Carragher et al., 2017). Other solutions such as elective courses may address hands on tools and simulation but are inconsistently offered based on an instructors' discretion. The most frequent delivery method for building technology is lecture (Carragher et al., 2017), which would not provide the desired weeks or months of hands on experience with tools and simulation programs. Thus, extracurricular opportunities for hands on tools and simulation are pursued.

Anecdotes from architecture educators at other schools show that students sometimes volunteer unpaid extracurricular time to work with existing buildings or real clients. At UH SoA, most students do not pursue unpaid extracurricular projects because they need to work to support themselves financially, which is a trend reflected in the following study. A National Public Radio story reported "non-traditional" students are the new normal, comprising 74% of today's college undergraduate students (Nadworny, 2018). Non-traditional students' qualities include, but are not limited to: financially independent from their parents; having a child or other dependent; and being a single caregiver (Radford, 2015). The need for student employment has shaped the Lab's pursuit of grants.

Another major factor shaping the Lab's student dedication and selection of project work is the desire for community engagement and to meet the UH's commitment to be a Hawaiian Place of Learning (UH, 2019). Community engagement projects are "collaboration between institutions of higher education and their larger communities ... for the mutually beneficial exchange of knowledge and resources in a context of partnership and reciprocity" (Carnegie, 2005). The Lab's work with the Department of Hawaiian Homelands (DHHL) serves the local Native Hawaiian community. In addition, studies on engaged research show it can have significant positive impacts on faculty and student recruitment from underrepresented populations (ACSA, 2019), which has been the experience in the Lab.

Given lack of sufficient time in the curriculum, the desire for hands on (non-lecture based) learning, need for paid work, and community engagement opportunities, the Lab's solution is to pursue grants to hire student researchers to improve energy conservation and thermal comfort in buildings.

### 3. METHODS

#### 3.1 Lab organization

Researchers may be interested in the replicability of the Lab's model of hiring and project selection. For nearly two decades the Lab employed over ninety students, self-supported by funding secured from sources outside the School of Architecture. The Lab is within the UH SoA is directed by one faculty member and employs one full-time staff member, multiple graduate research assistants, hourly student employees, occasional post-docs, and occasional consulting professional engineers from outside the University. The Sea Grant College Program provides funding for about one-third of one full time position.

Students from architecture, mechanical engineering, electrical engineering, computer science, and urban planning learn to work together, which will benefit their future careers. Students work 10-20 hours per week during the school year, and 20-40 hours per week during the summer. The summer work is especially effective for students to feel ownership over a project and gain a deeper understanding of it. Students typically work at the Lab for 1-3 years and work on 1-4 projects during that time.

The Lab's staff typically select projects with one or more of the following criteria: have a real-world beneficiary who could not otherwise afford consultation on building energy and comfort; significantly reduce greenhouse gas emissions; have a significant role for students to learn about building science; and inform future net zero energy buildings in sub-tropical climates.

Real-world beneficiaries include the Department of Hawaiian Homelands, which assists the under-served population of Native Hawaiians; public K-12 schools; and the University of Hawaii, which is a public institution of higher education.

### 3.2 Selected lab projects

This section briefly describes two applied research projects in which students gained hands-on experience using tools and computer simulation for energy efficiency and thermal comfort improvement in existing buildings, and influenced future building design.

In a three-year military housing study, the Lab's staff guided a team of interdisciplinary student researchers to: identify and quantify the end-uses of energy consumed by the existing homes; determine the factors that contribute to high consumption; provide recommendations to the building management company as well as residents; and provide data to consultants for building simulation studies to determine the best retrofit options. The building management company manages over 6,700 military houses in 37 neighborhoods. Any energy saving measures adopted could add up to a significant reduction in annual energy use, cost, and greenhouse gas emissions. The project involved three stages: (1) initial energy auditing to disaggregate energy use and identify key issues; (2) blower door testing, duct testing, and monitoring energy and temperature conditions pre- and post-retrofit of the HVAC systems in three houses; (3) identifying the points of failure in the solar water-heating systems. The student roles, equipment training, and energy reductions are described in the section below.

In a separate two-year project, the Lab's team worked with the [housing agency for an underserved population] and two developers. The team studied nine homes in a [neighborhood] in [location]. Computational building simulation (via BEopt software) was used alongside monitored data onsite (e.g., electricity usage at breaker level, temperature, and humidity levels of nine homes) to identify and quantify potential future design strategies and technologies to reduce energy and improve thermal comfort in existing homes and influence the design of hundreds of future homes.

### 3.3 Lab tools and equipment

Through work on the above (and other) research projects, the Lab's staff and outside professionals trained students to use tools to study existing buildings' energy use and occupant comfort. This section describes why students' hands-on tool use is valuable; how students learned to use physical and computational tools on the two projects above; how the Lab accumulated a tool kit over time; how students understood the significance of their work by comparing gathered data to energy and comfort standards; and how students learned to communicate their analyses to various audiences.

A paper on a tool kit for passive house education suggests tools that enhance learning outcomes and provide validation of design decisions for architecture faculty and students (Kwok, 2015). Of the six tools listed, Lab faculty and students acquired and used four of the tools on existing building work including: blower door; carbon dioxide meter; infrared camera; and data loggers. We plan to incorporate the suggested infrared temperature sensors into our suite of tools. For over two decades and dozens of projects, the Lab has built up a kit of physical tools that students use on projects including: energy submetering equipment (eGauges and current transducers); weather stations; airflow sensors (anemometers); globe thermometers; pressure differential sensors; water flow gauges; and illuminance meters.

#### 3.3.1. *Tools to measure existing military housing envelope performance and hvac energy use*

This section describes how student researchers learned the significance of their hands-on equipment use by comparing gathered data to energy and comfort standards.

On the existing military housing project the interdisciplinary team conducted blower door tests to measure air tightness and compared it to the performance standards in the construction

documents' specifications (see Fig. 2). In addition to learning to use the blower door themselves, the students also witnessed a blower door test by a Home Energy Rating System (HERS) rater. The students also used an infrared camera to identify locations in the façade with inadequate insulation and found that at the edge of the attic insulation had been pushed back to install cables but never replaced (See Fig. 1).

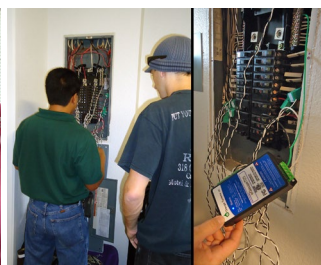
College of Engineering students monitored electricity, managed energy use data, and compared it to regional energy use data to identify unexpectedly high consumption. The Information and Computer Sciences team members imported vast quantities of fine-grained historical metering data into a database for further analysis with their open source software. The existing building data collected informed a separate consultant's inputs to a computational whole-building energy simulation, which was then used to compare various energy efficiency improvement options for retrofitting the structures.



**Fig. 1.** Student researcher using infrared camera to identify thermal bridges.



**Fig. 2.** Students conducting a blower door test for airtightness.



**Fig. 3.** Students watch a professional electrician install eGauges to submeter energy use.

### **3.3.2 equipment for energy and comfort monitoring at department of Hawaiian homelands**

This section describes how student researchers set up data gathering equipment and learned the significance of their hands-on equipment use by comparing gathered data to energy and comfort standards. Students also used the data to inform their computational models for the improvement of the current and future DHHL residents. The Lab's student researchers were trained in building monitoring, data analysis, and computer building performance simulations. Their research data and recommendations were shared with participating homeowners, DHHL, and housing builders.

An electrician taught electrical engineering students and architecture students to submeter electricity using eGauges and current transducers (see Figure 3). Submetering the breaker panel measured whole house use: AC compressor; AC air handler; clothes dryer; water heater; kitchen refrigerator; and photovoltaic system. "Other" loads were calculated by subtraction from the whole house use and included lighting and plug loads (any devices plugged into an outlet, e.g., extra refrigerators, TVs, other electronics, countertop oven, etc.). Data was recorded at one-minute intervals.

The Electrical Engineering students set up the eGauges to be remotely accessed via the Internet. The Information and Computer Science (ICS) students created a Python data pipeline to remotely access the eGauges and download the data and store it in a PostgreSQL database at the University campus. The ICS students also automated organizing the data with identifying information for later retrieval and graphing by architecture students. The ICS and Architecture students plotted the energy end uses in "R", MS Excel, and/or Tableau.

The architecture students compared the houses' energy use to other comparable houses using energy use intensities from a research paper studying a nearby housing development and from the State Energy Office. In addition to learning tools, by examining the disaggregated energy

use students learned to identify large differences in air conditioning and plug load energy use based on user behavior. This informed the energy efficiency measures they would later test with whole building energy modeling (described in the forthcoming computation section of this paper).

Architecture students deployed HOBO data loggers to record the temperature and humidity in the nine existing houses by selecting their locations and launching them (see Fig. 3). The information was collected, managed, and graphed, similar to above. Temperature and humidity were measured in four rooms inside each house and one outdoor location out of direct sunlight. In order to create one file of observed outdoor temperature and humidity, staff and students discarded the high and low readings and averaged the readings from multiple sensors. HOBO data loggers collected temperature and humidity in 15-minute resolution and staff and students manually downloaded data during site visits over the period of about a year. In addition, nine weather stations were installed throughout the neighborhood.

The students compared the data collected from the data loggers above to the ASHRAE 55 Standards for Thermal Comfort for conditioned spaces and the Adapted Comfort Standards for naturally ventilated spaces. The students graphed the monitored temperatures for each house according to the predicted mean vote value for conditioned houses and adaptive comfort chart for the natural ventilated house. The ICS students used the adaptive comfort code on GitHub for University of California, Berkeley's Center for the Built Environment to process and quantify the percentage of monitored hours considered comfortable (Hoyt et. al., 2017). The ICS students accommodated requests for specific graph colors for comfortable and uncomfortable hours, and quantified the percentage of time for each. The staff and students used ASHRAE 55 graphs correlating air speed and temperature perception to further inform the potential for improved thermal comfort using ceiling fans.

### **3.4. Simulation: whole building energy modeling**

Computation building performance simulation includes multiple types of analysis, including whole building energy modeling. While architecture students in a first professional degree program may learn energy modeling at an "awareness" level in required coursework, they probably would not achieve the "ability" level of comprehension without having an elective course or extracurricular activity. The Lab provides students an extracurricular research employment in which they learn to compare the existing physical building monitored data to energy models, CFD model, and established standards, such as the energy code and thermal comfort standards. The simulation iterations encourage students to be curious and develop their intuition about energy use and comfort in buildings.

Based on monitored data and with guidance from staff, students formulate hypotheses about strategies to reduce energy use or improve occupant comfort. For example, the section above describes a project with multiple houses' energy submetering and temperature and humidity monitoring. Under the guidance of an architect and engineer, students from Architecture and Mechanical Engineering created whole building energy models to: 1) compare to actual monitored energy use, temperature, and humidity data gathered from the existing houses; 2) create an energy model for comparison to represent a house that meets the new State of Hawaii energy code; 3) identify and quantify potential future design strategies and technologies to reduce energy and fossil fuel use and improve thermal comfort; 4) develop a speculative future net-zero site energy design; 5) communicate potential energy efficiency opportunities to developers, builders, and residents for consideration for inclusion in future thousands of homes planned for development. Testing potential future design strategies developed students' intuition most because of the structured process of changing one variable and understanding the resulting impact on energy use. Students referenced the Building America Simulation Protocol (NREL, 2014). The following anecdotes about the process demonstrate how students developed their intuition about energy use by changing models inputs and seeing the difference in energy use. We also describe how staff and students addressed challenges along the way.

For the first step, staff trained students to use BEopt, a software tool developed by the National Renewable Energy Laboratory (NREL) that uses the EnergyPlus simulation engine (DOE). Students created the energy models using the houses' construction documents and compared the monthly and annual energy use to the monitored monthly energy use. When some houses' simulated and monitored data were dissimilar, the students examined differences and concluded that the actual number of occupants and plug loads were higher, based on visual observation during site visits. Students were able to adjust the hot water use and plug loads in the energy models so that the simulated and monitored monthly energy use was similar. Students also followed guidance from ASHRAE 14 in calibrating the energy model. This gave the team confidence that the simulations reasonably represented the actual condition and were useful for testing design improvements.

In the naturally ventilated house, the students used the simulated indoor temperature and the weather file temperature to create the ASHRAE 55 adaptive comfort graph (the graphing method is described in the section above). We compared the percentage of time considered comfortable in the simulated and monitored data sets and found them to be quite different. After trying to determine what caused the difference, we discovered the window opening control thresholds in the simulation program needed to be adjusted to better represent the actual window-opening schedule. After this adjustment, the observed comfort and simulated comfort were reasonably similar.

## 4.0. RESULTS

### 4.1. Current student learning successes through extracurricular research

In this section of the paper, we reflect upon the ways in which the Lab successfully serves student needs in terms of lessons that are applicable to other architecture researchers.

1. The Lab enhances building science learning through hands-on study of existing buildings while performing research with tangible community benefit. For reasons previously mentioned in this paper, creating time for students through paid research positions is necessary to get students "in the door". Studies and student feedback shows performing research with real-life beneficiaries motivates students, particularly the engineering students who often have theoretical assignments.
2. The Lab is a growing resource to the School of Architecture. By purchasing equipment with various projects' funding over time, we have built a tool kit, which is a resource for faculty, students, and even other departments. Students are able to work with equipment to which they would not otherwise have access.
3. Students learn soft skills through communicating with students in other disciplines and learn management skills by organizing in-house teams and work flows.
4. The Lab meets students' employment needs by providing paid work in their area of study, with flexible hours during busy periods in the school year.

### 4.2. Current challenges to student learning through extracurricular research

In this section of the paper, we reflect upon challenges and potential mitigations to better enhance student learning in the extracurricular academic research environment.

1. The heavy course load in a professional degree program limits architecture students' time for work. Potential solutions include conducting work in the Lab as a course for credit, such as an undergraduate capstone project.
2. The required architecture coursework has limited physics and computation courses so students must enhance their knowledge of those subjects on the job. Our approach is for staff to offer informal refreshers and formal training sessions (1 hour) on subjects when we see that there is a gap in student knowledge.
3. The project-based funding provides a valuable, positive service, but has some challenges. First, the topic of the project determines the types of equipment and computer simulation to which the current students are exposed. There is limited knowledge transfer between

“generations” of students. One way to address this is through “tool training days” where student researchers practice using the Lab’s tools.

4. Student researchers’ employment is limited to a few semesters, which makes continuity on project work a challenge. To address this, all digital files are stored on a shared server. The staff students at the Lab address continuity of knowledge and file locations through explanatory videos for the internal lab audience. The ICS students also post versions of code and their explanations on a web-based version-control and collaboration platform for software developers called GitHub (Github, 2018). These records make it easier for staff and students to recall, recreate, and build upon past work.

### 4.3. Pedagogical assessment using bloom’s taxonomy

In this section, we examine evidence of student learning or positive influence on students’ future careers by benchmarking student experiences using the Bloom’s Taxonomy educational objectives framework (Bloom, 1956). Bloom’s Taxonomy describes a hierarchy of educational goals, progressing from knowledge-based goals, to skills-based goals, and affective goals. In this section, we describe how selected student researchers in the Lab progressed, meeting all three educational goals.

First, the cognitive, knowledge-based goals include knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, 1956). One example is a student who evaluated the monitored temperature and humidity and selected, compared, and graphed the ASHRAE 55 thermal comfort criteria for either conditioned or naturally ventilated buildings. A second example of this is an ICS student researcher with a software engineering background who developed the thermal comfort survey (in a project not described in this paper). The student applied his knowledge of programming to create a thermal comfort survey and analyze its responses, which was outside of his academic discipline and required comprehension and synthesis of multi-disciplinary knowledge.

Second, the affective, emotion-based goals include receiving, responding, valuing, organizing, and characterizing (Bloom, 1956). Because the student researchers often meet the people who benefit from the [Lab’s] projects, the students are often motivated and emotionally invested in the work. Students report that it is rewarding and fulfilling to see how the results of their work impact the building occupants and building developers. When conducting skills-based learning, such as existing building data collection or computer simulation, students showed eagerness and initiative in self-organizing to complete the work based on discrete skills they wanted to learn. Students also showed that they can organize the energy and comfort analyses and ideas, relate them to their own experiences, then hypothesize and test potential improvements.

Third, the psychomotor, action-based goal describes the ability to physically manipulate a tool or instrument, such as a hand or hammer, and usually focuses on a change in development in behavior or skills (Bloom, 1956). When considering equipment such as the computational whole building energy model, one student achieved a level of “mechanism”, the intermediate stage in a complex skill where the process of running parametric models and graphing results is habitual and can be repeated with some confidence and proficiency. When considering equipment such as the HOBO data loggers, the ICS students achieved a higher level of learning. Their data collection, organization, and retrieval skills are well developed and they modified the process to fit different buildings, types, or amount of data.

Quotes from students show evidence of learning using knowledge-based, emotion-based, and action-based goals. All of the following quotes demonstrate a growth in attitudes to valuing energy-efficient, comfortable design. The first two students demonstrate action-based, psychomotor skill development using equipment to study existing buildings.

“Working at the Lab really rounded out my experience at UH by adding great hands on experience to my mainly theoretical classroom studies. Besides training on the tools and techniques used in energy management it also allowed me to touch on subjects I never



got in my area of study such as computer simulation and modeling, database analysis and management, and behavioral psychology related to energy use and comfort. This took my experience level far beyond what I was expected to know when I began working after graduation.” – Former lab graduate student researcher from Urban Planning

“While studying at SoA, I was lucky to be part of the Lab team, and obtain so much knowledge and skills through taking part in blower door tests, full scale experiment of measuring air movement, energy modeling and wind tunnel testing. This knowledge and skills helped me to fulfill my thesis and is an invaluable resource for me in teaching sustainable architecture design in my home country.” – Former lab graduate student researcher from Architecture

In describing the lab training and career, another former student demonstrates comprehension and analysis using the building performance simulation software. The former student also demonstrates an emotional reaction with an affinity for the process of diverse student backgrounds and disciplines.

“The Lab has offered the most significant exploration and experience in BIM technology and advanced sustainable design. Indeed the Lab [had] great cultural and disciplinary diversity, showing leadership initiative in a built environment, with instructors and students working collaboratively.” – Former lab graduate student researcher from Architecture

## CONCLUSIONS

This paper shares examples of interdisciplinary students’ extracurricular applied research in building science through funded applied research in an academic lab. This is one method for students to develop the desire and skills to create tomorrow’s net zero energy buildings. The lab’s senior researchers guide architecture, engineering, computer science, and planning student researchers through existing building energy and thermal comfort monitoring as well as computer whole building energy simulation. Student researchers learn to use hands-on tools such as a blower door, carbon dioxide meter, infrared camera, and data loggers. Over time, the Lab built up a kit of physical tools that students used on projects including: energy submetering equipment (eGauges and current transducers); weather stations; airflow sensors (anemometers); globe thermometers; pressure differential sensors; water flow gauges; and illuminance meters. The student researchers also learn to collect, organize, and visually communicate the energy and comfort data they gather, and compare it to existing standards such as [energy code], ASHRAE 55, and ASHRAE 14. The student researchers develop their intuition when creating whole building energy models of the buildings they monitored. Students develop energy models through the stages of calibration, energy code compliance, individual parametric energy efficiency measure runs, combined proposed design, and on-site energy generation to create a net-zero energy building. The paper also reflects upon the Lab’s structure and pedagogy highlighting successes and giving suggestions for improvement. Finally, the evidence of the student learning and positive influence on students’ future careers are benchmarked against Bloom’s Taxonomy, a framework for categorizing educational objectives (Bloom, 1956). Students demonstrate various depths of learning in three categories. Students address knowledge-based goals by quantifying building energy by end uses and comparing it to regional averages, or by graphing monitored thermal comfort monitored data and comparing it to ASHRAE 55 PMV or Adaptive Comfort standards. Emotion-based goals are addressed through students’ initiative in pursuing careers in building. Action-based goals are considered through students’ skills, such as using the data loggers. Overall, the paper describes a working example of a funded, extracurricular applied research lab’s ability to deepen students’ knowledge in and affinity for designing and operating energy efficient, comfortable buildings.

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**REFERENCES**

- ACSA. White Paper on Assessing the Quality of Architectural Research and Scholarship. 2019.
- Architecture 2030. "Why the Building Sector?" Accessed December 17, 2018. [https://architecture2030.org/buildings\\_problem\\_why/](https://architecture2030.org/buildings_problem_why/)
- Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., Krathwohl, D. R. 1956. Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain. New York: David McKay Company.
- Carnegie Foundation for the Advancement of Teaching. Community Engagement Classification. 2005.
- Carraher, E., Smith R., Tripeny P., Young R. 2017. Building Technology within a New Architecture Curriculum. Building Technology Educators Society Proceedings.
- DOE. EnergyPlus software. <https://energyplus.net/>
- Hoyt, T., Schiavon, S., Piccioli, A., Cheung, T., Moon, D., and Steinfeld, K. 2017. "CBE Thermal Comfort Tool." Center for the Built Environment, University of California Berkeley. <http://comfort.cbe.berkeley.edu/>
- Github website. "Center for the Built Environment Comfort Tool for ASHRAE-55". Accessed August 11, 2018. [https://github.com/CenterForTheBuiltEnvironment/comfort\\_tool](https://github.com/CenterForTheBuiltEnvironment/comfort_tool)
- Kwok, A. et al, 2014. & Architecture 2030. <http://www.architecture2030.org/> 2013.
- Kwok, A., Grondzik, W., Klingenberg, K., and Kernagis, M. 2015. "Tool kit for passive house education: Questions, methods, tools." In Future of Architectural Research (Proc. 2015 ARCC Conference on Architectural Research—Chicago), 671-677. Architectural Research Centers Consortium: Chicago, IL.
- Melton, P. 2018. "AIA Ethics Code Now Covers Sustainability in Depth." Building Green, 27(10). <https://www.buildinggreen.com/news-analysis/aia-ethics-code-now-covers-sustainability-depth>
- Nadworny, E. "Today's College Students Aren't Who You Think They Are." Accessed September 4, 2018. <https://www.npr.org/sections/ed>
- NREL. Building America Simulation Protocol. 2014.
- Radford, A., et al. "Demographic and Enrollment Characteristics of Non-traditional Undergraduates: 2011-12." Web Tables U.S. Department of Education NCES 2015-025. <https://nces.ed.gov/pubs2015/2015025.pdf>
- Smith, R., Moore K., Workman J. 2017. Designing Curriculum for Building Science. Building Technology Educators Society Proceedings.
- University of Hawaii, "Institutional Learning Objectives" <http://manoa.hawaii.edu/undergrad/oavcue/institutional-learning-objectives/> last accessed March 10, 2019