Implementing High-Performance Building Codes:
A Hands-On Curriculum for Undergraduate Architecture Education

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ABSTRACT: This paper presents a novel approach to architectural education, focusing on the integration of hands-on building commissioning exercises within the curriculum to enhance undergraduate students' understanding of high-performance building codes and sustainable design practices. The course was structured into four modules: Indoor Air Quality, Thermal Comfort, Daylighting and Visual Comfort, and Building Envelope Efficiency. Each module combined theoretical lectures with practical applications, allowing students to engage directly with real-world environments. Observations indicated a significant improvement in students' comprehension and test scores compared to traditional lecture-based methods. This shift towards experiential learning not only deepened students' theoretical knowledge but also developed their practical skills in sustainable architecture. The approach demonstrates the effectiveness of hands-on learning in architectural education, preparing students to meet the challenges of sustainable design in their professional futures.

KEYWORDS: High Performance Buildings, Building Commissioning, Building Energy Codes, Energy-efficient Buildings Standards, Architectural Education

1. INTRODUCTION

A gap exists in conventional architectural education, which often emphasizes design and aesthetics while sidelining practical, sustainability-focused aspects like energy efficiency and environmental impact. This educational disconnect limits the ability of upcoming architects to effectively contribute to the sustainable development goals. To address this gap, there is a need for an integrated approach that combines theoretical knowledge with practical applications, particularly in the context of high-performance building codes.

This paper introduces an innovative educational framework developed for a net-zero energy class, which aims to bridge this gap. The framework emphasizes hands-on building commissioning tasks, drawing inspiration from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 0.2-2015 [1]. The curriculum is structured to provide students with in-depth lectures on topics such as indoor air quality codes, thermal comfort, daylighting, and ASHRAE 90.1 standards [2]. Following each lecture, students engage in practical tasks, surveying a classroom environment to apply their newly acquired knowledge.

The hands-on tasks are carefully designed to integrate seamlessly into the curriculum. Students work in teams to examine various aspects of the building environment, including indoor air quality, thermal comfort, daylighting and glare, employing tools like thermal imaging to evaluate insulation and air filtration. This practical approach not only ensures the application of theoretical knowledge but also fosters collaborative learning and critical thinking.

The impact of this hands-on approach on student learning has been significant. It has not only improved student engagement but also enriched their understanding of high-performance building codes. By effectively elevating theoretical knowledge to practical application, students are better prepared to contribute to sustainable architectural practices. The findings from this approach suggest that such educational frameworks have the potential to transform architectural education, making it more relevant to contemporary challenges in sustainability.

Moreover, the implications of adopting such frameworks extend beyond the classroom. They signify a shift in architectural education towards a more holistic approach, where sustainability is not just an optional module but a core component of the curriculum. This shift is essential for preparing future architects to play a pivotal role in creating sustainable and resilient built environments.

In conclusion, the integration of hands-on commissioning tasks in architectural education, aligned with high-performance building codes, is not only innovative but necessary. It paves the way for a new generation of architects who are not only skilled in design but also adept in creating buildings that are environmentally responsible and sustainable.

2. METHODOLOGY

The objective of this research was to evaluate the effectiveness of hands-on building commissioning tasks similar to the tasks detailed in ASHRAE's Guideline 0.2-2015, in enhancing undergraduate architecture students' understanding of high-performance building codes. The study adopted a multi-dimensional approach, involving both theoretical instruction and practical application. The curriculum was embedded within a net-zero energy class and aimed to transition students from a traditional lecture-based learning model to an interactive, hands-on approach.

Over the course of the semester, the class was divided into four modules, each focusing on a critical aspect of high-performance building codes: Indoor Air Quality, Thermal Comfort, Daylighting and Visual Comfort, and Building Envelope Efficiency. After a series of lectures in each module, students were tasked with commissioning activities, which involved surveying and evaluating one classroom environment. The parameters examined during these commissioning tasks were selected to align closely with the high-performance building codes and standards taught in the lectures.

Each module employed standardized instruments and research-grade equipment to ensure the consistency and reliability of the data gathered in commissioning one classroom within the school's building. The findings from these commissioning tasks were then compared to the high-performance building codes to assess compliance and identify areas for improvement.

One particularly engaging commissioning exercise for the students was the use of thermal photography through a drone, which captured their interest due to the innovative use of technology. This method was employed in the Building Envelope Efficiency module, where students utilized the drone to take thermal images of the building. The focus was on examining the thermal performance of the building envelope, specifically targeting walls and roofs. This hands-on approach not only provided a dynamic learning experience but also offered a practical perspective on assessing and understanding the thermal efficiency of architectural structures.

2.2 INDOOR AIR QUALITY MODULE

In the Indoor Air Quality module, students used Greywolf Sensing Advanced Sense meters, calibrated for precision by the manufacturer, to measure a range of air pollutants in a design studio over a 24-hour period. The instruments were calibrated to measure concentrations of Carbon Dioxide (CO2), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Ethanol (EtoH), Total Volatile Organic Compounds (TVOC), Particulate Matter 2.5 (PM2.5), and Particulate Matter 10 (PM10). Please see table one for an example measurement by the students over a 24-hour period. See Figure 1.

Students were instructed to compare their findings with established codes such as Environmental Protection Agency (EPA) guidelines [3], Occupational Safety and Health Administration (OSHA) standards [4], and the Leadership in Energy and Environmental Design rating system (LEED) [5] . By aligning the collected data with these established codes and standards, students were able to assess the level of compliance of the classroom environment and identify areas requiring improvement. See Table 1.

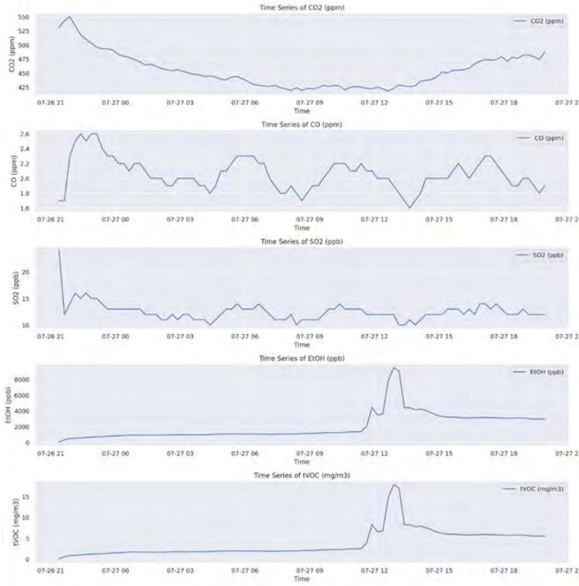

Figure 1: A graph of partial IAQ data collected by the students. The graphed data include CO2, CO, SO2, EoTH, and tVOC levels over 24-hour period.

Table 1: Partial list of the Measured pollutants by the students and comparison to the recommended limits by OSHA, EPA, and LEED. OSHA limits are based on 8-hour period.

Gas	AVG	OSHA	EPA	LEED
CO (ppm)	2	50	9	--
CO2 (ppm)	454	5,000	--	1,000
SO2 (ppm)	0.012	5	0.075	--
EtOH (ppm)	2	--	--	--
tVOC (mg/m3)	0.9	--	0.5	0.25

2.3 THERMAL COMFORT MODULE

In the Thermal Comfort module, students utilized research-grade instruments within a classroom to measure factors influencing human thermal comfort, consistent with their study in the Indoor Air Quality module. See Figure 2 for a list of the devices used to collect thermal comfort and IAQ data. They employed a heat index meter for data on air temperature and mean radiant temperature, while also assessing air speed and humidity. These parameters were carefully chosen to correspond with ASHRAE Standard 55, which outlines the thermal environmental conditions for human occupancy. Utilizing the Predicted Mean Vote (PMV) method outlined in ASHRAE 55 [6], students analyzed their findings, gaining a comprehensive understanding of how environmental factors contribute to thermal comfort in architectural spaces.

Figure 2: Equipment setup used by the students to collect data required for accessing thermal comfort and IAQ in the design studio. List of the devices: 1-Heat Index Meter, 2-Air Velocity Meter, 3-Gases Meter, 4- Particulate Matter Meter.

For their thermal comfort analysis, students measured conditions at three classroom points: adjacent to the window, centrally, and away from the window. Utilizing the Center for the Built Environment's Thermal Comfort Tool from the University of California [7], they applied the PMV method from ASHRAE Standard 55 (see Figure 3). Near the window, the air temperature and mean radiant temperature (MRT)—determined using a black globe thermometer—were both 20°C. The air speed was 0.1 m/s with a relative humidity of 37%. Accounting for a seated, quiet activity level (1 met) and typical classroom attire (0.61 clo), the PMV result was -1.96, suggesting a cooler than comfortable condition with a 75% probability of dissatisfaction (PPD). These conditions failed to meet ASHRAE Standard 55-2020's compliance, aligning with student feedback gathered through discussions and informal surveys indicating discomfort.

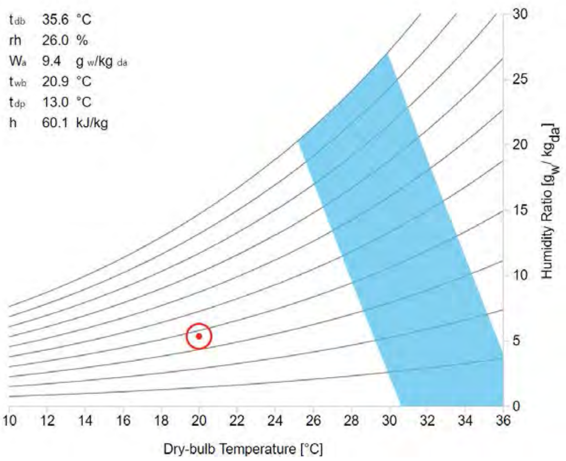

Figure 3: Psychrometric Chart utilizing PMV method showing cold sensation at the location next to the window.

2.4 DAYLIGHTING & VISUAL COMFORT MODULE

In the Daylighting and Visual Comfort module, an emphasis was placed on the pivotal role that daylighting and glare control play in creating comfortable and energy-efficient buildings. Understanding the balance between natural light benefits and the potential for visual discomfort is critical in architectural design. To this end, students engaged with research-grade equipment to evaluate the lighting conditions in the classroom, the consistent focus of the course's practical modules. They measured illuminance levels using a Konica Minolta Illuminance Meter to objectively assess the quality of daylight within the room (see Figure 4).To address glare and visual discomfort, students utilized both a luminance meter and a camera with a fisheye lens, capturing a wide view of the room's lighting scenario [8]. See Figures 5-7. The data obtained provided valuable insights into the interplay of light and space, which were then carefully compared to the guidelines provided by the Illuminating Engineering Society (IES) [9], integrating established standards with hands-on learning. Therefore, allowing the students to understand the practical implications of daylighting design and create strategies for balancing natural light benefits against the risk of visual discomfort.

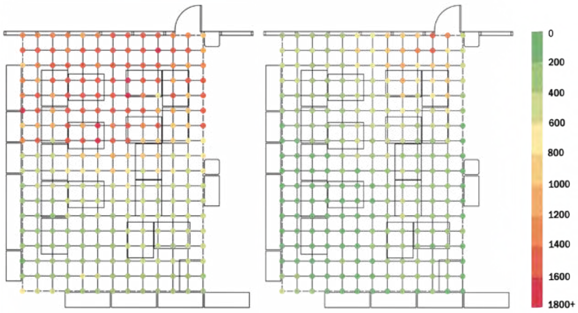

Figure 4: Daylight availability survey of the examined studio. The collected data show the daylighting availability in lux in the morning (left) and late afternoon (right).

Figure 5: A 180-degree fisheye view for glare analysis.

Figure 6: Glare analysis of the examined view. Glare sources are highlighted in green.

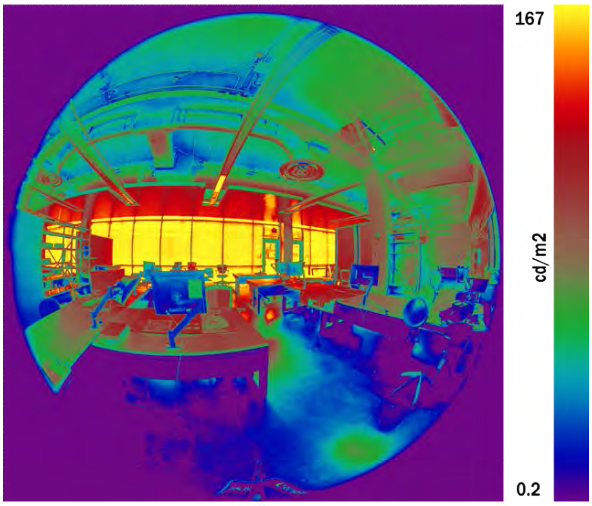

Figure 7: luminance map of the examined view.

2.5 BUILDING ENVELOP PERFORMANCE MODULE

In the Building Envelope Efficiency module, students utilized both a handheld FLIR thermal camera and a drone-equipped thermal imaging system to conduct an in-depth analysis of the design studio's thermal integrity. This dual approach allowed for a detailed examination of temperature variations on surfaces, pinpointing problems related to air infiltration, thermal bridging, and insulation deficiencies. By analyzing these thermal images alongside high-performance building standards, students were able to critically assess the envelope's efficiency. This practical experience not only reinforced their theoretical knowledge but also highlighted the importance of meticulous envelope design in achieving energy-efficient buildings. The outcomes of this module were visually documented.

students were tasked with creating 3D thermal models using photogrammetry, a method that involves taking overlapping photographs at various angles, including straight down shots. This technique requires a series of images taken around the object at a consistent flight altitude with significant overlap—usually 60-80%—between images. These overlapping images, when processed, allow for the reconstruction of a 3D space, giving detailed insights into the thermal characteristics of the building's envelope [10]. See Figure 8.

In the Building Envelope Thermal Analysis section, alongside photogrammetry for 3D thermal modeling, students also conducted detailed examinations of the envelope using a handheld FLIR thermal camera. This device complemented the drone's broad overview by allowing close-up inspections of areas suspected to have thermal inefficiencies. By juxtaposing the wide-ranging thermal perspectives from the drone with the precise, localized data from the handheld camera, students could obtain a holistic understanding of the building's thermal performance. This dual approach provided a comprehensive assessment of the envelope's insulation effectiveness, air leakage, and potential thermal bridges. See Figure 9.

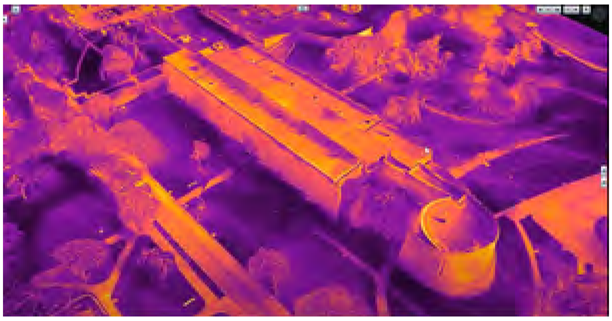

Figure 8: A thermal 3D model produced by the students to examine the thermal performance of the entire building envelope including the roof.

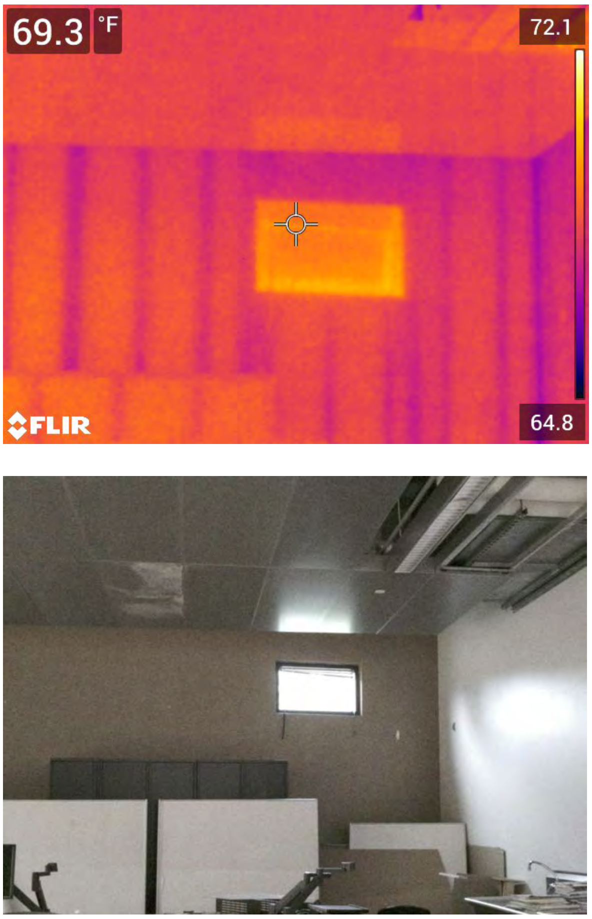

Figure 9: Top; A thermal picture taken with a handheld Flir Infrared camera. Bottom; a visible picture of the same scene. The thermal photo indicates some heat escape through the area right above the window located in the examined design studio.

3. FUTURE IMPLICATIONS AND RECOMMENDATIONS

This hands-on commissioning curriculum's success has significant implications for the future of architectural education. It suggests a shift towards more experiential learning models, which can be implemented in various architectural courses, enhancing student engagement and practical understanding of sustainable design principles. Recommendations for future courses include establishing partnerships with industry professionals and organizations for resource support, integrating newer technologies to keep pace with industry standards, and conducting formal studies to quantitatively measure the impact of such pedagogical approaches.

4. STUDENT FEEDBACK AND REFLECTIONS

Although formal data collection was not conducted, anecdotal observations and informal discussions indicated that students found the hands-on activities enriching and more engaging than traditional lecture-based learning. Many students expressed that the practical application of theoretical concepts greatly enhanced their understanding of high-performance building codes and sustainable design practices. The interactive nature of the exercises, particularly the use of innovative technologies like drones for thermal photography, was frequently cited as a highlight. This feedback underscores the value of experiential learning in architectural education, suggesting a positive reception and a deeper level of engagement from the students.

5. LIMITATIONS AND CHALLENGES

This section addresses the limitations and challenges encountered during the implementation of the hands-on commissioning curriculum. One of the primary challenges was the resource-intensive nature of the approach, requiring access to specialized equipment and tools, which may not be readily available in all educational settings. Additionally, the time required to conduct hands-on activities was significantly greater than traditional lecture-based methods, posing scheduling challenges. There was also a learning curve associated with the use of technology, such as drones and advanced sensing equipment, which required additional training for both students and instructors. These factors, while manageable, highlight the need for careful planning and resource allocation in adopting this experiential learning model in architectural education.

6. CONCLUSION

This study's exploration into hands-on commissioning exercises as a pedagogical tool in architectural education reveals a transformative impact on student learning. The integration of practical exercises in line with high-performance building codes has not only enriched students' theoretical understanding but also significantly improved their practical skills. This was evident in the notable enhancement of their test scores. It's important to note that this observation of improved scores is based on instructor assessments, as a formal analysis of the test results was not conducted. Nonetheless, this perceived enhancement in performance is a promising indicator when compared to the outcomes of past student groups who were primarily exposed to traditional lecture-based methods.

Crucially, the students' ability to apply complex theoretical concepts in real-world scenarios signifies a deeper level of learning. By participating in commissioning activities, students developed a nuanced understanding of sustainable design practices, a skillset indispensable in the modern architectural landscape. Their engagement in tasks like thermal imaging, air quality assessment, and daylighting analysis provided them with hands-on experience that is often lacking in conventional architectural education.

Furthermore, the method fostered a collaborative learning environment, enhancing students' teamwork and problem-solving abilities. These are key competencies that will benefit them in their professional careers. The integration of innovative technologies, such as the use of drones for thermal photography, not only captivated the students' interest but also prepared them for the evolving technological advancements in the field of architecture.

The success of this educational approach advocates for a paradigm shift in architectural education, where experiential learning becomes a core element of the curriculum. By bridging the gap between theory and practice, this method prepares students to be not just designers but architects capable of contributing significantly to sustainable and resilient built environments.

This hands-on commissioning curriculum has proven to be a necessary and innovative approach in architectural education. It has paved the way for a new generation of architects, equipped with a robust understanding of high-performance building codes and a passion for sustainable design. This approach is integral for cultivating architects who are not only adept in design but are also champions of environmental responsibility and sustainability in their professional practices.

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