Building Technology Educator's Society

Volume 2021 Article 8

6-2021

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Recommended Citation

Martinez-Molina, Antonio; Brown, Kelsey; Awolusi, Ibukun; and Alamaniotis, Miltiadis (2021) "The Impact of Different Building Assemblies on Thermal and Air Quality Performance: An Experimental Student Project in an Architectural Course Comparing City Building Code Versus Passivhaus Standard," *Building Technology Educator's Society*: Vol. 2021 , Article 8.
DOI: https://doi.org/10.7275/w3zn-gw65
Available at: https://scholarworks.umass.edu/btes/vol2021/iss1/8

The Impact of Different Building Assemblies on Thermal and Air Quality Performance: An Experimental Student Project in an Architectural Course Comparing City Building Code Versus Passivhaus Standard.

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Abstract

Building technology can promote environmental sustainability and is a critical component of energy conservation. Well-functioning indoor microclimates do not only affect buildings, however—occupant health must also be considered. Recent research has demonstrated that sustainability and occupant health go hand-in-hand when designing or retrofitting a building. What is the best way to accomplish these goals and to effectively preserve a balance among architecture, efficiency, and health when designing and constructing new buildings? What is then the best approach to integrating this building technology knowledge into an architecture course? This research-educational project introduced an investigation of the effects of two different building assembly strategies (located in the hot and humid climate of San Antonio, TX) to a building science course. With faculty guidance, architecture students designed (and will build next semester) two distinctive testbeds following the San Antonio building code and Passivhaus standard, a standard focused on energy efficiency and healthy architecture. The indoor air temperatures, relative humidity levels, and R-values of both structures were simulated and compared during class. The effects of the outdoor environment parameters like air temperature, relative humidity, solar radiation, and wind speed were also explored. The results underline the positive effect of the Passivhaus standard envelope, which considerably reduces the indoor temperature as compared to the city code assembly. Additionally, indoor air quality parameters such as carbon dioxide (CO_2), particle concentration ($PM_{2.5}$ and PM_{10}), total volatile organic compounds (TVOC) and formaldehyde (HCHO), will be also measured and analyzed once the building phase is complete.

Keywords: Thermal Performance, Indoor Air Quality (IAQ), Testbeds, Passivhaus Standard

Introduction

Building energy consumption grows year by year with the increase of built environment and the increasing demand for high level indoor environments [1,2]. The energy consumption for space cooling in Texas (ASHRAE climate zone 2A) is estimated to be over 15 million Btu per year, which accounts for 19.90% of the total energy consumption and is expected to keep growing every year [3]. However, although the space cooling consumed a very large amount of energy, the indoor temperature of a building in south Texas often reaches above 80°F in summer and falls below 65°F in winter. There are two main reasons for this poor indoor thermal environment. On one hand, due to the poor insulation property of the building envelope of residential buildings, the heat exchange through the building envelopes can reach up to 35%~45% of the total heat gain/loss of these structures. On the other hand, the air tightness of traditional envelope systems is less than ideal, creating a very leaky building skin that triggers massive infiltrations. These traditional wall assembly designs are widely used in south Texas and, unfortunately, city building codes are often not keeping up with material industry innovation and new energy efficiency standards. Since society is becoming more aware of sustainable design and building performance, it is essential to introduce and promote these important changes and improvements in the quality of higher education [4]. The growing awareness and influence of sustainability in the built environment has pushed architecture programs to incorporate sustainable design topics into the educational structure [5]. Traditional architectural and engineering teaching methodologies are primarily based on passive learning and have been frequently criticized by many authors due to their ineffectiveness in engaging students into professional practices [6]. In order to overcome this problem, many higher education institutions have approached the teaching of sustainable design in varied ways [7]. Clearly, it is necessary to introduce new pedagogies to teach and motivate students in this important topic. At present, architectural education is mainly based on Project-Based Learning (PBL), where students are asked to design and develop a proposal which follows the regular workflow implemented in a real architectural studio [8,9].

The present study explores a different learning practice by introducing an experimental project, the Ice Box Challenge, in a virtual course of sustainable design studio. The proposed learning experience seeks to engage students' knowledge on building science in the design, construction and assessment of two testbeds (designed following the San Antonio City code and Passivhaus standard). This article focuses on phase 1 of this educational and research initiative, course integration and design. Phase 2 (construction and assessment) will occur during the 2021 summer and fall semesters and will be presented in the next BTES Conference.

Authors planned this virtual learning environment and a set of learning outcomes as a model that can serve as a catalyst of students' building physics proficiency to address building performance challenges in a local context, incorporating multidisciplinary perspectives, and stressing how everyone and everything involved in a building envelope design are extremely interrelated. Additionally, this educational design-build methodology aims to assess students' interactions and skills which were emphasized in an active learning environment such as collaborative and cooperative pedagogy.

Case Study: Virtual Studio focused on an experimental building technology project.

The Ice Box Challenge

The Ice Box Challenge is an international synergistic competition that comprises two small structures: one built to standard building codes and the other built to the high energy-efficiency Passivhaus standard. Replicating two differently designed and built complete buildings, but simplified and at a much smaller scale, each "Ice Box" contains 1,800 pounds of ice and is left outside in the sun for approximately three to four weeks. At the end of the that time, the boxes are opened, and the leftover ice is measured to determine the distinctive building enclosure performance showing which standard reduces heat gain creating a more controllable, comfortable environment. The initiative is a simple and engaging way to raise students and public awareness of the critical role of high performing building envelopes to considerably save energy, reduce greenhouse gas emissions, and combat climate change, while increasing occupant comfort and health. To generate public interest, visitors are asked to guess how much ice would remain in each box for a chance to win a prize (still to be decided). This competition has occurred in many different cities in the nation such as New York City, NY; Philadelphia, PA; Washington, D.C.; Pittsburgh, PA; and Portland, OR. However, it is worth mentioning the fact that, as far as authors are aware of, it has not happened in an area with a hot and humid climate like San Antonio, TX.

Passivhaus standard

The Passivhaus concept has developed from many influences including: pioneering North American passive solar architecture and the super insulated housing formats established in Sweden in the 1970s. From the late 1980s until the mid 1990s German researchers Wolfgang Feist, Witta Ebel and Tobias Loga further developed this concept whilst working at the Institut Wohnen und Umwelt [10]. During the design of the first Passivhaus at Kranichstein in 1991, the idea evolved into that of a super insulated construction which could effectively work with a conventional heating system [11]. The Passivhaus standard is usually known to be an ultra-low energy building performance standard, characterized by the following basic concepts:

1. superinsulation;
2. thermal bridge-free construction;
3. compact form;
4. airtight building envelope;
5. optimal use of passive solar gains;
6. mechanical ventilation with heat recovery (HRV/ERV).

In addition to optimizing the energy efficiency of the building's envelope and systems, achieving clearly defined thermal comfort criteria is considered crucial to the concept. The practical definition of a Passivhaus building states that: 'A Passive House is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply air which is required for sufficient indoor air quality – without using additional recirculated air' [12]. This functional definition suggests that the heat losses (or heat gains in our case) from a Passivhaus must be sufficiently low that only a very small amount of supplementary heating or cooling (added to the mechanical ventilation supply air) would suffice to cover the entire peak heating or cooling load.

Studio Course

This article proposed an assignment in the course Advanced Topics Studio (ARC6136), offered at The University of Texas at San Antonio in the second semester of the Master of Architecture (M.Arch.), which is a professional program. This course brings 16 students and three professors (architecture, engineering and construction science) together in a collaborative studio designed to participate in the Ice box Challenge (Figure 1).

Fig. 1. Studio course virtual environment.

Students are in charge of developing their own box design following both, San Antonio building code and Passivhaus standard. Additionally, a local builder and two Certified Passive House Designers (CPHD) intermittently participated in the course development. Everyone shared information, held meetings, and offered critiques through multiple electronic means including Zoom, Miro, and Google Drive. The studio collaboration began in January 2021, incubated by the AIA San Antonio COTE committee that has continued to provide advisors and critics to the studio and host our workshops and reviews. They offered internships to two students, further building multidisciplinary relationships. The CPHD practitioners served as role models for high-performance building practice, reinforcing for students the real-world application of their studio education. Students based their designs on a green area of the UTSA Downtown campus.

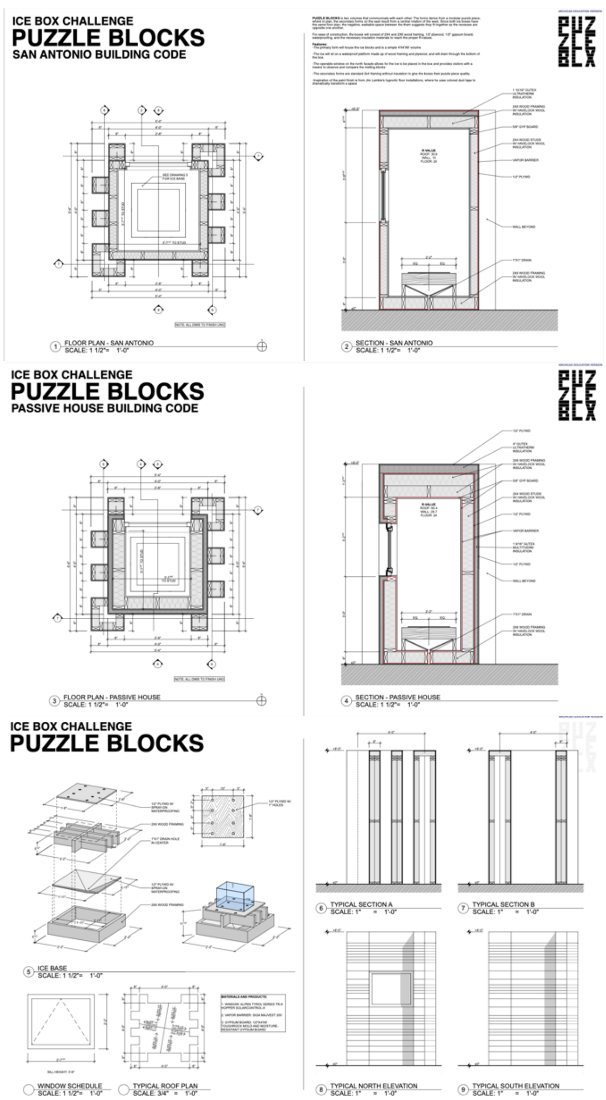

Fig. 2. Example of construction drawings of one design proposal (Source: Adam Perez)

Each student researched the site, local building city code and Passivhaus standard. Students next proposed their massing design projects, quick studies to begin to get to know their thermal performance and their problems, raised questions and provoke rapid responses. Students next launched into a set of research projects on topics including climate, daylighting, solar radiation, continuous insulation (thermal bridges), sustainable retrofits, airtightness, and hygrothermal performance. Based on the new multidisciplinary knowledge of building physics and technology, students worked on proposals for the boxes' development. Finally, individual students selected building materials and construction technologies for architectural design of their structures. Students were asked to propose design solutions and construction details (Figure 2) that would have continuous insulation, a very airtight envelope, and reduce or eliminate thermal bridges. The primary constraint was to meet both requirements San Antonio building code and Passivhaus standard, with the same indoor volume and openings' size and orientation, in order to be able to compare the boxes performance in the phase 2 of the project. The basic requirements for thermal transmittance that students needed to meet in their designs are shown in Table 1, and in the Passivhaus box the maximum thermal bridge value was Ψe = 0.01w/mK. Additionally, students needed to figure out a way of flushing out the melted ice in a safely and elegant manner without compromising the integrity of the building envelope (thermal performance and airtightness). Faculty and CPHD practitioners taught students a series of simulation software in order to reach the required performance level on their designs. Passive House Planning Package (PHPP) v.9 [13] was used to simulate the boxes performance, however, some simplifications were introduced in order to neglect some full building aspects such as mechanical ventilation. Additionally, THERM v.7 [14] was used to calculate the values of the thermal bridges in students' designs.

This multidisciplinary project has been made possible by support by the University of Texas at San Antonio (UTSA) Office of Sustainability and AIA San Antonio COTE Committee. AIA San Antonio COTE Committee contributes members' time and expertise and their facilities to support this project that prepares students for a high-performance building action that characterizes their practice. It is worth noting that the same Ice Boxes in San Antonio will be traveling through the summer to different locations within the city and other Texan cities to engage and educate the public, including Austin, Houston, Dallas, and El Paso.

Table 1. Thermal envelope assembly values (ft^2·°F·h/BTU).

	Walls	Roof	Floor	Windows
San Antonio	R-13	R-38	R-13	R-2.5
Passivhaus	R-28	R-58	R-19	R-3.5

Students Survey

One of the main goals of this initiative was to assess the students' interactions and gain a better understanding and feedback of the application of this interactive and interdisciplinary pedagogy in the education of architecture students in sustainable design. For this reason, a brief questionnaire was conducted before and after the project first phase (design), to collect the students' opinions and assess their learning experience. The main questions asked were: 1. Level of interest in high performance building envelopes before/after this course?; and 2. Will/Has this studio prepare/prepared you for professional practice?

Discussion and Learning Outcomes

This activity aims to target the sustainability scope of Sustainable Development Goals (SDG) such as *#4 Quality Education* and *#11 Sustainable Cities and Communities* [15] aiming to understand buildings that lessen their impact on our environment through energy and resource efficiency. Teaching sustainability topics is based on transmitting concepts and processes, and it requires a more interactive pedagogical process for successful learning experiences [16].

On February 13th - 17th Texas suffered the unofficially referred winter storm *Uri*, making that power grids were unable to sustain the higher-than-normal energy and heating demand from residential buildings. At the peak of the outages, at least 4.5 million Texas residents were left without electricity, leaving them without heating during a 5°F weather. In events like that, passive strategies should be able to keep indoor temperatures from dropping too low for a safe amount of time. AIA San Antonio COTE committee and UTSA School of Architecture and Planning partnered up to create a series of high-performance building design educational events in order to inform not only students and practitioners but also the local community. This studio experience and the Ice Box Challenge experiment is one of the many instructional events planned for the next few months in San Antonio, TX.

The shared virtual classroom between architecture graduate students and CPHD partitioners provides students the opportunity to see how to approach a highly efficient building design through experts' eyes, thereby broadening their education with a professional perspective. The first iteration of the studio collaboration evidenced a deficit in the students' ability to comprehend building physics and external walls' hygrothermal performance at a level expected in the sustainable professional community. The faculty collaborated on a grant proposal that funded this initiative at UTSA to elevate the ability of graduate students to design a high performing wall assembly and deliver construction documents that meet the international Passivhaus standard. By the fourth month of the collaboration, the quality of the student work had risen to a level that was recognized by the North American Passive House Network (NAPHN) [17], a national organization that reviewed students' final designs. The effects of the enhanced collaborative instruction should grow exponentially as each cohort of graduates produces new building technology professionals to spread their expertise along the state of Texas.

The studio projects focus on high performance strategies, preparing students for professional work addressing goals such as daylighting, shading, thermal comfort, airtightness, continuous insulation, etc. In the face of global warming, students learn valuable lessons about urban development from CPHD practitioners, whose expertise and knowledge have developed in response to the extreme summer heat of the region. This academic initiative helps enhance the capabilities of graduate students to work towards sustainability with help from their practitioner mentors to reflect the knowledge gained through the studio to develop their boxes, particularly focused on the South Texan climate, which suffers from extreme heat and high relative humidity values throughout the five months every year. The students provided through their designs, solutions for healthy and beautiful structures aiming to make an impact on all social and academic groups. Graduate students bring an ability to envision a sustainable future for this region and to create plans for the buildings that will support greener architectural design that can contribute to a healthier and responsible lifestyle.

Fig. 3. Examples of three design proposals (Sources: Lany Nguyen, Daniel Gonzalez, and Kelsey Williamson)

Graduate students participated in an internal design competition where CPHD experts, multidisciplinary faculty and students voted for the best and most performing design. The voting process was driven by a simplified rubric using qualitative and quantitative data. With regard to the qualitative data, aesthetics and potential community impact values were considered in the subjective opinions (Figure 3). On the other hand, quantitative data was included in the voting process based on the combination of R-value levels, thermal bridge calculations, and orientation and daylighting simulations. Ease of construction was also taken into account during the competition. Once the winner was announced, faculty began purchasing construction materials and students got involved in the assembly of the selected design (Figure 4).

Fig. 4. Some studio students working on the Ice Box Challenge phase 2 (construction and assessment).

Figure 5 shows that a large number of students thought that this sustainability learning experience would greatly improve their interest in the course topics and sustainability in general. However, students were already very interested in the course topics prior to taking the course and participating in the studio as positive responses are at 57.6% (before) and 91.9% (after), respectively.

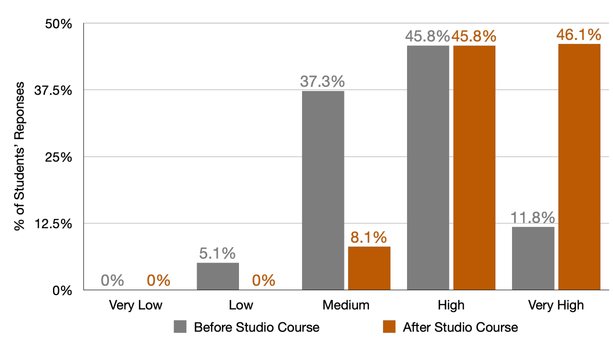

Fig. 5. Results from students to question: Level of interest in this class after this peer learning exercise?

To evaluate the success of this innovative studio, students were asked if this active learning experience will be useful for their development as professionals (considering they will be graduating on two semesters). The overall answers were again very positive, approaching 57.9% and 76.5% before and after the experience, respectively. These highly positive responses indicate the success of the pedagogical strategy by enriching the learning process and professional skills of the students (Figure 6).

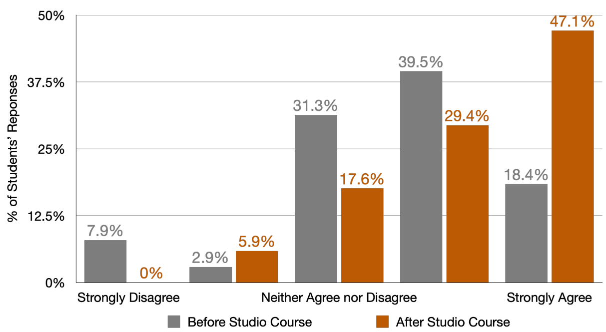

Fig. 6. Results from ST4 students to the question: You think that this tutoring has prepared you for a professional activity?

Finally, the academic team received very positive feedback while promoting this research activity, particularly focused on the community engagement aspect of it. The following quote from an officer of the Office of Sustainability of the City of San Antonio summarizes the community's opinion: *"The Ice Box Challenge is a visually appealing evidence for San Antonians that highlights the unbelievable opportunities we have to increase energy efficiency and health in buildings, which is essential both to fighting global climate change and to creating a fairer, healthier city."*

Conclusion

Analysis of the Ice Box Challenge virtual studio demonstrates that an integrated learning approach to design studio education has the potential to expand architectural education's contribution to a sustainable future. This virtual studio is in itself a sustainable initiative, a healthy low carbon alternative to comprehend and relate to colleagues around the country. This experimental studio elevates high performance architectural education, preparing Texan students for contributing to a more sustainable future through a hands-on project in architecture education. This benefit would extend to other collaborations between technical fields in the development of educational systems, such as engineering, construction management, etc. Interdisciplinary collaboration prepares students for participation in professional practice. The studio connecting students to expert practitioners prepares students to design inclusive, safe, resilient, and sustainable structures through the integration of building physics and different technical solutions. This experimental learning studio promotes healthy and sustainable societies and multidisciplinary partnerships for sustainable development by creating a virtual workspace in which our shared goals are the collaborative vehicle in a health, and climate crisis. When we introduce shared goals and objectives for designing a sustainable future, we move away from ideas of "us and them" towards the understanding that we are together in this endangered environment.

This virtual studio grants the students access that they would not otherwise have to expert colleagues in building technology and sustainable architecture. It leverages shared professional knowledge, expertise, and values to build empathy among students, and also between students and practitioners. The resulting working relationship offers the opportunity to work together towards creative solutions to complex sustainability issues. While the studio offers solutions to specific real-world issues, it also prepares students for leadership by teaching them how to work together in an integrative partnership. Authors propose this virtual learning environment and a set of learning outcomes as a model that can leverage students' shared discipline of architecture to address architecture's performance challenges, incorporating multiple perspectives, and stressing how everyone and everything are deeply interconnected.

Acknowledgements

Funding for this project was generously provided by UTSA Office of Sustainability. The authors are grateful to the students of the Department of Architecture at the University of Texas at San Antonio, for their participation in the project. The authors also acknowledge the contribution and support of staff members who helped in the design and construction of the testbeds and AIA San Antonio COTE committee.

References:

1. Walker, R. & Pavía, S. Thermal and moisture monitoring of an internally insulated historic brick wall. *Build. Environ.* **133**, 178–186 (2018).

2. Chen, B., Zhuang, Z., Chen, X. & Jia, X. Field survey on indoor thermal environment of rural residences with coupled Chinese kang and passive solar collecting wall heating in Northeast China. *Sol. Energy* **81**, 781–790 (2007).

3. U.S. Energy Information Administration. (2021). Available at: https://www.eia.gov. (Accessed: 2nd May 2021)

4. Leal Filho, W. *et al.* Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack? *J. Clean. Prod.* **232**, 285–294 (2019).

5. Boarin, P., Martinez-Molina, A. & Juan-Ferruses, I. Understanding students' perception of sustainability in architecture education: A comparison among universities in three different continents. *J. Clean. Prod.* **248**, 119237 (2020).

6. Stump, G. S., Hilpert, J. C., Husman, J., Chung, W. T. & Kim, W. Collaborative learning in engineering students: Gender and achievement. *J. Eng. Educ.* **100**, 475–497 (2011).

7. Disterheft, A., Caeiro, S. S., Leal Filho, W. & Azeiteiro, U. M. The INDICARE-model - Measuring and caring about participation in higher education's sustainability assessment. *Ecol. Indic.* **63**, 172–186 (2016).

8. Corral Manuel de Villena, I., Núñez Andrés, A., Rodríguez Jordana, J. J. & Buill Pozuelo, F. Proyecto geomático: Una aplicación práctica de integración de conocimientos. in *CIDUI Congrés Internacional de Docència Universitària i Innovació. Barcelona, 4, 5 i 6 de juliol, 2012* 1–6 (Universitat Pompeu Fabra, 2012).

9. Valls, F. *et al.* Urban data and urban design: A data mining approach to architecture education. *Telemat. Informatics* **35**, 1039–1052 (2018).

10. Institut Wohnen und Umwelt. (2021). Available at: https://www.iwu.de/1/aktuell/. (Accessed: 2nd May 2021)

11. Feist, W. *et al. Passive House Planning Package, version 8 (2013): Energy balance and Passive House Design Tool*. (2013).

12. Feist, W., Pfluger, R., Kaufmann, B., Schnieders, J. & Kah, O. *assive House Planning Package 2007: Requirements for Quality Approved Passive Houses. Technical Information PHI-2007/1 (E)*. (2007).

13. Passive House Planning Package (PHPP). Available at: https://passivehouse.com/04_phpp/04_phpp.htm#PH9. (Accessed: 2nd May 2021)

14. THERM. Two-Dimensional Building Heat-Transfer Modeling. *Lawrence Berkeley National Laboratory* Available at: https://windows.lbl.gov/software/therm. (Accessed: 2nd May 2021)

15. United Nations General Assembly. Sustainable Development Goals. (2015).

16. Barth, M. & Michelsen, G. Learning for change: An educational contribution to sustainability science. *Sustain. Sci.* **8**, 103–119 (2013).

17. North American Passive House Network. (2021). Available at: https://naphnetwork.org.