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Challenges and Opportunities of Implementing Passive House Standards in Large Residential Projects in Massachusetts

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The building sector contributes substantially to greenhouse gas emissions, which in turn exacerbates climate change in a positive feedback loop. As a result, there is an urgent need to improve energy-efficiency of buildings to lower their environmental impacts. The Massachusetts Specialized Opt-In code, which includes Passive House as a compliance path, supports the State's goals for reducing greenhouse gas emissions and promoting energy conservation. This paper examines the perception of industry professionals about implementing Passive House standards in large residential projects in Massachusetts as well as the cost impacts of implementing these standards. Through comprehensive literature review, case studies, and primary data collection via interviews with industry professionals, the analysis provides insights into the industry readiness and incremental costs associated with Passive House projects while explores the challenges and benefits of adopting these standards. The findings indicate that while there is an initial cost premium, typically ranging from 1% to 7.5%, the average cost increase is approximately 2.4%. Long-term savings and improved building performance make Passive House an attractive option for sustainable development. The study highlights the importance of industry experience and training in managing costs and achieving high-performance standards which underscores the need for continued education and collaboration among construction stakeholders. Additionally, the research underlines the critical role of policy and industry cooperation in fostering sustainable construction practices to ensure that the transition to high-performance buildings is economically viable and environmentally beneficial.

Keywords: Construction Cost, Energy Efficient, Large Residential Projects, Passive House, Sustainable Built Environment

Introduction

The push towards energy-efficient building practices is crucial in the global effort to combat climate change. The Passive House standard is recognized globally for its rigorous energy efficiency criteria which significantly reduces buildings' energy consumption while enhancing indoor comfort. The concept of Passive House (Passivhaus) originated in the late 1980s through a collaboration between Dr. Wolfgang Feist in Germany and Bo Adamson in Sweden. The methodology aimed to create buildings with ultra-low energy consumption while ensuring high indoor comfort. The first Passive House was constructed in Darmstadt, Germany, in 1991, which became a global benchmark for energy-efficient construction. In the early 2000s, Passive House principles were introduced to North America. The key principles of Passive House design focus on creating highly energy-efficient and comfortable buildings through strategies such as superinsulation, airtight construction, high-performance windows and doors, and the elimination of thermal bridges. Additionally, these buildings utilize mechanical ventilation with heat recovery and optimize solar orientation to maximize passive solar gains while minimizing energy consumption (Klingenberg, 2023a), (Klingenberg, 2023b).

While the Passive House standard offers a proven framework for achieving energy efficiency and comfort, its adoption often raises questions about cost implications. A growing body of research has sought to quantify these costs, shedding light on the financial challenges and opportunities associated with implementing high-performance building standards. These studies provide valuable insights into how design strategies, industry experience, and policy incentives influence the feasibility and affordability of energy-efficient construction. In 2021, Barry conducted a study on 16 Passive House mixed-use multifamily buildings, with the exception of two university dormitory buildings, which revealed the cost increase of 1% to 8%. This study found that the industry's lack of experience in building with Passive House methods significantly affected costs. Additionally, the study emphasized that the design team's experience played a crucial role in managing these costs effectively (Barry, 2021). Similarly, the City of Boston's Department of Neighborhood Development published a guidebook in 2020 focusing on the affordability of Zero Emission Buildings (ZEBs). The report found that construction cost increases before rebates ranged from 0% to 2.5%. Key strategies identified for achieving high efficiency in ZEBs included optimizing building shape, orientation, and density, as well as reducing glazing and eliminating thermal bridging (City of Boston, 2020). Home Innovation Research Labs (2021) studied the cost of switching from gas to all-electric homes. The study showed an increase in heating costs associated with northern climates due to the higher cost of electric heating (Home Innovation Research Labs, 2021). The NMR Group, Inc. (2020) estimated cost increases for energy-efficient construction based on surveys and interviews with building professionals. The cost increase ranged from 0% to 10%, averaging 5%. Data from Passive House multifamily units in Pennsylvania indicated reduced square footage and per unit costs attributed to straightforward, box-like designs. The study focused on low-income housing and highlighted factors like tighter building envelopes, certification and modelling costs, and mechanical ventilation requirements as primary drivers of increased costs. However, it lacked detailed cost comparisons for identical buildings transitioning from base code to Passive House standards (NMR Group, Inc., 2020). In a report by Peterson et al. (2019), the costs of building Zero-Energy (ZE) and Zero-Energy Ready (ZER) homes were analyzed, which showed increases of 6.7% to 8.1% and 0.9% to 2.5%, respectively. These increases were attributed to the high efficiency standards required for these homes, including advanced heating systems and improved insulation (Peterson, Gartman, & Corvidae, 2019). Simmons et al. (2022) provided an in-depth look at the scaling up of Passive House multifamily projects in Massachusetts. This report highlighted the state's journey from having one Passive House certified multifamily building to over 141 projects on the path to certification. The study emphasized the importance of incentives and support programs in driving the adoption of Passive House standards, noting that these buildings use 40%-60% less energy than typical new construction (Simmons, Craig, McKneally, & Lino, 2022). Zhao (2022) analyzed the affordability impacts of rising housing costs, noting that a $1,000 increase in home price could price out over 117,000 households. This study highlights the sensitivity of housing affordability to incremental cost increases, an important consideration when evaluating the cost implications of Passive House standards (Zhao, 2022). These studies collectively illustrate that while the initial cost of adopting high-performance building standards may be higher, implementing supportive policies can help alleviate the impact on housing affordability, ensuring that the long-term benefits of energy savings and improved indoor comfort are accessible to all.

Energy Code Evolution in Massachusetts

Massachusetts has consistently led efforts to address climate change through innovative building practices and progressive energy codes. In 2017, the state's Building Sector was responsible for 27% of its direct greenhouse gas (GHG) emissions, primarily due to on-site fossil fuel combustion for space heating (75%) and water heating (23%) (Executive Office of Energy and Environmental Affairs (EEA) & The Cadmus Group, 2020). This underscores the urgency of adopting more sustainable practices. As mandated by the Green Communities Act of 2008, Massachusetts updates its building code every three years. The latest update in 2023 introduces three distinct pathways for municipalities to enhance building efficiency and sustainability (Mass Department of Energy Resources (Mass DOER), 2023):

- **Base Energy Code:** This foundational regulatory framework applies to new constructions and renovations in municipalities that have not adopted the stretch code. It sets minimum standards for building energy use, ensuring that all constructions meet basic efficiency requirements.

- **Stretch Energy Code:** This code, applicable to new construction, additions, and renovations, sets more stringent energy efficiency guidelines than the base code. Adopted by "Green Communities," it reflects a collective ambition to exceed baseline efficiency standards and foster more environmentally friendly building practices.

- **Specialized Net-Zero Opt-In Code:** The most ambitious of the three, this code targets new constructions to align them with Massachusetts' goal of net-zero emissions by 2050. Municipalities adopting this code commit to its enforcement typically 6-11 months after adoption, marking a proactive step towards significant GHG emission reductions. Under this code, Passive House certification is a compliance option, alongside other performance measures such as the Total Energy Demand Intensity (TEDI) or Home Energy Rating System (HERS) pathways.

Since the introduction of the stretch energy code in 2009, its widespread adoption has demonstrated the community's dedication to energy efficiency and environmental stewardship. By December 2023, Massachusetts' commitment to a sustainable and equitable building sector is evident through the widespread adoption of these energy codes: 50 cities maintained the base code, 270 adopted the stretch code, and 31 opted for the specialized net-zero opt-in code (Mass Department of Energy Resources (Mass DOER), 2023). This widespread embrace of varying levels of energy efficiency regulations highlights the state's collective effort towards achieving a net-zero emissions future, ensuring Massachusetts remains a leader in sustainable building practices and climate change mitigation.

Methodology

The research team outreached and invited experts from companies involved with large residential Passive House projects to participate in semi-structured interviews. The team ultimately conducted interviews with nine experts involved in large residential projects to assess current practices, challenges, and cost implications of building to Passive House standards. Each interview lasted approximately one hour, providing a comprehensive opportunity for the interviewees to share their experiences, expertise, and knowledge. The interview questions were designed to capture a broad view of the challenges and experiences associated with Passive House projects. Key areas of focus included familiarity with the new Specialized Opt-In code, the frequency of sustainable certifications, the presence of sustainability departments within companies, incentives for Passive House certification, and specific challenges related to Passive House projects. The interview responses were analyzed using a thematic coding approach, as described by Braun and Clarke (2006). This method involved systematically identifying, organizing, and interpreting patterns and themes within the qualitative data. Key themes were identified based on their relevance to the research questions, such as challenges in implementation, cost implications, and industry readiness.

Additionally, the research team collected cost data for 11 large multi-family Passive House projects in Massachusetts that had been completed or were in the development phase. This data was then analyzed to determine the incremental costs associated with Passive House standards compared to traditional construction methods. The analysis provided insights into the cost variations and highlighted the factors influencing these costs. The incremental costs represent additional construction and verification expenses associated with achieving Passive House standards, excluding any incentives. These costs include enhanced construction verification, building consulting expertise, energy modeling, and upgrades to meet requirements such as advanced ventilation systems, high-performance windows, and enhanced insulation.

Results

Interview Findings

The majority of participants (85%) were moderately to extremely familiar with the new Specialized Opt-In code. LEED and Passive House were the most common certifications among projects. While most companies did not have a dedicated sustainability department, they promoted Passive House training and certifications. The following are the key findings:

- Passive House certification is not typically a reason for companies to refrain from bidding for these types of projects,
- These projects are not necessarily harder to estimate, but there are more steps involved, and they require more attention to details such as air barrier, vapor barrier, windows, and HVAC systems, and
- These projects do not have an increased contingency budget just because of being built based on Passive House standards.

Also, participants highlighted the following as the primary challenges for large residential Passive House projects:

- Lack of properly trained subcontractors that are willing to work on these type projects, and
- Control the cost of insulation and mechanical equipment.

Cost Implications for Large Residential Projects

The cost implications of implementing Passive House standards in large residential projects were analyzed based on the collected data. This data is summarized in Table 1.

Table 1. Cost delta for large multi-family projects (Conventional vs. Passive House*)*

Project ID	Units	Gross sq. ft.	Cost Delta
1	55	51,272	3.5%
2	53	55,538	4.3%
3	48	104,981	4.1%
4	98	111,450	1.4%
5	72	53,675	1.6%
6	30	33,186	1.8%
7	135	178,875	2.0%
8	50	45,031	1.0%
9	170	162,296	1.7%
10	44	49,476	3.1%
11	160	190,000	2.4%

The analysis of these projects reveals significant insights into the incremental costs associated with adopting Passive House standards compared to traditional construction methods. The cost delta for these projects ranges from 1.0% to 4.3%. The average cost delta across the 11 projects is approximately 2.4%, aligning with findings from other studies on Passive House cost implications. Projects 1, 2, 3, and 10 exhibit higher cost deltas of 3.5%, 4.3%, 4.1%, and 3.1%, respectively. These higher costs may be attributed to factors such as the complexity of the building design, the extent of Passive House components required, or the lack of experience among the construction teams. Although, analyzing the relationship between project size and cost delta does not reveal a clear correlation among all 11 projects but it indicates that three projects with the highest number of units and largest gross square footage have below average cost delta percentage which could be due to economy of scale and minimization of building envelope area to gross square footage ratio. For instance, Project 9, with the highest number of units (170), has a moderate cost delta of 1.7%, whereas Project6 with the lowest number of units (30) has a similar cost delta of 1.8%, while Project 2 with only 5344 units, has the highest cost delta of 4.3%. Figure 1 shows the relationship between cost delta percentage, number of units, and gross square footage of 11 projects. The size of each bubble represents the relative gross square footage.

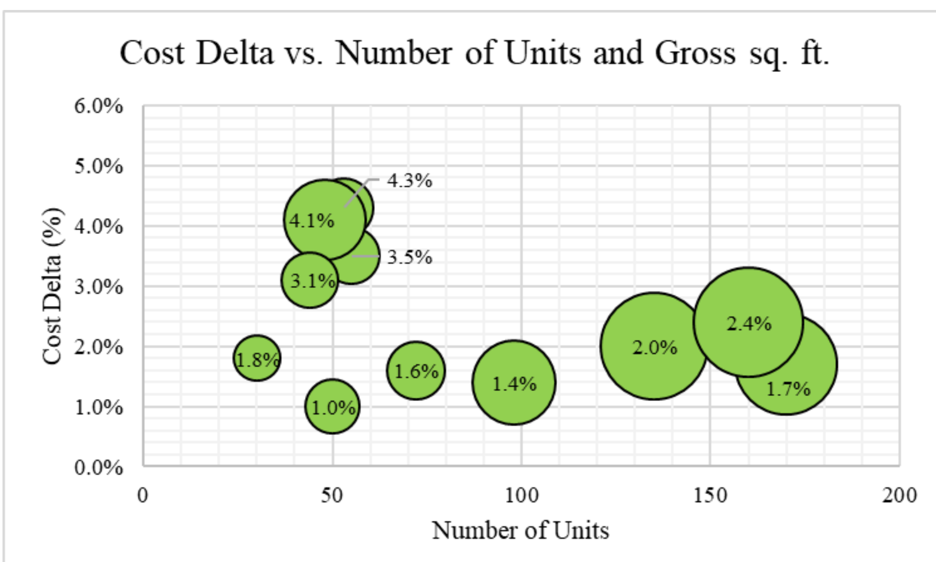

Figure 1. Relationship between Number of Units, Gross Square Footage, and Percentage Cost Delta

In summary, while there is variability in the cost deltas, the overall trend indicates that achieving Passive House standards results in a modest average cost increase of 2.4%. This aligns with studies in other regions, such as Barry (2021), which reported incremental costs ranging from 1% to 8%, with an average cost delta of 4.1%. These findings support the viability of Passive House standards as a sustainable construction approach that balances initial cost premiums with long-term benefits such as energy savings and improved building performance.

Discussion

The incremental costs associated with Passive House projects are influenced by various factors, including design complexity, team experience, and market conditions. For instance, projects with simpler designs and more experienced construction teams tend to have lower cost increases. This underscores the importance of building industry capacity and expertise in Passive House construction techniques.

Training and Education: One of the recurring themes from the interviews was the necessity for better training and education among subcontractors and construction teams. Passive House standards require precise construction practices, especially regarding insulation, airtightness, and HVAC systems. The lack of trained subcontractors can lead to higher costs and project delays. Addressing this gap through targeted training programs and certification courses can help mitigate these challenges.

Policy and Incentives: Policy frameworks and incentives play a critical role in encouraging the adoption of Passive House standards. In Massachusetts, Mass Save offers incentive programs for the design and construction of multi-family dwellings meeting the Phius (Passive House Institute US) Standard. These incentives are crucial for offsetting the initial cost premiums associated with Passive House projects and making them more attractive to developers.

Long-term Benefits: Despite the initial cost increase, Passive House projects offer significant long-term benefits, including energy savings, enhanced indoor air quality, and reduced greenhouse gas emissions. These benefits contribute to the overall value proposition of Passive House standards, making them an attractive option for sustainable development. Additionally, improved building performance and lower operational costs associated with Passive House buildings can result in higher property values and increased marketability.

Scalability and Replicability: The scalability and replicability of Passive House standards are essential considerations for broader adoption. While this study focuses on large multi-family projects, the principles of Passive House can be applied to various building types, including single-family homes, commercial buildings, and public infrastructure. Future research should explore the application of Passive House standards in different contexts and building typologies and explore industry gaps to understand the full potential and challenges in achieving energy efficiency and sustainability goals.

Conclusion

Passive House standards offer a viable path for achieving high energy efficiency in large residential projects. Despite the initial cost premium, the long-term benefits, including energy savings, improved indoor air quality, and enhanced building performance, justify the investment. The integration of Passive House standards into Massachusetts' energy code represents a significant step towards sustainable development. The Specialized Opt-In code provides a structured pathway for developers to achieve high energy efficiency, aligning with the state's goals for greenhouse gas reduction and energy conservation. The challenges identified, such as the need for trained subcontractors, highlight areas where the industry needs to focus its efforts. Addressing these challenges through targeted training programs and enhanced collaboration among project stakeholders can facilitate smoother implementation of Passive House projects.

Limitation and Future Work

This study sheds light on the challenges and opportunities associated with implementing Passive House standards in large residential projects in Massachusetts, but it does have certain limitations. A key limitation is the relatively small number of interviewees, although it is worth noting that the nine interviewees were selected carefully from major players in the design and construction of Passive House in Massachusetts. While the insights from the nine experts interviewed were valuable and informative, a larger and more diverse participant pool could provide a more comprehensive understanding of the barriers and opportunities experienced across various regions and project contexts. Including perspectives from a wider range of stakeholders, such as policymakers, subcontractors, and residents, could further enrich future research.

For future work, it is recommended to conduct a lifetime cost-benefit analysis of Passive House projects, incorporating initial and operational costs alongside broader benefits such as health improvements, occupant comfort, and long-term energy savings. This analysis would provide a comprehensive view of the value proposition of Passive House standards. Additionally, exploring the societal and environmental impacts of Passive House adoption, including carbon reduction and housing affordability, could offer valuable insights into the scalability and sustainability of this approach. Future research should also examine the application of Passive House standards across different contexts and building typologies.

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