How Much Does Zero Energy Building Cost?

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Keywords: construction cost, conventinal building, green building, zero energy building

Developers, building owners, and design teams often point to initial capital costs as the primary obstacle hindering the uptake of net-zero buildings. In-depth research and an understanding of whether net-zero buildings cost more to design and construct are still scattered and non-systemic. Accordingly, this study provides the first comprehensive investigation into actual net-zero building construction costs in the United States, based on qualitative and quantitative research. The aims of this research are to: (1) provide a comprehensive survey of the existing body of literature to aggregate the findings and identify the consensus and pattern, (2) compare the results and analyze the evidence with a focus on quantitative studies, and (3) conduct a quantitative comparative analysis of twelve built zero energy buildings (ZEB) in order to understand whether there is enough evidence of cost differences between ZEB, conventional building (CB) and green building (GB). Statistical tests were performed, with the results showing no significant differences between actual ZEB costs and modeled CB costs. Further details investigated the cost difference between actual ZEB and modeled GB. The findings of this research provide initial detailed insights into net-zero building costs in the United States, which may benefit the promotion of ZEB practices.

1.INTRODUCTION

The building industry contributes significantly to global CO2 emissions as well as energy consumption. Global energy consumption is assumed to increase by 33% from 2010 to 2030. The United Nations' Sustainable Buildings and Construction Programme published a report suggesting that building and construction sectors account for 40% of global energy use and 30% of energy-related GHG emissions. During 2016, the United States' building sector consumed 40% of primary energy, based on the U.S. Energy Information Administration's statics. Primary energy, deriving mainly from fossil fuels, while limited, is a major contributor to CO2 emissions, which are rising globally at a rate of more than 2% per year. Consequently, building green is one of the most effective strategies for overall energy consumption reduction and CO2 emissions reductions. However, design teams and building owners often cite the incremental initial costs of green (energy efficient) building as significant barriers to building high-performance buildings with the ultimate goal of achieving net-zero energy.

So far, there has been a large amount of research focusing on the benefits of green building (GB) for users, clients, and society. (Liu et al.) estimated that GB could create incremental economic benefits by saving energy and improving the environment while (Eihholtz et al.) pointed out how the green label affects the market rents and values of commercial space, potentially leading to the high resale value of a building. However, only a small portfolio of studies have investigated the cost obstacles20; regarding costs related particularly to net-zero building, there is very limited literature and reports to date. Meanwhile, despite the widespread perception of GB as expensive, the empirical studies and evidence needed to support this claim are inadequate, and the issue of a high green-cost premium is still debatable. It is foreseeable, though, that the cost concern could become one of the major obstacles to the promotion of zero energy building (ZEB). Therefore, a study of ZEB as a separate building type independent from GB will provide an opportunity to investigate the differences between ZEB and GB and the related cost indications.

2.RESEARCH METHODOLOGY

Cost definition

This research project focuses on the construction cost of ZEB since the perception of ZEB having expensive initial costs has been recognized as one of the critical obstacles to promoting net-zero energy building, and they are paid by the developer and investors. The construction costs of building include direct (hard) costs and indirect (soft) costs. Direct costs are related to cost materials, labor, construction equipment, energy, water, and other costs directly related to the activities of constructing a building. Indirect costs include costs related to the design, commission, permitting fee, documentation fees, and other legal fees. The post-construction costs comprise the building operation costs: energy, water, maintenance, repair, and management.12 Some researchers have indicated that general misunderstandings of construction costs for building green stems from individuals having no experience in the construction of green and energy-efficient buildings. The perceptions about the higher costs of GB has hindered the advancement of more energy-efficient building and construction.

Cost estimation and analysis method

There are several methods and techniques used for cost estimation in the building industry, including the traditional statistical analysis of detailed itemized costs, factor analysis of construction activities, , time-dependent cost trend projection, index number cost estimation, expert systems estimation, integrated analysis of multi-objectives, , , and BIM and ontology-based cost estimation. In the building industry, the traditional statistical analysis of detailed itemized costs is the wider used method due to its simplicity and availability of multiple itemized cost database. The other methods are presented and analyzed in research and academic settings, and their application in the field and actual projects are very limited. Since the primary goal of this research is to analyze the actual net-zero building cost and understand the perceptions from the field, the first traditional cost estimation method was selected. Two commercially available itemized cost databases are selected and used. The cost analysis of sustainable building can be categorized into two groups: paired comparison and unpaired comparison. An unpaired building cost comparison is a statistical analysis method based on a comparison of actual or simulated costs of unpaired GBs and conventional buildings. A paired building cost comparison involves comparing the costs of two identical buildings for the cost of conventional upgrades versus green upgrades.25 In this research project, paired comparison is used to compare the costs of simulated net-zero building, GB, and conventional building. Two construction cost databases were selected and compared: the 2017 National Building Cost Manual (NBCM) and RSMeans's Square Foot Costs Book (RSFCB).

Case studies selection

Three major programs in the United States have influenced the promotion of green building and net zero building practices, and they all have rating systems or tools to measure and quantify building performance. These three programs are (1) LEED, managed by the U.S Green Building Council, which is a private nonprofit organization; (2) the Energy Star Label, jointly managed by Department of energy (DOE) and Environment Protection Agency (EPA); and (3) the zero energy building certification organized by the International Living Future Institute (ILFI). All three are volunteer programs.The largest database of zero net energy (ZEB) building is the online database that was created, organized, and managed by the New Building Institute (NBI). In May 2017, the ILFI and NBI announced a partnership to track and certify ZEB building to drive a broader market adoption. Therefore, in this research project, that database was selected, and education buildings were chosen as the study types. Altogether, there are thirty-nine new constructed education buildings and four renovated education buildings, which is the largest building type group in the current database. The projects have a square footage ranging from 1,528 ft2 (141 m2) to 286,212 ft2 (26,590 m2) and an energy use intensity (EUI) of 50 kwh/m2/yr to of 432 kwh/m2/yr. The author then matched the addresses of the buildings included in the database with those in the LEED project database to acquire additional information, such as energy consumption reduction, water conservation, and recycled and reused materials. The match yielded twelve buildings for which the construction cost, area, energy efficiency, water efficiency, and building mechanical system characteristics could be identified. Table 1 provides a breakdown of these projects by building system and costs. The selected buildings were net-zero energy buildings that consider the following two aspects: electrical energy production and thermal energy production (heating, cooling and DHW).

There are three steps in cost estimation (refer to figure 1): (1) create an itemized unit cost database based on RSMeans's book and the National Building Cost Manual (NBCM); (2) build a three-dimensional building information model (BIM) based on verified ZEB construction information and export the building material and system information to Excel format; and (3) used the database from (1) and building information from (2) to estimate the cost of CB and GB.

Step 1: Cost estimation data collection: In this research project, a traditional itemized cost estimation method was used. The researcher initially sought to collect actual cost data of CBs or GBs with a compatible size and use it as a control group for comparison. However, since most building owners were reluctant to share cost information, this research was redesigned to compare actual net-zero building costs with modeled costs of CBs and GBs. Two construction cost databases were selected and compared: the 2017 National Building Cost Manual (NBCM) and RSMeans's Square Foot Costs Book (RSFCB).

Steps 2 & 3: Itemized cost calculation using BIM model

Based on available data from building floor plans, sections, elevations, detail drawings, and project descriptions, first, three-dimensional virtual models were created in Autodesk Revit for each case building, based on the information provided by building owners or found online. All building information was input in three-dimensional virtual models in a BIM environment so that users could extract and organize the cost-related information easily. The three-dimensional models include all primary building materials and systems to reflect the actual conditions of the case buildings. Some advanced materials and building systems, which are not included in the existing Revit library, were created and manually input in the models. Then, a material schedule was created within the Revit model, transferring three-dimensional data of materials into two-dimensional, quantitative itemized numbers, including volume, weight, dimensions, layers, and assemblies. Afterward, the schedules were exported to an Excel-format file and used as a cost estimation sheet for calculating the CB and GB with the same area, building construction, material assemblies, and systems as the net-zero building. The primary categories

Project	City State	Use	Building Area (ft²)	EUI (kwh /m²)	Cost ($)	Year	Net-Zero Energy Feature
Science House	St. Paul, MN	Museum	1,528	0	$650,000 ($425/ft² ≈$4250/m²)	2013	• Total ventilation energy recovery • Multi-modal natural ventilation • Efficient lighting • High heat pump efficiency • High insulation • Energy-efficient windows and doors
Leslie Shao-Ming Sun Field Station	Woodside, CA	Education	13,197	9.46	4,785,000 ($362/ft² ≈$3620/m²)	2002	• Energy-efficient windows and doors • PV system (A 22-kilowatt, grid-connected photovoltaic system makes the building a net producer of electricity
Omega Center for Sustainable Living	Rhinebeck, NY	Education	6,200	-25	2,800,000 ($451/ft² ≈$4510/m²)	2009	• Geothermal wells and heat pumps • PV system
Environmental Technology Center	Rohnert Park, CA	Education	2,196	-3.1	1,116,000 ($508/ft² ≈$5080/m²)	2001	• A 3-kW roof-integrated photovoltaic system • Insulated structural wall panel • Hydronic radiant heat
Adam Joseph Lewis Center	Oberlin, OH	Education	13,595	-34.7	4,854,600 ($375/ft² ≈$3750/m²)	2000	• Living machine • PV system • Ground-loop heat pumps • Water-to-water heat pump
Hawaii Gateway Energy Center	Kailua-Kona, HI		5,597	-6.3	3,400,000 ($607/ft² ≈$6070/m²)	2005	• A 20-kilowatt photovoltaic system • Seawater pump • High insulation
Living Learning Center	Eureka, MO	Education	2,917	-3.2	1,597,227 ($547/ft² ≈$5470/m²)	2009	• High efficiency variable refrigerant HVAC system • High insulation • Evergreen Solar roof & pole-mounted photovoltaic, 23.1 kWh
Putney School Field House	Putney, VT	Education	16,802	0	6,036,000 ($318/ft² ≈$3180/m²)	2009	• High insulation • 36.8 kW solar PV
Locust Trace Agriscience Campus	Lexington, KY	Education	69,998	0	15,620,000 ($234/ft² ≈$2340/m²)	2011	• 175kW solar PV
Richarsbille Elementary School	Bowling Green, KY	Education	72,280	3.2	14,927,000 ($207/ft² ≈$2070/m²)	2010	• 208 kW thin-film PV system
Hawaii Preparatory Academy Energy Lab	Waimea, HI	Education	5,889	-16	4,306,199 ($731 /ft²≈$7310/m²))	2010	• 27 Kw PV system
Bertschi School Science Wing	Seattle, WA	Education	1,421	0	935,000 ($658/ft² ≈$6580/m²))	2011	• Energy recovery system • Hydronic radiant floor • High insulation • 20Kw PV system

Table Case project details

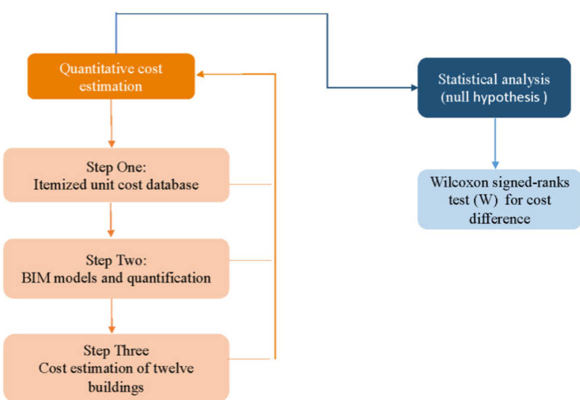

Figure 1: Cost estimation steps

included in the calculation were direct costs and indirect costs. The direct costs included the building substructure system (foundation), floor and roof system, exterior walls and windows/doors, interior walls and finish, ceilings, restroom fixtures and plumbing system, HVAC systems, and vertical transpiration system. The indirect costs included the designers' (architect and engineer) fee and contractors' fee. Instead of a rough per area cost estimation, which is often found in cost analysis in GB, in this study, the author conducted a detailed breakdown cost estimation by utilizing the advanced building information modeling software Autodesk Revit. In conventional methods, a cost estimator digitizes the architect's paper drawings or imports two-dimensional information of the building (data) into a cost estimation package. In either of these methods, human error could occur easily, and inaccuracies could propagate from the original data entry to the final cost number. Autodesk Revit, as a building information modeling (BIM) tool, allows the author to automate the task of quantification and then extract and transfer the data to an Excel format for a final cost estimation checkup.

3. STATISTICAL ANALYSIS

Null analysis is appropriate for this research project. From the literature review and ZEB actual cost information, there is no clear indication that ZEB has a higher premium than the national average for conventional building. Therefore, before analyzing the causes of a premium cost, understanding whether there is a cost difference is more important. This was conducted to determine if ZEB costs were indeed significantly different from the CB and GB. The Wilcoxon signed-rank test is commonly used to test for a difference in a paired observation, and a sign test is often used to test the null hypothesis.

The analysis considers two null hypotheses:

- H01:There is no significant cost difference between ZEB and CB.
- H02 There is no significance cost difference between ZEB and GB.
- The two alternative hypotheses are:
- Ha1:There is significant cost difference between ZEB and CB.
- Ha2 There is significance cost difference between ZEB and GB.

$$W = \sum_{i=0}^{n\prime} R_i^{(+)},$$

Descriptive results: The results from the Wilcoxon matched pairs signed-rank test for ZEB, compared to CB, are illustrated in table 2 and the tests for ZEB and GB are shown in table 3. The overall results of the two null hypotheses are provided in table 7. The equation used to obtain the statistic W is:

where n' is the actual sample size, Ri is rank, and W is the Wilcoxon test score.

For null hypothesis number 1(H01), the model costs of six CB are higher than the actual ZEB cost, and the rest six CBs costs are lower than the actual ZEB cost. The Wilcoxon test score (W), 35, is higher than the critical value used for a two-tier test of 14. Based on this result, we could not reject null hypothesis 1(H01), instead, we should reject the alternative hypothesis (Ha1). As conclusion, we consider there is no difference between the actual ZEB and modeled CB building cost, based on RSFCB and NBCM datasets. For null hypothesis number 2 (H02), there are model costs of ten GBs that are higher than the actual ZEB cost, and model costs of two GBs that are lower than the actual cost. The Wilcoxon test score (W), 11, is less than the critical value used for a two-tier test of 14. Based on this result, we could reject null hypothesis 2, and we conclude alternative hypothesis (Ha1) can be supported: there is difference between the actual ZEB cost and modeled GB cost, based on the RSFCB dataset.

4. FINDINGS

ZEB is not more expensive than CB: The first important findings is there is no significant cost difference between actual ZEB cost and modeled CBs cost. Regarding cost, 33.3% of ZEBs are equal to or 2% more expensive than CB, 33.3% of ZEBs cost 10–16% less than CBs, 16.7% of ZEBs cost 45–48% less than CB, and only 16.7% of ZEBs cost 45–68% more than CBs.

ZEBs cost is lower than national average of estimated cost of CBs

The second important finding is that data shows the actual cost of ZEBs examples to be lower than the national average. Based on the 20th annual College Construction Report published in 2015, the median cost of quality academic buildings per ft2 was $420.46, the median cost of high-quality academic buildings per m2 was $5384.6 (per ft2 was $538.46), and the median cost of sampled net-zero academic/technology buildings per m2 was $4678 (per ft2 was $467.80). In 2014, the national average construction cost for a region 1 K–12 building was $4000/ m2 and $2350/ m2 for region 2. The net-zero K–12 school's average cost was $2530/ m2, which is within the range of the national average. The reason for the actual lower cost than what was perceived as a high-cost net-zero building needs to be studied further.

Reasoning for higher modeled GBs cost than actual ZEBs cost

The rejection of null hypothesis 2 suggests a cost difference between the actual ZEBs and modeled GBs, so the author further investigated the cost difference between the actual ZEBs and modeled GBs, and which factors have correlation to the cost difference. The factors investigated are: location, year of completion, area and building types. Pearson correlation coefficient (r) was used to study the correlations factors and cost difference between ZEB and GB. Person's r measures the linear relationship between two level variables. There is positive relation between the year of completion, total area of the building to the cost differences, and negative relation between building types, location to the cost differences. And among the four factors, building area (0.966) has the strongest correlation to the cost differences, year of completion has the weakest correlation to cost differences.

Building size as the primary factor affecting the unit (square footage) cost of the building

Next, author further examined the relationship between cost differences and building size(area). Figure 2 shows that there is some negative correlation between the construction cost and building size. Overall, buildings with a lower unit cost show a larger difference between the actual cost and modeled cost whereas a building with a higher unit cost shows less difference.

Project	Modeled Cost $/m²($X_{1i}$)	Actual Cost $/sft ($X_{2i}$)	Difference ($D_i = X_{1i} – X_{2i}$))	Positive	[Diff] (D_i)	Rank (R_i)	Signed Rank	α = 0.05
Science House	4445.6	425	19.56	1	19.56	3	3	
Leslie Shao-Ming Sun	3369.6	362	-25.04	-1	25.04	5	-5	
Omega	4233.6	451	-27.64	-1	27.64	6	-6	
ETC	5286.7	508	20.67	1	20.67	4	4	
Adam Joseph Lewis Center (AJLC)	3940.2	375	19.02	1	19.02	2	2	
Hawaii Gateway	6058.3	607	-1.17	-1	1.17	1	-1	
Living Learning Center (LLC)	5044.7	547	-42.53	-1	42.53	8	-8	
Putney	3560.7	318	38.07	1	38.07	7	7	
Locust Trace Campus (LTC)	3977.5	234	163.75	1	163.75	9	9	
Richarsbille ES	3741.2	207	167.12	1	167.12	10	10	
Hawaii Preparatory Energy Lab (HPAEL)	5268.6	731	-204.14	-1	204.14	11	-11	
Bertschi	3677.6	658	-290.24	-1	290.24	12	-12	
							35	Positive sum
							-43	Negative sum
							35	Test statistic (W)

Table 2: Wilcoxon matched pairs signed-rank tests for ZEB cost compared to modeled CB cost

PROJECT	Modeled Cost (green)	Actual Cost	Difference	Positive	[Diff]	Rank	Signed Rank (W)	α = 0.05
Science House	569.04	425	144.04	1	144.04	7	7	
Leslie Shao-Ming Sun	431.31	362	69.31	1	69.31	2	2	
Omega	541.90	451	90.90	1	90.90	3	3	
ETC	676.70	508	168.70	1	168.70	9	9	
Adam Joseph Lewis Center(AJLC)	504.34	375	129.34	1	129.34	5	5	
Hawaii Gateway	775.46	607	168.46	1	168.46	8	8	
Living Learning Center (LLC)	645.72	547	98.72	1	98.72	4	4	
Putney	455.76	318	137.76	1	137.76	6	6	
Locust Trace Campus (LTC)	509.12	234	275.12	1	275.12	12	12	
Richarsbille ES	478.88	207	271.88	1	271.88	11	11	
Hawaii Preparatory Energy Lab (HPAEL)	674.38	731	-56.62	-1	56.62	1	-1	
Bertschi	470.73	658	-187.27	-1	187.27	10	-10	
							67	Positive sum
							-11	Negative sum
							11	Test statistic (W)

Table 3: Wilcoxon matched pairs signed-rank tests for ZEB cost compared to modeled GB cost

HYPOTHESE	BUILDINGS	COST	COST	(W)	(Z)	RESULT
H01	12	6	6	35	14	CANNOT Reject
H02	12	10	2	11	14	Reject

Table 4:Summary results of Wilcoxon matched pairs signed-rank tests (based on statistical significance at an alpha level of 0.05)

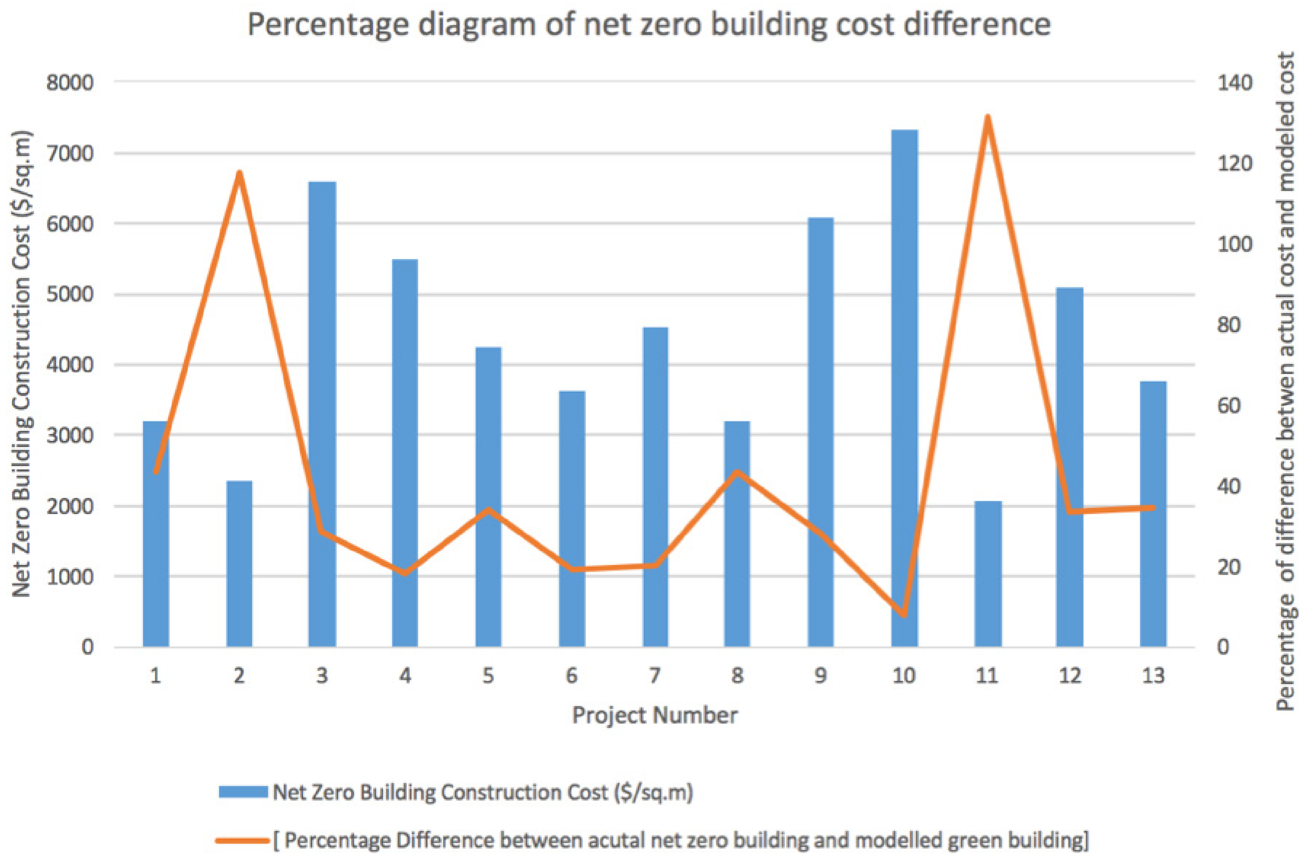

Figure 2: correlation between cost difference and building size

5. CONCLUSION

This study provides the first in-depth investigation into actual ZEB costs in the United States based on detailed information. With higher initial costs being perceived as major barriers to the uptake of ZEB, the findings from this research project could be critical to further understanding whether ZEB cost more. Based on the comparison of actual and modeled costs of twelve built and verified ZEBs, it can be concluded that, in general, there is no significance between actual ZEB costs and modeled CB costs. Although the data shows several net-zero buildings as having substantially higher costs than the modeled costs, a sizable portion of net-zero buildings have been found to be below the modeled cost. Interestingly, the study also shows a significant difference between actual ZEB costs and modeled GB costs. The magnitude of difference between those two are primarily affected by the size of the building.

This study has several limitations as well. Firstly, future research using data with different building types is needed to verify these findings and address the issue of variance within the building subgroups. Other building types should also be investigated, including commercial office and residential buildings. Secondly, out of the twelve case projects, four are more than ten years old. More recent projects and data should be used in future studies. The third limitation in this study was the small dataset of only twelve buildings; ideally, at least thirty buildings should be studied so that parametric statistical testing can be conducted, leading to a more detailed analysis. Furthermore, the collection of actual cost data from other sizable markets, such as the United Kingdom and EU member countries, could result in a considerably larger ZEB cost dataset 34 that would enable a more robust study and analysis.

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