

# **Architecturally Integrated Photovoltaic Panels: Residential Design Methods and Consumer Preferences**

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## **ABSTRACT**

Since the commercialization of photovoltaic (PV) panels, Architect, Engineers, and builders have sought creative methods for aesthetically integrating PVs into buildings through either PV embedded materials or architectural composition strategies. PV integrated materials represent one approach that will hopefully yield more breakthroughs in the coming years, but is currently seen as novel and costly, particularly in the home building industry. Standard PV panels are better understood and preferred, yet they introduce aesthetic, construction, and regulatory challenges. Neighborhood covenants often prohibit solar for aesthetic reasons, however we are finding evidence that solar panels which are “architecturally integrated” into residential design can be desirable while adding value.

This paper examines a number of examples of practical aesthetic solutions while presenting research findings from a survey of prospective home buyers which evaluates aesthetic preferences with solar and Zero Energy homes. In the survey conducted, four options have been shown including two solar option, one with typical solar and another with architecturally integrated solar. Initial data has shown a willingness in consumers to pay on average \$6,200 to \$7,300 extra for design integrated solar relative to standard rooftop solar, which indicates strong evidence of an aesthetic preference. In addition to presenting research findings, this paper explores residential solutions from multiple sources in search of a variety of PV integration solutions intended for future research and consideration.

## **INTRODUCTION**

Building codes have become more rigorous in terms of energy efficiency requirements. While increased efficiency approaches a point of diminishing returns, the cost of on-site energy production continues to drop. This drop, particularly in the wholesale cost of solar photovoltaics (PVs), provides the opportunity to create affordable buildings that can produce as much or more energy as they use. Zero Energy houses are poised to become a significant sector of the residential construction market (Sankaran et al. 2015).

Some examples seek maximum energy efficiency before incorporating PV energy production. One notable example, the National Institute of Standards Testing (NIST) Net Zero Energy Residential Test Facility, or NZERTF, offers a clear example of an excessive amount of money spent in reducing energy use compared to the cost of energy production through the installation of PV panels (Schneider et al 2016). We have concluded that Zero Energy buildings are more cost effective when preference is given to installing more solar panels, rather than to seeking the highest levels of energy efficiency or reduction. The insulation levels established by the 2012

International Energy Conservation Code represent a reasonable point of diminishing returns, where the focus should shift to incorporating more PV (Gardzelewski et al 2012).

Residential PV has received opposition from many home owners associations (HOAs) and restrictions from the International Fire Code (IFC). In the future, other challenges are likely to arise. The goal is to create design solutions which can address these challenges. To show that solar aesthetics can be desirable, we have spent much work exploring methods of architecturally integrated PV which we have tested through large survey mechanisms.

It is important to describe and analyze existing methods of integrating PV in architectural design. Further, this project aims to show new methods of designing with PV in a manner which will be considered attractive and add value to groups like neighborhood HOAs who may have conservative aesthetic tastes. The results may lead HOAs to modify their restrictions and to develop aesthetic guidelines and review committees which ultimately will promote Solar and Zero Energy homes.

## **AESTHETIC APPROACHES**

The most common challenge in getting Zero Energy homes built often comes from restrictive covenants by Home Owners Associations (HOAs). If you are an experienced builder in the spec housing market who is just branching out into the green housing market, the risk of incorporating solar panels into the design may not be as great of a risk as modifying any of your playbook of home designs that have proven to be successful. In this instance, a builder will use tested designs that fit the neighborhood masterplan based on style, lot size, vehicle access, and other influential siting and aesthetic factors. Using a tested design will be economically successful, but when solar panels are added they often fit awkwardly onto the roof. When unattractive solutions proliferate, where solar has clearly been an afterthought, it becomes more likely that HOAs and other regulatory mechanisms will engage in a backlash against PV.

This method, similar to solar retrofit projects, produces an architectural result that appears “undesigned,” even if the rest of the house may have a high level of visual refinement (figure 1). Simply stated, the panels do not look like they belong because they were not designed in congruence with the architectural form. The language found in restrictive covenants either forbids solar panels, or require that they are hidden from view (Starrs et al 2010). In a counter-effort, nearly half of all states in the US have adopted solar rights laws protecting solar access and limiting these types of restrictions (DSIRE 2013), but neither restriction addresses the root of the strained relationship.

Recognizing that there are aesthetic solutions where PV can be desirable, we have devoted our efforts to improve the desirability of PV through architectural means. What we learn from our research should lend itself well to HOAs looking to amend covenants or to reach a compromise with State regulations which simply prevent such covenants. In short, solar doesn’t always look good, but with the right approach and the right design we see it becoming more of an asset.

In 2002 the U.S. Department of Energy (DOE) hosted the first Solar Decathlon where students



Figure 1. A solar friendly neighborhood where home designs and PV panels are not aesthetically integrated.

from Universities around the world build Net Zero Energy solar powered homes. These houses, designed and engineered by their University teams, would be fully functional for a week before judges rating the projects and gave out awards. After the first Decathlon in 2002, the judges increased an emphasis on Aesthetics, but after the second decathlon in 2005 there was clearly no consensus for what the judges wanted in terms of aesthetic solutions (Denzer and Hedges 2007).



Figure 2. 2011 Solar Decathlon Aerial View.



Figure 3. The BrightBuilt Barn by Kaplan Thompson Architects and Bensonwood Homes, Winner of the 2009 LEED for Homes Innovative Project Award

The team at UW-BERG spent time understanding the various approaches of aesthetically incorporating solar panels that are believed to be successful. Aesthetics have been both objectively and subjectively evaluated, considering student designs from all years of the

Decathlon (ten decathlons to date) as well as real world examples of homes that have either won major awards or received notable press. Aesthetic strategies for the treatment of PV have not been carefully described and categorized. From an evaluation of successful examples of aesthetic integration, we have developed a taxonomy using architectural terminology describing the design strategies:

**Legibility**—From High-tech Modernism, revealing and celebrating building systems. The downside of this strategy is that the house may look industrial rather than residential in terms of popular tastes and the norms of the real estate industry.

**Material Planes**—From early Modernism, composing in planes, often to emphasize or celebrate the “richness” of a material, and often achieving a lightweight or floating visual effect.

**Form Follows**—From the Modernist phrase “form follows function,” the building form adapts to the need for a large area of PV panels facing south.

**Shading**—The PV panels also provide shading for the building or an outdoor space.

**Disguise**—The PV panels are hidden through either a compositional strategy or a technological innovation (PV embedded glass, etc). This includes a flat roof with a parapet to hide the panels.

**Undesigned**—The PV is applied after-the-fact to a predetermined form (Figure 1).



Figure 4. Arizona State University 2011 Solar Decathlon house. An example of “Legibility” and “Shading.”



Figure 5. University of Illinois at Urbana Champaign 2009 Solar Decathlon house. An example of “Material Planes.”



Figure 6. University of Calgary 2011 Solar Decathlon house. An example of “Material Planes,” “Form Follows,” Legibility,” and “Dual Function.”



Figure 7. Georgie Tech University 2007 Solar Decathlon house. An example of “Legibility.”



Figure 8. Università Degli Studi di Roma, Winner of Solar Decathlon Europe 2014. An example of “Material Planes.”



Figure 9. University of Minnesota 2009 Solar Decathlon house. An example of “Form Follows,” and “Disguise.”



Figure 10. Massachusetts Institute of Technology (MIT), Institute for Advanced Architecture of Catalonia (IAAC) and Global Fab Lab Network, 2010 Solar Decathlon Europe house. An eccentric example of “Form Follows”



Figures 11-12. University of Massachusetts 2011 Solar Decathlon house. An example of “Legibility” and “Shading.”



Looking at all of the Decathlon contestants over the years, most fit reasonably well into one or more of these categories. Even notable avant-garde outliers such as the Fab Lab house (Figure 10) from the first European Solar Decathlon, claim the “Form Follows” influence. While such a response is probably too unusual for the conservative homebuilding industry, where houses are seen as investments, it is worth learning from them—particularly considering that this house won the people’s choice award for that year.

Fundamental to making any of these strategies work is a careful consideration of the modular repetition and dimensional coordination of the panels and how they fit into a larger PV array. In some cases the form of the building (including the dimension) is carefully aligned with the size of the array (Figure 5). In other cases the array has its own modular & structural logic which is somewhat free from the dimensional logic of the building (Figure 4). The former has more compositional integrity in a high-modernist sense. The latter is more pragmatic, especially if you assume that the building will outlast the equipment. Some additive structures may be complementary to the architectural form (Figures 11-12), while others may be independent or even discordant.

## THE FRONTIER ZERO APPROACH

The authors represent the University of Wyoming Building Energy Research Group (UW-BERG). UW-BERG has developed a catalog of Zero Energy home designs intended to meet the growing market demands for affordable Net Zero Energy homes (Gardzelewski and Denzer, 2015). In the preface to the catalog, the Frontier Zero approach is defined:

The catalog includes a variety of sizes, types, and styles, to appeal to a wide range of Wyoming residents. We also sought to create designs that would address many economic levels.

In general we want to create homes that will be attractive and contextual in a Western aesthetic, sympathetic to the Wyoming landscape and building traditions. Although a Net- Zero home can be built in any style, we do not use the catalog to promote styles, like Colonial, which are essentially foreign to the traditions of the place.

We have also worked carefully to design the homes so that Solar PV panels are integrated into the architectural character of the homes, rather than ‘tacked on’ to the roof as an afterthought.



Figure 13. Images from Frontier Zero Home Catalog.

The Frontier Zero approach was developed by analyzing the Solar Decathlon Aesthetic Approaches discussed above, and other examples, while looking carefully at the aesthetics of current homes being

built in the region. The aesthetic is deliberately conservative, to appeal to a wide audience of potential homeowners. The PV panels are generally on display, because to hide them would play into the argument that they are simply unattractive. Instead we sought to find a sympathetic approach where they are coordinated with the building geometry or the architecture. In these designs, the PV panels have a designated place in the design where they fit well. Often, rectangular roof elements correspond to bumps, recesses or dormers in the architecture. This strategy draws from the lessons learned while studying precedent. Many options are explored, as shown in figure 14.

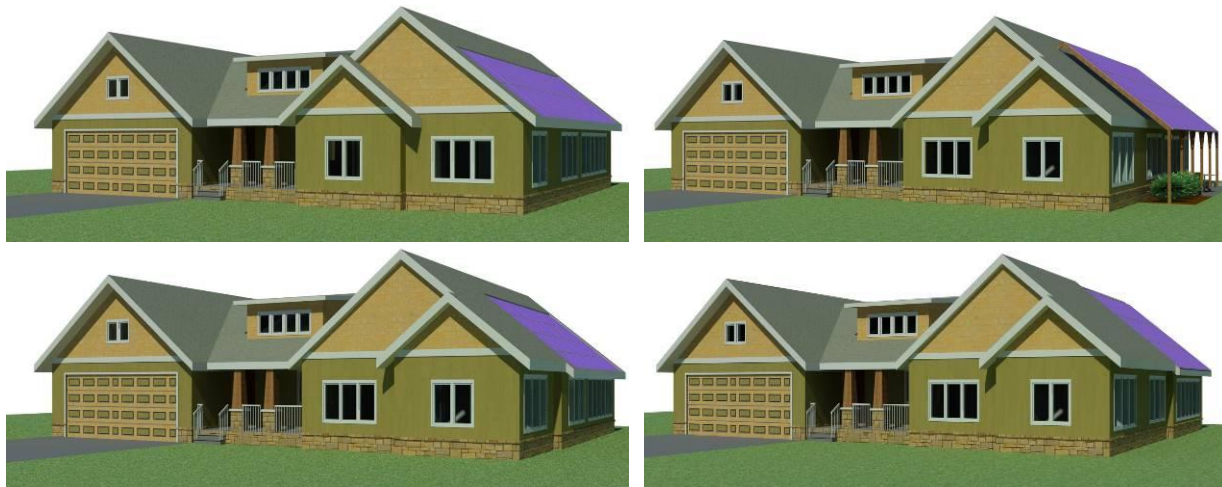


Figure 14. Variations on “Elk Mountain” from the Frontier Zero Catalog published by UW-BERG.

## SURVEY FEEDBACK

Initially, the Frontier Zero home catalog was used to gather informal data about homeowners’ aesthetic preferences, but later a more rigorous survey was conducted. Images from the catalog were modified and included in a regional survey of the Mountain West housing market to

provide concrete feedback on aesthetic preferences. The survey was administered online through a large market research firm, delivered to 1077 homeowners and potential homebuyers in Mountain West states, using something called a “discrete choice experiment” which is a common tool that can be used to assess demand in economics and marketing. The survey descriptions and results are described in a white paper written with the intent of describing in detail the survey’s use in assessing aesthetic preferencing (Gilbert et al 2016). This data comes from a larger effort testing the hypothesis that social image affects neighborhood sorting in the green home market.

The survey first asked respondents general questions to understand demographics, home purchase priorities, and their knowledge about public policy and energy efficiency. They were then asked to choose between different catalog home designs in an exercise designed to “reveal” their strength of preference for different home attributes such as: solar appearance, up-front costs, long-run energy bill savings, and energy efficiency rating. Respondents were divided in to two groups, each with a slightly different survey. In Group 1 the “price” displayed for each solar or energy efficiency feature(upgrade) was a hypothetical “net” price calculated as the difference between up-front costs and the present value of energy bill savings, discounted at an interest rate of five percent. In Group 2, the up-front price of the feature and the energy cost savings were presented as separate attributes so that the respondents’ importance of each component could be valued separately. Each group were given a range of energy performance targets whereas Group 1’s options included HERS 100 (a standard home), HERS 50, and HERS 0 (a Zero Net Energy home), and Group 2’s options included HERS 100, HERS 70, HERS 40, and HERS 0. Both groups were shown three solar options including: no solar panels, “undesigned” solar panels, and an architecturally-integrated option where the panels visually fit the roof design (figures 15-17). By observing the home designs chosen as "most preferred" at different hypothetical price points, we are able to calculate an estimate of the price premium for specific features of the designs.



Figure 15-16. Survey variations on “Thunder Basin” and “Red Dessert” used in the aesthetics preferencing survey.





Figure 17. Survey variations on “Medicine Bow” used in the aesthetics preferencing survey.

The results of the survey revealed a significant “Willingness to Pay” for architecturally-integrated solar in both survey groups. In Group 1, the premium for architecturally-integrated solar averaged \$7,300 above what respondents would pay for “undesigned” solar. The results of Group 2 were similar with an average premium of \$6,200 for architecturally-integrated solar. While the examples in this survey represent conservative approaches to aesthetic integration, there is perceived value in further exploring the various integration approaches in more detail.

## CLIENT FEEDBACK

Gaining knowledge of consumer preferencing can come from first-hand experience such as a single home design. In a recent Zero Energy home for the Fox family in Pavilion, Wyoming, UW-BERG found that the aesthetics of solar mattered considerably. The initial design includes an elongated south façade, a walk-out basement, a significant amount of windows for a passive solar heat gain in winter, and opportunities for both cross and stack ventilation in the summer. While the house is larger than average for Wyoming (4000 sf), the passive solar heating coupled with thermal mass and an efficient heating and cooling system (ground source heat pump; COP > 3) enabled a modest number of solar panels which did not dominate the appearance of the south facade. Initially choosing a conservative approach, the design located the PV panels on the garage roof, and stepped this roof back just from the other roofs to visually minimized the PV panels.



Figure 18. Fox residence initial design.

Before reaching a final design, a number of aesthetic options were explored with the clients. During this exploration it was found that the clients liked the look of the panels more than had been expected, and that they were willing to add more than the basic amount necessary to achieve Zero Energy. In going beyond the goal of Zero Energy, the financial payback is not immediately realized, and the decision becomes more complicated. In one sense this can be seen as a purely aesthetic decision, like a finish material, where for example a client might pay more for a more expensive material such as stone. Another viewpoint is that the addition of more PVs could be interpreted as a long-term investment in energy security and stability, or even flexibility to account for changes in lifestyle. Whether the decision was aesthetic, pragmatic, or a combination of the two, it was clear that, from the client's point of view, total benefits of additional PV outweighed the costs, and that they were swayed only after visualizing the aesthetic implications.

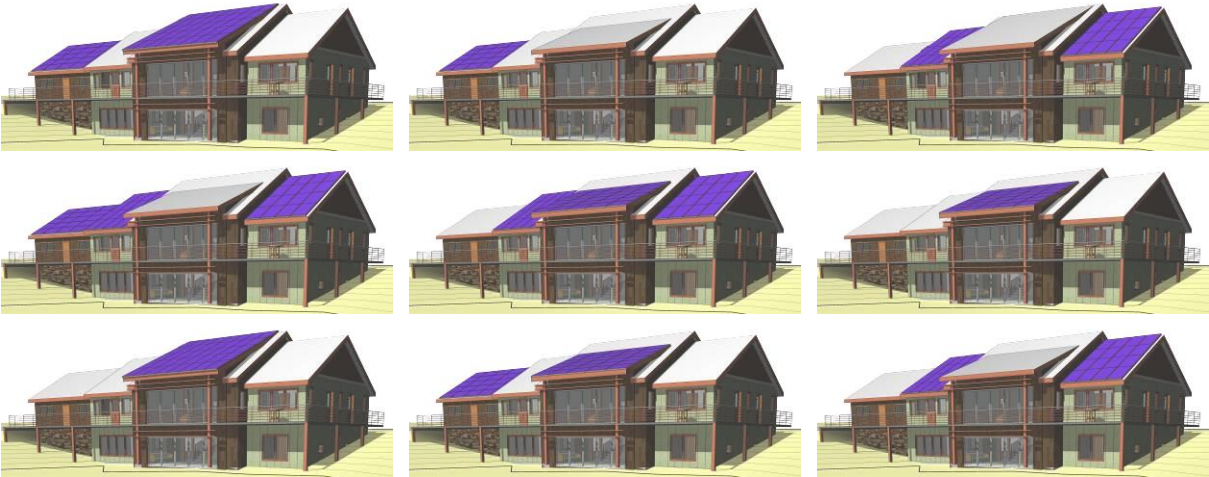


Figure 19. South Façade options for Fox residence.

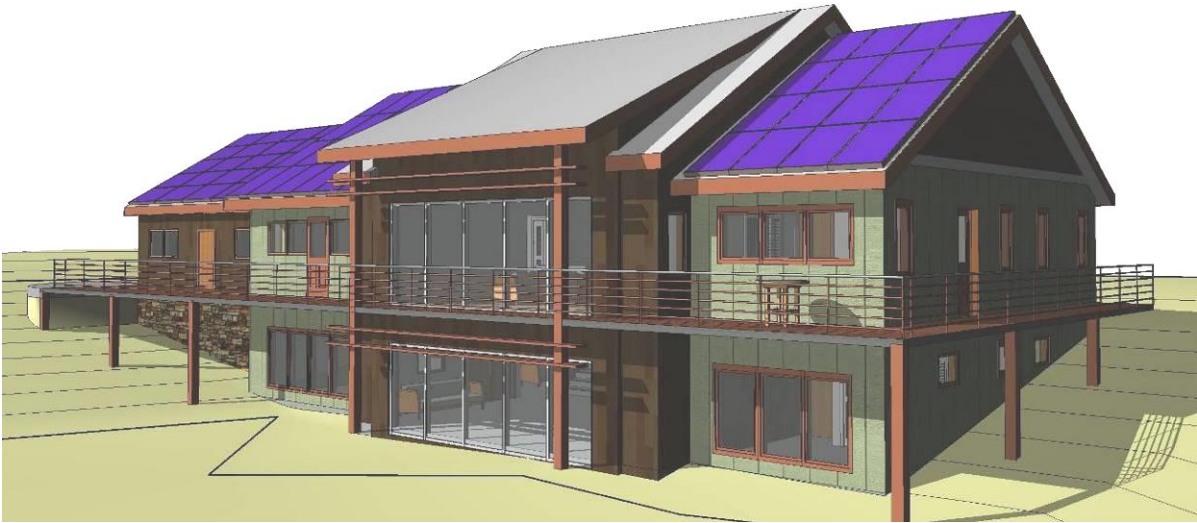


Figure 20. Final design of Fox residence

## **DISCUSSION**

UW-BERG's Frontier Zero approach has been focused on addressing the logistical and aesthetic concerns of residential solar with a focus on new construction and Zero Energy design. During this effort we have come to learn that solar panels not only add functional value, but that architecturally integrated PV can add aesthetic value. Specific compositional strategies are given by built examples including the Solar Decathlon competition entries, however there is so far no clear consensus on the most attractive approach. The best solution for any given project may be custom and subjective, or it may be a strategy adopted by an entire neighborhood interested in uniformity. It is possible to conclude that architectural integration of panels provides value, and it may even be possible to begin to quantify this value. Certainly, any given design may be appreciated by one individual but despised by another, but how does even a despised design rank standing next to something that is "undesigned?"

The advent of a new technology—PV—has introduced new matters of building aesthetics, which can and should be trusted to professionals in this field, architects. Well trained architects can be entrusted to make decisions of an aesthetic nature which influence both the value and public reception of a building. Further along these lines, if HOAs and other jurisdictions seek to regulate neighborhood aesthetics, they should consider engaging architects to either design or to serve on a review committee for solar homes. HOA covenants which are tailored to promote well-designed solar houses will naturally become opportunities for homeowners to realize added value from architecturally-integrated solar.

Like other fine arts and material possession, architecture is capable of tapping into a realm of consumer desire which ultimately transcends purely financial value. Combine functionality, ethics, economics, social image, and now aesthetics, and it seems more and more plausible that solar panels will become a permanent fixture in our culture (as well as on our buildings).

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