Marketing A Net Positive Future – The Demand Side

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Abstract

In many climatic regions, both in Europe and the US, it is possible to design and build homes that can be powered solely from a renewable resource. This paper will present the efforts taken in the US and Europe to aid home builders to quantify the performance of a building envelope and the levels of air-tightness that are required to achieve energy consumption goals that are 90% less than typical construction. As building codes evolve and energy efficient construction moves from the fringe to the mainstream, numerous computer simulating software packages have been developed to aid the designer in optimizing building performance. These packages serve the designer well. However, few inform a homeowner of the potential economic benefits of investing in a sustainable lifestyle, centered around a home that provides desired thermal comfort and monitored indoor air quality, all powered by a renewable resource. The first adopters of super insulated, airtight buildings, conditioned with small mechanical units have been eco-conscious architects and engineers. To reach a broader demographic the decision making process needs to be streamlined, the information delivered to potential homeowners needs to be condensed, and most importantly, delivered in a manner that an non-building professional can quantify. In most cases this will require expressing energy efficiency in terms of euros, pounds, and dollars of monthly expenditure, as opposed to kilowatt-hours per square ft, per year.

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The demand for energy efficient homes is a growing market. Building to standards that enable energy consumption to be reduced to the point where it can be satisfied by sustainable power sources is possible. However, further work is required to educate consumers, home builders and property developers, of the advantages of building beyond code compliance. With reference to the Gable Home, a house designed and built to satisfy the stringent Passive House (PH) standard, this paper will reflect on a designers interaction with the Passive House Planning Package. An evaluation of the simulated performance of the Gable Home will be made in light of data collected from the house since being established on a permanent foundation. The Passive House standard will be compared to the International Energy Conservation Code (IECC), and costs and benefits of building beyond code will be discussed. The paper concludes with a recommendation that could hasten the process by which the general public will gain an understanding of the financial benefits of living in an energy efficient building. Once the benefits are more widely known it is the authors belief that the demand for low energy consuming buildings will rise.

Iterative improvements in legally enforceable building codes have led to more energy efficient new construction. Energy rating systems such as the Home Energy Rating System (HERS) in the US, and Energy Performance Certification (EPC), mandated by an EU directive in 2013, have helped consumers compare the projected energy consumption of a home they may wish to purchase. However these codes and ratings have not produce a paradigm shift in the way the majority of buildings are designed, constructed, and operated. In contrast the Passive House standard has made a significant impact in the way buildings are built in a number of municipalities across Europe. For example The Brussels Capital Region, in Belgium, has looked to the PH standard to develop legislation that will enable it to achieve the ambitious energy performance goals, known as the “20-20-20 Targets”, established by the European Council (PassREg | the regions). In the US however, the number of Passive House certified homes remain a minute percentage compared to the large volume of houses that get built in the U.S. each year (PHIUS: project). The slow adoption of the Passive House Standard in the US could be influenced by the following factors:

1. It is not possible to gain political support to adopt the most current version of the International Energy Conservation Code in every state in the U.S. (Status of state energy code adoption). Therefore, going beyond the IECC, to comply with a much stricter voluntary code, is politically untenable in many parts of the US. Resistance to adoption is compounded by the fact there are additional costs to achieve Passive House certification.
2. Unlike Germany, the United States has a wide range of climatic variation within its boarders. This means a wide rage of specific construction details and insulation values are required to ensure Passive House compliance can be met throughout the US.
3. Although the definition of the Passive House Standard is succinct, the units of measure: kW/m^2/per year or Btu/ft^2/per year are not tangible values to an uninformed consumer.

Since its inception in 2000 the IECC has developed a model code to establish minimum design and construction requirements for energy efficiency. Following a process of proposal and review, submitted by those in the building profession, the code has become more stringent with each version that has been released. In parallel to the strengthening of the IECC the US Department of Energy (DOE) has provided concise and clear information on the differences between codes, and more importantly informing the public and state lawmakers about the financial benefits of adopting the most current version of the IECC. The DOE has modeled energy consumption and construction costs of numerous construction types, in various climatic regions to enable them to inform the public about life-cycle costs over a 30 year time period, and annual cash flow savings. In a seventeen-page document titled National Energy and Cost Savings for Single and Multifamily Homes, the DOE also breaks down the comparison of key elements in a buildings construction, e.g. insulation, window U values, and describes how they vary by climate zone (National energy and cost savings for new single – and multifamily homes). The Passive House movement, and the US Passive House organization in particular, offer some free advice on energy efficient building practices, the most useful being detailed descriptions of PH certified homes via their website (PHIUS: project detail). However to finance their work they need to license energy modeling software, such as the Passive House Planning Package (PHPP), or provide services, such as energy modeling and training seminars. Providing free and clear guidance as to what is required to build energy efficient homes is the first step towards creating an informed consumer market.

Despite the different roles the DOE, the International Codes Council and numerous Passive House accreditors play, their aims and objectives are very similar. All want to encourage the construction of more energy efficient buildings than those currently in existence. In the following section two key components of energy efficient construction will be addressed, insulation and air tightness. Reference will be drawn to the requirements prescribed by the IECC, and Passive House standard. Comment will be given on how compliance to these codes and standards can be achieved in the context of both the US and UK building traditions.

The energy crisis of the 1970's, public information distributed through various media outlets, and product promotional material, have all helped spread a broad understanding that high levels of insulation surrounding a building, will reduce the cost of conditioning rooms that are occupied. A second and much less understood principle of energy efficient construction is the creation of an airtight envelope. Air-tightness requirements have progressively become stricter in the IEEC over the years. In climate zone 4, defined by the IECC, the control on air changes per hour progressed from no requirement in 2006, to a recommended but not tested 7 Air Changes an Hour (ACH) in 2009 to the current IECC, released in 2012, requiring blower door testing to ensure new constructed homes have air leakage of 3 ACH or less. In comparison since its inception in the early 1990's the Passive House standard has always required tight control over air leakage. Figure 1 illustrates the energy and cost savings for a 2,000-ft^2 building that has been modeled using REM Rate software. When attention is given to the sealing of openings around doors and windows, as well as at junctions between floors, walls and roofs it is possible to achieve air-tightness that complies with the Passive House standard which states, "Uncontrolled leakage through gaps must be smaller than 0.6 of the total house volume per hour during a pressure test at 50 Pascal (both pressurised and depressurised states)" (Passivhaus institut).

The combination of high levels of insulation, with construction that prevents air leakage, or infiltration from the outside, is the key principle of energy efficient building. Markets in the US are more likely to embrace stricter air tightness controls than markets in the UK; the reason for this is twofold. The requirements for tighter control over taped joints in predominately wood framed construction, the norm in the US, is technically easier than achieving air tightness in masonry construction, the predominant form of construction in the UK. The US has also had a long tradition of using forced air to both heat and cool residential buildings. This has not been the case in the UK. One of the founding principles of the Passive House standard is to exchange the desired hot or cool air from the living space with incoming fresh air, which is mechanically drawn into the house to maintain good air quality. The Passive House standard gained traction in Germany in its early years due in part to the fact that economically it was viable to invest in added insulation, allowing costly furnaces and hydronic-heating systems to be replaced with less expensive forced air systems. Subsequent technical advances made heat recovery from air exiting a building possible, further reducing energy consumption.

The UK, being an island nation, has a climate that rarely sees sustained periods in which whole house air conditioning/cooling is required. Buildings with significant thermal mass, such as those built of masonry construction, in conjunction with natural ventilation; the opening of windows, or ‘leaky’ construction details has typically sufficed the needs of UK residence. Transitioning to airtight construction approaching the levels of those of the Passive House standard will require the introduction of whole house mechanical ventilation, without it interior air quality will rapidly deteriorate. Finding contractors who understand the principles of airtight construction is a challenge anywhere in the world. The challenge is compounded if there are few suppliers who have the ability to install mechanical systems that will maintain good air quality. In the US there is a growing market of products and services to satisfy the growing demand. In Germany, thanks in part to the Passive House movement, there are numerous products, and qualified installers who can install HVAC systems that are appropriately sized for an efficient domestic set up. In the UK the choices are much more limited, leading to a reliance on imported products that may lack the product support required to ensure the technology performs well and is accepted in a niche market.

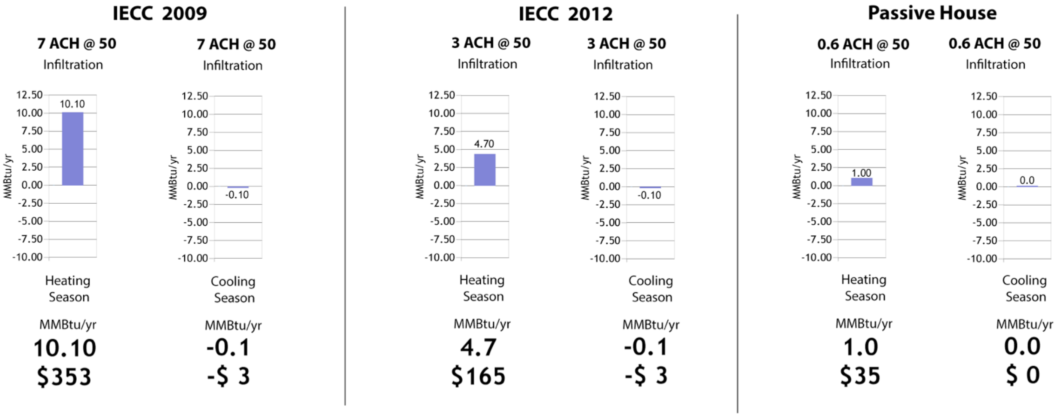


Figure 1. Energy and Cost savings modeled using REM Rate software.

In the following section data collected from the Gable Home will be presented. The data will be compared to the requirements of the Passive House standard, and discrepancies discussed. Built by a collaborative team of architecture and engineering students from the University of Illinois to compete in the 2009 version of the US Department of Energy's Solar Decathlon Competition, the Gable Home was a demonstration of how a Net Positive house could be built, (see figure 2). Informed by the Passive House Planning Package, and surpassing IECC requirements, the house performed extremely well in a competition that challenged collegiate teams from around the world to design and build energy efficient homes that are powered by the sun. During a weeklong competition each house was tested through contests that simulate typical occupancy. Following the competition the house returned to the University of Illinois where it has been monitored to see how it's performance relates to the energy simulation model built to aid the design process.

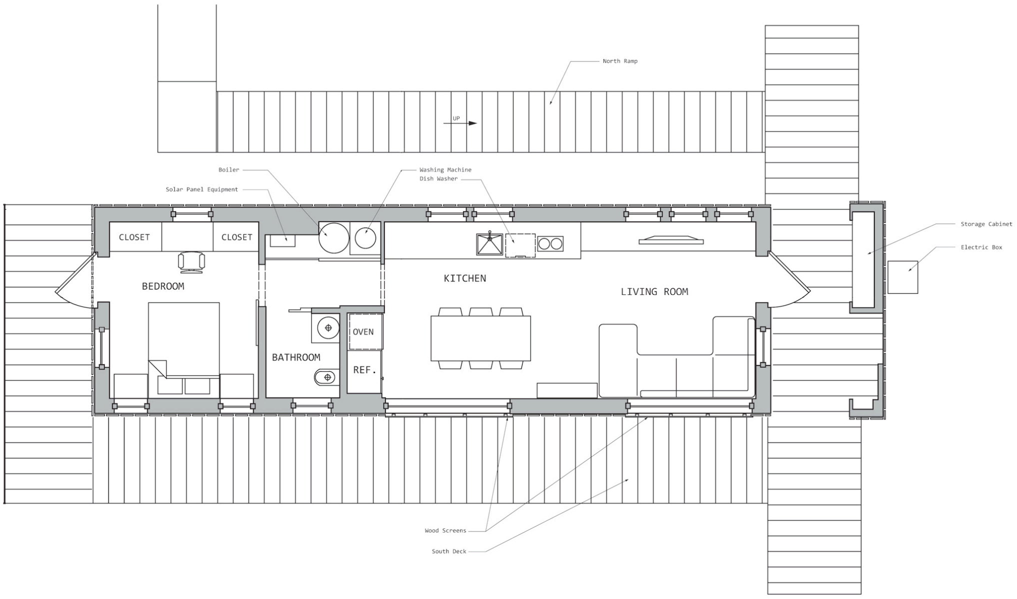


Figure 2. Floor Plan of the Gable Home

Although not required for the competition, the design team understood complying with the strict constraints of the Passive House standard would produce a house that would perform very well in comparison to one that simply satisfied the minimum requirements of the IECC. Air-tightness and insulation levels, prescribed by the 2009 version of the IECC in climate zone 4, are illustrated in figure 3. The IECC requirements are compared to those determined as acceptable by the Passive House Planning Package as it relates to the Gable Home's compliance with the Passive House standard, (see figure 3).

2009 IECC Requirement for Insulation in Climate Zone 4

Air Change Recommendation of 7 ACH (no required testing)

Insulation in Walls	**R 13 (U 0.077)**
Insulation in Attic	**R 38 (U 0.026)**

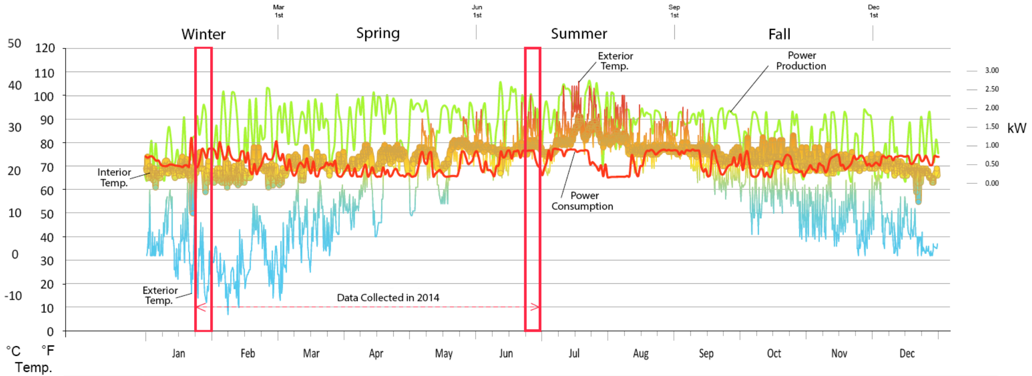
Passive House Planning Package Requirements for the Gable Home

Air Change of less than 0.03 ACH – (blower door tested)

Insulation in Walls	**R 50 (U 0.020)**
Insulation in Attic	**R 60 (U 0.017)**

Figure 3. Comparison of IEEC and Passive House Requirements

A Net Positive House, can be described as one that can produce more energy than it consumes, measured over a one-year period. Designing a Net Positive House requires an understanding of how a house will consume energy, and has the potential to produce it, through the four seasons of the year. In a similar way Passive House compliance is based on an energy model that simulates energy demand over a one-year period, in conjunction with the occupiable area within the house. Figure 4 illustrates numerous characteristics about the Gable Home, while figure 7 outlines the requirements of the Passive House standard.



Total Electricity Used [kWh]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014	545	454	371	205	313	47[1]	-	-	-	-	-	-	1936
2013	615	495	434	295	430	496	521	398	458	325	389	486	5341
2012	411	204	176	247	401	462	583	519	369	221	348	465	4406
2011	-	-	-	-	-	-	-	-	0[2]	0	89	220	132

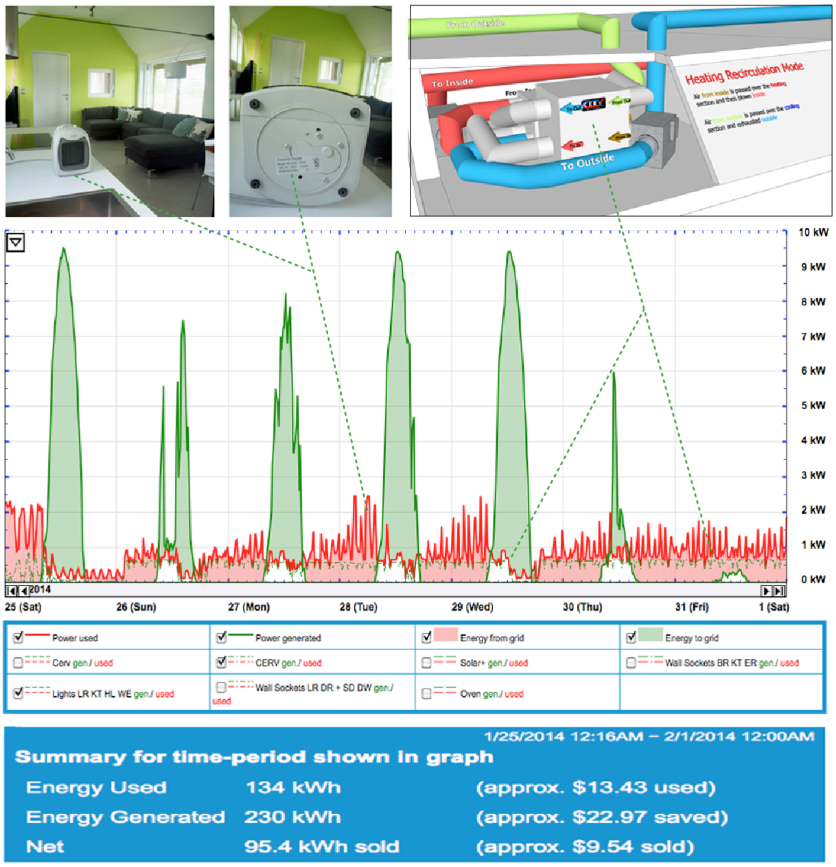
Net Electricity Used [kWh]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014	-77	-498	-712	-917	-925	-52[1]	-	-	-	-	-	-	-3182
2013	-251	-521	-837	-1088	-1003	-912	-922	-886	-713	-529	-414	-109	-8183
2012	-400	-481	-1002	-866	-918	-790	-646	-691	-694	-692	-549	-93	-7824
2011	-	-	-	-	-	-	-	-	-0[2]	0	-314	-371	-685

Figure 4. Data from the Gable Home

For a home to be comfortable, interior temperatures need to be maintained between appropriate set points that relate to the season of the year. There are a number of approaches to achieve this. In older, less efficient homes a thermostat within the living space can be set to trigger heating or cooling when a certain temperature is reached. Maintaining desired temperature in a poorly insulated house can be expensive, especially in summer and winter months. To mitigate for this cost some homeowners opt to switch off any heating or cooling when the house is not occupied. To accommodate this approach furnaces and air conditioning systems have historically been installed with a high capacity to bring a house back to desired temperature quickly, once the homeowner returns to the house. The operation of the Gable Home differs from this conventional approach. Instead of having large equipment with a lot of capacity to respond with large volumes of air in a short period of time, the Gable Home is equipped with a Conditioning Energy Recovery Ventilator (CERV) that provides small volumes of air-conditioned air that may be only a few degrees hotter or cooler than air contained within the living space. This 'low flow' approach to maintaining desired thermal comfort is only possible in a house that is well insulated and of airtight construction. The advantage of this approach is the heating and cooling systems can be down sized, and running costs reduced. Energy efficient heat-pump technology can be used to provide small amounts of conditioned air throughout the day, maintaining desired comfort, with little regard for occupancy levels. The thicker orange band in figure 4 illustrates the attempt to keep the interior temperature of the Gable Home between 68°F (20°C) and 77°F (25°C) throughout the year. The thinner line that fluctuates between blue and red, charts the exterior temperature that falls as low as 10°F (-12°C) in the winter and as high as 100°F (38°C) in the summer. The red line in the middle of the chart records the kW usage of the house to maintain desired interior temperature, other electrical usage, such as socket outlets and lights, are also accounted for in the kW plot. At the bottom of figure 4 a record of total, and net kWh usage per month is presented. Yearly kWh totals are highlighted in the right hand column of these charts.

The following figures describe the performance of the air conditioning systems during the periods of the year when demand is greatest. The airtight construction, and high levels of insulation in the Gable Home are good buffers against daily exterior temperature swings that may occur in the spring and fall. However, during the summer and winter month's greater demands are placed on the systems that maintain desired interior temperature.



1/25/2014 12:16AM – 2/1/2014 12:00AM

Summary for time-period shown in graph

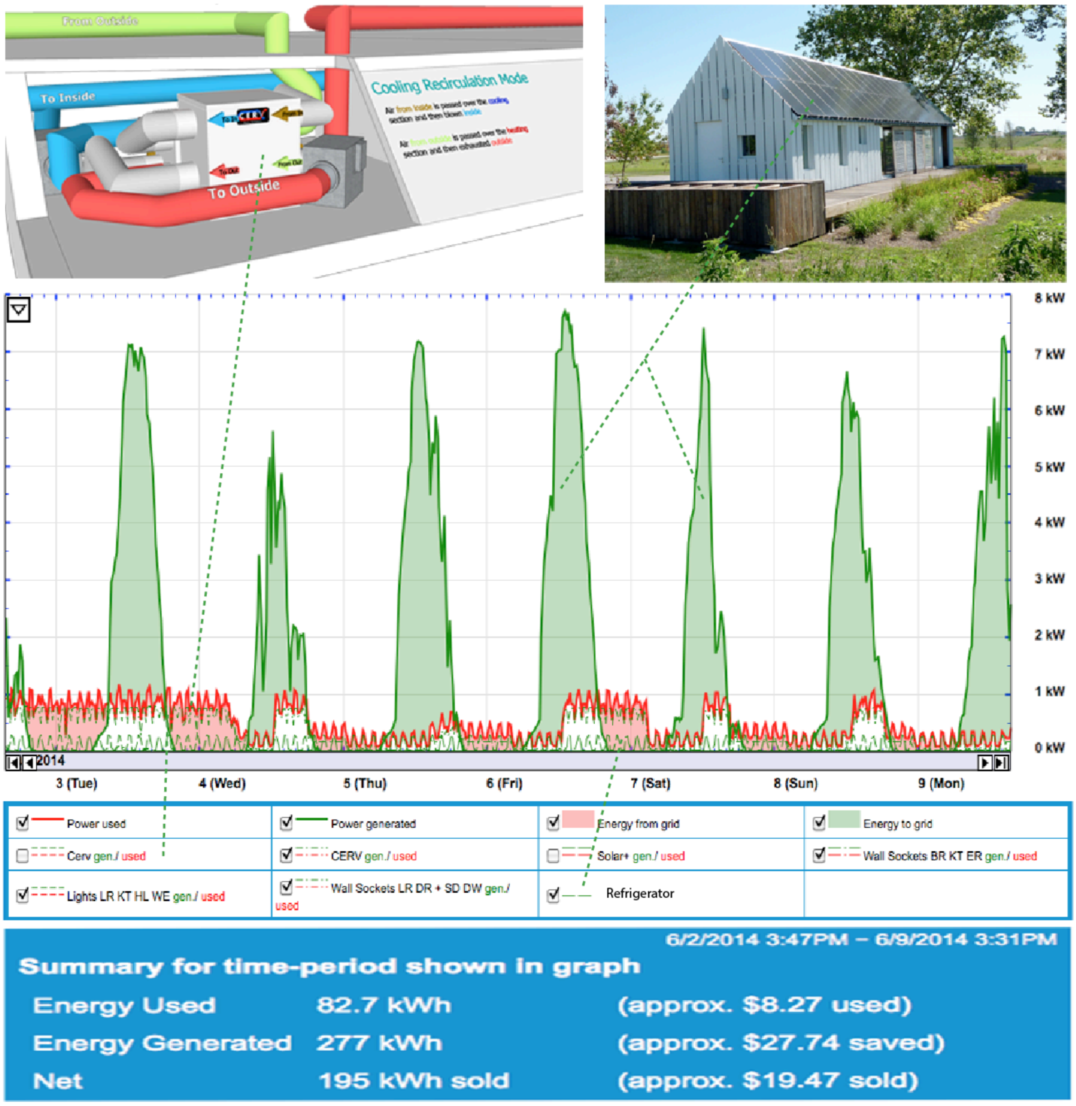
Energy Used	134 kWh	(approx. $13.43 used)
Energy Generated	230 kWh	(approx. $22.97 saved)
Net	95.4 kWh sold	(approx. $9.54 sold)

Figure 5. Data from the Gable Home in January 2014

In figure 5, data collected from the Gable Home, over a seven-day period at the end of January 2014 is illustrated. During that period exterior temperatures dropped to 12°F (-11°C) over night. During the early part of the week the sky was mostly clear, allowing significant amounts of electricity to be generated via a 9 kW solar array on the roof of the Gable Home. The plot of the green line on the graph records the generation of power, the red line on the graph tracks consumption. Two systems are used to maintain a desired interior temperature. The CERV is the primary air conditioning unit in the Gable Home. Utilizing heat pump technology it has the capability to heat or cool small volumes of air a few degrees depending if the unit is operating in a heating or cooling season. If the unit detects exterior temperatures that would help condition the space it will draw air in, if exterior temperatures are not desirable the unit will operate by recirculating air, heating or cooling it as required to keep the interior temperature at desired levels. Equipped with CO2 and VOC sensors the unit is also set to trigger fresh air ventilation cycles if air returning to the unit from the conditioned space is contaminated above acceptable levels. With exterior temperatures below 50°F (11°C) during the last week of January 2014 the CERV was in operation nearly 24 hours a day to maintain a desired interior temperature above 68°F (20°C). By tracking the red line on the graph, energy consumption can be seen to reduce in the afternoons of January 25th, 26th, 27th, 28th and 29th. The demand on the active heating systems reduced during these periods as the house was heated by passive means. The sun’s rays would have penetrated into the living space through large windows on the south side of the Gable Home during those afternoons, raising the interior temperature by a few degrees. Conversely additional mechanical heating is required in the home during the coldest part of the night, prior to sunrise. During those periods, to supplement the performance of the CERV, one or two 1,500 W fan heaters were in operation to maintain desired thermal comfort. These times of high heating demand can be seen represented as the peaks on the plotted red line, during the early mornings of January 28th and 29th.

Data collected from the Gable Home over a seven-day period at the beginning of June 2014 is illustrated in figure 6. The week of June 3rd to 9th was hot and sunny with exterior temperatures that peaked above 90°F (32°C). Fluctuations of the green line on the graph reflect the fact that there were some periods of cloud-cover during the week; this is particularly evident on June 4th. However, by comparing the size of the filled areas of green (Energy to Grid) to the filled area of red (Energy from Grid), it is clear to see the house created a net surplus of energy during the week. The quantity of surplus energy, and it's estimated value is presented in the blue box below the graph. Above the graph on the left is a diagram of the CERV unit that during the summer will typically operate in a cooling recirculation mode during the day. In the evening, if exterior temperatures drop sufficiently, air from outside will be drawn into the house. An indication of this change in operation can be seen occurring between June 6th and June 8th. As the sun rises during the morning of the 6th the well-insulated building requires little work from the CERV to maintain a desired interior temperature of below 78°F (25°C). The plot of the red line reflects a small draw on power from the CERV as it samples interior and exterior air approximately every 15 minutes. By midday on the 6th, when solar power production is at its peak the temperature inside the building would have been detected as rising above 78°F (25°C) and the CERV would have switched into its active recirculation cooling mode. The lag in time between the need for the CERV to operate in the morning, is mirrored in the evening, when exterior temperatures remain high after the sun has set. Only late into the night of the 6th is there the opportunity to draw in cooler air from outside the house. If conditions are favorable and a sufficient volume of air can be captured inside the airtight insulated envelope of the home the CERV will not be required to condition the living space until the middle of the following day.

The fluctuations in energy consumption are due to two factors. The larger fluctuation in consumption, which can also be seen as a dotted green line at the base of the graph, is the power draw of the refrigerator in the home. In addition to drawing energy, the refrigerator contributes heat by way of the refrigeration coils mounted on the outside of the appliance, something that provides some small benefit in the winter, however in the summer the refrigerator is adding to the cooling load. The smaller fluctuations in energy consumption relate to the performance of the CERV. To maintain optimal performance while recirculating cool air the CERV will stop operating for approximately 5 minutes in every one-hour cycle. This short period of rest prevents the evaporator within the CERV freezing over.



6/2/2014 3:47PM – 6/9/2014 3:31PM

Summary for time-period shown in graph

Energy Used	82.7 kWh	(approx. $8.27 used)
Energy Generated	277 kWh	(approx. $27.74 saved)
Net	195 kWh sold	(approx. $19.47 sold)

Figure 6. One Week of Data from the Gable Home in June 2014

As mentioned at the beginning of this paper, the definition of the Passive House Standard is succinct, however the units of measure: kW/m² per year or Btu/ft² per year are not tangible values to an uninformed consumer. It is also a challenge to determine if a house is operating in compliance with the standard once it has been built. Blower door tests can be repeated to confirm if air-tightness has been maintained, however of greater benefit to the home owner would be a mechanism by which the electrical meter could be read to see if the house was demanding energy at a rate lower than the 120 kWh/m² per year requirement of the PH standard. The advantage of this, beyond the satisfaction of knowing a house is operating in compliance with the standard, is that if the house is not in compliance there could be some re-commissioning of equipment, or changes in behavior that could bring the house back in line with the modeled performance on which certification is awarded.

	Passive House Standard for Source Energy	
Energy Demand	$\leq$ 120 kWh/m^2. yr	38.1 kBtu/(ft^{2}yr)
Heating Demand	$\leq$ 15 kWh/m^2. yr	4.75 kBtu/(ft^{2}yr)
Cooling Demand	$\leq$ 15 kWh/m^2. yr	4.75 kBtu/(ft^{2}yr)
Air Changes Per Hour	$\leq$ 0.6 @ n50	
or		
Specific Heating Load	$\leq$ 10 W/m2	3.17 Btu/(ft^{2}hr)

Figure 7. The Requirements of the Passive House Standard

The Passive House standard stipulates that only 15 kWh/m^2 per year can be consumed to either heat or cool a house. If other energy draws such as appliances, lights and plug loads are included the total energy consumption has to be less than 120 kWh/m^2 per year. (see figure 7)

In this concluding section an attempt will be made to quantify if the Gable Home operates within the confines of the Passive House standard. An assumption could be made that the 120 kWh/m^2 per year limit on total energy use would translate into 5,640 kWh per year, based on the Gable Home's 47 sq/m (506 sq/ft) of useable area, and by simply reading the electric meter in the house, compliance could be determined. Unfortunately for the end user/homeowner that assumption cannot be made. Energy consumed at the house is defined as Site Energy; the Passive House standard is based on Source or Primary Energy consumption. When the Passive Haus Institut established the Passive House standard they defined it in terms of Source Energy to account for all the possible forms of energy and fuel options available to consumers. While commendable for factoring in choice, the scaling factors, or source to site ratios that are built into the energy modeling software that determine PH compliance favor the use of natural gas or even coal, as opposed to electric power. For example the scaling factor for natural gas is only 1.1 where as electricity produced in a nuclear or coal powered plant is scaled by a factor of 2.7. This is understandable when one considers Source Energy accounts for all "losses that are incurred in the storage, transportation and delivery of fuel to a building." (The difference between source and site energy).

Fortunately there is a provision in the software used to determine PH compliance that caters to those who want to invest in producing their own power on site. The provision calculates both site produced and source energy, taking into account the different scaling factors that are applied to the different methods of power supply/production.

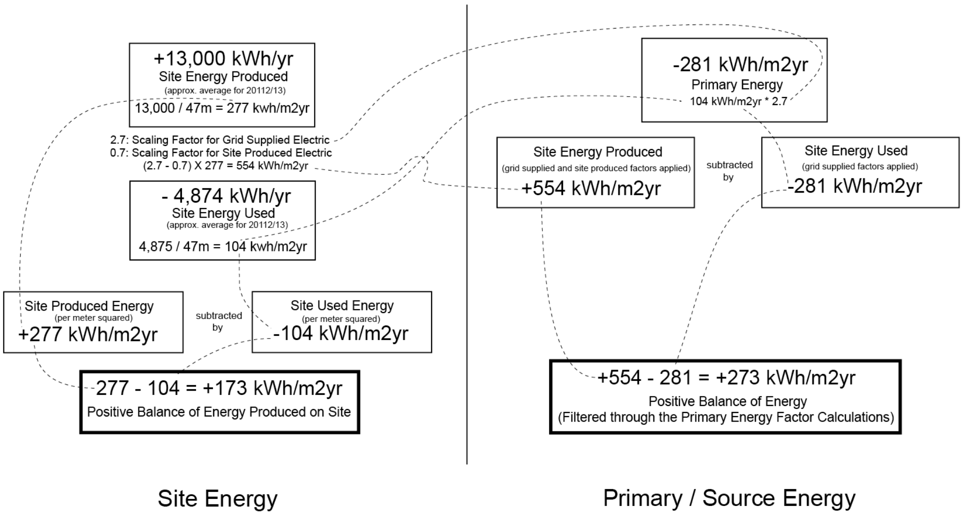


Figure 8. Illustration Showing Relationship Between
Site and Primary/Source Energy Using Data from the Gable Home

When two or more sources of energy are used to power and condition a home the calculations become complex; the interplay between different scaling factors needs to be accounted for. The spreadsheet format of the Passive House Planning Package (PHPP), the software used to determine PH compliance prior to construction, has the ability to deal with that complexity. Figure 8 is an illustration of the type of calculations the PHPP could carry out if known data for onsite energy use and production could be determined. The values entered in figure 8 are derived from performance data collected from the Gable Home in 2012 - 2013.

Replacing projected data with recorded data is probably the best way to determine if PH compliance is being met. In the case of the Gable Home, calculations presented in figure 8 confirm that on balance, the Gable Home is performing in line with Passive House requirements. It is true that the Energy Demand, or 281 kWh/m²yr Site Energy Used, as annotated in figure 8, is above the allowable limit of 120 kWh/m² per year. However, a surplus of 554 kWh/m² per year, site produced power, offsets the demand by 273 kWh/m² per year.

While not straightforward, taking meter readings on site and feeding that data into the Passive House Planning Package, or similar spreadsheet calculator, will determine if a house is operating in compliance with the Passive House standard. To encourage homebuilders to build homes that have the potential to be powered by a renewable resource, it is the author's belief that meter readings from PH compliant houses should be published. When onsite power production is coupled with energy efficient construction the result is typically small, or potential Net Positive energy bills. Publicizing this fact may be what is now required to move energy efficient construction from a fringe activity, into the main stream.

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