PASSIVHAUS AND NET ZERO ENERGY RESIDENTIAL DESIGNS IN A COLD CLIMATE: A SIMULATION BASED DESIGN PROCESS FOR THE NEXT GENERATION OF GREEN HOMES

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ABSTRACT

Today's residential construction industry is capable of producing exceptionally high performing houses that far exceed compliance with local building codes. We feel that setting a target of Net-Zero Energy (NZE) is feasible in the US considering the design and construction technology available.

This paper is part of an extensive project focusing on residential construction utilizing Passivhaus strategies with an emphasis on solar design and a target of Net-Zero energy use. The focus of this paper is on the role of simulation as a design aid in developing guidelines relating to building form, orientation, glazing, and roof area for solar electrical and thermal systems.

INTRODUCTION

The motivation behind the research is to develop prototype Net-Zero Energy (NZE) home designs that are constructible, desirable, and affordable. Every location presents unique constraints in terms of heating and cooling demands and solar availability, so it has been clear from the onset that a one-design-fits-all approach will not achieve success. The location and microclimate challenges associated with a NZE goal requires a simulation methodology that is not only integrated into the design process, but is the critical objective.

This paper documents our design and simulation methodology, exposing both opportunities and limitations with several software tools which are developed specifically for performance focused design. The conclusions may reveal opportunities in the US to design NZE homes using simulation for a better understanding of climate, constraints, and opportunities.

Initial House Layout

We began with an objective that our house designs must be not only be affordable and performance focused, but also desirable. In designing a house that is desirable or attractive to a large number of people, one takes a great risk once the hand of the designer is evident in arbitrary aesthetic decisions. To avoid such pitfalls we decided to find, rather than produce, an acceptable design. We reviewed hundreds of generic home plans intended for popular appeal, specifically looking for workable schemes that could achieve a high degree of energy efficiency. We specifically looked for designs: 1) without excessive corners or roof-lines, 2) compact shapes which could flexibly adjust to any number of lot sizes, 3) a high volume to surface area ratio to minimize heat loss, 4) a large solar envelope relating to the south wall and south facing roof top, and 5) a large enough design to accommodate an average family (3-4 bedrooms) with an efficient use of space. Following these sets of requirements we settled on an initial design for our first round of simulations: a two story rectangular house with 3 bedrooms, 2.5 baths and an office, and without a basement or garage.

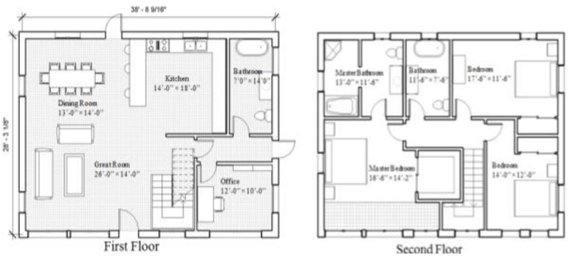


Figure 1 Initial House Design (Floor Plan)

We do not anticipate that the initial scheme will be the final scheme, but we simply needed a starting point for our simulation process from which an ultimate design could be easily derived.

Net-Zero Energy strategy

In Achieving NZE, it is important that we first reduce the energy demands, then, meet our reduced need with on-site energy production (Zaretsky, 2010). The definition of NZE buildings is dependent on many parameters. For example, what units of measurement do we use: primary energy, energy cost or CO_2 emissions? As reported by International Energy Agency Annex 52 Task 40 on ZEB definitions: "The Zero

Energy/Emission Building is a complex concept thus the development of one ZEB definition applicable for all case is not a simple task" (Tardif et al, 2011).

While there may not be a unique definition of Net-Zero Energy, we must choose a specific definition for our project. Torcellini et al. (2006) defines ZEB (Zero Energy Building) as "the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources. At the strictest level, a ZEB generates enough renewable energy on site to equal or exceed its annual energy use." We use the strictest definition with a target for on-site energy generation that meets the annual usage.

On-site energy generation commonly occurs in two forms: wind and solar. We chose to focus on solar energy because it is relatively more predictable and less affected by unique site constraints (even though solar availability remains unpredictable and remains affected by site constraints). Solar energy production is expensive relative to residential construction costs, so reducing the energy demand and thus the required solar production equipment is much desired.

Passivhaus as a path to Net-Zero Energy

As mentioned above, our first goal is a reduction in energy demand, the balance of which must be produced through solar systems enabling the building to reach NZE use. There are many international energy standards for residential construction, but we feel that the Passivhaus standard provides the most rigorous framework for energy efficiency that is both widely proven and fairly affordable (Passive House Institute 2007). Beginning with the Passivhaus standards enables us to design exceptionally energy efficient homes with the flexibility that the builder could stop at a Passivhaus, and then the owner could take the house to NZE down the road as solar production equipment becomes more affordable.

Simulation and interoperability

Architectural designers are, for the most part, lacking in-depth experience or knowledge about the proper use of simulation as an early design aid. An additional barrier is found in the segregation of software expertise by professional background—a mechanical engineer will often have the knowledge and experience to conduct energy simulations, yet their influence in the early stages of design is inconsistent (Gardzelewski, 2010).

However there are several energy analysis tools such as BEopt (Christensen, et al., 2005), we have chosen three tools which constitute a perfect package based on our requirements: Autodesk Vasari, Autodesk Ecotect, and Design Builder. Vasari, along with recent versions of Revit, has seen great improvements in interoperability, enabling easy export for evaluation of energy use in Design Builder, and solar availability using Autodesk Ecotect. The strength of this process is rooted in interoperability between these tools utilizing the .gbxml universal file exchange format.

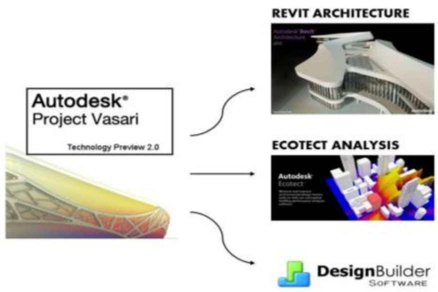


Figure 2 Design and Simulation Software.

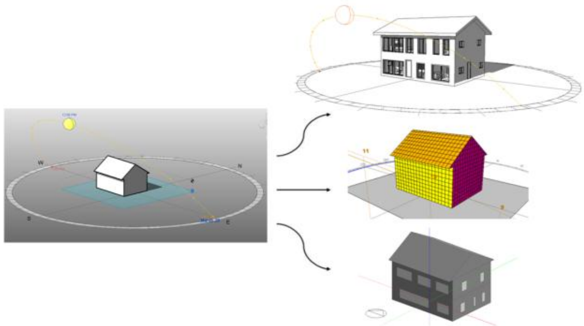


Figure 3 Building Model in Vasari, Revit, Ecotect and Design Builder.

Simulation strategy overview

Our simulation strategy can be summarized as a series of basic steps:

1) Assign Passivhaus standard default data
2) Determine south glazing wall-to-window ratio
3) Check heating and cooling loads
4) Determine solar availability by location
5) Determine required roof area based on angle and orientation for solar energy production

Having completed these steps, the designer is immediately aware of the best orientation, glazing, as well as an approximate square footage of roof area. These constraints can result in an infinite number of successful design solutions, however the instantaneous or near instantaneous simulation feedback is the crucial element missing from much of todays' design process. In our presented methodology, design solutions can easily stray from the simple Passivhaus box and solar roof, with near instantaneous performance feedback.

METHODOLOGY

Passivhaus methodology

Passivhaus specifies both prescriptive and performance requirements. The Passivhaus standard requires triple pane windows with a U value of 0.14 Btu/ (h°Fft²). There is a recommendation that the remaining envelope U values stay below 0.0264 Btu/ (h°Fft²), but this is not a prescriptive requirement. Instead, Passivhaus has developed performance based standards for maximum annual energy usage including a maximum annual heating and cooling energy use allowance: the total annual energy usage must be no more than 38kBtu/ft^2 (120 kWh/m^2) including a maximum usage of 4.8 kBtu/ft^2 (15 kWh/m^2) for heating and cooling separately (based on floor area). In addition, Passivhaus requires that air infiltration must be no more than 0.6ACH under 50 Pascal of pressure, and the ventilation utilizes heat recovery.

Table 1 Passivhaus Standard

Glazing Type: Triple Pane	U value of 0.14 Btu/ (h°Fft²)
Maximum Annual Total Energy Use	38kBtu/ft^2 (120 kWh/m^2)
Maximum Annual Energy Use for Heating	4.8 kBtu/ft^2 (15 kWh/m^2)
Maximum Annual Energy Use for Cooling	4.8 kBtu/ft^2 (15 kWh/m^2)
Air Infiltration	0.6ACH under 50 Pascal

Working with these standard enables us to keep the design simulations very schematic (we do not have to specify refrigerators, lights, etc), with the assumption that energy specific details can be manipulated later. Ultimately the annual energy-use must be as good as or better than the Passivhaus; a standard which has proven to be feasible and relatively affordable with current technologies (Passive House Institute 2007). Passivhaus limits are attainable, allowing us to direct our focus towards form specific schematic design issues, such as window design and solar production.

The infiltration and ventilation components of our simulation are lumped together into a combined air changes per hour. A combined infiltration/ ventilation rate of 0.12 ACH (0.05ACH based on N factor from LBL in addition to 0.7 ASHRAE residential accounting for heat recovery) is derived by adding the maximum Passivhaus infiltration requirement with the required residential ventilation rate for the US determined by AHSRAE (ASHRAE 62.2, 2003). We accounted for heat recovery by reducing our ventilation heat losses by 80%, which in theory represents the 80% heat recovery ratio for a Passivhaus ventilation system.

The internal heat gains are determined by the default residential template values from Design Builder, where each space is defined and scheduled separately by residential space type. The calculation guidelines in the Passive House Planning Package use 2.1W/m^2 of lumped internal gains (all internal gains including occupancy, computers, office equipment, miscellaneous, catering process and lighting gains), a value that has been considered unrealistically low (Dokka and Andresen, 2006). The average internal gain, in these simulations, is close to 3 W/m^2. In the end, internal gains will vary considerably due to user behavior as well as the heat output of the electrical equipment. The internal gain values are not as conservative as they could be, however we feel that they will realistically anticipate user behavior. The inputs like temperature are set based on schedule in the simulation.

Passivhaus to Net-Zero Energy methodology

We are working with the Passivhaus standard yet our ultimate goal is NZE, so while there can be tradeoffs with Passivhaus in terms of heating, cooling, and energy use including hot water and electricity, our strategy assumes the strictest allowance for each category. Specifically, we start with the maximum allowable energy use, subtract the maximum heating allowance, subtract the maximum cooling allowance, and are then left with an energy allowance for hot water and lighting/appliance electricity that we know is still attainable. Hot water can be heated more efficiently through solar thermal than solar electrical systems, so we subtract out the hot water demand and are left with an electricity allowance that, along with cooling, must be met by the solar PV roof system. Hot water must be addressed with a solar thermal roof system. Space heating is first dealt with through superinsulation and direct solar gain, while the remaining loads are best met through additional solar PVs and electricity powered heat pumps (while PVs for electric space heating are less efficient than solar thermal, for the same roof area PVs produce more annual electricity).

$$E_{total} = E_{heating} + E_{cooling} + E_{source} = 38 \text{ kBtu/ft}^2$$

$$E_{source} = E_{total} - E_{heating(allowed)} - E_{cooling}$$

$$= 38 – 4.8 – 4.8 = 28.5 \text{ kBtu/ft}^2$$

These formulas, based on the Passivhaus standards, help us undertand production targets that can be addressed through solar roof systems designs. In designing and sizing the systems, the basic formula is separated into solar thermal and solar electricity, where solar electricity is then separated into 1) an allowance for cooling and source, and 2) specific heating requirement for each climate. Solar thermal for domestic hot water (DHW) is initially designed around peak winter conditions, while solar electricity assumes connection to a smart grid, and is designed for annual conditions.

$$E_{thermal} = E_{dhw} = 5.3 \text{ kBtu/ft}^2$$

Sized by worst case (winter) solar availability and sun angles (insolation)

$$E_{electric1} = E_{cooling} + (E_{source} - E_{thermal}) = 28 \text{ kBtu/ft}^2$$

Sized by annual solar availability and sun angles (insolation)

$$E_{electric2} = E_{heating\ (actual)} = (\text{Annual Heating Load}) \times \text{COP}$$

Sized by annual solar availability and sun angles (insolation)

In sizing the PV area of the roof, we have to account for the efficiency of the solar energy conversion based on affordable technologies. At this time we use a common efficiency of 15% even though more efficient technologies should be viable in the near future. In sizing the additional PVs, $E_{electric2,}$ for climate specific heating needs we use a heat pump with an efficiency of COP 2.0 (Averaged efficiencies for PV and heat pump have be considered).

In sizing our solar hot water systems we utilize a different approach. Since we cannot easily store heat for more multiple days (Watson, 1977), we first focus on the worst case in terms of solar availability. We calculated the solar radiation for the darkest month (December 8^{th} through Jan 7^{th}) and used this value to design a solar thermal system that accommodates a typical month's hot water usage for three occupants (ASHRAE 2001). Solar thermal efficiencies will vary over time due to fluctuations in solar availability, heat loss during storage, ambient outdoor temperature, and usage. In choosing efficiency for the purpose of the solar hot water system, we used a conservative value of 30% (ASHRAE 2010, RETscreen) efficiency which we feel accounts for the large temperature differences in the winter. While this method of sizing the hot water system can provide all our needs, we risk oversizing for much of the year, particularly in climates with very low winter solar availability. We sized the system again, matching the heating demand with the annual solar availability (Brown et al., 2011) to come up with a range of required solar thermal area. Later with more detailed calculations we can find an optimal balance between full solar hot water and a hybrid solar/electric system, whereby reducing the size of the solar thermal system we could add more PVs to the roof which efficiently supplement the winter hot water heating shortage considering their annual energy generation.

Simulation Step 1: assign Passivhaus standard default data

In presenting the methodology we will first demonstrate using a single location, Laramie, WY. As mentioned, the house should first meet Passivhaus standards; therefore we will use their requirements for building tightness and window U values. Since Passivhaus standards do not specify U value for walls, roofs, or floors, we started with suggested super-insulation values for North Americ: Joe Lstiburek's 10-20-40-60 rule for North American homes north of the Mason Dixon line which suggests R40 walls (U=0.025) and an R60 roofs (U=0.017). In terms of wall to window ratio, we limited all walls to 10% glazing except for the south wall where we simulated a range from 30 – 50% glazing for solar heat gain purpose. These constraints again gave us a range of heating loads in each climate.

Passivhaus Values:

Window U Value	0.14
Infiltration	0.6ACH @ 50Pascals

North American Rules of Thumb (IECC 2009):

Wall U Value	0.025
Roof U Value	0.017
Slab Insulation U Value	0.033

Simulation Step 2: Determine south glazing wall-to-window ratio

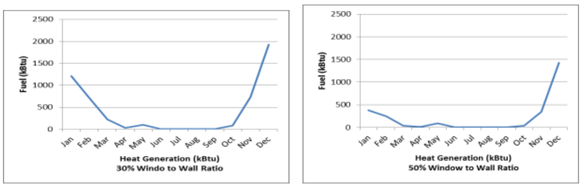
The glazing strategy plays a very important role in the passive solar heating strategy, both due to the heating by direct solar radiation and through conductive heat losses. Based on the Design Builder model, table 1 illustrates the results of solar gains and heating loads with different glazing to wall ration:

Table 1 Solar Gains and Annual Heating Loads with different Window to Wall Ratios for Laramie in December, Winter (Nov-Feb), and Annual

LOCATION/ GLAZINGTO WALL RATIO		DECEMBER SOLAR GAIN (KBTU)	WINTER SOLAR GAIN (KBTU)	ANNUAL HEATING LOAD (KBTU)
Laramie	30%	2788	8733	4946
	40%	6466	20288	2856
	50%	7958	24866	1642

When increasing window sizes the cooling load is increased. Our goal down the road is to develop both fixed and operable shading strategies to admit only wanted solar gains. At this design stage, an optimal shading strategy presents simulation challenges, so we are comparing only glazing in respect to heating.

The heating load is significantly influenced by the radiation gained through south facing windows. Figure 4 illustrates the change in fuel breakdown for heat generation (space heating) for Laramie with different window to wall ratios.



(a) (b)

Figure 4 Fuel Breakdown for different window to wall ratios (a) 30%, (b) 50% – Laramie Model.

Simulation Step 3: Check heating and cooling loads

To find the building's heating and cooling loads, we assume the building meets Passivhaus standards which reflect that the building must be designed to have the annual energy demand no more than 15 kWh/m^2 (4.8 kBtu/ft^2 per year) for annual heating and for annual cooling, respectively. For our case this gave us a maximum annual heating allowance of 9986 kBtu. To check Passivhaus compliance we did not assume a solar heating system, but a furnace with a high efficiency of 0.95 AFUE, giving us a maximum allowable load of 9487 kBtu.

Table 2 Heating Loads in Laramie

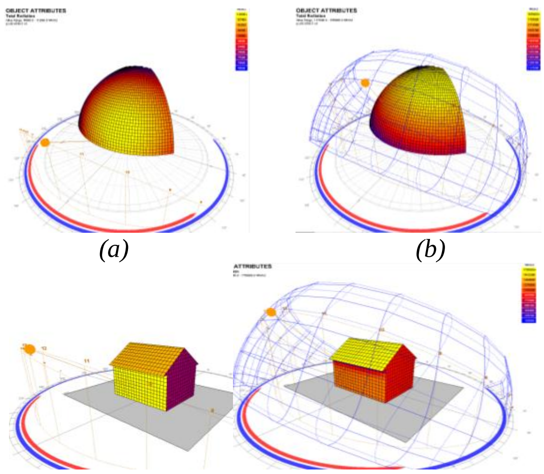
LOCATION/ GLAZINGTO WALL RATIO		DECEMBER HEATING LOADS (KBTU)	WINTER HEATING LOADS (KBTU)	ANNUAL (KBTU)
Laramie	30%	1639	4431	4946
	40%	1192	2625	2856
	50%	873	1526	1642

Simulation Step 4: Determine Solar Availability by location

The solar envelope defines the maximum building volume for a given site that will not shade adjacent sites, thereby assuring the availability of solar energy to those sites (Brown et al., 2011). Solar availability is location specific, and is determined based on TMY3 weather data projected onto various roof shapes. The simulations assumed a roof facing due south at a 35 degree tilt, but in addition we found the maximum solar angles for both annual and the darkest winter month conditions. Table 3 shows the annual solar availability and Table 4 shows the solar availability in the worst-case winter design period for Laramie.

Table 3 Solar Availability in Laramie per year

TILT		ORIENTATION	SOLAR AVAILABILITY (KBTU/FT^2)
Annual	35°	180°	579.5
	33°	162°	589 (max angle)
Dec07 -	35°	180°	30.8
Jan06	59°	170°	31.2 (max angle)



(a) (b)

(c) (d)

Figure 5 (a) Sphere Analysis Dec 07 – Jan 06; (b) Annual Sphere Analysis (c) Solar Radiation Analysis Dec 07 – Jan 06; (d) Annual Solar Radiation Analysis in Laramie, by Autodesk Ecotect.

Simulation Step 5: Determine required roof area based on angle and orientation

Based on the simulation's results in Autodesk Ecotect, the total required roof area is calculated as below:

Total roof area = Electricity Demand area required for PV (with 15% efficiency) + Space Heating area required for additional PVs (15% efficiency * COP 3 heat pump) + DHW area required for solar hot water panels (30% efficiency). As mentioned earlier, in determining the area for solar hot water we have found a range where we size for the annual average solar gains, then size for the worst case winter condition. The purpose again for this range is that *some* climates will find it impossible to meet the peak DHW demand with winter solar availability, while *all* climates will find that a or hybrid solar/electric system will ultimately provide the lowest area footprint when taking into account overproduction (wasted heat) with increased summer radiation levels.

Table 5 Required Roof Area for Photovoltaic (Annual Calculation) - Laramie Model

ROOF DESIGN (TILT, ORIENTATION)	SOLAR GAIN (KBTU/ FT^2)	PV @ 15% (FT^2)	HEATING PV @ 15% (FT^2)	DHW ANNUAL @ 30% (FT^2)
35°, 180°	579.5	677	6	63
33°, 162° (max)	589	666	6	62

Table 6 Required Roof Area for Solar Hot Water Panels (Peak Month Calculation) - Laramie Model

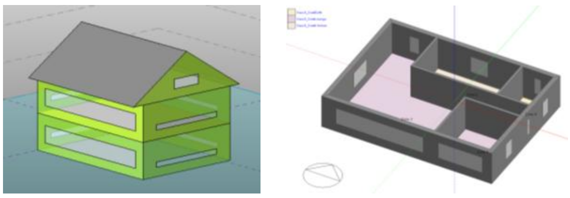
ROOF DESIGN (TILT, ORIENTATION)	SOLAR GAIN (KBTU/FT^2)	SHW @ 30% (FT^2)
35°, 180°	30.8	100
69°, 170° (max)	31.2	98

Table 7 Total Required Roof Area - Laramie Model with 35°, 180° Roof

ROOF DESIGN (TILT, ORIENTATION)	SOLAR GAIN (KBTU)	PV @15% (FT^2)	HEATING PV @ 15% (FT^2)	SHW @ 30% (FT^2)	SUM (FT^2)
35°, 180°	579.5	677	6	63 -100	750 - 787

Limitations

It is important to recognize limitations of the workflow. Our design tool of choice, Autodesk Vasari, is capable of quickly creating an energy model out of a building form for early design simulation. The modeling capabilities within the program do not easily facilitate detailed zoning of functional space types, nor do they enable a careful definition of envelope construction thermal resistance variables. While we believe that an ideal design/simulation tool will include this functionality, for now we rely on an export to Design Builder software where this information is assigned.



(a) (b)

Figure 7 Energy Simulation Models in (a) Vasari and (b) Design Builder.

Another limitation with Autodesk Vasari includes the solar radiation calculation which accounts only for direct radiation. Both direct and diffuse radiation can be converted into heat and energy, so the tool does not accurately describe the energy available. This built-in solar analysis is helpful in comparing solar energy improvements of different roof shapes in different climates; however it is not adequate for sizing solar systems, requiring us to export to Ecotect Analysis where the same analysis provides complete results.

As mentioned earlier, our simulation methodology focuses on heating and heating loads reduction in greater detail than cooling. Specifically, our methodology includes the sizing of additional PV systems to meet the annual heating demands. Cooling electricity-use is simply lumped into the total PV system sizing based on the Passivhaus cooling allowance. The reason for this is that both cooling systems and passive cooling strategies are often more complex than heating strategies, where the efficiencies are often dependent upon on the site and micro-climate.

RESULTS - ENERGY

Passivhaus strategies will greatly reduce heating loads in cold climates, particularly where there is a high level of winter solar availability. The energy simulations show heating loads are much lower than would typically be expected, making our target of NZE more easily attainable.

Table 8 Heating Loads in Different Locations Based on Window to Wall Ratio for December, Winter (Nov-Feb), and Annual Conditions

LOCATION/ GLAZING TO WALL RATIO		DECEMBER HEATING LOADS (KBTU)	WINTER HEATING LOADS (KBTU)	ANNUAL (KBTU)
Denver	30%	691	1789	2137
	40%	339	891	1029
	50%	122	406	462
Laramie	30%	1639	4431	4946
	40%	1192	2625	2856
	50%	873	1526	1642
Billings	30%	1885	7492	7896
	40%	1401	5865	5940
	50%	1001	4459	4470
Madison	30%	3958	13099	14016
	40%	3535	11288	11867
	50%	3133	9675	9987
Berlin	30%	3027	10269	11900
	40%	3016	9898	11132
	50%	2992	9530	10520

RESULTS - SOLAR

Table 9 Solar Availability based on optimal tilt and orientation, annually and in worst winter month

LOCATION	TILT AND ORIENTATION	SOLAR AVAILABILITY ($KBTU/FT^2$)
Denver	35°, 180°	585, 35 (annual, winter)
	31°, 164° (best)	594 (annual)
	61°, 178° (best)	39 (winter)
Laramie	35°, 180°	580, 30.8
	33°, 162°	589
	69°, 170°	31.2
Billings	35°, 180°	528, 26
	31°, 168°	533
	67°, 174°	30
Madison	35°, 180°	478 ,24
	25°, 170°	486
	59°, 174°	26
Berlin	35°, 180°	326, 4
	23°, 168°	332
	31°, 176°	4

NET-ZERO ENERGY DESIGN

Consistent Roof Angle, Modified Location

Through research and simulation we have developed guidelines for sizing the roof solar equipment and the required roof area based on both solar availability and required energy production. Starting with a roof that faces due south with a tilt of 35degress above the horizon, we evaluated each of the 5 locations to determine the required roof area to take the project to NZE. We accounted for an extra two feet in each direction (1 foot at edge) to give us flexibility of space along each roof edge and between the equipment. As stated in the methodology, we will later optimize the size of our solar hot water equipment by supplementing the winter peak condition with electrical heat, generated by the additional PV produced electricity which is collected year-round. Our range of solar hot water area includes sizing for the annual average, then sizing for the lowest production month (Dec 7 – Jan 6), giving us a range to work with at this time.

Table 10 Total Required Roof Area

LOCATION	PV @ 15% (FT^2)	HEAT PUMP PV @ 12% (FT^2)	SHW @ 30% (FT^2)	ROOF AREA (FT^2)	ROOF HEIGTH (FT)
Denver	671	1.6	63 - 88	734 - 759	20.4 - 21
Laramie	677	4.8	63 - 100	745 - 781	20.7 - 21.6
Billings	744	15	70 - 117	829 - 876	22.8 - 24
Madison	821	36	77 - 126	934 - 983	25.6 - 26.8
Berlin	1204	57	97 - 819	1358 - 2081	36.3 - 54.4

The resulting sizes were incorporated into similar shaped buildings where the south roof would lower to achieve more south facing area without increasing the peak height. As soon as the design started losing adequate head height along the upper level south wall, the depth of the building increased to keep our square footage the same (Madison and Berlin).

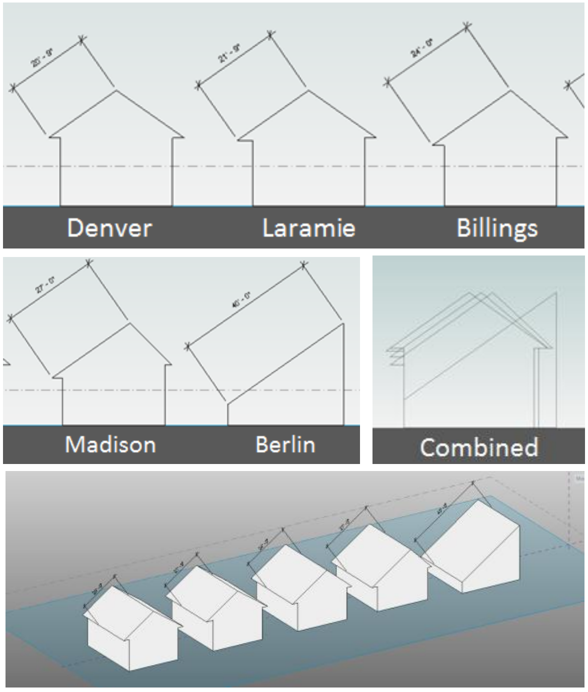
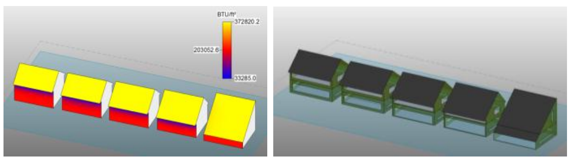


Figure 9 Roof and Corresponding House Shapes Needed to Achieve Net-Zero by Location, by Autodesk Vasari



(a) *(b)*

Figure 10 NZE homes by location showing (a) annual solar radiation, (b) energy model with optimal south glazing ratios, by Autodesk Vasari

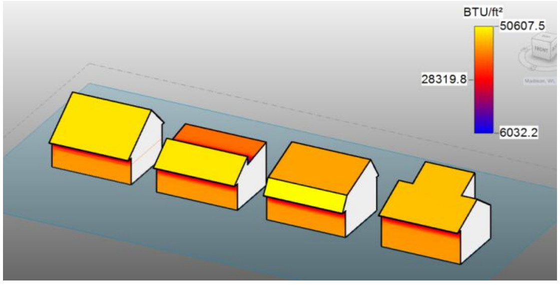
In preserving the necessary wall-to-window ratio, glazing area had to remain consistent with the optimal values, even though the south wall decreased in overall area.

These basic shapes immediately reveal opportunities in the Rocky Mountain region of the US, where increased solar levels enable NZE design without, or with only slight modifications to the traditional house form.

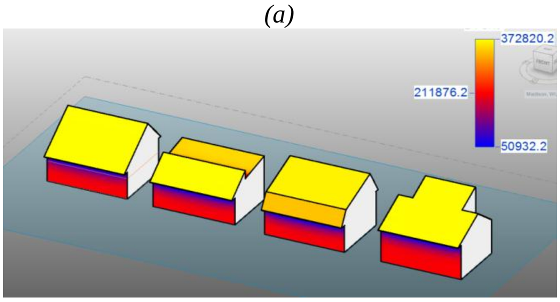
Madison required considerable reconfiguration, while the Berlin example would need at least its entire roof to meet the energy and heating demands with solar energy. The gives us a perspective on why Passivhaus rather than NZE houses is a target for Northern Europe.

Consistent Location, Modified Roof Angle and Shape

The ease in which design modifications can be re-simulated to validate their effeteness is presented in a series of quick schemes for Madison. As Madison house departs significantly from the traditional form, questions are raised about other house shapes where the NZE objective could be met. By altering the roof shape it becomes possible to add multiple roof angles, addresses both the optimal annual and winter solar conditions for PV and solar hot water. Considering acceptable solutions at this stage, one needs to investigate both aesthetics and structural concerns, which can be ignored other models, particularly in Denver and Laramie.



(a)



(b)

Figure 11 NZE homes for Madison showing, (a) winter radiation, (b) annual radiation, by Vasari

CONCLUSIONS

Passivhaus and NZE in cold climates both require the same energy conservation strategies and technologies. Once energy-use has been reduced to levels acceptable by the Passivhaus standard, taking a house to NZE can be achieved with Solar PV and Solar Thermal systems added to the roof. Every location has different heating requirements, as well as different solar insolation levels based on solar availability and sun angles. In addition, south glazing for direct solar heating is effective at reducing the heating loads in certain climates (Laramie, Denver, Billings, Madison), while in other climates (Berlin) the addition of south glazing adds a greater conduction heat loss than solar heat gain.

Starting with Passivhaus standards and strategies, we have developed quick guidelines for south glazing as well as the required roof area needed to produce all of required electricity and heating, assuming the house is grid tied and balanced annually. Two of the locations, Laramie and Denver, are able to meet the annual energy needs with a simple, traditional building form. In Billings we were able to meet the needs with only a slight modification to the roof form. In Madison, a much larger redesign is required including a reconfiguration of the internal layout and roof structure. For the last location, Berlin, we discovered why NZE is not a common goal in Northern Europe: the house went from a traditional form to one that is entirely solar oriented, unusual in appearance, and likely very expensive to build.

Through the simulation workflow we discovered some drawbacks in solar thermal heating: once Passivhaus standards have been incorporated, the resulting heating loads are relatively low, and meeting these demands through solar thermal systems will produce much waste heat in the summer. Assuming a grid-tied condition, the addition of PV panels coupled with electricity powered heat pump at COP of 2 or better is an economical method for meeting the annual heating demands. When sizing the DWH system, sizing for the annual condition wastes less heat, and can be augmented during the winter months by additional PV generated electricity power, which is recharged to the grid over the entire year. When sizing the solar DHW thermal system based on the lowest solar availability in the winter, it is noticeable that the system provides more hot water than the need in the summer.

For a methodolgy like ours to be successful it has to be easily understood by designers, and the simulation tools need to very easily integrate with preferred design software tools. We have experienced great success with new BIM developments in the form of Autodesk Vasari, however, when working with hard numbers in a results driven process, oversimplification can stand in the way of meaningnful results. Ease of use, a sortware trait demanded by designers, is currently very good in Vasari, but as Autodesk continues to develop this tool it will be of great benefit to their users if they work towards increased functionality and cotumization, with more results driven simulation capabilties.

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ACRONYMS

AFUE	Annual Fuel Utilization Efficiency
BTU	British Thermal Units
COP	Coefficient of Performance
DHW	Domestic Hot Water
NEB	Zero Energy Building
NZE	Net Zero Energy
PV	Photovoltaics
SHW	Solar Hot Water