Too Much of a Good Thing?

Southern Glazing Percentages + Shoulder Season Comfort Issues in a Passive House in the mid-Atlantic Climate Zone 4/5

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ABSTRACT

Though an invaluable part of low energy design, poorly managed solar gain can result in severe comfort issues, making some spaces almost unusable. The Passive House Standard, one popular approach to efficient design, has a heating energy limit of 4.75 kBtu/sf.yr. Passive House practitioners may be driven to increase southern glazing while attempting to hit the heating energy criteria.

The Passive House Planning Package calculates peak heating and cooling loads based on monthly average peak ambient conditions, but does not give an adequate sense of daily temperature spikes or localized comfort risk factors. As result, while a house models well in the PHPP in terms of annual space conditioning demand and peak loads, it may create uncomfortable conditions during unexpected times during the year, driving energy consumption when it should not be necessary. Hourly climate data modeling is beneficial for comprehending comfort risk factors in low load homes.

fig. 1;Gaddy House: Current Design - moderate solar gain scenario: image: Miche Booz Architect

1. COMPARATIVE MODELING OF A PASSIVE HOUSE PROJECT

The Gaddy House is a Passive House, LEED Platinum, and Living Building Challenge, single-family residence, designed for aging in place. It has a TFA of 1720sf on a single story. The project is currently going through precertification and will be starting construction in late winter, early spring. The house will be conditioned by one nominal 9000Btu min-split, wall mounted in the common area, and a second ducted unit in the private areas of the house to ensure even distribution of heating, cooling and dehumidification to the bedrooms. The units can operate a low output and run in "dry mode" to provide sufficient dehumidification despite the small cooling loads. The system lay-out was also planned with hourly and localized comfort risk factors in mind. Windows are by Zola with an average installed u-value of .15 and SHGC of .5. All of the appliances selected were among the most efficient available and all lighting is provided by LED's. DHW is provided by a solar thermal drain-back system with point source back up water heaters. The planned solar PV array will produce 150% of site energy demand.

1.1 Comparison of Heating Energy Demands and Peak Loads

Our research examined two design iterations of the Gaddy House, with 23% southern glazing window to floor area (original design), and 15% southern WFA. We also compared the results of each scenario to a home built to the IECC 2012. Using the PHPP along side an hourly climate data model created by Jay Hall, PhD, of Jay Hall and Associates, we compared results to determine risk factors for comfort and functionality. Each iteration, was evaluated by identifying peak condition days within each month and a variety of weather conditions. The authors attempted to identify peak hour conditions to gage risk factors for interior temperature swings, localized comfort issues, and the capacity of the systems sized to PHPP design conditions to handle unexpected loads. The same scenarios were then modeled with light and heavy mass to explore the tempering effects on both typical construction and Passive House construction homes.

1.2 Heating Demands and Peak Loads - Results

Our model comparisons revealed predictably that the Passive House iterations of the design both had drastically lower heating loads than a code built home with the same glazing percentages. With the reductions in southern glazing, the annual heating energy demand increased.

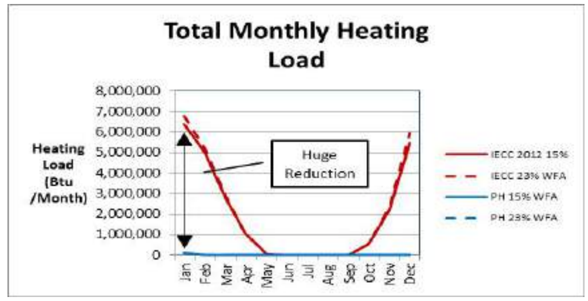

fig. 2: reductions in heating demand between IECC2012 and Passive House

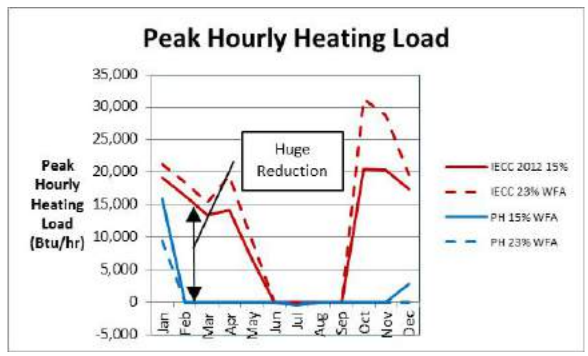

fig. 3: Peak heating load reduction

Energy Demands with Reference to the Treated Floor Area				
Treated Floor Area:	1720	ft²		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	4.19	kBTU/(ft²yr)	4.75 kBTU/(ft²yr)	Yes
Pressurization Test Result:	0.60	ACH_{50}	0.6 ACH_{50}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	25.8	kBTU/(ft²yr)	38.0 kBTU/(ft²yr)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	11.0	kBTU/(ft²yr)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	38.1	kBTU/(ft²yr)		
Heating Load:	5.19	BTU/(ft²hr)		
Frequency of Overheating:		%	over 77.0 °F	
Specific Useful Cooling Energy Demand:	0.43	kBTU/(ft²yr)	4.75 kBTU/(ft²yr)	Yes
Cooling Load:	2.09	BTU/(ft²hr)		

fig. 4; Passive House verification page

1.3 Comparison of Peak Cooling Demand - Results

The most important finding of the 8766 hr. climate data model was to reveal significant shoulder season cooling demands in the higher glazing scenario. Peak cooling conditions for the designs with more South glazing were actually more likely to fall in October/November or March/April than during the peak summer cooling period conditions. Loads were not insignificant, in fact the solar gain coupled with minimized heat loss through the envelope resulted in peak loads 3 times the capacity of our system design, pointing to serious shoulder season comfort issues as seen in fig. 5.

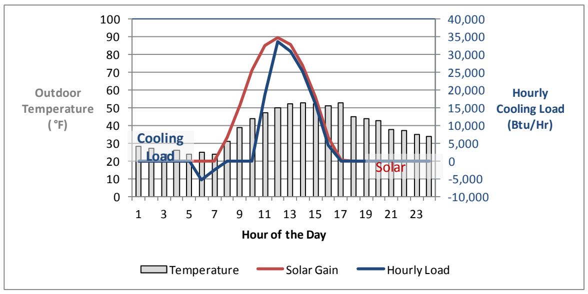

fig. 5: Peak cooling demand, November 11th

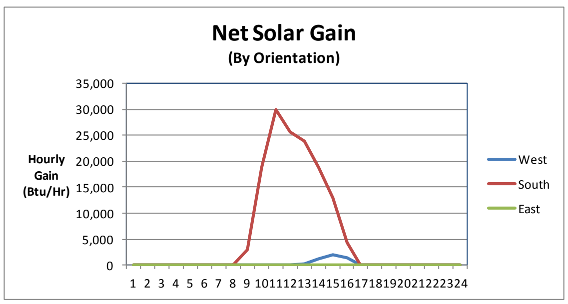

fig. 6: Corresponding Solar Gain, November 11th

Further analysis revealed that the fixed shading, tuned for the summer and winter months, kept summer sun at bay, while preserving the winter gain. However, due to the low sun angle and mild temperatures, the fixed shading is no longer effective in the shoulder months and the house may have a real comfort issue without the reliable use of operable shading.

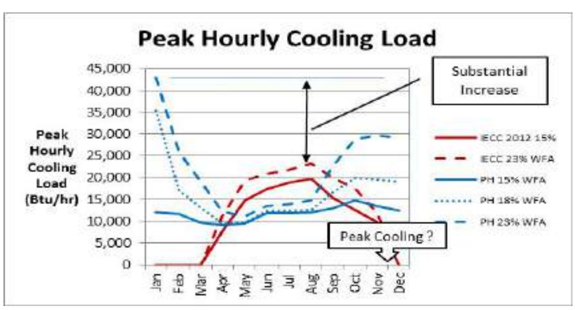

fig. 7: Peak cooling hours in the colder seasons in high glazing scenarios.

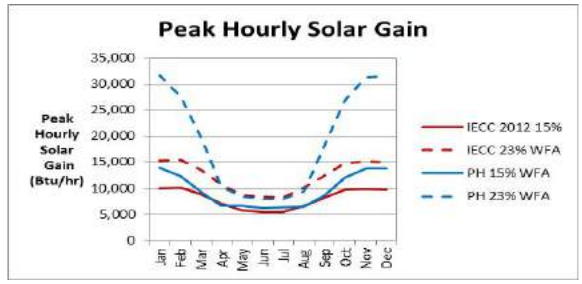

fig. 8: Solar gain, corresponding loads in fig. 7

1.4 <u>Timing of Peak Cooling Demand</u>

The cooling load analysis provided a clear argument for reduced glazing. The 15% glazing scenario yielded lower cooling loads, and an elimination of the shoulder season over-heating spikes. The peak-cooling load on the high-risk day in November dropped to within the capacity of the equipment specified for the house. The peak-cooling day of the year once again fell during the traditional cooling season.

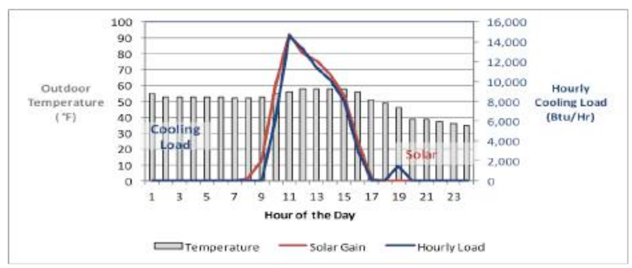

fig.9: Peak hour cooling on Nov. 7th at 23% WFA

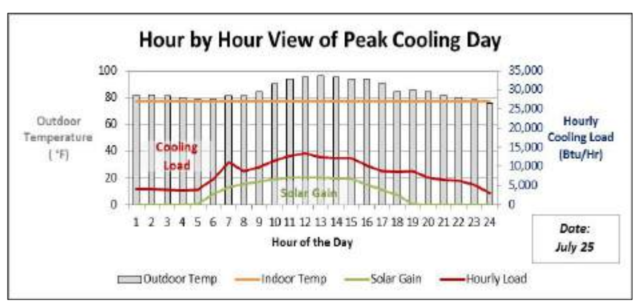

fig.10: Peak hour cooling on July 25th at 15% WFA

2. GLAZING REDUCTIONS IMPACT ON HEATING

2.1 Heating Energy Demand Increases

The reduction in glazing also predictably increased demand for heating energy. In fact the house with 15% south WFA ratio no longer hit the Passive House Standard at 5.89 kBtu/sf.yr. It was determined that in order to deliver better comfort in the shoudler seasons, the 15% Southern WFA galzing ratio was necessary. This in turn required a redesign of the enveope to reduce heating energy demand.

Energy Demands with Reference to the Treated Floor Area				
Treated Floor Area:	1720	ft²		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	5.89	kBTU/(ft²yr)	4.75 kBTU/(ft²yr)	No
Pressurization Test Result:	0.60	ACH_{50}	0.6 ACH_{50}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	24.4	kBTU/(ft²yr)	38.0 kBTU/(ft²yr)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	11.2	kBTU/(ft²yr)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	38.1	kBTU/(ft²yr)		
Heating Load:	4.91	BTU/(ft²hr)		
Frequency of Overheating:		%	over 77.0 °F	
Specific Useful Cooling Energy Demand:	0.28	kBTU/(ft²yr)	4.75 kBTU/(ft²yr)	Yes
Cooling Load:	1.77	BTU/(ft²hr)		

fig.11: PHPP Verification showing fail status at 15% WFA Southern glazing

3. MASS AS SOLAR GAIN BUFFER

3.1 Reduction in Interior Temperature Swings

In another effort to understand the comfort risks and possible solutions, the building was modeled in the hourly climate data model with both high and low mass construction.

The building mass largely eliminated the temperature swings associated with high solar gain. The effect was seen in both the code home design and the passive house design. The primary beneficial effect of thermal mass is to stablize the indoor tempertaure swings when the heating and or cooling system is off (i.e., the indoor temperature is floating). Itr does not substantially affect eergy use when the HVAC system is running.

Recall that the passive house design is usually in cooling mode, even in the winter. Consider the day scenario below (fig. 5a) where the indoor temperature is effectively floating between the heating and cooling setpoints. The interior temperature varied far more in the light mass model and edges upwards and out of the comfort zone. The heavy mass model showed almost perfectly stable interior temperatures right in an ideal comfort condition. These models suggest that the de-emphasis on mass in the Passive House approach may be under-estimating the value of mass, perhaps due to inadequacies in the PHPP model (2007).

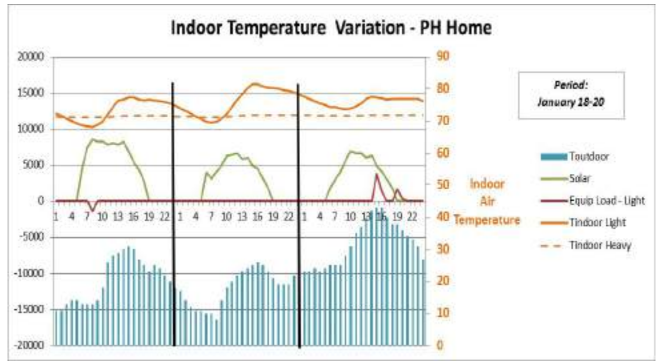

fig.12: yellow dashed line represents indoor temperature in high mass scenario, solid yellow line represents indoor temperatures in low mass scenario

3.2 **Is Mechanical Cooling in the Winter the Best Solution to Maiontain Comfort?**

Overheating in the winter season can happen for one of the two reasons:

1. The HVAC system is undersized, or
2. The cooling is switched-off.

The results for the Passive House design show that the heating loads are near zero throughout the winter, as expected. What is less intuitive, is that the Passive House design is under a cooling load almost every day of the year, including the winter (i.e., there are no swing seasons).

If the home is under a cooling load, there are two non-mechanical approaches to cool the space to prevent it from overheating. They will work only when the outdoor temperature is "substantially below" the desired indoor temperature:

Approach #1: Open the windows, if the occupants are home to do so.
Approach #2: Use a mechanical ventilation system - designed to pull cold outdoor air into the home.

For example, the energy model results show that the peak cooling load in the Passive House design ranges from 12,000 to 32,00 Btu/hr in January. Consider the two non-mechanical solutions above (assuming that the outdoor temperature is roughly 40 degrees).

> For Approach #1, a few windows would need to be wide open. If the day was sunny and windless, the cooling effect of the air coming in the window would have a relatively weak impact in offsetting the solar gains.
>
> For Approach #2, a mechanical ventilation system would need to be sized with an outdoor supply duct of approx. 2 feet in diameter, that would dump cold air into one localized interior area of the home.

With both approaches, there are likely to be undesirable comfort issues when the cold outdoor air is allowed to stream into the home (in an attempt to offset the excess solar gains).

4. PROJECT RESOLUTION

4.1 Reduced Gain Drives Envelope Improvements

Ultimately, for esthetic reasons, and the desires of the client, a balance was struck in the modeling and design of the project. Glazing was reduced to 19% WFA and operable exterior blinds were added to all high-risk areas. While the project would still have been certifiable as a Passive House, with modest improvements in thermal bridging conditions, the client wished to exceed the standard and aim for carbon neutrality. The envelope was subsequently bolstered to meet this end.

fig. 13: Gaddy House current design, Southern façade

Key Envelope Features:

- ✓ Glazing reduced to 19% WFA
- ✓ Effective exterior shading at all South and East glazing
- ✓ Envelope insulation improvements include the following R-values:
  - Walls R-73
  - Slab -53
  - Roof R-99
- ✓ Windows average, installed R – 6.5

On the peak heating day, the solar gains offset the thermal losses. Note that the peak cooling hour is in August. The summer time solar gains have been effectively minimized with window shading.

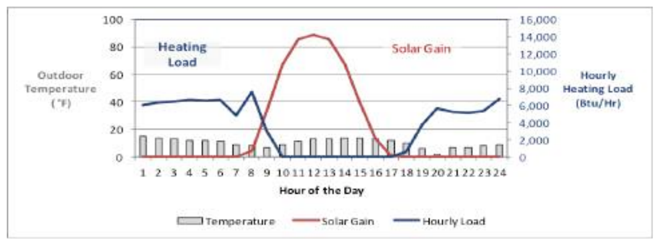

fig. 14: Gaddy House current design, peak heating load, January 18th

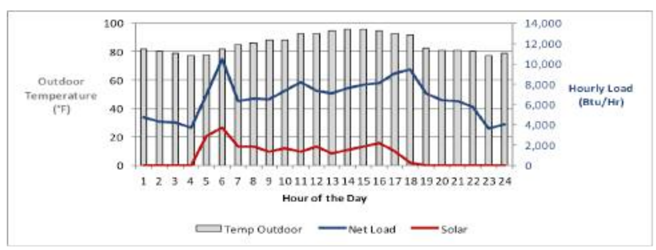

fig. 14: Gaddy House current design, peak cooling load, August 8th

Energy Demands with Reference to the Treated Floor Area

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Treated Floor Area:	1720	ft^2		
Specific Space Heat Demand:	3.00	$kBTU/(ft^2yr)$	4.75 $kBTU/(ft^2yr)$	Yes
Pressurization Test Result:	0.60	ACH_{50}	0.6 ACH_{50}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	24.3	$kBTU/(ft^2yr)$	38.0 $kBTU/(ft^2yr)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	10.2	$kBTU/(ft^2yr)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	38.1	$kBTU/(ft^2yr)$		
Heating Load:	4.17	$BTU/(ft^2hr)$		
Frequency of Overheating:		%	over 77.0 °F	
Specific Useful Cooling Energy Demand:	1.09	$kBTU/(ft^2yr)$	4.75 $kBTU/(ft^2yr)$	Yes
Cooling Load:	2.82	$BTU/(ft^2hr)$		

fig. 15: current demands well below Passive House

5. CONCLUSIONS

Modeling a house in PHPP may not be sufficient to identify comfort and performance risk factors associated with high glazing percentages and solar gain. The heating energy criteria may initially drive many to “optimize” for southern oriented glazing. The average daily temperature of the cooling load page fails to reflect the potential for daily spikes in cooling loads, and the PHPP has no mechanism to reveal the risks of overheating in the shoulder months.

Due to lower sun altitudes, SE and SW azimuths, and mild temperatures in the shoulder months, the timing and intensity of peak cooling demand hours often do not coincide with cooling load “design day” conditions (the design conditions for the PHPP). In a Passive House, the envelope losses are so small, that even glazing shaded 40% - 60% by the fixed shading and overhangs in the shoulder seasons, can provide too much solar gain for comfort. If operable exterior blinds fail to deploy reliably, the functionality of various spaces in the house could be impacted significantly and user response could drive up space conditioning related energy use during spring and fall. In high glazing scenarios the spikes in internal temperature may overwhelm systems “right-sized” to meet loads calculated based on the PHPP cooling load page.

The models suggest that mass may well be a suitable strategy to reduce the impacts of overheating, and combined with by-pass of the ERV, natural ventilation, and the deploying of shading devices, winter time spikes in temperature can be resolved.

While the PHPP is an excellent design tool in many ways, the authors feel that additional analysis is beneficial. The hourly climate data model reveals risks to occupant comfort and system performance that fall outside of the PHPP’s assumed design conditions. Further refining the analysis by examining conditions of different areas within a building, by splitting the building into zones reflecting differing glazing (and/or other) conditions and modeling them independently in the PHPP with adiabatic boundaries between the spaces, could also be helpful in revealing differences in monthly energy balances, and over-heating in particular zones. Consideration of mass beyond the PHPP’s current calculations is also advisable.

Ultimately, it is important to balance the heating and cooling energy demand criteria with wise planning of day-lighting, solar gain, operable shading, and natural ventilation, in keeping with common Passive House design strategies. However, in lower budget projects without the funds to support exterior operable blinds or shades, it is essential to understand the combined effects of glazing percentages and traditionally tuned, fixed shading on shoulder season comfort, and advisable to avoid relying too heavily on high solar heat gain to meet the annual heating energy demand criteria.