New York State Energy Research & Development Authority

High Performance House

Best Practices Guide

Design Intelligence for Energy Performance in Single Family Homes

NYSERDA
New York State
Energy Research and
Development Authority

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1.1 Initial Work

1.1 Initial Work

Preliminary analysis looked purely at geometric implications on energy use. This theoretical investigation tested a variety of building forms and found two general guidelines that govern performance. Across all building manipulations, results showed that forms minimizing volume and maximizing southern exposure perform best. This lines with rational thought; increased volume increases the volume of required conditioned space, while maximizing southern exposure allows for greatest winter solar gains and daylighting.

Following this study, energy analysis was given for three, previously conceived housing designs – "Slope House", "Underground House" and "X House". In all cases, formal design (siting, building form, orientation) were given, fixed parameters. This proved a challenge to the energy optimization of the house.

For the "Slope House", building volume opens to the west without the benefit of southern exposure on the open face. Passive solar gains were minimal, with excessive shading on south facing windows. The majority of glazing is to the north, which effectively cuts the building's thermal resistance/storage without the offsetting solar gains received on southern exposures. Siting does not use the mediating effect of ground cover.

Additive solutions, such as building construction, using ICF, SIPS and vegetative roof cover, high performance windows, and active sustainable systems, even at prohibitive cost levels, could not bring energy performance to desired levels.

Both the "Underground House" and the "X House" had similar challenges. Massing was not optimized to reduce volume and maximize southern exposure. Passive solar was relatively low. Siting, though improved in the "Underground House", could be taken further. Internal thermal mass used to store and re-radiate heat, (which is later shown to be extremely effective at cutting heating loads), is minimal.

To reach the highest level site EUI targets, initial conclusions suggest that energy testing and optimization should not be an additive process, but rather one integrated into building design through all levels of development. Testing and analysis should not confirm design decisions, but rather inform them.

1.2 Process

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As a follow-up to initial work, additional energy studies were conducted. Given standard EPA guidelines for home construction and energy use, we modeled a baseline "typical construction" home with similar requirements to those of the High Performance House and calibrated it to match energy use averages for the area.

Using this "baseline" as a starting point, we began making incremental changes to building construction, siting, building form and various passive and active sustainable strategies. The results below summarize these tests and provide design recommendations.

1.3 Testing

1.3.1 Building Construction:

Tightening the building envelope and increasing thermal resistance was the first step considered in reducing energy use and, when tested and compared to the baseline EPA standard, cut overall energy use rates by 36.73%.

Wall Construction:

Considering budgetary constraints, a modified version of standard stick frame construction was used. A cross section of our high performance wall construction (from inner to outer surface) includes 5/8" gypsum board, 3 ½" batt. insulated wood framing, ¾" OSB, vapor barrier, and 2" XPS Extruded Polystyrene with cement board siding.

Note: 2x6" framing was tested but only performed slightly better than standard 2x4" framing. With the 2x4" construction above, thermal wall resistance begins to plateau in performance, so increasing depth of insulation and reduction in the thermal breaks only produces minimal gains. Doors, windows and other breaks in wall construction generate most of the thermal resistance losses.

Roof Construction:

Materials from inner to outer surface, 5/8" gypsum board, 1" polyiso, 11 ¼" batt insulated wood rafters, ½" OSB, roofing felt, and asphalt shingles.

Ground Floor Construction:

Ground floor construction consists of 4 -inches of medium density concrete, above 2-inches of UF Form and 4-inches of gravel.

Window Construction:

High performance window construction includes 3mm double panes with a 13mm argon cavity and wood frame.

1.3 TESTING

Heating and Cooling Systems:
Forced air system with hot water radiator.

1.3.2 Building Form and Siting:

Building Form -
Best solar heating performance was achieved using a housing form stretched east to west with a long south façade. The narrower the depth, the better solar passive strategies can perform (reduction in heating load), however, as shown in the energy analysis, heating load can be reduced enough so that required heating energy is less than cooling energy. In this case, giving more depth to the building can level out these numbers and give an overall reduction in energy use.

Testing shows that stretched in an east/west direction, maintaining the given square footage, a building depth of 15 feet to 20 feet is ideal, with steady declines in performance the more depth is given. Energy performance was relatively equal between depths of 15 feet and 20 feet, with a 12.4% reduction in overall energy loads between 20 feet and 25 feet. This can be attributed both to the reduction in the exposed south face as you stretch the building back, and the reduced effectiveness of conductive heat transfer into the deeper space.

Note: At depths greater than 20 feet, consideration should be made to angling the roof plane to increase south facing surface area and light penetration deeper into the space. At depths between 15 to 20 feet, angling the roof plane had no impact in energy performance.

Siting -
Using a properly formed, well constructed building template, tests were run to see how building siting, using existing conditions, affected performance. Comparisons were made against a standard condition where the building sits on the hill slope, exposed on all sides.

Progressively set into the hill, gains were made in energy performance in both heating and cooling loads. West facing walls (prevailing wind side) received most of the improvements in energy loads, with northern walls having less of an impact. Optimized conditions have west walls fully set into the hill, with earth cover sloping down the north side, leaving the south faces fully exposed. This condition generated a 10.68% overall reduction in energy use. (see Figure 1).

Note: When siting the building into the hill, buildups of earth to the south should be angled back so as to not obstruct afternoon sun from the southern façade.

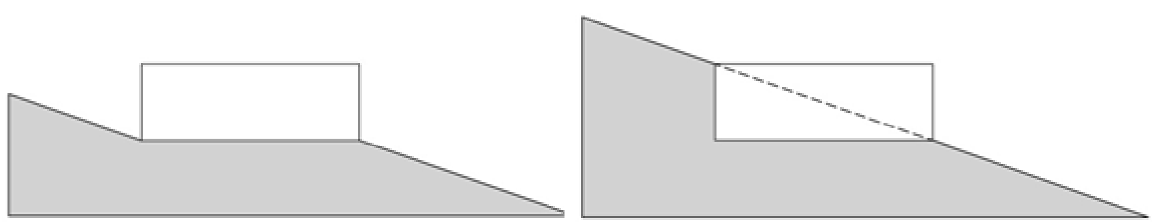

Figure 1 – Baseline condition (left) Ideal siting conditions (right)

1.3.3 Passive Sustainable Strategies:

Direct Gain

Initial tests considered direct heat gain as the exclusive passive solar heating strategy. With 100% south faced glazing, both heating and cooling greatly underperformed against the EPA benchmark. Heat loss was excessive, unaided by substantial thermal storage. Additionally, summer heating spikes were sizeable and, even with proper shading devices, cooling loads were above standards.

Trombe Wall

As the best performing strategy for thermal heat storage, the "best practice" trombe wall resulted in a 32.76% reduction in overall energy costs. (Energy reduction numbers for each passive strategy below is for the strategy alone and not overall reductions. Combining strategies results in greater reductions.)

- ***Trombe Construction -***

  Trombe construction should be either poured concrete or masonry. Sun exposed surfaces should be painted with a dark flat black paint or selective surface such as a dark metallic foil with high absorptance and low emittance.

- ***Glazing to Trombe Ratios -***

  Initial tests looked at combinations of south faced glazing to trombe wall ratios (see Figure 2). Results showed that as the percentage of trombe increased (and glazing decreased), there was an overall increasing trend in required heating load, which is due to a reduction in direct gain of the space, and a substantial decrease in cooling load, due as well to the reduced direct summer gain. Nevertheless, below 30% trombe, the effectiveness of the trombe decreases and heating load increases.

  Taken as a heating strategy alone, the 30% trombe – 70% south face glazing combination performs the best. Subsequent testing (as described later) showed that with optimized shading and ventilation, cooling numbers can be reduced substantially.

1.3 Testing

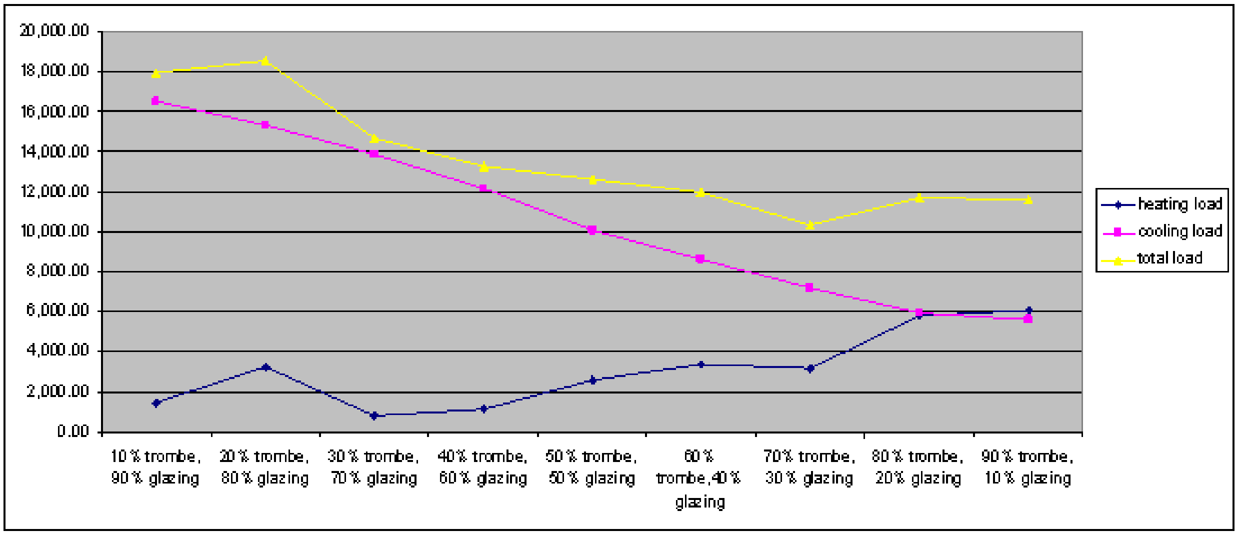

Figure 2 - Chart illustrating heating and cooling trends when altering trombe-to-glazing ratios.

- ***Split Trombe -***

  How the 30% Trombe area is distributed across the southern face aeffects the performance of this passive strategy. As a single mass, the Trombe allows for the greatest heat storage, but performs relatively poorly with cooling loads. Splitting the Trombe across the southern face, overall performance is improved. Twice split and evenly spaced, heating performance only slightly diminishes and is more than offset by improvements in cooling performance. This is primarily due to a more even distribution of direct solar gain and internal room shading from the trombe.

  Note: Splitting the trombe further to three evenly spaced segments reduces trombe heating performance (cuts thermal storage efficiency) with nearly almost no improvement in cooling load.

- ***Trombe Cavity Spacing -***

  Cavity spacing between external glazing and the trombe wall performed best at 6-inches. Additionally, summer venting of this cavity space improves overall performance.

- ***Trombe Width -***

  Trombe width for a 1500sq. ft. residence differs in requirements from larger scale commercial application. Where in commercial design, heating needs are more immediate and follow a standard work day, heating demands for residential application typically occur in the evening to following morning. For the commercial application, a thinner trombe wall (8”) allows for faster heat transfer into occupied spaces, whereas for residential application, a thicker trombe is required for greater thermal storage and delay of conduction into occupied spaces.

  Testing shows for the specifics of this residence, a thermal wall of 12” is recommended regardless of overall trombe area. (see Figure 2b).

Note: Venting of the trombe wall to interior spaces is not necessary, as the primary benefit of the trombe in residential application is radiation and conduction through the wall as opposed to convective heat transfer.

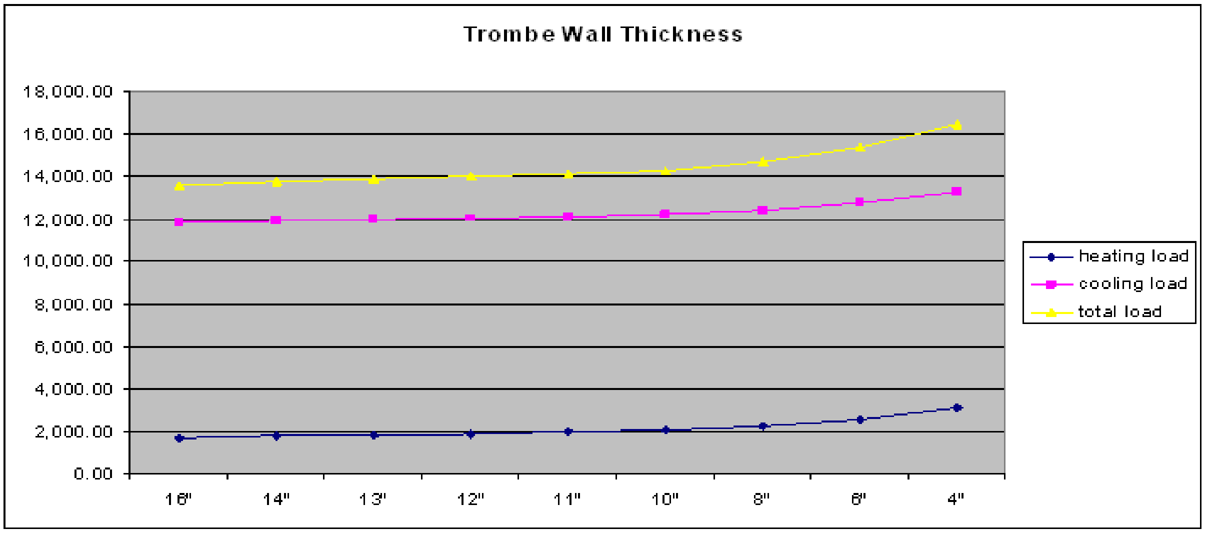

Figure 2b - Chart illustrating heating and cooling trends when altering trombe thickness.

- ***Shading Application -***
  Testing various combinations of shading applications for the trombe at a range of settings (vertical separation, projection lengths, louver distance from glazing, fixed angle and louver operability) showed that a louver application performed better than a single overhang. This can be attributed to improvements on summer cooling loads. Overhangs (see Figure 2c) protect only against summer sun at its highest angle, however, at lower angles in its daily path, the overhang fails to protect from solar gain. HoweverNevertheless, testing showed that operable louvers far exceeded performance on the fixed louver system (see Figure 2e and 2f).

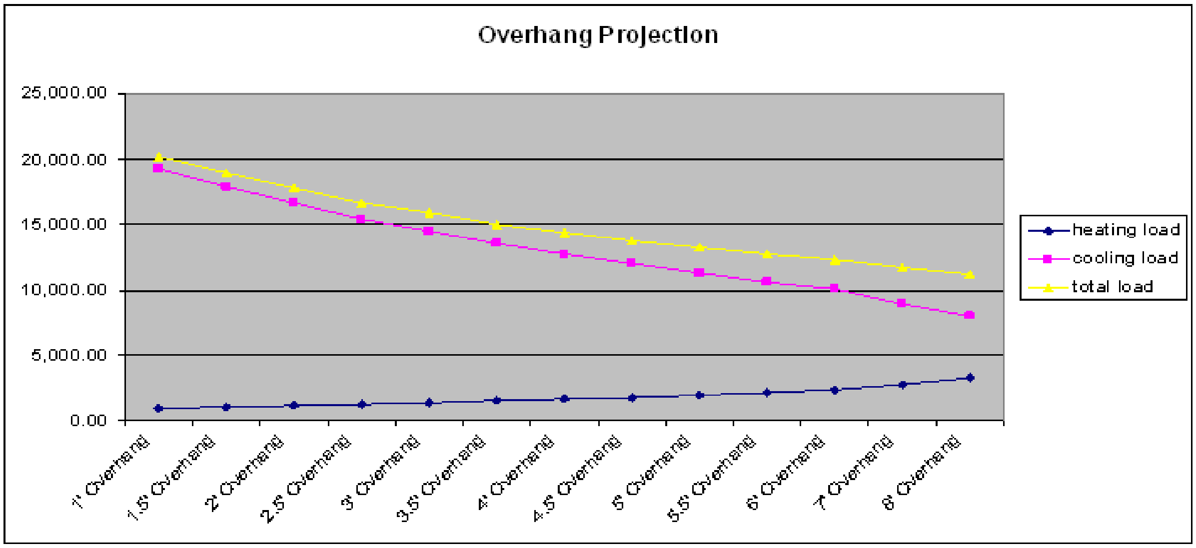

Figure 2c - Chart illustrating heating and cooling trends when altering overhang projections.

1.3 Testing

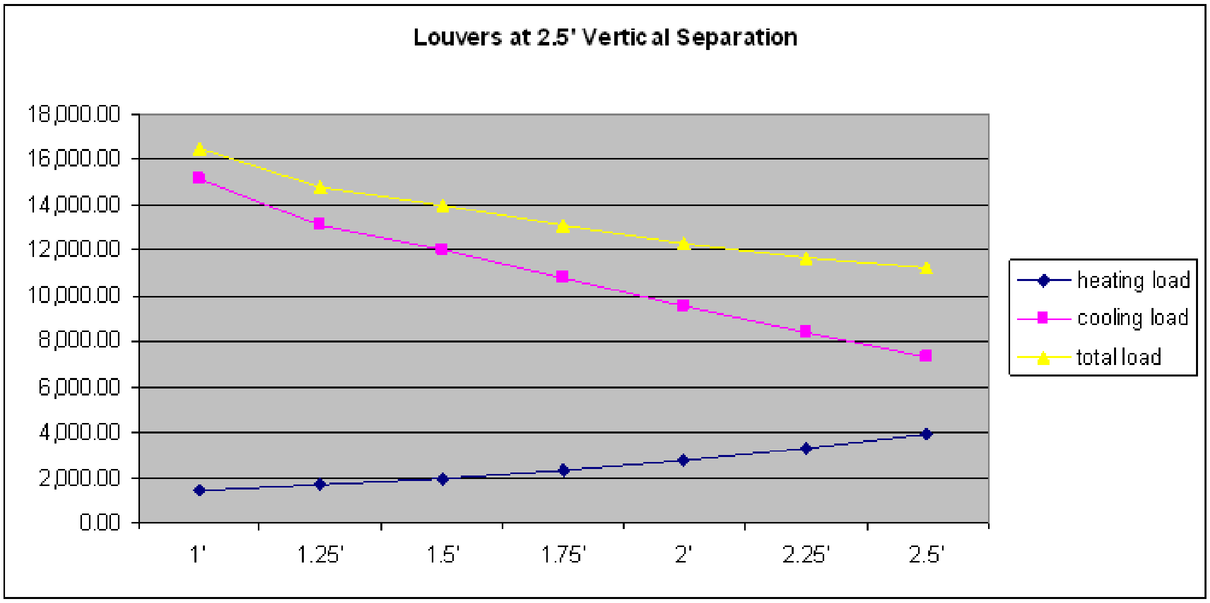

Figure 2d - Chart illustrating heating and cooling trends when altering louver projections.

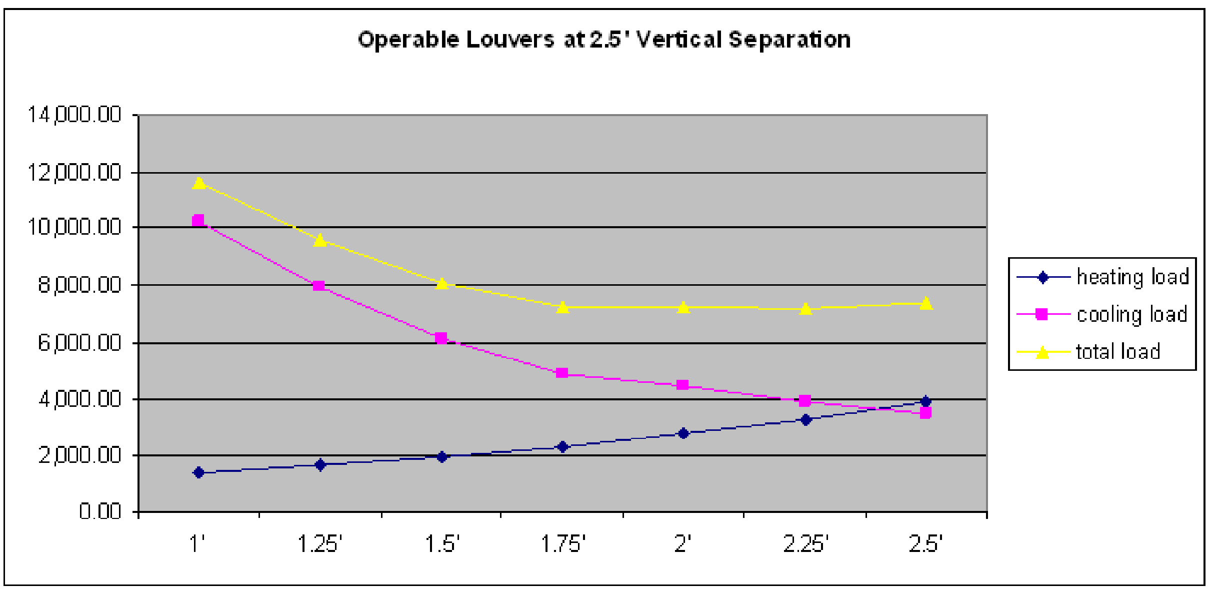

Figure 2e - Chart illustrating heating and cooling trends when altering operable louver projections.

1.3 Testing

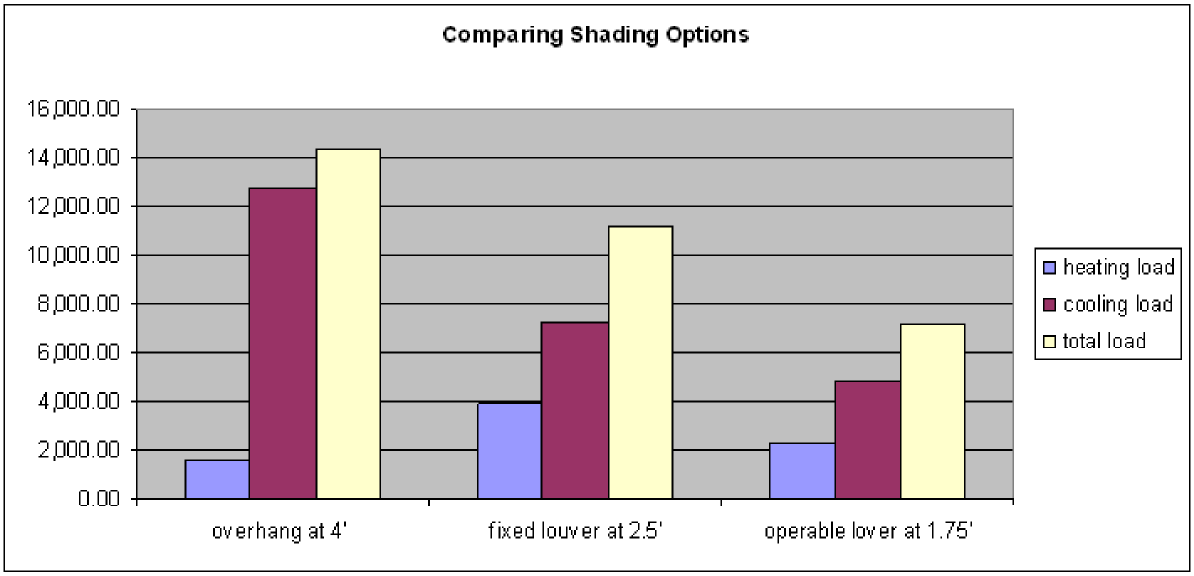

Figure 2f - Chart illustrating differences in performance between best versions of different shading options.

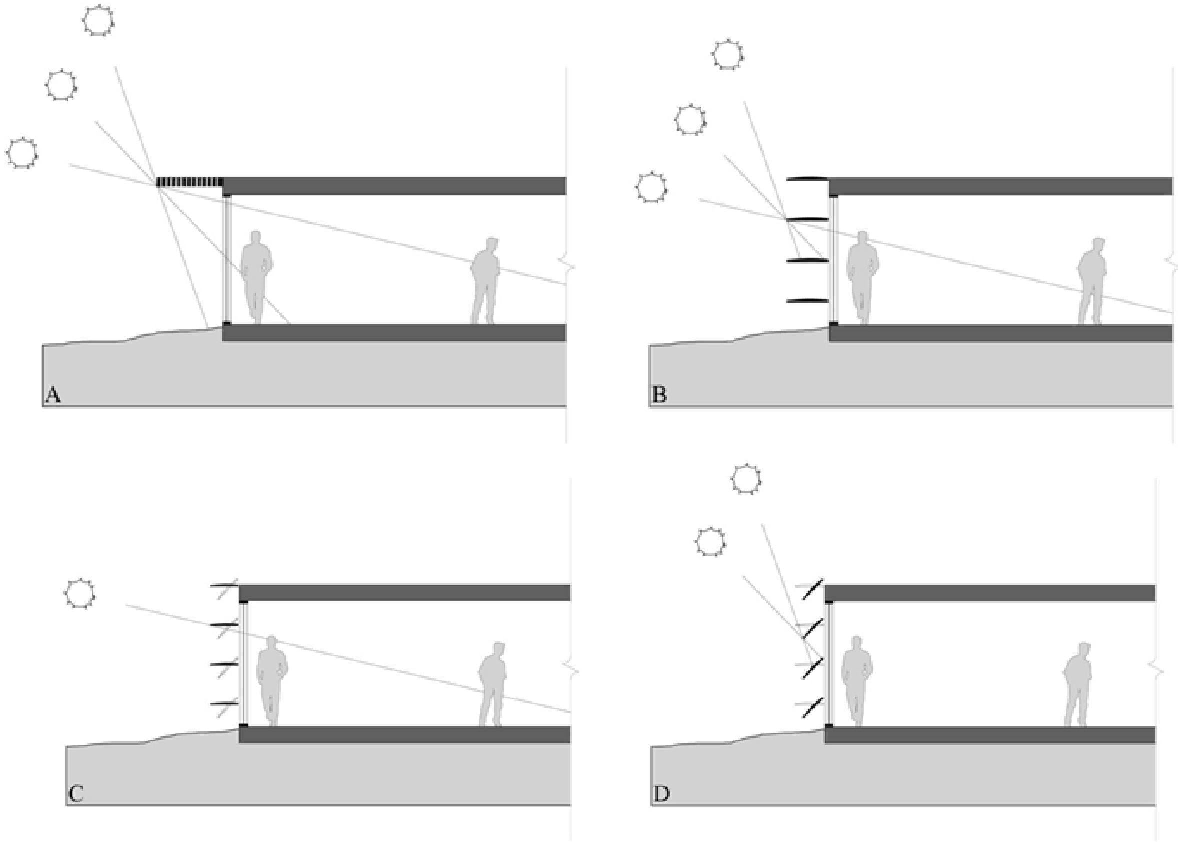

Figure 2g – Illustrations of different shading options – (A) Fixed overhang at 4 feet (B) Fixed louver at 2.5 feet (C) Winter operable louver at 1.75 feet (D) Summer operable louver at 1.75 feet

1.3 Testing

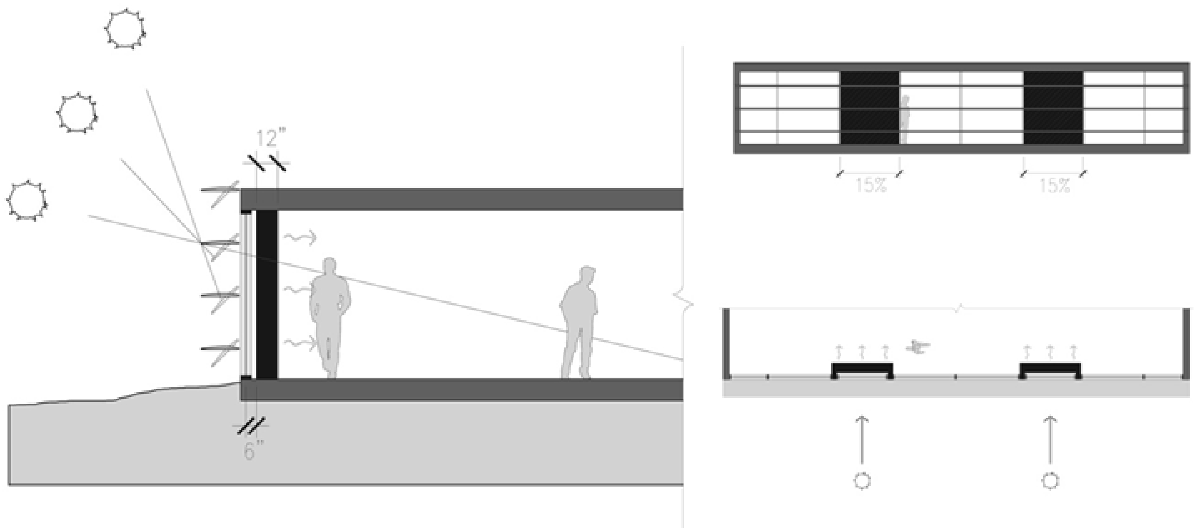

Figure 2h – Illustrations of optimum trombe application (correct louvers, cavity spacing, trombe width and a 30% trombe/70% glazing elevation and plan)

Preheat Wall -

Testing variations of a preheat wall strategy (also known as a transpired wall) failed to show much practical use for residential application. To function correctly, a variable PIU HVAC system is required. Additionally, the solar gains made by the preheat wall were limited to daytime hours with no capacity for heat storage and delayed thermal conduction.

Sunspaces -

As an alternative to the Trombe wall (later testing, as discussed below, looked at combining strategies), the use of the sunspace was found to perform relatively well. "Best practice" application reduced energy use by 25.57%.

- ***Internal vs. External Sunspace -***

  When testing sunspaces as either attached to the main space, sharing one common wall, or encompassed by the building, sharing three common walls (see Figure 3) – the encompassed sunspace performs better. This is due to the fact that the encompassed sunspace only loses heat at night through one exposed wall and has three walls acting as thermal storage instead of just one.

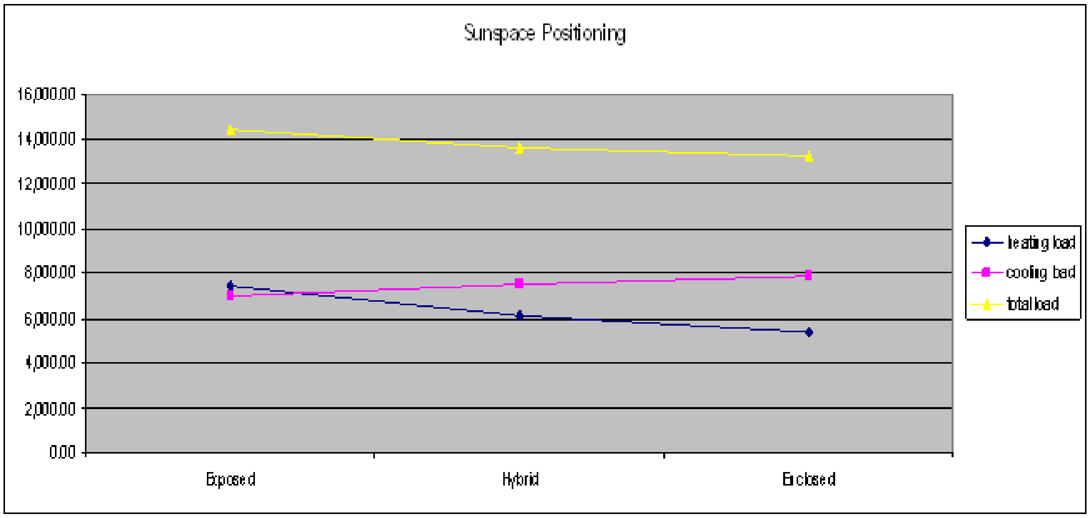

Figure 3 - Chart illustrating heating and cooling trends when moving between internal and external sunspaces.

- ***Depth of Sunspace -***

  Testing various depths of the sunspace (see Figure 3b), common wall construction, and common wall venting, showed that narrower spaces with massive, un-vented common walls perform slightly better. This mainlycan mostly be attributed to improved common wall exposure to direct sunlight (thermal heat storage). This suggests the sunspace functions best when performing as a deep trombe wall, reinforcing evidence that residential energy reduction in cold climates is a game of heat storage and delayed thermal conduction and not convection.

  Note: To optimize sunspace performance, mechanical air distribution of the sunspace in winter months to interior rooms is recommended.

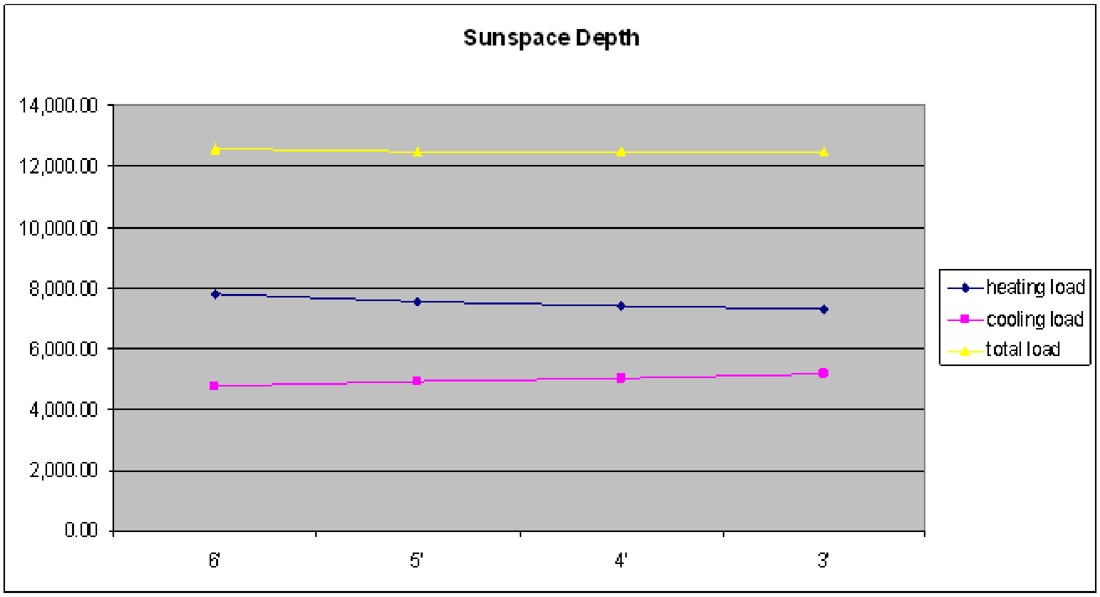

Figure 3b - Chart illustrating heating and cooling trends when altering sunspace depth.

Testing

1.3 Testing

Sunspace as a Percentage of South Facing Wall -

Testing variations of the sunspace as a percentage of the southern face (see Figure 3c) showed increased performance in both heating and cooling as the sunspace is stretched across the southern façade. At larger sunspace areas, you create a greater buffer between interior and exterior temperature swings, with the ability either to capture heat generated in the sunspace or vent it out.

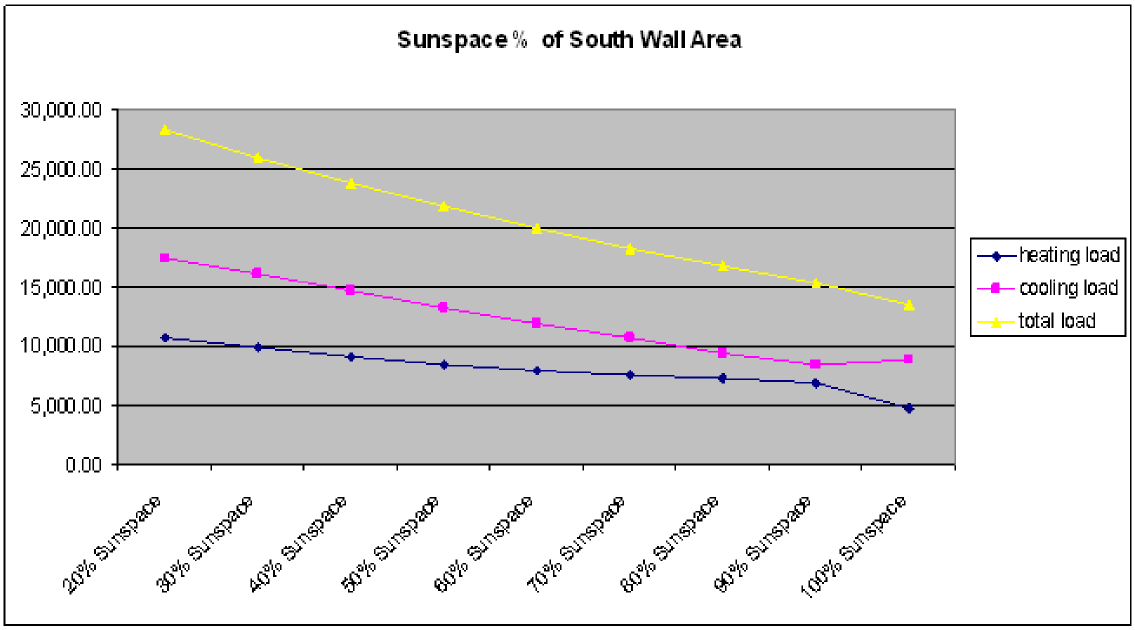

Figure 3c - Chart illustrating heating and cooling trends when varying sunspace as a percentage of overall south facing wall.

A practical application pulled from the results suggest that for a building stretched in the east/west direction, the 3-foot deep sunspace could function as a common circulation corridor with the thermal wall behind heating main living spaces. Results were optimized (lighting loads decreased without impact to heating and cooling loads) when adding a 2-foot strip of glazing (optimized height) to the upper portion of the common wall. This allows the lower portion still to receive heat gains from direct winter sun while allowing indirect light into living spaces. As operable interior windows, heated air from the sunspace could be brought into occupied spaces during heating months. This strategy yielded the best performance (25.57% energy reduction

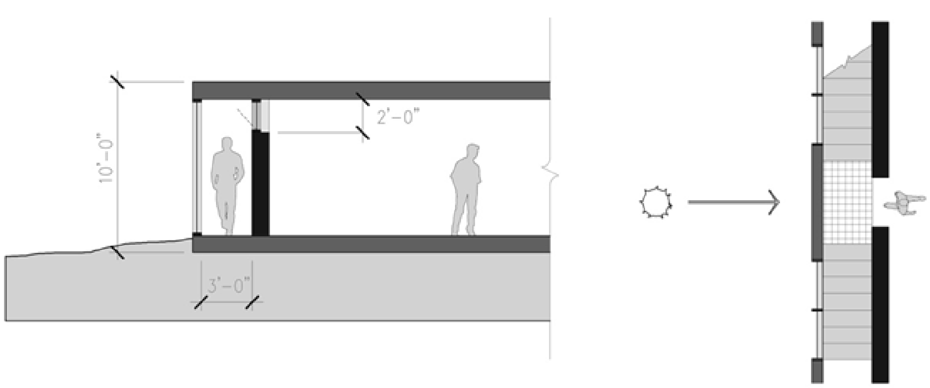

Figure 3d - Illustration of best practice sunspace condition (left). One alternative solution (right).

1.3 Testing

1.3.4 Active Sustainable Strategies:

Solar Hot Water Tubes -

Evacuated solar hot water tubes have several advantages as an active sustainable strategy. Thermal conduction and convection losses are minimal (under 2%) because of the vacuum gap while 93% of solar radiation is absorbed. Additionally, tubes can be replaced individually without special tools. Cost of installation for residential application is approximately $5,000-$7500. Nevertheless, this system produces approximately 10,000 kBtu's per year, which will effectively eliminate domestic hot water from overall energy demands.

Photovoltaic Panels –

PV panels are especially viable in this investigation because the energy load can be reduced so much. With the ideal passive solar design, the energy usage for a 1,500 square foot home would be approximately 12,900 kBTU, or 3,781 KWh. Each KW of PV panels makes approximately 1,123 KWh of electricity, and so a passive solar house would need 3.37 KW of PVs to be net zero. 3.37 KW is 17 solar panels (assuming 5 200 W panels per each KW). The cost of such an installation would be approximately 27,000 dollars before tax rebates and incentives.

Photovoltaic panels make sense

1.4 Conclusions

1.4 Conclusions:

Combining "best practice" components from above (construction, siting, building form, passive and active strategies), we are able to reach the 80% Energy Reduction Target with a kBtu/Sq.Ft/Yr of 8.6, as compared to an EPA average of 44.7 (see Figure 4)

2030 CHALLENGE Targets: National Averages

U.S. Average Site Energy Use and 2030 Challenge Energy Reduction Targets by Space/Building Type (CBECS 2003)[1]

From the Environmental Protection Agency (EPA): Use this chart to find the site fossil-fuel energy targets.

Primary Space/Building Type [2]	Available In Target Finder [3]	Average Source EUI [4] (kBtu/Sq.Ft./Yr)	Average Percent Electric	Average Site EUI [4] (kBtu/Sq.Ft./Yr)	2030 Challenge Site EUI Targets (kBtu/Sq.Ft./Yr)				
					50% Target	60% Target	70% Target	80% Target	90% Target
Residential Space/Building Type [5, 6]									
Single Family Detached		76.6	-	43.8	21.9	17.5	13.1	8.8	4.4
High Performance House			-			15.1			
with operable louvers			-				11.8		
with evacuated solar tubes			-					8.6	

Figure 4 – Graphic showing energy performance for the optimized High Performance House in comparison with EPA averages.

1.4 Conclusions

1.4.1 Additional Recommendations:

- **Interwoven Building and Planting -**
  Results from testing showed that passive solar strategies are effective at reducing heating loads, however, unwanted heat gain in summer months reduced the overall effectiveness of the strategies. Irrigated vegetation planted upwind of housing zones has been shown to effectively reduce building heating loads. Planted areas can be as much as 10-15 degrees cooler due to a combination of evapotranspiration, reflection and shading. Effectively venting the building to allow breezes through these zones into living spaces should be considered.

- **Program arrangement -**
  In two story, passively heated buildings, the temperature differences between upper and lower levels have been found to be at least 4-5 degrees. This temperature stratification should be used to zone rooms based on temperature requirements. Bedrooms should be in uppermost levels, with living/cooking zones below.

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