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# SIMULATED BUILDING ENERGY PERFORMANCE OF SINGLE-FAMILY DETACHED RESIDENCES DESIGNED FOR OFF-GRID, OFF-PIPE OPERATION

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## ABSTRACT

This paper presents the analysis of energy performance of single-family detached homes in three U.S. climates, in order to determine energy-efficiency measures for minimizing the loads and sizing requirements of renewable energy systems that are essential for its off-grid, off-pipe (i.e., utility-independent) operation. The analysis used a DOE-2.1e simulation model of a 2000/2001 IECC (International Energy Conservation Code) standard house as a base case in three climate locations: Minneapolis, MN, Atlanta, GA, and Phoenix, AZ. This selection of measures and determination of loads for renewable energy systems were accomplished by analyzing the energy use using DOE-2.1e simulations and heating/cooling load components using the Manual J Average Load Procedure. The analysis showed several aspects of building energy performance during different times of the year in terms of available energy resources that are critical for the sizing, utilization, and cost-effectiveness of renewable energy systems.

## INTRODUCTION

There are several approaches to implement energy-efficiency and renewable energy measures to minimize the use of fossil fuels in residences. Most of them aim to achieve ‘annual’ energy/carbon balance between on-site generated renewable energy sold to utilities vs. non-renewable energy purchased from utilities (Torcellini and Crawley 2006). On the other hand, the off-grid, off-pipe design aims to eliminate the use of non-renewable energy and water by achieving self-sufficiency using only on-site renewable resources (Vale and Vale 2000). In contrast with other approaches, which focus mainly on annual energy performance, the off-grid, off-pipe design approach requires analyses of building energy use vs. available energy resources during different times of the year to identify critical periods of high energy use and less energy resources, and minimize the energy use during such periods to minimize the sizing requirements of renewable energy systems.

## METHODOLOGY

The analysis presented here is part of a comprehensive study (Malhotra 2009) that investigated the feasibility of off-grid, off-pipe design approach in single-family detached houses in six U.S. climates: Minneapolis, MN (very cold), Boulder, CO (cold), Atlanta, GA (mixed-humid), Houston, TX (hot-humid), Phoenix, AZ (hot-dry), and Los Angeles, CA (marine). For the study, an integrated analysis procedure was developed for the analysis and design of off-grid, off-pipe homes that utilized DOE-2.1e, F-Chart and PV F-Chart programs (Winkelmann et al. 1993, Klein and Beckman 1993a,b) for analyzing building energy use, active solar thermal systems and PV systems, respectively, and spreadsheet tools for analyzing wind power and rainwater harvesting systems. This procedure was demonstrated for a 2000/2001 IECC standard design of a single-family detached house (ICC 1999, 2001) in six climate locations having dissimilar availability of solar radiation, wind and rainwater as renewable resources.

This paper discusses the analysis of building energy use in three climate locations including: Minneapolis, MN, Atlanta, GA, and Phoenix, AZ, for minimizing the sizing requirements of renewable energy collection/generation and storage systems. The analysis is presented in three steps: 1) analysis of base-case energy use and heating/cooling load components to identify possible critical periods and opportunities for energy use reduction; 2) selection of energy-efficiency measures, which was aimed at minimizing the energy use during these periods; and 3) determination of reduced energy use to investigate the impact of measures and obtain loads for the sizing of renewable energy systems. The procedure for obtaining building energy use and space load components (for the base case and proposed design), and criteria for the selection of measures are described below.

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### Determination of building energy use

The building energy use was obtained by performing DOE-2.1e simulations with TMY2 weather data. To obtain loads for the solar thermal and PV/wind electric systems, the thermal energy use (for space heating and domestic water heating) and electricity use (for space cooling, lighting, appliances, and HVAC fans) were investigated separately throughout the analysis. To accomplish this, two sets of simulations were performed using DOE-2.1e system types: (i) SUM, to obtain space heating loads without simulating a system, which were added to domestic water heating loads, and (ii) RESYS, to obtain electricity use for space cooling, which was added to other electricity end-uses. The thermal energy and electricity use, thus obtained, were analyzed on an annual, monthly, and peak days hourly basis.

### Determination of space load components

The space load components were obtained using the Manual J Average Load Procedure (Rutkowski 2004), but used with the building details that were simulated rather than those specified by Manual J. The building envelope loads were determined using the construction details. The infiltration loads were based on the infiltration rate for the summer as 1.2 times and for the winter as 1.6 times the average infiltration rate (FSEC 2009). For the internal loads, simulation inputs for lighting, appliances and occupants were included.

### Selection of energy-efficiency measures

The selection of energy-efficiency measures was aimed at minimizing the thermal energy and electricity use during critical periods. First, measures for the building envelope, lighting, appliances, and systems were considered, which reduced the thermal energy and/or electricity use. Certain strategies related to building geometry and windows (which determine building's thermal boundary and solar gains, respectively), which decrease heating energy use, may increase cooling energy use, and vice versa. Therefore, using parametric simulations of the house with other measures applied, an optimal building geometry and window design was identified for each location, which resulted in high energy savings for the dominant end-use and acceptable energy penalty for the other end-use.

## ANALYSIS AND RESULTS

The analysis is based on a 2,500 ft$^2$ single-family detached house in Minneapolis, MN, Atlanta, GA, and Phoenix, AZ. The base-case house was assumed to have light-weight wood frame construction, slab-on-grade floor, and all-electric systems. The building envelope, mechanical system, and operational characteristics were adopted from the 2000/2001 IECC standard design specifications. Table 1 lists the base-case house characteristics that were simulated for the analysis.

*Table 1: Base-case house characteristics*

| **GENERAL CHARACTERISTICS (ICC 1999, 2001, Hendron 2008, US Census 2009)** | |
|---|---|
| **Building Configuration:** | |
| Building type | Single-family detached house with 4 bedrooms/3 bathrooms for 4 occupants. |
| Building geometry | 2,500 ft$^2$, square-shape, one-story, south-facing; 8 ft. ceiling height; unconditioned, vented attic with an 18.4 deg. (4:12) roof tilt. |
| Surroundings | Grass on the ground (reflectance: 0.24); suburban terrain; no site shading. |
| **Construction Details:** | |
| Structure | Light-weight wood frame walls and roof; slab-on-grade concrete floor. |
| Exterior walls | 2x4 wall studs spaced at 16” on center (i.e., 25% framing factor); R-11 fiberglass-batt cavity insulation combined with continuous insulation on the exterior to achieve the 2000/2001 IECC standard design wall assembly U-values; facia brick exterior (absorptance: 0.75). |
| Ceiling/roof | 2x6 ceiling joists/roof rafter spaced at 24” on center (i.e., 7% framing factor); cellulose-fill ceiling insulation to achieve the 2000/2001 IECC standard design ceiling assembly U-values; grey asphalt-shingle roofing (absorptance: 0.75). |
| Foundation/ floor | Slab-on-grade floor with 4” heavy-weight concrete; slab perimeter R-value from the 2000/2001 IECC standard design requirements; carpet flooring over 80% of slab-on-grade floor area. |
| Windows | Window area: 18% of conditioned floor area, distributed equally on all orientations; Window U-factor and SHGC from the 2000/2001 IECC standard design requirements; No external shading, internal shade factor: 0.7 in the summer and 0.9 in the winter. |
| Infiltration | Specific leakage area (SLA): 0.00057 for the conditioned space and 0.0033 for the unconditioned, vented attic. |
| **Space Conditions:** | |
| Space temp. set-point | 68 °F for heating, 78 °F for cooling, 5 °F set-back in the winter (from 11 p.m. to 5 a.m.) and 5 °F set-up in the summer (from 9 a.m. to 3 p.m.). |
| Internal heat gains | Lighting: 1,964 kWh/yr electricity use converted to 100% sensible heat gains; Appliances: 6,808 kWh/yr electricity use converted to 62% as sensible heat gains, 8% as latent heat gains and 30% drained/exhausted to the outdoors; Occupants: From 3.5 persons, assuming 224 Btu/hr-person as sensible heat gains and 164 Btu/hr-person as latent heat gains. |
| **Mechanical Systems:** | |
| HVAC system | A central system with a SEER 13 air-conditioner and 7.7 HSPF heat pump; heating and cooling capacity determined from Manual J. |
| DHW system | 66-gallon tank-type electric water heater with 0.84 energy factor (EF) to supply approximately 70 gal/day hot water at 120 °F. |
| Air distribution system | Ductwork located in the unconditioned, vented attic; 5% supply and 5% return duct leakage, supply and return duct R-value based on the 2000/2001 IECC requirements; Static pressure: 0.5 in. of WG, Supply air-flow rate: 360 cfm/ton |

| **CLIMATE-SPECIFIC CHARACTERISTICS (ICC 1999, 2001)** | **Minneapolis, MN** | **Atlanta, GA** | **Phoenix, AZ** |
|---|---|---|---|
| Ceiling U-value (Btu/h. ft$^2$.°F) | 0.026 | 0.036 | 0.044 |
| Wall U-value (Btu/h. ft$^2$.°F) | 0.052 | 0.076 | 0.085 |
| Window U-value (Btu/h. ft$^2$.°F), SHGC | 0.28, 0.68 | 0.44, 0.40 | 0.47, 0.40 |
| Slab Perimeter R-value and Depth | R-6, 4 ft. | R-4, 2 ft. | None |
| Supply and Return Duct Insulation | R-11, R-6 | R-8, R-4 | R-8, R-4 |

Figure 1 shows climate characteristics of the three locations, including: TMY2 monthly statistics for heating degree-days, cooling degree-days, dry-bulb temperature, diurnal temperature range, dew- point temperature, global horizontal solar radiation (US DOE 2008), and monthly average wind speeds from 1997-2008 measured data (NOAA 2008). Table 2 shows the annual summary of climate data. These characteristics are referenced in the subsequent sections.

Figure 2 through 5 show the results for the base case and proposed design in each location, to demonstrate the impact of measures and compare the results across locations. Each figure includes separate plots for thermal energy use/space heating loads and electricity use/space cooling loads. Figure 2 (annual energy use)

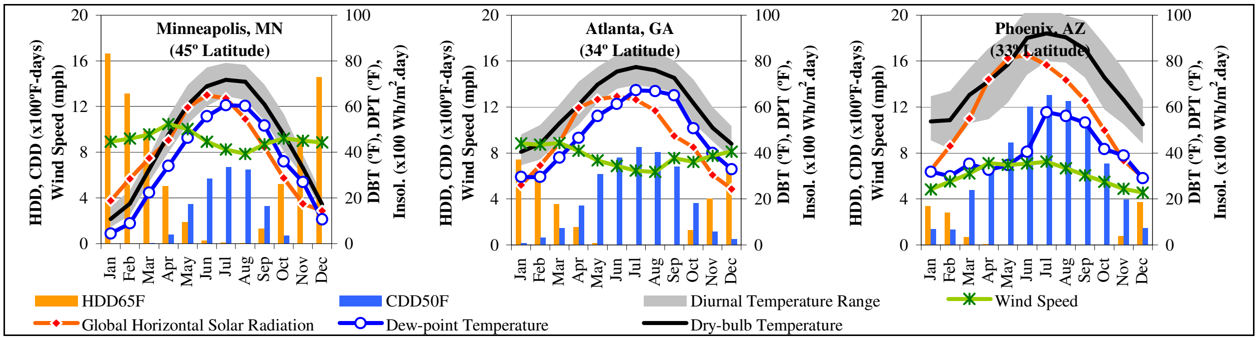

*Figure 1 Climate Characteristics*

*Table 2 Climate Characteristics*

| | Minneapolis, MN | Atlanta, GA | Phoenix, AZ |
|---|---|---|---|
| Climate region | Cold | Mixed-Humid | Hot-Dry |
| Latitude | 44°87' | 33°65' | 33°42' |
| HDD65 (ºF-days) | 7,735 | 3,013 | 1,129 |
| CDD50 (ºF-days) | 2,716 | 4,790 | 8,327 |
| Dry-bulb temperature (ºF) | 45.1 ºF | 60.6 ºF | 72.5 ºF |
| Diurnal temperature range (ºF) | 13.4 ºF | 15.5 ºF | 24.8 ºF |
| Dew-point temperature (ºF) | 34.9 ºF | 48.8 ºF | 40.2 ºF |
| Solar radiation (kWh/m2-day) | 3.96 | 4.66 | 5.80 |
| Wind speed (mph) | 9.07 | 7.68 | 6.05 |

identifies major energy end-uses. Figure 3 (monthly energy use) and Figure 4 (peak days hourly energy use) provide insights about the occurrence of energy end-uses. Figure 5 (space load components) identify major components of the heating/cooling loads. The monthly and peak days energy use plots were investigated to also determine the sizing requirements of renewable energy systems. The peak monthly thermal energy use in relation to the useful solar thermal energy would determine loads for the solar thermal system. The peak monthly electricity use in relation with the potential of PV/wind electricity generation would determine the PV array area and wind turbine capacity. The peak days hourly electricity use would determine the capacity of inverter. This combined with the length of a consecutive -day period with the least energy resources would determine the capacity of electricity storage system.

On these plots, energy use/loads are plotted against outdoor and interior conditions to show the interaction among them. Monthly energy use plots include outdoor dry-bulb temperature, global horizontal solar radiation and wind speed, to identify driving climate forces, compare the energy use against potential energy resources, and identify critical months with less energy resources and high energy use, which would be aimed for selecting energy-efficiency measures. Peak days hourly energy use plots include outdoor dry-bulb temperature, global horizontal solar radiation, room air temperature, and attic air temperature and plots of heating and cooling load components include design temperature difference, infiltration rates, and grains difference to see their impact on the energy use. Table 3 lists all energy-efficiency measures considered, including the optimal building and window design determined from Figure 6.

## Analysis of base-case energy use and peak loads

With the above considerations, following observations of the base-case energy use/loads in view of climate parameters are noteworthy:

Annual energy use

A comparison of annual energy use across locations shows that the space heating energy use was driven by dry-bulb temperature, and space cooling electricity use was mainly driven by solar gains[2]. The HVAC fan electricity use was large both – in heating-dominated and cooling-dominated climates. Electricity use for lighting and appliances was a major part of the total electricity use. The domestic water heating energy use[3] shows the impact of water mains temperature, which drove not only the temperature rise required to achieve hot water supply temperature but also the hot water volume required to achieve mixed water temperature.

Monthly energy use

In general, the peak winter month with high thermal energy use and low solar radiation would be the critical period for the sizing of solar thermal system. However, determination of the critical period for the sizing of PV/wind electric system would depend on the electricity use in relation to the useful solar/wind resources, which would further depend on individual energy end-uses. For example, i) the constant lighting and appliance electricity use, which became a major fraction of the winter electricity use in all locations; ii) the high space

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[2] The space cooling energy use in Minneapolis was as large as that in Atlanta, which was attributed to solar gains from the 0.68 SHGC windows in Minneapolis compared to 0.4 SHGC windows in Atlanta.

[3] Domestic water heating loads were simulated using a user-defined DOE-2.1e subroutine function based on the water heater analysis (WHAM) model (Lutz et al. 1998), which accounts for different water heater operating conditions in different climate locations.

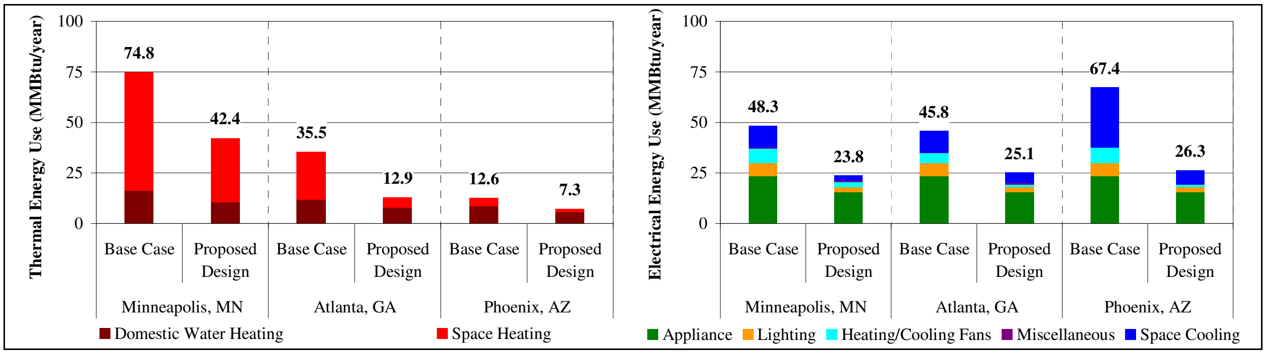

*Figure 2 Annual energy use*

heating energy use in Minneapolis, which resulted in a large fan electricity use (and would possibly result in auxiliary space heating and domestic water heating energy use, in case of unmet solar thermal loads) in the winter; and iii) the high space cooling electricity use in the beginning of fall, which were concurrent with diminishing solar radiation in all locations (especially, in Phoenix) and low wind speeds in Minneapolis and Atlanta, may shift the occurrence of critical period for the sizing of PV/wind electric system.

Peak day hourly energy use

Figure 4 shows the impact of thermostat setup/setback as a sudden drop followed by a sudden rise in hourly energy use. The impact of afternoon solar gains (with high ambient temperatures in the summer) is also evident in the dipping heating energy use and peaking cooling electricity use. The peak domestic hot water, lighting and appliance loads concur with and augment peak heating and cooling loads, though, by a small degree. The peak thermal energy use in the morning and peak electricity use in the afternoon would be examined when selecting energy-efficiency measures.

Heating and cooling load components

After identifying the influencing factors of the energy end-uses, critical periods to be tracked, and peak loads to be reduced, the heating and cooling load components were examined to identify dominant factors to be considered when selecting energy-efficiency measures. Figure 5 shows widely varied heat loss but similar contribution from heating load components across locations. Infiltration was the largest heat loss factor in all locations (as much as 50% of the total heat loss in Minneapolis due to low design temperature and high infiltration rates), followed by windows (20-25%), slab-on-grade floor (15-20%), ceiling and exterior walls (10-12%, each). Conversely, heat gains were similar but the contribution of cooling load components was different across locations. Windows were the largest heat gain factor (as much as 50% of the total heat gains in Minneapolis due to the high SHGC, unshaded windows). In Phoenix, heat gains from other envelope components were larger. In Minneapolis and Atlanta, infiltration heat gains were higher due to the latent fraction during the humid summer. Internal heat gains were only a small fraction of the total in all climates.

## Selection of energy-efficiency measures

In view of the climate characteristics (Figure 1) and base-case simulation results (Figure 2 through 5), the main criteria for selecting measures in Minneapolis would be to minimize heat loss and maximize solar gains in the winter, while minimize the resulting cooling penalty in the summer. In Atlanta, minimizing heat gains in the summer and avoiding the resulting heating penalty in the winter would be an additional criteria. In Phoenix, minimizing cooling loads in the summer would be the only criteria. With these criteria, first the measures which reduce both the heating and cooling energy use were selected. Then, the strategies which reduce the dominant space load in one season and result in the lowest penalty for other loads in other seasons, were considered. The selection of strategies should also ensure that the critical period for the sizing of PV/wind electric system occur when either the PV system output is high (e.g., in the summer) or wind power supplements reduced PV system output (e.g., in the winter).

Considering the peak energy use and load components, the selected energy-efficiency measures included: structural insulated panels (SIPs) for the exterior walls providing high insulation and airtight construction, heat-mirror windows, increased ceiling and slab perimeter[4] insulation. In addition, energy-efficient lighting and appliances, a high SEER air-conditioner with a heat pump[5], a high-efficiency water heater[5], and ducts in the conditioned space were considered.

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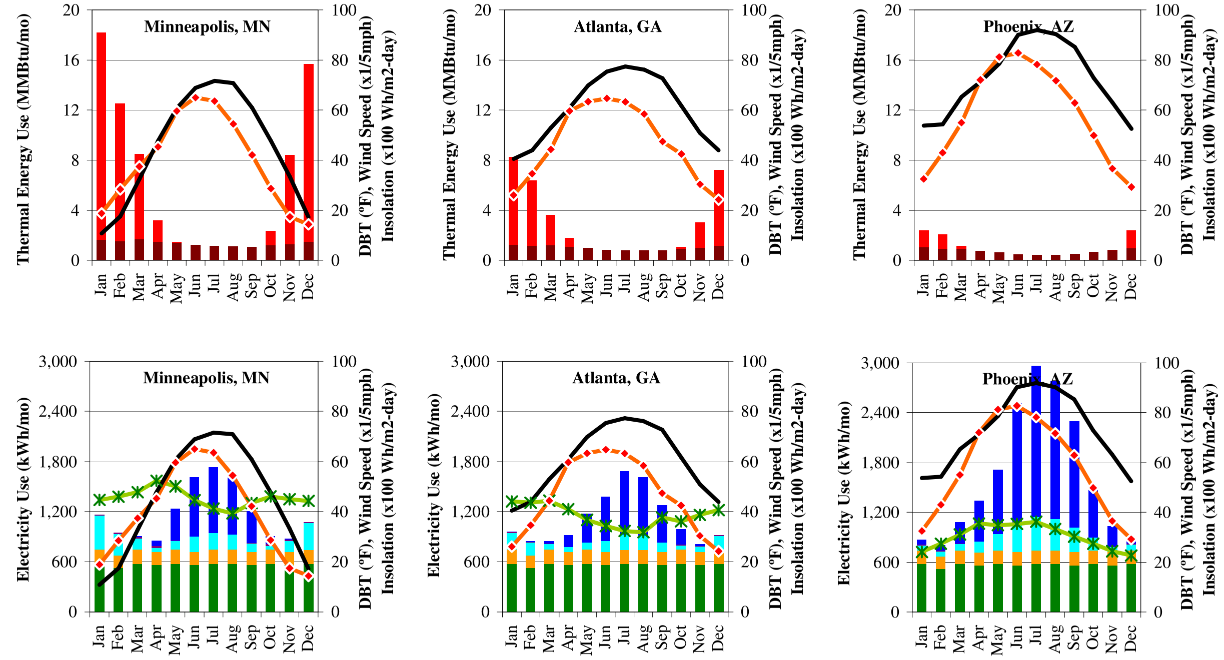
[4] Slab perimeter insulation was not considered for Phoenix due to the high termite infestation probability (ICC 1999).

[5] As back-up systems for the solar thermal system.

## Base-case House



## Proposed Design

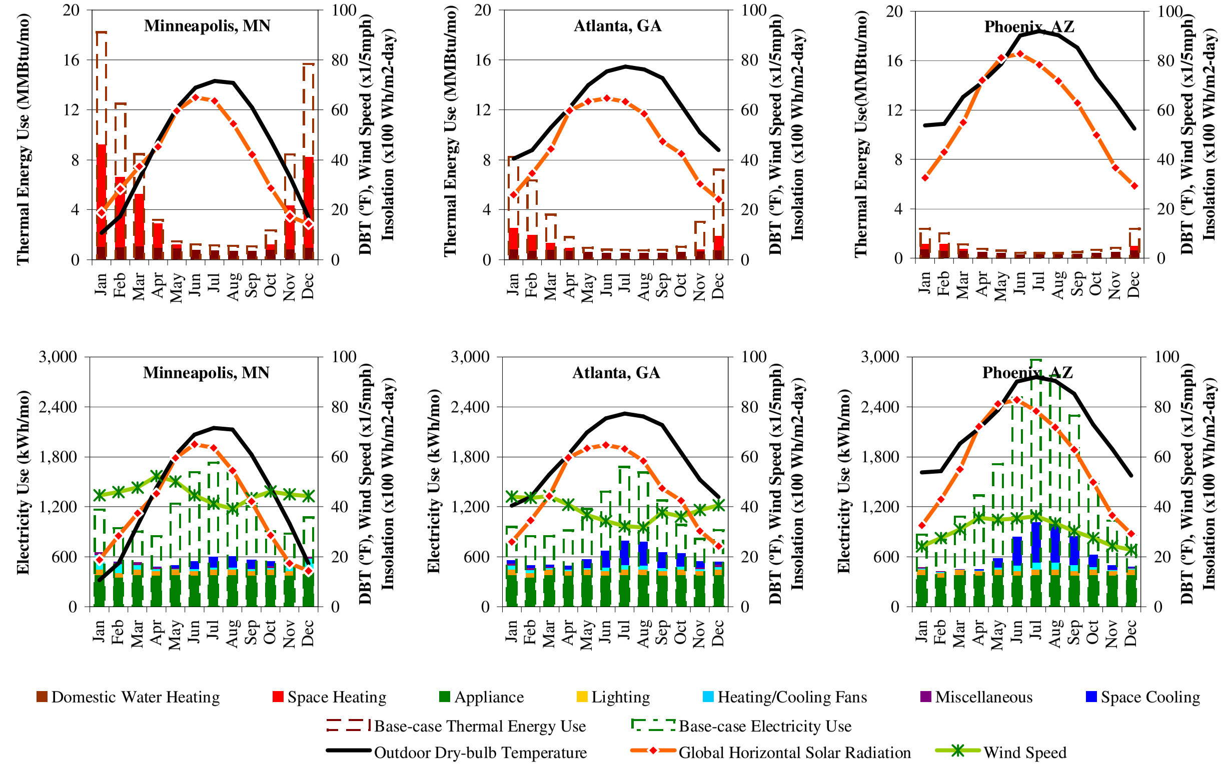
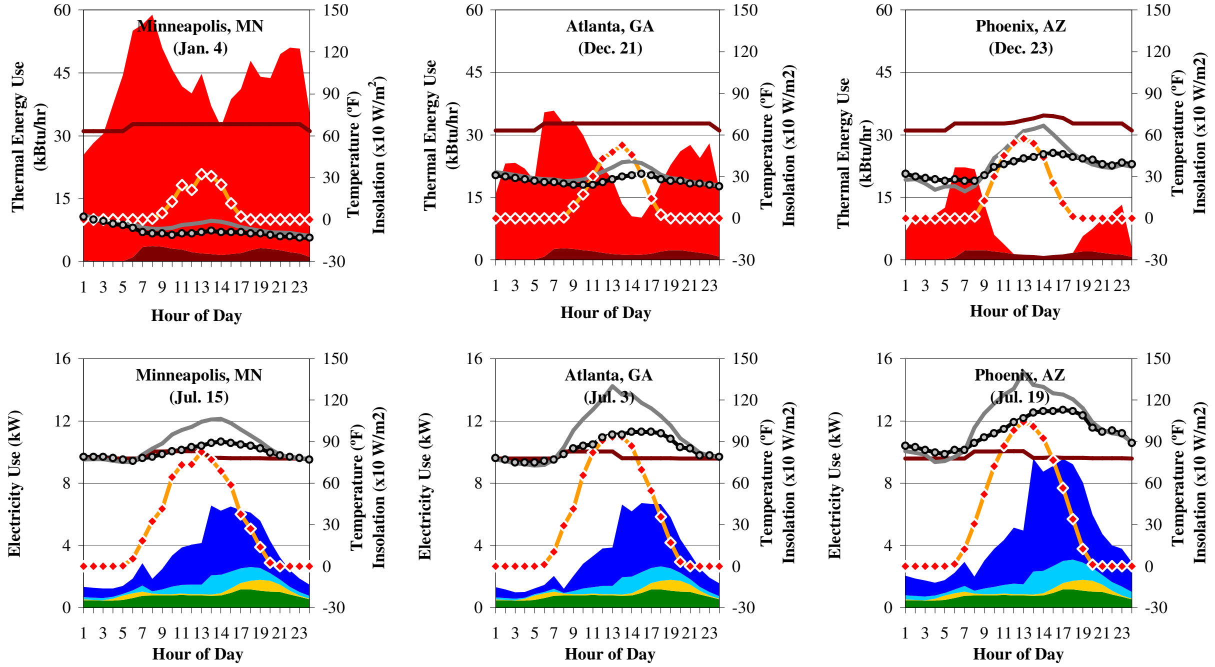


*Figure 3 Monthly energy use*

## Base-case House



## Proposed Design

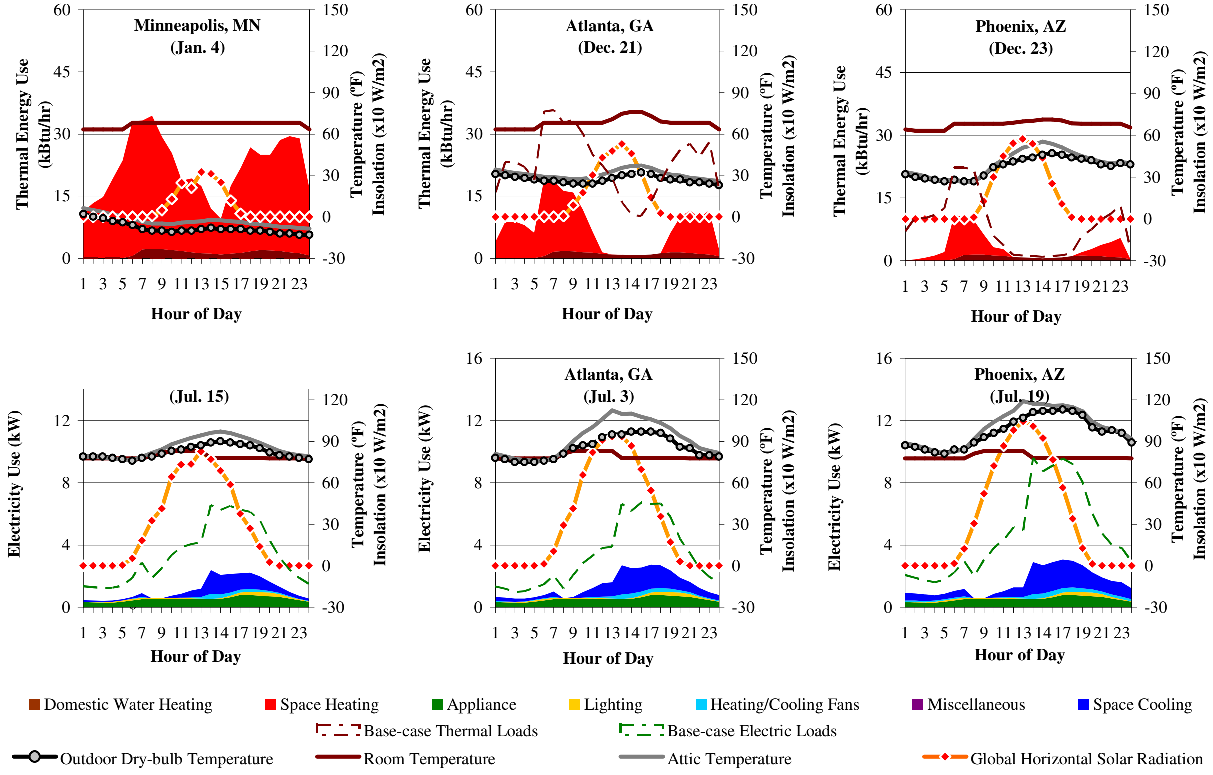


*Figure 4 Peak days hourly energy use*

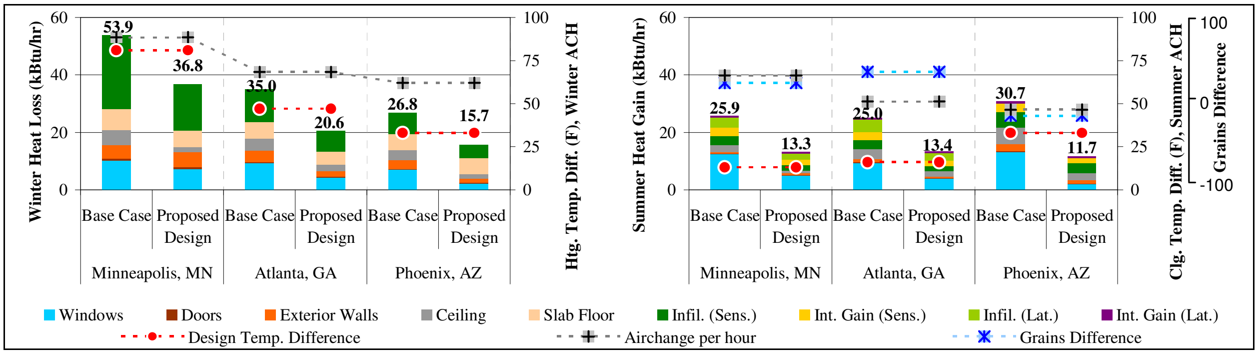


*Figure 5 Heating and cooling load components*

## Determination of the Optimal Building Configuration

To determine the optimal building geometry and window configuration, the house with the above measures was simulated for all possible configurations formed by incrementally changing the NS to EW aspect ratio from 1:1 to 1:3, window distribution from 55% to 75% on the south[6], overhang depth from 2 ft. to 4 ft., and number of floors - one and two story. The peak monthly heating energy and cooling electricity use were plotted on a scatter plot (Figure 6) to identify an optimal design for each location, which corresponds to higher reduction for the dominant end-use and smaller penalty for the other end-use. Figure 6 includes an inset plot showing results for different configurations compared to the base case. The number of story and window distribution are represented by different markers. The vertical scatter represents the impact of varying overhang depth and the horizontal scatter represents the impact of varying aspect ratio.

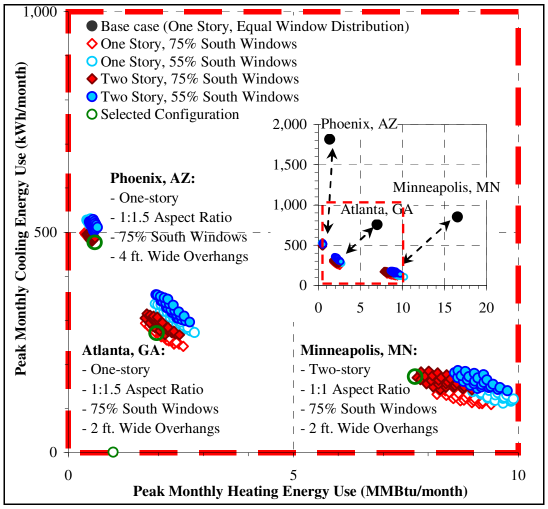


*Figure 6 Optimum Configuration*

Clearly, designs with more south windows had higher heating and cooling energy savings in all locations. However, with other measures implemented to the base-case house, building configuration had less impact (especially in Phoenix). Considering the priorities discussed previously, optimal design with preferred level of reduction in heating vs. cooling energy use was identified for each location[7] (as marked on Figure 6). In this manner, the building characteristics and measures[8] for the proposed design were determined (as listed in Table 3) and its energy use was further examined.

*Table 3 Base-case vs. Proposed House Characteristics*

| **Building Characteristics** | **Minneapolis, MN** | | **Atlanta, GA** | | **Phoenix, AZ** | |
|---|---|---|---|---|---|---|
| | **Base case** | **Proposed** | **Base case** | **Proposed** | **Base case** | **Proposed** |
| **Building Configuration** | | | | | | |
| Aspect ratio | 1:1 | 1:1 | 1:1 | 1:1.5 | 1:1 | 1:1.5 |
| Number of floors | 1 | 2 | 1 | 1 | 1 | 1 |
| **Building Systems and Equipment** | | | | | | |
| Ltg. & appl. kW | 0.22, 0.78 | 0.08, 0.52 | 0.22, 0.78 | 0.08, 0.52 | 0.22, 0.78 | 0.08, 0.52 |
| Duct location | Attic | Room | Attic | Room | Attic | Room |
| HVAC system efficiency | SEER 13<br>7.7 HSPF | SEER 15<br>9.0 HSPF | SEER 13<br>7.7 HSPF | SEER 15<br>9.0 HSPF | SEER 13<br>7.7 HSPF | SEER 15<br>9.0 HSPF |
| **Building Envelope** | | | | | | |
| Infiltration (SLA) | 0.00057 | 0.00036 | 0.00057 | 0.00036 | 0.00057 | 0.00036 |
| Radiant barrier | None | None | None | None | None | Yes |
| Ceiling R-value | R-38 | R-57 | R-27 | R-57 | R-22 | R-57 |
| Wall R-value | 11+7.5 | 26 | 11+2 | 26 | 11 | 26 |
| Slab perimeter insul. | R-6 | R-10 | R-4 | R-10 | None | None |
| Wall and roof abs. | 0.75, 0.75 | 0.75, 0.9 | 0.75, 0.75 | 0.75, 0.75 | 0.75, 0.75 | 0.25, 0.5 |
| **Fenestration System** | | | | | | |
| U-value (south/other) | 0.28 (all) | 0.2/0.13 | 0.44 (all) | 0.2/0.13 | 0.47 (all) | 0.14 (all) |
| SHGC (south/other) | 0.68 (all) | 0.52/0.19 | 0.4 (all) | 0.52/0.19 | 0.4 (all) | 0.16 (all) |
| Frame type | Wood | Vinyl | Wood | Vinyl | Aluminum | Vinyl |
| Distribution(S:N:E:W) | Equal | 75:15:5:5 | Equal | 75:15:5:5 | Equal | 75:15:5:5 |
| Overhang depth | None | 2 ft. | None | 2 ft. | None | 4 ft. |
| Int. shading (htg/clg) | 0.9/0.7 | 0.9/0.7 | 0.9/0.7 | 0.9/0.7 | 0.9/0.7 | 0.9/0.25 |
| Moveable night insul. | None | R-21 | None | R-21 | None | None |

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[6] This was accomplished by changing the east and west window area, and keeping the north window area fixed to 15% of the total area.

[7] The selected geometry includes: a 1:1 two-story for Minneapolis with the minimum peak heating energy use (the extreme left marker in the cluster), 1:1.5 one story for Atlanta with small heating and cooling energy use (among the lowest markers on the cluster), and 1:1.5 one-story for Phoenix with the minimum peak cooling energy use (the lowest marker among one story configurations in the cluster).

[8] Other potential measures, which were not considered in this study, include: natural ventilation, evaporative cooling, and daylighting.

### Resulting peak loads and energy use reductions

The energy use/peak loads for the proposed design are included in Figure 2 through Figure 5, which show that the selected measures resulted in reductions of 40-65% in annual energy use, 50-70% during peak months and peak days, 30-40% in peak heating loads, and 45-60% in peak cooling loads, when compared to the base case. The highest peak load reductions were from airtightness and window improvements.

With the selected measures, the peak daily loads for the solar thermal system were 534 kBtu in Minneapolis, 182 kBtu in Atlanta, and 72 kBtu in Phoenix. With appropriate thermal storage capacity, the sizing of solar thermal system can be reduced to provide average daily loads of 298 kBtu, 82 kBtu and 37 kBtu, respectively. The peak daily loads for the PV/wind electric system in these locations were 27 kWh, 33 kWh, and 38 kWh, which could be reduced to provide average daily electric loads of 19 kWh, 26 kWh and 33 kWh, respectively, by providing adequate electricity storage.

## SUMMARY

This paper demonstrated a methodology to analyze building energy performance during different times of the year in view of available energy resources, aiming at minimizing the loads for renewable energy systems, which is very important for their sizing, usability and cost-effectiveness for off-grid, off-pipe application. The analysis showed how the daily and seasonal variations in the climate parameters impact the sizing requirements of various components of renewable energy systems. The results demonstrated that large reductions in the building energy use and peak loads can be achieved from the selected measures.

The next step for off-grid, off-pipe design is the sizing of renewable energy systems for critical periods. It is to be noted that critical periods may not always align with the periods of peak loads, since that depends on the energy use vs. energy harvested at different times of the year. Also, the availability of energy resources does not accurately represent the output of renewable energy systems, since the performance of systems is affected by other climate parameters and load conditions. These concerns are addressed in Malhotra (2009) by integrating the analysis of energy use and renewable energy system performance during different times of the year to obtain better estimates of loads for the systems.

## ACKNOWLEDGEMENTS

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## REFERENCES

FSEC. 2009. EnergyGauge USA: Energy and Economic Analysis Software. Florida Solar Energy Center.

Hendron, R. 2008. Building America Research Benchmark Definition, Updated December 19, 2008. NREL/TP-550-44816. Golden, CO: National Renewable Energy Laboratory.

ICC. 1999. 2000 International Energy Conservation Code. Falls Church, VA: International Code Council, Inc.

ICC. 2001. 2001 Supplement to the International Energy Conservation Code. Falls Church, VA: International Code Council, Inc.

Klein, S. A. and W. A. Beckman. 1993a. F-Chart Solar Energy System Analysis: Windows Version. Middleton, WI: F-Chart Software.

Klein, S. A. and W. A. Beckman. 1993b. PV F-Chart Photovoltaic System Analysis: Windows Version. Middleton, WI: F-Chart Software.

Lutz, J., C.D. Whitehead, A. Lekov, D. Winiarski, and G. Rosenquist. 1998. WHAM: A Simplified Energy Consumption Equation for Water Heaters. Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings 1:171-183.

Malhotra, M. 2009. An Analysis of Off-grid, Off-pipe Housing in Six U.S. Climates. Ph.D. Dissertation. College Station, TX: Texas A&M University.

NOAA. 2008. Quality Controlled Local Climatological Data. National Oceanic and Atmospheric Administration. http://cdo.ncdc.noaa.gov/ulcd/ULCD.

Rutkowski, H. 2004. Manual J: Residential Load Calculation. 8th ed. Arlington, VA: Air Conditioning Contractors of America.

Torcellini, P., and D.B. Crawley. 2006. Understanding Zero-Energy Buildings. ASHRAE Journal 48:62-65.

US DOE. 2008. Weather Data. U.S. Department of Energy http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm.

U.S. Census Beaureu. 2009. Characteristics of New Housing for 2008. http://www.census.gov/.

Vale, B., and R. Vale. 2000. The New Autonomous House: Design and Planning for Sustainability. New York, NY: Thames & Hudson.

Winkelmann, F.C., B.E. Birdsall, W.F. Buhl, K.L. Ellington, A.E. Erdem, J.J.Hirsch, and S. Gates. 1993. DOE-2 Supplement, Version 2.1e. LBL-34947. Berkeley, CA: Lawrence Berkley Laboratory.