Proceedings of ISEC2006
ASME International Solar Energy Conference
July 8-13, 2006, Denver, CO

ISEC2006-99159

IMPLEMENTING SOLAR ENERGY IN THE COLORADO PRODUCTION HOME MARKET

Jeffrey R. Lyng
University of Colorado at Boulder
Lyng@colorado.edu

Michael J. Brandemuehl, PhD, PE
University of Colorado at Boulder
Michael.Brandemuehl@colorado.edu

ABSTRACT
A standardized deployment of solar electric systems in the Colorado production home market is crucial to the success of the renewable portfolio standard recently adopted by Colorado voters. This research uses the Built Green® program as a context for investigating energy conservation measures (ECMs), viable within the production home market, for their efficacy in curtailing new home annual energy consumption and peak electrical demand loads. The research examines the cost effectiveness and impact of residential solar systems compared to the energy conservation measures.

Colorado is a state with good solar resources and considerable production-scale residential development. However, most production homes built in the state today are not highly energy efficient. It is generally believed that improvements to energy efficiency – more insulation, better windows, more efficient appliances – are more cost-effective than solar production systems given current costs. In other words, most production homes in Colorado are not ready to don a solar home system (SHS).

The analysis uses extensive energy simulation to determine energy savings of selected energy-saving home features relative to the baseline Building America Benchmark for Denver, CO. This optimization process seeks to identify the least-cost combinations of improvements, assuming present day component costs, with the greatest annual energy savings, with the ultimate goal of implementing solar energy in the Colorado production home market.

The results of the analysis suggest that optimal characteristics of production home, designed to minimize total costs, are readily achievable in today's market. Moreover, when these optimal ECMs are implemented, the marginal cost of a SHS is found to be less than additional energy efficiency. With further energy efficiency improvements, site-based solar electric systems can compete economically given current state and federal incentive programs. The results also indicate that a solar system oriented west of due south can offer significant reductions in peak demand relative to both the household and utility load profiles.

1. BACKGROUND
In November, 2004 Colorado voters become the first in the nation to vote for and pass a statewide renewable energy requirement. Amendment 37 (A37) mandates the largest utilities in the state to ramp up the renewable energy allocation of their generation portfolios to 10% of retail electric sales by 2015.

A37's solar set-aside provision further requires 4% of the above renewable energy percentage targets to come from solar energy. Furthermore, half of that 4% must come from customer-sited solar energy for which any participating utility must offer a rebate no less than $2/watt for any eligible SHS [10].

Xcel Energy, the state's largest utility, will provide a standard rebate offer (SRO) of $2/watt and a performance-based renewable energy credit (REC) of $2.50/watt for any customer installing a grid-tied SHS within their service territory after December 1st, 2004. The PV Watts model, developed by the National Renewable Energy Laboratory (NREL) will be used to evaluate the performance, and therefore the REC payment, for every SHS installed within the utility's service territory [11]. Any installed SHS that produces ±10% of a system tilted at latitude and oriented south will be eligible for the full $2.50/watt REC payment [16]. In addition, the EPAct of 2005 provides for a federal solar rebate of 30%, up to $2,000, after all state and local rebates are deducted. Whereas the installed retail cost of a SHS in Colorado during 2005 was $10/watt, a consumer could expect to pay less than $5.00/watt in 2006. For this analysis, a SHS installed cost of $5.50/watt is used as a conservative average to account for those installations that will not receive the full REC payment due to less than optimal installation conditions.

The estimated total customer-sited PV installed capacity target is 40-50 MW by the year 2015. This ambitious goal will be difficult to attain given the existing number and size of Colorado's photovoltaic (PV) installation firms. However, that burden could be significantly reduced if the PV industry were to focus heavily on the production home market. The SHS implementation process (design, installation, commissioning) requires less time of an installer in a new construction scenario than with a retrofit.

There are many programs in the US to promote energy efficient building practices, seeking a balance between the many ECMs available and the realities of the production home market. The Colorado Built Green® Program [2] has been very successful in striking this balance using a 210 item, 18 category checklist. The program requires member builders to achieve a cumulative point total of 70 and meet a minimum Home Energy Rating System (HERS) score of 82.

This research uses the Built Green® program as a context for investigating ECMs, viable within the production home market. It compares the economics of these ECMs relative to SHS under the A37 rebate program. The research seeks to serve policy makers and builders in answering the following questions:

- What are the most cost effective ECMs for production homes?
- What ECMs are more cost effective than SHS?
- What impact do the optimal ECMs and SHS have on home energy consumption and peak electrical demand?

2. BUILDING ENERGY OPTIMIZATION

The economic evaluation of ECMs and SHS involves optimization of building design to minimize energy costs. For our analysis, we approach the problem through the following steps:

1. Identify a baseline home, representative of current production home construction practices, and a suite of ECMs with incremental capital costs.
2. For a given energy savings target relative to the baseline, determine the set of ECMs and SHS to achieve the target energy savings with the minimum total cost.
3. Compare the energy savings and total costs for this set of optimal home designs.

The baseline home is characterized by the Building America Benchmark Definition (BABD) [6]. The BABD is tailored to represent mid-1990's standard building practice as defined in the Home Energy Rating System (HERS) Technical Guidelines [13]. In addition, user profiles have been created by to represent the behavior of a "standard" set of occupants for incorporation into the benchmark. The BABD for Denver, CO is used as the energy baseline house against which all ECM configurations are compared. The BABD is a 2,600 s.f. house with a singe car detached garage and no on site generation. Monthly utility bills range from $150 to $175 (Figure 3).

For this analysis, energy calculations are performed based on source energy rather than site energy. Due to inefficiencies in energy production and transmission, a power plant typically consumes three times as much primary energy as that consumed at the site, giving a source-to-site energy ratio of 3:1 depending upon the fuel mix of the local utility [5]. Electrical energy generated by SHS and used on-site offsets the need for source energy production by the utility, giving a source-to-site ratio of 1:1. (Fuels consumed at the site also have a source-to-site energy ratio of 1:1.)

The evaluation of total costs is determined using an annualized life cycle cost analysis. The analysis assumes that a new production home is purchased using a conventional 30-year mortgage with a fixed loan interest rate. It is assumed that the mortgage interest rate is 4% greater than the nominal inflation rate (3%), that the discount rate is 5% and that the homeowner has an effective tax rate of 28%. Electricity and natural gas costs are $0.075 per kWh and $1.21 per therm respectively (2005 Colorado state average from the DOE Energy

Information Administration [7]) and are assumed to increase at the rate of general inflation. The life cycle costs are expressed as the sum of the annualize fuel costs and the incremental net mortgage costs relative to the baseline house.

The costs of the ECMs are obtained from RS Means [14] and include both capital and labor costs. While it is impractical to list all cost assumptions in this paper, the following examples of ECM incremental costs are provided for illustration.

- Increase A/C SEER from 13 to 15: $304
- Add 2 in. foam insulating sheathing: $0.96/ft^2
- Upgrade to low-e windows: $5.27/ft^2
- Change 20% of lighting to CFL: $0.03/ft^2

The energy analysis is performed using BEopt [1], a building energy optimization tool developed at NREL and the University of Colorado for the purpose of informing building energy efficiency decisions along the path toward Zero Net Energy (ZNE). A ZNE home produces an equal or greater portion of energy on-site as it consumes on an annual bases. The goal of ZNE is most commonly achieved with a grid-tied PV system installed on the home itself [4].

The BEopt optimization method entails a sequential search routine in which combinations of energy efficiency options are analyzed to determine the most cost-effective building configurations within a range of categories. BEopt calls the DOE2.1E [8] and TRNSYS [15] simulation engines, using TMY2 weather data [12], for each point in the optimization process in a method diagramed in Figure 1 below. Those efficiency combinations which result in the least-cost for a given energy savings define the optimal path to ZNE [3].

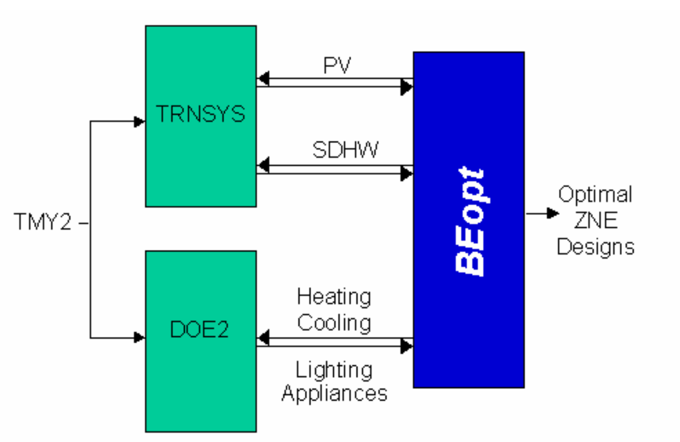

Figure 1. BEopt Optimization Method

BEopt seeks to determine the energy and monetary trade-offs associated with combinations of ECMs along the path toward ZNE. Adjacent iterations within any given optimization may exhibit very different ECM choices, yet equal Mortgage + Utility costs and Source Energy Savings. In this manner, BEopt optimization results represent more of a continuum of ECM choices on the path toward ZNE than discrete ECM transitions. Figure 2 depicts key points of interest within a BEopt optimization.

Point 1 – the *Energy Baseline* point – represents the BABD baseline home for Denver, CO. At the baseline, the percent source energy savings equals zero and the cost is the annual utility bills. Beginning at Point 1, BEopt performs several thousand annual energy simulations with hourly timesteps to determine the energy savings associate with various combinations of ECM options. Details of the optimization search techniques are described by Christensen, et al. [3].

Point 2 – the *Cost Minimum* point – represents a minimum annual cost optimum. At this point, the minimum annual Mortgage + Utilities cost has been achieved. Additional Source Energy Savings is still possible, but at increasing costs.

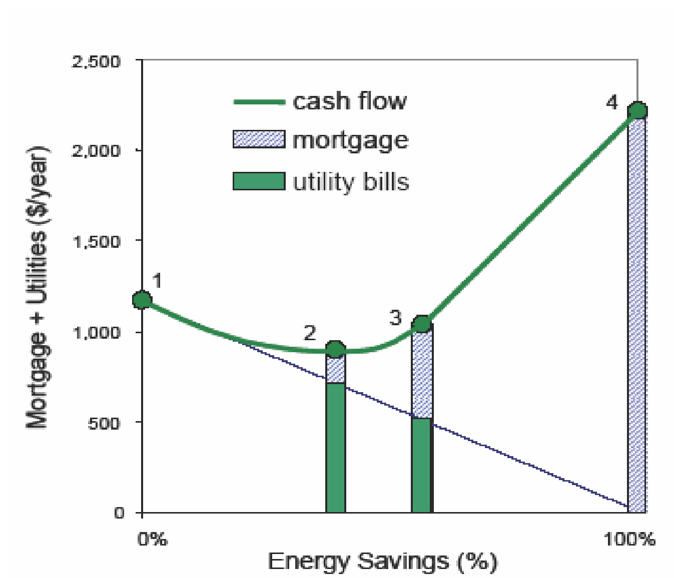

Figure 2. BEopt Output Conceptual Plot

From Point 2, BEopt continues to analyze ECMs as annual cost begin to rise while Source Energy Savings increases. This process continues until the marginal cost of additional energy efficiency improvements equals the marginal costs of adding a PV system, Point 3.

At Point 3 – the *PV Optimized* point – the marginal cost of saving energy equals the marginal cost of producing energy. Here, the incremental cost of energy efficiency is actually greater than the cost of using PV to produce that same unit of energy that would otherwise be saved through conservation. Beyond Point 3, it is always more cost effective to produce energy from PV than to save energy. Between Points 3 and 4, BEopt maintains the same ECM configuration as that which it determined to represent Point 3. The only change made is the continuous addition of PV capacity until the annual net energy production equals the annual energy consumption at Point 4 – the *ZNE* point.

While the energy costs at the Energy Baseline are covered entirely by the utility bills, the energy costs at ZNE are covered entirely by the mortgage payment. No utility payments are incurred at ZNE. Although BEopt is developed to inform energy efficiency options on the path to ZNE, Point 4 is only of limited interested in this analysis. Rather, we are interested in the characteristics of the homes that represent the Minimum Cost and PV Optimized points and their impact on energy and peak demand.

3. RESULTS

Figure 3 depicts the BEopt analysis of Built Green® ECMs relative to the Building America benchmark home. The dashed lines show the costs and energy savings associated with the PV Optimized home design.

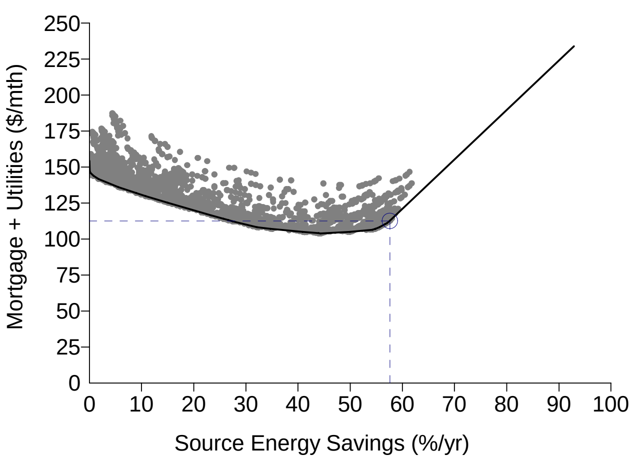

Figure 3. BEopt PV Optimized Point

The PV Optimized point occurs at 57% source energy savings relative to the Energy Baseline. In Colorado's heating-dominated climate (Boulder, CO – 6,020 HDD, base 65ºF), BEopt seeks to optimize heating equipment over all other end uses. As such, the reduction in heating energy is more than 85% from the Energy Baseline at the PV Optimized point (Figure 4). No other end use category exhibits a comparable level of savings to heating energy.

Table 1 outlines the ECM options for each category and feature modeled in BEopt that characterized the Cost Minimum and PV Optimized point. These ECMs occurred most often within a 2%/yr source energy savings by $2/month mortgage + utilities search window around the Cost Minimum and PV Optimized points. Note that the Cost Minimum characteristics describe construction features that are commonly used in residential construction. Compared to the Cost Minimum home, the PV Optimized home has more insulation, better windows, more thermal mass, and a gas range.

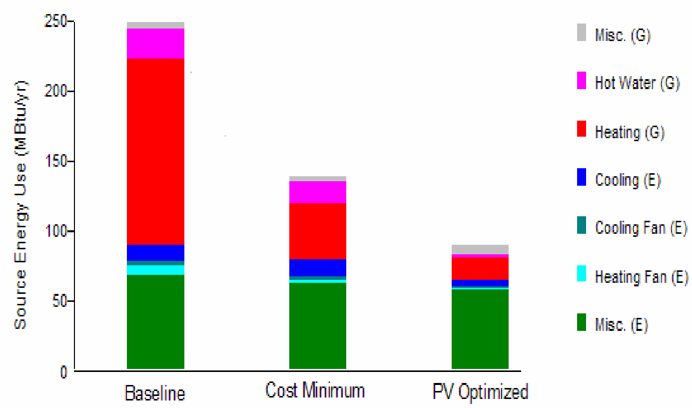

Figure 4. Energy Baseline vs. PV Optimized Source Energy End Use

With the exception of *Walls*, *Window Type*, *Eaves*, *Clothes Washer*, *Lighting* and *Air Conditioner*, BEopt has chosen the most energy efficient options available at the PV Optimized point. The marginal cost of saving an additional kWh within these six features is greater than the cost of a kWh generated from an on-site SHS system at a PV price of $5.50/watt.

At the heavily subsidized installed price of SHS in Colorado under the A37 provision, the results indicate that PV becomes a lower cost option than energy efficiency within two key categories:

- The marginal cost of installing a SHS is less than the cost of upgrading above a *SEER 13 AC* unit at the PV Optimized point (Table 1).
- Similarly, installing a SHS is also more economically advantageous than upgrading wall construction past an *R-19 batt, 2x6, 24"oc, +2" foam* at the PV Optimized point. In particular, SHS is more economical than the use of structural insulate panels (SIPs) with higher insulation.

Table 1. ECMs for Cost Minimum and PV Optimized Homes

Feature	Cost Minimum	PV Optimized
Building		
Orientation	South-facing [Az = 180º]	South-facing [Az = 180º]
Neighbors	None	> 30ft distance
Aspect Ratio	1.0	1.0
Envelope		
Walls	R-19 batts, 2x6, 24"oc	R-19 batts, 2x6, 24"oc + 2" foam
Ceiling Insulation	R-40 Blown-in Fiberglass	R-60 Blown-in Fiberglass
Thermal Mass	1/2" Ceiling Drywall	2 x 5/8" Ceiling Drywall
Infiltration	0.25 ACH	0.25 ACH
Window Type	Double Clear	Double Clear (Low-e, e3 = 0.04)
Total Window Area	14% Finished Floor Area	14% Finished Floor Area
Window Area per Wall	F25%, B25%, L25%, R25%	F25%, B25%, L25%, R25%
Eaves	Architects discretion	Architects discretion
Foundation		
Slab Insulation	R-10 15' Perimeter, R-5 Gap	R-10 16" Exterior, R-5 4' Horizontal
Basement Insulation	R-20 8ft Exterior	R-20 8ft Exterior
Crawl Space Insulation	Vented, R-10 Interior, R-10 4ft Perimeter	Vented, R-10 Interior, R-10 4ft Perimeter
Appliances & Lighting		
Refrigerator	ENERGY STAR	ENERGY STAR
Cooking Range	Electric	Gas
Dishwasher	Standard	ENERGY STAR
Clothes Dryer	Gas	Gas
Clothes Washer	Standard	Standard
Lighting	20% Interior CFL	20% Interior CFL
Water Heater	Gas Tankless	Gas Tankless
HVAC		
Air Conditioner	SEER 13	SEER 13
Furnace	AFUE 95%	AFUE 95%
Ducts	Inside Conditioned Space (Uninsulated, Joint Mastic)	Inside Conditioned Space (Uninsulated, Joint Mastic)
Renewables		
Solar DHW	None	None

The potential for household and utility peak load reduction for production homes at the PV Optimized point equipped with a SHS is also evaluated. The peak household electrical load is reduced from 3.4kW at the Energy Baseline to 2.4kW at the PV Optimized point. Both of these peaks occur on July 16^{th} at 6pm. Figure 5 shows the peak daily load profiles for the Baseline, Cost Minimum, and PV Optimized homes, as well as the average summer utility load profile [9]. Note that times on the figure are given as standard time rather than daylight savings time.

Typical utility peak hours occur on weekdays, between 3:00-7:00 pm during the months of June or July, with the average peak occurring at approximately 4pm [9]. Peak residential demand occurs at approximately 6:00 pm for the three home configurations. Note that the PV Optimized home has a lower demand due to reduced load on the air conditioner and the gas range.

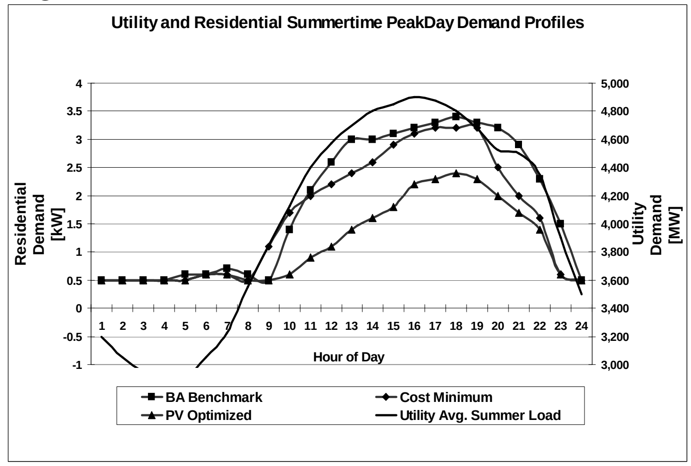

Figure 5. Utility and Various Household Summertime Demand Profiles Without PV Systems

Figure 6 shows the impact of adding a 5 kW PV system to the PV Optimized home design. The figure shows the effect of three different PV system orientations – south, southwest, and west. In addition, the average daily summer utility demand is overlayed as a temporal reference for utility peak.

For a PV Optimized house oriented south, the peak output from the 5 kW SHS occurs near 11:00 am (noon standard time) and produces more energy than can be used by the home. The SHS is capable of reducing the net household electric demand from 2.25kW to 0.5kW at the time of the utility peak. Household peak demand is reduced slightly from 2.4kW to 2.25kW at 6pm.

By shifting the same house configuration to the southwest, the SHS peak production occurs at approximately 2:00 pm. The net household electricity demand at time of utility peak is reduced from 2.25 kW to -0.25 kW, a 0.75 kW reduction over a south-facing array. In addition, household peak demand is reduced more substantially from 2.4kW to 0.75kW.

By shifting the same house an additional 45º to due west, the peak SHS production occurs still later in the day at approximately 3pm. The net household electricity demand at time of utility peak is further reduced from 2.25kW to -0.6kW, a 1.1 kW greater reduction than a south-facing array. In addition, household peak demand is reduced most significantly from 2.4kW to 1kW.

While household and utility demand are both reduced most substantially with a west-facing SHS, annual energy production is diminished at this orientation. Figure 7 illustrates the monthly energy produced form a SHS at various orientations in Denver, CO. The discrepancy between orientations is less substantial during the summer months and greater in the winter months.

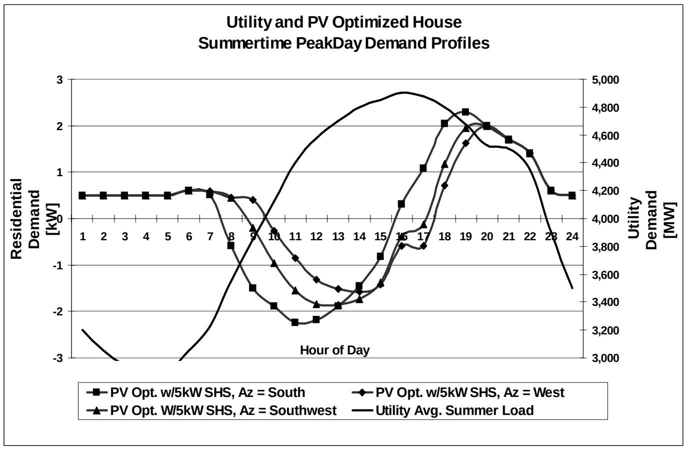

Figure 6. Utility and Household Summertime Demand Profiles With PV Systems at Various Orientations

The table in Figure 7 summarizes the annual energy production for each of the three SHS orientations evaluated using the NREL PV Watts model [11]. A 5 kW SHS located in Denver, CO, oriented to the west produces only 75% of the energy that it would produce if oriented due south. However, a southwest SHS orientation only reduces annual energy production by 10% from south.

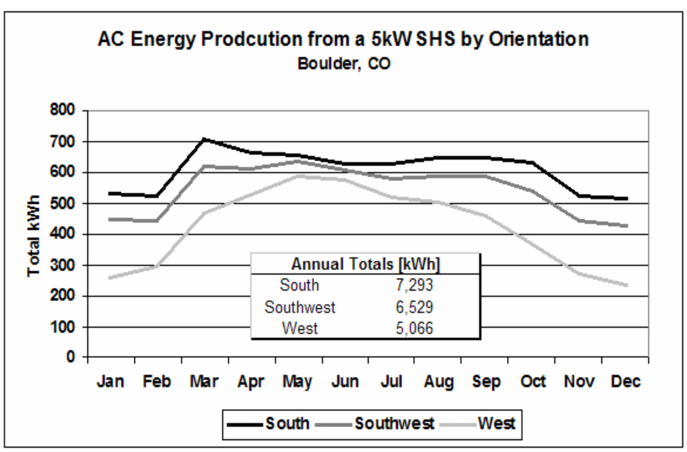

Figure 7. Annual Energy Production from a 5kW SHS by Orientation

Table 2 shows the monthly energy consumption of the baseline BABD, the PV Optimized home without SHS, and the PV Optimized home with a 5 kW SHS. Homes built to the PV Optimized configuration and including a 5 kW SHS oriented southwest stand to save as much as 2.5 peak kW (Figure 6) and 8 MWh (Table 2) annually over the built-to-code baseline home.

Table 2. BABD House vs. PV Optimized House Net Monthly Energy Savings

	BABD [kWh]	PV Optimized [kWh]	PV Optimized w/5kW SHS [kWh]	Net Savings [kWh]
Jan	599	483	36	563
Feb	530	431	-10	539
Mar	558	469	-154	712
Apr	500	445	-169	669
May	577	491	-144	721
Jun	675	522	-86	761
Jul	969	674	96	872
Aug	857	604	15	842
Sep	670	519	-67	737
Oct	502	457	-83	585
Nov	538	454	9	529
Dec	602	484	59	543
Annual	**7,577**	**6,033**	**-496**	**8,073**

4. CONCLUSIONS

Although the recommended ECMs in Table 1 do represent a hurdle for the average production home builder, this hurdle is not insurmountable. All ECMs considered in the analysis are currently part of the Built Green® checklist and viable for any production builder with relatively little re-tooling. The challenge is in implementing all of the ECM recommendations in a single home. That challenge is economic, educational, technical.

Home orientation is perhaps the most contentious issue in sustainable residential design facing production home builders in Colorado. While house orientation can have significant impacts on SHS performance, orientation in the main Colorado population centers are often dictated by the views of the mountains to the west. It should also be noted that BEopt optimized at a >30 ft. distance from neighbors, suggesting that a separation of at least 30 ft between homes lots is optimal.

Orienting a SHS to the south maximizes energy production yet is less effective at reducing a home's electric demand both at the time of the utility summertime peak demand (4pm) and at the time of the home's summertime peak demand (6pm).

Considering both demand and energy savings from the perspectives of the utility and homeowner, a southwest SHS orientation seems optimal. A 5 kW SHS oriented southwest produces 90% of the annual energy produced by a south-facing system and can result in a greater than 100% reduction (80% for south-facing) in residential demand at time of utility peak as well as a 70% reduction (7.5% for south-facing) in home peak demand.

In addition, a southwest SHS orientation would qualify for the maximum $2.50/watt REC from the state's largest utility since it produces 90% of annual energy that an identical SHS oriented due south is predicted to produce (assuming collector tilt remains equal to latitude).

Utilities stand to benefit from energy and demand reduction through basic residential energy efficiency and on-site solar generation. Wide-scale implementation of distributed solar resources will undoubtedly result in capacity, distribution and transmission benefits to the utility. Real time pricing mechanisms will also encourage net-metered households to shift their peak electricity usage away from the utility's summertime peak hours. Many utilities are exploring opportunities for storing energy from renewable sources to increase their capacity factor. Orienting SHS to the southwest ensures peak output closer to time of peak utility demand and reduces the need for expensive energy storage facilities.

5. FUTURE WORK

A detailed hourly net metering analysis incorporating a utility's time of use (TOU) demand rates for production homes at or near the Cost Minimum and PV Optimized points would elucidate the economic benefit of a south, southwest and west SHS orientation to the homeowner. In addition, decoupling the orientation of the PV Optimized home and the SHS (e.g. South home orientation and West SHS orientation) would provide valuable insight into a practical means of maximizing household energy and demand reduction.

6. ACKNOWLEDGEMENTS

This work was supported by Built Green® Colorado. The generous assistance of the entire NREL BEopt Team; Craig Christensen, Ren Andersen, Scott Horowitz, Todd Givler, and Adam Courtney, made this analysis possible.

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