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CONTRACT REPORT

Comparison of the *ENERGYGAUGE* USA and *BEopt* Building Energy Simulation Programs

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Authors:

Danny S. Parker
Jamie E. Cummings

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U.S. Department of Energy, Building America Program
Office of Energy Efficiency and Renewable Energy

1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu

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Danny S. Parker and Jamie E. Cummings
Florida Solar Energy Center
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Abstract

Two hourly energy simulation software, *BEopt* and *Energy Gauge USA*, were compared to ensure accuracy and evaluate agreement on the impact of various energy efficiency improvements. Within the *Building America* program, these software aid design teams working toward the U.S. Department of Energy's goal to make Zero Energy Homes economically viable by 2025. Builders use the software to achieve the extensive energy savings (70%-80%) from various measures before adding solar electric power generation. The study found that in general, *BEopt* and *EnergyGauge USA* agree fairly well on the impact of energy efficiency improvements, while identifying several discrepancies that need further review, such as differences in the effects of window conductance, crawlspace performance, heat pumps, and heating/air conditioning fan energy.

Disclaimer

Executive Summary

The U.S. Department of Energy seeks to make zero energy buildings cost-effective by 2020. This goal requires innovative energy efficiency solutions and sophisticated energy analysis. Energy simulation software such as *Energy Gauge* USA and *BEopt* allow builders to reduce home energy use by the ~70% necessary to make achieving zero net energy use a feasible goal.

EnergyGauge USA, created by the Florida Solar Energy Center, and *BEopt*, created by the National Renewable Energy Laboratory, use hourly energy simulations to estimate home energy use. Both of these software are used extensively by Building America teams to design both zero energy and low-cost energy efficient residences. Because they are used widely, a study was conducted to compare the two software. A base house in Atlanta, GA was simulated in each software. The base house was then simulated with increased efficiency for many different parameters. The savings from each efficiency improvement were compared between the two software.

The comparison identified some significant differences between the programs involving window conductance, slab performance and unvented crawlspace performance. Air conditioning and heat pump efficiency

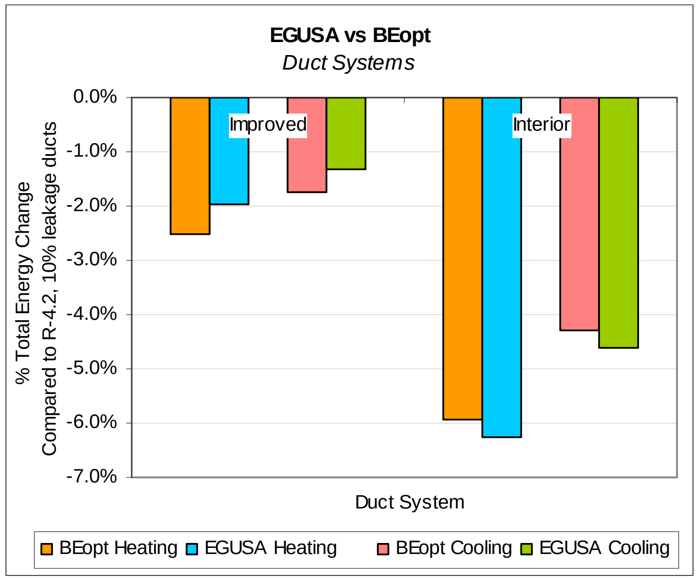


Figure 1 *Duct system analysis shows very close agreement on both heating and cooling energy savings.*

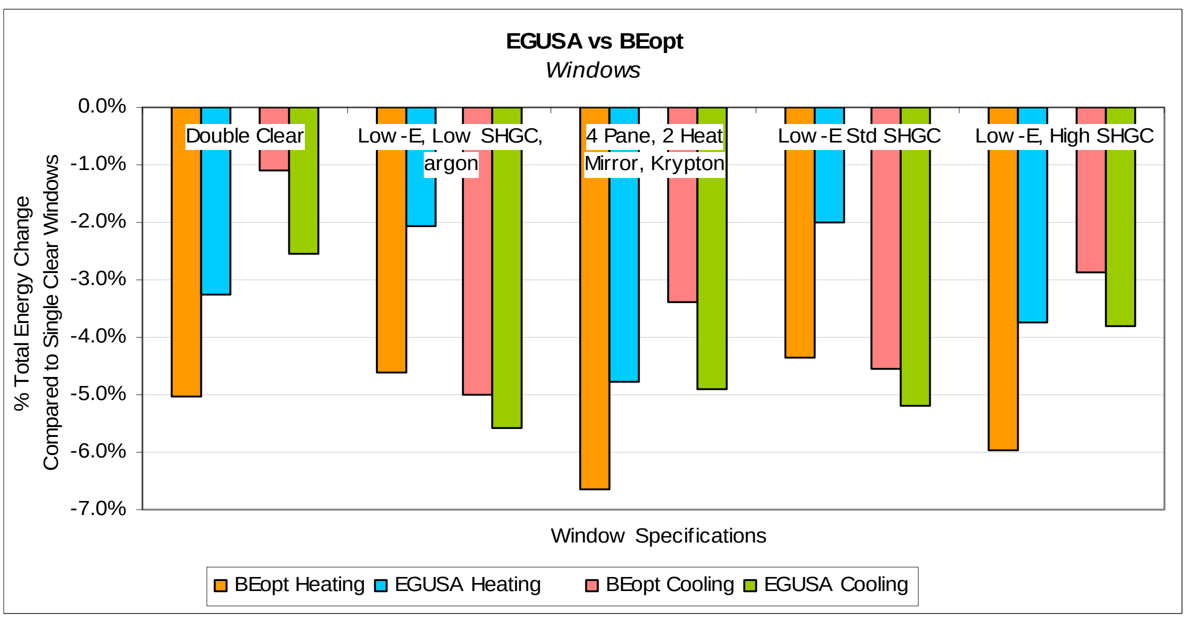


Figure 1 *Window analysis shows large heating differences between Energy Gauge USA and BEopt*

as well as heating/air conditioning fan energy also showed significant, systematic differences between the software.

Beyond these discrepancies, some of which should be addressed, most simulations differed only minimally on the magnitude of impact. In general, *BEopt* and *Energy Gauge USA* agree remarkably well on the influence of most energy efficiency improvements.

Introduction

The U.S. Department of Energy's objective of reaching Zero Energy Homes in the United States requires residences to achieve 70% reductions in loads with careful integration of onsite renewable energy generation, calling for a revolutionary approach to building design and operation. Since simulation software are used to estimate the savings levels associated with various improvement measures within Building America (BA), it is important to be certain that the calculation methods are as accurate as possible. Building America requires an hourly simulation software be used for establishing savings levels compared to the BA Benchmark (Hendron, 2005). The most commonly used simulations are *Energy Gauge USA (EGUSA*) created by the Florida Solar Energy Center and *BEopt*, produced by the National Renewable Energy Laboratory.

Energy Gauge USA (Parker et al., 1999) is a sophisticated home energy simulation software tool designed specifically for accurate evaluation of residential energy-efficiency. The software uses the powerful and widely-respected DOE 2.1-E hourly building energy simulation software to simulate energy use. It is also a powerful hourly simulation design tool for the design of low-performance homes, the evaluation of energy use and peak demand impacts of home energy-efficiency improvements, and the evaluation of renewable energy systems performance. The program came into existence as a tool to design the first zero energy home constructed in Florida (Parker et al., 2000). It has since been carefully indexed to the HERS BESTEST suite (Fairey et al., 2000). The program has been found to successfully predict the energy use of real monitored homes. (Fuehrlein et al., 2000). Currently, the software is very commonly used by BA teams to evaluate specific designs.

BEopt (Christensen et al., 2005) is a similar computer program designed to find optimal building designs along the path to zero energy. The program uses the DOE-2.2 calculation engine allowing users to select from many predefined options to be used in the optimization. An output screen allows the user to display detailed results for many optimal and near-optimal building designs. It is extensively used in analysis of ZEH designs within the Building America teams and was used in the design of the very successful Wheatridge cold-climate ZEH design (Norton and Christensen, 2006).

Given the common use of these two programs, it is important to examine the calculation procedures to establish both consistency and also reasonable results within known engineering knowledge. Given discrepancies identified by the BA teams, FSEC undertook the effort to compare the two software using a single prototype building. The objective was to clarify differences and correct unintentional errors.

Component Comparisons

EGUSA and *BEopt* were compared by systematically increasing the efficiency of each house component.[1] A two-story house in Atlanta was used as the base as originally produced by NREL for the comparison. Table 1 shows the particulars of the building and other relevant details:

Table 1. Base House Details

Two-story, 3-bedroom, 2-bath home in Atlanta, GA (TMY2)

Floor area	1824 ft^2
Wall height	8ft
Floor	Uninsulated Slab, 20% tile
Roof	Dark shingle, vented attic, no radiant barrier, R-30 ceiling
Walls	R-13 wood frame, 16 o.c.
Windows	Double clear, metal frame, U-value: 0.447, SHGC: 0.547, 20% window/floor area
Ventilation	54.4cfm exhaust (100% ASHRAE 62.2)
Infiltration	ACH_{50}: 9.84 ACH
A/C	13 SEER, 39 kBtu/hr
Heating	Natural gas furnace, 80 AFUE, 43.3 kBtu/hr
Ducts	R-4.2, Leakage Fraction: 0.10[2], Ducts/AH in attic
Water Heater	Natural gas in attic, EF= 0.59, 40gal
Lighting	14% fluorescent lighting
Appliances	Default appliances

The efficiency of a single parameter of the house was incrementally increased to compare the energy savings from the efficiency increase between the two programs.

For example, to study the differences between *BEopt* and *EGUSA* with regard to ceiling insulation, the energy use of the house was simulated with different levels of ceiling insulation: R-30 (the base), R-40, R-50, and R-60 insulation, in both *EGUSA* and *BEopt*. The savings from changing the ceiling insulation to R-40, R-50, and R-60 was compared between the two programs.

[1]Most of the comparisons were done in the fall of 2008 and early 2009. The following software versions were used: *BEopt* v0.8.7 and *EnergyGauge v. 2.8.0.*

[2]The original *EGUSA* file had 0.12% duct leakage (Qn=0.007) which was not identified until later in the simulation evaluations when a new base case was created.

Neighboring Buildings

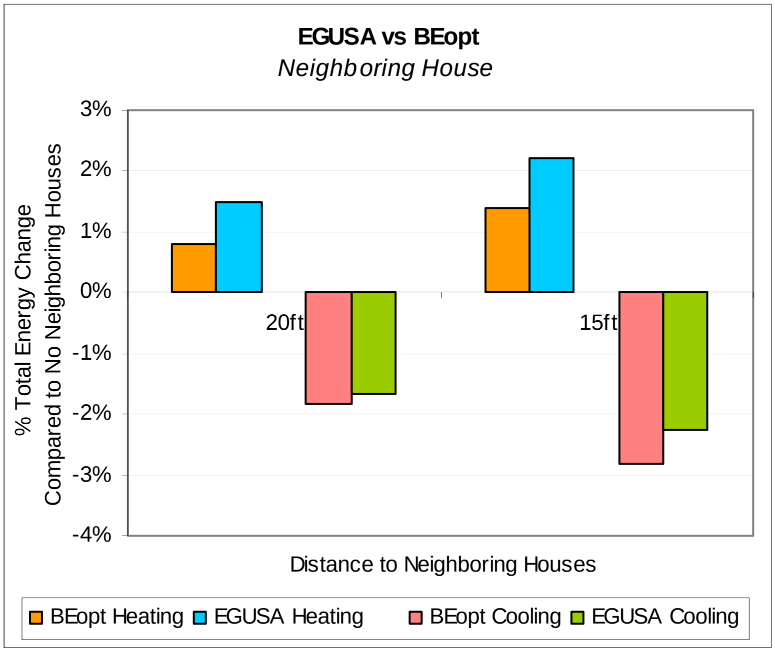
Neighboring buildings on all four sides 12ft high by 40ft wide

At 20ft distance

At 15ft distance

Compared to the base with no adjacent buildings.

EGUSA and *BEopt* agree well on the impacts of adjacent buildings, although *BEopt* calculates greater cooling savings and less heating impacts than *EGUSA*. They both agree that neighboring houses increase space heating and decrease cooling in all cases. The impact of the adjacent buildings on space cooling is large, and the closer the buildings are, the larger the effects.



The *EGUSA* model appears to be shading more of the windows in winter than *BEopt*. *BEopt* models slightly greater cooling savings and less of a heating increase (only 60% of *EGUSA*). Since the exact neighboring building shade plan is unknown in *BEopt*, this difference is likely accounted for by different assumed adjacent building heights in the programs.

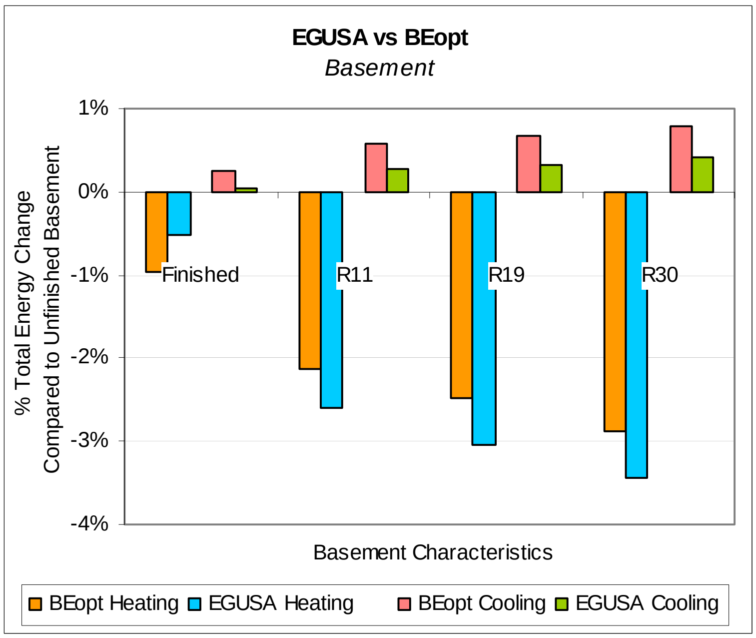
The impact of adjacent buildings is large enough that this measure should substantially influence both the benefits of solar control windows for cooling as well as the choice of window type in mixed climates. Not accounting for adjacent building shading will overestimate the savings of SHGC windows and likely undervalue the importance of U-factor for colder climates because less direct sun on the windows will increase the importance of the u-factor in the energy balance.

Since most houses are next to other houses, this is an important issue for RESNET and the HERS rating systems, as lot lines and plans are usually approximately known for most projects and developments before construction.

Basement Insulation

Comparing basements with the following characteristics:

Unfinished (Base)
Finished
R-11 basement wall insulation
R-19 basement wall insulation
R-30 basement wall insulation



Comparing the effects of basement insulation shows the two programs in reasonably close agreement regarding heating. Basement insulation mainly impacts heating energy. *BEopt* models slightly less savings than *EGUSA*. The simulations agree that insulating basement walls will increase space cooling a smaller amount, but *BEopt* models twice the impact as *EGUSA*.

<u>Slab vs. Basement</u>
EGUSA indicates that in Atlanta, slab construction has lower cooling than a basement (325 kWh less), while *BEopt* indicates the opposite (353 kWh more). This is likely caused by the fact that *BEopt* models higher heating and cooling for slab homes.

Crawlspace

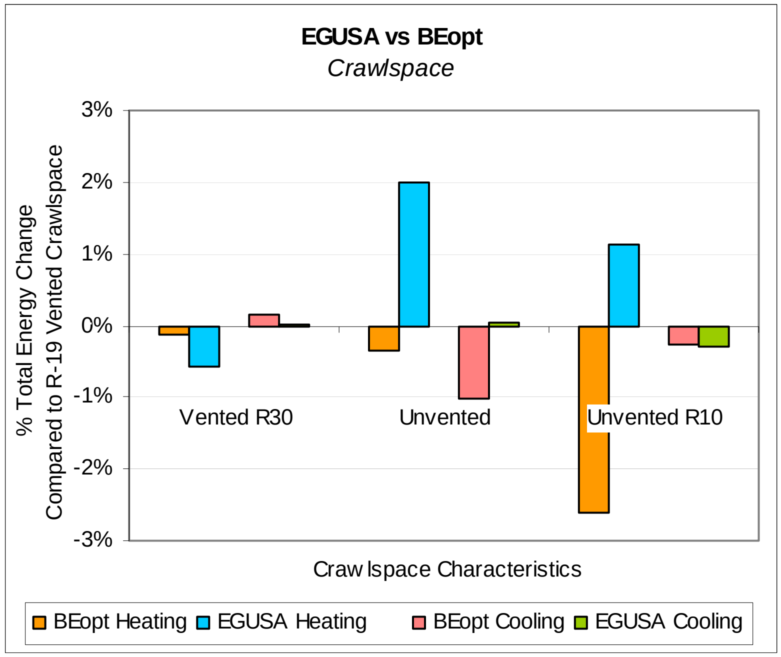
Comparing crawlspaces with the following characteristics:

Vented (Base)
Vented with R-19 floor insulation
Unvented
Unvented with R-10 wall insulation

Although close on vented crawlspace savings, *BEopt* and *EGUSA* show large differences in slab and unvented crawlspace energy savings.

Vented Crawlspaces

The programs agree that added floor insulation on vented crawlspaces reduces heating and slightly increases cooling, although *EGUSA* shows larger heating savings.



Unvented Crawlspaces

Both simulations show that if a crawlspace is unvented perimeter wall insulation will reduce heating. Unvented crawlspaces reduce cooling compared with insulating the floors, but *BEopt* estimates the influence to be much larger.

There is a large disagreement on the impact of unvented crawlspaces on heating. *BEopt* models them as significantly more efficient than vented crawlspaces whereas *EGUSA* shows them to be significantly less efficient (increases heating significantly).

Crawlspace heating change

	BEopt	*EGUSA*
Unvented	-6 therms	35 therms
Unvented R10	-46 therms	20 therms

In addition, *BEopt* models 169 kWh cooling savings for uninsulated unvented crawlspace, while *EGUSA* indicates no change.

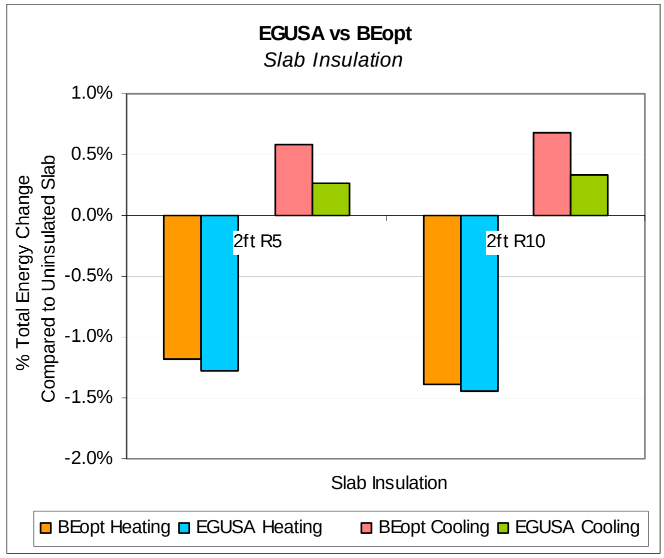
EGUSA models the crawlspace as an unconditioned zone connected to the living space. The crawlspace walls are modeled as conventional concrete block construction; floors are wood with an insulated part and a joist part. Infiltration to the vented crawlspace is modeled with the Sherman-Grimsrud algorithm. The specific assumptions in the *BEopt* crawlspace model were unknown.

<u>Comparison to Slab Floors</u>
Contrary to *BEopt*, *EGUSA* shows slab floors to be a big advantage to cooling over crawlspace floors. *BEopt* shows crawlspace floors to be a big advantage to heating compared with slab floors; *EGUSA* shows a smaller difference.

Slab Insulation

Comparing a slab home with the following characteristics:

Uninsulated
2 foot R-5 perimeter insulation
2 foot R-10 perimeter insulation

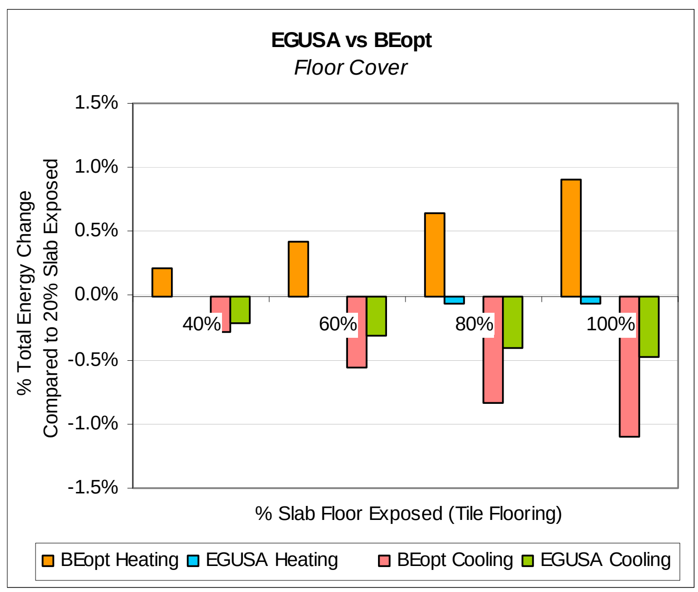


Both programs agree that adding slab perimeter insulation decreases space heating and increases space cooling in Atlanta. The two simulations gave essentially identical savings on space heating. They differed somewhat on the cooling energy penalty of adding slab insulation with *BEopt* indicating more than twice the impact of *EGUSA*.

Floor Cover (fraction carpeted)

Comparing an uninsulated slab home with the following characteristics:

20% slab exposed (covered in tile) (Base)
40% slab exposed
60% slab exposed
80% slab exposed
100% slab exposed



BEopt and *EGUSA* differ significantly on the energy impacts of exposed slabs. Both software agree that greater expanses of exposed concrete (tile) flooring will reduce cooling, however *BEopt* estimates significantly greater cooling savings from exposed tile flooring. Also, *BEopt* estimates that large amounts of tile flooring increases space heating whereas *EGUSA* estimates it as roughly neutral. These discrepancies may be caused by differences between the way solar gains through windows and their distribution on floors are handled.

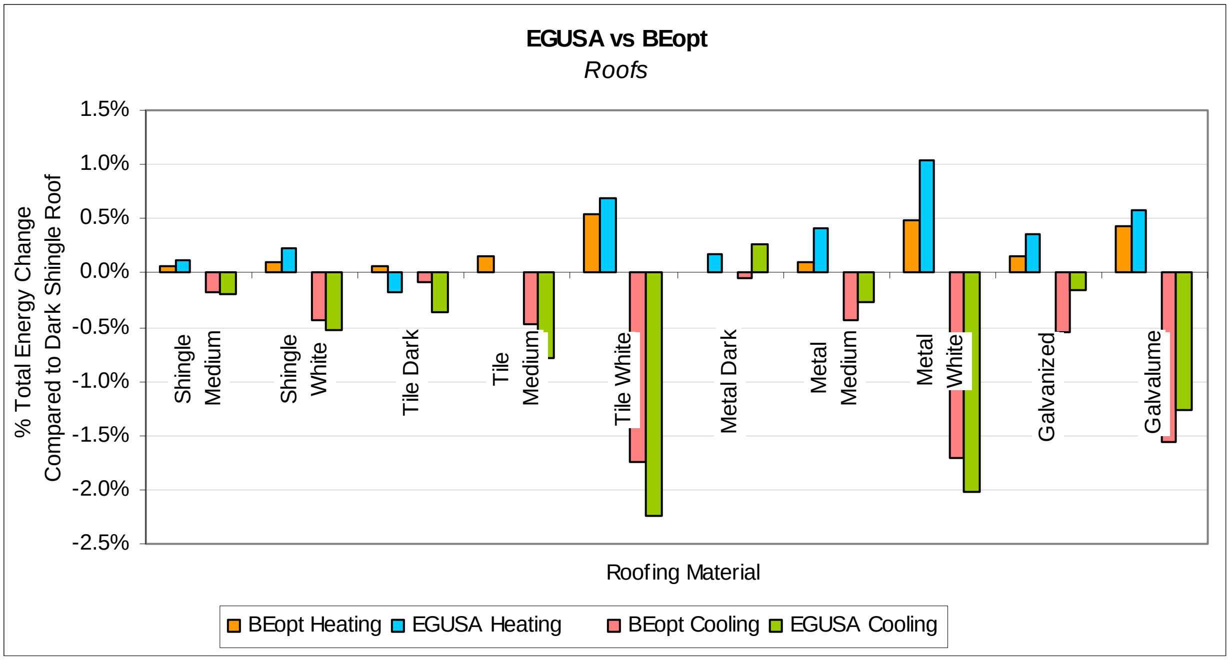
Understanding of these differences will be best revealed by examining the floor models within the simulations. *EGUSA*'s model[3] assumes that much of the apparent heat flowing into the slab toward the ground temperature is eventually returned via diminished heat flow due to storage under the slab. This added fictitious thermal resistance added to the floor tends to reduce the degree of heat transfer to the soil thermal boundary condition below the floor.

Roofs

Comparing the following roofs*:*

Shingle - Dark (Base), Medium, White
Tile – Dark, Medium, White
Metal – Dark, Medium, White
Galvanized
Galvalume

The two programs agreed that cooling is primarily affected by different roof types. Material type is much less important than the specific reflectance and emittance properties of the roof. Greater material reflectances impart some small increase in heating needs. All savings match within 1MBtu for cooling and heating. Thus, this can be considered a good level of agreement.

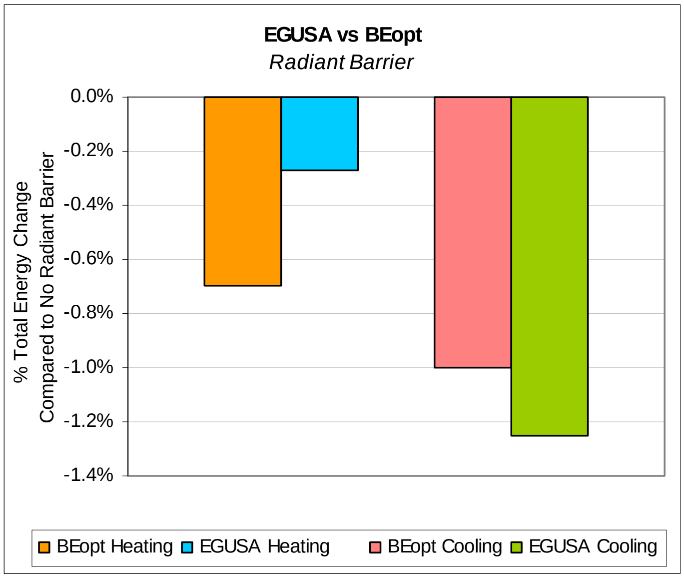


BEopt models higher energy savings for metal roofs and lower energy savings for tile roofs. *EGUSA* gives roof reflectance a greater influence on space cooling and to a lesser extent on space heating, likely due to interaction with the duct model. Differences are most likely the result

[3] *EGUSA* uses Huang's "fictitious insulation layers" method based on his earth contact model developed for the CEC along with Winkelmann's suggestions for floor modeling from *DOE2 User News.*

of the fact that the *EGUSA* model will show the interaction of roofing system with duct heat transfer due to changes in attic thermal conditions. *BEopt* does not have such a model.

Radiant Barrier



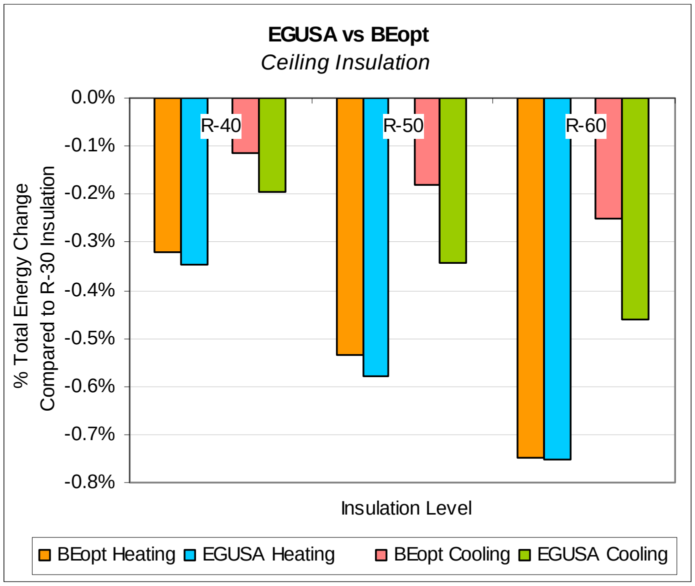
Comparing roofs with and without a radiant barrier

Both simulations show the main impact of a radiant barrier is to reduce space cooling: *EGUSA* shows slightly larger cooling savings (8% vs. 6% of cooling energy). Both simulations show a more minor impact on reducing space heating, although *BEopt* shows over twice the savings. A single story home with the same floor area would achieve higher percent savings.

Ceilings

Comparing the following ceiling insulation levels:

R-30 (Base)
R-40
R-50
R-60



Heating savings (therms) from improving ceiling insulation are virtually identical.

Cooling energy savings from improving ceiling insulation are about 40% lower for *BEopt* than *EGUSA*. This may result from differences in the attic models in the two programs. *EGUSA* uses a separate unconditioned zone model[4] for the attic whereas *BEopt* uses an unknown attic model. If the roof is modeled as a single assembly, it will result in significant differences in cooling dominated climates and as well as the impact of roofing reflectance.

[4] *EGUSA*'s attic model has been rigorously compared to monitored data and other detailed models in the following report: http://fsec.ucf.edu/en/publications/pdf/FSEC-CR-1526-05.pdf

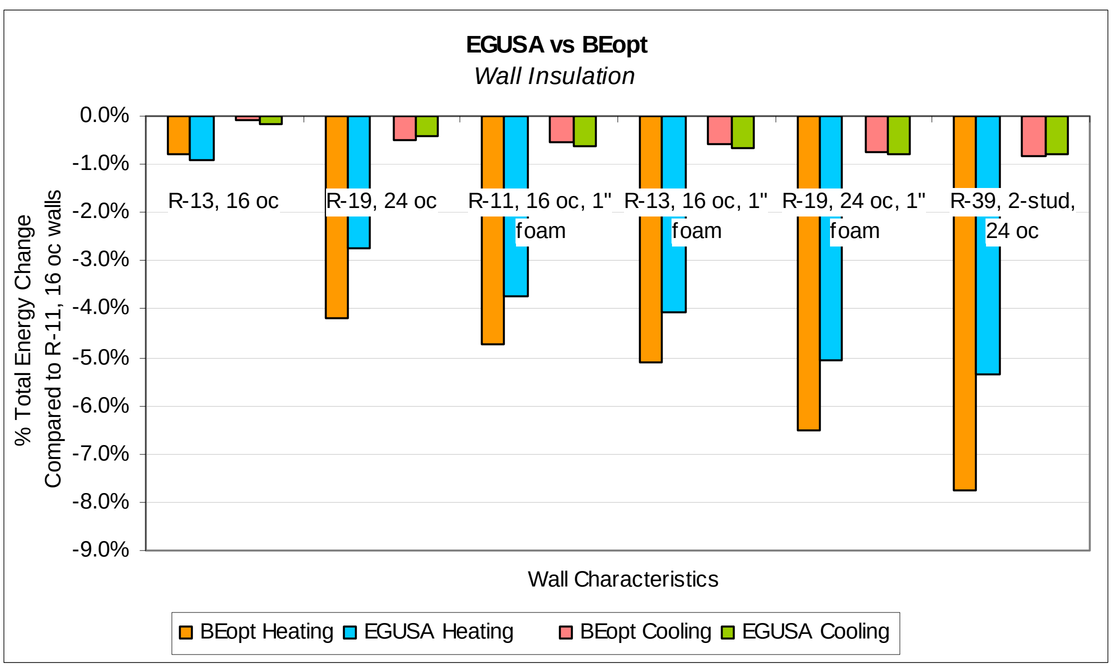
In addition, using the unmodified weather tape wind speed (10m height) for estimating the wind at roof height can easily understate solar impact on the attic relative to cooling.[5] The attic ventilation in *EGUSA* is predicted by a simple Sherman Grimsrud (S-G) model.

Walls

Comparing walls with the following characteristics:

R-11, 16 o.c. (Base)
R-13, 16 o.c.
R-19, 24 o.c.
R-11, 16 o.c., 1" foam sheathing
R-13, 16 o.c., 1" foam sheathing
R-19, 24 o.c., 1" foam sheathing
R-39, 2-stud framing, 24 o.c.

The two programs agree fairly well on the impact of added wall insulation on absolute energy use as well as the incremental cooling savings from adding wall insulation. However, *BEopt* indicates 44% greater heating savings compared to *EGUSA*. This discrepancy may be due to differences in how the wall sections are rendered in the appropriate input decks. However, those increments where the framing fraction (FF) is altered show a much larger impact in *BEopt* than in *EGUSA*. The same phenomenon is also seen in cooling, but to a lesser extent. *EGUSA* uses parallel path description of stud walls (insulation and wood parts equal to 1-FF and FF, respectively). This disparity has yet to be resolved.



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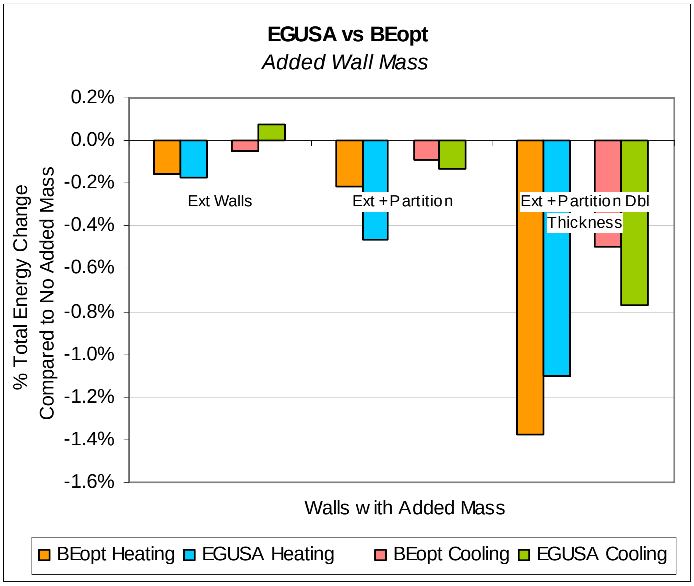
[5] See Figure 3 in the previously mentioned paper.

Interior Wall Mass

Houses with 5/8" sheetrock added on the following walls:

None (Base)
Exterior
Exterior and partition
Exterior and partition (double thickness on both)



Both calculations agree that added interior mass has a modest impact on building energy use. The specific area for the interior partition walls is not exactly known for *BEopt*, so the comparison is necessarily approximate. Both programs agree that adding mass will reduce space heating. *EGUSA* shows no cooling energy savings of adding 5/8" sheetrock to the exterior walls, but it does show improvements to performance when 5/8" sheetrock is used with both exterior and interior partition walls -- particularly in a two-story building with many interior walls. For the double thickness walls, both software indicate improvements although *BEopt* modeled greater heating and lower cooling savings.

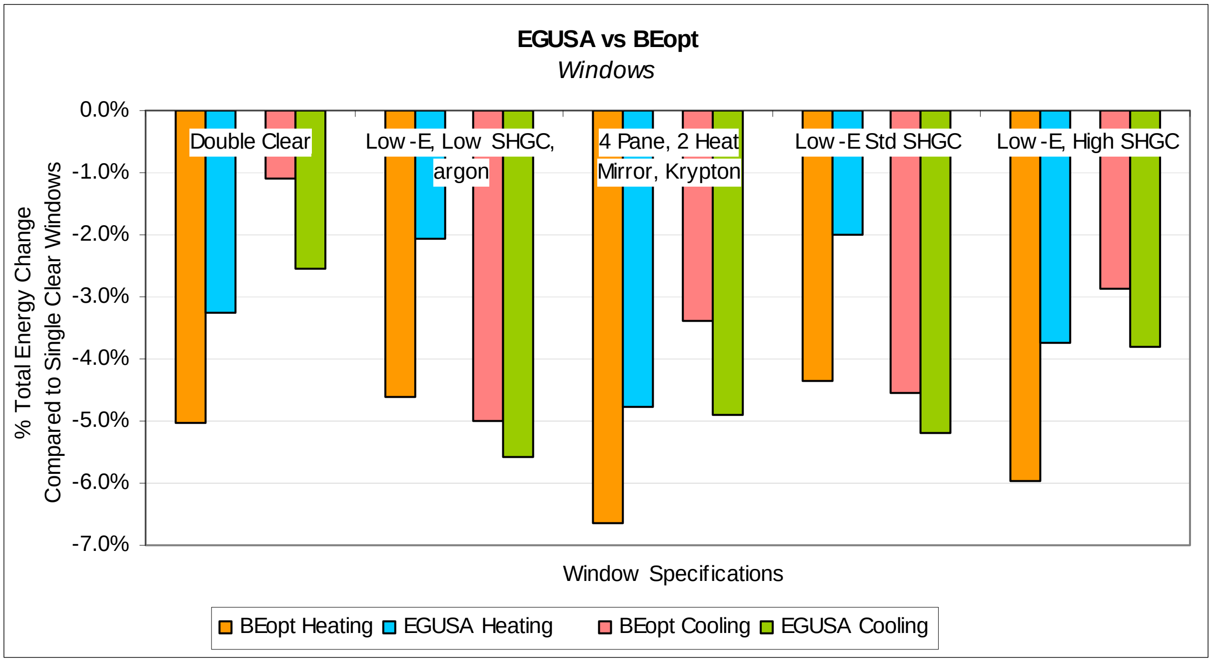
Windows

Comparing the following windows:

	u-value	*SHGC*
Single Clear	*0.87*	*0.79*
Double Clear	*0.447*	*0.547*
Low-E, Low SHGC, argon	*0.285*	*0.266*
4 pane, 2 heat mirror, krypton	*0.196*	*0.324*
Low-E, Standard SHGC	*0.318*	*0.302*
Low-E, High SHGC	*0.318*	*0.425*

This window comparison showed the two programs in close agreement on cooling savings due to window upgrades, but also showed a very large discrepancy in heating savings. *BEopt* models 1.5 to 2.5 times the heating savings of *EGUSA* for windows U-factor improvement. Since the differences on savings are often 50 therms or more, the impacts are large.

BEopt models lower cooling savings than *EGUSA* in double clear windows, low-e high SHGC windows, and the 4-pane, 2 heat mirror, krypton windows.



One possible reason for the large difference in heating savings may result from different assumptions about baseline U-values for the overall window unit. *BEopt* uses the *Legacy window library* in its analysis[6] while *EGUSA* uses ASHRAE literature.[7] The Legacy library only shows center of glass U-values which agrees closely with ASHRAE. Thus, the disagreement may be with the window frames or else how the *BEopt* U-factors are calculated that are shown.

BEopt and *EGUSA* assume the following default u-values for single clear and double clear windows:

Baseline U-value Comparison

	Single	Double
BEopt	0.87	0.447
EGUSA	0.94	0.565

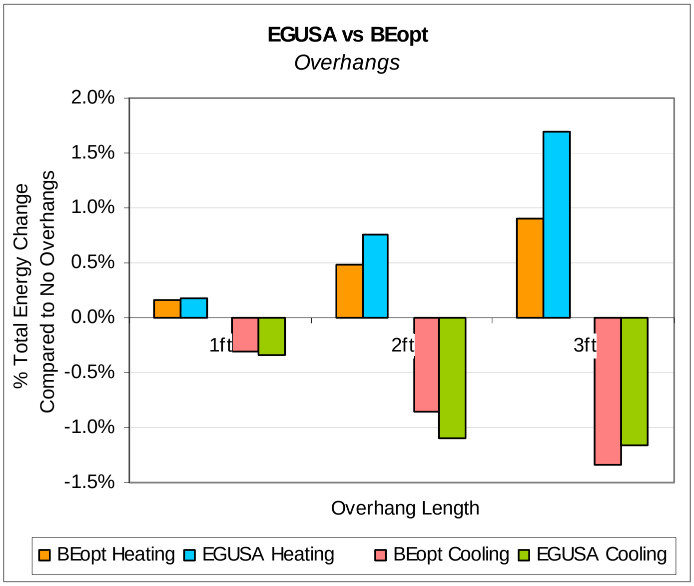
The U-factor for single glazed units is moderately higher, but there is a very large difference in the value for the standard double glazed clear window. After correcting the *EGUSA* u-value which assumes ¼" air space to reflect a ½" air space, the u-value for these selections are 0.53 and 0.50, for operable and fixed assemblies-- still considerably higher than what *BEopt* calls for at 0.447. In addition to differences in baseline u-value calculations, the calculation of the windows themselves are likely important to the difference. The large disparity on heating, however, suggests that the difference lies within windows conductance assumptions rather than

[6] The library descriptions can be found pages 20-26 of DOE2 Volume 4: Libraries & Reports: http://www.doe2.com/download/DOE-22/DOE22Vol4-Libraries.pdf

[7] From *2005 ASHRAE Handbook of Fundamentals*, p. 31.8 and 31.9., Table 4.

solar incidence angle modifiers or other such modeling differences. This large disparity between the two software should be further evaluated.

Overhangs



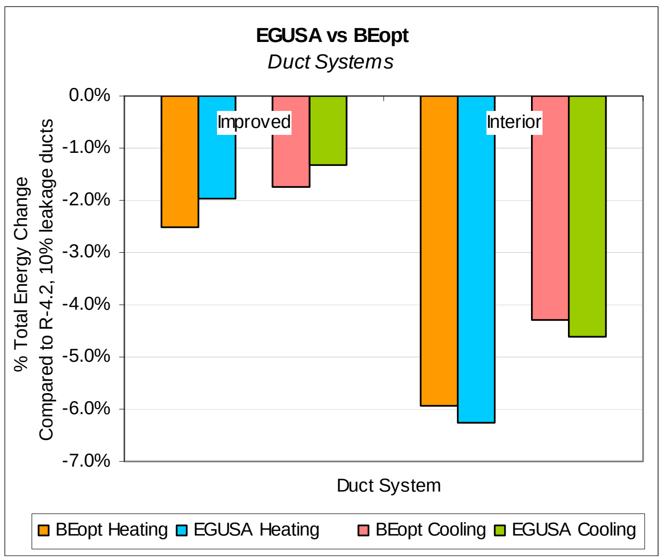
Comparing overhang lengths of:
0ft (Base), 1ft, 2ft, 3ft

Both *EGUSA* and *BEopt* agree that adding overhangs reduces cooling and increases heating. Increases in heating tend to be larger than decreases in cooling in this Atlanta house. Savings are nearly identical for 1ft overhang, but *BEopt* models 30% and 40% lower heating savings for 2ft and 3ft overhangs.

In this case, source energy savings are only achieved because of the energy used to produce electricity vs. natural gas. If the home was a heat pump, the eaves wouldn't save much. However, overhangs have a large impact on localized overheating in summer and glare.

Ducts

Comparing the following duct systems:
10% leakage fraction, R-4.2 (Base)
"Improved" 5.5% leakage fraction, R-8
"Interior" (No leakage, no duct heat transfer)



Modeling ducts systems well is important in Building America, since this option is typically a large influence both on heating and cooling. It is also a very popular option with builders. Fortunately, *EGUSA* and *BEopt* provide similar results for different duct systems.

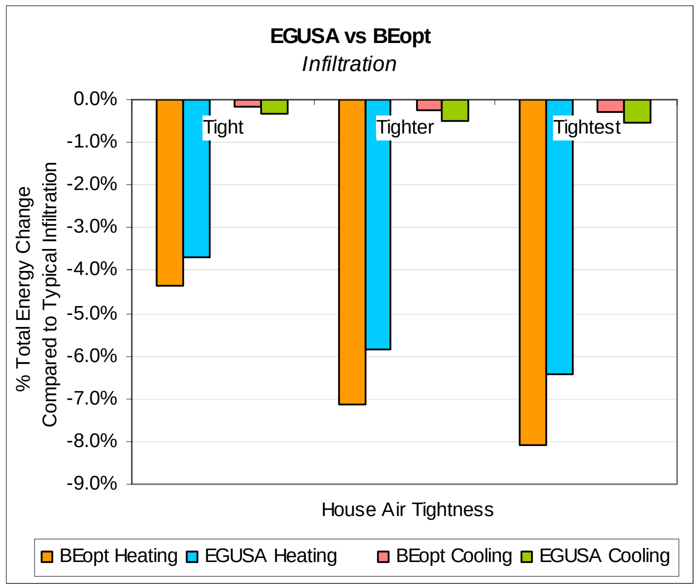
Duct system modeling in *EGUSA* is considerably more complex, requiring input on the specific location of the ducts (attic, crawlspace, garage, exterior) and air handler, the duct areas and leakages, and leak locations. For *EGUSA*, the ducts were assumed to be in the attic (with the exception of the interior ducts).

The overall comparison was very favorable; through an oversight the *EGUSA* base building had a very tight duct system. This was altered (changing the base) so that the typical duct had 10% fractional leakage with R-4.2 ducts. Generally, the change brought the cooling loads closer together but made the heating loads for *EGUSA* somewhat greater than before.

Savings for the improved and interior ducts were very similar both for heating and cooling. This was particularly surprising given likely differences in the way the models were being handled.

EGUSA showed interior ducts to save slightly more than did *BEopt*, although *BEopt* showed somewhat better savings from the "improved" case. *EGUSA* showed greater fan energy savings from interior duct systems due to reduce cooling system run-time.

Infiltration



Comparing the following infiltration levels:

0.00050 SLA (Base)
0.00030 SLA
0.00015 SLA
0.00008 SLA

A comparison of infiltration shows moderate differences between *BEopt* and *EGUSA*. On average, *BEopt* shows about 30% higher heating savings. Because increasing air tightness impacts heating energy so much, a 30% difference results in large differences. Though absolute values are small, *EGUSA* models twice the cooling savings as *BEopt*.

The biggest disparity in source energy savings comes from the fan power. Differences in the software are expected because *EGUSA* has infiltration interactions with duct leakage and mechanical ventilation through the addition of flows in quadrature. Further examination of the models could be done with duct leakage eliminated in the *EGUSA* model and mechanical ventilation eliminated in both models.

Fan Power for Heating and Cooling System

BEopt and EGUSA have very different assumptions about fan power for the indoor blower for the heating and cooling system.

There are also large disparities in fan power, particularly for heating. This immediately calls into question the comparative flow rates for the heating and cooling systems and the power required to produce that flow.

BEopt models 25% greater heating fan energy on average, while heating energy is modeled only 2% greater. Cooling fan energy is modeled 18% lower in *BEopt*, but cooling energy is 14% higher.

When the heating system is operating, *BEopt* assumes the blower is using about twice the fan energy that *EGUSA* assumes and this plays into the savings-- particularly for source energy savings since the fan electricity saved has a large impact.

EGUSA assumes 0.5 $^{W}/_{cfm}$ up to SEER 13. For SEER 14 and above, *EGUSA* assumes 0.375 $^{W}/_{cfm}$ regardless of SEER. Available data would tend to better support the baseline fan energy numbers in *EGUSA*[8] An immediate suggestion is to reduce the Benchmark fan power assumption in *BEopt* to *EGUSA*'s levels. Sizing may also influence the fan energy. In *EGUSA*, the blower used is based on the cooling system size if there is a cooling system, because in general, the flow rates for cooling systems are higher than the flow rates of furnaces with the same capacity.

Another reason for the discrepancy might be differences in sizing assumptions between the software: the heating capacity is much higher in *BEopt*.

	Benchmark		Prototype	
	Heating	Cooling	Heating	Cooling
EGUSA	43.8	39.3	36.8	39
BEopt	70	42	70	42

Air Conditioner Efficiency

Comparing the following air conditioning efficiencies:

SEER 13 (Base), 14, 15, 16, 17, 18

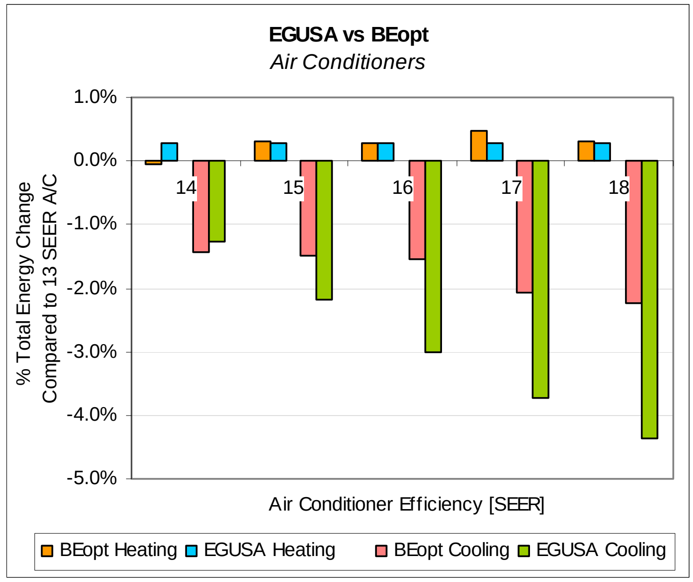
This comparison shows some differences in the impact of changing Seasonal Energy Efficiency Ratio (SEER) ratings. Likely the difference are the result of the differing calculation engines in DOE-2.1E vs. DOE 2.2.

Both simulations agree that increases to an air conditioner's SEER reduce cooling energy significantly. *EGUSA* generally shows larger reductions from more efficient equipment. Although *EGUSA* models greater cooling reduction, overall cooling difference is mitigated because of greater fan energy use. While *BEopt* assumes that fan power changes with SEER itself, *EGUSA* assumes the same fan energies for ranges of SEERs. *EGUSA* assumes that a permanent split capacitor (PSC) motor is used for the air handler up to SEER 13. For SEER 14+

[8] *EGUSA* estimates of fan power have been verified to be approximately correct given measurements made in the lab and field. Proctor, J and D Parker (2001). "Hidden Power Drains: Trends in Residential Heating and Cooling Fan Watt Power Demand," FSEC-PF361-01, Florida Solar Energy Center, Cocoa, Florida. http://fsec.ucf.edu/en/publications/html/FSEC-PF-361-01/index.htm

air conditioners, *EGUSA* assumes an electronically commutated motor (ECM) that uses the same power regardless of SEER.

Differences between the software are largest for the highest SEER equipment (e.g. for SEER 16+, *BEopt* models half the cooling savings). The simulations agree well enough to adequately characterize cooling energy savings for more efficient equipment.



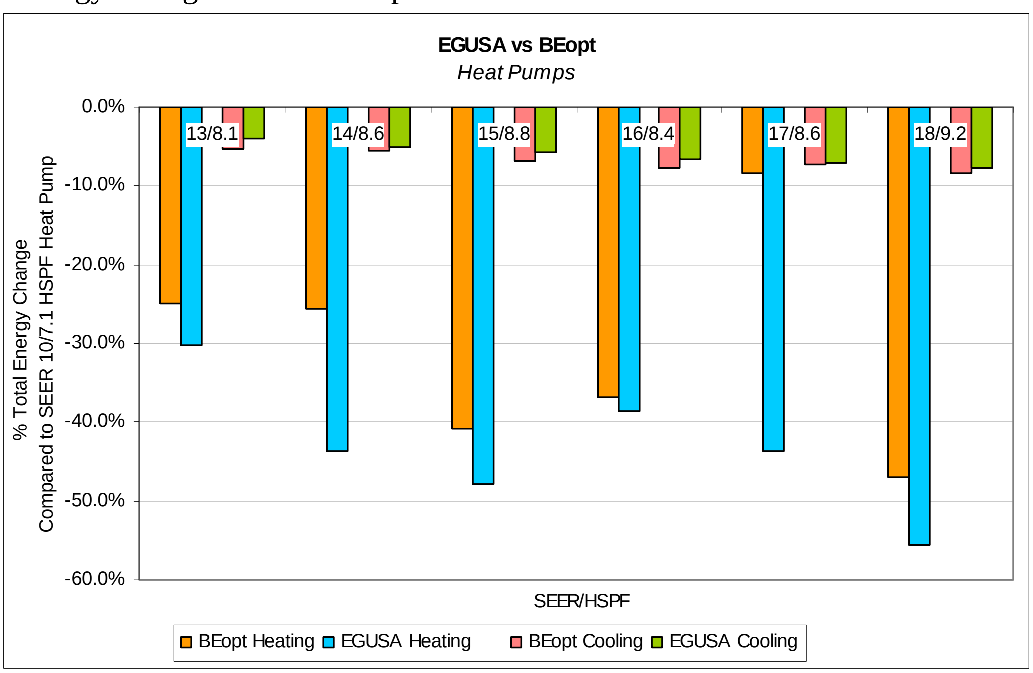
Heat Pumps

Comparing the following heat pumps:

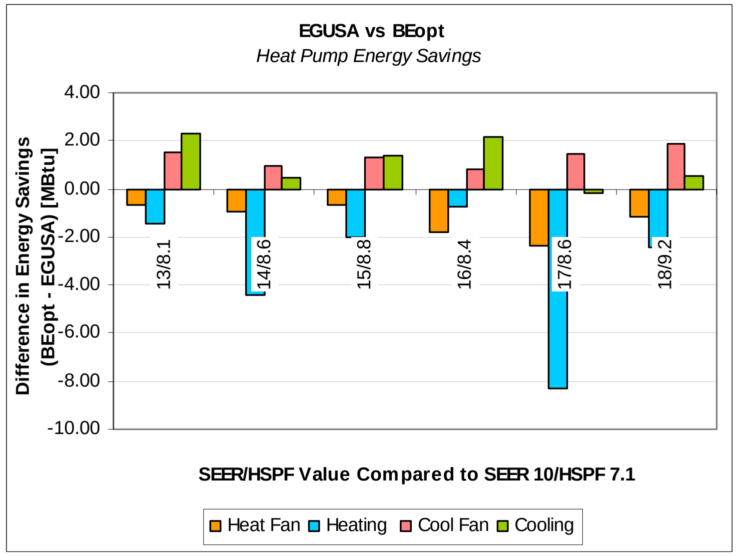
13 SEER/8.1 HSPF
14 SEER/8.6 HSPF
15 SEER/8.8 HSPF
16 SEER/8.4 HSPF
17 SEER/8.6 HSPF
18 SEER/9.2 HSPF

Compared to a base house with 10 SEER/7.1 HSPF heat pump.

This comparison showed a good correspondence on the relative impact of improving HSPF and SEER on energy savings from the compressor.



BEopt calculates greater savings in fan power on more efficient two speed equipment, particularly heating fan energy. These fan energy differences are especially large, on the order of 1MBtu differences.



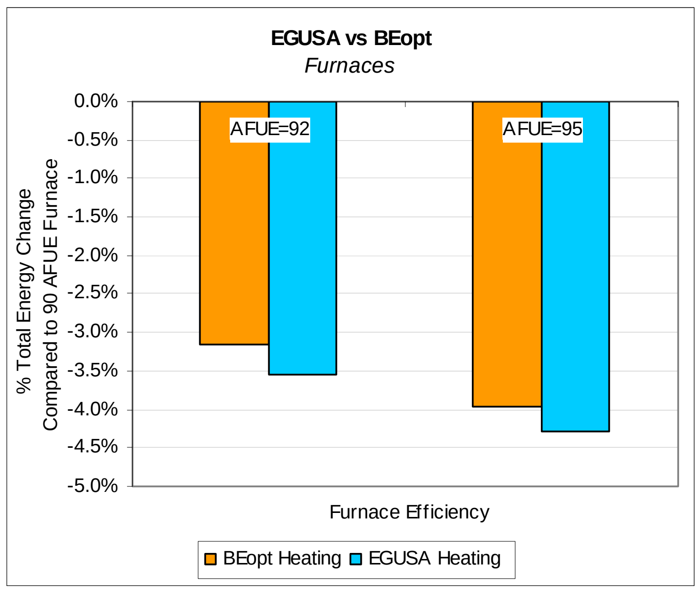
Heating savings differ greatly (0.75-8.3 MBtu difference, and up to 7% difference in total energy change) with no obvious trend. Although savings in this comparison is particularly large because the base case is very inefficient, these differences are still significant.

Natural Gas Furnaces

Comparing the following natural gas furnace efficiencies:

0.80 (Base)
0.92
0.95

This comparison shows very close agreement in the software on absolute energy use and energy savings. No change is seen to fan or cooling loads. The slightly higher fan power energy assumption within *BEopt* continues to be in evidence, but this exercise showed excellent agreement.

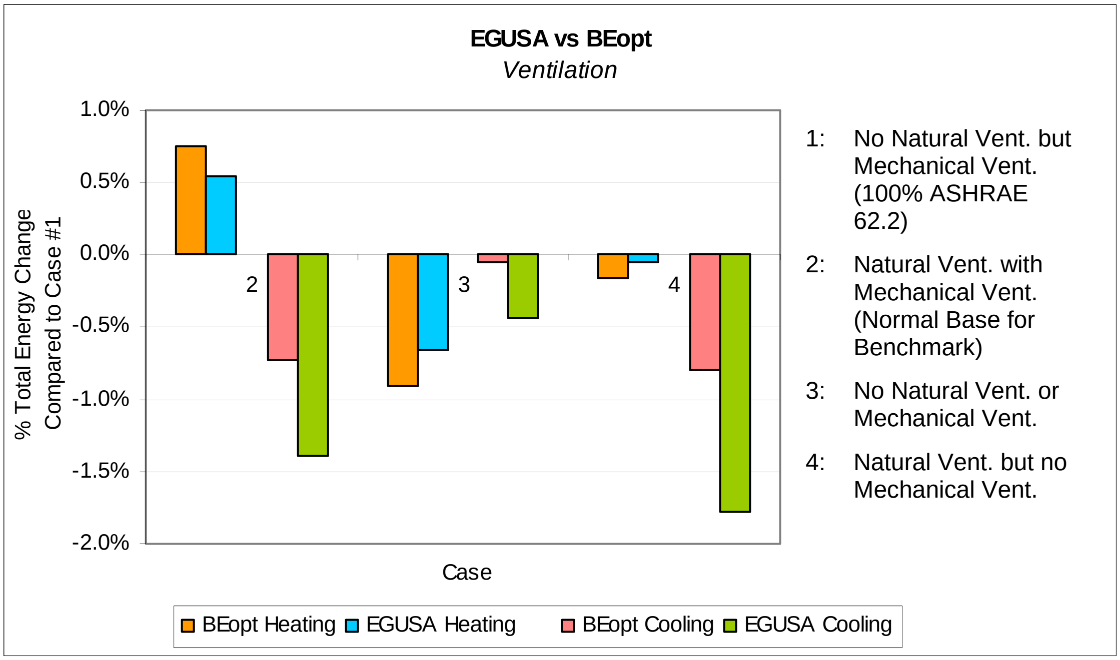


Ventilation

Comparing the following ventilation levels:

No natural ventilation, but mechanical ventilation (100% ASHRAE 62-2 ventilation) (Base)
Natural ventilation with mechanical ventilation (the normal mode)
No natural or mechanical ventilation
Natural ventilation, but no mechanical ventilation (majority of existing U.S. homes)

Both simulations showed the same trends, but the impact of natural and mechanical ventilation differed significantly between the two programs, particularly in cooling.



Both software do not readily perform benchmark calculations on homes with no mechanical or natural ventilation, so annual energy simulations were used for case #3.

Both simulations showed that added mechanical ventilation increases space heating. They show that natural ventilation greatly reduces air conditioning needs—although *EGUSA* shows a much larger impact on cooling[9]--and slightly increases heating when stored heat energy in the building is sometimes lost.

The simulations closely agree on the required fan power for the simulated case: 153 kWh in *BEopt* and 122 - 144 kWh in *EGUSA*.

Cooling Thermostat

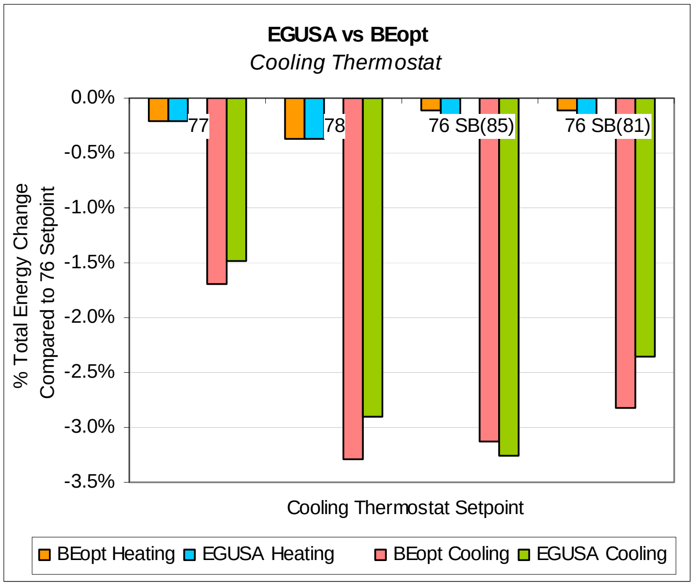
Comparing the following cooling thermostat setpoints:

76 F (Base)
77 F
78 F
76 F with M-F daytime setback to 85 F
76 F with M-F daytime setback to 81 F

For changes to cooling thermostat set points, absolute savings and percentage savings are generally very close. Both software show higher thermostat settings dropping cooling loads substantially--on the order of 10% per degree F -- and very mildly depressing space heating.

[9] *EGUSA* assumes 25% of the window as openable and then triggers this open and then simulates the building hourly ventilation rate using the Sherman-Grimsrud algorithm. Windows are opened or closed based on the running four day average of temperatures. The window "state" is not altered between midnight and 7 AM.

Florida Power and Light, a large Florida utility, did a number of end use studies that settled on 10% savings per degree F as well. Both simulations show a high weekday setback between 9 AM and 5 PM is quite effective; resulting in a 15% drop in cooling.

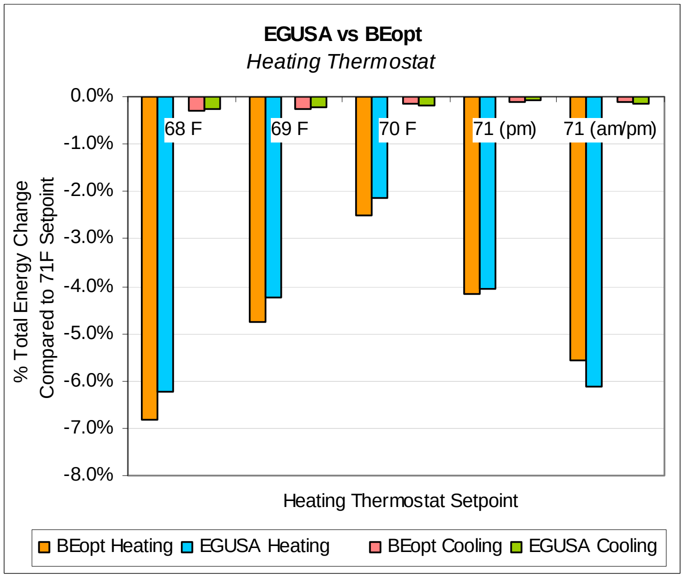


The key issue for Building America is a programmatic and behavioral one. Programmable thermostats don't help users obtain a setback; in fact manual thermostats are more likely to be setback. Home automation related thermostat technologies such as *Ecobee* may provide a more viable option for thermostat setbacks.

Heating Thermostat

Comparing the following heating thermostat setpoints:

71 F (Base)
68 F
69 F
70 F
71 with nighttime setback to 65
71 with M-F daytime setback and nighttime setback to 65



The simulations agree very well on the effects of changing the heating setpoint, although *BEopt* models 10%-15% higher heating savings. Both software show that lower thermostat settings drop heating loads substantially—on the order of 8-9% per degree F in Atlanta—and mildly depress space cooling. *BEopt* and *EGUSA* agree that an 11pm-6am setback to 65 F is quite effective, resulting in a 15% drop in heating. Adding a daytime weekday setback increased the space heating savings to about 20%.

Water Heating

Comparing the following water heaters:

Natural Gas

EF= 0.59 (Base)

EF= 0.62 (Improved)

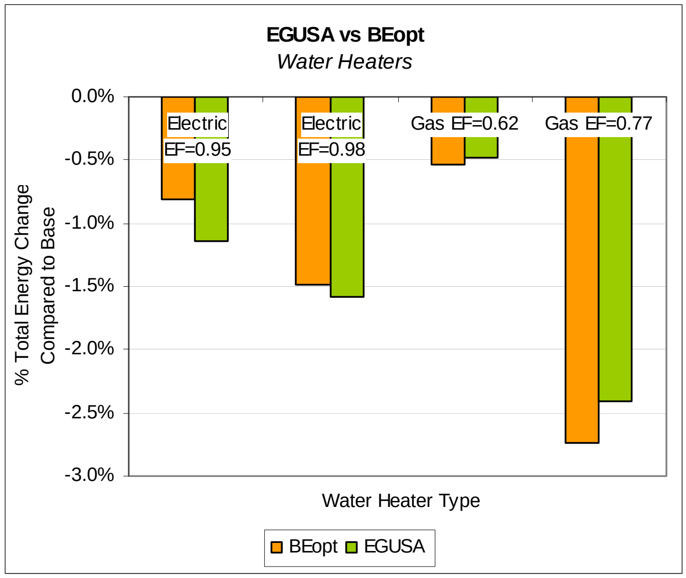
EF= 0.77 (Tankless)

Electric

EF= 0.90 (Base)

EF= 0.95 (Improved)

EF= 0.98 (Tankless)



Both simulations predict similar numbers for the magnitude of water heating energy and energy savings from more efficient units for both natural gas and electric. On average, *BEopt* models slightly more savings for gas water heaters. However, results are very close.

Solar Water Heating

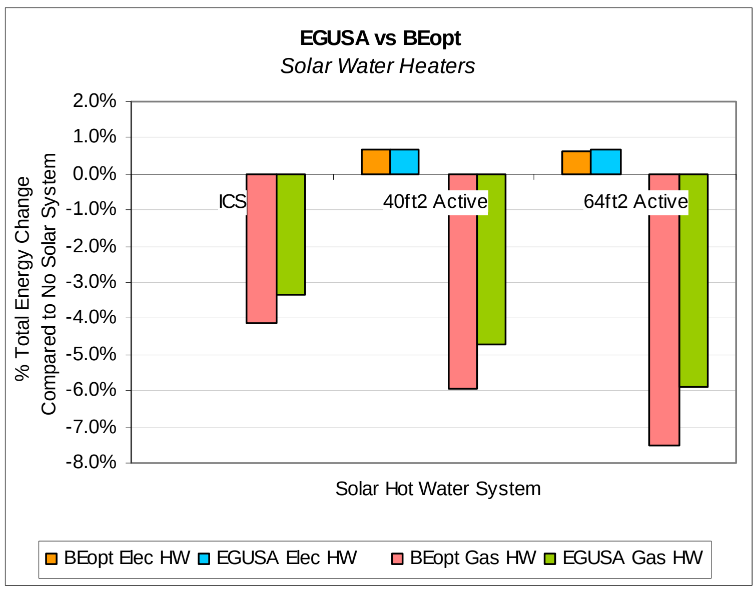
Comparing the following solar water heating systems:

None; gas water heater EF=0.59 (Base)

Integrated Collector Storage

40 sq ft active system

64 ft2 active system



Solar water heating savings shows fair agreement between *BEopt* and *EGUSA*.

Since the default system parameters for solar water heating in *BEopt* were unknown, the assumed systems in *EGUSA* will be somewhat different. Storage consisted of the conventional gas tank for the ICS system, a separate 80 gallon tank for the 40 sq ft system and a separate 120 gallon tank for the 64 gallon system. The system was closed loop with glycol, a 40 W circulation pump and a HX effectiveness of 90%.

The simulations estimated similar savings, with *BEopt* estimating about 25% greater savings for each system. *EGUSA* does assume some plumbing heat losses in two tank natural gas systems which form the NREL base case. Performance with a tankless auxiliary would look much better in *EGUSA* than these results.[10]

Both simulations agreed closely on the magnitude of the base water heating in Atlanta. It is noteworthy that *EGUSA* does not allow the ICS system to operate in any month where the temperature drops below 25 F. Agreement on pump energy is quite good as well.

Gas DHW Savings

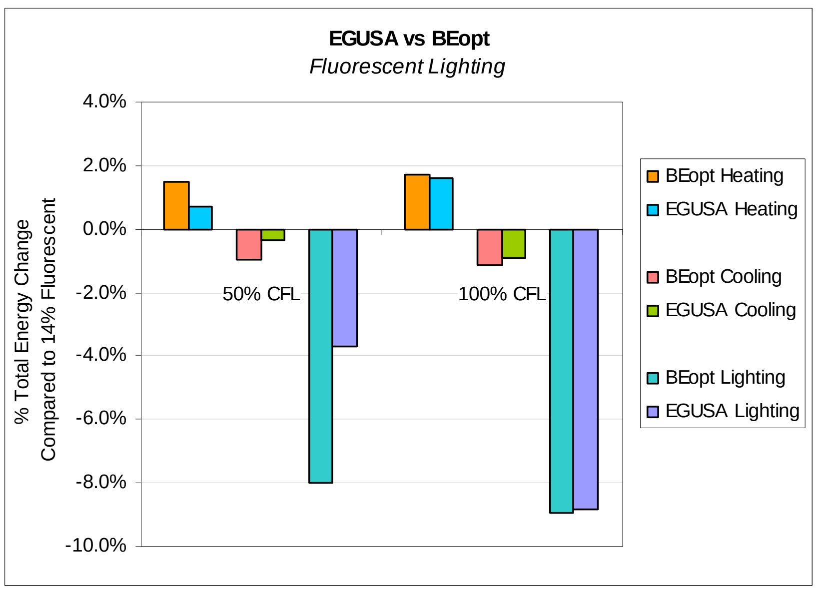
	BEopt	*EGUSA*
ICS	42%	35%
40ft2 Active	61%	50%
64ft2 Active	77%	63%

BEopt should be considered the more accurate calculation given that it uses TRNSYS itself as the hot water engine. *EGUSA* uses an hourly adaptation of F-Chart which was correlated against hourly runs using TRNSYS in several different climates. However, this analysis suggests very close agreement.

Lighting

Houses with the following fluorescent lighting:

14% fluorescent (Base)
50% fluorescent
100% fluorescent



A comparison of lighting raised several conflicts between the two programs.

Both software show fluorescent lighting has a powerful impact on the annual lighting budget. *BEopt* shows a much larger impact with 50% fluorescent fixtures because that software specifically assumes that the fluorescent lamps are first installed in the most used fixtures. *EGUSA* makes no such assumption.

This comparison was a drawn out process, because a problem arose in *EGUSA*'s method of handling lighting. Unlike *BEopt*, *EGUSA* does not allow the user to convert plug in, garage and outdoor lighting to fluorescent. That meant that in *BEopt* the amount of lighting available to be

[10] Savings with a 40 sq ft solar system goes from 50% to 74% savings with tankless gas as the auxiliary.

converted to fluorescent was about 1.5 times greater than *EGUSA*. This discrepancy, however, has been corrected for the next release. The change will have a significant impact on the percent savings relative to the BA Benchmark for homes with 100% fluorescent fixtures when analyzed using *EGUSA*. After corrections were made in *EGUSA*, the simulations agreed closely on the savings from 100% fluorescent lighting.

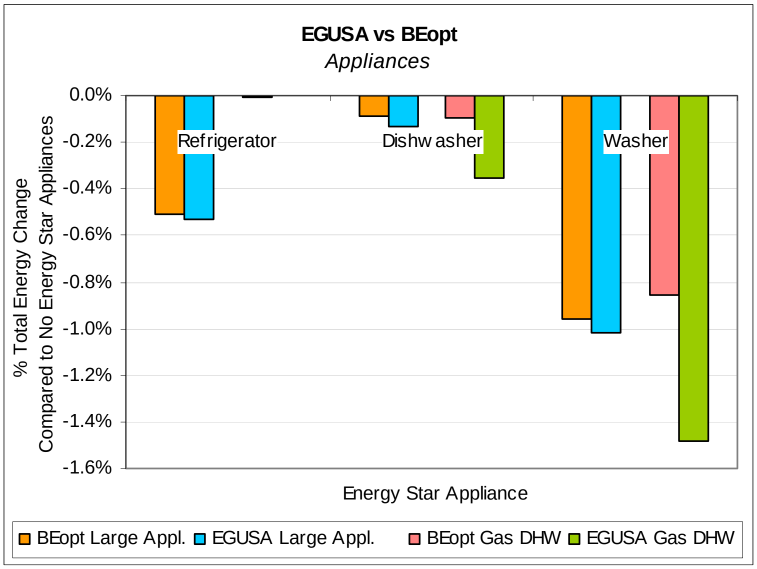
The software agree on the secondary impacts on heating and cooling. *EGUSA* shows slightly lower interactions with cooling since its ability to abate internal heat with natural ventilation is greater than *BEopt*.

Beyond the comparison are a couple of observations regarding deviation between HERS and BA on lighting.

1. The current HERS rules assume that only 80% of the potential savings from fluorescents can be achieved. The unstated reasons are that fixtures may be changed back to incandescent or cannot be converted in the first place. In any case, this means that the savings available in BA from better lighting are 25% greater than in HERS.

2. The level of absolute lighting in HERS is less than BA because, the HERS procedures currently do not include outdoor and/or garage lighting which is 350 kWh in the Benchmark.

Appliances



Houses with the following appliances:

Standard appliances (Base)
Energy Star refrigerator
Energy Star dishwasher
Energy Star clothes washer

In this comparison, Energy Star appliances were added to the base home. The appliance energy differed little between the two programs, but *EGUSA* modeled greater hot water energy savings from the dishwasher and the clothes washer.

Refrigerator

Savings from refrigerators are identical, at 99kWh saved for each. Both simulations show that similar slight reductions in internal gains from the better refrigerator results increased heating and decreased cooling energy.

The slight differences in cooling savings (14kWh in *BEopt*; 9kWh in *EGUSA*) from the lower internal gains likely reflect the fact that natural ventilation in *EGUSA* is more effective at avoiding cooling loads that otherwise require air conditioning.

Dishwasher

Without knowing the specific characteristics of the *BEopt* Energy Star dishwasher, a typical domestic model[11] with an EF of 0.68 (minimum dishwasher EF is 0.65) was chosen for *EGUSA*. Within uncertainty about the specific machine characteristics, the software provide indistinguishable results.

Both simulations agree that machine power is only slightly lower for a typical Energy Star dishwasher. Most of the energy savings results from reducing the water heating load. *BEopt*'s dishwasher reduces the annual hot water energy load by 2 therms; the Whirlpool model simulated in *EGUSA* reduces it by 6 therms. The biggest problem present with dishwashers is not in simulation, but in not having all the necessary information for dishwashers in one place for proper simulation.

Clothes Washer

This comparison was also complicated by difficulties in finding comparable dishwasher specifications for the two programs.

The *BEopt* simulation used the Energy Star Clothes Washer option in *BEopt*, while the *EGUSA* simulation used the *default minimum Energy Star Clothes Washer*[12]. The *EGUSA* washer barely complies with the Energy Star requirement. This (or some other similar model) should be made the new default Energy Star clothes washer for BA and *BEopt*.

Once this was done, the simulations produced virtually identical washer electricity use savings and agreed that the main savings are from less hot water use. *BEopt* estimated ~40% less hot water savings than *EGUSA*. Both software estimate electricity use of the clothes washer correctly and appear to properly estimate changes to hot water demand.

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[11] The dishwasher is a GU2275XTV** model dishwasher with the following Building America Inputs:

Efficiency:	0.68	Gas Cost:	$27	Test Year:	2008
Electric Cost:	$34	Gas Rate:	$1.218	Place Settings:	8
Electric Rate:	$0.1065	kWh/yr:	320	Water Use:	5.1 gal/cycle

[12] No clothes washer comparable to the one specified in *BEopt* could be found, so the *EGUSA* simulation used a minimum default energy star washer (GE WJR 5550H).

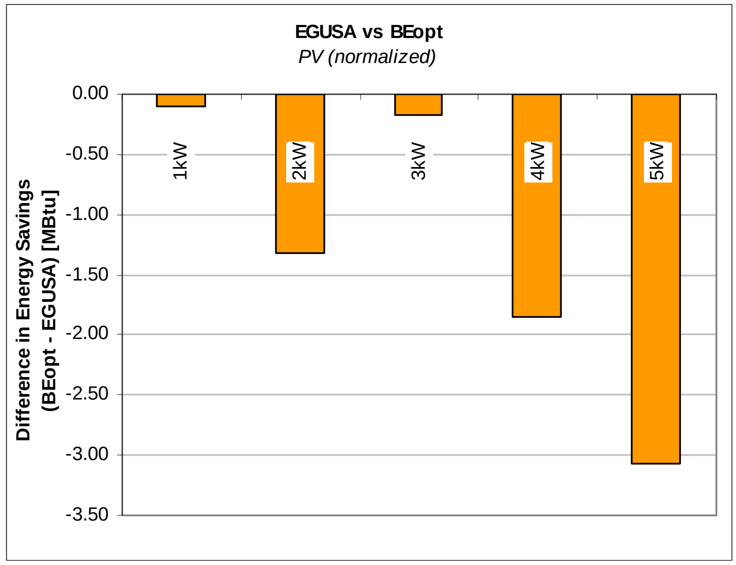
Efficiency:	1.78	Gas Cost:	$14	Test Year:	2006
Electric Cost:	$24.16	Gas Rate:	$0.91	Drum Volume:	3.5
Electric Rate:	$0.086	kWh/yr:	281	Water Use:	7.9 gal/cycle

Solar Electricity (Photovoltaics)

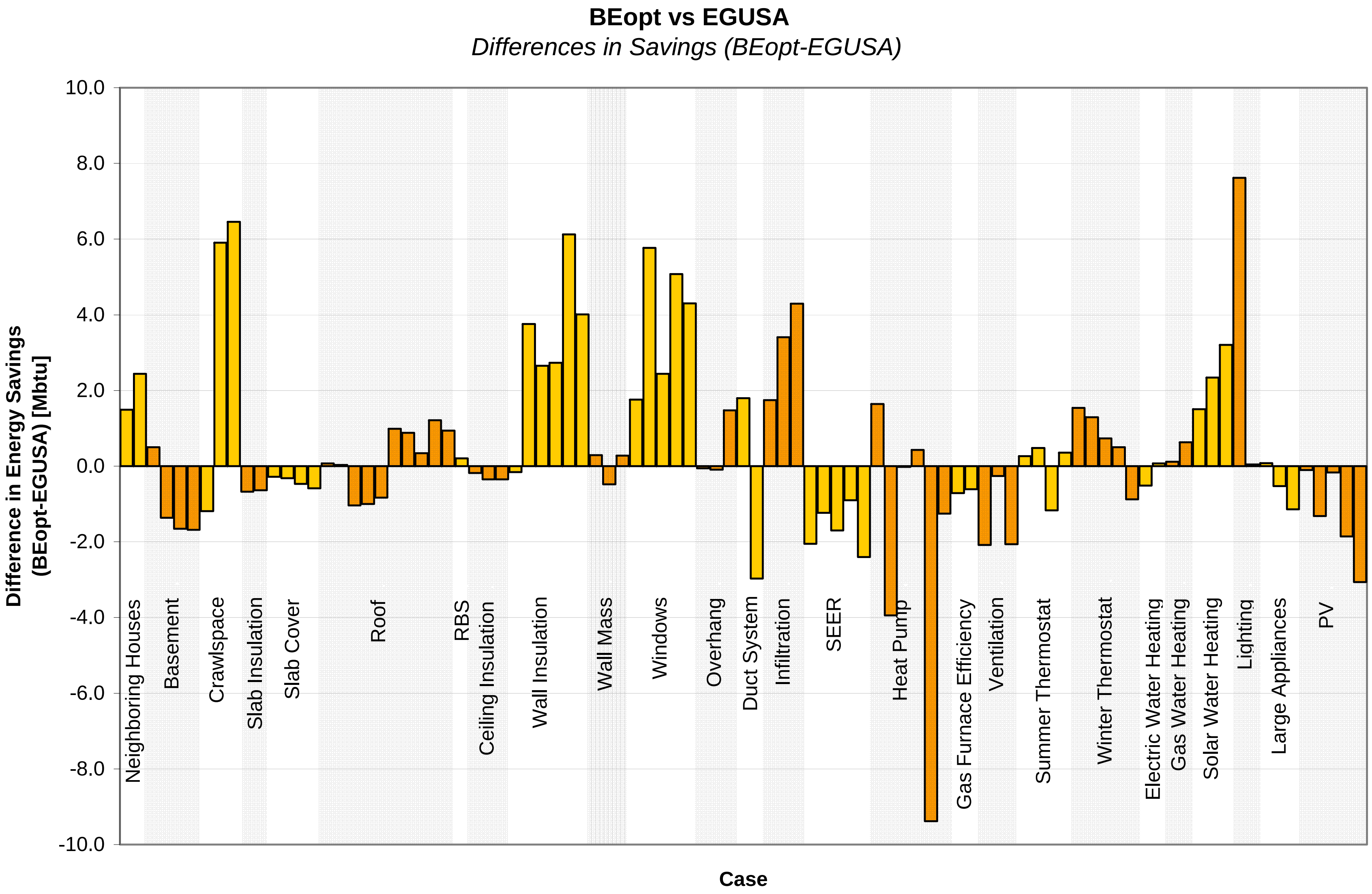
Houses with the following PV systems:

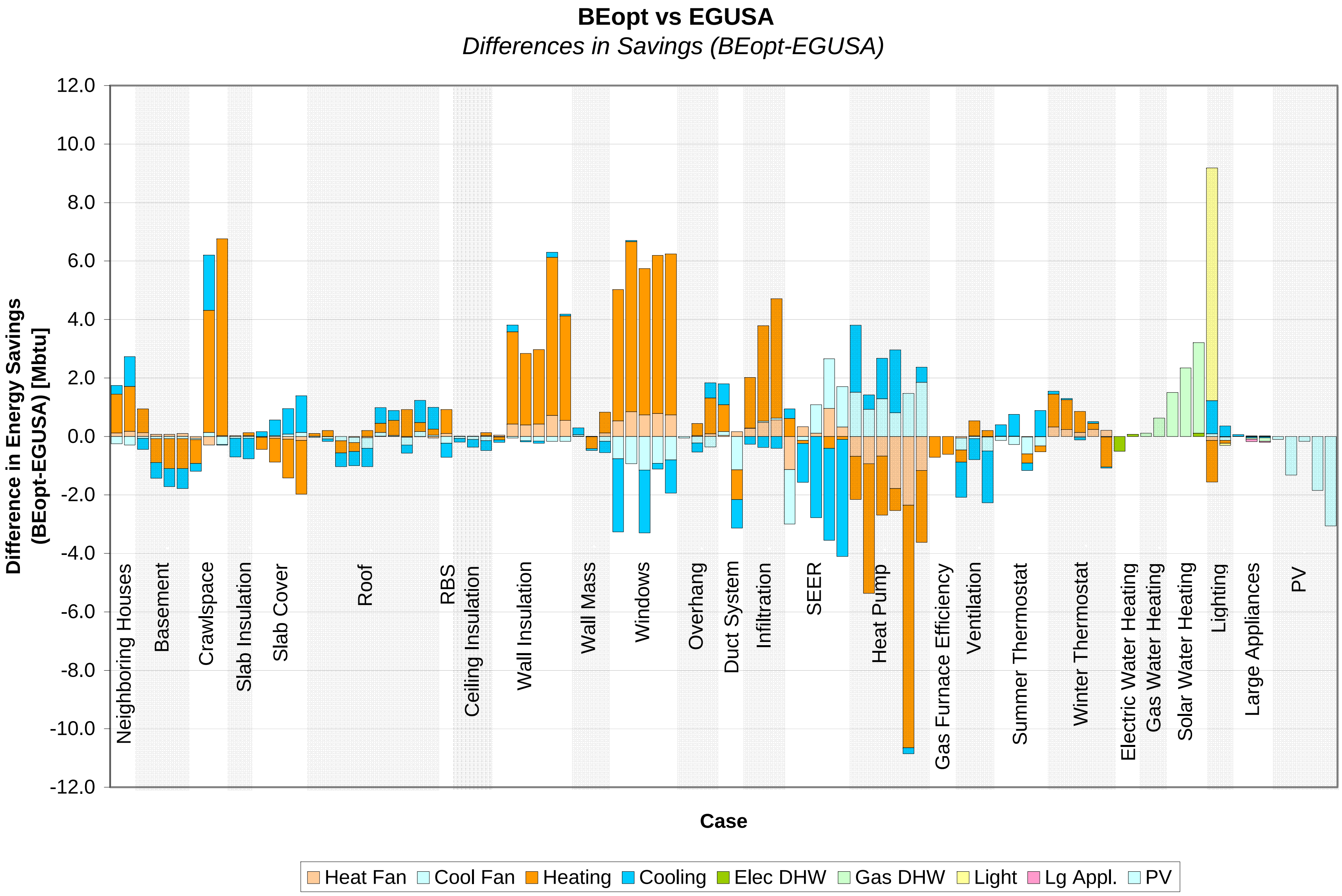
None
1kW
2kW
3kW
4kW
5kW

EGUSA and *BEopt* agree closely on PV system performance. *EGUSA* uses Sandia National Lab's PVFORM simulation of PV system performance; *BEopt* uses TRNSYS. A real system was assumed for *EGUSA*: Evergreen ES-190 modules (NOCT= 45.6 C; temperature degradation coefficient= 0.0049), a 93% efficient grid tied inverter, 3.5% line and mismatch losses.



Initially the two simulations do not appear close because *EGUSA* adds modules to reach the installed wattage and often goes a bit over (as actually happens in real systems). For instance the 1 kW system modeled in *EGUSA* was actually 1140 Watts (6 modules). After normalizing for this difference, both savings and absolute PV output are within 4% of each other. Both predict that system electrical energy to the grid produced is linear with system size and that matching inverter size to PV system size is important.


BEopt vs EGUSA
Differences in Savings (BEopt-EGUSA)
Difference in Energy Savings (BEopt-EGUSA) [Mbtu]
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Neighboring Houses
Basement
Crawlspace
Slab Insulation
Slab Cover
Roof
RBS
Ceiling Insulation
Wall Insulation
Wall Mass
Windows
Overhang
Duct System
Infiltration
SEER
Heat Pump
Gas Furnace Efficiency
Ventilation
Summer Thermostat
Winter Thermostat
Electric Water Heating
Gas Water Heating
Solar Water Heating
Lighting
Large Appliances
PV
Case


BEopt vs EGUSA
Differences in Savings (BEopt-EGUSA)
Difference in Energy Savings (BEopt-EGUSA) [Mbtu]
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
Neighboring Houses
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Summer Thermostat
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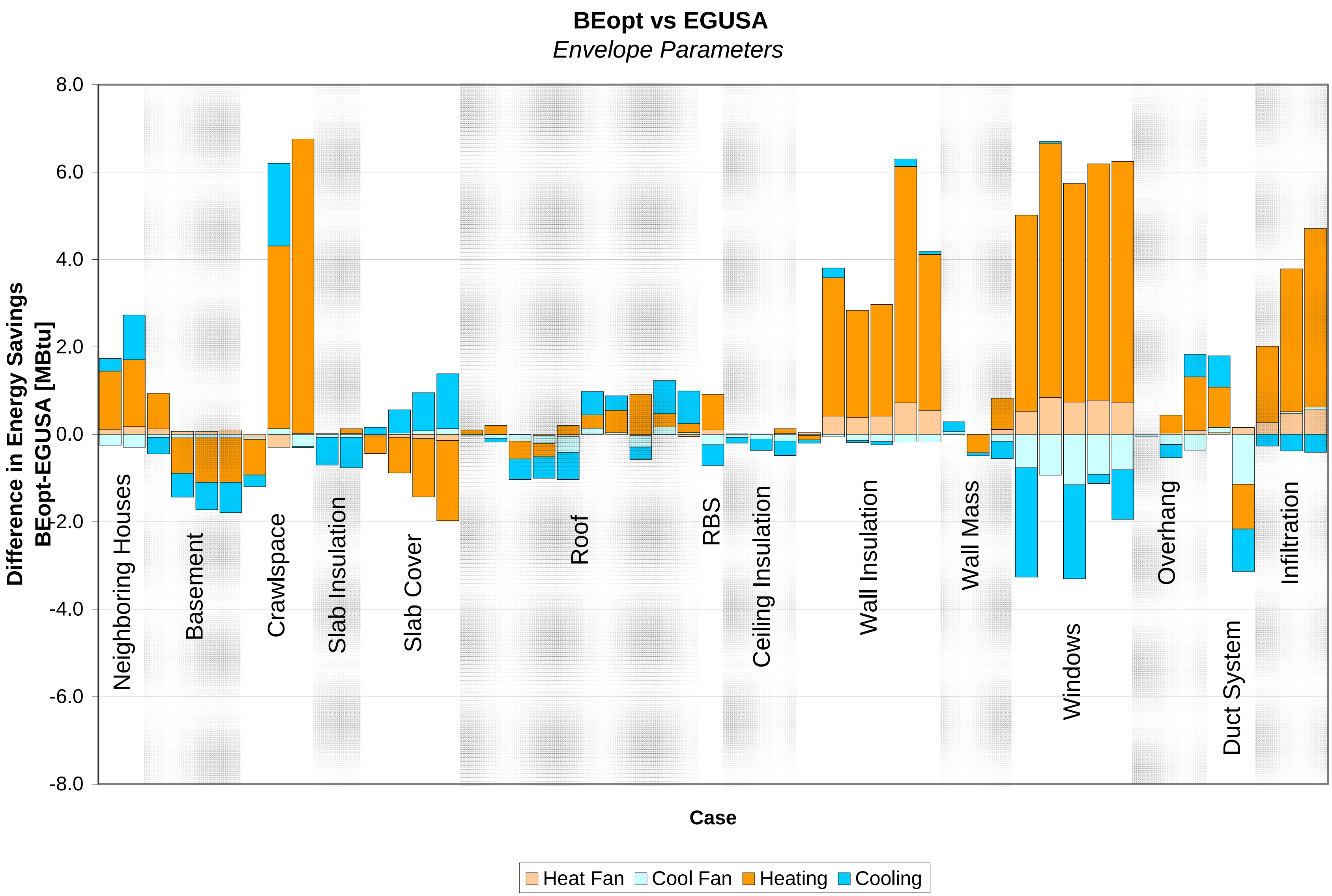
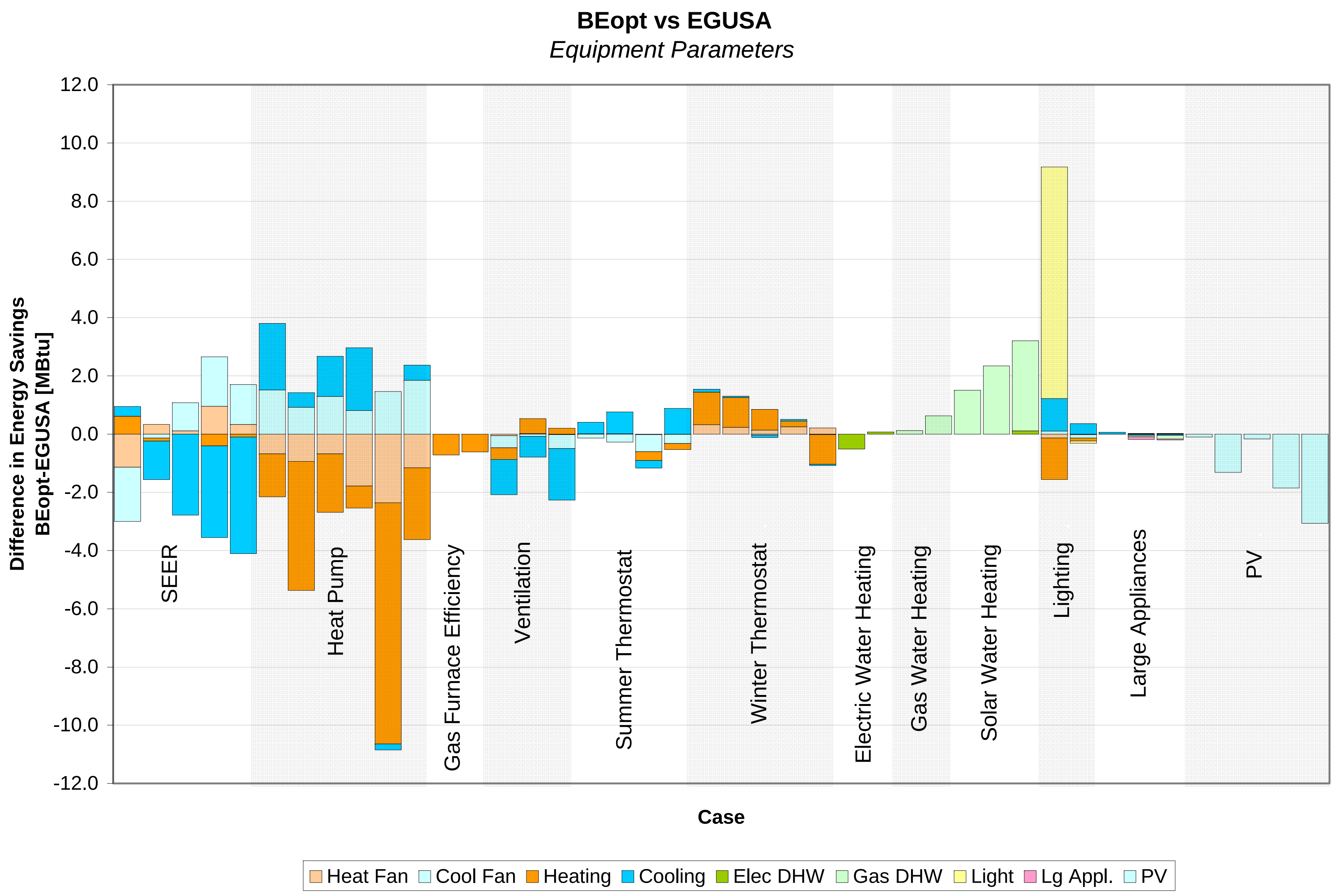
Solar Water Heating
Lighting
Large Appliances
PV
Case
Heat Fan
Cool Fan
Heating
Cooling
Elec DHW
Gas DHW
Light
Lg Appl.
PV



BEopt vs EGUSA
Envelope Parameters
Difference in Energy Savings
BEopt-EGUSA [MBtu]
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
Neighboring Houses
Basement
Crawlspace
Slab Insulation
Slab Cover
Roof
RBS
Ceiling Insulation
Wall Insulation
Wall Mass
Windows
Overhang
Duct System
Infiltration
Case
Heat Fan
Cool Fan
Heating
Cooling



BEopt vs EGUSA
Equipment Parameters
Difference in Energy Savings BEopt-EGUSA [MBtu]
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
SEER
Heat Pump
Gas Furnace Efficiency
Ventilation
Summer Thermostat
Winter Thermostat
Electric Water Heating
Gas Water Heating
Solar Water Heating
Lighting
Large Appliances
PV
Case
Heat Fan
Cool Fan
Heating
Cooling
Elec DHW
Gas DHW
Light
Lg Appl.
PV

Recommendations

Based on our detailed comparison of the *EGUSA* and *BEopt* simulation software, we found that the two simulation programs agree fairly well over a range of differing inputs and parameters. Also, calculation issues relative to wall framing, lighting and infiltration modeling were unearthed within the comparison that were all addressed by corrections to the *EGUSA* software. However, within the component calculations, we did find several areas where there were significant disparities that might be profitably investigated:

- <u>Crawlspaces</u>: crawlspace energy differs significantly on unvented crawlspaces, particularly on cooling related impacts. Test cases with monitored data should be used to show predicted unconditioned zone temperatures compare between the software to help resolve these issues.
- <u>Slabs</u>: uninsulated slab heating and cooling are much higher in *BEopt*, causing basements to be favored in *BEopt* while they are discouraged in *EGUSA*.
- <u>Slab exposure</u>: *BEopt* models a significant increase in heating energy from increased slab exposure while *EGUSA* models no change. Part of this difference likely comes from the fact that *EGUSA* assumes that much of the absorbed solar energy from windows on the slab are not permanently lost, but later emerge to impact space conditioning loads.
- <u>Windows</u>: there appears to be large and systematic differences in calculated impacts on window conductances on heating that should be addressed. Estimated impacts of improved windows on cooling agree well.
- <u>Walls</u>: there were also some differences in estimates that might be further examined since differences in the calculation procedures should show little or no difference.
- <u>Heat pumps</u>: there are significant differences in the computed heating energy for heat pumps. This is not a surprising result given the differences in the heat pump models used
- <u>Fan energy</u>: there are differences in fan energy computed between the software that affect savings levels for all components and measures. Baseline fan power in *BEopt* appears somewhat high relative to measured data.
- <u>Air conditioners</u>: *BEopt* estimates half the cooling savings as *EGUSA* for higher efficiency models. As with heat pumps the models are different as *EGUSA* uses tailor-made functions that are believed to better simulate these systems.

The windows conductance issue makes a large difference in the predicted savings of buildings relative to the BA Benchmark—particularly in cold climates. Since high performance windows are almost always a part of the suite of improvements in BA, this issue should be investigated further.

Acknowledgements

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