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Subject: Energy analysis for various Deltec home options

This report summarizes our analysis of various Deltec energy efficiency options for three representative climates: Miami, Sacramento, and Cleveland.

Results summary:
In all three climates, foam insulation applied to the walls and roof deck allowed an approximately 50% reduction in the size of the heat pump required for the home. This is because the foam insulation eliminates the unconditioned attic, bringing ducts into conditioned space, and eliminating high attic temperatures in the summer. The foam insulation options also showed superior energy performance in all three climates, even when compared to wall and ceiling insulation R-values that were much higher. Thicker applications of foam insulation with higher R-values were more beneficial in colder climates. In warmer climates, the primary benefit is more related to air sealing and closing the attic, and using more foam to achieve higher R-values brings only incremental savings.

Eliminating duct leakage alone accounted for an approximately 25% reduction in the size required for the heat pump, and in an annual energy cost savings that was roughly equivalent to a system efficiency upgrade. Options such as geothermal heat pumps and solar radiant floor heating resulted in substantial annual savings in colder climates, while high efficiency heat pumps provided savings in cooling-dominated climates.

Savings associated with energy efficient windows were small in some cases, primarily because code requires energy efficient windows in these climates. In code jurisdictions where efficient windows are not required, or for homes with larger than usual percentages of glass, the effect of energy efficient windows could be much larger.

Switching 75% of light bulbs to compact fluorescent saved $68 per year in electricity to operate the bulbs. The actual annual energy savings in Miami was higher, because using more efficient light bulbs decreases the demand for air conditioning. Savings in Cleveland (a heating dominated climate) was lower, but still $53 per year. Switching to energy efficient appliances averaged savings of $45 per year. This result was not as climate-dependent because the efficiency of the hot water heater, which costs more to operate in cold climates, partially offsets the effect of air conditioning impacts.

An 80 square foot solar hot water collector was theoretically adequate to provide all of the domestic hot water needed in Miami and Sacramento. In Cleveland, it provided nearly all of the domestic hot water. The annual cost savings was approximately $300. Depending on climate, this amounts to 15-20% of the home’s overall energy cost.

The energy recovery ventilator and air cycler had nearly identical energy use in the various climates. This is because the energy model included the effects of fan energy and interaction with natural infiltration. While ERVs have clear benefits in terms of ventilation performance, this analysis does not indicate significant energy savings in these climates.

<u>Model inputs and assumptions:</u>
Modeling tool, weather, and utilities: Energy modeling was performed using REMrate, a software tool

designed for home energy rating and used for certification of Energy Star homes. REMrate calculates peak load system sizes, annual energy use, and annual energy cost. Cost estimates are based on a 9 cent per kWh electricity rate, and a $16/MCF gas rate (for cases where gas is used in the home). All cases were simulated for three representative cities with different climates: cooling-dominated (Miami), mixed (Sacramento), and heating-dominated (Cleveland). All cases are based on a winter thermostat set point of 70F and a summer thermostat set point of 75F.

Rectangular base home: In each city, the performance of a rectangular base home was modeled. This home has 1678 sf conditioned space with a footprint of 33.4 ft by 50.25 ft. The foundation is slab on grade, and walls and ceilings are insulated using fiberglass batts, with an installation "grade 3" according to RESnet standards. This means that the insulation has gaps and voids amounting to between 2% and 5% of the insulated area. The window to wall ratio is 15%, with the glass divided equally between the four compass directions and no shading overhangs. Walls are 8 ft high. Building envelope infiltration is estimated at 5 ACH50.

The mechanical system is an air source heat pump with the federal minimum efficiency (13 SEER, 7.7 HSPF) installed in the attic with ductwork in the attic. The heat pump is sized to the nearest ½ ton of the cooling load, and backup resistance heat is provided if needed to meet the heating load. HVAC system losses include duct leakage of 10% of the conditioned floor area (168 cfm) into the unconditioned attic and thermal conduction through ducts insulated to an R-value of 6.5. Ventilation air is provided to meet ASHRAE Standard 62 using an air cycler. The air cycler provides 150 cfm of ventilation air for 8 hours each day, utilizing the main system air handling fan, which consumes 400 Watts. Air cyclers are inexpensive to install, and will cycle the air handler fan on days when the heating/cooling load is not high enough to achieve the required run time. Installed appliances include: and 86% efficient 50 gallon electric hot water heater, standard efficiency refrigerator and dishwasher, electric dryer and range, and lighting that is 10% fluorescent and 90% incandescent.

Actual insulation levels for the base home are in compliance with the 2004 International Energy Code (see Table A below). This code is a good basis for national comparison, as is arguably the most stringent residential energy code that is widely used. However, it should be noted that not all states have adopted a code that is as stringent as the 2004 IECC. Buyers in these states could see an even greater savings when purchasing an energy efficient home package. The following web site provides information on the current energy code for each state:
http://www.energycodes.gov/implement/state_codes/index.stm

City	Wall R-value	Ceiling R-Value	Slab insulation R-value and depth	Window U value	Window SHGC
Miami	11	13	none	0.89*	0.40
Sacramento	13	30	R-4/ 2 ft deep	0.60	0.40
Cleveland	18**	38	R-9/ 4 ft deep	0.35	0.55*

**the code does not have a requirement for these values, so the default value given in the code is used here.*
*** An R-19 batt was used in the analysis.*

Table A. Insulation values used for "base homes" (from 2004 IECC).

Deltec base home: The Deltec base home is identical to the rectangular base home except for its circular shape. It has the same floor area, which is accomplished through the use of eighteen 8 ft wide by 8 ft high wall Deltec wall sections. This decreases the exposed wall area from 1338 sf to 1152 sf, and decreases the exposed floor slab perimeter from 167 ft to 144 ft. The framing factor for a standard 8 ft Deltec wall panel is 0.25. The exposed ceiling area increases from 1678 sf (for a flat roof) to 1730 sf for blown or batt insulation placed at the bottom chord of the Deltec truss, which has a slope of 3:12. All systems and appliances otherwise remain the same.

Deltec insulation options: Five energy efficient Deltec insulation options are modeled. In many cases, the increased effectiveness of the insulation package allowed for a smaller heat pump to be installed in the home. When this was the case, the size of the heat pump was decreased to meet the new cooling load.

(a) Deltec Energy Wall with 5.5 inches of foam and 9 inches of foam at the roof deck: The Deltec energy wall has continuous R-5 rigid foam applied to the exterior, and its framing factor is 0.14. : Deltec foam insulation has an R-value of 4.2/inch, so the foam in the wall cavity has an R-value of 23.1, and the ceiling insulation has an R-value of 38. Both were modeled with a RESnet "grade 1", which means that it uniformly fills each cavity without substantial gaps, voids, or compressions. The air change rate for this case was modeled as 2.0 ACH50, and the roof area increases to 1876 sf for a 6:12 roof slope. The heat pump and ducts remain located in the attic, which is now part of the home's conditioned space. Therefore, the duct leakage to the outdoors is now zero.

(b) Deltec Energy Wall with 5.5 inches of foam insulation and 5.5 inches of foam insulation at the roof deck. For this case, both wall and ceiling have an R-value of 23.1, also modeled as grade 1 installation. As in the previous case, the air change rate is 2.0 ACH50, and the heat pump and ducts are included in conditioned space.

(c) Standard Deltec wall with 5.5 inches of foam insulation and 5.5 inches of foam insulation at the roof deck. For this case, both wall and ceiling have an R-value of 23.1, also modeled as grade 1 installation. As in the previous case, the air change rate is 2.0 ACH50, and the heat pump and ducts are included in conditioned space.

(d) Standard Deltec wall with 3.5 inches of foam insulation and 5.5 inches of foam insulation at the roof deck. For this case, the wall insulation is R-14.7 and the ceiling insulation is R-23.1. The air change rate is modeled as 2.0 ACH50, and the heat pump and ducts are included in conditioned space.

(e) Standard Deltec wall with R-13 fiberglass insulation and R-30 blown-in insulation in the ceiling. This case is modeled with installation grade 1, and the air change rate is modeled at 3.5 ACH50, which is achievable if good air sealing techniques are used. Both of these conditions are most likely to be achieved if a third-part verification system such as Energy Star is part of the construction process. Like the base case Deltec home, the heat pump and ducts are located in the unconditioned (vented) attic, and duct system losses are 18%. Standard roof trusses are used in this case.

(f) Standard Deltec wall with R-19 fiberglass insulation and R-48 blown-in insulation in the ceiling. This case is also modeled with installation grade 1, 3.5 ACH50, with heat pump and ducts in the unconditioned attic and with 18% system losses. Raised heel roof trusses are used.

Mechanical system options:

The location, installation, type, and efficiency of heating and cooling systems are a key factor in the overall energy efficiency of a home. Please note that since there is no heating load for the Miami home, all options labeled "heat pump" below are modeled as an air conditioner with the same cooling season efficiency in that climate. Several combinations are modeled.

(a) 5% duct leakage: This case is identical to the “base case” Deltec home, with the heat pump located in the unconditioned attic and duct leakage (measured in CFM25) equal to 5% of the home’s conditioned square footage. 5% duct leakage to the outdoors is the maximum allowed for a home to be certified for the Energy Star program. For a home with all of its ductwork located outside conditioned space, 5% leakage is a reasonably well-sealed system. Duct systems in many existing homes exceed this value.

(b) 0% duct leakage: This case is also identical to the Deltec base home, but assumes that the ducts are so well sealed that there is no duct leakage. This would be impossible to achieve with the air handler and ducts both located in unconditioned space, but gives an indication of the theoretical lower limit if a very good sealing job were obtained.

(c) Geothermal heat pump: This case is identical to the Deltec base home, but is heated and cooled using a geothermal heat pump sized to meet both the heating and cooling loads of the home. The analysis is based on a closed loop system that just meets the energy star criteria for geothermal heat pumps, which is 14.1 EER and 3.3 COP. Some available geothermal systems exceed these efficiencies by a significant margin. Some systems also provide some hot water heating capability, but that option has not been included in this analysis. In Miami and Sacramento the geothermal system is sized to meet the home’s cooling load. For the Cleveland case, the system is designed to meet the heating load, since this is necessary to realize the cost benefits of installing a geothermal system.

(d) Very high efficiency heat pump: This is the Deltec base home with an air-source heat pump with a cooling season efficiency of 16 SEER and a heating season efficiency of 9.5 HSPF. Note that SEER and HSPF values do not necessarily move in lock-step with one another, and that this unit has high efficiencies for both. A high HSPF is especially important in heating dominated climates.

(e) Energy Star qualified heat pump: This is the Deltec base home with an air-source heat pump that meets the minimum qualifications to carry the Energy Star label. It has a SEER rating of 14 and an HSPF rating of 8.2. For reference, the federal minimum efficiency is 13 SEER and 7.7 HSPF.

(f) Solar radiant floor with gas backup and air conditioning: This option includes an 80 sf liquid-direct, double glazing selective solar collector, oriented toward solar south and mounted at a 45 degree angle from horizontal with a 120 gallon storage tank. The hot water collected is used for space heating with a radiant floor. A backup system that includes a 92% AFUE gas boiler is also used. The air conditioning system is 13 SEER. An additional 1 inch of foam insulation (R-5) is applied to the underside of the entire floor slab, as is common practice with radiant floor heating systems. Note that this case is not modeled in Miami, where there is no heating load.

Energy Efficient glazing:

(a) Energy efficient windows: This is the Deltec base house with Marvin Integrity double pane low-e windows. The Wood Ultrex series double hung window has a U-value of 0.33 and a Solar Heat Gain Coefficient (SHGC) of 0.32.

(b) Sun-tempered design: This is the Deltec base house with windows and roof overhangs designed to address the solar situation at the site. In Cleveland and Sacramento, the windows are distributed with 7% facing south, 2% facing west, 3% facing east, and 3% facing north. The total window area remains unchanged at 15%. South facing windows have no internal shading in the winter for this case. All windows have a 2 ft overhang located 1 ft above the top of the window. In addition, one-third of the floor area is modeled as sunlit tile installed on a 4 inch thick concrete slab for thermal mass. In Miami, all windows have a 3.75 ft overhang located 1 ft above the top of the window. Windows in Miami are distributed 2% facing west, 3% facing east, 5% facing south, and 5% facing north. The reduction in east and west glazing helps reduce solar gain in the afternoon, but the south window area is not increased because Miami has no heating load.

Energy efficient appliances:

(a) Fluorescent lighting: This case is identical to the Deltec base home with 75% fluorescent lighting.

(b) Energy star appliances: This is identical to the Deltec base home, with higher efficiency appliances. Energy star refrigerators must use 15% less energy than a typical refrigerator of the same size. The refrigerator modeled in the base home uses 775 kWh/year, so the energy star equivalent is modeled as 659 kWh/year. To carry the Energy Star label, dishwashers must have an efficiency factor of 0.65. For reference, the base home assumes an efficiency factor of 0.46. This case also includes a high efficiency electric water heater, although water heaters are not officially rated by Energy Star. A 93% efficient 50 gallon water electric water heater is used for this case, compared to an 86% efficient model for the base home.

(c) Solar hot water heating: This is identical to the Deltec base home with a solar hot water heating system. The system option includes an 80 sf liquid-direct, double glazing selective solar collector, oriented toward solar south and mounted at a 45 degree angle from horizontal with a 120 gallon storage tank.

Ventilation system options:

Outside air ventilation, while not required in most geographical areas, is becoming more common and is desirable for homes with tight building envelopes. While it does consume some additional energy, the energy consumed is typically much less than would be consumed by infiltration in a very leaky house. The energy impact of ventilation air can also be mitigated by using an energy recovery ventilator (ERV) or heat recovery ventilator (HRV). The primary difference between the two technologies is that an ERV transfers both heat and moisture between the outgoing and incoming air, while an HRV transfers only heat.

(a) ERV: This option is the Deltec base home with 50 cfm of ventilation air (approximately the amount required by ASHRAE Standard 62 for this size home) delivered through an ERV, instead of using an air cycler. The ERV has a sensible recovery efficiency of 70%, a total recovery efficiency of 65%, and requires 100W to deliver the air. It operates 24 hours/day.

<u>Energy Analysis Results:</u>

The full set of raw data from the study is available in Appendix A. The data are interpreted below by comparison to the Deltec base house for each city. Both energy cost and energy consumption are compared. Since most of the modeled options are for all-electric homes, percentage changes in these two metrics are identical. For each case the change in required heat pump size is also noted, as many of the cases decrease the required size of HVAC systems significantly, which adds to the cost-effectiveness of some energy-efficiency options. Both energy efficiency and dehumidification are improved when HVAC systems are properly sized, therefore, homeowners who opt for energy efficient options should make sure that the heat pump is sized using a Manual J analysis to be sure that the house and HVAC work together as an efficient system. Please note that in the tables below, heat pump downsizing (tons) is based on the actual size of unit that was needed for the home option (heat pumps are typically available in ½ ton increments). The % downsizing shown in the table is the percent reduction in cooling load. Thus a small percent reduction in the cooling load would likely not allow the heat pump to be downsized to a smaller unit.

Cost and energy savings shown are based on total predicted energy use for the home, including appliances. Appliances consume a significant fraction of total energy for the home, thus some options that significantly impact only one type of energy use (i.e., space heating), may have a smaller than expected percentage impact on the home's total energy use.

Deltec insulation options:

The three insulation options that included foam insulation installed at the roof deck performed best in all three climates. These options also resulted in significant downsizing of the heat pump for the home.

- In Miami most of the energy-saving benefit comes from eliminating the unconditioned attic (which gets quite hot in the summer) and bringing the ducts into conditioned space. When foam insulation is used at the roof deck, the heat pump can be downsized by approximately 50%. One comparison to note is that the R-15 standard wall with an R-23 foam insulation ceiling saves over $100 per year compared with a wall that has R-19 fiberglass batts plus R-5 rigid insulation and R-48 blown insulation in the ceiling.
- The Sacramento house benefits both from increased insulation levels and the elimination of the attic. Here, the least insulated foam option is roughly equivalent to the most insulated non-foam option in terms of annual energy cost. However, foam insulation allows the heat pump to be downsized by 50%, while even a very well insulated non-foam house allows only a 5% reduction in cooling load.
- In Cleveland both insulation levels and insulation type are important. The foam insulation options allow a 1 ton reduction in heat pump size, but there is also a significant difference in annual energy cost among the foam options. The energy wall with R-23 foam plus R-5 rigid insulation and an R-38 foam roof saves $160 per year compared with R-15 foam standard walls and R-23 foam roof.

City	Insulation combination			Cost Savings		Energy Consumption		Heat pump downsize	
	Deltec wall	Wall insulation	Ceiling/roof insulation	$	%	MMBtu/yr	%	tons	%
Miami	Energy	R-23 foam	R-38 foam	221	14%	8.4	14%	2	55%
Miami	Energy	R-23 foam	R-23 foam	207	13%	7.9	13%	2	52%
Miami	Standard	R-23 foam	R-23 foam	201	13%	7.7	13%	2	51%
Miami	Standard	R-15 foam	R-23 foam	177	11%	6.8	11%	1.5	50%
Miami	Energy	R-19 batts	R-48 blown	66	4%	2.5	4%	0.5	11%
Miami	Standard	R-13 batts	R-30 blown	45	3%	1.7	3%	0.5	7%
Sacramento	Energy	R-23 foam	R-38 foam	178	12%	6.8	12%	2	58%
Sacramento	Energy	R-23 foam	R-23 foam	149	10%	5.7	10%	2	54%
Sacramento	Standard	R-23 foam	R-23 foam	135	9%	5.1	9%	2	52%
Sacramento	Standard	R-15 foam	R-23 foam	100	7%	3.8	7%	1.5	51%
Sacramento	Energy	R-19 batts	R-48 blown	94	6%	3.5	6%	0.5	5%
Sacramento	Standard	R-13 batts	R-30 blown	21	1%	0.8	1%	0	1%
Cleveland	Energy	R-23 foam	R-38 foam	353	18%	13.4	18%	1	51%
Cleveland	Energy	R-23 foam	R-23 foam	288	15%	10.9	15%	1	48%
Cleveland	Standard	R-23 foam	R-23 foam	249	13%	9.4	13%	1	46%
Cleveland	Standard	R-15 foam	R-23 foam	195	10%	7.4	10%	1	45%

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Cleveland	Energy	R-19 batts	R-48 blown	156	8%	5.9	8%	0	3%
Cleveland	Standard	R-13 batts	R-30 blown	-26	-1%	-1	-1%	0	0%

Cost savings, energy savings, and heat pump downsizing for insulation options.

Mechanical system options:

Various changes to mechanical systems, shown in the table below resulted in energy savings for the base house.

- For all of the climates, reduced duct leakage allows the heat pump to be downsized. 5% duct leakage to unconditioned spaces is the maximum allowed for homes participating in the Energy Star program. This level of leakage allows the system to be downsized by ½ ton in the warmer climates. 0% duct leakage is a theoretical lower limit that cannot be reached when ducts remain in unconditioned spaces. Since 0% duct leakage allows the system to be downsized by 25-30%, one can conclude that about half of the downsizing associated with using foam insulation at the roof deck is associated with duct leakage. The remaining half would be attributed to thermal conduction losses through the ducts and air sealing benefits of foam.
- The efficient heat pump options shown all save energy compared with the base case, with geothermal performing the best, the 16 SEER/9.5 HSPF option second, and the 14 SEER/8.2 HSPF third. However, it is useful to note that the actual dollar value of the savings is, in many cases, comparable to the savings achieved with duct sealing. Since duct sealing is relatively inexpensive relative to a system upgrade, the importance of sealing ducts in conjunction with upgrading to a high efficiency system should be emphasized.
- The geothermal heat pump and radiant floor with solar are efficient options for the colder climates. Because the solar radiant floor case uses gas as a backup, the cost savings depend on gas rates are not as directly linked to energy consumption savings.

City	Mechanical option	Cost Savings		Energy Consumption		Heat pump downsize	
		$	%	MMBtu/ yr	%	tons	%
Miami	0% duct leakage	86	5%	3.3	5%	1	23%
Miami	5% duct leakage	38	2%	1.5	2%	0.5	11%
Miami	Geothermal heat pump	199	13%	7.6	13%	0	0%
Miami	14 SEER heat pump	38	2%	1.5	2%	0	0%
Miami	16 SEER heat pump	99	6%	3.8	6%	0	0%
Sacramento	0% duct leakage	51	3%	1.9	3%	1	33%
Sacramento	5% duct leakage	20	1%	0.7	1%	0.5	16%
Sacramento	Geothermal heat pump	177	12%	6.7	12%	0	0%
Sacramento	14 SEER heat pump	33	2%	1.2	2%	0	0%
Sacramento	16 SEER heat pump	79	5%	3	5%	0	0%
Sacramento	Radiant floor with solar	154	10%	3	5%	0	0%
Cleveland	0% duct leakage	152	8%	5.8	8%	0.5	28%
Cleveland	5% duct leakage	85	4%	3.2	4%	0	13%
Cleveland	Geothermal heat pump	472	25%	17.9	25%	0	0%
Cleveland	14 SEER heat pump	19	1%	0.7	1%	0	0%
Cleveland	16 SEER heat pump	104	5%	3.9	5%	0	0%
Cleveland	Radiant floor with solar	319	17%	2.7	4%	0	0%

Cost savings, energy savings, and heat pump downsizing for mechanical system options.

Energy Efficient glazing:
The effect of glazing choices was also investigated. The results and strategy are highly climate and code dependent. The "energy efficient" window option modeled for all three climates had a U-value of 0.33 and a solar heat gain coefficient (SHGC) of 0.32. U-value indicates how the window will perform with respect to thermal conduction losses, while SHGC indicates how much solar gain the window will allow.

- In Miami, code requires a low-e window with a SHGC of 0.4. The $50 annual savings with the efficient window is primarily due to the further reduction in SHGC, and would be much larger in an area where code did not require a low-e window.
- In Sacramento, code also requires a low-e window with a SHGC of 0.4, but it allows a much higher U-value of 0.6. The $70 annual savings in Sacramento are related both to the lower SHGC and the lower U-value of the efficient window.
- In Cleveland, code requires an insulated window with a U-value of 0.35 (nearly the same as the efficient window used here), but allows a SHGC of 0.55. The higher SHGC allows more solar heat to enter the home, which increases cooling load, and decreases heating load. The lower U-value decreases both heating and cooling load. Because the code requires a window with low U-value, and because the SHGC has mixed effects, the performance of this window is not drastically different from the window required by code. Some cold climates have not adopted codes with window requirements that are this strict, and in that case, a much larger savings would be seen with the energy efficient window.

The sun-tempered design shows modest savings – about $50 per year in each climate. It is also likely that such a design would result in improved thermal comfort for the occupants. It should be mentioned that the base case energy model assumes that occupants will use some interior shading year-round. If occupants do not use shading on South, East, or West facing windows, summertime energy impacts could be higher.

City	Glazing option	Cost Savings		Energy Consumption		Heat pump downsize	
		$	%	MMBtu/ yr	%	tons	%
Miami	Energy efficient windows	45	3%	1.7	3%	0.5	7%
Miami	Sun-tempered design	43	3%	1.7	3%	0	3%
Sacramento	Energy efficient windows	70	5%	2.7	5%	0.5	5%
Sacramento	Sun-tempered design	46	3%	1.7	3%	0	3%
Cleveland	Energy efficient windows	4	0%	0.1	0%	0	7%
Cleveland	Sun-tempered design	51	3%	1.9	3%	0	5%

Cost savings, energy savings, and heat pump downsizing for energy efficient glazing options.

Energy efficient appliances:
Changing to 75% compact fluorescent light bulbs saves $68 per year in electricity used to operate the bulbs. The actual overall energy savings for the home is even higher in Miami, where the more efficient bulbs also create less heat and lower air conditioning costs. In Cleveland, the actual savings is $53 annually because switching to more efficient bulbs increases winter heating demand slightly. In Sacramento, heating and cooling benefits are of similar magnitude, and overall savings is $63 per year.

Energy Star labeled appliances saved approximately $45 per year in all climates. The savings were slightly higher in hotter climates than cold ones. This is because excess heat generated by less efficient appliances adds heat to the home, which consumes more energy for air conditioning, but lowers the heating energy required. It should be noted that the appliance efficiencies modeled here were the minimum required to qualify for the Energy Star label, and that even more efficient appliances are available.

In Miami and Sacramento, solar hot water heating theoretically provides all of the hot domestic hot water heating for the home. Of course, in reality there would be an occasional cloudy day or excess demand for hot water that would likely consume a small amount of backup water heating. In Cleveland, the specified system provided most of the domestic hot water for the home. The cost savings for the warmer climates is lower, however, due to tank thermal losses. Based on the thermostat settings for summer and winter, the Miami house will spend many more hours at 75 degrees, while the Cleveland house will spend more hours at 70 degrees. There will also be higher losses from hot water piping in colder climates. In all climates, solar hot water provides a savings of 15-20% of the home's overall energy use.

City	Appliance option	Cost Savings		Energy Consumption		Heat pump downsize	
		$	%	MMBtu/yr	%	tons	%
Miami	CFL lighting	86	5%	3.3	5%	0	1%
Miami	Energy Star appliances	46	3%	1.8	3%	0	0%
Miami	Solar hot water heating	249	16%	9.5	16%	0	0%
Sacramento	CFL lighting	63	4%	2.4	4%	0	1%
Sacramento	Energy Star appliances	44	3%	1.7	3%	0	0%
Sacramento	Solar hot water heating	315	21%	11.9	21%	0	0%
Cleveland	CFL lighting	53	3%	2	3%	0	1%
Cleveland	Energy Star appliances	43	2%	1.6	2%	0	0%
Cleveland	Solar hot water heating	327	17%	12.4	17%	0	0%

Cost savings, energy savings, and heat pump downsizing for energy efficient appliance options.

Ventilation system options:

Change in energy cost and consumption with the use of an Energy Recovery Ventilator (ERV) is shown in the table below. In all of the climates, the difference in energy use is small compared with the baseline system that ventilates the home using an air cycler. While this may seem counter-intuitive, this result has been obtained in other energy studies. Energy use attributable to a ventilation strategy depends on several factors: energy required to operate the ventilation fan, energy required to condition the ventilation air, and the actual volumes of air that are exchanged by the strategy. In this comparison, the air cycler strategy uses the main air-handling fan, while the ERV has its own dedicated fan that runs continuously. While the fan used by the air cycler uses significantly more electrical power to operate, there are many days of the year when the heating or cooling load is high enough that the main air handling fan would be operating anyway, and the air cycler would not cycle it on for very much additional time. In terms of energy needed to condition the ventilation air, the ERV requires less, since it is recovering energy from the exhaust air stream. However, most ERVs can recover sensible energy more efficiently than latent energy, so they will perform more efficiently in cold climates than hot/humid ones. Finally, it should be noted that some ventilation strategies including exhaust fans and supply-only strategies like the air cycler interact in a complex way with the natural infiltration that occurs in a house. Studies have demonstrated that this interaction actually causes less air exchange overall, even when the same volume of ventilation air is used. This effect is accounted for by the model.

The primary benefit of an ERV is that a constant amount of outside ventilation air is introduced to the house 24 hours a day. It is easy to measure and verify the amount of ventilation, and the heat recovery ensures that it is introduced in a way that is not uncomfortable to occupants and that does not introduce excess moisture to the home. The outside air intake for an ERV can be placed in a designated location to obtain "clean" ventilation air. The various other strategies for ventilating a home to satisfy ASHRAE Standard 62 share some of these benefits, but no strategy shares all of them. Thus, an ERV might be more accurately viewed as an excellent ventilation device, rather than as a device with large energy efficiency savings.

City	Ventilation option	Cost Savings		Energy Consumption		Heat pump downsize	
		$	%	MMBtu/ yr	%	tons	%
Miami	Energy Recovery Ventilator	-3	0%	-0.1	0%	0	3%
Sacramento	Energy Recovery Ventilator	4	0%	0.1	0%	0	2%
Cleveland	Energy Recovery Ventilator	18	1%	0.7	1%	0	2%

Cost savings, energy savings, and heat pump downsizing for ventilation system options.

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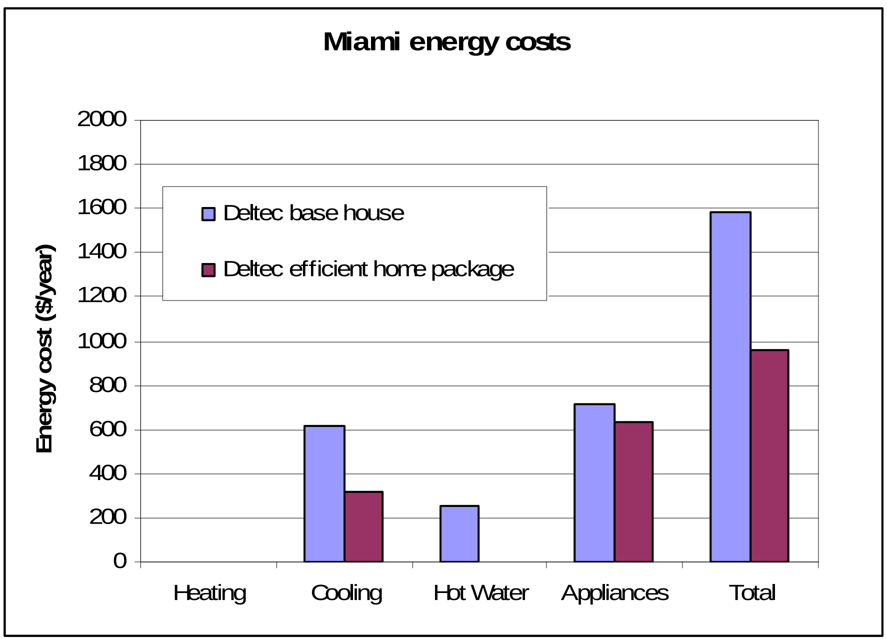
Efficient home packages:

The previous section reported savings for each strategy in isolation. Based on those results, we have selected an "efficient home" package for each climate. The efficiency savings for each strategy are not necessarily additive, so this allows us to show the savings for each package.

Miami:

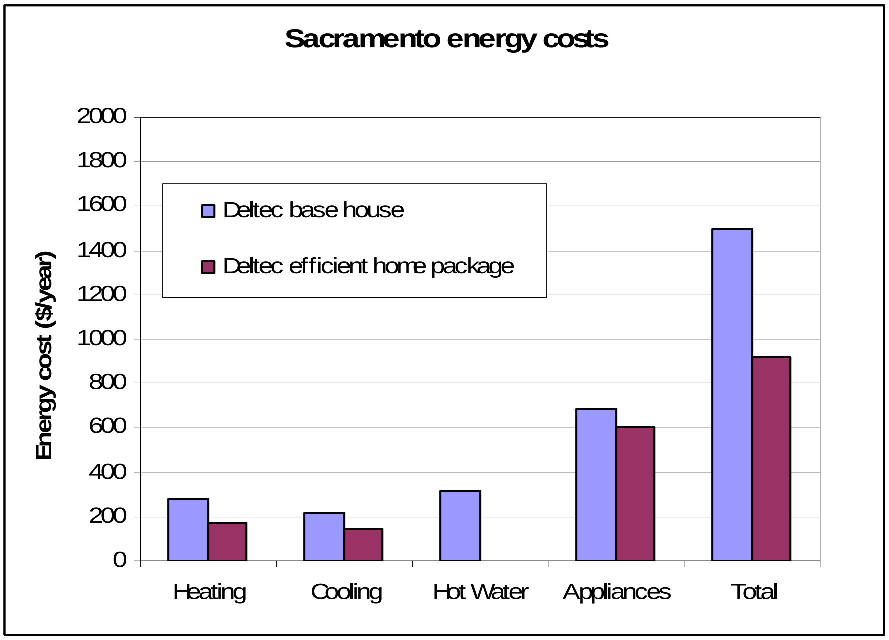
The Miami efficient home package included the Standard Deltec wall with R-15 foam insulation, R-23 foam insulation at the roof deck, a 16 SEER air conditioner, energy efficient windows, 75% compact fluorescent light bulbs, energy star appliances, and solar hot water.

The Miami efficient home package produces a 40% reduction in overall energy use and cost ($630 per year). It cuts cooling costs in half, and virtually eliminates hot water heating costs. The size of the air conditioner required for the home also drops by 60%. The figure below shows energy cost for the base home and the efficient home package



Sacramento:
The Sacramento efficient home package includes the Standard Deltec wall with R-23 foam insulation, R-23 foam insulation at the roof deck, a 16 SEER heat pump with HSPF=9.5, efficient windows, 75% compact fluorescent light bulbs, energy star appliances, and a solar hot water system.

The Sacramento efficient home package also produces a nearly 40% reduction in overall energy use and cost ($575 per year). It cuts heating and cooling costs by 35%, and virtually eliminates hot water heating costs. The size of heat pump required for the home also drops by 60%. The figure below shows energy cost for the base home and the efficient home package



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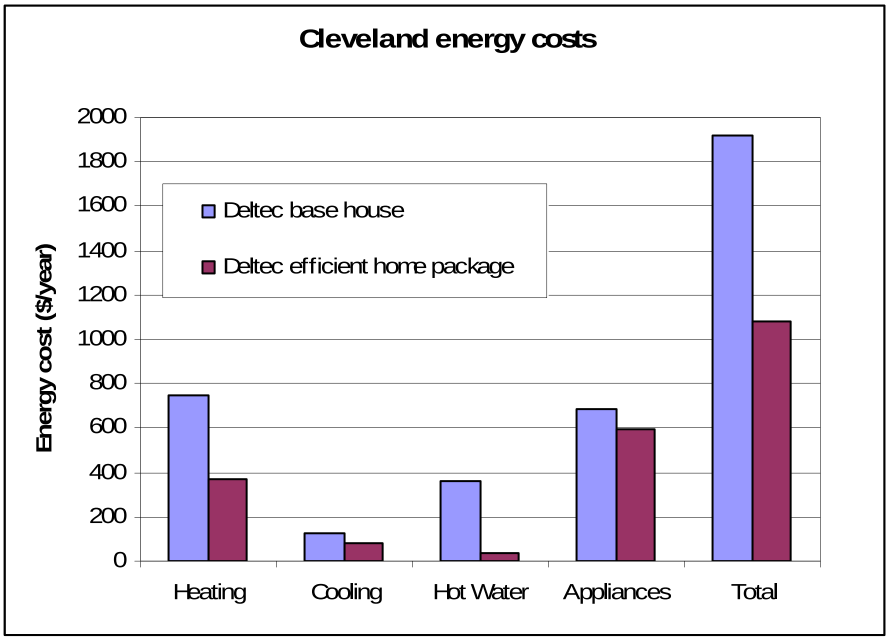
Cleveland:

The Cleveland efficient home package includes the Deltec Energy Wall with R-23 foam insulation, R-5 rigid foam exterior insulation, R-38 foam insulation at the roof deck, 75% compact fluorescent light bulbs, energy star appliances, a 16 SEER/9.5 HSPF heat pump, and a solar hot water system.

The Cleveland efficient home package also produces a nearly 45% reduction in overall energy use and cost ($840 per year). It cuts heating and cooling costs by nearly 50%, and reduces hot water heating cost by 90%. The size of the heat pump required for the home also drops by 50%. The figure below shows energy cost for the base home and the efficient home package



33 Melbourne pl Asheville, nc 28801 T: 828.337.2317 F: 828.253.8347

Appendix A. Raw Data.

	Annual Energy Cost ($)					Annual Energy Consumption (MMBtu/yr)					Design Load (kBtu/hr)	
	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling
Rectangular base house	0	625	249	718	1591	0	23.8	9.4	27.2	60.4	0	35.2
Deltec base house	0	619	249	718	1585	0	23.5	9.4	27.2	60.2	0	35.1
0% duct leakage	0	532	249	718	1499	0	20.2	9.4	27.2	56.9	0	26.9
5% duct leakage	0	581	249	718	1547	0	22.1	9.4	27.2	58.7	0	31.1
Efficient windows	0	574	249	718	1540	0	21.8	9.4	27.2	58.5	0	32.8
Solar hot water	0	619	0	718	1336	0	23.5	0	27.2	50.7	0	35.1
Geothermal heat pump	0	420	249	718	1386	0	15.9	9.4	27.2	52.6	0	35.1
14 SEER heat pump	0	581	249	718	1547	0	22.1	9.4	27.2	58.7	0	35.1
16 SEER heat pump	0	520	249	718	1486	0	19.8	9.4	27.2	56.4	0	35.1
Std. wall R-23 foam + R23 foam roof	0	418	249	718	1384	0	15.9	9.4	27.2	52.5	0	17.3
Std. wall R-15 foam + R-23 foam roof	0	441	249	718	1408	0	16.8	9.4	27.2	53.4	0	17.7
Energy wall R-23 wall +R-38 foam roof	0	398	249	718	1364	0	15.1	9.4	27.2	51.8	0	15.8
Energy wall R-23 wall +R-23 foam roof	0	412	249	718	1378	0	15.7	9.4	27.2	52.3	0	17
Standard wall R-13 batts + R-30 ceiling	0	574	249	718	1540	0	21.8	9.4	27.2	58.5	0	32.5
Energy wall R-19 batts _ R-48 ceiling	0	553	249	718	1519	0	21	9.4	27.2	57.7	0	31.4
ERV	0	615	249	724	1588	0	23.4	9.4	27.5	60.3	0	34
CFL lighting	0	601	249	649	1499	0	22.8	9.4	24.6	56.9	0	34.9
Energy star appliances	0	615	220	703	1539	0	23.4	8.4	26.7	58.4	0	35.1
Sun tempered design	0	576	249	718	1542	0	21.9	9.4	27.2	58.5	0	34.1
Efficient home package	0	319	0	635	955	0	12.1	0	24.1	36.2	0	15

Table. Results for Miami.

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	Annual Energy Cost ($)					Annual Energy Consumption (MMBtu/yr)					Design Load (kBtu/hr)	
	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling
Rectangular base house	328	222	315	687	1552	12.5	8.5	11.9	26.1	58.9	35.5	34.9
Deltec base house	278	215	315	687	1494	10.6	8.2	11.9	26.1	56.7	34.2	33.6
0% duct leakage	250	192	315	687	1443	9.5	7.3	11.9	26.1	54.8	20.9	22.4
5% duct leakage	266	206	315	687	1474	10.1	7.8	11.9	26.1	56	27.6	28.2
Efficient windows	223	199	315	687	1424	8.5	7.6	11.9	26.1	54	32.3	31.8
Solar hot water	278	215	0	687	1179	10.6	8.2	0	26.1	44.8	34.2	33.6
Geothermal heat pump	184	131	315	687	1317	7	5	11.9	26.1	50	34.2	33.6
14 SEER heat pump	258	202	315	687	1461	9.8	7.7	11.9	26.1	55.5	34.2	33.6
16 SEER heat pump	233	181	315	687	1415	8.8	6.9	11.9	26.1	53.7	34.2	33.6
Std. wall R-23 foam + R23 foam roof	195	163	315	687	1359	7.4	6.2	11.9	26.1	51.6	14.2	16
Std. wall R-15 foam + R-23 foam roof	221	172	315	687	1394	8.4	6.5	11.9	26.1	52.9	15	16.5
Energy wall R-23 wall _R-38 foam roof	161	154	315	687	1316	6.1	5.8	11.9	26.1	49.9	12.5	14.2
Energy wall R-23 wall _R-38 foam roof	182	161	315	687	1345	6.9	6.1	11.9	26.1	51	13.5	15.5
Standard wall R-13 batts + R-30 ceiling	258	213	315	687	1473	9.8	8.1	11.9	26.1	55.9	33.8	33.3
Energy wall R-19 batts + R-48 ceiling	198	201	315	687	1400	7.5	7.6	11.9	26.1	53.2	32	31.9
ERV	268	216	315	692	1490	10.2	8.2	11.9	26.2	56.6	32.9	32.8
CFL lighting	291	207	315	619	1431	11.1	7.9	11.9	23.5	54.3	34.2	33.4
Energy star appliances	280	213	283	673	1450	10.7	8.1	10.8	25.5	55	34.2	33.6
Solar radiant floor with gas backup	123	215	315	687	1340	7.5	8.2	11.9	26.1	53.7	14.7	33.7
Sun tempered design	250	197	315	687	1448	9.5	7.5	11.9	26.1	55	34.2	32.7
Efficient home pkg.	169	146	0	604	920	6.4	5.6	0	22.9	34.9	12.2	13.8

Table. Results for Sacramento.

33 Melbourne pl   Asheville, nc 28801   T: 828.337.2317   F: 828.253.8347

	Annual Energy Cost ($)					Annual Energy Consumption (MMBtu/yr)					Design Load (kBtu/hr)	
	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling	Hot Water	Appliances	Total	Heating	Cooling
Rectangular base house	791	127	364	682	1964	30.1	4.8	13.8	25.9	74.6	50	27
Deltec base house	745	128	364	682	1918	28.3	4.9	13.8	25.9	72.8	49.3	26.9
0% duct leakage	606	114	364	682	1766	23	4.3	13.8	25.9	67	28.2	19.4
5% duct leakage	664	124	364	682	1833	25.2	4.7	13.8	25.9	69.6	38.3	23.3
Efficient windows	768	100	364	682	1914	29.2	3.8	13.8	25.9	72.7	49	25.1
Solar hot water	745	128	36	682	1591	28.3	4.9	1.4	25.9	60.4	49.3	26.9
Geothermal heat pump	321	80	364	682	1446	12.2	3	13.8	25.9	54.9	49.3	26.9
14 SEER heat pump	734	120	364	682	1899	27.9	4.6	13.8	25.9	72.1	49.3	26.9
16 SEER heat pump	662	107	364	682	1814	25.2	4.1	13.8	25.9	68.9	49.3	26.9
Std. wall R-23 foam + R23 foam roof	522	101	364	682	1669	19.9	3.8	13.8	25.9	63.4	20.5	14.4
Std. wall R-15 foam + R-23 foam roof	576	101	364	682	1723	21.9	3.8	13.8	25.9	65.4	22	14.7
Energy wall R-23 wall _R-38 foam roof	421	99	364	682	1565	16	3.8	13.8	25.9	59.4	17.5	13.1
Energy wall R-23 wall _R-23 foam roof	483	101	364	682	1630	18.4	3.8	13.8	25.9	61.9	19.4	14.1
Standard wall R-13 batts + R-30 ceiling	770	129	364	682	1944	29.3	4.9	13.8	25.9	73.8	50.2	27
Energy wall R-19 batts _ R-48 ceiling	587	129	364	682	1762	22.3	4.9	13.8	25.9	66.9	47	26.1
ERV	717	129	364	690	1900	27.2	4.9	13.8	26.2	72.1	46.9	26.3
CFL lighting	766	122	364	614	1865	29.1	4.6	13.8	23.3	70.8	49.3	26.6
Energy star appliances	749	127	331	667	1875	28.5	4.8	12.6	25.3	71.2	49.3	26.8
Solar radiant floor with gas backup	424	130	364	682	1599	25.5	4.9	13.8	25.9	70.1	20.3	26.9
Sun tempered design	708	113	364	682	1867	26.9	4.3	13.8	25.9	70.9	49.3	25.6
Efficient home pkg.	368	79	33	599	1080	14	3	1.3	22.7	41	17	12.8

Table. Results for Cleveland.