FLORIDA SOLAR ENERGY CENTER®

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# Simulating the Energy Performance of a Foam Roof System:

**Final Report**

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**Submitted to 3 IN 1 ROOF, Inc.**

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# Simulating the Energy Performance of a Foam Roof System: Final Report


## Abstract

Annual residential simulations were run in 13 US cities to determine the energy savings of using an insulated foam tile roof in retrofit applications where ceiling insulation was only R-11 or R-19. Variations included leaving the attic vented and sealing the attic space. Two cities were also analyzed for energy savings for an uninsulated ceiling.

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## Introduction

3 IN 1 ROOF, Inc. has developed an insulated roof product that can be used for new construction or as a replacement on existing roofs. Such a product can reduce heat transfer to/from the attic. 3 IN 1 ROOF may particularly offer benefits as a retrofit product for existing homes that may not have potential for extra ceiling insulation or as an alternative when roof replacement is necessary. How much energy would it typically save? That is the scope of this project.

The Florida Solar Energy Center (FSEC) is a research institute of the University of Central Florida (UCF). FSEC has completed substantial research over the years regarding roofing material performance. FSEC has also written and developed algorithms and software solutions for a number of heat transfer and equipment types. FSEC has developed EnergyGauge® products based on the DOE-2 simulation engine. The residential model has some enhanced features for residences such as an attic model that can better account for duct heat transfer. FSEC has also helped the US Department of Energy develop the EnergyPlus model.

## Scope of Simulations

FSEC/UCF has evaluated the savings capability of 3 IN 1 ROOF systems by using EnergyGauge USA to simulate performance. The savings are sensitive to the specifications of the 3 IN 1 ROOF product used, the city and the attic/ceiling conditions.

The simulations run are summarized in Table 1.

**Table 1. Simulations Run**

| Cities (13) | Cases for each city (6) | Ceiling Insulation | Roof Material | Roof Reflec -tance | Duct Location | Duct Leakage (Qn) | Attic Ventilation | Total |
|---|---|---|---|---|---|---|---|---|
| Atlanta, Baltimore, Denver, Ft. Worth, Houston, Los Angeles, Miami**, Minneapolis, New York**, Phoenix, San Francisco, Seattle, St. Louis | R-11 Base | R-11 | Shingle | 0.15 | Attic for Houston, Miami, Phoenix; crawl-space for other cities | 0.11 | 1/300 | 78 (26 base-case runs with no product, 52 with product) |
| | R-11 Vented w ET | R-11 | R-14 3lb foam tile | 0.43 | | 0.11 | 1/300 | |
| | R-11 Sealed w ET | R-11 | R-14 3lb foam tile | 0.43 | | 0.11 or 0.03* | Unvented | |
| | R-19 Base | R-19 | Shingle | 0.15 | | 0.11 | 1/300 | |
| | R-19 Vented w ET | R-19 | R-14 3lb foam tile | 0.43 | | 0.11 | Unvented | |
| | R-19 Sealed w ET | R-19 | R-14 3lb foam tile | 0.43 | | 0.11 or 0.03* | Unvented | |

* For cities with ducts in sealed attics, Qn was reduced to 0.03

** Additional Miami and New York simulations were run for R-0 ceiling insulation houses

## House Characteristics

The characteristics of the R-11 ceiling insulation base-case houses used for report simulations are shown in Table 2. An otherwise identical R-19 vented attic base-case house was also simulated for each city, and R-0 ceiling insulation houses were also simulated for Miami and New York. The house

characteristics used for these simulations are representative of older houses that have not had previous retrofits and have older, inefficient heating and cooling equipment. The houses are also modeled with fairly leaky ducts, which if located in the attic, can have a large effect on results. If the 3 IN 1 ROOF product is retrofitted on a house with newer heating and cooling equipment and/or with sealed ducts or ducts located outside of the attic space, savings would be smaller.

**Table 2. Base House Characteristics**

| Component | Miami, Houston, Phoenix | Atlanta, Ft. Worth, Los Angeles | Baltimore, New York, San Francisco, Seattle, St. Louis | Minneapolis, Denver |
|---|---|---|---|---|
| | **R-11 Vented** | **R-11 Vented** | **R-11 Vented** | **R-11 Vented** |
| | **Attic** | **Attic** | **Attic** | **Attic** |
| | **Base-case** | **Base-case** | **Base-case** | **Base-case** |
| Conditioned floor area (ft2) | 1,600 | 1,600 | 1,600 | 1,600 |
| Foundation type | SOG | Crawl | Crawl | Bsmnt |
| AHU location | Garage | Crawl | Crawl | Bsmnt |
| Duct location | Attic | Crawl | Crawl | Bsmnt |
| Duct insulation R-value | 4.2 | 4.2 | 4.2 | 4.2 |
| Duct leakage (cfm25/ft2 floor area) | 0.11 | 0.11 | 0.11 | 0.08 |
| Envelope ACH50 (air chng/hr @ 50pa) | 12 | 9 | 9 | 7 |
| Roof solar absorptance | 0.85 | 0.85 | 0.85 | 0.85 |
| Wall solar absorptance | 0.55 | 0.55 | 0.55 | 0.55 / 0.75 Bsmnt |
| Ceiling R-value | 11 | 11 | 11 | 11 |
| Roof Configuration (pitch) | Hip (3/12) | Hip(3/12) | Hip (6/12) | Hip (6/12) |
| Roof R-value | 0 | 0 | 0 | 0 |
| Roof Framing Fraction | 0.1 | 0.1 | 0.1 | 0.1 |
| Roofing Material | Comp. Shingles | Comp. Shingles | Comp. Shingles | Comp. Shingles |
| Attic Ventilation | Vented 1/300 | Vented 1/300 | Vented 1/300 | Vented 1/300 |
| Frame wall insulation R-value | 0.01 for Miami (adj. to garage); 1.5 for Houston and Phoenix | 5 | 5 | 7 |
| Block wall insulation R-value | 0.01 for Miami; N/A for Houston and Phoenix | N/A | N/A | N/A |
| Slab on grade floor perimeter R-value | 0 | N/A | N/A | N/A |
| Crawlspace floor R-value | N/A | 5 | 5 | N/A |
| Basement ceiling (house floor) R-value | N/A | N/A | N/A | 0 |
| Basement wall R-value | N/A | N/A | N/A | 0 |
| Window U-factor | 1.2 | 0.75 | 0.75 | 0.6 |
| Window SHGC | 0.8 | 0.7 | 0.7 | 0.6 |

| | | | | |
|---|---|---|---|---|
| Window overhang horizontal depth (ft.) | 2.0 | 2.0 | 2.0 | 2.0 |
| Window overhang vertical separation (ft.) | 1.5 | 1.5 | 1.5 | 1.5 |
| Door U-factor | 0.5 | 0.4 | 0.4 | 0.3 |
| HP HSPF (y2004; standard; degraded) | 6.5 | 6.5 | N/A | N/A |
| HP SEER (y2004; standard; degraded) | 9.6 | 9.6 | N/A | N/A |
| AC SEER (y2004; standard; degraded) | N/A | N/A | 9.6 | 9.6 |
| Furnace AFUE (y2004; standard; degraded) | N/A | N/A | 76% | 76% |
| Gas HW EF (y2004; 40 gal; standard) | N/A | N/A | 0.59 | 0.59 |
| Elec HW EF (y2004; 40 gal; standard) | 0.92 | 0.92 | N/A | N/A |
| HW pipe insulation R-value | None | None | None | None |
| Lighting % fluorescent or equivalent | 10% | 10% | 10% | 10% |
| Lighting kWh/yr | 1,736 | 1,736 | 1,736 | 1,736 |
| Refrigerator kWh/yr (y2004; 20 cf; SS/TDI) | 717 | 717 | 717 | 717 |
| Range/oven kWh/yr | 447 | 447 | 447 | 447 |
| Dishwasher kWh/yr (y2004; standard) | 171 | 171 | 171 | 171 |
| Clothes Washer kWh/yr (y2004; standard) | 69 | 69 | 69 | 69 |
| Clothes Dryer kWh/yr (y2004; standard) | 970 | 970 | 970 | 970 |
| Miscellaneous kWh/yr | 2,000 | 2,000 | 2,000 | 2,000 |

The conventional roof construction modeled is shown in Table 3 and the 3 IN 1 ROOF construction was modeled with the layers shown in Table 4 using the DOE-2 simulation engine. Where specific heat or density was not found in literature for a particular layer, an estimate from a similar product was used.

**Table 3. Conventional Roof Construction**

| Layer | Material | Conductivity | Thickness | Thickness | Density | Specific Heat | Rvalue |
|---|---|---|---|---|---|---|---|
| | | Btu/hr-ft2-F | Inches | Feet | lbs/ft3 | Btu/lb-F | h·ft$^2$·°F/Btu |
| Attic Air | Air Film Coefficient | | | | | | 0.728 |
| Decking | Plywood | 0.0667 | 0.5 | 0.0417 | 34 | 0.29 | 0.62 |
| Insulation (R-0) | | 0.0238 | 0.012 | 0.0010 | 0.6 | 0.2 | 0.04 |
| Asphalt Shingle Prep Layer | Felt/Shingle | 0.0473 | 0.2496 | 0.0208 | 70 | 0.3 | 0.44 |
| Asphalt Shingle Layer | Shingle | 0.0473 | 0.2496 | 0.0208 | 70 | 0.3 | 0.44 |
| Outside air | Air Film Coefficient | | | | | | 0.25 |
| Total Roof | | | | | | | 2.52 |

**Table 4. 3 IN 1 ROOF Construction**

| Layer | Material | Conductivity | Thickness | Thickness | Density | Specific Heat | Rvalue |
|---|---|---|---|---|---|---|---|
| | | Btu/hr-ft2-F | Inches | Feet | lbs/ft3 | Btu/lb-F | h·ft$^2$·°F/Btu |
| Attic Air | Air Film Coefficient | | | | | | 0.728 |
| Existing Decking | Plywood | 0.0667 | 0.5 | 0.0417 | 34 | 0.29 | 0.62 |
| DensDeck | Dense Board | 0.0801 | 0.5 | 0.0417 | 48 | 0.29 | 0.52 |
| Peel and stick | Flintastic | 0.0473 | 0.3125 | 0.0260 | 70 | 0.3 | 0.55 |
| ETERNATILE | R-14 Foam | 0.0128 | 2.1538 | 0.1795 | 4.3335* | 0.38 | 14.00*** |
| Top Coat | Finish | 0.4200 | 0.1 | 0.0083 | 49** | 0.2 | 0.02 |
| Outside air | Air Film Coefficient | | | | | | 0.25 |
| Total Roof | | | | | | | 16.69 |
| | | | | | | | |
| * based on manufacturer indicating the finished product is 5.5 lbs and a volume of 0.808 cu. ft., applied 3.5 lbs to foam tile | | | | | | | |
| ** have created the top coat layer to account for two pounds | | | | | | | |
| *** Rvalue of 14.00 for foam based on test of 6.5 for one inch: http://www.gaco.com/products/PDS-GacoFlashFoam.pdf | | | | | | | |

## Simulation Results

*EnergyGauge USA* annual simulation runs included the above R-11 and R-19 vented attic base-case configurations and 3 IN 1 ROOF configurations for the 13 cities shown in Table 1. Simulation runs for each city included:

- R-11 and R-19 Vented Attic Base Cases
- R-11 and R-19 Vented Attics with R-14 3 IN 1 ROOF
- R-11 and R-19 Sealed Attics with R-14 3 IN 1 ROOF

The applicability of the savings results is limited to houses of similar efficiency as those indicated in the House Characteristics section. **Savings will be lower for more efficient houses.**

The energy use for cooling and heating are shown in Tables 5 – 17, one table corresponding to each city. The heating may be by gas or electricity as indicated in Table 2. Thus, heating results are shown in either kWh or Therms, while cooling is always in kWh. Central fan energy is not included in the Heating kWh column but is included in the Heating Btu and Heat & Cool Btu columns. The heating and cooling units are converted to Btus of energy use consumed. Savings are then indicated in the last column of the tables, representing the total heating and cooling savings relative to the base case with the same amount of ceiling insulation. Tables 5 -17 also show the average July attic temperature and the highest hourly attic temperature output by the simulation (it may not always be the same hour for each simulation). Figures 1 – 13 illustrate the simulated energy savings for each configuration relative to the respective base case for that city and ceiling insulation level. These results are shown on the next thirteen pages for each of the cities simulated.

Additional comparisons starting with vented attics with R-0 ceiling insulation were also run in Miami and New York. Savings results for these runs are provided in Table 18 and Figure 14.

## Miami

Miami simulation results are shown in Table 5. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 21.3% if the attic was left vented and 26.6% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 17.5% if the attic was left vented and 23.4% if the attic was sealed.

**Table 5. Miami Simulation Results**

| Miami, Florida Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 91 | 127 | 0 | 70 | 0.3 | 8688 | 29.7 | 29.9 | -- |
| R-11 Vented w R-14 ET | 81 | 87 | 0 | 45 | 0.2 | 6853 | 23.4 | 23.6 | 21.3% |
| R-11 Sealed w R-14 ET | 83 | 89 | 0 | 36 | 0.1 | 6394 | 21.8 | 22.0 | 26.6% |
| R-19 Vented Base | 92 | 131 | 0 | 56 | 0.2 | 8269 | 28.2 | 28.4 | -- |
| R-19 Vented w R-14 ET | 81 | 88 | 0 | 40 | 0.2 | 6829 | 23.3 | 23.5 | 17.5% |
| R-19 Sealed w R-14 ET | 84 | 90 | 0 | 34 | 0.1 | 6346 | 21.7 | 21.8 | 23.4% |

Figure 1 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Miami.

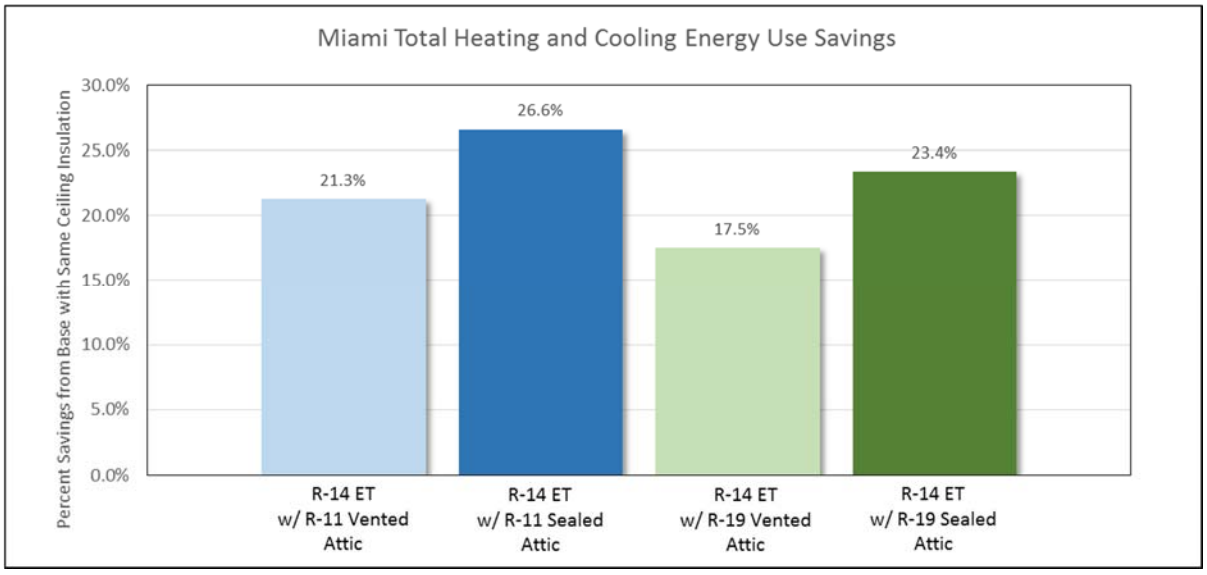


**Figure 1. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Miami.**

Miami temperature results showed an 8 to 11°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 38 to 43°F for the 3 IN 1 ROOFs.

## Houston

Houston simulation results are shown in Table 6. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 21.5% if the attic was left vented and 26.9% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 16.9% if the attic was left vented and 22.2% if the attic was sealed.

**Table 6. Houston Simulation Results**

| Houston, Texas Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 92 | 136 | 0 | 2292 | 8.8 | 5899 | 20.1 | 29.0 | -- |
| R-11 Vented w R-14 ET | 82 | 90 | 0 | 2030 | 7.8 | 4375 | 14.9 | 22.8 | 21.5% |
| R-11 Sealed w R-14 ET | 83 | 91 | 0 | 1825 | 7.0 | 4146 | 14.1 | 21.2 | 26.9% |
| R-19 Vented Base | 93 | 140 | 0 | 2132 | 8.2 | 5437 | 18.6 | 26.8 | -- |
| R-19 Vented w R-14 ET | 82 | 92 | 0 | 1944 | 7.5 | 4323 | 14.8 | 22.2 | 16.9% |
| R-19 Sealed w R-14 ET | 84 | 93 | 0 | 1781 | 6.9 | 4092 | 14.0 | 20.8 | 22.2% |

Figure 2 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Houston.

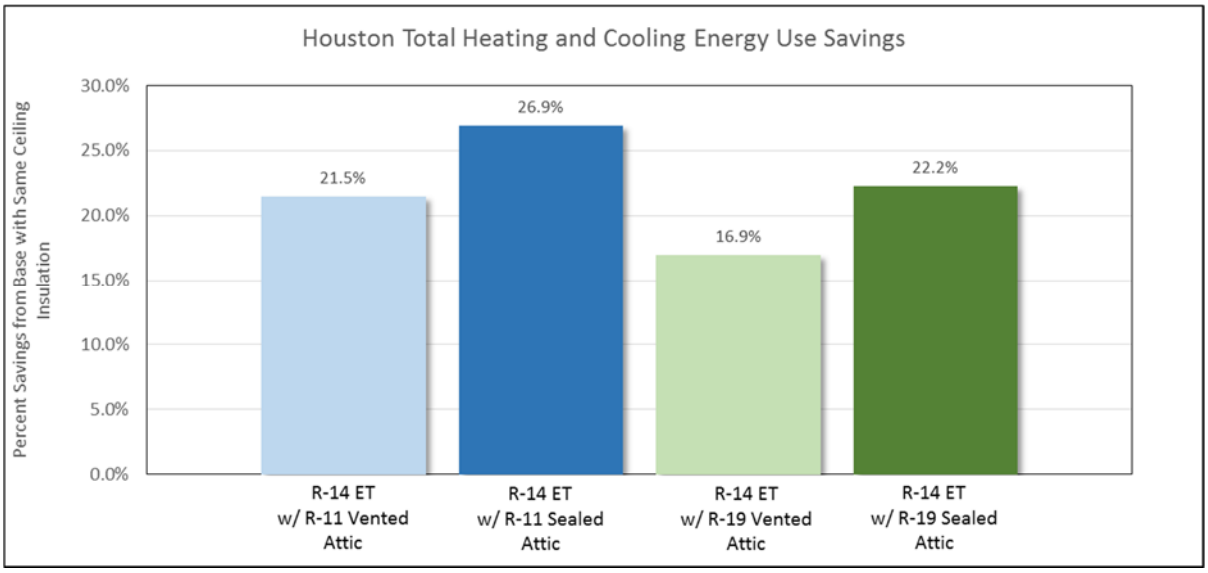


**Figure 2. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Houston.**

Houston temperature results showed a 9 to 11°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 45 to 48°F for the 3 IN 1 ROOFs.

## Phoenix

Phoenix simulation results are shown in Table 7. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 20.5% if the attic was left vented and 24.4% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 16.0% if the attic was left vented and 19.6% if the attic was sealed.

**Table 7. Phoenix Simulation Results**

| Phoenix, Arizona Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 104 | 145 | 0 | 924 | 3.6 | 11291 | 38.5 | 42.1 | -- |
| R-11 Vented w R-14 ET | 89 | 96 | 0 | 781 | 3.0 | 8929 | 30.5 | 33.5 | 20.5% |
| R-11 Sealed w R-14 ET | 89 | 96 | 0 | 702 | 2.7 | 8535 | 29.1 | 31.8 | 24.4% |
| R-19 Vented Base | 106 | 150 | 0 | 813 | 3.1 | 10479 | 35.8 | 38.9 | -- |
| R-19 Vented w R-14 ET | 91 | 98 | 0 | 723 | 2.8 | 8762 | 29.9 | 32.7 | 16.0% |
| R-19 Sealed w R-14 ET | 92 | 99 | 0 | 670 | 2.6 | 8410 | 28.7 | 31.3 | 19.6% |

Figure 3 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Phoenix.

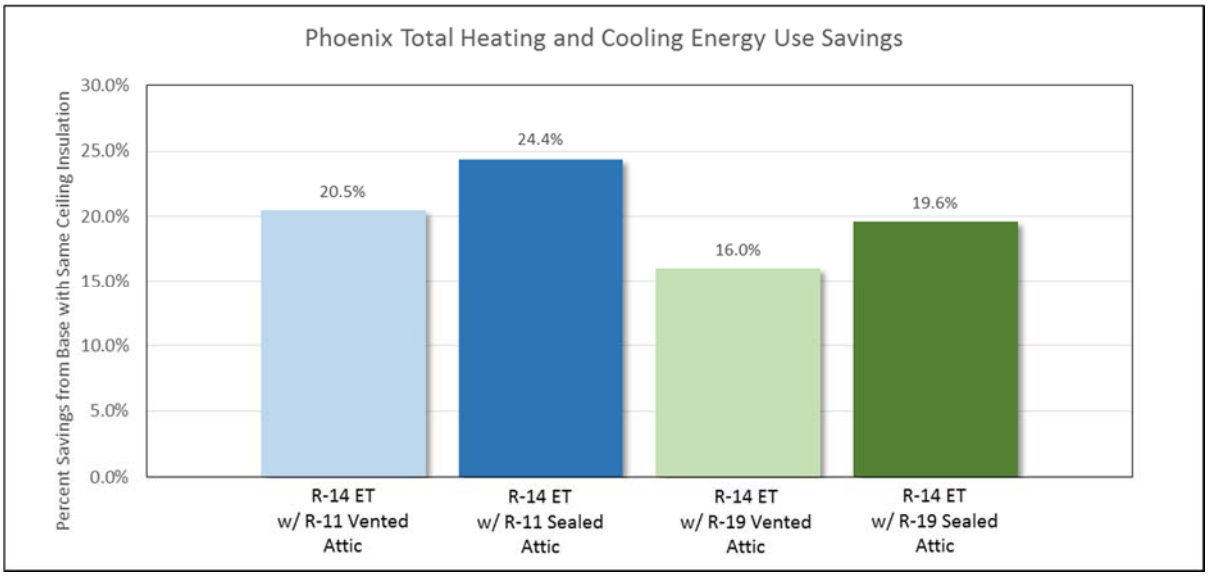


**Figure 3. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Phoenix.**

Phoenix temperature results showed a 14 to 15°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 49 to 52°F for the 3 IN 1 ROOFs.

## Atlanta

Atlanta simulation results are shown in Table 8. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 13.3% if the attic was left vented and 15.7% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 8.6% if the attic was left vented and 9.7% if the attic was sealed.

**Table 8. Atlanta Simulation Results**

| Atlanta, Georgia | Avg. July Attic | High Annual Attic | Heating | Heating | Heating | Cooling | Cooling | Heat & Cool | Percent |
|---|---|---|---|---|---|---|---|---|---|
| Attic/Roof Configuration | Temp (°F) | Temp (°F) | Therms | kWh | Btu x $10^6$ | kWh | Btu x $10^6$ | Btu x $10^6$ | Savings |
| R-11 Vented Base | 92 | 140 | 0 | 4756 | 18.4 | 3549 | 12.1 | 30.5 | -- |
| R-11 Vented w R-14 ET | 82 | 93 | 0 | 4501 | 17.4 | 2651 | 9.0 | 26.4 | 13.3% |
| R-11 Sealed w R-14 ET | 83 | 93 | 0 | 4261 | 16.5 | 2703 | 9.2 | 25.7 | 15.7% |
| R-19 Vented Base | 92 | 145 | 0 | 4352 | 16.8 | 3153 | 10.8 | 27.6 | -- |
| R-19 Vented w R-14 ET | 82 | 95 | 0 | 4228 | 16.3 | 2597 | 8.9 | 25.2 | 8.6% |
| R-19 Sealed w R-14 ET | 84 | 96 | 0 | 4105 | 15.9 | 2645 | 9.0 | 24.9 | 9.7% |

Figure 4 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Atlanta.

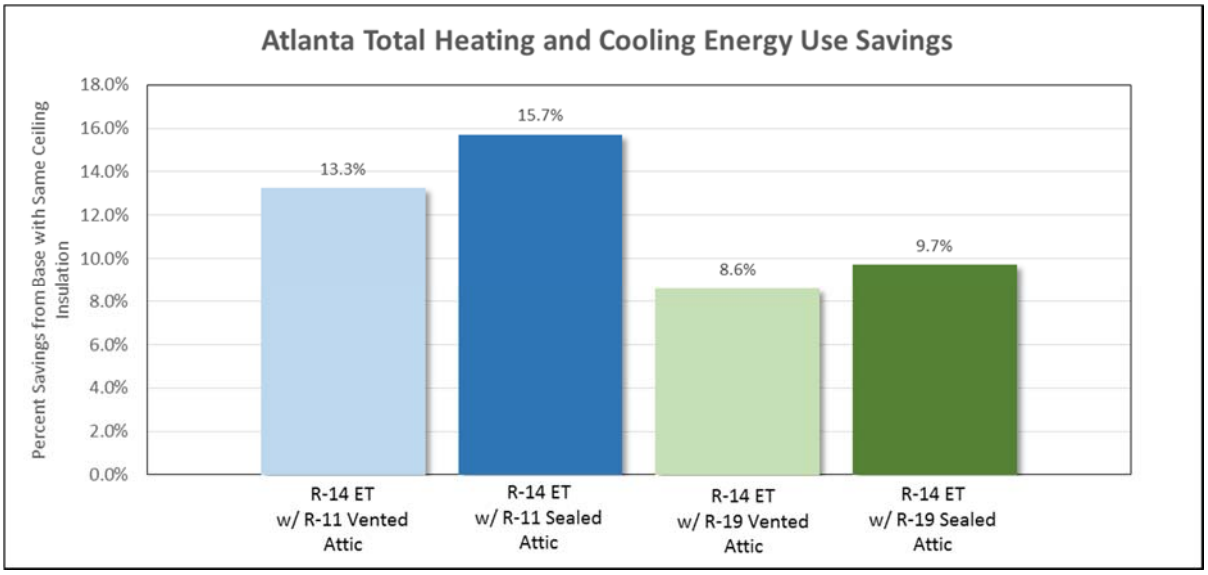


**Figure 4. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Atlanta.**

Atlanta temperature results showed an 8 to 10°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 47 to 50°F for the 3 IN 1 ROOFs.

## Fort Worth

Fort Worth simulation results are shown in Table 9. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 11.2% if the attic was left vented and 13.4% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 7.1% if the attic was left vented and 8.1% if the attic was sealed.

**Table 9. Fort Worth Simulation Results**

| Ft. Worth, Texas | Avg. July Attic | High Annual Attic | Heating | Heating | Heating | Cooling | Cooling | Heat & Cool | Percent |
|---|---|---|---|---|---|---|---|---|---|
| Attic/Roof Configuration | Temp (°F) | Temp (°F) | Therms | kWh | Btu x $10^6$ | kWh | Btu x $10^6$ | Btu x $10^6$ | Savings |
| R-11 Vented Base | 100 | 141 | 0 | 4308 | 16.6 | 5993 | 20.5 | 37.1 | -- |
| R-11 Vented w R-14 ET | 88 | 95 | 0 | 4078 | 15.7 | 5039 | 17.2 | 32.9 | 11.2% |
| R-11 Sealed w R-14 ET | 87 | 94 | 0 | 3848 | 14.8 | 5056 | 17.3 | 32.1 | 13.4% |
| R-19 Vented Base | 101 | 145 | 0 | 3933 | 15.2 | 5490 | 18.7 | 33.9 | -- |
| R-19 Vented w R-14 ET | 89 | 98 | 0 | 3821 | 14.7 | 4911 | 16.8 | 31.5 | 7.1% |
| R-19 Sealed w R-14 ET | 90 | 97 | 0 | 3702 | 14.3 | 4950 | 16.9 | 31.2 | 8.1% |

Figure 5 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Fort Worth.

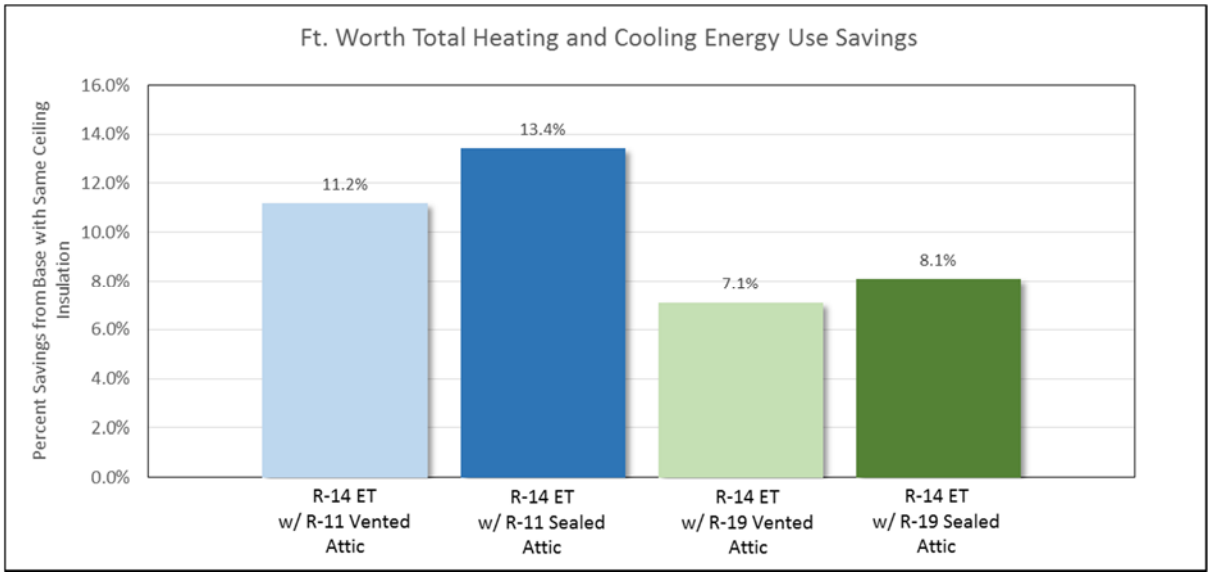


**Figure 5. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Fort Worth.**

Fort Worth temperature results showed an 11 to 13°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 46 to 48°F for the 3 IN 1 ROOFs.

## Los Angeles

Los Angeles simulation results are shown in Table 10. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 30.2% if the attic was left vented and 38.1% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 20.9% if the attic was left vented and 26.0% if the attic was sealed.

**Table 10. Los Angeles Simulation Results**

| Los Angeles, California Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 82 | 126 | 0 | 727 | 2.8 | 166 | 0.6 | 3.4 | -- |
| R-11 Vented w R-14 ET | 73 | 81 | 0 | 574 | 2.2 | 41 | 0.1 | 2.4 | 30.2% |
| R-11 Sealed w R-14 ET | 75 | 82 | 0 | 505 | 2.0 | 41 | 0.1 | 2.1 | 38.1% |
| R-19 Vented Base | 82 | 131 | 0 | 588 | 2.3 | 108 | 0.4 | 2.7 | -- |
| R-19 Vented w R-14 ET | 73 | 81 | 0 | 506 | 2.0 | 40 | 0.1 | 2.1 | 20.9% |
| R-19 Sealed w R-14 ET | 76 | 84 | 0 | 469 | 1.8 | 42 | 0.1 | 2.0 | 26.0% |

Figure 6 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Los Angeles.

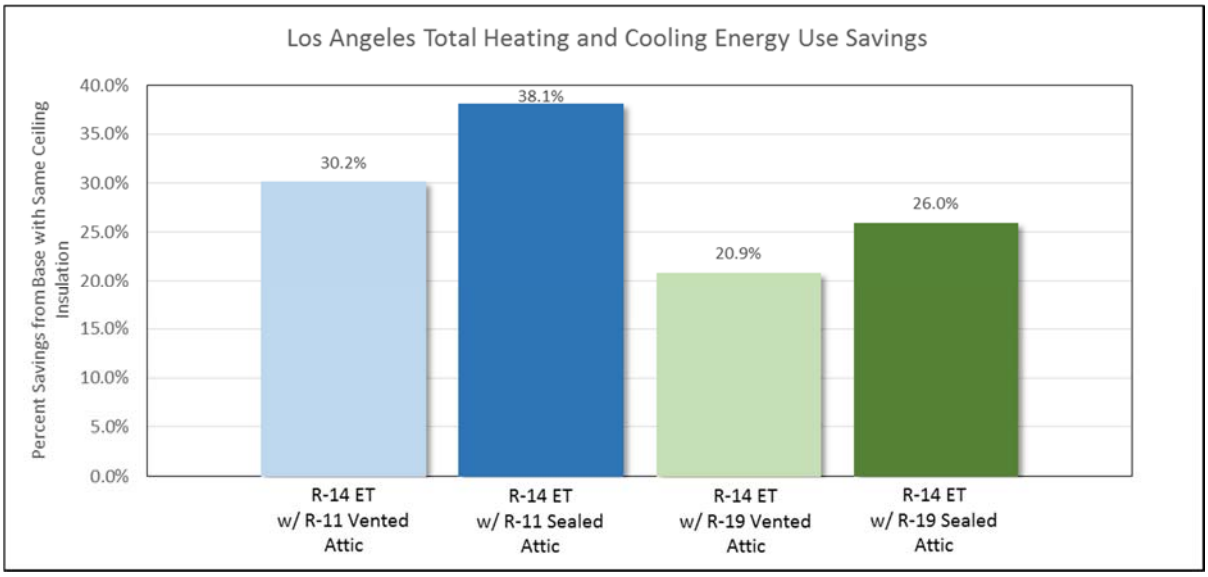


**Figure 6. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Los Angeles.**

Los Angeles temperature results showed a 6 to 9°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 44 to 50°F for the 3 IN 1 ROOFs.

## Baltimore

Baltimore simulation results are shown in Table 11. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 5.3% if the attic was left vented and 9.7% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 2.9% if the attic was left vented and 5.2% if the attic was sealed.

**Table 11. Baltimore Simulation Results**

| Baltimore, Maryland | Avg. July Attic | High Annual Attic | Heating | Heating | Heating | Cooling | Cooling | Heat & Cool | Percent |
|---|---|---|---|---|---|---|---|---|---|
| Attic/Roof Configuration | Temp (°F) | Temp (°F) | Therms | kWh | Btu x $10^6$ | kWh | Btu x $10^6$ | Btu x $10^6$ | Savings |
| R-11 Vented Base | 89 | 132 | 800.1 | 0 | 81.8 | 2237 | 7.6 | 89.4 | -- |
| R-11 Vented w R-14 ET | 80 | 91 | 771.9 | 0 | 78.9 | 1699 | 5.8 | 84.7 | 5.3% |
| R-11 Sealed w R-14 ET | 82 | 91 | 732.3 | 0 | 74.8 | 1737 | 5.9 | 80.8 | 9.7% |
| R-19 Vented Base | 89 | 135 | 734.7 | 0 | 75.1 | 2013 | 6.9 | 82.0 | -- |
| R-19 Vented w R-14 ET | 81 | 93 | 723.3 | 0 | 73.9 | 1666 | 5.7 | 79.6 | 2.9% |
| R-19 Sealed w R-14 ET | 83 | 94 | 703.5 | 0 | 71.9 | 1703 | 5.8 | 77.7 | 5.2% |

Figure 7 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Baltimore.

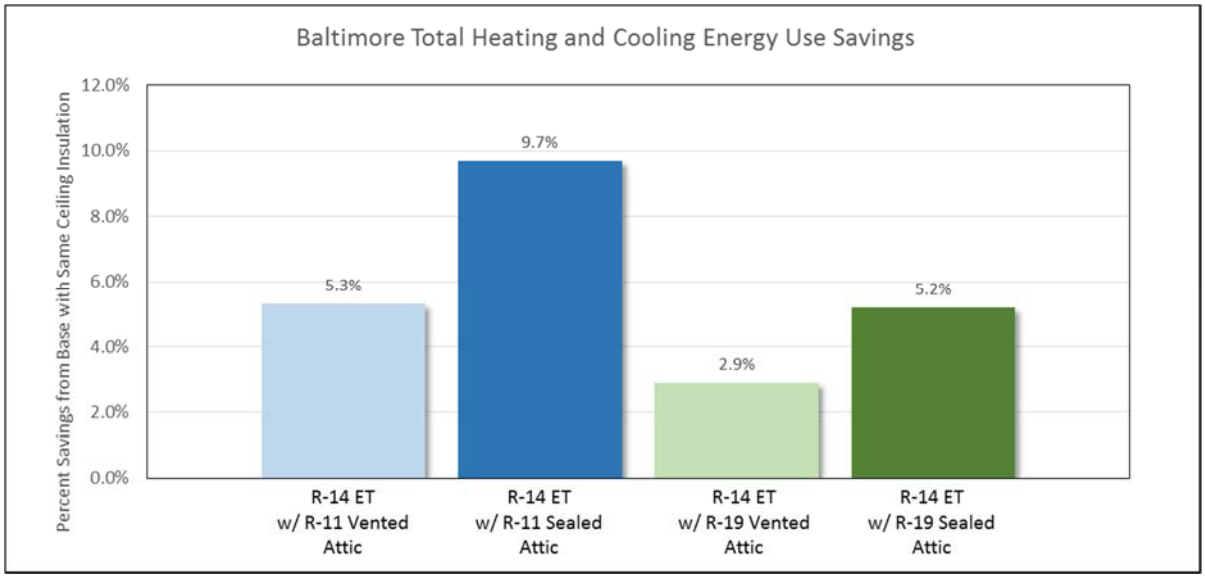


**Figure 7. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Baltimore.**

Baltimore temperature results showed a 6 to 9°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 41 to 42°F for the 3 IN 1 ROOFs.

## New York

New York simulation results are shown in Table 12. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 4.0% if the attic was left vented and 8.3% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 2.0% if the attic was left vented and 4.3% if the attic was sealed.

**Table 12. New York Simulation Results**

| New York, New York Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 88 | 129 | 933.6 | 0 | 95.4 | 1727 | 5.9 | 101.3 | -- |
| R-11 Vented w R-14 ET | 80 | 91 | 906.6 | 0 | 92.7 | 1365 | 4.7 | 97.3 | 4.0% |
| R-11 Sealed w R-14 ET | 81 | 90 | 862.6 | 0 | 88.2 | 1395 | 4.8 | 92.9 | 8.3% |
| R-19 Vented Base | 89 | 132 | 863.7 | 0 | 88.3 | 1567 | 5.3 | 93.6 | -- |
| R-19 Vented w R-14 ET | 80 | 92 | 853.1 | 0 | 87.2 | 1338 | 4.6 | 91.8 | 2.0% |
| R-19 Sealed w R-14 ET | 82 | 93 | 831.4 | 0 | 85.0 | 1366 | 4.7 | 89.6 | 4.3% |

Figure 8 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for New York.

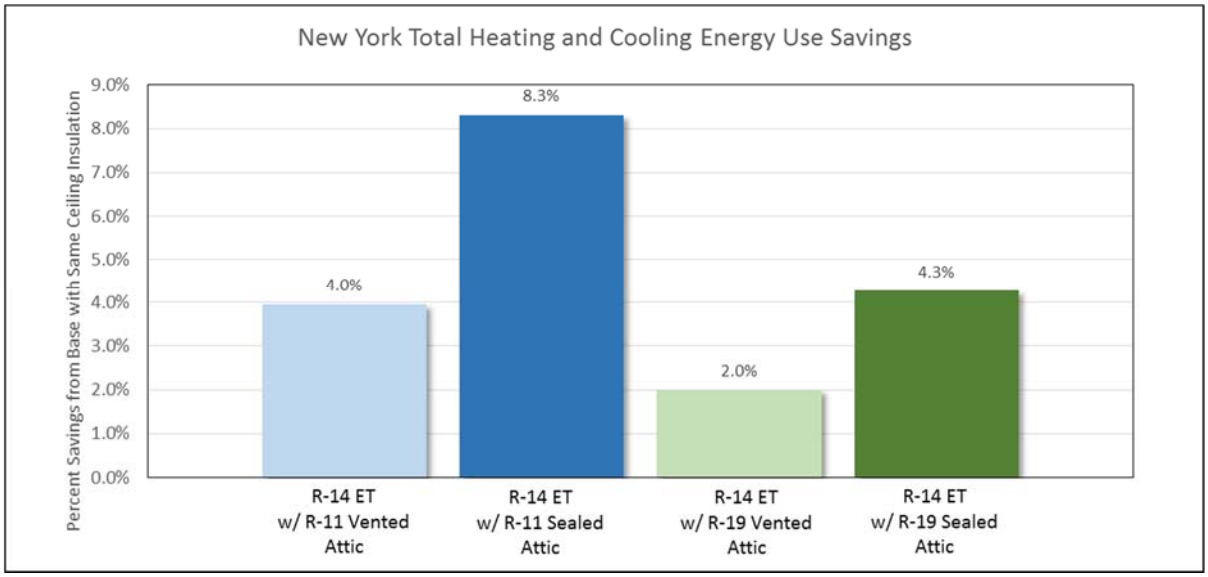


**Figure 8. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for New York.**

New York temperature results showed a 7 to 9°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 38 to 40°F for the 3 IN 1 ROOFs.

## San Francisco

San Francisco simulation results are shown in Table 13. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 11.1% if the attic was left vented and 19.3% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 6.5% if the attic was left vented and 11.9% if the attic was sealed.

**Table 13. San Francisco Simulation Results**

| San Francisco, California Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 73 | 125 | 341.3 | 0 | 34.9 | 62 | 0.2 | 35.1 | -- |
| R-11 Vented w R-14 ET | 67 | 82 | 304.7 | 0 | 31.1 | 18 | 0.1 | 31.2 | 11.1% |
| R-11 Sealed w R-14 ET | 70 | 83 | 276.8 | 0 | 28.3 | 18 | 0.1 | 28.3 | 19.3% |
| R-19 Vented Base | 73 | 128 | 296.2 | 0 | 30.3 | 46 | 0.2 | 30.4 | -- |
| R-19 Vented w R-14 ET | 66 | 82 | 277.9 | 0 | 28.4 | 18 | 0.1 | 28.5 | 6.5% |
| R-19 Sealed w R-14 ET | 70 | 84 | 261.7 | 0 | 26.7 | 19 | 0.1 | 26.8 | 11.9% |

Figure 9 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for San Francisco.

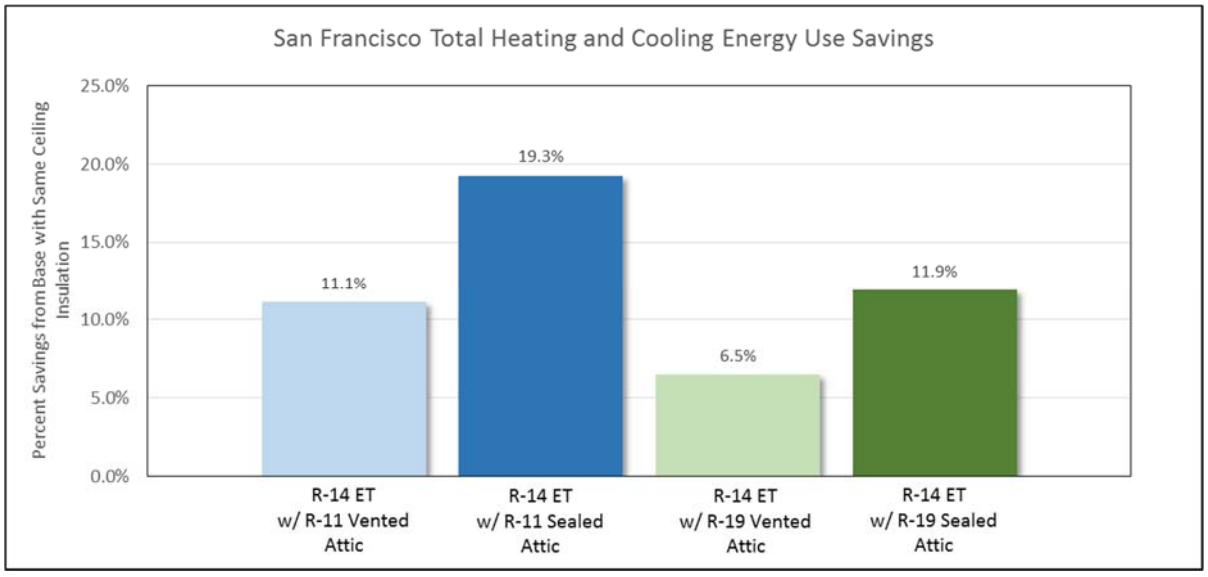


**Figure 9. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for San Francisco.**

San Francisco temperature results showed a 3 to 7°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 42 to 46°F for the 3 IN 1 ROOFs.

## Seattle

Seattle simulation results are shown in Table 14. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 4.7% if the attic was left vented and 10.1% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 2.0% if the attic was left vented and 4.6% if the attic was sealed.

**Table 14. Seattle Simulation Results**

| Seattle, Washington Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 77 | 122 | 812.7 | 0 | 83.1 | 213 | 0.7 | 83.8 | -- |
| R-11 Vented w R-14 ET | 69 | 85 | 777.9 | 0 | 79.5 | 95 | 0.3 | 79.8 | 4.7% |
| R-11 Sealed w R-14 ET | 72 | 85 | 734 | 0 | 75.0 | 100 | 0.3 | 75.3 | 10.1% |
| R-19 Vented Base | 77 | 124 | 740.8 | 0 | 75.7 | 172 | 0.6 | 76.3 | -- |
| R-19 Vented w R-14 ET | 69 | 91 | 728 | 0 | 74.4 | 104 | 0.4 | 74.7 | 2.0% |
| R-19 Sealed w R-14 ET | 73 | 94 | 708.8 | 0 | 72.4 | 109 | 0.4 | 72.8 | 4.6% |

Figure 10 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Seattle.

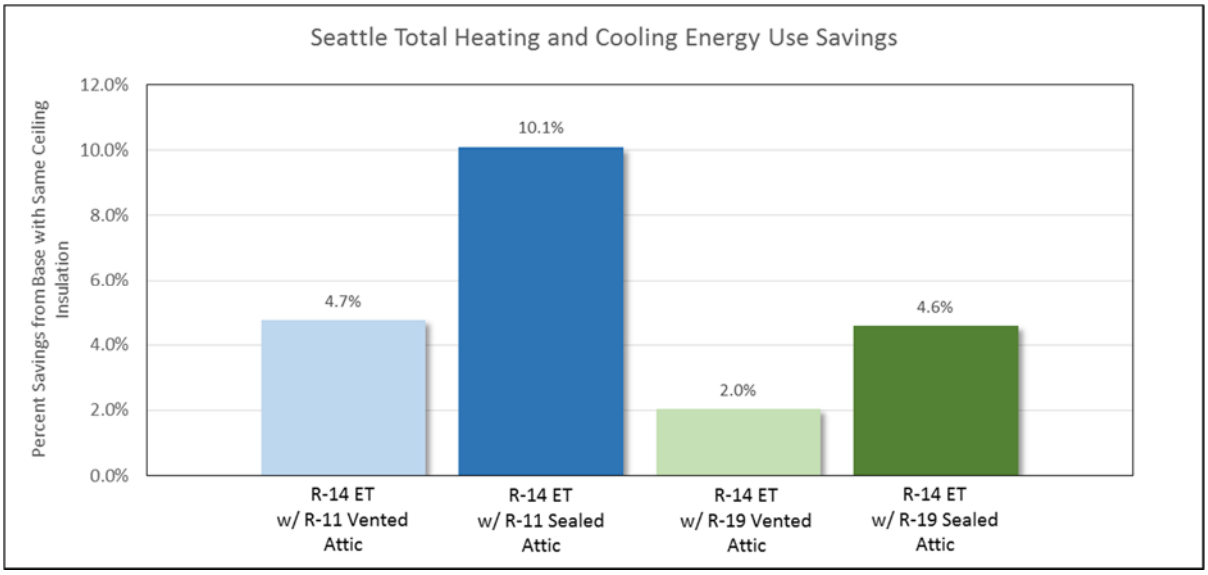


**Figure 10. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Seattle.**

Seattle temperature results showed a 4 to 8°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 30 to 37°F for the 3 IN 1 ROOFs.

## St. Louis

St. Louis simulation results are shown in Table 15. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 4.4% if the attic was left vented and 8.2% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 2.6% if the attic was left vented and 4.8% if the attic was sealed.

**Table 15. St. Louis Simulation Results**

| St. Louis, Missouri | Avg. July Attic | High Annual Attic | Heating | Heating | Heating | Cooling | Cooling | Heat & Cool | Percent |
|---|---|---|---|---|---|---|---|---|---|
| Attic/Roof Configuration | Temp ($^{o}$F) | Temp ($^{o}$F) | Therms | kWh | Btu x $10^6$ | kWh | Btu x $10^6$ | Btu x $10^6$ | Savings |
| R-11 Vented Base | 92 | 132 | 861.2 | 0 | 88.1 | 2887 | 9.9 | 97.9 | -- |
| R-11 Vented w R-14 ET | 83 | 97 | 837.5 | 0 | 85.6 | 2347 | 8.0 | 93.6 | 4.4% |
| R-11 Sealed w R-14 ET | 84 | 96 | 799.3 | 0 | 81.7 | 2389 | 8.2 | 89.9 | 8.2% |
| R-19 Vented Base | 93 | 135 | 794.5 | 0 | 81.2 | 2626 | 9.0 | 90.2 | -- |
| R-19 Vented w R-14 ET | 83 | 95 | 783.8 | 0 | 80.1 | 2252 | 7.7 | 87.8 | 2.6% |
| R-19 Sealed w R-14 ET | 85 | 95 | 763.3 | 0 | 78.0 | 2288 | 7.8 | 85.8 | 4.8% |

Figure 11 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for St. Louis.

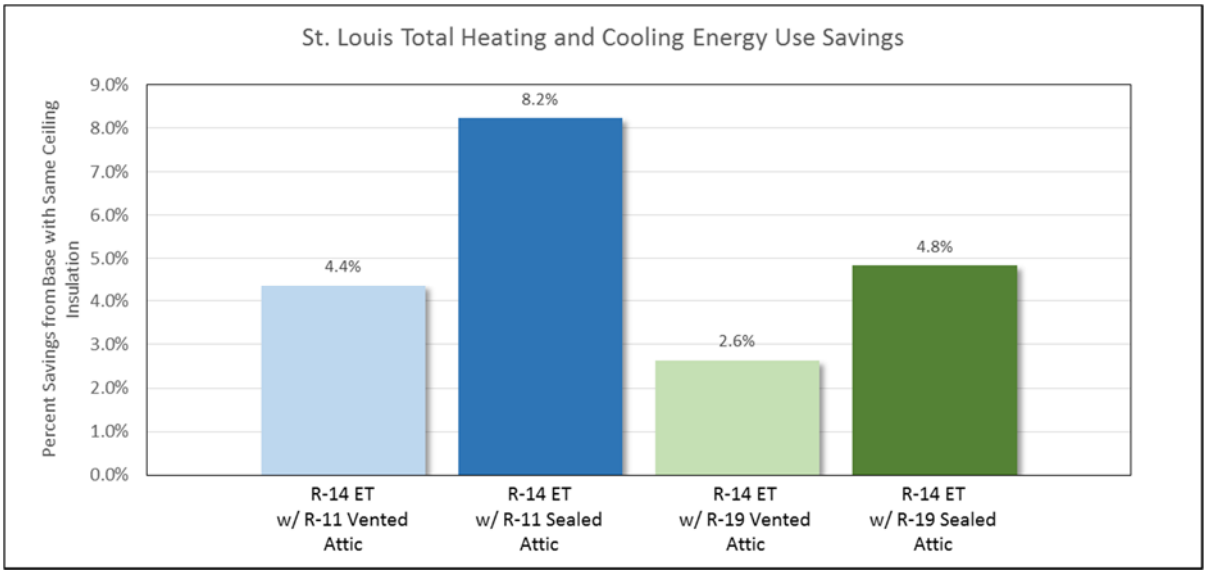


**Figure 11. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for St. Louis.**

St. Louis temperature results showed an 8 to 10$^{o}$F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 35 to 40$^{o}$F for the 3 IN 1 ROOFs.

## Minneapolis

Minneapolis simulation results are shown in Table 16. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 3.8% if the attic was left vented and 8.9% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 1.9% if the attic was left vented and 4.5% if the attic was sealed.

**Table 16. Minneapolis Simulation Results**

| Minneapolis, Minnesota Attic/Roof Configuration | Avg. July Attic Temp (°F) | High Annual Attic Temp (°F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| R-11 Vented Base | 85 | 126 | 1140.1 | 0 | 116.8 | 593 | 2.0 | 118.8 | -- |
| R-11 Vented w R-14 ET | 77 | 92 | 1104.6 | 0 | 113.1 | 334 | 1.1 | 114.3 | 3.8% |
| R-11 Sealed w R-14 ET | 79 | 90 | 1046.3 | 0 | 107.1 | 338 | 1.2 | 108.3 | 8.9% |
| R-19 Vented Base | 86 | 129 | 1045 | 0 | 107.0 | 477 | 1.6 | 108.6 | -- |
| R-19 Vented w R-14 ET | 78 | 93 | 1030.6 | 0 | 105.5 | 319 | 1.1 | 106.6 | 1.9% |
| R-19 Sealed w R-14 ET | 80 | 92 | 1002.7 | 0 | 102.7 | 328 | 1.1 | 103.8 | 4.5% |

Figure 12 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Minneapolis.

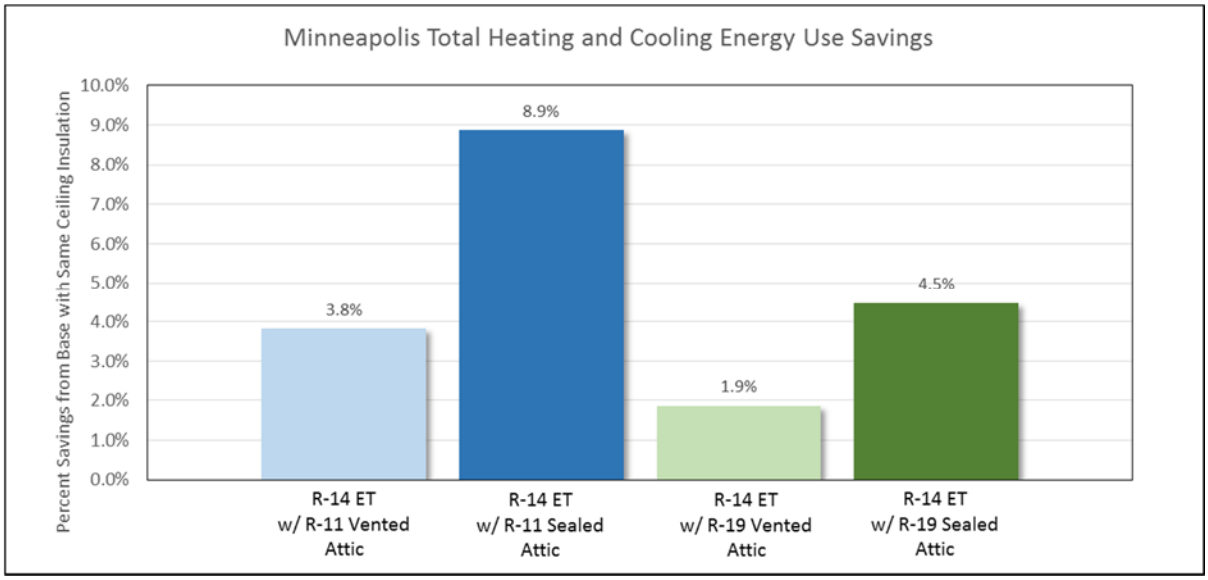


**Figure 12. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Minneapolis.**

Minneapolis temperature results showed a 6 to 8°F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 34 to 37°F for the 3 IN 1 ROOFs.

## Denver

Denver simulation results are shown in Table 17. Starting with an R-11 vented attic with a 1 to 300 attic vent ratio and composition shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 5.9% if the attic was left vented and 12.1% if the attic was sealed. Starting with an R-19 vented attic and shingle roof, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated at 3.0% if the attic was left vented and 6.4% if the attic was sealed.

**Table 17. Denver Simulation Results**

| Denver, Colorado | Avg. July Attic | High Annual Attic | Heating | Heating | Heating | Cooling | Cooling | Heat & Cool | Percent |
|---|---|---|---|---|---|---|---|---|---|
| Attic/Roof Configuration | Temp ($^{o}$F) | Temp ($^{o}$F) | Therms | kWh | Btu x $10^6$ | kWh | Btu x $10^6$ | Btu x $10^6$ | Savings |
| R-11 Vented Base | 86 | 139 | 699.6 | 0 | 71.6 | 886 | 3.0 | 74.7 | -- |
| R-11 Vented w R-14 ET | 76 | 92 | 674.1 | 0 | 69.0 | 367 | 1.3 | 70.3 | 5.9% |
| R-11 Sealed w R-14 ET | 78 | 91 | 628.7 | 0 | 64.4 | 376 | 1.3 | 65.6 | 12.1% |
| R-19 Vented Base | 86 | 143 | 628.9 | 0 | 64.4 | 662 | 2.3 | 66.6 | -- |
| R-19 Vented w R-14 ET | 76 | 94 | 620.1 | 0 | 63.5 | 351 | 1.2 | 64.7 | 3.0% |
| R-19 Sealed w R-14 ET | 79 | 94 | 597.4 | 0 | 61.1 | 364 | 1.2 | 62.4 | 6.4% |

Figure 13 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems compared with conventional roofs for Denver.

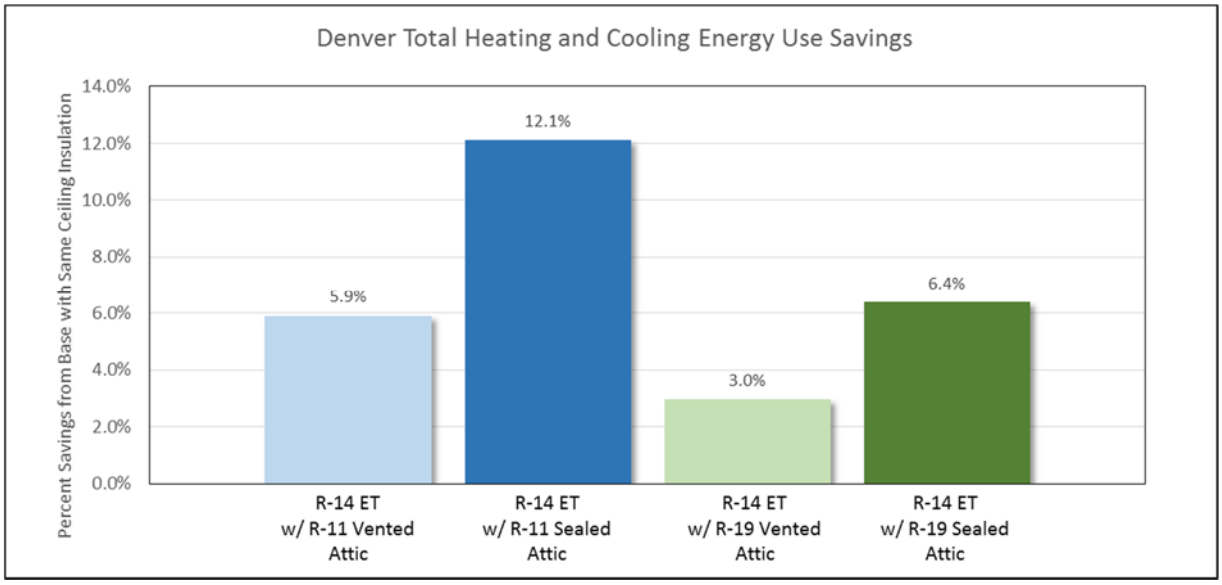


**Figure 13. Simulated total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Denver.**

Denver temperature results showed a 7 to 10$^{o}$F reduction in the average July attic temperature for the 3 IN 1 ROOFs compared with conventional composition shingle roofs, while peak attic temperature reductions ranged from 47 to 49$^{o}$F for the 3 IN 1 ROOFs.

## R-0 Ceiling Insulation Simulations

Results from additional simulations run in Miami and New York starting with R-0 ceiling insulation, 1 to 300 vent ratio vented attics and conventional barrel tile roof (Miami) or composition shingle roof (New York) are shown in Table 18. For Miami, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 29.3% if the attic was left vented and 33.8% if the attic was sealed. For New York, total heating and cooling energy savings from adding an R-14 3 IN 1 ROOF were estimated to be 19.1% if the attic was left vented and 33.5% if the attic was sealed. The uninsulated ceiling percentage savings for New York are much higher than savings for the cases with R-11 and R-19 ceiling insulation (2 to 8% savings). Figure 14 illustrates the simulated estimates of total heating and cooling energy use savings for R-14 3 IN 1 ROOF systems with R-0 ceiling insulation compared with conventional roofs with R-0 ceiling insulation for Miami and New York.

**Table 18. R-0 Ceiling Insulation Simulation Results**

| R-0 Ceiling Insulation | Avg. July Attic Temp ($^{o}$F) | High Annual Attic Temp ($^{o}$F) | Heating Therms | Heating kWh | Heating Btu x $10^6$ | Cooling kWh | Cooling Btu x $10^6$ | Heat & Cool Btu x $10^6$ | Percent Savings |
|---|---|---|---|---|---|---|---|---|---|
| Miami Vented Base | 85 | 103 | 0 | 142 | 0.6 | 9704 | 33.1 | 33.7 | -- |
| Miami Vented w R-14 ET | 79 | 83 | 0 | 66 | 0.3 | 6901 | 23.6 | 23.8 | 29.3% |
| Miami Sealed w R-14 ET | 80 | 83 | 0 | 43 | 0.2 | 6479 | 22.1 | 22.3 | 33.8% |
| New York Vented Base | 85 | 114 | 1431.4 | 0 | 146.3 | 2461 | 8.4 | 154.7 | -- |
| New York Vented w R-14 ET | 78 | 85 | 1177.7 | 0 | 120.4 | 1429 | 4.9 | 125.2 | 19.1% |
| New York Sealed w R-14 ET | 78 | 84 | 959.3 | 0 | 98.0 | 1432 | 4.9 | 102.9 | 33.5% |

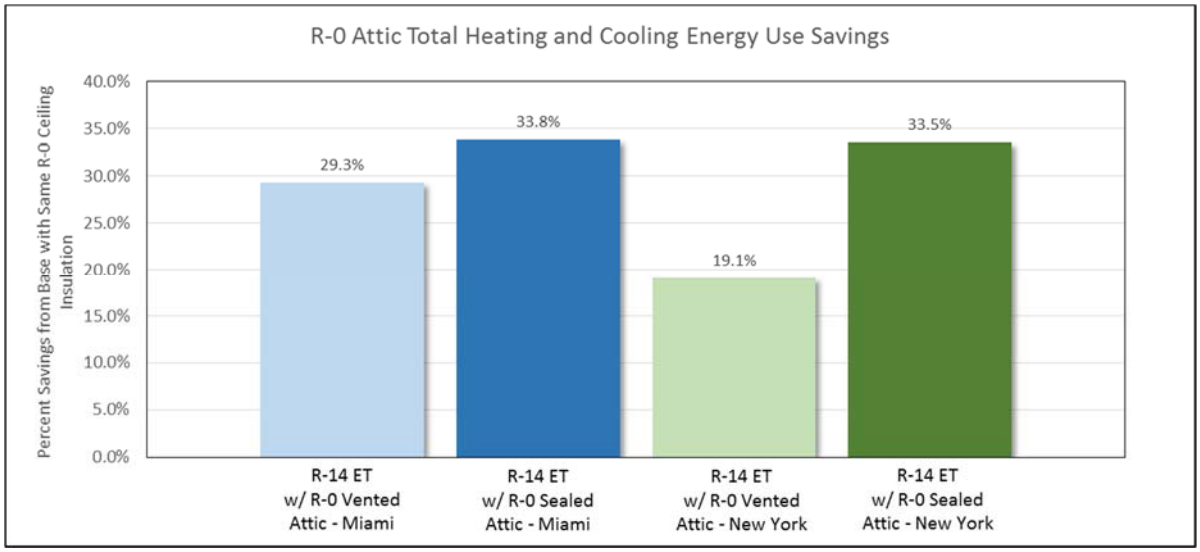


**Figure 14. R-0 ceiling insulation simulation total heating and cooling savings for 3 IN 1 ROOFs vs. conventional roofs for Miami and New York.**

Miami temperature results showed a 5 to 6$^{o}$F reduction in the average July attic temperature for the R-0 ceiling insulation 3 IN 1 ROOFs compared with R-0 ceiling insulation conventional barrel tile roofs, while the peak attic temperature reduction was 20$^{o}$F for the 3 IN 1 ROOFs. New York temperature results showed a 7$^{o}$F reduction in the average July attic temperature for the R-0 ceiling insulation 3 IN 1 ROOFs compared with R-0 ceiling insulation conventional composition shingle roofs, while peak attic temperature reductions ranged from 29 to 30$^{o}$F for the 3 IN 1 ROOFs.

## Summary and Conclusions

FSEC has simulated conventional roof configurations and 3 IN 1 ROOF configurations. Cities with more cooling energy use will tend to experience more energy savings than applications in heating climates. For example, applying the 3 IN 1 ROOF over an R-11 ventilated ceiling attic in Miami is projected to save over 20% of combined heating and cooling energy use, while the same application in Minneapolis is estimated to save under 4% of combined heating and cooling energy use.

Sealing the attic at the same time as the application of the foam tile may double the savings in heating dominated climates (e.g., Minneapolis and New York). Sealing the attic also increases savings in cooling dominated climates (e.g, savings for the R-11 ceiling insulation case go from 21.3% vented attic to 26.6% sealed attic in Miami and 21.5% to 26.9% in Houston).

The total savings and the percentage savings will tend to be reduced as the house becomes more efficient. As indicated in Table 2, the simulations run are for older, poorly insulated houses with inefficient heating and cooling systems and leaky ducts. The technology is somewhat sensitive to the level of ceiling insulation. A vented attic with R-19 ceiling insulation (instead of R-11 ceiling insulation) reduces savings from 21.3% to 17.5% in Miami and from 3.8% to 1.9% in Minneapolis.

Summer attic temperatures are greatly reduced with foam roofs as modeled. Peak attic temperature reductions ranged from 30 to 52$^{o}$F. The solar reflectance of 0.43 is a large improvement over a typical shingle or dark tile roof. Furthermore, the foam roof configuration has R-14 level of insulation protecting the attic. Some cities were modeled with ductwork in the attic, and the cooler attic for those cases is a significant benefit in summer; in winter however, there are times when a cooler attic may increase the need for heating. Prior to installation of a cool roof product, it is recommended that ducts be inspected for sections that may be uninsulated. Uninsulated supply ducts in cooler attics may lead to condensation (condensation may also occur in in hotter attics, but cooler attics may not dry out as well).

As expected, the R-0 ceiling insulation simulations showed increased 3 IN 1 ROOF savings compared with R-11 and R-19 ceiling insulation cases for both Miami and New York. The New York savings increased the most, going from 4.0% for an R-14 3 IN 1 ROOF with R-11 vented attic to 19.1% for an R-14 3 IN 1 ROOF with an R-0 vented attic, both compared with base vented attics. Similarly, savings for a New York R-14 3 IN 1 ROOF with a sealed attic increased from 8.3% with R-11 ceiling insulation to 33.5% for the same sealed attic with R-0 ceiling insulation, again both compared with base vented attics with composition shingle roof.

3 IN 1 ROOF, as modeled, offers great potential to reduce energy use in many older homes. It will also create a much cooler attic compared with traditional vented attics.