FSEC Energy Research Center

UNIVERSITY OF CENTRAL FLORIDA

Final Report

Review and Consider Possible Technical Changes to section 553.9065, Florida Statutes

Submitted to
Department of Business and Professional Regulation
Office of Codes and Standards
2601 Blair Stone Road
Tallahassee, FL 32399
Contract No. 132677

Prepared by:
Rob Vieira, Chuck Withers, Philip Fairey,
Florida Solar Energy Center

Date: 11/04/2024

Disclaimer

The Florida Solar Energy Center/University of Central Florida nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Florida Solar Energy Center/University of Central Florida or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the Florida Solar Energy Center/University of Central Florida or any agency thereof.

EXECUTIVE SUMMARY

Pursuant to section 553.9065, Florida Statutes, the Florida Building Commission (FBC) has been tasked with the review and consideration of the legislative requirements for unvented attics as outlined in section 553.9065, Florida Statutes. The purpose of the review is to provide proposed technical changes and to report such changes to the Legislature by December 31, 2024. Specific language of relevance is provided here:

Section 553.9065 Thermal efficiency standards for unvented attic and unvented enclosed rafter assemblies.

(1) Unvented attic and unvented enclosed rafter assemblies that are insulated and air sealed with a minimum of R-20 air impermeable insulation meet the requirements of sections R402 of the Florida Building Code, 8th Edition (2023), Energy Conservation, if all of the following apply:
   (a) The building has a blower door test result of less than 3 ACH50.
   (b) The building has a positive input ventilation system or a balanced or hybrid whole-house mechanical ventilation system.
   (c) If the insulation is installed below the roof deck and the exposed portion of roof rafters is not already covered by the R-20 air-impermeable insulation, the exposed portion of the roof rafters is insulated by a minimum of R-3 air-impermeable insulation unless directly covered by a finished ceiling. Roof rafters are not required to be covered by a minimum of R-3 air impermeable insulation if continuous insulation is installed above the roof deck.
   (d) All indoor heating, cooling, and ventilation equipment and ductwork is inside the building thermal envelope.

This report provides a literature review of moisture and energy research related to unvented attics. This report supplements that literature review with data on house tightness and duct tightness relative to vented and unvented Florida attics. This report also provides results of 348 hourly building simulations to examine the annual energy impacts of the Section 553.9065, Florida Statutes specifications with respect to the current prescriptive R402 code compliance requirements and other possible alternatives.

There are currently a number of builders using unvented attics in Florida. Most homes comply by the section R405 performance methodology. Under the R405 methodology, homes with R20 roof insulations can comply through energy-use trade-off allowances. There have been a limited number of research projects examining unvented attics in Florida as well as some in other parts of the country. The literature search finds mixed results regarding moisture and energy use in unvented attics. One of the key parameters that is not regularly measured is the air leakage between the unvented attic and the outside. This can significantly impact moisture and energy use. Most moisture research has not found issues with roof sheathing wood moisture content exceeding 20% in Florida homes with unvented attics having air-impermeable insulation at the roof sheathing. When this 20% moisture content threshold is approached the studies have found that it tends to occur for only short periods of time. Any regulatory changes to the application with respect to moisture would apply to unvented attic homes complying by both the prescriptive and the performance methods.

Published data on measured attic tightness and duct leakage shows there is a wide variability in both. Tests on duct leakage in unvented attics indicates on average there is some duct leakage to outdoors. On occasion, some unvented attics are found to be leakier than desired, which may result in more duct leakage lost to outdoors and increased infiltration. This may make attic moisture control more difficult. Excessive unvented attic moisture levels are sometimes remediated by supplemental dehumidification of the attic space, and if the attic is not well sealed this may result in much higher than expected energy costs for homeowners. An attic tightness-to-outdoors test protocol capable of indicating a reasonable assuredness of attic tightness to outdoors is needed. If possible, such a test should not require guarded testing, if possible, to enable a relatively quick and inexpensive means of evaluation. The legislation requires a tested house airtightness blower door test of less than 3 ACH50. That test should be conducted according to section R402.4.1.2 of the Florida Building Code, 8th Edition (2023), Energy Conservation where it states:

> *If an attic is both air sealed and insulated at the roof deck, interior access doors and hatches between the conditioned space volume and the attic shall be opened during the test and the volume of the attic shall be added to the conditioned space volume for purposes of reporting an infiltration volume and calculating the air leakage of the home.*

This requirement, combined with the less than 3 ACH50 requirement, should reduce the risk of excessive unvented attic leakage.

There is a dearth of detailed data on leakage from unvented attics to the outside and attic duct leakage to outside in the literature on energy simulations. As a result, it is still difficult or impossible to compare results between different simulation studies. This is due to issues such as using different assumptions about attic, house, and duct tightness, attic and house geometries, and different levels of roof and ceiling insulation R values being compared. Generally, energy simulations comparing benefit of unvented attic with insulation at the underside of roof sheathing to a conventional vented attic with insulation at the ceiling found that more benefit is likely: with cold dominated climates, with a greater proportion of attic ducts, with higher rates of assumed attic duct leakage, and with a very little unvented attic leakage to outside.

The simulations run by FSEC for this analysis indicate some increase in energy use for the minimal Section 553.906, Florida Statutes/R402 compliance path in many but not all simulated homes. Simulations were run in Miami (Climate Zone 1) and Tallahassee (Climate Zone 2) using three prototype homes: a detached 2000 ft^2 one-story home, a detached 2400 ft^2 detached two-story home, and a multifamily attached unit with 1200 $ft^2$of conditioned space. Our simulations indicate that reducing the prescriptive requirement from R30 on the ceiling in Climate Zone 1 (or R38 on the ceiling in Climate Zone 2) to a roof insulation level of R20 by itself, leaving all other parameters the same, will increase energy use even without any attic dehumidification. Also, higher roof pitches will diminish any energy benefit of an unvented attic as the thermal surface boundary area of the attic increases. However, since the statute change requires a very tight home with whole-house mechanical ventilation, the type of ventilation system and the energy impact it has must also be considered. Balanced mechanical ventilation with enthalpy recovery used less energy than the three other types simulated. The statute requirements for a tight house led to the legislative prescriptive alternative saving some energy in our two-story simulation results with best case whole-house mechanical ventilation, while using more energy in our single floor simulation results.

With respect to the current R402 prescriptive code base case, the worst case for the 2000 ft^2 single story home using the statute method of R20 roof insulation without any ceiling insulation, with a balanced ventilation system without enthalpy recovery, led to an increase of 18% in heating, cooling and ventilation energy in Climate Zone 2 and 9% increase in Climate Zone 1. The best-case scenario with R20 roof insulation and no ceiling insulation is the two-story home modeled with an enthalpy-recovery ventilation system. Relative to the current R402 levels of insulation and air tightness, this home saved 1% of HVAC energy in Climate Zone 2 and 4% in Climate Zone 1.

Two alternatives to the statute proposal were simulated. One alternative configuration had R20 insulation on the roof plane and R19 at the ceiling. This alternative should meet the current R402 code. The simulation results of this system were better than just having insulation at the ceiling or just at the roof for low slope (4 in 12) roofs prior to adding ventilation. The second alternative had R20 insulation on the roof plane and R11 at the ceiling. On average, of the 24 comparative cases we simulated for Climate Zone 2 this showed minimal difference (0.5% higher HVAC energy use) from the current R402 base case. In Climate Zone 1, the R20 roof with R11 ceiling insulation showed improvement on average for the 24 comparative cases simulated (1.6% reduction in HVAC energy use) versus the current Climate Zone 1 R402 base case. With 2x4 trusses, this level of ceiling insulation would allow plywood flooring in the attic for those residents desiring a safer storage area.

Because Section 553.906, Florida Statutes includes a targeted reduction in air leakage and employs whole-house mechanical ventilation, the homes complying by this method may have better air quality potential as long as the ventilation system runs and is maintained. Thus, it may be reasonable to accept slightly higher energy use for this alternative, as the home should have improved indoor air quality if the ventilation system is maintained. Unfortunately, previous research for the Florida Building Commission has shown that rarely are whole house mechanical ventilation systems maintained and operated in their designed condition.[1]

In summary, based on the current literature, there are no technical changes to the legislation required for unvented attics for moisture control. To achieve roughly the same equivalent energy use it is recommended that a requirement for at least R11 at the ceiling be included and that balanced ventilation systems would be required to have enthalpy recovery. Such changes are indicated with underline text below:

> Unvented attic and unvented enclosed rafter assemblies that are insulated and air sealed with a minimum of R-20 air impermeable insulation meet the requirements of sections R402 of the Florida Building Code, 8th Edition (2023), Energy Conservation, if all of the following apply:
>
> (a) The building has a blower door test result of less than 3 ACH50.

[1] https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-CR-2002-15.pdf

(b) The building has a positive input ventilation system or a balanced with enthalpy recovery system or hybrid whole-house mechanical ventilation system.

(c) If the insulation is installed below the roof deck and the exposed portion of roof rafters is not already covered by the R-20 air-impermeable insulation, the exposed portion of the roof rafters is insulated by a minimum of R-3 air-impermeable insulation unless directly covered by a finished ceiling. Roof rafters are not required to be covered by a minimum of R-3 air impermeable insulation if continuous insulation is installed above the roof deck.

(d) All indoor heating, cooling, and ventilation equipment and ductwork is inside the building thermal envelope inclusive of the unvented insulated attic.

(e) A minimum of R-11 insulation is located at the ceiling of the conditioned space below the attic.

Contents

Table of Figures

Table of Tables

Final Report

Review and Consider Possible Technical Changes to section 553.9065, Florida Statutes

University of Central Florida's Florida Solar Energy Center (FSEC)
Prepared by: Rob Vieira, Chuck Withers, Philip Fairey, Florida Solar Energy Center

1. Introduction

Pursuant to section 553.9065, Florida Statutes, the FBC has been tasked with the review and consideration of the legislative requirements for unvented attic as outlined in section 553.9065, Florida Statutes for the purpose of providing technical changes and reporting such changes to the Legislature by December 31, 2024. An unvented attic is the unoccupied volume above conditioned occupied space and has no intentional vent pathways directly to outdoors. Sometimes the term "sealed" attic is used in place of unvented more commonly found in older literature. Unvented may be more preferable since sealed may be interpreted by some to assure an adequate level of attic tightness has been achieved.

Section 553.9065 Thermal efficiency standards for unvented attic and unvented enclosed rafter assemblies.

(1) Unvented attic and unvented enclosed rafter assemblies that are insulated and air sealed with a minimum of R-20 air impermeable insulation meet the requirements of sections R402 of the Florida Building Code, 8th Edition (2023), Energy Conservation, if all of the following apply:

- (a) The building has a blower door test result of less than 3 ACH50.
- (b) The building has a positive input ventilation system or a balanced or hybrid whole-house mechanical ventilation system.
- (c) If the insulation is installed below the roof deck and the exposed portion of roof rafters is not already covered by the R-20 air-impermeable insulation, the exposed portion of the roof rafters is insulated by a minimum of R-3 air-impermeable insulation unless directly covered by a finished ceiling. Roof rafters are not required to be covered by a minimum of R-3 air impermeable insulation if continuous insulation is installed above the roof deck.
- (d) All indoor heating, cooling, and ventilation equipment and ductwork is inside the building thermal envelope.

FSEC was contracted to conduct a literature review of available field study and research papers published on the subject of moisture in unvented attics and evaluate the impact of the thermal efficiency standards for unvented attic of section 553.9065, Florida Statutes on moisture within unvented attics, and the energy use of Florida homes relative to the provisions of the Prescriptive Compliance Method of the 8th Edition (2023) Florida Building Code, Energy Conservation – Residential Provisions.

2. Scope of Work:

a. Literature Survey

The objective of this task is to review available research literature particularly as it applies to moisture in unvented attics. This review will help provide guidance for various installations that may become more prevalent with the new legislation.

- FSEC conducted a literature review of available field study and research papers published on the subject of moisture in unvented attics.
- FSEC provided a summary of the literature survey outlining the recommendations and conclusions of each research project reviewed.

b. Evaluate the energy performance of the thermal efficiency standards for unvented attic as depicted in section 553.9065, Florida Statutes

The objective this task is to evaluate the impact of the thermal efficiency standards for unvented attic of section 553.9065, Florida Statutes on the energy use of Florida homes relative to the provisions of the Prescriptive Compliance Method of the 8th Edition (2023) Florida Building Code, Energy Conservation – Residential Provisions.

- FSEC performed simulations to quantify the energy use differences between the unvented attic energy measures of section 553.9065, Florida Statutes, and that of the prescriptive compliance method of the 8th Edition (2023) Florida Building Code, Energy Conservation – Residential Provisions.
- The analysis recorded the expected change in energy use via a matrix of 280 simulations that vary residence types (one-story, two-story, flat), location, duct tightness, mechanical ventilation, roof pitch, and ceiling and roof insulation levels.
- Based on the simulation results, the likely predicted average change in energy use due to the new legislation is determined.

c. *Summarize findings and make recommendation in a final report to the Florida Building Commission.*

- FSEC presents results in a final report and, if requested, will present these results to the FBC Energy TAC or full commission.

3. Literature Review

Studies have found the measured air tightness of houses, unvented attics, and duct systems may vary significantly from house to house and that these are important variables shown to impact energy simulation results. House, attic and duct tightness as well as implicated energy conservation benefits are the most common discussed attributes of unvented attics with insulation on the sloped roof. Therefore, findings from studies characterizing air tightness and variability in energy simulations are discussed in some detail to provide, in part, a better understanding on why energy predictions may be significantly different. The literature review is organized into three primary sections. The first section provides a general synopsis of the review. The synopsis covers a broad timeline of unvented attic research, and concentrates on attic and duct airtightness, energy impacts, and attic moisture control in hot humid climates. The second section of review covers studies relevant to moisture control in unvented attics having sprayfoam applied to the underside of roof sheathing. This second section provides a brief summary of specific studies that are arranged chronologically with each summary focused primarily on attic moisture. The third section provides details of referenced studies noted within the synopsis or noted as a reference within another study discussed.

3.1. General Synopsis

The literature search found that unvented attic research began around the early 1990's. Attics without intentional venting are called "sealed" attics in some publications. The notation is to indicate a state of either not venting the attic by design or when pre-existing attic vents become sealed in a retrofitted effort to eliminate air flow from outdoors into the attic. Some within the building industry prefer the term "unvented" attic to avoid the potential insinuation that the attic is airtight by some regulation, standard, or definition. Since studies show unvented attics have a wide range in normalized airtightness, a term avoiding "sealed" appears warranted.

An early focus was on simulated space conditioning energy impacts and thermal impacts upon roof materials Parker et al. (1991), Beal et al. (1995), and Rudd (1996). The potential benefits of limiting condensation potential in attics by unventing attics in hot humid climates shows up in a 1993 HUD research report. In research on attic moisture problems in manufactured homes, TenWolde and Burch (1993) recommended that roof cavities not be ventilated in hot humid climates as a means to limit condensation in attics.

Published research found from the period covering years 2000 to 2022 focused on more simulation as well as measured moisture in attic air and attic materials in small studies in real homes. The most recent research in hot and humid climates involves measurements of attic air and attic wood moisture content (WMC) in occupied homes over a period of one to three years. Anecdotally, it is known that open cell low density spray foam or closed cell high density spray foam are used on sloped roofs in unvented attics in Florida. Specific performance will vary upon product, thickness applied, and quality of installation. Both types of spray foam insulations are air impermeable. Open cell, also known as low density, has a density of about 0.5 lbs/ft^3 and vapor permeability of about 16 perms through 3 inches and 10 perms through 5 inches thickness. Closed cell, also known as high density, has a density of about 2.0 lbs/ft^3 and much lower vapor permeability of less than 1 perm through 2 inches thickness CARB (2009). Only open cell insulation has been noted in the published research found in Florida. The consensus of all studies that regarded hot and humid dominated climates was that attic WMC was at acceptable levels in unvented attics with open cell spray foam applied to roof sheathing. The highest roof sheathing WMC occurred during the coldest weather overnight, when the roof sheathing would be coldest. WMC values over 20% in properly installed spray foam attics were rare. When they did occur, they did not last long enough to result in mold or moisture issues. WMC at 20% or higher is considered a threshold limit where there is much higher potential for mold or mildew growth when maintained for several weeks. Mold and mildew growth are dependent upon ample moisture, type of surface material, and temperature among other factors. In addition to WMC, the attic air moisture control is also of concern. Some research has measured elevated attic air RH maintained over 60%. High attic air RH is more likely to occur during warm moist weather as outdoor air infiltrates through air cracks and may permeate through some vapor permeable materials into the attic. Attic air RH is a function of attic tightness to outdoors and to indoors, internal moisture generation, as well as the drybulb air temperature within the attic.

Using conditioned air into the unvented attic with open cell spray foam as one method that may improve attic air humidity control within the attic (Lstiburek, J. 2016). This practice is now part of International Residential Code 2021, Section R806 only applying to when air-permeable insulation is applied against the roof sheathing within the attic with some exceptions. Some contractors resort to installing stand-alone dehumidifiers into unvented attics to control attic RH. One study (Rudd et al. 2005) found that this practice may significantly increase the home energy use. Two homeowners in this study having stand-alone dehumidifiers in the attic complained of high energy consumption, however accepted it since the attics were maintained very dry (Rudd et al. 2005 pg. 19).

3.1.1. Measured Energy Impacts

Brennan et al. (2016) compared measured energy impacts from a few available studies. The authors claim that actual measured energy impacts of "sealed and insulated attics" were rarely reported in literature. Four studies indicated benefits by either heat and/or cool energy, or peak cooling demand reduction (Hendron et al. 2002; Hendron et al. 2003; Parker et al. 2002; Rudd & Lstiburek 1996). No negative energy benefits were noted. Only two studies claimed measured energy savings, that varied from 6% to 20% (Hendron et al. 2002; 2003) (one home Las Vegas, NV) and (Parker et al. 2002) (one home Fort Meyers, FL). The Hendron studies compared one unvented attic with R22 at roof to one vented attic with R30 ceiling. They reported "max 20% cooling energy savings with very leaky ducts". The maximum duct leakage was reported as " > 100 cfm supply and return leakage". Parker et al. (2002) compared one unvented R19 at roof attic to a vented attic with R19 on ceiling. The roof was noted as a dark asphalt shingle. Duct leakage was variable in Hendron et al. 2002; 2003, which indicated that higher duct leakage in vented attic resulted in better savings when contained within an unvented attic.

3.1.2. Simulated Energy Impacts

Brennan et al. (2016) reviewed simulated energy results from thirteen different studies (Desjarlais, Petrie, & Stoval, 2004; GARD Analytics, Inc., 2003a; Hendron et al., 2002, 2003; Hoeschele et al., 2015; W. A. Miller et al., 2013; W. A. Miller & Kosny, 2008; Parker et al., 2002; Roberts & Winkler, 2010; Rudd & Lstiburek, 1996, 1998; Siegel, Walker, & Sherman, 2000; Wei et al., 2014). A summary of the thirteen studies claimed that a wide variety of results were noted. The range in simulated results may be attributed to varying climate, "*complex physics of attics*", varying insulation levels used for flat ceiling vs sloped roof, and type of roof covering. Most studies reported simulated annual energy savings mostly between 2%-10%, and no more than 20%. Two studies predicted increased energy use with unvented and insulated roof design (Hendron et al. 2002) and (GARD Analytics, Inc. 2003). Duct leakage appeared to be a big factor in predicted energy impact.*"Some simulations suggest that energy benefits disappear when duct leakage is reduced to low levels (<5 or 6%) (GARD Analytics, Inc., 2003a; Hendron et al., 2002, 2003), whereas others indicate that modest but meaningful differences still exist with tight ducts (Hoeschele et al., 2015; Rudd & Lstiburek, 1998; Siegel et al., 2000; Wei et al., 2014)."*

Recent simulation research by Janusz and Acosta (2021) had a goal to see how much the effective R-value of insulation at the unvented attic roof could be reduced without any energy use change compared to a vented attic with code-compliant insulation on ceiling. This study found the general trends of less benefit from unvented attic in warmest climates and with less ducts or duct leakage in attics similar to such trends of other studies previously noted. Janusz and Acosta (2021) concluded, "*The results show that by switching from a vented attic to an unvented attic design, insulation R-values can be significantly lower than would be required for insulation at the floor of a vented attic without increasing energy consumption. This result is only true because ducts were located in the vented attic, which means by switching to an unvented attic, thermal losses from ductwork to the unconditioned attic space are eliminated. The results also display a significant degree of climate dependence.*" Janusz and Acosta (2021) simulation study used EnergyPlus Version 9.5 and PNNL 2021 IECC Residential Prototype Building Models for 4 different heating systems and four different foundation types with many more variables such as duct fractional location in different zones accounted for. A curious trend of aggregated results for single-family construction (Table 4.1 Janusz and Acosta (2021)) showed effective R-value of unvented insulation at roof could be reduced the least (only 3%) in Climate Zone 1 having relatively little ducts in the attic, however the R-value reduction was claimed to be much higher at 46% for CZ1 having a high fractional amount of ducts in the attic. Janusz and Acosta (2021) discuss that some specific types of simulation runs did show a very small increase of less than 1% in EUI within Climate Zones 1 and 2. Janusz and Acosta (2021) conclude, "*Finally, if no ducts or air handling equipment are located in the attic, converting the vented attic to an unvented attic does not achieve energy savings, even if the roof R-value were to match that of the ceiling in the baseline vented attic case. This is because the building envelope area and house volume increases when insulation is placed at the roof line. Thus, assuming equivalent tested airtightness (ACH_{50}), reducing the effective assembly R-value of the unvented attic roof relative to the baseline vented attic scenario would increase energy consumption. This is both due to increased air leakage in the modified, unvented attic models due to greater building volume, as well as increased conduction through the roof assembly, due to greater surface area of the thermal enclosure*."

Available research has shown that attic and duct air tightness were important variables impacting energy use. Furthermore a wide variety in tightness was found within and among studies. For example, different studies used different test methods and often only certain attributes of attic or duct tightness were known. This can make it difficult or impossible to compare some test values to others. Some research tested various homes in different locations spanning several years. In other cases tests were conducted on unvented insulated roof homes either new or several years after constructed with age or spray foam industry maturity having some impact. Given the importance of attic and duct tightness details to simulation or measured energy impacts, the topic of unvented attic and duct airtightness are covered in more detail.

3.1.3. Unvented Attic Tightness

Canadians were among the first to test unvented attic leakage in the early 1990s in efforts to better understand roof sheathing moisture problems in cold climates soon to be followed by American researchers interested in performance in other Climate Zones. Different studies have measured attic tightness differently, which is problematic for establishing realistic simulation leakage inputs. An attic zone may have air leakage to outdoors, between the occupied space, and possibly to other unconditioned zones to consider. The most popular and expedient method to have some idea of the attic leakage is to test house leakage with one single test fan in an outside doorway with attic hatch to house closed and then repeat with it with attic hatch open. However, this method is likely to under-predict house + attic tightness and does not accurately determine specific components of tightness such as attic to out, house to out, house and attic to out and house to attic tightness. Different methods of characterizing attic leakage makes it more difficult to compare studies or determine reasonable values for simulations with any confidence. Another challenge is determining attic volume for many homes particularly with more complex roof geometry. This makes normalizing attic leakage by attic volume to outdoors difficult.

The studies noted within this section on attic tightness find the unvented attic tightness to outdoors as a percent of total house leakage represented a study-weighted average of 51% based on 67 homes (n=56 52%, n=6 54%, n=4 28%, n=1 69%) with a wide range varying from 4% to 69%. There was also a wide variation in unvented attic tightness across the adjacent ceiling ranging from 4% up to about 70% of the total house and attic tightness.

The most recent published unvented attic tightness test results in Florida come from Kaufman et al. (2024), Martin and Withers (2021), and Prevatt et al. (2017). Each study report provide substantial details on house characteristics. The Kaufman et al. (2024) study evaluated experimental attic designs and did not have insulation on sloped roof.

In the most recent published study found, new single family 2 story townhomes in Debary, Florida one unvented attic home had extensive airtightness testing completed (Kaufman et al. 2024). Guarded airtightness tests of attic and occupied space as well as unguarded house and attic tests with attic hatch to indoors were completed. The visual concept of a guarded airtightness test of attic and house is shown in Figure 1. Not all Airtightness test data collected by UCF/FSEC became fully reported in Kaufman et al. (2024). Table 1 shows the full complement of measured airtightness data not previously published to illustrate the breakdown of total tightness across different air boundary layers in a modest sample of one. The common energy rater air tightness test measure method (unguarded, one blower door fan in house doorway and attic hatch to house open) is shown to demonstrate that this type of test will tend to under-predict house + attic CFM50. The unguarded test of house + attic leakage is less than the guarded house + attic CFM50 test because the attic is not quite depressurized to -50 Pa wrt out due to some flow restriction from attic hatch size. This is common. The guarded house + attic test CFM50 was used as a baseline of comparison for other boundary tightness results in Table 1. The attic CFM50 leakage to out represented 69% of the total house with attic hatch open leakage and 68% of the total attic tightness. The attic volume was determined, thus the normalized attic leakage ACH50 to out was 36.8. When attic volume is not known, the base area of the attic is more easily derived and can also be used to normalize the attic leakage. Normalizing by attic floor area has not been observed in other literature and may have potential biases to consider that are not established at this time. The attic CFM50out/ft^2 of attic base area was 1522/758=2.01 CFM50/ft^2. The ceiling boundary between attic and 2nd floor represented 33% of the total leakage.

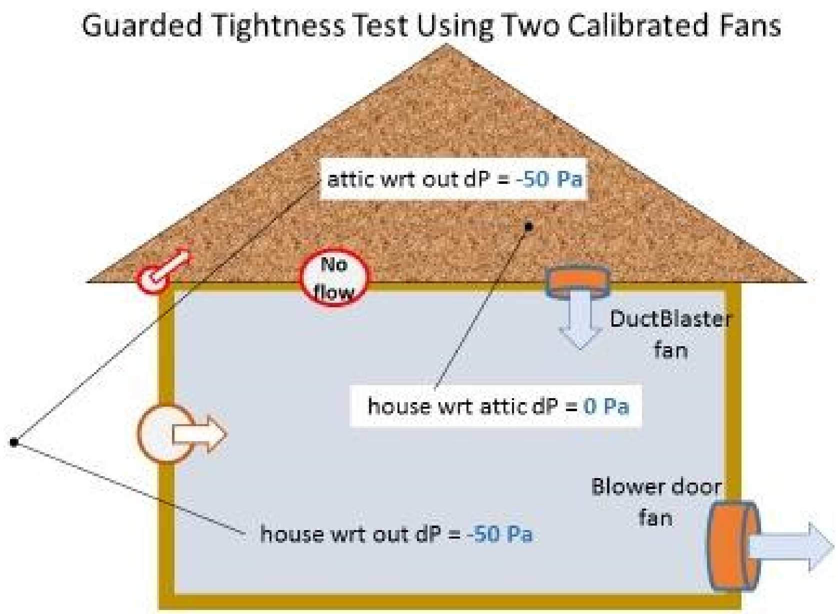

Figure 1. Illustration of guarded airtightness test in unvented attic.

Table 1. Guarded and Unguarded Air Tightness Testing Results of One DeBary, Florida Unvented Attic Home Used to Show Air Leakage Distribution Across Different Air Boundary Planes

Tightness Test	CFM50	ACH50out	Air boundary CFM50 as % of House and Attic CFM50
House leakage to out with attic hatch open (unguarded rater test- 1fan)	1,827	1827/ 11331 ft^3 x 60= 9.67	N/A
House + attic leakage to out (guarded-2 fans) Basis of Comparison	2,207	2207/ (11331 ft^3+2458 ft^3) x 60 = 9.58	100%
Attic to out (guarded)	1,522	1522 / 2458 ft^3 x 60= 36.75	69.0%
House to out (guarded)	685	685 / 11331 ft^3 x 60= 3.63	31.0%
Attic to indoor (guarded); 2nd floor ceiling	727*	N/A	32.9%*
House boundary characteristics; Production builder, two-story total 1,366 ft^2 under air, slab on grade, block wall, flat drywall ceiling to attic, 2nd floor ceiling to attic boundary was 758 ft^2 and had 27 ceiling penetrations (e.g. registers, light fixt., smoke alarms). Attic unvented using wood blocking between roof truss between soffit and attic as well as a vapor diffusion membrane cover on upper off-ridge vents.			

* ceiling cfm50 determined using attic total tightness – attic tight to out.

Detailed comparison of Martin and Withers (2021) and Prevatt et al. (2017) studies are provided in Martin and Withers (2021) Appendix E as these studies focused specifically on spray foam on sloped roofs in Florida. These studies conducted guarded tests of house and attic. Comparison of these two studies involving 10 homes show wide variability in attic to out tightness. The Attic CFM50 to out was normalized by dividing it by attic floor area (ft2) instead of attic volume. The

Martin study attic tightness to outdoor average was 0.233 CFM50/ft2 and Prevatt average almost two times higher at 0.422 CFM50/ft2. One Prevatt study home had attic to out CFM50/ft2 leakage 1.9 times leakier than Prevatt average. If that one value is eliminated, the Prevatt attic average drops to 0.153 CFM50/ft2. Table 2 from Martin and Withers (2021) is shown here to provide more details about the test results from both compared studies. House + Attic CFM50 represents guarded test with attic hatch open to house and both zones at – 50 Pa with reference to outdoors. The Attic Leak Ratio is the attic leakage to outdoors expressed as a percentage of the attic and house leakage total to outdoors (tested with attic hatch to house open). Attic Leak Ratio = Attic to out CFM50 / House + Attic CFM50. The guarded tests show that the average attic leakage to out represented 44% of the combined house + attic leakage total for Martin and Withers (2021). The two-story homes of Martin and Withers (2021) had attic leak ratio of almost half the six home average. When the House + Attic CFM50 is adjusted in proportion to the attic floor area to total floor area the attic leak ratio is much closer to average with house 2 and house 6 having attic leak ratios of 51.7% and 56.3% respectively. The Prevatt study showed an average attic leak ratio of only 27.9%, but this is mostly because the Prevatt house and attic leakage to outdoors were much leakier.

Table 2. Guarded Air Tightness Testing Results of Unvented Attic Homes Completed by Two Different Research Projects (Martin and Withers (2021)

House ID	House + Attic CFM50	Attic to out CFM50	House to Out CFM50	House to Out CFM50/ft^2 *	Attic CFM50/ft^2 **	Attic Leak Ratio	House + Attic ACH50***
FSEC Study							
N.E. Jacksonville 1	768	388	380	0.209	0.213	50.5%	2.8
Jacksonville Bch 2 (2story)	1450	324	1126	0.348	0.232	22.3%	2.9
Umatilla 3	1730	1198	532	0.150	0.338	69.2%	2.7
Fernandina Bch 4	1297	686	611	0.227	0.255	52.9%	2.7
Pontre Vedra Bch 5	623	271	352	0.159	0.123	43.5%	1.7
Pontre Vedra Bch 6 (2 story)	920	259	661	0.305	0.719	28.2%	2.6
Average	1131	521	610	0.233	0.313	44.4%	2.6
Prevatt et al. 2017 Study							
W.Palm 1	4298	2510	1788	2.104	1.229	58.4%	6.7
Venice 2 (2 story)	1820	656	1164	0.507	0.183	36.0%	2.2
Orlando 3 (2 story)	4143	506	3637	1.764	0.216	12.2%	8.6
Gainesville 4	3718	187	3531	1.217	0.061	5.0%	5.2
Average	3495	965	2530	1.398	0.422	27.9%	5.7

* Leakage per conditioned floor area ft^2

** Leakage per tested attic floor area ft^2

*** ACH50 is based on total of attic + house leakage CFM50 and House conditioned space volume. Attic volume is unknown and not accounted for in the ACH50. Adding attic air volume would slightly reduce the calculated ACH50.

The normalized results show that the Martin study homes average normalized house to out was much closer to attic to out (0.23 vs 0.31 CFM50/ft2)* ** than the Prevatt study. The Prevatt study normalized average house to out was 3.3 times more leaky than normalized attic to out tightness (1.393 vs 0.422 CFM50/ft2)* ** . It is not clear why some home tightness ratios varied much more than others. Two story homes have attics with a smaller floor footprint than single story homes that result in relatively less available leak area since most of the likely leak pathway is at the attic perimeter where roof sheathing approaches exterior walls. The homes in the Martin study were no more than about 18 months old at time of testing. The Prevatt homes were older and varied from approximately 4 to 14 years old at the time of testing. One of the four Prevatt study homes was a retrofit from vented to unvented attic, however, it was not made clear which home was the retrofit.

The Brennan et al. (2016) review study looked at unvented attic tightness data in 75 new and retrofit home wherever available and wrote, "*Results from three vented attic homes used in test protocol development suggest that ceiling interface leakage is highly variable, from 76 to 2,884 cm2 (from 4 to 63% of total house leakage area). Attic venting varied from slightly less leakage area than the house to 3.5 times the leakage area. In another Canadian study, 20 attics were tested for airtightness, and house-attic interface leakage area averaged 330 cm2 (varied from 200 to 450 cm2), which accounted for an average 38% of total house leakage area (from 4 to 63%) (Buchan, Lawton, Parent Ltd., 1991; Fugler, 1999). Measurements in 31 new California homes suggests that leakage area between the house and attic accounts for 51% of total house leakage area in traditional vented attic homes (Proctor, Chitwood, & Wilcox, 2011). This is comparable to the average 38% found in Canadian research.*"

Brennan et al. (2016) drew the following conclusions about attic air tightness from the their literature review:

- *"Attic airtightness criteria are not included in either the 2012 IRC, or in the U.S. Department of Energy (DOE) Building America Measure Guideline for Sealed and insulated Attic Insulation. We are unaware of any other programs that specify attic airtightness requirements."* As of 2024 no unvented attic tightness requirement exists for U.S. national building programs.
- *"Airtightness tests should be performed in sealed and insulated attic homes, with the attic access(es) fully open. The combined house and attic volumes should meet whatever performance requirement is desired (e.g., 3 air changes per hour at -50 Pascal (ACH50), <0.25 cubic feet per minute of airflow at -50 Pascal per square foot of building envelope surface area (cfm50/ft2SA)).*
- *Most sealed and insulated attics remain at least somewhat leaky to both the house and to outside; on average 52% of whole-house leakage area was located in the sealed and insulated attic surfaces (compare to 51% through the ceiling in conventional California (CA) attics).*
- *Sealed and insulated attics in modern, new California homes (compliant with 2013 Title 24 requirements) may be substantially more airtight than older homes described in earlier research, with median attic air leakage to outside of 246 cfm50 (newer homes) vs. 921 cfm50 (older homes).*

- *Sealed and insulated attics are generally somewhat leakier than the houses to which they are attached, but attics are still more coupled to the house than to outside, in terms of heat and mass transfer.*
- *Sealed and insulated attics insulated with fibrous insulation can achieve airtightness levels comparable to those in attics insulated with SPF.*
- *Detailed measurements in a single housing development of modern new California homes suggest that duct systems in sealed and insulated attics have very low air leakage to outside (averaging 1% of total system airflow, or 18 cfm), but substantial leakage still occurs within the envelope (median of 8%, 106 cfm). HVAC systems documented in older research were located inside leakier attics, and as a result, 55% of total duct leakage was to outside (32 cfm to outside on average).*
- *The airtightness of any duct system located in a sealed and insulated attic should be tested. For the purposes of energy calculations, leakage-to-outside tests should be used, which ignore duct leakage that occurs within conditioned space.*
- *Common locations for air barrier defects in sealed and insulated attics include (1) plumbing penetrations, (2) framing intersections, (3) roof and wall intersections, and (4) vent locations in existing homes. Common defects include foam delamination, as well as non-existent or inconsistent application of sealants (e.g., caulk, SPF or gaskets).”*

For this report, FSEC examined energy-rater-tested home air leakage for Florida homes from 2020 to 2024 with vented and unvented attics. We filtered for confirmed new construction homes and, if unvented, the test had to indicate hatch was open. If vented the test had to indicate the attic hatch was closed. Figure 2 shows the results. Average ACH50 was 2.9 for unvented attic homes and 5.1 average ACH50 for vented attic homes. As shown in Figure 2, the variability is considerable. Although the number of unvented homes is much smaller, the samples are large enough to conclude that on average the unvented homes are tighter than the vented homes. However, with the great variability shown, it is possible to have a leaky house with an unvented attic and a very tight house with a vented attic.

Cut off in Figure 2 are 68 vented attic homes that exceeded 12 ACH50. Any home that was higher than 7 ACH50 would not pass the Florida code. We are not sure why some newly constructed rated homes have test results higher than Florida code limits. Speculation is that some homes have tests conducted by a non-rater for code compliance and then the rater conducts the rating. There may also be a 10% difference due to methodology. A single-point blower door test is calculated with about 10% more leakage than a multi-point blower door test. In this large dataset of 27,904 vented attic Florida homes, 259 had ACH50 numbers over 10 ACH50. This is less than 1%. There were 709 (about 2.5%) of the vented attic Florida homes with greater than 8 ACH50 measurements.

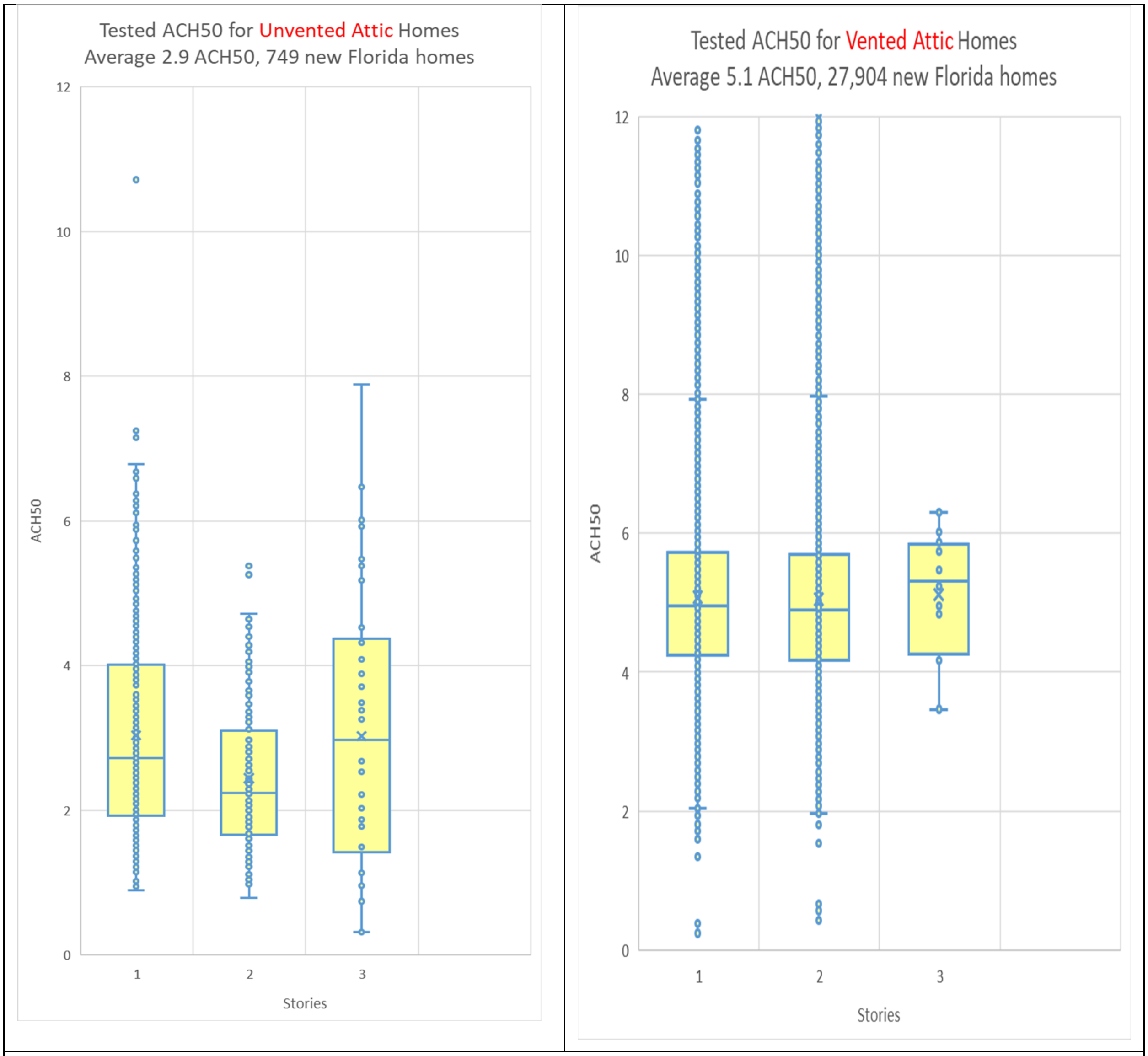

Figure 2 Air tightness levels of Energy rated Florida homes constructed in 2020 -October 20, 2024 with unvented and vented attics versus the number of stories. The median values are shown by the horizontal center lines, the bottom of the box to that midline represents the 25% to 50% range of values and similarly the top of the box to the midpoint represents the 50% to 75% range. The horizontal lines below and above the boxes represent 1.5x the range of the values in the box, points outside of this range are considered outliers.

The data in Figure 2 are shown for one, two and three story homes. The differences are rather insignificant. If there was much higher leakage coming from the home's ceiling than the rest of the infiltration areas we might have expected some trend. Overall surface area between house and attic is not fully captured by number of stories so further conclusions of leakage locations should not be made from this simple analysis.

3.1.4. Duct Airtightness in Unvented Attics

Literature review found that measured duct tightness in unvented attics may be reported in terms of volumetric air leakage with a duct system pressure maintained at 25 Pa (CFM25) or as an estimated air leakage based on normal duct system pressure operation (known as DeltaQ method). Results from these two types of tests are not directly comparable.

The CFM25 test, also known as a Duct Blaster test, is an integral part of home energy ratings. This test does not indicate duct leakage under normal operations, but is suitable for establishing targeted leakage limitations or for estimating operational leakage when a duct operational pressure is either measured or assumed. The CFM25 test can be used to determine total tightness of a duct system including leakage in house and from outdoors. A modification of the CFM25 test can be used to determine the duct leakage only to outdoors (CFM25out). The test method known as DeltaQ may be used to estimate the actual operational duct leakage on return and supply sides in cfm at normal duct system pressure. This test only uses a blower door fan in an exterior doorway to measure the house tightness with the central ducted system on and off. It requires specific equipment, laptop and software to run the test.

Overall duct tightness tests showed variable results. While total leakage of duct to home and outdoors was significant, the portion of duct leakage to outdoors was measureable but small around 1% (assumed leak % of system total flowrate). Tests were reported as total duct tightness and some differentiated total leakage from duct leakage to outdoors. Much of the Brennan et al. (2016) unvented attic duct tightness literature review contained studies based on California home tests, but a few were outside of California. Some pertinent findings and observations from Brennan et al. (2016) follow:

Reported measurements of air leakage in HVAC distribution ducts located in sealed and insulated attics were assembled from five difference sources for a total of 40 homes (GARD Analytics, Inc., 2003; Hoeschele et al., 2015; Rudd & Lstiburek, 1996; Sherman & Walker, 2002; Siegel & Walker, 2003).

HVAC ducts in sealed and insulated attics remained relatively leaky, with total leakage varying from 5 to 16% (median of 8%, n=24). It is important to remember that in sealed and insulated attic homes, the majority of this total leakage is within the conditioned volume, and it serves to condition the attic air and mix it with the house volume. Yet, Pallin et al. (2013) have reported that changing duct leakage in sealed and insulated attics from 4 to 20% can increase space conditioning energy demand by 5 to 15% (with high climate variability). Total system leakage to outside averaged 1% (from 1 to 6%, n=24). Older and newer homes differed sharply on how much of the total leakage was to outside the envelope, largely due to more airtight construction of the attic roof surfaces themselves in the newer homes (i.e., those reported by Hoeschele et al. (2015)). Whereas 55% (from 0 to 82%, n=20) of total leakage was to outside in the older set of sealed and insulated attic homes, only an average of 16% (from 6 to 32%, n=20) was to outside for the new homes. This supports the notion that overtime the industry has gained experience and skill in implementing successful, airtight sealed and insulated attics. The total duct leakage median was 101 cfm (from 28 to 302 cfm, n=40), with 21 cfm of duct leakage to outside (0 to 167 cfm, n=40).

It is noteworthy that many of these measurements are from homes built prior to inclusion of duct airtightness requirements in California's Title 24 building energy code. In general, we would expect new homes built to California Title 24 to have lower total duct leakage, as well as lower *leakage to outside. This is consistent with the measurements for new California homes reported by Hoeschele et al. (2015).*

Looking at some Florida energy rater data for this study we see duct leakage to outside as shown in Qn_{out} (tested duct leakage to outside at 25 CFM pressure difference per square foot of conditioned area) in Figure 2. Systems below Qn_{out} of 0.03 or 0.04 are generally considered tight systems. The average Qn_{out} for the unvented attic homes was 0.016 and for the vented attic homes 0.025. This means the unvented homes had tighter ducts on average, however there was still some duct leakage to outside in most unvented attic homes. The graphs are plotted versus the block number as multiple system houses will often have some system in conditioned space between floors. However, there was no obvious significant variance in the medians between block numbers.

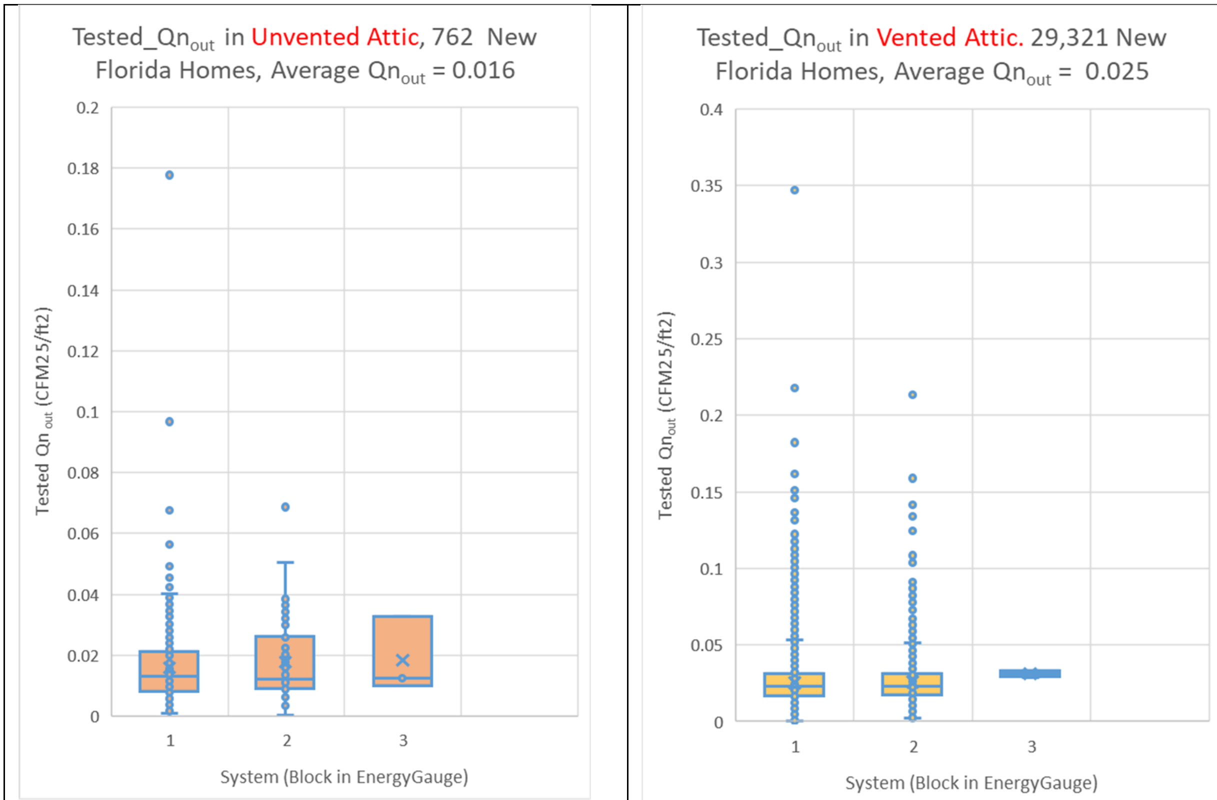

Figure 3. Tested duct tightness to outdoors results of energy rated Florida homes constructed in 2020 -October 20, 2024 with unvented and vented attics versus the number of systems. The median values are shown by the horizontal center lines, the bottom of the box to that midline represents the 25% to 50% range of values and similarly the top of the box to the midpoint represents the 50% to 75% range. The horizontal lines below and above the boxes represent 1.5x the range of the values in the box, points outside of this range are considered outliers.

3.2. Studies Relevant to Moisture Control in Unvented Attics With Spray Foam

Studies that involved unvented attics having spray foam on the sloped roof and providing useful information about attic moisture were identified. This section organizes studies starting from most recent to older and prioritizes attic moisture information. Each reference in this section includes a summary primarily focused on attic moisture germane to Florida. Reference details on the aforementioned studies and industry resources on wood moisture control guidance are at the very end of this review section.

Withers, C., and. E. Martin (2022). Seasonal Moisture Impacts on Roof Deck Moisture in Unvented Attics in North Florida. Published ASHRAE 2022 Thermal Performance of the Exterior Envelopes of Whole Buildings XV International Conference; pp.649-657. Peer reviewed. Presented at the Buildings XV Conference December 7, 2022. Available online as: FSEC-PF-1275-23 https://publications.energyresearch.ucf.edu/wp-content/uploads/2023/04/FSEC-PF-1275-23.pdf

This was a three-year study of attic moisture in six new (newer homes no more than 2 years old at start of monitoring) unvented attic homes in north central and north east Florida. Two new homes with conventional vented attics were also added to this study during the last two years. Low density open-cell spray foam attics. Research funded by The American Chemistry Council. Seasonal outdoor temperature had greater influence on roof sheathing WMC% than other measured variables such as indoor moisture, house, attic, or duct air tightness. Winter weather induced the highest roof sheathing WMC. Winter low temperature cold front events typically dropped into the 40's °F however a few events dropped into the 30's °F. "*The WMC was at its highest levels (between 15% - 20% WMC) during the colder periods when there was also less direct solar radiation. The WMC dropped to less than 15% WMC by March and remained between 10%- 15% WMC until the next winter*." Some homes had higher winter WMC in the first year than following years. This was noted as it was possibly due to greater material moisture levels within new construction materials, such as concrete, which takes several months to release moisture. For comparison to the unvented roofs, roof deck moisture was also measured in two conventionally vented attics in north east FL. "*The daily average moisture content of the vented attic roof decks rarely exceeded 10% WMC through all seasons*."

Five unvented homes were shingle and one unvented home had a metal roof. The metal roof had notably lower WMC all year round compared to the other shingle roof homes. This was particularly noticeable during cold weather compared to an asphalt shingle roof and demonstrated that the type of roof covering can also influence attic moisture and specifically roof deck WMC. During similar cold weather conditions, a shingle roof cooled down about 26°F colder than the metal roof deck (north slopes) and the shingle roof sheathing WMC averaged 3.6% WMC greater than the metal covered roof sheathing.

Generally, attic moisture was controlled well, however, some measurements found that the longer the cold weather event, the more the daily average sheathing WMC% trended upward. One measurement location in first year study during very cold weather lasting a few weeks had WMC near 30% which would damage wood if prolonged. It was determined that some small thin cuts in the foam around sensor location not adequately sealed permitted more moisture to move much more readily than non-disturbed foam. This site indicated the importance of protecting foam insulation from punctures or other damage. The prolonged cold weather also hinted that homes with open cell foam on roof sheathing in regions that more commonly experience longer uninterrupted cold weather for several weeks in a row may have roof deck WMC that exceeds 20% during that time.

Martin, E., and C. Withers (2021). Survey of Unvented Attics in Climate Zones 2. Florida Solar Energy Center, FINAL REPORT To Stephen Wieroniey, American Chemistry Council, March 17, 2021. FSEC-CR-2106-21
https://publications.energyresearch.ucf.edu/wp-content/uploads/2021/02/FSEC-CR-2106-21.pdf

This 102 page final report covers the three year study of 6 unvented attic homes and 2 vented attic homes conducted in north central and north east Florida. This report offers much greater details of the research paper Withers and Martin 2022 previously covered.

Withers, C., Fenaughty, K., and Sonne, J. Measured Energy and Moisture Performance Impacts from Vented and Unvented Attic with Insulation On Top of Ceiling in the Hot Humid Climate Zone. Published in ACEEE 2020 Summer Study on Energy Efficiency in Buildings Virtual; Conference Proceedings pp 1-415 – 1-430. Peer reviewed. Conference August 17-21, 2020.
https://publications.energyresearch.ucf.edu/wp-content/uploads/2021/05/FSEC-PF-1264-21.pdf

Research funded by the Florida Building Commission and conducted in an unoccupied manufactured test house facility measured indoor and attic air environment with conventional attic vents and without vents. Internal sensible and latent loads were generated to mimic occupancy. This study is different than others in that it intentionally looked at impact with R30 blown cellulose attic insulation remaining on the ceiling and the roof deck remained uninsulated. Central system supply ducts with R11 insulation jacket were located in the attic. "*The project showed unvented attic with attic ducts was warmer and had an 8% increase in cooling energy compared with vented attic with attic ducts, and had substantially drier attic space than vented attic. Moisture content and relative humidity levels were acceptable during all testing; however there was significant moisture increase with the unvented attic tests during cold weather periods.*"
"*Material moisture levels under all test configurations stayed below the upper target limit of 20% WME under the weather test conditions; however roof deck WME nearly approached 20% during short periods of the coldest weather. The trend of higher roof deck moisture occurring during cooler weather shows cause for not sealing attic vents in the configuration tested, especially if more heating is required than in the cooling-dominated climate where these tests were conducted. The vented attic was moister in summer and drier in the winter, when attic materials are more susceptible to moisture problems. Comparison between attic vented and attic vents sealed during two similar cool days found the roof deck wood moisture content was 33% higher during the sealed attic vent configuration peak WME value.*"

Prevatt, D., A. Viswanathan, W. Miller, P. Boudreax, S. Pallin, and R. Jackson. (2017). Phase II Analytical Assessment of Field Data for Sealed Attics in Florida Climate Zones 1 and 2 – Predicting Moisture Buildup in Roof Sheathing. Report Submitted to Florida Building

Commission, June 2017. University of Florida, Engineering School of Sustainable Infrastructure and Environment. [Link to Roofing report for FBC_TAC/Phase2](#) .

Prevatt et al. (2017) studied roof deck WMC in a sample of four unvented attic homes sealed with low density spray foam over a period of one year. Two of these homes were located in south Florida and two were in central Florida. The winter conditions were very mild with the coldest outdoor temperatures only reaching 60F to 65F. Data presented showed WMC below 15% for three homes all year with modest increases during winter. The fourth home in Gainesville, Florida had WMC below 15% for almost the entire year except during two separate periods during the January and February 2017 period when WMC spiked up to about 19-20%. The spikes generated limited discussion, but no conclusions were drawn about the cause, primarily since this home was occupied by seasonal residents. The occupancy status throughout the monitoring of this home was unknown. Prevatt (2017) noted within the report that the colder weather coincided with the spikes but, later concluded that the cause was unknown and presumed to be due to occupancy habits without any evidence to support the presumption.

Lstiburek, J. (2016). "Ping Pong Water and the Chemical Engineer" Building Science Insights BSI-016. Building Science Corporation. October 2016. https://buildingscience.com/documents/building-science-insights-newsletters/bsi-016-ping-pong-water-and-chemical-engineer

This document provides important description on how water vapor is higher at the top of unvented attics which can result in elevated attic air humidity. The process of diurnal adsorption and desorption of moisture from the roof sheathing passing through open cell low density spray foam and to attic air is described from a chemical engineering perspective.. "*When they* (water molecules) *exit the foam they are a little warmer than the attic air column and the surface of the foam has a higher molar concentration of water, so, they ride the buoyant film of gas skimming up along the surface of the foam – buoyant because it is both warmer and less dense...*". The process repeats nightly and results in higher moisture content at peak and stratification of moisture within the attic. The term "ping-pong" is coined to describe the nightly cycle of moisture movement adsorption, desorption, and thermal climb. The author claims this phenomena is not observed with close cell spray foam on roof sheathing as it has very low moisture permeability.

The conclusion of this document is that open cell spray foam is acceptable to use if the attic has some conditioned air to reduce moisture build up. In Climate Zones 1, 2, and 3 it was recommended that conditioned air be provided to the unvented attic at a rate of 50 cfm per 1000 ft^2 of ceiling (attic base).

The recommendation for conditioning unvented attics eventually became part of International Residential Code, however the provision for 50 cfm / 1kft^2 of ceiling only applied if air-permeable insulation was applied against the underside of roof sheathing. IRC 2021 does not require conditioned air into unvented attic where air-impermeable insulation, such as spray foam, is applied against the roof sheathing.

This opens up the question whether unvented attics with open cell spray foam on sheathing in Climate Zones 1, 2, and 3 should be conditioned for better moisture control. In the balance, there would be an increase in space conditioning energy use from providing conditioned air into the attic.

Excerpt from IRC 2021 R806:
5.2 In Climate Zones 1, 2 and 3, air-permeable insulation installed in unvented attics shall meet the following requirements:
…
IRC 2021 Section R806 5.2.10 Where air-permeable insulation is used and is installed directly below the roof structural sheathing, air shall be supplied a t flow rate greater than or equal to 50 CFM (23.6L/s) per 1,000 square feet (93m2) of ceiling. The air shall be supplied from ductwork providing supply air to the occupiable space when the space conditioning system is operating. Alternatively, the air shall be supplied by a supply fan when the conditioning system is operating.

Exceptions:

1. *Where both air-impermeable and air-permeable insulation are used, and the R-value in Table 806.5 is met, air supply to the attic is not required.*
2. *Where only air-permeable insulation is used and is installed on top of the attic floor, or on top of the ceiling, air supply is not required.*

Brennan, L., I. Walker, and R. Levinson. (2016). A Literature Review of Sealed and Insulated Attics—Thermal, Moisture and Energy Performance. Ernest Orlando Lawrence Berkeley National Laboratory. https://www.osti.gov/biblio/1340304/ or at https://www.osti.gov/servlets/purl/1340304

This document provided a very comprehensive literature review of 99 documents related to unvented attics insulated at the roof completed in 2016. The depth of review has shown this document to be a valuable source of information regarding airtightness, energy simulation, energy measurement in real homes and some moisture impacts. The primary purpose of this work was to support the California Energy Commission research in new California homes. Attic moisture and potential for duct condensation were addressed. The primary moisture concern noted was for excessive accumulated moisture in wood materials primarily at roof sheathing. The authors provided a summary of the greatest risk factors for uncontrolled moisture at roof sheathing within "sealed" (unvented) attics.
"The following factors increase moisture risk at roof sheathing surfaces over sealed and insulated attics:

- *Increased indoor or outdoor humidity*
- *Lower outdoor winter temperatures and higher levels of night sky radiation*
- *North-facing roof slopes*
- *Proximity to the roof peak*
- *Use of air permeable insulation*
- *Use of cool roof surfaces or radiant barriers*
- *Increasing vapor permeability of insulation (maybe)"*

The reader is reminded that Florida is dominated by much more humid climate than California, and does not experience prolonged cold weather periods like parts of California at higher altitudes or more northern latitudes. Sprayfoam is not an air permeable insulation so it much better at limiting attic moisture in air from reaching roof sheathing than air permeable insulation, such as fiberglass batts or netted loose-fill insulation. Open cell sprayfoam is vapor permeable. The vapor permeability of one specific brand of low density open cell foam with 5 ½ inch thick application and a core density of 0.5 lb/ft^3 is stated by the manufacturer to be about 11 perms. This means that in addition to controlling the sheathing temperature, internally generated moisture and attic air moisture control are also important considerations with spray foam attics. Brennan (2016) further support this stating:

"To reduce moisture risk, the first priority should be elimination of paths for bulk water intrusion from outside. Once bulk water is controlled, the primary means for controlling moisture levels in sealed and insulated attic roof assemblies are: (1) controlling the first condensing surface temperature, typically through use of continuous exterior insulation or air impermeable insulation in the roof rafter assembly; or (2) control of indoor moisture levels, typically through moisture removal by continuous whole house and intermittent local exhaust ventilation. Supplemental dehumidification or direct conditioning[2] of the sealed and insulated attic volume may be necessary in some cases, generally in hot-humid climates. Other proposed methods to reduce moisture risk include use of vapor permeable diffusion caps at roof peaks, enhanced roof deck ventilation and increased mixing of attic and house air volumes."

[2] *Air leakage from ducts located in sealed and insulated attics already provides some level of direct conditioning, albeit inadvertent.*

Other findings regarding moisture control found that:

- Major roof structural sheathing failures requiring repair were rare and the only example in literature was due to closed cell spray polyurethane foam applied incorrectly over wet roof sheathing.
- Indoor occupied space and unvented attic spaces have similar "moisture conditions" based on long-term averages. On this topic, the authors also stated, "*There is limited evidence that humidity levels are somewhat elevated in sealed and insulated attic homes, because the attic serves as a moisture source for the house. During humid periods, the attic stores rather than vents moisture, and this moisture is then released back to the conditioned volume when the driving forces reverse."*
- Observing guidance from ASHRAE Standard 160 may be useful for generally assessing moisture risks within unvented attics. This standard considers the type of material, surface temperature and surface humidity over thirty-day running averages to establish an estimated moisture risk for serious problems such as corrosion, mold, mildew, or decay. Wood surface humidity over thirty-day running RH averages should be below 80%. Less sensitive materials like metal may be ok at higher levels. It is noted that measurement of attic air RH is not the same as the RH at a specific surface.
- The general observation of diurnal movement of moisture from attic air into materials (adsorption) and back from materials into the air (desorption) was noted as an observation of various studies.

Colon, C. (2011). New Construction Builders Challenge: Sealed Attics and High Efficiency HVAC in Central Florida. Florida Solar Energy Center, Cocoa, FL: https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-PF-454-11.pdf

This research was funded through U.S. Department of Energy Building America Program and involved study of new unoccupied model home built in 2010 with R27 open cell spray foam on roof deck creating an unvented attic in Rockledge, Florida. Measurements of attic air near peak and at mid attic height indicated generally good indoor attic RH levels with daily average RH maintained below 60% RH. Data showed diurnal RH pattern with peak RH during afternoon and lowest RH during sundown hours. Highest attic RH was during May and June 2010 and then again similar values March and April of 2011.

Forest Products Laboratory. (2010). Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf

Publication of 509 pages is comprehensive document covering mechanical, structural, fastening, aspects of using wood in buildings. Chapters 13, 14, and 15 cover wood moisture control, bio deterioration of wood and wood preservation. Guidance to maintain WMC below 20% to avoid mold, stain and decay. Indicates serious wood decay begins when WMC maintained 30% or more for long period of time.

APA– The Engineered Wood Association. (2009). Water Vapor Permeance of Wood Structural Panels and Wood Wall Construction. Engineered Wood Systems APA, Tacoma, Washington. J450, February 2009. http://www.norbord.com/na/cms/wp-content/uploads/Moisture%20Vapor%20and%20Perms%20J450.pdf

APA – The Engineered Wood Association. (1999). Moisture Control in Low Slope Roofs. Engineered Wood Systems APA, Tacoma, Washington. EWS R525B, January 1999. https://www.buildgp.com/DocumentViewer.aspx?repository=bp&elementid=3208

Four page guidance document mentions considering use of insulation above the wood deck to maintain wood temperatures above the dewpoint in attic when low design temperatures or high interior humidity is expected.

3.3. Literature Review References Noted in Synopsis or Within Other Discussed Studies

Beal, D. and Chandra, S. (1995). Side by side testing of four residential roofing and attic ventilation systems. FSECCR-822-95. Florida Solar Energy Center, Cocoa, Fla.

Buchan, Lawton, Parent Ltd. (1991). Survey of Moisture Levels in Attics (No. BLP File No. 2497). Ottawa, Canada: Canada Mortgage and Housing Corporation: Research Division. ftp://ftp.cmhc-schl.gc.ca/chicccdh/Research_Reports-Rapports_de_recherche/Older16/CA1%20MH110%2091S74.pdf

Consortium for Advanced Residential Buildings CARB. (2009). *Which Spray foam Is Right For You? Appropriate applications for open-cell and closed-cell insulation.* Steven Winter Associates, Inc. https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/spray_foam_guide.pdf

Desjarlais, A. O., T. Petrie, and T. Stoval. (2004). Comparison of Cathedralized Attics to Conventional Attics: Where and When Do Cathedralized Attics Save Energy and Operating Costs? Presented at the Performance of Exterior Envelopes of Whole Buildings IX International Conference, Clearwater Beach, FL: ASHRAE. http://web.ornl.gov/sci/roofs%2Bwalls/staff/papers/new_62.pdf

Fugler, D. (1999). Conclusions from Ten Years of Canadian Attic Research. ASHRAE Transactions (pp. 819–825). Chicago, IL: ASHRAE. http://www.aivc.org/resource/conclusions-ten-years-canadian-attic- research

GARD Analytics, Inc. (2003). Cost & Savings for Houses Built With Ducts in Conditioned Space: Technical Information Report (Technical Report No. 500-03-082-A-31). Sacramento, CA: California Energy Commission. http://www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-31.PDF

Hendron, R., R. Anderson, P. Reeves, and E. Hancock. (2002). Thermal Performance of Unvented Attics in Hot-Dry Climates (No. NREL/TP-550-30839). Golden, CO: National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy02osti/30839.pdf

Hendron, R., S. Farrar-Nagy, R. Anderson, P. Reeves, and E. Hancock. (2003). Thermal performance of unvented attics in hot-dry climates: Results from Building America. In Proceedings of ISEC 2003 (pp. 1–8). Hawaii, USA. Retrieved from http://www.nrel.gov/docs/fy03osti/32827.pdf

Hoeschele, M., E. Weitzel, A. German, and R. Chitwood. (2015). Evaluation of Ducts in Conditioned Space for New California Homes (No. ET13PGE1062). Pacific Gas and Electric Co. Retrieved from http://www.davisenergy.com/publication/view/evaluation-of-ducts-in-conditioned-space-for-new-california-homes/

Janusz, A. and J. Acosta. (2021). Analysis of Unvented Attics For IECC – Residential Provisions. RDH Building Science, Inc., Seattle, WA. Project R-24554.000.

Kaufman, Z., A. Fontanini, C. Withers, C. Marden, K. Ueno, R. Philip, G. Barker, E. Hancock, L. Earle, R. Garber-Slaught, and S. Meleika. (2024). Moisture Performance of Unvented Attics With Vapor Diffusion Ports and Buried Ducts in Hot, Humid Climates. U.S. DOE Office of Energy Efficiency & Renewable Energy, DOE/GO-102024-6186, September 2024. https://www.nrel.gov/docs/fy24osti/86619.pdf

Pallin, S., M. Kehrer, and W.A. Miller. (2013). A Hygrothermal Risk Analysis Applied to

Residential Unvented Attics. Presented at the Thermal Performance of Exterior Envelopes of Whole Buildings XII, Clearwater Beach, FL: ASHRAE.
http://www.techstreet.com/products/1868077

Parker, D.S., P. Fairey, and L. Gu. (1991). A stratified air model for simulation of attic thermal performance. Insulation Materials: Testing and Applications, Vol. 2, ASTM STP 1116, R.S. Graves and D.C. Wysocki, eds. Philadelphia: American Society of Testing and Materials.
https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-PF-226-91.pdf

Parker, D., J. Sonne., and J. Sherwin. (2002). Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida (pp. 219–234). Presented at the ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA: American Council for an Energy-Efficient Economy. Retrieved from
http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1220-00- es/roofing.pdf

Proctor, J., R. Chitwood, and B. Wilcox. (2011). Efficiency Characteristics and Opportunities for New California Homes (ECO) (Final Project Report No. CEC-500-2012-062). Sacramento, CA: California Energy Commission, PIER Energy-Related Environmental Research Program.
http://www.energy.ca.gov/2012publications/CEC-500-2012-062/CEC-500-2012-062.pdf

Roberts, D. and J. Winkler. (2010). Ducts in the Attic? What Were They Thinking? Proceedings of the Summer Study for Energy Efficiency in Buildings. Pacific Grove, CA: American Council for an Energy-Efficient Economy. http://www.nrel.gov/docs/fy10osti/48163.pdf

Rudd, A. (1996). Vented and sealed attics in hot climates. Contract Report submitted to Building Science Corporation, Westford, Mass., and the U.S. Department of Energy, 30 October. Florida Solar Energy Center, Cocoa, Fla., FSEC-CR-911-96.

Rudd, A., and J. Lstiburek. (1996). Measurement of Attic Temperatures and Cooling Energy Use in Vented and Sealed Attics in Las Vegas, Nevada (No. RR-9701). Building Science Corporation. http://buildingscience.com/documents/reports/rr-9701-measurement-of- attic-temperatures-and-cooling-energy-use-in-vented-and-sealed-attics-in- las-vegas-nevada/view

Rudd, A. and. J. Lstiburek. (1998). Vented and Sealed Attics in Hot Climates. *ASHRAE Transactions 104(2)*. https://buildingscience.com/sites/default/files/document/rr-0981_vented_sealed_attics.pdf

Rudd, A., J. Lstiburek, P. Eng, and K. Ueuno. (2005). Residential Dehumidification Systems Research for Hot-Humid Climates. NREL/SR-550-36643 National Renewable Energy Laboratory, Golden, CO http://www.buildingscience.com/documents/bareports/ba-0219-residential-dehumidifications-systems-research-hot-humid-climates

Sherman, M. and I. Walker. (2002). Residential HVAC and Distribution Research Implementation (No. LBNL-47214). Berkeley, CA: Lawrence Berkeley National Laboratory.
http://epb.lbl.gov/publications/pdf/lbnl-47214.pdf

Siegel, J. A., I. S. Walker, and M. Sherman. (2000). Delivering Tons to the Register: Energy Efficient Design and Operation of Residential Cooling Systems. In Summer Study for Energy Efficiency in Buildings (pp. 1.295–1.306). Pacific Grove, CA: American Council for an Energy-Efficient Economy. http://aceee.org/files/proceedings/2000/data/papers/SS00_Panel1_Paper25.pdf

Siegel, J. A., I. S. Walker. (2003). Integrating Ducts Into Conditioned Space: Successes and Challenges. Presented at the Architectural Engineering Institute Conference, Austin, TX: American Society of Civil Engineers. http://doi.org/10.1061/40699(2003)24

Miller, W. A., and J. Kosny. (2008). Next-Generation Roofs and Attics for Homes. In Summer Study on Energy Efficiency in Buildings (pp. 180–195). Pacific Grove, CA: American Council for an Energy-Efficient Economy. http://aceee.org/files/proceedings/2008/data/papers/1_34.pdf

Miller, W., K. Biswas, M. Kehrer, A.O. Desjarlais, and S. Atherton. (2013). General Aniline and Film Report 2012: Analytical and Field Study of the Effects of Ventilation on Thermal Performance and Moisture Control in Residential Attics (No. ORNL/TM-2013/38). Oak Ridge, TN: Oak Ridge National Laboratory. http://web.ornl.gov/info/reports/2013/3445605703414.pdf

Wei, J., A. Pande, C. Chappell, M. Christie, and M. Dawe. (2014). Residential Ducts in Conditioned Space / High Performance Attics (Codes and Standards Enhancement Initiative (CASE) Report No. 2016-RES-ENVI-F). Sacramento, CA: California Public Utilities Commission. http://energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-21_workshop/final_case_reports/2016_Title_24_Final_CASE_Report_HPA- DCS-Oct2014.pdf

4. Simulation Analysis

4.1. Simulation Inputs

A matrix of EnergyGauge USA version 8.1 simulation runs were developed as shown in Table 3. This matrix of 348 simulations allow comparisons to reflect the potential impact of the changes. Two of the cases with unvented attic is more than proposed in the legislation. They have R20 roof insulation and R19 or R11 ceiling insulation. This configuration would allow the roof insulation to not exceed R20 while maintaining the current or near current overall R-value between the ceiling and the outside.

Table 3. Parameters that may vary during simulation analysis. Green type shows current R402 requirement. Red type shows new or repeated values in proposed change.

Current Prescriptive R402 Code Simulations		Total
Home Type	2000 ft2 single story detached, 2400 ft2 two-story detached, Multi-family unit	3
Cities	Tallahassee, Miami	2
Duct Leakage	Qn_{out}= 0, Qn_{out} =0.04	2
Mechanical Ventilation	None	1
Roof Pitch	4 in 12, 8 in 12	2
Roof/Ceiling Insulation	R0/R38 (Tallahassee) or R0/R30 (Miami), Vented attic, and R38/R0 (Tallahassee) or R30/R0 (Miami), Unvented attic	2
House Air Leakage	7 ACH50	1
Total Current Code Simulations		**48**
R20 Unvented Attic Simulations		Total
Home Type	2000 ft2 single story detached, 2400 ft2 two-story detached, 1200 ft2 Multi-family unit	3
Cities	Tallahassee, Miami	2
Duct Leakage	Qn_{out}= 0, Qn_{out} =0.04	2
Mechanical Ventilation	100% Whole house supply system, Hybrid: Central Fan Integrated w make up, Balanced system, Enthalpy Ventilation Recovery (ERV)	4
Roof Pitch	4 in 12, 8 in 12	2
Roof/Ceiling Insulation	R20/R0 R20/R19 R20/R11*	3*
House Air Leakage	3 ACH50 with mechanical ventilation and 7 ACH50 with no mechanical ventilation**	2**
Total Change Analysis Simulations		**300**

*R20 roof with R11 ceiling insulation only run with Qn=0.04, not Qn=0; 60 simulations;

** 48 simulations run for the 7ACH50 case as no variation with mechanical ventilation system

We also ran simulations of an in between point. This was a roof insulated to R20 with 7 ACH50 and no mechanical ventilation. This was run for the 2 cities, 3 building types, 2 roof pitches, 2 duct leakage values, and 2 ceiling insulation values (R0 and R19) for another 48 simulations bringing the total to 288 results.

The base case characteristics of the prescriptive buildings modeled are summarized in Table 4. For this project, the multi-family unit modeled is only a unit directly under an attic, unlike previous studies that also modeled non top-floor units.[2] The legislative change should not affect units without thermal connection to the roof/attic. EnergyGauge USA treats single unit entries for purposes of infiltration as though they are ground floor units. This detail is important for understanding this particular analysis where ACH50 inputs vary between the current prescriptive code value and the new alternative method in the statute.

Table 5 specifies the inputs to EnergyGauge USA for the whole house mechanical ventilation systems. The ventilation amounts were consistent with the Florida Building Code.

The attic vent area fraction used for the DOE2 simulation for unvented attics in EnergyGauge USA is 0.00015. For the vented attics it is 0.0016665 which is half of the entered infiltration rate of 1/300. Thus, 11 times more ventilation for the vented attic. This is one of the details missing from some of the simulation literature reviewed in section 3 of this report. Different results will be obtained by assuming absolute zero leakage from attic to outside. As shown in the limited test results in Section 3 of this report, there is usually some air exchange.

To simulate the statute's requirement for R3 minimum on the roof rafters the framing fraction of the roof was reduced to provide an equivalent U value as Energy Gauge has no method for adding insulation between and separately below roof rafters. This framing fraction adjustment was only done on the R20 roof with no ceiling insulation simulations.

[2] Sonne, Jeff, Rob Vieira, "Florida Building Code, Energy Conservation, 8th Edition (2023) vs. 2021 International Energy Conservation Code Residential Stringency Analysis," FSEC-CR-2124-24

Table 4. Characteristics of base house simulations compliant with Florida 8th Edition Prescriptive Compliance Path

Component	Climate Zone 1 2023 FBC-EC	Climate Zone 2 2023 FBC-EC
Conditioned floor area (ft²) (one story / two story / multi)	2,000 / 2,400 / 1,200	2,000 / 2,400 / 1,200
Floor Type	SOG/SOG/neighbor	SOG/SOG/neighbor
Floor perimeter *R*-value	0	0
Wall type	Wood Frame	Wood Frame
Wall insul. *R*-value	13	13
Wall solar absorptance	0.75	0.75
Common wall area (multi-family only)	720	720
Window area (ft²) (one story / two story / multi)	300 / 360 / 120	300 / 360 / 120
Window *U*-factor	0.5	0.4
Window SHGC	0.25	0.25
Roofing material	Comp. Shingles	Comp. Shingles
Roof solar absorptance	0.92	0.92
Attic ventilation	Vented 1/300	Vented 1/300
Ceiling insul. *R*-value	30	38
Envelope ACH50 (air chng/hr @ 50pa)	7	7
Equipment and Effic. Cooling / Heating	SEER2 14.3 / Elec. Strip	SEER2 14.3 / HSPF2 7.5
AHU location (one story / two story / multi)	Garage / Garage / Cond. Space	Garage / Garage / Cond. Space
Duct insul. *R*-value	8 / 8 / 8	8 / 8 / 8
Duct location (one story / two story / multi)	Attic /Attic/Attic	Attic /Attic/Attic
Duct leakage	Qn_{out}= 0.04	Qn_{out}= 0.04
Leakage split Supply-Return	50%-50%	50%-50%
Supply Duct Area ft²	400/240[3]/240	400/240[2]/240
Return Duct Area ft²	100/60/60	100/60/60
Heating / Cooling set points (°F)	72 / 75	72 / 75
# of bedrooms (one story / two story / multi)	3 / 4 / 2	3 / 4 / 2
Water heater size (gallons)	50 / 50 / 40	50 / 50 / 40
Water heater UEF (electric)	0.93	0.93
Water heater location (one story / two story / multi)	Garage / Garage / Cond. Space	Garage / Garage / Cond. Space
Water heater pipe insulation *R*-value	3	3
Water heater heat trap	Yes	Yes

[3] Fifty percent of supply and duct areas are assumed in conditioned space. Only the portions in attic are modeled.

Table 5. Whole-House Mechanical Ventilation Parameters Modeled

Modeled Ventilation Parameters	Climate Zone 1 & 2			
Cond. Floor area (ft2)	2000 ft² Single Family Detached			
	Supply CFM	Exhaust CFM	Power (W)	Recovery (%)
Supply Only	50	0	18	0
Balanced	35	35	25	0
ERV	35	35	25	60
Hybrid	0	50	18	0
Cond. Floor area (ft2)	2400 ft² Single Family Detached			
	Supply CFM	Exhaust CFM	Power (W)	Recovery (%)
Supply Only	54	0	19.28	0
Balanced	37.8	37.8	27	0
ERV	37.8	37.8	31.5	60
Hybrid	0	54	20	0
Cond. Floor area (ft2)	1200 ft² Multi Family Attached			
	Supply CFM	Exhaust CFM	Power (W)	Recovery (%)
Supply Only	34.5	0	12.32	0
Balanced	24.15	24.15	17.25	0
ERV	24.15	24.15	20.13	60
Hybrid	0	34.5	12.32	0

4.2. Simulation Results

Figure 4 shows the change just from going from R38 ceiling insulation to R20 roof insulation without any change in home air leakage or adding mechanical ventilation. On the left is with the prescriptive 0.04 duct leakage to outside. The comparison on the right is if the duct leakage were 0 in both attic configurations.

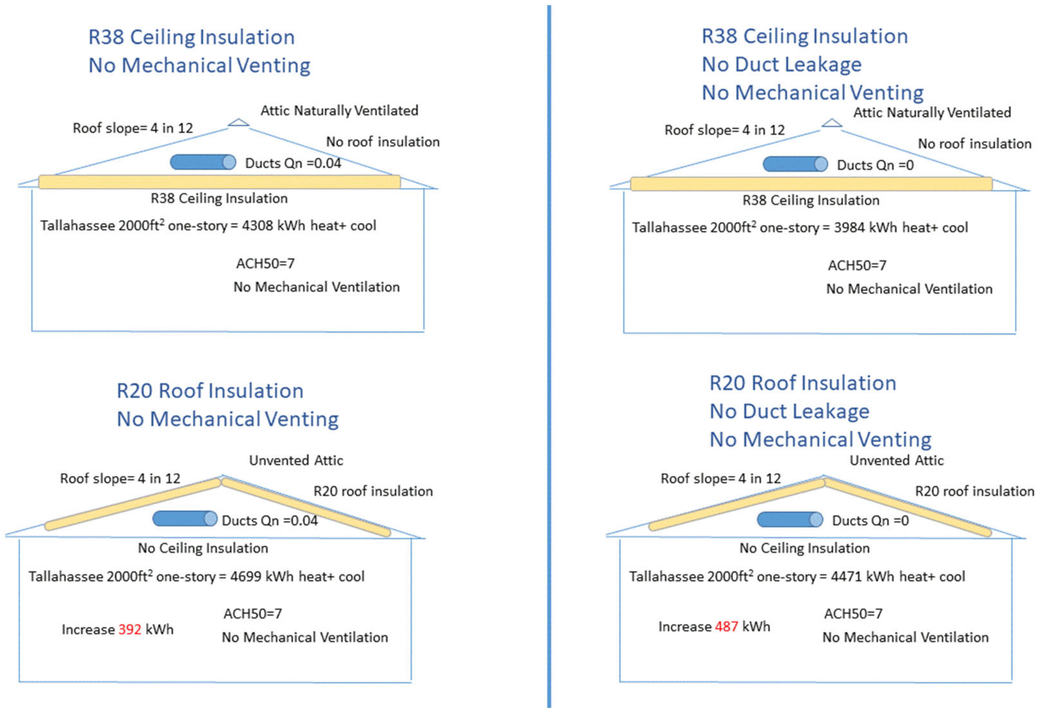

Figure 4. Illustration showing change in energy use from FBC, Energy Conservation R402 prescriptive code with conventional ceiling insulation to unvented attic with R20 rafter insulation for two different levels of duct leakage for Tallahassee simulated one-story, 2000 ft2 house. Qn_{Total} *=0.04 is maximum tested duct leakage allowed under the prescriptive code and 0 is no duct leakage.*

Figure 5 shows the impact when we compare the current prescriptive code air leakage of 7 ACH50 and no mechanical ventilation to the proposed change to 3 ACH50 under four different mechanical ventilation scenarios. This is the middle series of bars on the chart. The top series is with R20 at the attic and R19 insulation at the ceiling and the same requirements. This scenario should meet current code requirements and uses about the same amount of energy as the current R402 base case while adding 62.2 level of ASHRAE ventilation. The difference in kWh is shown in Figure 6. Depending on whole house mechanical ventilation system the energy use increase for the proposed change was simulated as 293 to 564 kWh in Tallahassee.

Figure 7 and 8 show similar graphs for simulations of a 2000 ft^2 home in Miami. The prescriptive code only calls for R30 insulation in Florida Climate Zone 1. Thus the differences in energy use are smaller than in Tallahassee.

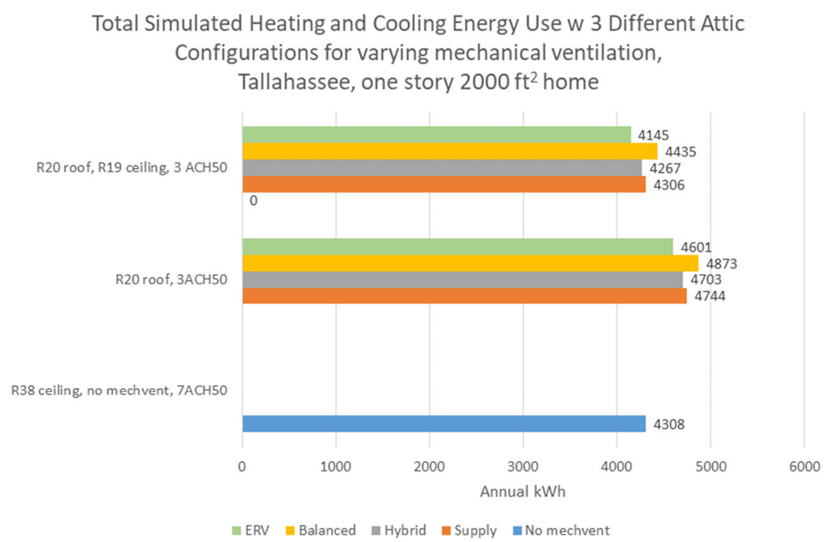

Figure 5. The bottom bar is current code with R38 ceiling insulation. The middle set of charts is proposed change showing increase in energy use regardless of ventilation strategy. Top bar shows an alternative with roof and ceiling insulation. Energy use is projected to be similar for this case as the R38 ceiling insulation case.

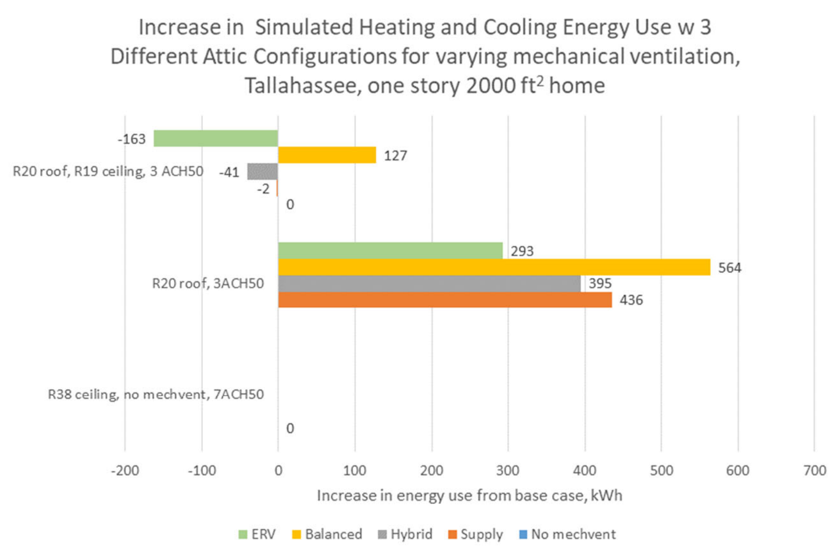

Figure 6. This figure depicts the increase (Negative values are savings) in energy use versus the base case for Tallahassee.

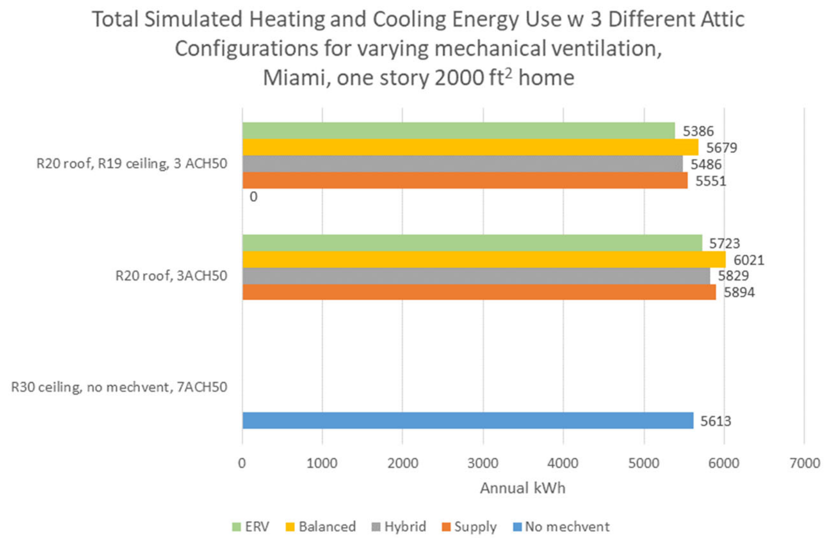

Figure 7. The bottom bar is current code with R30 ceiling insulation. The middle set of charts is proposed change showing increase in energy use regardless of ventilation strategy. Top bar shows an alternative with roof and ceiling insulation. Energy use is projected to be less for this case than the R30 ceiling insulation case.

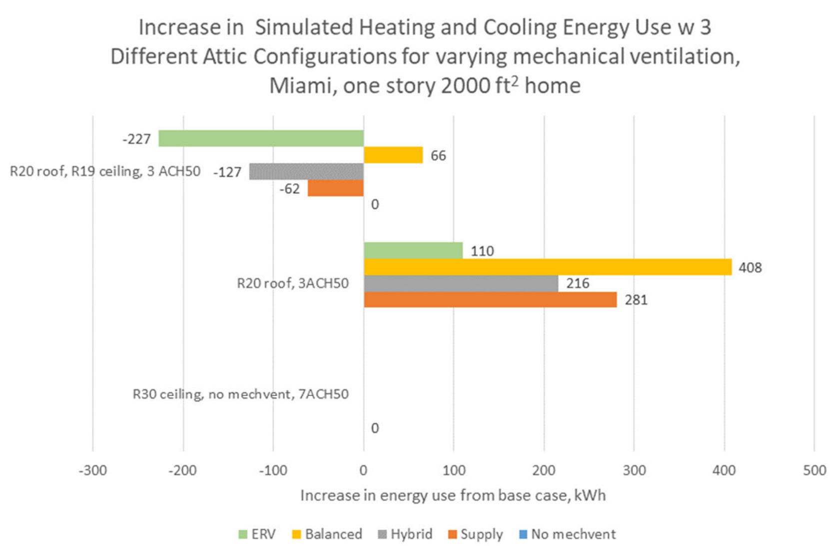

Figure 8. This figure depicts the increase (Negative values are savings) in energy use versus the base case for Miami.

The full set of results are presented in eight tables located in Appendix A. Overall, the results indicate increased energy use for minimum section 553.9065 R402 compliance relative to current 8th Edition, Florida Building Code, Energy Conservation R402 code minimums. How much increase varies with location, roof pitch, house and ventilation type employed. For the 4 in 12 roof pitch with Qn of 0.04 the Climate Zone 2 homes used 7% to 13% more HVAC energy depending on ventilation type for the one-story 2000 ft^2 home but only 0% to 5% more HVAC energy for the 1200 ft^2 multi-family home. In Climate Zone 1 that has minimal heating and is currently only requiring R30 ceiling insulation the differences were smaller. In Climate Zone 1 the results indicate only a 1% to 6% increase in HVAC energy use for the section 553.9065 R402 methodology in the 2000 ft^2 single-family detached home and 0% to 5% increase in energy use for the 1200 ft^2 multi-family home. Energy use increases at higher roof pitches as shown in Figure 9. This makes sense since the thermal barrier area increases as roof area increases for unvented attics.

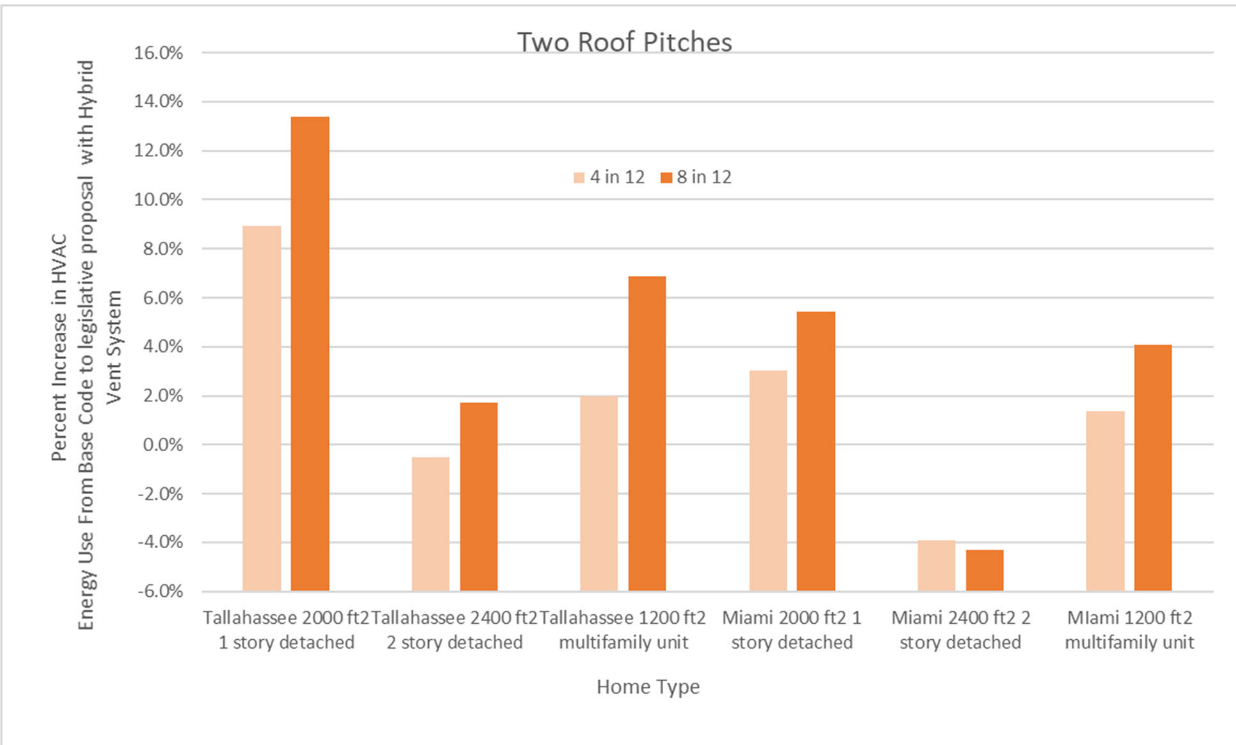

Figure 9. Difference in percent increase in HVAC energy use between base case ceiling insulation levels in current R402 and the new statute alternative R20 at roof deck. Results are shown for Qn_{out} *of 0.04 and hybrid ventilation case and for 4 in 12 and 8 in 12 roof pitches.*

However, the simulations of minimal code compliance for the 2400 ft^2 two-story home showed savings in some cases. This can be attributed to the difference in entered ACH50. For two-story homes the greater building height means the actual hourly calculation that adjusts for wind and height in the simulation will be higher as the building height increases. For very tight homes such as the 3 ACH50 home that impact is small. However, the base case current R402 homes with ACH50 of 7 results in more energy use than a similar one-story home. Thus, as shown in the Table A-3 for Miami and with the one case depicted in Figure 9 above, the R20 roof insulation simulation shows savings relative to the leakier base case 2-story home. Table A- 4 shows that only with an ERV or hybrid ventilation system are the R20 roof savings achieved in Tallahassee for the 2400 ft^2 home.

The comparison results we present compare the same duct leakage for the vented and unvented roofs. Based on recent duct tests on Florida unvented and vented home results presented in section 3.1.4, on average we might expect slightly lower Qn_{out} (0.016 unvented and. 0.025 vented) duct leakage to outside for the unvented attic than was assumed in simulation. That reduction of 0.09 Qn_{out} represents about a 1.7% reduction in HVAC energy for the 2000 ft^2 Tallahassee base case home. However, based on results in section 3.1.3 on average, we might expect the difference in home air tightness to not be as much as the difference in 7 ACH50 to 3 ACH50.

An energy efficient alternative to section 553.9065 would be to insulate both the roof plane and the ceiling. Depending on the ventilation system used, this configuration often saves energy relative to the base R30 or R38 ceiling insulation. This configuration is similar to one of the code paths that California employs. During peak summer afternoon hours our unvented attics are still warmer than the conditioned air below so having some ceiling insulation will help reduce energy use.

Figure 10 shows the increase in energy use (positive value on y axis of charts) for the legislative method with R0, R11 and R19 added ceiling insulation level relative to base case vented attic with no roof insulation and R38 ceiling insulation in Tallahassee as modeled for Climate Zone 2 for hybrid and supply-only ventilation systems. Since the hybrid ventilation system uses the central fan some of the time, it tends to use less energy that the modeled pure supply fan method. Note that in all cases shown in Figure 10 there is some energy penalty for the legislative method without ceiling insulation. All of the 4 in 12 pitch roof cases show neutral or some HVAC savings if R19 is added to the ceiling. There is a mixture of results with 8 in 12 pitch roof results with R19 ceiling insulation. If R11 is added to the ceiling, the 4 in 12 pitch roof cases with hybrid ventilation save HVAC energy use over the vented base case. The supply vent case for the one-story home uses more energy that the base case. With 8 in 12 roof pitches, two of the three simulated homes with supply ventilation use more energy than the base case.

Figure 10. Comparison of three different levels of ceiling insulation for unvented attics relative to base case vented attic with R38 ceiling insulation in Climate Zone 2 for roof pitches of 4 in 12 (charts on left) and 8 in 12 (charts on right) for hybrid ventilation (top charts) and supply-only ventilation (bottom charts).

Figure 11 presents results for balanced and enthalpy recovery ventilation for Tallahassee. Balanced ventilation without enthalpy recovery is not recommended due to energy use; while the 60% effective enthalpy recovery system modeled resulted in the lowest energy use among the four ventilation systems.

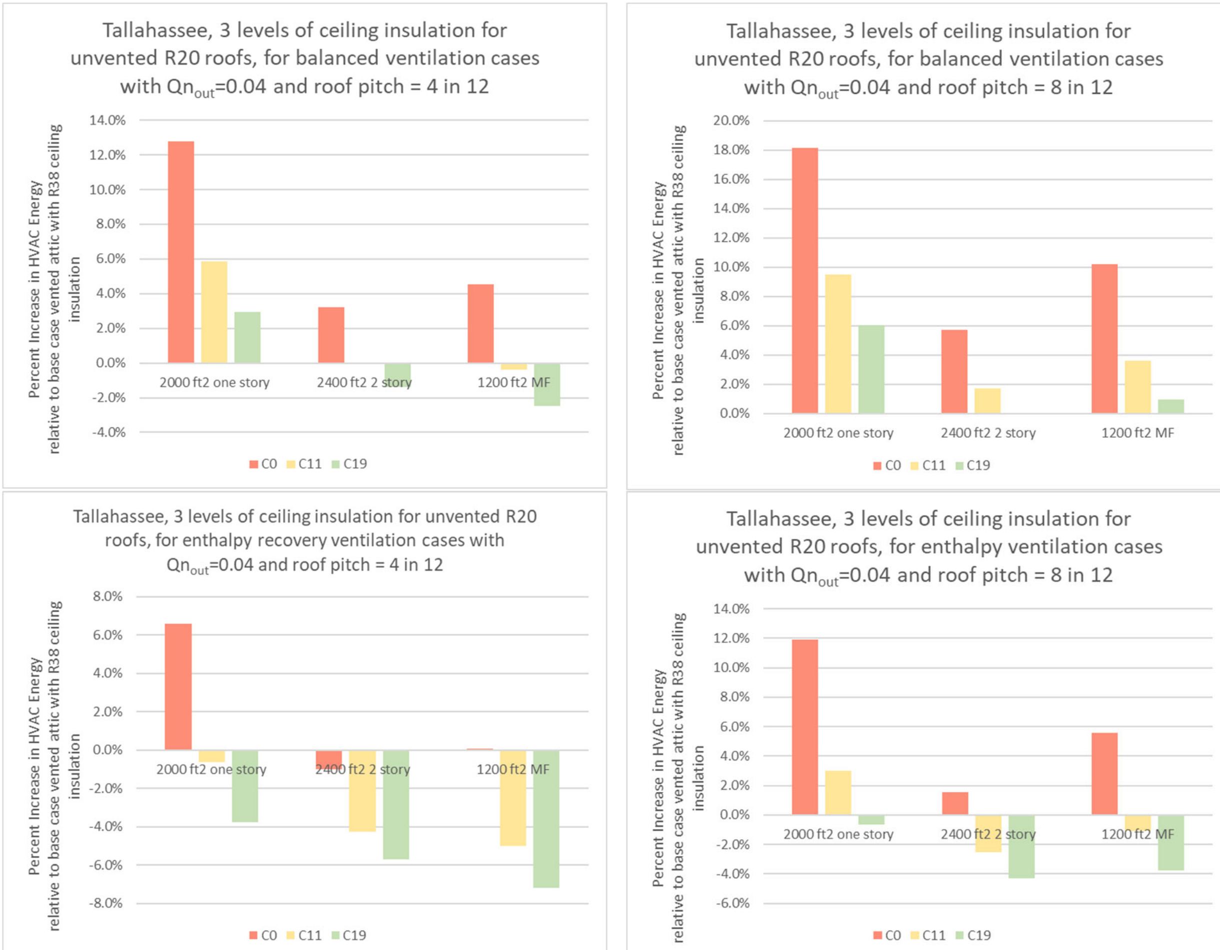

Figure 11. Comparison of three different levels of ceiling insulation for unvented attics relative to base case vented attic with R38 ceiling insulation in Climate Zone 2 for roof pitches of 4 in 12 (charts on left) and 8 in 12 (charts on right) for balanced ventilation (top charts) and balanced with enthalpy recovery ventilation (bottom charts).

Figures 12 and 13 show similar charts for Climate Zone 1. Since Climate Zone 1 only requires R30 ceiling insulation in the base case, the legislative methodology fairs better than in Climate Zone 2.

On average of 24 cases simulated for Climate Zone 2, R11 ceiling insulation added to the R20 unvented attic proposed in the legislation showed minimal difference (0.5% higher HVAC energy use) from the current R402 base case. In Climate Zone 1, the R20 roof with R11 ceiling insulation showed improvement on average for the 24 cases simulated (1.6% reduction in HVAC energy use) versus the current Climate Zone 1 R402 base case. With 2x4 trusses, this level of ceiling insulation would allow plywood flooring in the attic for those residents desiring a safer storage area.

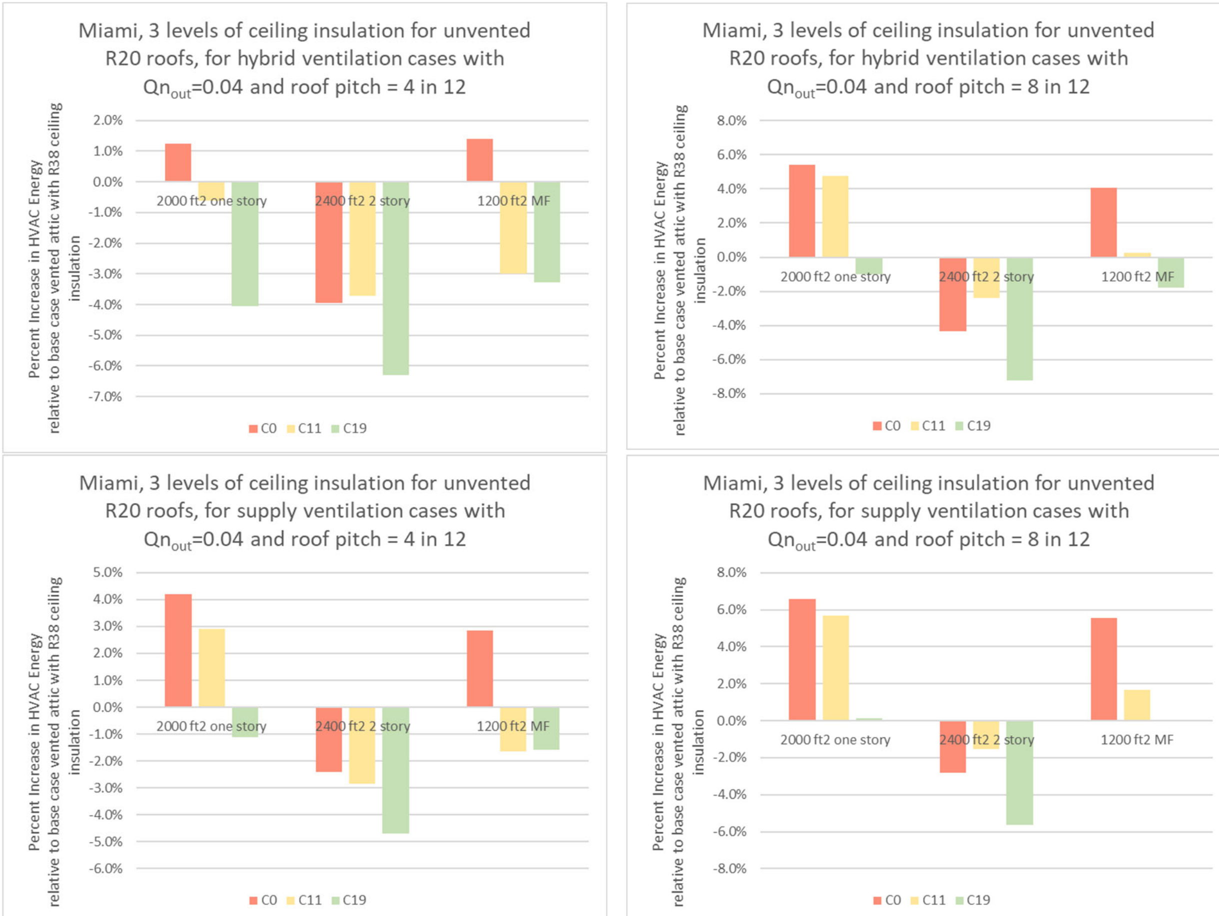

Figure 12. Comparison of three different levels of ceiling insulation for unvented attics relative to base case vented attic with R30 ceiling insulation in Climate Zone 1 for roof pitches of 4 in 12 (charts on left) and 8 in 12 (charts on right) for hybrid ventilation (top charts) and supply-only ventilation (bottom charts).

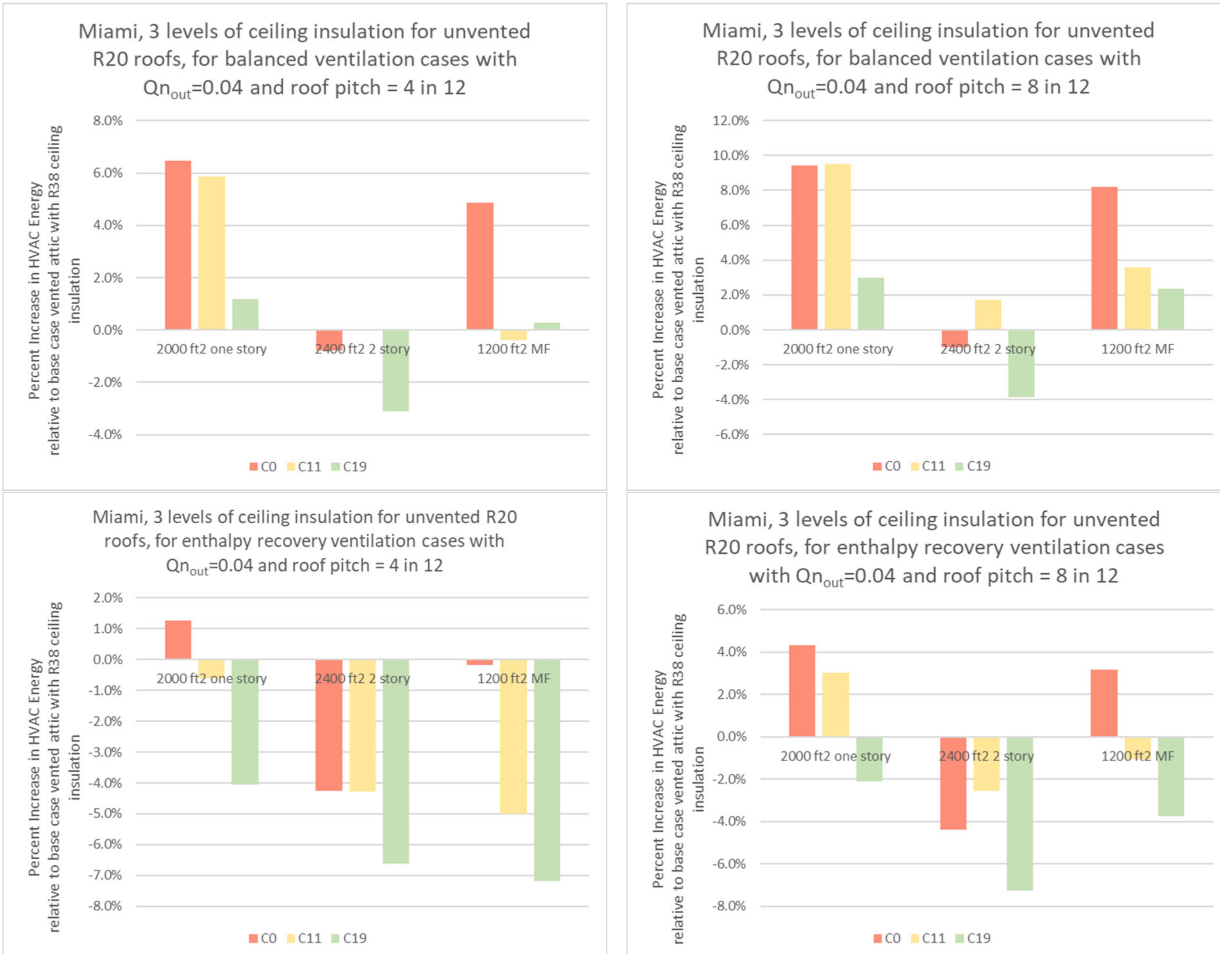

Figure 13. Comparison of three different levels of ceiling insulation for unvented attics relative to base case vented attic with R30 ceiling insulation in Climate Zone 1 for roof pitches of 4 in 12 (charts on left) and 8 in 12 (charts on right) for balanced ventilation (top charts) and balanced with enthalpy recovery ventilation (bottom charts).

5. Conclusions

There are currently a number of builders using unvented attics in Florida. Most homes comply by the section R405 performance methodology. Under the R405 methodology, homes with R20 roof insulations can comply through energy use trade-off allowances. There have been a limited number of research projects examining unvented attics in Florida as well as some in other parts of the country. The literature search finds mixed results regarding moisture and energy use in unvented attics. One of the key parameters that is not regularly measured is the air leakage between the unvented attic and the outside. This can significantly impact moisture and energy use. Most moisture research has not found issues with roof sheathing wood moisture content exceeding 20% in Florida homes with unvented attics having air-impermeable insulation at the roof sheathing. When this 20% moisture content threshold is approached the studies have found that it tends to occur for only short periods of time. Any regulatory changes to the application with respect to moisture would apply to unvented attic homes complying by both the prescriptive and the performance methods.

Published data on measured attic tightness and duct leakage shows there is a wide variability in both. Tests on duct leakage in unvented attics indicates on average there is some duct leakage to outdoors. On occasion, some unvented attics are found to be leakier than desired, which may result in more duct leakage lost to outdoors and increased infiltration. This may make attic moisture control more difficult. Excessive unvented attic moisture levels are sometimes remediated by supplemental dehumidification of the attic space, and if the attic is not well sealed this may result in much higher than expected energy costs for homeowners. An attic tightness-to-outdoors test protocol capable of indicating a reasonable assuredness of attic tightness to outdoors is needed. If possible, such a test should not require guarded testing, if possible, to enable a relatively quick and inexpensive means of evaluation. The legislation requires a tested house airtightness blower door test of less than 3 ACH50. That test should be conducted according to section R402.4.1.2 of the Florida Building Code, 8th Edition (2023), Energy Conservation where it states:

> *If an attic is both air sealed and insulated at the roof deck, interior access doors and hatches between the conditioned space volume and the attic shall be opened during the test and the volume of the attic shall be added to the conditioned space volume for purposes of reporting an infiltration volume and calculating the air leakage of the home.*

This requirement, combined with the less than 3 ACH50 requirement, should reduce the risk of excessive unvented attic leakage.

There is a dearth of detailed data on leakage from unvented attics to the outside and attic duct leakage to outside in the literature on energy simulations. As a result, it is still difficult or impossible to compare results between different simulation studies. This is due to issues such as using different assumptions about attic, house, and duct tightness, attic and house geometries, and different levels of roof and ceiling insulation R values being compared. Generally, energy simulations comparing benefit of unvented attic with insulation at the underside of roof sheathing to a conventional vented attic with insulation at the ceiling found that more benefit is likely: with cold dominated climates, with a greater proportion of attic ducts, with higher rates of assumed attic duct leakage, and with a very little unvented attic leakage to outside.

The simulations run by FSEC for this analysis indicate some increase in energy use for the minimal Section 553.906, Florida Statutes/R402 compliance path in many but not all simulated homes. Simulations were run in Miami (Climate Zone 1) and Tallahassee (Climate Zone 2) using three prototype homes: a detached 2000 ft^2 one-story home, a detached 2400 ft^2 detached two-story home, and a multifamily attached unit with 1200 $ft^2$of conditioned space. Our simulations indicate that reducing the prescriptive requirement from R30 on the ceiling in Climate Zone 1 (or R38 on the ceiling in Climate Zone 2) to a roof insulation level of R20 by itself, leaving all other parameters the same, will increase energy use even without any attic dehumidification. Also, higher roof pitches will diminish any energy benefit of an unvented attic as the thermal surface boundary area of the attic increases. However, since the statute change requires a very tight home with whole-house mechanical ventilation, the type of ventilation system and the energy impact it has must also be considered. Balanced mechanical ventilation with enthalpy recovery used less energy than the three other types simulated. The statute requirements for a tight house led to the legislative prescriptive alternative saving some energy in our two-story simulation results with best case whole-house mechanical ventilation, while using more energy in our single floor simulation results.

With respect to the current R402 prescriptive code base case, the worst case for the 2000 ft^2 single story home using the statute method of R20 roof insulation without any ceiling insulation, with a balanced ventilation system without enthalpy recovery, led to an increase of 18% in heating, cooling and ventilation energy in Climate Zone 2 and 9% increase in Climate Zone 1. The best-case scenario with R20 roof insulation and no ceiling insulation is the two-story home modeled with an enthalpy-recovery ventilation system. Relative to the current R402 levels of insulation and air tightness, this home saved 1% of HVAC energy in Climate Zone 2 and 4% in Climate Zone 1.

Two alternatives to the statute proposal were simulated. One alternative configuration had R20 insulation on the roof plane and R19 at the ceiling. This alternative should meet the current R402 code. The simulation results of this system were better than just having insulation at the ceiling or just at the roof for low slope (4 in 12) roofs prior to adding ventilation. The second alternative had R20 insulation on the roof plane and R11 at the ceiling. On average of the 24 comparative cases simulated for Climate Zone 2 this showed minimal difference (0.5% higher HVAC energy use) from the current R402 base case. In Climate Zone 1, the R20 roof with R11 ceiling insulation showed improvement on average for the 24 comparative cases simulated (1.6% reduction in HVAC energy use) versus the current Climate Zone 1 R402 base case. With 2x4 trusses, this level of ceiling insulation would allow plywood flooring in the attic for those residents desiring a safer storage area.

Because Section 553.906, Florida Statutes includes a targeted reduction in air leakage and employs whole-house mechanical ventilation, the homes complying by this method may have better air quality potential as long as the ventilation system runs and is maintained. Thus, it may be reasonable to accept slightly higher energy use for this alternative, as the home should have improved indoor air quality if the ventilation system is maintained. Unfortunately, previous research for the Florida Building Commission has shown that rarely are whole house mechanical ventilation systems maintained and operated in their designed condition.[4]

In summary, based on the current literature, there are no technical changes to the legislation required for unvented attics for moisture control. To achieve roughly the same equivalent energy use it is recommended that a requirement for at least R11 at the ceiling be included and that balanced ventilation systems would be required to have enthalpy recovery. Such changes are indicated with underline text below:

> Unvented attic and unvented enclosed rafter assemblies that are insulated and air sealed with a minimum of R-20 air impermeable insulation meet the requirements of sections R402 of the Florida Building Code, 8th Edition (2023), Energy Conservation, if all of the following apply:
> (a) The building has a blower door test result of less than 3 ACH50.

[4] https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-CR-2002-15.pdf

(b) The building has a positive input ventilation system or a balanced with enthalpy recovery system or hybrid whole-house mechanical ventilation system.

(c) If the insulation is installed below the roof deck and the exposed portion of roof rafters is not already covered by the R-20 air-impermeable insulation, the exposed portion of the roof rafters is insulated by a minimum of R-3 air-impermeable insulation unless directly covered by a finished ceiling. Roof rafters are not required to be covered by a minimum of R-3 air impermeable insulation if continuous insulation is installed above the roof deck.

(d) All indoor heating, cooling, and ventilation equipment and ductwork is inside the building thermal envelope inclusive of the unvented insulated attic.

(e) A minimum of R-11 insulation is located at the ceiling of the conditioned space below the attic.

Acknowledgement

Thanks to the Florida Building Commission and the Florida Department of Business and Professional Regulation for providing funding for this research.

6. APPENDIX A. Tables of Simulation Results

Tables A-1 through A-6 each represent 48 simulation results for a specific city and house type. There are eight simulations at the top –these are homes that would meet the current prescriptive R402 code of having R38 (Climate Zone 2) or R30 (Climate Zone 1) insulation. The first four simulations are with vented attic and insulation at the ceiling level. The next four rows are with an unvented attic and the insulation at the roof plane. The first of each of these four rows is shown with the maximum duct leakage Qn of 0.04 cfm25/ft^2 and a roof pitch of 4 in 12. The second row is with a Qn_{out} of 0.04 and a roof pitch of 8 in 12. The third row is with a Qn_{out} of 0 (no duct leakage to outside) and a roof pitch of 4 in 12. The fourth row is with a Qn_{out} of 0 and a roof pitch of 8 in 12. You will see horizontal lines every four rows in the tables.

After the first eight rows are four rows of a special case. These results are for R20 roof plane insulation with ACH50 house leakage of 7 and no mechanical ventilation. This insulation is too low to be allowed under current prescriptive R402 code, and the 2024 section 553.9065 legislation requires a tighter home and ventilation for the exception. However, these results allows direct comparison of the R20 with the current code level of insulation. Similar to above the four runs follow the base cases of Qn_{out} of 0.04 cfm24/ft2 and roof pitch of 4 in 12, then Qn_{out} of 0.04 and roof pitch of 8 in 12, followed by Qn_{out} of 0 and roof pitch of 4 in 12 followed by Qn_{out} of 0 and roof pitch of 8 in 12.

The four rows after that represent an alternative that has the R20 at the roof plane and R19 on the ceiling with ACH50 house leakage of 7 and no mechanical ventilation. This should be allowed under current code and would allow the roof plane to only have R20 insulation. The four row follow the same pattern regarding Qn and roof pitch values as described above.

The remaining rows are for different ventilation systems. The vent column indicates the whole house mechanical ventilation type: NV= no whole house mechanical ventilation, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting. The four rows for each follow the same pattern. The first four for a given ventilation strategy are for the legislative minimum R20 on the roof deck. The following four rows are for R20 on the roof deck and R19 on the ceiling plane. The nomenclature for each simulation are also provided at the bottom of each table.

The right hand columns in each table present the change from the relative base case. The first row of each set of 4 results is compared to the first row in base case at the top of the table, the second row in each set to the second row at the top of the table, the third row in each set to the second row at the top of the table third to third, the fourth row in each set to the fourth row at the top of the table.

The right most column on each table shows the percent increase (positive number) or decrease (negative number) from the respective base case. The column to the left of that column shows the delta kWh. Again, positive values indicate increase in energy use and negative values represent energy savings form the respective base case. Increases in energy use are highlighted in red and decreases in green.

Table A-7 Compares the Miami Climate Zone 1 base case R30 ceiling insulation with vented attic with the legislative alternative plus R11 ceiling insulation. These simulations were run to see if such an alternative could be close to equivalent to the current prescriptive code with regard to energy use. Only the code minimum of Qn_{out}=0.04 were run for this analysis, not the Qn_{out}=0. The first and second line for each home type are the base cases for a roof pitch of 4 in12 and 8 in 12 respectively. The next two lines show the intermediate step for just changing to R20 roof, R11 ceiling, unvented attic with no change in ACH50 and no mechanical ventilation (Vent column = NV). The following 8 rows represent the ACH50 =3 cases with supply ventilation at 4 in 12 roof pitch, supply ventilation at 8 in 12 roof pitch, then the similar pairs for balanced ventilation, enthalpy recovery ventilation and finally hybrid ventilation. Comparing the average of the 8 unvented ACH50=3 with mechanical ventilation cases for the 3 different homes (24 cases total) against the base cases showed an average *decrease* of 1.6% in HVAC energy use for Miami.

Table A-8 compares the Tallahassee Climate Zone 2 base case simulation of R38 ceiling insulation with vented attic with the legislative alternative plus R11 ceiling insulation. The layout of the table is the same as described for Table A-7. Comparing the average of these 8 unvented, ACH50=3 with mechanical ventilation cases for the 3 different homes (24 cases total) against the base cases showed an average *increase* of 0.5% in HVAC energy use for Tallahassee.

Table A-1 2000 ft^2 single-family detached home, one-story, Miami

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Heat+Cool+ Vent kWh	HCVΔ kWh	%
Miami	base	a7	q4	NV	p4	r00	c30	5613	0	0%
Miami	base	a7	q4	NV	p8	r00	c30	5600	0	0%
Miami	base	a7	q0	NV	p4	r00	c30	5108	0	0%
Miami	base	a7	q0	NV	p8	r00	c30	5084	0	0%
Miami	base	a7	q4	NV	p4	r30	c00	5532	-81	-1%
Miami	base	a7	q4	NV	p8	r30	c00	5769	169	3%
Miami	base	a7	q0	NV	p4	r30	c00	5093	-15	0%
Miami	base	a7	q0	NV	p8	r30	c00	5336	252	5%
Miami	roof	a7	q4	NV	p4	r20	c00	5694	81	1%
Miami	roof	a7	q4	NV	p8	r20	c00	5937	337	6%
Miami	roof	a7	q0	NV	p4	r20	c00	5279	171	3%
Miami	roof	a7	q0	NV	p8	r20	c00	5530	446	9%
Miami	roof	a7	q4	NV	p4	r20	c19	5392	-221	-4%
Miami	roof	a7	q4	NV	p8	r20	c19	5983	383	7%
Miami	roof	a7	q0	NV	p4	r20	c19	4920	-188	-4%
Miami	roof	a7	q0	NV	p8	r20	c19	5105	21	0%
Miami	roof	a3	q4	SV	p4	r20	c00	5849	236	4%
Miami	roof	a3	q4	SV	p8	r20	c00	5968	368	7%
Miami	roof	a3	q0	SV	p4	r20	c00	5390	282	6%
Miami	roof	a3	q0	SV	p8	r20	c00	5520	436	9%
Miami	roof	a3	q4	SV	p4	r20	c19	5551	-62	-1%
Miami	roof	a3	q4	SV	p8	r20	c19	5608	8	0%
Miami	roof	a3	q0	SV	p4	r20	c19	5033	-75	-1%
Miami	roof	a3	q0	SV	p8	r20	c19	5097	13	0%
Miami	roof	a3	q4	BV	p4	r20	c00	5976	363	6%
Miami	roof	a3	q4	BV	p8	r20	c00	6127	527	9%
Miami	roof	a3	q0	BV	p4	r20	c00	5516	408	8%
Miami	roof	a3	q0	BV	p8	r20	c00	5677	593	12%
Miami	roof	a3	q4	BV	p4	r20	c19	5679	66	1%
Miami	roof	a3	q4	BV	p8	r20	c19	5767	167	3%
Miami	roof	a3	q0	BV	p4	r20	c19	5156	48	1%
Miami	roof	a3	q0	BV	p8	r20	c19	5254	170	3%
Miami	roof	a3	q4	EV	p4	r20	c00	5683	70	1%
Miami	roof	a3	q4	EV	p8	r20	c00	5843	243	4%
Miami	roof	a3	q0	EV	p4	r20	c00	5221	113	2%
Miami	roof	a3	q0	EV	p8	r20	c00	5392	308	6%
Miami	roof	a3	q4	EV	p4	r20	c19	5386	-227	-4%
Miami	roof	a3	q4	EV	p8	r20	c19	5483	-117	-2%
Miami	roof	a3	q0	EV	p4	r20	c19	4861	-247	-5%
Miami	roof	a3	q0	EV	p8	r20	c19	4967	-117	-2%
Miami	roof	a3	q4	HV	p4	r20	c00	5784	171	3%
Miami	roof	a3	q4	HV	p8	r20	c00	5904	304	5%
Miami	roof	a3	q0	HV	p4	r20	c00	5323	215	4%
Miami	roof	a3	q0	HV	p8	r20	c00	5323	239	5%
Miami	roof	a3	q4	HV	p4	r20	c19	5486	-127	-2%
Miami	roof	a3	q4	HV	p8	r20	c19	5545	-55	-1%
Miami	roof	a3	q0	HV	p4	r20	c19	4963	-145	-3%
Miami	roof	a3	q0	HV	p8	r20	c19	5026	-58	-1%
		a3=3 ACH50		q4 = Qn=0.04		p4 =4 in 12 roof pitch		R0 to R30 are roof insulation R values		
		a7= 7 ACH50		q0 = Qn = 0.00		p8 = 8 in 12 roof pitch		C0 to C30 are ceiling insulation levels		

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-2 2000 ft² single-family detached home, one-story, Tallahassee

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Heat+Cool+ Vent kWh	HCVΔ kWh	%
Miami	base	a7	q4	NV	p4	r00	c30	5613	0	0%
Miami	base	a7	q4	NV	p8	r00	c30	5600	0	0%
Miami	base	a7	q0	NV	p4	r00	c30	5108	0	0%
Miami	base	a7	q0	NV	p8	r00	c30	5084	0	0%
Miami	base	a7	q4	NV	p4	r30	c00	5532	-81	-1%
Miami	base	a7	q4	NV	p8	r30	c00	5769	169	3%
Miami	base	a7	q0	NV	p4	r30	c00	5093	-15	0%
Miami	base	a7	q0	NV	p8	r30	c00	5336	252	5%
Miami	roof	a7	q4	NV	p4	r20	c00	5694	81	1%
Miami	roof	a7	q4	NV	p8	r20	c00	5937	337	6%
Miami	roof	a7	q0	NV	p4	r20	c00	5279	171	3%
Miami	roof	a7	q0	NV	p8	r20	c00	5530	446	9%
Miami	roof	a7	q4	NV	p4	r20	c19	5392	-221	-4%
Miami	roof	a7	q4	NV	p8	r20	c19	5572	-28	-1%
Miami	roof	a7	q0	NV	p4	r20	c19	4920	-188	-4%
Miami	roof	a7	q0	NV	p8	r20	c19	5105	21	0%
Miami	roof	a3	q4	SV	p4	r20	c00	5849	236	4%
Miami	roof	a3	q4	SV	p8	r20	c00	5968	368	7%
Miami	roof	a3	q0	SV	p4	r20	c00	5390	282	6%
Miami	roof	a3	q0	SV	p8	r20	c00	5520	436	9%
Miami	roof	a3	q4	SV	p4	r20	c19	5551	-62	-1%
Miami	roof	a3	q4	SV	p8	r20	c19	5608	8	0%
Miami	roof	a3	q0	SV	p4	r20	c19	5033	-75	-1%
Miami	roof	a3	q0	SV	p8	r20	c19	5097	13	0%
Miami	roof	a3	q4	BV	p4	r20	c00	5976	363	6%
Miami	roof	a3	q4	BV	p8	r20	c00	6127	527	9%
Miami	roof	a3	q0	BV	p4	r20	c00	5516	408	8%
Miami	roof	a3	q0	BV	p8	r20	c00	5677	593	12%
Miami	roof	a3	q4	BV	p4	r20	c19	5679	66	1%
Miami	roof	a3	q4	BV	p8	r20	c19	5767	167	3%
Miami	roof	a3	q0	BV	p4	r20	c19	5156	48	1%
Miami	roof	a3	q0	BV	p8	r20	c19	5254	170	3%
Miami	roof	a3	q4	EV	p4	r20	c00	5683	70	1%
Miami	roof	a3	q4	EV	p8	r20	c00	5843	243	4%
Miami	roof	a3	q0	EV	p4	r20	c00	5221	113	2%
Miami	roof	a3	q0	EV	p8	r20	c00	5392	308	6%
Miami	roof	a3	q4	EV	p4	r20	c19	5386	-227	-4%
Miami	roof	a3	q4	EV	p8	r20	c19	5483	-117	-2%
Miami	roof	a3	q0	EV	p4	r20	c19	4861	-247	-5%
Miami	roof	a3	q0	EV	p8	r20	c19	4967	-117	-2%
Miami	roof	a3	q4	HV	p4	r20	c00	5784	171	3%
Miami	roof	a3	q4	HV	p8	r20	c00	5904	304	5%
Miami	roof	a3	q0	HV	p4	r20	c00	5323	215	4%
Miami	roof	a3	q0	HV	p8	r20	c00	5323	239	5%
Miami	roof	a3	q4	HV	p4	r20	c19	5486	-127	-2%
Miami	roof	a3	q4	HV	p8	r20	c19	5545	-55	-1%
Miami	roof	a3	q0	HV	p4	r20	c19	4963	-145	-3%
Miami	roof	a3	q0	HV	p8	r20	c19	5026	-58	-1%
		a3=3 ACH50		q4 = Qn=0.04	p4 =4 in 12 roof pitch	R0 to R30 are roof insulation R values				
		a7= 7 ACH50		q0 = Qn = 0.00	p8 = 8 in 12 roof pitch	C0 to C30 are ceiling insulation levels				
Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting										
CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.										

Table A-3 2400 ft² single-family detached home, two-story, Miami

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+heat+ Vent kWh	HCV Δ kWh	%
Miami	base	a7	q4	NV	p4	r00	c30	6630	0	0%
Miami	base	a7	q4	NV	p8	r00	c30	6743	0	0%
Miami	base	a7	q0	NV	p4	r00	c30	5985	0	0%
Miami	base	a7	q0	NV	p8	r00	c30	6101	0	0%
Miami	base	a7	q4	NV	p4	r30	c00	6307	-323	-5%
Miami	base	a7	q4	NV	p8	r30	c00	6448	-295	-4%
Miami	base	a7	q0	NV	p4	r30	c00	5741	-244	-4%
Miami	base	a7	q0	NV	p8	r30	c00	5892	-209	-3%
Miami	roof	a7	q4	NV	p4	r20	c00	6417	-213	-3%
Miami	roof	a7	q4	NV	p8	r20	c00	6567	-176	-3%
Miami	roof	a7	q0	NV	p4	r20	c00	5870	-115	-2%
Miami	roof	a7	q0	NV	p8	r20	c00	6028	-73	-1%
Miami	roof	a7	q4	NV	p4	r20	c19	6268	-362	-5%
Miami	roof	a7	q4	NV	p8	r20	c19	6380	-363	-5%
Miami	roof	a7	q0	NV	p4	r20	c19	5661	-324	-5%
Miami	roof	a7	q0	NV	p8	r20	c19	5777	-324	-5%
Miami	roof	a3	q4	SV	p4	r20	c00	6471	-159	-2%
Miami	roof	a3	q4	SV	p8	r20	c00	6554	-189	-3%
Miami	roof	a3	q0	SV	p4	r20	c00	5867	-118	-2%
Miami	roof	a3	q0	SV	p8	r20	c00	5956	-145	-2%
Miami	roof	a3	q4	SV	p4	r20	c19	6319	-311	-5%
Miami	roof	a3	q4	SV	p8	r20	c19	6364	-379	-6%
Miami	roof	a3	q0	SV	p4	r20	c19	5651	-334	-6%
Miami	roof	a3	q0	SV	p8	r20	c19	5697	-404	-7%
Miami	roof	a3	q4	BV	p4	r20	c00	6579	-51	-1%
Miami	roof	a3	q4	BV	p8	r20	c00	6675	-68	-1%
Miami	roof	a3	q0	BV	p4	r20	c00	5982	-3	0%
Miami	roof	a3	q0	BV	p8	r20	c00	6086	-15	0%
Miami	roof	a3	q4	BV	p4	r20	c19	6424	-206	-3%
Miami	roof	a3	q4	BV	p8	r20	c19	6482	-261	-4%
Miami	roof	a3	q0	BV	p4	r20	c19	5769	-216	-4%
Miami	roof	a3	q0	BV	p8	r20	c19	5830	-271	-4%
Miami	roof	a3	q4	EV	p4	r20	c00	6348	-282	-4%
Miami	roof	a3	q4	EV	p8	r20	c00	6449	-294	-4%
Miami	roof	a3	q0	EV	p4	r20	c00	5736	-249	-4%
Miami	roof	a3	q0	EV	p8	r20	c00	5846	-255	-4%
Miami	roof	a3	q4	EV	p4	r20	c19	6192	-438	-7%
Miami	roof	a3	q4	EV	p8	r20	c19	6254	-489	-7%
Miami	roof	a3	q0	EV	p4	r20	c19	5523	-462	-8%
Miami	roof	a3	q0	EV	p8	r20	c19	5589	-512	-8%
Miami	roof	a3	q4	HV	p4	r20	c00	6369	-261	-4%
Miami	roof	a3	q4	HV	p8	r20	c00	6452	-291	-4%
Miami	roof	a3	q0	HV	p4	r20	c00	5769	-216	-4%
Miami	roof	a3	q0	HV	p8	r20	c00	5856	-245	-4%
Miami	roof	a3	q4	HV	p4	r20	c19	6213	-417	-6%
Miami	roof	a3	q4	HV	p8	r20	c19	6257	-486	-7%
Miami	roof	a3	q0	HV	p4	r20	c19	5552	-433	-7%
Miami	roof	a3	q0	HV	p8	r20	c19	5596	-505	-8%

a3=3 ACH50 q4 = Qn=0.04 p4 =4 in 12 roof pitch R0 to R30 are roof insulation R values

a7= 7 ACH50 q0 = Qn = 0.00 p8 = 8 in 12 roof pitch C0 to C30 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-4 2400 ft² single-family detached home, two-story, Tallahassee

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+heat +Vent kWh	HCV Δ kWh	%
Tallahassee	base	a7	q4	NV	p4	r00	c38	5126	0	0%
Tallahassee	base	a7	q4	NV	p8	r00	c38	5118	0	0%
Tallahassee	base	a7	q0	NV	p4	r00	c38	4665	0	0%
Tallahassee	base	a7	q0	NV	p8	r00	c38	4655	0	0%
Tallahassee	base	a7	q4	NV	p4	r38	c00	4923	-203	-4%
Tallahassee	base	a7	q4	NV	p8	r38	c00	5093	-25	0%
Tallahassee	base	a7	q0	NV	p4	r38	c00	4624	-41	-1%
Tallahassee	base	a7	q0	NV	p8	r38	c00	4784	129	3%
Tallahassee	roof	a7	q4	NV	p4	r20	c00	5221	95	2%
Tallahassee	roof	a7	q4	NV	p8	r20	c00	5407	289	6%
Tallahassee	roof	a7	q0	NV	p4	r20	c00	4904	239	5%
Tallahassee	roof	a7	q0	NV	p8	r20	c00	5081	426	9%
Tallahassee	roof	a7	q4	NV	p4	r20	c19	4991	-135	-3%
Tallahassee	roof	a7	q4	NV	p8	r20	c19	5123	5	0%
Tallahassee	roof	a7	q0	NV	p4	r20	c19	4605	-60	-1%
Tallahassee	roof	a7	q0	NV	p8	r20	c19	4726	71	2%
Tallahassee	roof	a3	q4	SV	p4	r20	c00	5146	20	0%
Tallahassee	roof	a3	q4	SV	p8	r20	c00	5251	133	3%
Tallahassee	roof	a3	q0	SV	p4	r20	c00	4822	157	3%
Tallahassee	roof	a3	q0	SV	p8	r20	c00	4921	266	6%
Tallahassee	roof	a3	q4	SV	p4	r20	c19	4907	-219	-4%
Tallahassee	roof	a3	q4	SV	p8	r20	c19	4956	-162	-3%
Tallahassee	roof	a3	q0	SV	p4	r20	c19	4516	-149	-3%
Tallahassee	roof	a3	q0	SV	p8	r20	c19	4560	-95	-2%
Tallahassee	roof	a3	q4	BV	p4	r20	c00	5291	165	3%
Tallahassee	roof	a3	q4	BV	p8	r20	c00	5410	292	6%
Tallahassee	roof	a3	q0	BV	p4	r20	c00	4962	297	6%
Tallahassee	roof	a3	q0	BV	p8	r20	c00	5074	419	9%
Tallahassee	roof	a3	q4	BV	p4	r20	c19	5054	-72	-1%
Tallahassee	roof	a3	q4	BV	p8	r20	c19	5120	2	0%
Tallahassee	roof	a3	q0	BV	p4	r20	c19	4657	-8	0%
Tallahassee	roof	a3	q0	BV	p8	r20	c19	4715	60	1%
Tallahassee	roof	a3	q4	EV	p4	r20	c00	5075	-51	-1%
Tallahassee	roof	a3	q4	EV	p8	r20	c00	5198	80	2%
Tallahassee	roof	a3	q0	EV	p4	r20	c00	4741	76	2%
Tallahassee	roof	a3	q0	EV	p8	r20	c00	4859	204	4%
Tallahassee	roof	a3	q4	EV	p4	r20	c19	4833	-203	-6%
Tallahassee	roof	a3	q4	EV	p8	r20	c19	4899	-25	-4%
Tallahassee	roof	a3	q0	EV	p4	r20	c19	4435	-41	-5%
Tallahassee	roof	a3	q0	EV	p8	r20	c19	4494	129	-3%
Tallahassee	roof	a3	q4	HV	p4	r20	c00	5101	-25	0%
Tallahassee	roof	a3	q4	HV	p8	r20	c00	5205	87	2%
Tallahassee	roof	a3	q0	HV	p4	r20	c00	4772	107	2%
Tallahassee	roof	a3	q0	HV	p8	r20	c00	4871	216	5%
Tallahassee	roof	a3	q4	HV	p4	r20	c19	4862	-264	-5%
Tallahassee	roof	a3	q4	HV	p8	r20	c19	4910	-208	-4%
Tallahassee	roof	a3	q0	HV	p4	r20	c19	4467	-198	-4%
Tallahassee	roof	a3	q0	HV	p8	r20	c19	4511	-144	-3%

a3=3 ACH50 q4 = Qn=0.04 p4 =4 in 12 roof pitch R0 to R38 are roof insulation R values

a7= 7 ACH50 q0 = Qn = 0.00 p8 = 8 in 12 roof pitch C0 to C38 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-5 1200 ft^2 multifamily unit directly below attic, Miami

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+heat+ Vent kWh	HCV Δ kWh	%
Miami	base	a7	q4	NV	p4	r00	c30	3174	0	0%
Miami	base	a7	q4	NV	p8	r00	c30	3158	0	0%
Miami	base	a7	q0	NV	p4	r00	c30	2857	0	0%
Miami	base	a7	q0	NV	p8	r00	c30	2830	0	0%
Miami	base	a7	q4	NV	p4	r30	c00	3000	-174	-5%
Miami	base	a7	q4	NV	p8	r30	c00	3122	-36	-1%
Miami	base	a7	q0	NV	p4	r30	c00	2729	-128	-4%
Miami	base	a7	q0	NV	p8	r30	c00	2854	24	1%
Miami	roof	a7	q4	NV	p4	r20	c00	3086	-88	-3%
Miami	roof	a7	q4	NV	p8	r20	c00	3211	53	2%
Miami	roof	a7	q0	NV	p4	r20	c00	2839	-18	-1%
Miami	roof	a7	q0	NV	p8	r20	c00	2966	136	5%
Miami	roof	a7	q4	NV	p4	r20	c19	2943	-231	-7%
Miami	roof	a7	q4	NV	p8	r20	c19	3031	-127	-4%
Miami	roof	a7	q0	NV	p4	r20	c19	2652	-205	-7%
Miami	roof	a7	q0	NV	p8	r20	c19	2744	-86	-3%
Miami	roof	a3	q4	SV	p4	r20	c00	3264	90	3%
Miami	roof	a3	q4	SV	p8	r20	c00	3333	175	6%
Miami	roof	a3	q0	SV	p4	r20	c00	2992	135	5%
Miami	roof	a3	q0	SV	p8	r20	c00	3066	236	8%
Miami	roof	a3	q4	SV	p4	r20	c19	3124	-50	-2%
Miami	roof	a3	q4	SV	p8	r20	c19	3157	-1	0%
Miami	roof	a3	q0	SV	p4	r20	c19	2810	-47	-2%
Miami	roof	a3	q0	SV	p8	r20	c19	2844	14	0%
Miami	roof	a3	q4	BV	p4	r20	c00	3329	155	5%
Miami	roof	a3	q4	BV	p8	r20	c00	3417	259	8%
Miami	roof	a3	q0	BV	p4	r20	c00	3058	201	7%
Miami	roof	a3	q0	BV	p8	r20	c00	3149	319	11%
Miami	roof	a3	q4	BV	p4	r20	c19	3183	9	0%
Miami	roof	a3	q4	BV	p8	r20	c19	3233	75	2%
Miami	roof	a3	q0	BV	p4	r20	c19	2869	12	0%
Miami	roof	a3	q0	BV	p8	r20	c19	2918	88	3%
Miami	roof	a3	q4	EV	p4	r20	c00	3168	-6	0%
Miami	roof	a3	q4	EV	p8	r20	c00	3258	100	3%
Miami	roof	a3	q0	EV	p4	r20	c00	2891	34	1%
Miami	roof	a3	q0	EV	p8	r20	c00	2986	156	6%
Miami	roof	a3	q4	EV	p4	r20	c19	3024	-150	-5%
Miami	roof	a3	q4	EV	p8	r20	c19	3073	-85	-3%
Miami	roof	a3	q0	EV	p4	r20	c19	2705	-152	-5%
Miami	roof	a3	q0	EV	p8	r20	c19	2756	-74	-3%
Miami	roof	a3	q4	HV	p4	r20	c00	3218	44	1%
Miami	roof	a3	q4	HV	p8	r20	c00	3287	129	4%
Miami	roof	a3	q0	HV	p4	r20	c00	2943	86	3%
Miami	roof	a3	q0	HV	p8	r20	c00	3018	188	7%
Miami	roof	a3	q4	HV	p4	r20	c19	3070	-104	-3%
Miami	roof	a3	q4	HV	p8	r20	c19	3102	-56	-2%
Miami	roof	a3	q0	HV	p4	r20	c19	2753	-104	-4%
Miami	roof	a3	q0	HV	p8	r20	c19	2787	-43	-2%

a3=3 ACH50 q4 = Qn=0.04 p4 =4 in 12 roof pitch R0 to R30 are roof insulation R values

a7= 7 ACH50 q0 = Qn = 0.00 p8 = 8 in 12 roof pitch C0 to C30 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-6 1200 ft^2 multifamily unit directly below attic, Tallahassee

City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+heat +Vent kWh	HCV Δ kWh	%
Tallahassee	base	a7	q4	NV	p4	r00	c38	2565	0	0%
Tallahassee	base	a7	q4	NV	p8	r00	c38	2539	0	0%
Tallahassee	base	a7	q0	NV	p4	r00	c38	2268	0	0%
Tallahassee	base	a7	q0	NV	p8	r00	c38	2240	0	0%
Tallahassee	base	a7	q4	NV	p4	r38	c00	2298	-267	-10%
Tallahassee	base	a7	q4	NV	p8	r38	c00	2445	-94	-4%
Tallahassee	base	a7	q0	NV	p4	r38	c00	2093	-175	-8%
Tallahassee	base	a7	q0	NV	p8	r38	c00	2232	-8	0%
Tallahassee	roof	a7	q4	NV	p4	r20	c00	2549	-16	-1%
Tallahassee	roof	a7	q4	NV	p8	r20	c00	2720	181	7%
Tallahassee	roof	a7	q0	NV	p4	r20	c00	2343	75	3%
Tallahassee	roof	a7	q0	NV	p8	r20	c00	2504	264	12%
Tallahassee	roof	a7	q4	NV	p4	r20	c19	2378	-187	-7%
Tallahassee	roof	a7	q4	NV	p8	r20	c19	2492	-47	-2%
Tallahassee	roof	a7	q0	NV	p4	r20	c19	2123	-145	-6%
Tallahassee	roof	a7	q0	NV	p8	r20	c19	2223	-17	-1%
Tallahassee	roof	a3	q4	SV	p4	r20	c00	2650	85	3%
Tallahassee	roof	a3	q4	SV	p8	r20	c00	2749	210	8%
Tallahassee	roof	a3	q0	SV	p4	r20	c00	2446	178	8%
Tallahassee	roof	a3	q0	SV	p8	r20	c00	2536	296	13%
Tallahassee	roof	a3	q4	SV	p4	r20	c19	2468	-97	-4%
Tallahassee	roof	a3	q4	SV	p8	r20	c19	2512	-27	-1%
Tallahassee	roof	a3	q0	SV	p4	r20	c19	2218	-50	-2%
Tallahassee	roof	a3	q0	SV	p8	r20	c19	2254	14	1%
Tallahassee	roof	a3	q4	BV	p4	r20	c00	2681	116	5%
Tallahassee	roof	a3	q4	BV	p8	r20	c00	2798	259	10%
Tallahassee	roof	a3	q0	BV	p4	r20	c00	2473	205	9%
Tallahassee	roof	a3	q0	BV	p8	r20	c00	2583	343	15%
Tallahassee	roof	a3	q4	BV	p4	r20	c19	2501	-64	-2%
Tallahassee	roof	a3	q4	BV	p8	r20	c19	2563	24	1%
Tallahassee	roof	a3	q0	BV	p4	r20	c19	2244	-24	-1%
Tallahassee	roof	a3	q0	BV	p8	r20	c19	2300	60	3%
Tallahassee	roof	a3	q4	EV	p4	r20	c00	2567	2	0%
Tallahassee	roof	a3	q4	EV	p8	r20	c00	2681	142	6%
Tallahassee	roof	a3	q0	EV	p4	r20	c00	2362	94	4%
Tallahassee	roof	a3	q0	EV	p8	r20	c00	2469	229	10%
Tallahassee	roof	a3	q4	EV	p4	r20	c19	2381	-184	-7%
Tallahassee	roof	a3	q4	EV	p8	r20	c19	2444	-95	-4%
Tallahassee	roof	a3	q0	EV	p4	r20	c19	2129	-139	-6%
Tallahassee	roof	a3	q0	EV	p8	r20	c19	2186	-54	-2%
Tallahassee	roof	a3	q4	HV	p4	r20	c00	2616	51	2%
Tallahassee	roof	a3	q4	HV	p8	r20	c00	2713	174	7%
Tallahassee	roof	a3	q0	HV	p4	r20	c00	2412	144	6%
Tallahassee	roof	a3	q0	HV	p8	r20	c00	2503	263	12%
Tallahassee	roof	a3	q4	HV	p4	r20	c19	2436	-129	-5%
Tallahassee	roof	a3	q4	HV	p8	r20	c19	2481	-58	-2%
Tallahassee	roof	a3	q0	HV	p4	r20	c19	2185	-83	-4%
Tallahassee	roof	a3	q0	HV	p8	r20	c19	2221	-19	-1%

a3=3 ACH50 q4 = Qn=0.04 p4 =4 in 12 roof pitch R0 to R38 are roof insulation R values

a7= 7 ACH50 q0 = Qn = 0.00 p8 = 8 in 12 roof pitch C0 to C38 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-7 Comparison of simulation results for base case vented attics to unvented attic with R20 roof insulation and R11 ceiling insulation, Miami (Climate Zone 1).

Home Type	City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+Heat+ Vent kWh	HCV Δ kWh	%
2000ft^2 1 story	Miami	base	a7	q4	NV	p4	r00	c30	5613	0	0%
2000ft^2 1 story	Miami	base	a7	q4	NV	p8	r00	c30	5600	0	0%
2000ft^2 1 story	Miami	roof	a7	q4	NV	p4	r20	c11	5456	-157	-3%
2000ft^2 1 story	Miami	roof	a7	q4	NV	p8	r20	c11	5646	46	1%
2000ft^2 1 story	Miami	roof	a3	q4	SV	p4	r20	c11	5610	-3	0%
2000ft^2 1 story	Miami	roof	a3	q4	SV	p8	r20	c11	5681	81	1%
2000ft^2 1 story	Miami	roof	a3	q4	BV	p4	r20	c11	5742	129	2%
2000ft^2 1 story	Miami	roof	a3	q4	BV	p8	r20	c11	5841	241	4%
2000ft^2 1 story	Miami	roof	a3	q4	EV	p4	r20	c11	5452	-161	-3%
2000ft^2 1 story	Miami	roof	a3	q4	EV	p8	r20	c11	5559	-41	-1%
2000ft^2 1 story	Miami	roof	a3	q4	HV	p4	r20	c11	5548	-65	-1%
2000ft^2 1 story	Miami	roof	a3	q4	HV	p8	r20	c11	5618	18	0%
2400ft^2 2 story	Miami	base	a7	q4	NV	p4	r00	c30	6630	0	0%
2400ft^2 2 story	Miami	base	a7	q4	NV	p8	r00	c30	6743	0	0%
2400ft^2 2 story	Miami	roof	a7	q4	NV	p4	r20	c11	6307	-323	-5%
2400ft^2 2 story	Miami	roof	a7	q4	NV	p8	r20	c11	6425	-318	-5%
2400ft^2 2 story	Miami	roof	a3	q4	SV	p4	r20	c11	6350	-280	-4%
2400ft^2 2 story	Miami	roof	a3	q4	SV	p8	r20	c11	6403	-340	-5%
2400ft^2 2 story	Miami	roof	a3	q4	BV	p4	r20	c11	6458	-172	-3%
2400ft^2 2 story	Miami	roof	a3	q4	BV	p8	r20	c11	6525	-218	-3%
2400ft^2 2 story	Miami	roof	a3	q4	EV	p4	r20	c11	6223	-407	-6%
2400ft^2 2 story	Miami	roof	a3	q4	EV	p8	r20	c11	6296	-447	-7%
2400ft^2 2 story	Miami	roof	a3	q4	HV	p4	r20	c11	6247	-383	-6%
2400ft^2 2 story	Miami	roof	a3	q4	HV	p8	r20	c11	6298	-445	-7%
1200 ft^2 MF unit	Miami	base	a7	q4	NV	p4	r00	c30	3174	0	0%
1200 ft^2 MF unit	Miami	base	a7	q4	NV	p8	r00	c30	3158	0	0%
1200 ft^2 MF unit	Miami	roof	a7	q4	NV	p4	r20	c11	2965	-209	-7%
1200 ft^2 MF unit	Miami	roof	a7	q4	NV	p8	r20	c11	3060	-98	-3%
1200 ft^2 MF unit	Miami	roof	a3	q4	SV	p4	r20	c11	3151	-23	-1%
1200 ft^2 MF unit	Miami	roof	a3	q4	SV	p8	r20	c11	3191	33	1%
1200 ft^2 MF unit	Miami	roof	a3	q4	BV	p4	r20	c11	3215	41	1%
1200 ft^2 MF unit	Miami	roof	a3	q4	BV	p8	r20	c11	3270	112	4%
1200 ft^2 MF unit	Miami	roof	a3	q4	EV	p4	r20	c11	3051	-123	-4%
1200 ft^2 MF unit	Miami	roof	a3	q4	EV	p8	r20	c11	3109	-49	-2%
1200 ft^2 MF unit	Miami	roof	a3	q4	HV	p4	r20	c11	3105	-69	-2%
1200 ft^2 MF unit	Miami	roof	a3	q4	HV	p8	r20	c11	3146	-12	0%

a3=3 ACH50 q4 = Qn=0.04 p4 =4 in 12 roof pitch R0 to R30 are roof insulation R values

a7= 7 ACH50 p8 = 8 in 12 roof pitch C0 to C30 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.

Table A-8 Comparison of simulation results for base case vented attics to unvented attic with R20 roof insulation and R11 ceiling insulation, Tallahassee (Climate Zone 2).

Home Type	City	config	ach50	Qn	Vent	roof pitch	Roof R	Ceiling R	Cool+Heat+ Vent kWh	HCV Δ kWh	%
2000ft^2 1 story	Tallahassee	base	a7	q4	NV	p4	r00	c38	4308	0	0%
2000ft^2 1 story	Tallahassee	base	a7	q4	NV	p8	r00	c38	4286	0	0%
2000ft^2 1 story	Tallahassee	roof	a7	q4	NV	p4	r20	c11	4388	80	2%
2000ft^2 1 story	Tallahassee	roof	a7	q4	NV	p8	r20	c11	4634	348	8%
2000ft^2 1 story	Tallahassee	roof	a3	q4	SV	p4	r20	c11	4433	125	3%
2000ft^2 1 story	Tallahassee	roof	a3	q4	SV	p8	r20	c11	4530	244	6%
2000ft^2 1 story	Tallahassee	roof	a3	q4	BV	p4	r20	c11	4561	253	6%
2000ft^2 1 story	Tallahassee	roof	a3	q4	BV	p8	r20	c11	4693	407	9%
2000ft^2 1 story	Tallahassee	roof	a3	q4	EV	p4	r20	c11	4281	-27	-1%
2000ft^2 1 story	Tallahassee	roof	a3	q4	EV	p8	r20	c11	4415	129	3%
2000ft^2 1 story	Tallahassee	roof	a3	q4	HV	p4	r20	c11	4394	86	2%
2000ft^2 1 story	Tallahassee	roof	a3	q4	HV	p8	r20	c11	4490	204	5%
2400ft^2 2 story	Tallahassee	base	a7	q4	NV	p4	r00	c38	5126	0	0%
2400ft^2 2 story	Tallahassee	base	a7	q4	NV	p8	r00	c38	5118	0	0%
2400ft^2 2 story	Tallahassee	roof	a7	q4	NV	p4	r20	c11	5064	-62	-1%
2400ft^2 2 story	Tallahassee	roof	a7	q4	NV	p8	r20	c11	5211	93	2%
2400ft^2 2 story	Tallahassee	roof	a3	q4	SV	p4	r20	c11	4980	-146	-3%
2400ft^2 2 story	Tallahassee	roof	a3	q4	SV	p8	r20	c11	5040	-78	-2%
2400ft^2 2 story	Tallahassee	roof	a3	q4	BV	p4	r20	c11	5127	1	0%
2400ft^2 2 story	Tallahassee	roof	a3	q4	BV	p8	r20	c11	5206	88	2%
2400ft^2 2 story	Tallahassee	roof	a3	q4	EV	p4	r20	c11	4907	-219	-4%
2400ft^2 2 story	Tallahassee	roof	a3	q4	EV	p8	r20	c11	4987	-131	-3%
2400ft^2 2 story	Tallahassee	roof	a3	q4	HV	p4	r20	c11	4935	-191	-4%
2400ft^2 2 story	Tallahassee	roof	a3	q4	HV	p8	r20	c11	4996	-122	-2%
1200 ft^2 MF unit	Tallahassee	base	a7	q4	NV	p4	r00	c38	2565	0	0%
1200 ft^2 MF unit	Tallahassee	base	a7	q4	NV	p8	r00	c38	2539	0	0%
1200 ft^2 MF unit	Tallahassee	roof	a7	q4	NV	p4	r20	c11	2424	-141	-5%
1200 ft^2 MF unit	Tallahassee	roof	a7	q4	NV	p8	r20	c11	2556	17	1%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	SV	p4	r20	c11	2523	-42	-2%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	SV	p8	r20	c11	2581	42	2%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	BV	p4	r20	c11	2555	-10	0%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	BV	p8	r20	c11	2630	91	4%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	EV	p4	r20	c11	2437	-128	-5%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	EV	p8	r20	c11	2512	-27	-1%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	HV	p4	r20	c11	2488	-77	-3%
1200 ft^2 MF unit	Tallahassee	roof	a3	q4	HV	p8	r20	c11	2545	6	0%

a3=3 ACH50   q4 = Qn=0.04   p4 =4 in 12 roof pitch   R0 to R38 are roof insulation R values

a7= 7 ACH50   p8 = 8 in 12 roof pitch   C0 to C38 are ceiling insulation levels

Vent: NV= No Venting, SV = Supply only venting, BV= Balanced venting. EV= Balanced with enthalpy recovery, HV=Hybrid CFIS venting

CFIS: Central Fan Integrated System. Hybrid version uses an efficient exhaust fan to supplement when AC or heat is not in use.