

Hygrothermal Analysis of California Attics

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The majority of the configurations evaluated are well understood and have been addressed in previous published work or in the model building codes. However, the focus of this report is on modifying conventional, ventilated attics, constructed with impermeable roof shingles (with fiberglass batt insulation on the ceiling plane) by adding fiberglass batt (or netted fiberglass or netted cellulose or spray applied fiberglass) insulation to the underside of the roof deck (i.e. on the slope) while leaving the attic air space ventilated to outdoors.



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The hygrothermal simulations suggest that adding air permeable insulation to the underside of vented attic roof decks constructed with impermeable roof shingles or impermeable roof membranes is a viable option in many climate zones in California. In climates with cooler wintertime temperatures and/or more night sky radiation, there is a potential for some increase in the moisture content at the inside face of the OSB roof sheathing. The risk of moisture problems is less when the attic ventilation rate is higher than the ceiling leakage rate. Attic moisture problems are strongly connected to indoor humidity levels and it is recommended that indoor humidity be actively controlled.

The key technical issue addressed is the effect on the moisture content of the roof deck sheathing when air permeable thermal insulation is added to the underside of the roof deck.

Specifically, Figure 1, Modified Vented Attic Asphalt Shingles – can be used in all CEC Zones except 16. More broadly speaking, Figure 1 can be used only in International Energy Conservation Code (IECC) Climate Zones 2B and 3B.

The roofing paper in Figure 1 can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

A ventilation ratio of 1:300 is recommended wherever attics are vented irrespective of climate zone and is a basic code requirement in the International Residential Code (IRC) for vented attic assemblies.

It is further recommended that field exposure experimental work be conducted to verify these results.

1. Introduction

This report summarizes hygrothermal analysis of specific attics constructed in California. The analysis was done using historical experience, published work in journals and trade publications, current building code requirements and WUFI hygrothermal simulations to assess benefits and risks associated with insulating the roof decks in both vented and unvented configurations.

The majority of the configurations evaluated are well understood and have been addressed in previous published work or in the model building codes. However, the focus of this report is on modifying conventional, ventilated attics (with fiberglass batt insulation on the ceiling plane) by adding fiberglass batt (or netted fiberglass or netted cellulose or spray applied fiberglass) insulation to the underside of the roof deck (i.e. on the slope) while leaving the attic air space ventilated to outdoors.

The key technical issue addressed is the effect on the moisture content of the roof deck sheathing when air permeable thermal insulation is added to the underside of the roof deck.

2. Standard Configurations

Attic roof assemblies can be divided into two categories: vented and unvented. The basic principles of both approaches can be found in:

(<http://www.buildingscience.com/documents/digests/bsd-102-understanding-attic-ventilation?topic=doctypes/digests>) and

(<http://www.buildingscience.com/documents/published-articles/pa-crash-course-in-roof-venting>).

A more detailed review evaluation can be found in:

(<http://www.buildingscience.com/documents/bareports/ba-1006-ba-high-r-roofs-case-study-analysis>).

The standard vented and unvented attic configurations are presented in Appendix A. The recommended limits of their applicability are specified and are based on current language in the Model Building Codes. The language in the Model Building Codes is based on previous published work (<http://www.buildingscience.com/documents/bareports/ba-1001-moisture-safe-unvented-wood-roof-systems/view>).

Two factors that affect the performance of these assemblies are the temperature of the roof deck and the ability of moisture laden air to access the underside of the roof deck. In vented attic configurations it is expected that moisture laden air is able to access the underside of the roof deck. The function of the attic ventilation is to remove this moisture before it can damage the roof deck.

In unvented attic roof assemblies the primary approach to provide acceptable performance is to either warm the underside of the roof deck by insulating the top surface of the roof deck so that it remains sufficiently warm that excessive moisture accumulation does not occur or to prevent moisture laden air from accessing the underside of the roof deck by installing an air impermeable layer of insulation. The function of the air impermeable layer of insulation is three fold – to prevent air from reaching the underside of the roof deck, to provide an interior surface facing the attic space that is warm enough to control condensation and finally to provide sufficient vapor

diffusion resistance to control moisture migrating through the air impermeable insulation such that moisture damage to the roof deck does not occur.

3. Modified Conventional Vented Attics

A conventional, ventilated attic (with fiberglass batt insulation on the ceiling plane) can be modified by adding fiberglass batt (or netted fiberglass or netted cellulose or spray applied fiberglass) insulation to the underside of the roof deck (i.e. on the slope) while leaving the attic air space ventilated to outdoors. Figure 1 shows the placement of deck insulation and the venting details necessary to ensure continued ventilation of the modified attic assembly; Figure 2 shows a range of deck insulation options. The modified conventional vented attic configuration is not well understood and is examined in detail in this study.

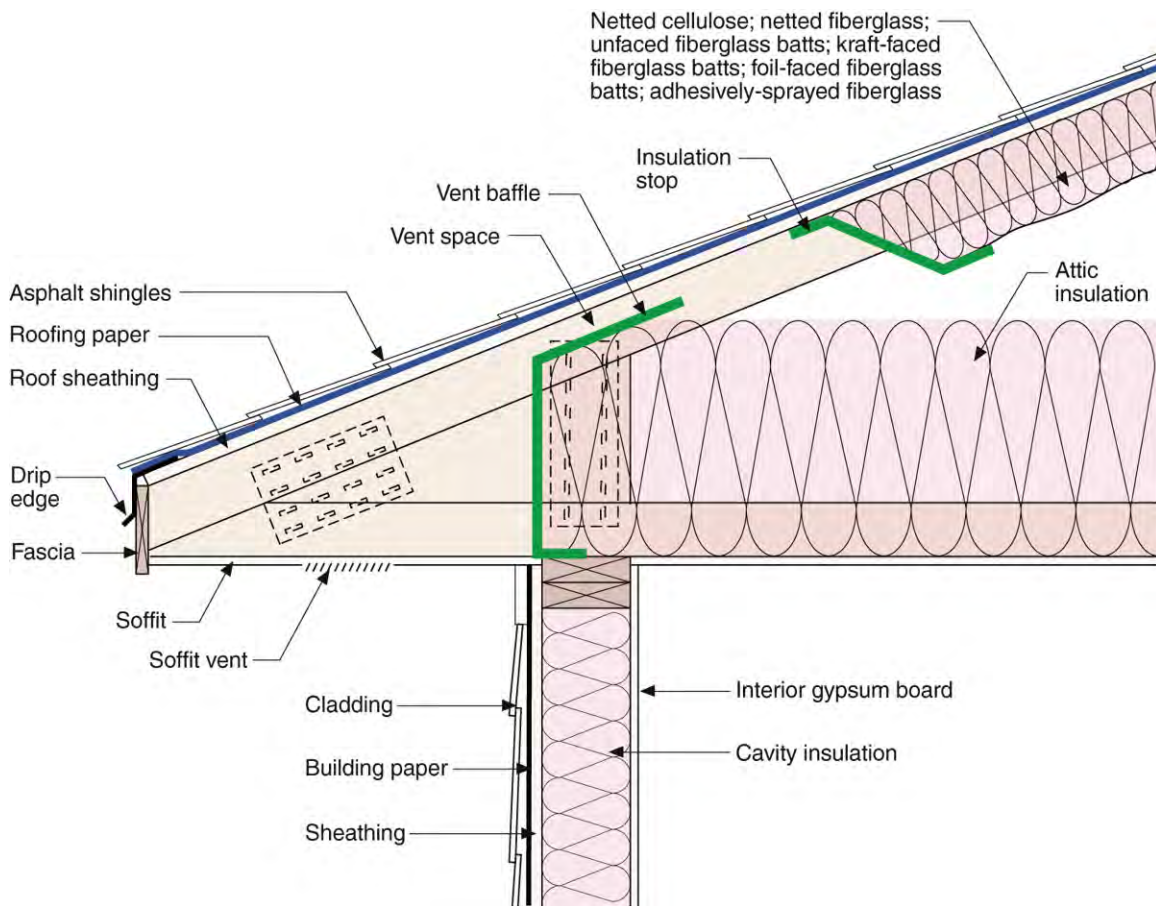


Figure 1: Venting Details for Modified Conventional Vented Attic

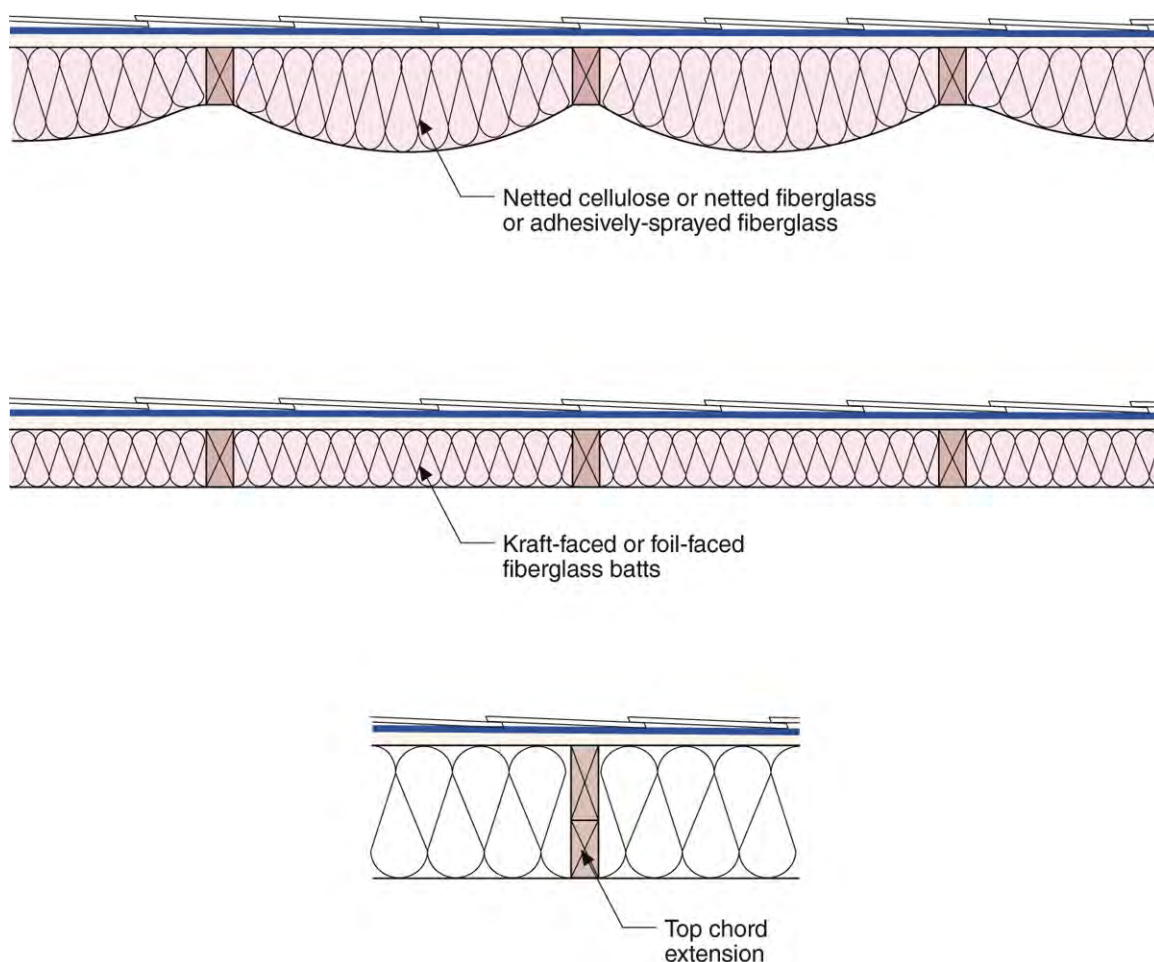


Figure 2: Insulation Options for Modified Conventional Vented Attic Assembly

Modified conventional vented attic assemblies are created through the addition of insulation at the underside of the existing roof deck. This insulation strategy aims to reduce heat transfer between the roof deck and the attic space. On hot, sunny days the roof deck insulation will have the benefit of reducing heat gain from the solar heated roof surfaces so that attic temperatures are lower, there is less heat gain to the living space and cooling loads are smaller. In this scenario, the roof deck temperature will be higher than it would be without insulation.

Conversely, on cool, clear nights, the roof deck insulation will reduce heat transfer from the attic space to the roof deck so roof deck temperatures are lower and the relative humidity at the deck and moisture content of the sheathing are both higher. Night sky radiation may cause the roof deck temperature to be much cooler than the air temperature and the potential for condensation will be greater.

A series of hygrothermal simulations were performed to assess the anticipated benefits (i.e. reduced attic temperatures and cooling loads) and risks (i.e. increased roof temperatures and elevated sheathing moisture content) associated with the proposed strategy and to determine the effect of various parameters:

- Climate
- Indoor Humidity
- Roofing
- Ceiling Insulation
- Roof Deck Insulation
- Ceiling Air Leakage Rate
- Attic Ventilation Rate

This report summarizes the inputs for and results of the hygrothermal simulations.

The key parameter examined is the moisture content of the roof deck and the effect various insulation strategies have on the moisture content of the roof deck.

4. **Hygrothermal Simulations**

The WUFI Pro 5.1 computer model was used to simulate the effects of insulating the roof decks on the moisture and temperature conditions of the roof deck structure. WUFI is one of the most advanced commercially available hygrothermal moisture programs in use today. Its accuracy has been verified (by the Fraunhofer Institut Bauphysik in Holzkirchen, Germany – www.wufi.de) against numerous full-scale field studies of enclosure performance (roofs, walls, foundations, parking garage decks, etc.) over a number of years. Much of the field verification work supporting the model has been related to the hygrothermal performance of residential roof systems.

It is one of the few models in the public domain that can properly account for adsorption of water vapor, absorption/redistribution of liquid water, and night sky radiation. Given the appropriate inputs, WUFI calculates heat and moisture flow every hour under the influence of sun, rain, temperature and humidity (see also www.wufi.de). The analysis is, however, only as accurate as the assembly data, the material properties, and the interior and exterior conditions input.

Climate Data

Outdoor Climate

While WUFI 5.1 Pro includes climate data files for dozens of cities around the world; however, the only Californian city included is San Francisco. Custom climate files for other cities were created from .csw files provided by the CEC:

- Sacramento, CTZ 12
- Red Bluff, CTZ 11
- Fresno, CTZ 13
- Riverside, CTZ 10
- Los Angeles, CTZ 9
- Palm Springs, CTZ 15
- Palmdale, CTZ 14
- Blue Canyon, CTZ 16

It should be noted that the .csw climate files do not include rain data. This is not a problem for the roof simulations, as the roofing materials do not absorb any rainwater; however, *the generated*

climate files should not be used for other applications where rainwater absorption may influence predicted hygrothermal performance.

For the purposes of this study, it is important to consider the effects of night sky radiation. WUFI Pro 5.1 uses counter radiation (emission from the roof cladding to the exterior) to predict these effects. Counter radiation was estimated using the sky temperature data from the .csw files. The generated climate files include this estimate of counter radiation.

Indoor Climate

Indoor climate conditions were predicted using EN 15026, one of WUFI Pro 5.1's built-in indoor climate models. This model uses simple functions to relate indoor temperature and relative humidity to the outdoor temperature. Table 1 shows the indoor temperature and relative humidity assumed for various outdoor temperatures. In BSC's experience, this indoor climate model makes reasonable predictions of indoor conditions with a minimum of assumptions and inputs.

Simulations were performed using assumptions for normal and high indoor RH (Table 1) conditions to assess the impact that indoor RH has on the hygrothermal performance of the proposed retrofit. As noted earlier the impact on roof sheathing moisture content of and the RH at the inside face of the roof sheathing were of particular interest.

Table 1: Assumed Indoor Temperature & RH vs Outdoor Temperature

Outdoor Temperature		Indoor Temperature		Normal RH	High RH
deg C	deg F	deg C	deg F	%	%
-30	-22	20	68	30	40
-20	-4	20	68	30	40
-10	14	20	68	30	40
0	32	20	68	40	50
10	50	20	68	50	60
20	68	25	77	60	70
30	86	25	77	60	70
40	104	25	77	60	70
50	122	25	77	60	70

Material Properties

It is often not convenient (or even possible) to determine the many material properties necessary for hygrothermal simulations so WUFI Pro 5.1 includes a database of several hundred common materials. Hygrothermal computer models are only as reliable as their input data, and it is advisable to measure and use key material properties whenever this can easily be done. However, this project considers the potential performance of a 'typical' CA house hence no actual materials are available to be measured. For the purposes of the simulation of the proposed roof retrofits, we have used the generic material properties from WUFI Pro 5.1's 'Generic North American Materials' database.

Air Movement

The WUFI Pro 5.1 computer model has the capacity to account for air movement through an assembly; the algorithms predict the amount of heat and moisture that are introduced or removed as a result of this air movement. For the purposes of this study it is essential that several air movement mechanisms be considered:

- Air leakage through the ceiling (i.e. from the living space into the attic)
- Ventilation of the roof (i.e. attic air changes facilitated by soffit and roof vents)

- Air movement through the space between the underlayment and the roof tiles when present

Ceiling Air Leakage

For this study it was assumed that ceiling air leakage accounts for 50% of the house air leakage. Three different house air leakage rates were considered: 3, 5 and 7 ACH50. These were divided by 20 (to convert to ACH4 values), then multiplied by 0.5 (to get the leakage through the attic relative to the house volume) and finally adjusted for the ratio of the house volume to the attic volume (assumed 4:1). Table 2 summarizes the assumed whole house and ceiling leakage rates.

Table 2: Assumed Natural Ceiling Leakage Rates (Relative to House Volume & Attic Volume)

House Air Leakage		Ceiling Air Leakage	
ACH50	ACH4	ACH4(V_{house})	ACH4(V_{attic})
3	0.15	0.075	0.30
5	0.25	0.125	0.50
7	0.35	0.175	0.70

Attic Ventilation Rate

Few studies have been conducted to measure the ventilation rates of ventilated attic assemblies. In 1998 Walker et. al. measured ventilation rates of two test houses at the University of Alberta and found that the ventilation rate most often fell between 2 and 4 ACH during calm hours or times when stack effect (i.e. temperature difference between the attic space and the outdoors) was the main driving force. Attic ventilation rates increased to as much as 10 ACH during windy hours (Walker and Wilson, 1998). For the purposes of this study we have considered both a conservative (i.e. lower) average attic ventilation rate and a higher (but plausible) ventilation rate. These summarized in Table 3.

Table 3: Assumed Attic Ventilation Rates (Relative to Attic Volume)

Attic Ventilation Rates	
Condition	ACH4(V_{attic})
Average	1
High	4

Simulation Model

Figure 3 presents a schematic of the modified ventilated attic assembly. In this schematic, R13 (RSI 2.29) or R19 (RSI 3.35) fiberglass batt insulation is installed against the underside of OSB roof sheathing. The fiberglass batt insulation on the ceiling plane (assumed to be R20 (RSI 3.52) or R40 (RSI 7.04)). No efforts are made to reduce air leakage through the ceiling plane (Q_{leak}) or guarantee adequate attic ventilation through soffit and roof vents (Q_{vent}). Table 4 summarizes the options simulated for each layer considered in the parametric study.

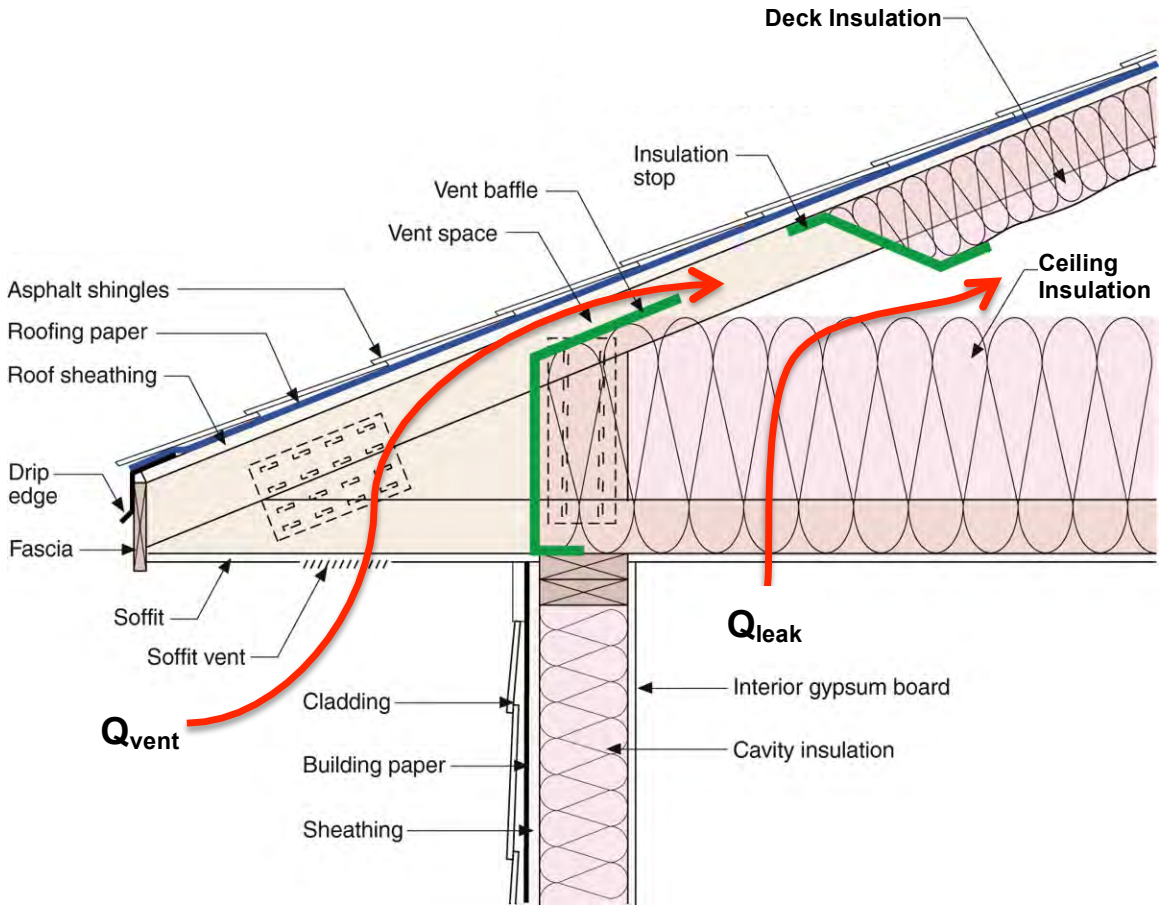


Figure 3: Modified Ventilated Attic

Table 4: Composition of Pre- and Post-Retrofit Ventilated Attic Assemblies

Assembly Composition	
Layer	Options
Roofing	Composite Shingles Poorly Ventilated Clay Tiles (5 ACHtile) Well Ventilated Clay Tiles (50 ACHtile)
Underlayment	#30 Felt Paper
Roof Sheathing	0.5 in. (12.7 mm) OSB
Deck Insulation	None R13 (RSI 2.29) Fiberglass Batt R19 (RSI 3.35) Fiberglass Batt
Attic Ventilation	Average Ventilation Rate (1 ACHattic) High Ventilation Rate (4 ACHattic)
Ceiling Air Leakage	Low Ceiling Leakage Rate (0.3 ACHattic) Average Ceiling Leakage Rate (0.5 ACHattic) High Ventilation Rate (0.7 ACHattic)
Ceiling Insulation	R20 (RSI 3.52) Fiberglass Batt R40 (RSI 7.04) Fiberglass Batt
Ceiling Finish	0.5 in. (12.7 mm) Gypsum Wall Board, primed & painted

Other Considerations

Simulations were conducted for North-facing roof slopes with an inclination of 30 degrees above the horizontal. The coldest annual average sheathing temperatures and highest sheathing moisture contents will occur in assemblies that get the least amount of solar heating and give up the most heat to night sky radiation. These are likely to be light-colored, North-facing roof slopes with middle to higher inclinations (e.g. roof slopes of 30-60 degrees).

Insulation Considerations

Worst case assumptions coupled with practicality of construction assumptions were used to bound the simulation boundary conditions. The worst case was assumed to occur when air permeable insulation of a high level of thermal resistance was installed at the underside of the roof deck. The higher the thermal resistance of this layer, the colder the roof deck temperature under winter conditions and the greater the moisture risk.

It was deemed impractical to install more than R-19 fiberglass insulation on the underside of the roof deck. Hence this limit was selected as the upper bound for insulation in the simulations. A lower level of thermal resistance at the roof deck was also examined – R-13. This lower level was assumed to be the practical limit for a lower bound as it appeared to make no sense to go to the effort to insulate the underside of a roof deck with less insulation if one were going to insulate at this location.

Levels of ceiling insulation were selected also based on practical concerns. R-20 and R-40 were selected as likely being most representative of a “low” level of ceiling thermal resistance and a “high” level of thermal resistance respectively. The worst case assumption was assumed to be a high level of ceiling insulation.

Combining the two yields the worst case boundary condition considered: R-19 at the underside of the roof deck and R-40 at the ceiling plane. Combinations of lower levels of thermal resistance at the underside of the roof deck and at the ceiling plane were deemed to be less risky in terms of moisture content.

5. Results and Discussion

Several simulations were performed using the Sacramento (CTZ 12) climate file that was generated from the CEC provided .csw files. The results of the initial simulations of the pre-retrofit roof were compared to field experience and measurements as a check on the hygrothermal model. Micro climate parameters (i.e. ventilation rate, ceiling leakage rate & indoor humidity levels) were varied to assess their influence on the RH and moisture content at the inside face of the roof sheathing. These simulations were then repeated for a range of roof assemblies to assess the influence of the amount of insulation installed at the underside of the roof deck and on top of the ceiling plane. Finally, simulations were performed using the generated climate files to assess the impact of climate.

Sacramento Base Case Attic

Table 5 summarizes the composition of a base case attic (an attic without roof deck insulation) that was simulated in the climate of Sacramento (CTZ 12).

Table 5: Base Case Attic Assembly Modeled in Initial Simulations

Assembly Composition	
Layer	Description
Roofing	Composite Shingles
Underlayment	#30 Felt Paper
Roof Sheathing	0.5 in. (12.7 mm) OSB
Deck Insulation	None (i.e. exist, pre-retrofit condition)
Ceiling Insulation	R20 (RSI 3.52) Fiberglass Batt
Ceiling Finish	0.5 in. (12.7 mm) Gypsum Wall Board, primed & painted

Figure 4 shows predicted moisture content at the inside surface of the OSB roof sheathing. The light blue area indicates the range of daily moisture content swings that would happen right at the surface. The dark blue line is a 3 day running average and is representative of the moisture content that would be measured in the first 1/8 in. (3 mm) of the sheathing.

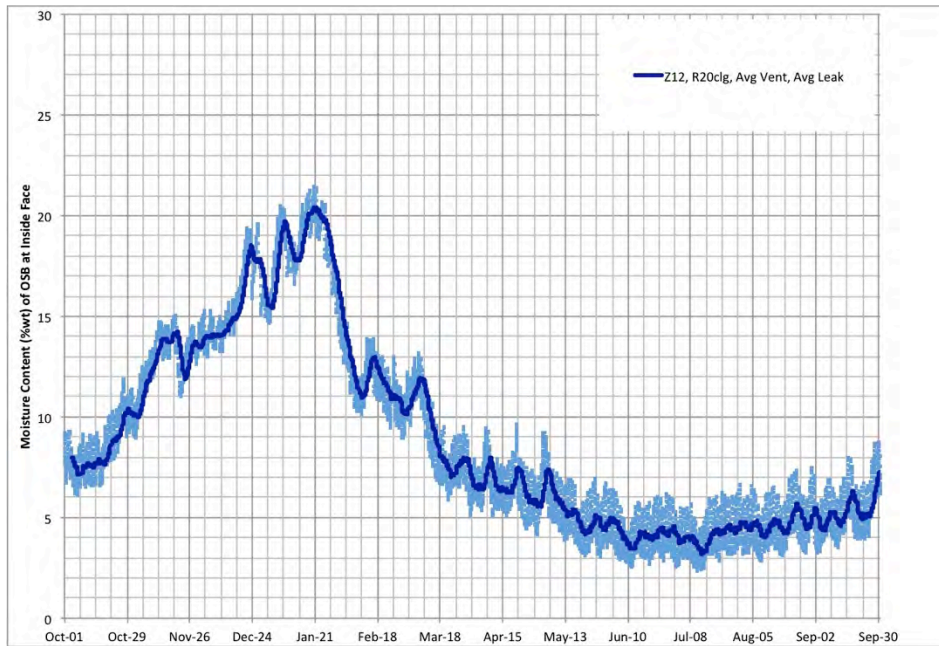


Figure 4: OSB MC for Base Case Attic Assembly in Sacramento (Z12)

Average attic ventilation rates, average ceiling leakage rates and normal indoor RH levels were assumed for this first hygrothermal simulation. The predicted moisture content is very low (less than 8% by weight) during the summer months and peaks at approximately 20% during the winter months. The predicted moisture content trends agree well with BSC field experience.

Attic Ventilation Rate

Hygrothermal simulations were next performed to assess the impact of attic ventilation rate on the predicted sheathing moisture content. Average ceiling leakage rates and normal indoor RH levels were assumed for these simulations. Figure 5 compares the predicted moisture content at the inside surface of the OSB roof sheathing for an attic with an average ventilation rate (blue line) and an attic with higher ventilation rate (green line).

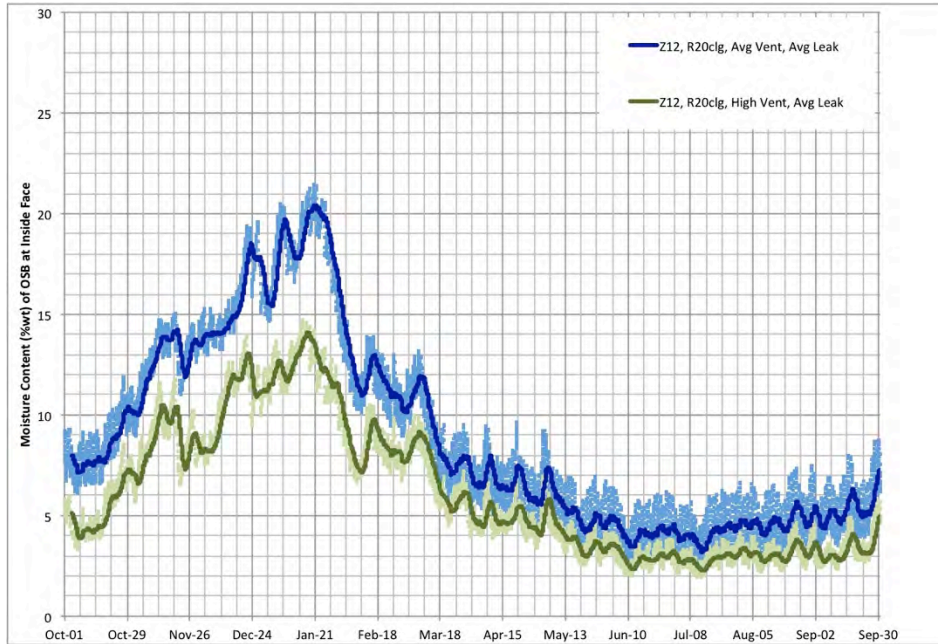


Figure 5: OSB MC for Base Case Attic Assembly (Z12) - Effect of Attic Ventilation Rate

The attic air is a mixture of outdoor air that enters through vent openings and indoor air that leaks through the ceiling plane. The absolute humidity (i.e. moisture content) of the attic air is reduced as the attic ventilation rate is increased. The hygrothermal simulations reflect this trend. Predicted peak winter-time sheathing moisture content is approximately 20% for the average attic ventilation case and less than 14% for the high attic ventilation case. Attic ventilation rate has a significant impact on the sheathing moisture content.

Ceiling Leakage Rate

Further Hygrothermal simulations were performed to assess the impact of ceiling leakage rate. Average attic ventilation rates and normal indoor RH levels were assumed for these simulations.

If a ceiling plane is made extremely airtight, very little indoor moisture will make its way into the attic space and, if the attic is ventilated, its absolute humidity will closely match the outdoor air; however, this level of airtightness would only be achieved if conscious measures were taken to seal the ceiling plane. For this study, we have considered ceiling leakage rates that are intended to represent conditions typical for recently constructed homes.

Figure 6 compares the predicted moisture content at the inside surface of the OSB roof sheathing for an attic with an average ceiling leakage rate (blue line) and a higher ceiling leakage rate (orange line).

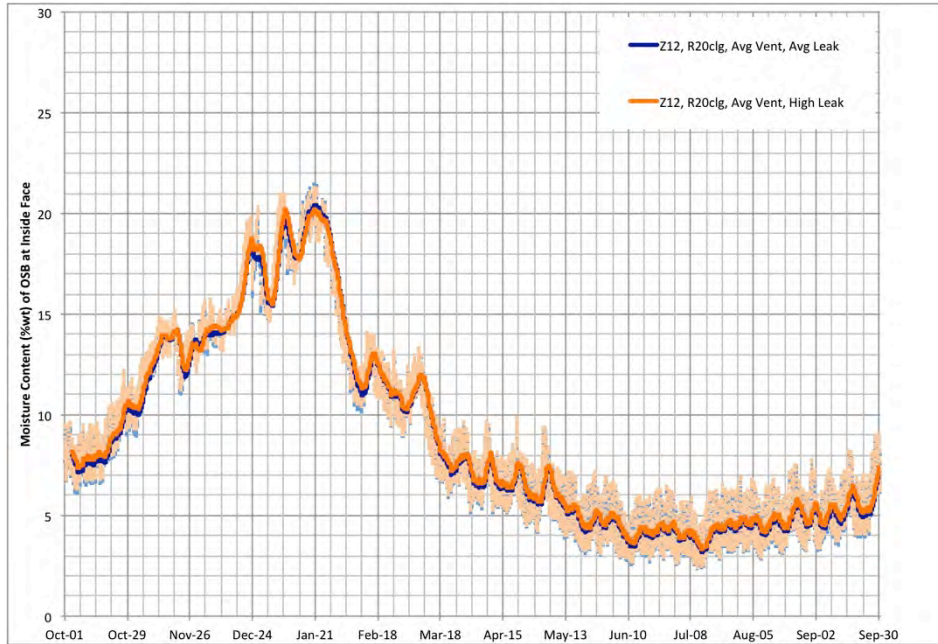


Figure 6: OSB MC for Base Case Attic Assembly (Z12) - Effect of Ceiling Leakage Rate

There is little difference between the predicted sheathing moisture contents for the two cases. For the range of ceiling leakage rates considered, there is little impact on sheathing moisture content.

Indoor Humidity

Hygrothermal simulations were also performed to assess the impact of indoor humidity. Average attic ventilation rates and average ceiling leakage rates were assumed for these simulations.

Figure 7 compares the predicted moisture content at the inside surface of the OSB roof sheathing for an attic with over a house with normal indoor RH levels (blue line) and an attic over a house with higher indoor RH levels (dark red line).

The predicted peak winter-time sheathing moisture content is approximately 20% when normal indoor RH levels are assumed. In contrast, the predicted peak MC increases to almost 40% when high indoor RH levels are assumed. Again, the predicted trend agrees well with field experience and measurements. Indoor humidity levels have a significant impact on the humidity conditions in the attic and the moisture content of the roof sheathing.

Attic assemblies with high ventilation rates can tolerate/survive high indoor humidity levels. However, high indoor humidity levels are not recommended as a general principle. Controlled ventilation and moisture source control should be a basic requirement for all houses.

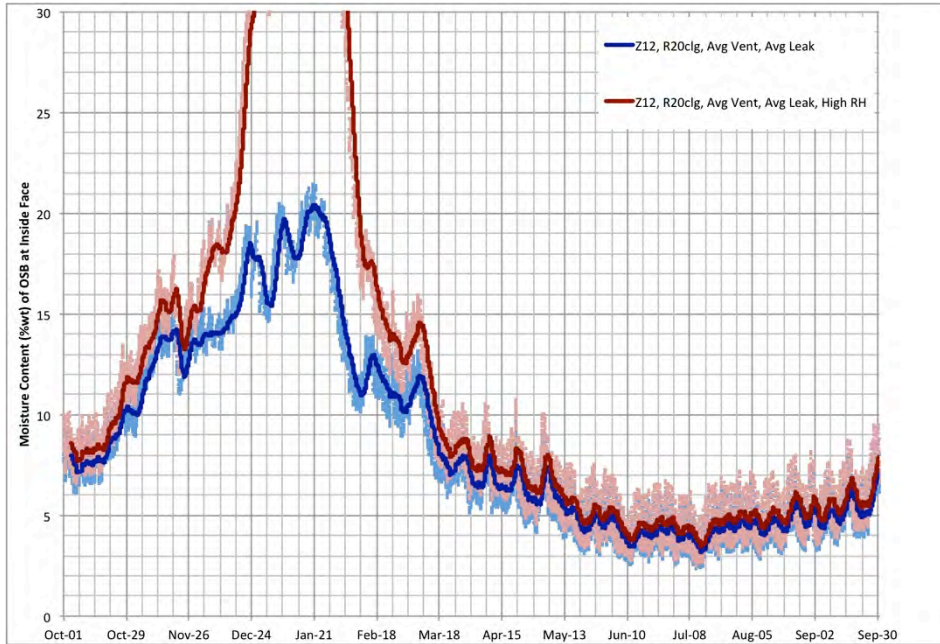


Figure 7: OSB MC for Base Case Attic Assembly (Z12) - Effect of Indoor Humidity Level

The plots of the previous graphs are incorporated into Figure 8. The four lines plot the predicted OSB MC assuming average or ‘typical’ conditions (blue line), high attic ventilation (green line), high ceiling ventilation (orange line), and high indoor RH (red line).

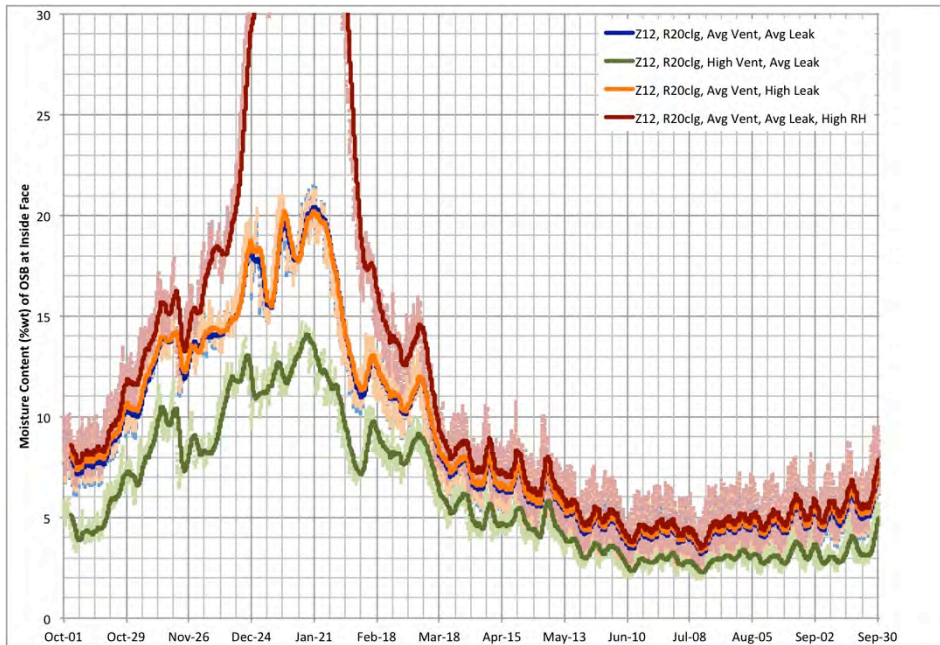


Figure 8: OSB MC for Base Case Attics in Sacramento (Z12)

Sacramento Modified Attics

Three modified attic scenarios were considered and simulated in the climate of Sacramento:

- An R13 deck insulation to an attic assembly with R20 on the ceiling
- An R19 deck insulation to an attic assembly with R20 on the ceiling
- An R19 deck insulation to an attic assembly with R40 on the ceiling

These levels of thermal resistance were based on worst case scenarios as discussed earlier. Air permeable insulation was selected as air impermeable insulations (spray polyurethane foam) have already been extensively studied as well as combinations of both air impermeable insulation and air permeable insulation hybrid systems. Air permeable insulation systems have not been previously examined.

Modified Attic 1: R13 deck insulation and R20 ceiling insulation

Table 6 summarizes the composition of the first modified attic assembly considered.

Table 6: Assembly Modeled for Simulation of R13 Deck and R20 ceiling

Assembly Composition	
Layer	Description
Roofing	Composite Shingles
Underlayment	#30 Felt Paper
Roof Sheathing	0.5 in. (12.7 mm) OSB
Deck Insulation	R13 (RSI 2.29) Fiberglass Batt
Ceiling Insulation	R20 (RSI 3.52) Fiberglass Batt
Ceiling Finish	0.5 in. (12.7 mm) Gypsum Wall Board, primed & painted

Figure 9 plots the predicted OSB MC for the R13 deck assembly assuming average or ‘typical’ conditions (blue line), high attic ventilation (green line), high ceiling leakage (orange line), and high indoor RH (red line).

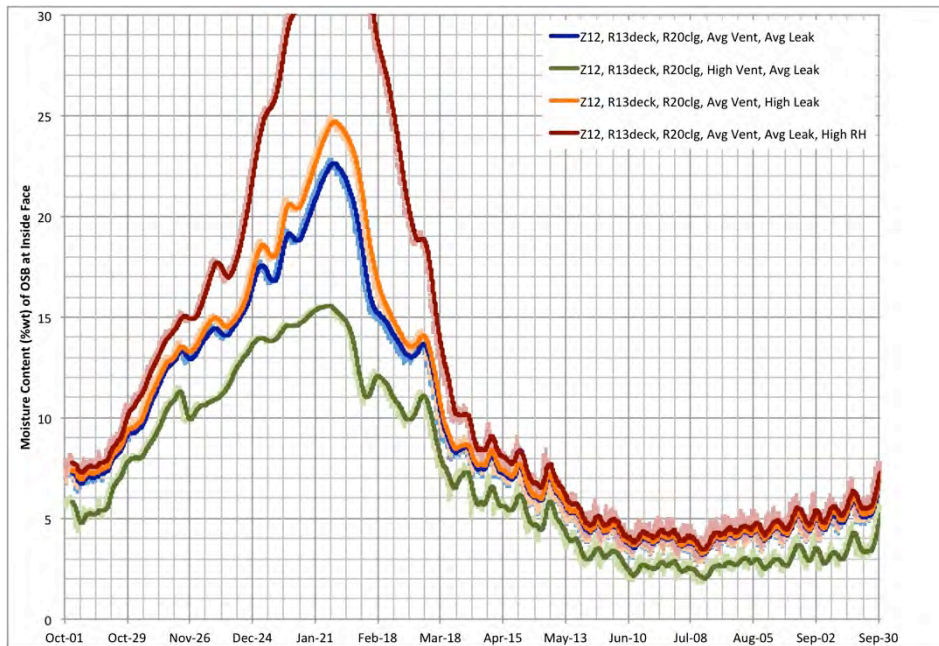


Figure 9: OSB MC for R13 Retrofit to R20 Ceiling in Sacramento (Z12)

For the average or ‘typical’ case (blue line), the predicted winter-time peak moisture contents increase from approximately 20% base case to approximately 23% modified. If the ceiling leakage rate is high (orange line), the predicted peak MC increases from approximately 20% to just under 25%. If the attic ventilation rate is higher (green line), the predicted peak MC only increases from 14% base case to just over 15% modified. If the indoor humidity levels are high, the modified attic is actually predicted to reduce the peak from approximately 42% base case to 36% modified attic.

The addition of deck insulation changes the temperature regime of the OSB roof sheathing. At night, deck temperatures are lower, relative humidity at the deck is higher and there is an increased potential for condensation. These all tend to increase wetting of the roof deck. During the day, deck temperatures are higher and there is an increased vapor drive to dry out the roof deck. The hygrothermal simulations suggest that, for the R13 deck retrofit, the increased drying almost offsets the increased wetting and only modest increases in MC are predicted.

Modified Attic 2: R19 deck insulation and R20 ceiling insulation

Table 7 summarizes the composition of the second modified attic assembly considered.

Table 7: Assembly Modeled for Simulation of R19 Deck and R20 ceiling

Assembly Composition	
Layer	Description
Roofing	Composite Shingles
Underlayment	#30 Felt Paper
Roof Sheathing	0.5 in. (12.7 mm) OSB
Deck Insulation	R19 (RSI 3.35) Fiberglass Batt
Ceiling Insulation	R20 (RSI 3.52) Fiberglass Batt
Ceiling Finish	0.5 in. (12.7 mm) Gypsum Wall Board, primed & painted

Figure 10 plots the predicted OSB MC for the R19 modified attic assembly assuming average or ‘typical’ conditions (blue line), high attic ventilation (green line), high ceiling ventilation (orange line), and high indoor RH (red line).

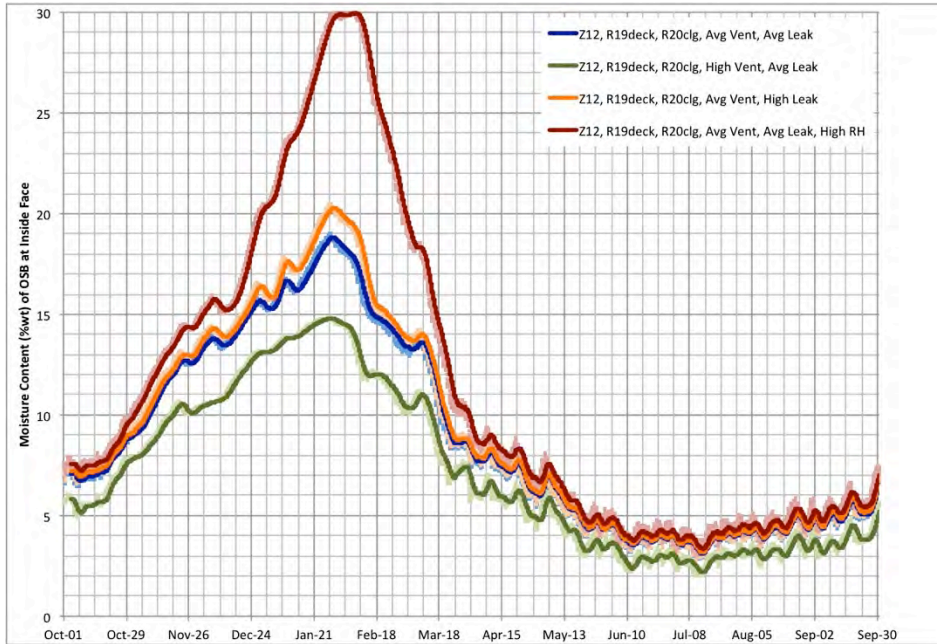


Figure 10: OSB MC for R19 Deck and R20 Ceiling in Sacramento (Z12)

For the average or ‘typical’ case (blue line), the predicted winter-time peak moisture contents decrease from approximately 20% base case to approximately 19% modified. If the ceiling leakage rate is high (orange line), the predicted peak MC remains unchanged from the base case of approximately 20%. If the attic ventilation rate is higher (green line), the predicted peak MC barely increases from 14% base case to just under 15% modified. If the indoor humidity levels are high, the modified attic is predicted to significantly reduce the peak from approximately 42% base case to approximately 30% modified.

The hygrothermal simulations suggest that adding R19 deck insulation may result in modest decreases in the moisture content at the interior face of the OSB roof sheathing.

Modified Attic 3: R19 deck insulation and R40 ceiling insulation

Table 8 summarizes the composition of the third modified attic assembly considered.

Table 8: Assembly Modeled for Simulation of R19 Deck and R40 ceiling

Assembly Composition	
Layer	Description
Roofing	Composite Shingles
Underlayment	#30 Felt Paper
Roof Sheathing	0.5 in. (12.7 mm) OSB
Deck Insulation	R19 (RSI 3.35) Fiberglass Batt
Ceiling Insulation	R40 (RSI 7.05) Fiberglass Batt
Ceiling Finish	0.5 in. (12.7 mm) Gypsum Wall Board, primed & painted

Figure 11 plots the predicted OSB MC for the R19 modified attic assembly assuming average or ‘typical’ conditions (blue line), high attic ventilation (green line), high ceiling ventilation (orange line), and high indoor RH (red line).

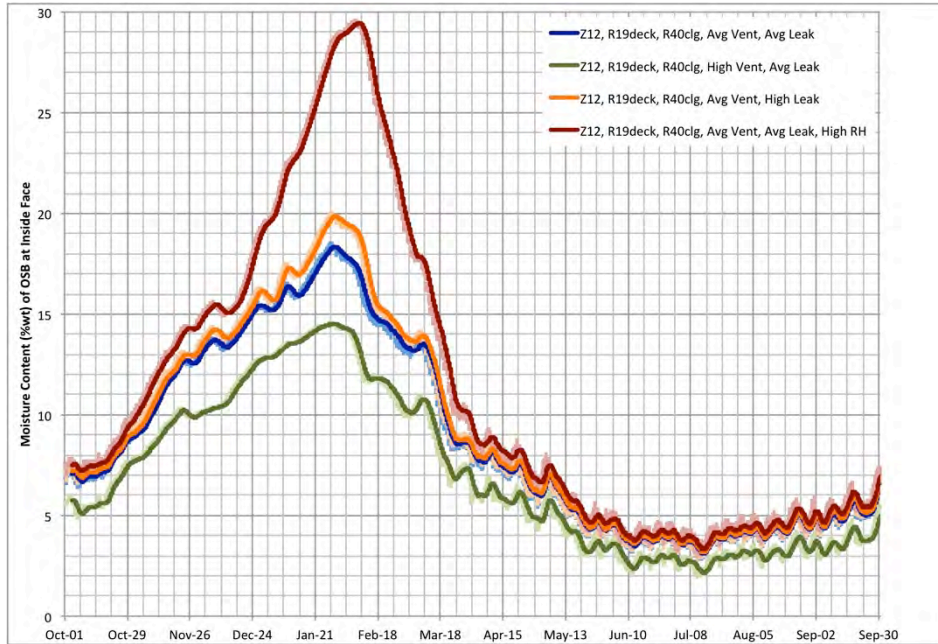


Figure 11: OSB MC for R19 Deck and R40 Ceiling in Sacramento (Z12)

For the average or ‘typical’ case (blue line), the predicted winter-time peak moisture contents decrease from approximately 20% base case to approximately 18% modified. If the ceiling leakage rate is high (orange line), the predicted peak MC remains unchanged from the base case of approximately 20%. If the attic ventilation rate is higher (green line), the predicted peak MC barely increases from 14% base case to just over 14% modified. If the indoor humidity levels are high, the modified assembly is predicted to significantly reduce the peak from approximately 42% base case to just under 30% modified.

The hygrothermal simulations suggest that, if R19 deck insulation is added to an attic with R40 at the ceiling, the approach may result in modest decreases in the moisture content at the interior face of the OSB roof sheathing.

For the ventilation rates, ceiling leakage rates and indoor humidity levels considered, the predicted performance of the R19 modified attic with R40 ceiling insulation is almost the same as the R19 modified attic with R20 ceiling insulation. The ceiling insulation appears to have little impact on the OSB temperature when insulation is installed against the underside of the deck.

Potential Energy Savings

Figure 12 presents a summary of the predicted hygrothermal performance for an R13 deck insulation with a ventilated attic (with R20 insulation at the ceiling) in the climate of Sacramento (Zone 12). The grey and blue lines in the top graph represent the predicted base case and modified attic OSB moisture content. These predicted trends were discussed earlier but included again here for convenience.

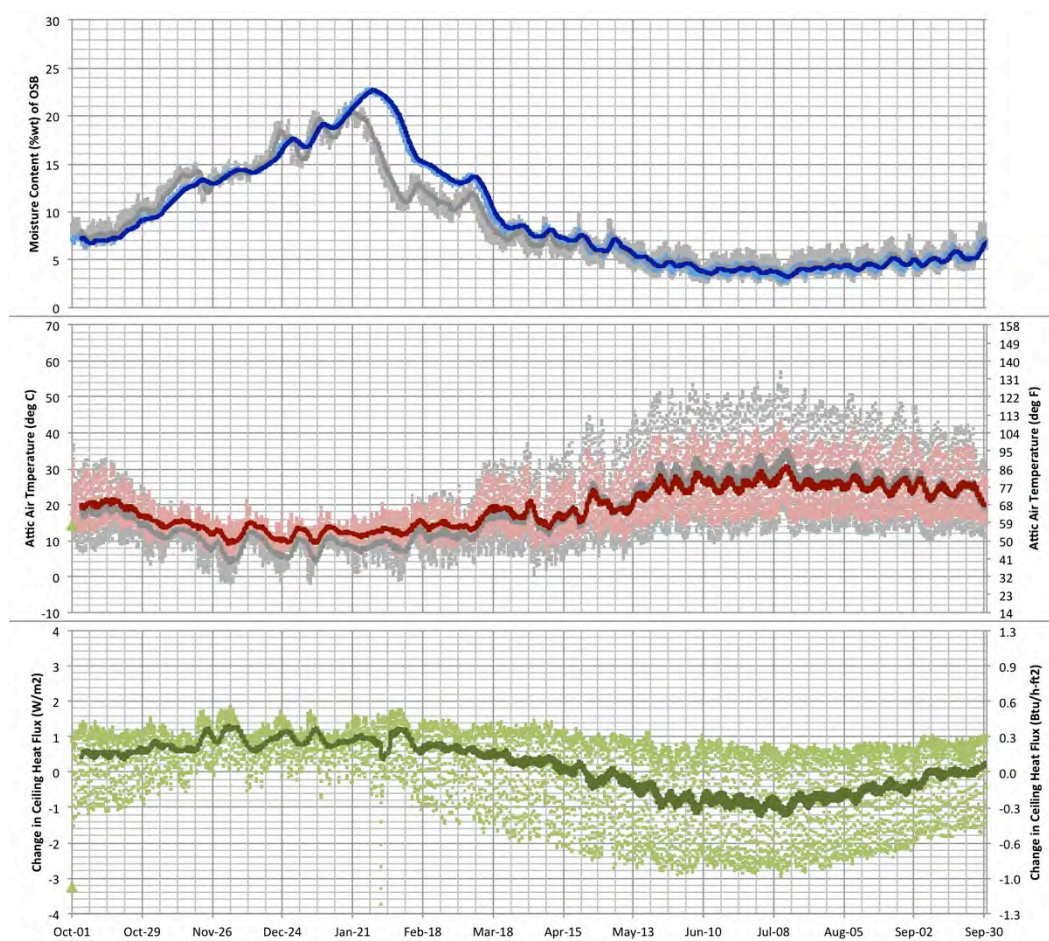


Figure 12: Sacramento (Z12) R13 deck, R20 ceiling Simulation Summary

The grey and red lines in the middle graph represent the predicted base case and modified attic air temperatures. Energy savings are directly related to changes in the attic air temperature. The simulations predict that the R13 deck insulation will result in attic air temperatures that are an average of 5.3 F (3.0 C) warmer in the winter and 2.7 F (1.5 C) cooler in the summer. Reductions in peak temperature are predicted to be as great as 23.3 F (12.9 C).

The green line in the bottom graph represents the predicted change in ceiling heat flux (i.e. heat transfer due to conduction through the ceiling plane). Positive values represent reductions in winter-time heating load while negative values represent reductions in summer-time cooling load. The net reduction in winter heating load is predicted to be 1026 Btu/ft² (3237 Wh/m²) while the net reduction in summer cooling load is predicted to be 615 Btu/ft² (1939 Wh/m²).

The ceiling heat flux reductions do not account for air leakage or interactions with other parts of the building but they do provide some sense of the potential energy savings. For a typical 2000 ft² home, the annual savings could be on the order of 1000 kWh/yr.

Modified Attics in Other CA Climates

A series of hygrothermal simulations were performed to assess the potential moisture risks and energy benefits of R13 deck insulation applied to ventilated attics (with R20 insulation at the ceiling) in other California climates.

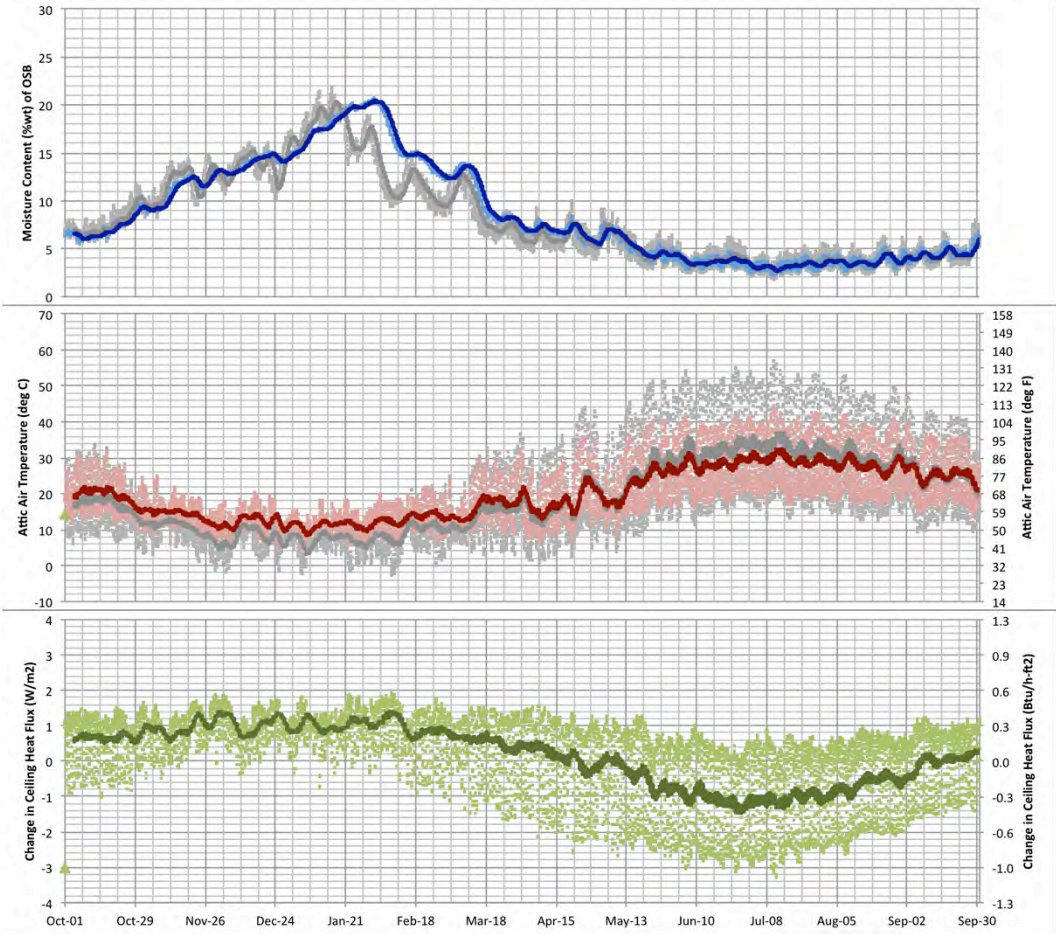


Figure 13: Red Bluff (Z11) R13 deck, R20 ceiling Simulation Summary

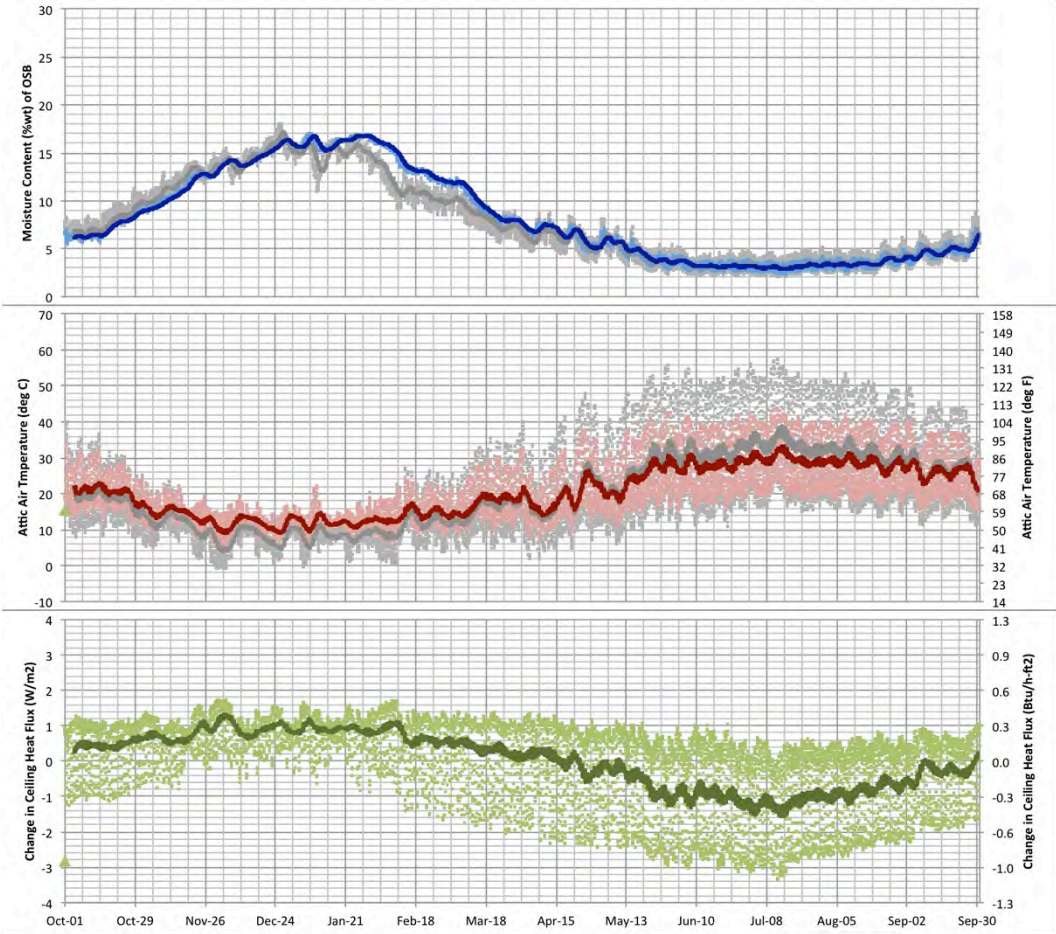


Figure 14: Fresno (Z13) R13 deck, R20 ceiling Simulation Summary

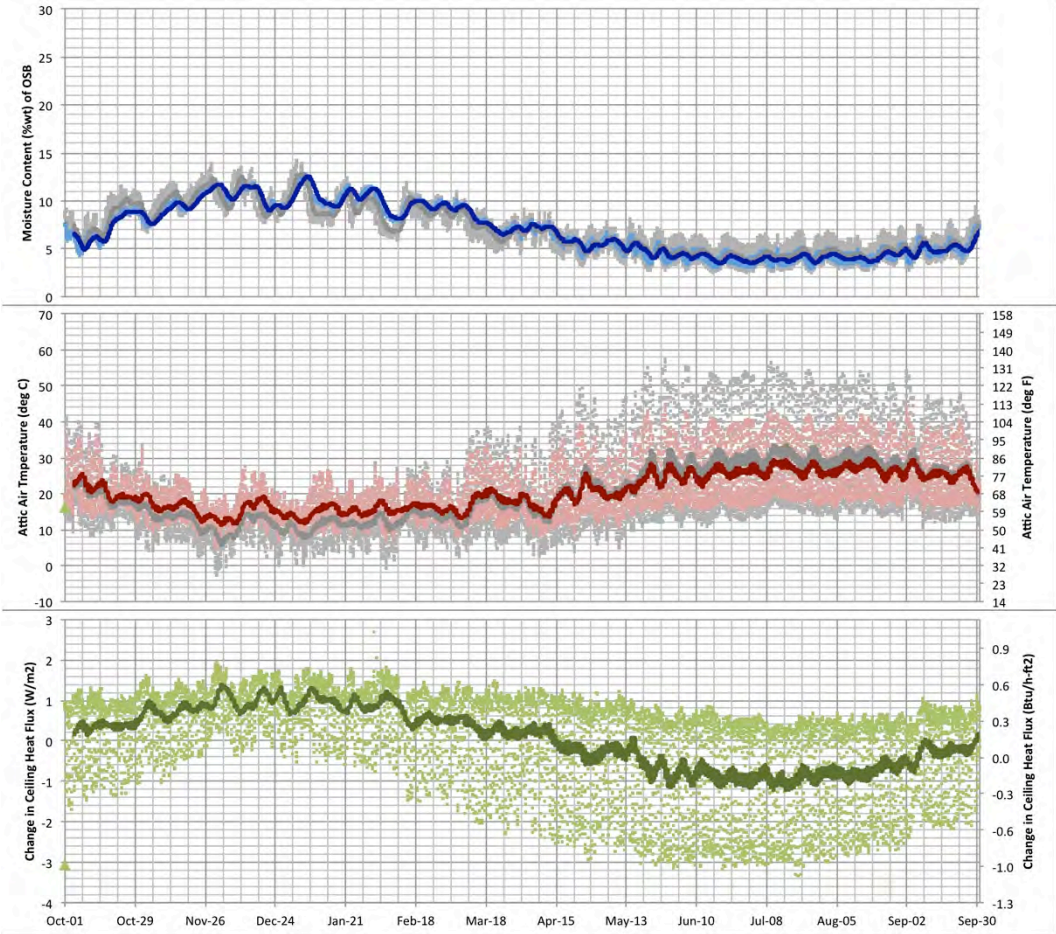


Figure 15: Riverside (Z10) R13 deck, R20 ceiling Simulation Summary

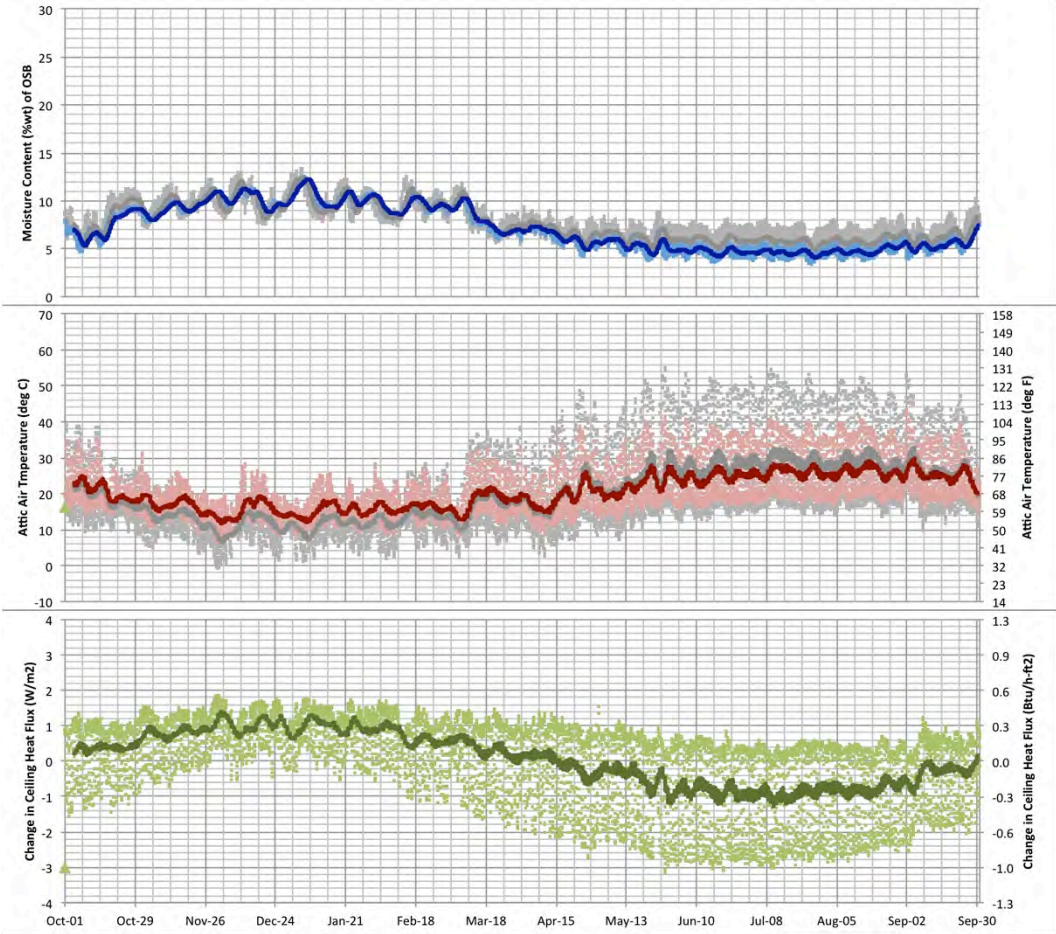


Figure 16: Los Angeles (Z9) R13 deck, R20 ceiling Simulation Summary

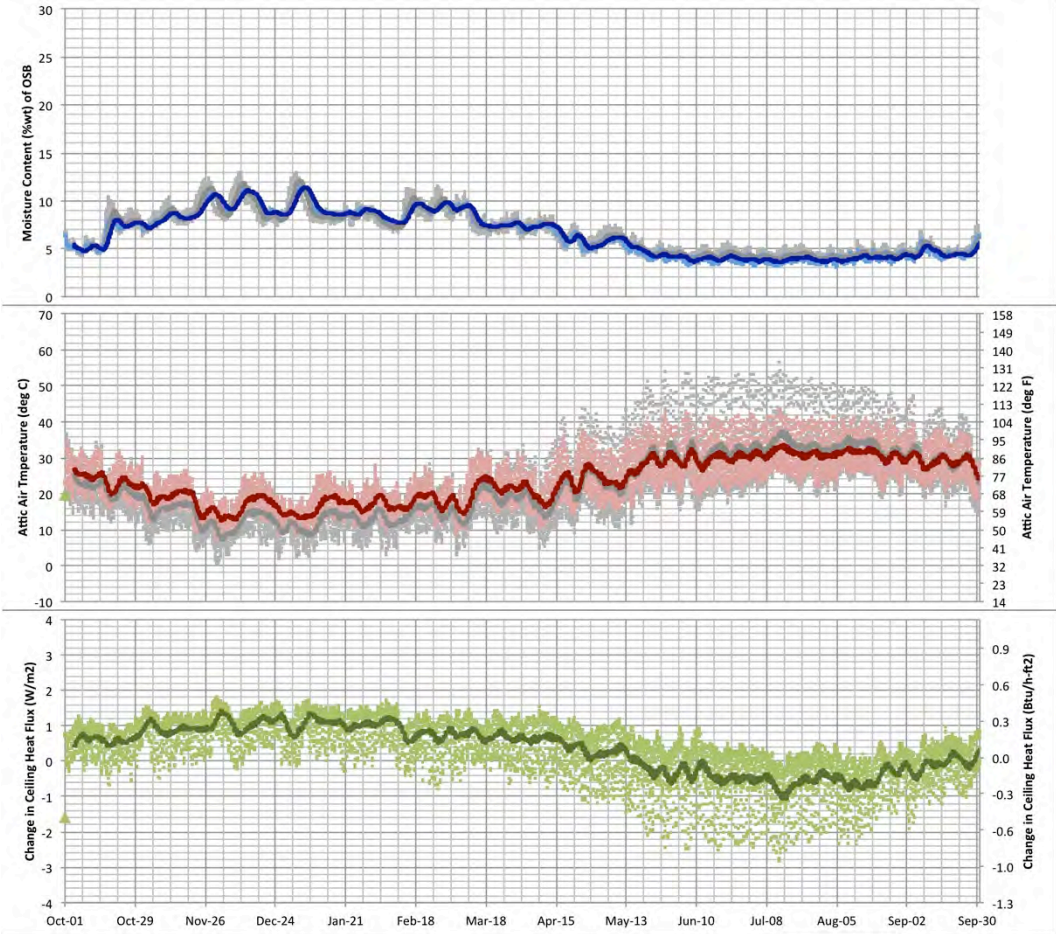


Figure 17: Palm Springs (Z15) R13 deck, R20 ceiling Simulation Summary

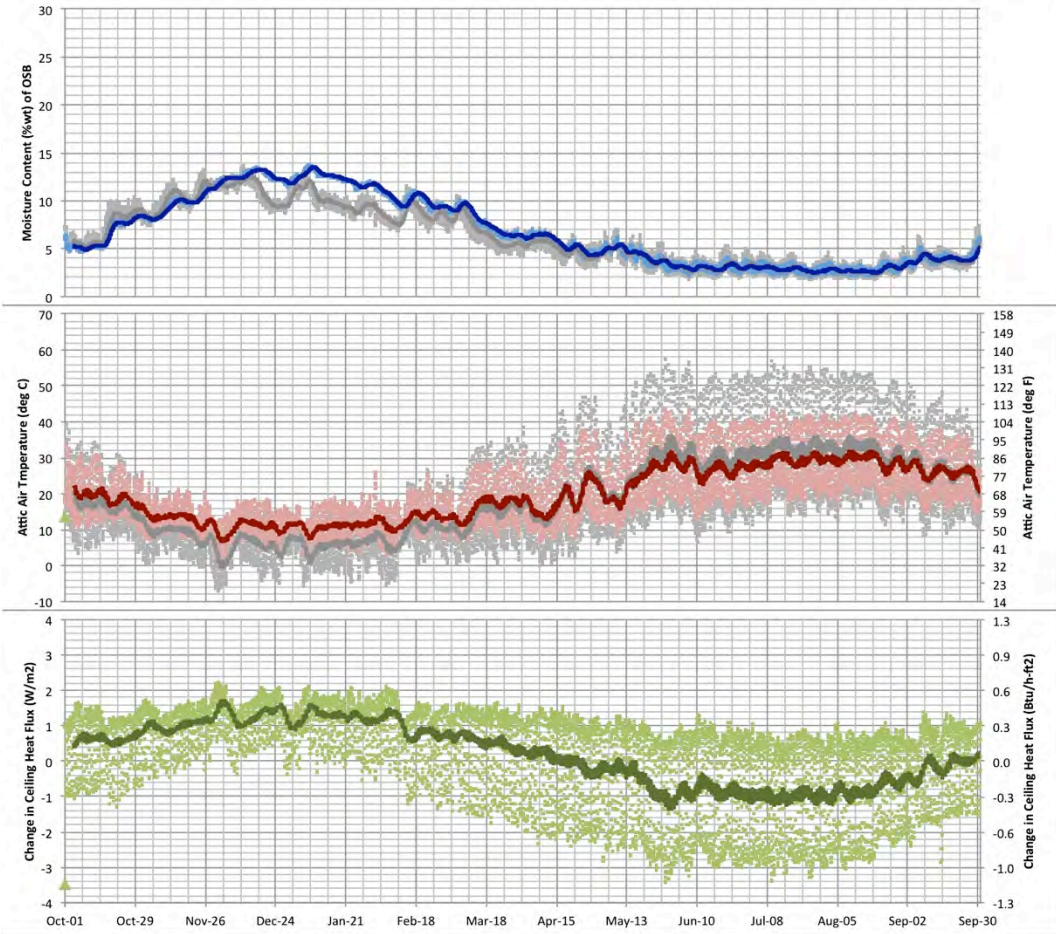


Figure 18: Palmdale (Z14) R13 deck, R20 ceiling Simulation Summary

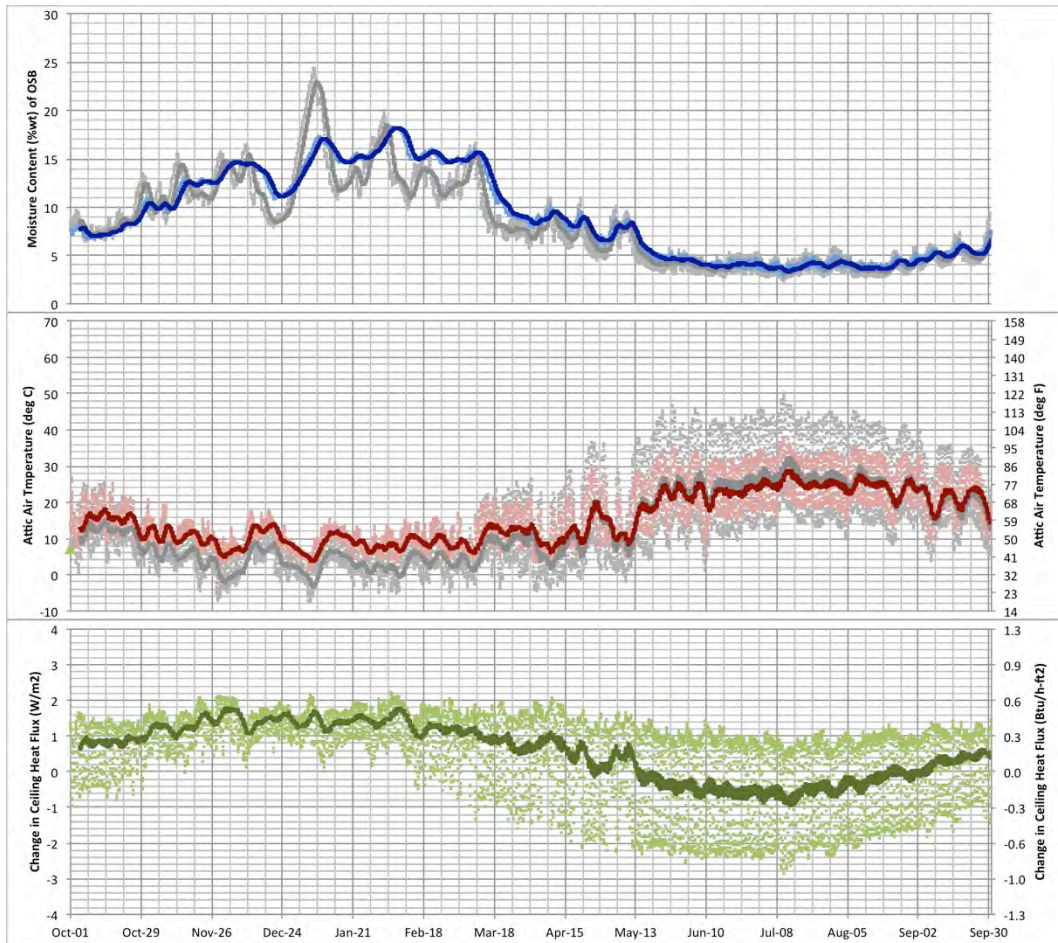


Figure 19: Blue Canyon (Z16) R13 deck, R20 ceiling Simulation Summary

One might expect that higher sheathing moisture contents be predicted for assemblies located in colder climates; however, that is not necessarily the case. Figure 12 presents a summary of the predicted hygrothermal performance for an R13 deck insulation with a ventilated attic (with R20 insulation at the ceiling) in Sacramento (Zone 12), a climate with 2666 HDD and 1248 CDD. Figure 19 presents a summary for the same roof assembly in Blue Canyon (Zone 16), a much cooler climate with 5599 HDD and only 423 CDD. The simulations suggest that the sheathing moisture content will actually lower in colder zone 16 climates than in warmer zone 12 climates.

The climate of Blue Canyon is colder but it is also drier than Sacramento. If average attic ventilation rates, average ceiling leakage rates and normal indoor RH levels are assumed, then the condition of the air in the attic will largely be determined by the condition of the outdoor air and the assembly will be drier in Blue Canyon than in Sacramento, despite the fact that the roof deck is colder. However, the predicted results are highly dependent on the attic ventilation rate and ceiling leakage rate.

Figure 20 and Figure 21 present summaries of the predicted performance for the same roof assembly (R13 deck insulation with ventilated attic & R20 insulation at the ceiling) but assuming very low attic ventilation rates (i.e. 0.5 ACH_{attic}) and high ceiling leakage rates (i.e. 0.7 ACH_{attic}) for zone 12 and 16 climates respectively.

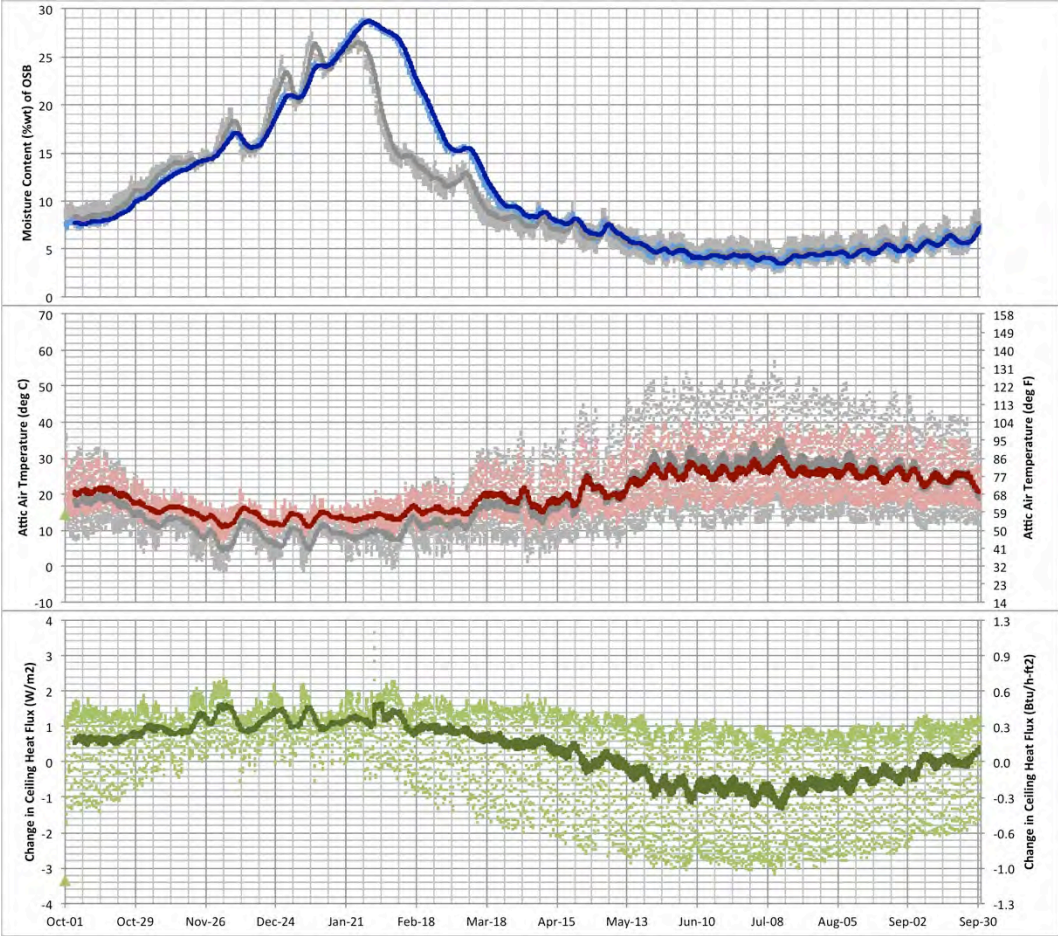


Figure 20: Sacramento (Z12) R13 deck, R20 ceiling, Very Low Attic Vent, High Ceiling Leakage Simulation Summary

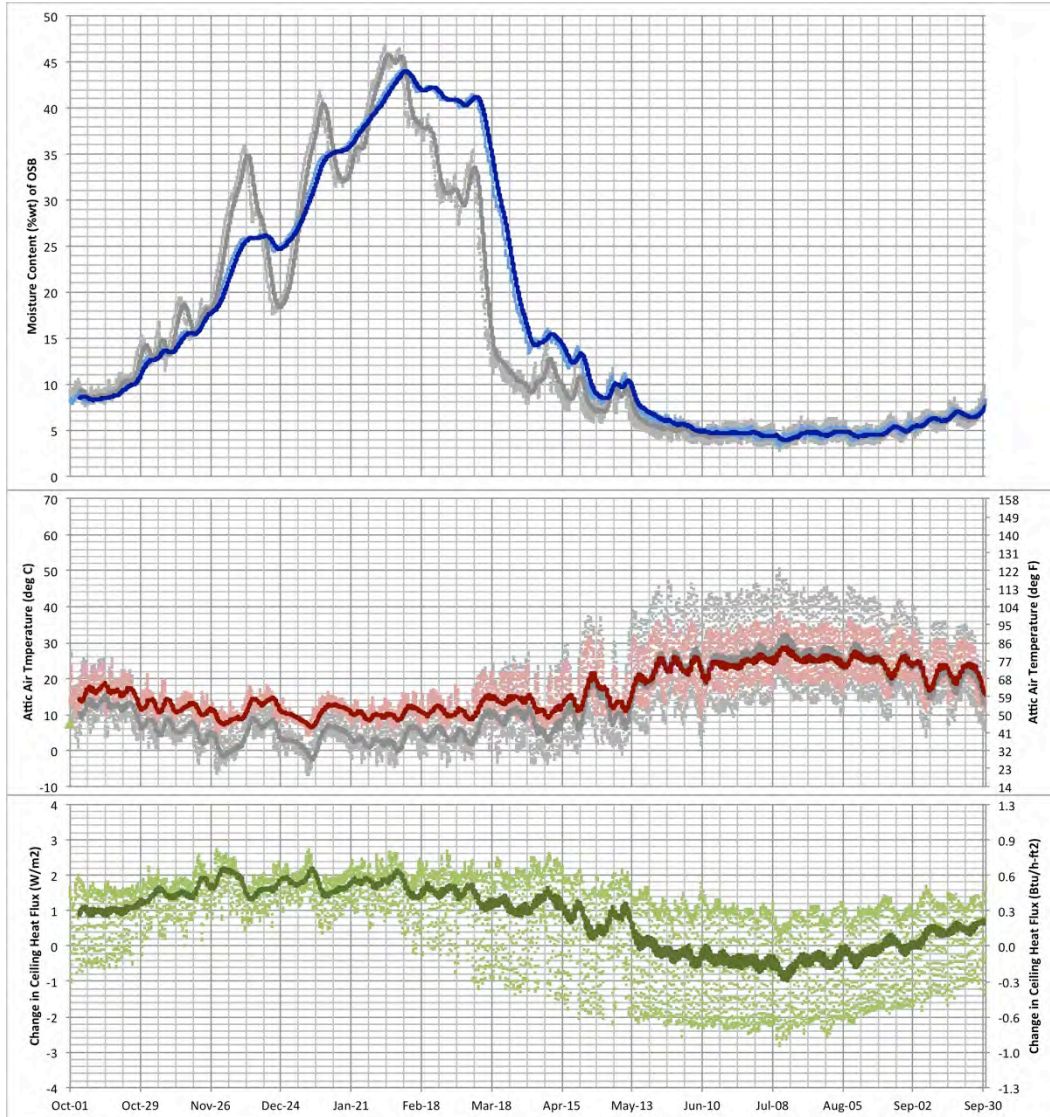


Figure 21: Blue Canyon (Z16) R13 deck, R20 ceiling, Very Low Attic Vent, High Ceiling Leakage Simulation Summary

Higher sheathing moisture contents are predicted for the assembly in both climates. The peak sheathing moisture content for the Sacramento roof is predicted to increase from approximately 22% to 29% whereas the peak sheathing moisture content for the Blue Canyon roof is predicted to increase from approximately 18% to almost 45%!

The deck insulation retrofit solution appears to be highly sensitive to the balance between moisture introduced through ceiling air leakage and moisture removed by attic ventilation. In moderate climates the assembly may tolerate an upset in the attic ventilation – ceiling leakage moisture balance but in colder climates the assemblies are likely to experience significant moisture problems.

6. Conclusions

A large array of both vented and unvented roof assemblies can be used in all climate zones in California. Many have been extensively studied and have proven performance and are code accepted. These code accepted assemblies are described in Appendix A.

One type of vented assembly has not been previously studied in detail – a vented attic assembly where air permeable insulation has been added to the underside of a roof deck where an impermeable roofing membrane or impermeable roof shingles have been installed.

The hygrothermal simulations suggest that adding air permeable insulation to the underside of vented attic roof decks constructed with impermeable roof shingles or impermeable roof membranes is a viable option in many climate zones in California. In climates with cooler winter-time temperatures and/or more night sky radiation, there is a potential for some increase in the moisture content at the inside face of the OSB roof sheathing. The risk of moisture problems is less when the attic ventilation rate is higher than the ceiling leakage rate. Attic moisture problems are strongly connected to indoor humidity levels and it is recommended that indoor humidity be actively controlled.

Specifically, Figure 1, Modified Vented Attic Asphalt Shingles – can be used in all CEC Zones except 16. More broadly speaking, Figure 1 can be used only in International Energy Conservation Code (IECC) Climate Zones 2B and 3B.

The roofing paper in Figure 1 can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

A ventilation ratio of 1:300 is recommended wherever attics are vented irrespective of climate zone and is a basic code requirement in the International Residential Code (IRC) for vented attic assemblies.

It is further recommended that field exposure experimental work be conducted to verify these results.

Appendix A

The standard vented and unvented attic configurations are presented in the following figures. The recommended limits of their applicability are specified and are based on current language in the Model Building Codes. The language is based on previous published work (<http://www.buildingscience.com/documents/bareports/ba-1001-moisture-safe-unvented-wood-roof-systems/view>).

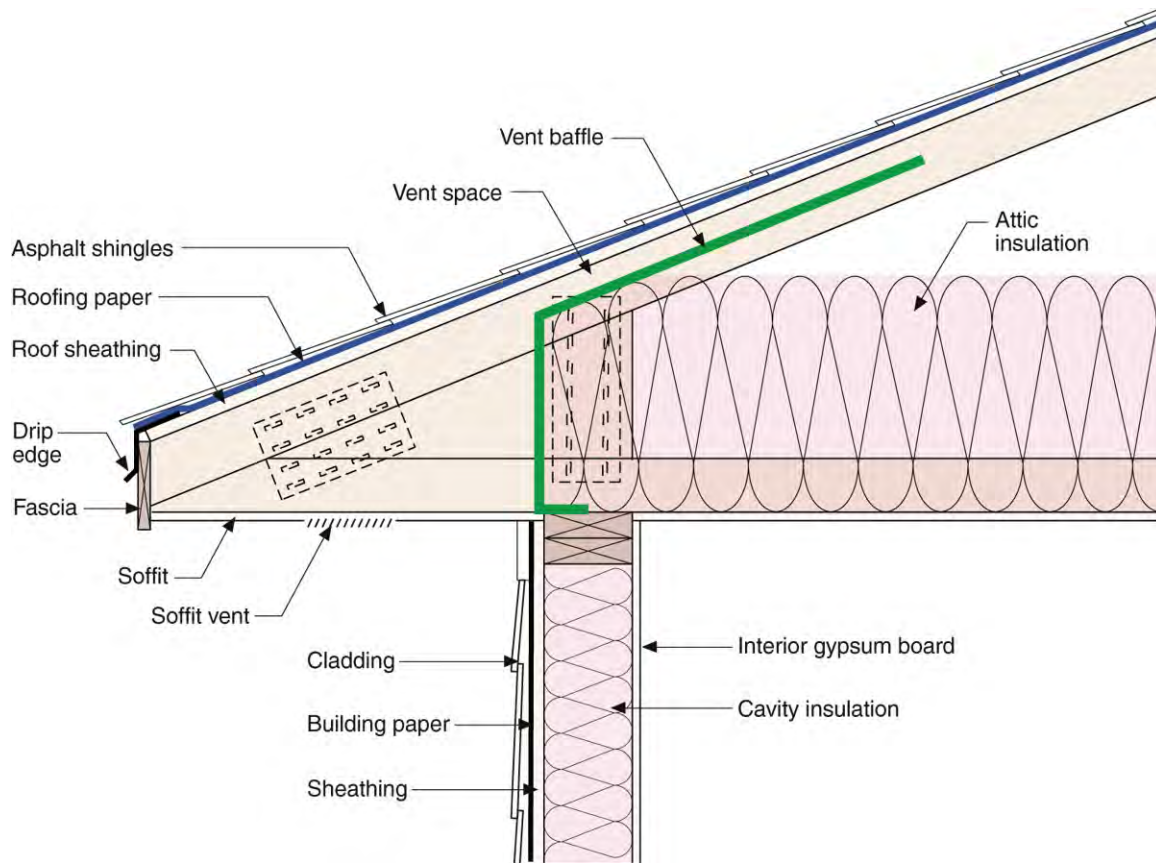


Figure 22: Vented Attic Asphalt Shingles – Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

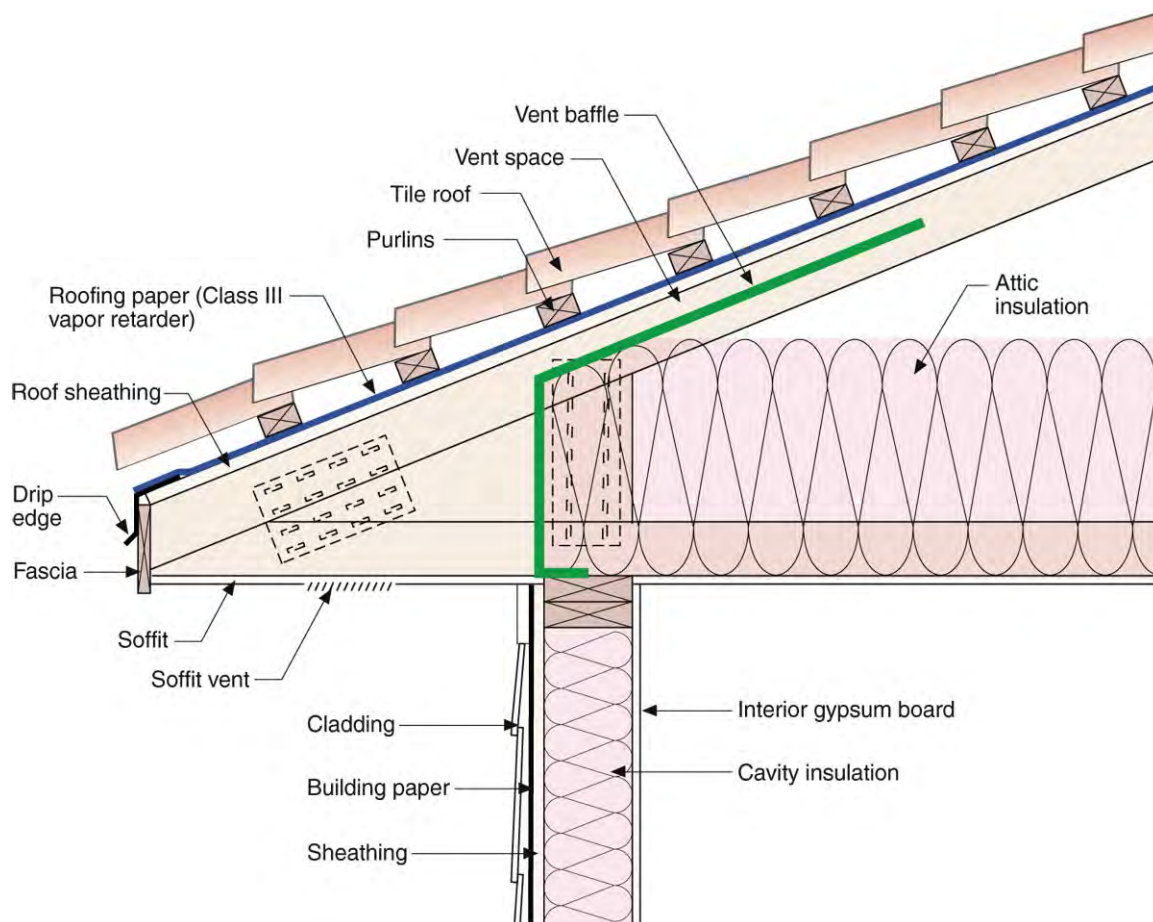


Figure 23: Vented Attic Tile Roof – Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

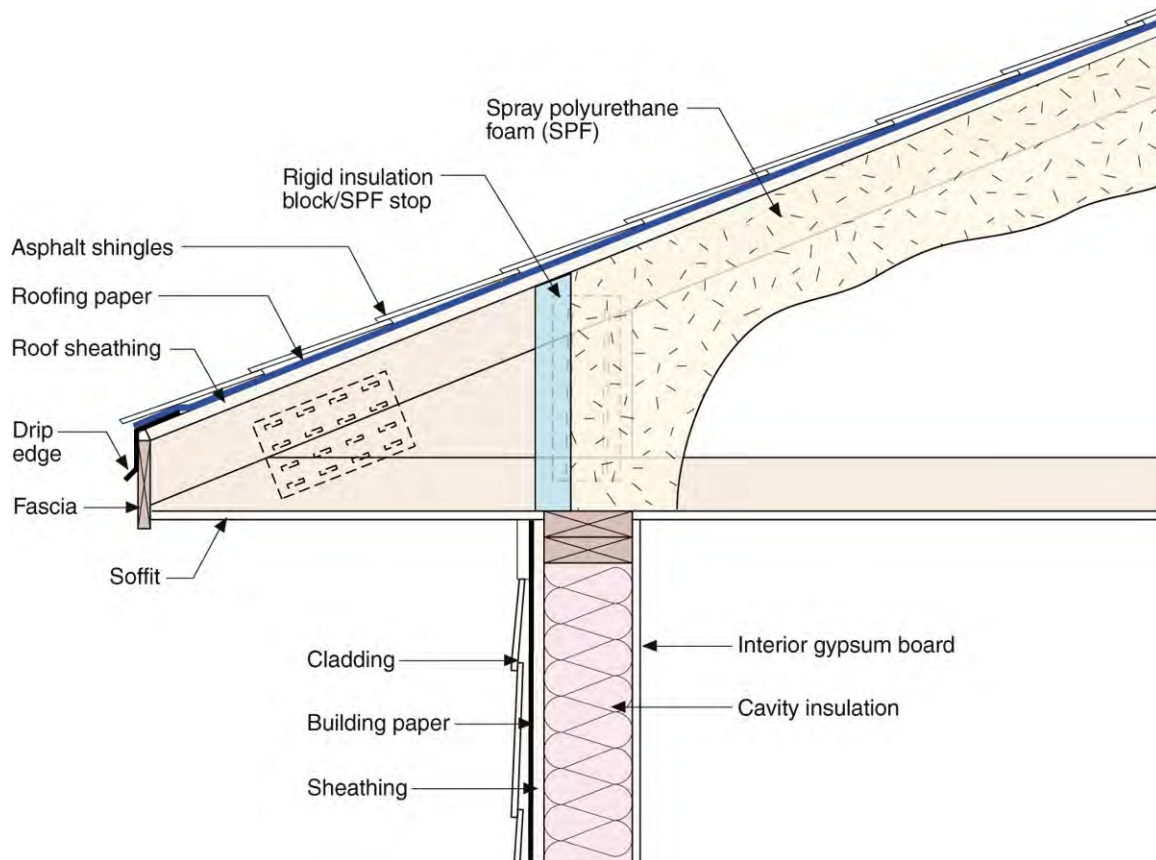


Figure 24: Unvented Attic – Asphalt Shingles - Can be used in all climate zones. Either low density or high density spray polyurethane foam (SPF) can be used. However, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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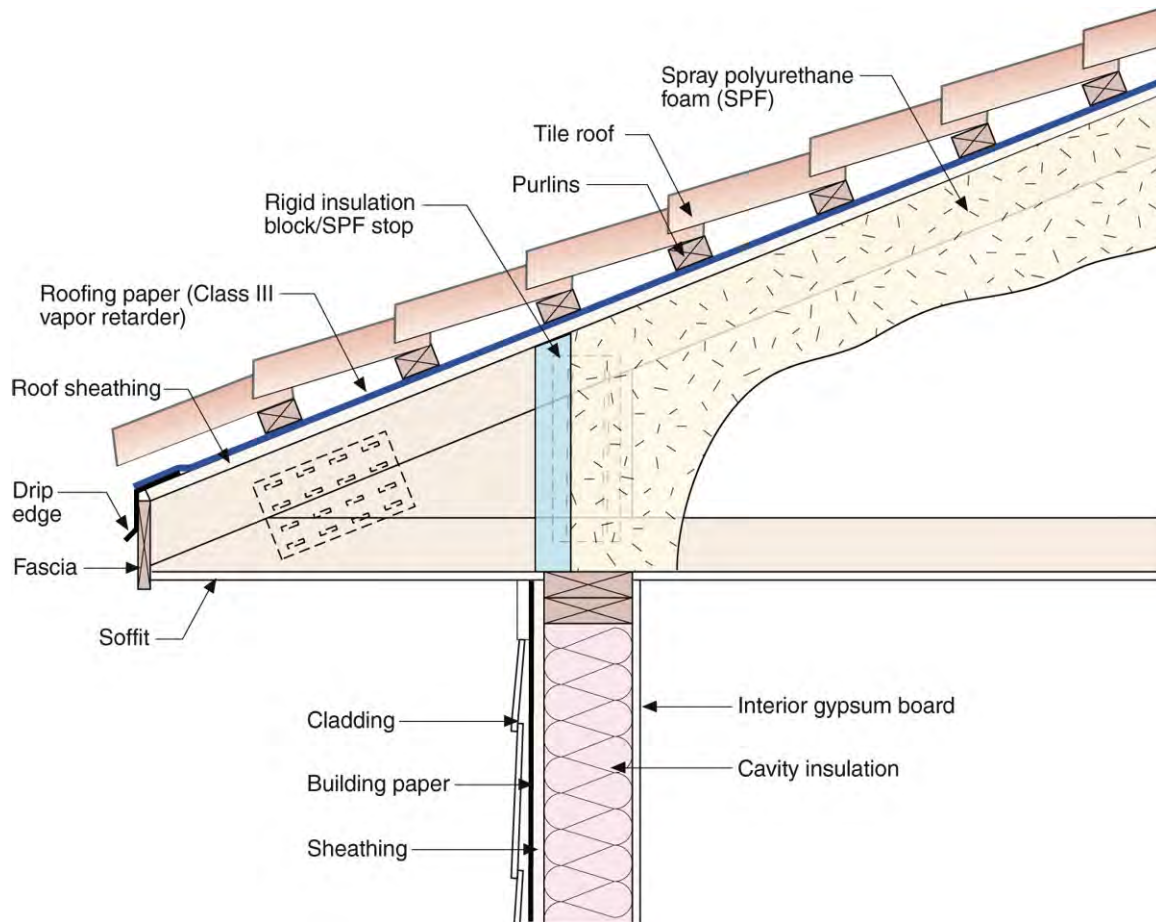


Figure 25: Unvented Attic – Tile Roof- Can be used in all climate zones. Either low density or high density spray polyurethane foam (SPF) can be used. However, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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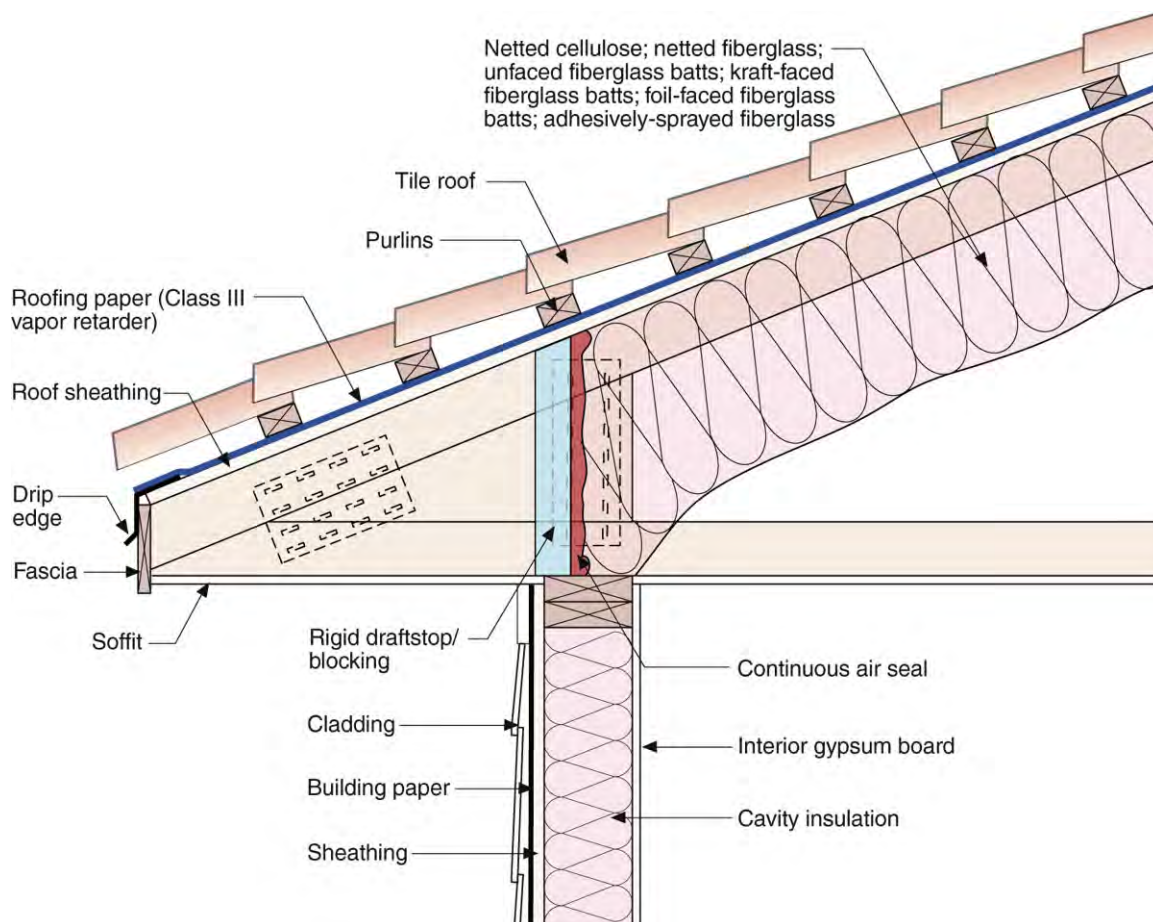


Figure 26: Unvented Attic – Tile Roof – Air Permeable Insulation - Can be used in all CEC Zones except 16. More broadly speaking this assembly can be used only in IECC Climate Zones 2B and 3B. Note that the tile roof provides top side ventilation of the roof sheathing and this top side ventilation of the roof sheathing should be coupled with a vapor semi permeable roofing paper (Class III vapor retarder). Class II or Class I vapor retarders – typically fully adhered vapor impermeable membranes should not be installed in place of roofing paper in this attic configuration. Because of this top side ventilation of the roof sheathing coupled with a vapor open roofing paper this assembly has fewer restrictions than other assemblies.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

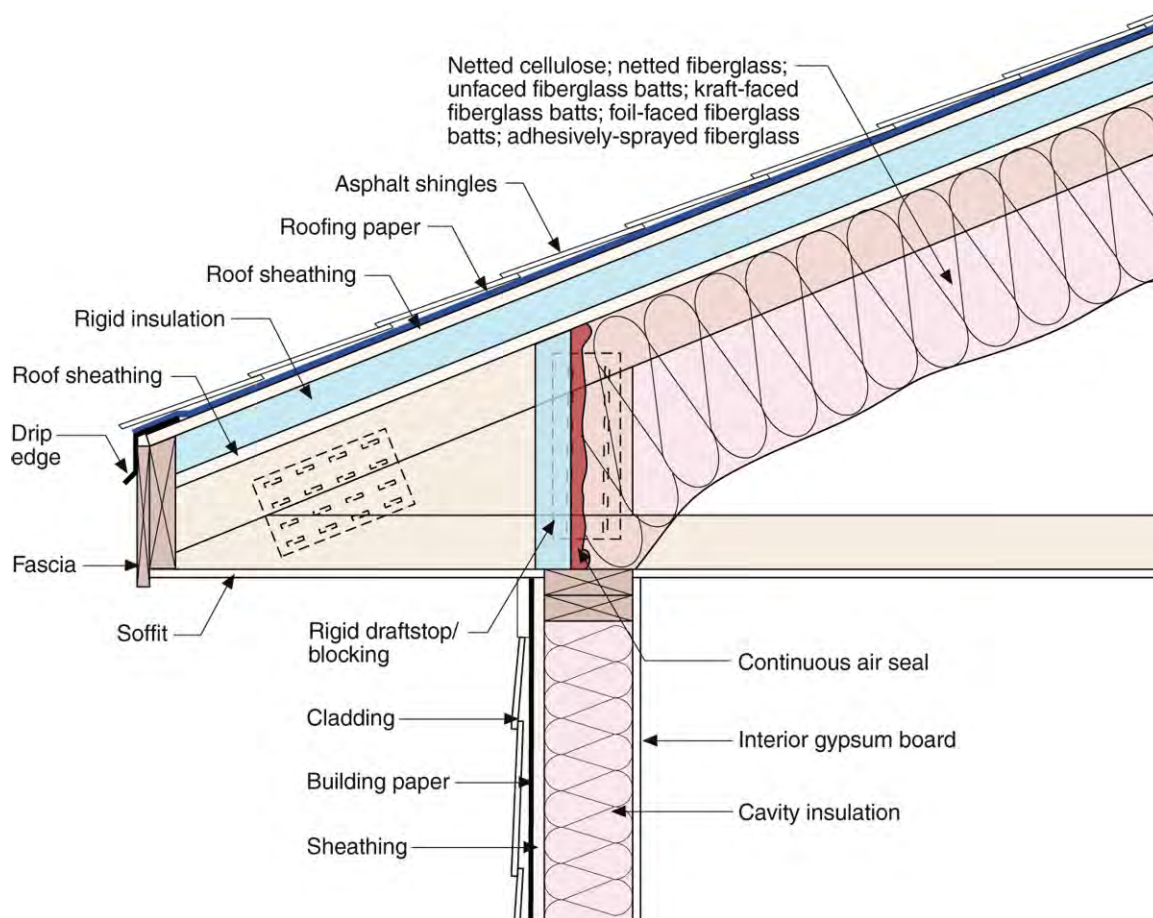


Figure 27: Unvented Attic – Asphalt Shingles – Air Permeable Insulation – Rigid Insulation Above Roof Deck - Can be used in all climate zones. However the thermal resistance of the rigid insulation applied above the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this rigid insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this rigid insulation layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

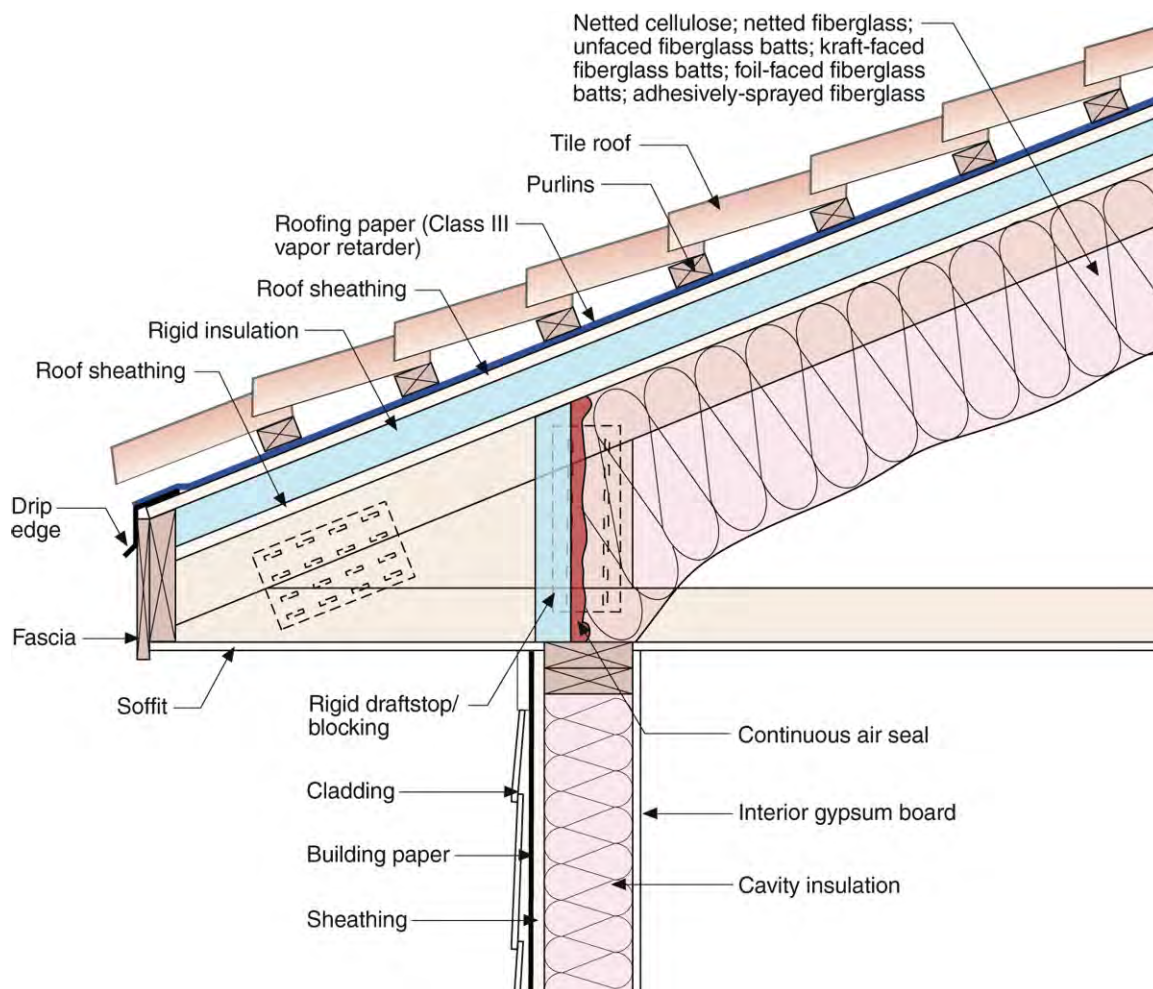


Figure 28: Unvented Attic – Tile Roof – Air Permeable Insulation – Rigid Insulation Above Roof Deck - Can be used in all climate zones. However the thermal resistance of the rigid insulation applied above the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this rigid insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this rigid insulation layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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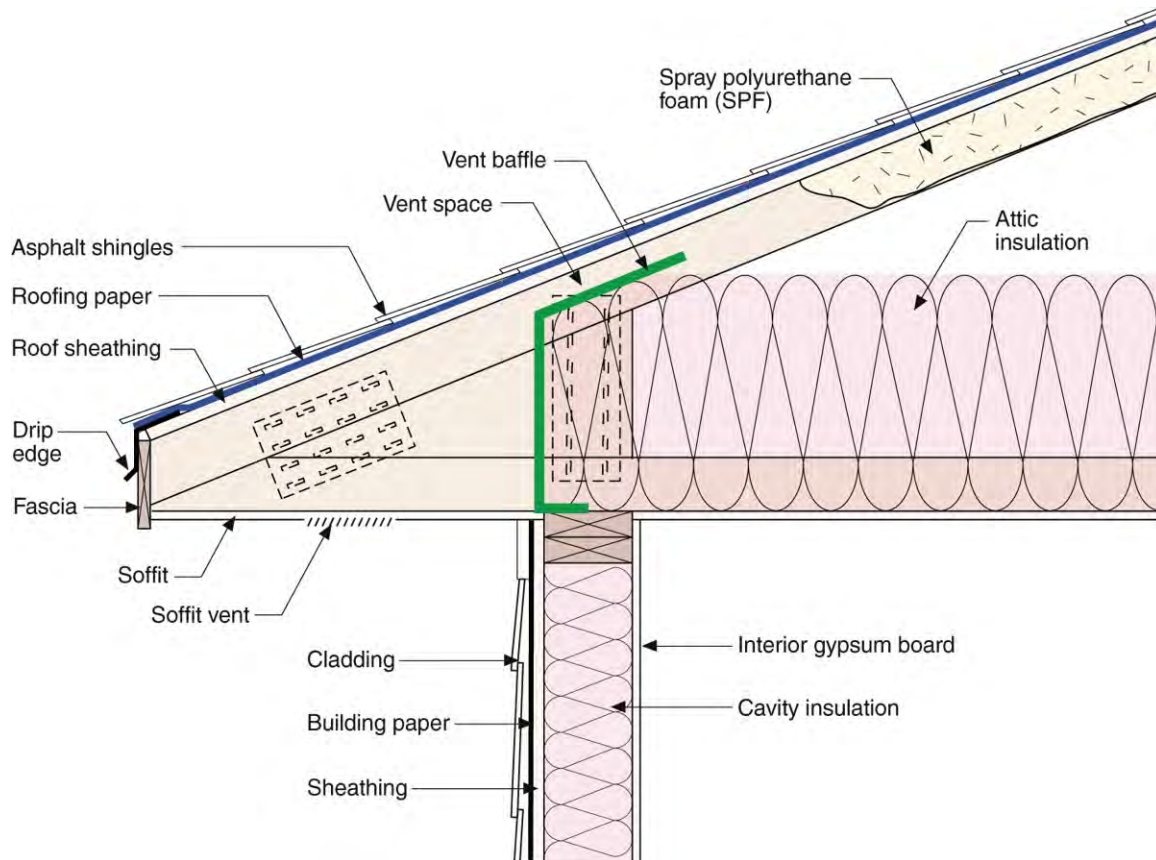


Figure 29: Vented Attic - Asphalt Shingles – Air Impermeable Insulation On Underside of Roof Deck - Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk. In this configuration – the attic space is vented - the vapor transmission characteristics of the SPF are not significant. Accordingly, either low density or high density SPF can be used in all climate zones including CEC Zone 16.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

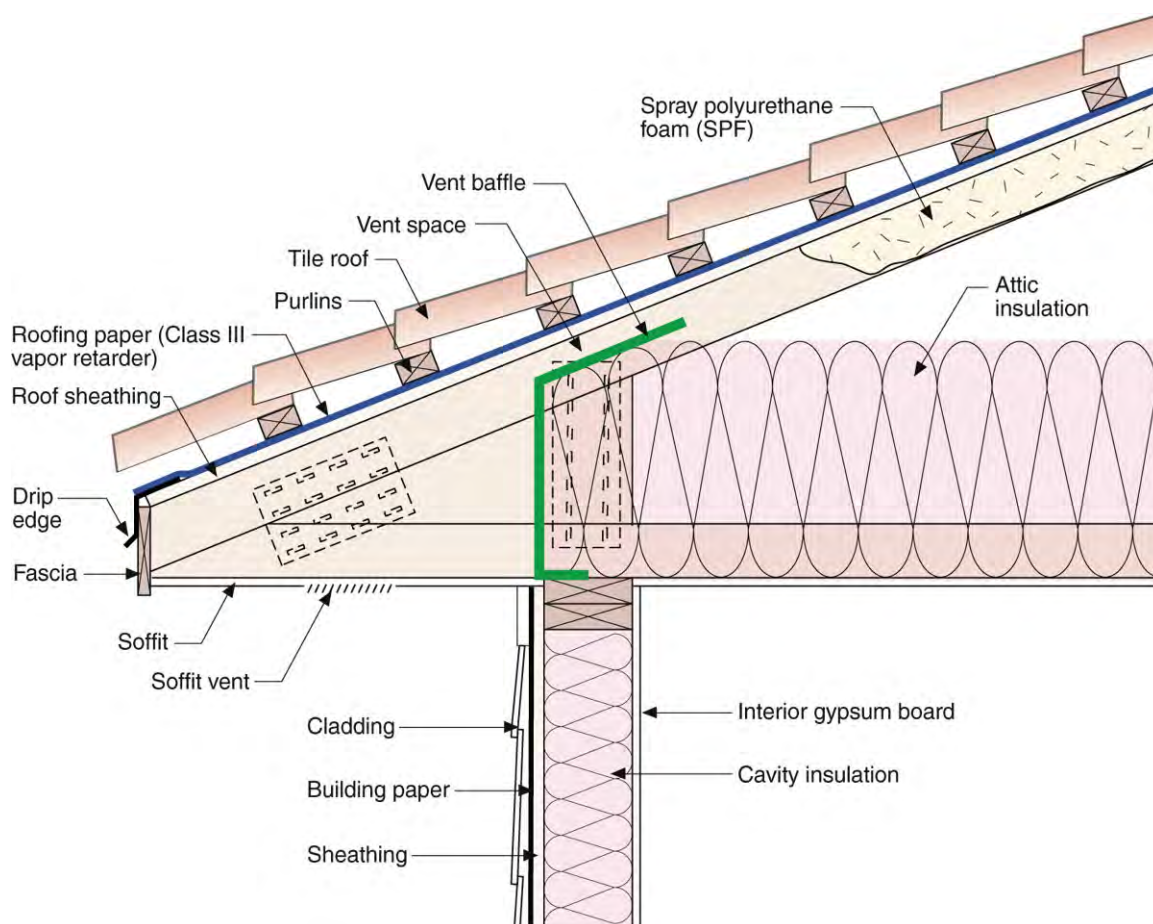


Figure 30: Vented Attic – Tile Roof – Air Impermeable Insulation On Underside of Roof Deck - Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk. In this configuration – the attic space is vented - the vapor transmission characteristics of the SPF are not significant. Accordingly, either low density or high density SPF can be used in all climate zones including CEC Zone 16.

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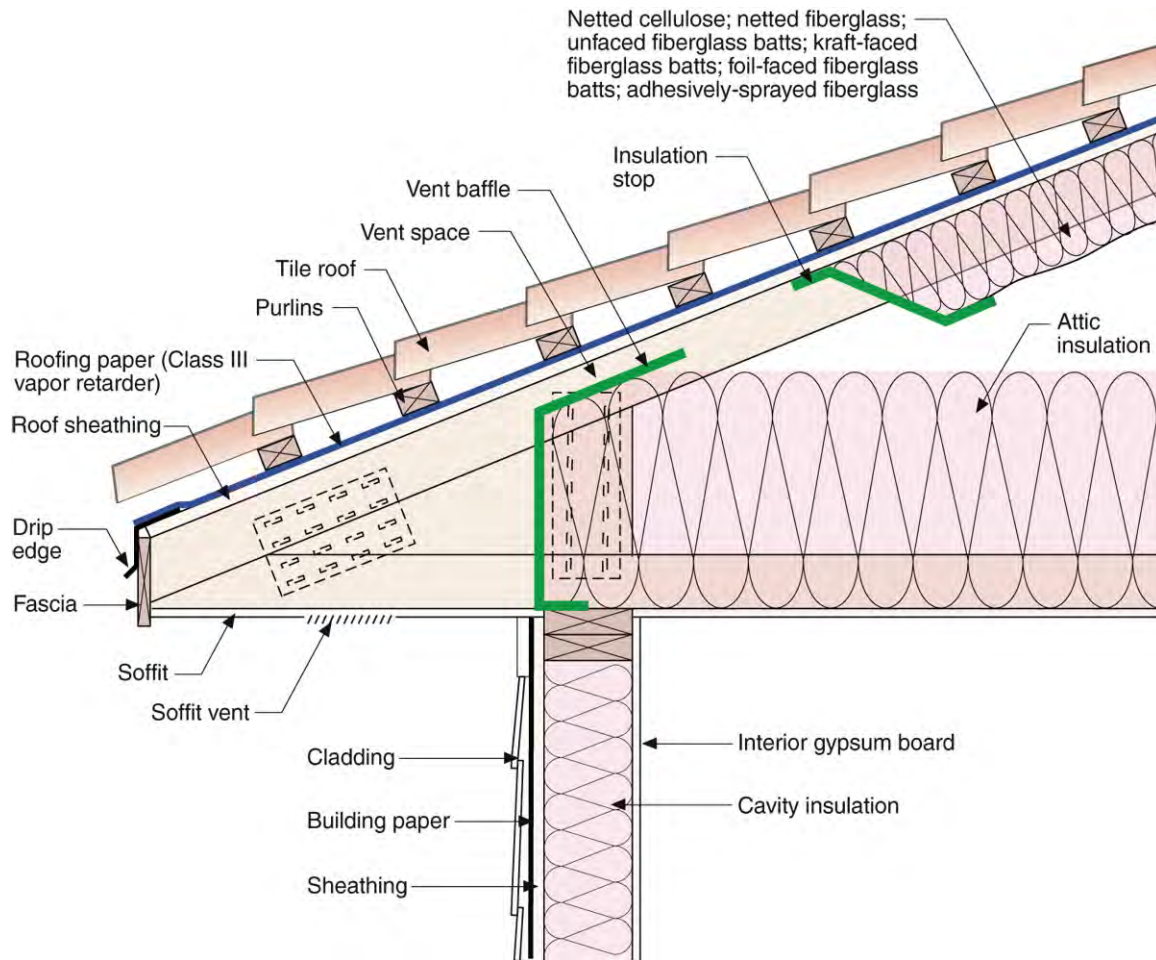


Figure 31: Vented Attic – Tile Roof – Air Permeable Insulation On Underside of Roof Deck - Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies.

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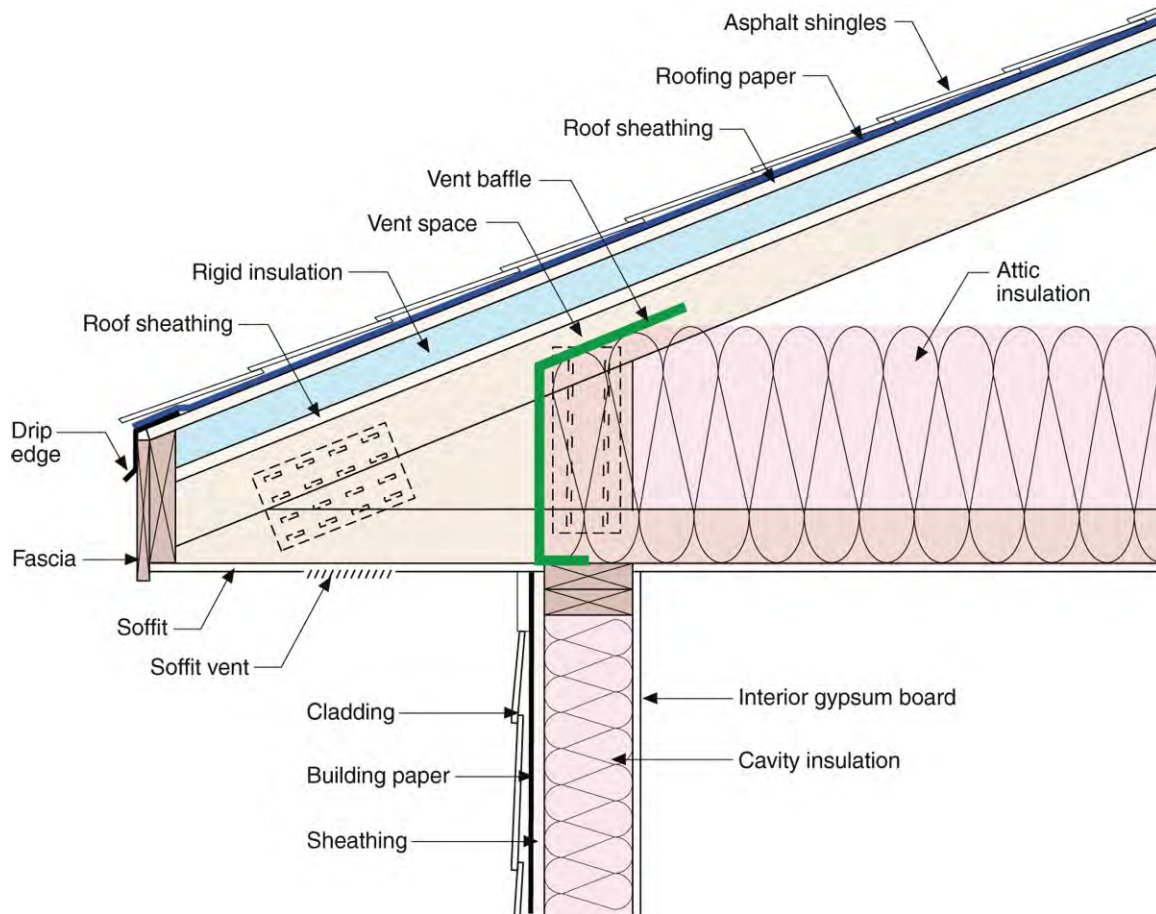


Figure 32: Vented Attic – Asphalt Shingles – Rigid Insulation On Top Side of Roof Deck - Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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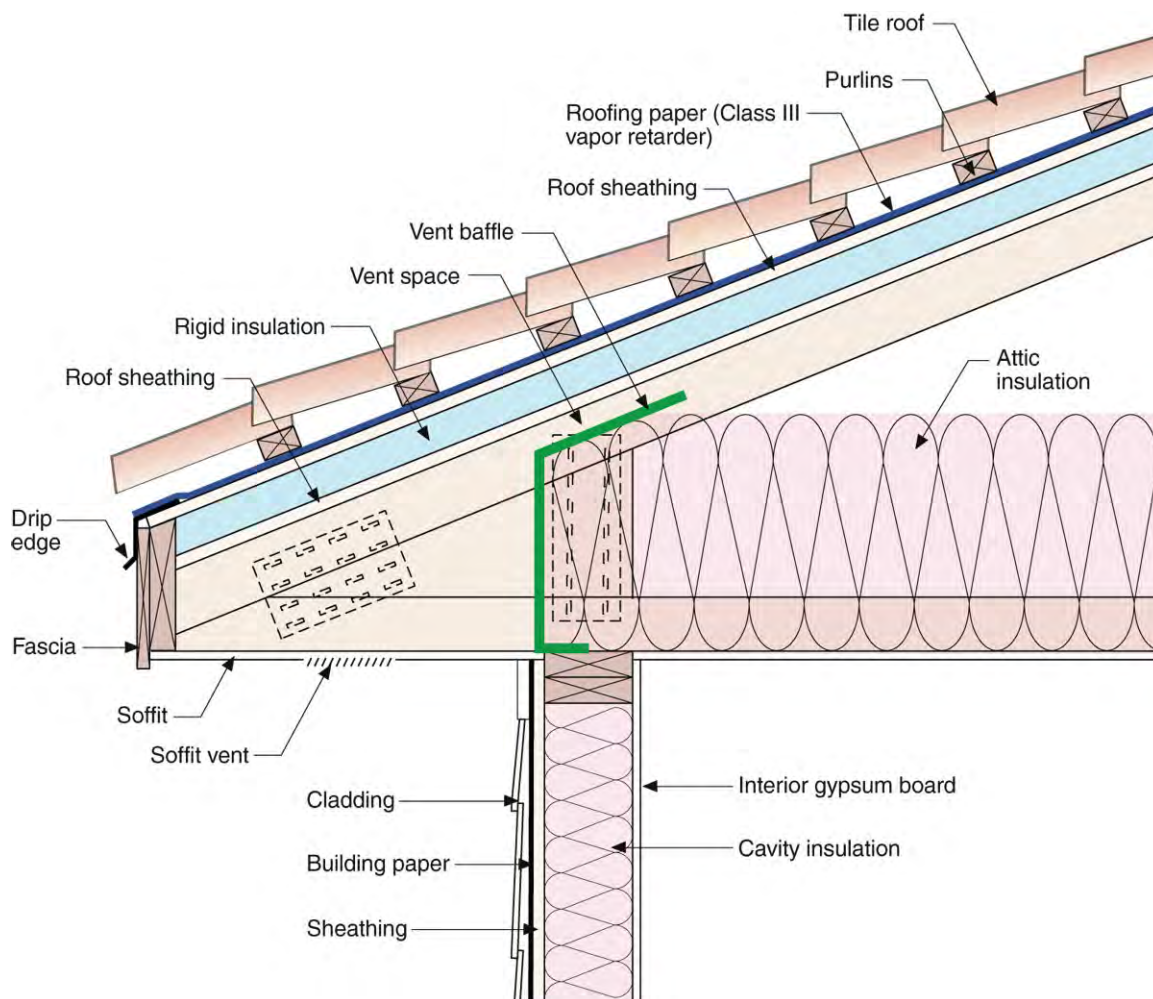


Figure 33: Vented Attic – Tile Roof – Rigid Insulation On Top Side of Roof Deck - Can be used in all climate zones. In CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be installed at the ceiling plane below the insulation. In all other climate zones a vapor retarder is not required. A ventilation ratio of 1:300 is recommended in all climate zones and is a basic code requirement in the IRC for vented attic assemblies. The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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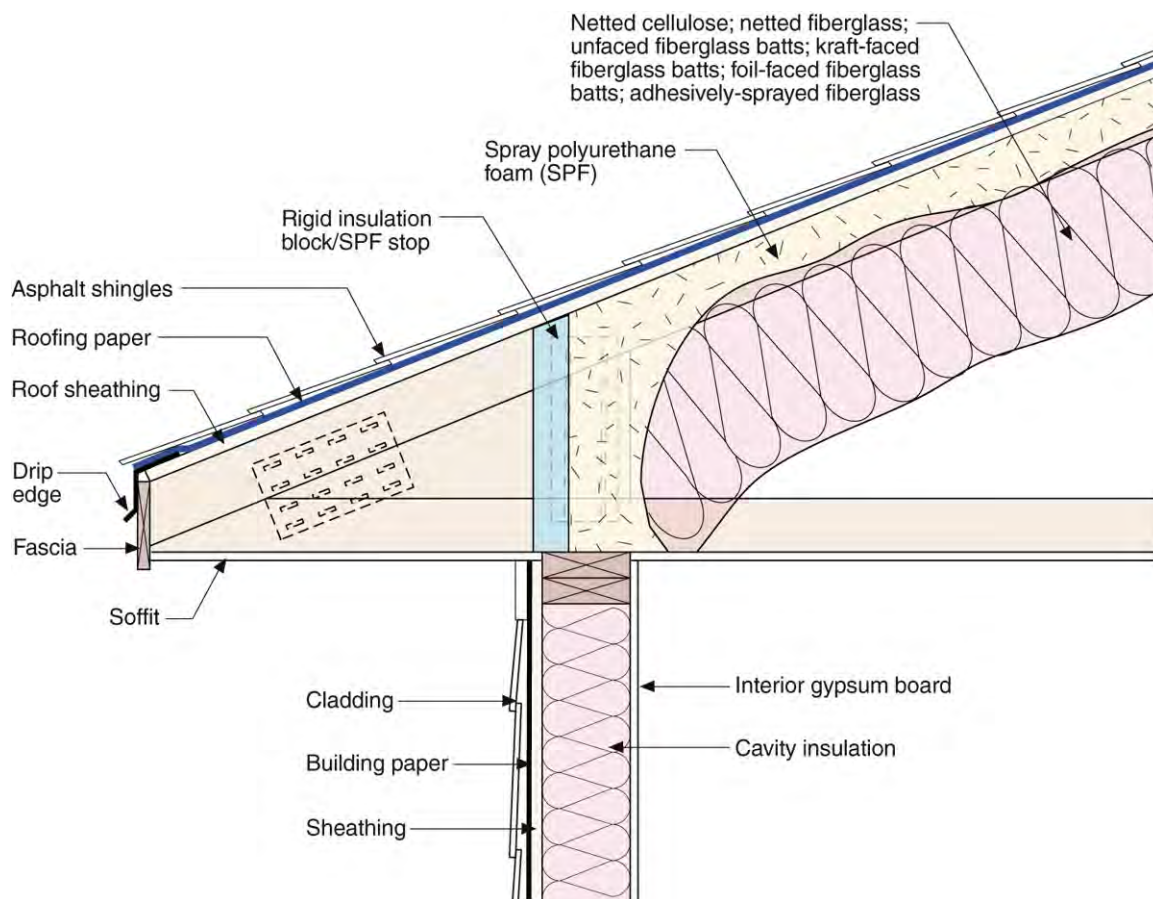


Figure 34: Unvented Attic – Asphalt Shingles – Air Impermeable Insulation/Air Permeable Insulation Under roof deck - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended. Furthermore, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF.

The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

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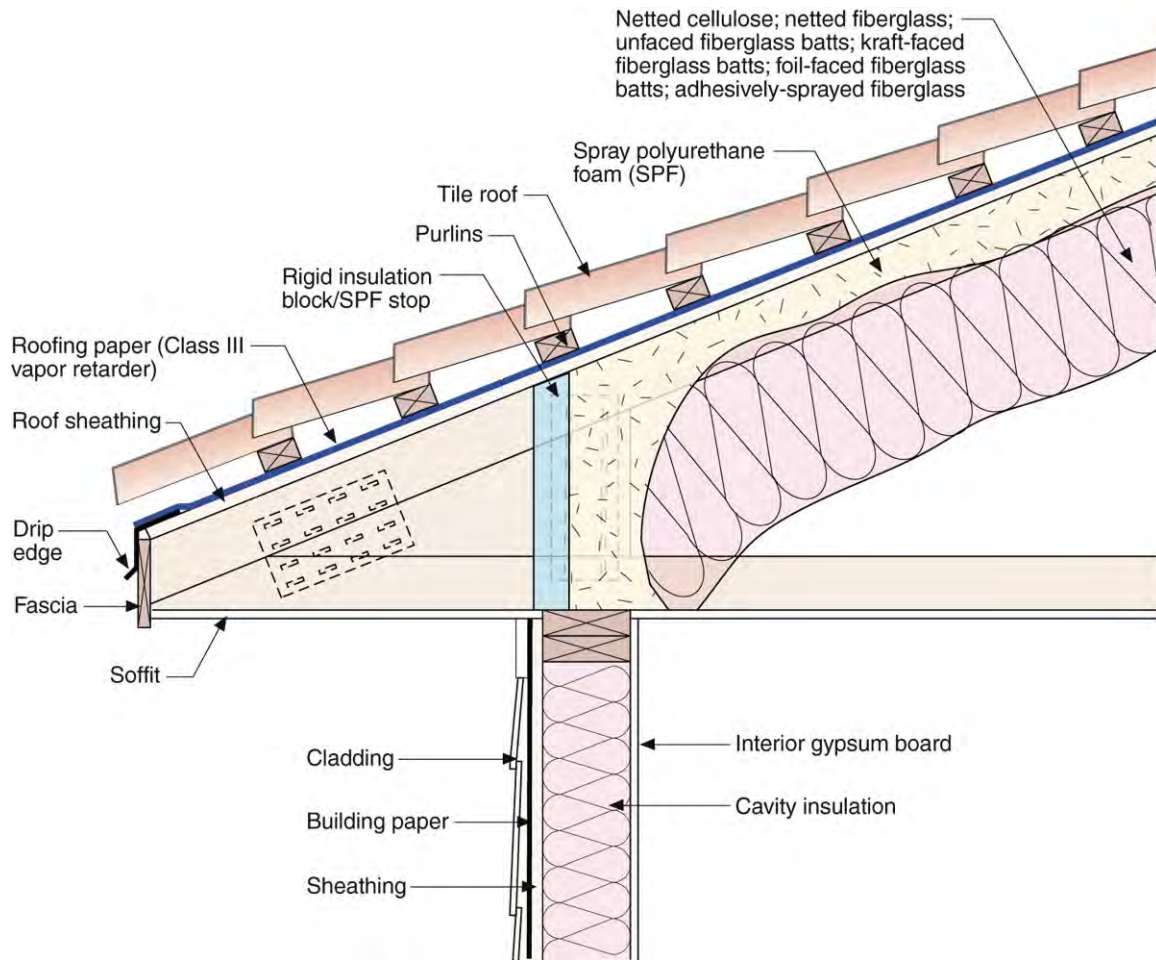


Figure 35: Unvented Attic – Tile Roof – Air Impermeable Insulation/Air Permeable Insulation Under roof deck - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended. Furthermore, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF.

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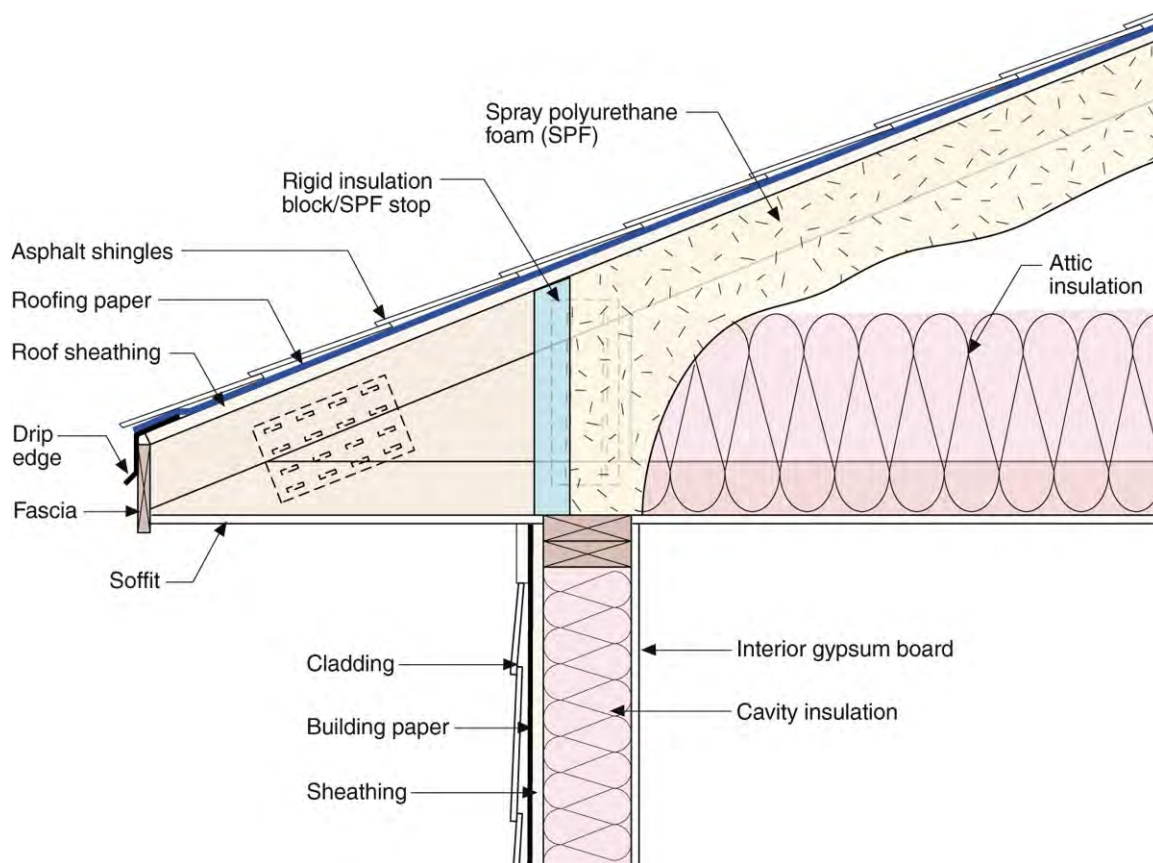


Figure 36: Unvented Attic – Asphalt Shingles – Roof Deck Insulation – Ceiling Insulation - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

Additionally, in CEC Zone 16 (IECC Climate Zone 5 or higher) the thermal resistance of the insulation installed at the roof deck must be equal to or greater than the thermal resistance of the insulation on the ceiling plane.

Furthermore, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF.

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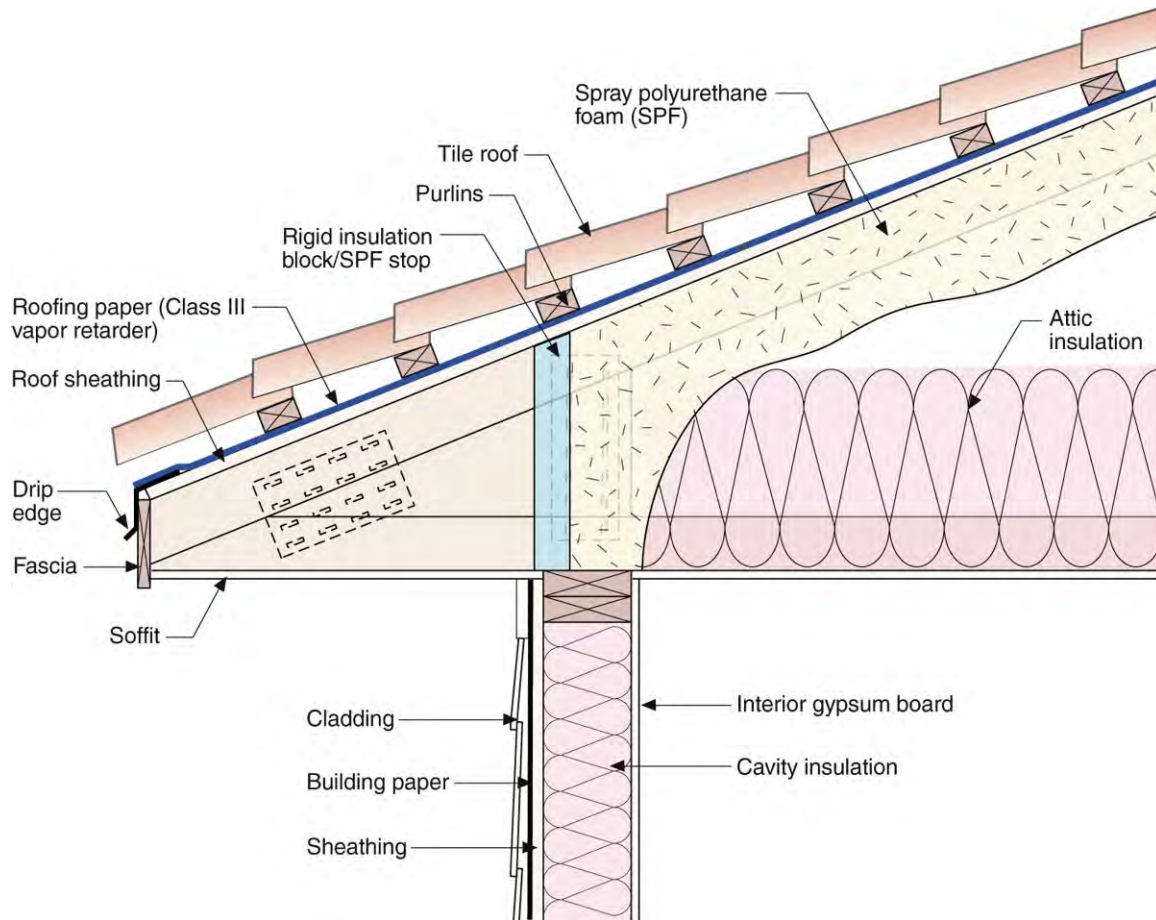


Figure 37: Unvented Attic – Tile Roof – Roof Deck Insulation – Ceiling Insulation - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

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The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

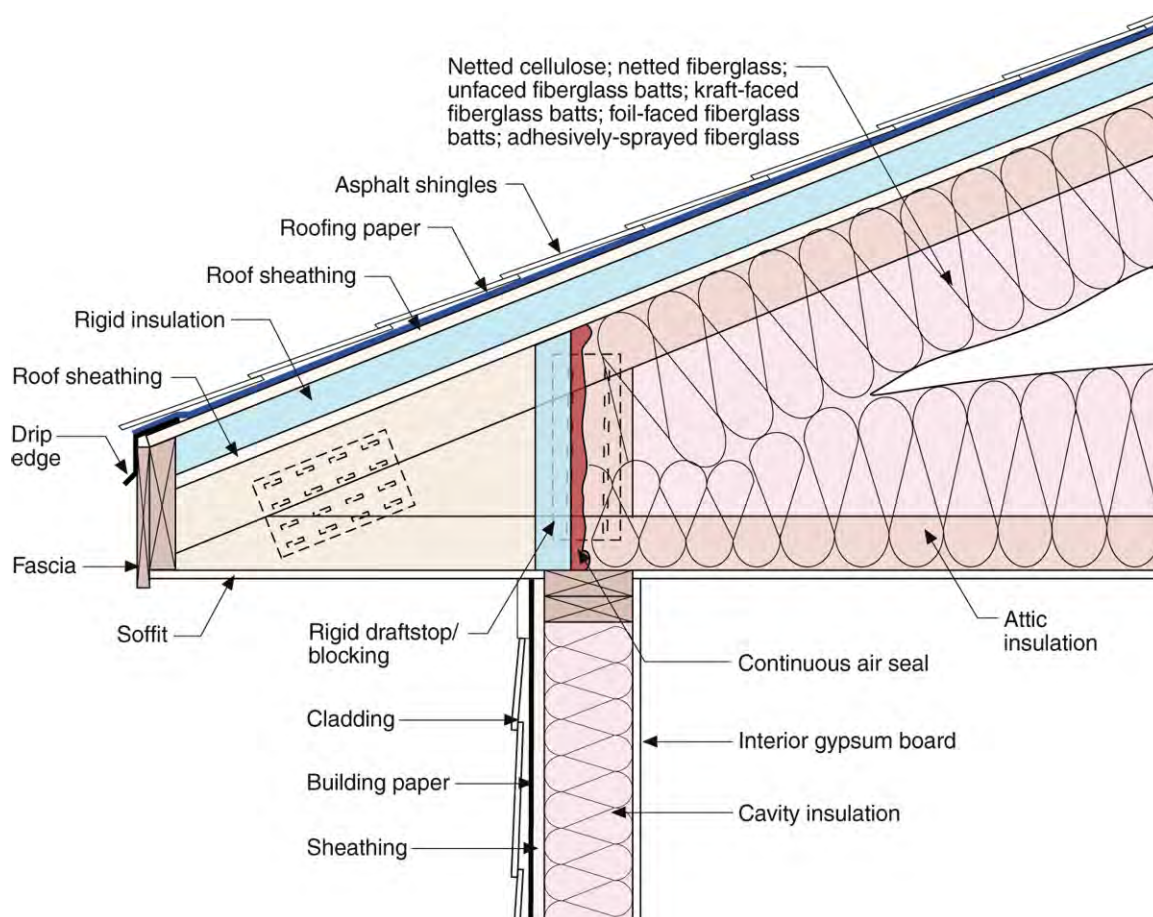


Figure 38: Unvented Attic – Asphalt Shingles – Roof Deck Insulation – Ceiling Insulation - Can be used in all climate zones. However the thermal resistance of the rigid insulation applied above the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this rigid insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this rigid insulation layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

Furthermore, in IECC Climate Zone 5 or higher (CEC Zone 16) the thermal resistance of the insulation installed at the roof deck must be equal to or greater than the thermal resistance of the insulation on the ceiling plane.

The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

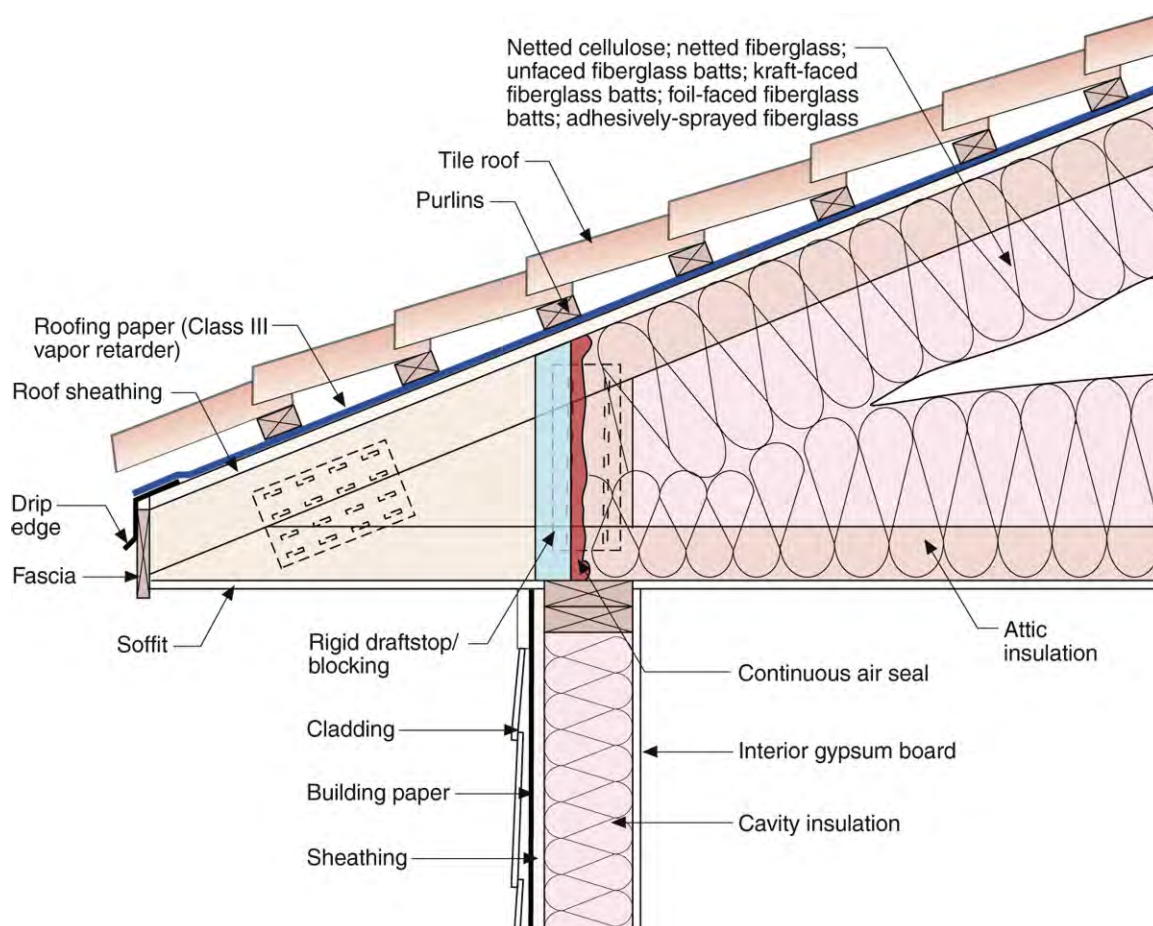


Figure 39: Unvented Attic – Tile Roof – Air Permeable Insulation On Underside of Roof Deck – Ceiling Plane Insulation - Can be used only in IECC Climate Zones 2B and 3B (All CEC Zones except 16). Note that the tile roof provides top side ventilation of the roof sheathing and this top side ventilation of the roof sheathing should be coupled with a vapor semi permeable roofing paper (Class III vapor retarder). Because of this top side ventilation of the roof sheathing coupled with a vapor open roofing paper this assembly has fewer restrictions than other assemblies. Class II or Class I vapor retarders – typically fully adhered vapor impermeable membranes should not be installed in place of roofing paper in this attic configuration.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

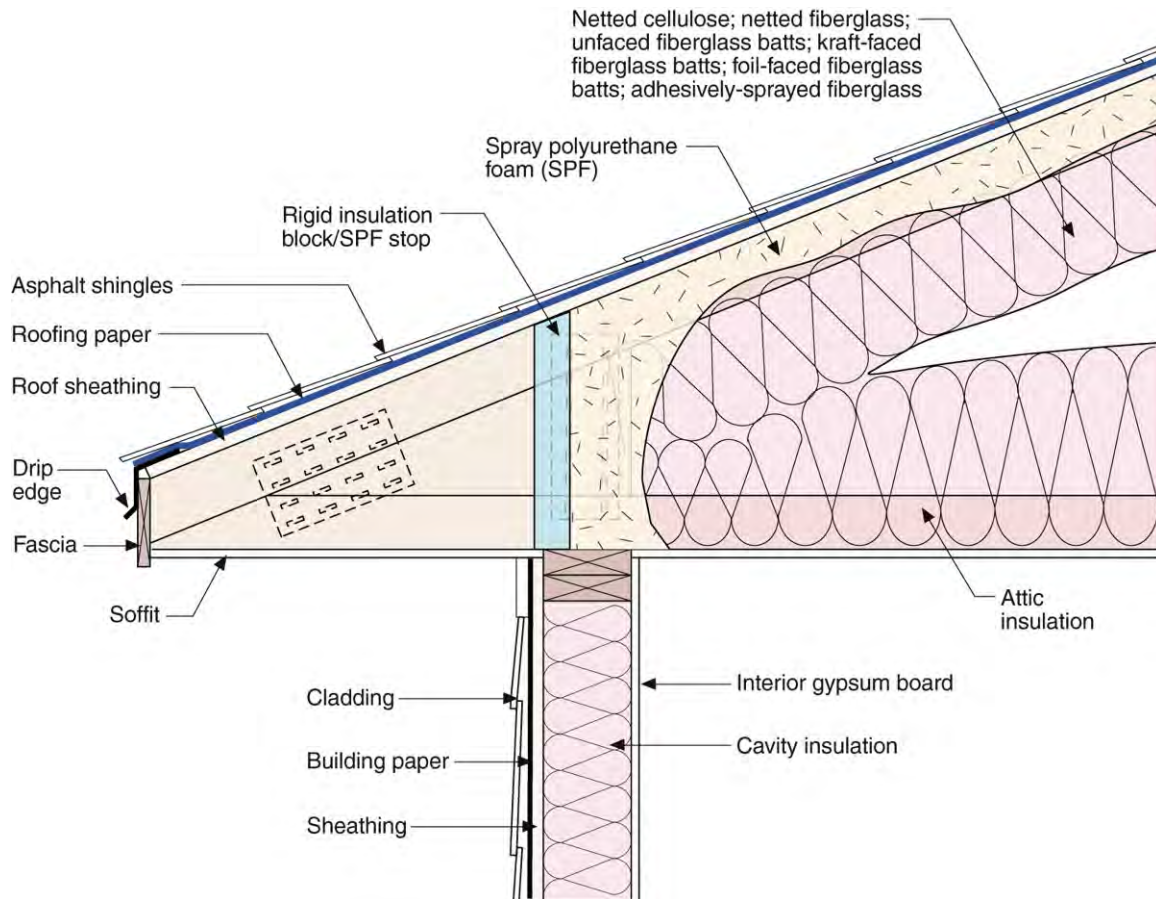


Figure 40: Unvented Attic – Asphalt Shingles – Roof Deck Insulation – Ceiling Insulation - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

Additionally, in CEC Zone 16 (IECC Climate Zone 5 or higher) the thermal resistance of the insulation installed at the roof deck must be equal to or greater than the thermal resistance of the insulation on the ceiling plane.

Furthermore, in CEC Zone 16 (IECC Climate Zone 5 or higher) a Class II vapor retarder should be applied to the underside of low density SPF. A spray applied vapor retarder is recommended in this particular application as sheet applied vapor retarders have not been shown to be effective. Vapor retarders are not required with high density SPF in any climate zone due to the permeability characteristics of high density SPF.

The roofing paper can be substituted with an impermeable fully adhered impermeable membrane with no apparent moisture risk.

Note that most conventional attics constructed in CA do not use soffit construction. Soffit construction is more typically associated with oversized trusses that allow high levels of thermal resistance at building perimeters (ie. “energy trusses”) and are shown for that reason. The recommendations provided are equally valid for attics constructed without soffits.

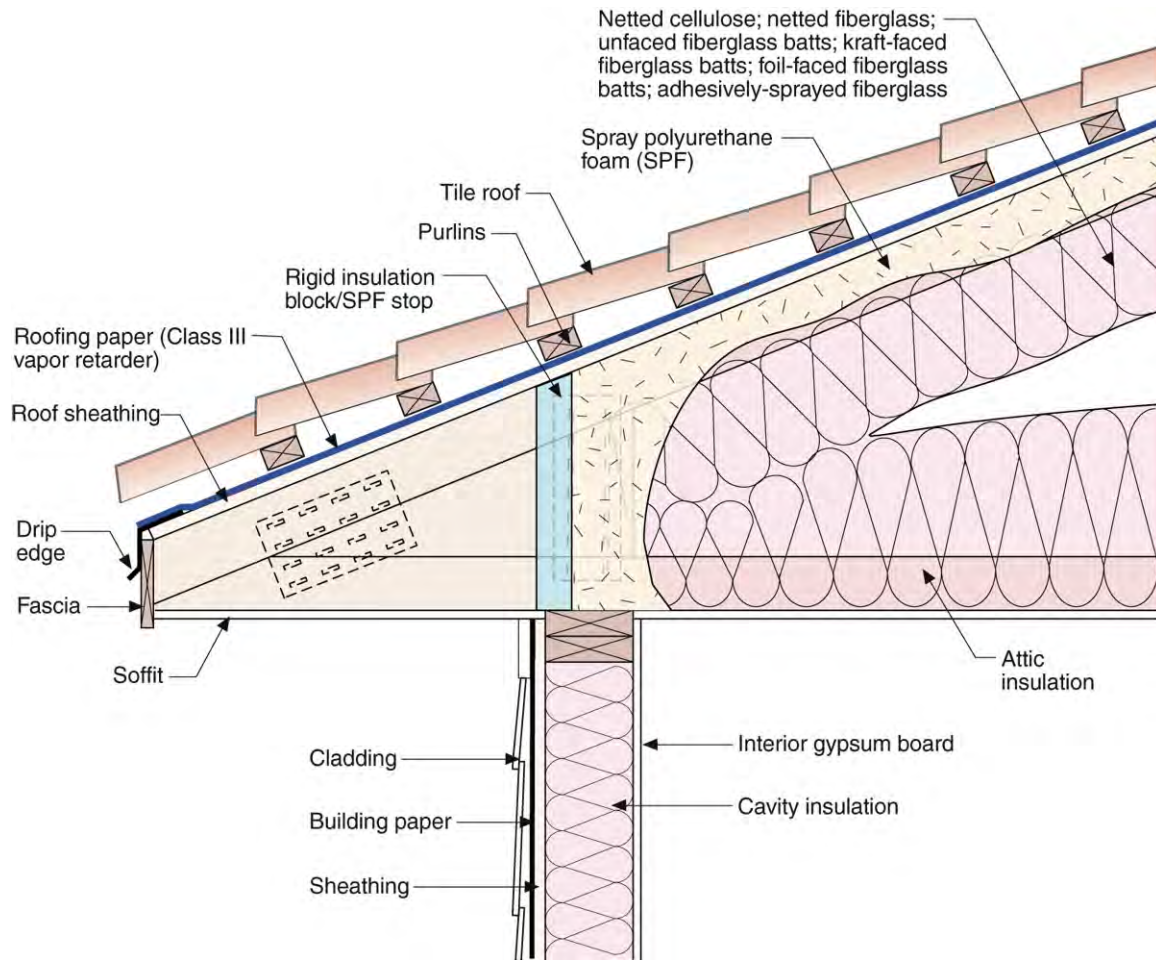


Figure 41: Unvented Attic – Tile Roof – Roof Deck Insulation – Ceiling Insulation - Can be used in all climate zones. However the thermal resistance of the air impermeable spray applied insulation applied directly to the underside of the structural roof sheathing is dependent on climate. Table 4 – 209 IRC Unvented Attics Table 806.4 provides a prescriptive requirement for the thermal resistance of this SPF insulation layer necessary to control condensation. Based on this table it is recommended that R-10 or greater be used as the minimum thermal resistance for this SPF layer in all CEC Zones except CEC Zone 16. For CEC Zone 16 a minimum thermal resistance of R-20 is recommended.

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