Design Options for Locating Ducts within Conditioned Space

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE Zero Energy Ready Home

Technical Training

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DOE Zero Energy Ready Home

Ducts are Trending…

- *Get them tight, tested, & inside!*

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	2006 IECC	2009 IECC	2012 IECC	2015 IECC	ENERGY STAR V3.1
Duct Insulation	R-8 supply & returns; R-6 if in floor joist*	R-8 supply (attics) R-6 return & other supplies*	R-8 supply (attics) R-6 return & other supplies*	R-8/R-6 Supply & Return(attics) R-6/R-4.2 Supply & Return (other) (≥3"/<3")*	R-8 supply (attics) R-6 return & other supplies
Duct Leakage Testing** *(Mandatory unless noted)*	N.R.	Total ≤ 12 cfm25/100 SF CFA (post)*	Total ≤ 4 cfm25/100 SF CFA (post)*	Total < 4 CFM25/100 SF CFA (post or rough-in)* Testing Mandatory, but not Targets	Ref Design: Total ≤ 4 cfm25/100 F CFA (rough-in)
Building Cavities?	No supplies	No supplies	No supplies or returns	No supplies or returns	Restrictions w/ exceptions
Cond.'nd Space Location	N.R.	N.R. – but waives duct leakage test and Insulation	N.R. – but waives duct leakage test and Insulation	N.R. – but waives duct leakage test and Insulation	Ref. Design: Ducts in cond.nd space

***Not Required if Ducts & Air Handler Located in Conditioned Space**

** Not all duct leakage thresholds shown; we highlight leakage here for sake of comparison

Why the Trends towards Ducts in Conditioned Space?

- **Significant Thermal Losses:**
  - Thermal losses triple for ducts in unconditioned vs. conditioned space
  - Total thermal losses can range from 10-45%
  - Extensive unconditioned space penetrations

- **Significant Performance Impacts:**
  - IAQ
  - Comfort
  - Durability

Motivations…

- **Code Compliance:**
  - Duct leakage testing required since 2009 IECC
  - Increasingly stringent leakage levels required 09…2012…2015
  - But code offers exceptions if ducts & air handler located in conditioned space
- **Efficiency: which is better?**
  - 90 AFUE furnace & 60% efficient distribution system….

  or
  - 80 AFUE furnace & 90% efficient distribution system

54% Total System Efficiency vs. 72% Total System Efficiency

- **Variable speed HVAC systems**….
  - SEER 21 has twice the run time vs SEER 13
  - 40% savings (cond space) vs just 27% (uncond.)

Energy Penalties

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Climate Zone 4 – 2600 ft² High Performance Home

Configuration	Design Heating (kBtu/hr)	Design Cooling (kBtu/hr)	HERS Index
100% Conditioned space	23	19	52
50% Conditioned / unconditioned	30	26	55
100% Unconditioned (attic – R-8, exposed)	34	30	56

Zero Energy Ready Homes & Ducts

- For a home to qualify with DOE Zero Energy Ready Home, ducts must be located within the home's thermal and air barrier boundary. Several alternate compliance approaches are allowed b/c of comparable performance.

- ***Selected strategically*** and ***implemented correctly*** – this "toolkit" of approaches offers cost-effective solutions for highly efficient distribution systems

- This training will cover several possible approaches to locating ducts within the home's air and thermal barriers, with particular emphasis on the spray foam encapsulation approach.

Design Options for Locating Ducts within Conditioned Space

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Mandatory Requirements

Exhibit 1: DOE Challenge Home Mandatory Requirements for All Labeled Homes

Area of Improvement	Mandatory Requirements
1. ENERGY STAR for Homes Baseline	☐ Certified under ENERGY STAR Qualified Homes Version 3[5]
2. Envelope[6]	☐ Fenestration shall meet or exceed latest ENERGY STAR requirements [7, 8] ☐ Ceiling, wall, floor, and slab insulation shall meet or exceed 2012 IECC levels[9]
3. Duct System	☐ Ducts located within the home's thermal and air barrier boundary[10]
4. Water Efficiency	☐ Hot water delivery systems shall meet efficient design requirements[11]
5. Lighting & Appliances[12]	☐ All installed refrigerators, dishwashers, and clothes washers are ENERGY STAR qualified. ☐ 80% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in minimum 80% of sockets ☐ All installed bathroom ventilation and ceiling fans are ENERGY STAR qualified
6. Indoor Air Quality	☐ EPA Indoor airPLUS Verification Checklist and Construction Specifications[13]
7. Renewable Ready[14]	☐ EPA Renewable Energy Ready Home Solar Electric Checklist and Specifications[15] ☐ EPA Renewable Energy Ready Home Solar Thermal Checklist and Specifications[16]

Ducts in Condit. Space Exemptions

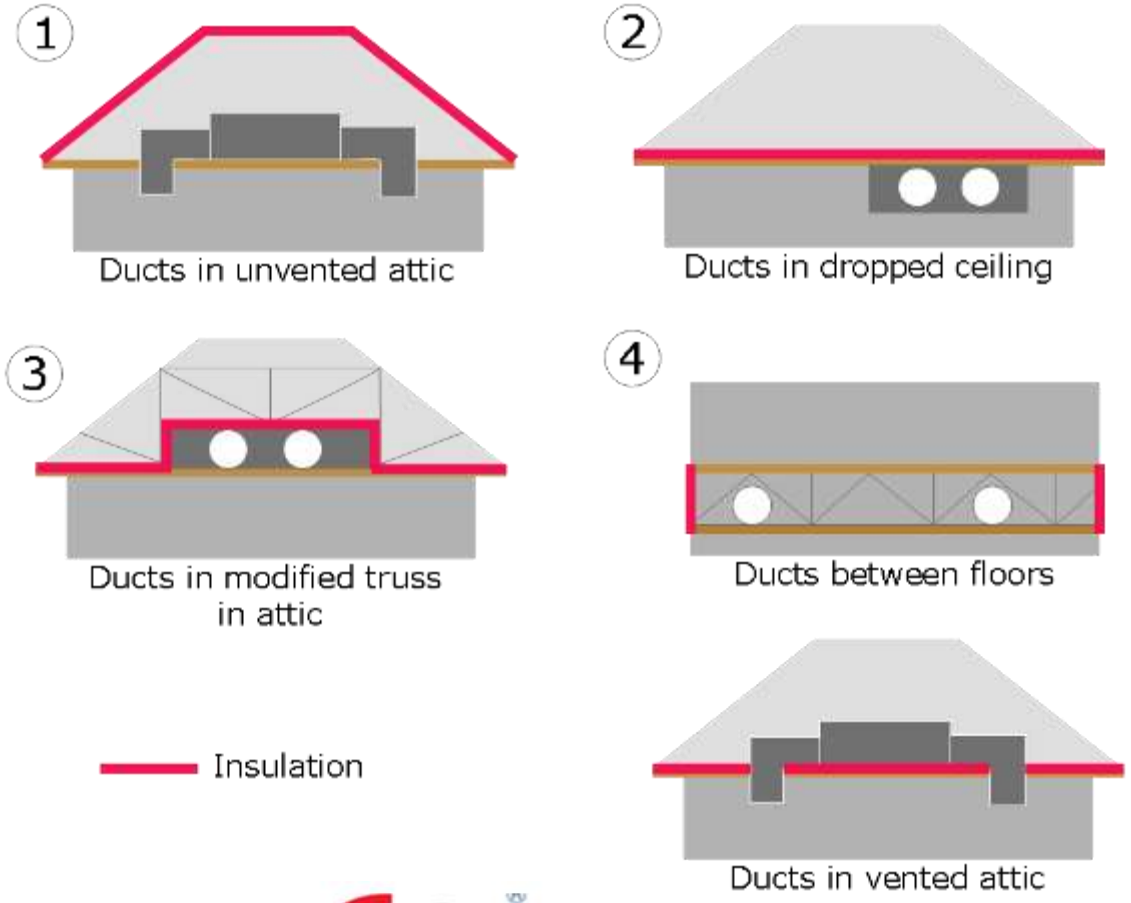
- **Short Duct Run**
  up to 10’ of total length is permitted to be outside of the home’s thermal and air barrier boundary.
- **Jump Ducts**
  may be located in attics if all joints, including boot-to-drywall, are fully air sealed with mastic
- **Ductless HVAC system**
  e.g. mini-splits can offer a non-ducted alternative

Ducts in Condit. Space Options

- **Conditioned Floor Space [3 options]**
  within the thermal boundary
- **Conditioned Basement**
  which is within the home's thermal boundary
- **Unvented / Insulated / Air Sealed Crawlspace**
- **Unvented Attic**
  regardless of whether conditioned with a supply register
- **Vented Attic**
  "hybrid" approach with ducts very well air sealed and embedded in home's thermal envelope

Available Options

- Multiple Interior duct options exist
- Selecting the “best” option depends on multiple factors…



Option: Ducts in Unvented Attic

- By moving the thermal boundary from the ceiling plane up to the roof plane, additional interior volume is created allowing the placement of ducts and HVAC equipment within the conditioned space

Option: Ducts in Unvented Attic

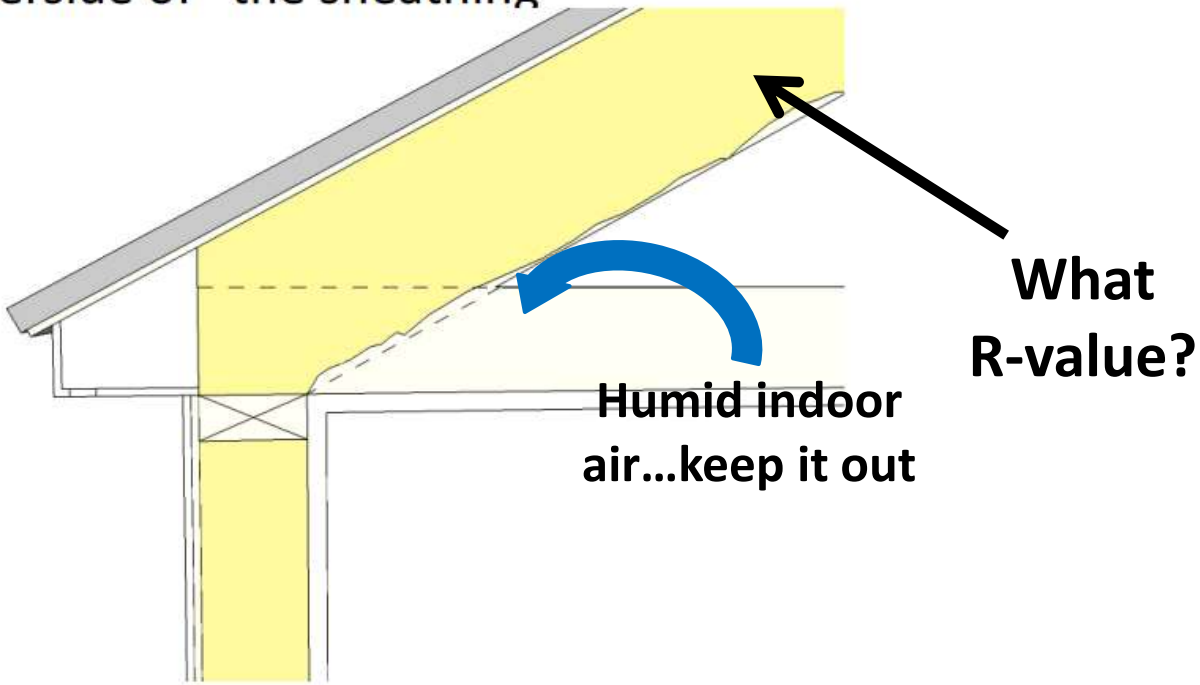
- Insulation at the roof-deck can be used to form a vaulted-ceiling living space (left) or to create an attic-level mechanical space within the thermal envelope (right)

Option: Ducts in Unvented Attic

- This method of protecting the HVAC is well suited for retrofits when relocating existing equipment is impractical

Insulating/Air Sealing Options

AIR-IMPERMEABLE INSULATION: In direct contact with the underside of the sheathing



Insulation for Condensation Control

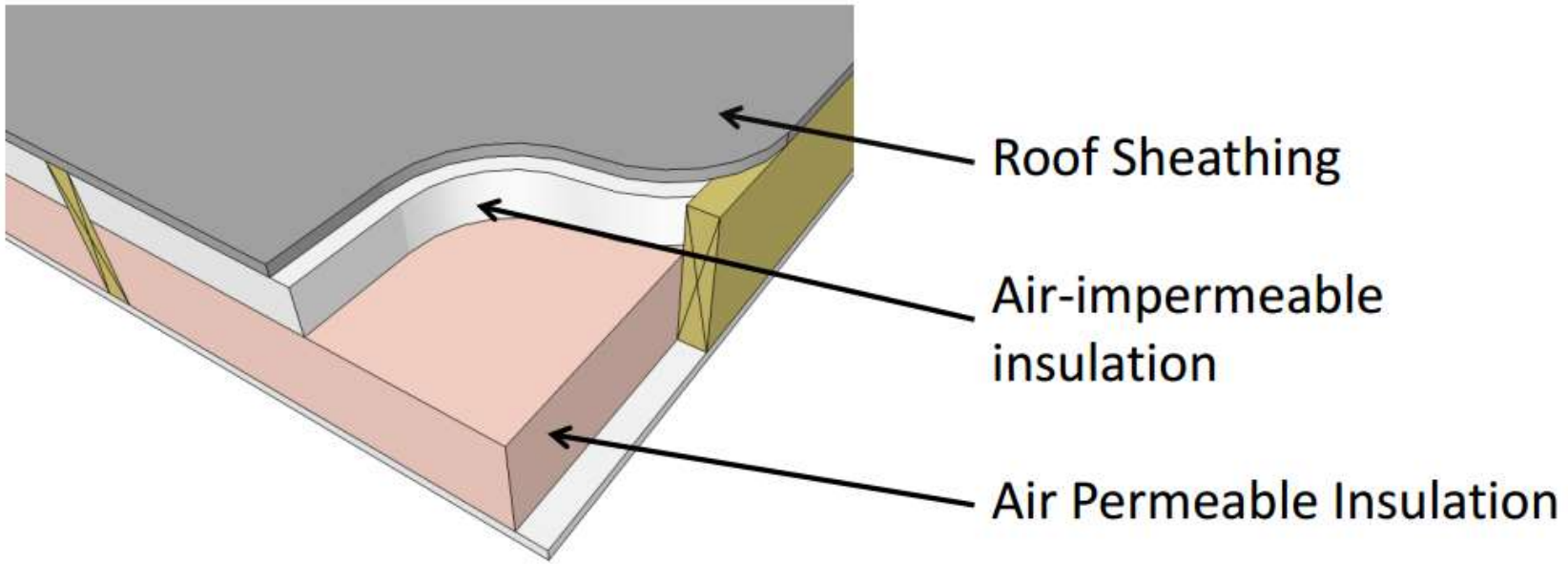
Minimum R-value of Impermeable Insulation

Climate Zone	Minimum Impermeable Insulation R-Value*	2012 IECC Ceiling R-Values
2B and 3B Tile Roof	None Required	30
1, 2A, 2B, 3A, 3B, 3C	R-5	38
4C	R-10	38
4A, 4B	R-15	49
5	R-20	49
6	R-25	49
7	R-30	49
8	R-35	49

*contributes but doesn't supersede 2012 IECC insulation requirements

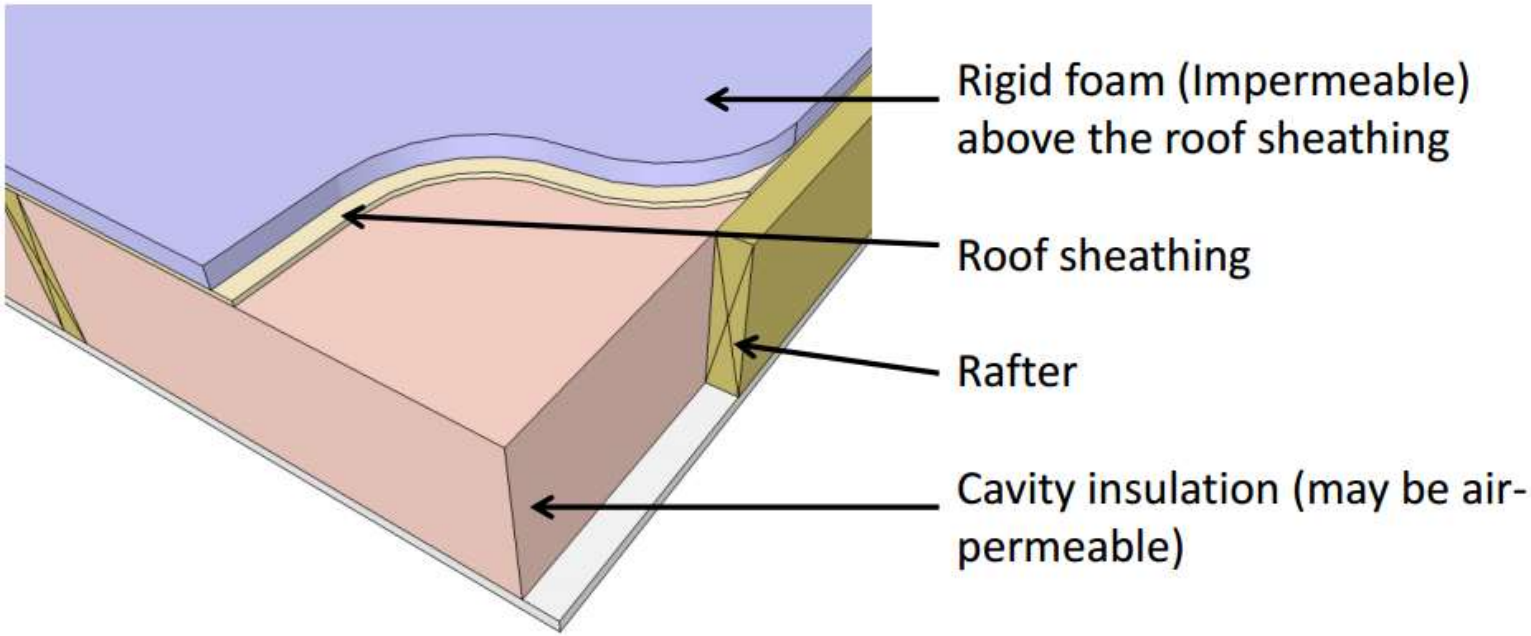
Insulating/Air Sealing Options

AIR-IMPERMEABLE and AIR-PERMEABLE insulation.



Insulating/Air Sealing Options

Rigid Insulation Board above structural roof sheathing + air-permeable insulation in direct contact with the underside of the sheathing



Thermal & Ignition Barriers

- Attic with Limited Access & No Storage

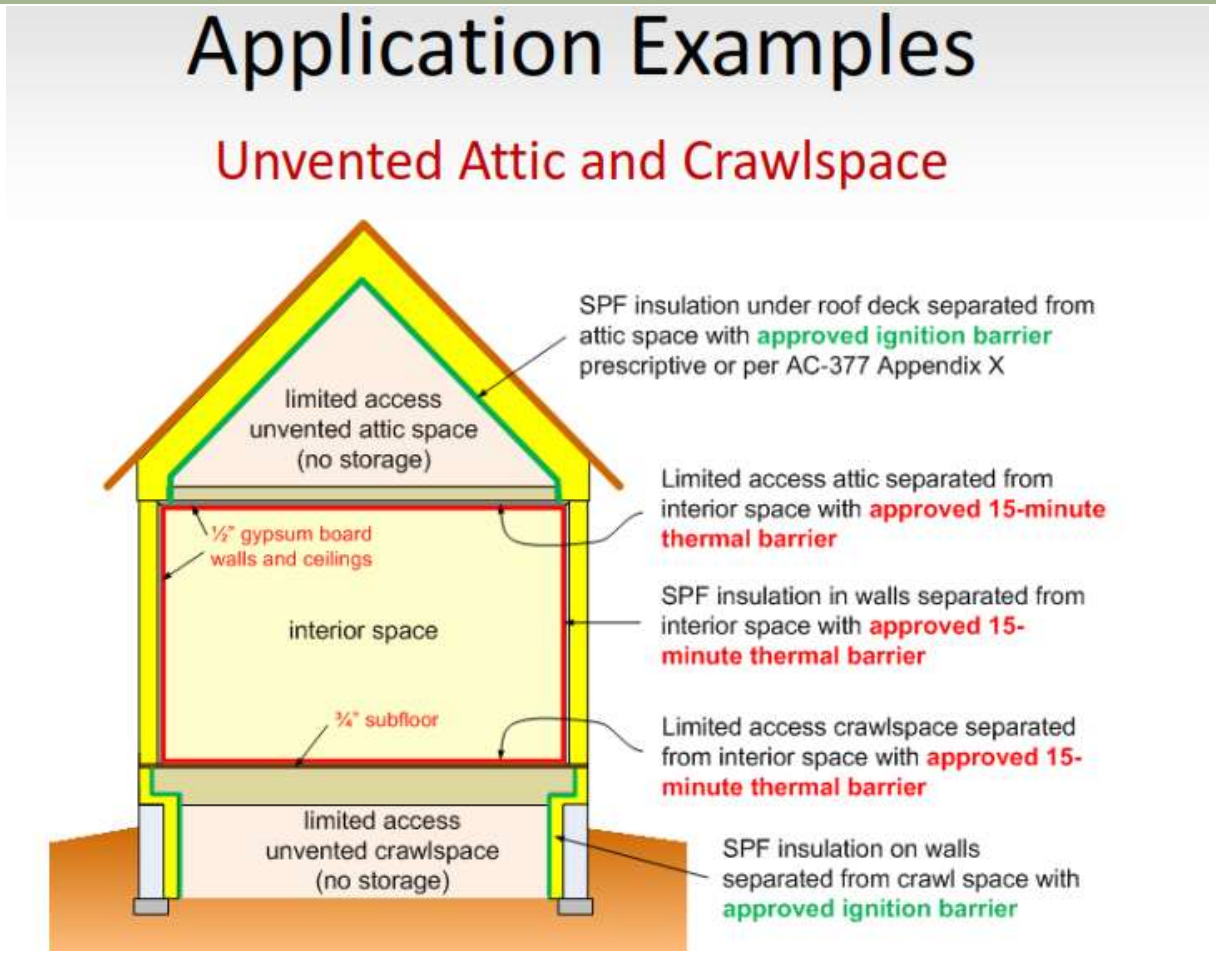


Image Source: SPFA Presentation at 2012 RESNET Conference: 'Decoding' Thermal and Ignition Barrier Requirements for SPF

Thermal & Ignition Barriers

- Attic with Storage

Application Examples

Unvented Attic and Crawlspace – w/ Storage

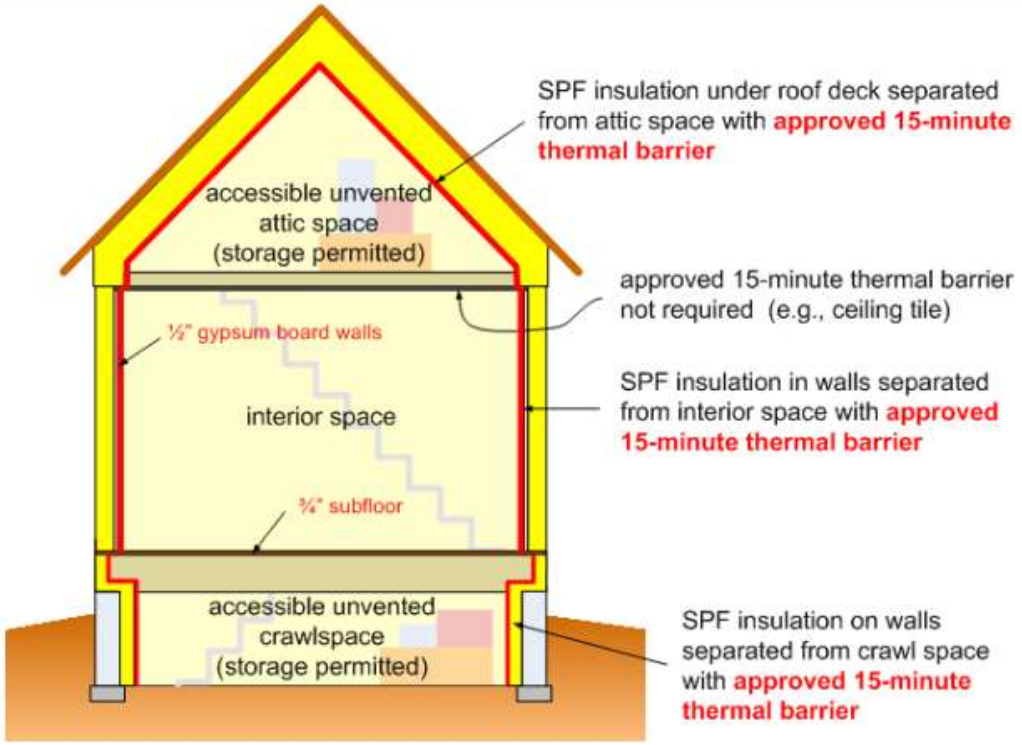


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Image Source: SPFA Presentation at 2012 RESNET Conference: 'Decoding' Thermal and Ignition Barrier Requirements for SPF

Option: Ducts in Unvented Attic

Advantages and Limitations

- Provides option for AHU placement as well as ducts
- Not as plan-dependent as other options
- Viable for retrofits
- Often the highest cost option
- Code requirements on roof deck insulation
- Increases heating/cooling loads by increasing surface area of thermal boundary

IRC Sections R806.4 Unvented Attic Assemblies,
and R316 FOAM PLASTIC control these assemblies

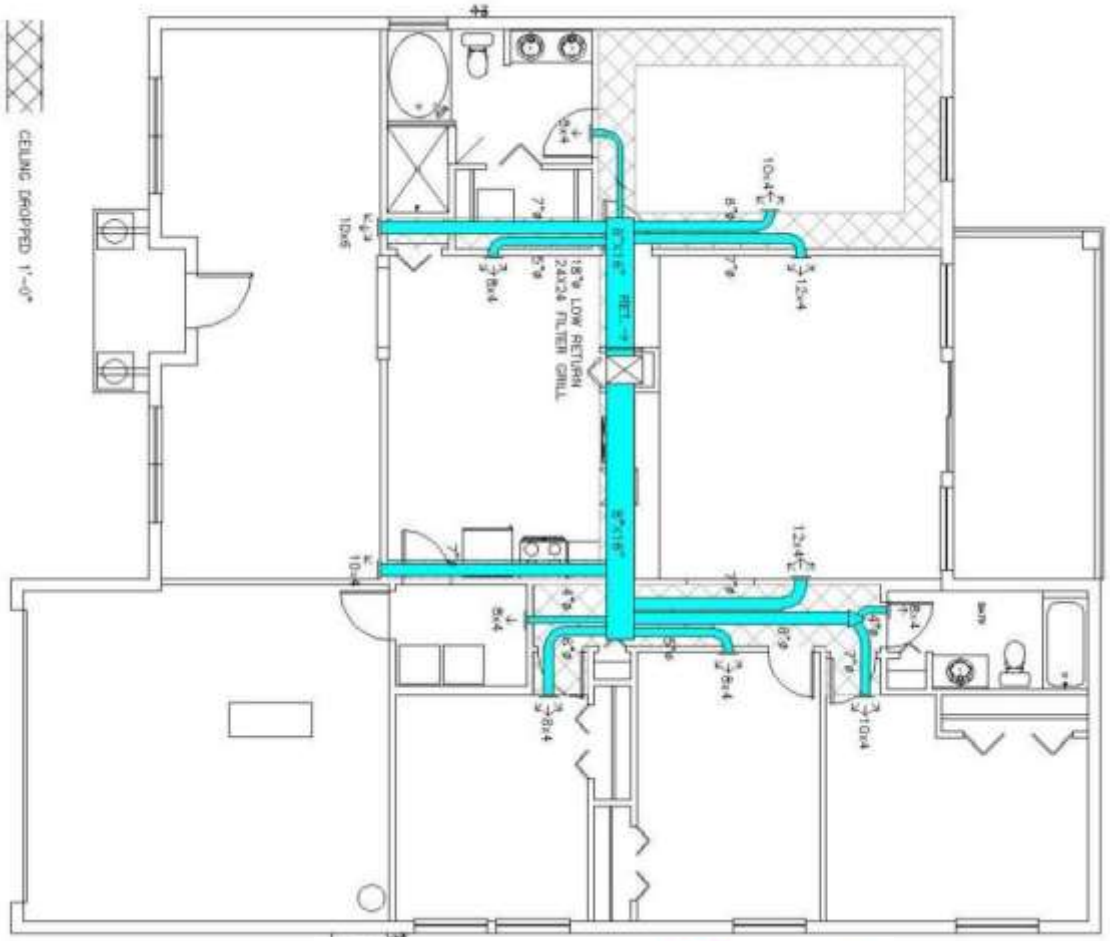
Option: Ducts in Dropped Soffit

- Ducts are placed in soffits and dropped ceilings below the primary ceiling plane level
- Architectural integration and aesthetics are critical considerations

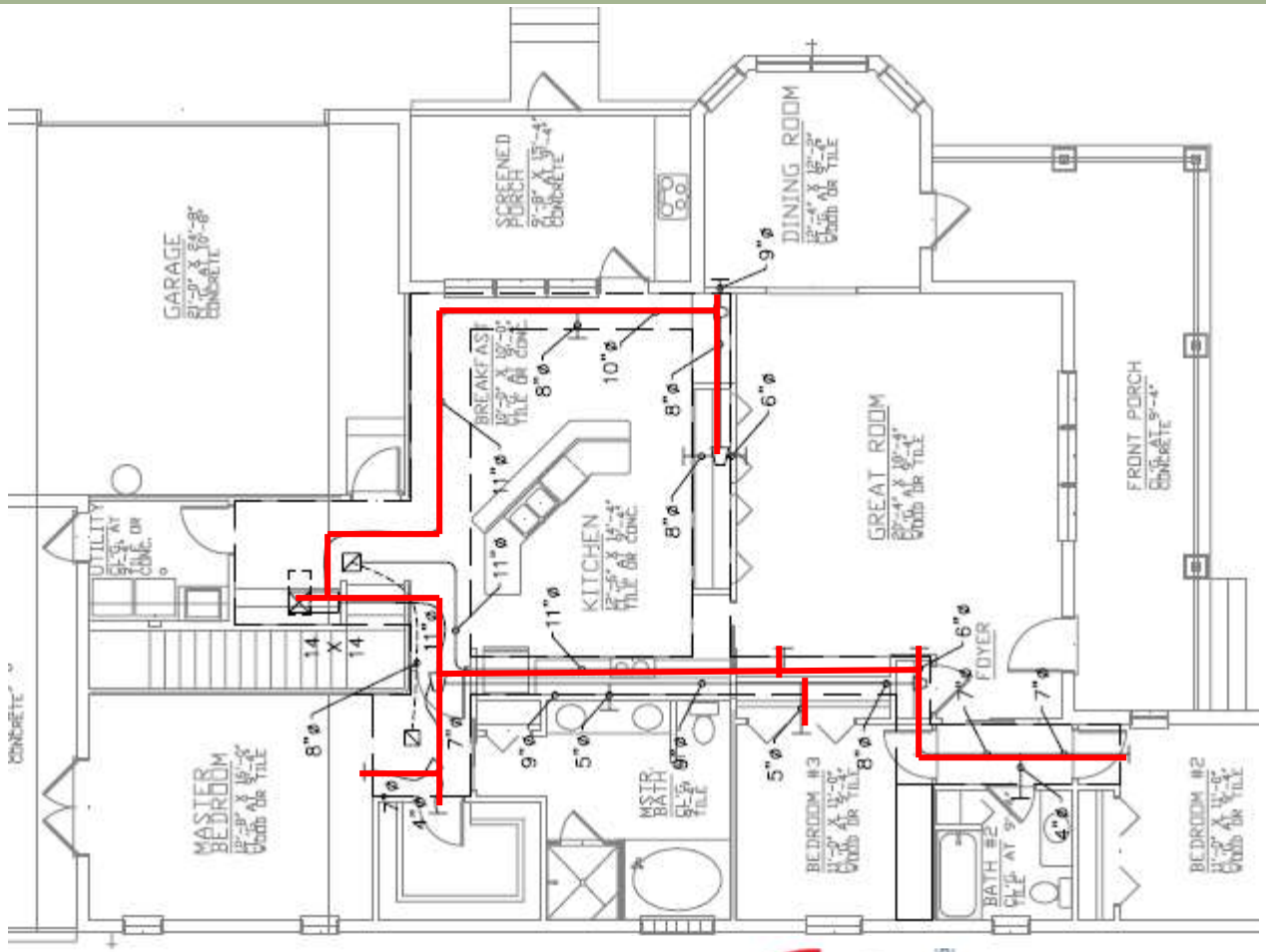
Option: Ducts in Dropped Soffit

- This option can be viable in both economy construction and more high-end designs.

Linear Dropped Soffit Config.



Perimeter Dropped Soffit Config.



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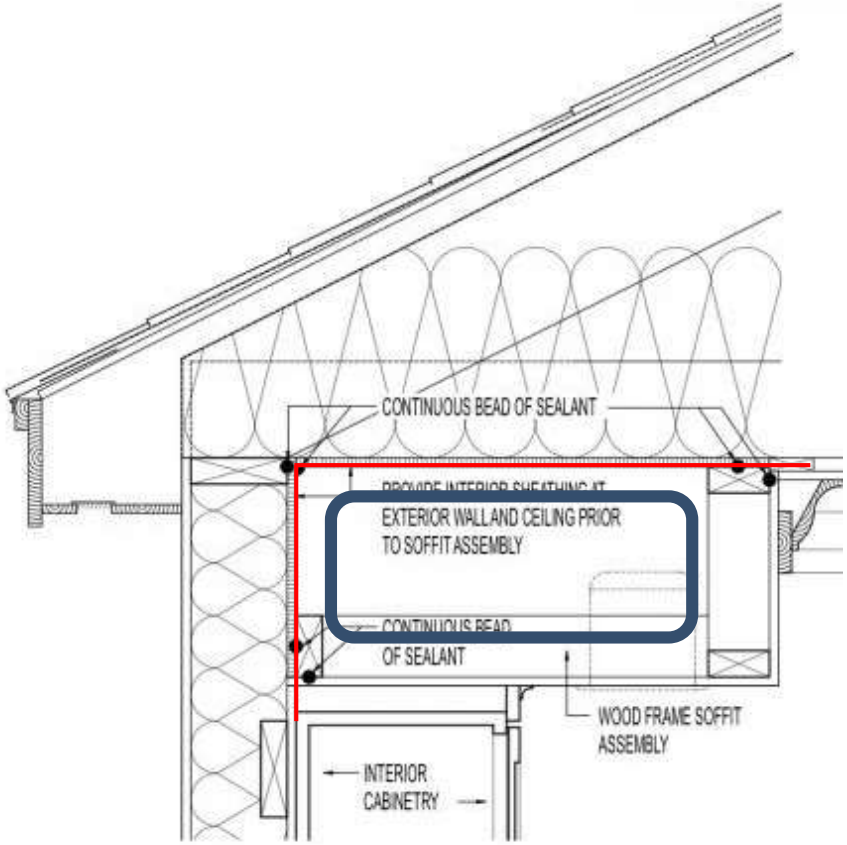
Soffit Construction Details



What we're trying to avoid

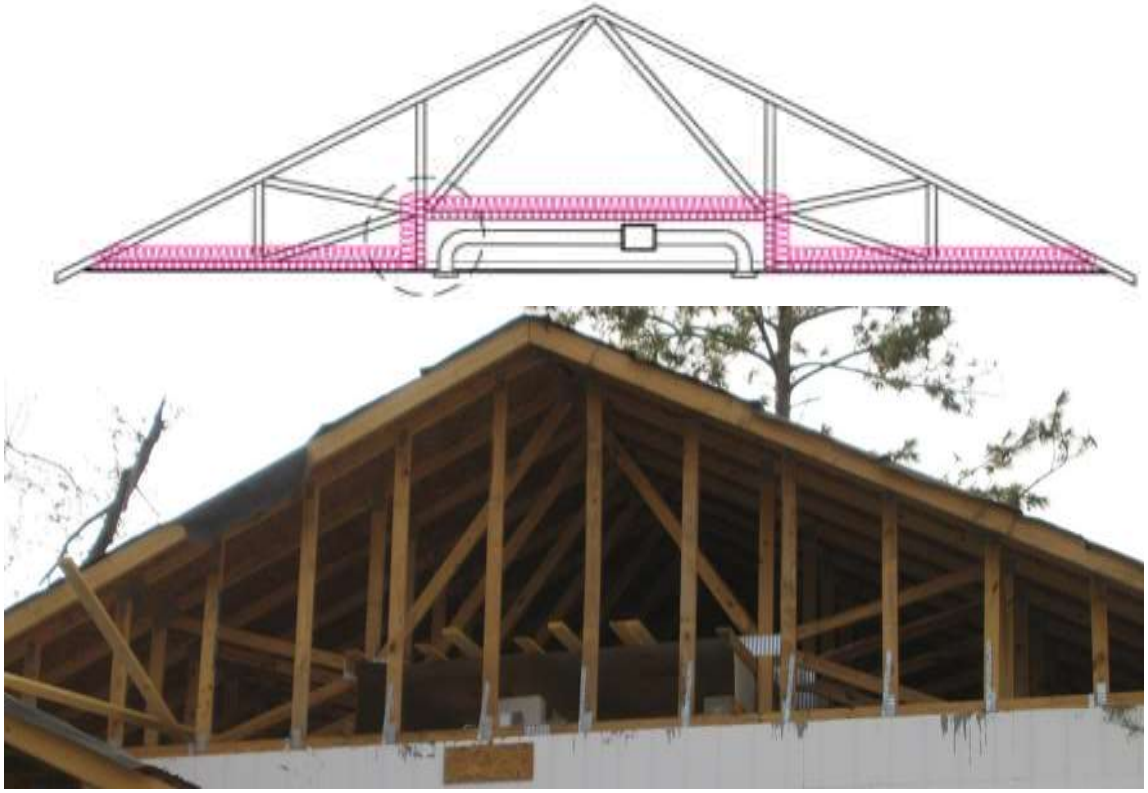
Option: Ducts in Dropped Soffit

Advantages and Limitations

- Low-cost in simple plans
- Easy to understand and implement
- Minimal code restrictions

- Heavily plan dependent
- Advanced planning and design integration is essential
- May be limited by throw distance – duct design critical
- Additional air barrier step and unique air-sealing
- No provision for AHU

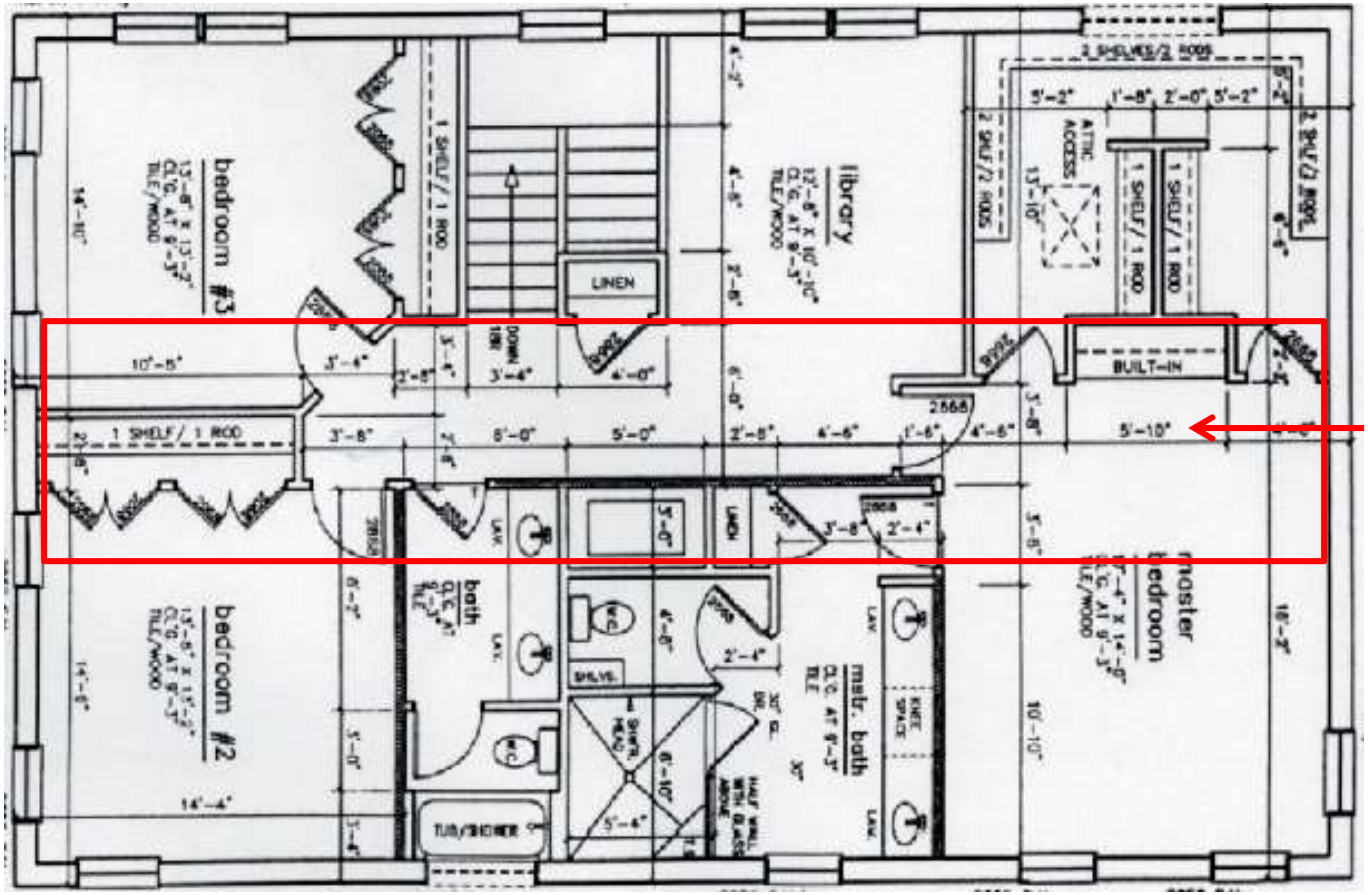
Option: Ducts in Modified Truss



- A space for ducts is created above the ceiling plane by using a modified roof truss configuration and moving the thermal boundary up into the attic.

Option: Ducts in Modified Truss

Option: Ducts in Modified Truss



Plenum space area

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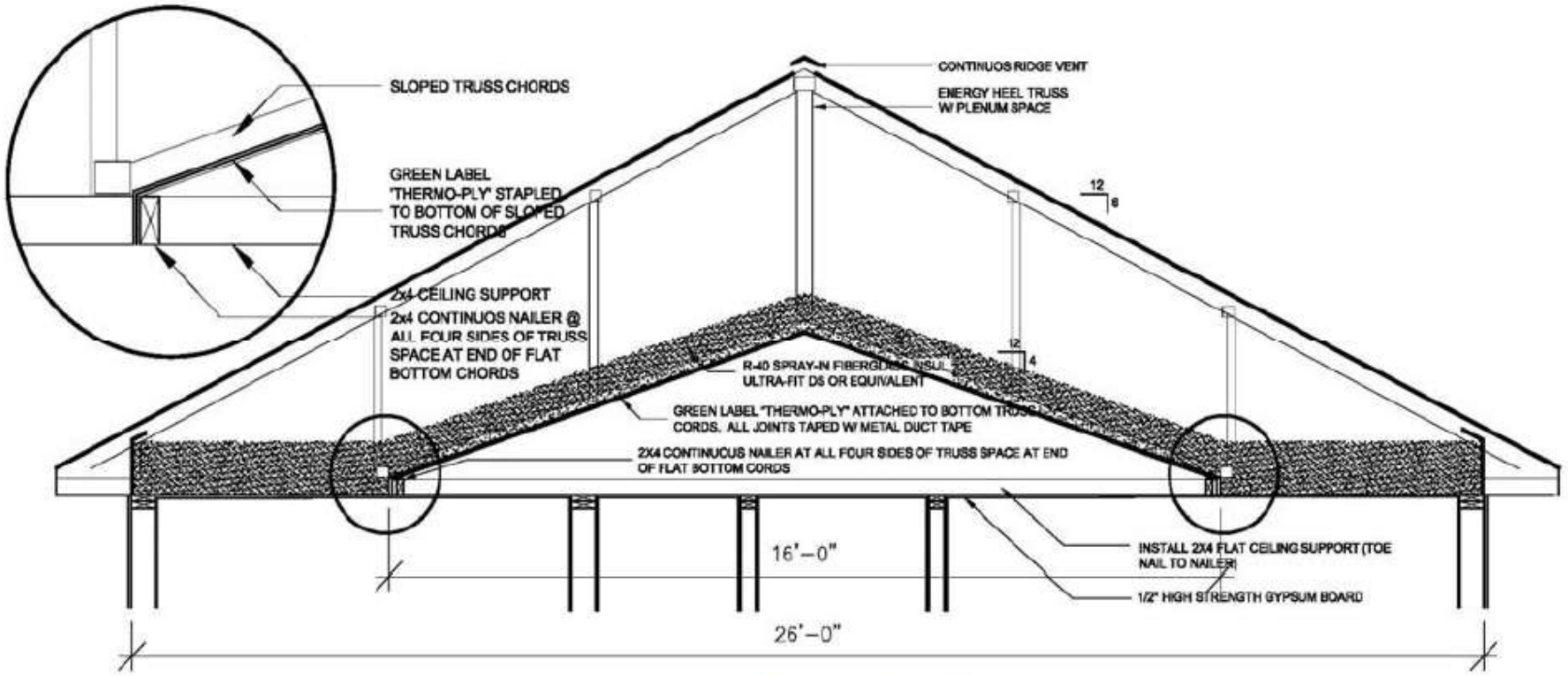
Modified Scissor Truss Method



Plenum Truss Detail

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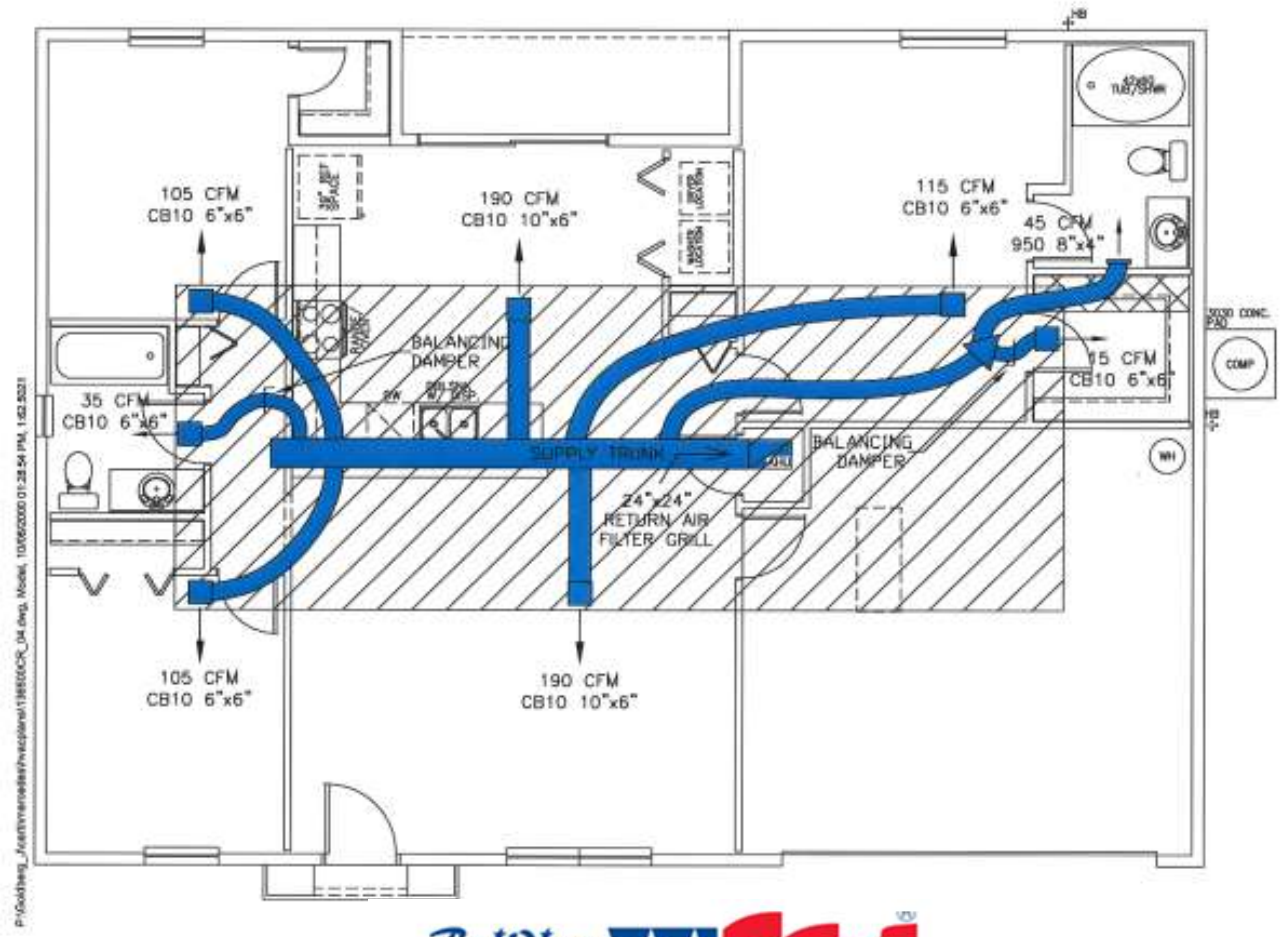
Option: Ducts in Modified Truss



Option: Ducts in Modified Truss

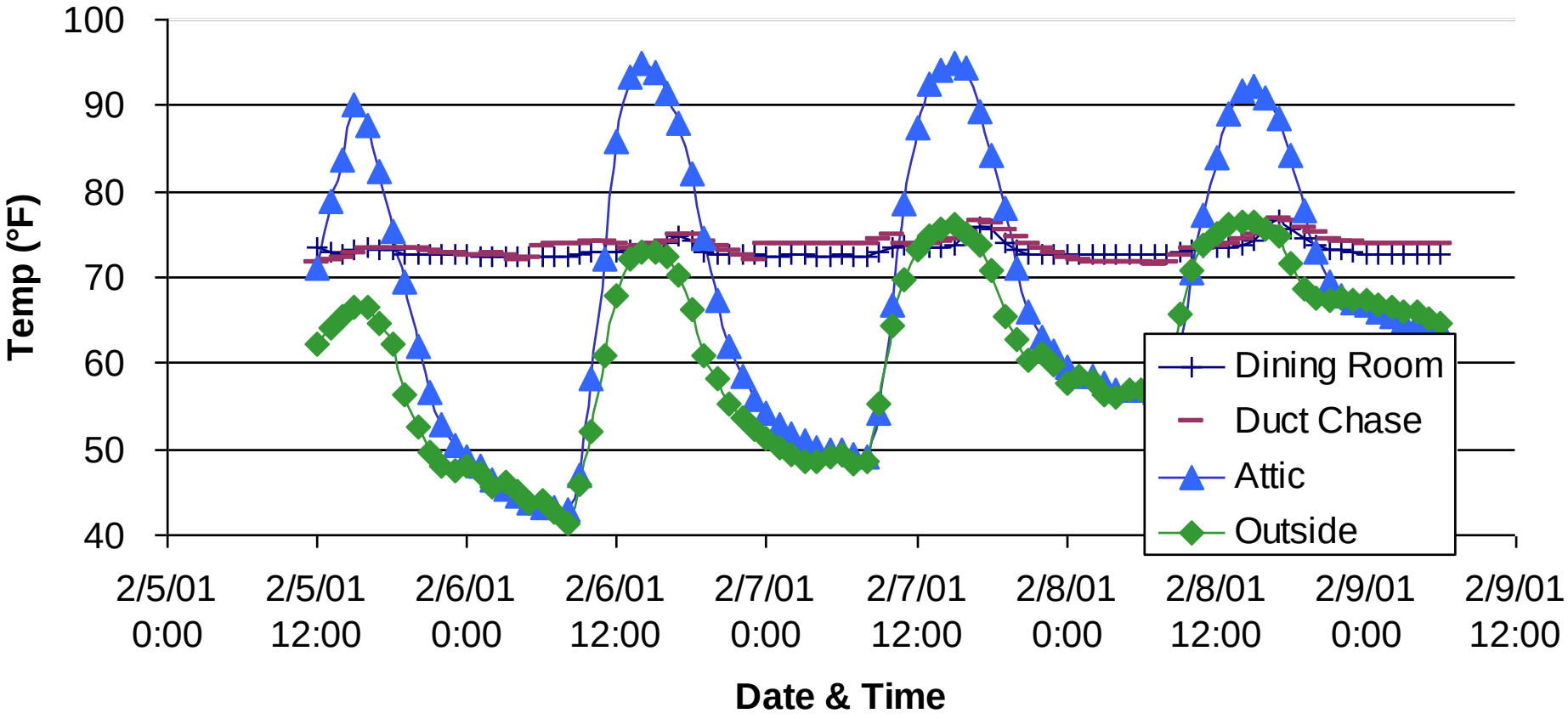
- View of scissor truss bottom chord from attic

- View of plenum space from below

Option: Ducts in Modified Truss

- View of scissor truss bottom chord from attic after and during application of ccSPF skim application

Plenum Space Thermal Testing



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Option: Ducts in Modified Truss

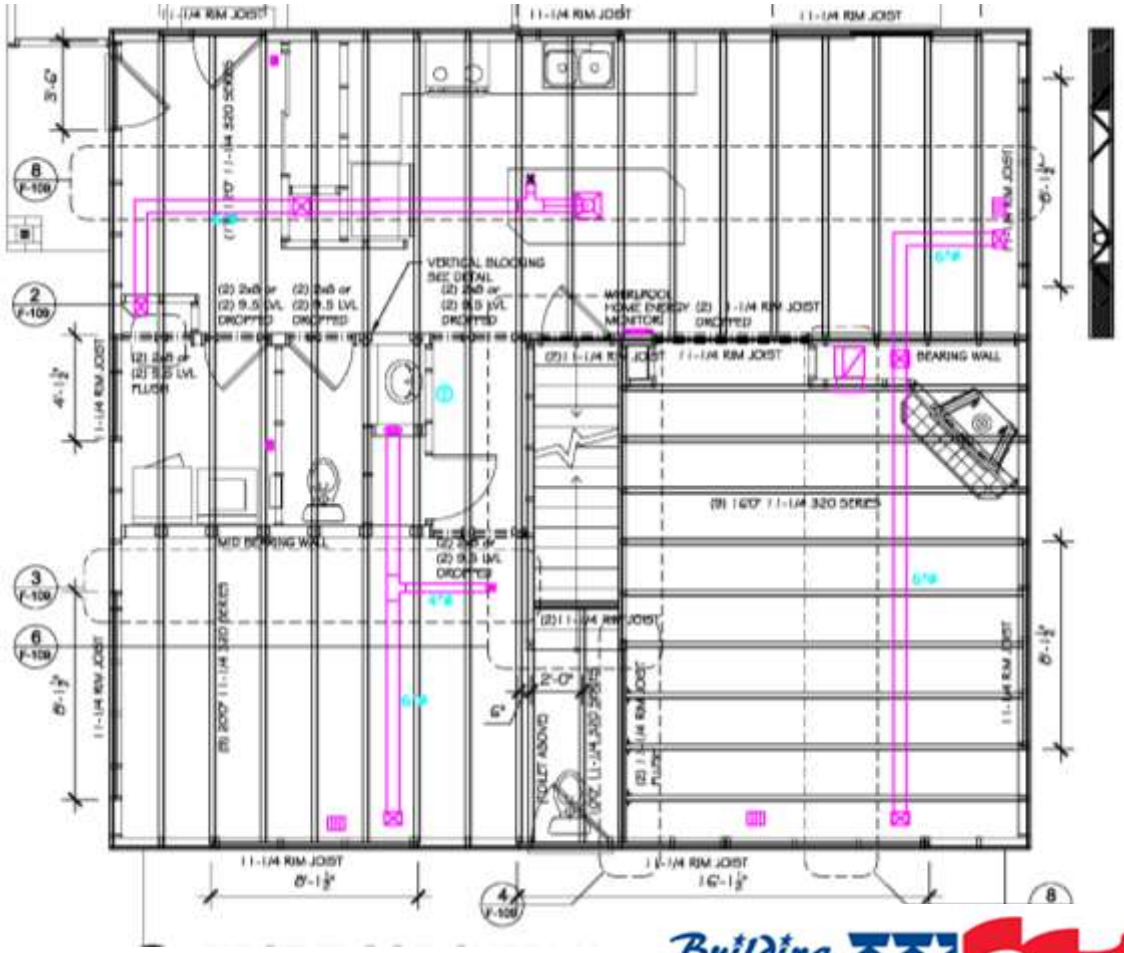
Advantages and Limitations

- Low-cost in simple plans
- Not as plan dependent as dropped soffit solution
- Minimal code restrictions
- Works best in linear plans
- Additional air-barrier and unique air-sealing
- Requires custom, non-standard roof trusses
- No provision for AHU

Option: Floor Truss-Integrated Ducts

- HVAC ducts and supply registers are placed within the vertical space created by the floor trusses

Option: Floor Truss Integrated Ducts



- A high degree of planning and coordination between the floor structure and the HVAC design is required
- 12” member depth or greater generally
- Need to coordinate duct sizes with permissible opening size, location

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Option: Floor Truss Integrated Ducts

- Ceiling registers blowing down and floor registers blowing up can be used. High wall registers are better than floor registers for cooling and can also be accommodated.

Option: Floor Truss Integrated Ducts

Advantages and Limitations

- Low-cost in simple plans
- Easy to execute w/ no changes to enclosure
- Uses existing conditioned space volume
- Flexible register locations
- Minimal code restrictions
- Works best in two-story plans
- Requires structural, HVAC, and architectural coordination
- Requires deeper trusses
- No provision for AHU

Option: Ducts in Sealed Crawlspace

- Bring the crawlspace (or basement) inside conditioned space and use the volume to place HVAC equipment and ducts

Option: Ducts in Sealed Crawlspace

Advantages and Limitations

- Improves enclosure performance
- Accommodates AHU and other equipment
- Flexible register locations
- HVAC/ducts accessible for service
- Only an option with a crawl foundation
- Code thermal insulation requirements
- Code mechanical ventilation requirements

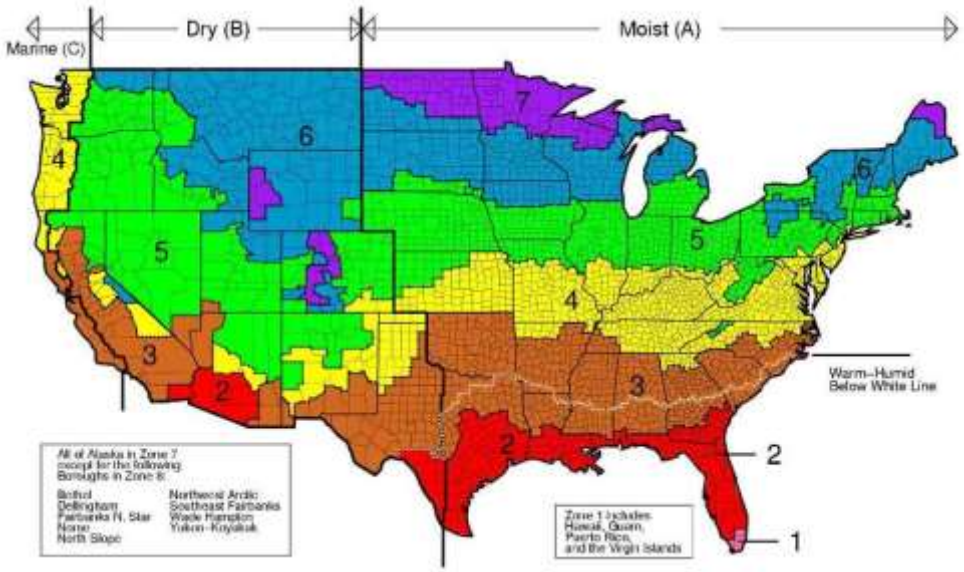
Buried/Encapsulated Duct Categories

- Buried Ducts

- Buried and Encapsulated Ducts

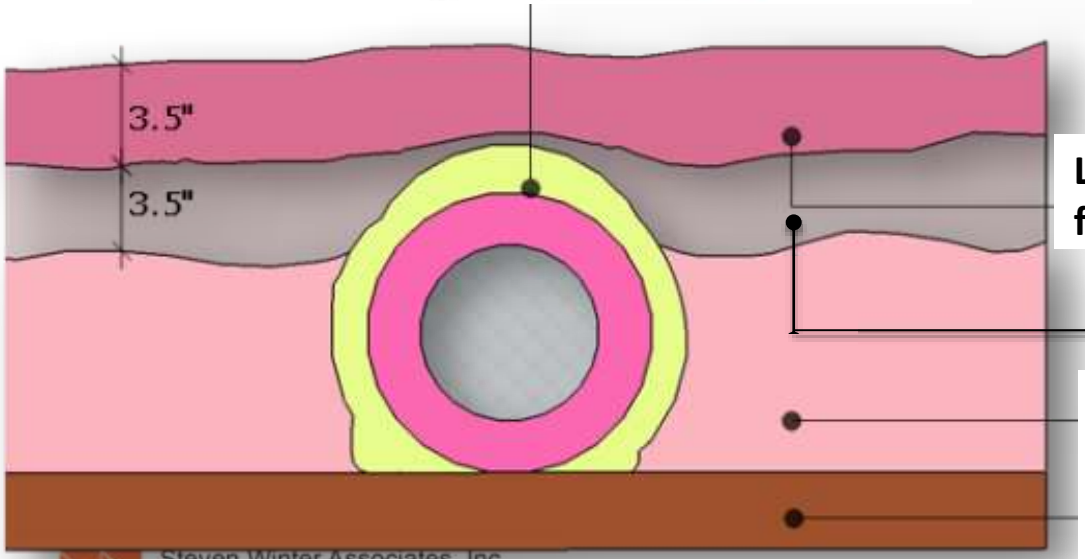
- Encapsulated Ducts

Ducts in Vented Attic: Moist CZs



Buried Encapsulated Ducts (BEDs)

Ducts with R-8 insulation encapsulated in 1.5 in of ccSPF



Leakage to Outdoors ≤ 3 CFM25 per 100 ft² CFA

Fully-buried **under min 2" (~R-25)**

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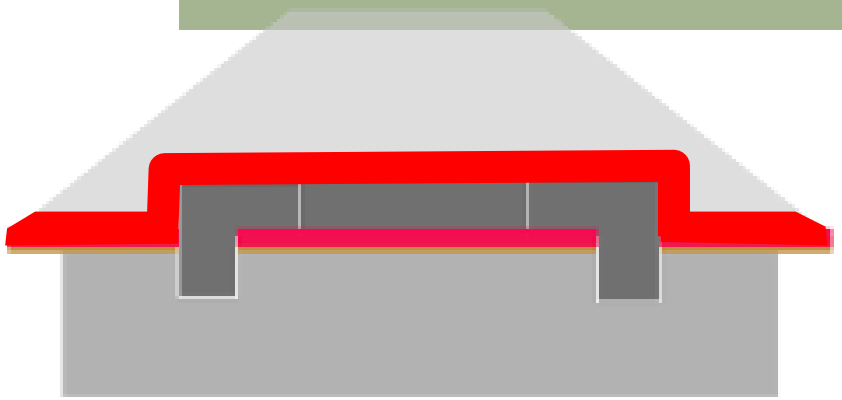
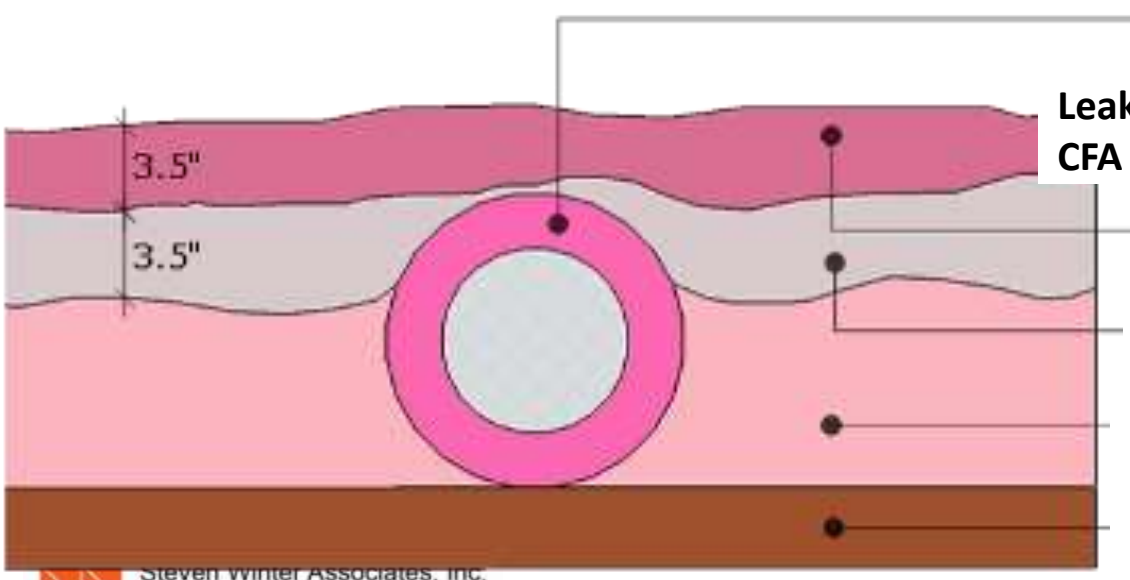
Ducts in Vented Attic: Dry CZs



Ducts in vented attic

Buried Ducts

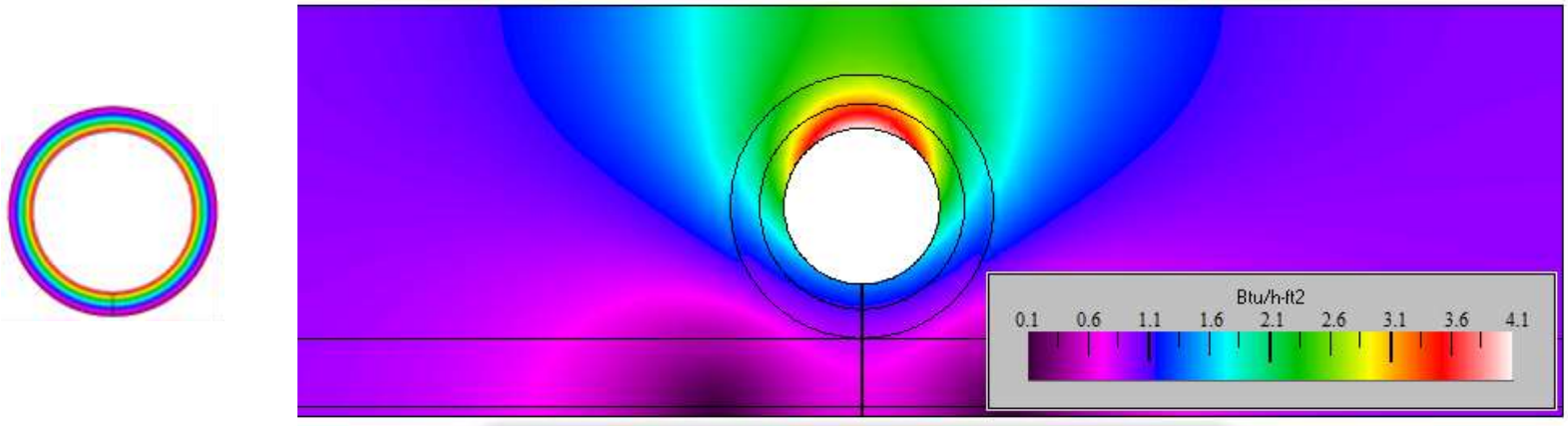


Leakage to outdoors ≤ 3 CFM25 per 100 ft^2 CFA

Effective R-Value: R-23.5

Effective R-values

- R-value metrics:
  - Nominal – listed values for duct insulation
  - Effective – heat loss/gain from duct to attic
- Buried duct effective R-values calculated using FEA



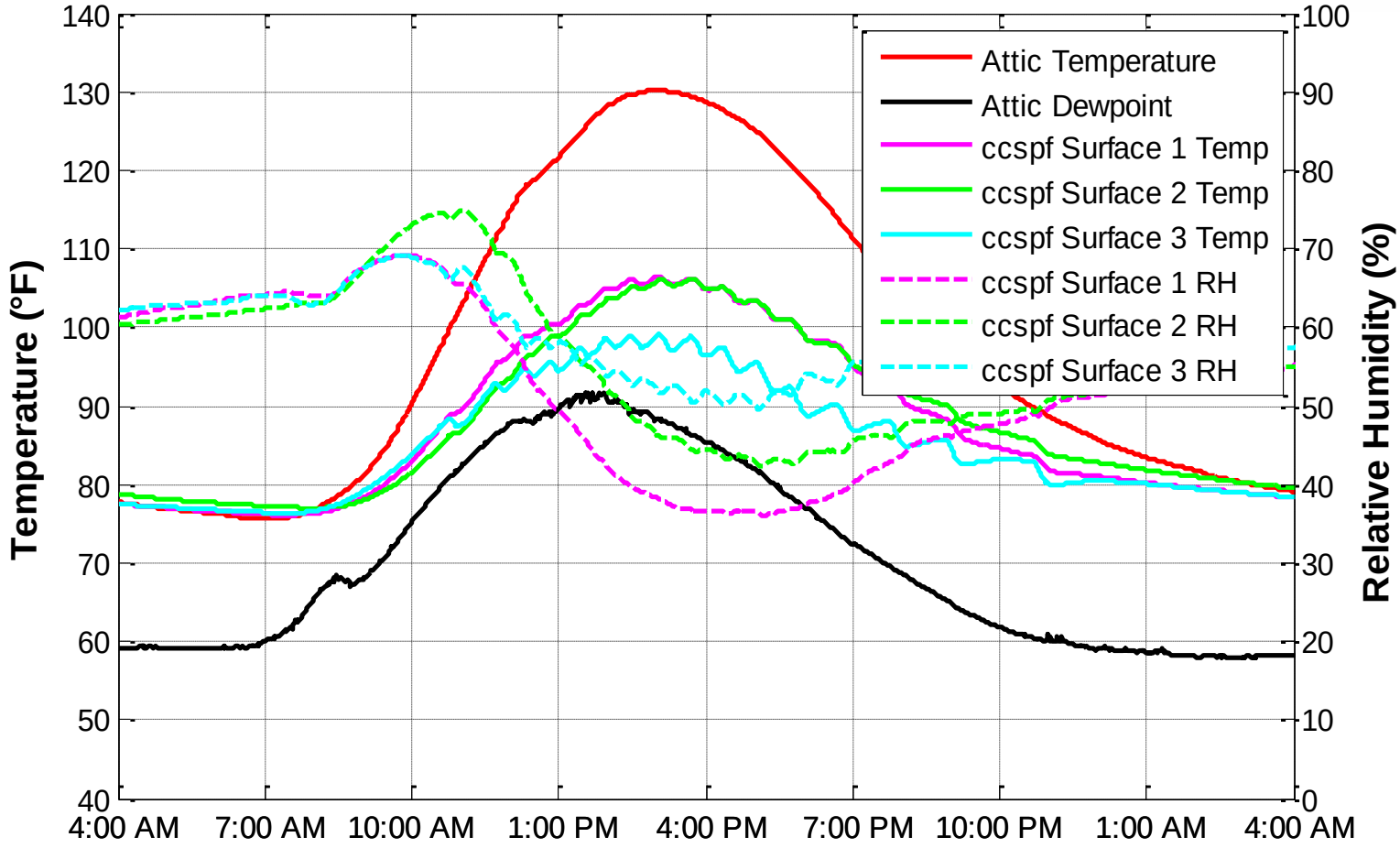
Heat flux magnitude through a hung duct, and an encapsulated and fully-buried 8-in diameter duct

Effective R-values

Duct Configuration	R-4.2 Ducts	R-6 Ducts	R-8 Ducts
Traditional hung ducts	4.6	5.9	7.2
Hung ducts encapsulated in 1.5” of ccSPF	11.3	12.0	12.7
Partially-buried	8.1	10.2	12.3
Fully-buried	12.0	14.1	16.2
Deeply-buried	20.7	22.1	23.5
Encapsulated in 1.5” of ccSPF and partially-buried	18.4	19.7	21.0
Encapsulated in 1.5” of ccSPF and fully-buried	22.6	23.8	25.0
Encapsulated in 1.5” of ccSPF and deeply-buried	29.6	30.3	31.1

Condensation Potential

- Monitoring of ATL Test Site



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Install Low-Profile, Compact Duct Design

- Before ceiling drywall
- After ceiling drywall

Mastic seal ducts, and test

- **Test leakage** to assure performance levels are met (leakage to outdoors < 3 cfm25 per 100 ft2 of conditioned space)

Apply 1.5” minimum ccSPF

- Apply min. 1.5” ccSPF prior to or after ceiling gypsum board

Install Loose-fill insulation



- Insulation covering the SPF-encapsulated ducts must meet IRC R316.5.3, which includes 1.5” mineral fiber and 1.5” cellulose (added to 2012 IRC)
- Some foams are exempt from this requirement…

Code Compliance

- 2012 IRC requires that spray foam insulation applied to the exterior of ductwork (Section M1601.3) in attics (Section R316.5.3) meet several requirements:
  - Flame spread index less than 25
  - Smoke-developed index less than 450
  - No attic storage or occupancy
  - Spray foam protected by ignition barrier (1.5” mineral fiber or 1.5” cellulose insulation)
    - Or meets R316.6 Specific Approval (no ignition barrier required)

Option: Buried Encapsulated Ducts

Advantages and Limitations

- Low-cost in simple plans
- Easy to execute w/ no changes to enclosure
- Minimal plan coordination
- Flexible register locations
- Requires HVAC design coordination
- No provision for AHU

Performance Comparison

- Total Heating & Cooling Energy for a CZ5 Home

	Roof slope			
	4:12	6:12	8:12	10:12
Benchmark[1]	0.0%	0.0%	0.0%	0.0%
Improved benchmark[1,2]	9.2%	9.2%	9.2%	9.2%
Partially-buried (R-33)	10.4%	10.4%	10.4%	10.5%
Fully-buried (R-42)	11.6%	11.7%	11.7%	11.7%
Deeply-buried (R-51)	13.2%	13.4%	13.4%	13.4%
Unvented[1]	13.7%	13.3%	12.7%	12.2%
Encapsulated[1]	11.9%	11.9%	12.0%	12.0%
Partially-buried & encapsulated (R-37)	12.9%	13.0%	13.0%	13.0%
Fully-buried & encapsulated (R-46)	14.2%	14.3%	14.4%	14.4%
Deeply-buried & encapsulated (R-54)	15.3%	15.5%	15.5%	15.6%
Interior ducts[1]	15.4%	15.5%	15.5%	15.5%

[1] Benchmark ceiling or roof deck insulation is R-38 in Zone 5B. Ceiling insulation R-values for buried ducts may be higher than the benchmark.

[2] Improved Benchmark includes IECC 2012 requirements for infiltration (3 ACH50) and duct sealing (4 cfm per 100 sq ft conditioned living space).

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Builder Resources

- Code-related considerations:
  - Building America Solution Center
    - www.basc.pnnl.gov
  - IRC Sections R806.4, M1601.3, R316.5.3, R316.6
  - California Title 24
- Technical References:
  - Multiple research reports since 2000
  - Published BA Technical Reports
  - Published BA Measure Guidelines

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Thank You

Questions?

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For More Information:

www.buildings.energy.gov/zero

e-mail Contact:

zero@newportpartnersllc.com