

**References for Building America Industry Partnerships for High Performance Housing Innovation FOA 0001117**  
**Topic Areas/Technical Areas of Interest****1. Evidence that risk of moisture problems prevents adoption of high performance building envelope assemblies:**

Building America Envelope Standing Technical Committee (STC) and Expert Meeting reports identify moisture risk in High-R walls as the highest technical priority:

**STC Report:**

Lstiburek, J.; Ueno, K.; Boucher, K. (2011). *Enclosure Standing Technical Committee Strategic Plan, v. 2011a*. Somerville, MA: Building Science Corporation, Dec. 2011. Draft accessed November 21, 2014, at:  
[http://energy.gov/sites/prod/files/2013/12/f5/strategic\\_plan\\_enclosures\\_2\\_12.pdf](http://energy.gov/sites/prod/files/2013/12/f5/strategic_plan_enclosures_2_12.pdf)

**STC Presentation:**

Lstiburek, J. (2011). *Enclosures STC*. Presented at the Residential Energy Efficiency Stakeholder Meeting, February 29, 2012–Austin, Texas. Accessed November 21, 2014 at: [http://energy.gov/sites/prod/files/2013/12/f6/enclosures\\_stc.pdf](http://energy.gov/sites/prod/files/2013/12/f6/enclosures_stc.pdf)

**Expert Meeting Reports:**

Baker, P. (2013). *Expert Meeting Report: Cladding Attachment Over Exterior Insulation*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-57260; DOE/GO-102013-3841. Accessed November 21, 2014, at:  
<http://www.nrel.gov/docs/fy14osti/57260.pdf>.

Ojczyk, C. Huelman, P.; Carmody, J. (2013). *Expert Meeting Report: Foundations Research Results*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-57061; DOE/GO-102013-3828. Accessed November 21, 2014, at:  
<http://www.nrel.gov/docs/fy13osti/57061.pdf>

Ojczyk, C.; Carmody, J.; Haglund, K. (2013). *Expert Meeting Report: Windows Options for New and Existing Homes*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-57062; DOE/GO-102013-3829. Accessed November 21, 2014, at:  
<http://www.nrel.gov/docs/fy13osti/57062.pdf>

Levy, E.; Mullens, M.; Tompos, E.; Kessler, B.; Rath, P. (2012). *Expert Meeting Report: Advanced Envelope Research for Factory Built Housing*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-54439; DOE/GO-102012-3563. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy12osti/54439.pdf>

Ueno, K.; Van Straaten, R. (2012). *Expert Meeting Report: Interior Insulation Retrofit of Mass Masonry Wall Assemblies*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-53496; DOE/GO-102012-3475. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy12osti/53496.pdf>

Building America team test hut study (Home Innovation Research Labs, 2013) of 9 IECC 2012 compliant assemblies shows risk of high moisture content in Oriented Strand Board (OSB) exterior wall sheathing (Zone 4):

Wiehagen, J.; Kochkin, V. (2012). *High-R Walls for Remodeling: Wall Cavity Moisture Monitoring*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-55205; DOE/GO-102012-3628. Accessed November 21, 2014, at:  
<http://www.nrel.gov/docs/fy13osti/55205.pdf>

**Related Reports:**

Grin, A.; Smegal, J.; Lstiburek, J. (2013). *Application of Spray Foam Insulation Under Plywood and Oriented Strand Board Roof Sheathing*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-59526; DOE/GO-102013-4257. Accessed November 20, 2014, at: <http://www.nrel.gov/docs/fy14osti/60431.pdf>.

PNNL (2013). *Building America Top Innovations 2013 Profile: Exterior Rigid Insulation Best Practices*. Richland, WA: Pacific Northwest National Laboratory, PNNL-SA-98655. Accessed November 21, 2014, at:  
[http://apps1.eere.energy.gov/buildings/publications/pdfs/building\\_america/ba\\_innovations\\_3-1-7\\_exterior\\_rigid\\_insulation.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_innovations_3-1-7_exterior_rigid_insulation.pdf)

ORNL test hut study (2013) of 8 air-tight assemblies with IECC 2012 insulation indicates risk of mold on sheathing (Zone 5):

Hun, D.E.; Childs, P.W.; Atchley, J.A.; Desjarlais, A.O. (2013) *Effects from the Reduction of Air Leakage on Energy and Durability*. Oak Ridge, Tennessee: Oak Ridge National Laboratory, ORNL/TM-2013-507. Accessed November 21, 2014, at: [http://apps1.eere.energy.gov/buildings/publications/pdfs/building\\_america/reduction\\_airleakage\\_energy\\_durability.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/reduction_airleakage_energy_durability.pdf)

Building America team hygrothermal simulation study (Building Science Corporation, 2013) of 8 High-R wall assemblies with defects indicate risk of high moisture content in sheathing (Zones 2-7):

Lepage, R.; Schumacher, C.; Lukachko, A. (2013). *Moisture Management for High R-Value Walls*. Golden, CO: National Renewable Energy Laboratory; NREL/SR-5500-60487; DOE/GO-102013-4266. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy14osti/60487.pdf>

Lepage, R.; Lstiburek, J. (2013). *Moisture Durability with Vapor-Permeable Insulating Sheathing*. Golden, CO: National Renewable Energy Laboratory, NREL/ SR-5500-58062; DOE/GO-102013-3910. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy14osti/58062.pdf>

Patterns of failure observed by numerous building science experts on Building America teams:

Prahl, D.; Shaffer, M. (2014). *Moisture Risk in Unvented Attics Due to Air Leakage Paths*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-57061; DOE/GO-102013-3828. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy15osti/63048.pdf>

Ueno, K.; Lstiburek, J. (2012). *Measure Guideline: Hybrid Foundation Insulation Retrofits*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-54208; DOE/GO-102012-3637. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy12osti/54208.pdf>

Straube, John (2006). *Moisture and Materials*, Building Science Digest BSD-138. Westford, MA: Building Science Corporation. Accessed November 21, 2014, at: [http://www.buildingscience.com/documents/digests/bsd-138-moisture-and-materials/?searchterm=moisture damage](http://www.buildingscience.com/documents/digests/bsd-138-moisture-and-materials/?searchterm=moisture%20damage)

Chandra, S.; Parker, D.; Beal, D.; Chasar, D.; Martin, E.; McIlvaine, J.; Moyer, N. (2004). *Alleviating Moisture Problems in Hot, Humid Climate Housing*, Report No. FSEC-GP-255-04. Cocoa, FL: Florida Solar Energy Center. Accessed November 21, 2014, at: <http://www.fsec.ucf.edu/en/publications/pdf/FSEC-GP-255-04.pdf>

## **2. Evidence that comfort (HVAC) system performance risks can be significant and may prevent adoption of high performance home technologies and systems:**

Building America Space Conditioning Standing Technical Committee and Expert Meeting Reports identify air distribution issues, high relative humidity, and equipment sizing problems affecting comfort in low load homes as highest technical priority:

### **STC Report:**

Martin, E.; McIlvaine, J. (2011). *Space Conditioning Standing Technical Committee Strategic Plan, v2011a*. Florida Solar Energy Center. Draft accessed at: [http://energy.gov/sites/prod/files/2013/12/f5/strategic\\_plan\\_space\\_cond\\_2\\_12.pdf](http://energy.gov/sites/prod/files/2013/12/f5/strategic_plan_space_cond_2_12.pdf)

### **Presentation:**

Martin, E.; McIlvaine, J. (2012). *Space Conditioning Standing Technical Committee*. Presented at the Building America Stakeholder Meeting at the 2012 RESNET Building Performance Conference, February 29, 2012. Accessed November 21, 2014, at: [http://energy.gov/sites/prod/files/2013/12/f6/space\\_conditioning\\_stc.pdf](http://energy.gov/sites/prod/files/2013/12/f6/space_conditioning_stc.pdf)

### **Expert Meeting Reports:**

Brand, L., Rose, W. (2013). *Expert Meeting: Combustion Safety*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-56656; DOE/GO-102013-3808. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy13osti/56656.pdf>

Arena, L. (2013). *Expert Meeting: Optimized Heating Systems Using Condensing Boilers and Baseboard Convectors*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-53562; DOE/GO-102013-3842. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy13osti/53562.pdf>

Brand, L. (2012). *Expert Meeting Report: Achieving the Best Installed Performance from High-Efficiency Residential Gas Furnaces*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-54267; DOE/GO-102013-3536. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy12osti/54267.pdf>

Dentz, J. (2011). *Expert Meeting Report: Hydronic Heating in Multifamily Buildings*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-52692; DOE/GO-102013-3383. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy12osti/52692.pdf>

Stecher, D. (2011). *Expert Meeting Report: Simplified Space Conditioning Strategies for Energy Efficient Houses*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-52160; DOE/GO-102013-3344. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy11osti/52160.pdf>

Building America team study (IBACOS, 2012) investigated most promising efficient HVAC solutions for low-load houses and found significant comfort risks related to latent performance and distribution effectiveness:

Poerschke, A.; Stecher, D. (2014). *Simplified Space Conditioning in Low-Load Homes: Results from Pittsburgh, Pennsylvania, New Construction Unoccupied Test House*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-62122; DOE/GO-102014-4436. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy14osti/62122.pdf>

Stecher, D.; Poerschke, A. (2014). *Simplified Space Conditioning in Low-Load Homes: Results from the Fresno, California, Retrofit Unoccupied Test House*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-60712; DOE/GO-102014-4299. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy14osti/60712.pdf>

Numerous studies and surveys have concluded that typically installed residential HVAC systems can operate inefficiently and waste considerable energy due to different installation errors (faults) – see NIST report below for relevant literature review.

Recent NIST study (<http://dx.doi.org/10.6028/NIST.TN.1848>) assessed the impacts of single and simultaneous HVAC system installation faults on annual energy consumption. The report found that the faults with the most potential for causing increased annual energy consumption included duct leakage, incorrect duct sizing or system airflow, and incorrect refrigerant charge. The report also found that the impact of multiple faults can be additive, and that excessive indoor humidity levels due to installation faults can also lead to significant increases in annual energy use. (Note: this report also includes an extensive reference list to publications with related findings.)

Domanski, P.A.; Henderson, H.I.; Payne, W.V. (2014). *Sensitivity Analysis of Installation Faults on Heat Pump Performance*. Washington, D.C.: National Institute of Standards and Technology. Accessed November 21, 2014, at: <http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1848.pdf>

### **3. Evidence that indoor air quality (IAQ) risks prevent adoption of high performance home technologies and systems:**

Building America Space Conditioning Standing Technical Committee and Expert Meeting Reports identify IAQ in efficient air-tight houses as high technical priority:

#### **STC Report:**

Lstiburek, J.; Ueno, K.; Boucher, K. (2011). *Enclosure Standing Technical Committee Strategic Plan, v. 2011a*. Building Science Corporation, Somerville, MA, Dec. 2011. Draft November 21, 2014, accessed at: [http://energy.gov/sites/prod/files/2013/12/f5/strategic\\_plan\\_enclosures\\_2\\_12.pdf](http://energy.gov/sites/prod/files/2013/12/f5/strategic_plan_enclosures_2_12.pdf)

Martin, E.; McIlvaine, J. (2011). *Space Conditioning Standing Technical Committee Strategic Plan, v2011a*. Florida Solar Energy Center. Draft accessed at: [http://energy.gov/sites/prod/files/2013/12/f5/strategic\\_plan\\_space\\_cond\\_2\\_12.pdf](http://energy.gov/sites/prod/files/2013/12/f5/strategic_plan_space_cond_2_12.pdf)

**Expert Meeting Reports:**

Rudd, A. (2013). *Expert Meeting: Recommended Approaches to Humidity Control in High Performance Homes*. Golden, CO: National Renewable Energy Laboratory, NREL/SR-5500-57483; DOE/GO-102013-3856. Accessed November 21, 2014, at: <http://www.nrel.gov/docs/fy13osti/57483.pdf>

U.S.EPA (Indoor Environments Division) documents identify increased health risks due to indoor pollutant exposures (2 to 5 times), associated with air-tight homes and homes without adequate ventilation and/or pollutant source control measures:

“The Inside Story: A Guide to Indoor Air Quality.” (2012). U.S. Environmental Protection Agency. Accessed November 21, 2014 at: <http://www.epa.gov/iaq/pubs/insidestory.html>.

EPA (2008). *Care for Your Air: A Guide to Indoor Air Quality*. Washington, D.C.: U.S. Environmental Protection Agency. Accessed November 21, 2014 at: <http://www.epa.gov/iaq/pdfs/careforyourair.pdf>.

EPA (2009). *Residential Air Cleaners: A Summary of Available Information*. Washington, D.C.: U.S. Environmental Protection Agency. Accessed November 21, 2014 at: [http://www.epa.gov/iaq/pdfs/residential\\_air\\_cleaners.pdf](http://www.epa.gov/iaq/pdfs/residential_air_cleaners.pdf).

ASHRAE Standard 62.2, Guideline 24, and other documents identify IAQ risks and best practices for acceptable IAQ; these practices are not widely or fully adopted/enforced in codes due to cost, education, and standards limitations:

ANSI/ASHRAE Standard 62.2-2013, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. Accessed November 21, 2014, at: <https://www.ashrae.org/resources--publications/bookstore/standards-62-1--62-2>

ASHRAE Guideline 24-2008, *Ventilation and Indoor Air Quality in Low-Rise Residential Buildings*, Section 7: Moisture. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. Accessed November 21, 2014, at: <https://www.ashrae.org/standards-research--technology/standards--guidelines/titles-purposes-and-scopes#Gdl24>

EPA (2013). *Indoor airPLUS Construction Specifications, Revision 2*. Washington, D.C.: U.S. Environmental Protection Agency. November 2013. Accessed November 21, 2014, at: [http://www.epa.gov/indoorairplus/pdfs/construction\\_specifications.pdf](http://www.epa.gov/indoorairplus/pdfs/construction_specifications.pdf)

EPA (2011). *Healthy Indoor Environment Protocols for Home Energy Upgrades*. Washington, D.C.: U.S. Environmental Protection Agency. October 2011. Accessed November 21, 2014, at: [http://www.epa.gov/iaq/pdfs/epa\\_retrofit\\_protocols.pdf](http://www.epa.gov/iaq/pdfs/epa_retrofit_protocols.pdf)

Bernstein, H.M., Editor (2014). *Smart Market Report: The Drive Toward Healthier Buildings: The Market Drivers and Impact of Building Design and Construction on Occupant Health, Well Being and Productivity*. Bedford, MA: McGraw Hill Construction, American Institute of Architects. Accessed November 24, 2014 at: <http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab104164.pdf>

Significant evidence that IAQ issues increase financial risk due to construction defect litigation; expert estimates range from \$1 Billion and above industry wide, but accurate estimates are not available due to confidentiality issues:

Mosca, Peter (2005). “Cost-Effective Liability Insurance Still Dulls Bright Builder Marketplace.” *Realty Times*. Accessed November 21, 2014 at: [http://realtytimes.com/todaysheadlines1/item/10088-20050705\\_costeffective](http://realtytimes.com/todaysheadlines1/item/10088-20050705_costeffective)

“Mold, Moisture, and IAQ Quality Assurance Program for Construction Projects.” Healthy Buildings website (no date). Accessed November 21, 2014 at: <http://healthybuildings.com/mold-moisture-iaq-quality-assurance/>

“Industrial Hygiene & Safety: Indoor Air Quality & Mold/Fungi.” Health Science Associates website (no date). Accessed November 21, 2014 at: <http://www.healthscience.com/asbestos-lead-based-paint-iaq/> (accessed 11/21/14).

EC2 (2011). “Construction Defect Litigation on the Rise.” *EC2’s Building Science Newsletter*, February 2011. Accessed November 21, 2014, at: <http://myemail.constantcontact.com/EC2-s-Building-Sciences-Newsletter.html?oid=1103305117944&aid=vOIY9OSgvpk>