Pacific Northwest
NATIONAL LABORATORY

PNNL-28788

Wall Upgrades for Residential Deep Energy Retrofits: Expert Meeting Report

June 2019

CA Antonopoulos
MC Baechler
CE Metzger
JM Zhang

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

The Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and the University of Minnesota are conducting a 3-year, multipart study of residential retrofit wall assemblies. The project is funded by the U.S. Department of Energy Building Technologies Office. Researchers will identify, test, and verify the hygrothermal performance of wall assemblies in retrofit applications. This study includes engagement with leading thermal enclosure experts from industry, academia, national laboratories, and state and federal program administrators, through an expert meeting held in Arlington, Virginia, on April 19, 2019. In addition to the expert meeting held in April, this project will involve the formation of an ongoing, expert advisory committee. This report summarizes the discussions and outcomes of the expert meeting. References made to specific organizations or products do not constitute endorsements or recommendations.

Acknowledgments

The Pacific Northwest National Laboratory is partnering with Oak Ridge National Laboratory and the University of Minnesota to conduct a 3-year, multipart study of residential retrofit wall assemblies. The authors acknowledge Andre Desjarlais and Florian Antretter at the Oak Ridge National Laboratory for support with experimental design and WUFI modeling, and Patrick Huelman and Garret Mosiman at the University of Minnesota for experimental design and physical experimentation of wall assemblies at the Cloquet Residential Research Facility. The project team gratefully acknowledges and thanks the DOE Building Technologies Office for funding this project, and Eric Werling, manager of the U.S. Department of Energy's Building America Program, for his managerial and technical guidance.

This project will involve the formation of an expert advisory committee. Thirty-five people registered and 33 people attended an expert meeting to help identify and characterize candidate wall systems. We thank all of the participants in the expert meeting and advisory committee for their time and acumen in building science and wall design, deployment, and performance.

Acronyms and Abbreviations

BSC	Building Science Corporation
DOE	U.S. Department of Energy
E+	EnergyPlus™ building simulation software
EIFS	exterior insulated finish system
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
RIPS	retrofit insulated panels

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1.0 Meeting Background

The Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and the University of Minnesota are developing an in-situ evaluation and techno-economic study of retrofit wall systems. The project is being funded by the U.S. Department of Energy's Building Technology Office. This 3-year multipart study will involve identifying, testing, and verifying the hygrothermal performance of wall assemblies in retrofit applications.

There is a significant need for cost-effective methods to increase wall insulation, reduce infiltration, and provide moisture durability for older homes in the United States. In current practice, wall retrofits seldom include strategic air, vapor, and thermal control layers. Thoroughly testing and documenting wall retrofit systems can help determine which system could provide the most energy savings, while improving home durability, comfort, and health. As a means of reducing costs, one approach we will consider is the performance of wall systems that can be applied over existing cladding. Many of the comments received during the meeting were directed to this point.

As an initial step in the study, the research team invited experts from industry, academia, the national laboratories, and other research organizations to join an expert advisory committee and participate in an expert meeting to help identify and characterize candidate wall systems. The meeting was held on April 19, 2019, in Arlington Virginia. Thirty-three of the 35 experts invited were able to attend (see Figures 1 and 2).

The objective of this meeting was to bring together leading researchers and innovators to review the research methodology and to encourage suggestions, information sharing, and collaboration. Outcomes will inform potential retrofit systems to be developed and tested. Specific topics that were discussed in detail include:

1. Data characterization for proposed wall selection
2. Wall selection for in-situ testing
3. Techno-economic study criteria.

Table 1. Expert Meeting Agenda

AGENDA April 19, 2019 Location: DoubleTree by Hilton, 300 Army Navy Drive, Arlington, VA 8:00 am – 4:00 pm - Potomac View Room	
8:00-8:15 am	**Introductions and Overview** - Introductions - Meeting purpose and desired outcomes

8:15 – 9:45 am	**Overview of Study Purpose, Scope, and Process:** - Project objectives - Literature review - Techno-economic analysis process (providing context for the modeling and in-situ testing) - Thermal and moisture modeling (including baseline and retrofit candidates) - Assembly testing
9:45-10:00	**Break**
10:00-12:00 pm	**Identification of Potential Retrofit Wall Assemblies:** - Presentation of pre-identified wall systems (15 min). - In small, preassigned groups, we will introduce the Wall Selection spreadsheet and will discuss the following questions along with other comments arising from the groups. o What existing siding is a show stopper? o Have we missed any retrofit wall systems for over-cladding installations? o Do you know of a protocol for inspecting existing walls to avoid sealing in moisture damage or other problems? o What wall systems would you choose to include in the experiment?
Working Lunch 12:00-1:00 pm Summarize outcomes & findings from small group activity	
1:00—2:00 pm	**Develop Weightings for Wall Assembly Attributes** - Rank wall systems (voting exercise) - Discuss additional attributes - Identify weights for each attribute - Identify additional wall assemblies not discussed in small groups.
2:00-2:15	**Break**
2:15 – 3:00 pm	**Filling in the Blanks on Techno-Economic Data and Analysis** - Exercise to rank the attributes on the worksheet - Are we asking the right questions on the worksheet? - If time permits: how do we reduce costs for wall systems?
3:00 – 3:45 pm	**Continuing Involvement Opportunities** - Advisory Group Formation - Expert webinar series - Reminder to provide comments on the literature review - Any other questions/topics
3:45 am – 4:00 pm	**Wrap-up & Next Steps**

Figure 1. Expert meeting group

Figure 2. Expert meeting group discussions

Attendees included 33 experts from government, national laboratories, manufacturing companies, trade associations, universities and research organizations. A full attendee list is presented in Table 2.

Table 2. Expert meeting attendee list

Name	Organization
Antonopoulos, Chrissi	Pacific Northwest National Laboratory
Antretter, Florian	Oak Ridge National Laboratory
Baechler, Michael	Pacific Northwest National Laboratory
Bianchi, Marcus	Owens Corning
Borowiec, Joseph	New York State Energy Research & Development Authority
Burkett, Lena	National Renewable Energy Laboratory
Campbell, Martha	Rocky Mountain Institute
Cobb, Al	Structural Insulated Panel Association
Curcija, Charlie	Lawrence Berkeley National Laboratory
Desjarlais, André	Oak Ridge National Laboratory
Duncan, Richard	Spray Polyurethane Foam Alliance
Dunn, Steve	U.S. Department of Energy
Gatland, Stanley	CertainTeed Saint Gobain
Ge, Hua	Concordia University
Glickman, Joan	U.S. Department of Energy
Haramati, Mikhail	California Energy Commission
Harris, Chioke	National Renewable Energy Laboratory
Hasz, Adam	U.S. Department of Energy
Huelman, Patrick	University of Minnesota
Karagiozis, Achilles	National Renewable Energy Laboratory
Liaukus, Christine	New Jersey Institute of Technology
Metzger, Cheryn	Pacific Northwest National Laboratory
Mosiman, Garrett	Center for Sustainable Building Research
Mumme, Sven	U.S. Department of Energy
Rashkin, Sam	U.S. Department of Energy
Rathi, Sahas	CertainTeed Saint Gobain
Rothgeb, Stacey	National Renewable Energy Laboratory
Ueno, Kohta	Building Science Corporation
Walker, Iain	Lawrence Berkeley National Laboratory
Werling, Eric	U.S. Department of Energy
Weston, Theresa	DuPont
Zhang, Jian	Pacific Northwest National Laboratory
Zhang, Jianshun	Syracuse University

2.0 Summary of Meeting Discussions

Experts in attendance were asked to provide input on the study structure and provide input regarding wall selection and techno-economic criteria. The text following each heading summarizes key points that were raised in each portion of the agenda. No attempt is made here to respond to the comments. However, each of the comments will be considered in defining study research questions and experimental approaches. We did not attempt to capture comments verbatim. Rather, we focused on capturing the substance of the comments and how they could make this study as beneficial as possible. In a few cases we supplemented a comment with links to relevant information. Some commenters also suggested changes to the literature review (Antonopoulos et al. 2019) conducted as part of the overall study. The literature review was published in June 2019 and includes references and links for a variety of sources of relevant information. Unfortunately, not all comments can be simultaneously addressed in this particular study. However, all of the points raised may lead to future research questions or experimental designs that help advance the science.

The morning sessions of the expert meeting included the broadest discussion, related to scope and experimental design. Comments raised in these sessions are reported in this chapter. References made to specific organizations or products do not constitute endorsements or recommendations.

2.1 Project Objectives

Experts provided the following input on the overall project objectives (comments are paraphrased):

- Define single-family focus.
- There is another wall testing facility at Syracuse University in New York that could potentially collaborate on an expanded scope. Oak Ridge National Laboratory also has a wall test facility in South Carolina. Neither of these facilities are currently part of this project but could help to facilitate future studies or an expanded scope for this study.
- Intersections and interfaces might be the most important aspects of walls; maybe not the assembly as a whole. Consider a primary research question: how do the interfaces perform over a period of time? What is a “deep” energy retrofit?
- Perhaps this project should focus on post-WWII track homes? Only look at homes built between 1930 and1960?
- We need to have a consistent nomenclature for all of the parts of the walls. Be careful how you use the term “wall system.” Some prefer terms like “existing wall” and “retrofit wall system.” We need a term for the new wall that combines the existing wall and the retrofit wall system.
- Big questions for wall systems:
    - Factory-produced versus on-site fabrication?
    - Use existing windows, reset or upgrade existing windows, install new windows, use integrated windows like in some approaches like Energie Sprong?
    - Can this contribute to resilience (which types)? Does this require a regional approach?

  - Does the system need to dry to the exterior?
  - Should you maintain the ability to fill the cavity later?
  - Does an air control layer come with the system or is it field applied (liquid-applied, AeroBarrier)?
  - How big are fire resistance and emissions concerns? Does this exclude products?
- Reducing complexity and simplifying constructability has to be a large focus.
- Can you add thermal mass with variable R-control layers to the inside and outside allowing you to tune the performance for energy, loads, and grid interaction?
- This project is focused primarily on single-family detached homes but it can be applied to multifamily. The baseline wall is wood frame, so that could be considered a limit for the multifamily question. Consider adding a multifamily perspective in subsequent years.
- In many urban areas buildings cannot go beyond lot lines, per local code. It may not be possible to apply insulation from the exterior in some circumstances. Can we consider filling the wall cavity as a minimum and a more applicable option everywhere?

2.2 Literature Review

Experts provided the following input on the literature review:

- Search for international wall options that might not be published in a journal but might have a website with specific product information.
- Look at the Weatherization Assistance Program for additional literature to support various sections of the literature review.
- Look at the Natural Resources Canada studies. Deep retrofits Canada inter-can. Foam glass insulation.

2.3 Techno-Economic Topics

Experts provided the following input on techno-economic topics:

- Are we looking for costs per square foot or some other cost metric?
- Are we looking at cost and economics to inform the wall choice?
- To guide the economic criteria, are we engaging with building owners to understand the financial constraints? Like financing criteria, etc.
- Get advice from contractors and builders.
- Look at what fits inside utility cost effectiveness frameworks.
- Cost analysis should also include multifamily buildings.
- Choose one consistent price for materials and labor across the country. That will make it easier to compare wall solutions.
- Physics are the same for single and multifamily, but the economic criteria are much different. Multi-family may offer the best opportunity from a cost perspective.
- What will banks and insurance companies require?

- Currently available commercial loan products did not exist 50 years ago.
- How to normalize for energy costs? Use EIA regional based costs.
- 1.2 million residential home improvement projects every year according to Joint Center for Housing Studies of Harvard University.[1] Often (about half) of the time new siding goes over old siding. New siding often goes over asbestos. Look at this as an opportunity to include energy retrofits.
- Deep energy retrofits do not necessarily make economic sense.

2.4 Techno-Economic Attributes

Experts weighed in on techno-economic attributes presented in the spreadsheet. The list below captures some additional attributes to consider, along with edits and modifications to the current list. The spreadsheet with all attributes and wall system categorization is available in Appendix A.

- Consider CO2 savings instead of cost effectiveness.
- Include a resilience metric. If you consider resilience, the solution becomes region-specific. A regional filter is needed. Fire, flood, seismic etc.
- Add insurance benefits.
- Find a way to capture the use of a minimal number of construction materials and installation components on site.
- Add embodied energy.
- Capture the change in R-value pre/post installation.
- Add air leakage.
- Add the ability to block sound.
- Attributes important to consumers should be used. Example attributes of this type were not discussed but could include cost, comfort, health, risk of failure, and aesthetics.

2.5 Modeling and Simulation

Experts provided the following information specific to modeling and simulation:

- Look at the potential savings of simulated walls with ResStock[2].
- Introduce bulk moisture in the simulation. Deposit it inside the assembly and see if it dries out over time.
- We (a general reference to the state of the science not to any particular organization or group) do not know a lot about the existing wall and interior conditions that will be retrofitted. There are some uncertainties that we are not sure how to handle. Does the building have air conditioning? What is the climate on the inside? How are you going to put enough of an error band around this to get meaningful results? What the people are doing on the inside? We need to define all the inside conditions.

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[1] https://www.jchs.harvard.edu/research-areas/reports/improving-americas-housing-2019

[2] https://resstock.nrel.gov

- What weather files are you using? What will you do for thermal bridging? Will you do 2D simulations?
    - Florian Antretter response: We are planning to use real weather from the experimental location to help calibrate the model related to the experiment and then use TMY3 weather files for extrapolating to other climate zones. When TMY data are available, we want to align E+ and WUFI for the wall heat transfer calculations. For sensitivity of walls for moisture durability, the weather data traditionally used for WUFI analysis will be used.
- WUFI Plus is suggested.
- Are we modeling the whole building?
- Suggest to account for pre-retrofit moisture conditions in the hygrothermal modeling because this is for existing wall upgrades.
- Modeling for comfort is important to occupants.
- We need to account for thermal bridging.

2.6 Wall Inspection Protocol

One area of focus during most conversations was the need to develop protocols for inspecting the wall that will be retrofitted. Questions arose around how to tell what was inside the current cavities, if they remain unopened. Furthermore, experts wondered about assessment of existing conditions, including moisture durability. Specific questions and comments include the following.

- What type of inspection criteria are we going to propose?
- How are we going to address the existing building? Again, how can we tell what is inside the cavities if we do not open them up?
- An inspection protocol will be one of the most important outcomes of the project.
- It is important to know where the studs are in order for new panels to be properly attached.
- Inside framing cavities might have serious issues that would prohibit retrofit (knob-and-tube wiring, asbestos, etc.).
- We need a protocol to handle mold, when the existing wall structure has high moisture. Mold can be hard to detect.
- We need a process for assessment of hazardous materials, such as knob-and-tube wiring and asbestos.
- CertainTeed is working to develop assessment protocols for existing homes; we may be able to align efforts.
- How do we assess/evaluate the house?
    - Is the house worthy of a “deep” energy retrofit?
    - Does the house have sufficient structural integrity?
    - Are there pre-existing conditions that might preclude certain treatments?
    - How do we deal with lead or asbestos? Is encapsulation a plus?

  - What are protocols for inspection? What type of instruments does the contractor need (borescope, infrared camera, etc.)?
  - Are there protocols from EIFS or stucco failures that can be used?

2.7 Experimental Design

The experts provided the following input on the in-situ experimental design.

- Does the baseline wall include a vapor retarder?
- Are we going to use vintage weathered materials for the baseline? How are we going to address the old weathered conditions of the existing building?
- It was suggested to consider a completely dried material as the initial condition; probably better than wet material.
- Drawing on an experiment conducted by Kohta Ueno, it was suggested that we remove any wall assembly that is clearly failing after year one. Take out walls that fail the first year and use that bay for more space next year. Develop thresholds for passing the initial experimental year.
- Relative humidity inside: what is going to be appropriate to stress these assemblies? Do pre-modeling to find the humidity breaks.
- Divide solutions into what is affordable/good enough, vs. expensive/highest-performing. Add a disaster resistance option and a non-resistance option. This becomes the “Optimum Risk Management.”
- Whatever you use as a baseline, also include drill and fill.
- We could select a baseline wall system that is masonry (in the second year).
- Probably will end up with two baselines, one for masonry, and one for stud wall.
- We have to decide on the indoor boundary conditions.
- We should identify wall systems that work on both single-family and multifamily buildings, depending on the vintage of the home.
- How will cladding be selected? Urban centers have all brick. Cladding type will predetermine what insulation systems are possible. A historic look, or other aesthetics might also be important.
- Define what a “bay” is (how wall systems will be installed in bays for the experiment).
- Describe insulations and isolation between bays.
- Does steel framing in the bays matter?
- Define “squishy layer.”.
- Will need flat surface to install EIFS – cladding most likely removed.
- Windows are the number one source of air leakage; will they be installed in the bays?
- Rocky Mountain Institute is working on developing a monitoring plan for their Realize approach to field monitoring. Suggested aligning tasks.
- Testing questions:

- Pre and post air leakage – is there an air leakage target?
- How about future introduction of water?
- Is there degradation of the R-value due to air leakage, windwashing, etc.?
- What are the interior boundary conditions? Typical vs. stress?
- Do we need original and aged products for the tests?

3.0 Wall System Breakout Groups

After the larger group discussion outlined in Section 2.0, participants broke out into four small groups where they were asked to brainstorm wall systems, based on criteria provided in the accompanying spreadsheet. (See Appendix A for a copy of the spreadsheet.) Each group self-identified one of the group members to be a leader, who guided the discussion and reported outcomes to the larger group. The notes below were taken by the facilitators of each group and reported here. References made to specific organizations or products do not constitute endorsements or recommendations.

3.1 Group One Notes

Materials

- Building envelope materials – closed-cell foam, pinhole solution (interior applied foam into wall cavity).
- Consider Aeroseal/Aerobarrier to air seal during the retrofit. Depressurize the structure to make the seal from the outside.
- Can we use a liquid-applied air barrier from the exterior?
- Re-side with attractive cladding.
- What if we air seal and do not insulate? That (air sealing) seems more important. And if nothing else, air sealing should be done first anyway.
- Recycled products are desirable from a sustainability perspective, but it is hard to control purity of materials.
- Consider using vacuum insulated panels.

Wall Systems

- Consider an integrated water and air barrier that will increase moisture and thermal performance at the same time. Something that is applicable on the exterior of existing buildings like that would be great.
- Whatever the solution, we should consider using sizes (i.e., panel sizes) the industry is already working with.
- Consider using 3D printing to print a skin. Customize the foam to modify the back of the foam.
- Whatever we choose needs to be simple. When push comes to shove, thermal performance is not as important as air sealing.
- Can one assembly not have cladding?

Considerations

- Many homes are built to the lot lines, especially in older neighborhoods. Code prevents building out past the original setback. Can we consider filling the wall as a minimum and a more applicable option everywhere?

- Building code may not always have a rainscreen. What kind of siding would you use? Some siding is inherently self-ventilating, and some is not.
- This group decides there is a need to focus on opportunistic retrofits, where you are already removing the existing cladding.

3.2 Group Two Notes

- This group defined a “deep” Energy Retrofit as R-20 or code. The minimum performance of the wall system should at least meet this threshold. If we bring the entire wall assembly to code levels, this means traditional vinyl insulated siding is out of the game.
- Criteria should include air leakage and long-term performance. This could be a measure of scalability.
- A key challenge is the connection between the existing wall and new components. Some prefabricated options have the opportunity to integrate windows.
- Honor the control layers. The new assembly has to include bulk water, vapor, and thermal control layers.
- How will we assess the conditions of the existing walls? Need to open original cavities somehow. The group is not aware of an existing protocol for wall moisture inspection.
- Real estate transactions provide an opportunity for cladding replacement.
- The only way to assess mold is smell or visual inspection. What do we do if part of the wall is condemned?
- Describe the service life of the retrofit. Do not lose the opportunity while you are touching the walls.
- [The retrofit] Cost might get close to rebuilding the house, in some cases.
- What percent of the homes are historical that are not insulated? Historic homes present additional challenges.
- Better opportunity when the house is going to be re-sided. Or possibly during the [real estate] transaction process.

3.3 Group Three Notes

- The wall system should be flexible about how windows are treated – Must they be moved from the inside (existing wall) to the outside (retrofit wall system)?
- The ability to block sound is an important factor or selling point.
- Do we need a new squishy layer (I Like spray foam) to get a perfect seal? Add Aerobarrier from outside to fill holes (put house under negative pressure).
- Talk to people who build/engineer other things (airplanes, submarines, adhesives) to get ideas for innovation.
- Take into account how the wall will dry.
- Be sure to talk to BASF (BASF representative was not present at the expert meeting).
- Consider use of 3D printer to create walls.

- Need integrated solution that includes windows and sealants.
- CertainTeed preparing to launch retrofit closed-cell cavity insulation product.
- Consider phase-change materials.
- Look into NREL's Solar Wall.
- For fire and flood resiliency, materials should be able to dry to the exterior.
- Constructability is really important. Who is going to do it and how easy will the protocol be?
- Controllable thermal mass. Add thermal mass to the cavity. Allows you to control and discharge the thermal mass. Pre-charge your system using an HVAC system. A wider range of strategies to control that thermal mass. Concrete, sand, etc. Variable R-value materials on the outside.
- Use a Larson truss for the standout.

3.4 Group Four Notes

Going over Existing cladding:

- More risk because you cannot assess the existing wall.
- Can be hard to go over.

Certain cladding you don't want to take off:

- Hazardous materials.
- Need to add line of cost for construction waste disposal and cost of removing the existing siding.

Focus on a specific application:

- Cold climate
- Wood frame, single family
- Exterior application.

How are we going to assess the existing wall for suitability?

Window/door integration is imperative. Fenestration retrofits should be added.

Capitalize off homeowner drivers for retrofits:

- Cost
- Aesthetics—changing the look, architectural details
- Adding property value
- Comfort
- Resiliency.

Consider using Building Science Corporation's (BSC) exterior foam wall retrofit:

- Fill existing cavity with insulation
- If hazardous materials or really heavy cladding materials are present, there is a need to encapsulate.
- Ideally we should have a system to go over existing cladding, but we also need an option to take off cladding. Ideally, you'd take off cladding to get the most energy/moisture benefit. Overall recommendation—if no hazardous products are present, take the cladding off.
- Removal of existing cladding is an opportunity to retrofit the envelope.
- A mechanically fastened air control layer doesn't get you as airtight as liquid applied.
- Taping foam is viable as an air/water barrier.
- Semi-rigid mineral fiber. Mineral fiber dries out.

BSC argues deep energy retrofits do not necessarily make economic sense, although we should push this for re-siding projects.

4.0 Voting Exercises

The experts were asked to vote on two topics, both of which will be used in the wall selection process and the final techno-economic analysis. The first topic covered wall systems the experts thought would be best to study in the in-situ experiments. The second vote was for criteria to be used in the techno-economic study. References made to specific organizations or products do not constitute endorsements or recommendations.

4.1 Wall Systems Voting Exercise

Participants were asked to vote on wall assemblies that the project should focus on for in-situ testing. Each expert was given seven total votes and asked not to put more than one vote on a single category. In total, six wall systems and two baseline walls will be tested. Results from the voting exercise are presented in Table 3 in order from most votes to least.

Table 3. Wall system voting outcomes

Wall Assembly Name	Expert Meeting Votes
Exterior Rigid Insulation	16
European Panels	16
Inso Fast: Foam Panel with Plastic	16
Minimally Invasive Cavity Spray Foam	15
Nail Base RIPS	14
Canadian Composite Concrete Material	13
Insulated Vacuum Vinyl Siding	13
3D Printed Skins: On or Off Site	10
Simple Infiltration Control: Aeroseal	9
Fluid Applied WRB	5
Dynamic Controlled Thermal Mass	4
Modified Ext. Spray Foam Stand Off Wall	3
Thermal Break Shear Wall	3
Thermal Mass	3
2x4 Framing with Spray Foam	2
EnergieSprong Assembly	1

4.2 Techno-Economic Criteria Voting Exercise

Experts were asked to identify the most important criteria that should be considered as part of the economic assessment of each wall system to be tested. Each expert was given seven total votes and asked not to put more than one vote on a single category. The outcomes are reported in Table 4 in order of most votes to least.

Table 4. Techno-economic criteria voting outcome

Criteria	Description	Expert Meeting Votes
Air infiltration	Amount of air leakage measured by air changes per hour	23
Constructability	How "fool proof" is this assembly to install?	22
Cost/ft^2 (labor)	Labor cost	18
How easy are control layers to install?	Easy, Intermediate, Hard. Are they applied onsite or pre-fab?	16
Time to install	How long does the assembly take to install?	14
Cost/ ft^2 (materials)	Material cost	13
Service life	How long is the expected life of this assembly?	13
Improved disaster resilience	Does this wall system improve resistance to other risks (includes earthquake, flood, pest, fire and wind)?	11
Considerations for roof/foundations (easy, medium, hard)	Refers to roof/wall and foundation/wall intersections	10
Embodied energy measurement	Does the assembly have a LCA? Is there improved performance from a sustainability perspective?	10
Applicability to existing wall type	Refers to the exterior material of the existing wall (e.g., stucco, cedar shake, masonry, etc.).	8
Insulation R-value (cavity, continuous or both)	Type of insulation and R-value	8
Must re-install windows/doors?	Refers to the difficulty of addressing issues at the openings	7
Climate adaptable	Which climate zone would this be cost effective in? Do you see issues with this wall being in multiple climate zones?	5
Impact on indoor environment	Are components toxic? Will they have an impact on IAQ?	5
Is the wall system assembled on site, or pre manufactured?	Refers to entire wall assembly, including control layers	4

How disruptive is the retrofit approach?	Are there code barriers? Are there homeowner disruptions?	3
Low sound transmission	Does the assembly provide sound protection?	2
Removal of existing cladding required?	Does the cladding typically need to be removed to apply this retrofit?	1
Removal of existing sheathing required?	Does sheathing need to be removed before application?	1
Technical readiness	Early stage R&D, testing/data collection complete, or market ready? Is this a widely available material/technology?	0

5.0 Outcomes/Next Steps

Some common themes were identified during both large and small group discussions. Based on these discussions, the research team is considering refinements to the following areas within the overall research.

5.1 Wall System Selection

The experts brought up points about refinement of the general research question for this study. They suggested a few points:

- There may be uses for wall retrofits that can be applied over existing cladding; however, our general research should not be limited to this requirement and should also include retrofits that are applied to walls with cladding and possibly sheathing layers removed.
- The research question should be refined to be as specific as possible; consider the input discussed in Section 2.
- What should the targeted performance metric(s) be for these potential deep energy wall upgrades? Some participants suggested that renovation should remain focused on practical, readily available, and cost-effective approaches that could be easily adopted by the marketplace. Others suggested bringing these existing homes up to current code levels or beyond. Still others were pushing for more aspirational levels to maximize savings (and other benefits) and minimize "lost opportunity" costs.
- In a similar vein, one commenter suggested that it is important that one or more wall systems be included in the study that would likely result in aggressive market uptake. But this commenter also pointed out that the study should not be tied only to incrementalism.
- Another commenter pointed out that the study could address the best systems available that meet different needs. For example, one system could be geared to siding installers to incorporate into their jobs. This system may not be as aggressive. Another system could target deeper energy retrofits. And a third could be focused more on a factory-built system.
- Finally, several commenters suggested that it would be important to focus on wall systems that have not received a lot of scientific scrutiny. These commenters felt that walls that had received little study deserved the most attention in this study.

5.2 Pre-Retrofit Wall Assessment Protocol

Many experts discussed the need to develop a comprehensive protocol for assessing the existing wall before retrofit. Some suggested the need to develop a new task aimed at providing a means for the assessment of the current wall system to determine its applicability and appropriateness for a specific "deep energy wall upgrade."

5.3 Cladding Removal

As a means of reducing costs, one approach we will consider is the performance of wall systems that can be applied over existing cladding. Many of the comments received during the meeting were directed to this point. Experts were not convinced this study should focus only on wall systems that can be applied over existing cladding. A general consensus by the group is that deeper energy savings can be achieved by retrofitting the envelope down to the cavity from the exterior side of the wall. Some noted that, regardless of the approach, cavity insulation should always be added as missing this would be a lost opportunity.

In addition, experts noted that re-siding projects present a good opportunity to retrofit the envelope in a way that adds thermal and moisture protection. The wall systems that come out of this study should capitalize on this opportunity.

5.4 Moving Forward – Voting Results

The voting exercises provided guidance on possible wall systems to include in the study and on metrics to be used in evaluating those systems. Seven retrofit wall systems received the top votes (all were within three votes of one another). These top contenders included:

- Exterior Rigid Insulation
- European Panels
- Inso Fast: Foam Panel with Plastic
- Minimally Invasive Cavity Spray Foam
- Nail Base RIPS
- Canadian Composite Concrete Material
- Insulated Vacuum Vinyl Siding.

Because the project is constrained to testing eight wall systems total, the project team has discussed the possibility of testing three systems both with the existing cladding removed and with the cladding in place (six wall types total), plus two baseline walls. This approach would help to identify and document the difficulties and opportunities associated with both the cladding on and cladding removed approach, as well as the resulting energy and moisture performance of each system. The baseline assemblies will include a drill-and-fill cavity insulation assembly and a non-insulated wall assembly.

The project team is investigating these systems and may combine some of them. Some of them may also prove to be similar to one another in terms of installations and modeled performance, which may help to weed out some contenders. The wall selection process is underway, and final walls for laboratory testing will be identified in July, 2019.

Meeting participants were also asked to help rank criteria that may be applied in a techno-economic study. These criteria may also prove useful in evaluating which wall systems to include in the physical experiments. Two points jumped out from the voting.

First, many of the top criteria were related to labor and ease of installation (see most voted for criteria in Table 5 below). If the votes for all the measures related to this topic (constructability, cost/ft^2 (labor), how easy are control layers to install, and time to install) were added together, the total would amount to 70 votes. On their own, these four criteria made up the second through fourth most voted for options.

Second, the criterion receiving the most votes was air infiltration with 23 votes. In reporting the results of the break-out discussions, one team declared that reducing air infiltration was the single most important aspect of wall performance. In comparison, as a physical measure of wall performance, a counterpart to air infiltration was “Insulation R-Value (cavity, continuous or both),” which received 8 votes. The importance of air infiltration as noted in the voting will influence the physical experiments as well as the techno-economic study.

Many other important metrics were raised in the exercise and will also be evaluated in our planning.

Table 5. Top topics receiving votes in techno-economic criteria voting exercise

Criteria	Description
Air infiltration	Amount of air leakage measured by air changes per hour
Constructability	How "fool proof" is this assembly to install?
Cost/ ft^2 (Labor)	Labor cost
How easy are control layers to install?	Easy, Intermediate, Hard. Are they applied onsite or pre-fab?
Time to Install	How long does the assembly take to install?
Cost/ ft^2 (Materials)	Material cost
Service Life	How long is the expected life of this assembly?
Improved Disaster Resilience?	Does this wall system improve resistance to other risks (including earthquake, flood, pest, fire and wind)?
Considerations for Roof/Foundations? (easy, medium, hard)	Refers to roof/foundation intersections
Embodied Energy Measurement	Does the assembly have a LCA? Is there improved performance from a sustainability perspective?

6.0 References

Antonopoulos, C., Metzger, C., Zhang, J., Ganguli, S., Baechler, M., Nagda, H., & Desjarlais, A. 2019. *Wall Upgrades for Residential Deep Energy Retrofits: A Literature Review*. PNNL-28690 Pacific Northwest National Laboratory, Richland, Washington.

Appendix A – Wall System Spreadsheet

Wall assembly name	Type of Insulation and R-value	What are the control layers	How easy are control layers to install	Applicability to existing wall type	Removal of existing cladding required?	Removal of existing sheathing required?	Must re-install windows / doors?	Roof / Foundation considerations? (easy, med, hard)	Climate adaptable?	Improved disaster resilience?	TRL	Cost / ft2 (materials)	Cost/ ft2 (labor)	Pre-fab?
Exterior Rigid insulation	Cavity and continuous. Varies	Foam, tape, combo barrier	Added onsite	Masonry, or existing sheathing	Yes	No	Yes	Hard	Best in cold climates	No	Widely available	$16.82/ ft^2		No
Thermal break shear wall	1.25 rigid insulation, cavity batts	WRB on rigid insulation	Added onsite	Removal of layers down to framing	Yes	Yes	Yes	Medium	Tested in marine climate	Yes. Seismic	Widely available	$23.05/ft2		No
2x4 frame over siding	R-25 in cavity	Depends on type / density of foam	Unknown	Applied over existing siding	No	No	Sometimes	Hard	All climates	No	Widely available	19.26/ft2		No
Insulated vinyl siding	R-2 to R-12	Depends	Added onsite	Maybe not over brick facades	No	No	Sometimes	Medium	All climates	No	TRL5	TBD	TBD	Yes
EIFS	2 in. rigid insulation	WRB, drainage panel, sealant, caulking	Added onsite	Masonry and wood	Yes	No	Yes	Medium	Cold climates	No	Widely available	Onsite: $15.5/ft2 (4-in) and $0.20–$0.35/ft2 per additional inch; Prefab: $7-9/ft2 for panel and $8/ft2 installation including WRB		Both
RIPS	R-7.9 to R-15.1	Air retarder incorporated-, Thermal barrier incorporated, vapor barrier provided by foam but requires added glue or caulk, WRB must be added.	WRB added onsite	Existing cladding typically removed	Typically	Not typically	Yes	Medium	All climates	No	Available from specialized manufacturers	$2.50-3/50	$1.50-2.00	Yes

EnergieSprong	R-24 Roxul	Built into system	Built into system	All types	No	No	Sometimes	Medium	All climates	Maybe	TRL5	TBD	TBD	Yes
ComfortFill	R-6 in.	Closed cell foam	Easy, no extra steps	Most walls	No	No	No	None	All climates	Yes	Pilot scale	End user price: 5.5-6.5 (40-50% labor, 50-60% materials)		

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