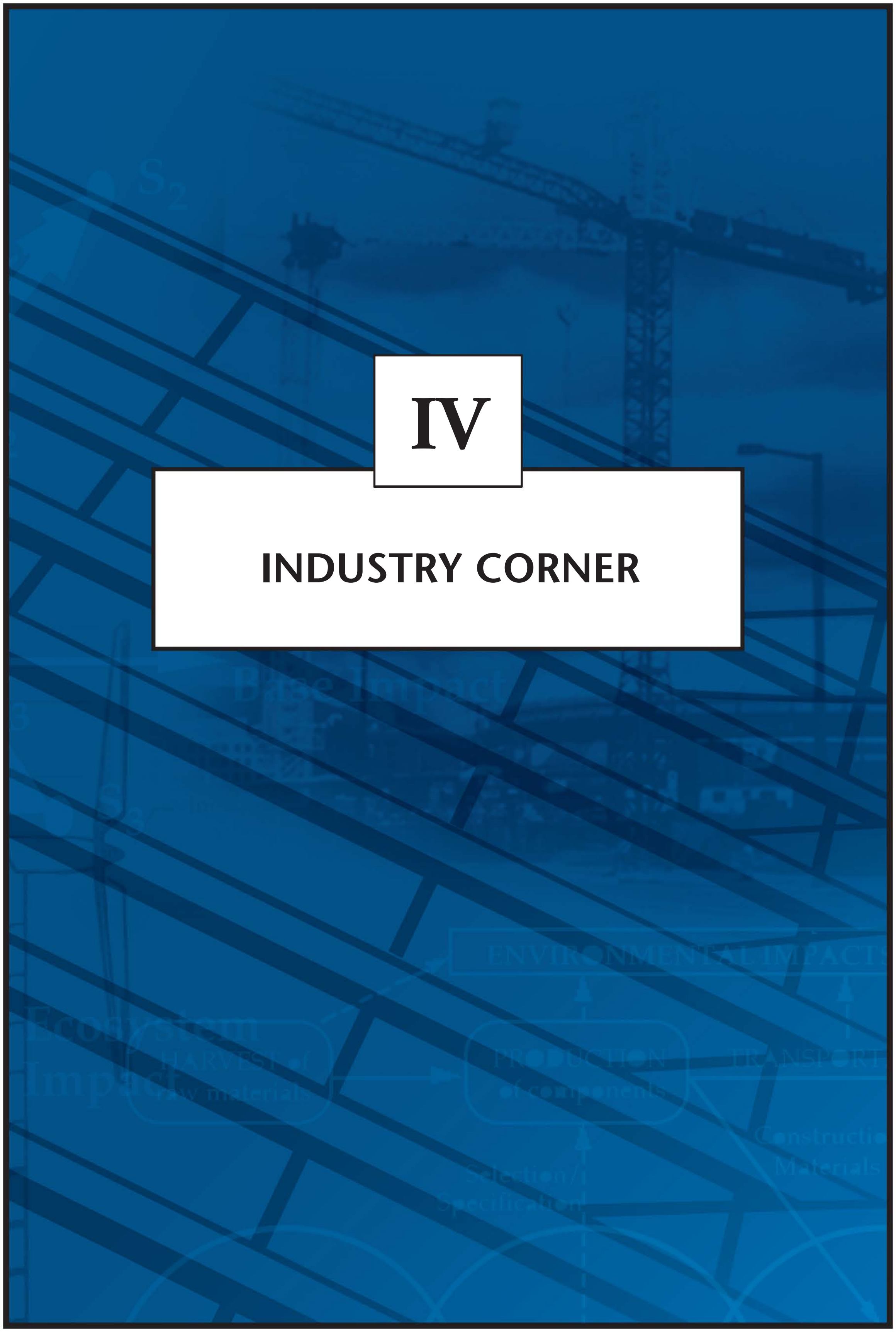

IV

INDUSTRY CORNER

ENERGY USE EXCELLENCE AND THE BUILDING ENVELOPE

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ABSTRACT

We have spent the last 40–50 years working for energy efficiency in our buildings, and we have done so by increasing the performance of the heating, cooling, lighting, and ventilation systems we use. Only recently have we realized the importance of the building envelope in this endeavor. The spaces within a building are created to support the purpose and programs of that building, and it is the envelope made up of the walls, windows, doors, roof, skylights, and floor that protect and shelter those programs and purpose. In this article we will explore various components of the building envelope and discuss ways to achieve optimal energy use.

KEYWORDS

building envelope, air barrier, greenhouse gas (GHG), embodied carbon, operational carbon, zero-net energy, R-value, U-factor, fenestration

INTRODUCTION

The building envelope is an imperative component of any building performance goals including, to name a few, energy use, user comfort, building durability, building and community resiliency, operational cost control, stewardship of resources, and intrinsic beauty. We need to broaden our comprehension of the building envelope as a system and in relationship to the building energy systems, use of the building, community connections, and natural systems affecting that building so that we can improve performance in all these areas. The location, siting, configuration, and building envelope compositions rarely change over the life of a building. By optimizing the envelope, we ensure the bulk of the cost investment is in the durable parts of the buildings, and not solely in mechanical, electrical, and plumbing (MEP) systems that have a shorter life-span.

Here are some broad-based concepts to help us understand the impacts of the building envelope.

- Are we talking about Energy Efficiency (EE) or Greenhouse Gas (GHG) emissions reductions?
  - EE is often solely about energy cost savings. With this metric, we sometimes will choose fossil fuels for their lower up-front costs.
  - This focus on EE can create long term ineffectiveness for short term gains, such as remaining with a central steam plant.

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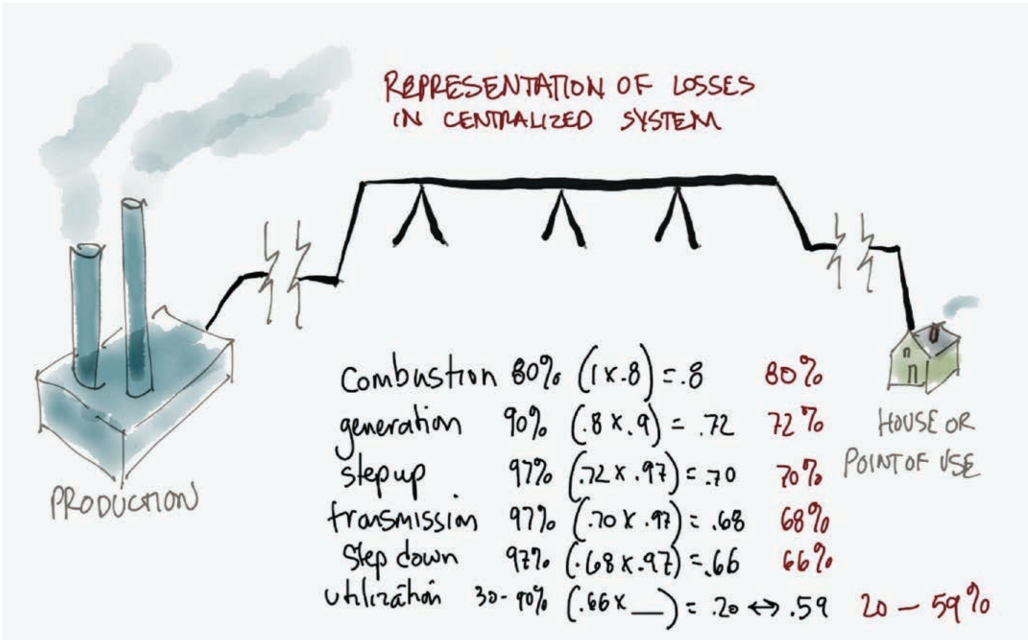
FIGURE 1. Sketch Detailing Typical Transmission Losses of Greater than 40%. *Source:* Bob Dooley, 2017



- GHG emissions is a better metric because it helps teams to consider renewable energy solutions and district (decentralized) approaches with fewer transmission losses.
- Are we concerned with operational carbon or embodied carbon?
  - Looking beyond operational energy use to include the energy impacts of certain materials can help us make informed full life-cycle impact decisions.

FIGURE 2. Greater GHG Burden of Some Insulations Than Life of Operations GHG Reductions. *Source:* BuildingGreen 2010

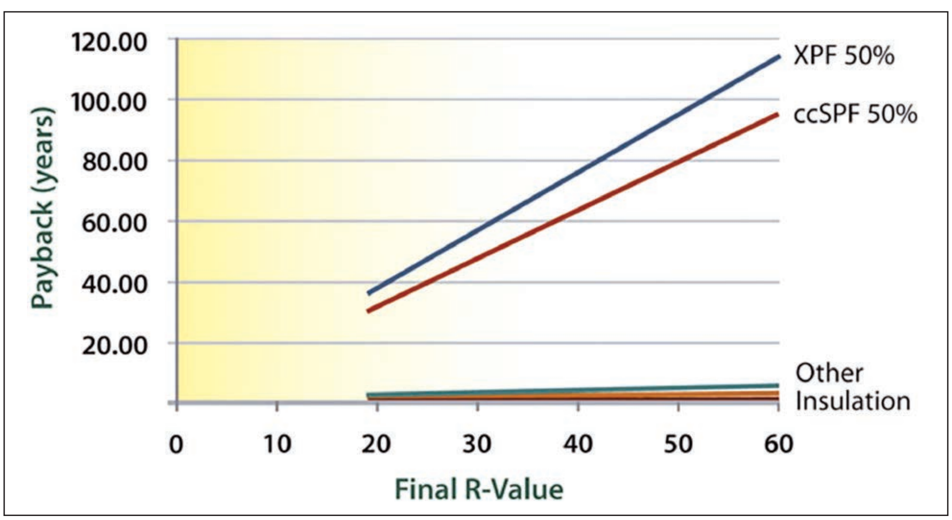
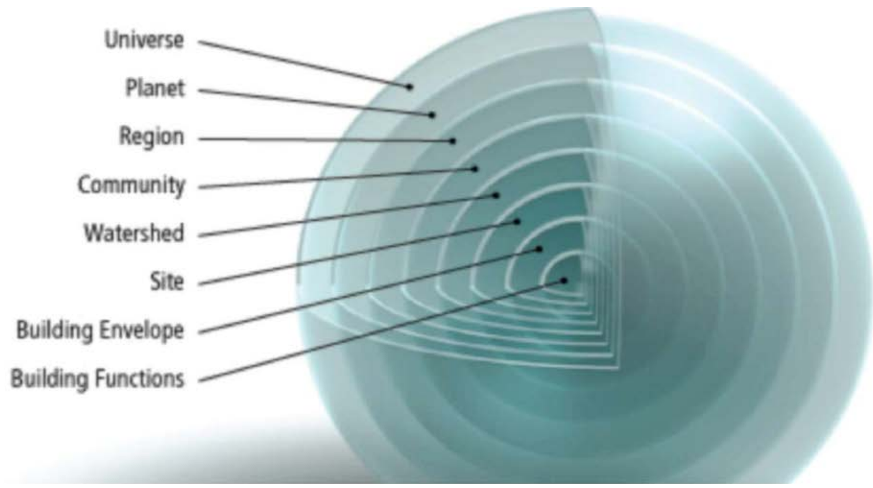


FIGURE 3. Indicator Lights to Engage Building Occupants in Building Energy Management and Personal Comfort Control at UVM George D. Aiken Center. *Source:* Jodi Smits Anderson, 2014

  - For example, it will not benefit our greenhouse gas emissions projections if the insulation in our walls, such as Extruded Polystyrene (XPS), creates more GHG in its production than it can possibly save through efficiency over the life of the building.
- User engagement for better performance.
  - If we can strive to understand the comfort, health, and productivity of the people within the building we can select systems and envelope designs that they can understand, and that they can directly manage in some ways.
  - The users will then be partners in the ongoing performance, instead of creating work-arounds to improve their own individual comfort that may undermine the building-wide goals.
- What of the community and the related larger systems?
  - The most comprehensive goal is to design the building for regeneration of the nested systems so that we identify and amplify mutual benefits for all systems. These systems are, at minimum, the project, the community, and the related ecological systems.
  - This level of design integration supports our long-term resiliency at all levels of interaction.

In this article, we will discuss the building envelope in practical terms related most directly to energy use. We will also briefly explore concepts of carbon reductions (operational and embodied), and user engagement and considerations. A small portion of this article will be spent on support of ecological systems and how that interdependency can improve the envelope design and performance. However, it is important to understand that broader systems thinking will always provide information, insights, and synergies that will maximize benefits and avoid any unintended burdens.

FIGURE 4. Nested Systems. *Source:* 7group and Bill Reed, 2009



We will approach the main components of the building envelope: opaque areas including walls, roof, and floors; fenestrations including skylights and windows; air barrier; and thermal bridging. We will then discuss existing buildings to illustrate the importance of improving the building envelope in our aging building stock as well as the complexities that will be encountered in doing so.

To set the tone, let's consider a successful commercial project, certified zero-net energy, market-rate construction, with deep user engagement and connectivity to nested systems: the Bullitt Center in Seattle Washington. This building was one of the first of its kind, built in 2011 at a cost of approximately 23% above comparable Class A new office building cost, with a confirmed zero-net energy performance, meaning no cost for operational energy … ever. They achieved this by calculating the energy that could be produced on site, predominantly with rooftop photovoltaics (PV), then designing to an Energy Use Index (EUI) below that limit. This took careful design of the building envelope, as well as engagement of the occupants (it has direct-occupant heating and cooling in the desk chairs), and collaboration with the resources of the site (Seattle is not in an exemplary solar region). http://www.bullittcenter.org/?s=financial+case+study&cat=2

Also consider the Net Zero Village in Rotterdam, NY, which is a market-rate apartment complex built by a local developer. Using contemporary design approaches and paying great attention to the building envelope, and to weighing the costs and benefits of aggressive insulation goals as compared to installation of solar thermal and PV, the developer has created a zero-net energy performing apartment complex at no additional cost to his planned expenditures. He did have to address zoning and planning resistance as the buildings face away from the approach road to get the greatest solar benefit. He also had to petition to be allowed to include PV parking canopies. He has recently completed a second zero-net energy, luxury, apartment complex.

OPTIMIZE OPAQUE ELEMENTS FOR GREATEST IMPROVEMENT

Approximately 60–70 percent of the wall surface, and usually most of the roof areas, are opaque. These areas provide us the best opportunities for thermal control. Continuity of the insulation layer, otherwise known as the thermal plane, is imperative, and transitions between wall and

FIGURE 5. Net Zero Village, Rotterdam, NY. *Source:* Albany Business Review, 2018

roof, around corners, and between wall types with differing materials are each vastly important to performance, and often missed in design or in construction process.

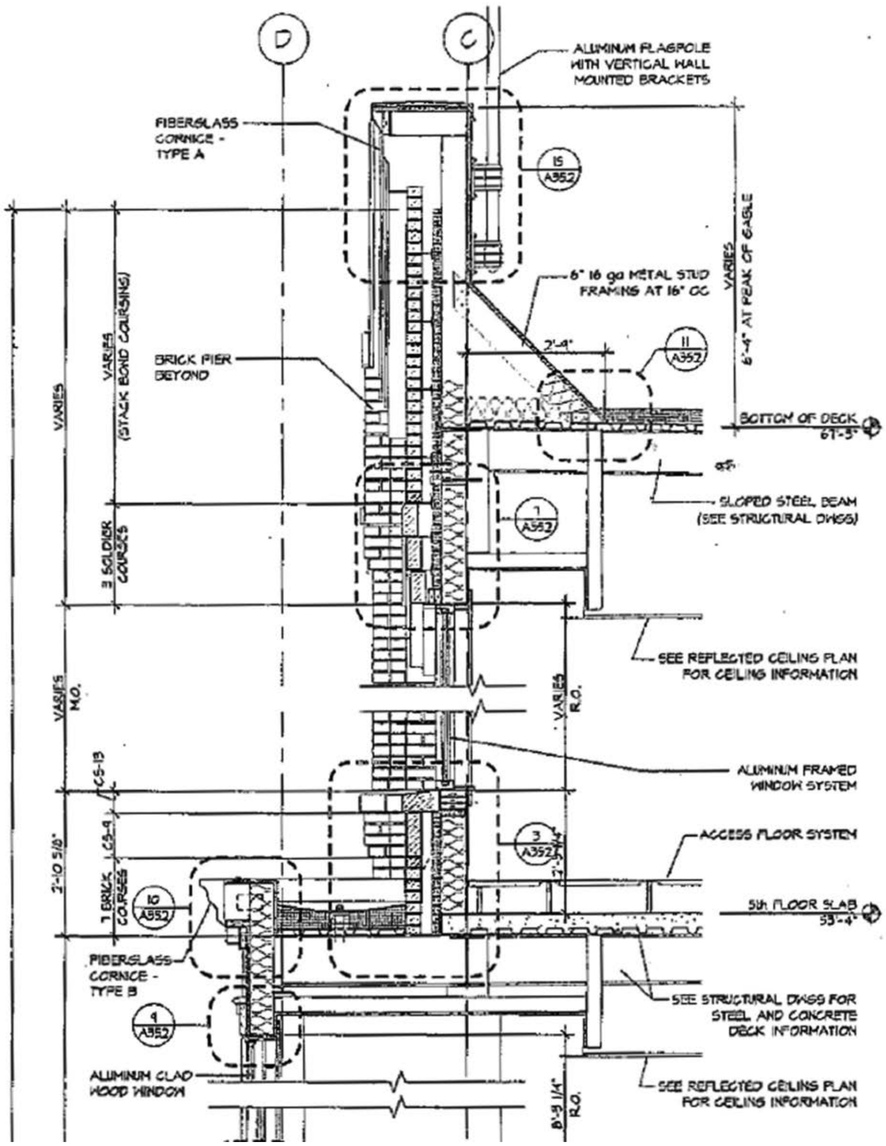
Walls include a dizzying array of materials in complex relationships, as illustrated in the wall section below. Possible wall components include interior finish material, sheathing, studs, ladders (complex stud assemblies), cavity insulation, continuous insulation, air barrier, structural elements, air space, thermal mass, exterior finish material or system. And these can be configured in many different approaches including stud wall; mass wall using concrete, stone, or brick; rain-screen systems with air space to allow better water control; double wall to increase insulation; opaque curtain wall; and more. They can be below grade walls or above the grade plane. In every case the thermal performance as defined by code needs to be at least met, the thermal plane needs to be continuous, and the air barrier must be complete and aligned with as well as affixed to the thermal plane. The air barrier is discussed in more depth later in this article.

Roofs are no less complex in that they can be pitched or flat, insulated or vented, and can use a plethora of materials and systems. They are also affected by snow load in some regions, on-roof equipment and access, roof drains and other penetrations, and more recently by inclusion of PV, solar thermal installations, and green roof designs. Again, key elements for performance include continuous thermal plane (transitioning completely to walls) and air barrier location and completeness.

The slab is a valuable component of the envelope system that cannot be overlooked. It must be insulated, at least at the perimeter, and that insulation must transition completely to the wall plane insulation to provide a complete thermal envelope. A floor over a crawl space or basement comes with additional challenges in provision of a complete thermal plane. The Energy Code provides standard details for slab edge insulation in Figure 402.2.5. (Author Query: Figure 7?)

How do we work toward at least energy code compliance and preferentially complete thermal control and greater resiliency? When discussing energy code, I will be referring to the

FIGURE 6. Masonry-clad, Commercial Building Wall Section. *Source:* Collins + Scoville Architects, now CSArch, 2003



2015 International Energy Conservation Code (IECC), which was adopted with supplements in New York State in October of 2016.

It is important to understand the energy code compliance paths and the use of various calculations to improve wall and roof performance. Note that once a performance path is selected, the Energy Code requires compliance be demonstrated using only that path.

The most direct way to meet code is to use the R-value prescriptive method, which entails doing exactly what the code book says regarding the performance of the insulation aspects of the opaque wall system. Make sure the products used in the wall have at least the R-values listed in Table C402.1.3 (Author Query: Figure 8?) in the ECCC, NYS, 2016, for example. However,

FIGURE 7. Graphic describing the U, C, and F factor approach to Energy Code compliance per the NYS ECCC. *Source:* Urban Green Council *Conquering the Energy Code* presentation, 2017.

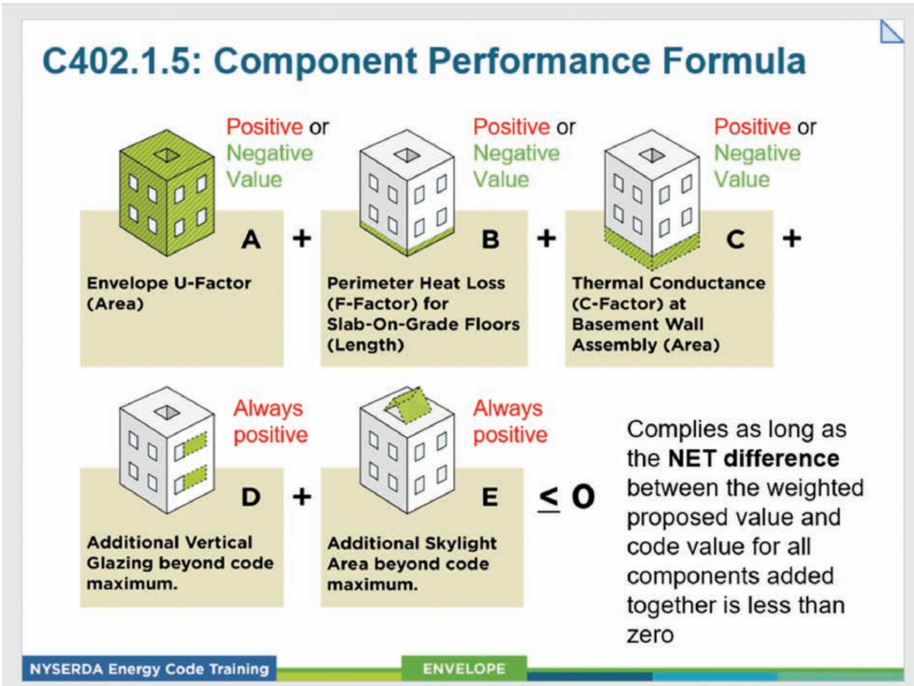
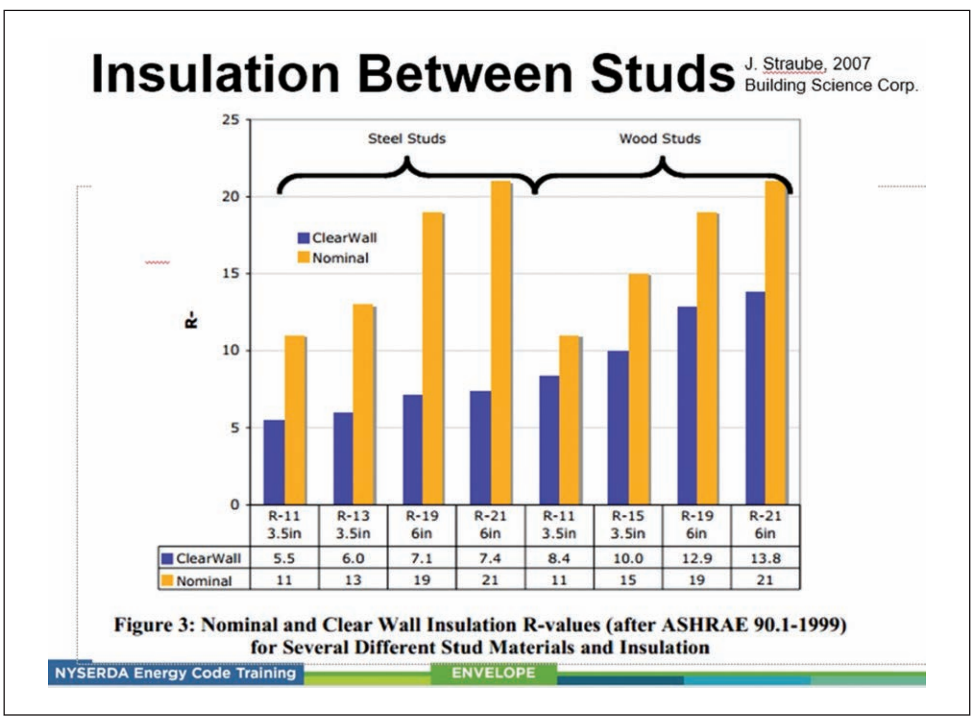


FIGURE 8. Graphic from J. Straube illustrating the actual R-value including degradation of stud thermal bridging. *Source:* Urban Green Council *Conquering the Energy Code* presentation, 2017.



for more flexibility and accuracy, another prescriptive path is the U, C, and F factor with trade-offs method. This method is more able to deal with the complexities of every opaque system in your building and to maximize the control of heat flow. In brief, this method determines the U-factor (i.e. heat flow) for each system and relates them, based on code minimum compliance, in percentages of the full building envelope. If one aspect has a slight improvement in thermal performance, it can potentially make up for a deficiency elsewhere.

You can, as a third prescriptive method, add-up the R-values of the materials in a wall system, or in layers of roofing, for example. This can include the R-value of air films as additive component in performance. Even paint may contribute a tiny amount. Please note that the nominal performance of insulation in the cavity of a stud wall is NOT the actual performance of that stud wall plane of the system. The energy code provides the actual R-value, understanding the thermal bridge detriment of the studs related to their spacing and the performance of the insulation material. And this detrimental effect is much larger in using cold formed metal framing (CFMF) studs versus wood, because heat transfers faster through metal.

You cannot, however, average R-values. In a very simple example, addressing insulation values only, envision a 1,200 square foot (sf) roof with 400 sf each of R-2 insulation, 400 sf of R-6 insulation and 400 sf of R-10 insulation. If these R-values are averaged one might think the average roof R-value is 6, which is incorrect. The R-value represents the thermal resistance, but thermal flow is what needs to be understood to gauge overall performance and required heating load. Heat speeds faster through areas with less insulation, so the magnitude of heat loss effect is heightened. In this roof example:

- Inverse the R-values to get the U-factor for each area. U-0.5, U-0.17, and U-0.10 respectively
- Add the U-factors and divide by three to get an average U-factor of 0.26.
- To compare this to the incorrect R-you thought you had, invert the U and you'll see the performance of this roof is an average of R-3.9 which is significantly less than the assumed R-6.

This story above is important especially when we seek to understand energy performance for sizing of equipment, and for predictive modeling to make design choices (or to meet code requirements). If the faulty R-6 had been used as the input value in an energy model, all resultant design decisions would be based on inaccurate data, and the finished building would not perform as expected.

FENESTRATIONS FOR LIGHT, VIEWS, AND HIGH PERFORMANCE

Windows and skylights are incredibly important because they connect the building user to the outside; they can help reduce lighting energy use, and they create the patterns and the "face" of the building. Their installation creates complexities in the thermal plane and air barrier continuity. Out of over 1,400 projects reviewed for energy code compliance, only 1% of those projects had provided the required information for Energy Code compliance for air infiltration, solar heat gain coefficient (SHGC), visible light transmission (VT), or U-factor. Almost the same percentage failed in on-site inspections due to incomplete air barriers and improperly installed insulation at the windows. (T. Y. Lin International, 2018) And remember that windows are much worse in thermal performance than a horrible wall, even when properly designed, detailed, and installed.

The best market-available window units in the USA, currently, are Passive House rated windows that can approach a unit performance of R-7. When windows can be easily 30–40% or more of area in a wall, even these high-performing windows represent a significant energy loss factor. The benefits to daylight harvesting, user comfort and productivity, and to building design and beauty must be maximized to create lasting value.

Windows and skylights give us the opportunity to speak about user engagement and even about synergies with nested systems of community and ecology. There is quite often a debate about operable windows versus fixed pane windows when speaking of energy efficiency. Fixed windows are easier to understand because there is a tighter level of control in temperature and humidity that can then be managed by building systems. There are an increasing number of projects, however, that have provided control of operable windows to the building users. These successful buildings engage the users in their own comfort control, allow a wider thermal range in the building management system, and link the windows themselves to the heating, ventilation, and air conditioning (HVAC) controls. When the windows are open, the heating or cooling shuts off or ramps down. Beyond this simple system shut-down, the most advanced buildings will use these operable windows as part of a planned natural ventilation system, promoting night-time flush-out to cool the building in the summer months, e.g., as part of the energy strategy.

This indicates a cooperation with nature's systems that can improve resiliency as well as comfort of the building users. How can we further benefit from nature's systems while we support it by reducing our energy use? Most buildings will have windows, so what if we understand the micro-climate of the site and place the windows and select the type of window operation based on wind data? Perkins + Will did this with a net zero "ready" residence hall in Massachusetts. Net zero ready means the building is designed for very low energy use specifically to achieve zero-net energy performance once a renewable energy system is installed to feed the energy requirements. By studying the wind patterns, they selected casement windows and placed them to either scoop air into spaces to improve natural ventilation flow, or to shield spaces where gusty winds could push papers off desks. There was a small additional cost for the casement windows over fixed or double hung, but the performance improvement of the windows regarding air leakage was significant, and the gains for the user and for the overall building energy performance were also significant.

FIGURE 9. Window Types and Wind Effect. *Source:* Perkins + Will, 2013

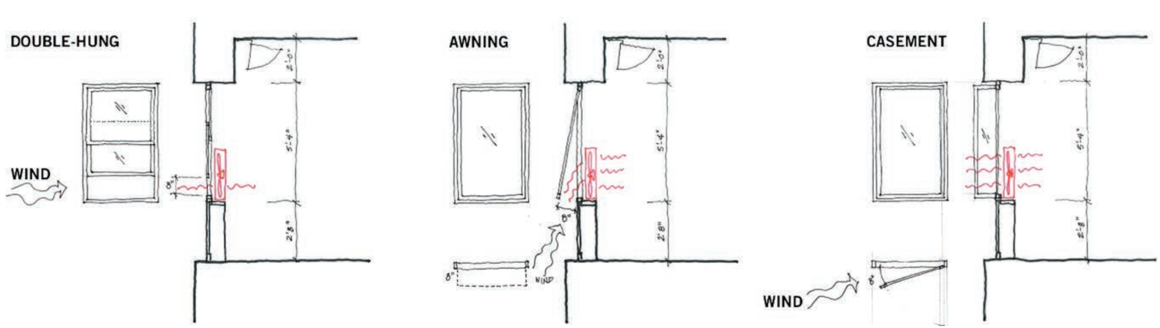
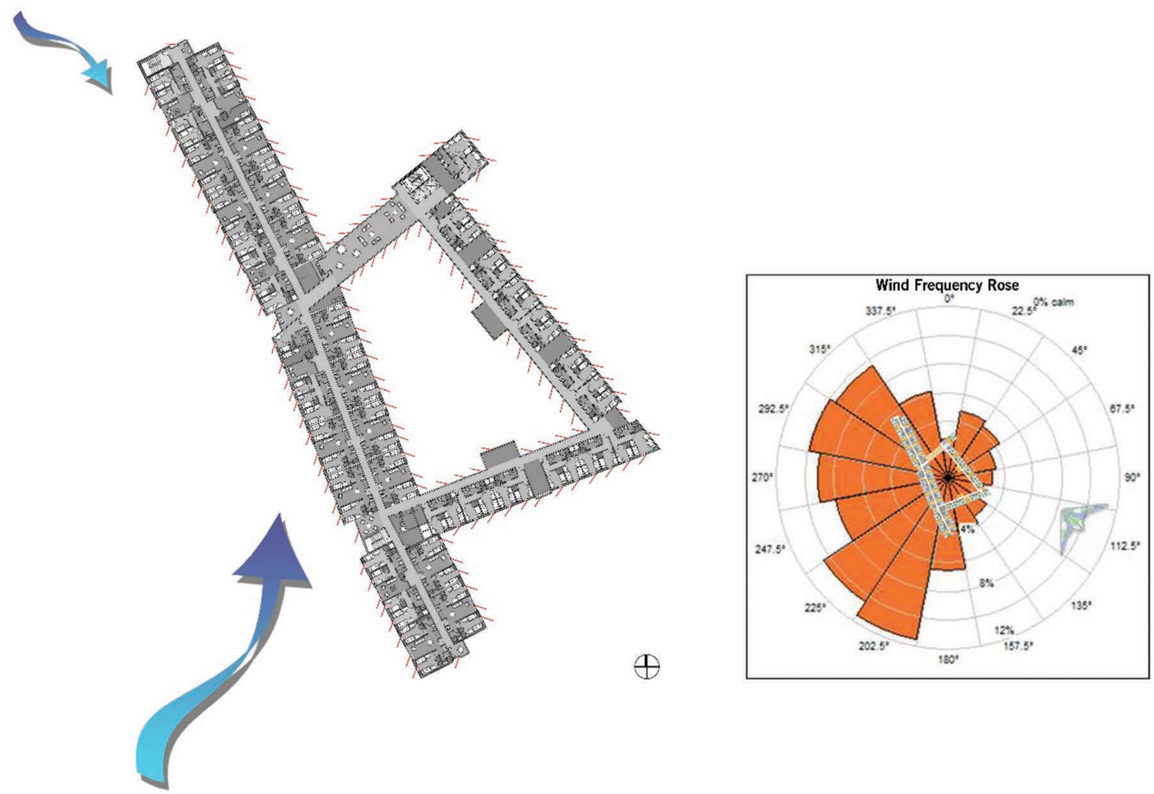


FIGURE 10. Wind Rose Study to Inform Window Placement and Selection. *Source:* Perkins + Will, 2013

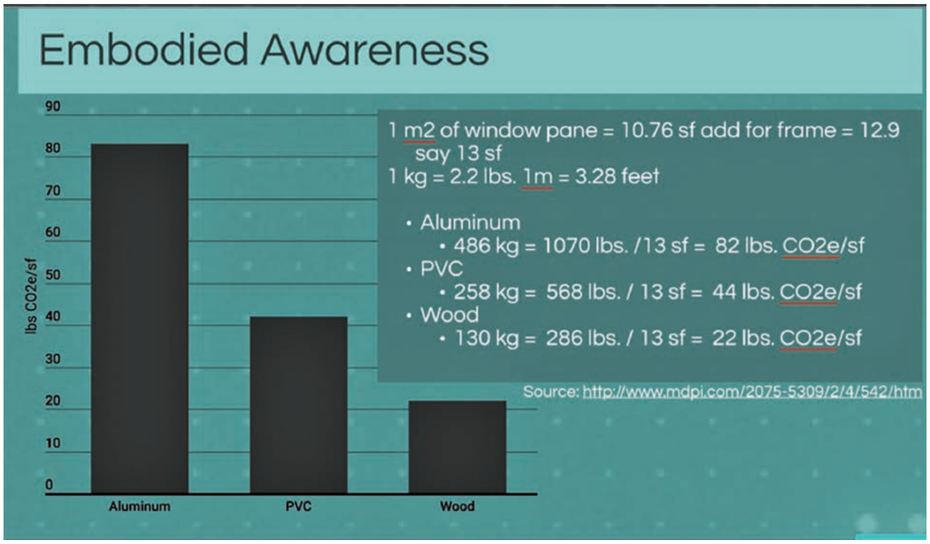


There are many important things to remember about windows.

- Every delivered window (to a job site) should have a sticker with performance information. Even so, about 10% of randomly tested window units do not meet the listed performance, especially for infiltration, so on larger projects or on projects where energy performance is critical, test at least a random portion of the delivered units.
- The center of glass U-factor (thermal flow performance) is not the whole unit U-factor. The mullions and window unit edges reduce the performance and you must understand the performance of the full window.
- Code compliance, including energy models and COMcheck, requires window wall areas based on the rough openings of the windows.
- Installation is imperative—maintain a continuous air barrier, install flashing properly, and make sure the insulation remains free of gaps and connects to thermal break placement in the windows to have a complete system with no "holes."

Embodied carbon can also be a consideration if the goal for the work is to reduce GHG emissions up-front and related to the life of the building. Window frame materials include metal, wood, metal clad wood, pultruded fiberglass, and poly-vinyl chloride (PVC). When

FIGURE 11. Embodied Carbon of Three window types from Escalating Excellence in Envelopes presentation. *Source:* Jim D'Aloisio (data) and Jodi Smits Anderson (graphics), 2017.



you understand the embodied carbon for each, you can make informed decisions. Aluminum windows are poor thermal performers, supporting very fast transfer of heat, and they have the highest embodied carbon burden. They are about twice as problematic as PVC which are, in turn, about twice as burdensome with embodied carbon as wood windows. Wood windows, however, will take more maintenance care than PVC or aluminum. Understanding the Total Cost of Ownership of the window units as well as the embodied carbon issues is necessary for intelligent decisions.

Current glazing configurations include double pane, triple pane, argon, or krypton gas filled, interior film glass, and more. Inert gases, such as argon and krypton, leak over time, with perhaps a 10% loss over 20 years. This does not sound like much, however the inert gas is likely only buying you a tiny improvement in overall U-factor, so the 10% loss can quickly eliminate the value of the added window unit cost.

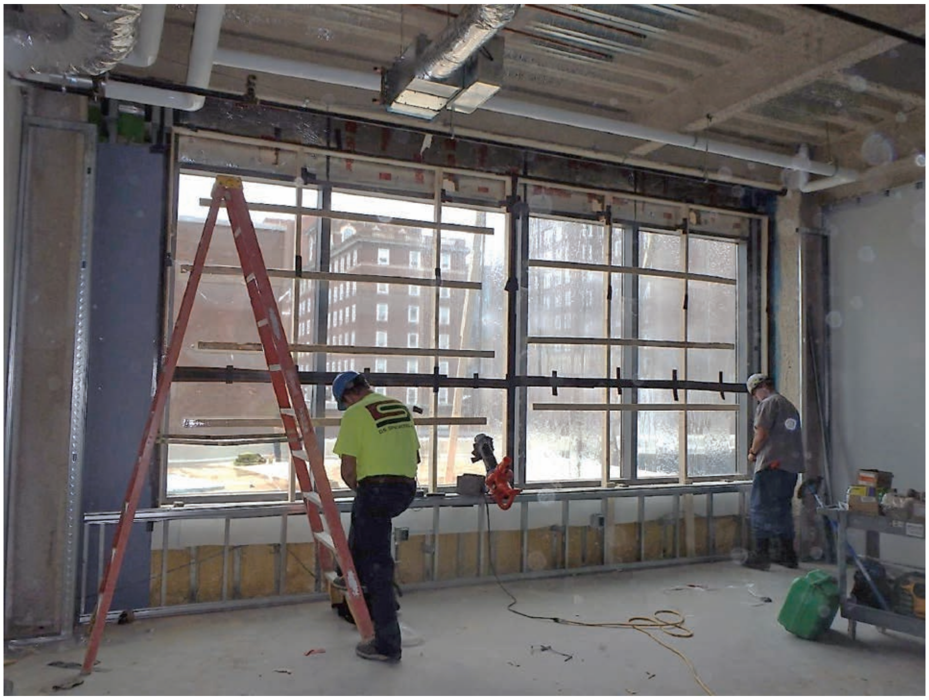
There are also storefront and curtain wall systems. These should be defined with significant thermal breaks to reduce heat loss and with good water control within the system. When using complex systems such as these for expanses of the building envelope, especially if they comprise more than 30% of the envelope, call for mock-ups in your bid documents and contracts with the contractors. Also define the required on-site inspections and any testing of the full system and connections to the other aspects of the building envelope to ensure good detailing.

ELIMINATION OF THERMAL BRIDGING IS IMPERATIVE

Elimination of thermal bridging is so important to building energy performance, durability, and comfort, that PHIUS (Passive House International United States) and PHI (Passive House International) call for elimination of thermal bridging as a requirement for certification.

It is easy to understand the energy loss aspect of thermal bridging. Structural steel transfers heat about 1,000 times faster than wood does, so when you use metal studs, for example, you transfer energy through the wall faster than if you use wood studs. This is remedied by inclusion

FIGURE 12. On-site Water Testing of Fenestration Assemblies. *Source:* Jim D'Aloisio, 2017.



of a plane of continuous insulation on the outside of the studs. In the case of structural shelf angles, typically used to hold exterior cladding brick up at each floor, the issue is severe at the location of that angle. The support angle needs to be thicker to support the brick, e.g., in the exterior wall if there is greater continuous insulation, so there is a thick sectional area pumping heat out past that insulation. This heat is conducted into the brick above and below the shelf angle, and calculations reveal a 3' area of wall above and below that shelf angle is affected by this heat conduction. The thermal performance of that expanse of wall is brought down to U-0.44, which is worse than a bad window. However, this heat bleed is easy to avoid by simple structural offsets. This creates a cheaper construction approach as less metal is used. Making this structural decision ensures a wall performance for that same 3' area of U-0.13, which is better than a very good window. You can also employ stainless steel, which conducts heat significantly slower than carbon steel.

Thermal bridging can decrease the durability of a building significantly. Discrete bridging can cause condensation within the thermal envelope, or worse, within the wall itself. This can, over time, rot out wood, wet the insulation and decrease performance, rust steel components, or lead to mold. Even with no condensation, the warming of the mass elements will create a differential freeze/thaw stress on the materials and joints over time, which can lead to cracking or spalling.

The most compelling aspect of thermal bridging, to a building occupant such as myself, is the comfort factor. Below is a thermal photo of an uninsulated slab edge/wall juncture, from the inside. That area of cooler surface creates cold eddies underneath the work surface, especially in the harsh winter months of Upstate NY, leading to discomfort and an increase in occupant complaints.

FIGURE 13. THERM study of thermal bridging and effect on performance. *Source:* Jim D'Aloisio, 2017.

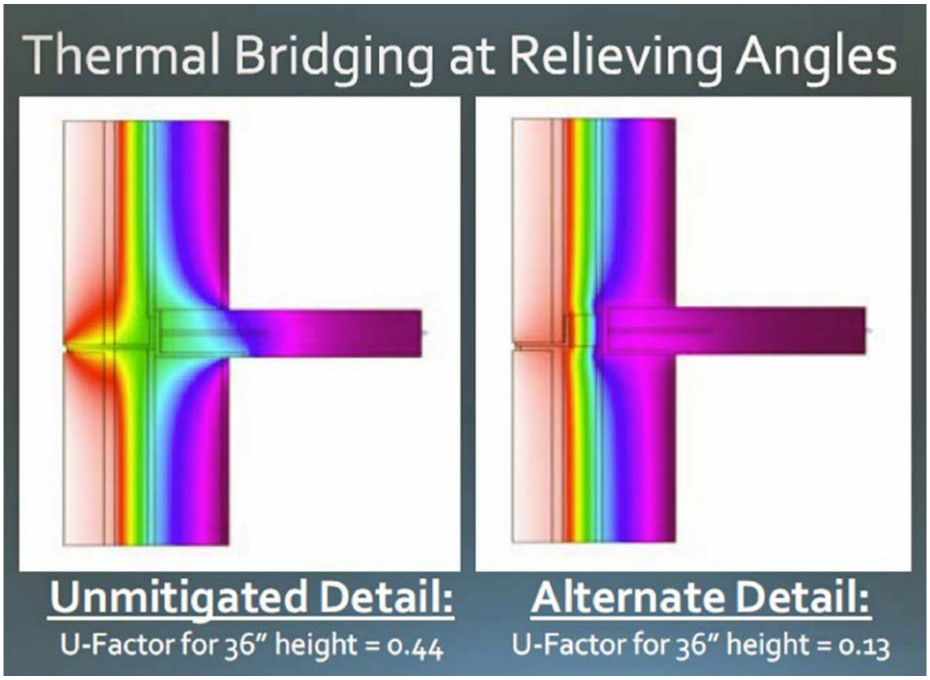
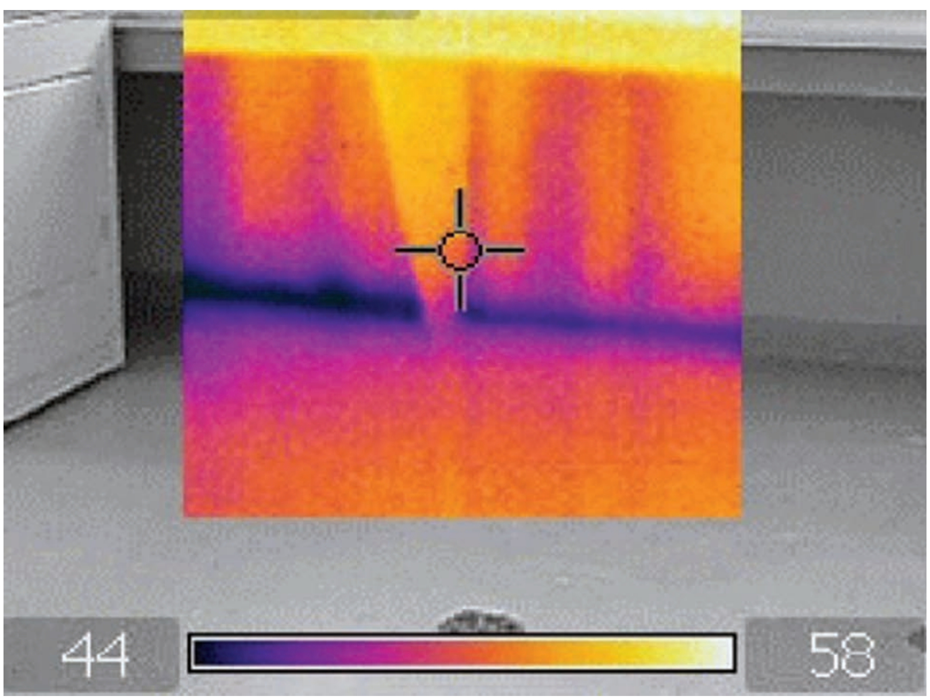


FIGURE 14. Thermal image of cold slab edge condition in office. *Source:* Jim D'Aloisio, 2017



As mentioned earlier, there is a growing awareness of the importance of eliminating thermal bridging. In Germany, Manufactured Structural Thermal Break Assemblies (MSTBA) have been used successfully for decades to eliminate heat losses, especially when concrete slabs penetrate exterior walls for balconies or other external continuities. MSTBAs are now available in the USA. They do cost more than no thermal break, but create excellent operational efficiencies, improve user comfort, and protect building durability.

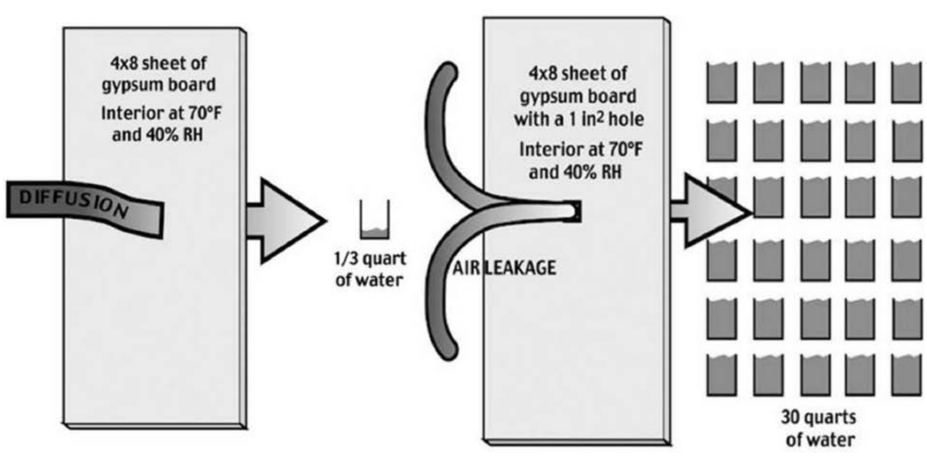
A significant take-away regarding thermal bridging is that it is an un-noticed issue. The performance data is not properly included in COMcheck, the typical submission tool for energy code compliance, or in energy modeling inputs, and the heat loss is not comprehensively addressed. The other lesson to understand is that thermal bridging is primarily a design problem, or a problem of thought, rather than a money problem. Detailing done in communication with the structural engineer, clarity in the documents, and a good, iterative relationship with your energy modeler are all significant help in this effort, along with an active increase in communication with construction companies to help them familiarize themselves with these new systems and approaches.

COMPLETE AIR BARRIERS FOR A COMPLETE SYSTEM

One of the ironies of building tighter envelopes is summed up by this statement: "When you build it tighter, you have to build it tighter" (Jim D'Aloisio, 2018). The truth in this is undeniable. Depicted below is the classic graphic illustrating the amount of water that is moved by air. In ensuring a continuous air barrier we create a complete and dependable envelope for the building so that we can not only control the conditions within the building but protect the building itself from degradation by water and water related deterioration. When you build tighter, each break in the system needs to be sealed.

This is a change in approach that has taken some time as the building industry has learned and adapted. We first recognized the need for tighter buildings but did not address the need for ventilation, drying of water that did get into the envelope, or reduction of toxins in our building materials, hence "sick building syndrome." We then learned to bring in ventilation in a controlled manner, and we focused on keeping water out of our walls, mostly by applying

FIGURE 15. Water Intrusion Through Diffusion Versus Through Air Leakage. *Source:* Building Science Corporation, 2017.



a vapor retarder. The notion at that time was that moisture in a high humidity interior space would migrate through materials and condense in the wall when the dew point in the transition was reached, causing water related damage including mold. Mold needs water, food, and the spores themselves to grow and proliferate. The vapor retarder and detailing to prevent water intrusion became common. There are, however, a few problems with this. First, keeping water out is a goal, but must be backed up by a way to get water out or dry it once it does get in, such as hydrophobic materials that do not absorb moisture, an air space, and weeps. Another approach can be materials that are hygroscopic, meaning they absorb and release moisture with no negative affect to the material. If using hygroscopic materials, you must design the wall so that the material can dry to at least one side. The current methodology, fully entrenched into the energy code, relies on an air barrier, provided on one side of the thermal plane, and affixed to it. Air moves a significant amount of moisture as compared to vapor transmission through materials, as illustrated above. With an air barrier, the movement of air is stopped. It is important to note that weather resistant building wraps, such as felt papers and Tyvek, are great in protecting materials from weather for reasonable periods during construction, but they are not usually installed to be reliable air barriers. "If house-wraps and other film membranes are not fully supported on both sides, as is the case in a brick cavity wall, they cannot support negative wind loads without tearing at the staples and brick anchors or rupturing under load." (Bosack and Burnett, 1998).

The air barrier must be complete: no penetrations, no gaps, and every detail at every condition illustrating how the air barrier will be constructed and made complete via the manufacturer's approved methods. This may be lapping and taping with a provided tape system as in Zip-sheathing, it may be a self-sealing barrier such as an ice and water shield, or it may be an applied spray to seal up each over drilled screw.

A hole or a gap will be as a highway to air, especially in pressurized conditions, (every conditioned building will experience pressure differential) and this highway will drive moisture through that gap and allow that moisture to reach a dew point and condense. Ice dams on roofs are often due to thermal bridging which can melt snow and ice, but also contributed to by a faulty air barrier system. In winter, in the northeast USA for example, interior air is directed out that small gap or hole, bringing with it moisture and heat, causing a melt of snow and ice and then a freeze at the roof edge, driving that ice up into the building envelope.

Current IECC calls for blower door testing for residential buildings. This is the performance-based method for testing air barrier completeness. In NY City, there is an additional requirement for blower door testing for commercial buildings up to 50,000 square feet. Blower door testing can be done to identify areas of leakage by using a smoke generator, so that these leaks can be fixed. It is easier, of course, to focus on the construction process and adherence to details and completeness than to try to fix errors once the envelope is mostly complete.

This same code calls out several materials and assemblies that qualify as air barriers. Remember, however, that transitions between materials must support that complete air barrier system to achieve compliance and the anticipated performance. For example, a concrete masonry unit (CMU) wall with two layers of latex paint is considered an air barrier in the code, but it will function as such only if the control joints are fully air sealed and remain complete and attached as the system flexes over its life.

The construction of the building must be monitored to ensure a complete air barrier. More job sites are restricting sharp implements on the site such as utility knives or even hand-held screw drivers to reduce accidental and purposeful cuts that are not then repaired. In a recent

FIGURE 16. Blower Door Test in Commercial Building. *Source:* Urban Green Council *Conquering the Energy Code* presentation, 2017.

Passive House blog by Elrond Burrell, he shared an excellent story about "Joe," a ubiquitous name for a contractor on the site who would be responsible for continuity of the air barrier. Every needed hole had to be approved and witnessed by Joe and every needed hole required Joe to have a plan ready to seal it up and every needed hole repair received a confirming inspection, from Joe.

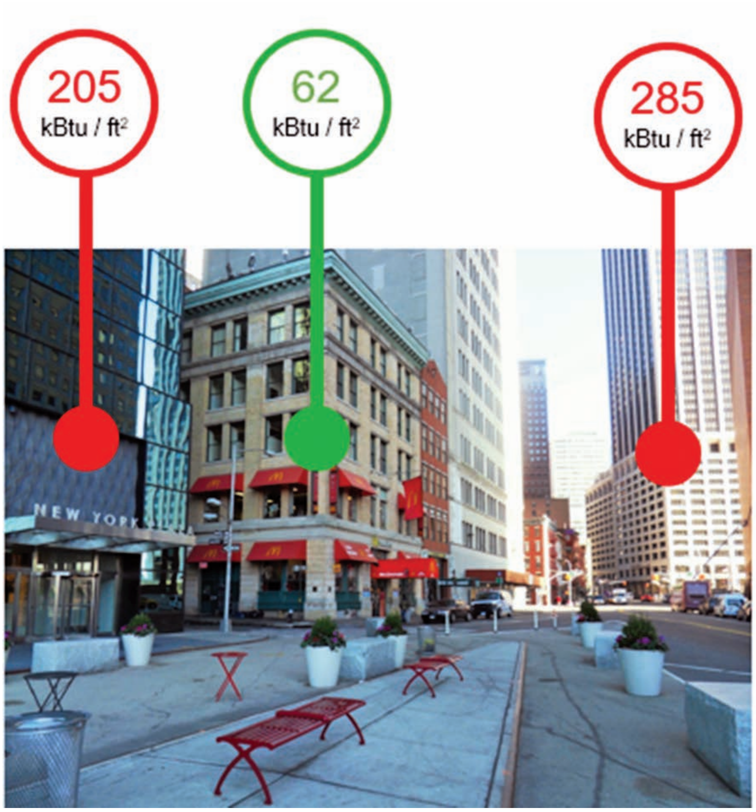
EXISTING BUILDINGS ARE A CHALLENGE AND AN OPPORTUNITY

Our biggest opportunity and resource is our existing building stock. Our biggest challenge is updating these buildings to be good energy performers. In this section we will talk about the value in this effort and the complexities in updating existing building envelopes. We will also touch on some current efforts to ramp up our retrofitting of existing buildings.

The opportunity is massive as noted by www.architecture2030.org where 85% of the buildings that will exist in 2035 already exist today. Further, 60% of existing commercial buildings in the U.S were constructed before 1980, and, as shown in the illustration below, the EUI of commercial buildings varies tremendously. We will be doing work on these buildings, so we should focus on doing this work to reduce energy waste and overall use. By addressing energy use and bringing that down to net zero or to near net zero, we are accomplishing a few major goals: 1) preserving many buildings that are of cultural or community value, 2) increasing the resilience of those buildings, and 3) making sure that volatile operational energy budgets can be reduced and used in projects or programs more important to the mission of that building owner.

There is some irony in the fact that historic buildings are exempt from meeting the energy code. This is because of the complexity in improving the energy performance and tightness of

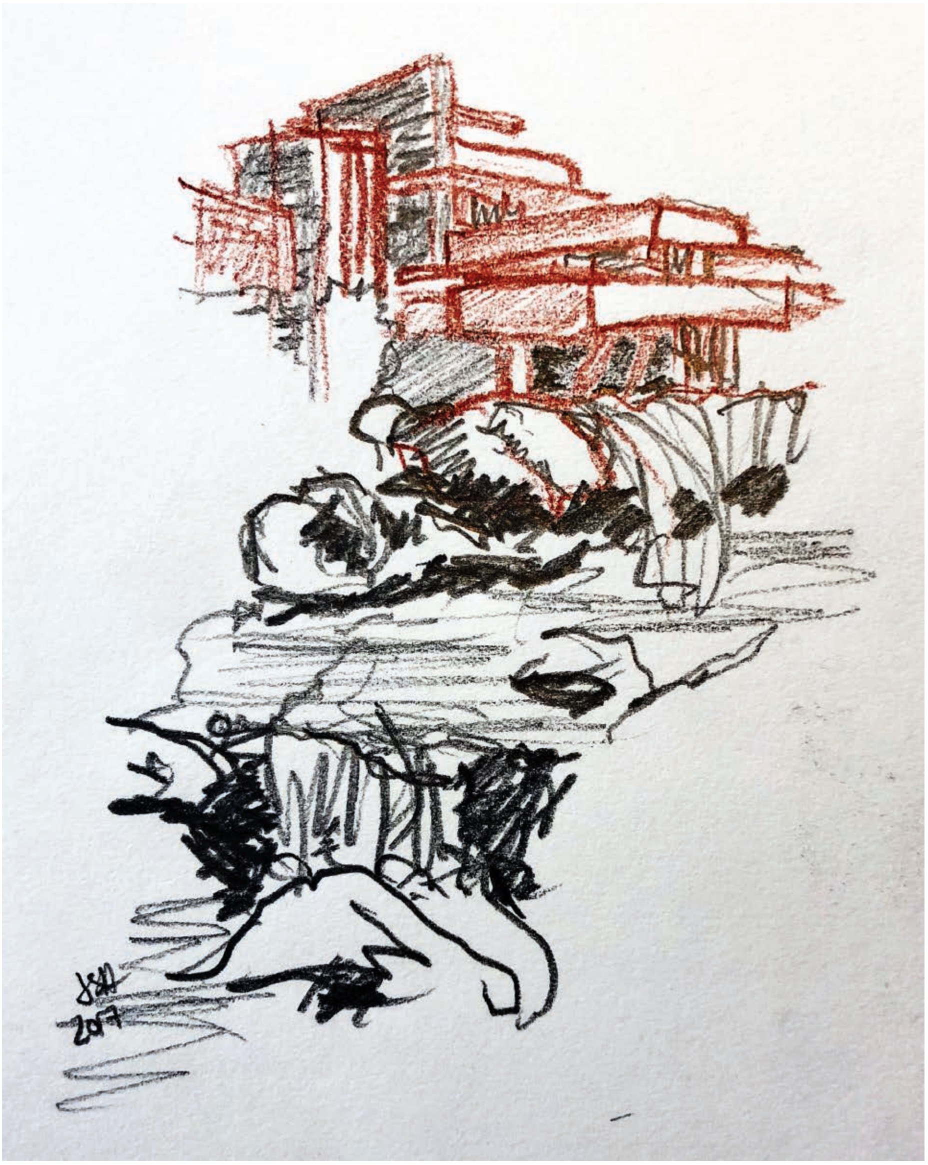
FIGURE 17. Actual NY City Benchmarking Data. Source: Urban Green Council *Metered NY*, 2015.



a building that was never designed to be tight in the first place. It is also that in updating an historic building, the revelations of that period in history may be obscured or re-defined inappropriately. Fallingwater, depicted below, is an historic icon that has been renovated to improve structural safety, however, there is no way to improve thermal performance without diminishing the original design intents. As this building is no longer a home/camp, but a museum to display the architectural innovations of Frank Lloyd Wright, this is acceptable. Yet some historic buildings could benefit greatly from improved energy performance, reducing operational costs and improving the comfort and durability of the buildings. Even with setting exempt historic edifices aside, we have a tremendous number of existing buildings in need of energy efficiency upgrades.

Let's talk first about buildings that were built before central HVAC systems. These buildings often related well to the site by at least protecting entry doors from prevailing winter winds and providing shade porches shielding the occupants and interiors from harsh summer sun. We did not have the engineering capabilities to maintain tight parameters of temperature and humidity. Additionally, people were accustomed to wider ranges of comfort. Many buildings did not have insulation and the occupants relied upon gathering near heat sources as opposed to heating the full volume expanse of the space. Warmth, for example, was created by warming bedsheets with hot stones and providing thick duvets instead of heating the entire bedroom. Also, there was no active cooling readily available for our buildings until well into the first decades of the 20th century, after Willis Carrier installed the first A/C unit in 1902. However,

FIGURE 18. Sketch of Frank Lloyd Wright's Fallingwater. *Source:* by Jodi Smits Anderson, 2017



labor was cheap compared to materials, and the craftsmanship and detailing of older buildings has given us durable gems often worthy of adaptive reuse. In addition, the location, typically in what has become a well-developed city, town, or campus, can make the building value significant enough for further investment.

My home was built in 1922. It was one of the first suburban developments outside Albany, NY, and is now part of the city, on several bus lines, and less than three miles from the heart of the Capital of NY State. It has a small footprint of 1,160 sf and the walls are, from inside out, paint, lathe and plaster, wood studs, and exterior clapboards; No insulation, no air barrier. Fire safety is provided by scraps of brick at the rim joist above the concrete basement walls. The wood studs create minimal thermal bleed. There is a lot of leakage especially through double-hung wood windows and the spaces for the window weights. Heat was provided by a furnace and a gravity steam system with large iron radiators. With a broader comfort range typical of the time, this was a comfortable home. Sitting near radiators was mostly cozy and radiant heat did not create air movement that would have exacerbated air currents or air movement through walls. The heavier materials such as lathe and plaster and wood afforded some thermal mass, somewhat attenuating the comfort curve. Any needed fresh air was provided by opening windows, and the make-up air for fireplaces, furnaces, and boilers was provided by leaky walls. This was fine as drying occurred in both directions and the pressure differential was minimal if any existed at all. If we were to add central cooling to this house and strive to maintain a tight temperature and humidity range, we would have a lot of work to do.

The challenges in these buildings, as well as in masonry buildings that rely more on thermal mass to mitigate temperature swings, are surmountable yet costly. They become costly due to our contemporary need for restrictive parameters for humidity and temperature, and changes in our climate that may require the addition of a cooling system as well as improvement of heating systems. Adding cooling to a building certainly makes the envelope system more challenging. The walls must be tightened, and the R-values increased in a way that protects the exterior walls, meaning that the application of insulation and air barrier must be done to allow drying to one side at a speed that will not cause freeze/thaw in colder climates to spall the masonry. Most buildings are more humid inside in the northeast in the winter, yet there is more humidity outside in the summer when using cooling systems within that dry out the building. Therefore, an air barrier is vital.

This can be simply done if you can do the improvements fully on the outside of the existing exterior walls. A wonderful example of this is taking place in the Netherlands, and we are now working in NY to develop similar, market transforming, retrofit strategies for our existing multi-family and residence hall buildings. The idea is to overlay existing buildings with panelized systems that function as complete thermal and air barrier planes, as well as exterior finish materials, and in some cases including energy production for heating or cooling. The systems change and update the appearance of the buildings, but, more importantly, create a complete envelope, with no interruptions at floor plates or transition to roof. For an excellent example, look to the work detailed at http://energiesprong.eu/.

However, if you want to maintain the beauty of the exterior masonry, or other detailing, how do you create a complete air barrier and thermal plane from the inside? The complexity of that situation is revealed especially at transition points. How do you access the space at the roof to wall connection, at each floor and at the point where the building meets grade or goes below grade? Is there any way to create a continuous air barrier and thermal plane? And once you have addressed thermal containment and the air barrier, you must provide the proper amounts of mechanical ventilation often requiring entirely new mechanical and distribution systems, which will add penetrations, and can reduce usable space.

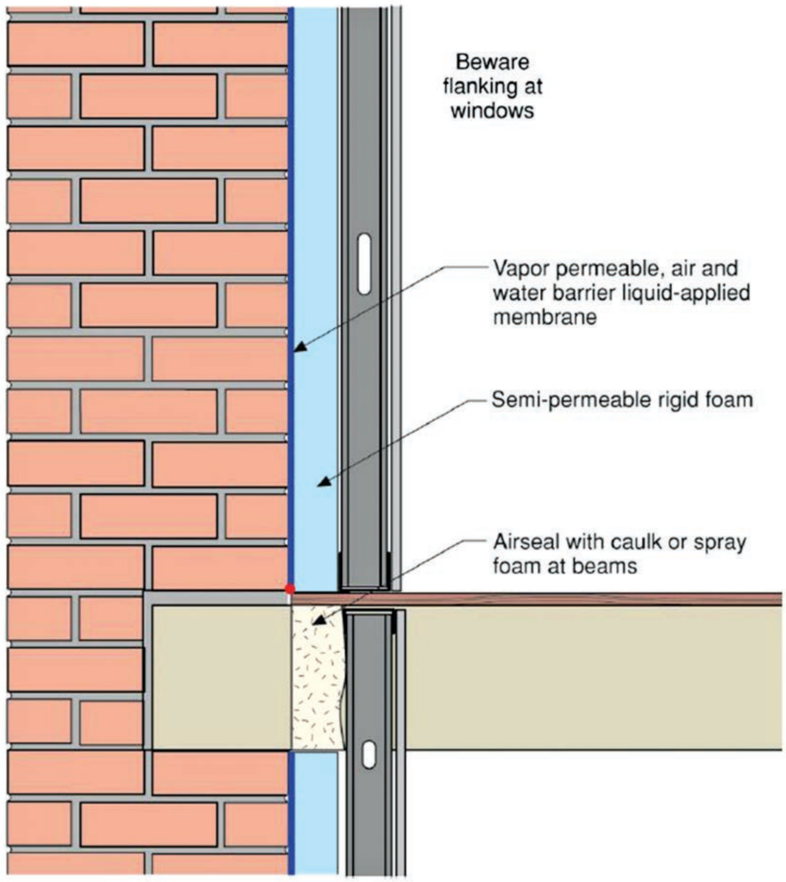
When adding insulation to the interior, the temperature of the masonry outside the new thermal enclosure will be reduced, which will in turn reduce the drying capacity of the masonry and potentially add to freeze/thaw damage or salt efflorescence. This is true of a solid masonry wall with interior insulation as well as of a cavity wall system. The greatest increase of water into masonry is via capillary flow. To mitigate this risk, all installations of interior insulation should also seek to reduce exterior wetting of the masonry, and thereby reduce the water intake via capillary action. Rain, especially wind driven rain, splash-up at grade, flow of water off the roof and down the walls, should all be considered and ameliorated. Locations with significant impact include corners at windows, any variances in plane such as at decorative detailing, lintels, or water table lines, and this means that drip edges should be replaced or maintained as well. Masonry can and should be repointed, and damaged units replaced. Increasing the overhang of the roof as well as removing trees and shrubs to reduce the drying time can also be very helpful.

Avoid adding a system of stud and batt insulation to the interior side of an exterior masonry wall, as this will always create gaps between the existing wall and the new materials that can unfortunately function as stack spaces, pulling moisture into the wall from the interior spaces through the hard to avoid gaps at floor and ceiling/roof structure. With air comes moisture, and this will condense against cold masonry at the outer portions of the wall. Therefore, stud and batt approaches create condensation in the worst month for freeze/thaw risk, and increase risk of mold within the wall system, all while reducing the effective R-value of the insulation through airflow.

"The use of semi-permeable foam insulation in contact with the back of the existing masonry is the most common successful strategy for interior insulation retrofits with a track record of success." (Straube, 2007) This approach is also the most reasonable approach in the field as the interior walls are accessible without extensive scaffolding and there is no blatant exposure to weather during construction. However, occupants cannot stay in place.

FIGURE 19. New London, CT Union Station by H.H. Richardson, circa 1887. *Source:* Jodi Smits Anderson, 2018

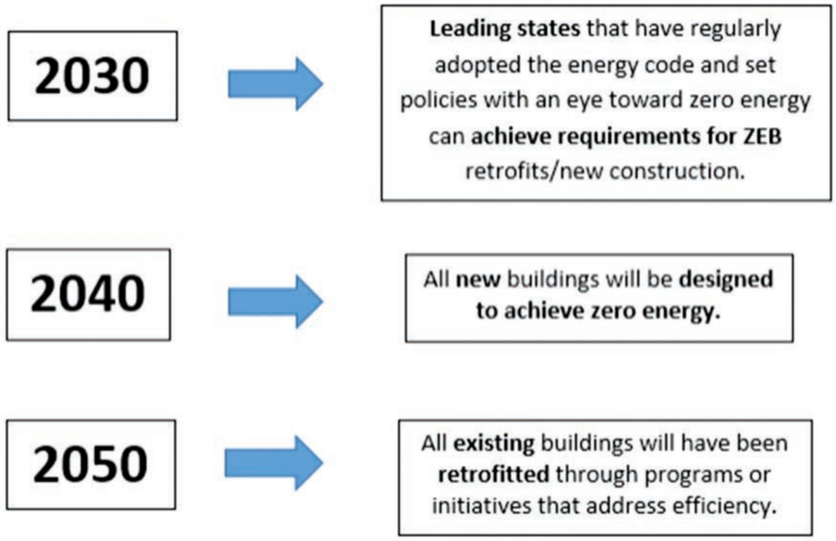
FIGURE 20. Increasing Insulation in an Existing Masonry Wall from Interior. *Source:* John Straube, Building Science Corporation, 2007.



Buildings built in a time before the energy crisis, in the 40's through early 70's, did not seek to reduce energy use but were faced with tightening parameters of personal comfort, as well as quality issues created by a huge building boom after WWII. Buildings may have included insulation, yet they still leaked like a sieve, and they certainly relied on energy use and HVAC systems to maintain comfort control. Fuel was cheap and even a full glass building, or a complex concrete or metal building with exposed structure for visual drama, was a good investment because you could simply engineer the fix and apply heat in the winter and cooling in the summer as needed, regardless of the quantity or cost of the fuel use. These buildings are likely harder to improve, but the energy benefit will be enormous because of the opportunity to eliminate so much thoughtless waste. Full-glass walls may or may not be double glazed, likely have aged sealants, and do little to benefit from the movement of the sun or the prevailing wind directions on-site. We can encounter fiberglass and blown-in insulations that are gaping or settled, and walls that include no sign of any reasonable air barrier. If improvements are to be made, it may be that a pre-manufactured, exterior, panel approach, nearly a building surrounding the existing building, will create the least disruption of existing materials.

The issue is truly how to fix something so intensely bad, and a building of this type may, in the end, be cheaper to demolish, especially if it also includes the challenges associated with

FIGURE 21. Building Energy Goals Based on Trends and Analysis by U.S. Department of Energy (DOE) and Pacific Northwest National Labs (PNNL) *Source:* NEEP 2017



hazardous materials such as polychlorinated biphenyls (PCB) in window caulk, and asbestos in joint compound insulation, floors tiles, and mastic.

The first USA energy code came into play in the mid-1970s in response to the energy crisis of that time; the first revelation of the limits of fossil fuel energy supply. Buildings built to-code, post energy code, will either be well-performing, needing only additional thermal value and air barrier in their walls to further reduce energy use, or they may be experiencing air quality issues due to toxic materials or improper understanding of moisture movement in wall systems. Decisions will have to be made about the problems to be addressed and the value of the building itself. Adding ventilation will help with air quality but using this approach without dealing with the envelope issues will decrease energy performance and exacerbate energy costs.

Roofs must be addressed. For a flat roof, you have several choices including simple re-coating with sheet membranes such as EPDM and TPO, or liquid roof coatings, which can easily improve Solar Reflective Index (SRI). Higher SRI is useful even in the upper NE, as lighter color will reflect sunlight away in hot months, reduce ambient temperatures on the roof and localized urban heat island effect, and reduce freeze/thaw ranges, all which can improve roof life. You can do a minimal replacement by cutting out wet spots and then repairing and adding insulation or rip off the existing insulation and membrane for full replacement.

It is important to note that there is nothing wrong with a well-maintained flat roof with ample insulation and proper drainage. However, another consideration is to raise the roof and create a sloped roof on what was previously flat. Shedding snow and rain well can help a roof last longer, but be aware of where the precipitation lands, including any effect due to subgrade conditions or if there is melting, draining or splash-up onto walls. In existing sloped roofs, often the insulation is at the "lid" or attic floor above the ceiling of the top livable space, and this is intended to be the thermal and air barrier, but it may be perforated in many places or not continuous to the walls. In retrofits, you can opt to move this thermal and air barrier plane up to the roof or leave it where it is, and repair it. For any roof, make sure the thermal plane and the aligned, attached, air barrier are continuous between roof and walls or attic "lid" and walls.

One exceptionally tough remediation for energy efficiency performance is below grade and slab. Buildings typically are slab-on-grade with footings/frost walls, crawl spaces, or basements conditioned or unconditioned. The key to any retrofit work is, of course, to define and maintain the continuous plane for the insulation and air barrier and eliminate thermal bridging. Many slabs were not insulated, and although soil is at a decent 55 degrees year-round and is warmed a bit over time by occupancy of the building above, heat will still be lost to the earth. Insulation can be added on top of the slab, raising the floor level, or can be added outside the building by excavations either tight to the foundation and footing to below the frost line, or by providing protected horizontal insulation to the distance called for in the energy code. There may not be an ability to fully connect the insulation planes at this existing transition, especially if the insulation is being added to the building from the inside at the occupied areas. Great attention should be paid to the possibility of moisture drive to the inside, and provision of space allowing drying to occur to one side of the wall. Worse than allowing moisture in is not allowing it to get out.

If the building is of value, then it is important to increase the R-value in the building envelope and add an air barrier, using building science to determine the moisture conditions within the wall including drying potential and dew point/point of condensation. Then the building will continue to be of value.

Of course, any intervention is difficult if funding is not available. In some cases, we can only begin by identifying an efficiency that can be created through behavior change or change in operational parameters, capturing the savings, then investing the savings into the future energy efficiency work. It is a worthy process. For example, in a six story, 180,000 square foot office building built in 1997, our first step was to change temperature set-points to broaden the comfort range, along with changing the dress code for employees. We saved approximately $10,000 a year in energy costs from, primarily, reductions in needed electric cooling, and we then used this "seed" money for other efficiency work over time.

Another way to understand the costs of upgrades to the building envelope is to engage in Total Cost of Ownership accounting. Set a palatable return on investment timeframe. This may be tied to the repayment agreement for a loan. Then do the math to understand the envelope investments, savings on energy use, cost of energy systems, and costs of maintenance and replacement over that timeframe, to determine what is cost-manageable or beneficial over that total timeframe of ownership. It quickly becomes evident that cheap approaches up-front are often not cheap over a decade or more.

Some main thoughts in retrofitting buildings:

- We are going to be doing work on existing buildings; Let's do it well.
- We need to avoid replacing solely MEP systems because those systems must be sized for the actual load. Only building envelope improvements can reduce load, allowing use of smaller and likely less-costly MEP systems.
- Though window upgrades are a large expense with a long return on investment (ROI), they provide excellent potential improvement in user comfort and building durability, provided they are well-installed.
- Make sure insulation and air barriers are complete at transitional points: at eaves, at penetrations, between materials, etc.

- Consider the usefulness of additional performance achievements to a renovated roof, such as higher SRI, skylights, green roofs, or adding PV or solar thermal on roof.

SUMMARY

As shared throughout this article, there is great potential to reduce energy use and GHG emissions, improve user comfort and health, increase personal and community resiliency, and protect the value of our buildings when we focus on exemplary envelopes. The challenges are easy to face in new construction, and can be quite complex and challenging in existing buildings. In all cases, the investment in the building envelope can improve performance and yearly operational costs over the *full life* of the building. This is a target of investment in the durable portion of the work as many buildings will be around for hundreds of years, while the energy systems within those buildings change more often, having an anticipated life of about 15 years.

Create a consistent and complete thermal plane with a performance level that helps maintain comfort levels for a week or more with no energy inputs, ensure the air barrier is also complete and aligned with that thermal plane, even over transitions, make sure the building is usable and maintained. Then it will be cost effective to provide right-sized ventilation and energy supply systems.

The best buildings seek exceptional "engineering without engines" (Bjark Ingels, BIG 2016), meaning the needed energy inputs are reduced significantly through engagement of the full design team. Building envelope performance is the first and most significant element in making this achievable.

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