Section J-3

Building Envelope

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1. Introduction

As building enclosure systems are becoming more advanced, building and energy codes are becoming more stringent, and the need to conserve energy is more critical than ever, it has become increasingly important for architects, contractors, and owners to have a more thorough understanding of how the building envelope functions and how it can be designed and constructed to be more efficient and effective. Building codes and certification systems, including the International Codes, ASHRAE, LEED and other sustainable design rating systems provide detailed requirements for how building enclosure systems should be designed, constructed and evaluated. In addition, building owners now demand greater performance from their buildings and rely on advanced QA and QC testing practices that have become more prevalent and sophisticated.

Building Envelope Components

The enclosure system for every building includes a number of primary components including *walls, glazing systems, doors, roofs, floors, slabs, and foundations*. When evaluating the performance of a building enclosure system, each component must be considered individually and collectively as a whole system. Traditionally, walls and roofs are typically the most scrutinized components, but the other components can be equally as important to the overall performance of the entire envelope.

Within most of the components listed above, there are a few parts that are common to most components. An easy mnemonic to remember is “SPAIGR”, which was developed by Steve Lee of Carnegie Mellon University. These components are listed in order from inside to outside (for most typical building assemblies).

- S = Structure
- P = Panel
- A = Air Barrier
- I = Insulation
- G = Gap
- R = Rain Screen

Structure consists of a structural layer that may be metal or wood studs, columns and beams, masonry or concrete walls, slabs, or decks. This component may not be the building’s primary structural system, but it ultimately serves as the component that supports the exterior envelope. Additionally, an interior layer of drywall or other finish material may be present.

Panel is the layer that includes drywall or wood sheathing, or wood or metal decking. The panel component may not exist in envelope assemblies with solid structural elements like masonry or concrete walls. The panel component may provide structural stability while also providing a solid surface for the attachment of the air barrier.

Air Barrier is the layer that restricts or reduces the flow of air from inside to outside or vice versa. It may also restrict the flow of water and/or vapors from moving into or out of the building. In some assemblies, this layer may also be the layer exposed to the elements, i.e. roof membranes or foundation waterproofing.

Insulation is the layer that reduces the transfer of heat through the wall. It may consist of foam insulation boards or spray material, fiberglass or mineral wool insulation. In most situations, it is more advantageous to locate this layer outboard of the panel and air barrier layer. Additionally, most current energy codes require or encourage that the insulation layer be located outside of the air barrier layer. This is why this layer is sometimes referred to as “outsulation”.

Gap is a layer consisting of an air gap. The air gap contributes to the insulation value of the wall while also providing a location for water to collect and drain out of the wall before it enters the building. Rain Screen is the portion of the envelope that is exposed to the weather. This component is primarily associated with walls. Rain screen systems typically include masonry veneer, metal panels, cement fiber, terra cotta, and precast concrete panels. A true rain screen is an exterior cladding material that is held away from the air barrier and insulation layers and provides an air space that allows for water drainage and air movement.

Heat Transfer

The transfer of heat through an exterior envelope typically occurs by means of conduction, convection, or radiation. The highest performing thermal envelopes are those that restrict heat transfer to the greatest extent.

Conduction is the transfer of heat between materials which are in direct contact with each other. This may occur through continuous building materials like masonry ties, fasteners, metal studs, beams or columns that penetrate the envelope, or masonry. In most cases, heat transfer by conduction is not desirable and may greatly reduce the thermal qualities of the envelope. Wherever possible, conduction should be reduced.

Convection is the transfer of heat through gases or liquids. In buildings, this typically occurs when air passes through the envelope. In most cases, reduction or elimination of air movement through an envelope is highly desirable. It is important to provide a continuous air barrier on all exposed faces of a building. To achieve a continuous air barrier, it is important to select materials that both perform at a high level and are compatible with each other.

Radiation is the transfer of heat through electromagnetic waves of energy that radiate through space and transfer heat into building materials. Sunlight is the most common source of radiation heat transfer through a building envelope, mostly through glazing.

Moisture, vapor and air transfer

The control of moisture, air, and vapor transfer through the envelope play a key role in the reduction of the transfer of heat and the reduction of condensation, mold, and water damage.

Condensation occurs when warm, moist air comes in contact with a cooler surface. The moisture in the air will condense in liquid form on the cool surfaces. When condensation occurs within the building envelope, detrimental results may occur. Water will remain inside the envelope if it does not have a way to get out, either through evaporation or drainage. Water that is trapped inside the envelope may cause mold, especially if is in contact with building components that contain organic materials. The water may also greatly reduce the effectiveness of insulation products in the envelope. Additionally, some materials may rust or rot when in contact with water for a prolonged period of time.

Control of moisture, air, and vapor can be greatly improved through the use of high-performance air, vapor, and water resistive barriers. The selection of the appropriate type of air, vapor, and water resistive barrier and its location within the envelope assembly play an important role in the performance of the exterior envelope.

2. Energy Codes

Energy Codes and Sustainable Design Rating Systems

Codes and Standards are mandatory. Pennsylvania currently enforces the 2015 International Code Council suite of codes. As newer editions are adopted, the energy conservation requirements will become more stringent. For example, the current edition requires continuous insulation to the exterior of wall framing for Pennsylvania, newer editions increase the R-value of the continuous insulation and requires it for all climate zones.

Primary Energy Codes and Standards

- International Code Council's International Energy Conservation Code (IECC) – Residential and commercial requirements
- International Code Council's International Green Construction Code (IgCC), 2012 and following editions, not in force in PA now but will be when newer editions are adopted.
- American Society of Heating, Refrigeration, and Air-Conditioning Engineers' ANSI/ASHRAE/USGBC/IES Standard 189.1, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings (ASHRAE 189.1) - For all types of buildings except single-family homes, multifamily homes with three or fewer stories, and modular and mobile homes. Reference Standard for IgCC.
- ANSI/ASHRAE/IES Standard 90.1 - Energy Standard for Buildings Except Low-Rise Residential Buildings) - For all types of buildings except single-family homes, multifamily homes with three or fewer stories, and modular and mobile homes. Reference Standard for IECC
- U.S. Department of Energy (DOE) COMcheck – Software program to determine whether new commercial or high-rise residential buildings, additions, and alterations meet the requirements of the IECC and ASHRAE Standard 90.1.
- U.S. Department of Energy (DOE) REScheck - Software program to determine whether new single-family homes, multifamily homes with three or fewer stories, and modular and mobile homes, additions, and alterations meet the requirements of the IECC.

Rating systems are voluntary. They encourage utilization of current green technologies and are consciousness-raising for the public. They also are used for benchmarking the energy performance of buildings compared to that of other similar buildings of the same space type, based on a national average.

Primary Rating Systems:

- US Green Building Council's Leadership in Energy and Environmental Design (LEED®) – Rating systems for Building Design & Construction, Interior Design & Construction, Building Operations & Maintenance, Neighborhood Development, and Home Design and Construction
- Green Building Initiative's ANSI/GBI 01-2010: Green Building Assessment Protocol for Commercial Buildings (Green Globes)
- The International Living Future Institute's Living Building Challenge
- National Association of Home Builders' ICC 700 National Green Building Standard (NGBS)
- U.S. Department of Energy (DOE) Builders Challenge
- U.S. Department of Energy (DOE) Energy Star – Rating system for major appliances, office

- equipment, lighting, home electronics, new homes and commercial and industrial buildings and plants.
- Living Building Challenge – A tool and certification program that promotes the measurement of sustainability in the built environment.
- Green Guide for Healthcare – Provides tools to assist healthcare organizations and their design and operations teams in creating high performance healing environments.

References:
- EPA Comparison of Green Building Standards
https://www.epa.gov/smartgrowth/comparison-green-building-standards
- US DOE Building Energy Codes Program
https://energy.gov/eere/buildings/building-energycodes-program

3. Integration with HVAC

Integration of Envelope with Mechanical and Electrical Systems

In 2015, about 40% of the total U.S. energy consumption was for the Heating, Ventilating, and Air Conditioning (HVAC) and electrical systems of commercial buildings. The design of the building envelope and integration of these systems can greatly reduce that consumption. For commercial, industrial, and institutional buildings, careful design of the glazing system can reduce lighting and HVAC costs by 10%–40%.

Window framing systems should always incorporate a thermal break which isolates the interior surfaces of the framing from the outside temperature. This thermal break needs to be designed so that it is coincidental with the continuous insulation plane of the building envelope. The use of warm-edge spacers for insulating glass units which either incorporate a thermal break in the spacer assembly or are constructed from a low-conductivity material also thermally isolates the inner and outer panes of glass, reducing heat transmission, and reducing condensation during cold outside temperatures. The glass should also be carefully selected to balance a high (> 70%) Glass Visible Transmittance for increased daylighting to reduce lighting energy consumption with a low Solar Heat Gain Coefficient to reduce HVAC loads. The use of exterior shading devices is also beneficial in reducing heat loads and controlling glare within the occupied areas of the building. Another critical design feature of the fenestration system is the continuity of the Weather Resistant Air Barrier (WRAB) at transitions between various building envelope components. This will help minimize moisture, infiltration, mold, and humidity issues. The HVAC system needs to be zoned to allow for individual and independent control to address differing temperature conditions in various sections of a building or space due to their orientation to the sun or occupancy.

The energy usage of the HVAC and lighting systems can also be greatly reduced by incorporation of a sophisticated Building Automation System (BAS). Some features these systems can control are temperature, night set-backs, holiday operation, optimum system start and stop, occupancy sensors, peak load shedding, and chiller / cooling tower optimization.

The use of high efficiency fixtures such as LEDs can drastically reduce lighting loads. These will also reduce the heat load on the HVAC system. Daylight harvesting systems which measure daylight and dim or switch off artificial lighting in response to changing daylight availability can also be incorporated to reduce energy consumption. The use of task lighting is another component of overall lighting energy reduction.

4. Impact on Indoor Air Quality

The composition of the building envelope can have a major impact on indoor air quality (IAQ). Recent studies have indicated that the cognitive abilities of students and the performance and well-being of office workers can be negatively affected by poor indoor air quality. Additionally, a poorly designed or constructed building envelope can contribute to health problems for building occupants.

The WELL Building Standard was established as a system to measure and rate a building's interior environment and the effect on building occupants. Much like the LEED rating system, a building can be certified Silver, Gold, or Platinum. Four of the eight rating categories: air, light, comfort, and mind, can be impacted by the building envelope.

Pollutants

Many construction materials emit undesirable gases or pollutants long after they are installed. Most building codes require materials with low VOCs (volatile organic compounds) to be installed in buildings, but do not fully restrict all materials that emit potentially harmful pollutants. The immediate health effects of being exposed to indoor pollutants include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Long term effects may include respiratory disease, heart disease, and cancer. Building materials and products should be carefully selected to minimize the introduction of pollutants into the interior environment.

Natural Light

Studies have indicated that the introduction of natural light into buildings can improve the well-being and performance levels of building occupants. Strategically placed exterior glazing can contribute to building occupant comfort without creating excessive heat gain or loss.

Heat Loss or Gain

Building envelopes with inadequate or discontinuous insulation can cause excess heat loss or gain on outside wall, floor, or ceiling surfaces. In addition to wasting energy, uncomfortable interior spaces may result. Incomplete air barriers can also contribute to this effect while causing excessive air movement inside the building. It is important to install insulation that is appropriate for the region and meets or exceeds building code requirements. Additionally, the air barrier system should be continuous around the entire building.

Mold

Probably the most harmful effect of a poorly designed building envelope is the introduction of moisture and mold into the building. Moisture migration into building cavities can be caused by leaks in the envelope or condensation problems caused by improper air and vapor barriers or inadequate insulation. Excessive moisture in the air can promote asthma and allergy problems. It can also contribute to discomfort caused by high humidity inside the building. Mold and airborne fungi can contribute to a number of serious health problems including "sick building syndrome" and some types of cancer.

5. Thermal Barriers

Thermal barriers play a very large role in the overall performance of the envelope of a building. When renovating or constructing a new building, at a minimum, consideration should be given to insulation, thermal bridging, continuous insulation / outsulation, composite systems, and code requirements. Insulation is typically the first building material that comes to mind when somebody mentions an energy efficient building. The purpose of insulation is to reduce the rate of heat transfer between conditioned and non-conditioned spaces. This can be accomplished with a number of types of insulations that are available in the market, including batt, rigid, blown-in, spray foam (open cell or closed cell, depending upon the needs of the project), etc. There are advantages and disadvantages to each type of insulation that will need to be explored before you decide upon the type of insulation to be utilized for your project. At a minimum, it is recommended that you consider the following when deciding upon the type and thickness of insulation to be utilized:

- Optimal R-Value
- Off-Gassing / Environmental Considerations
- Fire Resistance / Ignition Barriers
- Temperature Profile / Dew-Point Calculation
- Cost / Benefit

Another topic that needs to be considered for thermal barriers is thermal bridging. Thermal bridging is the transfer of heat between a conditioned space and a non-conditioned space, which effectively reduces the efficiency of the insulating system in place. This can occur when conductive materials (i.e. metal / wood studs, mechanical fasteners, etc.) create a direct path from a conditioned space to a nonconditioned space. Care needs to be taken to avoid designs where this can occur, by incorporating some sort of break in the conductive materials. The effective R-value of the building envelope will be greatly reduced if a thermal bridge exists in the system.

A very good option for reducing thermal bridging and increasing the effective R-value of a wall system is continuous insulation in the form of outsulation. Outsulation is the inclusion of insulating material that is exterior to the stud cavity. Ideally it will be located outboard of the air / vapor barrier, allowing it to minimize the risk of dew-point concerns. Outsulation minimizes thermal bridging by limiting the number of locations with heat conductive material that spans between conditioned and nonconditioned spaces. The disadvantage of this type of system is that it requires a more complex façade. In particular, the details associated with the attachment of the outsulation and outboard finish materials becomes a much more difficult task.

Another great option to consider when deciding upon a thermal barrier is the use of composite systems. Composite systems integrate the stud and the insulation system to provide a compact system with reduced thermal bridging (compared to stud and cavity insulation). In some cases, composite systems can also incorporate the finish façade materials also. They have the advantage of requiring less labor to complete the installation, as multiple steps are combined into one.

A final consideration when deciding upon a thermal barrier is the requirements of your local codes. The requirements in a colder region of the U.S. will vary drastically from those in a warmer region. Some locales may even require a different system to be utilized on different faces of the building, depending upon the orientation of the building. So please, review the code requirements.

References:
-http://www.greenbuildingadvisor.com/blogs/dept/guest-blogs/case-continuous-insulation
-http://www.greenbuildingadvisor.com/blogs/dept/musings/are-dew-point-calculationsreally-necessary

6. Air, Vapor and Moisture Barriers

The composition of Air Barrier, Moisture/ Weather Barrier, and Vapor Barrier systems vary by type but are generally meant to keep the Exterior Environmental conditions from directly affecting the Interior conditioned building spaces and to keep moisture from building up within the envelope systems. They can also be used to separate high moisture environments within a building like pools, kitchens, and shower rooms, from spaces with drier needs. Depending on the makeup of the walls and the roofs these systems may be the same elements or they may be separate elements. An Air Barrier System must keep Air from passing between the Exterior Environment and the Interior Spaces so that the Heating, Ventilating and Air Conditioning System can more efficiently control Temperature, Moisture, and Air Quality within the building. The Moisture which is often referred to as the Weather Barrier is primarily meant to keep the rain and other water from the exterior making its way into the building. This barrier consists of roof membrane and flashings, wall membrane and flashings as well as the foundations, floor slabs and associated membranes. When the Moisture Barrier is combined with the Air Barrier then all of the roof, wall, and floor assemblies must continuously be tied together and have penetration barriers (HVAC ducts, vents, stacks and plumbing pipes), opening barriers (windows, doors, and sky lights) and specialized flashing and sealants between all of the exterior building components to effectively create a balloon. The vapor barrier can also be a part of this system depending on the type of insulation used in the roof and the walls however for most building assemblies it is separate. This is because most insulation is vapor and air permeable by its properties or the nature of its typical installation.

Barriers Versus Retarders

The definitions above look at the ideal, in terms of preventing all air and moisture from passing through the building envelope barriers without being moderated by the building's HVAC systems. Vapor barriers with a permeance of 0.1 perms or less are meant to prevent all air, moisture and most vapor from passing through them. Retarders with a permeance of 0.1 to 1 perms limit or control the passage of water vapor though them. Vapor permeable membranes greater than 5 perms under ASTM E96 are meant to allow the passage of water vapor as a gas while preventing the passage of liquid water. Vapor permeable membranes are used as weather barriers on one side of the insulation where there are already vapor barriers on the other side of permeable insulation to allow that insulation to dry out. Typically, in order for a material to be vapor permeable and to maintain its intended permeance it needs to be a certain thickness. Sheet goods are preferable for this application because it is much easier to control the thickness. Fluid applied systems tend to be better for air and moisture barriers because there are less seams that might need to be lapped in the wrong direction creating sealed troughs that can be worked on by water, air, and gravity over time. There are vapor retarders being developed that react differently depending on the amount of moisture and temperature to allow more beneficial drying of wall and roof assemblies but are not currently in common use.

Why use AVB's (AVB = Air moisture weather Vapor Barrier)

Studies have indicated that if you have a 10' square section of wall insulated to meet code requirements for an exterior wall and build an identical wall next to it only without the insulation and a third wall identical to the first wall with a 1" hole in the center of it that the second and third walls will perform roughly the same under the majority of temperature ranges. This is due to the passage of air through the third wall moving as much heat as will pass though the sealed wall assembly that does not have insulation. Likewise, air passing through that 1" hole will carry a lot more water vapor than can diffuse through the building materials without a vapor barrier over the same time period. Therefore, it is most important to seal up any potential air pathways through the wall assembly to cut down on water and air movement through the wall assembly. Water vapor always moves from higher concentrations to lower concentrations just like warmer air always moves toward colder air. When this warmer higher vapor content air comes into contact with a colder surface it will condense causing moisture at that location. Moisture in an assembly can negate the effectiveness insulations, cause corrosion or rot, and in high enough concentrations over time with growth media like dirt, paper, or wood will encourage mold growth.

Types of Wall and Roof AVB Assemblies

For the present the ideal of a single barrier that prevents the passage of Air, Liquid and Gaseous Water is limited by the insulation systems of the roof, wall, and slab on grade assemblies. If the insulation used allows the passage of water vapor then a membrane vapor barrier needs to be placed on the side of the insulation that is going to have the majority of and strongest vapor pressure over time. In Western Pennsylvania this is still considered to be the interior surface as there are considered to be more heating days than cooling days with the exterior air generally being dryer than the interior air for the same time. This Vapor barrier in addition to needing to always being on the same side of the insulation needs to be continuous around the building envelope.

The one barrier assembly that comes closest to meeting the ideal is a spray applied polyurethane closed cell foam assembly on masonry wall and concrete roof deck construction. This is because a continuous closed cell foam with 1% or less open cells is considered to be an air and in proper thicknesses a vapor barrier. Why this theory is considered ideal is because if the dewpoint always occurs in the nonvapor permeable insulation then there is no water generated that can cause issues in the wall or roof assemblies. In the case of closed cell polyurethane foams there is significant water in the foam at installation some of which stays in the insulation. Initially the air around the applied SPF has a lot of moisture that will condense on cold surfaces and can cause problems with installation but dissipates as the foam cures. Because some moisture stays in the foam when there are colder outside temperatures there is a measurable drop in the R-value of the foam. Therefore, SPF performs better in warmer climates but is still a good option in colder regions like ours due to the fluctuations between where the warmer moister air is throughout the year. There are also significant limitations for this application including the building needs to be limited in size as there should not be building expansion joints through it due to the need to have moveable joints. It is subject to NFPA 285 as a plastic and due to its ability to combust and support flame, needs to have fire protection barriers around it. It has been argued that the interior masonry on these systems do not need to have thermal expansion joints as there is less likely hood of thermal movement within the structure due to constant temperature inside of the insulation but seismic joints still have to pass through all the layers of the envelope causing issues with rigid foam and special detailing. There also needs to be external cladding with minimal penetration of this Moisture/Thermal/Air/Vapor Barrier. This assembly can be run from just above grade up the walls and over the roof in a continuous assembly forming an insulated dome over the building and can be tied into the AVB at the slab for a continuous separation or balloon.

The most common type of commercial construction in our region is the cavity wall with flat roof that has continuous insulation above the deck.

The second most common type of construction in our region is the cavity wall with sloped roof. Within this second type there are two different strategies which are dependent on whether there is a desire to condition the area to the underside of the roof or whether there is an unconditioned attic. The conditioned attic is considered the best option because it allows for the AVB and insulation to more easily be continuous and in proximity to each other around the building. With the option for unconditioned attics much more care in the design and construction is required to make certain all the additional pieces that must be used to create the continuous AVB and Insulation work together.

Types of Floor and Foundation AVB Assemblies

It has been more common to think about the continuation of the Air, Moisture and Vapor Barriers between the Roof and the Wall Assemblies, it has been less common to pay attention to the detailing between the wall and the floor/ foundation assemblies. This is because concrete slab on grade assemblies are assumed to be Air Barriers and as long as the wall air barrier is sealed to the concrete slab it is considered continuous. It has also been discussed that with the advent of liquid locking additives in the concrete that it can also be considered a water barrier. To be certain that this is the case it is still considered important to run a continuous puncture resistant structural vapor barrier below the concrete slab to the exterior of the building over top of the foundation wall and run up thus forming the slab edge to the exterior of the building within it so that the wall AVB can run down over it. Tying a wall vapor barrier to the slab vapor barrier that can not easily be punctured during construction limits the possibility of natural cracking in the slab to cause gaps for airways from the exterior to the interior. This becomes more important when there are crawlspaces below the firs floor. It is always better to have a structural air barrier under a concrete slab at the bottom of the crawl space as it is much more difficult to create a continuous AVB at the floor line above this crawlspace. It can also be problematic with a crawlspace to separate the vapor barrier and the air barrier because there is often significant moisture from both sides. Crawl spaces tend to be vented which means there is the potential for more of an air movement than if there is a slab on grade with the AVB below tied into the wall AVB. Heat transfer tends to be moderated by the ground in slab ongrade conditions as there is typically an insulation that runs to the bottom of the foundation walls on the exterior. With a ventilated crawlspace there needs to be insulation and air barrier at the floor line with similar conditions to the walls.

Miscellaneous Materials and Compatibilities

Always keep in mind that the Air Moisture and Vapor Barriers are more than individual products, they include everything in the building envelope continuously around the building and must be sealed continuously one to the other. One of the things that can be difficult in open bid situations is that products are selected separately under different contracts and that no one keeps track of the compatibility of all of the products and sealants from one to the other. Sealants have to be considered from the stand point of are they to achieve one or all of the following: to seal for air flow, water flow or are they also to be insulating. Some of the individual elements to keep in mind are engineered expansion joints, sheet metal and various types of flashing for bridging gaps in sheathing, at windows, doors, louvers, ducts, pipes, stacks, conduits and the sealants between all of these elements and their chemical compatibility with each other as they connect in various ways around the entire envelope. This must also be considered with compatibility with other building code requirements like fire stopping from floor to floor aggregate area separations and fire conditions for roof wall connection.

Negative Consequences

The most harmful effect of poorly designed or installed Air, Moisture, Vapor, Barrier Systems is the introduction of moisture into the interior portions of exterior walls causing, corrosion, rot, and mold.

- http://www.airbarrier.org/technical-information/master-specification/
- http://www.airbarrier.org/technical-information/whole-building-air-tightness-testing-2/
- https://www.nibs.org/page/bec

7. Rain Screens, Cavity Ventilation, and Water Management

The composition of Rain Screen systems vary by type but generally consist of a pressure balanced airspace between the exterior cladding and the weather barrier toward the inside. The intent of the rain screen is to keep the weather barrier which is often also the air and sometimes a vapor barrier from becoming and staying wet. It is also used to moderate heat transmission from warm to cool areas. Cavity Ventilation is provided through the rain screen at various points but always at the top and the bottom to provide uninterrupted airflow through the cavity and allow residual moisture in the air cavity to naturally drain and evaporate. A min. of 3/8 inches is required for the airspace to pressure equalize. Water Management is provided by the rain screen to direct water away from the cavity and any water that gets through the rain screen directly back out to the exterior of the building. This is done by lapping, flashing, and tilting surfaces to drain from the inside toward the outside of the structure. Not allowing anyplace for water to lay or puddle is a key component of any building envelope. These layers of protection from the weather are to keep the sheathing and the building structure dry to allow the interior environment to be controlled entirely by the HVAC systems.

Why Rain Screens
Rain Screens provide the outer layer of separation between nature's elements and the controlled built environments that humans create to live and work in. When properly built they naturally shed water out and away from the building keeping it dry.

What Makes a Good Rain Screen
The most flexible rain screen is the pressure equalized Rain Screen that compartmentalizes the cavity at each floor as a zone in the exterior wall. This provides vents at the base of the zone with flashing to allow water out and vents generally at the top below flashing and air blockage to prevent the further up flow of air above the cavity cell while allowing evaporation of cavity moisture. This configuration allows the pressure between the exterior environment and the interior spaces to balance at the cavity space and decrease the likelihood of water being forced through imperfections in the weather/ air and/or vapor barriers. Careful attention to the location and size of vents and drainage needs reviewed for the type of cladding for buildings over four stories so that pressure does not build up in the cavity. Flashing needs to be durable and sealed continuous around levels to help with the compartments and to direct water to the exterior. All materials used must be compatible with each other chemically to not corrode or otherwise deteriorate and must be tied into the other building exterior wall systems. Cavities for masonry need to be a minimum of 2" to be effectively cleaned or have other mortar control.

Harmful Effects
Moisture pressure on the weather barrier and air and vapor barriers can be caused by rain screens that are not shedding water from the cavity or have inadequate air flow between the cladding and sheathing. Building envelopes with inadequate rain screen systems or with pressure on the outside of the rain screen can cause water to build up against the weather, air and vapor barriers which can lead to negative impacts on the building. Probably the most harmful effect of a poorly designed rain screen is the introduction of water into the building causing loss of insulation, corrosion, other decay and mold.

8. Passive House
Passive House is quite simple in concept, but very technical and calculated in the implementation. That level of detail allows for actual measuring of building performance to verify that the building is performing as designed. While the standards are very high the results are proven to reduce heating and cooling demand by more than 75%. This alone is reason enough to build to Passive House standards but another aspect is the Indoor Air Quality (IAQ) and comfort of the occupants. All the principles in Passive House design add to the overall wellbeing of the end user.

The idea of Passive House is relatively new in America – even in the building industry. Passive House is a design and building process that creates buildings that perform on a very high level. It is essentially LEED on steroids. While they have some similarities – Passive House focuses mainly on building performance with the main aspect being the building envelope.

Passive house originated in Europe and the concept is widely accepted there. In fact, Brussels has been mandating Passive House standards for energy efficiency in their new construction for the last two years. In some ways it is easier to gain passive house standards in new construction, however it is possible to apply it to a retro fit project as well. House comes from the German word ‘Haus’ which means building. So even though House is in the name, the standards apply to all building types. Passive House standards are easier to achieve in some climates than others – depending on heating and cooling loads.

To achieve passive house standards the entire design and building processes must be integrated. It can be much more easily obtained if the entire project team is on board working toward this same goal – that would include owner, architect, engineers, contractors, and subcontractors. The owner needs to set the tone and show that this standard is a priority to the project. The designers need to get all the details designed properly and the construction team has to implement those details and make sure they are executed to a very high standard.

The Design Principles of Passive House

Exterior Envelope

- **High R-values and Continuous insulation around the entire envelope**
  Minimum of R-38 insulation continuous around the entire envelope including underground. Typical roof value R-60. Typical wall value R-40. Typical slab value R-30.
- **Continuous air-seal layer at all joints and seams**
  This reduces drafts and mold growth (cold surfaces) Standard to achieve is less than 0.6ACH@50 (air changes per hour)
- **Eliminate thermal bridging**
  This reduces heat loss as well as surface temperature differences which can lead to building envelope damage or deterioration. Standard is to achieve thermal bridge free and be less than .006 BTU/(hr ft F)
- **High Performing Glass**
  High performing glazing adds more energy to the building than it loses
  Minimum glazing requirement is U=0.14 BTU/(hr sf F)

Mechanical Systems

- **Mechanical ventilation with Heat Recovery** – this is to bring in fresh air, remove pollutants, control moisture, and recover heat exiting the building
- **Heating and Cooling Supply** – depending on your climate (heating, cooling, and humidity) there are varying systems that can be utilized

Site Design

- Orient Glazing to the south (in the Northern Hemisphere) uses the natural light from the sun to lower lighting needs and heat gain from those lights. In the winter when the solar path is lower in the sky the heat is utilized rather than mechanical heating.
- Utilize shading devices (built or natural) this stops the heat gain before it enters the building

Achieving these Standards, requires a combination of high performing materials, good design practices, and highly executed construction practices.

- https://passivehouse.com/01_passivehouseinstitute/01_passivehouseinstitute.htm
- http://www.phius.org/what-is-passive-building/passive-house-principles

9. QA & QC Systems

When it comes to the building envelope the Terms 'QA' & 'QC' are often used interchangeably in the Design & Construction Industry; however, QA & QC are somewhat different. Quality Assurance (QA) is the process or set of processes used to measure and assure the quality of a product. Quality Control (QC) is the process of ensuring products and services meet the Owners and Design Team's expectations. Quality Assurance is process oriented and focuses of preventing defects whereas Quality Control is product oriented and focuses on identifying defects. As such, Quality Assurance activities are commonly performed during the design and procurement phases of the project where Quality Control activities are commonly performed during the construction and post construction phases of the project.

One of the main reasons that QA & QC are often used interchangeably is that the building envelope is unique. There are many components that ultimately make up the product or system. In addition, there are often various systems that comprise the overall building envelope. As such, the actual building envelope product is not completed until all of the various building envelope systems are installed and tested. Unfortunately, the final test does not usually occur until occupancy and use.

The following is a summary listing of QA & QC activities to be performed during the Design, Construction, and Post Construction Phases of a typical construction project. The one major item to note is that no two projects are the same especially as it relates to Quality. As such, it is very important to create a project specific QA/QC plan along with thoroughly understanding the Design approach to keeping water out of the building along with the Construction response to the Design approach. The most successful projects are collaborative and engage all members of the project team during the design, procurement, construction, and post-construction phases of the project.

Quality Assurance (QA) Activities

1. Define/Confirm Quality Expectations of Owner/Design Team
    a. Understand Approach to Keeping Water Out
    b. Understand Primary vs Secondary Barriers
    c. Define Warranty Expectations
    d. Understand Owner's Facility Management Resources; Owner's Resources May Drive Simplicity of Building Envelope Design
    e. Evaluate the Need to Engage a 3rd Party Building Envelope Cx Professional
2. Engage Manufacturer(s) and Installers During the Design Process
    a. Ensure Adjacent Building Envelope Systems are Compatible with One Another
    b. Ensure the Correct Products are Being Specified for the Project Location
    c. Define Area of Demarcation for Each System and Respective Responsibility that will Ultimately be Passed Down to the Respective Subcontractor
3. Evaluate the Benefit of Engaging Design-Assist Specialty Subcontractors
4. Perform a Page Turning and Specification Review with Entire Project Team
5. Prepare and Issue Coordinated Trade Specific Scopes of Work (SOW)
    a. SOW to Clearly Define What Trade is Responsible for the Various Furnish and Install
    b. SOW to Summarize Warranty Requirements
    c. SOW to List Mock Up Requirements
    d. SOW to Clarify Testing & Inspection Requirements
6. Perform a Thorough Bid Evaluation that Includes Participation by the Design Consultant and 3rd

Party Building Envelope Cx Professional
7. Prepare a Project Specific QA/QC Playbook
    a. Playbook to Itemize all Specified Testing & Inspection Activities Including Off Site and On Site
    b. Playbook to Itemize all Specified Mock-up Requirements
    c. Playbook to Itemize all Specified Warranty Requirements
8. Perform Diligent Review of All Submittals and Shop Drawings Prior to Submitting to Design Team
    a. Send Submittals to Owner
    b. Send a Copy of each Submittal to All Subcontractor Parties Involved

Quality Control (QC) Activities

9. Construct Coordinated On-Site Mock-Ups
10. Facilitate a Mock-Up Review and Approval Meeting that Includes Participation by Owner, Design Consultants, and All Subcontractor Parties Involved
11. Release Material for Fabrication Upon Submittal and Mock-up Approval
12. Review Material Delivered to Jobsite for Compliance with Contract Documents, Approved Submittals, and Approved Mock-up.
13. Facilitate Pre-Installation Meeting(s) with Subcontractors; Recommend Participation by Manufacturer's Representative
14. Review On-Site Installation and Take Progress Photos
15. Engage Design Team, 3rd Party Cx Professional, and Manufacturer(s) During On-Site Installation
16. Perform Comprehensive Record Keeping Including Taking Photos of All Wall Cavities Prior to Closing Up Walls
17. Perform All Specified Testing and Inspection Including 3rd Party Testing and Inspection
18. Complete As-Built Documents that Incorporate All RFI's and/or Approved Revisions
19. Submit As-Built Documents to Owner and Design Team
20. Perform Regular On-Site Inspections Post Building Turn Over
    a. Inspections Should Occur During Each Season to Ensure Exterior Envelope is Performing in Accordance with Design Intent
    b. Perform Inspections During a Heavy Rainfall and Snow Storm

More so than ever, there are newer and what is advertised to be "better" products that make up the overall building envelope assembly. Many products have not been around long enough to stand the test of time. As such, it is important for the entire project team (Designer, Builder, and Owner) to plan for and invest the appropriate time during the design phase of the project collecting all of the information that will be necessary to make a comprehensive and informed decision. It is also recommended to engage senior personnel who have the experience to comment on the likelihood of success for a newer product that may be specified for the project. The above QA/QC listing will help project team's make the correct long-term building envelope decisions; however, as noted above, each project is different and the final solution should have "buy in" from all members of the project team.

10. Commissioning Best

There are two standards that outline the Building Enclosure Commissioning (BECx) Process: *ASTM E2947 Standard Guide for Building Enclosure Commissioning* (formerly *ASHRAE/NIBS Guideline 3, The Building Enclosure Commissioning Process)*; and *ASTM E2813 Standard Practice for Building Enclosure Commissioning.* Both standards view the building enclosure commissioning philosophy as a collaborative approach throughout the four main phases of the process: Pre-Design, Design, Construction, and Occupancy and Operation.

The BECx process is dynamic and adaptable to achieve, verify, and validate the performance of the building enclosure based solely upon the individual merits and challenges of each project which need to be defined in the Pre-Design Phase. During this phase, the BECx Authority (BECxA) should work closely with the Owner to develop the Commissioning Plan and the Owner's Project Requirements (OPR). The Commissioning Plan determines the process, procedures, and appropriate level of commissioning for the project. The appropriate level of commissioning is determined through a comprehensive analysis of each design, performance criteria, environment, function or use, operation, and Owner requirement. This analysis considers not only the physical materials of the enclosure, but also the Owner's tolerance for risk. The building enclosure must consider not only the aesthetic design and functional attributes of the building; but it must also consider how each component of the enclosure relates as a whole to provide protection from the external environment. The enclosure assembly must control the path of water, vapor, air, heat flow, light, and noise, and be durable and structurally sound. The enclosure assembly must consider the building's structure, applied loads, resistance to fire and pests, security, and be constructible and economical. The BECx process and applicable mock-up, laboratory, and/or field testing to validate performance are outlined in the Commissioning Plan which is developed by the BECxA.

The OPR should outline the objectives and requirements that highlight the Owner's expectations for the building enclosure. As it relates to the building enclosure, the OPR should include the following:

- Site Description and Existing Facilities
- Building Code Requirements
- Sustainability
- Architectural Programming
- Thermal Performance Criteria
- Structural Performance Criteria
- Roofing and Skylight Performance Criteria
- Exterior Wall and Fenestration Performance Criteria
- Below Grade and Plaza Waterproofing Performance Criteria
- Accessibility
- Acoustical Performance Criteria

While the OPR will be modified during the Design Phase to maintain a reasonable balance between performance and cost, the OPR provides the BECxA and the Architect with direction by which a basis of design can be developed in the Design Phase.

During the Design Phase, the BECxA should strive to understand the Architect's design intent, while reviewing the material and details to achieve the Owner's expectations. To achieve quality during the Design Phase, the BECxA should perform a peer review of the design documents at each phase (i.e. Schematic Design, Design Development, and Construction Documents), focusing on the building enclosure and any details that may impact the long-term performance and durability of the enclosure, as well as achieving the Owner's requirements.

During the Construction Phase, the BECxA continues to work closely with the Architect, Owner, and Contractor. The desire is to achieve effective and timely communications with all parties, allowing work to progress in a quality manner in accordance with the OPR and schedule. At this stage, the BECxA should review submittals and shop drawings to confirm conformance with the design intent and the

OPR. Prior to construction, for complex projects it is recommended that an on-site or laboratory mock-up is constructed and field performance tested by the BECxA. The benefit of the mock-up is to realize potential sequencing and workmanship issues that can be rectified prior to construction of the building. The mock-up then serves as the construction standard for the remainder of the project.

The BECxA's schedule of work is driven by the overall construction schedule and should endeavor to integrate their work into the normal design and construction process to achieve quality and maintain schedule. The work schedule is developed in coordination with the demands of the project. As trades mockup work or begin complex details, the BECxA performs site observations and field quality control testing shall be coordinated with these site visits to maximize efficiency while on site. All issues observed in the field by the BECxA are communicated and documented in a timely manner to assure the Contractor can identify which systems may be affected and ensure the issues are addressed in a timely manner. In the event that additional detailing of the building enclosure is required, the BECxA should bring these issues to the attention of the Architect and Owner and may need to provide conceptual sketches for the Architect's consideration to address the issues. To ensure that issues are addressed in a timely manner and prevent them from being covered by subsequent work, the BECxA should conduct routine BECx meetings. These meetings assure regular communication amongst the project team and provide an opportunity for the team to discuss, track, and resolve enclosure-related field issues.

The BECxA should consciously maintain a collaborative work environment working closely to become familiar with the materials and the job site team. The BECxA should endeavor to assist the contractors in developing quality control practices and review all observations with the on-site team and encourage the Owner's representatives and the Architect to accompany the BECxA on job site walks and discuss issues to maintain a collaborative environment.

After Substantial Completion, the BECxA compiles all necessary project documentation, such as warranty information and enclosure maintenance information, for inclusion in the final BECx Report and Maintenance Manual. Also, at this time, the BECxA engages the Owner's facilities and maintenance personnel to review and train them to properly operate and maintain necessary components of the building enclosure to maximize functionality, efficiency, and serviceability that will ultimately lead to reduced energy and operation costs for the Owner.

11. Life Cycle Cost Analysis

When you initially approach the design and construction of a building, you are hopefully thinking that you want to make it the best possible project. However, the reality is that the best may cost more than the budget is capable of handling. As such, it is advantageous to approach a project by evaluating the avenues that can provide the most value. These considerations should include the initial cost, the operating cost, the maintenance cost, the replacement cost, and the disposal cost.

Considering the above, it is recommended that a holistic approach be implemented when deciding upon the overall design and construction of the building envelope. A holistic approach takes into consideration that all of the parts and pieces of a building are connected and have an effect on the other. For example, the sizing of the HVAC is based upon the planned heating / cooling needs. As such, by improving the air tightness, thermal efficiencies, etc. to the façade, the heating / cooling needs can be reduced. In turn, the needs for the HVAC system become less intense, allowing for the size of the system to be reduced. So, the thought process behind the holistic approach in this example is as follows:

- Increased spending on façade = Decreased spending on HVAC (smaller units)

- Smaller units = Less energy consumption
- Less energy consumption = Lower average heating / cooling bills
- Lower average heating / cooling bills = Increased Return on Investment (ROI)

To get the most from your building project, you need to evaluate the options available. Determine what makes the most sense for the given project / situation. Keep in mind that if you can spend a dollar that is available now to save ten dollars down the road, it is probably worth considering acting upon it.

References:

- https://www.wbdg.org/resources/lcca.php