Critical Industry Research

Exterior Wall Systems and Building Envelope Study

Background Information

Energy efficiency in buildings has become a very important facet in the construction industry, not only as a means of sustainability, but also as an important way of reducing energy consumption and costs. With rising energy costs, it is critical to deliver a well designed and constructed building. A building's envelope is a critical aspect of energy efficiency and sustainability, as thermal losses though the exterior of a building can be very costly, and make for an uncomfortable space to work and live in. GreenWorks Development incorporated a more efficient exterior wall assembly as a means to mitigate thermal loss, as well as sustainability implications. Although the system used was more expensive than a standard masonry veneer assembly, the owner was willing to pay more upfront, with the thought of savings in operational costs attributing to a faster payback period.

Goals

The goal of this analysis is to research emerging technologies and trends associated with building envelopes, specifically exterior wall assemblies, as well as the constructability impacts associated with these technologies.

Methods

- Conduct literature reviews and professional articles associated with building envelope technologies
- Research systems which have proven to be thermally efficient
- Analyze systems which could be implemented on Campus Square
- Understand constructability constraints of different exterior wall systems
- Develop conclusions about the importance and impacts of efficient exterior wall systems

Resources

- Professional journals and articles on the topics of building envelopes
- Whole Building Design Guide (www.wbdg.org)
- ToolBase Services (www.toolbase.org)
- Wohlsen Construction

Expected Outcome

Through this analysis, I hope to become more familiar with the importance of high performance exterior wall systems, as well as emerging trends and technologies on this topic. Also, it will be important to realize constructability issues of implementing difference systems onto Campus Square. Furthermore, I hope to discover potential systems which may be applied to Campus Square in order to propose an alternative system which would make the building an even more efficient and sustainable structure.

General Considerations for Exterior Wall Systems

Perhaps the most important aspects which can affect an envelope system are the impact of air and moisture through the assembly. Understanding how material selection, design, and construction relate to the long-term durability and performance of a building enclosure is paramount. Moisture travels from high temperatures to lower temperatures, from a higher pressure to a lower pressure, and from areas of higher moisture content. However, these can be affected by interior and exterior air pressure differences, moisture loads, and material vapor pressure differences. The location, source, and prevention of air and moisture through an assembly must be realized during the design and construction process in order to properly deliver a durable building.

An effective building enclosure should also include a continuous and defined air barrier that is rigid enough to survive wind loading and air pressures across it, durable enough to remain intact throughout construction, and installed in such a way that it is continuous between building elements. In a mixed-humid climate, a wall assembly should not incorporate an air barrier material that also has vapor retarder properties. Depending on where the air barrier is placed in the assembly it has the potential to hamper drying to the interior in warmer months and to the exterior in colder months. In other climates (cold, hot-humid) it is not desirable to have the air barrier material have vapor retarder properties if it is to be placed on the cold side of the wall, since this can create a moisture problem during drying. Figure 3 below demonstrates potential air and moisture infiltration paths.

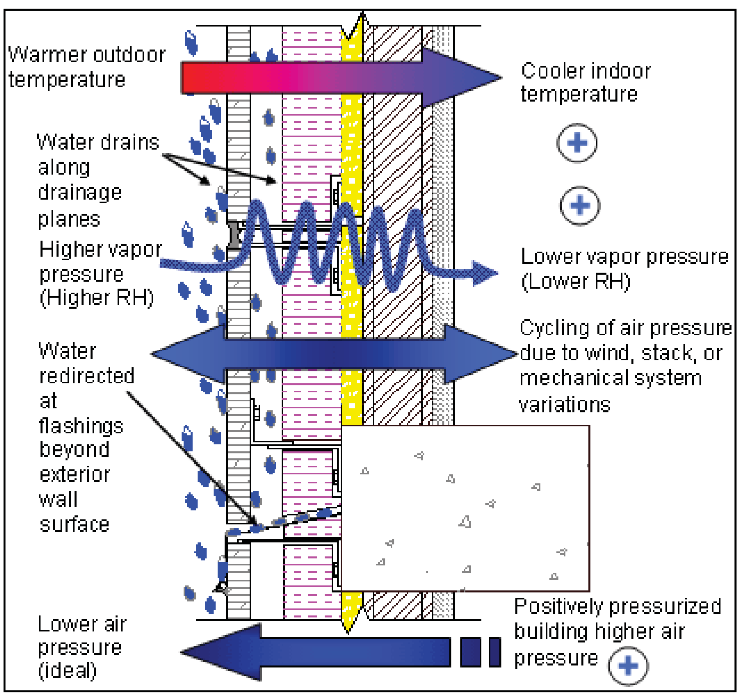


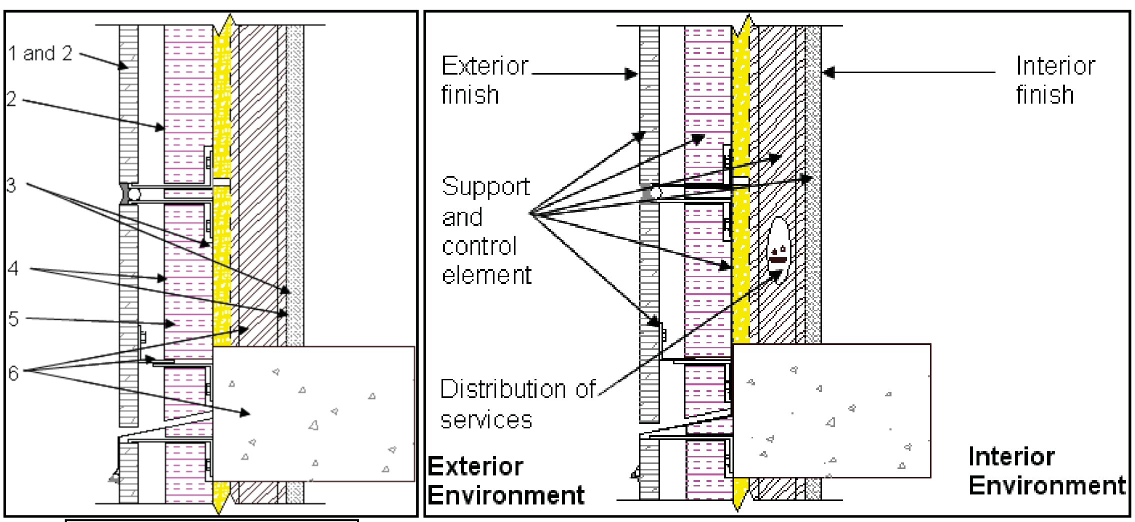
Figure 3 –Air and Moisture Transfer Diagram

Image courtesy the Whole Building Design Guide

A moisture problem generally occurs when the building element susceptible to damage (such as rot, corrosion, and microbial growth) is exposed to air, and allowed to remain "wet" at a level that is above its safe storage capacity for moisture for an extended period of time. This can occur when a building element is exposed to direct and repeated rainwater penetration, or is otherwise inhibited in some way from effectively "drying" due to improper design and/or construction. If left untreated, these materials will then create a condition inside the wall assembly that is prone to mold development and other moisture related damages. Many thermal and moisture problems can be prevented with proper installation of a wall assembly. Joints, cracks, penetrations, and other areas on the wall surface where air and moisture barriers are compromised must be properly sealed and designed for. These problematic areas commonly occur around windows, doors, panel and wall joints, flashing locations, MEP rough-in locations, and termination points.

Campus Square's Exterior Wall System

Campus Square implemented a cavity wall as the primary exterior wall system throughout all faces of the building. This common exterior wall type and method of construction is fairly popular in many regions of the United States. This is due to the redundancy of this type of wall assembly to resist rainwater infiltration, as well as its routine construction sequence. The cavity wall system used for Campus Square relies upon a concealed air space and drainage plane to effectively resist moisture penetration, as well as improve upon the thermal performance of the building enclosure where the cavity acts as an insulator. Figure 4 below demonstrates a typical cavity wall assembly.



1. Exterior Cladding
2. Drainage Plane
3. Air Barrier System
4. Vapor Retarder
5. Insulating Element
6. Structural Element

Figure 4 –Typical Cavity Wall Assembly

Image courtesy the Whole Building Design Guide

Cavity walls, such as the one used for Campus Square include an exterior cladding element; in this case a brick veneer, to act as the main defense against the majority of outside weather conditions penetrating through the wall. A drainage and air space backs the brick veneer, which is designed to collect, control and drain moisture penetration which passes through the exterior cladding. This space is passively ventilated in order to prevent moisture from traveling into "dry" sections o the wall assembly through penetrations. Furthermore, the cavity space is backed by a Tyvek® drainage plane which serves as a barrier within the wall assembly between "wet" and "dry" sections of the wall. This material prevents condensation and mold growth within the dry space of the assembly. It is important that this layer have well sealed areas where penetrations occur in order to reduce moisture penetration. Finally, the insulating layer, which is located behind the DensGlass® sheathing, protects against thermal infiltration between the inside and outside temperature gradient. Figure 5 on the following page depicts the cavity wall assembly installed on Campus Square. Exterior insulation (outside of the sheathing) was not implemented on Campus Square, and may have resulted in better thermal properties through the assembly. Instead, batting insulation was placed between the metal studs.

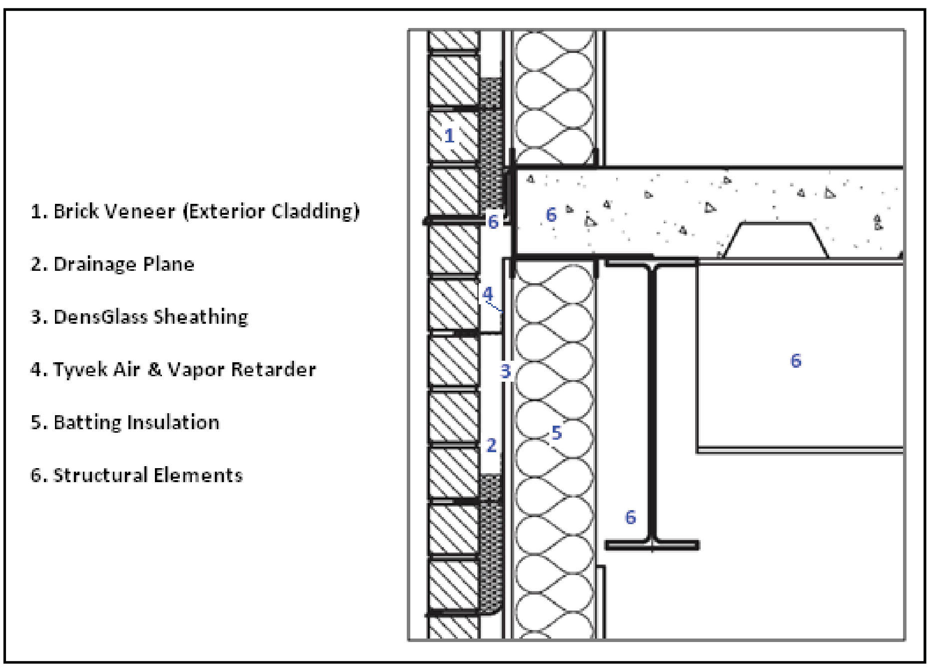


Figure 5 –Campus Square Exterior Wall Assembly

Drawing provided by Wohlsen Construction

Cavity Wall Constructability Concerns

Cavity walls offer an array of aesthetic designs, material selections, as well as versatile construction methods and tolerances for various building types. The different assembly options for cavity walls can produce effective thermal and moisture barriers; however construction methods of this wall type can severely reduce the efficiency of the system, resulting in costly deficiencies. It is also important to understand that improperly designed/ constructed cavity wall systems can be costly to properly repair after construction is complete. Throughout installation of the cavity wall system, it is important to maintain an effective envelope quality assurance program in order to ensure each wall element is properly designed for, and installed to specification standards. Similarly, it is critical that joints and penetrations along the wall face be properly sealed to prevent additional thermal and moisture leaks. Because this is true, flashing locations along the exterior wall must be installed carefully.

If moisture is able to leak into the "dry" space of the building, it can result in corrosion of steel elements, as well as mold growth, which may remain undetected before the issue become evident. Repairing these deficiencies can result in negative aesthetic impacts, as well as interfering with the use of the space. Similarly, pressure-equalized, "rain screen" cavity wall systems, place the primary drainage plane, and principal air barrier in the same plane between the wet and dry zones of the wall assembly. Rain screens diminish the forces attempting to drive moisture into the wall. There are two types of rain screens: simple rain screens and pressure-equalized rain screens (PER). Examples include brick veneer cavity walls, furred-out clapboard walls, and drainable EIFS.

However, the principal advantages of the rain screen system, which is to prevent a negative air pressure differential from occurring across the exterior wall assembly (a condition that can "draw" rainwater through the enclosure and into the building), can also be extremely difficult to effectively achieve in the field. This constructability issue can be attributed to the complicated detailing required at penetrations through the air barrier and drainage plane; including the attention to detail and workmanship needed to correctly seal the penetrations to prevent undesired inward airflow through the assembly.

Alternative Exterior Wall Systems

Barrier Wall

Another commonly used exterior wall system is the barrier wall, which implements a weather-tight outermost exterior wall surface and construction joints to resist moisture and thermal infiltration. A barrier wall system, if effectively installed, can improve upon the thermal performance of the building. Due to the reduced amount of penetrations through the air and moisture barrier, thermal bridging is mitigated. This wall type is commonly associated with precast concrete spandrel panels, certain types of composite and solid metal plate exterior cladding systems, and early generation exterior insulation and finish systems (EIFS). Barrier walls are often considered a more cost-effective and preferable alternative to cavity and mass wall assemblies. Figure 6 on the following page compares a cavity wall system with a barrier wall assembly.

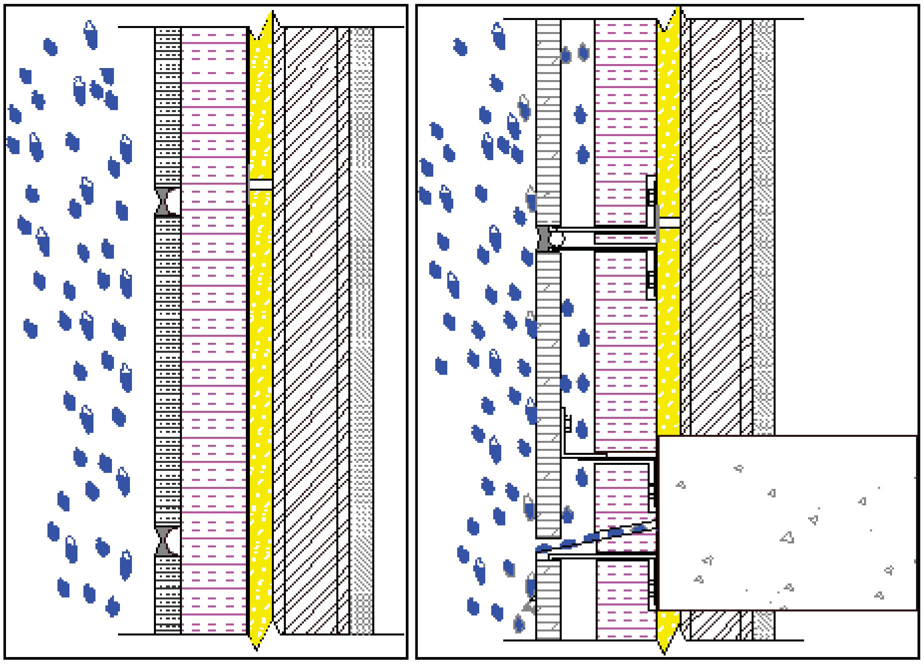


Figure 6 –Left: Barrier Wall Diagram; Right: Cavity Wall Diagram

Image courtesy the Whole Building Design Guide

Barrier Wall Constructability Concerns

Barrier wall systems only offer a single line of defense against moisture penetration due to the lack of cavity/drainage space. Also, they require more sophisticated design and constructability efforts, including workmanship in the field. Furthermore, barrier walls require a high degree of maintenance in order to keep the design performance of the assembly. Because this is true, any defect in design, installation, or workmanship can result in immediate moisture and thermal penetrations through the wall. In order to reduce the amount of field installation and construction, barrier walls offer the ability for prefabrication. The controlled environment of the prefabrication manufacturing process assists in reducing constructability issues such as moisture and thermal leaks through seam and penetrations. However, joints will still exist where each panel is connected when installed on-site; thus, close supervision and quality control is essential in ensuring construction is performed to design specifications.

Exterior Insulation and Finish Systems (EIFS)

A potential finish material which could be applied to Campus Square is EIFS. The EIFS systems can be implemented in both drainable or barrier systems, accomplishing a traditional masonry brick exterior. Because Campus Square is aesthetically confined to the historical design requirements of the area, not all wall systems will be applicable as a potential substitution. Although EIF systems can be more costly when compared to a traditional masonry façade, if installed properly, can provide improved thermal properties and efficiency.

EIFS is available in two basic types: a barrier wall system or a wall drainage system. Barrier EIFS wall systems rely primarily on the base coat portion of the exterior skin to resist water penetration. Therefore, all other components of the exterior wall must either be barrier type systems or be properly sealed and flashed to prevent water from migrating behind the EIFS and into the underlying walls or interiors. Wall drainage EIFS systems are similar to cavity walls; they are installed over a weather barrier behind the insulation that acts as a secondary drainage plane. The weather barrier must be properly flashed and coordinated with all other portions of the exterior wall to prevent water from migrating into the underlying walls or interiors.

EIFS Constructability Concerns
As with other barrier and cavity wall systems, failure to correctly install joint sealants around penetrations through the wall and wall seams can severely reduce the advantage of an EIFS system. Proper flashing at the wall/roof termination point, as well as around windows is essential during construction. Also, because EIFS is not as durable as masonry or metal cladding systems, it is more prone to damage. Because this is true, damage from ropes, cables, impact damage, etc. must be corrected immediately to prevent further thermal and moisture damage to the integrity of the assembly.

Precast Concrete Spandrel Panels
Wohlsen Construction performed nearly all the concrete work for Campus Square. This helped reduce costs in paying for installation fees from subcontractors. However, precast concrete panels may reduce construction duration, accelerating the building envelope construction time. Precast concrete wall systems allow a wide variety of colors, finishes and architectural shapes. Precast concrete can be used in environments that allow the use of conventional cast-in-place concrete, which benefits Wohlsen's self-perform concrete advantage. In addition, precast concrete may be made in a controlled environment, improving quality, and erected in an environment that would not allow site casting of concrete. Applicable precast concrete panel types for Campus Square include cladding or curtain walls, load-bearing wall units, and shear wall.

Precast cladding or curtain walls are the most common use of precast concrete for building envelopes. These types of precast concrete panels do not transfer vertical loads but simply enclose the space. They are only designed to resist wind, seismic forces generated by their own weight, and forces required to transfer the weight of the panel to the support. Common cladding units include wall panels, window wall units, spandrels, mullions, and column covers. These units can usually be removed individually if necessary.

Load-bearing wall units resist and transfer loads from other elements and cannot be removed without affecting the strength or stability of the building. Typical load-bearing wall units include solid wall panels, and window wall and spandrel panels.

Precast concrete shear wall panels are used to provide lateral load resisting system when combined with diaphragm action of the floor construction. The effectiveness of precast shear walls is largely dependent upon the panel-to-panel connections. Panel-to-panel connections, as well as construction joints, as with the previously mentioned systems, must be designed considering structural, thermal, and panel movement.

Mass Wall Systems

Different from cavity wall systems, where the wall assembly hosts a wall cavity and through-wall flashing to collect moisture to the building exterior, mass walls incorporate a combination of wall thickness, storage capacity, and bonds between masonry units and mortar to resist thermal and moisture penetration. These systems are usually more expensive, and therefore, less common in application because of material and installation costs. Furthermore, moisture penetration through mass walls systems is more difficult to track and repair due to the nature of the assembly. Evaporative drying across this type of wall assembly can result in efflorescence, deterioration of interior cement finishes, and organic growth on the interior and/or exterior wall surfaces. These problematic features not only degrade the aesthetic appeal of the wall, but also can lead to severe moisture damage if not remedied.

Rain protection of mass walls, and understanding the rate the wall will get wet, the amount of moisture it is capable of storing, and the drying rate become important design considerations, as exceeding the safe storage capacity for long periods of time may create long term moisture problems for the surrounding materials that might come in contact with the mass wall. Cavity walls operate similar to barrier walls in that they rely on the materials used to resist moisture and water penetration. However, unlike barrier systems, they tend to be more prone to infiltration due to the amount of absorption that occurs through the porous mortar and masonry units. Figure 7 below demonstrates moisture infiltration, as bulk rainwater penetrates through the mass wall assembly.

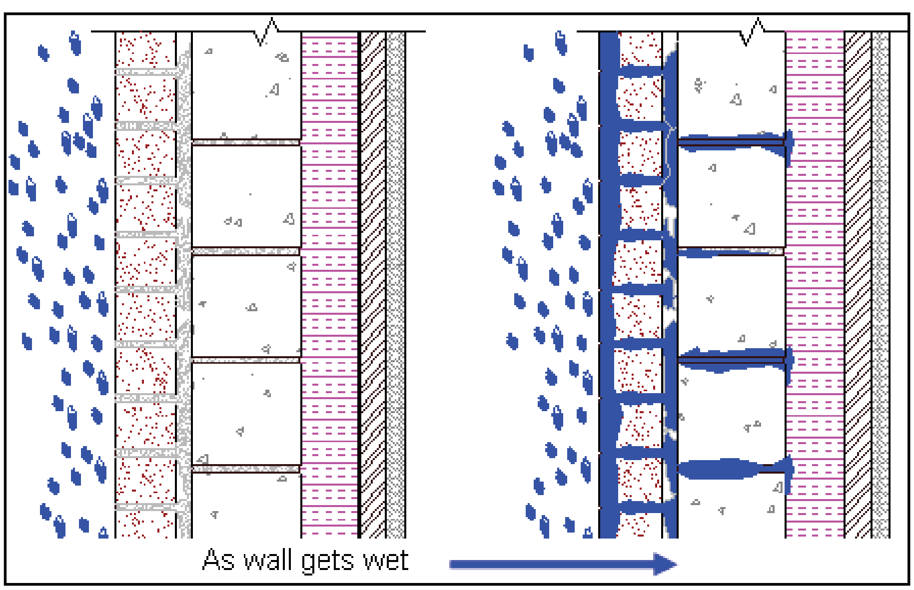


Figure 7- Mass Wall Moisture Penetration

Image courtesy the Whole Building Design Guide

Mass Wall Constructability Impacts

The installation of the brick veneer system of Campus Square consumed approximately eight weeks before it was complete. The incorporation of a mass wall system using masonry block would probably result in an even longer installation duration. Because this is true, implementing a mass wall would not be a practical substitution to the as-built assembly. Furthermore, due to the amount of on-site construction this wall takes, it can be assumed that a lesser quality of construction may occur. This degradation may result in a poorer performing envelope, resulting in higher operational costs.

Emerging Issues- Hybrid Exterior Wall Systems and Emerging Technologies

In recent years, technological advancements in the design and manufacture of building enclosure materials, components and systems, together with an increasingly refined understanding of air/moisture transfer and the behavior of wind-driven rain on the building enclosure have lead to the development of several hybrid and sustainable exterior wall systems. The following wall systems could act as possible additions to Campus Square, in an effort to further enhance the sustainable features and efficiency of the building.

Hybrid wall systems typically include design features and individual building elements that are intended to improve or enhance the long-term durability and performance of the building enclosure, and are often adapted in response to issues and concerns that are unique to a particular geographic area and/or climatic region in which a building or structure is to be designed and built. Many of these hybrid systems have varying short and long-term costs, maintenance burdens, durability, and modified performance areas of the building enclosure.

Trombe Walls

A trombe wall system is made of dark-colored masonry, stone, or concrete which have the ability to absorb and store energy from the sun. The advantage of implementing this system is to reduce mechanical heating and cooling costs throughout the year. Installed on a south facing wall, which experiences the most sun exposure of any direction, the thermal massing element is fronted with glazing which allows sunlight to pass through into the wall. Throughout the day, sun heats the south face of the wall and warms it. The heat is released back into the interior occupied space when the sun is no longer shining. Ideally, an appropriately-sized overhang is necessary to block out the high summer sun when heat gain is unwanted, yet still allow the low winter sun to penetrate through the trombe wall. As the sun heats the wall, causing heated air to rise in the air space, the heated air is directed into the building through vents at the top of the wall, passively drawing cooler air into the vents at the base of the wall to be heated in turn. At night, dampers close off the walls, preventing reverse thermo-siphoning (cold air from the cavity falling and entering the building at night), while heat stored in the mass walls is released throughout the space at this time. In summer, the walls are vented at night, allowing for passive cooling. Thermal mass has a lower initial temperature than the surrounding air and acts as a heat sink, therefore cooling the room. Figure 8 on the following page captures the basic idea and application of a trombe wall system.

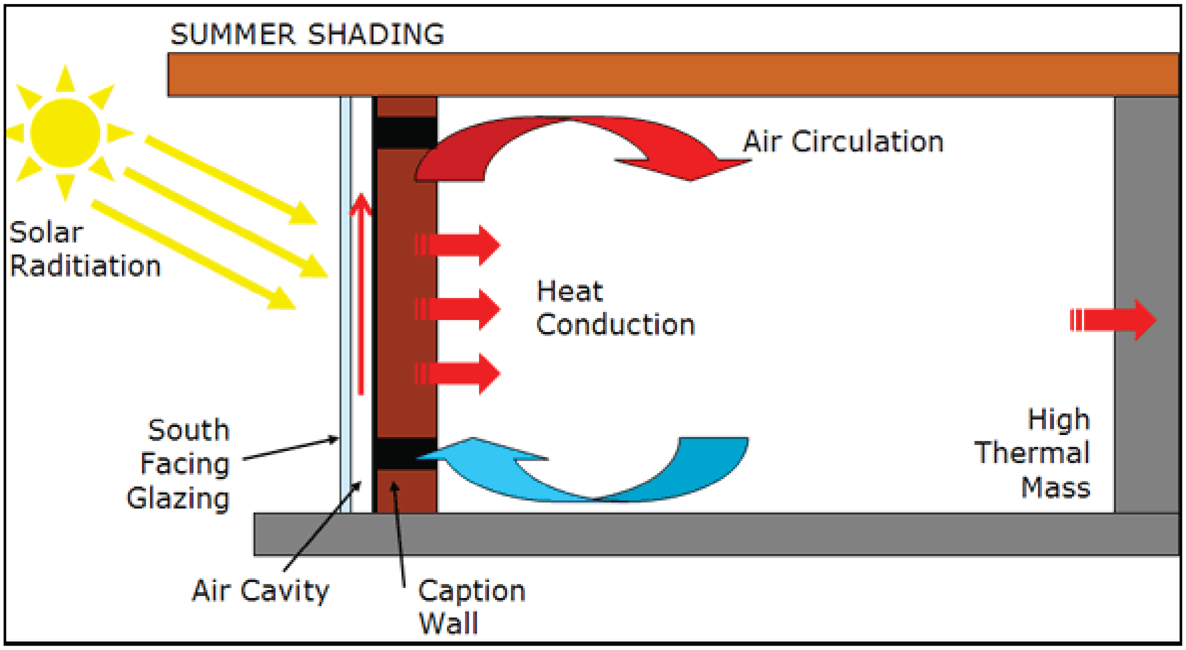


Figure 8 –Trombe Wall Heating and Cooling Diagram

Image courtesy the Druk White Lotus School

A trombe wall system could be implemented along the south face of the Campus Square building. However, due to the tight property line to adjacent buildings, the effectiveness of this system would be limited. Neighboring buildings may prevent too much shading onto Campus Square, preventing winter solar radiation to actively penetrate the wall space. Therefore, additional solar studies would need to be performed in order to justify the installation of a trombe wall system.

Dynamic Buffer Zone Systems

A Dynamic Buffer Zone (DBZ) performs the function of the air barrier in a building envelope, which protects the exterior façade from exposure to interior air moisture. The DBZ system creates conditions in an existing or purpose built air space (DBZ cavity) located within an exterior wall that effectively separates the interior and the outdoor environments. Conditions within the DBZ cavity that need to be controlled are air pressure, moisture content, and temperature.

To effectively prevent exfiltration of humid interior air through the building envelope during cold weather, the air pressure of the DBZ cavity is maintained slightly higher than the interior air pressure. Theoretically, the cavity air pressure needs only to be nominally higher than that of the interior space to prevent air leakage from the interior. During winter conditions, outdoor air will have a low moisture content which makes it an ideal air supply for the DBZ cavity. The requirement for pressurization of the DBZ cavity will ensure that interior humid air will not leak outwards into the building envelope. If any leakage of air from the cavity to the outside occurs, the low moisture content of the DBZ air will eliminate the threat of condensation within the building envelope.

There are two possible modes of operating the DBZ system. The first option is known as a "balloon" system where air is pumped into the cavity with no intentional exhaust air. That is, when the pressure inside the cavity drops below a specified lower limit, fans are activated to pressurize the cavity to the specified upper limit. The air inside the cavity will then leak out through the cracks of the exterior wall and through any imperfections in the interior wall finish until the lower prescribed pressure limit is reached, after which the process will repeat itself. The alternate mode is the exhaust system. This system entails supplying a continuous flow of air into the cavity and intentionally exhausting air from it so that the pressure within the cavity is maintained at a predetermined level. How and where the air is exhausted is dependent on a number of factors that are largely determined by the particular building involved.

The exhaust mode of operation allows for a great amount of versatility to the DBZ system. By controlling the flow rate and the initial temperature of the DBZ air, the system can act as both an air barrier and as a dynamic insulation system that can provide greater thermal efficiencies when compared to the same envelope without airflow.

Additional advantages of the exhaust DBZ system are its ability to promote drying of the masonry following rain penetration, to allow airborne contaminants to be contained in a space and controlled, and to increase the temperature of interior finishes of the exterior wall by supplying warm DBZ air. This will eliminate drafts associated with uninsulated walls and will increase thermal comfort.

In addition to walls and roofs, the DBZ system can also incorporate windows. Additional thermal comfort and condensation control can be provided by increasing the interior surface temperature of windows, allowing higher indoor humidities. This system can also eliminate the need for convection units below windows that are used to mitigate cold drafts.

Outdoor air is an ideal source for the DBZ air because of its low moisture content during winter conditions. Since winter outdoor air temperatures are much cooler in northern climates, some heat must be added to the DBZ air before it is introduced into the cavity. Although the temperature of the cavity air supplied is not important when dealing with the prevention of air exfiltration, it is important from the perspective of thermal comfort, surface condensation, and operating costs.

Buildings which are humidified and pressurized often suffer from wall or roof cavity condensation due to imperfect air sealing, higher indoor humidity and an air pressure difference. Air pressure differences may occur from stack effect, fan pressurization or wind. Efforts to upgrade the air tightness of building envelopes to prevent condensation have not been entirely successful. Furthermore, ventilation design produces ever increasing indoor building pressure conditions. For these reasons an alternate technology such as a DBZ system, which can control construction cavity condensation effectively, without the necessity of perfect design or perfect construction is gaining understanding and market acceptance for many types of buildings, including high and low-rise office buildings.

Double-Skinned Façades

A Double Skin Façade is a system consisting of two glass skins placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical. Apart from the type of the ventilation inside the cavity, the origin and destination of the air can differ depending mostly on climatic conditions, the use, the location, the occupational hours of the building and the HVAC system implemented. The glass skins can be single or double glazing units with a distance up to 6ft. Often, for protection and heat extraction reasons during the cooling period, solar shading devices are placed inside the cavity.

The solar properties of the Double Skin Façade do not differ from the Single Skin Façade. However, due to the additional skin, a thermal buffer zone is formed which reduces the heat losses and enables passive solar gains. During the heating period, the preheated air can be introduced inside the building providing natural ventilation with retained good indoor climate. On the other hand, during the summer overheating problems were mentioned when the façade was poorly ventilated. Different configurations can result in different ways of using the façade, proving the flexibility of the system to different climates and locations.

Double Skin Façades for office buildings were developed mostly in Europe in order to arrive at increased transparency combining acceptable indoor environment with reduced energy use. The main disadvantage of this system is that in countries with high solar gains the air temperatures inside the cavity are increased during periods with warm weather, leading to overheating problems. The thermal discomfort leads to higher energy consumption for cooling, in turn, leading to lesser energy efficiencies. The Double Skin Facades are systems that highly depend on the outdoor conditions (solar radiation, outdoor temperature, etc) since they allow the outside conditions to influence the indoor climate. Thus, it is obvious that each Double Skin Façade has to be designed for a certain building location and façade orientation otherwise the performance of the system will not be beneficial.

Different panes and shading devices result in different physical properties. The interior and exterior openings can influence the type of flow and the air temperatures of the cavity. All together these parameters determine the use of the Double Skin Façade and the HVAC strategy that has to be followed in order to succeed in improving the indoor environment and reducing the energy use. It is necessary for the design approach to be overall considering the façade as an integrated part of the building and detailed enough in order to determine all the parameters that will lead to a better performance. Figure 9 on the following page demonstrates the functionality of a double-skinned façade system.

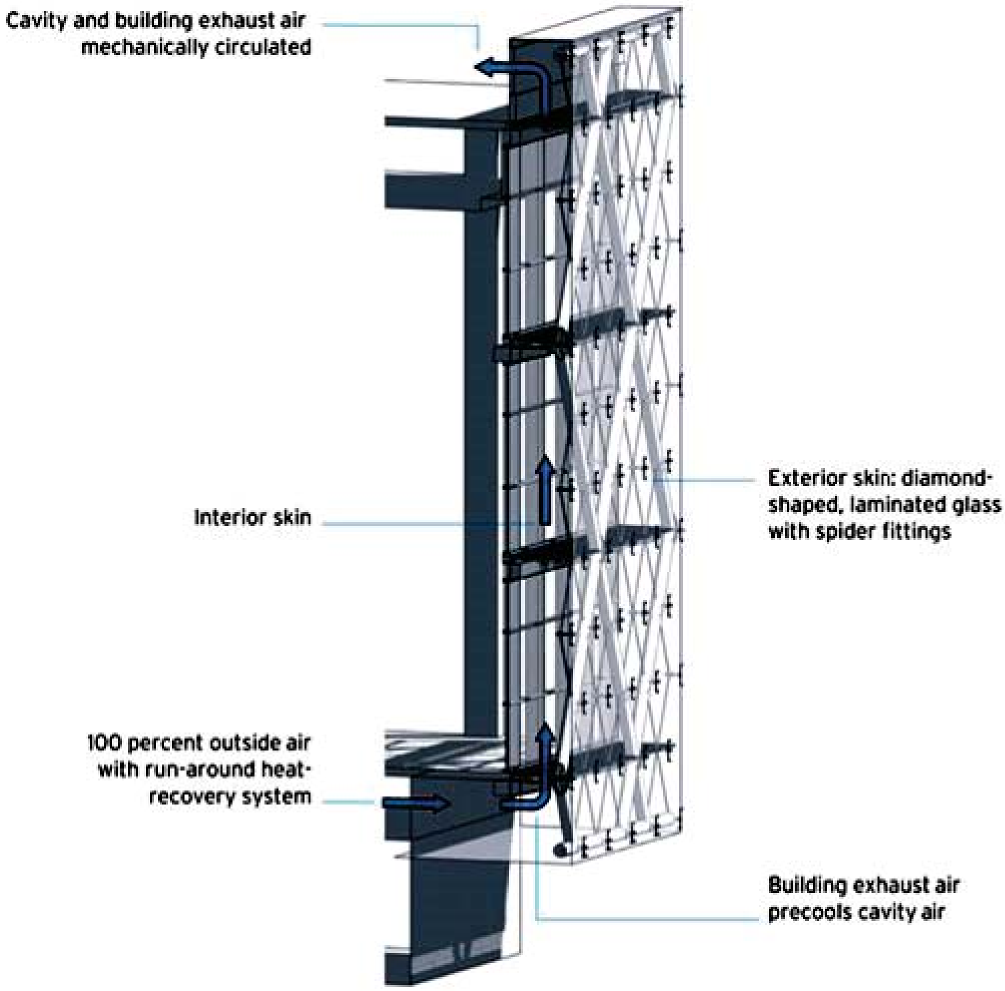


Figure 9 –Double-Skinned Façade System
Image courtesy of the Design Build Network

As mentioned in the description of this system, a double-skinned façade depends greatly on the existing conditions of the building, as well as its location. The implementation of this system on Campus Square could potentially be realized, however, further mechanical analysis, as well as solar studies would need to be performed.

Conclusions and Recommendation
The incorporation of sustainability in Campus Square is evident in GreenWorks efforts to build a LEED® Gold building. Additional sustainable systems could indeed be incorporated into Campus Square as means to advance the building to a LEED® Platinum structure. The aforementioned exterior wall types and envelope systems are a few potentially applicable methods which could be used to accomplish that

feat. However, extensive analysis would need to be performed in determining the associated costs and payback periods of each system. Although these systems may prove beneficial to the structure, the limitations of the physical site location may impede upon application due to the dependence of thermal efficiencies on non obstructed solar gains. In short, perhaps under a different site location, with more exposure on the faces of the building, these systems may be more appropriate. However, the south face of Campus Square is backed with more buildings, masking much of the wall from sun exposure. The construction management depth analysis will focus more on a prefabricated wall system as a substitute for the as-built methods.