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HOLDING THE SUN AT BAY:

A Study in the Development of the Double-skin Façade for the Case Western Reserve University Tinkham Veale University Center

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ABSTRACT

Early in the development of the design for the Tinkham Veale University Center, the team determined that the west-facing glass wall of the Commons space presented challenges to the usability and conditioning of that space. The team proceeded to explore several options to control solar heat and light gain, including electrochromic glass, internal sun shading, fixed external sun shades and a double-skin wall with operable shading. Once the team determined that the double-skin wall was the best solution, they proceeded to perform a series of studies to validate that choice and determine overall functionality.

The configuration of the glazing for each plane of the double-skin was studied to optimize performance. Multiple types and configurations of integral shading were studied for cost-effectiveness, durability and function. The team engaged in extensive study and exploration of the airflow through the double-skin cavity to guide the configuration of ventilation components. This work helped the team determine that passive ventilation was not a workable option and ultimately guided the team's selection of ventilation fan locations, quantities and capacity as well as the locations and sizes of intake. Finally, the design team addressed issues of maintenance access and interface with the adjacent underground parking garage and completed the architectural detailing.

The final combination of design elements for the double-skin façade (monolithic glass exterior plane; insulated glass interior plane; mechanical ventilation; 3'-0" wide cavity; and sun-controlled operable roller shades) met all of the project's functional, aesthetic and energy goals and was deemed to be the best solution.

KEYWORDS: double-skin; curtain wall; solar control; computational fluid dynamics

1.0 INTRODUCTION

The 2005 Case Western Reserve University master plan identified the need for a strong physical and functional campus center to deemphasize the physical and psychological boundaries that exist between the historical Case Institute of Technology and Western Reserve University campuses. Openness, light and transparency emerged as primary design directions to achieve these goals and drove much of the design of the Tinkham Veale University Center. The new student center was envisioned to serve as the figurative heart of the unified campus and to be a beacon to students, staff and visitors. Thus, the site identified for the project occupies a prime open space at the center of the campus and is easily accessible from all corners of the University.

The central campus location, shown in Figure 1, proved to be challenging due to the proximity of numerous buildings, including a two-story below-grade parking

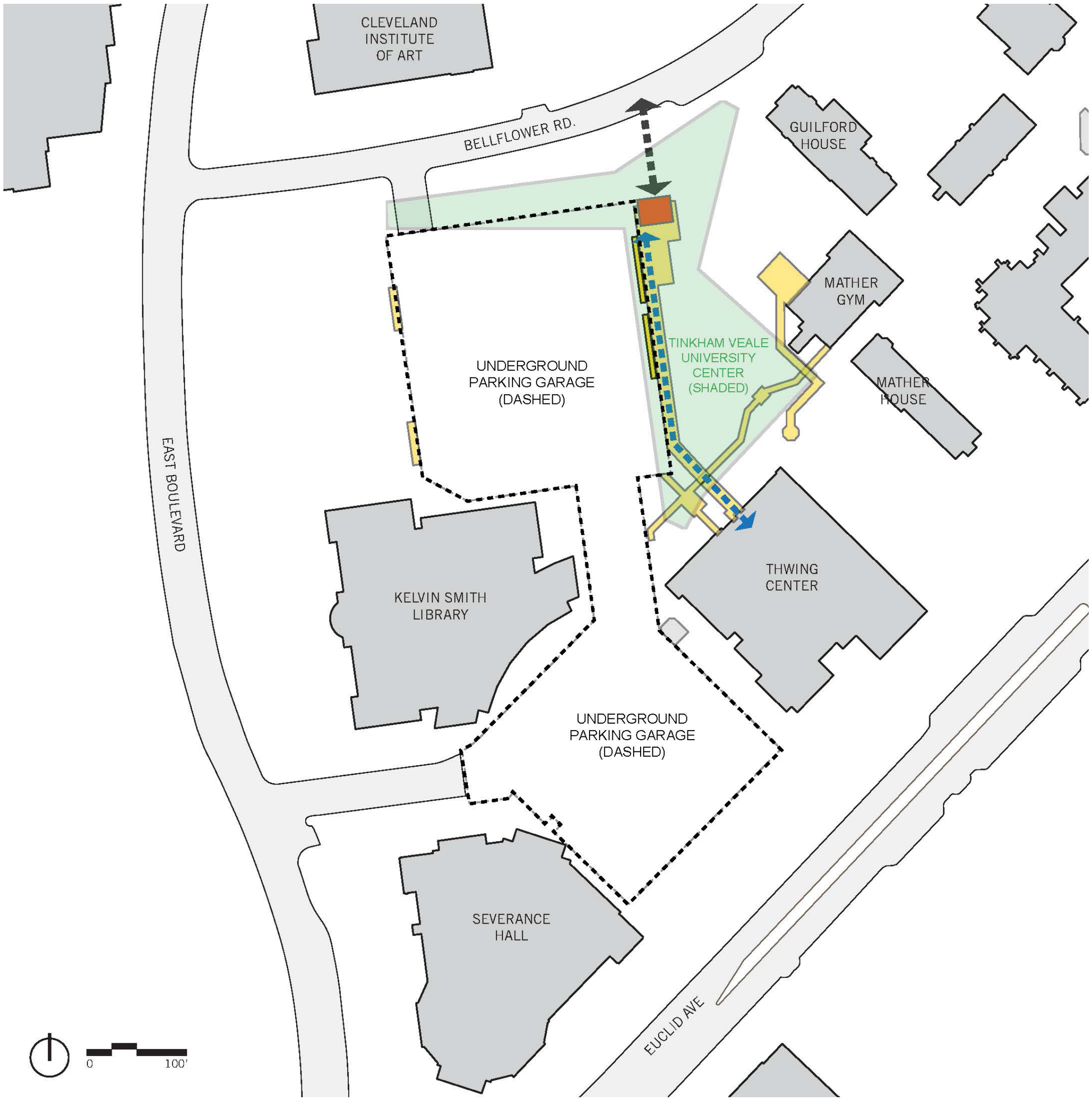


Figure 1: Site plan.

structure; a crossing network of infrastructure; and important pedestrian paths leaving limited space to build.

These challenges drove the building form, massing and layout that resulted in the placement of the large central Commons space along the west building orientation and overlooking the open field above the parking garage.

Case Western Reserve University's desire for transparency drove the decision to use an ultra-clear glass curtain wall for the entire west wall of the Commons space; sustainability, occupant comfort and functionality dictated that the design team then develop a means to control solar heat and light gain.

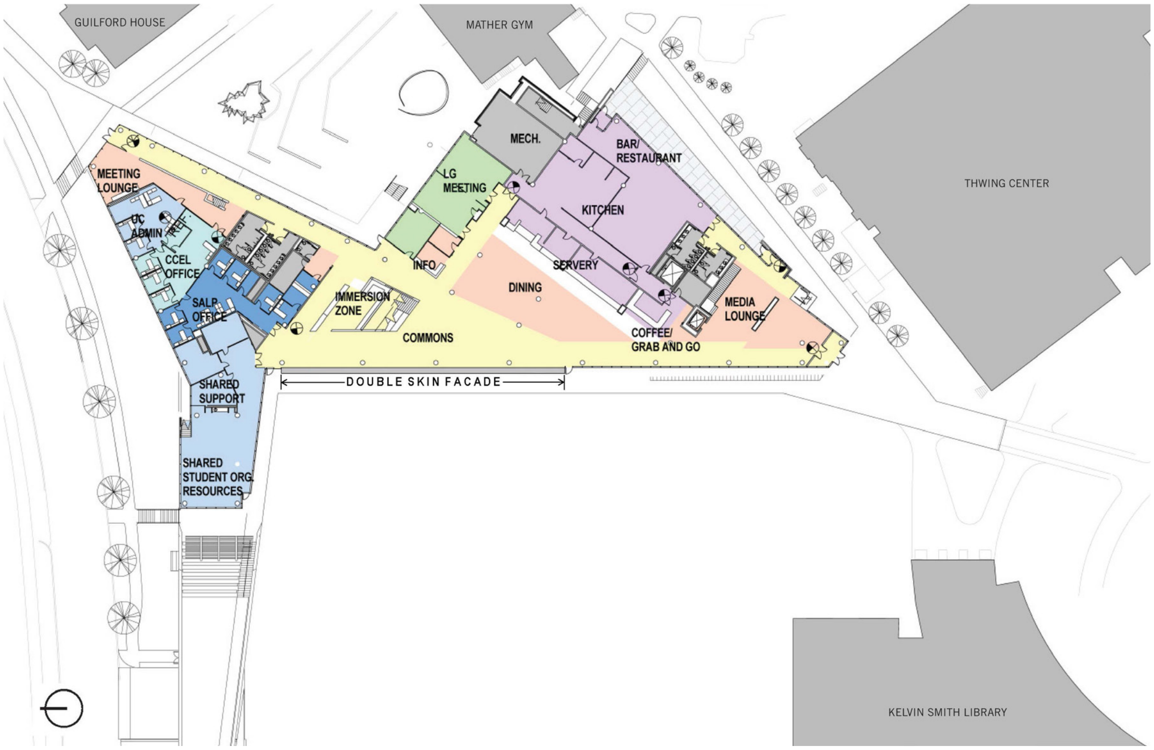


Figure 2: Level 1 plan.

1.1 Identifying the Issue

The Tinkham Veale University Center is intended to be open and occupied 24 hours a day, 7 days a week and the Commons space is anticipated to be a major hub of activity. The double-height space is not programmed for a specific function, but is rather designed for gathering, studying, lounging and all manner of activity, both sedentary and active; some occupants will simply pass through, some will stay for hours. The Commons' western exposure means that there will be numerous hours of the day, throughout the year, when the space is bathed in direct sunlight. While this serves the goal of using daylighting in lieu of electric lighting and of creating an energizing space, it also has the potential to create significant heat gain and glare and adversely affect occupant comfort. The design team's concern about these issues was supported by a study by Hendricksen, et al that identified high lighting contrast in open plan areas and glare as major negative issues associated with large, glazed facades[1]. Thus two primary design challenges arose: controlling solar heat gain; and controlling solar light gain, glare and high lighting contrast; while maintaining transparency and views (both outside looking in, and inside looking out).

Occupants in a space such as this can be expected to want to take in the expansive views of the surroundings, but they can also be expected to work on computers, read, converse and linger for hours. These activities benefit from sunlight, but too much of it becomes detrimental and diminishes functionality. Infiltration of direct sunlight can create glare on computer screens, discomfort from sun in occupant's eyes and strong visual contrasts created by bold shadows. The building design needed to deal with these issues or risk significant occupant dissatisfaction.

As sustainability was a major project goal, the heating and cooling system for the space was designed to be as energy efficient as possible. The resulting system provides both heating and cooling through radiation from the floor. All of the air supplied to this space is used for ventilation only and does not appreciably contribute to heating or cooling the space. While this is an extremely efficient system, both in terms of energy use and equipment space required, it does have its limitations. In this case, the limitation is in the capacity of the system to cool the space under very high heat loading conditions.

Unobstructed views to the west, and ultra-clear glass allow significantly more heat gain than the radiant cooling system can counteract and required some form of solar control.

1.2 Literature Review

While this paper is primarily a case study on the selection and design of the double-skin façade for the Case Western Reserve University Tinkham Veale University Center, the authors believed that it was important to understand the state of current research and writings related to double-skin façades. Several recent articles were reviewed and are summarized below.

Ole J. Hendriksen, Henrik Sorensen, Anders Svensson and Pontus Aaqvist – *Double-Skin Façades-Fashion or a Step Towards Sustainable Buildings* – This undated paper explores the general concepts of configuration and typology of double-skin façades[1]. The authors discuss some of the environmental factors that should be considered when designing double-skin façades including: daylight, glare, view and transparency; heat loss; venting and natural ventilation; solar shading; noise; and fire. They conclude that double-skin façades can have beneficial effects in each of these areas if designed for the building's specific climate and environmental conditions.

Terri Meyer Boake – *The Tectonics of the Double Skin: Green Building or Just more Hi-Tech Hi-Jinx?* – This undated paper endeavors to explain the basic concepts behind double-skin façades and how these affect the façade's performance[2]. One of the more important conclusions of this work is the classification of double-skin façades into four major categories: buffer system; extract air system; twin face system; and hybrid system. Major elements and aspects of double-skin façades are briefly explained: division of the cavity; cleaning the cavity; ventilation strategies; and solar heat gain. The author discusses environmental claims of designers of double-skin façades and economic considerations related to the design and construction of double-skin façades. The author concludes that double-skin façades can mitigate the high energy use endemic to highly glazed buildings, particularly high rises.

Matthias Hasse and Alex Amato – *Simulation of Double-Skin Facades for Hot and Humid Climate* – This paper focuses on the efficacy of double-skin façades in the Hong Kong area in reducing peak cooling loads during the summer[3]. Simulations of the double-skin façade take several factors into account, including the building HVAC control strategy and the urban context. The authors conclude that a double-skin façade can reduce peak cooling load on the interior of a building by up to 30 percent over a baseline single glazed curtain wall.

Brett Pollard and Mary Beatty – *Double-Skin Façades More is Less?* – This paper was produced for the 3rd International Solar Energy Society Conference-Asia Pacific Region (2008)[4]. It begins as an inquiry into the proclaimed benefits of double-skin façades. The authors then summarize recent trends in the design and categorization of double-skin façades, explain some proposed design considerations and briefly discuss the application of double-skin façades in hot climates. The paper includes brief descriptions of several buildings in North America and Australia that include double-skin façades.

Harris Poirazis – *Single and Double Skin Glazed Office Buildings, Analysis of Energy Use and Indoor Climate* – This extensive report was published under the auspices of Lund University Department of Architecture and Built Environment[7]. The main focus of the report is to explain how highly glazed facades affect the energy use and occupant comfort in office buildings. The author also makes the case for needed improvement in building energy simulation tools to assist in designing energy-efficient buildings. The paper includes a description of a baseline single skin building model and proceeds to explore numerous options for single- and double-skin façades and their energy performance. The author's conclusion is that double-skin façades can be very effective in reducing energy use in highly glazed buildings.

Mauricio Torres, Pere Alavedra, Amado Guzman, Eva Cuerva, Carla Planas, Raquel Clemente and Vanessa Escalona – *Double-Skin Façades-Cavity and Exterior Openings Dimensions for Saving Energy on Mediterranean Climate* – This paper explores three primary aspects of double-skin façades: cavity depth; external opening area; and single-story vs. multi-story cavity configurations, with the goal of determining the best performance in a Mediterranean climate[8]. The study ultimately concludes that the depth of the cavity and the single/multi-story configuration were less important to the efficacy of reducing cooling loads than the influence of the exterior opening area. The authors note, however, that the simulation tools used were not particularly sensitive and the models were somewhat specific to the simplified double-skin façade configurations and the particular climatic conditions that were used, limiting transferability of the results.

2.0 EXPLORATION OF POTENTIAL SOLUTIONS

After the team identified the need to control both solar heat and light gain, we began to explore potential systems, both active and passive, that could be employed.

Exterior Solar Shading

One of the first systems we explored was fixed, exterior solar shades. The western exposure and the potential for 24/7 use of the space suggested that vertical shading elements would be most effective. Our initial idea for this system had airfoil-shaped aluminum fins generously spaced along the entire west building façade as seen in Figure 3.

We performed solar studies on the preferred layout and determined that this spacing would not provide effective shading. In order to adequately shade the interior spaces and meet the occupant comfort and conditioning needs, the shade spacing would had to have been reduced significantly. The dense spacing and the required depth of the shade elements would have compromised the desired transparency of this façade and could have created maintenance issues, so this approach was abandoned.

Interior Solar Shading

The team investigated the use of interior solar shading, specifically fabric roller shades, to control the solar heat and light gain. Physically, this solution presented a challenge because the ceiling in the Commons area follows the sloping roof line and created difficulties in mounting shades, which must be installed horizontally. Beyond that, there were functional issues that made this solution unworkable. While internal shades would provide sufficient protection from light gain, they would actually compound the solar heat gain. By locating the shades on the building interior, they would act as a heat sink; collecting and redistributing the solar heat inside the building, overloading the mechanical system on the hottest and sunniest days. Since this approach was unable to satisfy all of the functional requirements, it was also abandoned.

Electrochromic Glass

Electrochromic glass is a glazing product that has a coating that changes from transparent to tinted state when electric current is applied, integrating the shad-

Figure 3: Southwest aerial view – vertical solar shades.

ing into the glazing units. This solution offered much promise, as it satisfied the need to control heat and light gain; was variable and controllable based on weather conditions; and would not require separate shading devices. The efficacy of the product was investigated from both architectural and mechanical perspectives and it appeared to perform well in both areas. The difficulties in using this product that emerged were primarily aesthetic. First, the electrochromic coating that was on the market during the design phase was only available in blue. While the color palette of the building does rely heavily on the use of blue, as the official color of Case Western Reserve University, blue-tinted glass did not fit the design vision of the project. Further, and more importantly, the electrochromic coating had size limitations that were not compatible with the building design. The effective width of the electrochromic coating, the distance that an electric current could travel through the film to activate it, was 60 inches. As a result, any glazing panel that exceeded this width would need an additional electrical conductor located no more than 60 inches from one vertical edge. The building module is 6ft-3in, meaning that each glazing panel would require a conductor. These conductors are clear, so they are not readily visible when the electrochromic coating is not energized; however, they remain clear even when energized, so when the electrochromic coating is tinted for shading, the conductor is easily visible. These added vertical elements in the curtain wall would disrupt the carefully implemented building module in a way that seriously compromised the design. So, in the end, while electrochromic glass was an excellent functional choice, the aesthetic compromises it required were unacceptable.

Double-Skin Curtain Wall

The final option that was investigated was a double-skin curtain wall. By carefully designing the support structure to be as unobtrusive as possible and by selecting ultra-clear, low-iron glass, the wall achieved the desired transparency. The wall cavity provided an opportunity for solar shading that was outside the conditioned space and an ability to create a buffer between the indoor and outdoor temperatures. Having dismissed the other potential solutions, the design team began to investigate the configuration of the double-skin wall and validate its performance.

Supporting Energy Analysis

Energy modeling was conducted to provide answers to many of the concerns related to each of the potential façade choices. EnergyPlus modeling allowed the design team to understand the energy impact of each design and the potential number of hours of occupant discomfort. EnergyPlus was chosen for its high level of accuracy, its ability to simulate multiple façade schemes and the capability of including variables like electrochromic glazing controls and double skin façade ventilation effects. EnergyPlus allowed the design team to estimate the summer cooling savings associated with the shading effects of each façade as well as any winter heating savings. It should be noted that only the double skin façade demonstrated winter heating savings as it was the only façade type capable of providing a thermal buffer space to trap heat in the winter. Estimates of the change in peak thermal load for each option were also generated, allowing the design team to understand the mechanical system capacities needed to serve the Commons.

Figure 4 shows the modeled energy use in the Commons space for some of the strategies that were investigated. Electrochromic glazing and double-skin façades provide superior energy use reduction over fins, with the thermal buffering properties of a double-skin façade providing additional savings beyond electrochromic glass. Energy modeling estimated that the double-skin façade will yield a nearly 50 percent reduction in cooling energy and a 53 percent reduction in heating energy for the Commons space when compared to a conventional curtain wall with insulated glazing. While the electrochromic glazing offers greater cooling savings (74 percent) this is achieved with a small increase in heating energy as the electrochromic glass must tint in order to minimize glare, thereby cutting out beneficial solar heat gains during the colder months. The objective data generated by the energy modeling meshed well with the aesthetic goals and reinforced the decision to provide a double-skin façade.

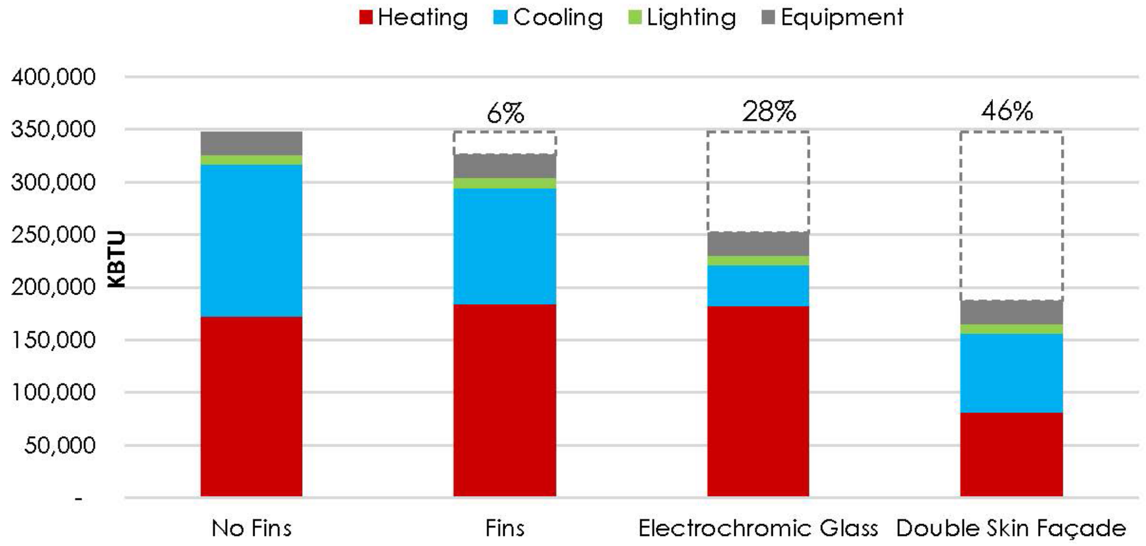


Figure 4: Energy use and savings in commons space for different façades.

2.1 Double-Skin Curtain Wall Development

General Operational Concept

As the double-skin façade provides an interface between the interior and exterior environment for a large, public space, special care was given to the understanding and design of the façade. Chief among the duties of the double-skin façade is to limit solar heat gain, particularly in the summer evening hours when the direct sunlight passing through the façade can lead to a spike in air conditioning loads and energy use. Operable shades provide much of the protection from solar infiltration, but heat gains to the occupant space are also minimized by flushing the cavity with outside air. Figures 5 and 6 illustrate the general operational concept.

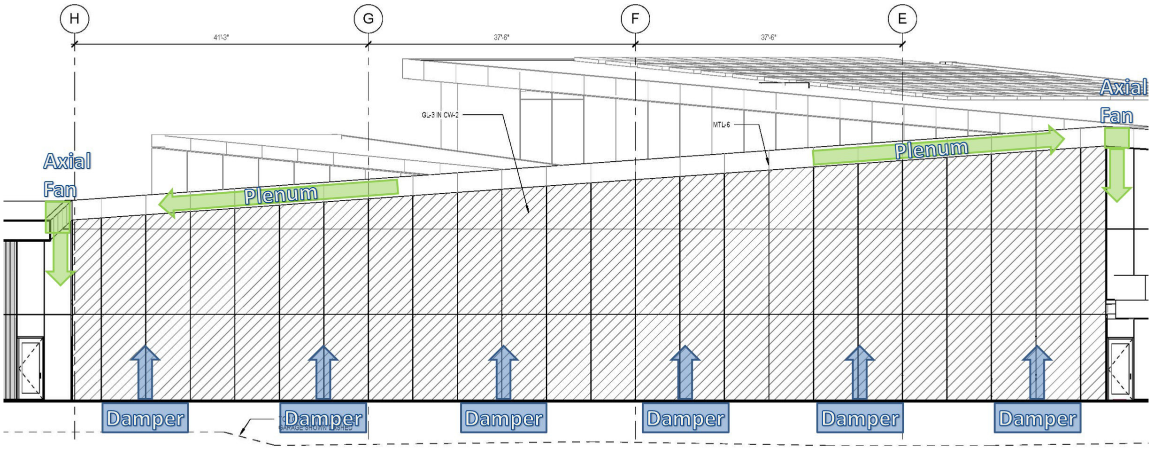


Figure 5: General operational concept-elevation.

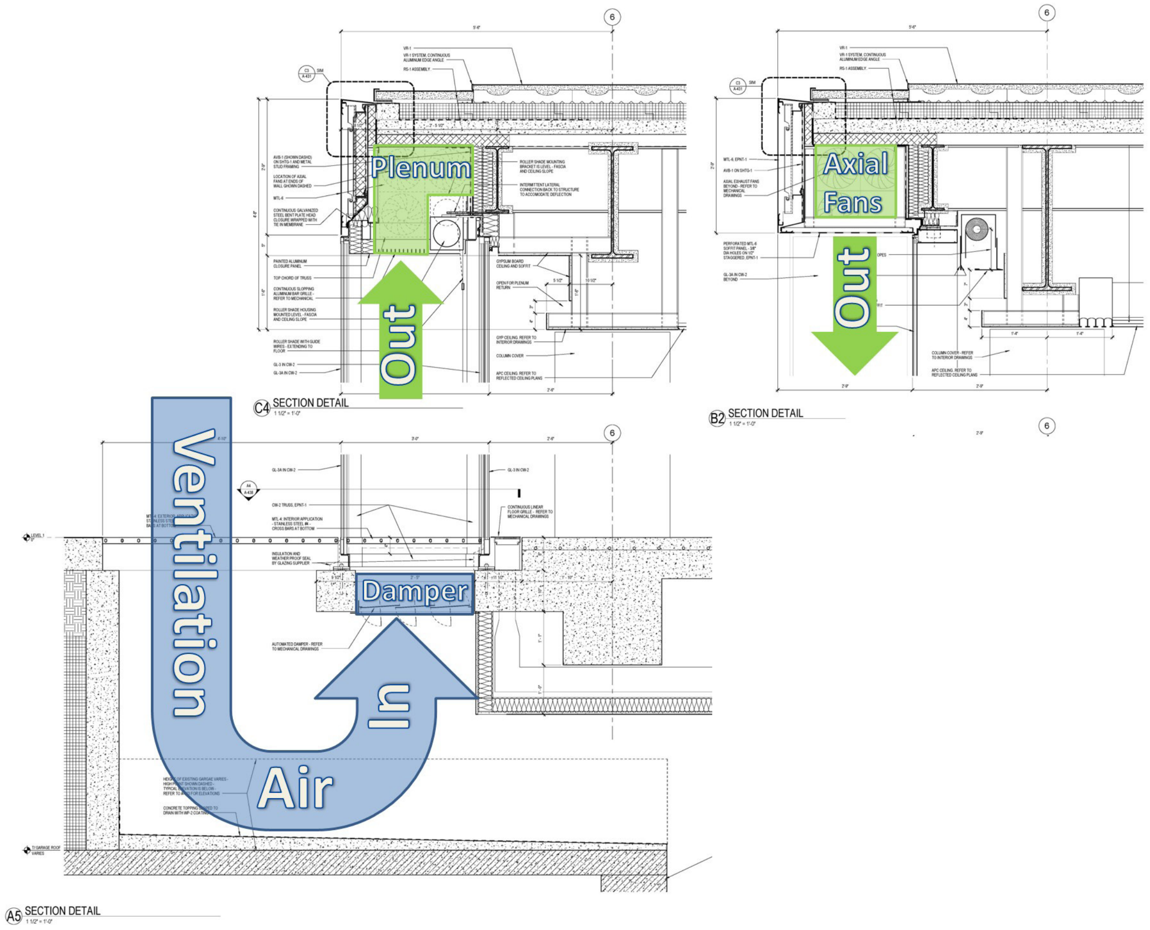


Figure 6: General operational concept-sections.

The general configuration of the double-skin façade used here can be categorized as a "buffer system" as identified by Boake[2]. Variations of this configurations have been used for over 100 years and have proven to be an effective means of controlling both visual discomfort (glare) and thermal gains/losses. In fact, Haase and Amato, and Pollard and Beatty suggest that this configuration is the most effective means of controlling external heat loads for buildings with active HVAC systems in cooling-intensive climates[3,4]. Given these established opinions on the efficacy of the configuration, the operational scheme was developed to optimize efficiency, respond to outside air conditions and control direct solar gains.

Summer/Warm Weather Operation

When the temperature at the top of the double-skin cavity reaches 95 degrees F, as measured by three equally-spaced sensors, all of the dampers at the bottom of the cavity open and fans begin pulling air through the space, preventing the buildup of excessively warm air within the cavity. When the cavity temperature drops below 95 degrees F, the dampers close and the fans stop. This sequence of operations prevents the cavity from becoming a heat source for the adjacent interior space and minimizes the energy used by the fans. When the roof-mounted radiometers detect that the sun has moved into the western sky, particularly in the evening hours when direct sunlight begins to create glare in the Commons, the roller shades within the cavity are lowered.

Winter/Cool Weather Operation:
When the temperature at the top of the double-skin cavity is below 95 degrees F, as measured by three equally-spaced sensors, the dampers at the bottom of the cavity remain shut and the fans do not operate. The resulting closed cavity is allowed to trap heat from the sun and serve as a thermal buffer between the cold exterior and warmer interior. The shades operate in the same manner as described above for the summer/warm weather operation.

CFD Ventilation Studies
Opening and closing the double-skin façade cavity is a primary means of controlling heat gain through the façade. When the cavity begins to overheat, air must be flushed from the cavity, either through natural convection and buoyancy, or forced air movement with fans. Understanding the nature of the airflow needed to remove this trapped heat was a crucial part of developing the doubling skin façade design.

One of the unifying architectural elements of the building is an aluminum-clad band that is employed throughout the building envelope and is used to "wrap" areas of curtain wall and define volumes. In the area of the double-skin façade, the band occurs at the roof line and caps the curtain wall below. The nature of this architectural relationship meant that a traditional, passive buoyancy driven approach to ventilating the cavity would not work. It was not possible for the design team to place openings at the top of the façade (interrupting the expanse of curtain wall) or above the roof (breaking the continuity of the aluminum "wrapper"), the traditional approaches to cavity ventilation, so a large number of possible design alternatives were investigated in order to determine what other designs would provide a level of performance similar to a buoyancy-driven design.

Thirteen design alternatives were investigated using computational fluid dynamics (CFD) analysis. CFD is an analysis approach that uses numerical methods to solve the equations governing fluid dynamics and heat transfer in order to simulate the effects of different conditions and parameters. Simulation results provide the temperature, velocity, and direction of flow for the fluid being simulated given geometric and thermal information provided by the analyst, and this information allowed the design team to select the alternative capable of providing the best heat removal from the cavity.

The design alternatives analyzed using CFD techniques include:

1. Natural Ventilation w/ 2 sided exhaust
2. Fan Assisted w/ 1 sided exhaust at 6,000 cfm
3. Fan Assisted w/ 2 sided exhaust at 6,000 cfm
4. Fan Assisted w/ 2 sided exhaust at 9,000 cfm
5. Natural Ventilation w/ lower and upper face openings
6. Fan Assisted w/ 2 sided exhaust at 6,000 cfm (3+2 Fans)
7. Fan Assisted w/ 2 sided exhaust at 6,000 cfm (5 + 2 Fans)
8. Fan Assisted w/ 2 sided exhaust and in-cavity fans (6,000 cfm)
9. Fan Assisted w/ 2 sided exhaust and in-cavity fans (9,000 cfm)
10. Fan Assisted w/ 2 sided exhaust and in-cavity fans (8x 6,300 cfm)
11. Fan Assisted w/ 2 sided exhaust and in-cavity fans (10x 6,300 cfm; in series)
12. Fan Assisted w/ 2 sided exhaust and in-cavity fans (10x 6,300 cfm; in parallel)
13. Fan Assisted w/ 2 sided exhaust, in-cavity fans and adjusted bottom intake (8x 6,300 cfm).

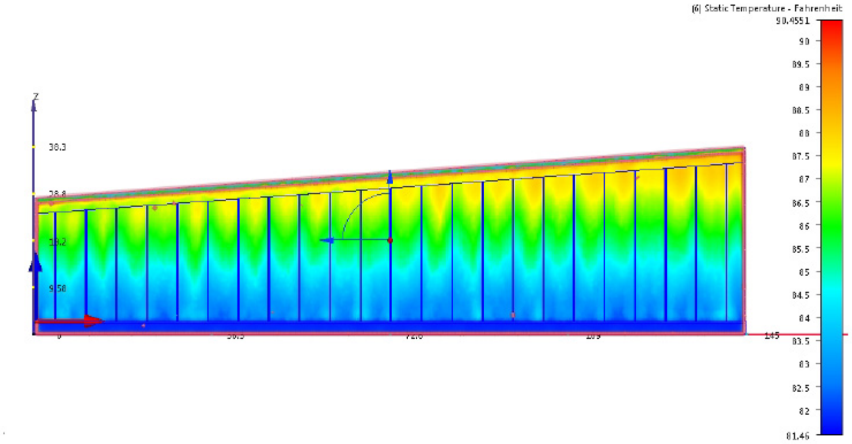
The methodology for the CFD modeling involved modeling a worst case scenario representing the highest summer heat gain hour for the façade. The conditions at this hour were determined using an annual energy simulation model created in EnergyPlus from which hourly results were extracted to determine the conditions external to the façade responsible for creating the highest thermal flux through the double-skin. This approach was chosen as it would estimate the moment requiring the highest airflow through the double skin to avoid excessive heat gain in the summer months. Steady-state analysis was chosen over transient for the sake of analysis time and because the use of worst case conditions limited the design team's need to understand the transient nature of the heat gains within the façade.

The Launder-Sharma formulation of the K-epsilon model (also called the "Standard" model) was chosen for this analysis as an industry best practice for situations without large adverse pressure gradients[5]. K-epsilon, as a two equation model, allows for the CFD analysis to account for certain effects such as convection and turbulent energy diffusion where other turbulence models would ignore these effects[6].

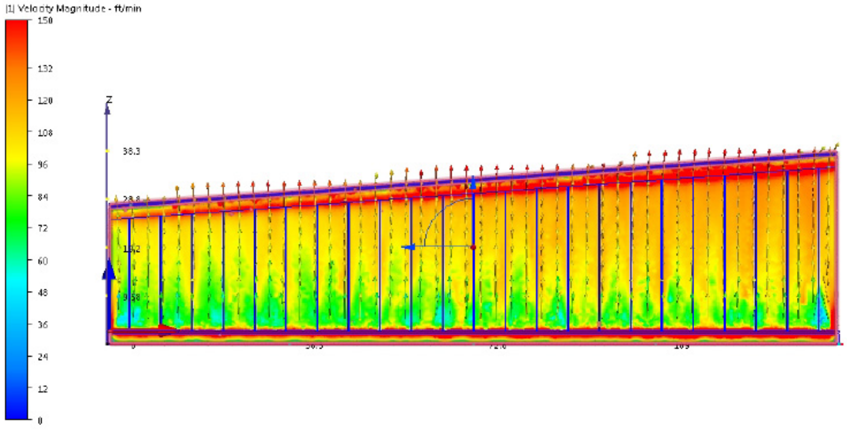
General physical and thermal conditions of the analysis were as follows:

Model Type:	Simple; airflow driven
Heat Gain through glazing surfaces:	Q_{ext_window} = 90,097 Btu/hr Q_{int_window} = 201,614 Btu/hr
Peak Outdoor Air Temperature:	81.5 degrees F
Cavity Ventilation:	Fan-assisted
Type of Analysis:	At equilibrium with peak conditions
Turbulence Model & Iterations:	k-ε, 100 iterations

As a baseline case, the team modeled an idealized version of a naturally ventilated double-skin façade with intake and exhaust openings running continuously along the bottom and top of the cavity, respectively. Poizaris has pointed out that a naturally ventilated strategy for double-skin façades can be problematic and somewhat unpredictable, particularly in an urban context such as this one[7]. This consideration, in addition to functional, technical and aesthetic issues (identified above) precluded the use of this configuration, but it was useful in determining the temperatures and airflows possible without the use of ventilation fans. Figure 7 shows the temperature and airflow profiles within the cavity during peak design conditions for this condition. Even with an outside air temperature of 81.5 degrees F, the cavity air temperature does not exceed 90 degrees F, minimizing any additional heat gains through the façade without the need for fans. Had this configuration been achievable, this would have been the best solution.



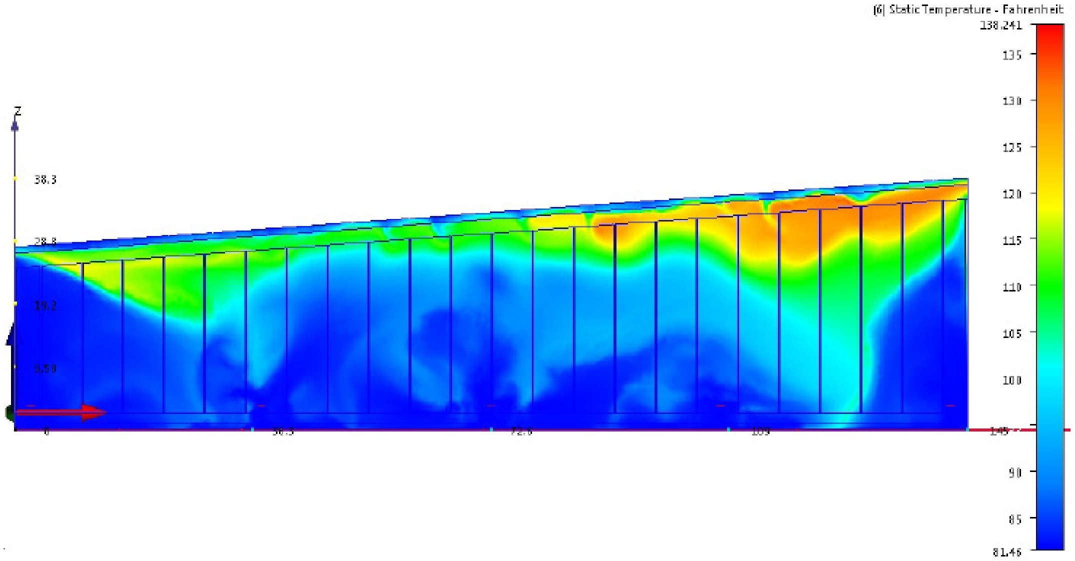
Temperature Profile – Front View (middle of cavity)



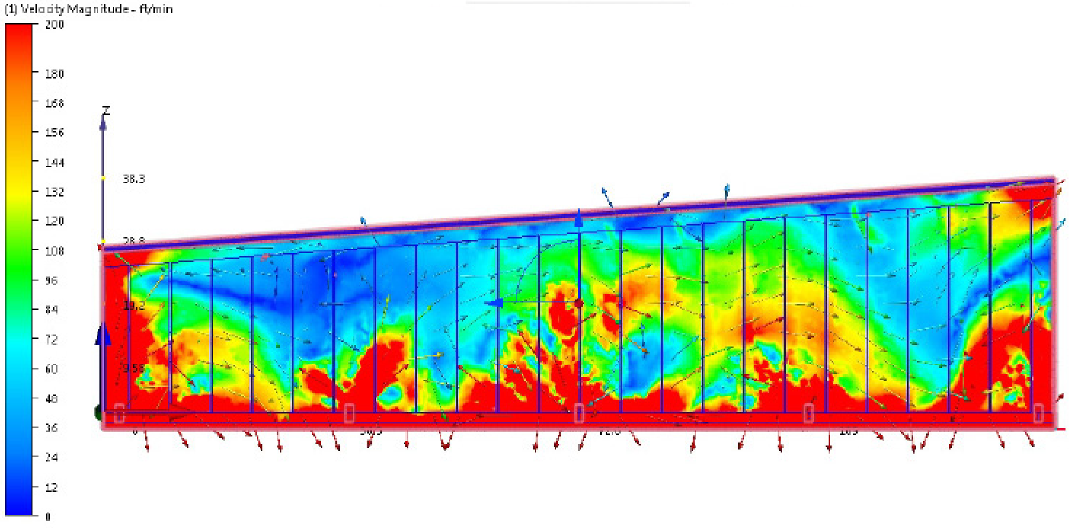
Airflow Profile – Front View (middle of cavity)

Figure 7: Temperature and airflow profiles in the façade cavity (natural ventilation option).

With information in hand on the baseline case, the team began the exploration of configurations that were compatible with the building design, all of them involving mechanical ventilation. In the course of trying multiple fan-based ventilation schemes, problematic design options were encountered. Figure 8 is the same temperature profile as the baseline case, but for a system with two large fans (9000 CFM), one exhausting from either side of the cavity. The upper portion of the cavity reaches a temperature of 140 degrees F, which is not excessively hot for such a small portion of the façade, but additional velocity analysis indicated extremely fast and turbulent airflow. This high velocity and turbulence brought up concerns about fluttering and damage to the roller shades when they are deployed.



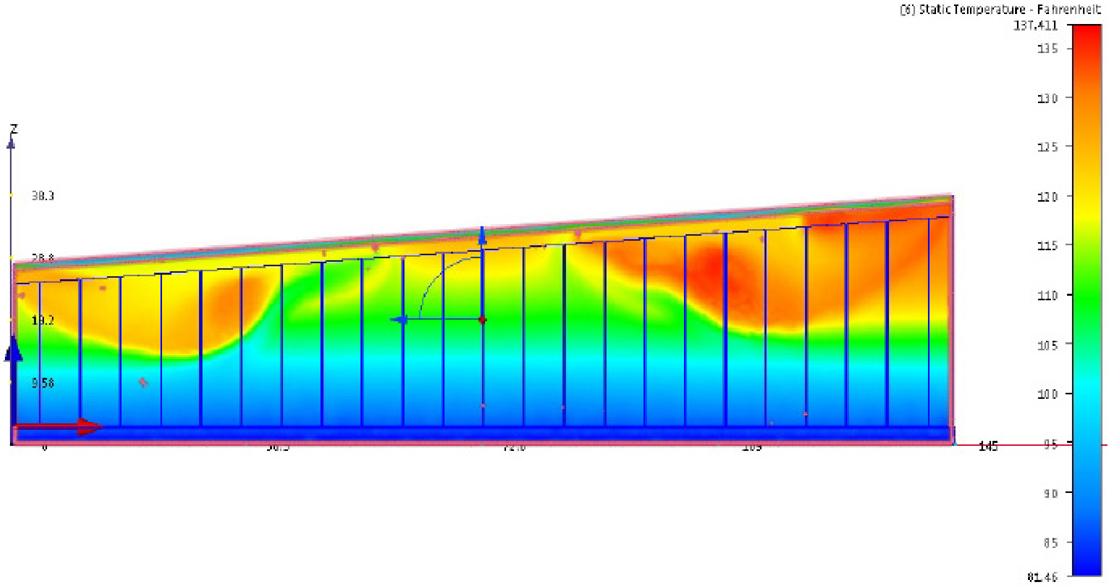
Temperature Profile – Front View (middle of cavity)



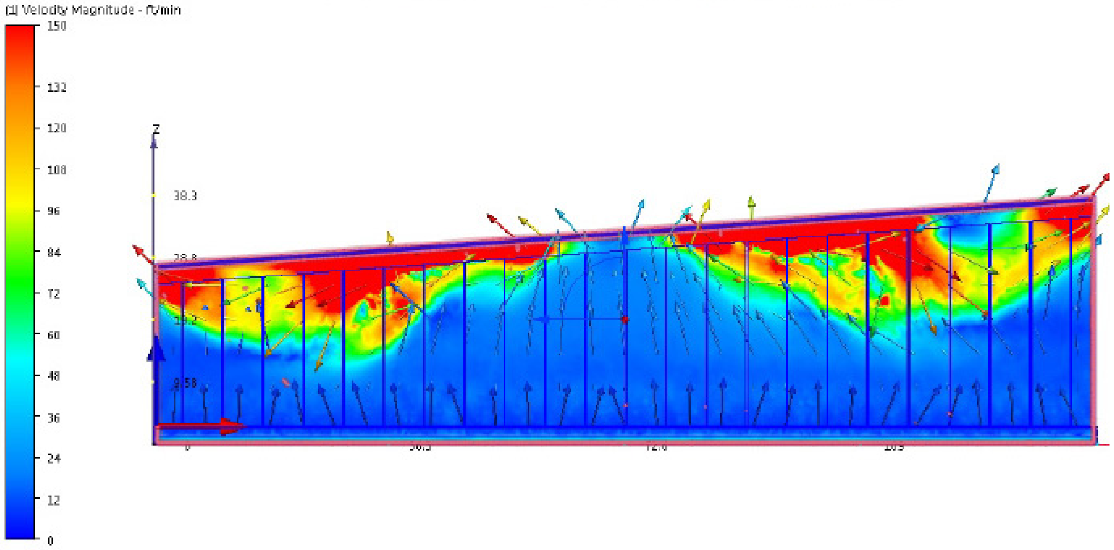
Airflow Profile – Front View (middle of cavity)

Figure 8: Temperature and airflow profiles in the façade cavity (fan assisted,two-sided exhaust, 9,000 CFM).

The team developed more options until finally settling upon a design using 8 fans at the top of the cavity, three on each side and two in the center. The temperature and airflow profiles for this design are shown in Figure 9. This design provided a good temperature profile, while minimizing turbulence and providing lower air velocities in the cavity. Overall, the CFD analysis helped the team to develop the input and fan configuration that optimizes thermal and airflow performance of the double-skin façade.



Temperature Profile – Front View (middle of cavity)



Airflow Profile – Front View (middle of cavity)

Figure 9: Temperature and Airflow Profiles in the Façade Cavity (Fan Assisted, 2 sided exhaust, 8x 6300 CFM).

Cavity Depth

The team studied several different options to determine the optimal depth of the double-skin façade cavity. The simulations done by Torres et al. generally indicated that deeper cavities yielded better results in reducing the cooling load in hot climates[9]. Further, Aksamija's study on different configurations of double skin facades and their effects on energy consumption, concluded that a 28 in (0.7 m) to 38 in (1.0 m) width was optimal in cold climate conditions. Cavities narrower than 28 in (0.7 m) were determined to be too difficult to access and maintain. Cavities wider than 38 in (1.0 m) add the expense of additional material and increase summertime energy use in mechanical ventilation of the large cavity space. Thus, the design team selected 3ft-0in (0.9 m) outside face of glass to face of glass as the ideal double wall width.

Glazing Configuration

The choice of the glass type for the interior and exterior panes depends largely on the façade ventilation strategy. In case of a facade ventilated with outdoor air, an insulating pane (sealed double-glazed unit) is usually placed at the inner plane of the cavity as a thermal break and a monolithic pane is placed at the outer plane to serve as the primary weather barrier. The design team studied this configuration relative to a single plane of insulated glass and to a configuration with the insulated plane to the exterior. Figure 10 shows that the results of this study validated the initial conclusion. Consequently, the final design of the double-skin façade is configured with monolithic glass at the exterior plane and low-e coated, insulated glazing units at the interior plane.

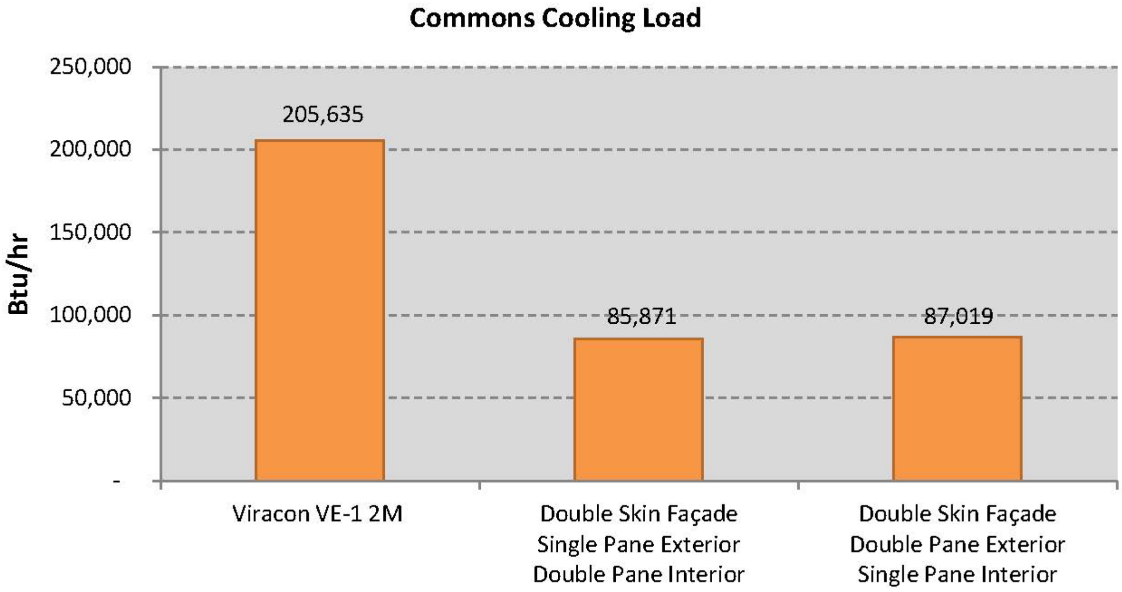


Figure 10: Cooling load comparison of glazing configurations.

Solar Shading Options

It has been suggested that operable solar shading devices are the most effective means of controlling solar heat gain in large glazed facades[2]. With this in mind, the design team explored two primary options for the solar shading devices that would be installed within the double-skin curtain wall cavity: horizontal blinds and roller shades.

Early in the process the horizontal blinds were the favored solution for a number of reasons. Aesthetically, they worked well with the horizontal nature of the building design and they could be finished to match the other curtain wall elements. Furthermore, horizontal blinds offer a nearly endless degree of adjustability as they can be raised or lowered and the slats can be tilted to vary the overall openness of the system. This level of variability did, however, come with prices in both cost and complexity. The systems that were investigated had, by their very nature, very complex control and activation equipment that included numerous sensors, motors and actuators. The complexity is reflected in the system first-cost and creates ongoing maintenance and operational costs for the life of the building.

There were also physical constraints that worked against this type of system. As previously mentioned, the roof in the area of the double-skin wall slopes and, thus, creates difficulties when the shading system needs to be mounted horizontally. As we will explain later, the design team was able to effectively conceal roller shade housings that were not parallel to the roof structure in the ceiling of the cavity; but the physical size of the horizontal blind systems proved to be nearly impossible to conceal. Additionally, the height of the curtain wall, and the required drop of the shading system, exceeded the total length that a horizontal blind system could accommodate. This type of system would, then, require that an intermediate shade housing be located somewhere in the height of the wall cavity and would seriously compromise the transparency of the wall.

In the end, first cost, operating cost and the sheer physical size and complexity of this type of system combined to make it unworkable.

Roller shades, the solution that was initially less favored, ultimately proved to be the better choice. The height of the cavity and concealing the shade housings in the ceiling were challenging, but were issues that could be solved without compromising the building design intent. For roller shades, the overall drop determines the total fabric length and the resulting size of the housing that conceals the fabric, roller and motor. In this case the long fabric drop required that the housing be 9 inches deep, a dimension that the team was able to conceal in the cavity ceiling. The roof and cavity ceiling in this area slopes up from north to south and the shades must be installed level to operate, so fitting the housing into the ceiling became something of a challenge at the south end of each shade. The shades are designed to fit between the double-skin wall trusses and are, thus, slightly less than 6 feet long. By splitting the shades up in this way, we were able to work with the building geometry to conceal the shades in the ceiling as shown in Figure 11.

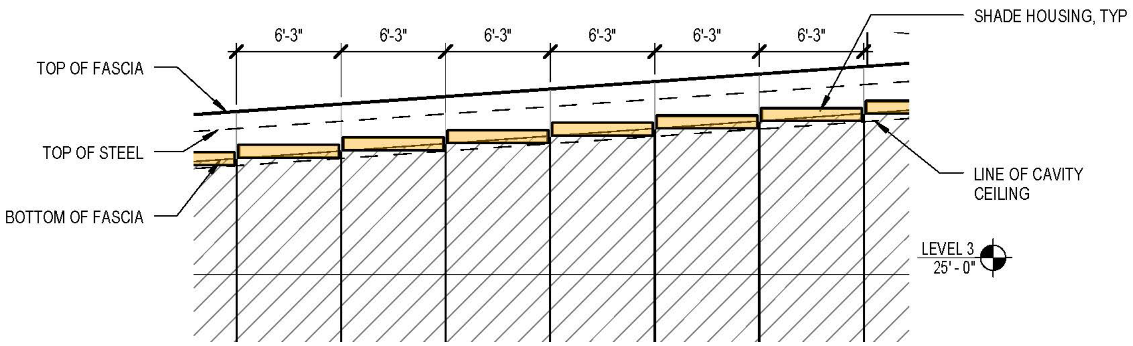


Figure 11: Roller shade geometry.

Given the length of the shade drop, and the fact that there would be airflow within the cavity at some times of the year, it was necessary to provide guides to stabilize the shades and to keep them from curling at the edges. In keeping with the minimal aesthetic of the double-skin wall, the team included guide cables that run from the top of the cavity to the bottom and are anchored to the concrete floor below the bar grate floor. This solution provides the necessary stabilization and is as unobtrusive as possible.

As the shading will only be required when there is direct sunlight on the west façade, it was important to include a control system that would minimize the amount of time that the shades were deployed (and thus hindering the views into and out of the building). The decision made on this is twofold. First the shades are programmed so that they never drop below 7 feet above the floor, insuring that Level 1 occupants and those outside will always have an unobstructed view through the double-skin wall. Secondly, the shade position was specified to be controlled by a radiometer mounted on the roof. The radiometer tracks the position and intensity of the sunlight and sends that information to a controller that then drops shades only when necessary and only to the level required to block solar infiltration into the Commons space. In order to preserve visual consistency, all shades in the double-skin wall will move in unison. The design team worked closely with the shade manufacturer to insure that the motors and controls system could achieve the desired operation. The system that was ultimately chosen was provided by Mechoshade and includes the following key components: IQ2 Electronic Drive Unit; I-Con Intelligent Motor; and SunDialer WindowManagement System.

Implications of the Adjacent, Underground Parking Garage

The addition of the double-skin façade required demolition of existing ground level air intake grilles that previously occupied this area. These grilles provided makeup air for the adjacent underground parking garage exhaust system through a large vertical shaft that extended down to the garage lower level.

Locating the building, and particularly the west façade, over this intake required that it be re-configured and integrated into the new construction. Figure 12 presents for a schematic section showing the final configuration. The challenge was to create a new air intake system that would maintain the required air intake for the existing garage exhaust system and supply the double-skin façade ventilation system.

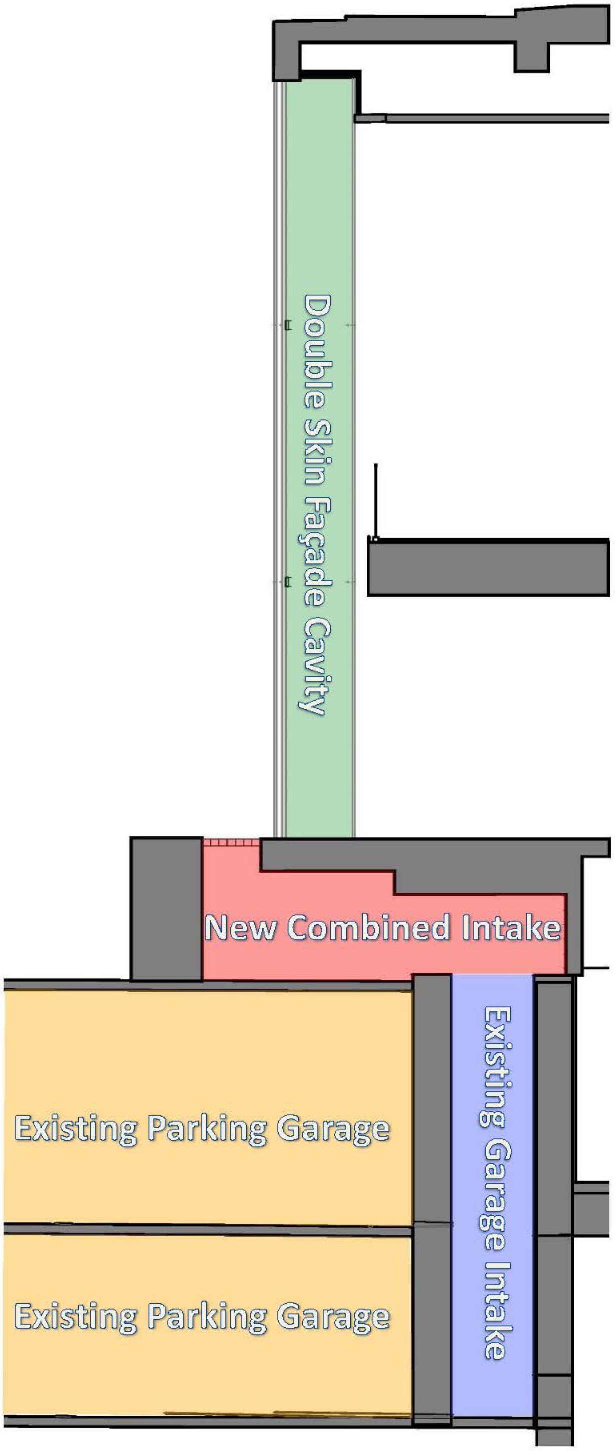


Figure 12: Schematic section showing new construction at garage intake.

The team first investigated two options that tied the garage and double-skin façade systems together. The first option was to use the double-skin façade as the intake for the parking garage fans by pulling air down through the cavity, into the garage intake and then through the garage. We discovered that the garage fan system is run continuously and the garage is, therefore, constantly at a negative pressure to the air intake cavity. The second option was to reverse the airflow through the garage, route the exhaust through the double-skin facade and use the double-skin fans to expel air from the cavity. The probability of entraining polluted garage air inside the double wall cavity was deemed to be an inherent, and insurmountable problem with this solution. Beyond this specific issue with the latter idea, there were additional challenges that were common to both combined-airflow options. The implementation of either solution would mean that air would constantly be pulled through the cavity, which is counterproductive to the effectiveness of the double-skin façade in the cooler seasons of the year when it is beneficial to trap warm air in the cavity. Further, determination of the operational efficacy of either option would have been difficult and would have required that the entire parking garage be modeled and included in the CFD analysis. Precise modeling of the existing garage building and determining the performance characteristics of existing fans would have been an enormous undertaking that was well outside the scope of the project. In the end, the design team concluded that it was best for the two systems to act independently of one another.

With the goal of allowing separate operation of the double-skin façade and existing garage air systems; a new intake grating was sized with enough cross-sectional free area to accommodate adequate makeup airflow for both garage exhaust and double wall exhaust. Since the garage exhaust system operates all year long, an unobstructed air path was created down to existing wall openings at the east end of each of the two garage levels. Existing louvers in these wall openings were removed, and replaced with 2-hour fire dampers of equal airflow capacity. The intent was to keep air flow to the double-skin wall completely separate from the flow into the garage, as shown in Figure 13. In the event of a fire within either space, the new garage fire dampers act to isolate the garage from the double-skin wall.

As explained above, motorized dampers were provided at the bottom of the double-skin wall and were interlocked with the exhaust fans at the top of the cavity through the building automation system (BAS). The fans and motorized dampers are controlled via temperature sensors inside the cavity, and the fans operate to relieve heat from the cavity to maintain a maximum allowable summer temperature setpoint, as determined by the CFD analysis. When the building is in heating mode, the BAS commands the double-skin wall fans to shut off and motorized dampers to close. The design goal was to trap heat in the space (largely gained from solar radiation) and use the double-skin wall an insulated heating mechanism, reducing the load on the building's heating system.

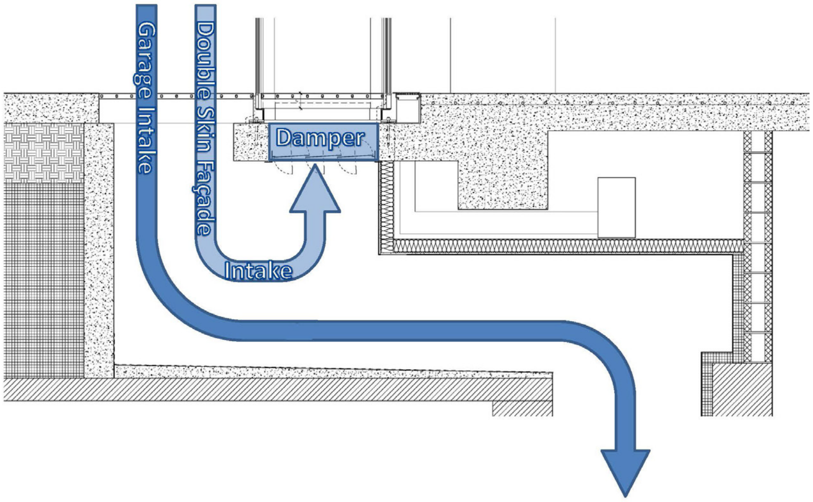


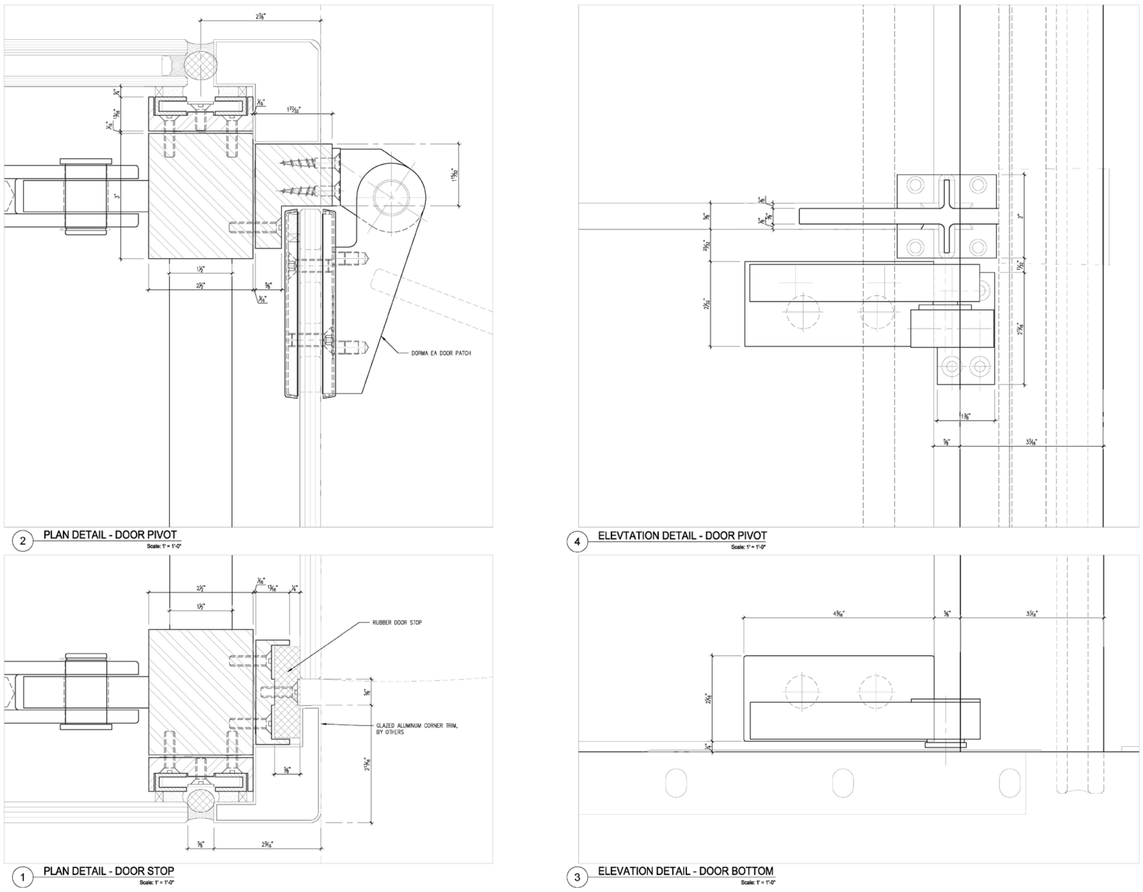
Figure 13: Intake airflow diagram.

Maintenance Access

Once the double-skin wall aesthetics and functions were determined, the final issue to contend with was maintenance access. Introducing exterior air into the cavity will, inevitably, result in the deposit of dirt, dust and other contaminants on its surfaces. The glass and metal surfaces inside the cavity will have to be cleaned periodically and the shades and ventilation fans will have to be maintained and serviced. The limited space between the planes of the double-skin wall, the cavity height, the frequency of the support trusses, the inclusion of shades at the ceiling and the sloping roof plane all have an impact on the means chosen for maintenance access.

The very first issue to tackle was accessing the cavity. The building configuration precluded access at Level 2 or the roof, leaving only the ground floor as the entry level. To preserve the minimalist aesthetic of the curtain wall construction, doors were located on the narrow ends of the cavity and the final design includes only the hardware necessary for periodic access. This approach maintains the uncluttered appearance the design team strove for. Figure 14 shows for shop drawings of the final details.

For vertical access within the cavity, the design team explored a number of solutions that included suspended cradles or baskets with both manual and powered lateral and vertical operation. These all, necessarily, in-



2 PLAN DETAIL - DOOR PIVOT
Scale: 1" = 1'-0"

4 ELEVTATION DETAIL - DOOR PIVOT
Scale: 1" = 1'-0"

1 PLAN DETAIL - DOOR STOP
Scale: 1" = 1'-0"

3 ELEVATION DETAIL - DOOR BOTTOM
Scale: 1" = 1'-0"

Figure 14: Cavity access door shop drawings.

cluded a track at the top of the cavity and a carrier that would move and lift maintenance personnel. It quickly became apparent that a track running the length of the double-skin wall cavity would present insurmountable problems: it would be interrupted by the support trusses, it would interfere with the shade placement and/or operation; it would not be possible to conceal the carrier in a stowed position; and any system that could provide the necessary access would, undoubtedly, be very costly. The team determined that even if a system could be devised that met all of the functional and aesthetic criteria, its costs would far outweigh its benefits.

The next avenue was to include a mobile, powered lift in the cost of the project. The constraints of width imposed by the access doors and the support trusses severely limited the possible choices. Of the machines that would fit through the access doors and could move laterally in the cavity, none approached the height necessary to reach the highest portions of the cavity. A custom-built machine was briefly considered, but was believed to be cost-prohibitive.

The appropriate solution turned out to be the simplest one. The team looked at the geometry of the cavity and access doors and determined that the most effective means of maintenance access was a simple extension ladder. We studied standard ladder sizes and made sure that they were maneuverable within the cavity and tall enough to reach the top. We then drew diagrams, for the Owner's use, showing how to maneuver and place one or more ladders within the cavity to reach every area (Figure 15).

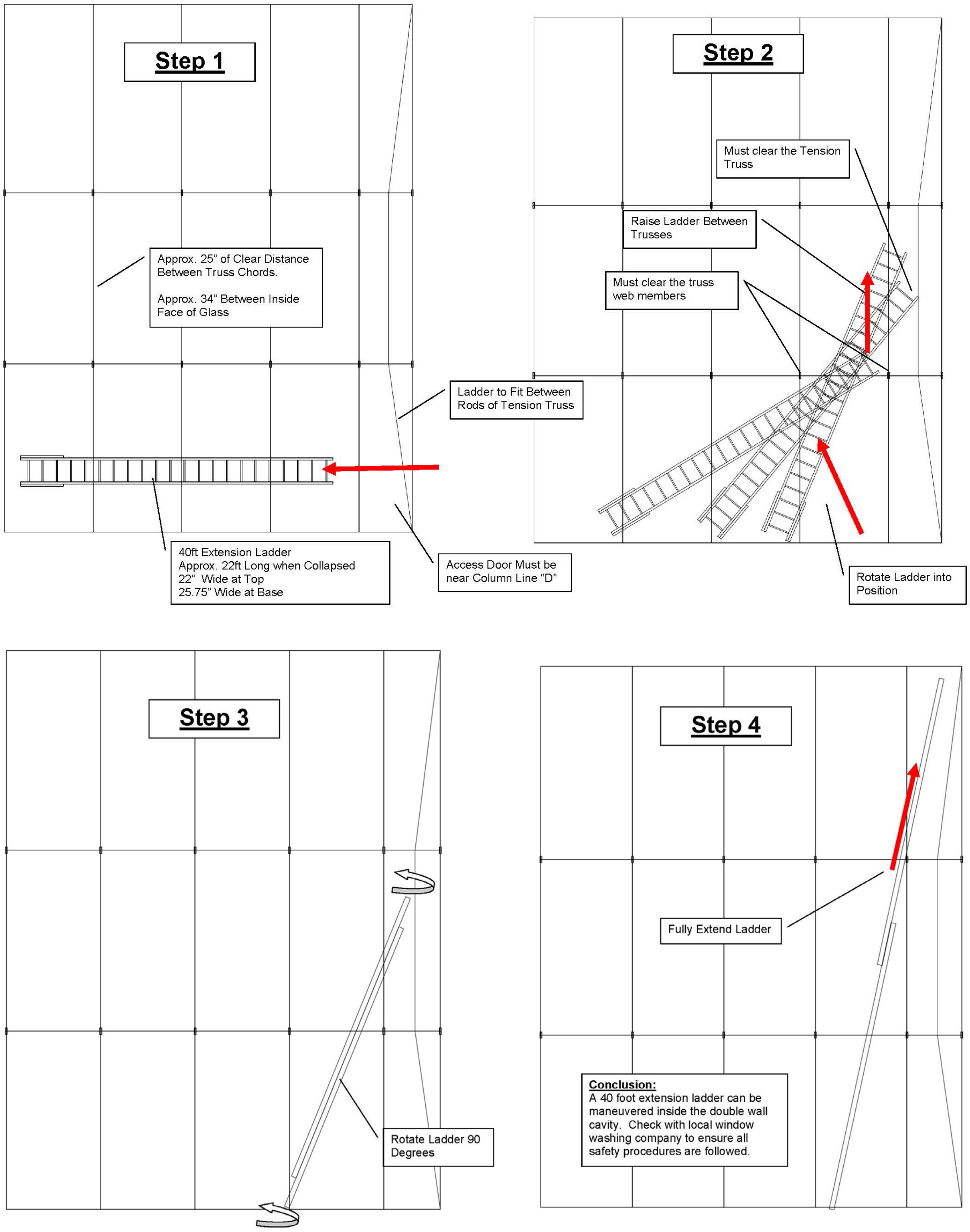


Figure 15: Cavity ladder access diagrams.

3.0 CONCLUSIONS

The unique programmatic requirements and site constraints of the Case Western Reserve University Tinkham Veale University Center resulted in a building design that included a number of challenging conditions. Paramount to this paper is a large west-facing wall that needed to be as transparent as possible and, at the same time, protect the occupants from solar light and heat gain. The design team investigated solar protection using exterior vertical fins, interior shading, electrochromic glass and a double-skin façade with integral shading.

After it was determined that the most appropriate solution for this building was the double-skin façade, the design team proceeded to develop the configuration and details.

The team determined that natural ventilation was not compatible with the building design and how the double-skin façade fit into it; and that ventilation would be fan-driven with intake from the bottom of the cavity through dampers and exhaust via a plenum and eight axial fans at the top. While this is not the optimum solution from an energy-use perspective, the fans will only run when the in-cavity temperature requires ventilation and should only occur when the sun is directly on the wall and the exterior temperature is relatively high. Environmental studies lead us to believe that these conditions will only occur for a small percentage of hours during the year. Having determined a ventilation strategy, the team then set out to optimize the use of the air layer within the double-skin façade. The resulting sequence of operations is: the cavity will be ventilated in the warm months to mitigate heat buildup and closed in the cooler months to create a pre-heated “buffer” of air between the interior and exterior.

The glazing configuration that was found to be most efficient for the Cleveland climate was to have monolithic glass in the exterior plane and insulated glass with low emissivity coating in the interior plane. Not only is this expected to provide the best thermal performance, it also allowed the aesthetic benefit of having the monolithic glass, with its flatter surface, on the building exterior. To further mitigate solar light and heat gain, roller shades were included in the cavity and were designed to be controlled based on the position and intensity of the sun. By automating the operation of these shades, they will deploy only when needed to block direct sunlight and, consequently, minimize obstruction of views into and out of the building. Lastly, the team examined multiple options for accessing and maintaining the cavity; ultimately settling on the simplest solution, ladder access to all areas.

We would like to note that all of the above conclusions contributed to the design of the double-skin façade and that final validation of these conclusions will not be complete until the building is occupied and operational. We anticipate that tuning of the various building systems and parameters (shade operation, mechanical setpoints, fan operation) will likely involve engagement over the first year of occupancy to address seasonal variations and optimize performance.

Finally, we would like to emphasize that, as is true with many aspects of building design, the conclusions reached here and the resulting design of the Tinkham Veale University Center double-skin façade has been tailored for this particular project in this particular location. Original research done for this project and the reviews we have done of double-skin façade literature reinforces the fact that final solutions are necessarily unique to every building. Components and concepts are translatable from precedent and published research, but to achieve optimal performance (be it functional, aesthetic or operational) a building design must react to vagaries of site, program, architectural vision and the myriad of other forces that exist in every project.

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