Optimization of a Thermal Flue Façade: The Seattle Justice Center's Naturally Vented, Double-skin Façade

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1. INTRODUCTION

There are always trade-offs that must be made in 'optimizing' building façade performance. From project inception it has been NBBJ's and the City of Seattle's intention with this Seattle Justice Center project:

- to create a working environment that will provide increased occupant satisfaction,
- to create a building with an appropriate image for the City of Seattle, and
- to incorporate sustainable building design and components.

In addition, the project brief emphasizes the ideals of maximizing daylight penetration, views and connection to the outdoors, but not at the expense of increased air-conditioning (A/C) energy and potential thermal discomfort.

To provide both a thermally comfortable work environment and an energy efficient building, it is imperative to look at both overall building envelope conformance to local energy minimizing codes and standards, as well as the specifics of different building facades (in this case, the proposed southwest facing, fully glazed, vented, double-skin façade) and their impact on the adjacent interior perimeter zone spaces. There is therefore a number of interdependent parameters that need to be understood to make the most of matching the façade and building sustainable brief to the budget:

1. Specific façade impact on adjacent perimeter zone thermal comfort
2. Specific façade impact on adjacent perimeter zone energy performance

These two topics as they relate to the Seattle Justice Center's southwest facing, fully glazed, vented, double-skin façade system are the primary focus of the analysis represented in this paper. However there were some additional, related and integral topics the design team needed to consider in parallel.

3. Specific façade impact on perimeter zone daylight penetration (and anticipated reduction in supplemental lighting)
4. Façade first costs
5. Building façade impact on total building energy performance

These three topics were addressed in detail by other design team consultants: (daylighting analysis performed by 'The Lighting Lab' on physical scale models provided by NBBJ, cost estimates provided by 'Hoffman Construction', total building energy modeling provided by 'CDi'.)

1.1 Comfort

One of the primary aims of the architectural envelope and the mechanical systems strategy is to provide the building occupants with a comfortable interior environment. Thermal comfort is typically thought of only in terms of air temperature. However, there are a number of additional environmental factors that influence a person's perceived level comfort:

- air temperature
- relative humidity
- radiant surface temperature
- air movement

as well as:

- daylight availability
- views & connection to the outdoors
- occupant control

Design guidelines recommend target air temperatures, RH levels and radiation asymmetry (temperature differences between different surrounding surfaces and between surrounding surfaces and the resultant air temperature) to limit potential thermal discomfort. However, all of these environmental parameters are included (and assessed in conjunction with a number of subjective, human parameters) in representing predicted levels of occupant thermal discomfort (and hence thermal comfort.) thermal Comfort design guidelines recommend target average comfort levels for perimeter zone, open office of not more than 10% PPD (percentage of people dissatisfied) within a 3' to 4'-0" perimeter zone (conversely, 90% of the occupants will be comfortable with the resulting thermal environment provided.) This paper represents anticipated occupant thermal discomfort in its assessment of the perimeter zone environment resulting from different building envelope options.

1.2 Preliminary Double-skin Façade Proposal

Figure 1 illustrates NBBJ's preliminary proposal for a vented, double skin façade for the Seattle Justice Center. Previous projects have shown these types of façade systems to be *an* appropriate approach to maximize transparency, daylight penetration, view, and connection to the outdoors while minimizing sun penetration and associated building energy requirements and thermal discomfort for easterly or westerly, highly glazed façades.

The first question always asked is: Do these double-skin façade systems, so prevalent in European climates, work in the climates we have here in the USA? The short answer is YES. The longer answer is that just as external shading devices are matched to specific building site, climate and orientation needs, so the nuances (components, ventilation strategy, etc.) of a vented double-skin façade system should be matched to the specific climate, façade orientation and building program/use to realize an optimal performance and cost benefit.

So not surprising, considering the added first cost of a multi-skin façade, NBBJ and the City of Seattle were interested in:

- understanding what they would be getting for their initial investment
- maximizing the performance of this type of façade system for the Seattle climate and specific Seattle Justice Center program.

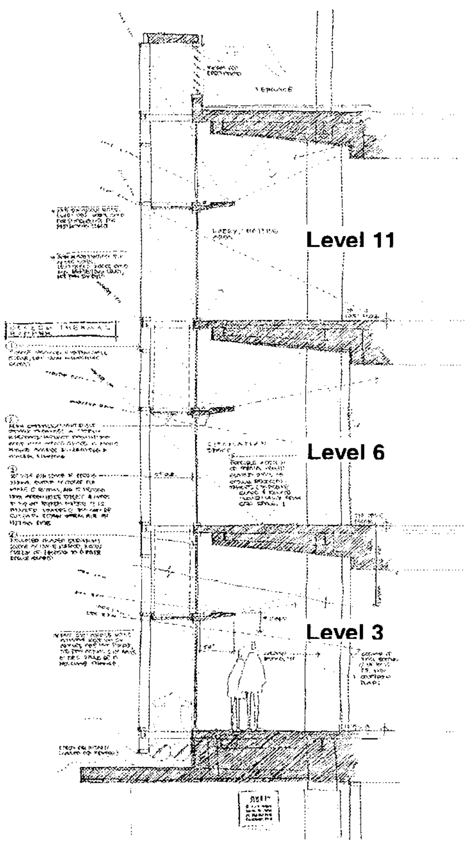


Fig. 1. Preliminary Schematic Section (by NBBJ)

2. ANALYSIS

There are four areas of façade + perimeter zone energy performance and thermal comfort assessment that require analysis to influence design decisions appropriately:

- **Preliminary Thermal Sensitivity Assessment** – to allow the design team to prioritize design decisions and further analysis of façade system component and control options.
- **Vented Façade Analysis** – to allow the design team to understand the relationship between the façade system components and control and the resulting temperatures and air velocity through the system to be expected for three representative Seattle seasons; summer, winter, and a swing (generic spring/autumn condition.)
- **Perimeter Zone Comfort** – to allow the design team to understand the implications of cavity air temperatures and material choices on the anticipated thermal comfort in the perimeter zone adjacent to the vented, double skin façade.
- **Perimeter Zone Energy** – to allow the design team to understand the implications of the proposed façade system at reducing the amount of a/c and energy required to the perimeter zone yet still create a thermally comfortable environment.

Note: To make valid comparisons and resulting design decisions one must make sure to 'compare apples to apples' across the 4 areas of assessment above. Thus, the design team discussed and carefully chose spatial geometries, façade component options and other relevant parameters to be consistent throughout all of the comparative analyses.

2.1 Sensitivity Assessment

A sensitivity analysis of the proposed south-west facing double-skin façade, for the specific Seattle climate and the 'open office' use of the building indicated:

1. **Summer Cooling** and associated cooling thermal comfort far outweighed the impact on perimeter zone heating and associated heating thermal comfort.

2. **Shading to control direct solar gain** was of primary importance in providing a thermally comfortable perimeter zone environment.

   Note: Operable shading located in the cavity (as opposed to internal blinds located in the internal perimeter zone:

   a) stops direct solar heat gain before it enters the perimeter zone space and becomes an air-conditioning load.

   b) provides high transparency when open (for significant times of the day and year when direct sunlight is not an issue) yet can be closed to shade from low angle sun when required.

   c) absorbs and re-radiates direct solar heat that is then trapped within the cavity of the double skin, inducing a 'thermal stack', which is the driving mechanism for the cavity natural ventilation.

3. **Cavity temperature** was a second order effect to appropriate shading (by an order of magnitude) in providing a cool, thermally comfortable perimeter zone environment.

2.2 Vented Façade Analysis

Simply, a double-skin façade system uses a cavity located shading device to absorb solar gain and re-radiate it as heat, which is then trapped in the cavity. Openings are then provided at the top and bottom of the cavity, such that the heat's natural tendency to rise pulls fresh, cool air in at the bottom while exhausting hot air out the top. Controlling the capture or venting of this trapped heat allows control of the cavity air temperature and subsequently, the inner glass surface temperature.

To assess predicted cavity air temperatures and air flow, a computer model of the vented, double-skin cavity façade system was built which included:

- A 9-story cavity with sealed glazing on both sides; external single, clear glazing and internal, double glazing with low-e performance coating.

- Fixed, horizontal catwalk / shading located at floor level and operable, perforated (15% Visible Light Transmission) roller shades, closed to 6'-6" above the finished floor at each level in the cavity.

- Operable, louvered openings at the top of the cavity, in the roof terrace parapet and fixed openings at the bottom of the cavity of the same or greater free area than the top opening.

2.2.1 Summer Design Day Cavity Analysis

The analysis results represented in figures 2 and 3 indicate the importance of maximizing the size of the openings (within the constraints of the architectural parapet height) to keep both the cavity air temperatures and velocities to reasonable levels. They also indicate air velocity performance requirements that exhaust louvers and cavity blinds be designed to in order to resist flutter induced noise. (**Note:** *that air flow and temperature results are for an Ashrae 95% Seattle summer design day.)*

Figure 3 indicates the anticipated resulting cavity air temperatures at the different levels within the cavity, with 60% free area louvers in the given parapet opening, for a Seattle summer design day. This graph also validates that the operable, cavity shading and corresponding ventilation would not be required during the morning hours (up until approximately 11:00am in July.)

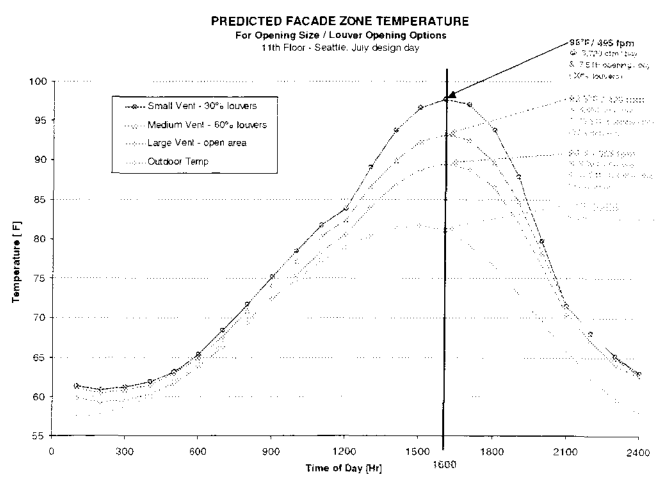


Fig. 2. Predicted Façade Zone Temperatures at 11th Floor (varying vent opening size)

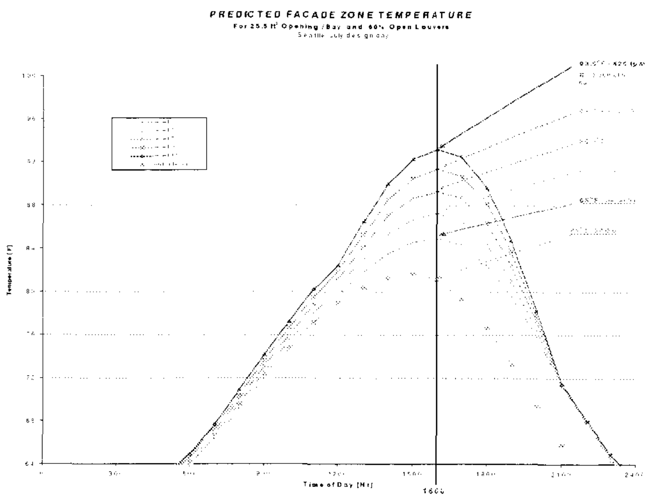


Fig. 3. Predicted Façade Zone Temperatures by level (for given opening size)

2.2.2 Winter Design Day Cavity Analysis

An assessment of a typical overcast, Seattle winter design day indicated the closed double-skin façade's ability to trap solar heat, increasing the cavity air temperature to up to 64 °F even when the outdoor air temperature may only be 35 °F. This warmer cavity air then has some capacity to migrate through the surface between the cavity and the internal perimeter zone (depending on the material chosen) via conduction and provide a warm interior surface.

These two seasonal analyses illustrate the need for *operable* cavity openings to allow a variety of ventilation rates; 'flushing' to keep cool in summer, venting to a lesser degree on sunny winter afternoons, and closing to 'capture' heat on overcast, winter days. (**Note:** that cavity temperature results are for an Ashrae 97.5% Seattle winter design day.)

3. PERIMETER ZONE COMFORT

The team's ultimate goal was to create a comfortable working environment for the occupants of this (any) building. And anticipated thermal comfort in the adjacent perimeter zone is directly tied to the thermal performance of the building façade. Thus, what we really want to compare is the effectiveness of the proposed vented, double-skin façade system (compared to other façade system options) at providing a comfortable thermal environment in the adjacent perimeter zone.

The conventional way to create a thermally comfortable environment is to add as much air-conditioning to the perimeter zone as is required to meet the design 10-15% PPD thermal comfort standards, given the existing building envelope. However:

- a design philosophy of low performance façade and increased a/c goes against the sustainable and energy minimizing design principles of this project.

- increasing a/c to offset solar loads from highly glazed westerly facades often still can not provide a thermally comfortable perimeter zone environment.

An alternative approach was therefore taken; to assess the effects of decreasing façade system performance (for different façade component options) on perimeter zone thermal comfort *given a fixed amount of a/c supplied to the perimeter zone space* (set to the minimum required to achieve an average of 10% PPD in the perimeter zone office space with a highly effective façade.)

The Seattle Justice Center program locates a variety of space types in the perimeter zone adjacent to the highly glazed, south-west facing façade at the different floor levels. The following analysis represents the effects of decreased façade system performance on occupant satisfaction as resulting perimeter zone PPD contours for the open office environment for the summer-time, cooling season (agreed to be the 'worst case'.)

3.0.1 Façade System Component Options

The following façade system component options were assessed:

1. base case = 'traditional, fully glazed façade'

Clear, high-performance, selective, low-e, double glazing (heavily tinted or reflective glazing was not considered due to the desire to maximize daylight and view) un-shaded (operable *external* shading considered to be aesthetically, technically and financially in-appropriate.)

2. vented, double-skin (V-Ds) façade system

Shading and glazing components as outlined in section 2.2 above.

3. single-glazed internal skin

High-performance, low-e, pyrolytic coated, single glazed internal cavity skin (proposed as a potential cost saving measure to the double-glazed internal skin in the V-Ds option 2 above - all other shading and glazing parameters as in option 2 above.)

3.0.2 Typical Perimeter Zone Configuration

Figure 4 illustrates the configuration of the typical bay of open office space adjacent to the south-west facing façade assessed and represented with resulting PPD contours in the subsequent sections.

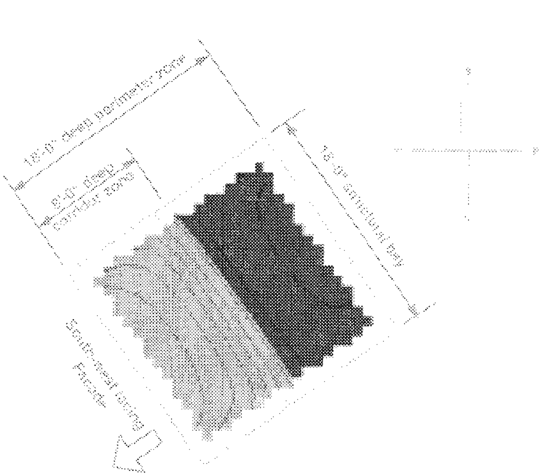


Fig. 4. Plan view of comfort (PPD) contours in a 'typical' perimeter zone adjacent to the southwest facing façade.

3.1 Traditional vs Vented, Double-skin (V-Ds) Façade System

The comparison in figure 5 illustrates the significantly higher levels of discomfort in a perimeter zone adjacent to a south-west facing 'traditional' highly glazed façade compared to the proposed vented, double-skin system. Predicted discomfort levels of up to 80%-100% PPD at 4:00 and 5:00pm seen with a traditional highly glazed façade as compared to the 10%-20% PPD expected with the proposed vented, double-skin system.

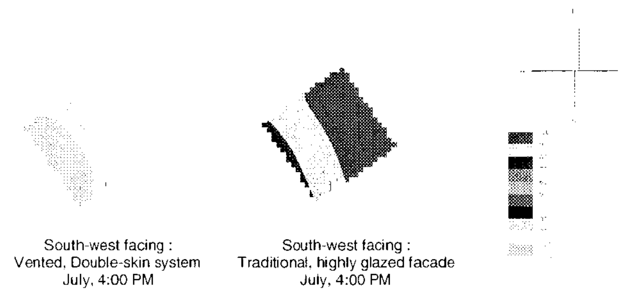


Fig. 5. Comparison of Predicted Thermal Comfort Adjacent to Different Façade Systems

3.2 Proposed V-Ds Façade vs V-Ds with Single-glazed Internal skin

The comparison in figure 6 illustrates the higher levels of thermal discomfort in the perimeter zone adjacent to a vented, double-skin system with a *single glazed internal skin*. As anticipated, single glazing the internal skin allows for a higher conductive transfer of the high cavity air temperatures resulting in warm interior radiant surface temperatures. As the diagrams indicate, this warm internal surface also heats up the adjacent, interior air, which in turn migrates back into the open office area and increasing thermal discomfort in the perimeter zone office areas as well. Predicted discomfort levels of up to 50%-70% PPD at 4:00pm would be expected as compared to the 10%-20% PPD expected with the proposed vented, double-skin system with internal double glazing.

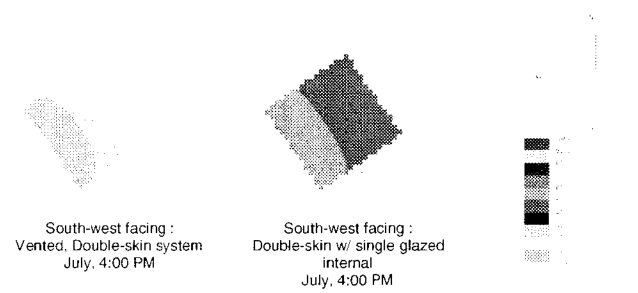


Fig. 6. Comparison of Predicted Thermal Comfort Adjacent to Different Façade Systems

3.3 V-Ds Façade with Single-glazed Internal skin at Lower Levels

Given the natural break in programmatic use adjacent to the south-west façade at level 9, it was anticipated that there might be an opportunity to specify single-glazing for the internal skin of the double-skin façade at the lower levels (levels 3 – 8) where cavity air temperatures would be lower. Unfortunately, analysis indicates unacceptable thermal discomfort in the adjacent perimeter zone even at these lower levels. Additionally, the marginal savings in glazing (material) did not offset the design expense inherent in a mullion system that would accommodate both single and double glazing over such a small wall area.

These comparative thermal comfort analyses firstly reiterate the importance of incorporating appropriate external shading in a highly glazed, south-west facing façade system to control low angle, solar gains. Secondly, the results indicate that the heat buildup within the proposed 9 story tall cavity on a typical Seattle summer day is significant, even at the lower levels. Double-glazing the internal skin of the vented, double-skin façade system will reduce conductive transfer of these high cavity temperatures through to the adjacent interior.

4. PERIMETER ZONE ENERGY

While the previous comparative analyses illustrate the anticipated increase in thermal comfort and occupant satisfaction adjacent to sequentially more effective building façades, another method of illustrating façade performance is to assess the reduction in amount of a/c (and associated energy) that would be required to provide an equivalent thermally comfortable environment for increasingly more effective façades.

Given the specifics of the air-conditioning system proposed for the project, preliminary computer modeling indicates fairly significant cooling related energy reduction for the perimeter zone adjacent to the specific south-west facing façade discussed:

> **Note:** Additional analysis of the 'traditional, low-e, double glazed façade' indicated that increasing a/c supply to the perimeter zone to offset the façade load, while meeting code calculations, **could not** provide a thermally comfortable environment in the afternoon hours (due to direct solar gains.) Not surprising when considering the thermal environment one might perceive when sitting in direct sun with potentially large quantities of very cool air blowing from another direction.

	A/C supply [cfm / perim. zone structural bay]	Est. Energy [KW / floor-perim. zone]	Energy Savings [over perim. zone floor area]
Traditional low-e double glazed fa ade (no shading)	750	0 (base case)	0 (base case)
Vented fa ade with operable cavity shading and single glazed internal skin	590	-24.2	21%
Vented fa ade with operable cavity shading and double, low-e glazed internal skin	500	-32.1	33%

Fig. 7. Perimeter Zone Energy Summary

Comparing the final, proposed naturally vented, double-skin façade system to a 'traditional' double glazed façade, figure 7 indicates a **1/3 reduction in required A/C** supply and related energy savings **to the adjacent perimeter zone.**

5. TOTAL BUILDING ENERGY

This paper has addressed the effectiveness of proposed south-west facing, vented, double-skin façade options at controlling thermal transfer (including estimated reduction in A/C) to provide a thermally comfortable environment in the adjacent perimeter zone. But it is also important to understand this component of energy savings within the context of the project – the total building energy use.

Unfortunately, experience has shown that more benign climates (such as Seattle) and projects with a high percentage of core floor area to perimeter zone floor area (as in the Seattle Justice Center project) work against realization of significant overall building energy savings. Additionally, the currently low cost of energy typically inhibits realization of overall building energy savings offsetting anticipated additional façade system first costs. Not surprisingly, therefore, while the highly effective façade system proposed for the south-west facing façade indicates a 33% energy savings (reduction in A/C) in the adjacent perimeter zone, preliminary estimates indicate this to result in only a **2% overall building energy savings.**

As with any project the quality of the environment desired must be weighed against cost – in this case, the increase in first cost of the final vented, double-skin façade. Cost estimates indicate the final vented, double-skin proposal to be $320,000 or $17.50 per face-ft² over a traditional highly glazed façade. And while the previous technical analyses allowed the design team to realize aesthetic desires of increased glazing and increased perimeter floor to ceiling heights (and associated daylight penetration) with associated restricted A/C system distribution and perimeter supply, these variables were difficult to quantify into a façade first cost offset rationalization.

6. SUMMARY

Figure 8 summarizes the thermal comfort implications, additional A/C and energy implications on the perimeter zone adjacent to the south-west facing, double-skin façade options for the Seattle Justice Center project:

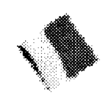
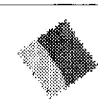
	Thermal Comfort [PPD]		A/C Supply	Est. Energy	Energy Savings
Traditional low-e double glazed fa ade (no shading)		81% [ave PPD 4:00pm L11]	750 [cfm / perim. zone bay]	0 (base case)	0 (base case)
Vented fa ade with operable cavity shading and single glazed internal skin		58% [ave PPD 4:00pm L11]	590 [cfm / perim. zone bay]	-24.2 [KW / floor-perim. zone]	21% [over perim. zone fl. area]
Vented fa ade with operable cavity shading and double, low-e glazed internal skin		20% [ave PPD 4:00pm L11]	500 [cfm / perim. zone bay]	-32.1 [KW / floor-perim. zone]	33% [over perim. zone fl. area]

Fig. 8. Façade Impact on Perimeter Zone Comfort & Energy Summary Comparison

7. RECOMMENDATIONS

The analyses above (along with concurrent design discussions) resulted in some primary decisions for certain elements of the vented, double-skin cavity system to maximize solar, thermal and related energy performance of the façade and perimeter zone:

Re-locate fixed, horizontal shading/catwalk - from the proposed location (at the level of the internal light-shelf) to the slab level above, still within the cavity, primarily enhancing build-ability of the vented, double-skin façade system, however, additional benefits to view, cost and procurement realized as discussed below.

Provided operable shading in the cavity - designed to close to a height of at least 6'-6" aff. (operable shading then closes to a point lower than the previous location of the fixed, horizontal shading/catwalk would allow) automated on a timing sensor (rather than on daylight sensors) to close at 11am daily (with potential for seasonal fine-tuning.)

Provide operability of natural cavity ventilation - via. 60% free area louvers located within the roof terrace parapet along the top of the vented cavity system.

(Note: the specifics of the project, Seattle climate, façade orientation and make-up, and building use, indicate this project's south-west facing interior to be particularly cooling sensitive. The façade system has therefore been analyzed and component and system control recommendations made to optimize performance for the summer-time, cavity venting condition. If the project and climate were particularly heating sensitive, ie: more important to trap heat in the cavity for supplemental winter-time heating, different façade components and glazing choices would most likely be considered.)

A couple of relevant additional implications of the above decisions relating to visual, cost and procurement issues of the façade system were also discussed and noted:

7.1 Visual

Relocating the fixed horizontal shading at floor level, within the cavity helped to control view of the bright sky and associated glare for occupants in workspaces located deeper in the floor plan. (Confirmed in geometric studies provided by the architect and in results of the physical daylight modeling by 'The Lighting Lab'.) And the proposed operable cavity blinds/ shades optimize view and solar control, providing infinite variability to control solar and daylight protection while allowing for unencumbered views when control is not needed, for the south-west facing, fully glazed façade.

7.2 Cost

Moving the fixed, horizontal shading/catwalk from mid-window height to the slab level above provided significant cost savings in:

- simplifying façade system construction – eliminating expensive hanging structure + hardware and/or additional reinforcing within the curtain wall mullions required of the initially proposed mid-window wall location.
- simplifying façade system construction – reducing potential for contractors to 'add contingency' to the construction cost of an innovative and *perceived* new technology.
- simplifying access to the catwalk (for maintenance) – eliminating the ladder system required to get from slab/floor level to the originally proposed mid-window wall catwalk location.

7.3 Procurement

Additional methods to reduce potential for design-build, curtain wall contractors to 'add contingency' to the construction cost of a vented, double-skin façade were discussed at length, ideas such as:

- detailing familiar components and simple construction methods into the façade system design.
- educating bidding contractor(s) that the proposed façade system is just a different way of putting together a kit of parts that they are already familiar with.
- involving a potential curtain wall contractor (as part of the design team) in the final design of the façade system. This would have the added benefit of utilizing the contractors intimate knowledge of least cost curtain-wall solutions during the final design phases.