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Shadow Box Design:

To Vent or Not To Vent

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ABSTRACT

Shadow boxes are commonly used in curtain wall construction, but can be problematic if not designed and detailed correctly and appropriately for the climate. Much has been written about shadow box design, both successes and failures, but there is no consensus about how, or if, the cavity should be vented. This article presents a literature review about shadow box design, and ventilating strategies. There are four approaches to ventilating the shadow box cavity: venting directly to the exterior environment, venting indirectly to the exterior through the mullion cavities; venting directly to the interior building environment and sealing the cavity. These approaches have been assessed for a temperate-to-cold climate, where the use of insulated glazing units (IGUs) are assumed for the vision light. Venting the cavity directly to either the exterior or the interior building environment introduces moisture- and particulate-laden air that can condense under certain climatic conditions and will likely deposit dust and debris on the interior surfaces of the cavity, creating both permanent and temporary aesthetic concerns. When venting to the exterior, exterior air can produce extreme hot or cold temperatures inside the cavity that is transferred to the surfaces of the surrounding mullions that are exposed to the building interior to detrimental effect. Sealing the cavity typically eliminates condensation and debris buildup, but the cavity can become overheated as in venting to the exterior. Additionally, there is some evidence that heat and pressure may build up to a point where it could damage the glass and degrade the sealants and coatings inside the cavity. After considering all of the options, indirect venting to the exterior appears to address most of the issues, but with the caveat that it is only feasible with certain unitized curtain wall systems. This approach vents the cavity into the vertical mullions, which ultimately connect to the exterior environment, but do so indirectly, relieving the heat and pressure but also tempering the exterior air that is allowed to enter.

KEYWORDS: curtain wall, condensation, design processes, shadow box

1.0 INTRODUCTION

A curtain wall shadow box is a spandrel assembly consisting of vision glass at the building exterior and an opaque infill at the interior side of the curtain wall system (Figure 1). Shadow boxes are generally used for one of these aesthetic reasons: (1) to maintain the visual continuity of a curtain wall system as it crosses from vision glass to spandrel areas, and (2) to give the spandrels the quality of having visual depth. Shadow boxes are often preferred over opaque-fritted spandrel glass because they use the same glass as adjacent vision areas, and render the opaque areas of the curtain wall nearly indistinguishable from the vision areas.

Architects have used shadow boxes for visual effect for decades and all indications are that we will continue to do so. Consequently, this article will not argue for, or against, the use of shadow boxes. Rather, the focus of this study was to determine the optimal strategy for ventilating the shadow box cavity that will balance reduction of the likelihood of performance failure with constructability. Research into this topic was twofold: first, through a review of the available literature on shadow box construction and failures; and, secondly, through examination of recent projects in which the author has been involved. It is important to emphasize that shadow boxes will behave differently in different climatic con-

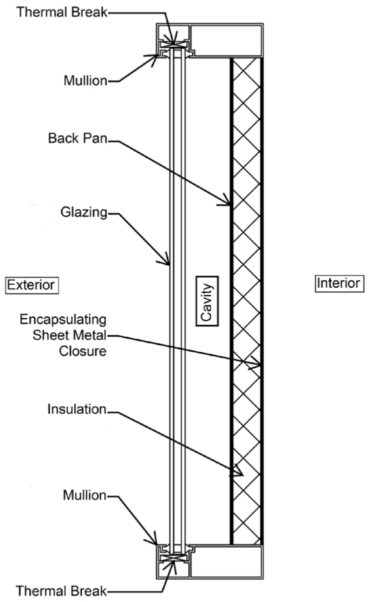

Figure 1: Components of a typical shadow box.

ditions. The examples and recommendations here are based on use in a temperate-to-cold climate with significant temperature swings across the course of the year, from hot in the summer to very cold in the winter, and assume the use of insulated glass units for the vision light.

2.0 LITERATURE REVIEW

A review of relevant literature, published in the recent past and which represents the most rigorous and scholarly resources, was executed for the purpose of informing the recommendations in this article. Salient points from each of the resources have been summarized in this section below. As stated previously, it is important to note that there is no industry consensus on the recommended design or construction of shadow boxes and there is a conspicuous absence of position papers on the subject by industry groups like American Architectural Manufacturers Association (AAMA), American Institute of Architects (AIA), Construction Specifications Institute (CSI), Glass Association of North America (GANA) or National Glass Association (NGA). Therefore, the following section reviews pertinent literature and findings of previous studies.

A study conducted by Michno evaluated three shadow box configurations: sealed, vented, and pressure equalized. The author concluded that, in a sealed cavity, the effect of temperature rise on cavity pressure is negligible, amounting to 4.5 psf for 280°F temperature rise[1]. Additionally, the sealed cavity created a load transfer from the outer panel to the inner panel, especially if the outer panel is flexible (e.g., 1/4” monolithic glass.) Sealed cavity systems provide a marginally higher benefit than vented systems, but rely heavily on high manufacturing standards. Pressure-equalized systems provide good performance in harsh environments, but need to be protected prior to installation to prevent contamination of the cavity.

Another study, conducted by Boswell and Walker, examined a sealed cavity installation in Beijing, China where the low-E coating was installed on the #3 surface to reflect heat back into the cavity and minimize condensation on the #4 surface[2]. The suggested solution to prevent condensation in the cavity and “scum” buildup is to provide either a sealed cavity or a cavity that is vented internally, from the cavity to the insulation layer, but not through the vapor barrier.

In terms of potential problems with shadow boxes, McCowan et al. identify two issues: imperfect seals between the shadow box back pan and the mullion framing that allow condensation into the cavity, and offgassing of sealants inside the cavity due to high temperatures[3]. As a potential solution to prevent condensation in the cavity, Vigener and Brown suggest adding an interior back pan behind the insulation[4].The use of laminated glass (for structural performance or impact resistance) could limit the acceptable temperature inside the cavity, according to Kragh et al.[5]. Manufacturer information on the temperature limits of laminated glass should be consulted before using it in a shadow box assembly. The study concluded that non-vented cavities can cause deformation of the glass or back pan, resulting in a compromised appearance[5]. In these non-vented conditions, the back pans should be sealed to the surrounding framing with flexible material, rather than rigidly attached, to prevent deformation from differential movement and pressure cycling. In vented cavities, baffles should be provided in the vents to reduce the possibility of dust and debris entering the cavity. The final conclusion suggests sealed, desiccated systems as a new standard.

Kaskel and Ceja published a paper that reviews a case study of a hospital project, located in the U.S. Midwest and constructed in 2005[6]. Condensation and ice formation was observed both in the shadow box and in the corners of lights adjacent to the shadow box. The back pan insulation was observed to be incomplete in filling some shadow box cells, and the sealing tape was incomplete or poorly adhered to the mullions. The building was designed to maintain interior humidity at a minimum of 30% throughout the winter. Testing indicated that the insulation at the back of the shadow box, in conjunction with venting to the outside (by cutting gaps in the interior glazing seal) reduced the temperature inside the shadow box enough to cause condensation on mullions at vision glass panels adjacent to the shadow box. The high interior humidity levels contributed to this effect.

The stated purpose of another paper was to respond to recent interest in shadow box failures by insurance companies[7]. Venting the shadow box cavity to the exterior in cold climates can bypass the curtain wall thermal break and create cold mullions surrounding the shadow box. Annealed glass is not suitable for the inner light of the IGU as it may break due to thermal stress caused by high temperatures inside the shadow box cavity. The authors suggest heat-strengthened or tempered glass. An alternative suggestion is laminated glass, but the interlayer must be suitable to withstand the expected high temperatures. Authors suggest that shadow boxes be vented to the exterior in UK-like climates. When this approach is taken, ventilation openings should be located at the top of the shadow box to maximize the effectiveness in rejecting heat and humidity. The authors state that there is no current guidance on calculating the area of ventilation openings. Ventilated shadow box cavities should not be considered pressure equalized because the openings will be too small to allow the rapid pressure changes that an equalized system requires. A fine mesh or open-cell foam in the ventilation openings will reduce the amount of dust entering the cavity, but will not eliminate all dust and could become clogged and close the ventilation openings.

A technical bulletin suggests that shadow box glass must be heat strengthened to avoid thermal stress failure[8]. The difference in temperature between the interior of the shadow box and the adjacent vision glass areas may be transferred through the shadow box's perimeter mullions. In cold climates, this can result in condensation on mullions at vision areas. In hot climates, mullions in vision areas can become hot to the touch due to high temperatures inside the shadow box. Shadow box venting is required by code in Massachusetts. At the perimeter of shadow boxes, horizontal-to-vertical-mullion seals must be full depth to prevent interior air from entering the shadow box cavity around the installed vapor barrier. The shadow box cavity cannot be vented to the exterior in face-sealed (four-sided-SSG) systems. If the cavity is generously vented to the exterior, the back pan may be required to resist the same wind pressures as the building exterior. Smaller vents will reduce the wind pressure on the back pan. Residual solvent release from aluminum finishes due to high cavity temperatures is not an issue due to the high application temperatures of these finishes. Other materials in the cavity, including sealants and foam plastic insulation, must be suitable for the expected high temperatures. If laminated glass is required, venting may be required to keep the cavity temperature below 170°F to prevent damage to the laminate. Any vents to the exterior should be baffled to minimize transmission of dust and debris into the cavity. Fixed connections at the back pan perimeter should be avoided to minimize oil canning due to thermal expansion. Care must be taken with vented, unitized curtain wall sections to ensure that water and debris are not introduced into the cavity when the units are stored on site. Use of solvent-release sealants, such as butyl, acrylic, or acetoxy-cure silicone, is not recommended in the cavity. Silicone, SCR, or EDPM glazing gaskets are recommended. It is recommended to maintain a seal between the shadow box cavity and the building interior[8].

Barry and Hartog published a literature review paper that summarizes issues with shadow box design[9]. The paper discusses measured and speculated maximum temperatures in shadow boxes, with instances well over 100°C cited in Britain and Australia. The authors asserted that the interior temperature of shadow boxes is underestimated. Heat strengthened glass used in IGUs may be weakened against thermal stress fracture with the application of ceramic frit, though only fully opacified panels have been tested. Materials in the shadow box cavity that contain volatiles, like insulation, gaskets and sealants, may off gas in the cavity and leave deposits on the inner surface of the glass. Fire-retardant additives in insulation and glazing tape are thought to have produced iridescent plumes in shadow boxes in Australia. The depth of a shadow box cavity is assumed to have negligible effect on the cavity temperature. Minimum cavity depth is suggested as the smallest dimension that will prevent the back pan from touching the back of the glass in the most extreme conditions of wind-load glass deflection, temperature-induced outward deformation of the back pan and negative fabrication tolerances. Permanent, whitish encrustations have been observed on the #2 surface of monolithic shadow box glass in Singapore and Australia. The origin and cause of the encrustation is not known[9].

Lastly, Vos developed a test method that can be employed during performance mockup testing to confirm adequate vapor equalization to prevent condensation[10]. The general idea is to build a performance mockup near the building location and monitor glass surface temperature, air temperature and dew point both inside and outside the shadow box cavity. The author suggested that the testing and monitoring occur for a minimum of three weeks. Plotting all six variables on the same line graph will reveal condensation events where the surface temperature and dew point lines cross. Comparison of the interior and exterior values will confirm if the cavity is vapor equalizing. The testing protocol was implemented on a mockup in a northern-hemisphere climate. Initially, the shadow box was vented to the building interior, resulting in significant condensation in the shadow box. Subsequently, the mockup was modified to seal the connections to the interior and vent to the exterior. The revised venting strategy eliminated all condensation events[10].

3.0 MODES OF SHADOW BOX FAILURE

Following a review of the literature referenced in the previous section relating to the design of shadow boxes, the next section identifies major modes of failure and subsequent possible remediation. The review revealed that there are four broad categories of shadow box failure: condensation in the shadow box cavity; dust and debris infiltration into the shadow box cavity; thermal transfer (either excessively hot or cold) from the shadow box cavity to the interior surfaces of surrounding curtain wall mullions; and structural failure of the exterior glass or shadow box back pan.

Condensation can form inside a shadow box cavity when moisture-laden air in the cavity is cooled to the dew point. In cold and temperate climates, winter interior building air is typically warmer and has a higher relative humidity than outside air, so infiltration of interior building air into the cavity can become a source of shadow box condensation. In warmer climates, daytime outdoor air that is introduced into the shadow box can be a source of condensation when temperatures drop at night. Condensation itself is aesthetically objectionable, but tends to be transient and dissipates. It can, however, have long-term consequences that affect shadow box performance and appearance. The condensation can leave visible deposits on the interior surfaces of the shadow box cavity that cannot be easily cleaned. Additionally, the condensation can deposit solvents or particulates from finishes, adhesives or sealants that can deteriorate other finishes and seals inside the cavity.

Since the exterior glass of a shadow box is vision glass, the presence of dust or debris in the cavity is aesthetically objectionable and undesirable. Shadow box cavities are generally inaccessible after they are installed, so dust or debris that gets inside the cavity is difficult and costly to clean or remove. Dust and debris can enter the shadow box cavity during assembly of the units, while they are stockpiled on site, during installation of the curtain wall or by way of cavity vents after the shadow box has been installed.

The shadow box cavity is typically located to the interior of the curtain wall mullion thermal break and, therefore, allows thermal conductivity between the cavity and the interior surfaces of curtain wall mullions at the perimeter of the shadow box. If the shadow box cavity is excessively hot, it can heat the interior surface of adjacent mullions to temperatures that can be painful or scalding in extreme conditions. If the shadow box cavity is excessively cold, surfaces of adjacent mullions that are exposed to the building interior can be cooled below the dew point, causing uncontrolled condensation inside the building.

Excessively high or low pressure inside a sealed shadow box cavity, due to very hot or cold (respectively) air trapped inside the cavity, can deform the shadow box back pan, damage seals or break the exterior glass.

The primary means to combat these failures can be some form of cavity ventilation, or a complete and deliberate lack thereof. Shadow boxes can be vented directly to the exterior; vented indirectly to the exterior by way of the mullion cavities; vented to the building interior; or sealed.

4.0 VENTILATION STRATEGIES

4.1 Ventilation Directly to the Exterior

Shadow box cavity ventilation directly to the exterior is commonly done by leaving gaps in the glazing gaskets of the vision glass and putting porous baffles in the resulting openings. This approach is only possible with a captured system and cannot be done on a structurally-glazed curtain wall. Typical practice is to provide vents in the vertical mullions near the top of the shadow box unit and in the horizontal mullion at the bottom (Figure 2). This arrangement prevents the direct infiltration of liquid water (rain) and insects through the vents and promotes a convective flow of air through the cavity.

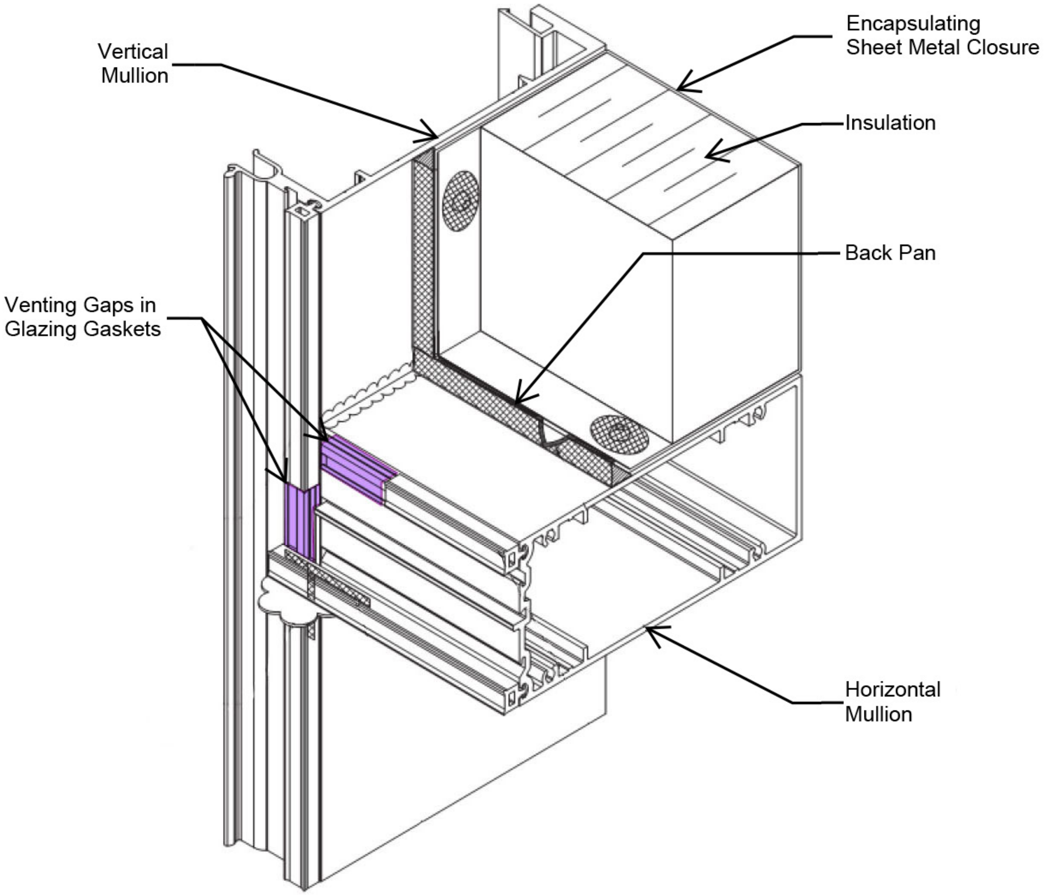

Figure 2: Diagram of shadow box ventilation to the exterior.

There are several potential benefits of venting the cavity directly to the exterior. The direct connection equalizes the pressure between the cavity and the exterior environment, preventing pressure buildup inside the cavity. The introduction of unconditioned exterior air also discourages condensation inside the cavity as long as the flow of air through the cavity is sufficient to ensure that the air inside the cavity has similar temperature and relative humidity to the exterior environment[1, 10]. In the event that condensation does form inside the cavity, the convective flow of air promotes drying and dissipation of the condensation.

There are, however, potential drawbacks to direct ventilation to the exterior. In temperate or cold climates, the introduction of very cold exterior air into the cavity can cool the mullions at the perimeter of the shadow box to a point where uncontrolled condensation can form on mullion surfaces inside the building and result in water damage to adjacent materials[7, 8]. Exterior air that enters the cavity can also carry particulates that can collect on the inner surfaces of the shadow box. This is of particular concern in sandy or heavily polluted environments[5]. Finally, it is very likely that intermittent condensation will occur in any climate that experiences moderate-to-large temperature swings in a short period of time, as with the passing of a cold front or at nightfall. This condensation is likely to dissipate in relatively short order, but is aesthetically objectionable in the meantime and can leave deposits on the cavity surfaces that can accumulate over time.

4.2 Ventilation to Mullion Cavities – Indirect to the Exterior

Ventilation to the mullion cavities is done by providing baffled holes in the vertical mullions bounding the shadow box. In most curtain wall systems, the mullion cavities are used as a weeping system and have holes to the exterior to drain any water that gets inboard of the primary water seal. The weep holes provide a connection between the exterior environment and the mullion cavity and since the shadow boxes are ventilated into the mullion cavity, they have an indirect connection to the exterior.

Indirect ventilation provides pressure relief for and air flow through the shadow box cavity without a direct connection to the exterior, and can introduce very cold air or dust and debris. A small amount of dust may make its way through the mullion cavities and to the shadow box, but the baffled vent holes prevent the vast majority of that dust from entering the cavity. The mullion cavity is typically on the interior side of the curtain wall thermal break, so it will be tempered by the interior environment. The shadow box ventilation air has to pass through this moderately-tempered zone and is, thus, brought closer to the interior building temperature before it is introduced into the shadow box cavity. This tempering mitigates the likelihood that the cavity, and the surrounding mullions, will become excessively hot or cold.

There are no significant drawbacks to this approach, but there two important limitations. First, this approach is impractical in stick-built curtain wall systems due to the difficulty of ensuring complete separation of the interior mullion cavities from the interior building environment. Joinery and assembly of stick-built systems introduce a multitude of potential paths for infiltration of interior building air into the mullion cavity through splices, screw holes or other openings in the mullion walls. This necessitates the quality control and controlled environment, which is only possible with a factory-assembled, unitized curtain wall system. This has its own challenges. Many unitized curtain wall systems have a water and air barrier at the outboard split mullion joint that is near, or in line with, the plane of the glass (Figure 3). This barrier prevents the mullion cavity from having a direct connection to the exterior. There is, however an inboard split mullion connection which, if not sealed, would provide a direct connection between the mullion cavity and the interior building environment. There are also potential paths for interior air infiltration at the intersections of horizontal and vertical mullions and at stack joints or sills. It is possible to seal these during shop fabrication, but care must be taken by the designer in specifying these requirements and by the manufacturer in the subsequent fabrication. In the absence of a complete seal between the mullion cavities and the building interior, ventilation into the mullion cavity would provide an environmental connection between the shadow box and the interior building environment, which is not desirable (see section 4.3 below.)

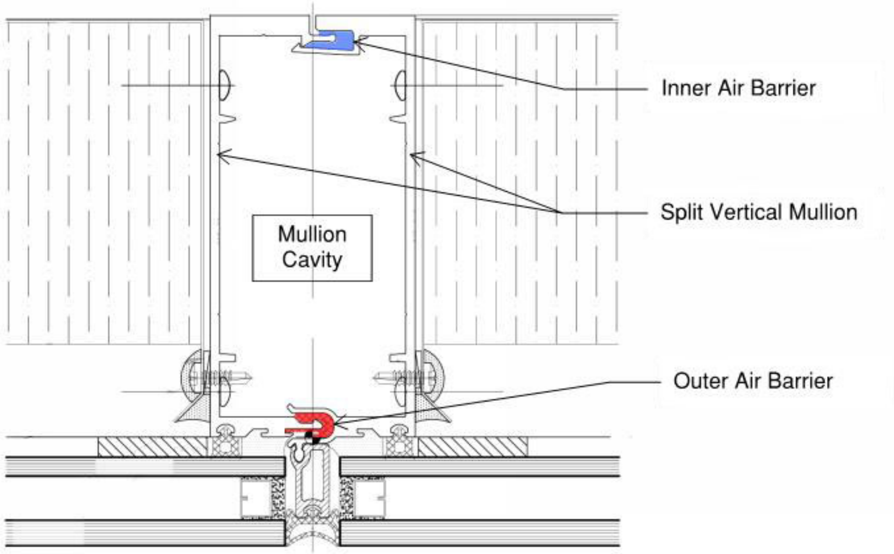

Figure 3: Unitized curtain wall split mullion showing the air barriers required for ventilation to the mullion cavity.

4.3 Ventilation to the Building Interior

Ventilation to the building interior is usually accomplished by leaving gaps between the shadow box back pan/insulation/closure assembly and the adjacent mullions (Figure 4).

There are serious risks in ventilating the shadow box cavity to the building interior, especially in cold or moderate climates. First, the shadow box cavity and its interior surfaces tend to be colder than the interior building environment in the winter. When warm, moisture-laden air from the building interior is allowed into a cooler shadow box cavity, the risk of condensation is very high. Since the relative humidity of the interior building air will be fairly stable, dissipation of the condensation through introduction of interior building air will likely be slow. Additionally, the interior building environment is likely to have significant particulate matter in the air that can get into the into the shadow box cavity and leave aesthetically unappealing deposits. The risks of this approach have been demonstrated in performance mockup testing where cold exterior conditions created repeated condensation events[10].

The only real benefit of ventilation to the building interior is that it offers pressure relief for the shadow box cavity.

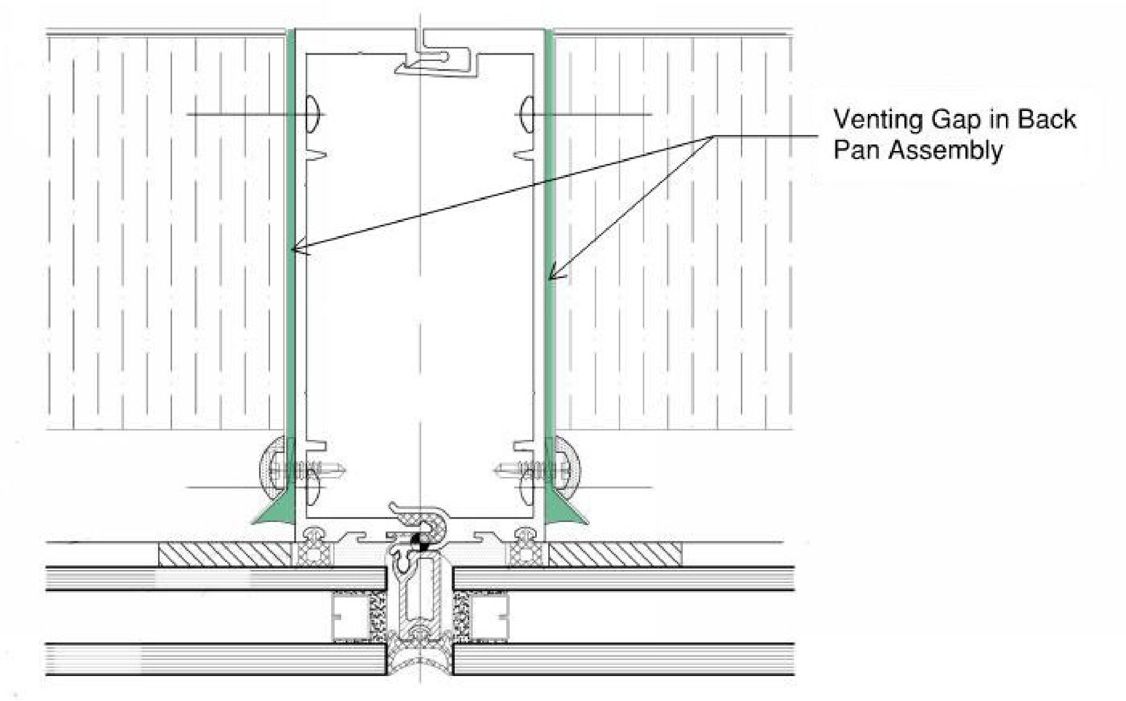

Figure 4: Shadow box ventilation to the building interior.

4.4 Sealed Cavity

The final ventilation strategy is not to provide any ventilation at all. In this case, the shadow box cavity is completely sealed from both the interior building environment and the exterior.

The lack of any airflow into or out of the cavity can lead to elevated temperatures and pressures, especially on hot days and at times where there is direct sunlight on the shadow box. Excessive heat can degrade sealants and finishes inside the shadow box cavity to the point where they fail. If a sealed cavity is the chosen solution, the designer must ensure that all finishes, sealants and other materials in, or adjacent to, the shadow box cavity are stable at high temperatures. In similar fashion to the direct ventilation to the exterior, extreme temperatures inside the shadow box cavity can transfer to the mullions bounding the shadow box and result in interior mullion surfaces that are hot, or even scalding, to the touch. There is some evidence that heat buildup in the cavity can induce elevated pressure inside the shadow box. The pressure can build to a point where an annealed (rather than heat-strengthened or tempered) glass light can break. There is little evidence of this mode of failure in completed buildings, however, the party responsible for engineering the curtain wall system should calculate potential pressure buildup (based on design criteria) and verify that both the vision glass and the shadow box back pan can withstand anticipated pressures without failure[1].

The other major risk of sealing the cavity is that dust, debris or very humid air is trapped inside during the fabrication process. If dust or debris is trapped inside, there is no way to remove it other than disassembling the shadow box (usually from the building exterior). If very humid air is trapped inside the cavity, it can condense during cool weather or at nighttime after installation, leaving condensation and the resultant debris on the inside surfaces of the shadow box. This risk can be mitigated by specifying that the cavity be protected from infiltration of dust, debris and moisture throughout fabrication, delivery and installation. Protection from dust, debris and liquid moisture infiltration is readily achievable with established quality assurance and quality control processes, but the control of humidity requires careful climate control at the fabrication facility that may be difficult for some manufacturers to achieve. This should be taken into account in the selection of acceptable manufacturers.

5.0 CONCLUSION AND RECOMMENDATIONS

Having considered the benefits and drawbacks of the ventilation strategies identified above, it is this author's primary recommendation that shadow box cavities be ventilated indirectly to the exterior through the mullion cavities. This recommendation does come with the caveat that the curtain wall must be a unitized system and that careful specification and fabrication ensure a complete seal between the mullion cavities and the interior building environment and that the shadow box cavity be protected from infiltration of dust, debris and moisture throughout its fabrication, delivery and installation.

If a unitized system is not feasible, or if the chosen unitized system does not allow a complete seal between the mullion cavities and the building interior, the alternative recommendation is to specify a completely sealed shadow box cavity. When specifying a sealed shadow box cavity, it is critical that all materials inside the cavity are suitable for high-temperature applications. It is also recommended that the shadow box glass be tempered or heat strengthened and that the specifications require the curtain wall contractor to determine the highest anticipated temperature inside the cavity and verify the ability of the glass and the back pan to withstand the resultant pressure. Finally, if the shadow box can be anticipated to receive direct sunlight, some consideration should be given to the possibility that the interior surfaces of the bounding mullions can get hot to the touch. It is recommended that the mullions adjacent to the shadow box not be in highly trafficked areas or in locations where they can be touched by children or others who are heat-sensitive.

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