

Thermal optimization of curtain wall façade by application of aerogel technology

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Abstract

The paper illustrates the use of aerogel technology in façades to reduce thermal bridging and limit condensation. Additionally, by mitigating local thermal bridges the indoor climate, especially draught and molds creation, can be eliminated as the surface temperature increases and prevents these negative factors. Curtain walls, in comparison to opaque wall, are often not designed in an energy efficient way and can be large contributors to heat loss of buildings. This is common for curtain walls in Asia and North America, where the energy requirements are not as demanding as in Europe. Building envelopes have many details which can easily introduce thermal bridge due to limited space of insulation or incorrectly solved construction detail. The heat flow through a poor thermally-performing detail, e.g. exposed concrete slab, could account for over 40% of the heat loss of the façade. The contribution of a well-insulated slab could be less than 10%. Unfortunately, traditional insulation techniques are often not suitable due to limited installation space. This paper discusses several case studies whereby the performance of a reference case is compared to a case with a thermally optimized façade implementing Building Insulation Blanket (BIB), which uses silica based aerogel technology. The thermal conductivity of BIB can be as low as 0.015W/mK, and together with its high flexibility and fire resistance enables new design possibilities. The use of BIB in the case studies, contributed to the reduction of overall curtain wall thermal transmittance up to 30%. Additionally, condensation risk was significantly reduced.

Keywords

Aerogel, Building Insulation Blanket, Façade Thermal Breaks, High Performance Façade, Energy Efficiency, Curtain Wall Thermal Optimization

DOI 10.7480/jfde.2017.1.1430

1 DIVERSE USAGE OF BUILDING INSULATION BLANKET

This paper discusses aerogel based Building Insulated Blanket (BIB) through several case studies in North America and Asia, architecture details, and performance data from simulations and real-life applications. Furthermore, low thermal conductivity and physical properties of aerogel technology are discussed and demonstrated on unique application of BIB into a building envelope (Casini, 2016). Thermal bridges can be found in many different details within the building envelope for example; the junction between wall – floor slab – balcony/overhang, curtain wall framing system, stem walls, jamb between walls and windows/doors, spandrel or areas with limited space available for insulation. Solutions for addressing thermal bridges already exist on the market and have been successfully used in the past and present. In the field of energy efficiency research, many different solutions have been already developed to improve the building envelopes performance (Brunner, Wernery, & Koebel, 2015). However, there is no universal solution addressing all types of thermal bridges, therefore we selected four very different case studies where the usability and performance of BIB are demonstrated. In most of the cases the insulation applications are limited to small amount of BIB, which is in contrast with traditional use of an insulation on entire wall area. The optimized application improves significantly a ration between added value and cost of the material, which consequently increase economical usability and accessibility of such a technology.

Continuous building envelope insulation is one of the most important criteria for achieving sustainable and continuous energy performance of buildings. Using conventional insulation materials in tight spaces or for insulation of complicated details is often challenging. Application of Dow Corning® HPI-1000 Building Insulation Blanket (BIB) at fenestration transitions and slab edges can effectively contribute to the enhancement of the thermal performance of the building envelope. Aerogel technologies, including BIB, offer new opportunities for design of building envelopes combining high insulation properties, flexibility, durability as well as aesthetics and design freedom (Aegerter, Leventis, & Koebel, 2011) (Koebel, Rigacci, & Achard, 2012). Additionally, the condensation on cold internal surfaces, caused by thermal bridges, can be effectively addressed in cost efficient ways. The BIB material is based on the silica based aerogel which allows good compatibility with silicone based adhesives which can provide good adhesion to most building substrates. Due to BIB's simple implementation into construction details, field work on detail insulation can be executed without impacting schedules while keeping high level of quality.

In this paper, we address four cases in which the main issue is the limited space available for sufficient insulation and whereby the flexibility of insulation material is required in order to insulate non-standard and unique shapes and conditions. The focus is mainly on new construction, nevertheless we are also aware about large potential of the technology in retrofits, which is illustrated in the first case.

2 METHODOLOGY FOR OPTIMIZATION OF FAÇADE PERFORMANCE

The performance of a building envelope is evaluated as a whole construction, including all details, therefore emphasis has to be placed on an optimally configured solution. This includes heat loss through panels (vision and non-vision), framing and connections between panels and framing systems. The heat flow through a poor thermally-performing condition, could account for over 40% of the total heat loss through the building envelope and eliminate the energy improvement of thermal efficient solutions, such as thermally broken framing systems or IGU. In comparison, a thermally efficient detail, such as an insulated slab edge, could contribute for less than 10% (Lawton & Norris, 2013). Typically, poorly performing details are in areas where there is space limitation and traditional insulation techniques cannot be used. Thermal bridges can be categorized into following:

- Planar thermal bridge: panels, spandrels, IGUs (U-value)
- Linear thermal bridge: façade framing systems, spacer bars (Ψ -value)
- Point thermal bridge: point fixing hardware (χ -value)

All the above mentioned thermal bridges have to be added together to define the overall U-value of curtain wall/façade (EN/ISO 12631, 2012), (NFRC 100, 2004). Individual construction details and their heat loss contribution can be calculated accordingly to various ISO or ASTM standards (NFRC 100, 2004), (EN ISO 10077-2, 2012), (ISO 15099, 2003) with finite element method (FEM) and simulation programs, such as THERM and Flixo (Flixo Pro), (Mitchell, Kohler, Arasteh, 2006). In this paper we look also at other thermal bridges beyond curtain walls and windows, and thus methodologies for thermal bridges in constructions can be used as well (ISO 10211, 2007). The structure details studied in this paper are unique and their evaluation is sometimes outside the mentioned standards evaluation method, therefore we adapted the procedure to fit the individual needs.

2.1 HIGH PERFORMANCE INSULATION AEROGEL TECHNOLOGY

Building Insulation Blanket (BIB) has significantly improved thermal conductivity, see Table 1, as compared to conventional insulation products, see Table 2, (DowCorning, 2014). BIB material has high compression resistance which allows to compress the material without losing its insulation properties, compared to insulation materials, such as mineral or glass wool. This is due to closing micro structural air cavities within the material under compression which further limit convection. The blanket is also fire-resistant, hydrophobic and does not settle over time, which ensures long term uninterrupted performance.

BUILDING INSULATION BLANKET - HPI-1000	
Thickness	10 mm
Thermal Conductivity	0.0146 W/mK
Weight	0.013 kg/m ²
Maximum Service Temperature	200 °C
Compression Strength	SI Units (10 psi)
Fire Resistance	Class A; FSI 5, SDI 10
Hydrophobic	Yes
Water vapour resistance factor (μ -value)	4.7 (-)
Color	Gray

TABLE 1 Material properties of BIB

MATERIAL	THERMAL CONDUCTIVITY [W/MK]
BIB	14.5
Polyisocyanurate	23.6
XPS	28.4
Mineral wool	33.8
EPS	37.3
Glass wool	40.5

TABLE 2 Comparison of thermal conductivity of conventional insulation materials

3 APPLICATION OF AEROGEL TECHNOLOGY BASED INSULATION IN CURTAIN WALLS

Advanced building envelope design has good potential to lower energy demand and reduce the capital costs of heating and cooling systems, as the need for heating and cooling can be reduced by up to 60% (ORNL, 2012) (IEA, 2014). Large portions of these savings can be addressed by energy improvement of building envelope and the rest by efficient mechanical equipment (IEA, 2014). Four different case studies with various application purposes within a building envelope are described in this article. The results are discussed based on a comparison between the original base case scenario and the optimized scenario utilizing BIB in order to clearly demonstrate the improvement.

3.1 RETROFITTING FAÇADE WITH FOCUS ON POINT THERMAL BRIDGES

This case study demonstrates a usage of BIB and its benefits when extremely tight space needs to be insulated. The refurbished structure does not allow any increase of the space for insulation. A canopy above the entry level of a commercial shopping center was constructed without any thermal breaks and insulation 15 years ago. Not-thermally broken structure resulted in excessive condensation during colder months and made the usage of the interior commercial space unpleasant. The space of the shops was undertaking an upgrade and renovation, and the contractor and architect were charged with removing the condensation issue while keeping the original structure and cladding. At the Fig. 1 and Fig. 2 you can see a 3D sketch and section through the metal frame which is going through the thermal envelope of the building without any thermal break. In this case the focus was poorly on elimination of the condensation.

This thermal problem can be considered as 3D, however after initial validation of 2D model by 3D model we continued only with 2D modeling as the results were nearly identical. The design temperatures for the building were -8.6°C and 23°C . From the Fig. 3 and Fig. 4 it is clearly visible that the condensation occurs on an interior side of the metal frame structure, when interior humidity is 50%. The condensation areas are highlighted by thick red line in Fig. 4.

Several options of insulating this detail were modeled and evaluated, also the feasibility of different applications were discussed. Due to the space limited areas around the water gutter, there were places allowing only 10-20 mm of available space under the existing cladding. Modelling with conventional mineral or glass wool showed that the condensation would remain as not enough insulation could be used. Considering problematic and very limited space only flexible high performance insulation would solve the condensation problem. Also an option with insulating internal part of the structure was considered, as there was more space for insulation. However, this solution would have high requirements on making the entire structure vapour tight, and prevent warm interior air from movement to the areas close to the façade where the metal structure would be cold and thus condensation would occur again.

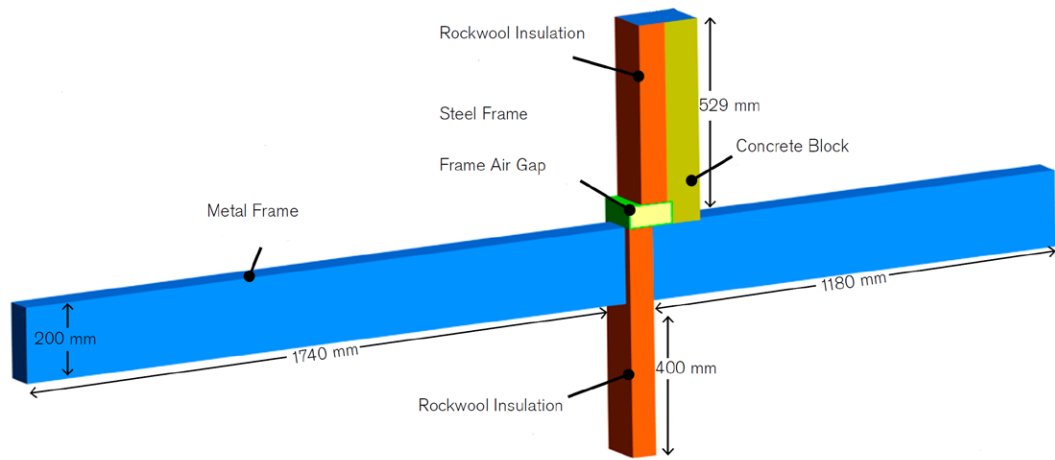


FIG. 1 3D illustration of metal structure penetrating façade continuously from interior to exterior

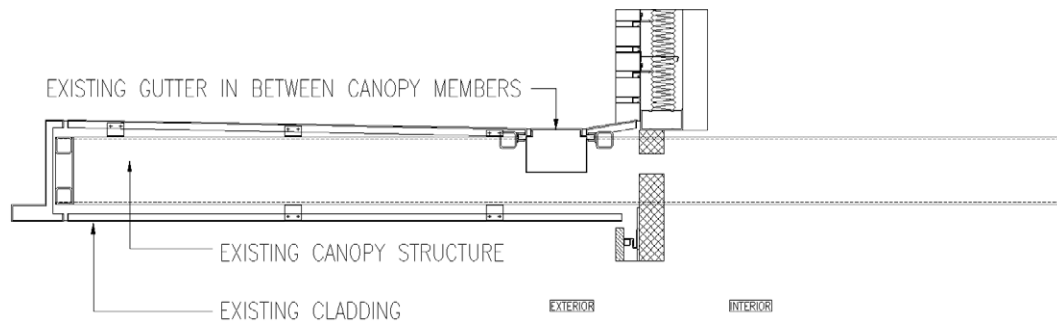


FIG. 2 Detail section of the canopy structure including water gutter

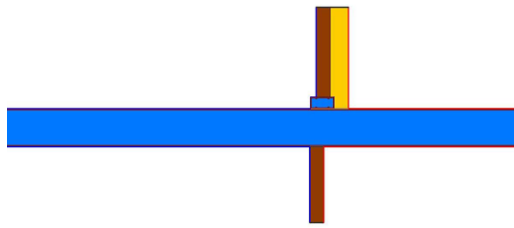


FIG. 3 Simplified model of canopy structure - before renovation.

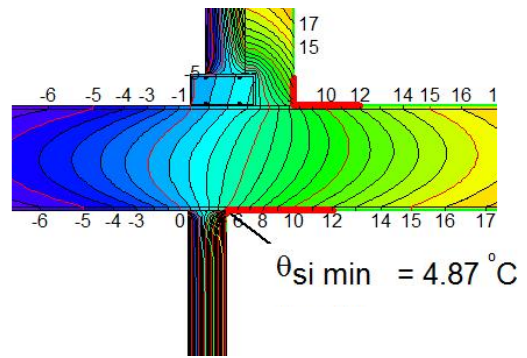


FIG. 4 View at the section of canopy structure and wall, with highlighted areas with condensation risk- before renovation

When the detail was modeled with BIB, see Fig. 5 and Fig. 6, then the structure and its insulation wrap could achieve required performance to remove the condensation. In fact, according to the model, the condensation would not appear until the relative humidity would reach around 57%; this gives a safety margin for small thermal bridges which were not accounted for due to the simplified 2D model. The temperature of the area with highest risk of condensation increased from 4.87°C to 14.05°C. The warmer metal structure would not facilitate warm internal air condensation and hence the condensation would be eliminated. This solution was approved and implemented, and the results from simulations were confirm by fact that the condensation was removed.

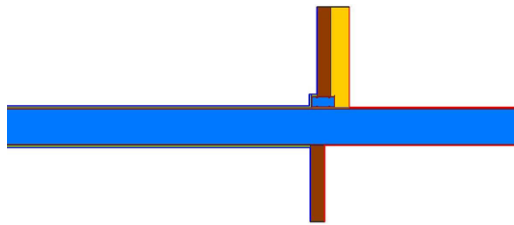


FIG. 5 Simplified model of canopy structure with BIB - after renovation

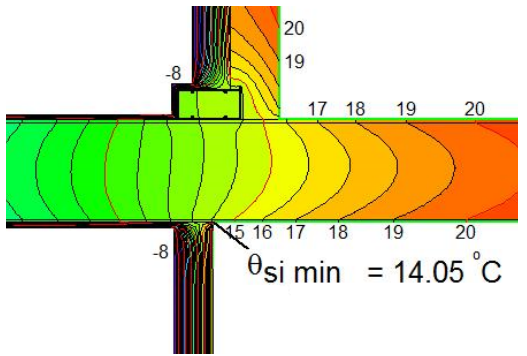


FIG. 6 View at the section of canopy structure and wall, with highlighted areas with condensation risk- before renovation

3.2 THERMAL OPTIMIZATION OF THE CURTAIN WALL FRAMING SYSTEM

When a limited space needs to be highly insulated, as could be the case for a non-thermally broken curtain wall system or opaque walls with not sufficient thermal resistance and without adequate space for conventional thermal insulation, then the traditional insulation techniques often do not fulfil the demand. In these cases an aerogel based technology Building Insulation Blanket (BIB) can be used to mitigate thermal bridges in curtain wall framing systems and other structures. The thermal conductivity of the blanket can be as low as 0.0146 W/mK.

The performance of BIB is illustrated on an optimization of a curtain wall façade where a base case is compared to an optimized case with BIB. The façade is a traditional unitized mullion/transom type with opaque rectangular spandrel, with vision area thermal transmittance of $U_g = 1.45\ \text{W/}$

m²K and unitized module dimensions of 3.8 m x 1.5 m. Fig. 7 illustrates the curtain wall framing elements on the building before and after design optimization, including the temperature field, which indicates thermal bridges and their reduction (U_g - thermal transmittance of glazing). The thermal transmittance of the system is presented in a form of thermal joints (U_{TJ}), which represents both thermal transmittance of frame and edge of the glazing, see Table 3. The use of BIB reduced the overall thermal transmittance of the façade by 26% and the thermal transmittance of framing itself by an average of 50%. In some cases this reduction was up to 65%. The risk of condensation was removed as the temperatures of internal façade surfaces raised above the dew point. The proposed design solution allowed to reduce U_{cw} from initial 2,7W/m²K to required 2,0W/m²K (U_{cw} – thermal transmittance of curtain wall). The benefits of the curtain wall performance improvement contributes additionally to investment optimization as e.g. triple insulated glass units may not be needed and cheaper double insulated glass units can be used. This consequently reduces loads on structures and thus more subtle framings can be used. This is a very large project, and the implementation did take around 2 years as the several levels of validation were needed. Starting with conceptual design in early stage with façade consultant until production design with the fabricator. This process included validation by full scale mockup, before the product was integrated in final solution.

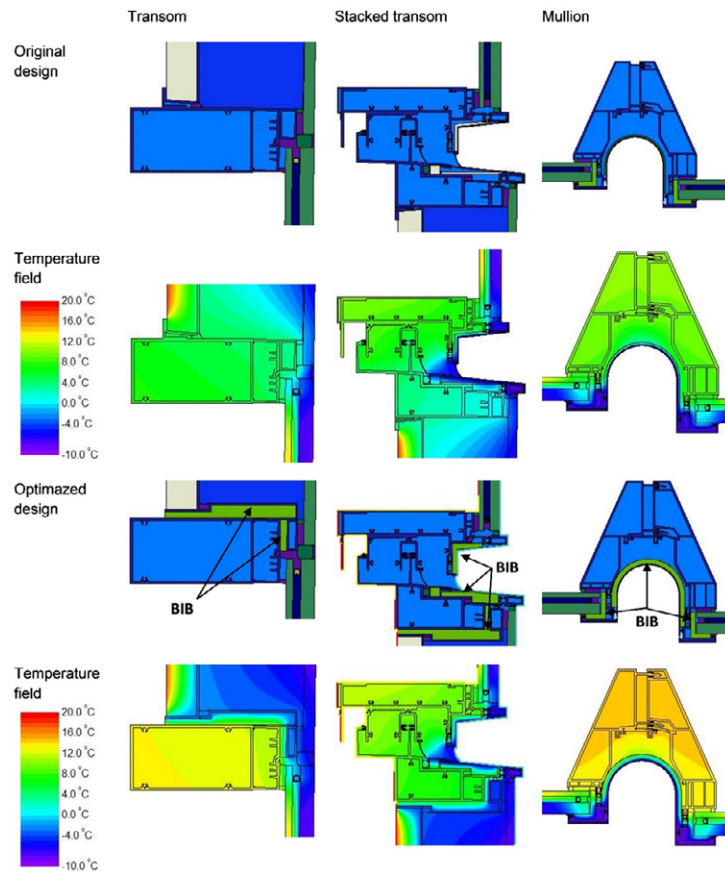


FIG. 7 Illustration of design and performance of curtain walling system optimized by BIB

	TRANSOM	STACKED TRANSOM	MULLION	U_{CW} - VALUE
U_{TJ} before [W/m ² K]	11.3	8.0	5.8	2.7
U_{TJ} before with BIB [W/m ² K]	3.8	5.6	3.2	2.0
Improvement [%]	66%	30%	44%	26%

TABLE 3 Results of the Uvalue of frames reducing by BIB optimization of thermal bridges

3.3 THERMAL SEPARATION OF A ROOF SLAB AND A STEM WALL

Every building has unique features and needs individual approach to solve thermal bridges. In this case study a casted steel reinforced concrete stem wall was used on a roof slab to create a roof garden seedbed. The reinforcement re-bars continuing from the roof slab to the stem wall create linear thermal bridge. As the re-bars are local thermal bridges, two models for each option were evaluated and averaged (first - only concrete, second – concrete with re-bars).

The BIB material consists mainly of silica which creates excellent insulation properties due to its nano-pours in the silica particles. The nano-pours encapsulated in the silica prevent pressing out air when the insulation is compressed. For this feature, BIB can be exposed to a load generated by e.g. stem wall standing on top of a roof. Two options of insulating the stem wall were evaluated. The option 1 removes the thermal bridge by placing BIB between the roof and stem wall. The option two solves the thermal bridge by wrapping the entire stem wall by BIB. The illustration of the reference case and two options are shown in Fig. 8.

This stem wall can be considered as liner thermal bridge and Ψ -value of the individual wall can be derived by the calculations. The reference case which is not insulated has a Ψ -value of 1.39 W/mK, option 1 with BIB under the stem wall gives a Ψ -value of 1.05 W/mK, and the option 2 reduced the Ψ -value to 1.00 W/mK. The reduction of the heat flow through the liner thermal bridge is slightly under 40%. By comparison of the option 1 and the option 2, the difference is around 5% in a favor of option 2, complete wrap of the stem wall. However, if the economic aspects and consumption of the material are considered, then the option 1 would be the most reliable from added value perspective.

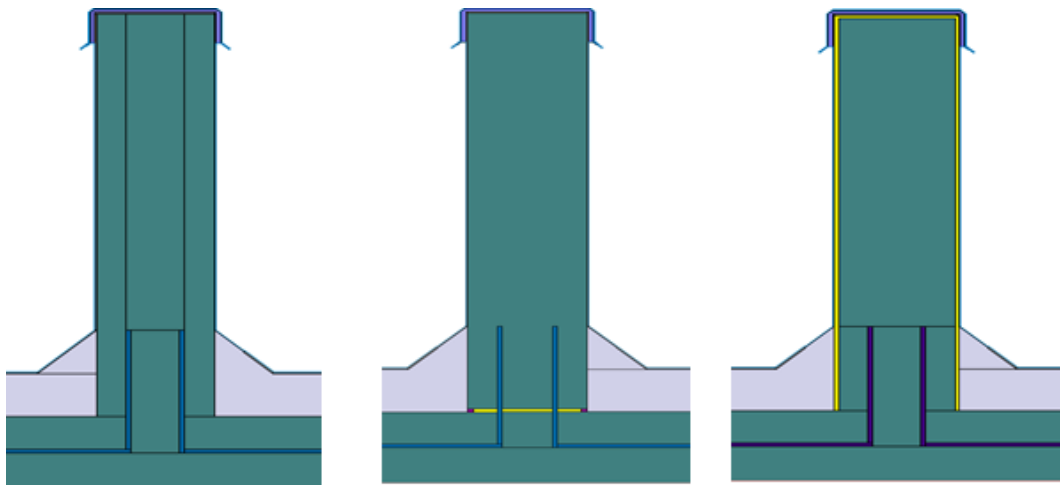


TABLE 4 Base case of a stem wall (left), Option 1 with BIB under a stem wall (middle), Option 2 with BIB wrap of a stem wall

3.4 INCREASING WALL THERMAL RESISTANCE IN SPACE LIMITED STRUCTURES

New buildings as well as renovated building in some cases may have a limited space for an insulation to reach required performance. Not sufficient insulation levels may lead to thermal bridges and other major issues with building envelope. In this case we will demonstrate an example where wrong communication led to situation when cladding system was not designed with sufficient space for insulation. This situation could escalate into a large time delays and construction cost increase. As the construction was already delayed, a solution with high performance insulation was sought, while keeping the existing cladding system. The building envelope consists of large amount of windows, therefore the façade has large window-to-wall ration and requires high demand thermal insulation in the walls.

The requirement of a local building code for the thermal insulation of the exterior wall assembly specifies that U_w -value of wall assembly should be max. $U_w = 0.36 \text{ W/m}^2\text{K}$ (U_w - thermal transmission of a wall). The design of the building did not allow to have sufficient amount of conventional fiber insulation and thus entire façade would not comply with the regulation.

One of the wall window connection detail is shown on Fig. 9, including indication of the available space for insulation, which was just around 40mm. By thermal modelling it was calculated that 3 layers would not be enough. To achieve required thermal resistance of the wall, 4 layers of BIB would be needed, as each layer is 10mm thick. This solution would give an U_w -value of the center of wall $0.3 \text{ W/m}^2\text{K}$, compared to a situation where there would be 40mm of mineral wool with thermal conductivity $\lambda=0.04 \text{ W/mK}$, which would provide U_w -value = $0.56 \text{ W/m}^2\text{K}$.

Using 4 layers of high performance insulation may seem too excessive, however considering the given situation and potential risks, it gives the most optimal solution for cost vs. performance. In this situation none of the structures need to be adapted or removed to accommodate more insulation.

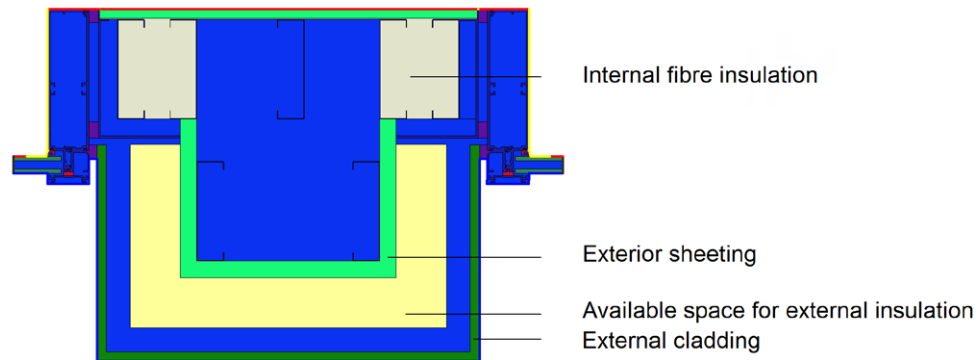


FIG. 8 Wall window connection detail with indicated available space for insulation

4 CONCLUSION

Through this paper we demonstrated the usage of aerogel insulation blanket in four projects in North America and Asia in applications in curtain walls, façade penetration, roof and perimeter wall. Each of these projects has different application, which indicates the versatile and broad application of BIB in construction. The low thermal conductivity of 0,0146 W/mK allows to insulate space limited details and structures with sufficient efficiency. Also, the flexibility of the material allows to insulate complicated details where the use of rigid insulation would not be feasible.

Due to the high thermal insulation performance and flexibility it was possible to optimize the curtain wall framing system by 50% on average which contributed to overall façade U_{cw} reduction by 26%. Additionally, the condensation risk was removed at wall penetration by large metal structure during a refurbishment. Furthermore, BIB can be used to limit heat loss through walls, parapets or spandrels by insulating whole planar area which has limited available space and does not allow to have bulky amount of conventionally used fiber-based or rigid foam insulation. This can be done at the moment of the construction or even during building operations in a quick and efficient way. There is also large potential for BIB in retrofit, as there, the space is usually given and cannot be adapted to large amount of bulky insulation.

Another important finding was that the attention to the critical details in mitigation of thermal bridges is crucial. By optimal use of BIB, the thermal performance of window-wall façade could fulfil building code requirements and the façade of the new building would not need to be expensively changed in order to accommodate large amount of standard insulation.

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