The Use of Aerogel-Enhanced Blankets for Thermal Bridging Correction in Concrete & Steel Buildings

Aerogel particles (left) are transparent, lightweight, and effective insulators, making them a nice addition to enhance thermal blankets for the building envelope.

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Thermal bridges have been widely proven to significantly impact building energy performance. This study used an aerogel-enhanced blanket to provide a solution for improving thermal bridges.

In building science, more effort should be given to design building envelopes with improved connection details. The common method to consider thermal bridges in the whole energy modelling is the equivalent U-value method; however, this does not take into account the dynamic effect of thermal bridges. Minimizing thermal bridges in a building not only reduces the annual heating and cooling loads but also reduces the error in the modeling performance of the equivalent U-value method.

The equivalent U-value method can underestimate the annual heating energy demand by up to 13 per cent for the poured-in-place concrete building with standard connection levels.[1] While the difference between 3D dynamic modeling and equivalent U-value method was reduced to less than three per cent when the connections are improved. This suggests that improved connection details help reduce modeling errors. While the 3D dynamic method is more accurate and should be used preferably, this research was focused on the dynamic effect of the thermal bridges before and after the application of the aerogel-enhanced blanket in a mid-rise residential building.

This study includes:

- Two different building systems:
  1. Concrete building; and
  2. Steel building.

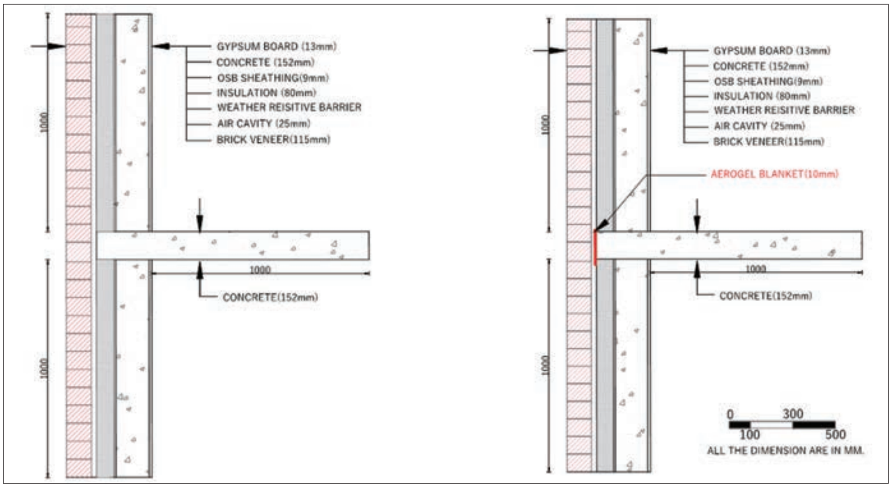

Figure 1. Wall and floor connection with concrete structure (standard on the left, improved on the right).

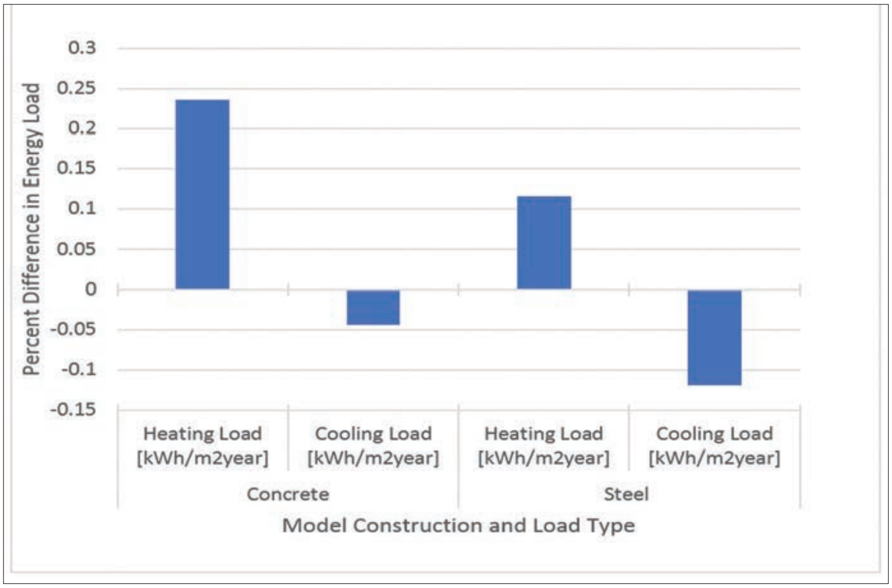

Figure 2. Per cent difference between energy loads for the base case model and improved model with aerogel blankets at thermal bridges.

- Five different details:
  1. Balcony to floor;
  2. Shelf angle location;
  3. Foundation to wall;
  4. Wall to floor; and
  5. Wall to roof.
- Two different modeling approaches:
  1. Equivalent U-value method; and
  2. 3D dynamic method.

Aerogel-enhanced blankets are super insulating materials developed from silica aerogel and reinforced fibre. Pure silica aerogels have high compressive strength but low-tension strength. To strengthen the tensile property of aerogel, it is interwoven with a fibrous material. Aerogel-enhanced blankets are mechanically strengthened, flexible and highly porous material with a very low thermal conductivity.

Due to the unique nature of aerogel blankets, they can be used in both interior and exterior applications. Aerogel-enhanced blankets have a high fire resistance, making it possible for interior application for a retrofit. Its hydrophobic properties help it for the exterior insulation. Aerogel-enhanced blankets composed of synthetic amorphous silica dioxide have been proposed in retrofitting projects or whenever space and weight constraints exist.[2,3] It is also found to be more advantageous in building retrofits for space saving, since they achieve high thermal resistance with thin layers.[4] The thermal conductivity of an aerogel-enhanced blanket is in the range of 0.014 to 0.016 watts per metre Kelvin (W/mK).

According to the National Energy Code of Canada for Buildings,[5] thermal bridges can be reduced by providing the continuous insulation in the details. These standards do not specify any temperature distribution calculations. The standard requires that thermal bridges, due to the repetitive structural members such as studs and joists, and of ancillary members such as lintels are taken into account for the calculation of effective thermal resistance. However, minor penetrations or minor structural members and major penetrations, like balconies with a cross-section less than two per cent of the penetrated wall area, are not taken into account for effective thermal resistance.

The ASHRAE 1365-RP, Thermal Performance of Building Envelope Details for Mid- and High-Rise Building guidelines include thermal transmittance data focusing on 3D thermal bridges. It contains 40 typical building assembly details with thermal bridges in North America.[6] ASHRAE Standard 90.1 provides the maximum U-value to the building envelope components for mass, steel, wood frame, and for all climatic zones.[7]

With the complex 3D thermal bridges, steady state method of the calculation for building energy demand is obsolete. For a proper calculation of overall assembly thermal resistance, dynamic analysis is necessary. The method calls for calculating the energy by taking into consideration the realistic daily condition of the calculation time, like daily temperature changes, interior conditions, the rate of natural and artificial ventilation in different seasons, and solar gains.

In this study, the equivalent U-value method was employed using THERM 7.6 and 3D thermal bridges were modelled with WUFI Plus. A total of six connections were analyzed for both steel and concrete constructions. The connections were modelled in a mid-rise residential building in Toronto, ON (Climate Zone 6). The building is two storeys, 31.9 metres long by 17.78 metres wide by six metres tall, with approximately 1,114 square-metres' gross floor area. The building is designed per a baseline model with the different building envelope. A window-to-wall ratio of 40 per cent was used for the study.

The typical thermal bridges in each building included are:

1. Floor-to-wall junction;
2. Balcony-to-wall junction;
3. Shelf angle detail;
4. Foundation-to-wall;
5. Wall-to-roof; and
6. Sill and lintel detail.

An example of the aerogel blanket placement is shown in Figure 1 (on page 17) for the wall-floor connections with concrete structure. A similar insertion of aerogel blanket was made in similar thermal bridges in other connections of the case building and with a steel structure instead of concrete.

First, the results of the equivalent U-value method calculated the linear thermal transmittance for both details with and without the addition of an aerogel blanket. The wall-to-balcony connection with concrete structure resulted in the greatest improvement in linear thermal transmittance (88 per cent lower). For the steel structure details, an aerogel blanket placed in a roof showed the largest improvement in linear thermal resistance (89 per cent lower). For both concrete and steel constructions, other typical thermal bridges showed reduction of linear thermal transmittance in the range of 64 per cent and 89 per cent.

In terms of the 2D heat transfer method used to analyze the details, the standard ψ-value are higher than the improved ψ-value. In general, improvement can be achieved if the ψ-value gets close to 0 W/mK. Since ψ-value is the additional heat flow from the junction, the higher ψ-value shows there is more energy loss from the thermal bridges and there are more opportunities to improve them. The improved ψ-value is less as the use of an aerogel-enhanced blanket acts as a thermal break. The varying reduction of ψ-value depends on the thickness and strategies of the aerogel-enhanced blanket used. The use of an aerogel-enhanced blanket not only helps reduce heat transfer but also helps provide a comfortable interior surface temperature.

The thickness of an aerogel-enhanced blanket used to correct the thermal bridges in this research is 10 millimetres and 20 millimetres, which can be further increased to achieve lower ψ-value. We should also consider that changes cannot compromise the structural performance of the building. The aerogel-enhanced blanket has allowed insulation in the air gap, but it is still limited to the thickness of the air gap available. For the aerogel-enhanced blanket on the exterior surface, moisture management should also be considered.

In the 3D simulations, the reduction of the thermal bridge impact is measured by the change in heating and cooling load after adding aerogel in the detail. A total of three 3D simulations were performed for both concrete and steel constructions where:

- Base case buildings had thermal bridges;
- Case building with an aerogel blanket placed at thermal bridges; and
- Thermal bridges used the equivalent u-value calculations to draw comparisons between the two methods.

The purpose of these three different models was to determine the effect of thermal bridges to the base case building energy loads and to quantify the improvement

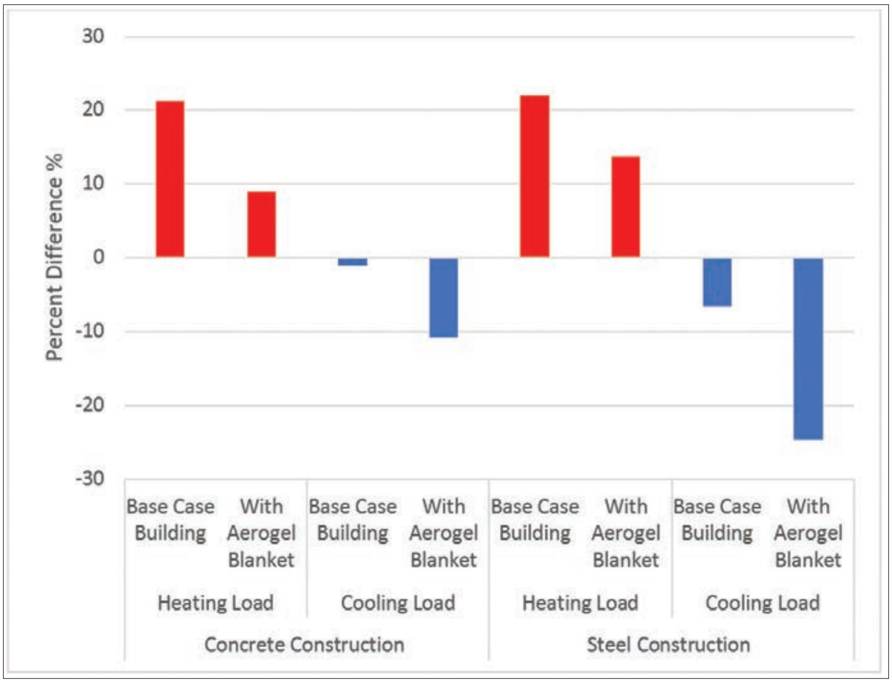

Figure 3. Per cent difference between 3D thermal bridge and equivalent U-value modelling methods.

> ...the thermal inertial effect not only changes the resistance but also changes the dynamic behaviour of the wall, which is consistent with the findings from the comparison of the 3D dynamic method and the equivalent U-value method.

with the aerogel blanket thermal bridge correction.

It was observed that the annual heating and cooling energy increased in the model with the thermal bridges in the building. From the study, concrete buildings saw up to a 32 per cent increment, whereas steel buildings saw up to a 35 per cent increment when thermal bridges were accounted to the model. This was expected, as the thermal bridges increase the amount of heat loss, thereby increasing the energy demand of the building.

The use of an aerogel-enhanced blanket in the steel and concrete building significantly reduced the amount of space heating energy. Figure 2 (on page 18) shows the improvement that can be achieved annually per square-metre of the conditioned area for concrete and steel buildings, respectively, for Toronto's climate.

The equivalent U-value method underestimates the space heating load and overestimates the cooling load, which is similar to the previous studies.[1,6] Figure 3 (on page 19) illustrates the comparison in percentage difference of the energy demand calculated using the equivalent U-value method and the 3D dynamic method for concrete and steel buildings, respectively.

The difference of heating load between the 3D dynamic method and the equivalent U-value method was found to be 21 per cent in the concrete building and 22 per cent in the steel building. The cooling load difference was found to be one per cent in the concrete building and six per cent in the steel building. With the use of an aerogel-enhanced blanket to correct the thermal bridges, the discrepancy in annual heating load decreases. It was found that the difference between the 3D dynamic and the equivalent U-value method is reduced by between nine per cent and four per cent, respectively, for the concrete building and steel building. The discrepancy in annual cooling load between the 3D dynamic and equivalent U-value method seems higher, as the annual cooling load is comparatively much less than the annual heating load. The reduction of the discrepancy is due to the improvement of the thermal bridges. As a result, it also reduces the thermal inertia effect in the building.

From the literature studies, the thermal inertial effect not only changes the resistance but also changes the dynamic behaviour of the wall, which is consistent with the findings from the comparison of the 3D dynamic method and equivalent U-value method. The decrease in difference suggests the equivalent U-value method can also give accurate results if the details are improved. The improved details not only save the energy demand but also avoid the complex and time-consuming 3D dynamic method.

In this research, the aerogel-enhanced blanket of 10 millimetres / 20 millimetres was proven to improve the construction details in two different building models. A significant reduction of the heating load was observed with the application of an aerogel-enhanced blanket in the building. This study shows that the aerogel-enhanced blanket can provide a better opportunity for the thermal bridging correction, as it lowers the building heating by six to eight per cent in the concrete construction and by 11 to 18 per cent in the steel construction. This shows that an aerogel-enhanced blanket with a thickness of 10 millimetres / 20 millimetres can be used as a thermal break in both new and retrofit buildings. A higher improvement can be achieved with an increased thickness. Due to high thermal performance, low density, weight, and thickness of an aerogel enhanced blanket, it can be applied in air spaces and areas with both space and weight constraints.

The two different modeling approaches in the building suggest the equivalent U-value underestimates the heating energy and overestimates the cooling load. The 3D dynamic method is more accurate than the equivalent U-value method for proper calculation of the energy demand. The difference between the 3D dynamic method and the equivalent U-value method decreases when the details are improved with the aerogel-enhanced blanket, as the dynamic effect of the thermal bridging will be reduced. Nonetheless, for standard details, the 3D dynamic method is required for the most accurate results, but if details are improved, the equivalent U-value method can also predict an accurate energy demand. ■

Rashmi Sharma, B.Arch., CPHC, has an undergraduate degree in architecture from Tribhuwan University and a master's degree in building science from Ryerson University. In addition, Sharma is a certified Passive House consultant. For extended results from this study, please contact the authors.

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