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THERMAL TRANSMITTANCE REDUCTION THROUGH EXPOSED BALCONY SLABS

T. T. ZHANG, P. MUKHOPADHYAYA [a]

University of Victoria, British Columbia, Canada
[a] E-mail: phalguni@uvic.ca

Thermal bridging caused by exposed concrete balcony slab is a major source of heat loss through energy efficient building envelopes. Moreover, thermal bridging can also create moisture management and indoor comfort challenges. Numerous investigations have been carried out to reduce heat transmittance through exterior building envelopes and minimize the energy use in buildings. The most effective way to minimize heat transmittance of exposed concrete balcony slabs is to thermally separate the exterior structure from the interior structure using thermal breaks. To enhance thermal separation, this paper investigates the effects of replacing high conductive materials such as reinforced concrete or structural steel with a multilayer composition of high-performance hybrid insulating systems. Reinforcing bars, such as fiber reinforced plastics (FRPs), having lower thermal conductivity than steel are used to connect interior to exterior and transfer loads. Numerical simulation tool THERM is used to study the effects of thermal breaks on energy performance of the concrete slab balcony joints. Simulation results indicate significant thermal performance improvement while high-performance hybrid insulating systems were used for exposed concrete balcony slab constructions, compared to traditional insulating systems used in similar constructions

Keywords: *thermal break, vacuum insulation panels, cocncrete balcony, THERM, numerical simulation*

1. Introduction

In Canadian residential buildings, energy consumption due to heating and cooling accounts for more than 60% of the total energy use (Natural Resources Canada, 2013). Optimization of every element of building envelope should be investigated to improve whole building thermal performance and therefore reduce energy consumption, increase indoor comfort, and reduce risks of condensation and mold growth due to low interior temperature.

Balcony is one of the critical elements in building envelope that leads to undesired heat loss. Concrete balcony slabs create a discontinuity in building envelope insulation, offer a less resistant path for heat flow, and result in a multidimensional heat flow phenomenon called thermal bridging. Next to windows and doors, exposed concrete balcony slabs are the second-largest source of thermal bridging in building envelope (Finch et al., 2014). They can reduce the *R* value of a typical building code compliant wall in Canada (between R10–R20) to 42% – 62% (Finch et al., 2014).

One effective method to minimize thermal bridging in balcony slabs is the use of a thermal break to interrupt the heat flow path. A thermal break is comprised of insulation material placed between interior slab and balcony slab, and low thermal conductance reinforcement bars connecting the two floor slabs to maintain its structural integrity (Totten et al., 2008). A more recent study found that the inclusion of thermal break in balcony increases the interior floor slab surface temperature by about 3.5 °C – 6.4 °C, depending on the geometry and thermal resistance of the adjacent assemblies (Ge et al., 2013). Furthermore, another study evaluated the thermal and cost-effectiveness of four concrete balcony and slab edge thermal break solutions: i) structural slab cut-outs with beam reinforcement, ii) concentrated slab reinforcement with insulation inserts, iii) full and partial balcony slab insulation wraps, and iv) manufactured purpose-built concrete slab thermal breaks (RDH Building Engineering Ltd., 2014). The results from this study show that the manufactured purpose-built concrete slab thermal break has significant advantages over the other three options. The commercially available thermal break evaluated in RDH's report is comprised of expanded polystyrene (EPS) foam and stainless steel rebar, and the product manual reported that this type of thermal break could increase the overall thermal resistance or *R* value of the exterior wall at a standard balcony junction from R-6.9 to R-9.4 (Morrison Hershfield, 2014).

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In recent years the global focus on energy efficiency of buildings has intensified the search for high performance thermal insulation for building envelope applications. At the moment, there are commercially available new insulation materials that can achieve higher thermal performance and can be used to substitute traditional insulation materials used in building applications. Vacuum insulation panel (VIP) is thermal insulation that is made of open porous core enclosed by an air and vapour tight barrier as shown in Fig. 1. The core has open pore structure, from which air has been evacuated. Compared to traditional insulation materials, VIP further reduces the heat loss by eliminating heat transfer through air and vapour molecules. It is a new and promising insulating material in building applications, and the thermal conductivity of VIP can be between 0.002–0.008 W/m·K (i.e. up to 10 times higher thermal resistance than traditional thermal insulation), depending on specific core and envelope material used, manufacturing process and the stage of its service life (Kalnæs and Jelle, 2014).

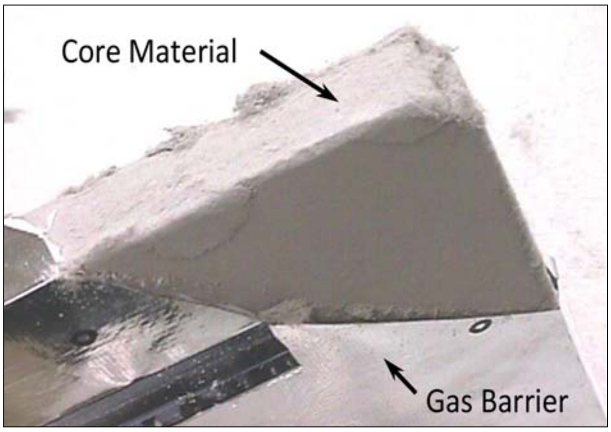

Fig. 1. Components of VIP

The study reported in this paper examined the thermal performance of a commercially available thermal break for concrete balcony using numerical simulation software THERM. Furthermore, the study investigated the thermal performance of a thermal break comprised of hybrid insulating materials, namely, expanded polystyrene (EPS) foam and vacuum insulation panel (VIP). In addition, this research also conducted parametric studies involving parameters such as thermal conductivity of reinforcement material, thickness of the insulation, configurations of the hybrid insulation materials and exterior temperature. The aim of this paper is to identify critical parameters in the performance of a thermal break, and evaluate the potential improvement on thermal performance through a novel design that is comprised of hybrid materials.

2. Methodology

The numerical analysis was carried out by THERM, a finite element analysis software developed at Lawrence Berkeley National Laboratory (LBNL) for modelling two-dimensional heat transfer (LBNL, 2013).

Two balcony–wall junctions with and without the commercial thermal break were modelled and simulated using THERM, and the temperatures at the ceiling–wall junction were recorded for both scenarios. The schematic of balcony–wall junction model and the location of thermal break are shown in Fig. 2.

The exterior temperature set for simulation is –18 °C and the convective film coefficient is 26 W/m^2·K, the interior temperature is 21 °C and the convective film coefficient is 3.12 W/m^2·K, as per National Fenestration Rating Council simulation standard (LBNL, 2013).

The thermal properties of the materials are listed in Table 1.

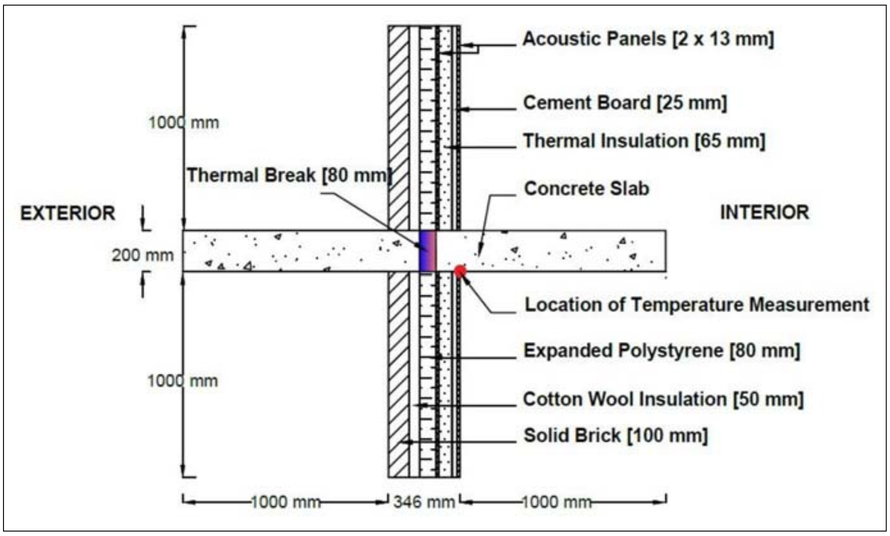

Fig. 2. THERM model of wall configuration with the location of thermal break and temperature measurement

Table 1. Thermal properties of the junction materials

Material	Thermal conductivity (W/m·K)	Emissivity
Solid brick	0.700	0.85
Cotton wool insulation	0.025	0.70
Expanded polystyrene foam	0.033	0.97
Acoustic panel	0.580	0.96
Other thermal insulation	0.040	0.80
Cement board	0.025	0.96
Concrete slab	2.200	0.54
Commercially available thermal break	0.190	0.90

The temperature increase at the ceiling–wall junction (see the location of temperature measurement in Fig. 2) was used to quantify the heat gain due to the presence of thermal break.

2.1. Simplified model development and baseline thermal performance establishment

The commercially available thermal break consists of expanded polystyrene (EPS) foam, stainless steel tension and shear bars, and compression modules (Schöck Design Department, 2015). Due to the irregular shapes and locations of rebar and compression modules, a simplified cross-section model was developed for this study. As shown in Fig. 3, the simplified model comprises of rigid EPS foam and stainless steel reinforcement section only. The thermal conductivity of EPS foam was 0.031 W/m·K, as indicated in the product technical manual (Schöck Design Department, 2015), and the thermal conductivity of the reinforcement section was determined to be 3.9 W/m·K by trial and error using THERM and based on the overall thermal performance indicated in the product technical manual.

2.2. Parametric studies

2.2.1. Simplified thermal break model

The two components in the simplified model (Fig. 3) are expanded polystyrene foam (EPS) and stainless steel reinforcement section. Parametric studies on both materials were carried out to determine the impact of each part on the overall thermal performance.

The first parameter studied was the thickness of EPS. Five different thicknesses were considered: 80 mm (3.145 inch) to 25 mm (1 inch), 38 mm (1.5 inch), 50 mm (2 inch), and 63 mm (2.5 inch). Alignment at the inner end of thermal break was fixed, and the balcony slab was extended accordingly in these models.

Then, the thermal conductivity of the reinforcement section was set from 0.05 W/m·K to 6.0 W/m·K, with an increment of 0.5 W/m·K, and the temperature was measured for each value correspondingly.

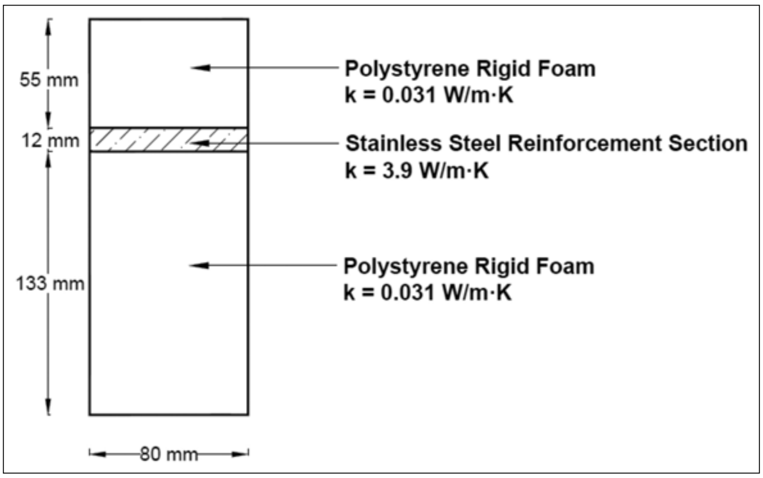

Fig. 3. Schematic of simplified commercially available thermal break model

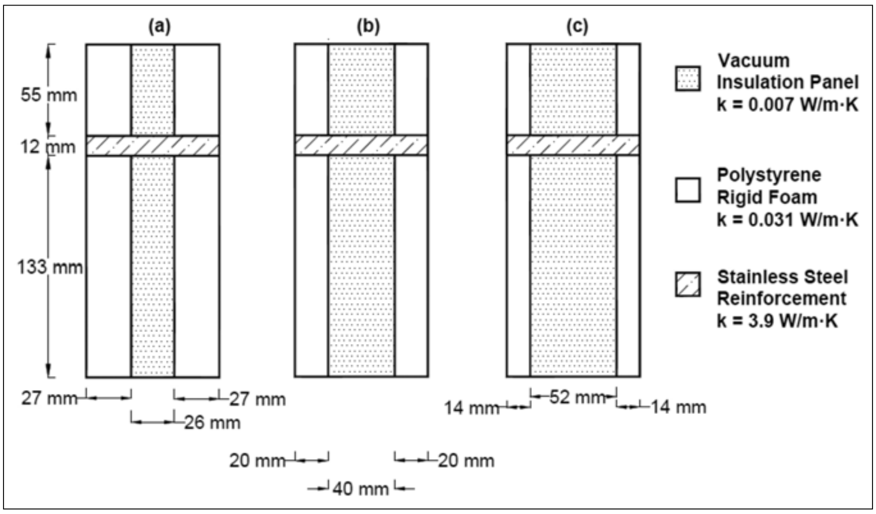

Fig. 4. Schematics of hybrid thermal break model (a), (b) and (c)

2.2.2. Hybrid thermal break model

Three configurations of a hybrid thermal break consisting of EPS and VIP were simulated using THERM, as shown in Fig. 4. The center of EPS was replaced by VIP of three different thicknesses. The thermal conductivity and emissivity of VIP used in the simulations was 0.007 W/m·K and 0.05, respectively, while the thermal properties of other materials and boundary conditions remained the same.

In addition, the simulations of model (a) in Fig. 4 were carried out with thermal conductivities of VIP varying from 0.001 to 0.008 W/m·K to evaluate the effect of thermal properties of insulation material on the thermal break performance.

Furthermore, stainless steel reinforcement in hybrid model (a) in Fig. 4 was replaced with low thermal conductance reinforcement bar (such as fiber reinforced plastic or FRP). The thermal conductivity of the reinforcement section was set to 0.5–3.5 W/m·K, with an increment of 0.5 W/m·K. The simulations were performed to investigate the combined effect of low thermal conductance materials (e.g. VIP insulation and FRP rebar).

2.2.3. Exterior temperature

The last parametric study was conducted on exterior temperature to which the balcony slab and exterior wall would be exposed. The exterior temperature was set from –40 °C to –60 °C, with an increment of –10 °C, while the interior temperature and film coefficients remained unchanged. An optimized VIP model was developed from the hybrid model (a) in Fig. 4, by assigning the thermal conductivity of 0.5 W/m·K to the reinforcement section.

Five balcony junction configurations were simulated using THERM. Scenarios include: i) without thermal break, ii) with the simplified commercially available thermal break model, iii) with the hybrid model (a), iv) with simplified commercially available thermal break with low conductance reinforcement section, and v) with the optimized VIP model. These scenarios were simulated in standard and extreme temperatures.

Table 2. Resulting temperatures at the ceiling–wall junction for scenarios without and with thermal break subject to exterior temperatures of –18 °C, –40 °C, –50 °C and –60 °C

Exterior temperature (°C)	Ceiling–wall junction temperature (°C)				
	Without thermal break	With thermal break			
		Simplified commercially available model	Hybrid model (a)	Commercially available model with low conductance reinforcement section	Optimized VIP model (EPS replaced by VIP and steel rebar replaced by FRP)
–18	10.1	16.3	16.5	18.6	18.9
–40	3.80	13.6	13.9	17.3	17.7
–50	0.90	12.4	12.8	17.2	17.2
–60	–2.00	11.2	11.6	16.0	16.7

3. Results and discussion

Temperature measured at the ceiling–wall junction with the commercially available thermal break is 16.3 °C, and is 10.1 °C without thermal break (Table 2).

The primary variables which define the thermal performance of a thermal break are the thickness and thermal conductivity of insulation material, and the thermal conductivity of reinforcement bar. Figure 5 shows that the temperature at the ceiling–wall junction increases linearly as the thermal conductivity of the reinforcement section decreases. Similarly, the temperature increases linearly as the thickness of insulation material increases. This can be seen both in the test results of parametric study involving EPS, presented in Fig. 6, and high performance insulation material (i.e. VIP that replaced EPS in the hybrid models) shown in Table 3. Table 4 shows the temperature at the ceiling–wall junction only decreased by 0.2 °C as the thermal conductivity of VIP increased from 0.001 W/m·K to 0.008 W/m·K.

From these results, it can be concluded that the thermal performance of a thermal break is more

Table 3. The effect of VIP thickness in a hybrid thermal break model on temperatures at the ceiling–wall junction

Configuration of hybrid model	Ceiling–wall junction temperature (°C)
(a) 27 mm EPS – 26 mm VIP – 27 mm EPS	16.5
(b) 20 mm EPS – 40 mm VIP – 20 mm EPS	16.5
(c) 14 mm EPS – 52 mm VIP – 14 mm EPS	16.6

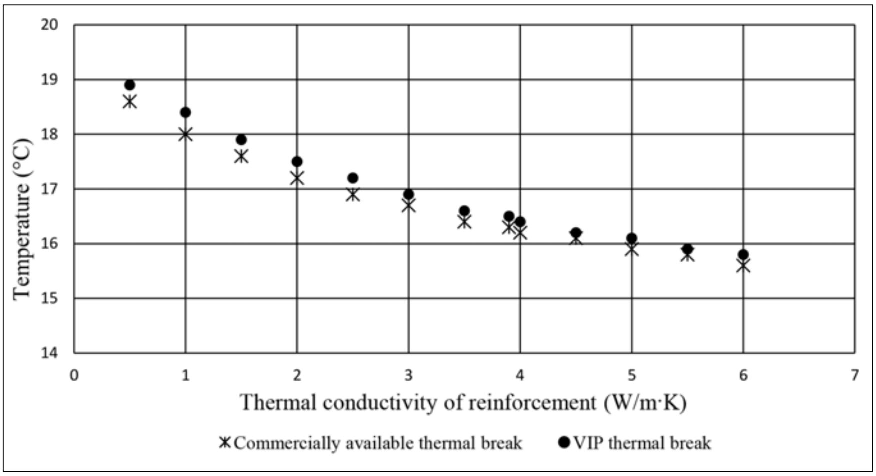

Fig. 5. Comparison of thermal effectiveness of various reinforcement bar conductivity in commercially available and hybrid thermal break

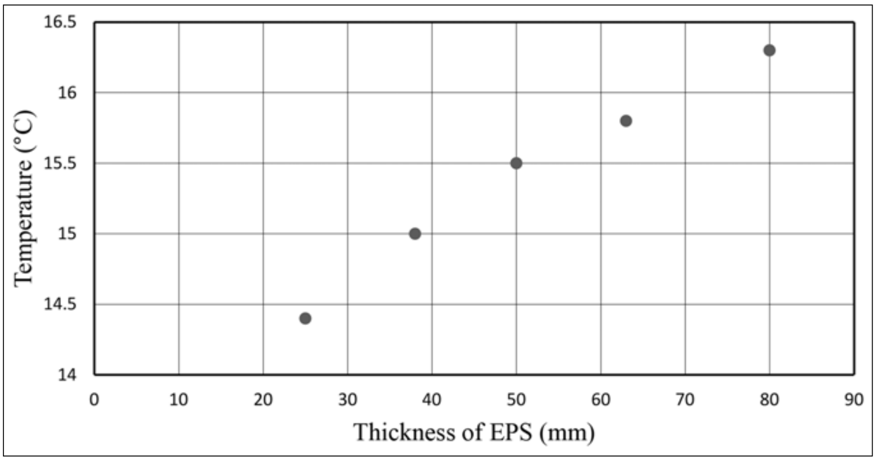

Fig. 6. The effect of the thickness of EPS thermal break on temperatures at the ceiling–wall junction

Table 4. The effect of VIP thermal conductivity in a hybrid thermal break model on temperatures at the ceiling–wall junction

Thermal conductivity of VIP (W/m·K)	Ceiling–wall junction temperature (°C)
0.001	16.6
0.002	16.6
0.003	16.6
0.004	16.6
0.005	16.5
0.006	16.5
0.007	16.5
0.008	16.4

FRP thermal break further increases the temperature by about 0.3 °C – 0.7 °C.

The effective thermal conductivities and *R* values of the aforementioned four thermal breaks were determined by trial and error using THERM and are summarized in Table 5 below.

4. Conclusions

The potential effects of thermal breaks, for balconies, constructed with high performance insulation material (i.e. vacuum insulation panel or VIP) and low conductance reinforcement bar (i.e. fiber reinforced plastic or FRP), on heat loss were investigated and quantified. Using low conductance reinforcement bar in thermal break has shown an increase of 2.3 °C – 4.8 °C in temperature at the ceiling–wall junction. Thermal break that replaces traditional EPS insulation material with VIP did not show very promising improvement, but the thermal break model that utilizes both VIP and low conductance reinforcement further increased the temperature by about 0.3 °C – 0.7 °C.

Table 5. Summary of thermal properties of four thermal breaks studied

	Insulation material		Thermal break	
	Thermal conductivity (W/m·K)	*R* value (ft^2·F·h/Btu)	Thermal conductivity (W/m·K)	*R* value (ft^2·F·h/Btu)
Simplified commercially available model	0.031	14.65	0.190	2.39
Hybrid model (a)	0.023	19.58	0.175	2.60
Commercially available model with low conductance reinforcement section	0.031	14.65	0.060	7.57
Optimized VIP model	0.023	19.58	0.045	10.10

dependent on the thermal properties of the reinforcement bar than the insulation material. To achieve the best results, the thermal break needs to be at least 80 mm (3.15 inch) of EPS insulation or equivalent, and a decrease in insulation material thickness will decrease the effectiveness of the thermal break. Moreover, the hybrid models that replaced EPS with VIP only increased the ceiling–wall junction temperature by 0.2 °C – 0.4 °C. Hence, at this point, it is not evident that replacing EPS with VIP alone is a significantly more effective design strategy due to the thermal bridging at the reinforcement section.

Table 2 shows the resulting ceiling–wall junction temperatures with four different thermal improvement products (i.e., i) simplified commercially available model, ii) hybrid, iii) commercially available model with low conductance reinforcement bar (i.e. FRP), (iv) optimized VIP) subjected to exterior temperatures of –18 °C, –40 °C, –50 °C, and –60 °C. Scenarios with thermal breaks improve the thermal performance at the junction by resulting in higher temperatures at ceiling–wall junctions. The improved commercially available thermal break (using low conductance FRP reinforcement) increases the temperature at the ceiling–wall junction by 2.3 °C – 4.8 °C, compared to commercially available product. The optimized VIP +

Overall, this study shows that thermal breaks significantly increase the interior temperature at the concrete balcony junction and reduces the condensation potential during the winter. However, further research on the constructability of thermal breaks with high performance insulation material and low conductance reinforcement bar should be carried out.

Acknowledgement

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