Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 118 (2015) 1030 – 1037

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Impact of Insulated Concrete Curb on Concrete Balcony Slab

Chafik Murad*, Hitesh Doshi, and Ramani Ramakrishnan

Department of Architectral Science, Ryerson University, 350 Victoria treet, Toronto, Ontario M5B 2K3, Canada

Abstract

Cantilevered concrete balcony slab in high-rise residential buildings that create a thermal bridge is under scrutiny due to an increasing demand for energy efficient and thermally comfortable occupied spaces. In North America balcony slabs with thermal breaks are uncommon among the current residential stock. The investigation reported in this article focussed on the impact of an alternate slab design with a concrete curb that was successfully used in the past. The alternate design consisted of using an insulated concrete curb at the sliding balcony door. The thermal performance of this design was carried out using THERM. Comparison of the simulation results of the alternate design were done with simulation results using non-thermally broken conventional slab, and thermally broken slab with proprietary details. The results showed that measurable increase in surface temperatures are possible with the insulated curb design. The results of the current investigation provided a framework for practical procedure that can be incorporated for cantilevered concrete slabs for better energy efficiency and thermal comfort as compared to conventional construction practices and as an alternate to thermally broken slab design.

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015

Keywords: *THERM Simulation; Thermal Comfort; High-Rise Multi-Unit Residential Buildings; Cantilevered concrete balcony slab; Thermal Break; Balcony Thermal Performance*

* Corresponding author at: Tarion Warranty Corporation, 5160 Yonge Street, 12th Floor, Toronto, Ontario M2N 6L9, CANADA.
Tel.: +1 877 982 7466 x2167
E-mail address: chuck.murad@tarion.com (C.Murad).

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015
doi:10.1016/j.proeng.2015.08.545

1. Introduction

Many older buildings in Ontario, constructed prior to 1980s, have exposed concrete slabs at the floor level, providing an easy avenue for thermal bridging. Newer buildings avoided thermal bridging by the use of curtain wall or a window-wall type construction. However, thermal bridging at balconies could still not be avoided with this approach. The simplest architectural solution, to avoid thermal bridges at balconies, would be to enclose them. But unenclosed balconies were still considered as very desirable feature by potential purchasers. The growing need for energy efficiency in buildings would pressure the design and construction community to examine the role of balconies. One of the design solutions, in improving thermal efficiency, was to provide various types of thermal breaks in the protruding concrete slab at the balcony. The design options have resulted in proprietary and non-proprietary thermal break technologies. Studies have demonstrated that using a thermal break improves the energy performance of the buildings. However there is anecdotal evidence that in North America there is still some reluctance in adopting the use of such thermal breaks due to its cost.

The focus of current practices has been on the introduction of thermal breaks in the concrete balcony slab and its effect on energy consumption [1, 2]. The thermal performance of the window-wall assembly was largely unaffected by the thermal break introduction but has direct impact on performance related issues such as condensation potential and thermal comfort [2]. Roppel and Norris investigated and analyzed an important construction detail of a sliding door supported directly on an insulated raised concrete curb that has achieved significant results in terms of a lower overall U-value and higher surface temperature without using a thermal break in the concrete slab [3]. It appears that this construction detail is no longer used by designers in concrete balcony slabs of high-rise Multi-Unit Residential Buildings (MURBs).

The current study investigated the thermal performance of concrete balcony thermal bridge condition with modifications to the thermal performance of adjacent wall assemblies. Its focus has been the impact of improvements in the thermal characteristics of the frame of the envelope at the thermal bridge location. The MURB industry may not readily accept a higher level of envelope with its additional costs as an alternative; however, the current study seeks to study the level of impact provided by alternate designs.

The focus of this research project is to study the thermal performance of lower U-value envelope conditions at the thermal bridge location. Cost issues are important but are not part of the scope of this work. As part of the study the construction assembly of the proposed alternatives were developed and modeled in THERM [4]. The results of THERM for the alternative construction assemblies were then compared to the results from previous studies particularly as they related to the comfort and condensation potential.

2. Description of the Simulated Assembly

A balcony typically involves a concrete floor slab which projects to the exterior through a wall assembly which consists of a sliding door assembly. The projecting concrete slab acts as a thermal bridge across the vertical wall assembly. The current study investigated the use of an insulated curb detail located just below the sliding door. The study also used a low U-value framed glazing system and/or spandrel panel. The new detail, as shown in Figure 1, consisted of 12.5 mm depression (curb) in the concrete balcony slab right beneath the sliding door/spandrel panel frame. The depression was filled with a 25.4 mm thick Extruded Expanded Polystyrene (EPS) rigid insulation.

The above detail eliminated any water or moisture ingress into the interior space through balcony sliding door sill and would keep the bottom sill frame and the adjacent interior vicinity of concrete surface warm during winter months. The detail would also create the a flat construction detail with horizontal insulation, similar to the vertically insulated raised concrete curb, but would avoid the potential of tripping hazard because of the raised curb.

A proprietary thermal break was used in the simulation scenarios for comparison purposes.

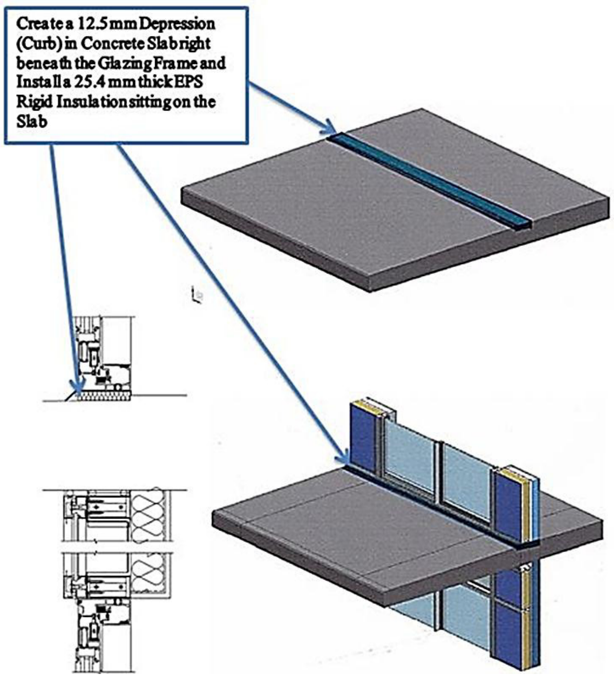

Fig. 1. Schematic details of a proposed concrete slab modification with a curb

Thermal analyses were conducted for the two details described above for different scenarios using THERM. The different scenarios are described next.

2.1. Design Details

The sectional details of the concrete curb are shown in Figure 2. Curb thickness could have been greater than 12.7 mm. However, the larger thickness requires maintaining the concrete cover of tension bars and structural integrity of the cantilevered slab.

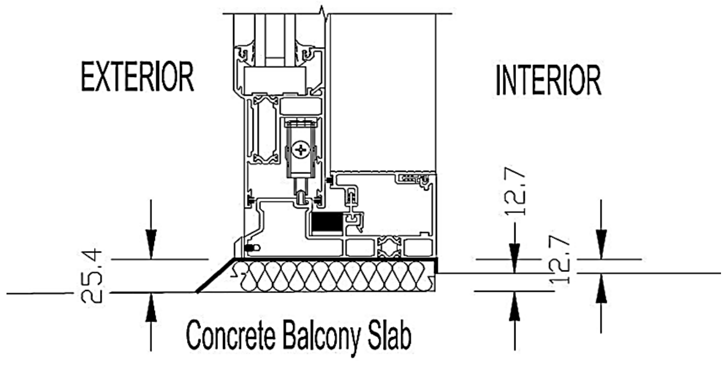

Fig. 2. Sectional details of the concrete slab modification with a curb

A few of the scenarios have incorporated a proprietary thermal break [5], certain dimensions must adhere to the manufacturer requirements in terms of height, thickness and placement of thermal break, cantilever maximum length, and concrete cover for tension bars. These details were adhered to as shown in Figure 3.

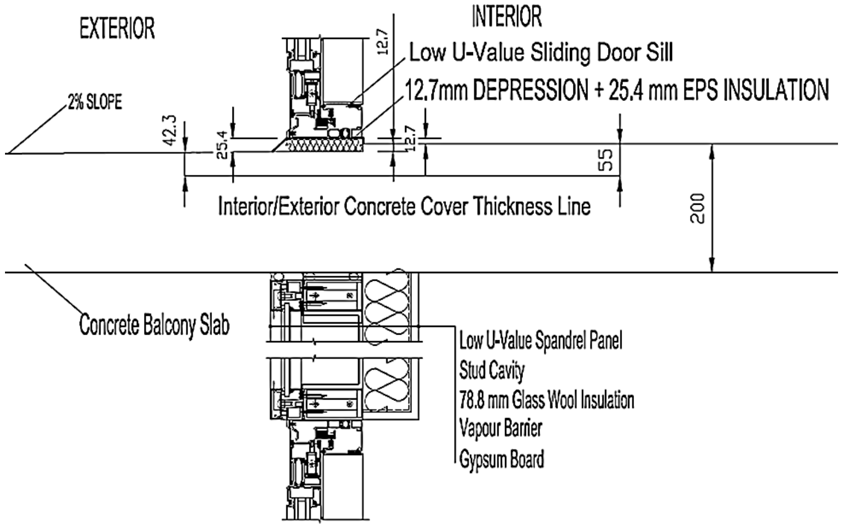

Fig. 3. Cross Section of the model showing a Lower U-value framed glazing system Sliding door above/Spandrel Panel below

The total thickness of the concrete slab is 200 mm and the concrete cover for tension bars, from exterior, is 55 mm and from interior is 40 mm to accommodate the 2% slope of the cantilevered concrete balcony slab. In the case of a 12.7 mm depression in the concrete, the remaining concrete cover is 42.3 mm which is above 40 mm, and hence, the concrete cover conditions are met.

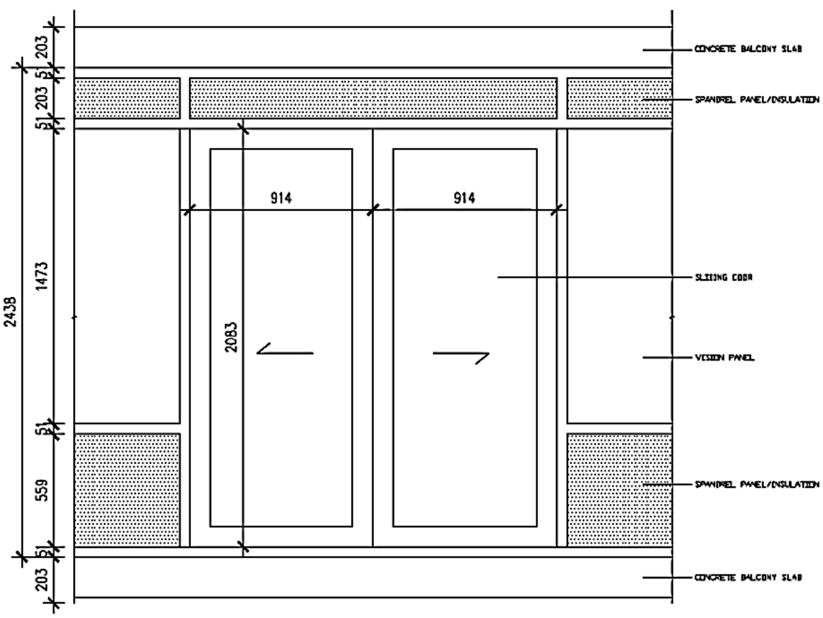

Fig. 4. Plan view of standard height floor-to-ceiling window-wall glazing system

Overall details of a door-balcony system are shown in Figure 4. The glazed façade is a 2438 mm standard height floor-to-ceiling system, typically used in high-rise condominium balcony. Sliding door glazing used is a 25.4 mm total thickness (2x6 mm glass and 12.7 mm spacer) double glazed unit (DGU) with Argon gas-filling and low-e coating with a Centre-Of-Glass (COG) U-value of 1.324 W/m^2.K. Spandrel panel used is of an R-value of 2.645 m^2.K/ W, or an equivalent U-value of 0.378 W/ m^2.K.

2.2. Simulation scenarios

Various scenarios were analysed to evaluate the thermal performance of the concrete slab. The eight scenarios were grouped into two: All scenarios of Group 1 were modelled with low U-value framed spandrel panel sill and head above and below balcony slab with an equivalent U-value of 0.378 W/m^2.K. Group 2 scenarios were modelled with low U-value framed sliding door sill with a U-value used of 1.324 W/m^2.K above balcony slab and a low U-value spandrel panel head below balcony slab an equivalent U-value of 0.378 W/m^2.K. The eight scenarios are listed in Tables 1a and 1b.

Table 1a. The four scenarios of Group 1.

Scenario Number	Scenario Type	Curb Condition	Glazing Type	Glazing U-Value, W/m^2.K
1	Conventional	-NA-	Spandrel above and below	0.378
2	Insulated Curb condition	12.7 mm curb with 25.4 mm EPS insulation only	Spandrel above and below	0.378
3	Conventional	Proprietary Thermal Break only	Spandrel above and below	0.378
4	Insulated Curb condition	12.7 mm curb with 25.4 mm EPS insulation and Proprietary Thermal Break	Spandrel above and below	0.378

Table 1b. The four scenarios of Group 2. (Above means on topside of the slab and below means underside of the slab)

Scenario Number	Scenario Type	Curb Condition	Glazing Type		Glazing U-Value, W/m^2.K
5	Conventional	-NA-	above	Sliding door	1.324
			below	Spandrel	0.378
6	Insulated Curb condition	12.7 mm curb with 25.4 mm EPS insulation only	above	Sliding door	1.324
			below	Spandrel	0.378
7	Conventional	Proprietary Thermal Break only	above	Sliding door	1.324
			below	Spandrel	0.378
8	Insulated Curb condition	12.7 mm curb with 25.4 mm EPS insulation and Proprietary Thermal Break	above	Sliding door	1.324
			below	Spandrel	0.378

It should be noted that the stud cavity for all scenarios was left open with no insulation. However, for comparison purposes, each scenario was remodelled by installing a 78.8 mm (3.1 inches) of glass wool insulation in the frame cavity with an equivalent U-value of 0.481 W/m^2.K and a thermal conductivity of 0.0380 W/m.k.

All scenarios had shared the low U-value framed glazing system. The boundary conditions chosen are applicable to an extreme winter scenario in the Canadian environment. Exterior and interior boundary conditions were used for Toronto's cold climate conditions which are close to the values given in ASHRAE 2009 Handbook-Fundamentals [6]. Exterior boundary conditions are -18° C, and R.H. of 50%. The surface film coefficient is ho=26.00 W/m^2.K. Interior boundary conditions are 21° C, and R.H. of 30%. The surface film coefficient is hi=8.3 W/m^2.K.

The vertical face of the slab on the interior was specified as an adiabatic surface. Dew point for interior boundary conditions is 3° C.

Each section was modelled with a balcony slab length of 1.95 m on the exterior and the floor slab was continued for 0.65 m on the inside of the wall assemblies. The thickness of the concrete slab is 200 mm with 55 mm concrete cover over the reinforcement bars from interior and 42.3 mm from exterior due to 2% slope towards the outer edge of the cantilevered concrete balcony slab. For the scenarios/models that incorporated the proprietary thermal break, an equivalent thermal conductivity keq-value of 0.194 W/m.k was used. Materials used in the proposed scenarios are as per technical details provided by manufacturer for the low U-value framed glazing system and proprietary thermal break. Specific material properties are consistent between all scenarios.

3. Results and discussion

The interior surface temperatures at slab/frame intersection above and below slab were evaluated to highlight the improvement of the thermal performance of the insulated curb condition. Dew-point of 3° C and R.H. of 30% with 21°C interior temperature are the interior boundary conditions used to verify potential risk of condensation.

Figure 5 shows temperature profiles for the eight scenarios. The point at which the interior slab temperature reaches 20º C is also highlighted in Figure 5.

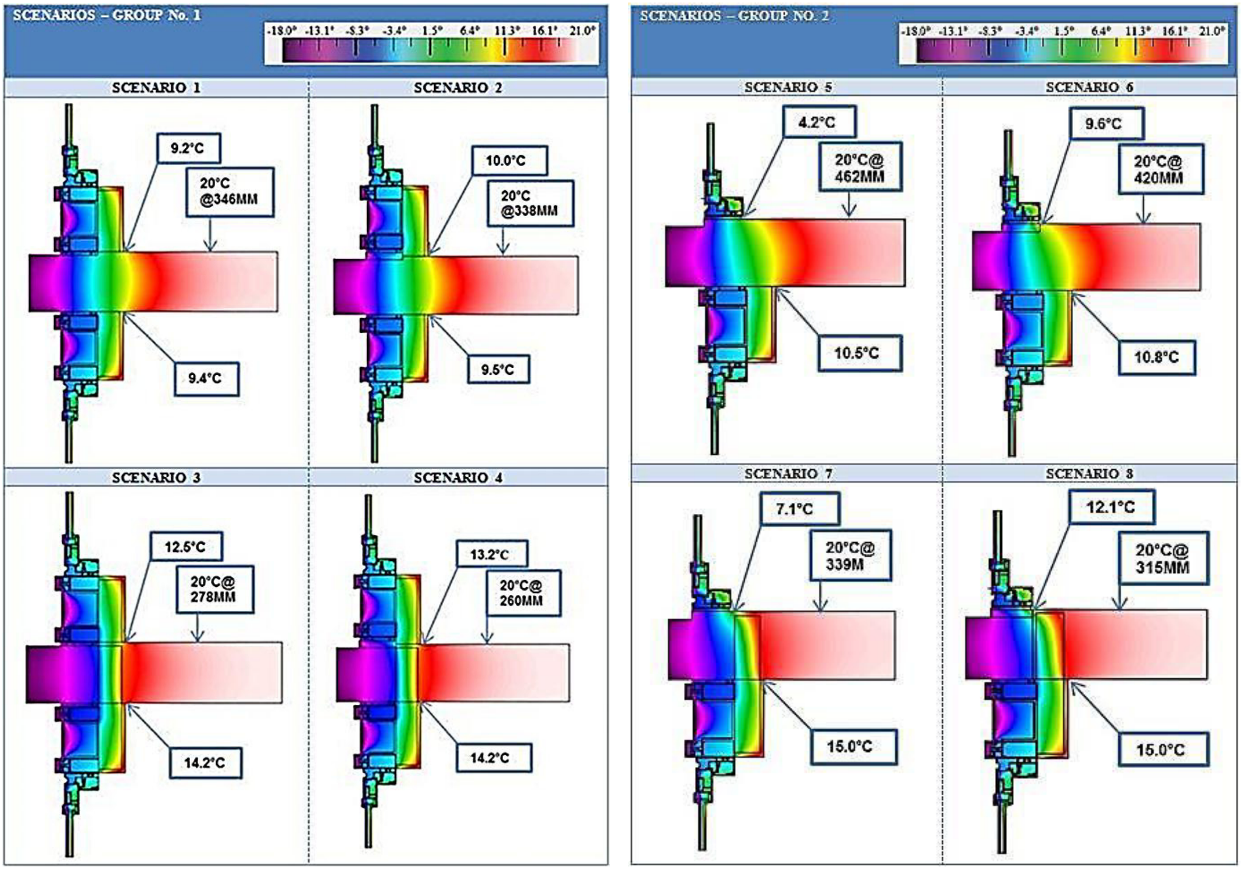

Fig. 5. Interior surface temperature of each scenario.

A summary of the results for the eight scenarios are presented in Table 2. The interior concrete slab surface temperatures for each scenario at the slab/frame intersection above and below slab as well as the length of the interior concrete surface that reaches 20° C were highlighted in Table 2. The results of Table 2 also included scenarios where the stud cavity was filled with glass wool insulation.

Table 2: Interior surface slab temperatures for the eight scenarios.

Scenario	Above Balcony	Below Balcony	Length Until 20° C	With Cavity Insulation	
				Above	Below
1	9.2° C	9.4° C	346 mm	9.6° C	9.7° C
2	10.0 ° C	9.5° C	338 mm	10.5° C	10.2° C
3	12.5 ° C	14.2° C	278 mm	13.7° C	15.8° C
4	13.2 ° C	14.2° C	260 mm	14.4° C	16.0° C
5	4.2 ° C	10.5° C	462 mm	4.8° C	11.3° C
6	9.6 ° C	10.8° C	420 mm	9.5° C	11.6° C
7	7.1 ° C	15.0° C	339 mm	7.0° C	16.7° C
8	12.1 ° C	15.0° C	315 mm	11.0° C	16.7° C

The results showed a significant increase in interior surface temperature from 4.2° C to 9.6° C for Scenarios 5 and 6 respectively, when the insulated curb condition was incorporated. The interior slab length when 20° C was reached decreased by 42 mm when the insulated curb was introduced. Similar significant increase was seen from 7.1° C to 12.1° C for Scenarios 7 and 8 when the insulated curb condition was incorporated in addition to the proprietary thermal break as well as a decrease of 24 mm in length until 20° C.

It can be surmised from Table 2 results that adding 77.8 mm of glass wool insulation in the stud cavity had no appreciable change in the thermal performance.

A review of the isotherm lines of each scenario showed that the dew point of 3° C was found within the low U-value framed glazing system (sliding door section and spandrel panel section), inside the concrete slab and in the stud cavity. Hence, the risk of surface condensation is mitigated for the modeled scenarios.

Finally, the current results were compared with the results of Ge et. al. [1] evaluated the thermal performance of concrete slab with thermal breaks with 2D THERM simulations. The boundary conditions used by Reference 1 were similar to the current study. The exterior boundary conditions were specified as -18° C and *ho* of 30 W/m^2.K and the interior boundary conditions were specified as 22° C and *hi* of 8.3 W/m^2.K as per CSA A440.2 [7]. The interior surface temperatures were measured at slab/frame intersections above and below balcony slab and even measured the length of concrete surface temperature until it reached 20° C. The results of Reference 1 are presented in Table 3 below.

Table 3: Interior Surface Temperatures for Scenarios III and IV [1].

Scenario	Reference 1 #	Balcony Slab Scenario		Below Balcony	Above Balcony	
				Temperature	Temperature	Length
1	III	Above: Clear DGU-RSI 0.35 (U=2.86 W/m^2.K) Below: Spandrel RSI 2.50 (U=0.4 W/m^2.K)	No Break	6.7° C	6.2° C	390 mm
2	III		Break	16.2° C	11.5° C	280 mm
3	IV	Above: Clear DGU-RSI 0.73 (U=1.369 W/m^2.K) Below: Spandrel RSI 2.50 (U=0.4 W/m^2.K	No Break	6.7° C	6.3° C	390 mm
4	1V		Break	16.3° C	12.3° C	280 mm

Interior surface temperatures above and below balcony slab, with and without a proprietary thermal break were presented in Table 3 above. Scenario III was a hypothetical section with generic solid material to imitate a clear DGU with a U value of 2.86 W/m^2.K and spandrel panel with a U value of 0.4 W/m^2.K below balcony slab. Scenario IV was a hypothetical section with generic solid material to imitate a clear DGU with Argon gas filling and low-e-coating above with a U value of 1.369 W/m^2.K and a spandrel panel with a U value of 0.4 W/m^2.K below the balcony slab [1].

The data presented in Table 3 showed the worst case in terms of interior concrete surface temperatures were in scenario III and IV (no thermal break) where interior concrete surface temperature was 6.2° C and 6.3° C respectively above slab.

When comparing the results of Reference 1 with the interior surface temperatures presented in Table 2 for Scenarios 2 and 6 with the insulated curb condition solution, the interior surface temperatures above slab tended to increase from 6.2° C and 6.3° C to 10.0° C and 9.6° C respectively. Similarly, the temperatures below the slab from 6.7° C to 9.5° C and 10.8° C respectively, which is significant. Also, the length measured until the interior surface temperature reaches 20° C for Scenario III and Scenario 2 decreased by 52 mm (390 – 338).

4. Conclusions

The thermal performance of incorporating an insulated curb condition was investigated in the current study. Eight different scenarios, including the use of proprietary thermal break were evaluated using conventional 2D heat transfer simulation methods. The surface temperatures; the interior slab length from the sliding door when the surface temperature reaches 20° C and potential condensation locations were the main outcome of the investigations.

The current results showed that the surface temperatures tended to increase when using a lower U-value framed glazing door assembly along with the insulated curb condition solution of 12.7 mm curb in concrete slab and 25.4 mm thick EPS rigid insulation in conventional concrete balcony scenarios. The results showed that the surface temperatures even doubled when compared to a traditional glazing door assembly with higher U-values. Concrete surface temperatures also had the tendency to increase in values when the insulated curb condition solution is incorporated with a proprietary thermal break.

Further, the incorporation of the insulated curb condition solution contributed to the benefit of the human thermal comfort by increasing the warmth and decreasing the length of the interior concrete surface until the temperature reaches 20°C.

The main conclusion of the study was that there is an alternative construction detail option that could provide similar benefits to human thermal comfort in lieu of increasing interior concrete surface temperatures and minimize the risk of condensation than the options of using a proprietary thermal break in concrete balcony slab. That alternative construction detail option can be done by utilizing more efficient glazing frame assembly with a lower U-value than the traditional glazing assembly commonly used in the high-rise MURB community and by utilizing a insulated curb condition solution of 12.7 mm curb in concrete slab and 25.4 mm thick EPS rigid insulation installed beneath the glazing frame.

Acknowledgements

The authors acknowledge the contributions from Ms. Melissa Morlidge.

References

[1] Hua Ge, V.R. McClung, S. Zhang, Impact of balcony thermal bridges on the overall thermal performance of multi-unit residential buildings: A case study, Energy and Buildings. 60 (2013) 163–173.
[2] Christian Cianfrone, Patrick Roppel, Thermal and Whole building Energy Performance of Thermal Break Technology for Concrete Balconies in High-Rise Multi-unit Residential Buildings, Morrison Hershfield, Final Report #5120962.00, 2013.
[3] Patrick Roppel, Neil Norris, Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings (ASHRAE Research Project – 1365 RP), Morrison Hershfield, Final Report #50852263.01, 2011.
[4] Therm/Window – Heat Transfer Program, Lawrence National Laboratory, Berkeley, California, 2014.
[5] Technical Manual, Schöck Isokorb® Type CM, 2014.
[6] ASHRAE Handbook – Fundamentals, American Society of Heating, Refrigerating and Air-Condition Engineers Inc., Atlanta 2009, pp 26.1-pp 26.22
[7] Canadian Standard, Fenestration energy performance, CSA A440.2-09, Canadian Standards Association, Rexdale, Ontario 2009.