IMPACT OF SOLAR REFLECTANCE OF GLAZING ADJACENT ROOFS

Patrick Roppel[1], Laurence Matzek[2], Katie Hay[3], and Nicolas Proulx-Jones[4]

[1]Evoke Buildings, 4415 Juneau Street, Burnaby, BC V5C 4C4, Canada
[2]Roofing Contractors Association of British Columbia, 9734-201 Street, Langley, BC V1M 3EB, Canada
[3]Formely affiliated with Morrison Hershfield, 310- 321 Still Creek Drive, Burnaby, BC V5C 6S7, Canada
[4]Evoke Buildings, 4415 Juneau Street, Burnaby, BC V5C 4C4, Canada

ABSTRACT

Exposed roof membranes are designed to withstand exposure to direct solar radiation. However, when roofs are adjacent reflective glazing, flashing, and/or cladding then the roof membrane will be exposed to more radiation and elevated temperatures. Elevated temperatures can cause issues related to membrane bonds, increased blistering, and in some cases holes in the membrane. There is anecdotical evidence and reporting of the consequences, but not definitive studies showing how much of an impact that reflective windows and walls adjacent roofs can have on roof temperatures.

The objective of this paper is to highlight the findings of a research study of a roof at the University of British Columbia, where roof areas adjacent clearstory windows were monitored over a year and compared to 3D thermal simulations. The study investigated the impact of membrane colour, overburden, overhangs, and varying reflectivity of adjacent window and walls scenarios.

The findings show how solar reflectance increases the temperature of the roof membrane and how the risk of blistering and membrane degradation increases. The paper is intended for designers, researchers, contractors, manufacturers, and building owners to increase awareness of the impact of solar reflectance from adjacent windows and walls and provides guidance for minimizing the risk.

INTRODUCTION

Building materials exposed to the outdoor environment are designed to withstand the energy from solar radiation and the expected service lives of materials and systems presume direct exposure to the sun. However, reflection of radiation from adjacent surfaces can amplify the exposure and elevate the surface temperatures beyond what is expected in service and cause damage. There have been high profile examples of this phenomenon that attract attention, such as “death rays” that burn skin and hair at the pool at a Los Vegas resort (NBC News 2010) as seen in Figure 1, melting cars and setting carpets on fire in London UK (NBC News 2013), or a recent fire during construction in Vancouver (CTV News 2021). These examples are extreme because the glazing systems form a concave glass exterior, as seen in Figure 1, that focus solar radiation to a concentrated area and significantly increase temperatures at a concentrated area.

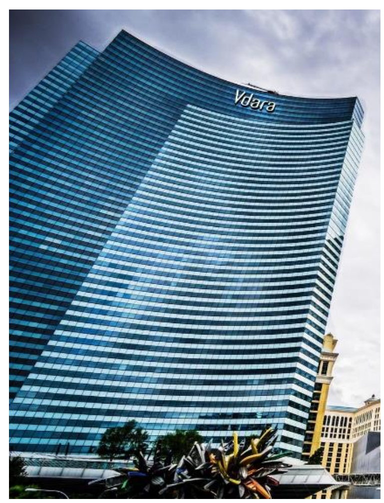

Figure 1: The curved glass at the Vdara hotel in Los Vegas on the south elevation focuses solar radiation on the pool area below

There are also more everyday examples of reflected solar radiation causing damage on walls and roofs. Melted vinyl siding or holes in TPO roofs are examples of more commonly reported damage that is visually apparent and associated to adjacent reflective windows, metal flashing, and cladding. These everyday examples also occur in regions with more moderate temperatures, such as Vancouver, BC.

The long-term durability of TPO roof membranes subject to higher service temperatures because of dirt build up and reflective adjacent surfaces was a topic of a 2009 ASTM International TPO task group and research sponsored by one of the TPO manufacturers (McGroarty and Taylor 2014, Dupuis 2014, Taylor 2016). This work highlighted how heat aging from elevated temperatures can reduce the service life of TPO membranes and there were significant differences among products in terms of life expectancy (Taylor 2016).

In 2019, widespread blistering was identified of a 2-ply modified SPB roof membrane adjacent clerestory windows at a building at the University of British Columbia that was less than 15 years old. Of the three roof areas on the building, only the southeast roof showed premature aging, blistering, and racking of the exposed 2-Ply modified SBS membrane. The pattern of the blistering and racking followed a particular pattern that was not replicated on the other roof areas on the building and the blistering reappeared after conducting repairs.

After an extensive examination of all three roofs, including cut tests, questions were raised if the reoccurring issues might be connected to the adjacent clerestory windows. The possible connection to the clerestory windows was made even though the prevailing perception was that issues with reflective walls and windows adjacent roofs appear to be isolated to plastic materials, concaved windows, and hot climates. Unanswered questions about how the clerestory windows affected the membrane temperatures and possibility increasing the risk of blisters developing led to the initiation of a research project to further investigate.

The objective of this paper is to highlight the RCABC solar study and findings, in which roof areas adjacent to clearstory windows were monitored over a year and compared to 3D thermal simulations. The study investigated the impact of membrane colour, various overburden, overhangs, and varying reflectivity of adjacent window and walls scenarios.

THE STUDY LOCATION

The Aquatic Ecosystems Research Laboratory (AERL) at the University of British Columbia is a concrete building as seen in Figure 2. The long rectangular building is less than a kilometer from the Georgia straight. There are three roof areas as seen in Figure 3; a narrow upper roof supporting ventilation hoods for the office spaces below, a wide lower-level roof at the northwest side of the building for nearly all the mechanical equipment servicing the building, and a southeast roof on the same lower level that does not have equipment and

Figure 2: AERL Building at UBC with issues at roof areas adjacent to clerestory windows and exposed to direct and reflected solar radiation throughout the day

is narrow.

All three roofs were constructed with a compact roof assembly as follows:

- 2 ply torched applied SBS membrane with grey cap sheet
- 3/16" asphaltic overlay board, mopped on
- Polyisocyanurate insulation, mopped on
- 2 plies of 15 lb felt, mopped on
- Concrete deck

Figure 3: The AERL Roof Study Area Orientation as viewed from google maps

The southeast roof abuts an aluminum framed double-glazed curtain wall (clerestory) along the length of the roof. Blisters appeared adjacent the curtain wall and extended into the roof field by as much as 2.7 m (9') from the glazing. Notably the blisters were not present along the parapet wall that shades the roof as seen in Figure 4. The windows receive full sun exposure, except for some shading from trees on the west at low sun angles.

Figure 4: Study roof location, looking south-west. Note repair patches along the glazing and not along the parapet that provides shade.

The blistering phenomenon was unique to the southeast roof. Cut tests showed debonding of materials inside and around blisters, but there was no discernable liquid moisture between the plies or in the insulation. The blisters reoccurred at the same locations where membrane blisters had been repaired over the previous two years as seen in Figure 5.

Figure 5: Test cut at a blister that reappeared after repairs

The findings were perplexing because nothing in the roof installation indicated any obvious design or installation issues.

The orientation of the building and presence of the curtain wall adjacent the roof lead RCABC to wonder how reflected solar radiation from the curtain wall might be contributing to growing the blisters and affecting the adhesion of the membrane layers. This was the impetus of initiating a study to explore the impact of the clerestory windows on the roof temperatures and how the issue can be mitigated.

STUDY MONITORING OVERVIEW

To investigate the impact of solar reflectance of membrane temperatures, sensors and monitoring equipment were installed at a section of roof that is adjacent to clerestory windows. The AERL roof study area and sensor locations are shown in Figure 6.

Figure 6: Roof sensor layout with various sections of different membrane colours and overburden

Four roof colours and two overburden types were investigated: black, brown, grey, and white; pavers and gravel respectfully. Surface temperatures and solar radiation were measured and collected between September 2019 – September 2020 for each test area that also included a control area that was unmodified.

Sensors were also installed on the glazed surface, on the vertical membrane flashing beneath the glazing, and on the inside of the parapet to collect temperature data that was not exposed to direct sunlight. All field sensors were placed along the centerline of the roof. Solar radiation sensors were mounted on an isolating wood block affixed to rigid insulation, which inadvertently cast shadows on the surface mounted temperature sensors that will be discussed later in the paper.

ANALYSIS AND SIMULATIONS

The monitoring data was compared to simulations of a model roof section using Siemens Simcenter 3D (NX) software as shown in Figure 7.

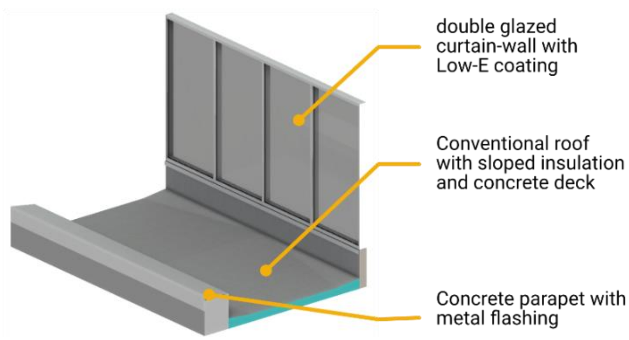

Figure 7: Model of Roof Section

The model incorporated the complex radiation exchange between the roof, including the concrete parapet with metal flashing, and double-glazed aluminum framed curtain wall. The analysis was a transient analysis, taking into consideration the dynamic solar flux and thermal capacity of the materials throughout the day.

The simulations were used to investigate the impact on temperatures from various roof finishes, glazing configurations, seasonal weather variations, building orientation, adjacent wall composition, and building location. More details on the simulation parameters follows.

Roof Finish: Modelling replicated the same finishes used on the study area at the AERL. The SBS cap sheet surface properties were determined using various sources as outlined in Table 1. Other properties such as the density and specific heat capacity of materials were taken from the ASHRAE Handbook of Fundamentals (2017).

Table 1: Roof Surface Emissivity and Reflectivity

Roof Surface	Source	Roof Colour	Emissivity	Spectral Reflectivity
2-Ply SBS	Cool roof rating council product directory https://coolroofs.org/directory	Grey	0.89	0.54
		Black	0.84	0.09
		Brown	0.88	0.24
		White	0.87	0.76
Overburden	Mandanici et al. 2016	Pavers	0.90	0.42
	Marceau et al 2008	Gravel	0.96	0.56
Green Roof	Mahmoodzadeh et al 2019	-	0.95	0.25

Ambient Conditions: The analysis focused on three days during the study period: January 29, 2020, March 2, 2020, and July 26, 2020. These days represent different cloud cover characteristics, with January 29 being 50% cloudy and 50% sunny, March 2 as 100% cloudy, and July 26 as 100% sunny. The simulations included direct and indirect solar radiation on all exposed surfaces using data from the Weather Underground and Environment Canada for Vancouver. The simulated solar radiation considered the building latitude and orientation. In addition, the models were also simulated for Kelowna, BC to explore the impact of hotter summers.

Adjacent Wall Composition: To investigate the impact of the glazing reflection on the roof surface temperatures, the models were run with an adjacent opaque wall with low reflectance properties. These scenarios were compared to a baseline model that did not include an adjacent wall or parapet.

RESULTS AND DISCUSSION

The monitoring data and simulations were in good agreement, after some challenges with the sensor installation were overcome and all parameters were taken into consideration. Wood blocks and rigid insulation were used to mount the solar radiation sensors and isolate the sensors from the roof. Temperature sensors were installed in the vicinity of the solar radiation sensors but varied by location in relation to the build-up as seen in Figure 8.

This condition resulted in the wood block and insulation shadowing the temperature sensors at different times of the day and year. This made direct comparison of the surface temperatures using the monitoring data not possible. Nevertheless, this provided an opportunity to enhance the validation of the simulations by including the wood block and insulation in the model as seen in Figures 9 and 10.

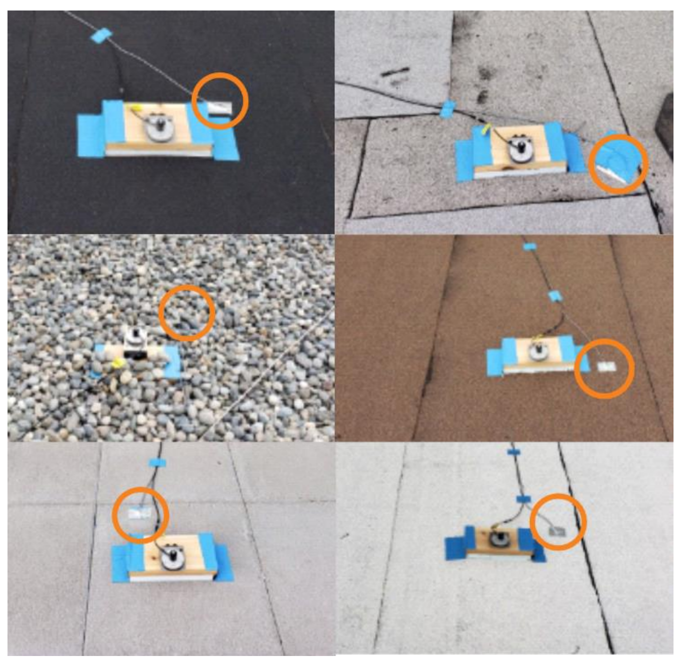

Figure 8: Simulations showing the shadowing of the temperature sensors for different times of the day and year for the black membrane roof section

The model was able to accurately simulate the shadowing of the wood and insulation blocks and the reflection of the adjacent glazing. The net outcome was a very good agreement with the monitoring data and high degree of confidence in the simulated results. This is relevant because the location of the hottest temperatures varies, and the simulations are necessary to evaluate the impact.

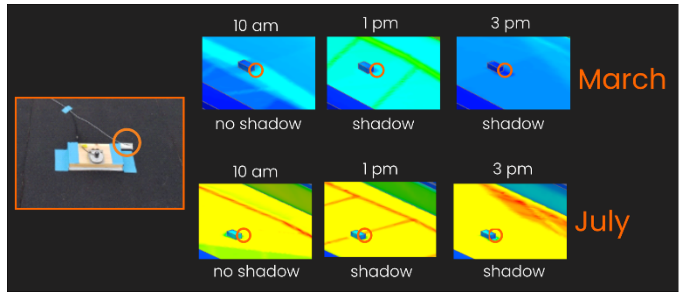

Figure 9: Temperature sensors were installed in the vicinity of the solar radiation sensors but varied by location in relation to the wood and insulation build-up (orange circles indicate the temperature sensors)

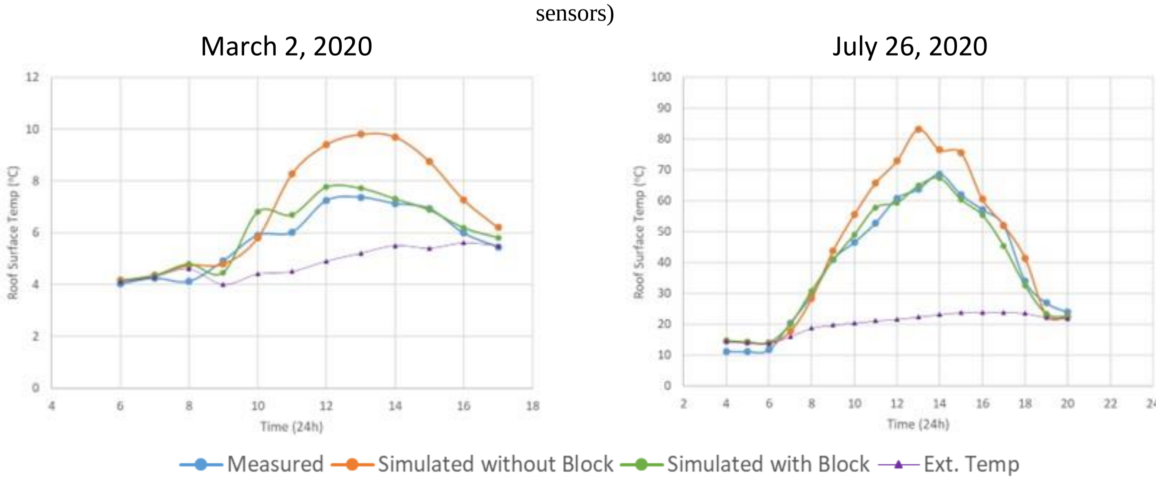

Figure 10: Comparison of the measured data to the simulations with and without the mounting block

For all the roof surfaces and days, the hottest roof surface temperatures were not from the glass but from the reflection of the aluminum curtain wall frames onto the roof membrane. An example of the variability of roof surface temperature between the glass and aluminum frames is shown below in Figure 11 for the grey roof on July 26, 2020. The location of the mullion reflection temperature is transient and dependent on the time of day and sun angle, as is shown in Figure 11. As such, the mullion reflections are localized 'hot spots' shorter in duration than compared to the reflection of the glass.

The impact of the reflective glazing has little impact on the roof membrane for the roofs with overburden, but as much as 33°C for the exposed darker membrane roofs during sunny conditions as seen in Figure 12.

Interestingly, the curtain wall aluminum frames raised roof surface temperatures more than the glass surfaces and a non-reflective opaque wall and corrugated metal cladding adjacent the roof resulted in lower roof surface temperatures than curtain wall.

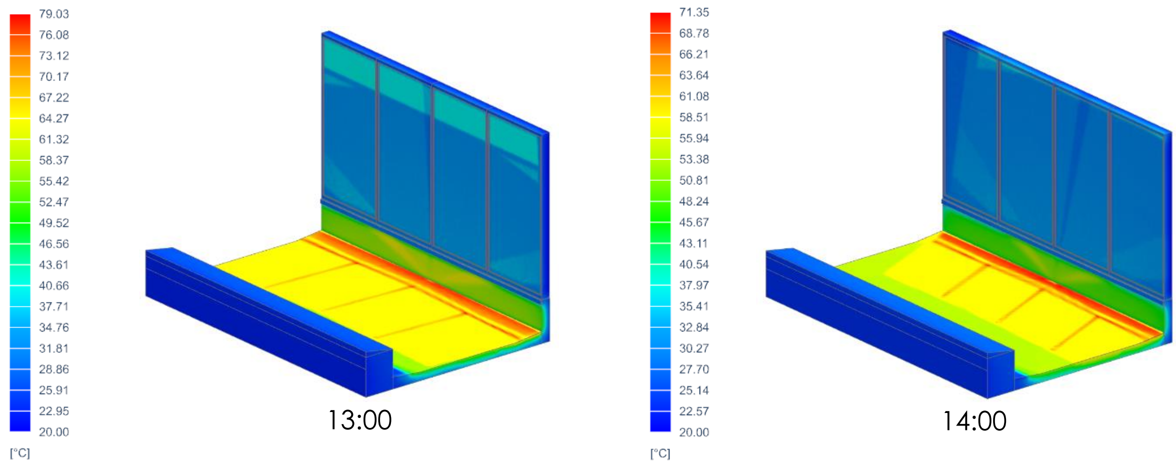

Figure 12: Reflection from the curtain wall frames and flashing resulted in the hotter roof temperatures than the glass

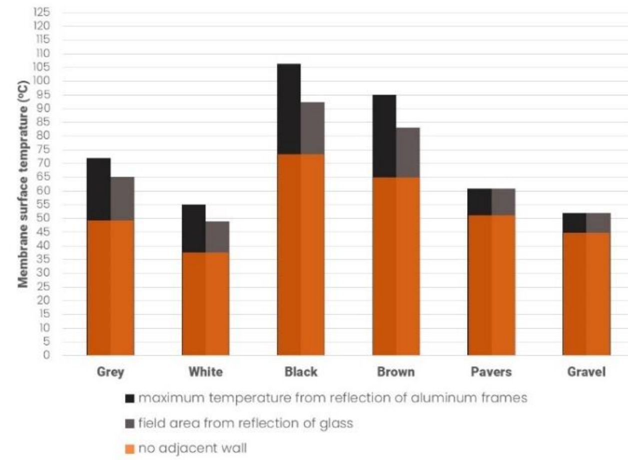

Figure 11: Membrane surface temperatures with and without adjacent curtain wall

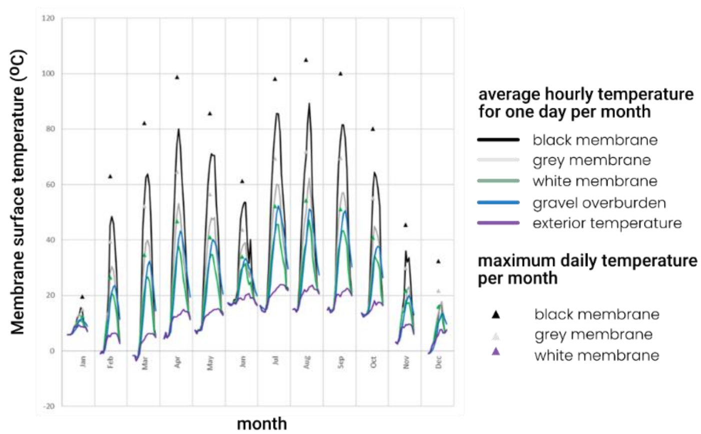

Figure 13: Measured membrane temperatures over the year for daily average and maximum monthly temperature

Reflected solar radiation can raise the membrane surface temperature significantly throughout the year as seen in Figure 13, but clearly there is less of a concern during the winter months in Vancouver when it is frequently raining and overcast.

The impact of the building orientation and climate was also explored for the black membrane for due south, southwest, and southeast (AERL) orientations and compared to Kelowna, BC for the same building orientation.

The peak summer temperatures for all the orientations were all similar when completely sunny but the AERL orientation had a 10ºC higher peak in January than a completely south orientation due to the timing of cloudy periods. The same trends were found for Kelowna as the Vancouver results, but the Kelowna peak temperatures were approximately 5ºC higher during July 26, 2020 conditions.

There is an impact of hotter temperatures for roofs adjacent to reflective windows or walls with vegetation due to potentially drier soil or accelerated trans-evaporation. To investigate the relationship between surface temperature, distance, and time for applications of green roofs, a green roof was simulated with 75 mm (3 inches) of

60% saturated soil as part of a protected membrane roof assembly.

The roof surface was divided into 305 mm (1 ft.) increments starting from the adjacent wall for each window panel. The average and max temperature of each grid section was recorded for the three analyzed days as shown in Figure 14.

The findings show high temperatures (60 to 80^{o}C), well above the temperatures that plants thrive in our climate, that extends well into the roof field area over a period of four or more hours.

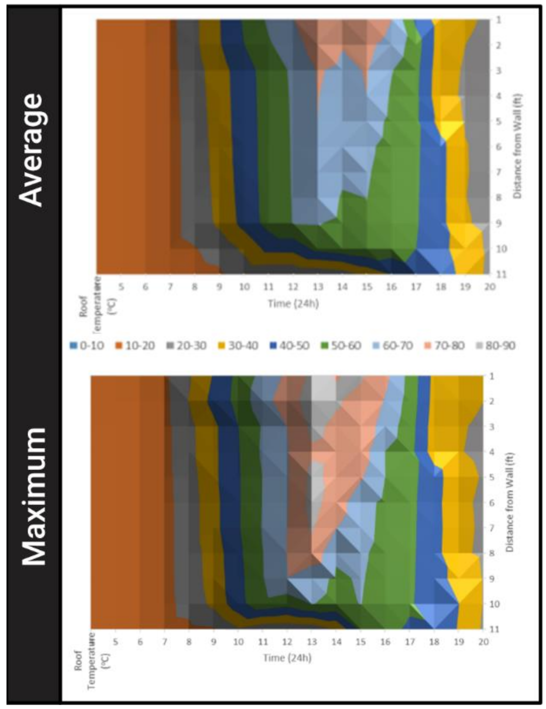

Figure 14: Surface temperatures of a green roof per time of day and distance from the curtain wall for July 26, 2020

KEY FINDINGS AND SOLUTIONS

The following key findings and conclusions emerged from the study:

1. Roofs adjacent reflective glazing and/or walls that are exposed to direct solar radiation from the south are affected the most and preventative measures should be taken to avoid issues.
2. Entrapped moisture, voids, and weak bonds that lead to blisters are related to workmanship. Nevertheless, higher membrane temperatures add pressure that increases the risk of blisters developing and growing.
3. Higher temperatures age the membrane more quickly and lead to more expansion and contraction of the materials below the membrane, affecting the performance of the roof assembly
4. Reflections from reflective metal are as much as a concern as glass.
5. Regardless of the season or climate, reflected solar radiation raises the membrane surface temperature significantly, but the biggest differences will likely occur in the summer.

Strategies to prevent issues related to reflective glazing and/or walls adjacent roofs are as follows and shown in Figure 15:

1. Protect the membrane with overburden that will reduce the risk of issues arising from deficiencies and aging of the membrane.
2. If the membrane must be exposed (conventionally insulated assemblies), first select a membrane and systems with high temperature resistance, such as high softening point and ability to accommodate movement. Also consider a lighter membrane with the acknowledgement that a lighter membrane will get dirty, and grey is likely just as good as a white membrane.
3. Incorporate overhangs or other shading devices above or integrated into the glazing system to

reduce solar exposure on the glazing system. Not only will this solution reduce the solar reflection on the roof, but shading also provides energy-efficiency benefits, reduces glare for indoors spaces, and provides protection from the rain.

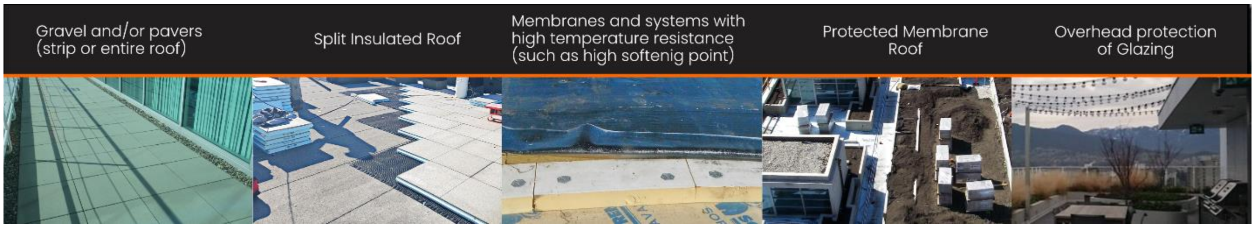

Figure 15: Strategies to prevent issues related to reflective glazing and/or walls adjacent roofs

The study roof deck is concrete and concrete decks are ideal for adding overburden. Solutions that focus solely on the membrane colour should not be a takeaway from this study. Light coloured membranes get dirty and ambient solar heating is often a good thing from a durability perspective. A recent study of over 70 projects in the lower mainland of BC as part of the low-slope roof study revealed how there are less issues with wood decks with dark membranes than with light membranes for roofs with no insulation outboard of wood sheathing and roofs without overburden (Roppel et al 2020).

NEXT STEPS AND CONCLUSIONS

This study demonstrated the impact of a curtain wall system adjacent a roof using field monitoring and 3D thermal simulations. The study highlighted the effectiveness of the thermal models that simulate the complex radiation exchange between the sun, roof, and walls. The confidence in the findings where significantly enhanced by doing both field monitoring and simulations, but ultimately the simulations provided the clearest picture of how the reflected radiation affected the roof surface temperatures. Accordingly, simulations may be useful to extend the findings of this study to more parameters and help assess the impact of solar radiation during design.

Entrapped moisture, voids, and weak bonds that lead to blisters are related to workmanship. Nevertheless, higher membrane temperatures add pressure to these deficiencies that increases the risk of blisters developing and growing. This study provided insight to not only how roof membranes are elevated by reflected solar radiation at select locations, but also provided a broader picture of the distribution of temperatures across the entire membrane system due to the complex radiation exchange between the wall, roof, and windows.

Higher temperatures not only can increase the risk of blisters growing, but can also age the membrane more quickly and put more stress on the system due to increased expansion and contraction of the materials below the membrane. How much the added stress affects the service of roofing system is not entirely known (Cash et al 2005, Cash et al 2004, Baily et al 2002, Lounis et al 1999), but there has been some work done in this subject in the past to qualify. Nevertheless, overburden or shading that reduces elevated membrane temperatures reduces the risk of issues arising from deficiencies and aging of the membrane and should be considered when reflective windows and walls are adjacent roofs.

The next step for this work is to further disseminate the findings and incorporate into design and practice guidelines.

ACKNOWLEDGMENTS

The authors collaborated with Morrison Hershfield and Structure Monitoring Technologies (SMT) for this study. We would like to thank them for their contribution.

REFERENCES

ASHRAE. 2017. ASHRAE Handbook of Fundamentals. Atlanta, GA. Chapter 26

Bailey, D.M., C.G. Cash, A.G. Davies. 2002. "Predictive Life Test for Roofing Membranes: Phase II Investigation of Accelerated Aging Tests for Tracking Degradation of Roofing Membrane Materials". US Army Corps of Engineers (CERL) Final Report ERDC/CERL TR-02-02.

Cash, C.G., D.M. Bailey, A.G. Davies, A.H. Delgado, D.L. Niles, R.M. Paroli. 2004. "Service life tests for roofing membranes". Proceedings of the CIB World Building Congress 2004: Building for the Future, Toronto, Canada.

Cash, C.G., D.M. Bailey, A.G. Davies, A.H. Delgado, D.L. Niles, R.M. Paroli. 2005. "Predictive Service Life Tests for Roofing Membranes. Proceedings of 10DBMC International Conference on Durability of Building Materials and Components, Lyon, France.

CTV News. 2021. "Highrise fire in Vancouver caused by magnifying effect: fire department". July 27, 2021. https://bc.ctvnews.ca/highrise-fire-in-vancouver-caused-by-magnifying-effect-fire-department-1.5524759. Last viewed on June 7, 2022.

Dupuis, R.M. 2014. "Final Report on 2013-2014 Broad Sampling TPO Test Program". Structural Research Inc. Middleton, WI.

Lounis, Z., M.A. Lacasse, D.J. Vanier, B.R. Kyle. 1999. "Towards standardization of service life predication of roofing membranes". Roofing Research and Standard Development: Fourth Volume, ASTM STP 1349, 3-18.

Mahmoodzadeh, M., P. Mukhopadhyaya, C. Valeo. 2019. "Effects of Extensive Green Roofs on Energy Performance of School Buildings in Four North American Climates". Water. MDPI. 12(1):6. https://doi.org/10.3390/w12010006

Mandanici, E., P. Conte, V.A. Girelli. 2016. "Integration of Aerial Thermal Imagery, LiDAR Data and Ground Surveys for Surface Temperature Mapping in Urban Environments". Remote Sensing. MDPI. 8:880 https://doi.org/10.3390/rs8100880

Marceau, M., M. VanGeem. 2008. "Solar Reflectance Values of Concrete". Concrete International. Portland Cement Association. Vol 30, Issue 8. 52-58

McGroarty, C., T.J. Taylor. 2014. "A Study of Longevity. Long-term performance of TPO roof membranes can vary". Professional Roofing. National Roofing Contractors Association (NRCA). Vol 44 Issue 2.

NBC News. 2010. "Death Ray" at Vegas hotel pool heats up guests. September 28, 2010. https://www.nbcnews.com/id/wbna39403349. last viewed on June 7, 2020.

NBC News. 2013. "This London skyscraper can melt cars and set buildings on fire". September 3, 2013. https://www.nbcnews.com/sciencemain/london-skyscraper-can-melt-cars-set-buildings-fire-8c11069092. Last viewed June 7, 2022.

Roppel, P, L. Ricketts, G. Suri, J. Tatara. 2020. "Renewal Strategies for Low-Slope Ventilated Wood-Framed Roofs", Digital Proceedings of 20220 IIBEC Virtual Canadian Building Enclosure Symposium. International Institute of Building Enclosure Consultants (IIBEC), Raleigh, NC.

Taylor, T.J. 2016. "Pushing the Limits of TPO Testing". IIBC Interface. International Institute of building Enclosure Consultants (IIBEC). Raleigh, NC. February 2016, 36 to 38