Lendlease

One Sydney Harbour

Residential Building R4B

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Job number 239304-00

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Contents

Appendices

1 Project Description

1.1 Introduction

This report supports a State Significant Development Application (SSD 6965) submitted to the Minister for Planning pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The Development Application (DA) seeks approval for construction of a residential flat building (known as Residential Building R4B) and associated works at Barangaroo South as described in the Overview of Proposed Development section of this report.

1.2 Overview of Proposed Development

The Residential Building R4B DA seeks approval for the construction and use of a 60 storey residential flat building comprising 297 apartments, ground floor retail, the allocation of car parking, services, plant and storage within the Stage 1B Basement (subject of a separate concurrent DA), and the construction of ancillary landscaping and temporary public domain.

Approval for the construction of Residential Building R4B's core and associated plant and services within the basement is being sought as part of the concurrent Stage 1B Basement DA and do not form part of this DA.

1.3 Site Location

Barangaroo is located on the north western edge of the Sydney Central Business District, bounded by Sydney Harbour to the west and north, the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east; and bounded to the south by a range of new development dominated by large CBD commercial tenants.

The Barangaroo site has been divided into three distinct redevelopment areas (from north to south) – Barangaroo Reserve, Barangaroo Central and Barangaroo South.

The R4B DA Site area is located within Barangaroo South as shown in Figure 1. The DA Site is located on land generally known and identified in the approved Concept Plan as Block 4A.

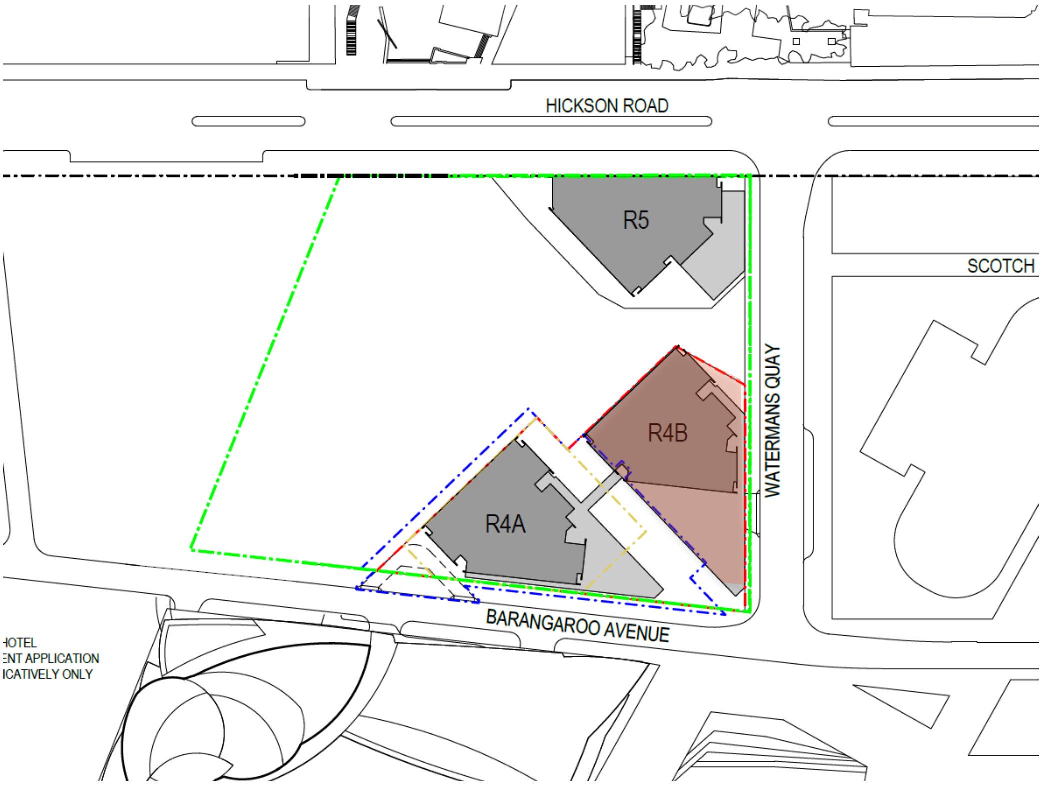


Figure 1: R4B Residential Building Development Application Site Location Plan

2 Executive Summary

This reflectivity study assesses the impact of solar reflections on pedestrians and road traffic participants in the area surrounding the proposed residential tower R4B proposed at Barangaroo South. The study seeks to address requirements for limiting reflectivity impact similar to those noted in local council development controls (e.g. Sydney DCP 2012 Provision 3.2.7). As per this provision, the report focuses on the impact to traffic participants (e.g. vehicle drivers, cyclists and pedestrians).

This assessment is performed following the methodology of David N.H. Hassall of the University of New South Wales[1]. The Hassall methodology proposes a limit of acceptability of equivalent veiling luminance of façade reflections for traffic of 500Cd/m². Where this is exceeded, solar reflections are considered as potentially causing disability glare.

The proposed Building R4B performs well in terms of solar reflectivity, and glare affecting drivers on surroundings streets is not expected to exceed the constraints of acceptability according to the Hassall methodology, as long as the external normal specular reflectance of glazing and cladding is kept within **28%.**

Glare risks to drivers have been discounted for all façade aspects, for either of the following reasons:

- They do not reflect the sun towards traffic
- The intensity of any reflections will be below the limit of acceptability set out by Hassall (500 Cd/m²)
- Surrounding buildings and topology or other parts of the building itself will be blocking reflections that could cause glare to drivers; or
- The position of reflections within the visual field is not critical and would allow drivers to block with sun visor.

Pedestrians are easily able to adjust their view in any location where unwanted reflections may be received, and move at a rate significantly slower than that of a vehicle. For this reason it is acceptable to assume that it will be safe for pedestrians to divert their vision in order to avoid glare.

[1] Hassall, D. N. H. (1991): *Reflectivity. Dealing with Rogue Solar Reflections*, Faculty of Architecture, University of New South Wales, ISBN 0 646 07086 X

3 Aim and Methodology

3.1 General

Figure 2: Perspective of site from north east. Image courtesy of Lendlease

Arup has been commissioned by Lendlease to carry out a reflectivity study of the proposed residential Building R4B. This reflectivity study assesses the impact of solar reflections on pedestrians and road traffic participants in the area surrounding the site. The study addresses requirements as laid out for reflectivity in of the Central Sydney DCP 2012 Provision 3.2.7.

The assessment in this report is performed following the methodology of David N.H. Hassall of the University of New South Wales, which contemplates potential rogue reflections giving more detailed consideration to geometry, viewing angles, and sun positions. It is described in more detail in section 3.4.

3.2 Reviewed buildings

Barangaroo South plot comprises three residential towers, namely Buildings R4A, R4B and R5 (Tower 4A: 72 storeys, Tower 4B: 60 storeys, Tower 5: 29 storeys) on the site bounded by Hickson Road to the east, Waterman's Quay to the South and Barangaroo Avenue to the west. The assessment in this report relates to Building R4B only. The other towers are included in the model as overshadowing elements.

The building faces onto Waterman's Quay to the south, with the podium extending to the corner of Barangaroo Avenue. The R4B tower building rises above the majority of neighbouring properties, such that its principal elevations can be seen from road level. However, the view towards the building is restricted mostly to the streets that lead directly past the site and areas to the north of the site where building density is reduced around the Sydney Harbour.

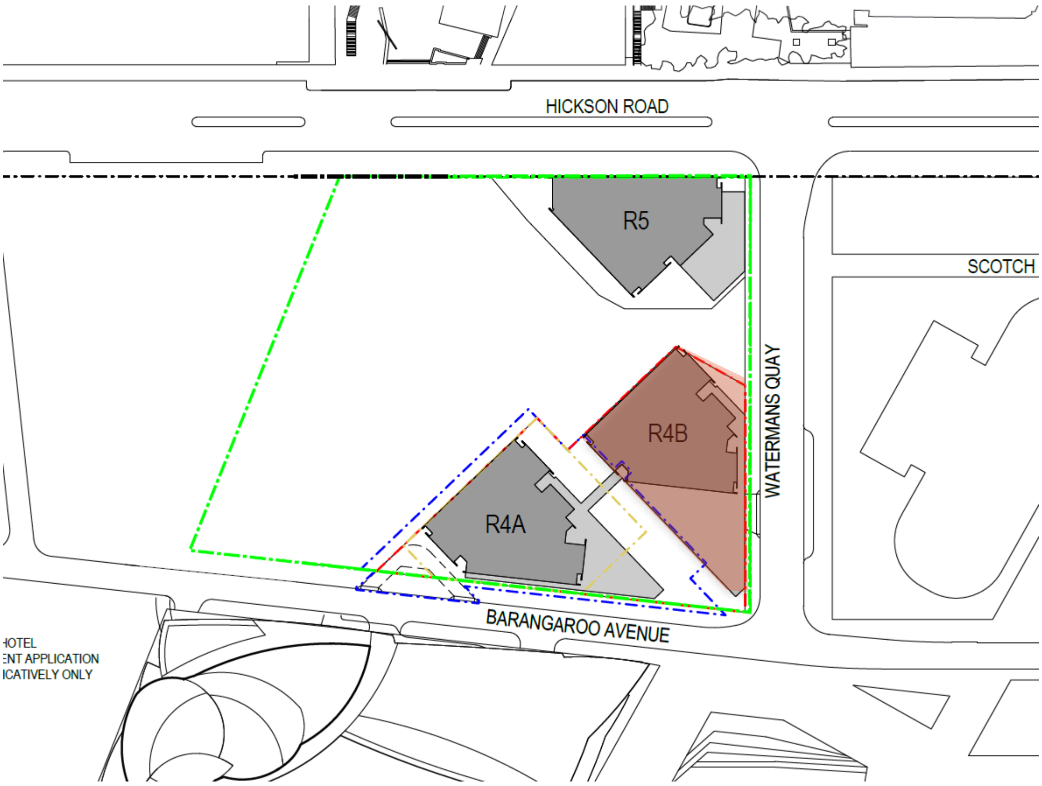


Figure 3: Site plan showing location of three residential towers in relation to each other.

3.3 Description of Facades

The façade design is shown in the Architectural drawings that accompany this DA.

For the purposes of reflected glare analysis, façade elements to be considered are those that have a specular (i.e. mirror-like) reflection component. The primary specular reflective elements of the proposed building designs are window and balcony glazing. The intent for vision areas is for a double layer glazing with flush exterior surface.

3.4 Criteria for Assessment

The method for this study follows that of David N. H. Hassall of the University of New South Wales, which has been widely used to assess reflections off building projects in Sydney. It has been specifically developed for the purpose of reviewing the potential glare impact of solar reflections from facades on traffic in detail, beyond a nominal facade material reflectivity limit.

The term "glare" describes adverse visual effects caused by large ratios of luminance in the visual field. Glare can generally be defined in two ways by its impact on observers (these may coincide):

- Discomfort glare – resulting in psychological annoyance, desire to avert view
- Disability glare – impacting the ability to recognise objects in the visual field, and thus ability to carry out visual tasks (such as reading or driving)

It is critical that a driver's view is unaffected by disability glare as this has the potential to cause road accidents, thus the Hassall methodology focuses on prediction of this aspect of glare.

It further singles out veiling glare as the predominant mode of glare that can occur from façade reflections towards traffic. Veiling glare is defined in this context as glare due to the effect of multiple reflection and scattering within the eye of direct light from a bright source. This produces a perception similar to a thin veil being overlaid on the visual scene, and reduces the contrast in the scene, potentially impairing visual tasks. A prerequisite for veiling glare is thus that reflections of the sun are visible relatively close to the direction of view of an observer.

Veiling glare is form of perceptive effect of glare; whether it leads to discomfort or disability glare depends on the intensity of the effect.

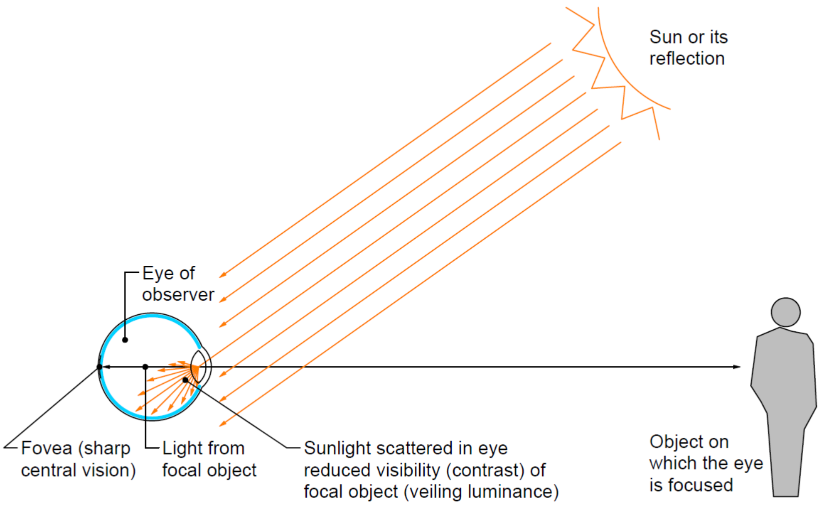


Figure 4: Veiling glare: bright sunlight falling into the eye reduces contrast and visibility of objects. This effect can be quantified by the equivalent veiling luminance measure.

Hassall proposes a workflow to track solar geometry, estimate sun intensity, establish actual façade reflectance, and numerically calculate a measure for the veiling effect. This measure, the equivalent veiling luminance, measured in Cd/m^2 (candela per metre squared), is a representation of apparent brightness to the human eye corrected for the angular distance of the glare source from the focus of vision, which reduces the veiling effect.

The Hassall methodology further proposes a limit of acceptability of equivalent veiling luminance of façade reflections for traffic of 500Cd/m². Where this is exceeded, solar reflections are considered as potentially causing disability glare.

Beyond this Hassall provides guidance through examples as to in what cases it is appropriate to assume that the position of glare sources relative to a driver's view of a scene may make adaptation (e.g. by use of sun visor or hand to block glare) possible to limit the risk of glare. This is illustrated in the example below.

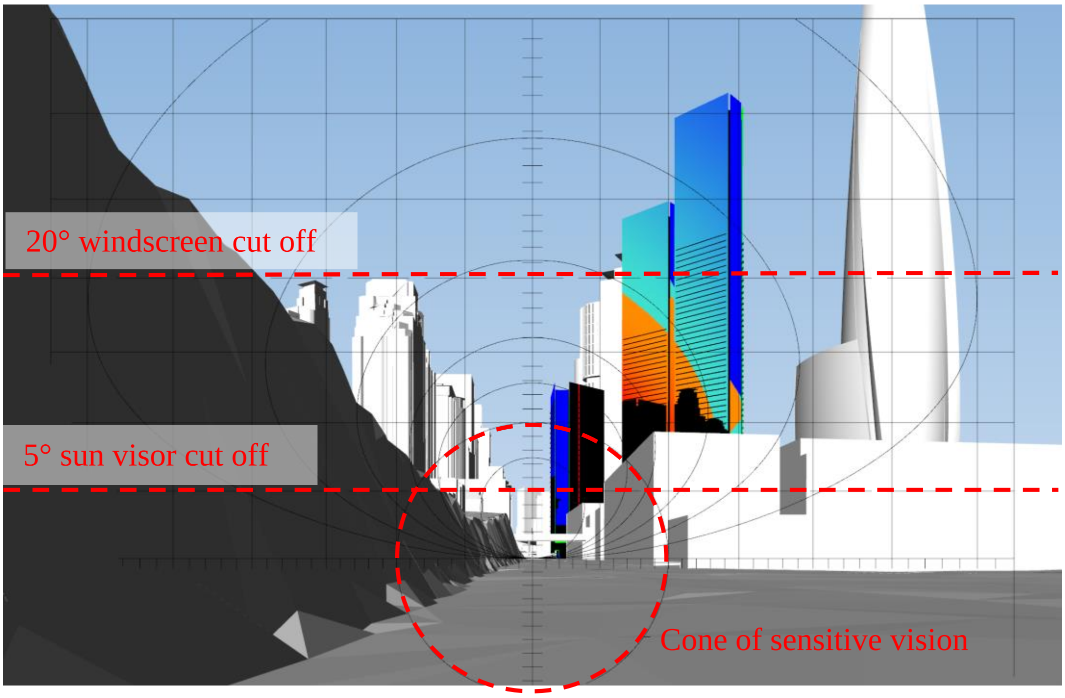


Figure 5 Example image highlighting sensitive cone of vision and angles above which glare sources can be blocked with windscreen or sun visor.

The example provided above shows a glare source outside the cone of sensitive vision and above the 5° windscreen cut off angle i.e. according to Hassall, this glare source can be blocked by the sun visor.

3.5 Methodology

The assessment of undesirable solar reflections is based on the methodology described by Hassall. This involves several steps, as outlined below.

- The size, orientation and extent of reflective objects on each facade are determined by examination of drawings provided by the architect, the site and surrounds, and expected glazing materials.
- Several observer locations are chosen for critical facades, representing locations from which traffic participants may observe the facades.
- Times at which the sun is reflected off the facade are determined, as well as the directions in which it is reflected.
- If the sun is reflected towards any observer, the equivalent veiling luminance in the eye of the observer is calculated and evaluated against the maximum allowed level of 500 Cd/m² according to Hassall. This involves calculations of the strength of solar illumination, the position of the sun in front of the facade,

the apparent position of the sun reflected in the facade, and the reflected solar illumination received by the observer.

- If the limit is exceeded, further assessment is carried out to evaluate if other factors such as facade shading make the situation acceptable or not. Within sections 5.5 and 5.6 of his methodology, Hassall discusses situations where an undesirable amount of veiling glare is experienced but reflections fall outside the cone of sensitive vision and / or can be blocked by sun visor, hand or hat.

3.6 Assumptions

- For the purposes of this assessment, all glazed facades have been assumed to have a reflectivity of 28% (external specular reflectivity at normal incidence). This is to be taken as the overall (i.e. combined) reflectivity of any multi-layer glazing.
- It is assumed that to carry out the visual tasks required for traffic participation, drivers and pedestrians face parallel to the ground, and parallel to their direction of travel.
- Buildings R4A and R5 have been included in the modelled geometry as overshadowing buildings.

3.7 Modelling and Assessment Approach

This reflectivity study used a 3D model of the Stage 1B residential buildings and the surrounding buildings and topography. The 3D model was developed from the architectural 3D model as a simplified massing model, however retaining accurate orientations of façade surfaces. Relative road elevation information was taken from available 3D topography.

Facades have been analysed in true elevation angles as provided with 3D model information by Renzo Piano Building Workshop. Small scale details such as joints, any expressed framing profiles, downpipes, etc has been omitted from the model. They subtend insufficient angles in the visual field to reflect a large enough portion of the sun disk to cause unacceptable glare.

The north east façade and west façade have wind deflectors at every level. The intent is for these deflectors to be fritted glass. These deflectors are approximately 500mm deep. From Level 1 to Level 52, deflectors are angled at 45° downwards. From Level 53 to the roof, deflectors project horizontally at 90° to the façade. Horizontal deflectors at Level 54 and above have not been modelled because reflections at this angle will not been seen from the drivers viewing direction. Deflectors angled at 45° have been modelled.

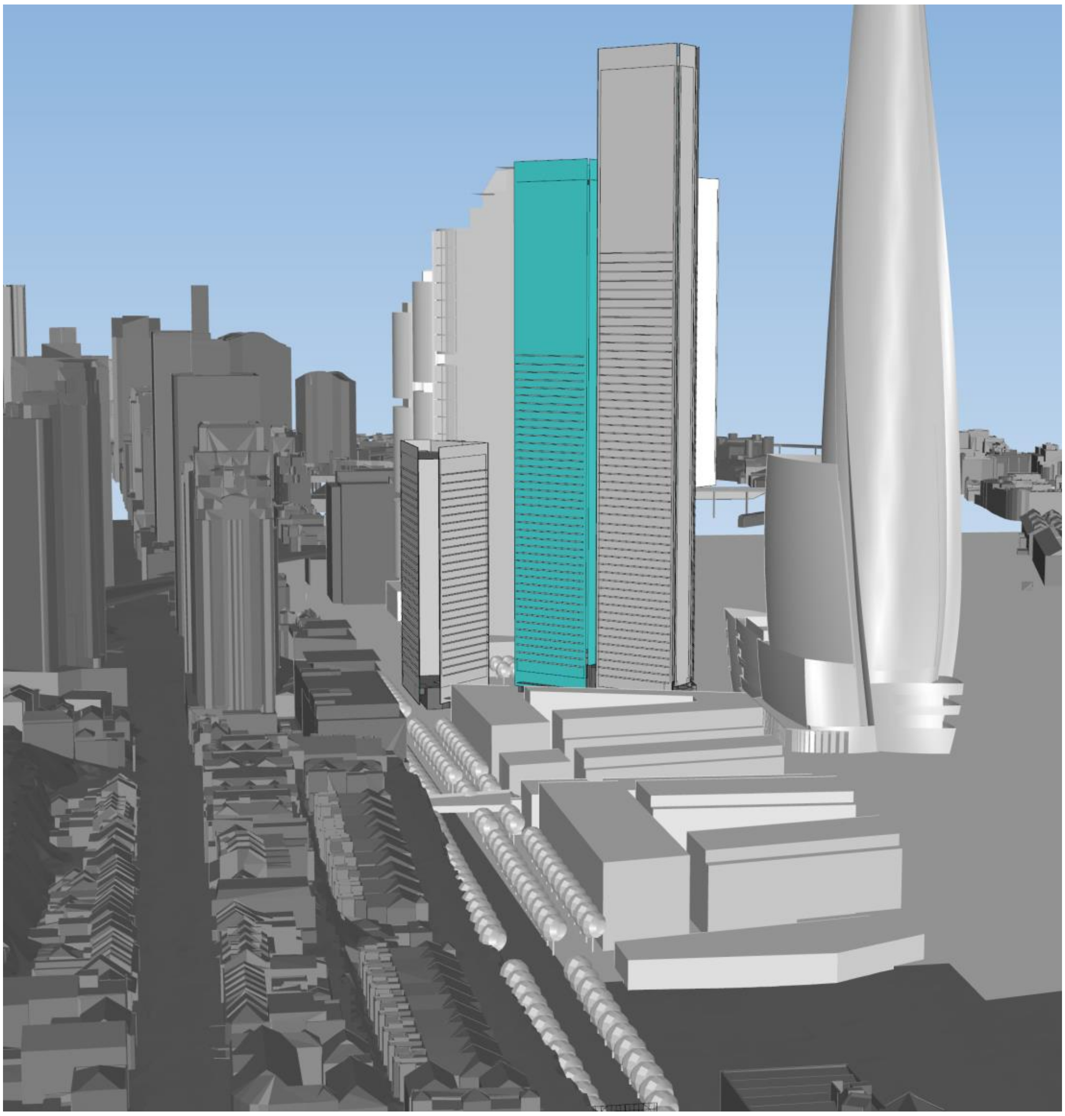


Figure 6: Image of the 3D building and context model. Surfaces shown in blue have been assumed as specular reflective in the analysis. Surrounding buildings are included as overshadowing elements.

This model was used to interrogate the view of the building and solar reflections originating from it along the paths shown in Figure 7.

Ref.	Road	Dir.
A	Barangaroo Avenue	N
B	Barangaroo Avenue	S
C	Hickson Rd	S
D	Kent St	S
E	Western Distributor	S
F	Grosvenor St	W
G	Margaret St – Napoleon St	W
H	Hickson Rd	N
I	Waterman’s Quay	W
J	Waterman’s Quay	E

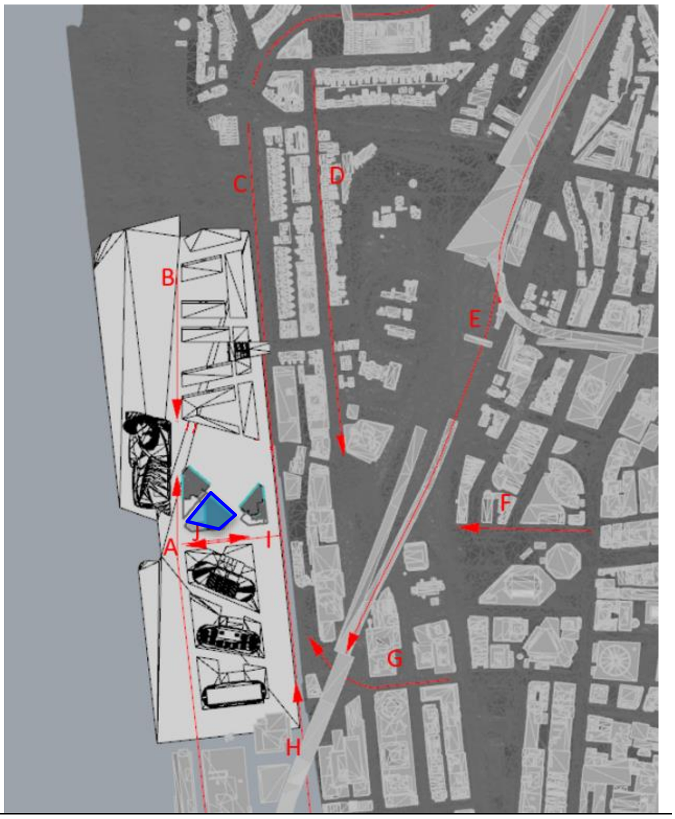


Figure 7: Site map showing observer paths from which glare has been assessed and Building R4B highlighted in blue.

4 Assessment Results

4.1 Results for Analysed Traffic Travel Paths

Observed model analysis outcomes for each of the travel paths are summarised below. Indicative perspective views and reflected sun charts are shown for a single viewpoint on these paths. Note however the modelled paths have been reviewed along their entire lengths.

The sun charts indicate the times of the year when solar reflections are visible from each view location. The coloured region on each chart shows the projected façade. Where this region intersects the reflected sun path, the façade can reflect the sun's light towards the location.

The equivalent veiling luminance of these reflections is calculated with respect to a driver's heading direction, and is colour coded in projected facades in sun charts and in perspective views. Façade areas are shown orange to red where reflections exceed the Hassall limit of 500Cd/m² for prevention of disability glare. Reflections off projected façade area shown in blue to cyan are below this limit in intensity.

A. Traveling north on Barangaroo Avenue

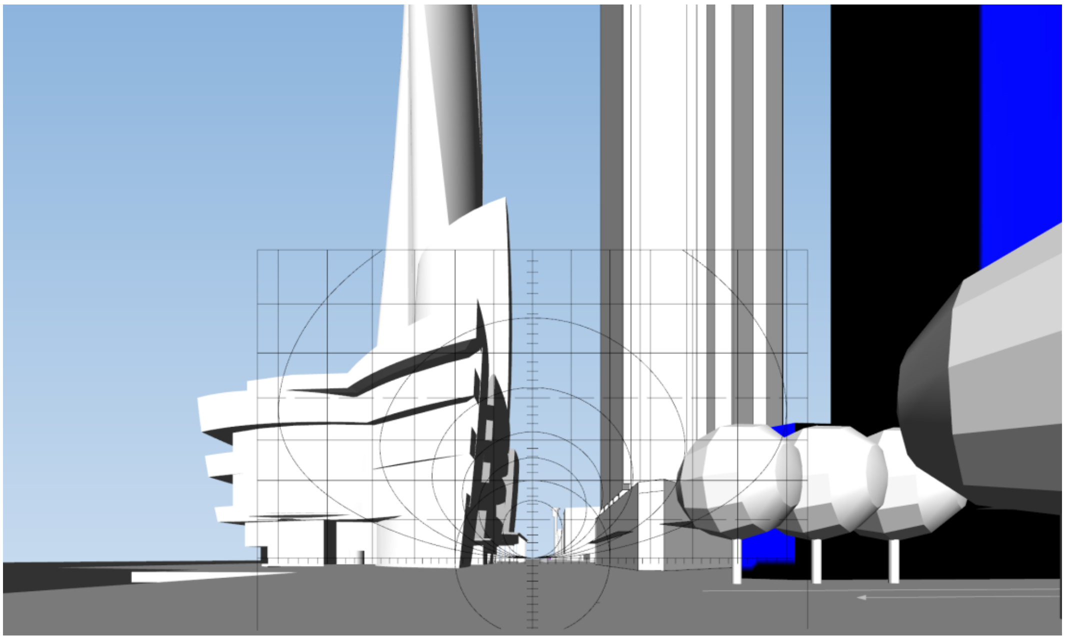


Figure 8: Perspective view from road

Viewed from locations along this stretch of road it has been found that:

- Visible equivalent veiling reflections for tower R4B fall well below the Hassall threshold of 500Cd/m².

B. Traveling south on Barangaroo Avenue

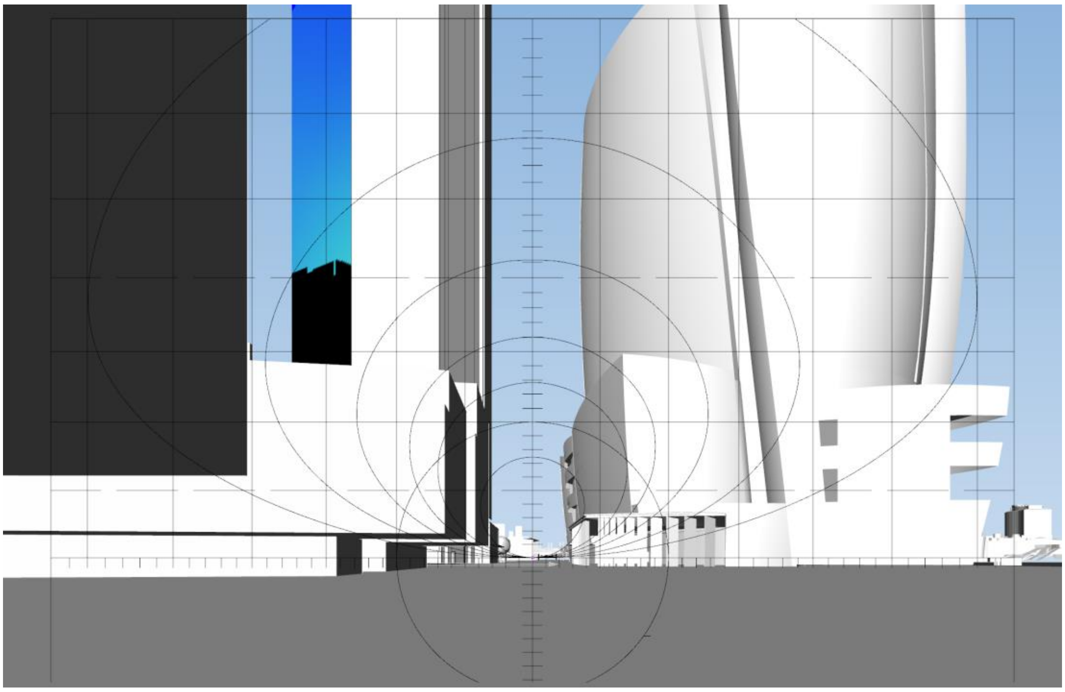


Figure 9: Perspective view from road– north east facade

Viewed from locations along this stretch of road it has been found that:

- Visible equivalent veiling reflections of tower R4B fall below the Hassall threshold of 500Cd/m².

C. Traveling south on Hickson Road

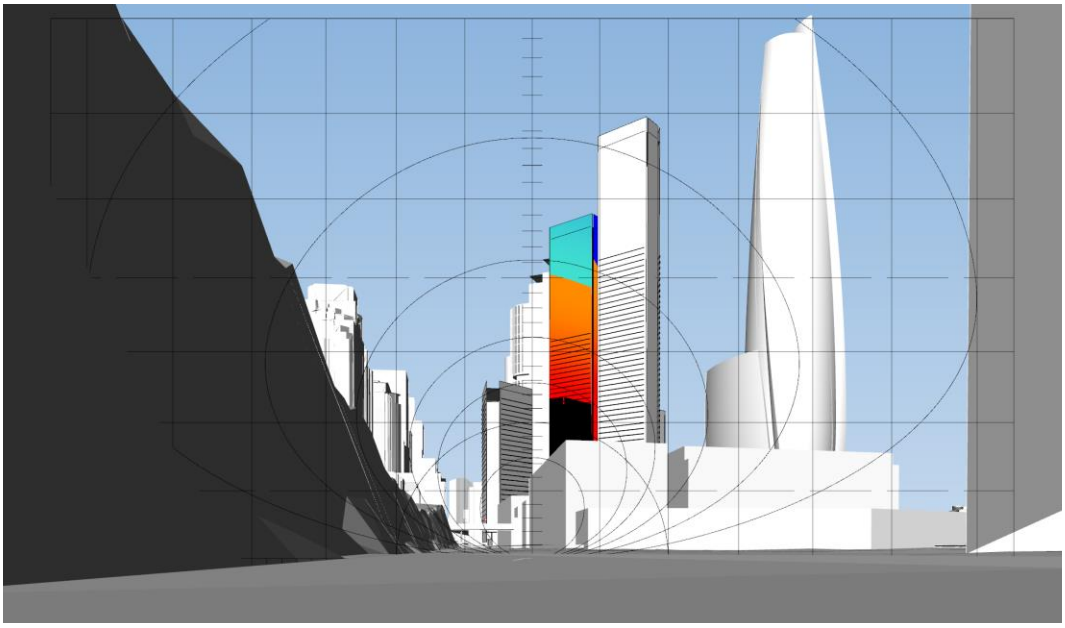


Figure 10: Perspective view from road

Viewed from locations along this stretch of road it has been found that:

- The north east façade of tower R4B reflects sun towards drivers for 15 minutes during April and August between 7am and 8am. Equivalent veiling luminance reaches 1000Cd/ m², exceeding the Hassall threshold of 500Cd/m².
- These reflections occur over the full width of the north east façade and to a height of up to 158m above ground.

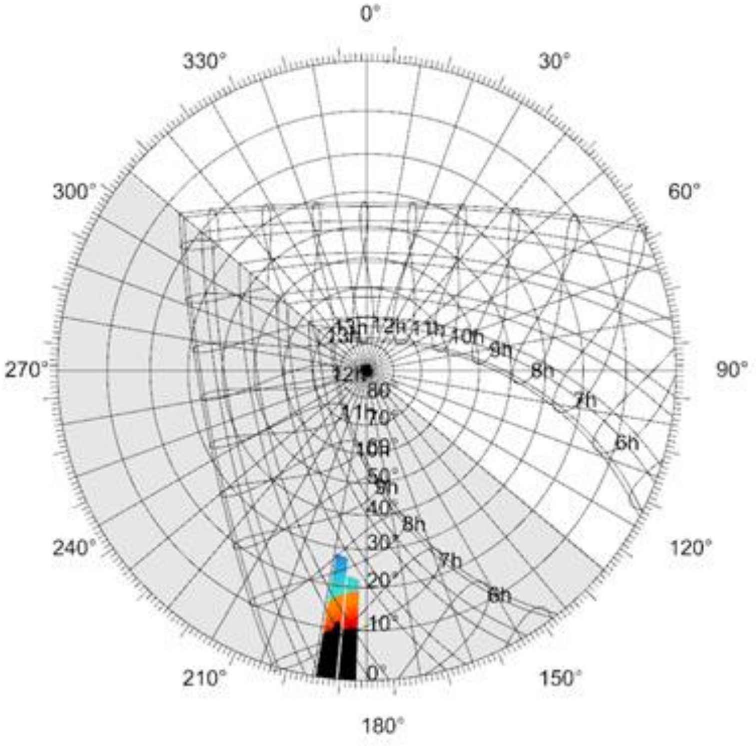


Figure 11: Stereographic sunchart of north east facades

However, note that from this viewing direction any reflections occur outside the cone of sensitive vision (defined by a circle of radius 10°) and above the 5° sun visor cut off angle. Within section 5.6 of Hassall (1991) a similar example is given, described as point P4. Using this example, it can be argued that there is the potential for drivers to lower their sun visors to mitigate glare reflections that occur at angles above 5° from the horizontal.

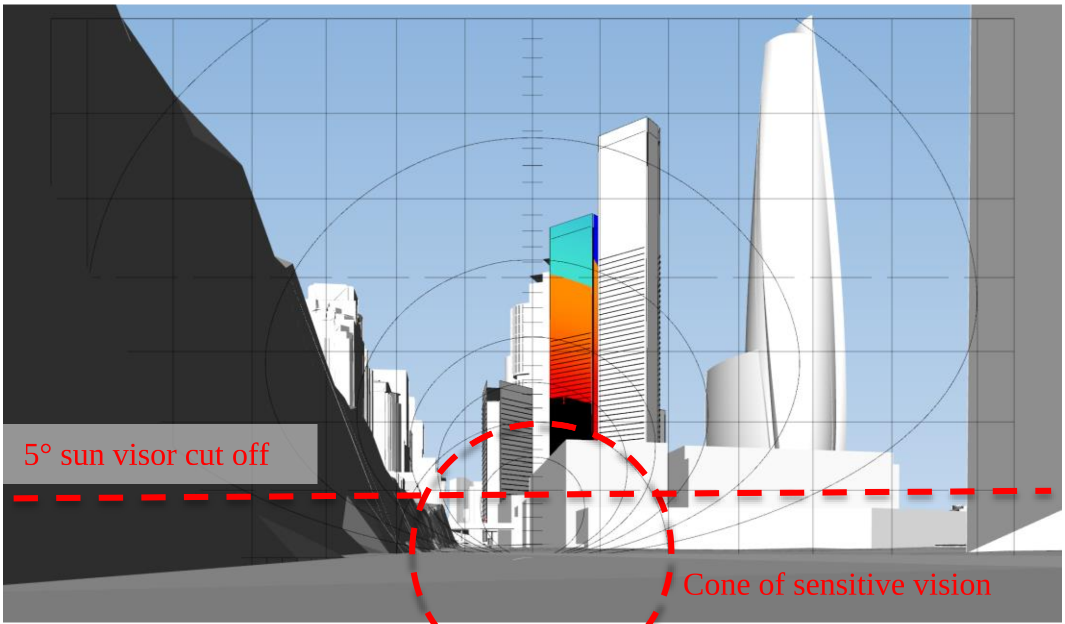


Figure 12: Reflections outside cone of sensitive vision and above sun visor cut off angle.

For the above reasons reflections are not expected to result in unacceptable glare towards drivers.

D. Traveling south on Kent Street

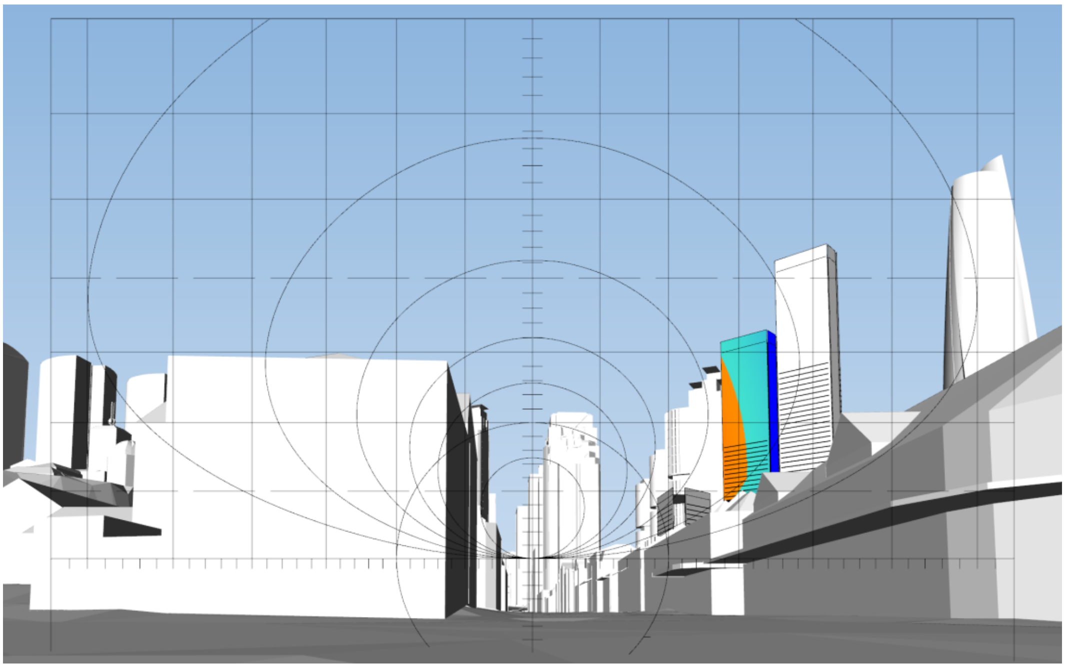


Figure 13: Perspective view from road

Viewed from locations along this stretch of road it has been found that:

- The north east façade of tower R4B reflects sun towards for 10 minutes during April and August between 7am and 8am. Equivalent veiling luminance reaches 890Cd/ m², exceeding the Hassall threshold of 500Cd/m².

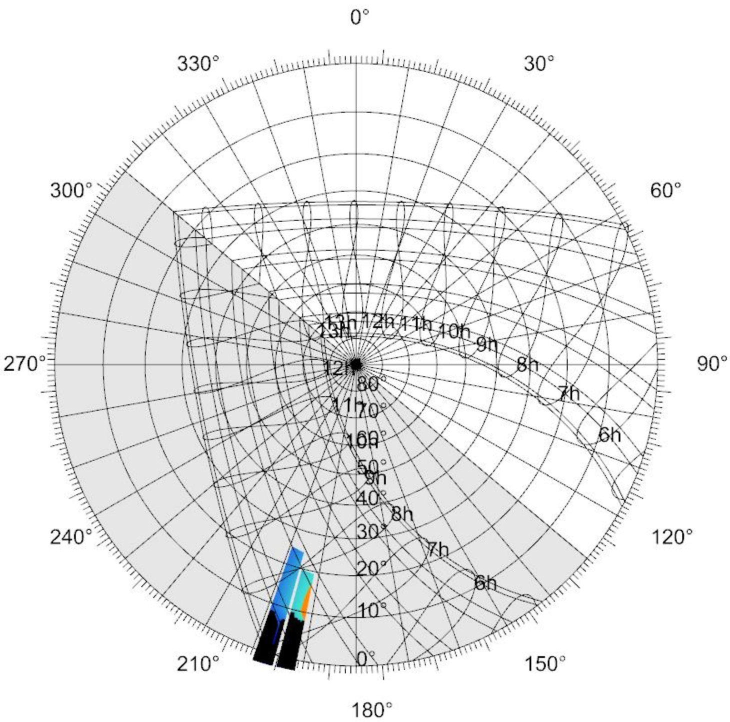


Figure 14: Stereographic sun chart of north east facades

However, note that from this viewing direction any reflections occur outside the cone of sensitive vision (defined by a circle of radius 10°) and above the 5° sun visor cut off angle. Within section 5.6 of Hassall (1991) a similar example is given, described as point P4. Using this example, it can be argued that there is the potential for drivers to lower their sun visors to mitigate glare reflections that occur at angles above 5° from the horizontal.

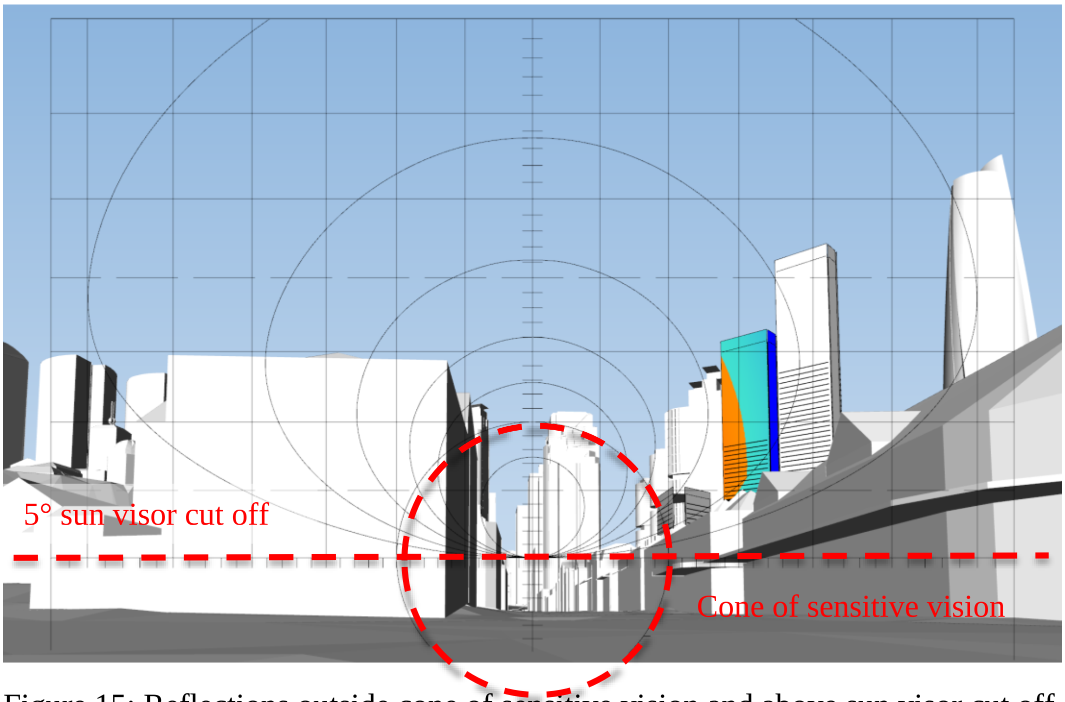


Figure 15: Reflections outside cone of sensitive vision and above sun visor cut off angle.

For the above reasons reflections are not expected to result in unacceptable glare towards drivers.

I. Traveling west on Waterman's Quay
i) South façade of tower

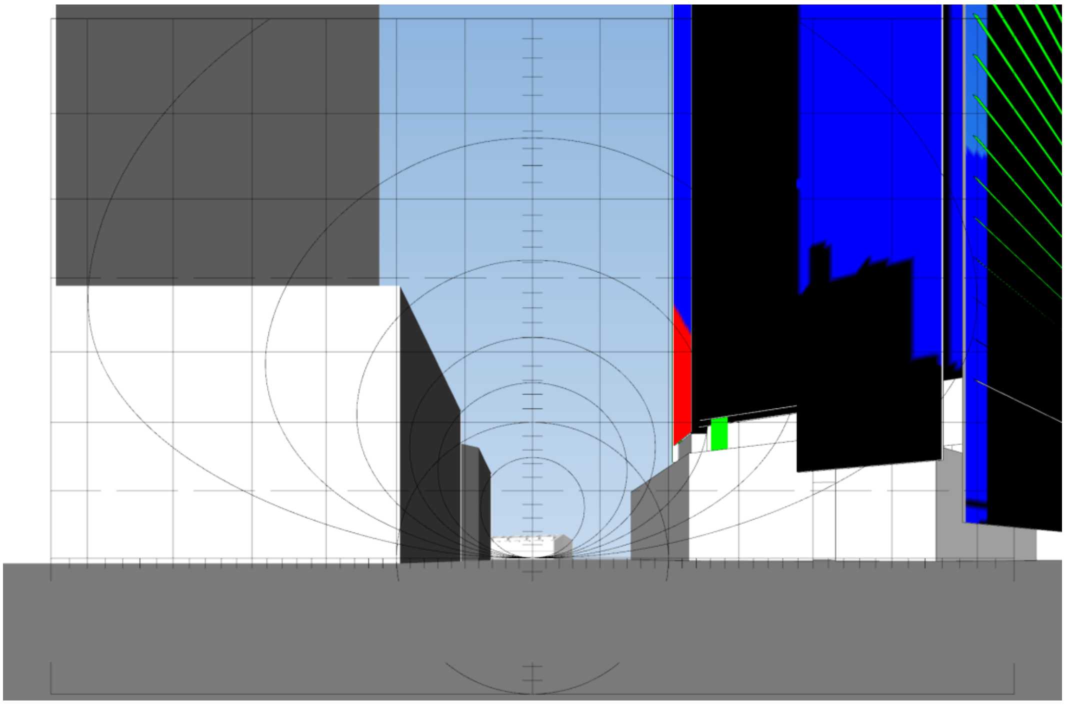


Figure 16: Perspective view from road (green indicates back of surface i.e. no reflection)

Viewed from locations along this stretch of road it has been found that:

- The south facade of tower R4B reflects sun towards drivers for 5 minutes during January and December between 6pm and 7pm. Equivalent veiling luminance reaches 1450Cd/ m², exceeding the Hassall threshold of 500Cd/m².

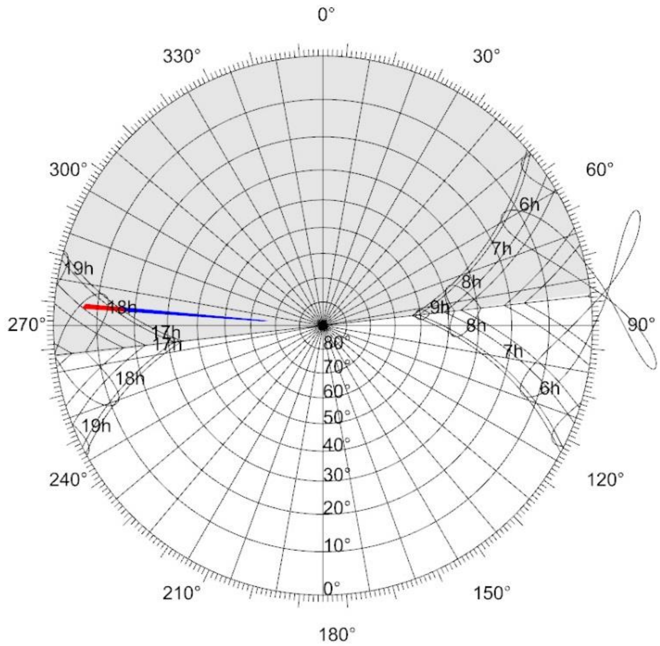


Figure 17 Stereographic sun chart of south facade

However, note that from this viewing direction any reflections occur outside the cone of sensitive vision (defined by a circle of radius 10°) and above the 5° sun visor cut off angle. Within section 5.6 of Hassall (1991) a similar example is given, described as point P4. Using this example, it can be argued that there is the potential for drivers to lower their sun visors to mitigate glare reflections that occur at angles above 5° from the horizontal.

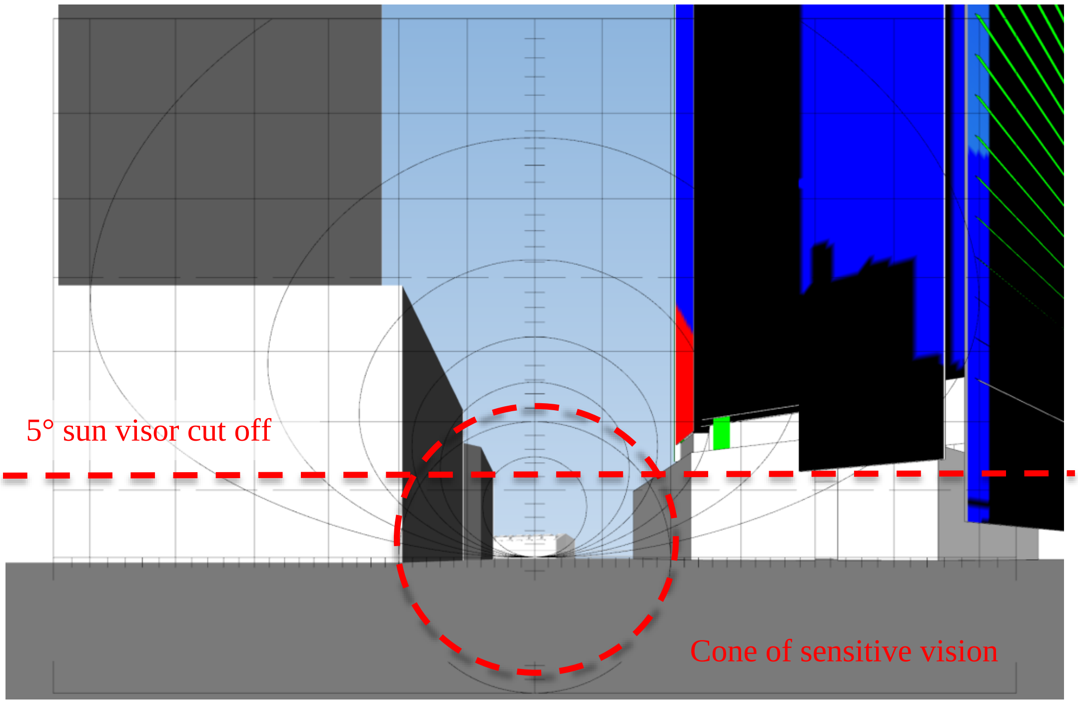


Figure 18: Reflections outside cone of sensitive vision and above sun visor cut off angle.

For the above reasons reflections are not expected to result in unacceptable glare towards drivers.

I. Traveling west on Waterman's Quay
ii) South façade of podium

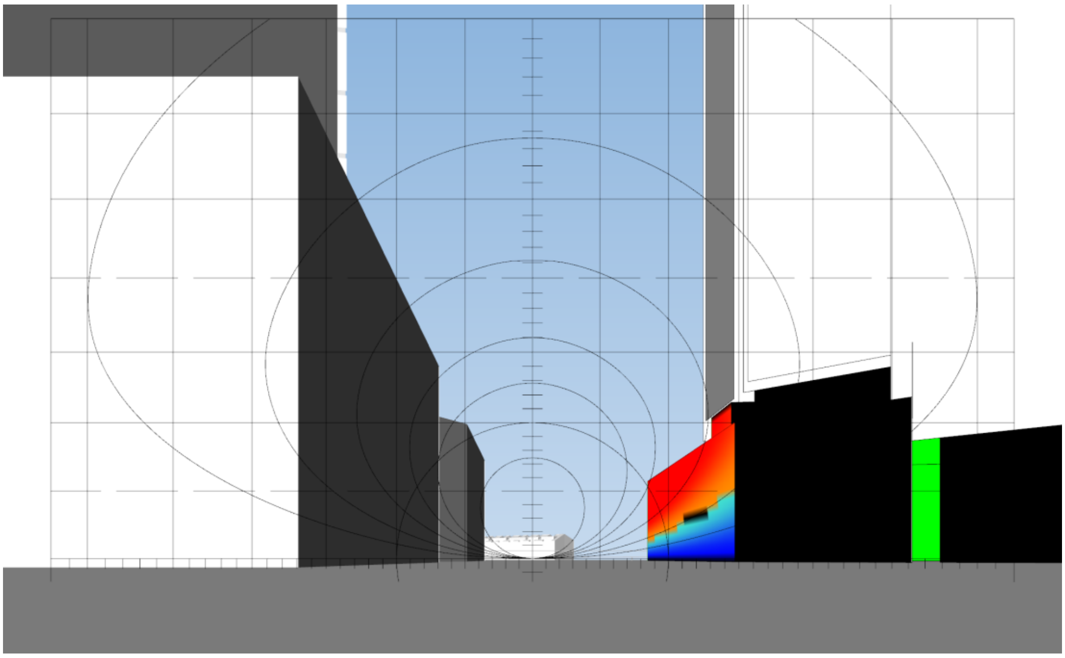


Figure 17: Perspective view from road (green indicates back of surface i.e. no reflection)

Viewed from locations along this stretch of road it has been found that:

- The south facade of podium R4B reflects sun towards drivers for 10 minutes during February and November between 6pm and 7pm. Equivalent veiling luminance reaches 1730Cd/ m², exceeding the Hassall threshold of 500Cd/m².

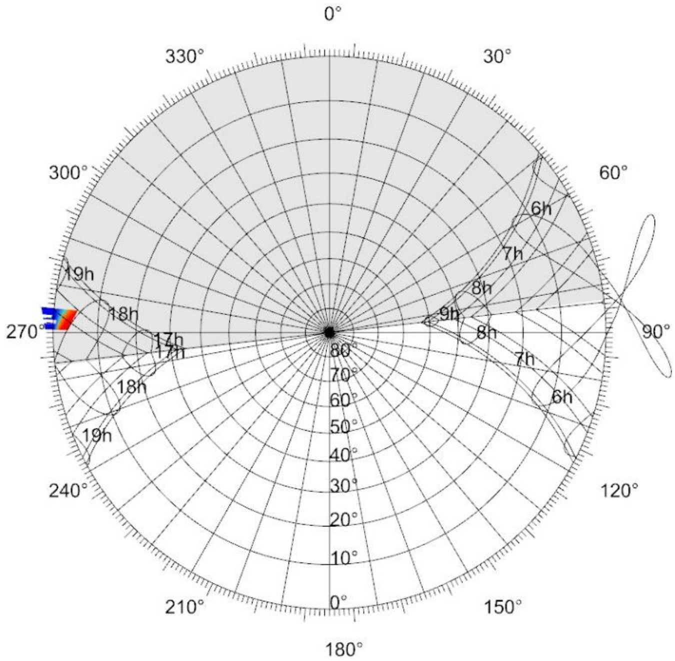


Figure 17 Stereographic sun chart of south facade

However, within section 5.6 of Hassall (1991) a similar example is given, described as point P7. Using this example, it can be argued that although undesirable, there is the potential for drivers to lift their head or lower their line of site to mitigate glare reflections which is acceptable on slow roads only. Waterman's Quay is expected to be a slow speed traffic thoroughfare and there is a pedestrian crossing half way along the road, so it is expected traffic will be moving at slow speeds.

Further, trees are to be planted along the length of the road which will act to mitigate glare to the driver as shown in the image below.

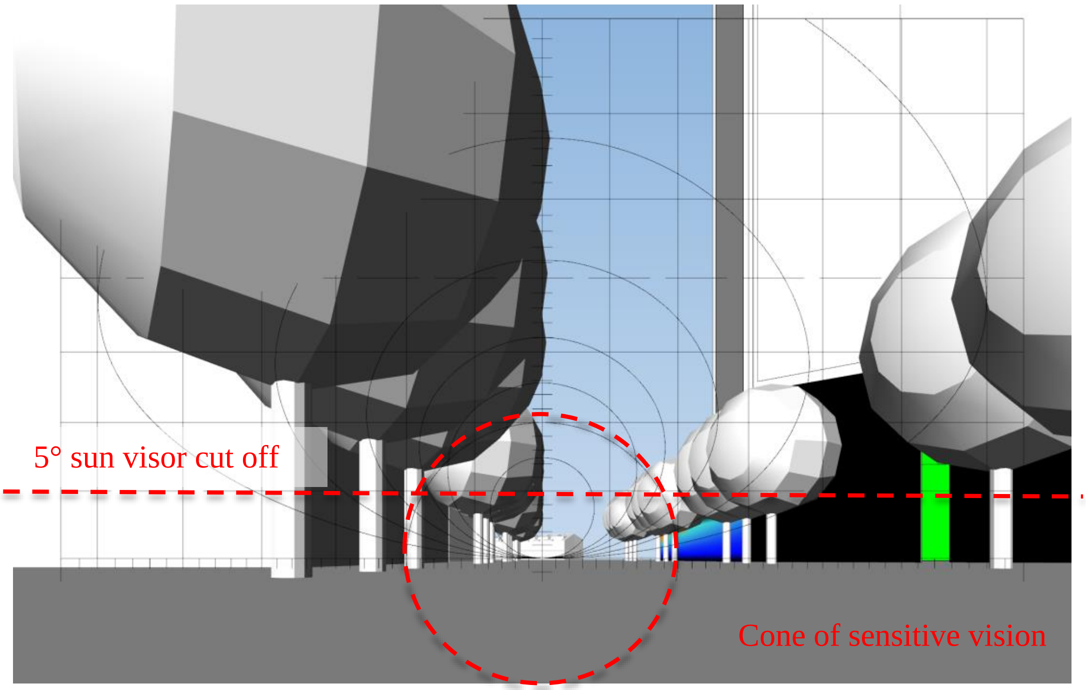


Figure 18: Reflections outside cone of sensitive vision and above sun visor cut off angle.

For the above reasons reflections are not expected to result in unacceptable glare towards drivers.

E. – H. and J. Other travel paths

For all other analysed travel paths E. – H. and J. listed above in section 3.7 it has been found that visible equivalent veiling reflections fall well below the Hassall threshold of 500Cd/m^2.

Summary

The following table summarises the outcome of the reflectivity assessment for individual roads reviewed:

Ref. Letter	Road	Driving direction	Maximum Lv identified at 28% reflectivity	Note
A	Barangaroo Avenue	N	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
B	Barangaroo Avenue	S	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
C	Hickson Rd	S	1000 Cd/m^2	Reflections that occur are outside the cone of sensitive vision and can be mitigated using sun visor which is deemed acceptable by Hassall.
D	Kent St	S	890 Cd/m^2	Reflections that occur are outside the cone of sensitive vision and can be mitigated using sun visor which is deemed acceptable by Hassall.
E	Western Distributor	S	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
F	Grosvenor St	W	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
G	Margaret St – Napoleon St	W	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
H	Hickson Rd	N	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.
I	Waterman’s Quay	W	1730 Cd/m^2	Reflections expected to be obscured by landscaping and therefore not visible to driver.
J	Waterman’s Quay	E	<500 Cd/m^2	Not expected to result in unacceptable glare towards drivers.

Table 1: Summary of roads reviewed for sun reflections

4.2 Impact on Traffic in Other Locations

From further afield (e.g. on hill areas in other suburbs) it may be possible that other locations exist where the building can be seen from road level. These would however be at a distance where typical glazing surfaces of the building would subtend angles significantly smaller than the sun disk, and scattering effects from small misalignments (e.g. due to construction tolerances) would reduce the observable intensity of reflections, so that it is not expected to be high enough to create unacceptable glare.

4.3 Impact on Pedestrians

From the perspective of pedestrians moving along roadways, the incidence of reflections from the building is generally similar to the examined road traffic locations. Glare from reflections is therefore expected in similar locations.

Furthermore, pedestrian observers are easily able to adjust their view and thus reduce the glare impact of reflections. They move at a rate significantly slower than that of a vehicle. For this reason it can be assumed that it will be safe for pedestrians to divert their vision in order to avoid glare.

4.4 Impact on Air and Water Traffic

This report focuses on the impact of reflections on pedestrians and drivers. The effect of reflections on air and water has not been included in the assessment of this report.

In general, the visual task requirements of air and naval traffic operators differ from those of drivers, such that the methodology according to Hassall used in this report to assess reflections may not apply.

Air traffic to be considered would include airplanes travelling in the approach corridor towards Kingsford Smith airport from the north. Reflections from the building’s vertical facade of the sun above the horizon are generally directed downwards and will not affect airplanes travelling at heights above the building height.

While no water traffic routes directly lead towards the building, water traffic potentially affected by oblique reflections off the facades of Building R4B would include ferries and other vessels travelling into and out of Darling Harbour. Water traffic generally operates at lower speeds and densities than road traffic, making safety impact from reflections off the proposed building unlikely.

5 Conclusion

The proposed Building R4B performs well in terms of solar reflectivity, and glare affecting drivers on surroundings streets is not expected to exceed the constraints of acceptability according to the Hassall methodology, as long as the external normal specular reflectance of glazing and cladding is kept within **28%.**

Glare risks to drivers have been discounted for all façade aspects, for either of the following reasons:

- They do not reflect the sun towards traffic
- The intensity of any reflections will be below the limit of acceptability set out by Hassall (500 Cd/m²)
- Surrounding buildings and topology or other parts of the building itself will be blocking reflections that could cause glare to drivers; or
- The position of reflections within the visual field is not critical and would allow drivers to block with sun visor.

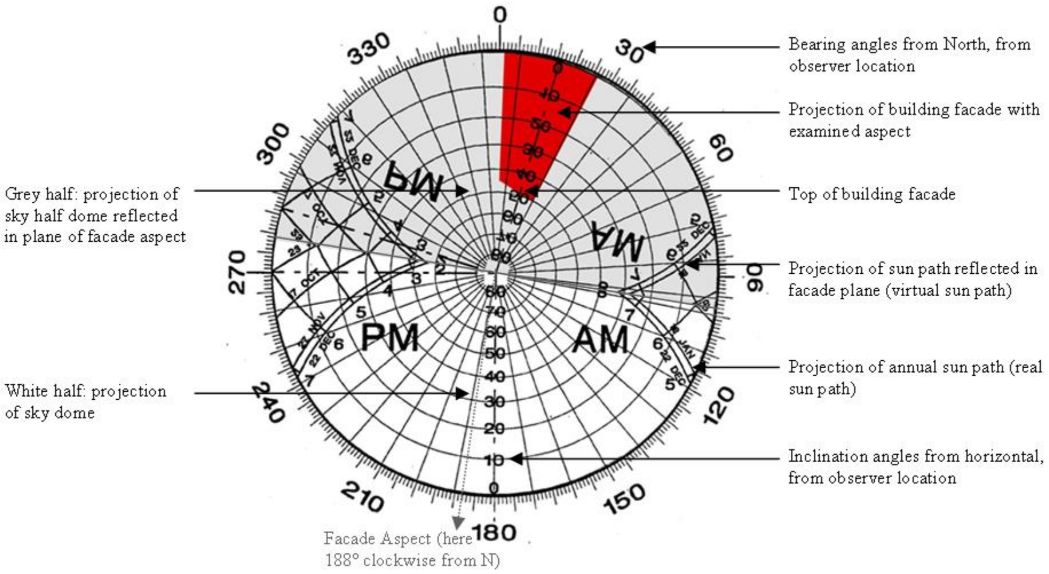
Pedestrian observers are easily able to adjust their view and thus reduce the glare impact of reflections. They move at a rate significantly slower than that of a vehicle. For this reason it can be concluded that it will be safe for pedestrians to divert their vision in order to avoid glare.

Appendix A

Notes on Diagrams

A1 Reading Virtual Sun Path Diagrams

These diagrams combine a projection of the sky dome with the sun's annual path across it with a projection of the sky and sun path as it would be reflected in an infinite plane with the aspect of the facade being examined. The building facade outline as seen from the observer location examined is then plotted onto the diagram. If the reflected sun path intersects the projection of the building facade, the sun would be reflected from this facade towards an observer at this location. The sun path marks indicating months and times of day provide an indication of the times at which reflections would be cast towards the observer.



Example virtual sun path diagram

Appendix B

Reference Information

B1 Architectural Drawings

The reflectivity study presented in this report was based on 3D model information provided by Renzo Piano Building Workshop through Lendlease on 23 June 2015 and the following drawings:

Drawing Number	Drawing Title
BR4B_ASD_PA1_0000	Title Sheet and Drawing List
BR4B_ASD_PA1_0001	Context Plan
BR4B_ASD_PA1_0002	Site Plan
BR4B_ASD_PA1_2000	Plan Ground Floor Level 00
BR4B_ASD_PA1_2001	Plan Podium Level P1
BR4B_ASD_PA1_2002	Plan Podium Level P2
BR4B_ASD_PA1_3001	Plan Lower Plate Level 01
BR4B_ASD_PA1_3002	Plan Lower Plate Level 02-03
BR4B_ASD_PA1_3004	Plan Lower Plate Level 04-19
BR4B_ASD_PA1_3020	Plan Plant Level 20
BR4B_ASD_PA1_3021	Plan Lower Plate Level 21-32
BR4B_ASD_PA1_3033	Plan Mid Plate Level 33
BR4B_ASD_PA1_3034	Plan Mid Plate Level 34-38
BR4B_ASD_PA1_3039	Plan Mid Plate Level 39
BR4B_ASD_PA1_3040	Plan Mid Plate Level 40-48
BR4B_ASD_PA1_3049	Plan Plant Level 49
BR4B_ASD_PA1_3050	Plan Mid Plate Level 50-55
BR4B_ASD_PA1_3056	Plan Penthouse Level 56
BR4B_ASD_PA1_3057	Plan Penthouse Level 57
BR4B_ASD_PA1_3058	Plan Roof Level 58
BR4B_ASD_PA1_4001	Elevation North-East (Park)
BR4B_ASD_PA1_4002	Elevation West (Barangaroo Ave)
BR4B_ASD_PA1_4003	Elevation South-East (Lift Lobby)
BR4B_ASD_PA1_4004	Elevation South (Waterman's Quay)
BR4B_ASD_PA1_5001	Overall Section AA
BR4B_ASD_PA1_5002	Overall Section BB

B2 References

Hassall, D. N. H. (1991): *Reflectivity. Dealing with Rogue Solar Reflections*, Faculty of Architecture, University of New South Wales, ISBN 0 646 07086 X