# Solar Photovoltaic (PV) Ready Building Design Guidelines

**Date – August 2022**
**Status – Version 1**

Kāinga Ora
Homes and Communities

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## Contents

# Introduction

This document provides guidelines for the design of Kāinga Ora buildings that are to include solar PV systems. It is provided as a resource to the Kāinga Ora Renewable Energy Trials and future versions, will be informed by learning from the trials. Note, this document does not currently constitute part of the Kāinga Ora performance requirements (M-134/ M-135).

Kāinga Ora development teams may wish to adopt solar ready design[1] for buildings that are not yet earmarked for solar. This will minimise installation cost and maximise the solar production potential of future solar installations. Some features, such as orientation or shading, cannot be modified later. Other features could involve prohibitive remedial work (such as roof reinforcements) before solar systems can be installed.

These guidelines provide both solar ready design requirements and requirements for actual solar PV installations.

The document seeks to highlight the key areas of consideration during the design of the building. It is not intended to be a detailed technical resource. It is expected that the design team would include suitably qualified and experienced experts in the relevant areas.

# PV/Roof Orientation

| Solar Ready Design | Solar Installation Design |
|---|---|
| The location of the building on the proposed site has been chosen to maximise the potential for solar generation throughout the year.Error! Bookmark not defined.<br><br>Solar PV arrays have been designated only for roofs with good year-round solar access.<br><br>Unrestricted solar access is likely to exist for the expected lifetime of the system (25yrs +).[2] | The building load profile has been obtained and the proposed array sized accordingly.<br><br>Solar PV arrays should ideally be north facing but east/west facing arrays are also possible.[5]<br><br>Systems facing more than 30° from north may require modelling to confirm their feasibility.<br><br>Solar PV arrays will usually be mounted flush to the roof, as most homes have a |

[1] Lisell, L., Tetreault, T. and Watson, A (2009) *Solar Ready Buildings Planning Guide*, Colorado: National Renewable Energy Laboratory.
https://www.energystar.gov/partner_resources/residential_new/related_programs/rerh
[2] Lunning Wende Associates Inc. (2010). *Solar Ready Building Design Guidelines* [Technical Report]. Minneapolis Saint Paul Solar Cities Program., 9

[5] Ibid

It should be possible to orient the PV array towards the north (or north-west/ north-east where possible). Arrays with modules facing between east and west can also provide beneficial characteristics. [3]

If a building is designed with sloping roofs, the roof space on the north facing slope has been optimised to fit the solar PV array/s. [4]

The tables in Appendices A & B illustrate the percentage of solar resource available for a variety of array orientations and azimuths in New Zealand.

roof pitch of ideally 20° to 30° (absolute minimum of 10°).

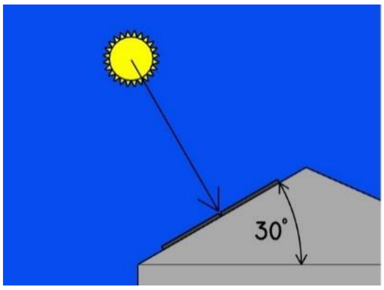


*Figure 1 Near-optimal tilt for year-round generation in New Zealand.*

This is near the optimum for year-long solar power generation[6] in New Zealand and recommended for stand-alone homes.

Tilt systems could be considered for apartments to optimise for seasonal performance and loads. (i.e. increase tilt to maximise winter generation).

Flush mounted arrays are less affected by shadowing from neighbouring modules and can be arranged more densely than tilted arrays. As a result, they may collectively output more energy than tilted arrays despite a lower output per module.

A tilt system is required for Solar PV arrays mounted on roofs with a pitch of less than 10° to ensure self-cleaning by rainfall. [7]

Where building orientation or space constraints exist, east/west facing arrays may also be feasible and provide a longer generation profile that is better matched to morning and afternoon peak load periods.[8]

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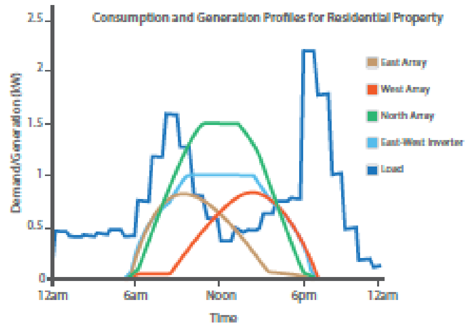
[3] *EastWest Arrays: Are they worth it?* (2015). [Technical Report]. GSES Global Sustainable Energy Solutions. https://www.gses.com.au/wp-content/uploads/2016/03/GSES_East-west-arrays.pdf
[4] Lisell et al., *Solar Ready Buildings Planning Guide*, 6
[6] Jacobson, M., & Jadhav, V. (2018). World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels. *Solar Energy*, *169*, 55–66.
[7] Global Sustainable Energy Solutions (2017). *Grid-connected PV Systems: Design and installation.*, 151
[8] Ibid, 227

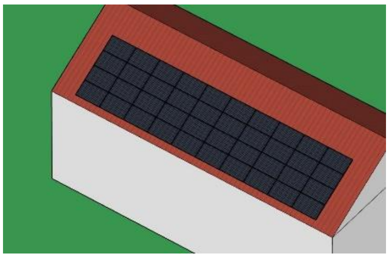
| | |
|---|---|
| |  <br>Figure 2 Comparison of generation profiles for PV array orientations. From EastWest Arrays: Are they worth it? (2010)[9] |

# Shading

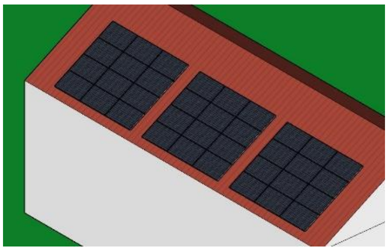
| Solar Ready Design | Solar Installation Design |
|---|---|
| The shadowing effects of complicated roof angles have been factored into the roof design for north facing surfaces and will not impact the proposed array.<br><br>The roof design avoids structures or equipment that might shade the PV array such as high parapets, aerials or roofs to the north that are higher than roofs to the south. [10]<br><br>Landscaping and future construction planned for the site should avoid shading of any north facing rooftops. | Avoid any shading of the solar array from trees and adjacent buildings and topography. Even small amounts of shading, particularly during peak sunlight hours (9am-3pm) can dramatically reduce the system performance.**Error! Bookmark not defined.**<br><br>Be mindful of vertical features or equipment on the roof such as poles and antennae that might cast shadow on the array during peak sunlight hours. |

# Roof Layout

[9] GSES Global Sustainable Energy Solutions. (2015)
[10] New Zealand, & Ministry of Business, I. & E. (2012). *Best practice guidelines for working at height in New Zealand.* Watson, A., Giudice, L., Lisell, L., Doris, L., & Busche, S. (2012). *Solar Ready: An Overview of Implementation Practices* (Technical Report SM10.17X6; p. 42). NREL, U.S. Department of Energy.

| Solar Ready Design | Solar Installation Design |
|---|---|
| The roof has been designed with a safe and convenient access point to facilitate the safe movement of installers, inspectors and maintenance personnel.<br><br>Rooftop equipment is minimised on north facing roofs to allow more space for the PV array.**Error! Bookmark not defined.**<br><br>The allocated space is free of obstructions and the presence of a PV array will not impede natural drainage.[11]<br><br>DC cable routes have been identified and documented. | The aesthetic impact of the PV Panel layout on the roof needs to be considered as part of the design. A symmetrical configuration will have a more pleasing appearance [12].<br><br>Where possible, conduit and cable runs should be concealed.<br><br>Flush mounted arrays usually detract less from the appearance of the roof than tilted arrays and experience less wind loading.[13]<br><br>Adequate clearance (>0.5m) is provided around minor roof features such as skylights and air vents.<br><br>The array does not impede natural drainage channels, nor does it obstruct cleaning of the roof surface. [14]<br><br>Vertical features or equipment are grouped together and located far enough from the array to reduce the risk of shadowing.<br><br>The array layout is not so densely packed that access to any individual PV module requires the removal of many other modules.<br><br><br><br>*Figure 3 PV modules packed too closely for safe access and efficient maintenance.* |

[11] *NZ Metal Roof and Wall Cladding Code of Practice* (Version 2.2, p. 380). (2012). NZ Metal Roofing Manufacturers Inc.
[12] BRE and CPRE (2016) *Ensuring place-responsive design for solar photovoltaics on buildings - A good practice guide for designers, manufacturers, and installers*. Eds J. Williams and K. Hagen.
[13] Global Sustainable Energy Solutions (2017)., 150
[14] *NZ Metal Roof and Wall Cladding Code of Practice* (Version 2.2, p. 380). (2012). NZ Metal Roofing Manufacturers Inc.

| | |
|---|---|
| | Instead, sub-arrays and strings are grouped into smaller units with space on both sides for easy access and movement around by installers and maintenance personnel.  *Figure 4 Larger array split to allow access by maintenance personnel.* |

# Array Mounting

| Solar Ready Design | Solar Installation Design |
|---|---|
| The suitability of the roof for PV mounting systems has been investigated and the estimated weight allowed for.[15] The findings have been documented.<br><br>If a mechanically fixed mounting system is deemed necessary to fix a membrane roof, mounting hardware/plinths will be installed at the time of roof construction.[16] | Frame mounted systems are usually mechanically fixed to the roof structure, requiring penetration of the roof cladding with bolts or screws.<br><br>This can increase the risk of water leaking into the building and void the roof warranty.[17] The designers should coordinate with the roofing supplier to ensure a compatible fixing is selected so as to not void the warranty.<br><br>Some frames can be mounted on non-penetrating clamps where a compatible roof type has been specially selected. [18]<br><br>Ballasted systems are best suited to strong flat roofs and remove the need for penetrations at the cost of extra weight loading of the roof structure. [19]<br><br>Ballasted systems can greatly increase the dead load on the structure of the roof, and cause sagging that can lead to the pooling of water on flat roofs. |

[15] Lisell et al., *Solar Ready Buildings Planning Guide*, 14
[16] Ibid, 4
[17] Photovoltaic (PV) design (BRANZ FACTS: Sustainable Construction #2). (2018). BRANZ., 5 https://www.branz.co.nz/pubs/branz-facts/sustainability-construction/2-photovoltaic-design/
[18] Global Sustainable Energy Solutions (2017). *Grid-connected PV Systems: Design and installation*., 157
[19] Ibid, 154

# Structural

| Solar Ready Design | Solar Installation Design |
| --- | --- |
| Adequate provision for expected roof loading has been incorporated into the roof design with respect to 'dead weight', wind loading and the effects of seismic activity. Refer to AS/NZS1170 series of standards for all structural design requirements.<br><br>Roofs need to be able to support the weight of solar PV equipment – generally around 10-20 kg/$m^2$.[20]<br><br>Tile roofs should be avoided, as they present challenges for installing a solar array.**Error! Bookmark not defined.** . | Ensure that the roof structure and solar array mountings can withstand expected wind, dead and seismic loads.[21] This is particularly the case with rack mounted arrays, which can introduce additional sheer and normal forces and bending moments to the roof structure.<br><br>Steel roofing materials will require a proportion of the roof to be exposed to rain to prevent the build-up of corrosive deposits from the air.[22]<br><br>The design has been checked so that frames and racking systems are not installed across expansion joints. [23] |

# Access for Safe Installation and Maintenance

| Solar Ready Design | Solar Installation Design |
| --- | --- |
| A clear section of roof is reserved for an appropriately sized PV array with adequate space for installation crews and their equipment.[24]<br><br>The reserved space is free of obstacles and includes space for safe and efficient | All PV System components installed must comply with Kāinga Ora Product Performance Requirements (M-135).<br><br>Solar PV arrays will ideally be mounted with a minimum of 2m to the roof edge.<br><br>Safe access routes to the roof, and around the array shall be provided including fall |

[20] Lisell et al., *Solar Ready Buildings Planning Guide*, 14
[21] BRANZ (2018), 4
[22] NZ Metal Roofing Manufacturers Inc., (2012)
[23] Lunning Wende Associates Inc. (2010). *Solar Ready Building Design Guidelines* [Technical Report]. Minneapolis Saint Paul Solar Cities Program.
[24] Lisell et al., *Solar Ready Buildings Planning Guide*, 3

| | |
|---|---|
| movement by maintenance staff and emergency personnel.[25]<br><br>Provision is made for the installation of a safety access systems which may include permanent proprietary anchor points for static safety lines.[26] | restraint and arrest systems to allow safe installation and maintenance of the PV array.[27]<br><br>Strings of modules are restricted to groupings of no more than three modules in width to allow easy access for maintenance.<br><br>A space of 0.5-1.0m should be allowed between sub-array groupings to enable easy movement around the array.<br><br>The design process should include a complete safety assessment for installation and maintenance, considering:<br>• roof edge protection/scaffolding.<br>• safe access to, and movement around the roof.<br>• instructions on how to safely isolate the system.<br>• the accessibility of the inverter to non-authorised people<br>• Ability for emergency responders to identify that there is a PV array and safety disconnect it. |

# Cable Route

| Solar Ready Design | Solar Installation Design |
|---|---|
| Cable management needs to be routed from the solar PV system to the inverter location and from the inverter to the distribution board(s). These pathways are included in the building design.<br><br>The cable routes are as short as possible to minimise voltage losses. | DC cables are required to be run in HD conduit to the requirements of AS/NZS 5033.<br><br>Roof penetrations for DC cables should be minimised, but multiple penetrations may be necessary to achieve the most direct |

[25] Ibid, 3
[26] Ibid, 13
[27] New Zealand, & Ministry of Business, I. & E. (2012). *Best practice guidelines for working at height in New Zealand., 20*

| | |
|---|---|
| Cable containment must meet the requirements of the relevant electrical standards.<br><br>Prewiring of oversized cables has been considered to allow for system upgrades in the future. [28]<br><br>Similarly, AC cable routes from the inverter location to the Solshare unit (if appropriate) and main distribution board should be designated and proposed cable routes documented. | route to the inverter if located inside the building.<br><br>Conduit should be elevated at least 100mm above the surface of the roof to allow for drainage and cleaning of the roof surface.[29]<br><br>Combiner boxes and Array Disconnection switches are well protected from sunlight and rain. |

# Equipment Space

| Solar Ready Design | Solar Installation Design |
|---|---|
| Allow for a suitably sized, shaded, and secure space for an inverter near the distribution board (estimated at 1.3m x 1.3m, at least 1m above the floor for domestic sized inverters).[30]<br><br>More space may be required for larger arrays. Where the inverter is not designed for external installation it must be located inside the building.<br><br>If wall mounted, the designated wall must be able to support the inverter's full weight.<br><br>Inverters are noisy and if located inside the building should be positioned where they will not cause nuisance to building occupants.**Error! Bookmark not defined.**<br><br>Space has been allowed for future upgrades or system expansion, such as | Inverters should be located out of the sun, in a position that is accessible for maintenance and where they will not cause a noise nuisance to building occupants. The location should also be chosen to minimise the risk of tampering/ vandalism.<br><br>A suitable inverter housing will allow for adequate ventilation to prolong the life of the inverter.<br><br>The inverter should be well clear of all other equipment and obstructions and not be mounted so high on the wall as to require a ladder to reach. **Error! Bookmark not defined.**<br><br>The inverter manufacturer will specify the clearance space required around their specific product. |

[28] BRANZ (2018), 5
[29] Global Sustainable Energy Solutions (2017). *Grid-connected PV Systems: Design and installation.*, 357
[30] https://basc.pnnl.gov/resource-guides/inverter-meter-and-shut-mounting-surface-solar-pv-systems#edit-group-description

related Solshare equipment and distribution boards.

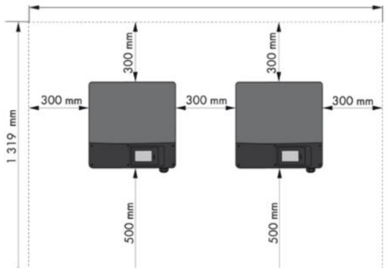



*Figure 5 Example of spacing recommended for SMA wall mounted inverters. From https://www.sma-sunny.com[31]*

Space adjacent to the inverter must also be allocated for AC and DC disconnectors, where required.

*Figure 6 AC and DC disconnectors installed next to a wall mounted inverter.*

[31] https://www.sma-sunny.com/en/service-tip-give-it-space/

# Distribution Board and Metering

| Solar Ready Design | Solar Installation Design |
|---|---|
| Ensure the distribution board is adequately sized to accommodate a future PV system and that it includes space for a PV circuit breaker and any metering required (e.g. by Solshare).<br><br>Utility metering should be centrally located.<br><br>Apartment buildings with more than six units may consider future installation of an Allume Solshare unit to distribute the solar electricity between the homes. In this case, space needs to be provided to mount the Solshare unit/s near the main switchboard.<br><br>Consultation has been carried out with Kāinga Ora Renewable Energy Team and where necessary, the Allume Solshare installation manual consulted for guidance. | Metering should be centralised and the system connected to suit the configuration.<br><br>Where a Solshare unit is to be installed refer to the manufacturer's guidance documentation.<br><br>Solshare units should be located adjacent to the main distribution board to ensure a reliable connection for power cables and measuring devices.<br><br>Connection should be allowed to each apartment and the common services (if possible).<br><br>Sufficient space should be allowed for the CT clamps and additional circuit breakers required by the Solshare unit. |

# Roof Warranty

| Solar Ready Design | Solar Installation Design |
|---|---|
| The expected lifetime of the roof should exceed the expected lifetime of the proposed solar array.<br><br>Select a roof system that is compatible with the future installation of a solar array.[32]<br><br>The roof system chosen may determine whether roof penetrations are needed to mount the panels, which could void the roof warranty. | Ensure that the solar PV roof mounting system chosen is fully compatible with the roofing system and will not affect the roof warranty contract terms.[33]<br><br>Ensure the array is installed correctly to allow cleaning and maintenance requirements of the roof in order to meet the roof warranty requirements.<br><br>A minimum spacing of PV modules > 100mm above the surface of the roof will ensure accessibility for water run-off and |

[32] Bauder (2019) *PV Design Considerations Flat Roofs*, United Kingdom.
[33] BRANZ (2018), 5

| | |
|---|---|
| | scheduled roof cleaning.[34] Some roof manufacturers may prefer to see 200mm clearance.<br><br>Tilted array frame systems will facilitate roof cleaning.<br><br>A roof washing methodology should be prepared with the roof maintenance contractor that allows for cleaning of the array under the PV modules. |

# Resource Consent

| Solar Ready Design | Solar Installation Design |
|---|---|
| Resource consent may be required depending on the local district plan:<br>• In areas with special interest or heritage zones.<br>• If the additional height of future solar arrays will impinge on height-to-boundary restrictions.[35]<br><br>Building consent may be required by some local authorities. Building consent will always be required where the array is to be incorporated into the roof cladding. | Consent requirements have been checked and if necessary, the appropriate resource and building consent have been obtained. |

[34] *NZ Metal Roof and Wall Cladding Code of Practice* (Version 2.2, p. 380). (2012). NZ Metal Roofing Manufacturers Inc.
[35] https://www.aucklandcouncil.govt.nz/building-and-consents/building-renovation-projects/heat-your-home/install-photovoltaic-solar-panels/Pages/check-consent-install-photovoltaic-solar-panels.aspx

# Appendix A – National average radiation as proportion of maximum

| | Direction | Inclination angle | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0° | 20° | 40° | 60° | 80° | 90° |
| West | 270° | 0.85 | 0.85 | 0.80 | 0.72 | 0.60 | 0.53 |
| | 300° | 0.85 | 0.92 | 0.92 | 0.86 | 0.73 | 0.65 |
| | 330° | 0.85 | 0.98 | 0.99 | 0.93 | 0.80 | 0.71 |
| True north | 0° | 0.85 | 0.97 | 1.00 | 0.94 | 0.80 | 0.70 |
| | 30° | 0.85 | 0.94 | 0.95 | 0.88 | 0.74 | 0.65 |
| | 60° | 0.85 | 0.88 | 0.86 | 0.77 | 0.65 | 0.57 |
| East | 90° | 0.85 | 0.80 | 0.73 | 0.64 | 0.52 | 0.46 |

Ideal orientation

Good orientation

Poor orientation

*From Photovoltaic (PV) design* (BRANZ FACTS: Sustainable Construction #2). 2018[36]

[36] *Photovoltaic (PV) design* (BRANZ FACTS: Sustainable Construction #2). (2018). BRANZ. https://www.branz.co.nz/pubs/branz-facts/sustainability-construction/2-photovoltaic-design/

# Appendix B – Auckland average radiation as percentage of maximum

| | | Plane inclination | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Azimuth | 0 | 96% | 99% | 100% | 99% | 97% | 92% | 87% | 79% | 70% | 60% |
| | 10 | 96% | 98% | 99% | 98% | 96% | 91% | 85% | 78% | 69% | 60% |
| | 20 | 96% | 98% | 98% | 97% | 94% | 90% | 84% | 77% | 69% | 59% |
| | 30 | 96% | 97% | 97% | 96% | 93% | 88% | 82% | 76% | 67% | 59% |
| | 40 | 96% | 97% | 96% | 94% | 91% | 86% | 80% | 74% | 66% | 58% |
| | 50 | 96% | 96% | 95% | 92% | 89% | 84% | 78% | 72% | 65% | 57% |
| | 60 | 96% | 95% | 93% | 90% | 86% | 82% | 76% | 70% | 63% | 56% |
| | 70 | 96% | 94% | 91% | 88% | 84% | 79% | 73% | 67% | 61% | 54% |
| | 80 | 96% | 93% | 90% | 86% | 81% | 76% | 70% | 64% | 58% | 52% |
| | 90 | 96% | 92% | 88% | 83% | 78% | 73% | 67% | 61% | 55% | 49% |
| | 100 | 96% | 91% | 86% | 80% | 75% | 69% | 64% | 58% | 52% | 46% |
| | 110 | 96% | 90% | 84% | 78% | 72% | 66% | 60% | 54% | 49% | 43% |
| | 120 | 96% | 89% | 83% | 75% | 69% | 62% | 56% | 50% | 45% | 40% |
| | 130 | 96% | 89% | 81% | 73% | 66% | 59% | 52% | 47% | 42% | 37% |
| | 140 | 96% | 88% | 80% | 71% | 63% | 55% | 49% | 43% | 39% | 34% |
| | 150 | 96% | 88% | 79% | 70% | 61% | 53% | 46% | 40% | 36% | 32% |
| | 160 | 96% | 88% | 78% | 68% | 59% | 51% | 44% | 37% | 33% | 30% |
| | 170 | 96% | 88% | 78% | 68% | 59% | 50% | 43% | 36% | 32% | 29% |
| | 180 | 96% | 88% | 78% | 68% | 59% | 51% | 43% | 37% | 32% | 29% |
| | 190 | 96% | 88% | 79% | 69% | 60% | 52% | 44% | 38% | 33% | 30% |
| | 200 | 96% | 88% | 80% | 71% | 62% | 54% | 47% | 40% | 36% | 32% |
| | 210 | 96% | 89% | 81% | 73% | 64% | 56% | 50% | 44% | 39% | 35% |
| | 220 | 96% | 90% | 83% | 75% | 67% | 60% | 54% | 48% | 43% | 38% |
| | 230 | 96% | 91% | 84% | 78% | 71% | 64% | 58% | 52% | 47% | 42% |
| | 240 | 96% | 91% | 86% | 81% | 75% | 69% | 63% | 57% | 51% | 46% |
| | 250 | 96% | 92% | 88% | 83% | 78% | 73% | 67% | 61% | 55% | 50% |
| | 260 | 96% | 93% | 90% | 86% | 82% | 77% | 71% | 66% | 59% | 53% |
| | 270 | 96% | 94% | 92% | 89% | 85% | 80% | 75% | 69% | 63% | 56% |
| | 280 | 96% | 95% | 94% | 91% | 88% | 83% | 78% | 72% | 66% | 59% |
| | 290 | 96% | 96% | 95% | 93% | 90% | 86% | 81% | 75% | 68% | 61% |
| | 300 | 96% | 97% | 97% | 95% | 93% | 89% | 83% | 77% | 70% | 62% |
| | 310 | 96% | 98% | 98% | 97% | 94% | 91% | 85% | 79% | 71% | 63% |
| | 320 | 96% | 98% | 99% | 98% | 96% | 92% | 86% | 80% | 72% | 63% |
| | 330 | 96% | 98% | 99% | 99% | 97% | 93% | 87% | 80% | 72% | 63% |
| | 340 | 96% | 99% | 100% | 99% | 97% | 93% | 88% | 80% | 72% | 62% |
| | 350 | 96% | 99% | 100% | 99% | 97% | 93% | 87% | 80% | 71% | 61% |

1. Auckland average annual in plane radiation as percentage of maximum.

| | | Plane inclination | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Azimuth | 0 | 100% | 98% | 95% | 90% | 84% | 76% | 67% | 58% | 48% | 37% |
| | 10 | 100% | 98% | 94% | 89% | 83% | 75% | 67% | 57% | 48% | 37% |
| | 20 | 100% | 98% | 94% | 89% | 82% | 75% | 67% | 58% | 48% | 39% |
| | 30 | 100% | 97% | 94% | 89% | 82% | 75% | 67% | 59% | 50% | 41% |
| | 40 | 100% | 97% | 93% | 88% | 82% | 75% | 67% | 59% | 51% | 43% |
| | 50 | 100% | 97% | 93% | 88% | 81% | 75% | 68% | 60% | 52% | 45% |
| | 60 | 100% | 96% | 93% | 87% | 81% | 75% | 68% | 60% | 53% | 46% |
| | 70 | 100% | 96% | 92% | 87% | 81% | 74% | 68% | 61% | 54% | 47% |
| | 80 | 100% | 96% | 92% | 86% | 80% | 74% | 67% | 61% | 54% | 47% |
| | 90 | 100% | 96% | 91% | 85% | 79% | 73% | 67% | 60% | 53% | 47% |
| | 100 | 100% | 96% | 91% | 85% | 78% | 72% | 65% | 59% | 52% | 46% |
| | 110 | 100% | 96% | 90% | 84% | 77% | 70% | 63% | 57% | 51% | 45% |
| | 120 | 100% | 96% | 90% | 83% | 76% | 68% | 61% | 55% | 48% | 43% |
| | 130 | 100% | 96% | 89% | 82% | 75% | 67% | 59% | 52% | 46% | 41% |
| | 140 | 100% | 96% | 89% | 82% | 74% | 65% | 57% | 50% | 44% | 38% |
| | 150 | 100% | 96% | 90% | 82% | 74% | 64% | 55% | 47% | 41% | 36% |
| | 160 | 100% | 96% | 90% | 83% | 74% | 64% | 54% | 44% | 37% | 33% |
| | 170 | 100% | 96% | 90% | 83% | 75% | 65% | 55% | 43% | 36% | 32% |
| | 180 | 100% | 96% | 91% | 84% | 75% | 66% | 56% | 44% | 36% | 32% |
| | 190 | 100% | 96% | 91% | 85% | 76% | 67% | 57% | 46% | 38% | 33% |
| | 200 | 100% | 96% | 92% | 85% | 77% | 68% | 58% | 48% | 41% | 36% |
| | 210 | 100% | 97% | 92% | 86% | 78% | 70% | 60% | 52% | 45% | 40% |
| | 220 | 100% | 97% | 93% | 87% | 80% | 72% | 63% | 56% | 49% | 43% |
| | 230 | 100% | 97% | 93% | 88% | 81% | 74% | 67% | 59% | 53% | 47% |
| | 240 | 100% | 98% | 94% | 89% | 83% | 77% | 70% | 63% | 56% | 49% |
| | 250 | 100% | 98% | 95% | 90% | 85% | 78% | 72% | 65% | 59% | 52% |
| | 260 | 100% | 98% | 95% | 91% | 86% | 80% | 74% | 67% | 60% | 53% |
| | 270 | 100% | 98% | 96% | 92% | 87% | 81% | 75% | 68% | 61% | 54% |
| | 280 | 100% | 99% | 96% | 93% | 88% | 82% | 76% | 69% | 62% | 54% |
| | 290 | 100% | 99% | 96% | 93% | 88% | 82% | 76% | 69% | 61% | 54% |
| | 300 | 100% | 99% | 96% | 93% | 88% | 82% | 75% | 68% | 60% | 52% |
| | 310 | 100% | 99% | 96% | 93% | 88% | 82% | 74% | 67% | 59% | 50% |
| | 320 | 100% | 99% | 96% | 93% | 87% | 81% | 74% | 65% | 56% | 48% |
| | 330 | 100% | 99% | 96% | 92% | 86% | 80% | 72% | 63% | 54% | 44% |
| | 340 | 100% | 99% | 96% | 91% | 85% | 78% | 70% | 61% | 51% | 41% |
| | 350 | 100% | 98% | 95% | 91% | 85% | 77% | 68% | 59% | 49% | 39% |

## 2. Auckland average January in plane radiation as percentage of maximum.

| | | Plane inclination | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Azimuth | 0 | 68% | 77% | 85% | 92% | 96% | 99% | 100% | 97% | 94% | 87% |
| | 10 | 68% | 76% | 85% | 91% | 96% | 98% | 98% | 96% | 92% | 85% |
| | 20 | 68% | 76% | 83% | 89% | 94% | 96% | 96% | 93% | 89% | 82% |
| | 30 | 68% | 75% | 82% | 87% | 90% | 91% | 90% | 88% | 83% | 76% |
| | 40 | 68% | 74% | 79% | 83% | 85% | 86% | 84% | 82% | 76% | 70% |
| | 50 | 68% | 73% | 76% | 79% | 80% | 80% | 78% | 75% | 70% | 64% |
| | 60 | 68% | 71% | 73% | 75% | 75% | 74% | 72% | 68% | 64% | 58% |
| | 70 | 68% | 68% | 69% | 70% | 69% | 68% | 65% | 61% | 58% | 53% |
| | 80 | 68% | 67% | 66% | 65% | 64% | 61% | 59% | 55% | 51% | 46% |
| | 90 | 68% | 65% | 62% | 61% | 58% | 55% | 53% | 49% | 45% | 40% |
| | 100 | 68% | 63% | 59% | 55% | 53% | 49% | 46% | 42% | 39% | 35% |
| | 110 | 68% | 61% | 55% | 51% | 47% | 44% | 39% | 37% | 33% | 30% |
| | 120 | 68% | 59% | 52% | 46% | 42% | 38% | 34% | 31% | 28% | 25% |
| | 130 | 68% | 58% | 49% | 42% | 37% | 32% | 30% | 26% | 25% | 22% |
| | 140 | 68% | 56% | 46% | 39% | 32% | 28% | 25% | 24% | 22% | 20% |
| | 150 | 68% | 55% | 44% | 35% | 29% | 25% | 24% | 23% | 21% | 19% |
| | 160 | 68% | 54% | 42% | 32% | 26% | 25% | 24% | 23% | 21% | 19% |
| | 170 | 68% | 54% | 40% | 30% | 26% | 25% | 24% | 23% | 21% | 19% |
| | 180 | 68% | 54% | 40% | 29% | 26% | 25% | 24% | 23% | 21% | 19% |
| | 190 | 68% | 54% | 40% | 30% | 26% | 25% | 24% | 23% | 21% | 19% |
| | 200 | 68% | 54% | 42% | 32% | 26% | 25% | 24% | 23% | 21% | 19% |
| | 210 | 68% | 55% | 44% | 35% | 29% | 25% | 24% | 23% | 21% | 19% |
| | 220 | 68% | 57% | 46% | 39% | 33% | 29% | 26% | 24% | 22% | 20% |
| | 230 | 68% | 58% | 50% | 43% | 38% | 34% | 31% | 28% | 25% | 23% |
| | 240 | 68% | 60% | 54% | 47% | 43% | 39% | 36% | 33% | 30% | 27% |
| | 250 | 68% | 62% | 57% | 53% | 48% | 46% | 42% | 39% | 36% | 32% |
| | 260 | 68% | 64% | 61% | 57% | 54% | 52% | 48% | 46% | 42% | 38% |
| | 270 | 68% | 66% | 64% | 62% | 61% | 58% | 55% | 52% | 48% | 44% |
| | 280 | 68% | 68% | 68% | 68% | 67% | 64% | 61% | 59% | 54% | 50% |
| | 290 | 68% | 70% | 71% | 72% | 72% | 71% | 68% | 65% | 61% | 56% |
| | 300 | 68% | 72% | 75% | 77% | 78% | 77% | 75% | 72% | 68% | 61% |
| | 310 | 68% | 74% | 78% | 82% | 83% | 83% | 82% | 79% | 74% | 68% |
| | 320 | 68% | 75% | 81% | 85% | 88% | 89% | 88% | 85% | 81% | 74% |
| | 330 | 68% | 75% | 82% | 89% | 92% | 94% | 93% | 91% | 86% | 80% |
| | 340 | 68% | 76% | 84% | 90% | 95% | 97% | 97% | 95% | 90% | 84% |
| | 350 | 68% | 77% | 85% | 92% | 96% | 99% | 99% | 97% | 93% | 87% |

## 3. Auckland average July in plane radiation as percentage of maximum.