TENSYS

SolPod – Guide to Structural Adequacy

DG100 – Version 1.0

Prepared for Solpod

Project Number PE0624

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REVISION HISTORY

	Prepared by	Revision Date	Revision
v0.1	Nicholas Barbaro	26th Mar 2020	Initial draft
v0.2	Nicholas Barbaro	29th Apr 2020	Revised to incorporate Gamcorp initial feedback
V1.0	Nicholas Barbaro	6th August 2020	Revised with MEL Consultant Feedback

1 INTRODUCTION

1.1 This Guide

Placing solar panels on a roof has an effect on the underlying structure both by adding mass to the roof framing and altering the wind loads on the structure roof. There is limited guidance in Australian codes for the effects of wind loading coefficients on solar panels, with the main guidance being in Appendix D6 of AS/NZS 1170.2:2011. Generally the Code derived loads are quite conservative and more accurate, refined loads can be achieved through undertaking wind tunnel testing.

Wind loading for solar panels has been derived with the assistance of the wind tunnel test undertaken by MEL Consulting (refer Appendix A of this report). MEL Consulting regularly undertake wind tunnel testing throughout Australia and overseas, and thus it is prudent and good practice to base designs and reviews on the outcomes of wind tunnel testing.

The commentary in the report is that the structure would be considered suitable for a "typical warehouse building", ie a structure with a very large surface area in comparison to the surface area of an individual panel, as opposed to a smaller residential building (to which the provisions in Appendix D6 of AS/NZS 1170.2 wind code provisions are more relevant). The typical testing parameters are shown in Figure 1 and 2 below, adapted from Figure 1a of Appendix A (wind tunnel test report).

The analysis and design of the Solpods, along with review of existing buildings, can be based on the results of this wind tunnel test provided the building is considered within the valid bounds of the testing parameters. These bounds are outlined in Section 2 of this report and are based on code values and advice from MEL Consulting.

This Design Guide intends to provide Structural Engineers and Solpod customers a basis for interpreting the Wind Tunnel Tests and the typical process in verifying the structural adequacy of their roof.

1.2 Disclaimer

This report is intended to be read and utilised by a qualified, experienced structural engineer with the knowledge and understanding of steel-framed structures, structural analysis and an understanding of the relevant Codes, Standards and Practices.

While it is intended to serve as a checklist, each structural review should be treated uniquely and additional verification may be required. This is not a prescriptive or exhaustive guide and reasonable engineering judgement should be used as required.

In a large number of cases, full structural documentation may not be provided or visible. As far as is reasonably possible, guidance on existing structure or proprietary products should be based on documentation. Where this documentation is not available, site measurements and relevant Codes and Standards should be used in preparing assumptions on elements, loading and properties.

This Design Guide covers the most typical structure type – Solpod panel arrays fixed using proprietary clamps or tape, on a steel framed roof. Such a roof would typically consist of thin metal sheeting compliant with AS 1562.1, supported by lightweight steel battens or purlins, supported by a series of beams, rafters and columns. Various other roofing conditions may apply (such as anchor studs to a concrete roof or plant deck). These will require a specific certification and the recommendations outlined in this Design Guide may not be valid.

1.3 Design Codes & Aids

The design process for structures such as these shall be carried out using the following design codes and aids:

- Building Code of Australia (BCA): NCC 2016 vol 1 – National Construction Code 2016 incorporating amendment no.1 section B
- AS/NZS 1170.0:2002 – Structural Design Actions Part 0: General Principles.
- AS/NZS 1170.1:2002 – Structural Design Actions Part 1: Permanent, Imposed and Other Actions.
- AS/NZS 1170.2:2011 (R2016) – Structural Design Actions Part 2: Wind Actions
- AS4100:1998 (R2016) – Steel Structures
- AS 1562.1:2018 – Design and installation of sheet roof and wall cladding Part 1: Metal
- Wind tunnel Measurements of Pressures on Solar Panel Arrays – Report 53-18-WT-PRE-00 Rev 0, prepared by MEL Consultants on 11 April 2018. – Refer Appendix A
- Proprietary structural design and installation manuals for products such as Cladding, Clamps, Purlins

2 BASIS OF WIND LOADS AND BUILDING APPLICABILITY

2.1 Building Geometries

The example warehouse building has the following parameters as defined in the wind tunnel report prepared by MEL Consultants:

Warehouse Building

Site Locations:	Light industrial estate, TC3 approach wind conditions
	Greenfield site, TC2 approach wind conditions
Aspect Ratio:	2:1 aspect ratio (length:width)
Building Size:	180m x 90m x 14m (at roof apex) [2 : 1 : 0.155]$_{apex}$ 180m x 90m x 10m (at eave height) [2 : 1 : 0.111]$_{eave}$
Scale Model size	1:75
Roof Pitch angle :	~3^0

Figure 1: Section 2.1 of MEL Report outlining design parameters

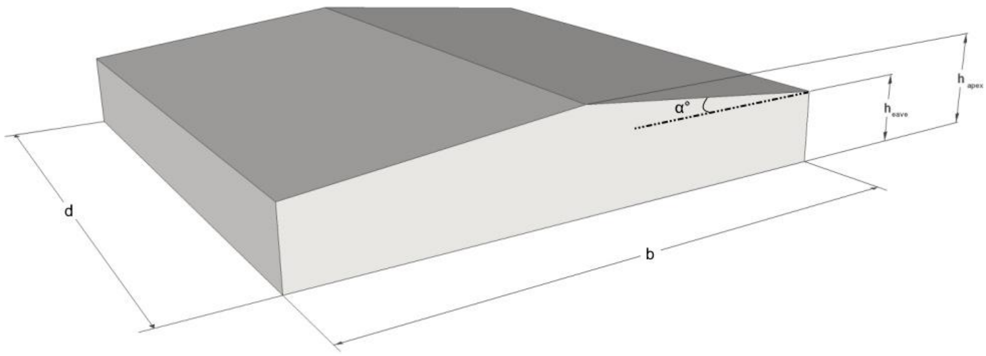
The commentary in the report is that the structure would be considered suitable for a “typical warehouse building”, ie a structure with a very large surface area in comparison to the surface area of an individual panel, as opposed to a smaller residential building (to which the AS/NZS 1170.2 wind code provisions are more relevant). These buildings are assumed to be closed and mostly impermeable in a high-wind event. There should be no permanent, dominant openings. All openings such as roller doors and access hatches are assumed to be closed in a critical wind event. The dimensions are as shown in figure 2, where depth ‘d’ runs parallel to the ridge line.

A typical warehouse building is short and squat with a h/d ratio < 0.5, with a minimal roof pitch (<5%). Generally, where h/d > 0.25, the wind uplift on the roof is increased due to the flow pattern over and around such buildings. The wind tunnel test is not appropriate for these taller, more slender buildings.

For buildings with d/b ratios between around 0.75-4, it is expected that wind flow over the roof will be unchanged. For “long” buildings with d/b > 4, there will be additional effects from frictional drag. This is in accordance with Section 5.5 of AS/NZS 1170.2.

Self-weight deflection from Solpod panels on typical roof sheeting is generally no more than 5mm over a span of 1.2-1.8m. This deflection results in a rotation of less than 1°. As typical roof sheeting minimum slopes are 2-3° this additional deflection is not seen as problematic but should still be reviewed for serviceability and ponding. This is outlined in Section 4. Some roofing profiles allow slopes below 2° and even as low as 1°. While installation on a roof pitch of 1° is, it is not recommended without a significant ponding assessment being undertaken.

For roof sheeting angles above 5°, AS/NZS 1170.2 indicates that the behaviour under wind loading will begin to vary. As such, a typical valid range of roof sheeting pitch is 2°-5°. For roof pitches above 5° the Solpod arrangement should be independently reviewed as additional lateral/sliding loads may be applied.



NOTE: $d \geq b, h = \frac{1}{2}(h_{eave} + h_{apex})$

Figure 2: Building Design Parameters (Adapted from Figure 1a of MEL Wind Tunnel Test)

PARAMETER	**MINIMUM**	**MAXIMUM**	**REMARKS**
d/b	0.75	N/A (No Limit)	For long buildings (d/b > 4), consideration should be made to skin friction on the panels and roof surface however typically this is no different to the typical friction on the roof.
h/d, h/b	H >= 5m	0.25	For smaller buildings, h/d can be <0.5 with caution – contact a wind engineer for specialist consideration.
Roof angle α°	1°	5°-10°	Where pitch exceeds 5°, Solpod and fixings must be independently reviewed. For low pitches, extra consideration shall be taken to deflection and risk of ponding.

2.2 Solpod Arrangements

A Solpod panel layout should be generally uniform. A single panel or series of intermittent panels could cause stress concentrations due to the variation in the sail area profile of the roof. As such, Solpod panels should be installed in arrays with minimum 4 panels.

Walkway gaps between panels should typically be kept to a minimum of 300 mm for access, and a maximum of 2m (one panel width).

Where a single panel is installed, or panels are spaced further apart than ‘typical access zones’ as above, all Solpod units should be considered ‘Edge’ zones for the purposes of loading and thus treated with higher wind loads (Refer Section 2.5).

Solpod panels are to be installed as per Figure B1, Appendix B of the wind tunnel report. As per advice from MEL Consultants, there should be an exclusion zone of min(0.25h, 0.2b, 0.2d) (where d, b h denotes the building parameters outlined above). This is shown in Figure 3.

2.3 Plant and Roof Equipment

The presence of plant equipment on the Pod will have a possible detrimental effect on the loading of the solar panels. The zone of influence of any plant or upstands such as lift overruns, large equipment etc should be considered to be ‘H’, were H is the height of the object. For that reason, all Solpods within a zone of influence of H should be considered ‘Edge’ zones for the purposes of loading and thus treated with higher wind loads (Refer Section 2.5).

2.4 Design Life

Solpod panels are typically designed for a 25 year design life. The reference wind tunnel testing loads (refer 2.5 and 2.6) are based on an Annual Probability of Exceedance (APE) of 500 years for wind. This corresponds to an Importance Level 3 structure with a 25 year design life (refer AS/NZS 1170.0 Appendix F).

Most typical structures including warehouses and shopping centres are designed for a 50-year design life. Hence a typical Importance Level 2 structure will have a 500 year APE, consistent with that of the Solpod. Importance Level 3 structures require a more onerous wind loading with a 1000 year APE. While the Solpod is still only certified for the 500 year APE, all fixings along with the cladding and existing structure should be reviewed for the design loads consistent with the Importance Level defined for the base building. This is because the Solpod unit may last well beyond its 25 year design life, or the panels could be replaced within the design life of the base structure. Therefore loads on cladding, fixings and supporting structure should be scaled to suit the existing building's design criteria, per Section 2.6.

If a structure is designated as Importance Level 4 or greater, or it is required for post-disaster functions, we do not consider the wind tunnel report and certifications valid as it is not possible to guarantee the structural integrity of the Solpod in a high wind event.

Further guidance can be found in AS/NZS 1170.0 Appendix F and the Building Code of Australia (BCA).

2.5 Wind Loads

See extracted Table 2a below for wind tunnel loads. These have been separated into Centre and Edge locations. Appendix B of the wind tunnel report defines an Edge zone as any zone within 'h' of an eaves edge, or '2h' of any gable edge. Due to the irregularity of structures it is recommended to utilise Edge location loads within '2h' of any gable edge (ie for a 5 m building, 10 m from any edge). No panels are to be installed within h/4 of the building edge or ridge as per Section 2.2.

Note that Table 2a corresponds only to the Solpod Panels and its fixings. The net loading on the roof structure differs and is outlined in Section 5.

TABLE 2a

Design wind loads for flush mounted solar panels for a 500 year return period wind speed at a reference height of 10m in TC2

	500 year return period design wind loads for TC2, Pa			
Solar panel location	*Measurements*		AS/NZS 1170.2:2011	
	peak +ve	*peak -ve*	peak +ve	peak -ve
Edge	771	-638	610	-2070
Centre	215	-302	610	-2070

TABLE 2b

Design wind loads for flush mounted solar panels for a 500 year return period wind speed at a reference height of 10m in TC3

	500 year return period design wind loads for TC3, Pa			
Solar panel location	*Measurements*		AS/NZS 1170.2:2011	
	peak +ve	*peak -ve*	peak +ve	peak -ve
Edge	395	-414	420	-1425
Centre	118	-165	420	-1425

Tables 2a and 2b from MEL Consulting wind tunnel report showing calculated loads on Solpod panels, frames and their fixings based on test measurements. This shows a comparison to values derived using AS/NZS 1170.2 Appendix D, with the method outlined in Section 6 and Appendix A of the wind tunnel report.

The wind loads derived in the wind tunnel report from MEL Consulting are provided for a baseline Annual Probability of Exceedance (APE) of 500 years, for both Terrain Category 2 (TC2) and Terrain Category 3. For an intermediate Terrain Category between TC2, and TC3, linear interpolation is valid, but the values should not be scaled outside this range.

The wind test results are not valid for structures in TC1. For structures in TC4, it is recommended to use the TC3 values conservatively. Section 2.6 below shows how these reference wind values can be scaled using AS/NZS 1170.2 provisions.

Note that the values in the third and fourth column of these tables "AS/NZS 1170.2:2011" have been derived in accordance with the (conservative) code definitions of PV Panels modelled both as flush PV units (Appendix D6 of AS/NZS 1170.2) and as a monoslope free roof (Appendix D3). They are included for information/comparison purposes only. Refer Section 6 and Appendix A of the wind tunnel report.

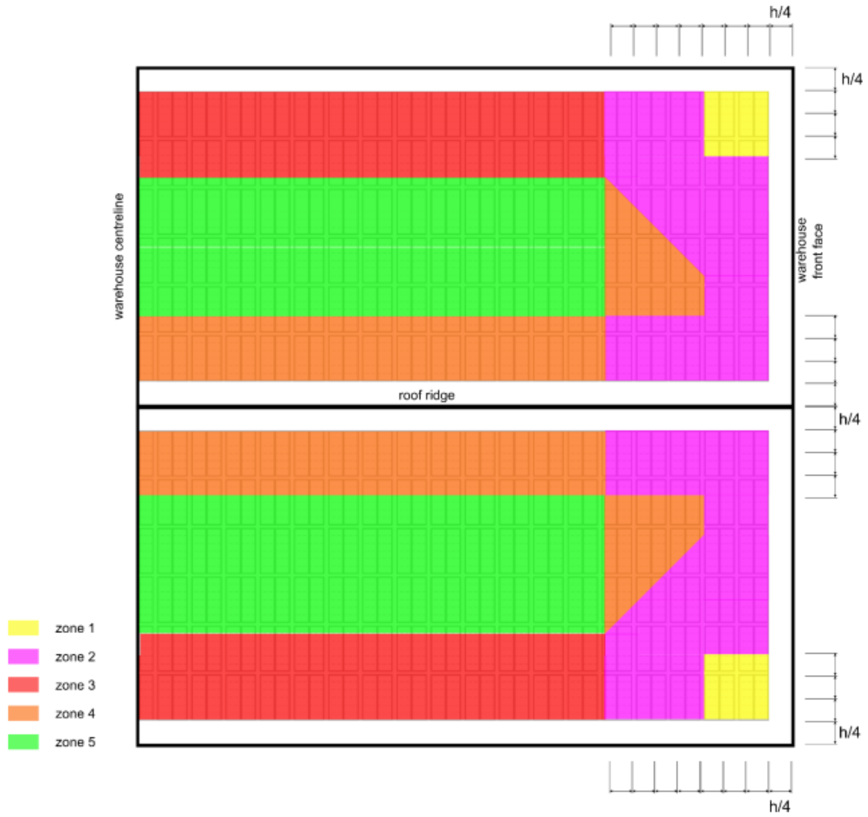


Figure B1 – Key roof zones identified from the wind tunnel pressure coefficient data.

Figure 3: Extract from Appendix B of the MEL wind tunnel test, defining critical wind zones. Zones 1,2 and 3 are considered 'Edge' regions, while Zones 4 and 5 are considered 'Central' regions.
Note the white portions which are exclusion zones, and should be considered to be at least min(2m, 0.2b, 0.2d, 0.25h) from the eaves or ridge.

2.6 Scaling and Interpretation of Wind Loads

The pressure coefficients defined in the wind tunnel test are independent of wind speed. Reference loads use a wind speed of 45 m/s, corresponding to Region A, 500 year APE. This can be scaled to different regional wind speeds including regions B, C and D. Depending on the Importance Level as defined in the BCA, it is valid to scale to different return periods (Such as shopping centres which generally qualify as Importance Level 3, and require a 1000 year Annual Probability of Exceedance wind of 46 m/s).

Similarly, the reference wind loads are for a building of 10 m height. For building heights above 10 m, the loads used are appropriate provided that the wind loads are appropriately scaled by the $M_{z,cat}$ factors found in table Note that for buildings less than 10 m, the wind loads should not be reduced from the reference values.

As an example, consider a building 20 m high in TC3, for a structure of Importance Level 3, Region A5.
IL3 requires a wind Annual Probability of Exceedance of 1000 years.

$M_{z,cat}$ = 0.94 ($M_{z,cat}$ = 0.83 at reference)
V_{1000} = 46 m/s (V_{500} = 45 m/s)

From the Wind Tunnel Testing results, the peak pressures on the solar panel are 771 Pa and -638 Pa, respectively. Given the relationship between pressure and velocity is a function of V^2 we can scale as follows:

$$p = (V_{1000}/V_{500})^2 \times (M_{z,cat}/M_{z,cat,ref})^2 \times p_{ref}$$
$$= (46/45)^2 \times (0.94/0.83)^2 \times p_{ref}$$
$$= 1.34 p_{ref}$$

Thus the pressures on the solar panels for this example building would be 1033 Pa and -855 Pa.

2.6.1 Scaling for Cyclonic Regions

For Wind Regions C and D that are prevalent to cyclone conditions, MEL Consultants have advised that it is acceptable to scale regional wind speeds to the values outlined in AS1170.2 Table 3.1 (Including factors F_C and F_D as per Clause 3.4).

Note that while Pod v3 unit is certified for Region C, TC3, 10 m high, Solpods do not currently have a general certification that includes the additional checks required for cyclonic regions, such as debris impact and fatigue/cyclical loading of fixings. As such, any installations in Region C and D would require a specific review and certification.

3 REVIEW OF SOLPOD AND FIXING CAPACITY

3.1 Certification of Solpods

Each Solpod solar PV frame consists of beams, brackets and joints, designed to withstand a certain load. The structural adequacy of the Solpod can be ensured in the following ways:

- Installing in a manner that is compliant with the ‘one size fits most’ certification issued by Tensys structural engineers – Generally these are buildings and arrangements compliant with Section 2 of this Guide – there are limits on wind region, terrain category, roof height, distance to the edge of the roof.
- Obtain a site specific certification from a qualified structural engineer, to be reviewed by Tensys. The certification should be in accordance with the guidelines in this report and should involve a review of cladding and fixings, along with the building frame/structure. Tensys are to review the Solpod unit itself.

The Solpod frame and members have been typically designed using NDN structural analysis software. The structural certification will outline the maximum Wind Region and Building Heights for use. In the case of v2.1, the current certification is for Region A up to 30 m, and Region B up to 10 m. For Pod v3, the certification is Region A and B to 30 m, and Region C to 10 m.

This design is valid for installation on rectangular enclosed buildings with near flat roofs (pitch less than 5 degrees) with a roof height as noted in table in wind design region A & B terrain category 3 (suburban housing and industrial areas), ref to design code AS/NZS 1170.2.

Solpod V2.1 feet length

Wind Design Region	Building Height	Edge Foot	Centre Spine Foot
	m	*mm*	*mm*
Region A	10	7 x 500	7 x 1000
Region A	20	7 x 500	7 x 1000
Region A	30	12 x 500	12 x 1000
Region B	10	12 x 500	12 x 1000

Extract from L019 Solpod v2.1 Certification (Refer Appendix B)

The design reports accompanying certification of these Solpod units outlines the loading and analysis process. Some below reports show the framing arrangements and typical outputs. The frame has been designed for the permanent load, the relevant wind load, and the lifting/installation phase loads.

A typical Certification is provided in Appendix B. It outlines the parameter limits for which the typical Solpod, fixing and cladding are all structurally adequate.

When a panel is to be installed outside the recommendations of the certification, this typically means that the building geometry is not valid with the wind tunnel test or the loads are too high. Tensys may not be able to verify the Solpod units themselves as being adequate.

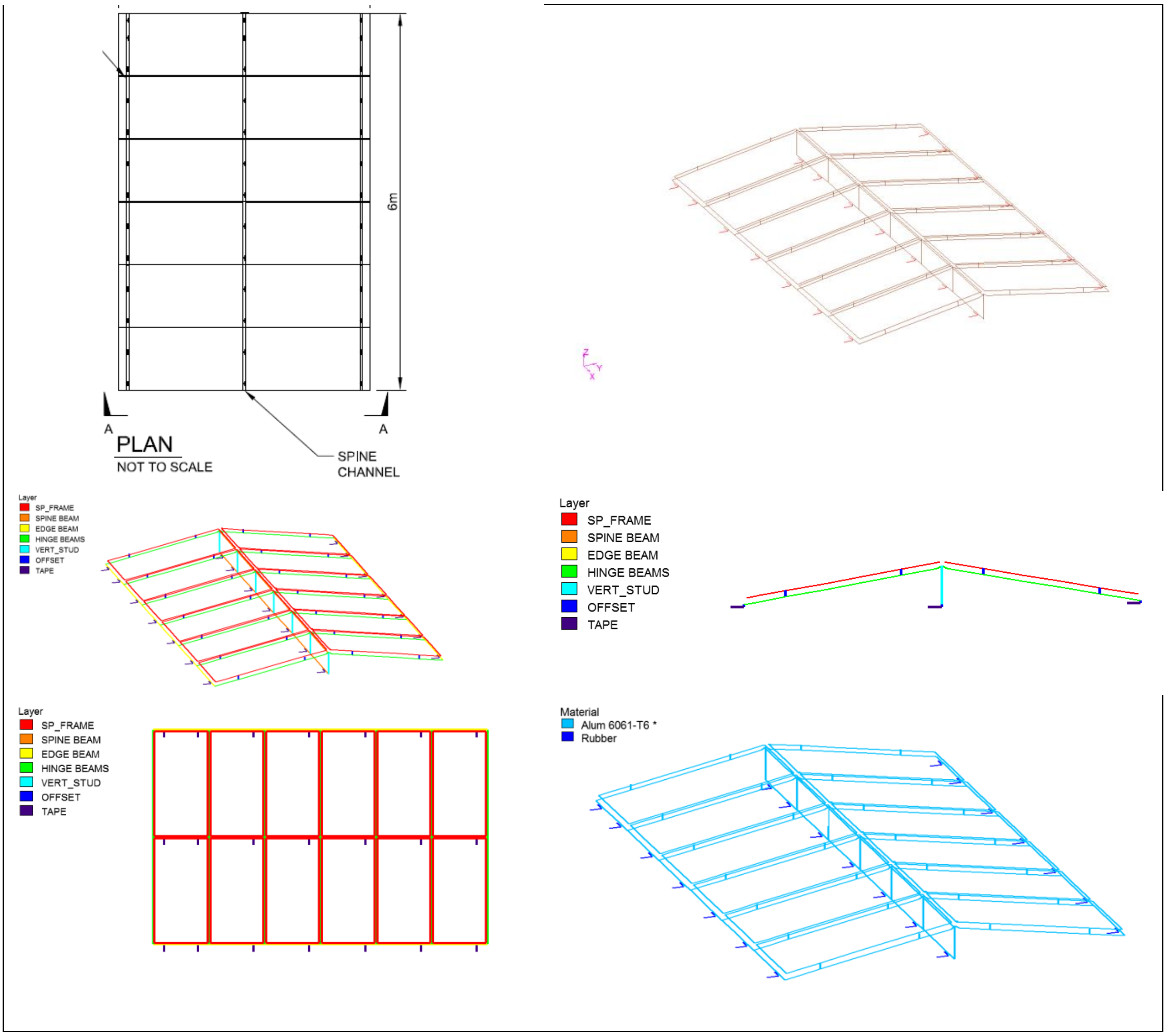


Figure 4: Extracts from Structural Analysis & Design Report showing framing arrangement of Pod v2.1

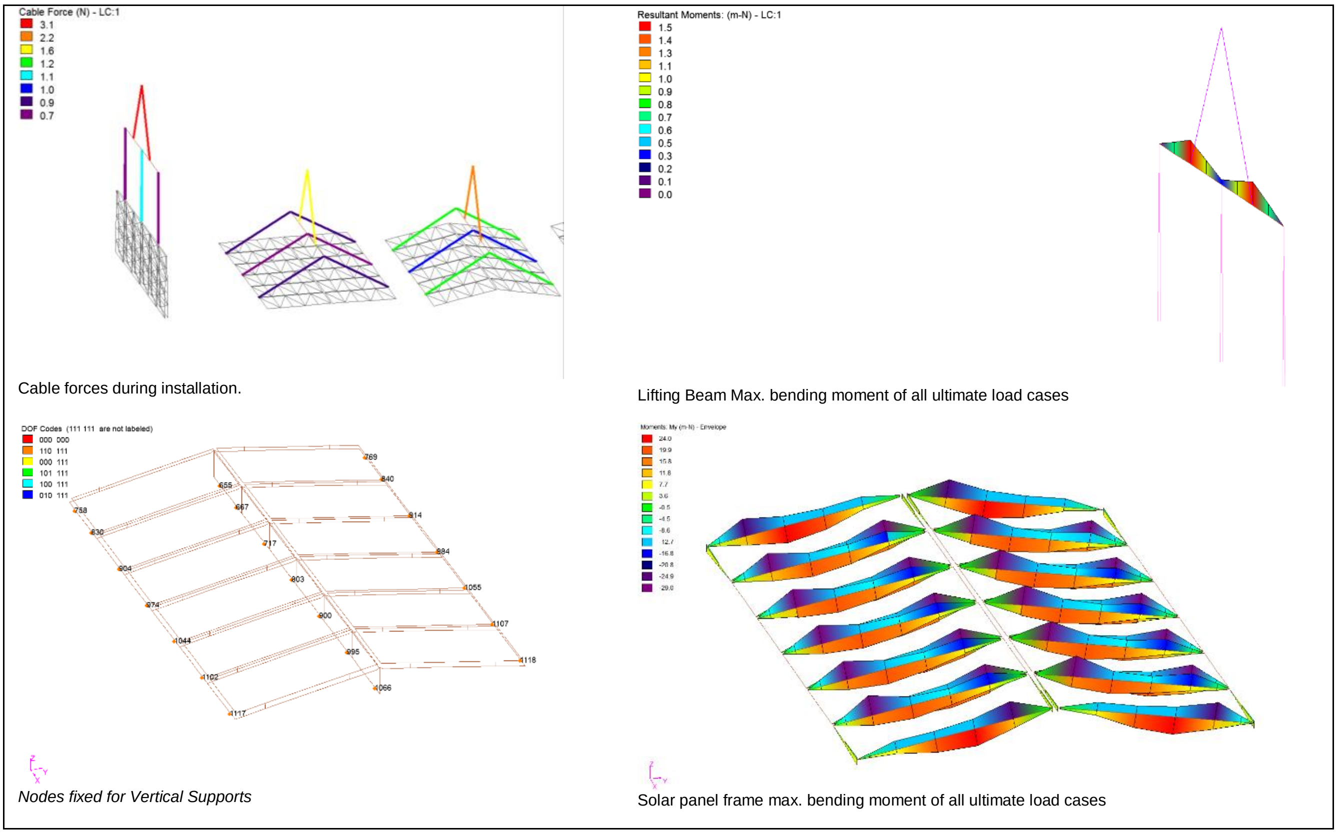


Figure 5: Extracts from Structural Analysis & Design Report showing typical Analysis conditions and outputs of Pod v2.1. All results shown for information only

3.2 Review of Fixings

Solar PV array frames can be structurally connected to the roof frame in a variety of ways. The connection transfers wind loads from the solar PV modules to the roof frame, so each element in the connection needs to be able to withstand the wind loads. Typically, fixings are governed by the uplift load from wind. Panels are typically fixed to a steel framed roof in one of the following ways:

- Adhesive tape to the roof sheet, roof sheet transfers load to the roof purlin fixing, which transfers load to the purlin.
- Roof clamp to the roof sheet (typically at rib locations), roof sheet transfers load to the concealed clip, which transfers load to the purlin.

While these fixings are typically different depending on the roof sheeting profile and wind conditions, depending on the fixing configuration one can derive a ‘typical foot load’ at the central spine and edge foot. By ensuring feet are equally spaced at (±0.25 m) apart, the load is distributed uniformly between each foot based on its tributary area. A ‘typical foot load’ is derived by multiplying the scaled based pressures from Section 2 by the Tributary area. The certificate in Appendix B shows a typical range of foot loads.

For example, with a 7-foot configuration, an edge foot will support 1 m x 1 m. In Region A, TC3, 10 m the maximum uplift on a Solpod Panel and its fixings is -0.414 kPa. Hence the Foot Load from wind uplift at this point is 0.414 kPa x 1 m x 1 m = 0.414 kN. The table below from Appendix B shows a summary of typical foot load combinations acting at the fixings.

Solpod V2.1 Min/Max Design loads normal to roof (TC 3)

Load Case	**Edge Foot**			
	Region A 10m 7 feet	Region A 20m 7 feet	Region A 30m 12 feet	Region B 10m 12 feet
	kN	*kN*	*kN*	*kN*
G	-0.15	-0.15	-0.12	-0.12
0.9G + Wu(-ve)	*(-0.15x0.9 + 0.414) =* 0.28	0.39	0.40	0.40
1.2G + Wu(+ve)	-0.58	-0.69	-0.61	-0.61
Load Case	**Spine Foot**			
	Region A 10m 7 feet	Region A 20m 7 feet	Region A 30m 12 feet	Region B 10m 12 feet
	kN	*kN*	*kN*	*kN*
G	-0.31	-0.31	-0.12	-0.12
0.9G + Wu(-ve)	0.51	0.73	0.62	0.62
1.2G + Wu(+ve)	-1.13	-1.33	-1.01	-1.01

Note: under non-uniform ultimate wind loads up to 0.1kN parallel to roof surface are possible.

Example Table from Solpod v2.1 Certification (Extract from Appendix B) showing typical foot/fixing loads to the cladding or fixing surface.

4 REVIEW OF ROOF CLADDING CAPACITY

4.1 Certified Claddings

Solpod panels have been designed and certified to a number of commonly used claddings including, but not limited to:

- Trapezoidal Profile (Lysaght Trimdek)
- Concealed Fixing (Lysaght Klip-lok, Longline)

Refer to the respective certification document for information on maximum purlin spacings and arrangements etc.

Where a commonly used cladding does not have a ‘one size fits most’ certification, please contact Solpod to review and update the certification.

It is essential that cladding is installed in accordance with manufacturer’s instructions and AS 1562.1 – Design and installation of sheet roof and wall cladding Part 1: Metal, with regard to correct lapping, and an adequate fixing.

For example, Trimdek and similar trapezoidal profiles require a screw fix at every rib location (4 crest fixings per support per panel).

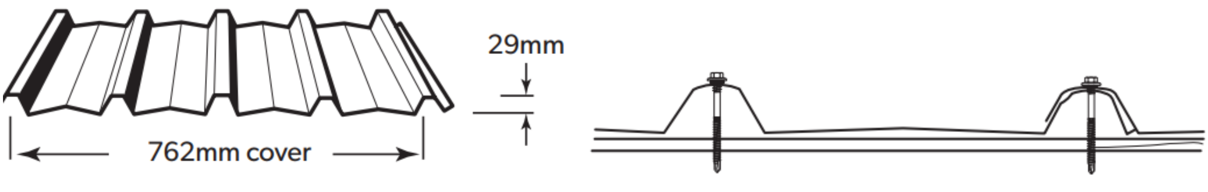


Figure 6: Lysaght Trimdek Fixing guide showing fixings every rib

For concealed fix roof sheeting, this can be more difficult to verify across the entire roof but where possible, spot checks should be undertaken at roof sheeting locations where possible, to provide confidence that the correct rails and fixings have been used.

4.2 Deflection/Serviceability of Cladding

Section 2.1 mentions the risk of sag and ponding due to the additional weight of the panels on the cladding. Each cladding item should be reviewed based on the foot loads defined in the certification. For the example outlined in Appendix B, the maximum foot dead load is 0.31 kN (approx. 33 kg, or ~0.15 kPa x 2 m x 1 m on a spine foot).

For a central point load P, the ‘deflection equivalent’ UDL for cladding spanning between

$$w_{eq} = \frac{1.6P}{L} = \frac{1.6(0.31)}{L} = \frac{0.496}{L}$$

AS/NZS 1170.2 Table 3.2 gives a reference live load for structural elements of (1.8/A + 0.12) kPa, but not less than 0.25kPa. Assuming a 1 m width of cladding, this pressure would be defined as

$$w_Q = \frac{1.8}{L} + 0.12$$

For typical purlin spans of 0.9 m-1.8 m, it is clear that the maximum deflection across cladding will be less than the live load allowance.

However, the additional deflection due to the Solpod weight is a dead load and must be reviewed for ponding. Proprietary cladding catalogues can provide either EI values for the cladding, or serviceability pressure capacities in span tables based on prescribed span/deflection ratios. Deflections can be calculated from the above P value, or scaled from the tables using the w_{eq} value derived above.

4.3 Fixings for Cladding

Assessments and certifications relating to the above can be issued by a capable, registered structural engineer, based on the extra loads imposed by the solar frame, as defined for that wind region, terrain category and roof height as per Section 2 of this report. Solpod (in partnership with Tensys) can offer certification for the connection to the roof for certain common makes and models of roof sheeting, both with screw fixings and with concealed fixings.

- For roof sheets with screw fixings, certification is based on documentation (engineering guide) from the manufacturer of the roof sheet, and on the standard for roof screws.
- For roof sheets with concealed fixings, certification is based on documentation (engineering guide) from the manufacturer of the roof sheet, and on load testing of the roof clamp with that specific make and model of roof sheet (e.g. Lysaght Klip-lok 700 HS).

4.4 Testing of Unidentifiable/Aged Cladding and Fixings

Registered structural engineers can't certify a proposed installation if certain information is not known, such as the make & model of a roof sheet that uses concealed fixings. There are many different suppliers of roof sheeting in Australia, each with their own design for the concealed clip, and each clip is able to withstand a different load. Two elements need to be considered:

- The load capacity of the fixing between the roof clamp and the roof sheet.
- The load capacity of the concealed clip and the fixing of the cladding to the purlin.

These two elements can be addressed by conducting on-site testing. Professional assistance is recommended, to avoid damage to the roof sheet. Various contractors offer on-site testing services across Australia, including Gamcorp and Melbourne Testing Services (MTS).

Typically, the proposed roof clamp is fixed to the roof and a defined uplift load is applied for a defined duration. The required load and duration for each clamp is a function of the wind region, terrain category and roof height and the basis of these loads are outlined in Section 2.5. Section 4.3.1 defines the specific foot load.

Along with a testing protocol, roofing should be visually inspected for any signs of wear, corrosion or damage. Where roof sheeting has been physically damaged or shows notable signs of corrosion, it shall not be used to support the roof (sheets to be replaced or reinforced, or feet relocated).

4.4.1 Testing Acceptance Criteria

All testing procedures for verification of cladding should confirm to AS 1562.1—2018

A valid testing process would involve using pull tests on the fixing applied directly to the cladding. The cladding should be tested to the loads outlined in section 2.5. The design loads are as follows:

- Cladding at midspan between purlins: Load to 1.3x Maximum Foot load.
- Cladding at support (Purlin): Load to 2.4x Maximum Foot load, to account for the possibility of multiple feet spanning to a single purlin.

Each test should be repeated for a minimum of three (3) independent trials to confirm the adequacy of the cladding.

Current testing indicates that there is a significant reduction in capacity of clamp fixings at roof sheeting lap locations. As such, any feet. As per Solpod typical certification, edge feet can be offset a maximum of 250 mm from the design location. This offset allows a foot to be fixed to an adjacent sheeting rib where there is no lap.

5 ASSESSMENT OF EXISTING BUILDING FRAME

Assessment of existing buildings will generally rely on a number of assumptions and engineering judgement decisions. It is very rare that the engineer who originally designed the structure is the same engineer reviewing the presence of Solpod. As such it is unlikely that there is clear guidance on what loadings have been allowed for in the original design. It may also be unclear what the proposed limits are for deflection and serviceability. A designer should seek to obtain as much information as possible from as-built structural documentation, and guidance provided by Codes and Australian Standards.

5.1 Roof Battens/Purlins

- From the wind tunnel testing, there is an assumption that the loads applied on the roof from beneath the solar panel will be equalised, ie there is an equal and opposite pressure from the panel to the roof. As such, the uplift applied to the subsequent purlin structure can be seen as just the load on the tops of panels.
- Appendix C of this Design Guide outlines the theory behind the derivation of the wind loads on the existing purlins. By scaling Table 2a and 2b, we can derive the worst case Edge Pressures to apply to purlins

  TC2: Max Pressure = (1.4/1.79) x 771 = 603 Pa
  Min Pressure = (3.43/1.48) x -638 = -1478 Pa

  TC3: Max Pressure = (1.3/1.68) x 395 = 306 Pa
  Min Pressure = (3.45/1.76) x -414 = -811 Pa.

  These base pressures should be further scaled by the parameters in Section 2.6.

- In areas where there are no solar panels, it is assumed that the structure has been designed in accordance with AS/NZS 1170.2 Section 5, ie deriving pressure coefficients from Table 5.3(A).
- Overall**, purlins are to be designed for the most critical of the peak solar panel loads (to the wind tunnel results) and the bare roof** (to AS/NZS 1170.2).
- Typically, Solpod panels stacked at maximum density provide a weight of 15 kg/m², or 0.15 kPa. As the panels are typically installed with minimal stand-off from roof sheeting, it is acceptable common practice to assume that no additional person or stacking loads can accumulate in the footprint of the panel. Therefore, provided the roof structure has been designed for a live load of >0.15 kPa (AS 1170.1 requires a minimum of 0.25 kPa live load) then **the live load allowance is considered sufficient to account for additional PV panels**. (This is most applicable to the 1.2G+1.5Q case)

5.2 Rafters and Columns

- Internal rafters pick up a large tributary area (a typical 30 m spanning rafter at 8.4 m centres picks up a tributary area of over 250m²). This is common for large warehouse building and over this greater area, it is understood that that the local peaks on solar panels are equalised over the entire roof structure. Therefore, the code values in AS/NZS 1170.2 are appropriate. For the worst case downwards load combination (ie $1.2G+\psi_L+W_u$), the code value for W_u should be used but an additional superimposed dead load typical for the solar panels should be used. Conservatively, a dead load of 0.15 kPa is used, based on a uniform panel weight.
- For the wind uplift case (ie $0.9G + W_u$ reversal), the code values for wind loading are still applicable. Typically this case will not be critical as the additional mass of the panels will reduce the global uplift on rafters and columns.
- As per Section 5.1, provided the roof meets the minimum requirements of AS 1170.1 (0.25 kPa roof load), the weight of the panel on the roof can be included in the live load allowance for the 1.2G+1.5Q load case and thus this case will not govern.

Note that an understanding of the lateral system and framing is required to accurately analyse and check structural members. Warehouse structures are typically portal frames which rely on fixed connections to transfer lateral bending load between rafters and columns. As a result the bending and axial forces in rafters and columns are not necessarily resolvable by simple statics as they depend on the relative stiffness of beams and rafters. In this case it is best to use structural frame analysis software such as GSA or Spacegass in determining the actions in these structures.

5.3 Foundations

Lightweight steel framed structures are generally governed by uplift load on the foundations, or by the dominant dead and live loads on the columns. While a cursory check of the bearing pressures on foundations should be made, the additional dead load is typically not significant increase to the foundation loads. The resulting settlements due to additional permanent load are generally negligible. As per Section 5.1, the additional weight of the panel can be included in the live load allowance for the roof, and hence the max bearing pressure G+Q will still be within allowable limits.

6 APPENDIX A – WIND TUNNEL TEST REPORT

WIND TUNNEL MEASUREMENTS OF PRESSURES ON SOLAR PANEL ARRAYS ON INDUSTRIAL WAREHOUSE BUILDINGS

By

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SUMMARY

A 1:75 scale model of a generic warehouse building with solar panel arrays installed on the roof has been tested in a simulated natural wind boundary layer over open terrain (Terrain Category 2) and suburban terrain (Terrain Category 3) to measure the pressures on the building roof (with and without the solar panels) and net pressures across the panels themselves. The solar panel configuration tested comprised panels installed inclined to the roof at an angle of 10 degrees. Surface pressures on the solar panels and building roof were measured with reference to the free-stream static pressure for 36 wind directions at 10° intervals. All the measurements on the scale model warehouse were for a rectangular building (2:1:0.11 length-to-width-to-height$_{eave}$ ratio) with roof pitch of approximately 3°.

The pressure test data were normalised with the mean free-stream wind speed at a height of 10m above ground (corresponding to the building eave height) producing mean, standard deviation, minimum and maximum pressure coefficients. This pressure coefficient data has been plotted for the tested configurations in the form of highest magnitude maximum and minimum values across all wind directions at each measurement location. An Excel spreadsheet containing this information has been provided (Addendum A) with tabulated pressure coefficients as a function of wind direction. This specific directionality information on the pressure coefficients can be used for further optimisation of the design for the wind direction(s) of interest. In such a case the directionally dependent wind speeds applicable to the building location should be used for the determination of design pressures.

Report 53-18-WT-PRE-00

April 2018

SOLPOD PTY LTD WAREHOUSE SOLAR PANEL ARRAYS
PRESSURE WIND TUNNEL MODELLING

MEL CONSULTANTS REPORT NO: **53-18-WT-PRE-00**

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CONTENTS

1. INTRODUCTION

The design wind loads for the fitting of photovoltaic (PV) solar panel arrays on large commercial warehouses are, at present, not rigorously defined in the Australasian Wind Loading Standard AS/NZS 1170.2:2011. The current state of research in this area also provides little information of the effects of solar panel arrays on warehouse wind loads.

The primary outcome of the wind tunnel testing is for Solpod Pty Ltd to obtain a proprietary set of data to use for the calculation of structural design loads for the fitting of photovoltaic solar panel arrays on commercial warehouses. These data, in the form of coefficients, are an alternative to Standard based design loads which would be expected to be conservative in comparison. The data obtained from this study would be more directly relevant to the installation of solar panels on large warehouse buildings than the load coefficients from the AS1170.2:2011 wind Standard which we understand originally stemmed from research for solar panel installations on residential buildings and only relates to panels mounted parallel to the roof surface.

2. MODEL AND TEST PROCEDURES

2.1 WIND TUNNEL MODEL

A 1/75 scale model of a generic warehouse building was considered for the wind tunnel studies. A specific solar panel configuration was mounted on the scale model warehouse roof. The warehouse/solar panel configuration was instrumented with approximately 500 surface pressure taps to measure the pressures acting upon the solar panels themselves.

The specifications of the warehouse building, as tested in the wind tunnel, are summarised below, with a schematic of the building illustrating key dimensions shown in Figure 1a:

<u>*Warehouse Building*</u>

Site Locations:	Light industrial estate, TC3 approach wind conditions Greenfield site, TC2 approach wind conditions
Aspect Ratio:	2:1 aspect ratio (length:width)
Building Size:	180m x 90m x 14m (at roof apex) $[2 : 1 : 0.155]_{apex}$ 180m x 90m x 10m (at eave height) $[2 : 1 : 0.111]_{eave}$
Scale Model size	1:75
Roof Pitch angle :	~3^0

This particular scale was chosen for several reasons.

1. This was the largest scale to be able to be comfortably installed in the wind tunnel whilst avoiding any significant blockage effects.
2. The large scale of the model reduced any Reynolds number scaling effects, common with very small wind tunnel models, thus avoiding the need to have an unpractical test wind speed.
3. The large scale model meant that the physical size of the solar panels were easy to handle and work with.

Two hypothetical site locations were chosen as follows:

1. Light industrial estate, TC3 approach wind conditions for all wind directions. The definition of this approach terrain, as described in the AS1170.2:2011 wind standard, is as follows :

   "Terrain with numerous closely spaced obstructions having heights generally from 3m to 10m. The minimum density of obstructions shall be at least the equivalent of 10 house-size obstructions per hectare, e.g. suburban housing or light industrial estates."

2. Greenfield site, TC2 approach wind conditions for all wind directions. The definition of this approach terrain, as described in the AS1170.2:2011 wind standard, is as follows :

   "Open terrain, including grassland, with well-scattered obstruction having heights generally from 1.5m to 5m, with no more than two obstruction per hectare, e.g. farmland and cleared subdivisions with isolated trees and uncut grass."

The specifications of the solar panel array, as agreed with Solpod Pty Ltd for the purposes of the wind tunnel testing, are summarised below:

<u>Solar PV panel array</u>
Panel Installation: Inclined, at 10^0 to warehouse roof
Array location: ≈ 2m from building edges and roof ridge
Solar Panel Size: *941mm x 1956mm*
Panel stand-off height above roof: ≈ 150mm

A representative panel size of 940mm x 1950mm, was used for the tests. The vertical stand-off of the panels from the roof and inter-panel spacing were artificially increased at model scale to minimise Reynolds number effects and minimise any potential flow restriction from having a too small gap under and in between adjacent panels, but were kept close to the geometric specifications defined above. Schematics of the solar panel arrangement are shown in Figures 1b and 1c.

The solar panel array configuration was instrumented with surface pressure taps and installed on the scale model warehouse in the wind tunnel. The model surface pressure taps were connected via PVC tubing to an electronic pressure system which enabled each tap pressure to be read and referenced to the free-stream static pressure. Pressure measurements were made on the top and underside surfaces of the solar panels and the warehouse building roof. This allowed the net pressure across the panels (top surface pressure – underside surface pressure) to be determined.

The density of taps was increased in the regions of high pressure gradients i.e. near corners and building discontinuities. This required multiple pressure taps to be installed on individual panels in these areas and provided additional redundancy in these critical areas in the case of an unforeseen tube blockage or suddenly non-functioning pressure transducer.

The shape of the warehouse and arrangement of solar panel array configurations permitted the application of geometrical symmetry. This aided with the selection of which areas to instrument and avoided the necessity of pressure tap the entire warehouse building and solar array. One quarter of the warehouse roof was instrumented, while dummy (i.e. un-instrumented) panels were installed on the remaining roof areas.

Photographs of the wind tunnel model, as tested, are shown in Figures 3 - 6.

2.2 WIND TUNNEL PRESSURE MEASUREMENTS

The scale model of the warehouse building was tested in a simulated natural wind environment. Scaled natural wind properties were developed from roughness elements and vorticity generators upstream of the model. The basic natural wind model was for TC2 and TC3 as per AS/NZS1170.2.2011. A profile of the mean longitudinal wind tunnel velocity for TC2 and TC3 is presented Figure 2.

Prior to beginning every wind tunnel test a start-up procedure was undertaken requiring the transducers of the pressure measurement system to be zeroed, then calibrated against a known calibration pressure, and finally zeroed again. Additionally, all pressure lines from the reference Pitot tubes were, in turn, sealed, pressurised, and monitored for 20 seconds to ensure that there were no leaks and the reference lines were correctly connected to electronic pressure system. The next stage of the pressure measurement procedure was to operate the wind tunnel for 5 minutes while monitoring and checking the performance of reference and pressure transducers. The last stage of the checking procedure was to stop the wind tunnel and check that the electronic pressure system transducers all returned to the nominal zero values. If a channel was found not to return to the nominal zero value this was investigated and the cause determined and rectified prior to the continuation of the start-up procedure. The start-up procedure was detailed in a test procedure document, which the operator was required to tick off the stages of the procedure and record calibration and pressure tapping details for quality purposes and internal peer review prior to starting the wind tunnel testing and data recording.

The mean wind tunnel test velocity was selected based on exceeding the requirements of the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-2001) for Wind Tunnel Testing of a minimum Reynolds number of 5×10^4.

For TC3, based on the selected freestream wind tunnel mean test wind velocity of 17.5 ms^{-1}, the model scale test Reynolds number achieved was 7×10^4, based upon building height and wind speed at the building height. The model to full scale velocity ratio (relative to 500 year return period wind speed) is approximately 0.41 for a model length scale of 1/75.

For TC2, based on the selected freestream wind tunnel mean test wind velocity of 17.5 ms^{-1}, the model scale test Reynolds number achieved was 8×10^4, based upon building height and wind speed at the building height. The model to full scale velocity ratio (relative to 500 year return period wind speed) is approximately 0.30 for a model length scale of 1/75.

These give model to full scale time ratios of:

$$T_{R_{\mathrm{TC3}}} = \frac{L_R}{V_R} = \frac{1}{75} \cdot \frac{1}{0.41} = 0.033$$

$$T_{R_{\mathrm{TC2}}} = \frac{L_R}{V_R} = \frac{1}{75} \cdot \frac{1}{0.30} = 0.044$$

and the model to full scale frequency ratio is:

$$n_R = \frac{1}{T_R}$$

Based on the model to full scale time ratio, 1.0 hour in full scale was equal to approximately 190 seconds at model scale for both TC3 and TC2, and the model scale frequency response was approximately 25 - 30 Hz for both TC3 and TC2 to give a full scale frequency response of approximately 1 Hz.

The above time/frequency scaling intends to ensure this data is recorded for an equivalent of 1hr in full scale. However it is also important for the duration of the sampling period at model scale piecewise stationarity of the data is ensured. This implies that the mean and standard deviation of the data becomes independent of the sampling duration (at model scale). This consistency check is conducted during the data acquisition and if necessary, a larger duration model sampling period is chosen to achieve piecewise stationarity of the data.

Therefore, data were recorded for 190 seconds at a sampling frequency of 1250 Hz with a low pass filter at 312.5 Hz in order to avoid aliasing effects on the acquired data. The sampling frequency was more than 3 times higher than the highest frequency required in the pressure signal (50 Hz model scale ≡ 2Hz full scale) as per the requirements of the AWES-QAM-2001 for the digital sampling rate. The data from the pressure transducers were digitally corrected for the resonance and attenuation effects of the pressure measurement system.

The pressure transducers are referenced to the free-stream static pressure. The reference dynamic pressures, measured at the height of the top of warehouse model

(10m in TC2 and TC3), are used to normalise the pressures. The measured reference dynamic pressures are measured free from the influence of obstructions in the approach terrains and the warehouse model itself. The mean, standard deviation and maximum and minimum peak pressures were determined and normalised to pressure coefficient form, defined as follows:

Mean $$C_{\bar{p}} = \frac{\bar{p}}{\frac{1}{2}\rho\bar{V}_h^2}$$

Standard deviation $$C_{\sigma_p} = \frac{\sigma_p}{\frac{1}{2}\rho\bar{V}_h^2}$$

Maximum (+ve) $$C_{\hat{p}} = \frac{\hat{p}}{\frac{1}{2}\rho\bar{V}_h^2}$$

Minimum (-ve) $$C_{\check{p}} = \frac{\check{p}}{\frac{1}{2}\rho\bar{V}_h^2}$$

Where	$\bar{p}$	=	mean pressure at tap referenced to free-stream static pressure
	σ_p	=	standard deviation pressure
	$\hat{p}$	=	maximum peak pressure (+ve)
	$\check{p}$	=	minimum peak pressure (-ve).
	ρ	=	air density (1.2 kgm^{-3}).
	$\bar{V}_h$	=	mean wind speed at a reference height of 51m
	h	=	top of the building height (51m)

The peak positive, negative, and mean pressure coefficients for all pressure taps (surface and net) are presented as a function of wind direction in Appendix A.

The design pressures are calculated from the pressure coefficient data using the ultimate limit state wind speeds for any prescribed location as follows:

$$p = \frac{1}{2}\rho\bar{V}_h^2\ C_p$$

3. DESIGN WIND SPEEDS

The design wind speeds used are those given in the Australian/New Zealand Standard, Structural Design Actions, Part 2: Wind actions, AS/NZS1170.2:2011. The Regional peak gust design wind speeds are given as a function of return period, and the design return period to be used is determined on a performance basis from the Building Code of Australia.

A typical warehouse building, as considered in this study would be assumed to fall under Importance Level 2 and hence be subject to a 1:500 year return period design wind speed. The eave height (10m) will be used as the reference height of the building here and all calculated mean wind speeds will be determined relative to this height.

Design mean wind speeds, to which all wind tunnel model measurements are referenced, are no longer directly available in AS/NZS1170.2:2011, as they were in AS1170.2:1989. However the basis of the conversion from peak gust wind speeds (the Regional Wind Speeds given in AS/NZS1170.2:2011) was based on the Deaves and Harris model. The Regional Wind Speeds from AS/NZS1170.2:2011 used as the basis for the design mean wind speeds in this report have been determined for TC3 and TC2 as follows:

For Region A (Melbourne, VIC)

$$\hat{V}_{\substack{10m \\ Cat\,2 \\ 500}} = 45 \text{ ms}^{-1}$$

The wind load design would be based on the Ultimate Limit State wind speed (500 year return period). Hence any design pressures determined from pressure coefficients given in this report are based on an ultimate limit state design wind speed.

The Ultimate Limit State design (gust) wind speed at a height of 10m over Terrain Category 3 conditions is given by

$$\hat{V}_{\substack{10m\\Cat3\\500yr}} = \hat{V}_{\substack{10m\\Cat2\\500}} \times M_{\substack{z,cat3\\10m}}$$

= 45 * 0.83

= 37.4 ms^{-1}

The Ultimate Limit State design (gust) wind speed at a height of 10m over Terrain Category 2 conditions is given by

$$\hat{V}_{\substack{10m\\Cat2\\500yr}} = \hat{V}_{\substack{10m\\Cat2\\500}} \times M_{\substack{z,cat2\\10m}}$$

= 45 * 1.00

= 45.0 ms^{-1}

where the Terrain/Height multipliers, $M_{Z,cat}$, are obtained from AS/NZS1170.2:2011 Table 4.1.

From the Deaves & Harris Model the design mean wind speed for the Regional Wind Speed for all wind directions over Terrain Category 3 conditions is given by

$$\bar{V}_{\substack{10m\\Cat3\\500yr}} = \frac{\hat{V}_{\substack{10m\\Cat3\\500yr}}}{1+3.7I_Z}$$

$$= \frac{37.4}{1+3.7\bullet 0.239}$$

= 19.8 ms^{-1}

From the Deaves & Harris Model the design mean wind speed for the Regional Wind Speed for all wind directions over Terrain Category 2 conditions is given by

$$\overline{V}_{\substack{10m\\Cat2\\500yr}} = \frac{\hat{V}_{\substack{10m\\Cat2\\500yr}}}{1+3.7I_Z}$$

$$= \frac{45.0}{1+3.7\bullet 0.183}$$

$= 26.8\ ms^{-1}$

where the turbulence intensities, I_Z, is obtained from AS/NZS1170.2:2011 Table 6.1.

4. SURFACE PRESSURE MEASUREMENTS

The roof single point pressure tap identification labels and locations are displayed in plan schematics in Figures 7 (without solar panels) and 10 (with solar panels). The solar panel surface pressures have been processed to yield area-averaged, net *(top pressure – underside pressure)* pressure coefficients. These have been determined from a weighted sum of the net pressure difference across each instrumented panel and are presented in tabular, text format in Addendum A (electronic file).

Each solar panel label has been named according to its row and column index locations from the warehouse building edge and front face as follows:

e.g.

R06C08 is the solar panel 8 columns in from the warehouse edge and 6 rows down from the warehouse front face.

All solar panel labels and their locations for each panel are defined in Figure 13.

The basic warehouse roof surface pressure measurements, are presented as maximum and minimum pressure coefficients. For the determination of ULS (or similar) design pressures an allowance for an internal pressure based on an equally permeable facade (i.e., no dominant openings) should be made; for example, (Cp_i = -0.3 to 0.0, whichever is the more severe) would have to be factored in as well. Mean, standard deviation and peak pressure coefficients are presented in tabular, text format in Addendum A (electronic file); note: electronic data (pressure coefficients) does not allow for a building internal pressure.

For the warehouse roof pressures the sign convention of the pressure coefficients are defined as follows:

- A positive surface point pressure coefficient is into the surface
- A negative surface point pressure coefficient is out of the surface

For the solar panel net pressures the sign convention of the pressure coefficients are defined as follows:

- A positive net pressure coefficient acts downwards (towards the ground)
- A negative net pressure coefficient acts upwards (towards the sky)

Example output from Addendum A (Bare Roof in TC3)

xxxx
runABCDEFGH
Maximum Pressure Coefficients

wd	1A	2A	3A	4A	5A	6A	7A
0	0.05	0.02	-0.02	-0.02	0.04	0.06	0.12
10	0.14	-0.08	-0.1	-0.06	-0.11	0.02	0.08
20	0.71	0.67	0.48	-0.09	-0.11	-0.06	0.15
30	0.82	0.9	0.8	0.53	0.27	0.03	0.04
40	0.81	1.01	1.02	0.58	0.36	0.46	0.47
50	0.66	0.83	0.86	0.64	0.79	0.73	0.71
60	0.84	0.71	0.69	0.57	0.75	0.69	0.62
70	0.82	0.6	0.58	0.49	0.55	0.55	0.56
80	0.52	0.45	0.42	0.41	0.4	0.45	0.47
90	-0.15	0.03	0.16	0.12	0.22	0.31	0.47
100	0.01	-0.01	0.03	-0.02	0.06	0.23	0.19
110	-0.06	-0.06	-0.07	-0.04	-0.03	0.23	0.09
120	0.07	0.01	0.01	0.08	0.15	0.13	0.2
130	0.27	0.29	0.28	0.31	0.26	0.21	0.23
140	0.27	0.29	0.32	0.31	0.26	0.28	0.22
150	0.31	0.29	0.27	0.26	0.24	0.23	0.27
160	0.44	0.42	0.38	0.34	0.33	0.35	0.31
170	0.44	0.44	0.43	0.44	0.46	0.46	0.44
180	0.4	0.38	0.37	0.37	0.39	0.36	0.33
190	0.44	0.41	0.4	0.42	0.45	0.46	0.44
200	0.45	0.41	0.39	0.38	0.39	0.4	0.4
210	0.39	0.38	0.36	0.36	0.35	0.34	0.34
220	0.4	0.38	0.37	0.39	0.39	0.38	0.39
230	0.49	0.47	0.43	0.44	0.47	0.47	0.47
240	0.55	0.54	0.54	0.54	0.57	0.56	0.53
250	0.42	0.42	0.44	0.45	0.47	0.47	0.46
260	0.31	0.31	0.33	0.35	0.35	0.36	0.36
270	0.32	0.31	0.3	0.29	0.3	0.3	0.3
280	0.25	0.23	0.24	0.25	0.27	0.27	0.25
290	0.14	0.11	0.11	0.13	0.14	0.13	0.12
300	0.07	0.04	0.03	0.06	0.1	0.07	0.02
310	0.02	0.04	0.03	0.04	0.06	0.05	0.01
320	-0.02	-0.02	-0.01	0	-0.01	-0.05	-0.07
330	0.04	0.09	0.09	0.09	0.06	0.04	0.04
340	0.1	0.07	0.07	0.07	0.07	-0.02	-0.07
350	0.04	0.04	0.02	0.04	0.05	0	-0.01
max	0.84	1.01	1.02	0.64	0.79	0.73	0.71
wd	60	40	40	50	50	50	50

Following the project title and the run designation the data are arranged in columns with wind direction (wd) in the first column. Each subsequent column has the tap label designation at the top and the maximum, mean, or minimum design pressures or pressure coefficients arranged with wind direction. The above example shows the maximum design pressures at the pressure tap locations 1A – 7A. At the bottom of each column, after 36 wind directions, the output gives the highest maximum, mean, or minimum pressure or coefficient and the wind direction at which this occurred.

The peak pressure coefficients in the data of Addendum A have been compared against a design probability level of 0.0001 from a Weibull distribution fit of the measured data as well as against the international ISO standard (Wind Actions on Structures). This is to smooth the effect of outliers in the measured maxima and minima and to more accurately define an average peak relating to a full-scale frequency response of approximately 1Hz. It should be noted that the pressure coefficient data do not include any allowances for dynamic response.

The pressure coefficients presented in Addendum A are summaries of the lowest minimum and the highest maximum values for pressure coefficients at each pressure tap location and solar panel array location.

To aid with the interpretation and visualisation of the wind tunnel data, the pressure coefficients of both the roof and solar panels have been plotted in the form of contour plots, for each configuration. The point pressure coefficients for the warehouse roof without solar panels are presented in the contour plots of Figures 8 and 9. The point pressure coefficients for the warehouse roof with solar panels are presented in the contour plots of Figures 11 and 12. It should be noted that the plots if Figures 8, 9, 11 and 12 do not make an allowance for an internal pressure. The net, area averaged pressure coefficients across the solar panels are presented in the contour plots of Figures 14 and 15.

5. DESIGN EXAMPLES

Minimum and maximum pressure coefficients for all wind directions are given in detail in the computer output in Addendum A, with contour plots of the pressures given in Figures 8, 9, 11 and 12 (where no allowance for internal pressure has been considered, see below). The contour plots present the highest magnitude maximum, minimum and mean pressure coefficient measured over all wind directions. However, if more specific directionality information on the pressure coefficients is required then the tabulated data in Addendum A should be interrogated for the wind direction(s) of interest. In such a case the directionally dependent wind speeds for the applicable locations should be used for the determination of design pressures.

An example of the derivation of the design pressures from pressure coefficients will be presented in the following Section 5.1 Design Pressure Examples

The warehouse roof surface point pressures are external pressures to which some allowance for internal pressure must be made. In this instance the warehouse has been assumed to have general porosity for the case of all external doors and windows closed (i.e., no dominant openings). The Australian Wind Loading Standard, AS/NZS1170.2 2011, defines the case for all walls equally permeable and for which, from Table 5.1(A) the values of the internal pressure coefficients (C_{pi}) are given as -0.3 to 0.0 (based on gust wind speed) whichever is the most severe for combined forces. In terms of Ultimate Limit State design pressures, the Ultimate Limit State internal pressure range, based on a height of 10m and a Terrain Category 2 and Terrain Category 3, in Region A5 becomes

$$P_{int,\ TC2} = -0.3 \times ½ \times 1.2 \times (45.0)^2 \text{ to } 0$$
$$= -365 \text{ Pa (i.e. inward acting) to } 0$$

$$P_{int,\ TC3} = -0.3 \times ½ \times 1.2 \times (37.4)^2 \text{ to } 0$$
$$= -252 \text{ Pa (i.e. inward acting) to } 0$$

The most severe combination is to add 365 Pa for TC2 and 252 Pa for TC3 to the positive external design pressures and 0 Pa to the negative external design pressures. It must be noted that for the net panel pressure values an internal pressure has no relevance.

5.1. DESIGN PRESSURE EXAMPLES

The wind tunnel data has been examined to find the peak positive and peak negative pressure coefficients.

Terrain Category 2

For the solar panels in Terrain Category 2, the peak positive and negative net pressure coefficients are as follows:

$C_{\hat{p}}$ = 1.79 at panel R04C19

$C_{\check{p}}$ = -1.48 at panel R22C01

Using these pressure coefficients the net design pressures are given as follows, noting that a mean design wind speed at the eave height (as determined in Section 3 and given in Table 1) has been used with no directional dependence, i.e. M_d = 1.0,

$$\hat{p} = \tfrac{1}{2} \times 1.2 \times 26.8^2 \times 1.79$$

$$\hat{p} = 771 \text{ Pa}$$

$$\check{p} = \tfrac{1}{2} \times 1.2 \times 26.8^2 \times -1.48$$

$$\check{p} = -638 \text{ Pa}$$

Terrain Category 3

For the solar panels in Terrain Category 3, the peak positive and negative net pressure coefficients are as follows:

$C_{\hat{p}}$ = 1.68 at panel R02C35

$C_{\check{p}}$ = -1.76 at panel R26C01

Using these pressure coefficients the net design pressures are given as follows, noting that a mean design wind speed at the eave height (as determined in Section 3 and given in Table 1) has been used with no directional dependence, i.e. M_d = 1.0,

$\hat{p}$ = ½ x 1.2 x 19.8^2 x 1.68

$\hat{p}$ = 395 Pa

$\check{p}$ = ½ x 1.2 x 19.8^2 x -1.76

$\check{p}$ = -414 Pa

Generally, the highest magnitude pressures are realised near the edges and corners of the solar array, as these panels are most directly exposed to the wind. Furthermore edge and corner vortices can often impinge onto these edge and corner panels resulting in high localised positive and negative pressures.

Inspection of the wind tunnel data shows that the magnitude of the pressure coefficients drops off significantly towards the central portion of the roof, which is far away from any corner vortices or edge vortical flows and is significantly shielded by the rest of the surrounding array. For the solar panels, typical positive and negative net pressure coefficient values for TC2 and TC3 are:

$C_{\hat{p}}$ = 0.50 in central portion of the solar array

$C_{\check{p}}$ = -0.70 in central portion of the solar array

For TC2, these coefficients equate to design wind loads of:

$\hat{p}$ = ½ x 1.2 x 26.8^2 x 0.50

$\hat{p}$ = 215 Pa

$\check{p}$ = ½ x 1.2 x 26.8^2 x -0.70

$\check{p}$ = -302 Pa

For TC3, these coefficients equate to design wind loads of:

$$\hat{p} = ½ \times 1.2 \times 19.8^2 \times 0.50$$

$$\hat{p} = 118 \text{ Pa}$$

$$\check{p} = ½ \times 1.2 \times 19.8^2 \times -0.70$$

$$\check{p} = -165 \text{ Pa}$$

These net coefficient values have been used to calculate the net design wind pressures on the panels and are presented in Table 2.

A number of key areas on the warehouse roof and solar panel array can be identified, from the wind tunnel data, which can assist with the selection of applicable pressure coefficients for the determination of design wind loads. These are discussed in Appendix A and shown schematically in Figure A1. A brief design guide methodology for determining the design wind pressures is presented in Appendix B.

6. DESIGN PRESSURES FROM AS/NZS1170.2:2011

An example of the calculation of design pressures is given here. The determination of net design pressures coefficients on 10^0 - 15^0 inclined panels on a roof using the Australian Wind Loading Standard AS/NZS1170.2:2011 is presented in Appendix A and has used a monoslope free roof approximation as there is no pressure coefficient information specific to inclined solar panel installations in the wind Standard. The net pressure coefficients obtained from these estimates will be used here for the calculation of the 500 year return period net design pressures on the solar panels mounted on an approximately 10m high rectangular planform building in Terrain Category 2. The same as is used in the present experimental study. The evaluation uses Table A1 in Appendix A.

For Terrain Category 2, Region A5, and a basic Ultimate Limit State design gust wind speed of $45.0ms^{-1}$ (M_d = 1.0) the net design pressure is as follows:

For flush mounted PV panels

$$\check{p}_{flush} = -1.70 \times ½ \times 1.2 \times 45.0^2$$
$$= -2070 \text{ Pa}$$
$$\hat{p}_{flush} = 0.50 \times ½ \times 1.2 \times 45.0^2$$
$$= 610 \text{ Pa}$$

For inclined PV panels

$$\check{p}_{inclined\ 0deg} = -1.50 \times ½ \times 1.2 \times 45.0^2$$
$$= -1820 \text{ Pa}$$
$$\hat{p}_{inclined\ 180deg} = 0.40 \times ½ \times 1.2 \times 45.0^2$$
$$= 490 \text{ Pa}$$

For Terrain Category 3, Region A5, and a basic Ultimate Limit State design wind speed of 37.4ms^{-1} (M_d = 1.0) the net design pressure is as follows:

For flush mounted PV panels

$\check{p}_{flush}$ = -1.70 x ½ x 1.2 x 37.4^2

= -1425 Pa

$\hat{p}_{flush}$ = 0.50 x ½ x 1.2 x 37.4^2

= 420 Pa

For inclined PV panels

$\check{p}_{inclined\ 0deg}$ = -1.50 x ½ x 1.2 x 37.4^2

= - 1260 Pa

$\hat{p}_{inclined\ 180deg}$ = 0.40 x ½ x 1.2 x 37.4^2

= 335 Pa

7. EXPERIMENTAL VS. STANDARD BASED DESIGN PRESSURES

It must be emphasised that a direct comparison of pressure coefficients obtained from the wind tunnel studies and pressure coefficients obtained from the AS/NZS1170.2:2011 cannot be made as each of these coefficients is normalised by a different reference velocity. In the case of the wind tunnel coefficients, these are normalised by a mean freestream velocity at the height of the building, while the wind standard based coefficients are normalised by the reference gust wind speed at the reference height of the building. As such, the only meaningful comparison between wind tunnel results and the wind standard based results is through the determination of a design wind load for each. This procedure is highlighted in the calculation methodologies of Sections 5.1 and 6.

Table 2 summarises the critical design load cases for the solar panel configuration tested and the results are compared to the AS/NZS1170.2:2011 based design wind loads (as calculated in Section 6). In the case of the wind tunnel data, the design loads reference the *mean*, 500 year return period, wind speed at a height of 10m in Terrain Category 2 (= 26.8m/s, M_d = 1, Region A5) and Terrain Category 3 (= 19.8m/s, M_d = 1, Region A5), whilst the Standard based design wind loads reference the 500 year return period *gust* wind speed at a height of 10m in Terrain Category 2 (= 45.0m/s, M_d = 1, Region A5) and Terrain Category 3 (= 37.4m/s, M_d = 1, Region A5).

It is evident from the data that the most significant savings compared to a Standard based approach of design net wind pressures on the solar panels lie in the peak negative pressures. The peak negative net wind pressures begin to increase only for the corner or edge solar panels which have direct exposure to the wind. Further inboard from the array edges the loads begin to drop off and significant savings can be realised in the peak negative pressures. The net positive pressures on the solar panel arrays display a close correlation with the Standard based pressure estimates. In some cases the peak positive pressures exceed the Standard based values, however it would be expected that the peak negative pressures are controlling the design.

8. CONCLUSIONS

A 1:75 scale model of a generic warehouse building with solar panel arrays installed on the roof has been tested in a simulated natural wind boundary layer over open terrain (Terrain Category 2) and suburban terrain (Terrain Category 3) to measure the pressures on the building roof (with and without the solar panels) and net pressures across the panels themselves. The solar panel configuration tested comprised panels installed inclined to the roof at an angle of 10 degrees. Surface pressures on the solar panels and building roof were measured with reference to the free-stream static pressure for 36 wind directions at 10° intervals. All the measurements on the scale model warehouse were for a rectangular building (2:1:0.11 length-to-width-to-height$_{eave}$ ratio) with roof pitch of approximately 3^0.

The pressure test data were normalised with the mean free-stream wind speed at a height of 10m above ground (corresponding to the building eave height) producing mean, standard deviation, minimum and maximum pressure coefficients. This pressure coefficient data has been plotted for the tested configurations in the form of highest magnitude maximum and minimum values across all wind directions at each measurement location. An Excel spreadsheet containing this information has been provided (Addendum A) with tabulated pressure coefficients as a function of wind direction.

The data showed that for the solar panel configuration tested, and compared to a Standard based approach of design net wind pressures, the most significant savings on the solar panels lie in the peak negative pressures. The peak negative net wind pressures begin to increase only for the corner or edge solar panels which have direct exposure to the wind. Further inboard from the array edges the loads begin to drop off and significant savings can be realised in the peak negative pressures. The net positive pressures on the solar panel arrays display a closer correlation with the Standard based pressure estimates. In some cases the peak positive pressures exceed the Standard based values, however it would be expected that the peak negative pressures are controlling the design. If more specific directionality information on the design pressures or pressure coefficients is required for further optimisation of the design then the tabulated data in Addendum A should be interrogated for the wind direction(s) of interest. In such a case the directionally dependent wind speeds applicable to the building location should be used for the determination of design pressures.

W. H. Melbourne

W. H. Melbourne
MEL Consultants Pty Ltd
April 2018

TABLES

TABLE 1

SUMMARISED 500 YEAR RETURN PERIOD DESIGN MEAN WIND SPEEDS (ms^{-1}) FOR REGION A5 FOR TERRAIN CATEGORY 2 AND TERRAIN CATEGORY 3

Wind direction	β (deg)	Regional wind speeds from AS/NZS1170.2:2011 $\hat{V}_{10m}$ Cat2 500 year return ms^{-1}	$\bar{V}_{10m}$ Cat2 500 year return ms^{-1}	$\bar{V}_{10m}$ Cat3 500 year return ms^{-1}
N	0	45.0	26.8	19.8
NE	45.0	38.3	22.8	16.8
E	90.0	36.0	21.5	15.8
SE	135.0	36.0	21.5	15.8
S	180.0	38.3	22.8	16.8
SW	225.0	40.5	24.1	17.8
W	270.0	45.0	26.8	19.8
NW	315.0	42.8	25.5	18.8

TABLE 2a

Design wind loads for flush mounted solar panels for a 500 year return period wind speed at a reference height of 10m in TC2

	500 year return period design wind loads for TC2, Pa			
Solar panel location	*Measurements*		AS/NZS 1170.2:2011	
	peak +ve	*peak -ve*	peak +ve	peak -ve
Edge	771	-638	610	-2070
Centre	215	-302	610	-2070

TABLE 2b

Design wind loads for flush mounted solar panels for a 500 year return period wind speed at a reference height of 10m in TC3

	500 year return period design wind loads for TC3, Pa			
Solar panel location	*Measurements*		AS/NZS 1170.2:2011	
	peak +ve	*peak -ve*	peak +ve	peak -ve
Edge	395	-414	420	-1425
Centre	118	-165	420	-1425

FIGURES

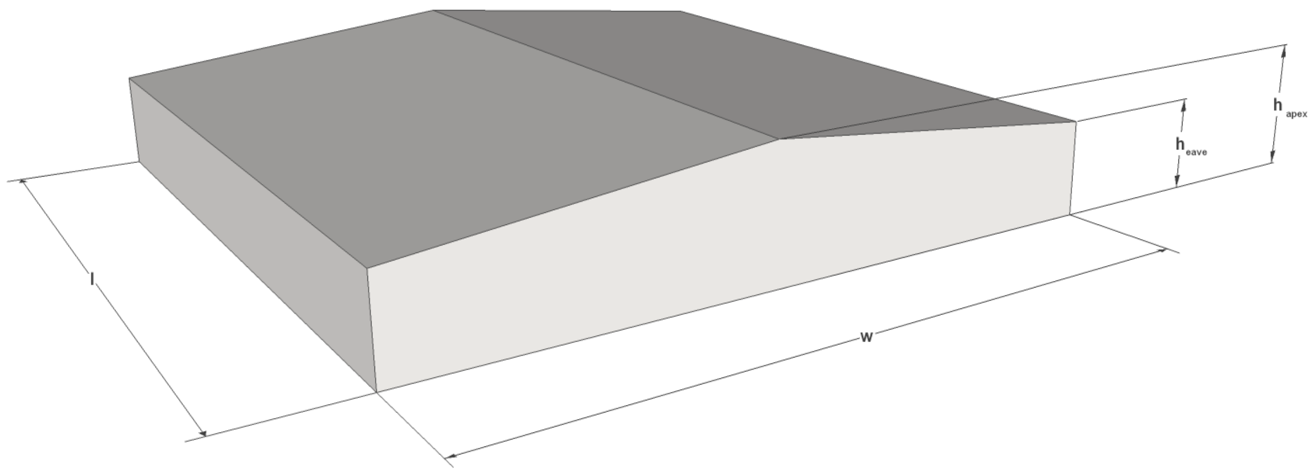

Figure 1a - Warehouse building geometry with key geometric dimensions indicated

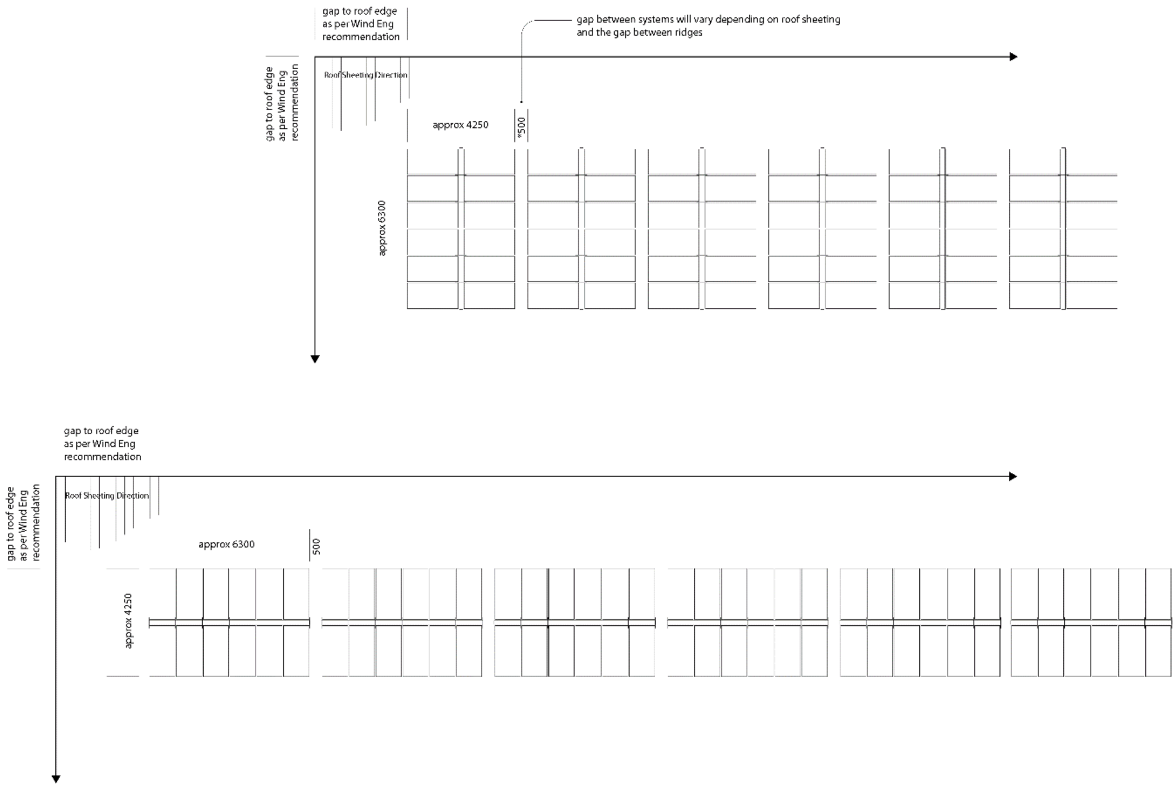

Figure 1b - Solar panel array layout, as used in the wind tunnel testing.

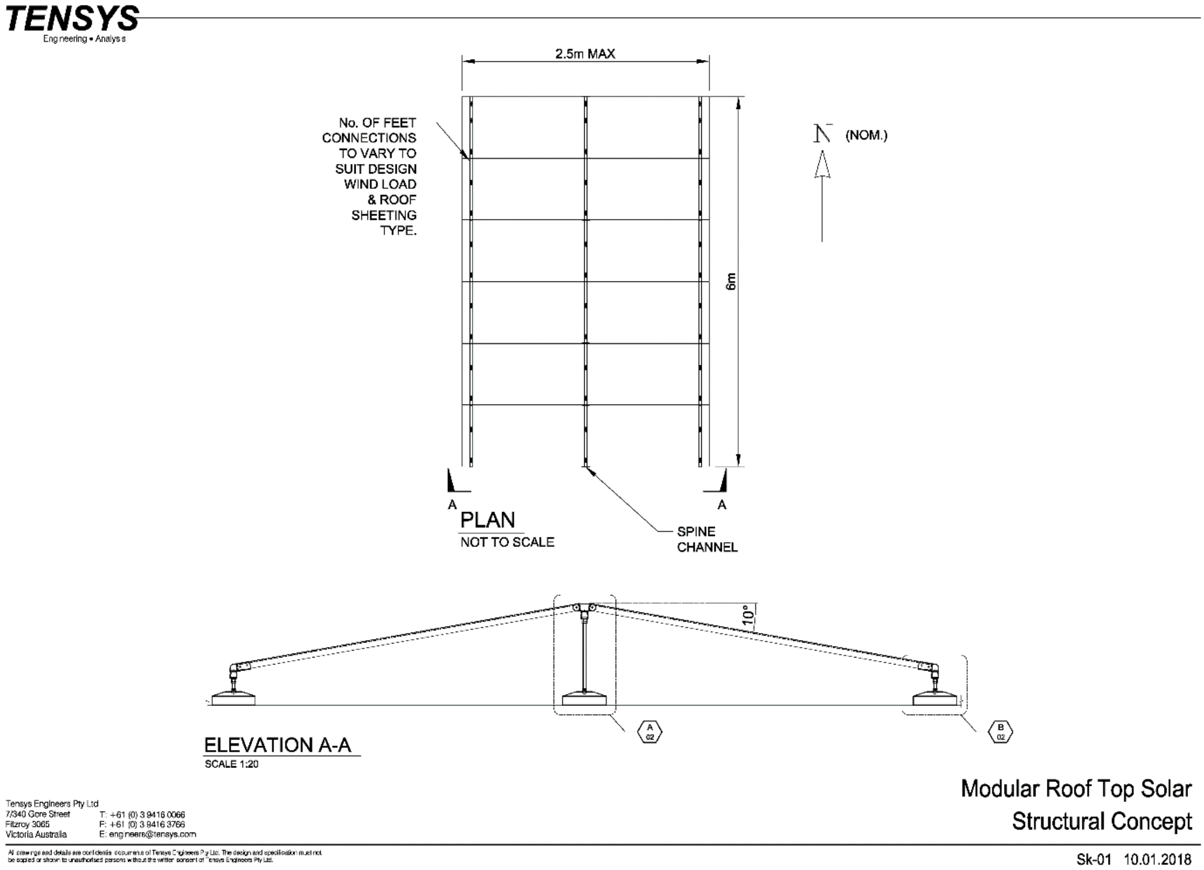

Figure 1c - Solar panel module geometry, as used in the wind tunnel testing.

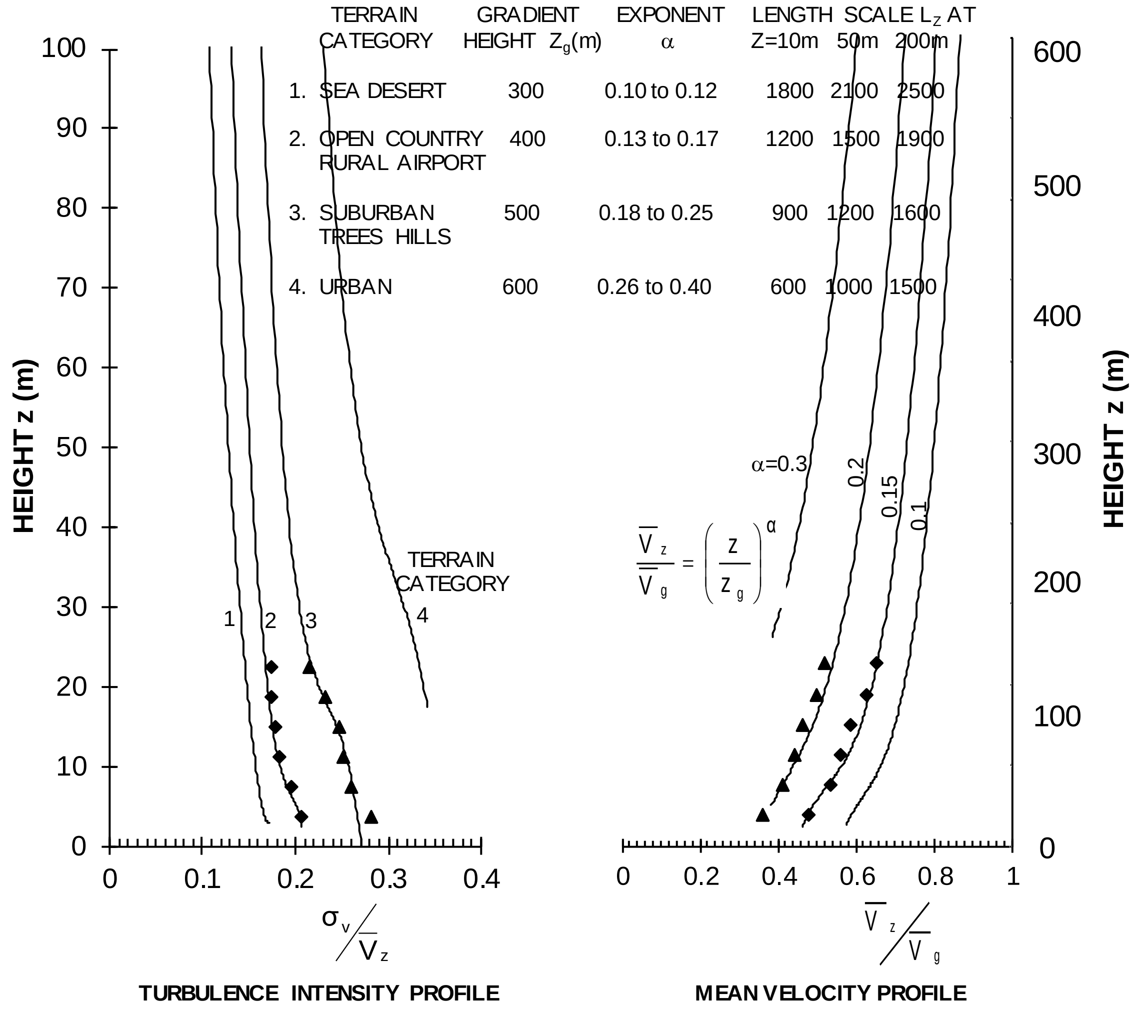

Figure 2 - 1/75 scale TC3 boundary layer turbulence intensity and mean velocity profiles and spectra in the MEL Consultants Boundary Layer Wind Tunnel 4.8m x 2.4m working section, scaled to full scale dimensions

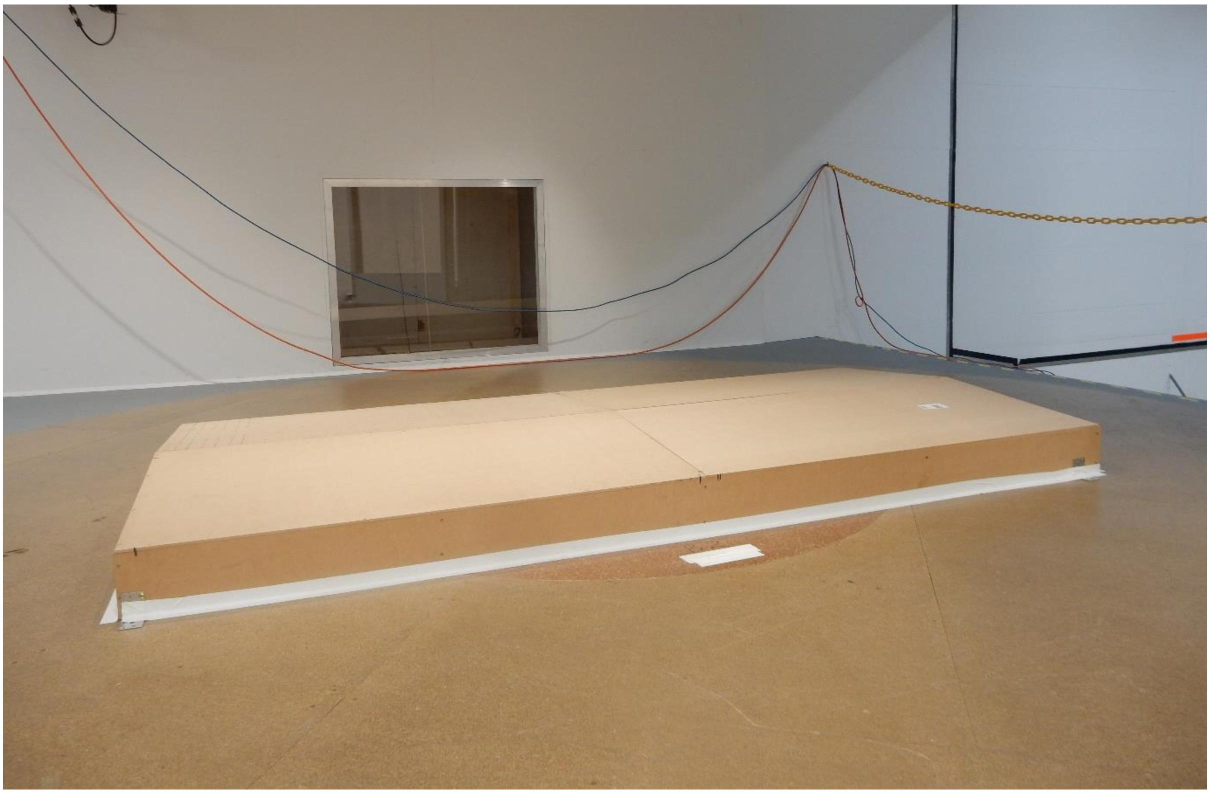

**Figure 3 -	Photo of warehouse model without panels in the wind tunnel**

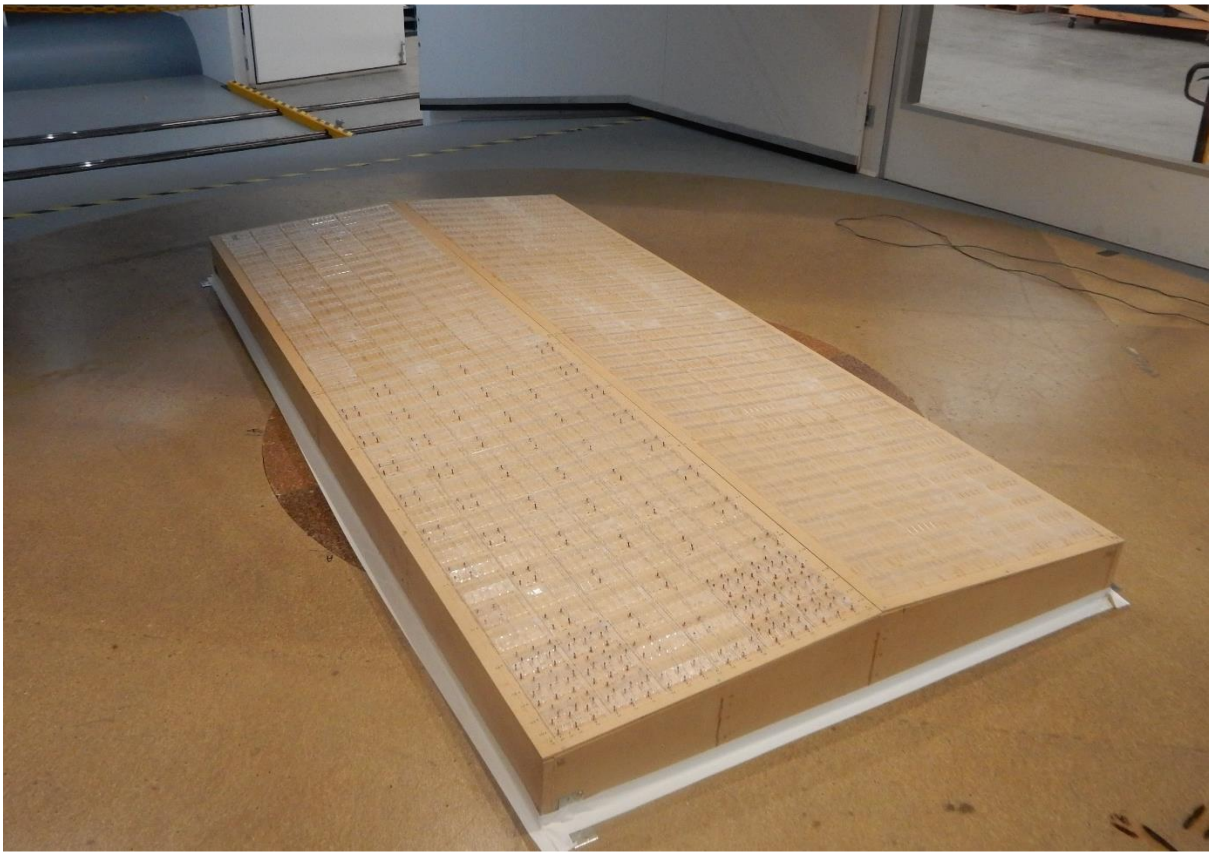

**Figure 4 -	Photo of warehouse model with panels in the wind tunnel**

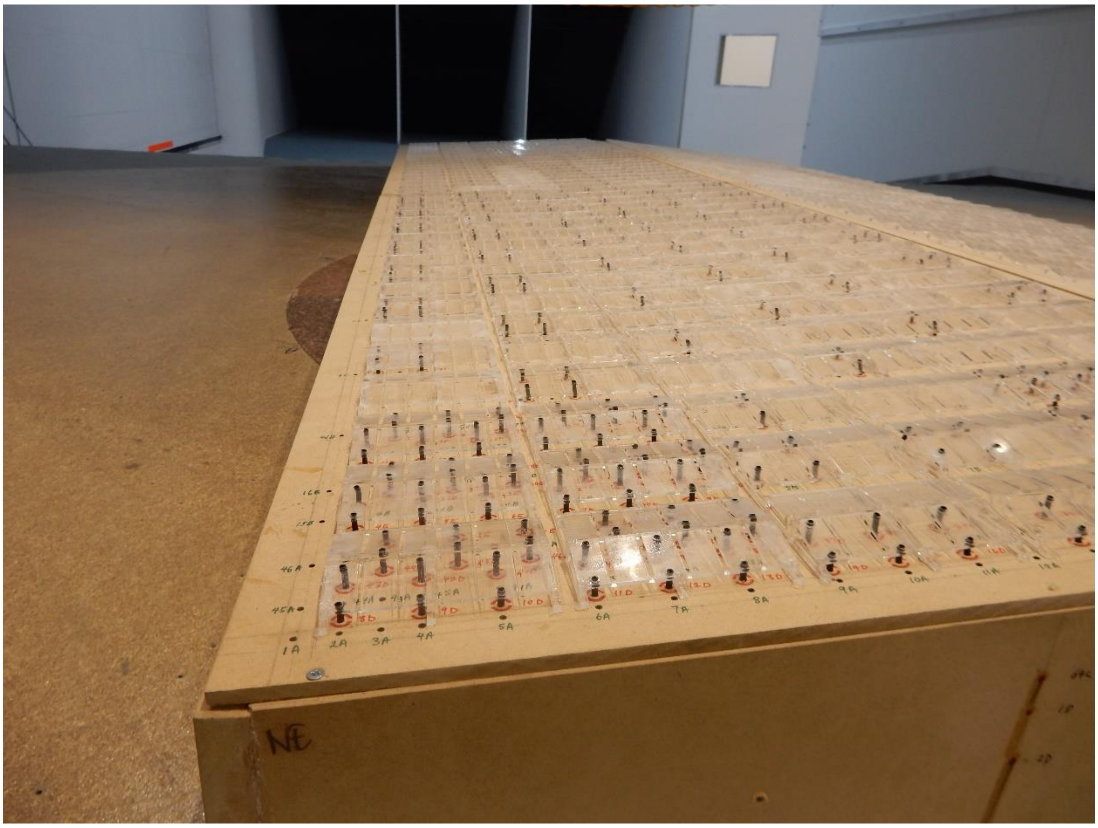

Figure 5 - **Photo of warehouse model showing pressure tap locations**

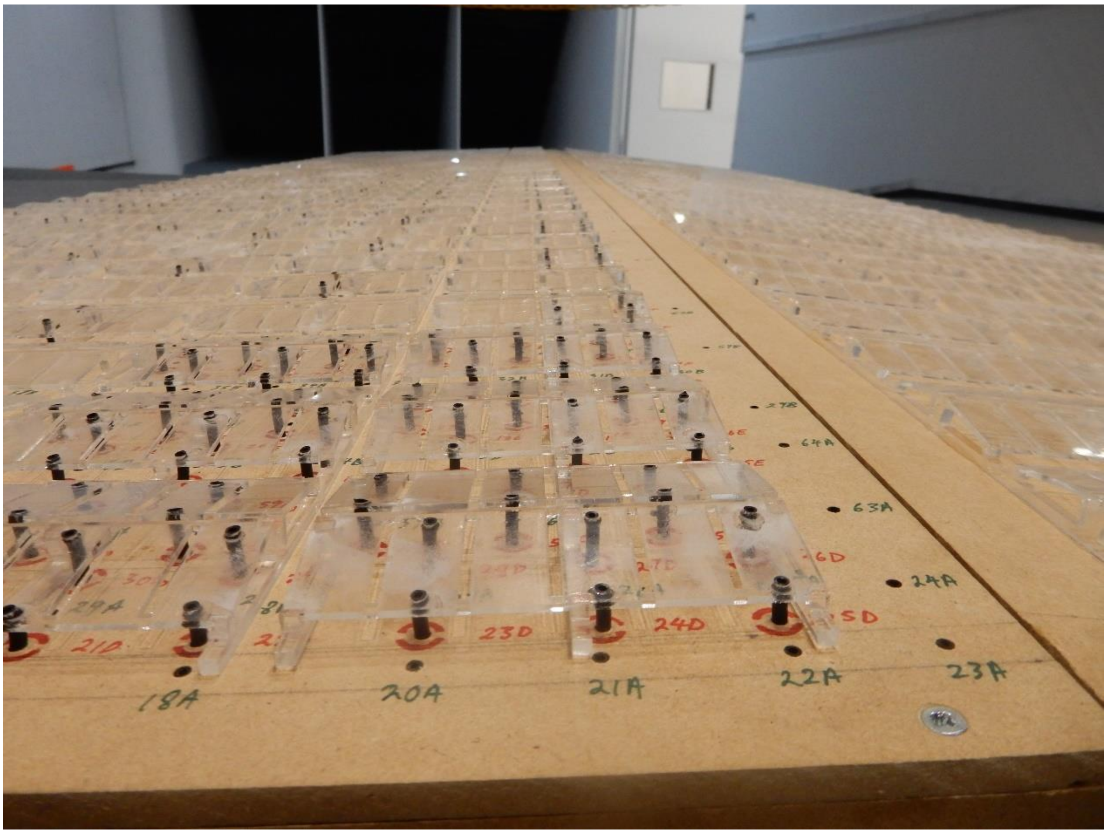

Figure 6 - **Close-up photo of the individually instrumented solar panels**

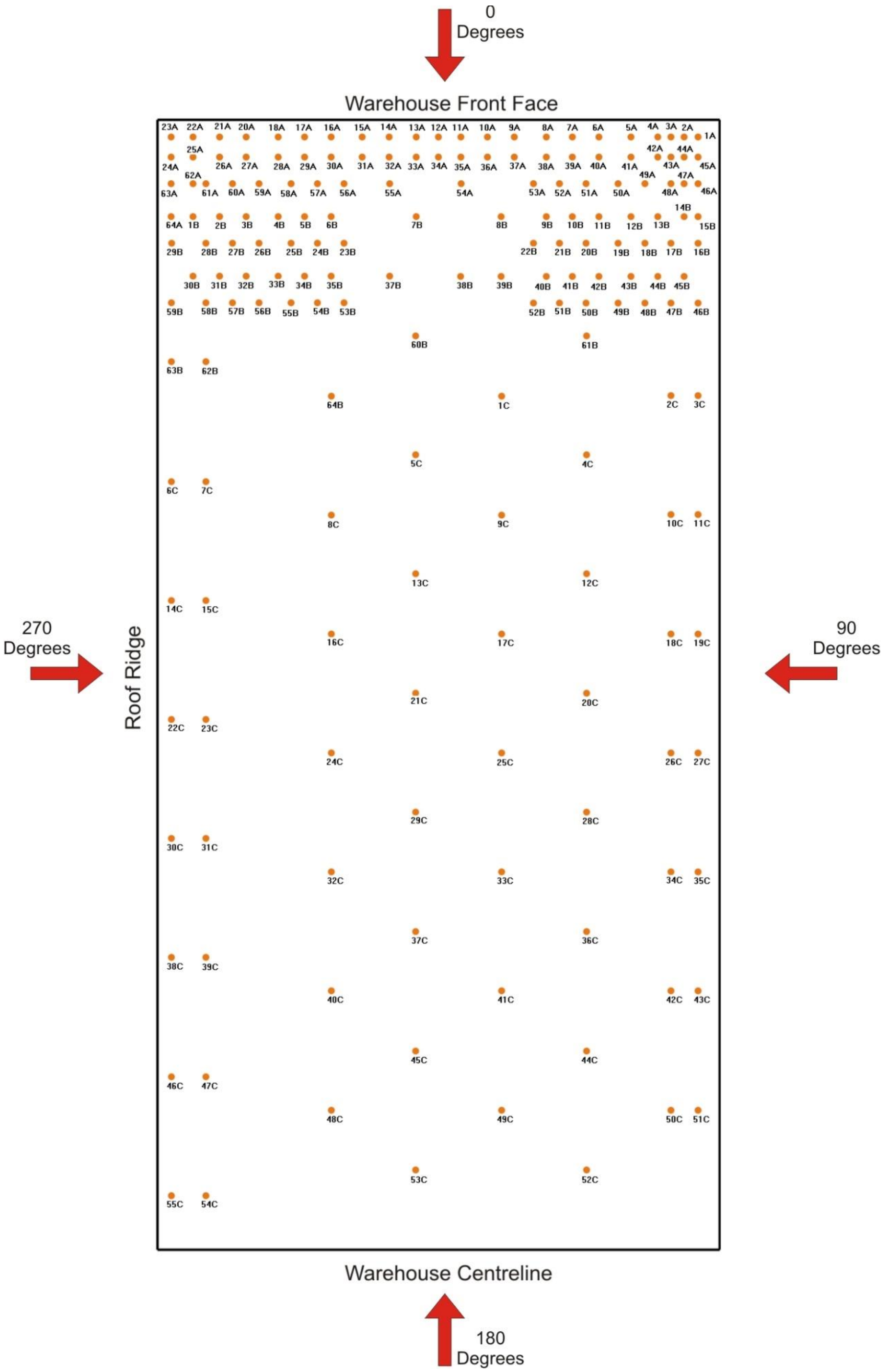

Figure 7 – **Plan view of one quarter of the warehouse model <u>without solar panels</u> showing roof tap locations and labels**

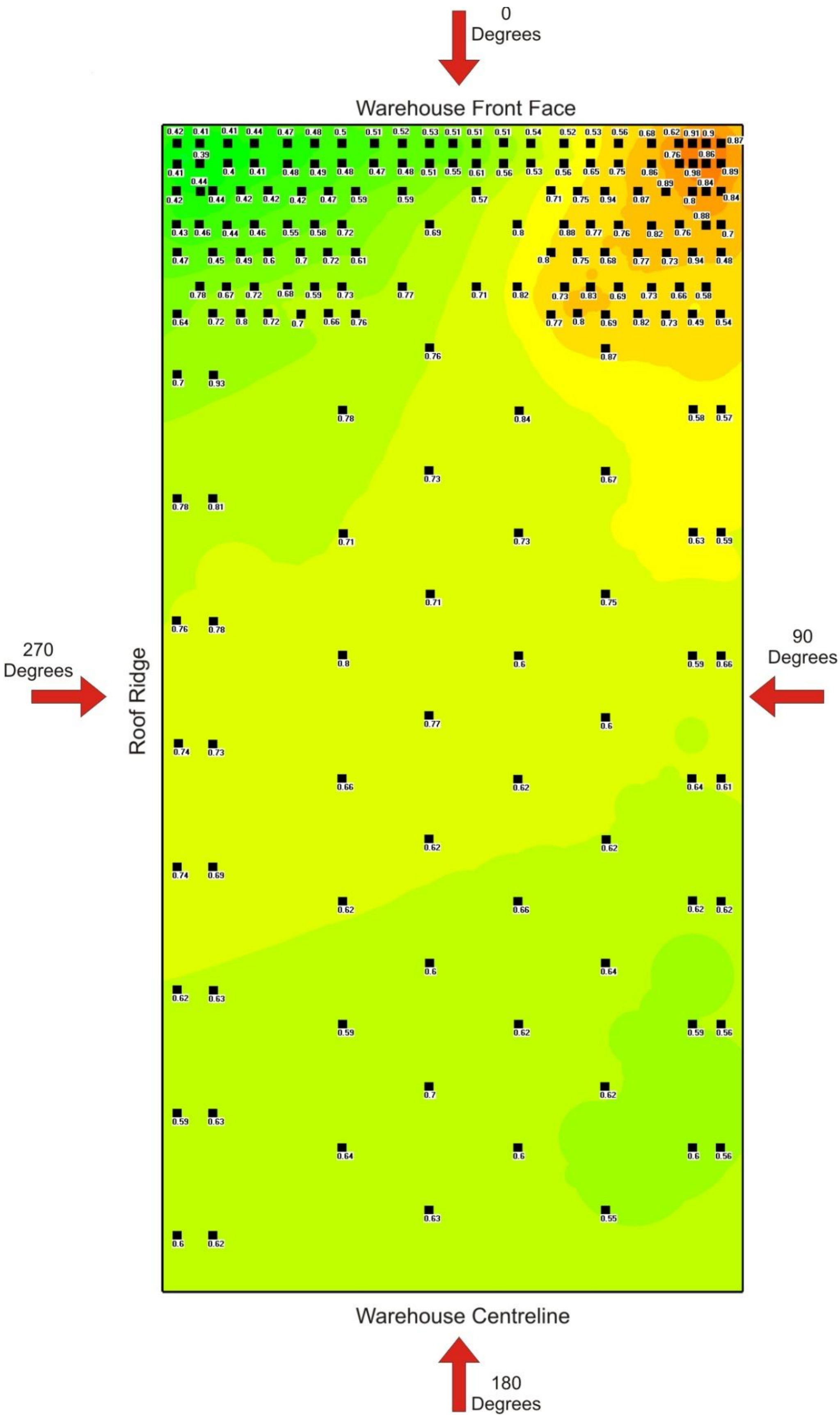

Figure 8a – **Highest magnitude roof maximum pressure coefficient for one quarter roof model <u>without solar panels</u> for all wind directions <u>for TC2</u>**

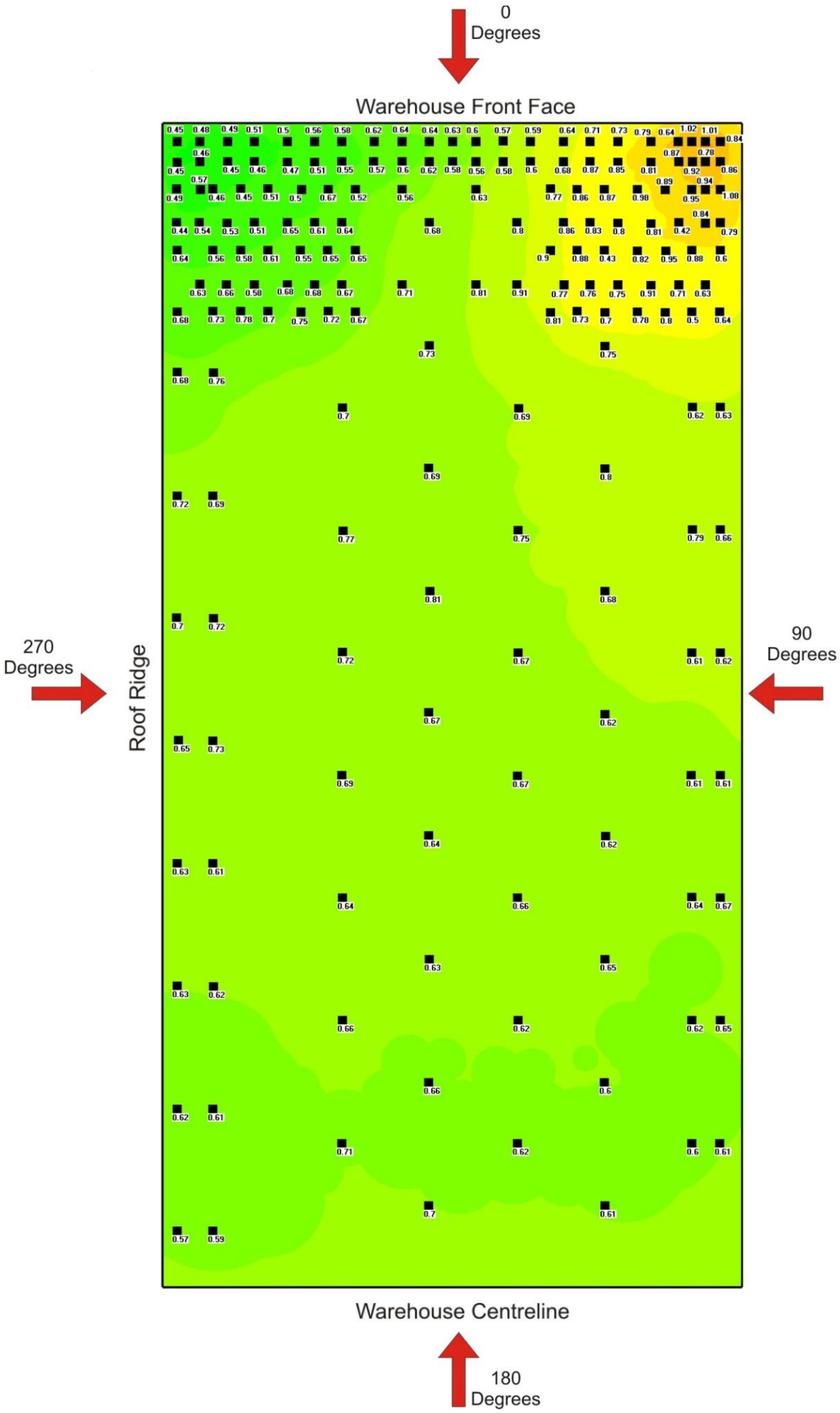

Figure 8b – Highest magnitude roof maximum pressure coefficient for one quarter roof model <u>without solar panels</u> for all wind directions <u>for TC3</u>

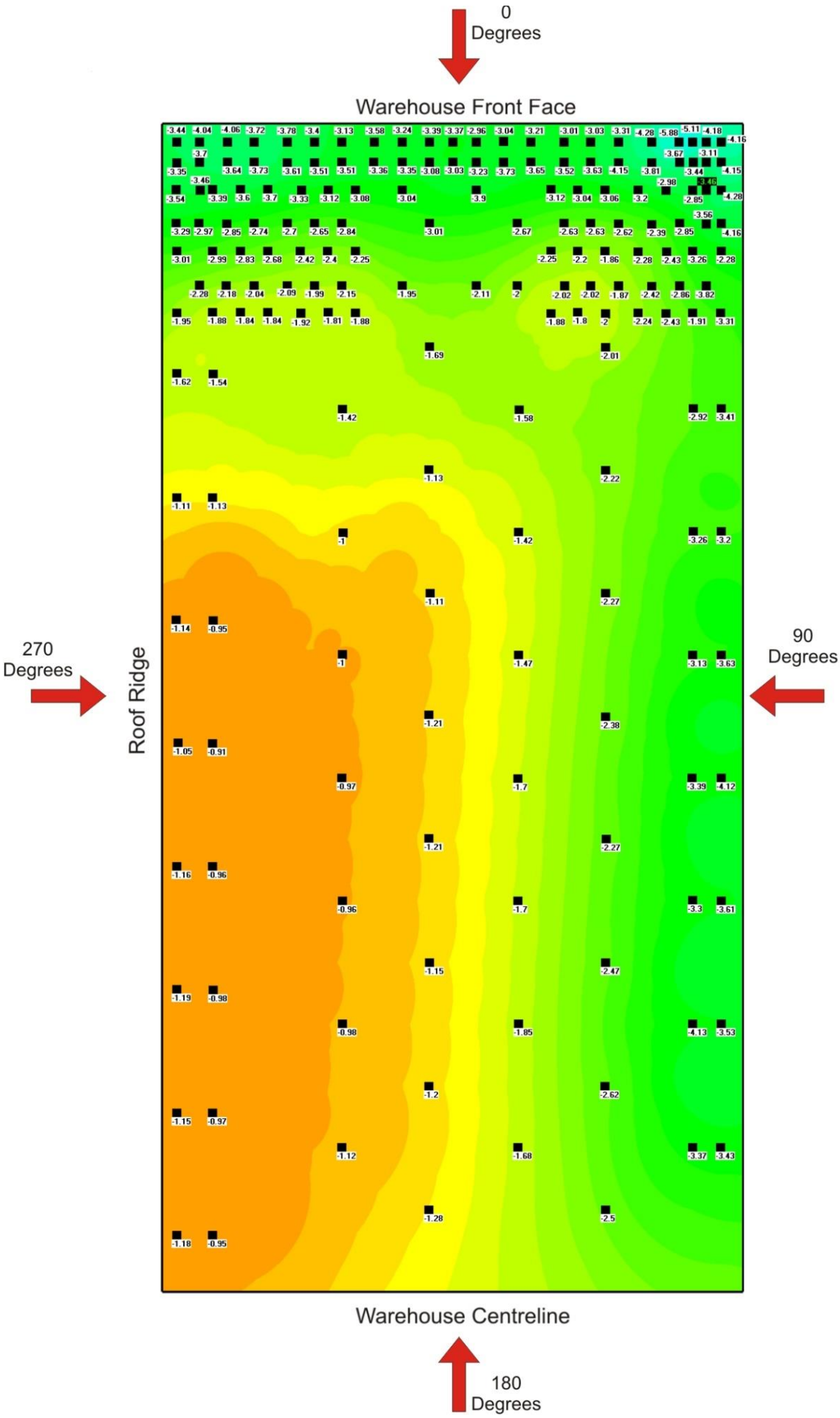

Figure 9a – Highest magnitude roof minimum pressure coefficient for one quarter roof model <u>without solar panels</u> for all wind directions <u>for TC2</u>

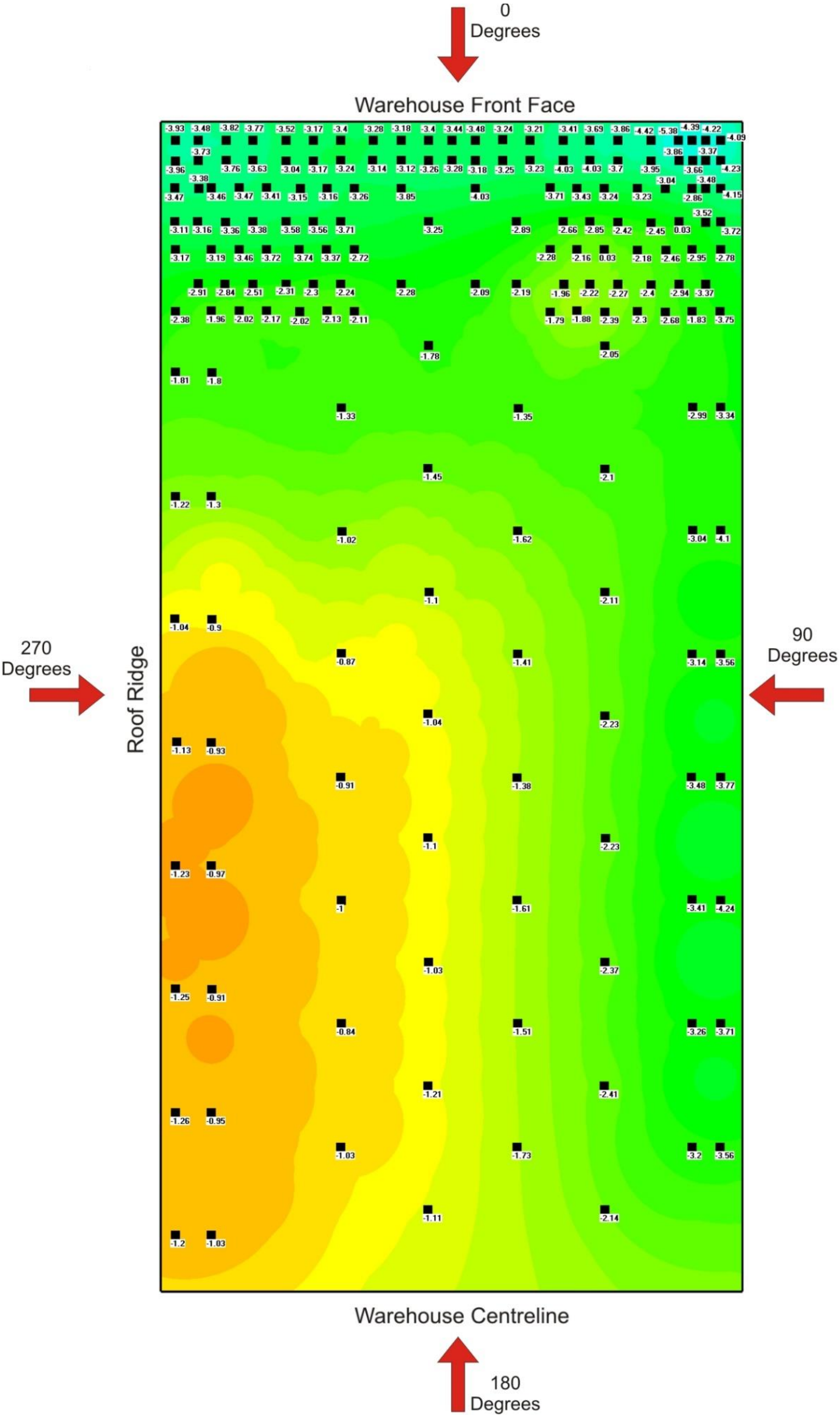

Figure 9b – Highest magnitude roof minimum pressure coefficient for one quarter roof model without solar panels for all wind directions for TC3

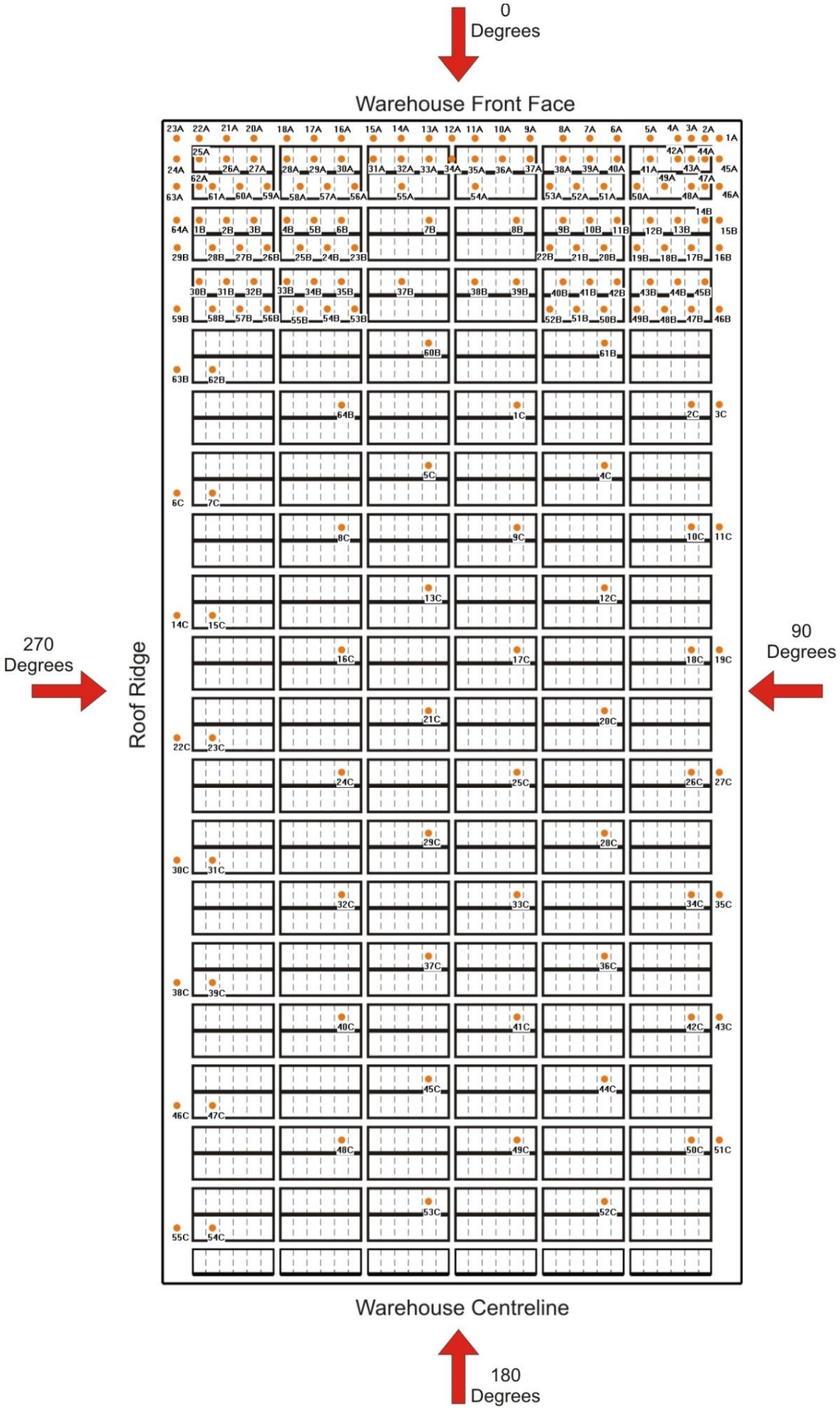

Figure 10 – Plan view of one quarter of the warehouse model <u>with solar panels</u> showing roof tap locations and labels

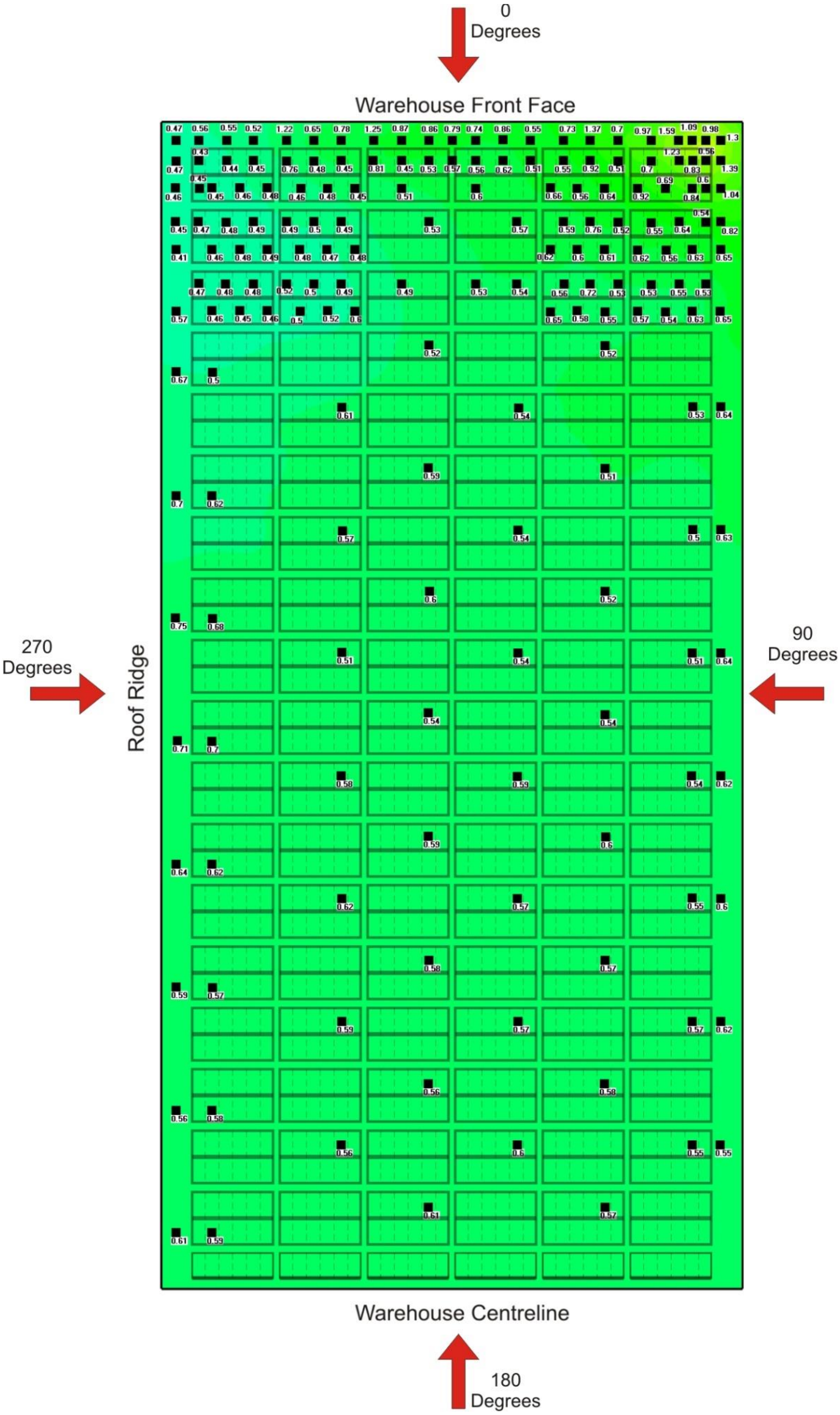

Figure 11a – Highest magnitude roof maximum pressure coefficient for one quarter roof model with solar panels for all wind directions for TC2

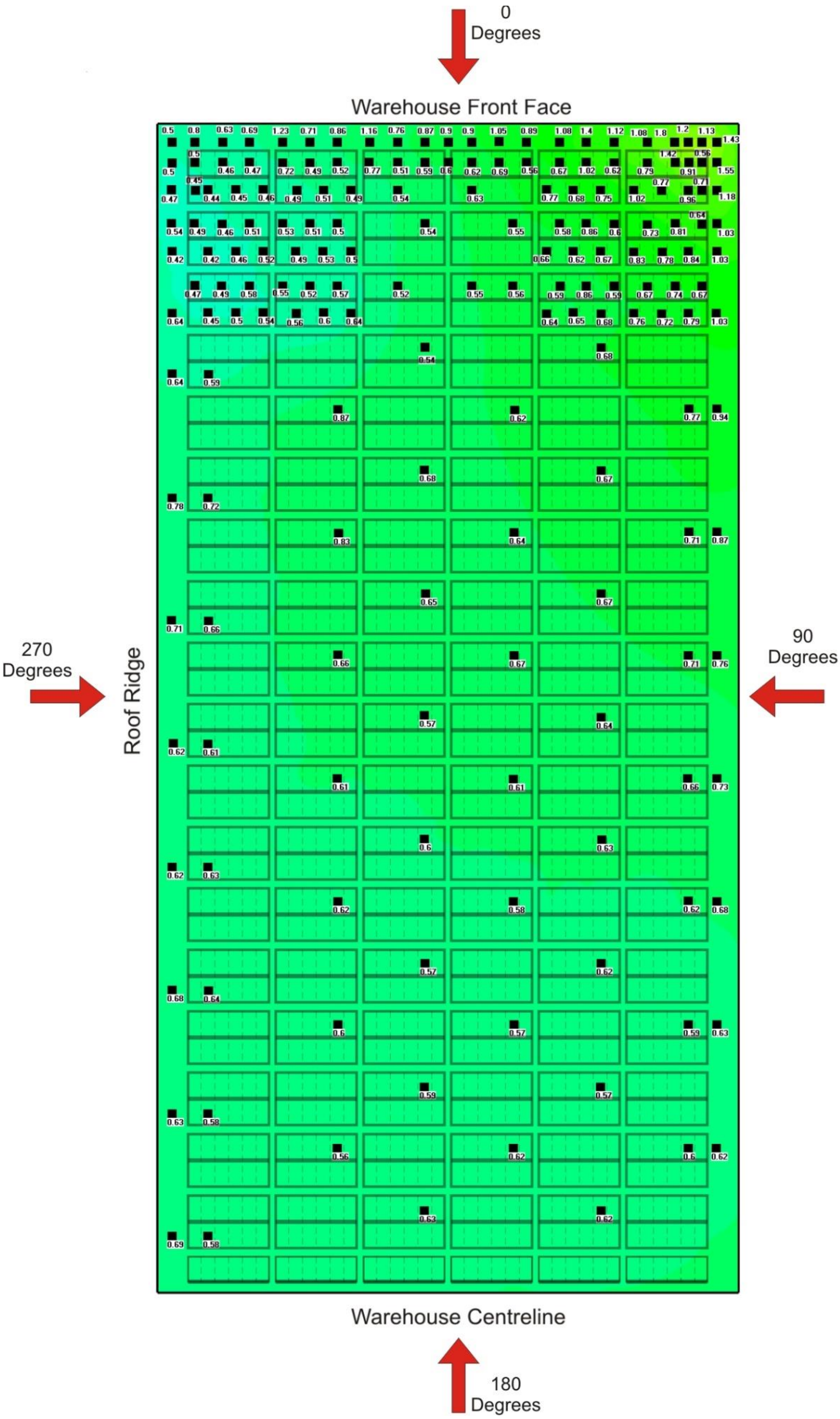

Figure 11b – Highest magnitude roof maximum pressure coefficient for one quarter roof model with solar panels for all wind directions for TC3

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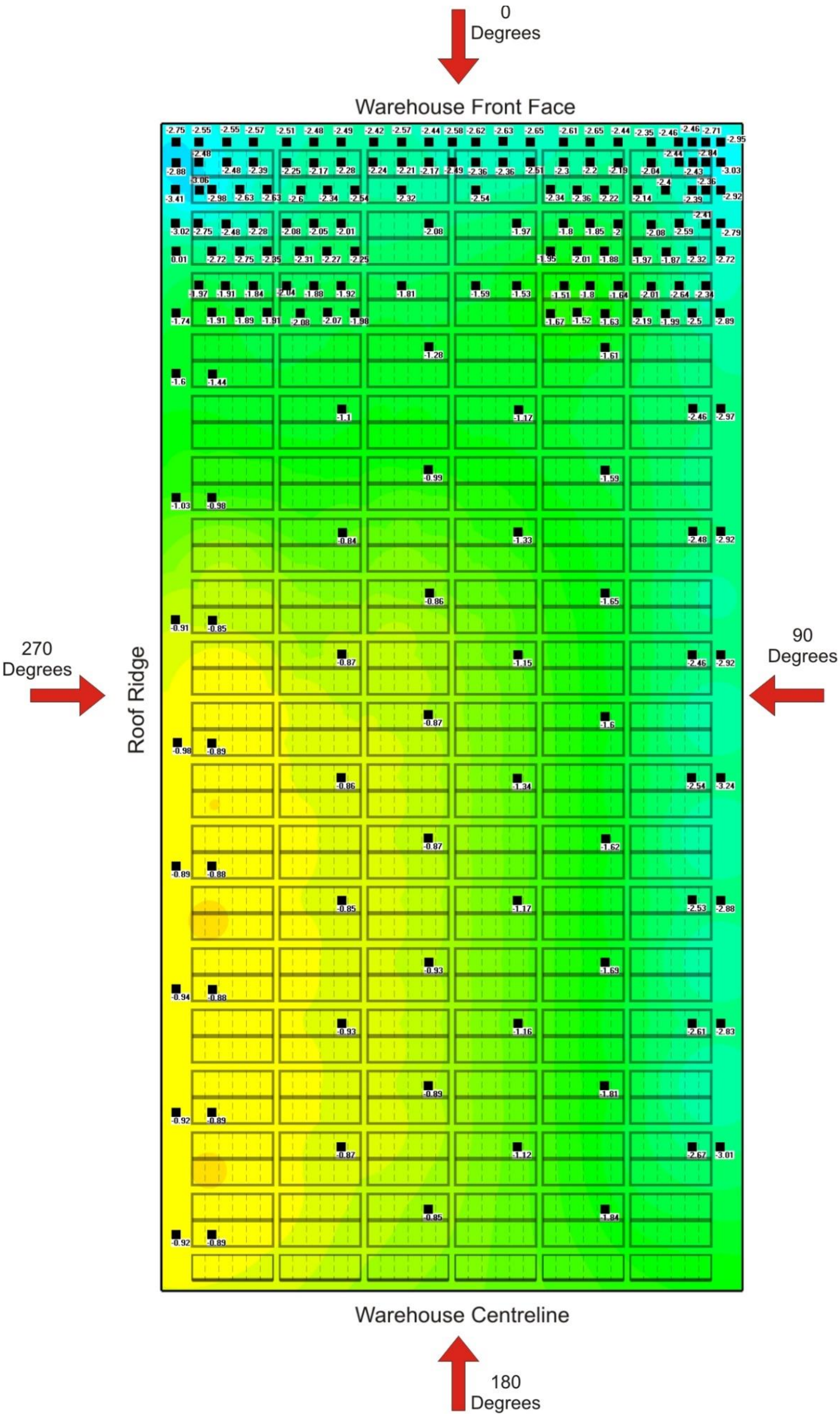

Figure 12a – Highest magnitude roof minimum pressure coefficient for one quarter roof model with solar panels for all wind directions for TC2

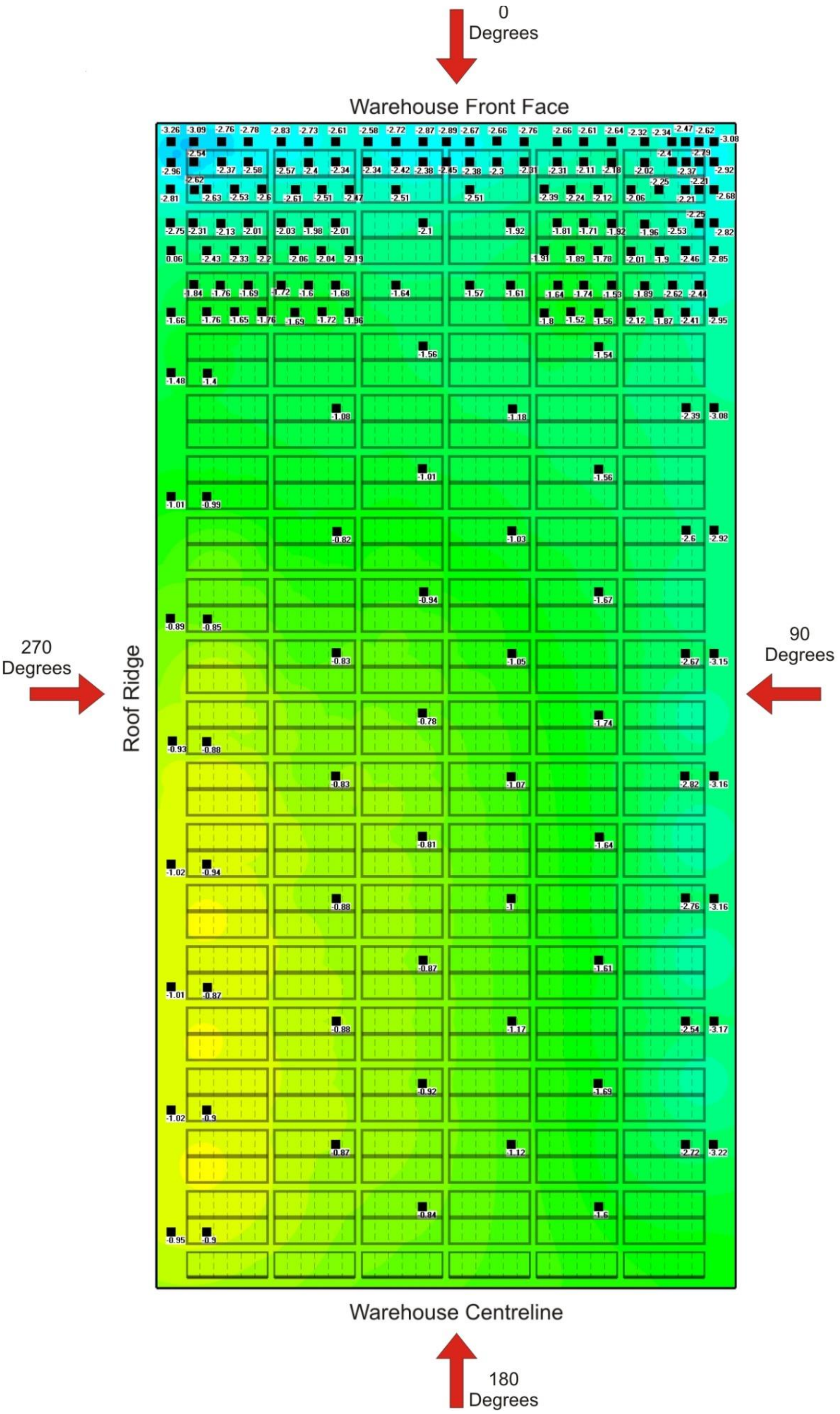

Figure 12b – Highest magnitude roof minimum pressure coefficient for one quarter roof model with solar panels for all wind directions for TC3

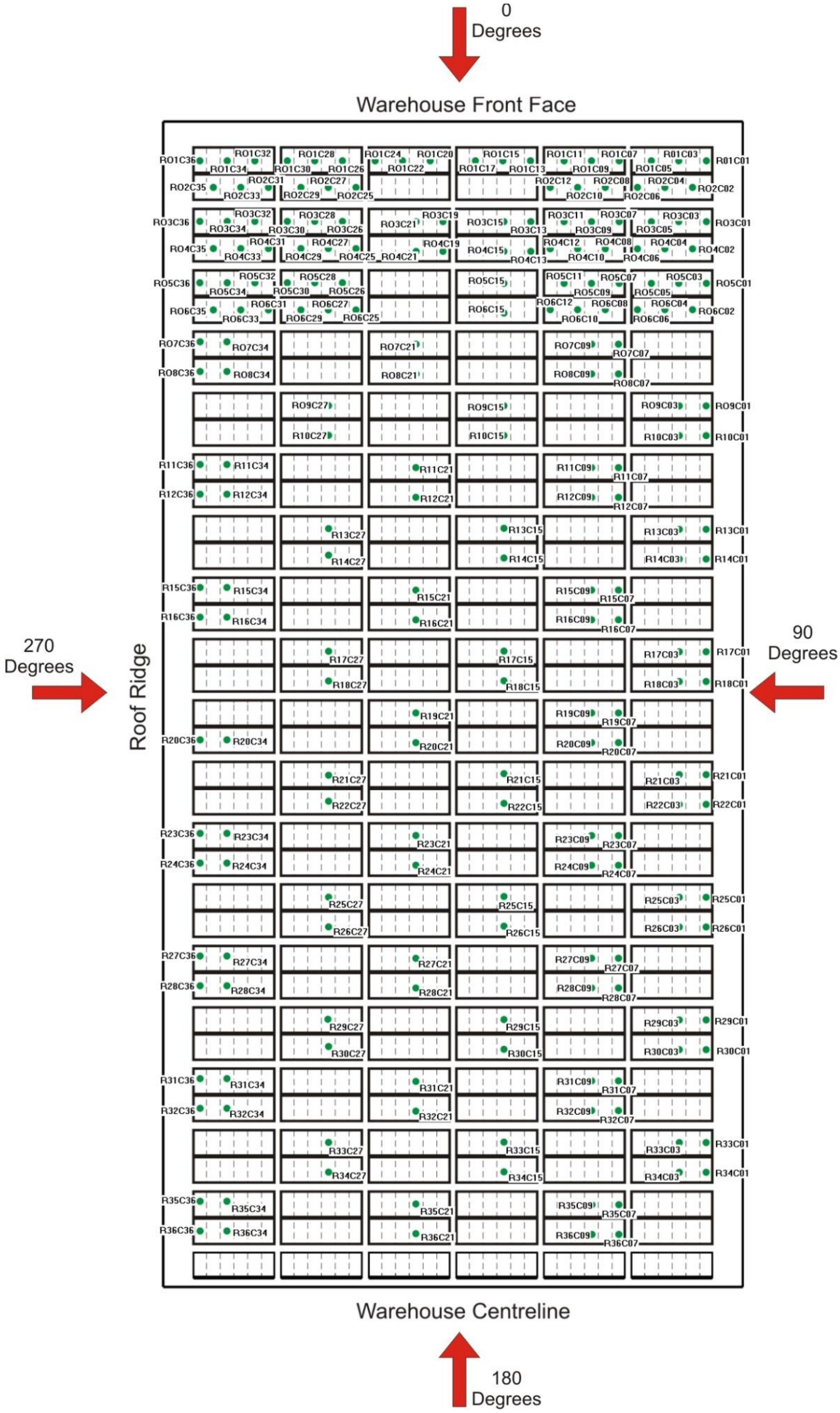

Figure 13 – Plan view of one quarter of the warehouse model showing the solar panels area averaged net pressure tap locations and labels

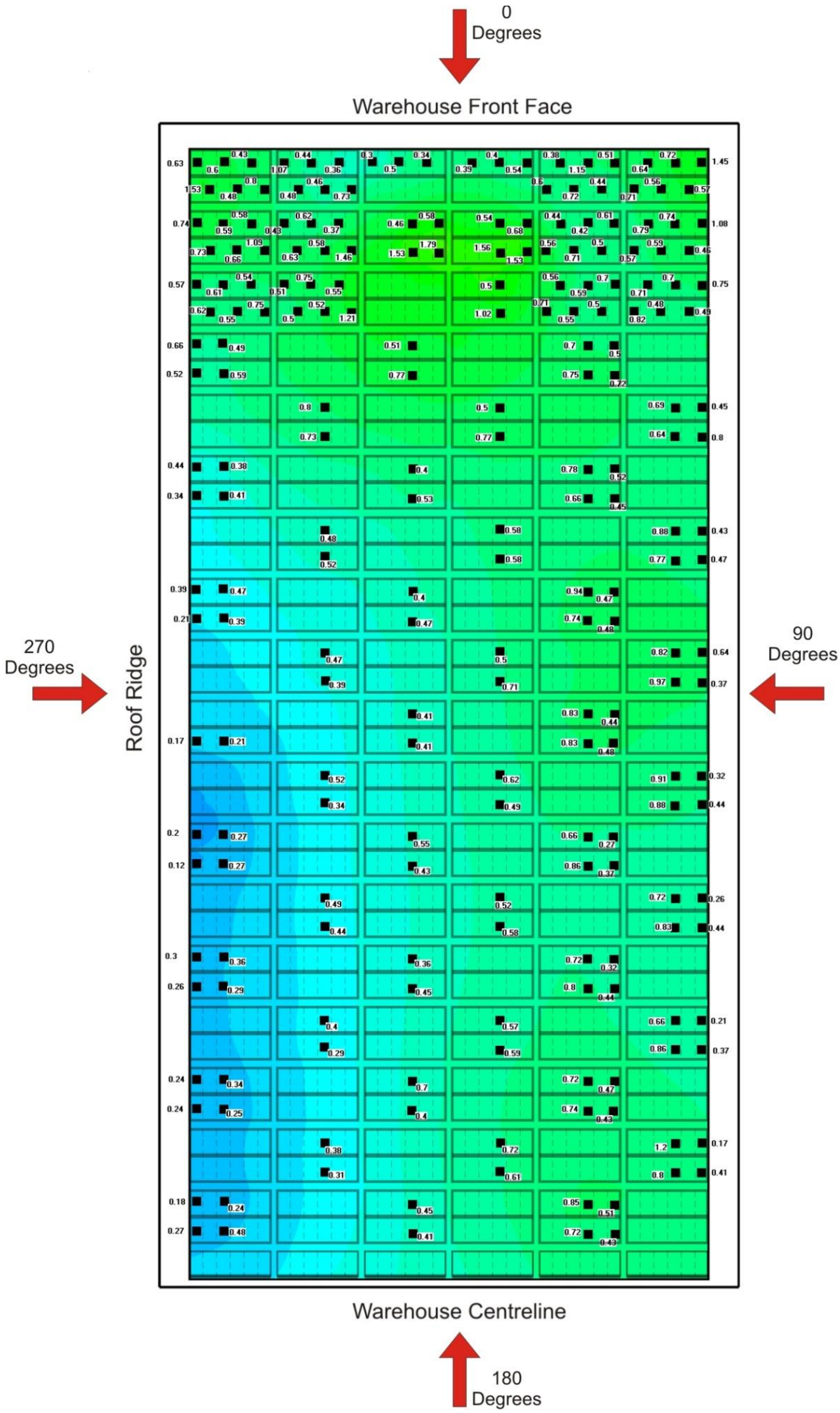

Figure 14a – Highest magnitude maximum net area averaged pressure coefficient on solar panels on one quarter roof model for all wind directions <u>for TC2</u>

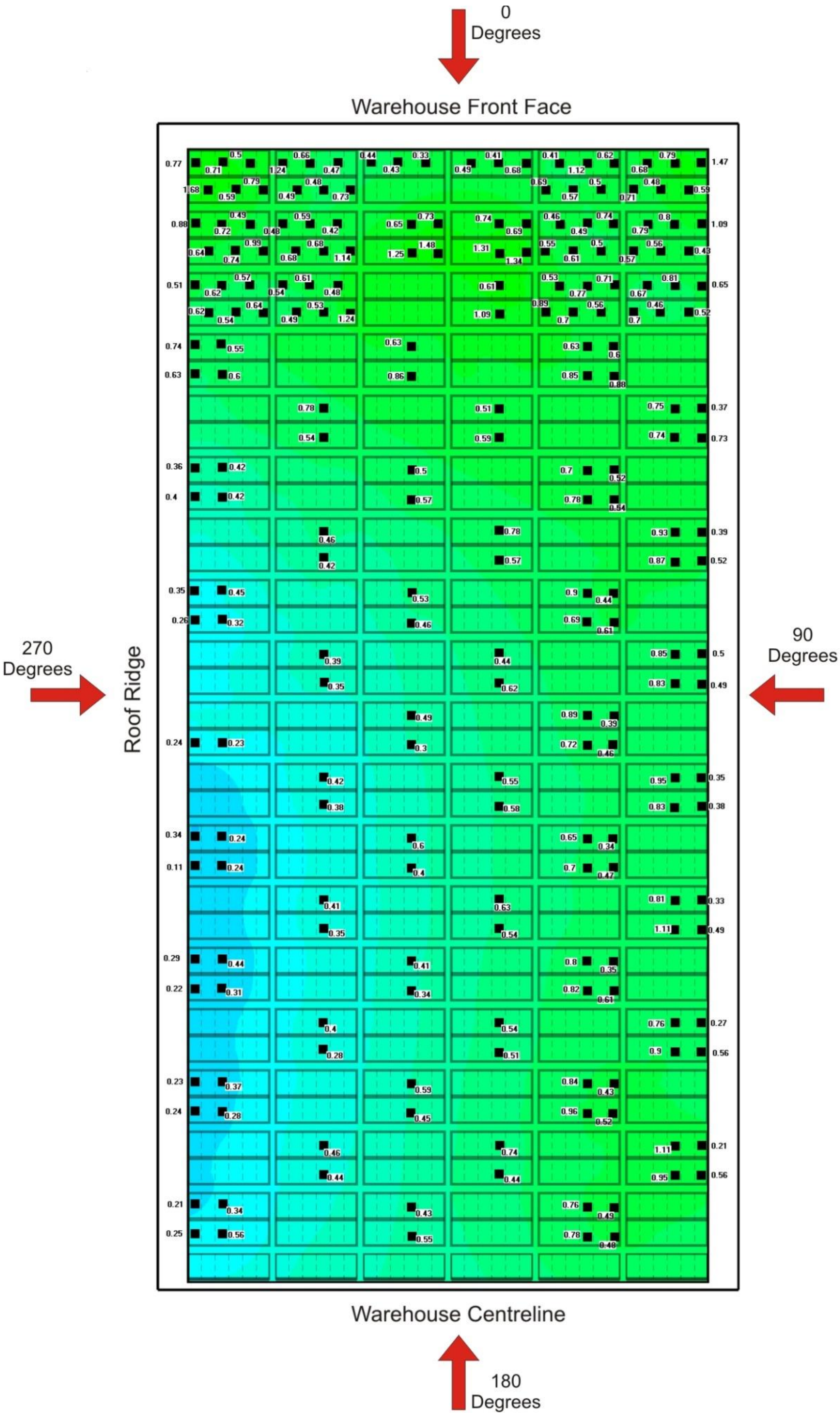

Figure 14b – Highest magnitude maximum net area averaged pressure coefficient on solar panels on one quarter roof model for all wind directions <u>for TC3</u>

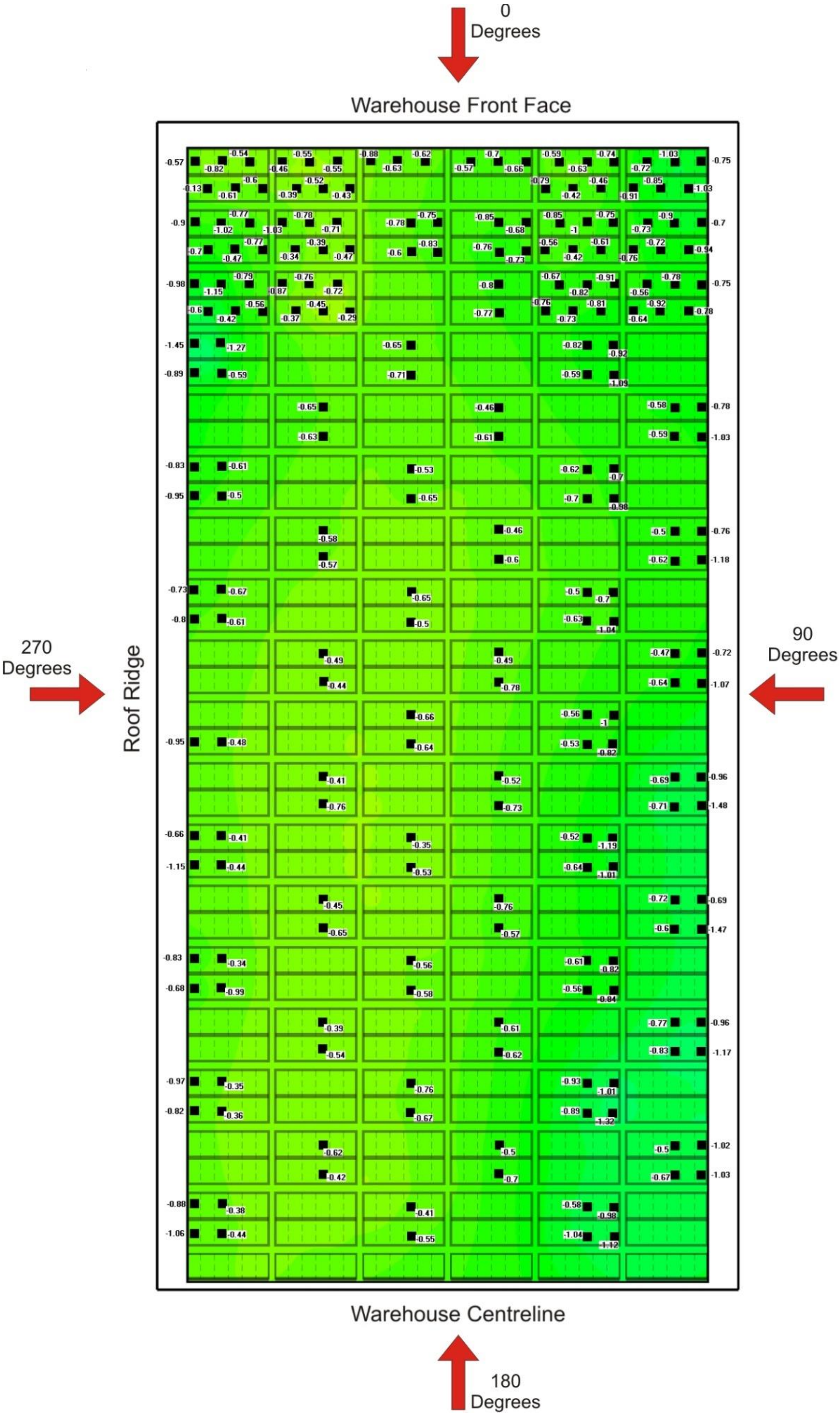

Figure 15a – Highest magnitude minimum net area averaged pressure coefficient on solar panels on one quarter roof model for all wind directions <u>for TC2</u>

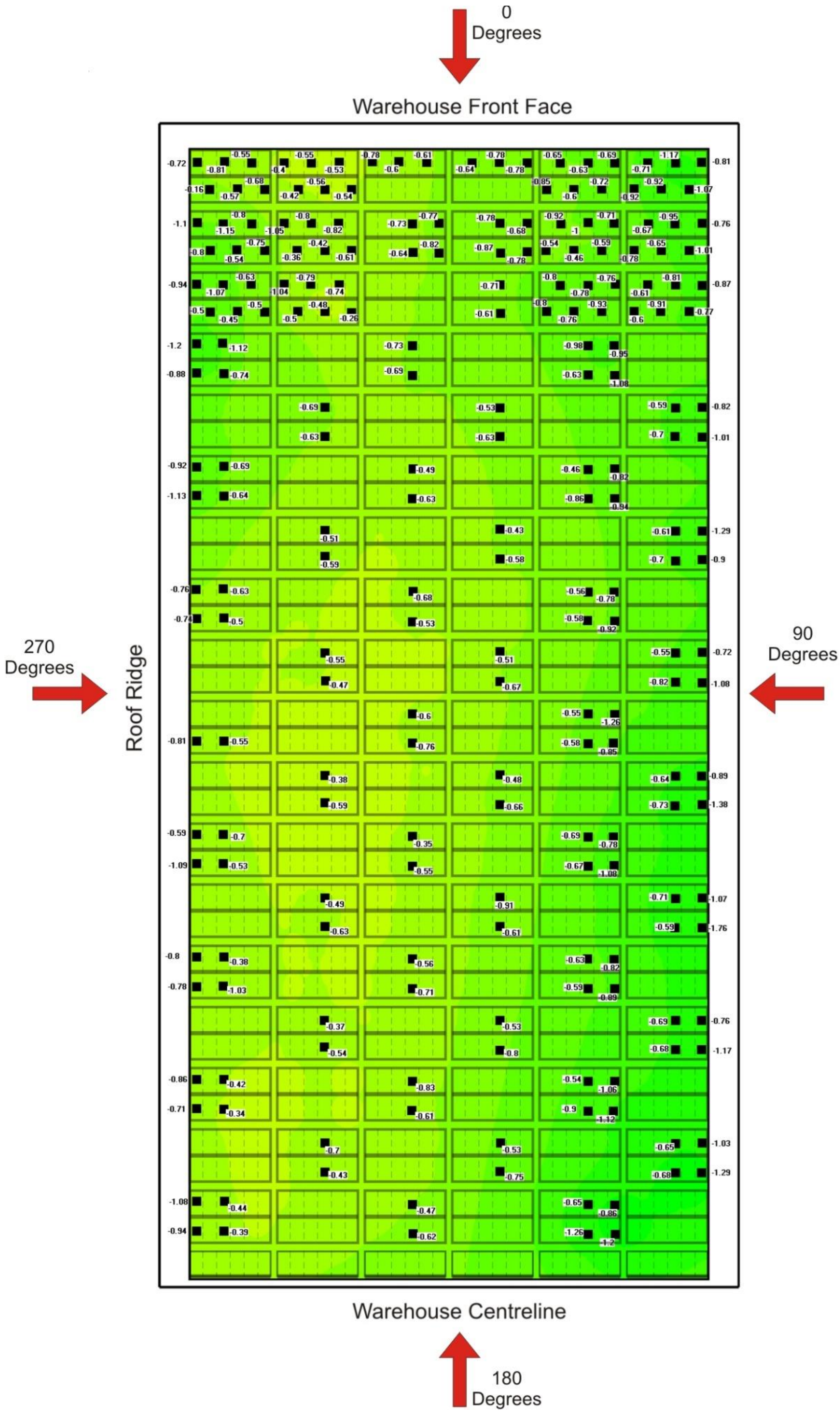

Figure 15b – Highest magnitude minimum net area averaged pressure coefficient on solar panels on one quarter roof model for all wind directions <u>for TC3</u>

APPENDIX A : AS1170.2:2011 SOLAR PANEL PRESSURE COEFFICIENT ESTIMATES

x/h	net pressure coeff on plain roof using AS1170.2[1,2,3]	net pressure coeff on solar PV panels using AS1170.2 flush PV[4]		net pressure coeff on solar PV panels using AS1170.2 tilted PV[5] wind incidence angle 0°	net pressure coeff on solar PV panels using AS1170.2 tilted PV[5] wind incidence angle 180°
0.0	-1.80	-1.70	0.50	-1.50	0.40
0.5	-1.80	-1.70	0.50	-1.50	0.40
0.5	-1.35	-1.70	0.50	-1.50	0.40
1.0	-1.35	-1.70	0.50	-1.50	0.40
1.0	-0.50	-1.70	0.50	-1.50	0.40
2.0	-0.50	-1.70	0.50	-1.50	0.40
2.0	0.40	-1.70	0.50	-1.50	0.40
3.0	0.40	-1.70	0.50	-1.50	0.40
3.0	0.50	-1.70	0.50	-1.50	0.40
4.0	0.50	-1.70	0.50	-1.50	0.40

Table A1. Summary of net pressure coefficients acting on various roof elements obtained from the wind loading standard AS/NZS 1170.2:2011. Note: these coefficients a normalised by **gust** wind speed and so cannot be directly compared to the coefficients obtained from the wind tunnel testing which are normalised by a **mean** wind speed.

Notes

[1]. No corner effects were considered in the determination of the plain roof pressures.

[2]. No dominant opening scenarios were to be considered in the analysis. An equally permeable building internal pressure of C_{pi} = -0.3 was therefore assumed.

[3]. Local pressure factors have been applied to determine the wind forces on the cladding, their fixings, the members that directly support the cladding and the immediate fixings of these members as stipulated in section 5.4.4 of the AS1170.2:2011 wind loading standard.

[4]. The Australian wind loading standard does not give any dependence of the net pressure coefficient as a function of distance from the leading edge of the roof for flush mounted solar PV panels. Therefore the pressure coefficients within the specified array positions, as seen in table D11, have to be taken as constant.

[5]. A monoslope free roof approximation with blocked under effects was considered for the solar PV panels in their tilted orientation. As per Note[4], above, the Australian wind loading standard does not give any dependence of the net pressure coefficient as a function of distance from the leading edge of the roof, and so a fixed net pressure coefficient has been taken.

APPENDIX B: SPATIAL DISTRIBUTION OF NET PRESSURES ON THE SOLAR PANEL ARRAY

A number of key areas of pressure distribution on the warehouse roof and solar panel array can be identified, from the wind tunnel data, which arise due to the local and global fluid mechanics of the flow around the warehouse building and solar panels themselves. A knowledge of these areas can assist with the appropriate design and positioning of solar panel arrays on warehouse roofs and in the selection of applicable pressure coefficients for the determination of design wind loads. These are shown in Figure B1.

ZONE 1: The building corner areas extending 0h - 1.0h in from the building edges and corners. The highest peak negative roof pressures were measured in this zone. These high peak negative pressures arise due to the strong corner and edge separations resulting in extremely low pressure areas. It would be strongly recommended not to mount solar panels in this area. The peak positive pressures also attained the highest values in this zone compared to other areas on the roof.

ZONE 2: The building edge areas extending 0 – 1.0h either side of the roof ridge and within 0 – 2.0h from the warehouse front face. High negative peak pressures were also measured in these areas, due to the strong corner vortices and separated flow predominantly originating at the building corner. Peak positive pressures were moderately high in this zone compared to other areas on the roof.

ZONE 3: The edge of the solar panel array which occupies and area of 0h – 1h in from the building edge. Solar panels mounted in these areas were shown to experience localised high peak negative pressures due to the separation of wind flow from the edge of the building. The peak positive pressures were observed to attain moderate levels as a result of the flow reattachment off the edge of the warehouse impinging onto the solar panels.

ZONE 4: Peak positive pressures were measured to be lowest in this zone. Peak negative pressures were measured to be moderate as a result of the flow separating off the roof ridge.

ZONE 5: The spatial distribution of pressures was measured to be relatively uniform in this area. Low positive peak pressures were measured in this area. Peak negative pressures were measured be the lowest in magnitude in this zone. The solar panels in this area were also subject to the most shielding from direct wind flow by the other surrounding solar panels.

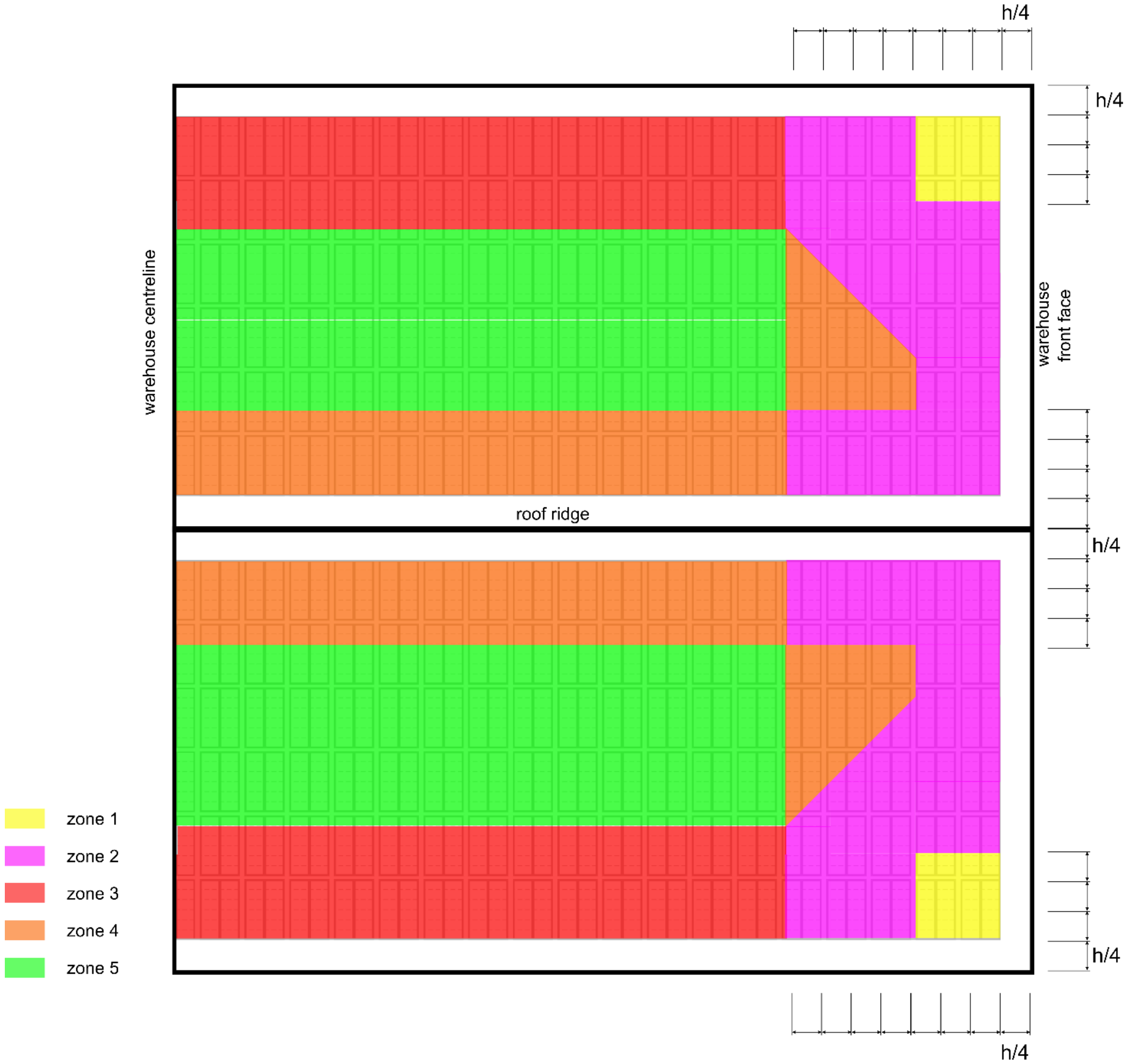

Figure B1 – Key roof zones identified from the wind tunnel pressure coefficient data.

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7 APPENDIX B – EXAMPLE CERTIFICATE (SOLPOD V2.1)

TENSYS

9th April 2019

Solpod Pty Ltd
Unit 1, 95 Wellington St
St Kilda, 3182

Attention: Jeremy Lawrence

SOLPOD V2.1 STRUCTURAL CERTIFICATION

Solpod V2.1 is a preassembled framed system to mount 12No. PV panels to existing roof sheeting without penetrations using 3M tape in one unit. It is documented in the following drawings

SLP001_4005 Solpod V2.1 Asm sheet 1 of 2 rev 01 15/01/19
SLP001_4005 Solpod V2.1 Asm sheet 2 of 2 rev 01 15/01/19
SLP001_3012 Main Panel V2.1 Asm sheet 1 of 3 rev 01 15/01/19
SLP001_3012 Main Panel V2.1 Asm sheet 2 of 3 rev 01 15/01/19
SLP001_3012 Main Panel V2.1 Asm sheet 3 of 3 rev 01 15/01/19
SLP001_3011-1 Roof Edge Foot V2.1 Asm sheet 1 of 1 rev 01 24/10/18
SLP001_3011-2 Roof Spine Foot V2.1 Asm sheet 1 of 1 rev 01 24/10/18
SLP001_2028 Solpod Beam Foot Asm sheet 1 of 1 rev 00 24/10/18
SLP001_2025 Spine V2.1 Asm sheet 1 of 1 rev 02 15/01/19
SLP001_2024 Hinge Beam V2.1 Asm sheet 1 of 1 rev 02 15/01/19

Tensys' design covers the structural design of the Solpod, its fixing to the existing roof sheeting and the roof sheeting connection to the purlins as per the limitations noted in this design summary. While the additional loads imposed by the Solpod on the existing roof are relatively small, the existing structure (purlins, rafters etc) need to be checked by appropriately qualified structural engineer for the loads given in this summary. The roof should also be checked to ensure the existing roofing has been installed as per the manufacturers requirements for water tightness and drainage as well as structurally fixings.

This design is valid for installation on rectangular enclosed buildings with near flat roofs (pitch less than 5 degrees) with a roof height as noted in table in wind design region A terrain category 3 (suburban housing and industrial areas), ref to design code AS/NZS 1170.2.

Solpod V2.1 feet length

Wind Design Region	Building Height	Edge Foot	Centre Spine Foot
	m	*mm*	*mm*
Region A	10	7 x 500	7 x 1000
Region A	20	7 x 500	7 x 1000
Region A	30	12 x 500	12 x 1000

Lengths given allow foot bracket bolt to be +/-25mm from centre of foot for installation tolerance. Feet to be located with 250mm of hinge beam.

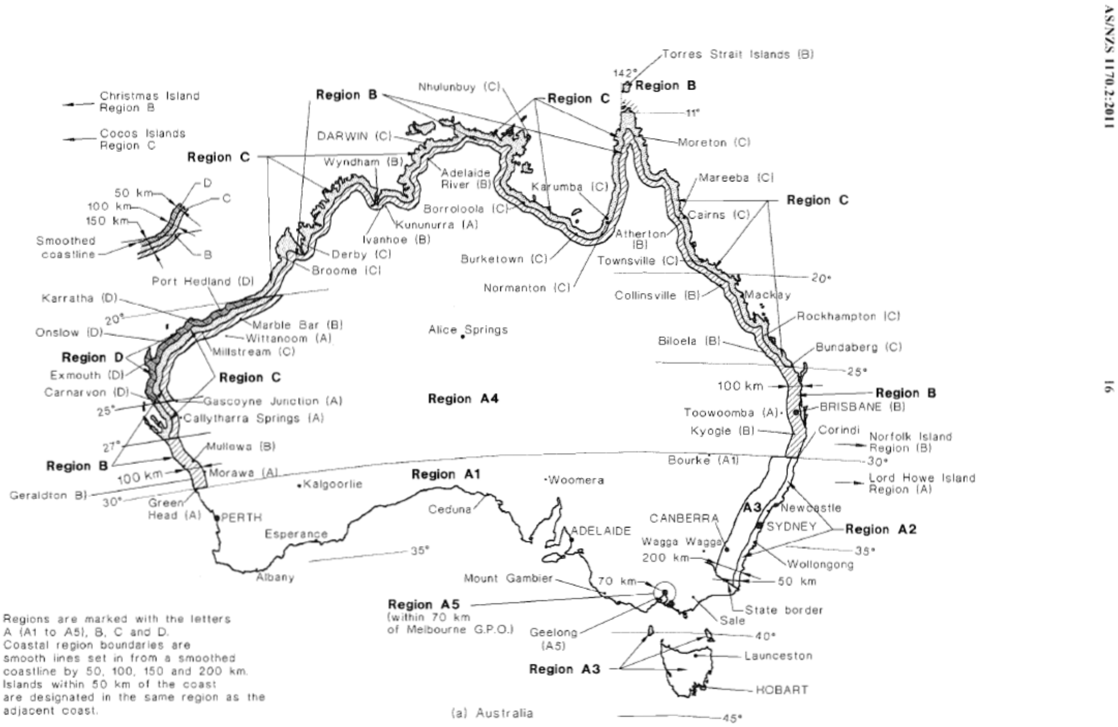

FIGURE 3.1(A) WIND REGIONS

Design Codes & Aids

The design of the Solpod has been carried out using the following design codes and aids:

- NCC 2016 – volume one
- AS/NZS 1170.0:2002 – Structural Design Actions Part 0: General Principles.
- AS/NZS 1170.1:2002 – Structural Design Actions Part 1: Permanent, Imposed and Other Actions.
- AS/NZS 1170.1:2011 – Structural Design Actions Part 2: Wind Actions.
- 53-18-WT-PRE-00 – Warehouse Solar Panel Arrays Pressure Wind Tunnel Modelling for ERM Business Energy by MEL Consultants Pty Ltd
- AS/NZS 1664.1:1997 – Aluminium structures Part 1: Limit state design
- AS/NZS 4673:2001 - Cold Formed Stainless Steel Structures
- 3M design guide for structural VHB tape
- Solar panel supplier certification of proprietary panels

Design Assumptions

Proprietary Products

The design is based on framed 72-cell module solar panel with mass of 22kg and nominally 2mx1m.
Adhesive tape to be 3M VHB installed strictly in accordance with 3M recommendations.
M8 socket head cap screws to be grade A4-50

Roof sheeting material

Existing roof to be grade fy = 500MPa steel trapezoidal profile sheeting with screw fixings (e.g. Lysaght Trimdek or concealed fixed profile roof sheeting (e.g. Lysaght Klip-Lok 406 or 700HS) installed in accordance with manufactures guidelines (every rib should be fixed). 4m dimension of Solpod to be parallel to roof sheeting ribs. Solpods are not to be installed bridging roof sheeting or building expansion joints.

Maximum Purlin Spacings

Roof Sheeting	0.42 micron BMT	0.48 micron BMT
trapezoidal profile (e.g. Lysaght Trimdek)	1.4m	1.8m
concealed fixed (e.g. Lysaght Klip-Lok 406)		1.3m
concealed fixed (e.g. Lysaght Klip-Lok 700HS)	1.3m	

Roof sheeting install slope

For trapezoidal profile (e.g. Lysaght Trimdek) minimum roof sheeting slope to be 2 degrees. For concealed fixed (eg Klip-Lok 406 or 700HS) minimum roof sheeting slope to be 2 (Note some manufactures allow concealed fixed to be installed to 1 degree. Impact of Solpod on roof drainage needs to be assessed further for these roofs). Solpod will locally deflect roof sheeting by less than 5mm which will have minimal impact on roof draining capacity however if large penetrations cause concentration of water flows in localised areas then impact of Solpod on roof drainage should be assessed further.

Due to low shear capacity of tape the maximum slope Solpod can be installed on is 3.5 degrees.

Design Loads

Dead (G)
Solpod 2.1 weighs maximum 350kg / nominally 15kg/m2

Wind (W)
The design wind pressure is taken from wind tunnel report 53-18-WT-PRE-00;

TABLE 2b

Design wind loads for flush mounted solar panels for a 500 year return period wind speed at a reference height of 10m in TC3

	500 year return period design wind loads for TC3, Pa			
Solar panel location	*Measurements*		AS/NZS 1170.2:2011	
	peak +ve	*peak -ve*	peak +ve	peak -ve
Edge	395	-414	420	-1425
Centre	118	-165	420	-1425

Solpod V2.1 Min/Max Design loads normal to roof (TC 3)

Load Case	**Edge Foot**			
	Region A 10m 7 feet	Region A 20m 7 feet	Region A 30m 12 feet	
	kN	*kN*	*kN*	
G	-0.15	-0.15	-0.12	
0.9G + Wu(-ve)	0.28	0.39	0.40	
1.2G + Wu(+ve)	-0.58	-0.69	-0.54	
Load Case	**Spine Foot**			
	Region A 10m 7 feet	Region A 20m 7 feet	Region A 30m 12 feet	
	kN	*kN*	*kN*	
G	-0.31	-0.31	-0.12	
0.9G + Wu(-ve)	0.51	0.73	0.62	
1.2G + Wu(+ve)	-1.13	-1.33	-1.01	

Note: under non-uniform ultimate wind loads up to 0.1kN parallel to roof surface are possible.

Yours Faithfully,

James Marr RBP EC 46982

for Tensys Engineers Pty Ltd

8 APPENDIX C – DERIVATION OF LOADS ON SOLAR PANEL AND CLADDING

Loading of solar panels can be seen in the form of the Free-Body Diagram (FBD) below. In the Wind Tunnel Report, measurements are taken at the top of the panel and the roof, shown as $P_{top\ of\ panel}$ and P_{roof} respectively.

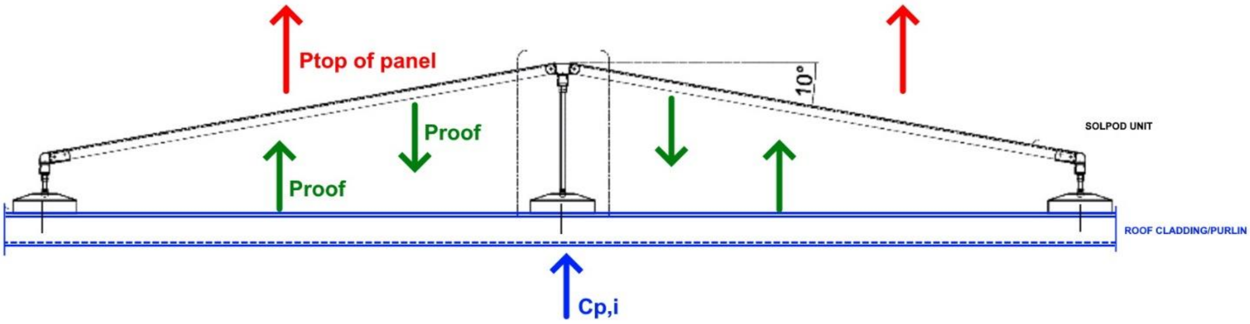

Figure C1: FBD of the Solar Panel and Roof System

Refer the below diagrams showing the loads on the

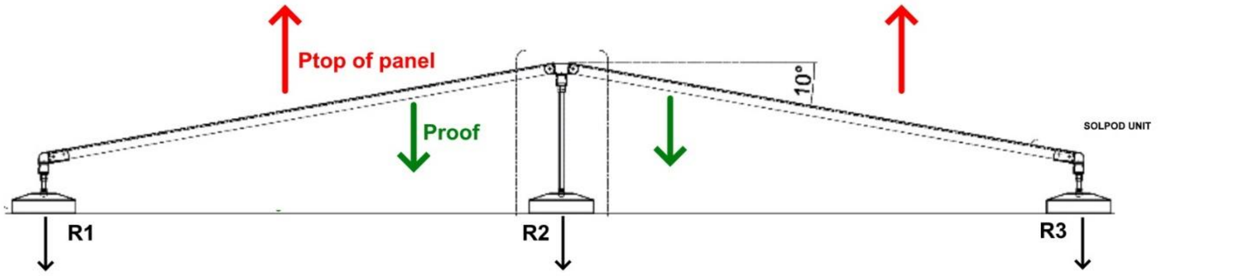

Figure C2: FBD of the Solpod Panel and Fixings

$$R_1 + R_2 + R_3 = P_{top\ of\ panel} - P_{roof}\ (1)$$

The force on the panel and its fixings are the "Net Averaged Values" provided in Table 2a and 2b of the Wind Tunnel Report.

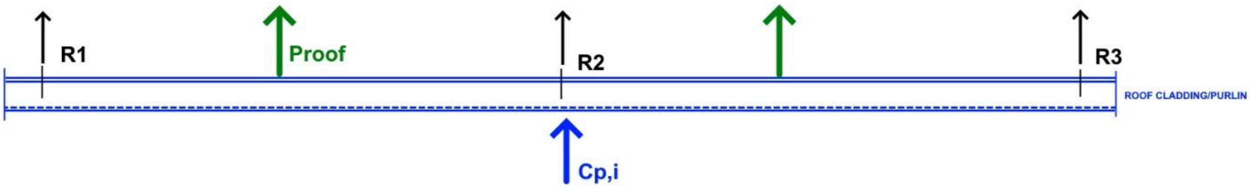

Figure C3: FBD of the Roof and Purlins

$$\begin{aligned} Total\ force &= R_1 + R_2 + R_3 + P_{roof} + C_{p,i} \\ &= P_{top\ of\ panel} - P_{roof} + P_{roof} + C_{p,i}\ [\text{from } (1)] \\ &= P_{top\ of\ panel} + C_{p,i}\ (2) \end{aligned}$$

Thus the load on the roof structure is equivalent to the top of panel load.

The Wind Tunnel report does not clearly outline the top of panel loads and their respective pressures however it can be extracted from the data. The maximum, minimum and mean loads on the solar panel taps have been tabulated as an Addendum to the report for all directions (Not provided in this Design Guide). To conservatively assess the worst case load applied on the solar panels, the table below shows the worst case maximum (ie highest downward force) and worst case minimum (ie highest upward force) for the pressure taps, separated by taps on the roof and taps on the panels. Coefficients from the 'net area averaged' panels are also shown. Section 5, ie deriving pressure coefficients from Table 5.3(A).

TC2

	From Test with Panels (Roof taps only)	From Test with Panels (Top of Panel taps only)	Area Averaged Net Values (Used in deriving Table 2a)
TAPS:	1A-7D	8D-55H	R01C01-R36C36
Max CP	3	1.4	1.79
Min CP	-3.41	-3.43	-1.48
Mean CP	0.91	0.32	0.63

TC3

	From Test with Panels (Roof taps only)	From Test with Panels (Top of Panel taps only)	Area Averaged Net Values (Used in deriving Table 2b)
TAPS:	1A-7D	8D-55H	R01C01-R36C36
Max CP	2.82	1.3	1.68
Min CP	-3.26	-3.45	-1.76
Mean CP	0.89	0.31	0.63

As the relationship between pressure and pressure coefficients is linear, it is possible to scale the pressures outlined in Table 2b to obtain the worst case top of solar panel (and hence purlin) pressure. Hence, the base pressures used for 'edge panels' are as follows:

	Table 2a/2b Value (Pa)	Area Averaged Coefficient (Section 5.1)	Top of Panel Coefficient (Table Above/Addendum A of Wind Tunnel Report)	Scaled Pressure (Pa)
TC2 Peak +ve	771	1.79	1.4	(1.4/1.79)x771 = 603
TC2 Peak -ve	-638	-1.48	-3.43	-1478
TC3 Peak +ve	395	1.68	1.3	306
TC3 Peak -ve	-414	-1.76	-3.45	-811

These coefficients are conservative but provide a maximum load on the roof structure. As these are based on maximum panel loads across edge and centre zones, this allows for local pressure factors.