Wind tunnel study into PV support systems Metabuild Solar Belgium

Report number W 15616-2-RA-001 d.d. October 14th, 2024

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1 Introduction

MetaBuild Solar of Riemst, Belgium, has commissioned Peutz to perform additional wind tunnel tests on behalf of the development of their solar energy system for landscape and portrait panels on flat roofs. Photo-voltaic (PV) panels are placed on flat roofs for the sustainable production of electricity. They must be provided with sufficient ballast in order to keep them from moving or tilting during a storm. But, in order to save costs and to minimize the dead weight loads on the roof, the amount of ballast must be kept as low as possible.

The photograph at the cover of this report shows one of the wind tunnel tests, with panels fixed to prototype scale models of the supports from MetaBuild Solar, models which are made of a plastic by means of a 3D printer. The panels with pressure taps have been 3D printed too, in order to obtain a smooth surface without external tubes that might disturb the air flows.

Along the bottom and top of the solar supports, ventilation slits have been provided in order to enhance the pressure equalization between the top and the bottom of the panels.

In the test series of April 2024, eight additional different configurations have been tested for MetaBuild Solar. The panel size is approximately 1.1 m x 1.7 m. The panels are placed in 8 different lay-outs in which the panels are tilted at an angle of 12° for the South facing systems, with row to tow distance of 1600 mm for landscape and 2400 mm for portrait. East-west pairs are coupled in this system and form a triangle in which the panels are tilted at an angle of 10° and row to row distance 2450 mm. Here, the top slit between the two panels has a width of 64 mm.

Measurements of the fluctuating pressures at the top and bottom of the panels and backplates have been undertaken for 11 up to 16 panels, depending on the lay-out studied, on the flat roof of a rectangular building. From the fluctuating pressures the fluctuating lift force and drag force have been determined for the lay-outs. The measurements have been carried out and been elaborated conforming to the Dutch CUR- Recommendation C103 'Wind tunnel studies of wind loads on (high rise) buildings' [1] and the Dutch standard NEN 7250:2021 'Solar-energy systems – integration in roofs and façades – building aspects' [2]. They have been elaborated for the single panel pairs as well as coupled panels in groups, since this accounts for the favourable load sharing effect in which the pressure and suction peaks are averaged over the panels. The definite number of coupled panels in a group has been been based upon lift tests conducted by MetaBuild Solar with Voxdale of Belgium.

In this report, the results of the wind tunnel study are presented. In chapter 2, the approach of the wind tunnel and the measurement system and method are described. Finally, in chapter 3 the most important results and the conclusions of the study are given and some additional remarks are made regarding the interpretation of the results as well as some recommendations. The complete results have been delivered by means of an XLSX-spreadsheet.

2 Measurement method and analysis

2.1 Determination of wind loading following CUR-Recommendation 103

In the Netherlands the standard for determination of the local wind loading at solar energy systems is the NEN 7250:2021 [2]. This standard offers the possibility to determine the wind loading by wind tunnel measurements. The Dutch guidelines for doing these measurements are given in CUR-Recommendation 103 [1]. One of the advantages of using the CUR-Recommendation is that a wind direction dependent peak wind velocity can be taken into account. However, the current elaboration is done without the Dutch wind direction factors, but when needed, or for another country, local wind speed values and wind directional factors can be used, without being obliged to perform a new wind tunnel study. To this end, a spreadsheet has been delivered to MetaBuild Solar separately.

In the table below the Dutch wind direction factors analogue to the CUR-Recommendation 103 have been depicted. These values can be used to multiply the reference wind speeds with, if wished so, for the applications in The Netherlands. In deviation from the CUR Recommendation, which was based on the old wind loading standard NEN 6702:2001 [8], newer safer values have been determined by TNO Bouw en Ondergrond that match with the current wind loading standard NEN-EN 1991-1-4:2011 [7]. The new recommended values are to be published in a book about the wind loading standard that is currently written by TNO Bouw en Ondergrond and have been communicated to us by the writer, Prof. dr. ir. C. P. W. Geurts of TNO Bouw en Ondergrond.

The recommended values are depicted in the table down here (taken from table 2.11 of the draft version of the TNO book).

Tabel 2.11 Aanbevolen waarden voor c_{dir} voor Nederland
recommended values for the Netherlands

windrichting [graden] **wind direction [degrees from N]**	c_{dir}
0 – 195 graden	0,85
195 - 225	0,9
225 - 315	1,0
315-360	0,85

The CUR-Recommendation prescribes the use of dynamic pressure measurements in determining the local wind load. This implies the recording of time series of the local wind pressure in the wind tunnel, using fast pressure sensors.

The CUR-Recommendation describes three possible methods to determine the wind loading in the wind tunnel (A, B and C). The choice depends on the goal of the measurements.

Method A uses measurements of the time averaged wind loading to determine the representative wind loading on the main structure of a building. It is however not allowed to use this method to determine the local wind loading on façades or building parts.

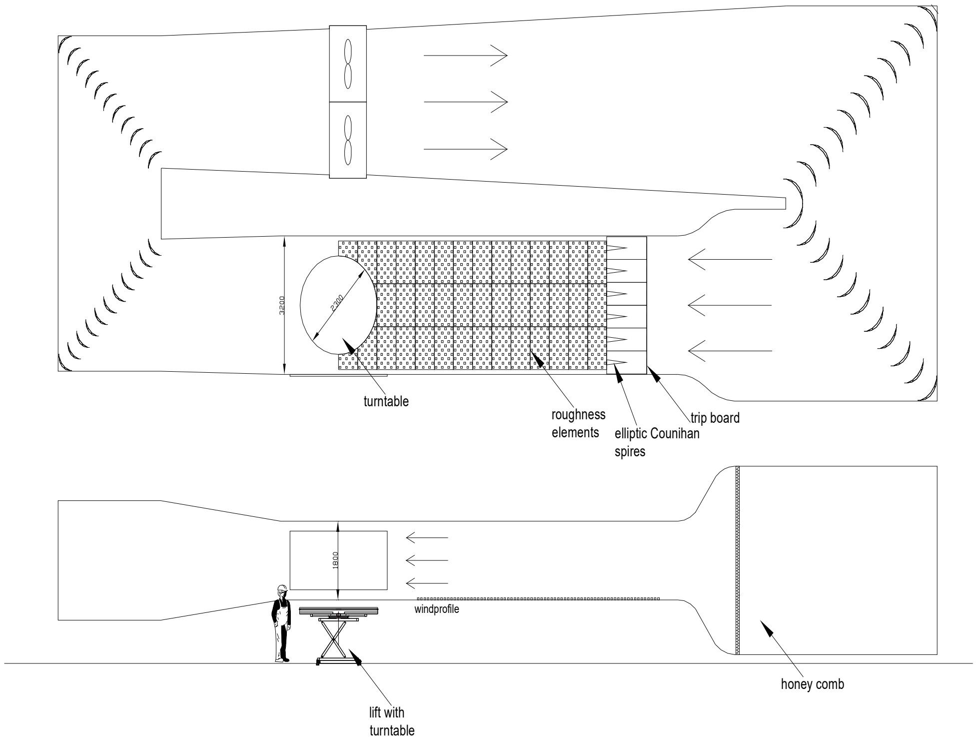
Method B uses an extreme value analysis of the measurements. In method C not only the measured wind loading, but also the reference wind speed is described statistically. Both methods B and C use the work of Cook [3] and are applicable for determination of both local wind loading and the wind loading on the main structure.

In this report the maximum and minimum representative wind pressures will be determined using method B. Using this method, the wind loading can be determined with an accuracy that matches the Dutch standard NEN 7250:2021.

2.2 Wind tunnel

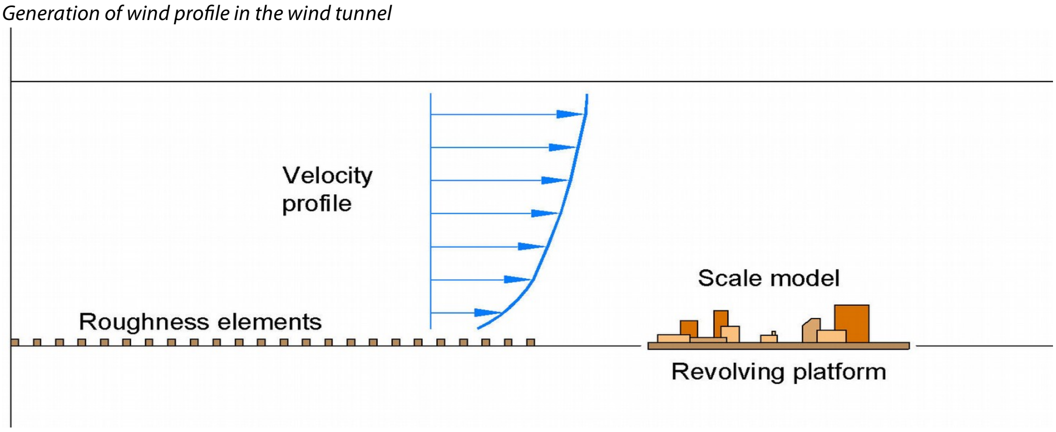
In order to carry out wind tunnel research, Peutz bv owns a closed boundary wind tunnel. A schematic overview of the wind tunnel is given in figure 2.1.
In the wind tunnel the earthly boundary layer is modeled at model scale, resulting in the right velocity profile and turbulence intensities at the upstream edge of the model.

f2.1 Overview of wind tunnel Peutz bv



As shown in figures 2.1 and 2.2 in the wind tunnel roughness elements and spires are present for the generation of the wind profile and turbulence. These have been adapted for the measurement on behalf of the PV panels, as discussed in the sequel. The measurement section of the tunnel has a width of 3.2 m and a height of 1.8 m. The turn table with the model has a diameter of 2.3 m.

f2.2 Generation of wind profile in the wind tunnel



2.3 Model and instrumentation

The measurements are performed at a scale of 1:15 in order to be able to model sufficient detail of the panels and the ventilation slits, which is very important to be able to measure the right amount of pressure equalisation between the top and the bottom faces of the panels. The scale model consists of a rectangular block with dimensions of 1.2 m x 1.2 m x 0.6 m. For the variants with the solar panels at the center of the roof, the height of the model was adjusted to 0.4 m in order to reduce the width of the roof edge zones F and G and the size to 1.6 m to obtain a larger distance to the roof edge. The distance between the system and the roof edge in the scale model at the center of the roof amounts to 400 mm along the southern and northern roof edge and 400 mm along western roof edge. For the other variants, the outer rows of panels are placed close to the southern, western and northern roof edge, at 15 mm from the roof edge. This means the edge panels and solar supports are placed in the roof edge zone as defined in figure A12 of the Standard NEN 7250:2021 and the Eurocode NEN-EN 1991-1-4:2011 [7] (width of the roof edge zone approximately 2 m at full scale).

The heart-to-heart row distance of the MetaBuild Solar system studied is 1.6 m for landscape and 2.4 m for portrait at full scale for the South system and 2.45 m for the East-West system.

All provided information has been archived under project number W 15616.

The measurements are done with a mean velocity of 7.7 m/s at reference height of 6 m and with a mean velocity of 8.5 m/s at reference height of 9 m, and have in this report been elaborated for area II in an unbuilt environment conforming to the definitions in [1] and [2]. These reference velocities are measured at the upstream edge of the turntable. Using these measured values of the reference velocities, inaccuracies due to translating the velocity at reference height in the Standard to the reference height in the calculations (general roof height in the in environment) are avoided.

As mentioned, so as to be able to accurately measure the pressure equalisation among the top and the bottom face of the panels, a large 1:15 scale has been adopted. In this way, all details can be modeled properly and undesirable scaling effects, particularly in the ventilation slits, can be avoided. However, since normally the wind tunnel has been laid out for a model scale in the region of 1:250, some adaptations have been made to the turbulence generating spires and arrays with blocks as shown in figures 2.1 and 2.2. Much larger spires have been used and the white blocks have been provided with sharper edges in order to increase the turbulence intensity.

The turbulence intensity in the wind tunnel at reference height is approximately equal to the prescribed turbulence intensity in the CUR-Recommendation, i.e. 19 % at 0.4 m.

At the different panels at in total 112 points, pressure measurements have been performed. The measurements have been performed using micro manometers as described in section 2.4. The panels with pressure taps have as well been 3D printed, in order to obtain a smooth surface with taps at the bottom and top face and integrated tubing, without external tubes that might disturb the air flows, see figures 2.3 to 2.5, showing the set up for runs 1 to 8 and some detailed photographs of the pressure taps in the panels and backplates.

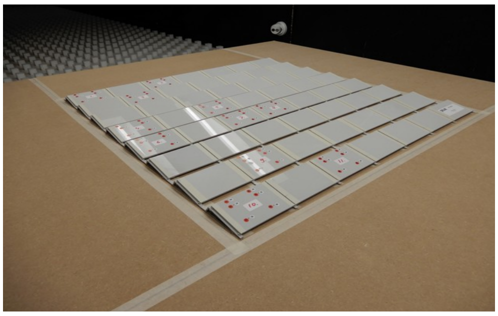
The location of the measurement points and panel numbers corresponding to the lay-outs studied is given in the appendix to this report.

At the front cover of the report the first set-up, run 1), is shown and figure 2.3 at the next page shows model photo's of all runs: i.e.:

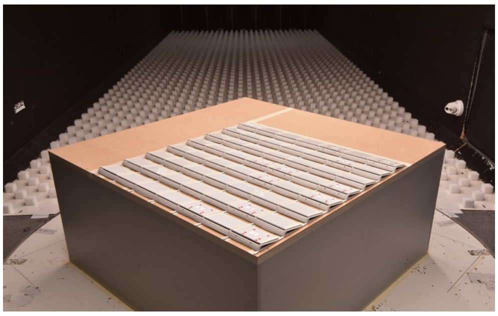
1) 11 landscape panels in 7 x 7 south facing array in the middle of the roof, model height 40 cm,
2) 11 landscape panels of the same array a northwest corner of the roof (distance to roof edge 1.5 cm), model height 60 cm
3) 11 landscape panels of the same array at the southwest corner of the roof (distance to roof edge 1.5 cm), model height 60 cm
4) 11 portrait panels in 7 x 7 south facing array in the middle of the roof, model height 40 cm,
5) 11 portrait panels of the same array a northwest corner of the roof (distance to roof edge 1.5 cm), model height 60 cm
6) 11 portrait panels of the same array at the southwest corner of the roof (distance to roof edge 1.5 cm), model height 60 cm
7) 16 panels, i.e. 8 coupled pairs of east-west system in the middle of the roof, model height 40 cm,
8) 16 panels, i.e. 8 coupled pairs of east-west system in the same array at the southwest corner of the roof (distance to roof edge 1,5 cm), model height 60 cm

f2.3 Photographs of the runs 1-8

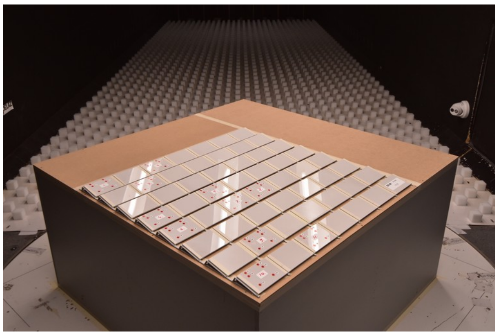
Run 1



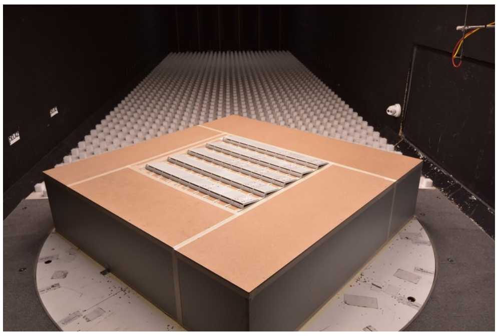
Run 2



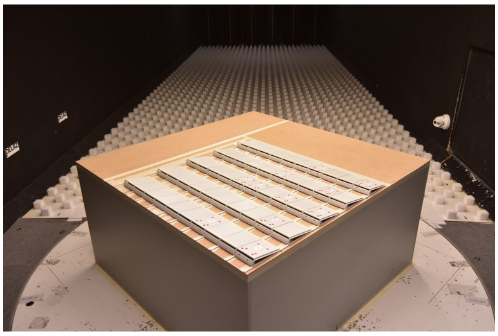
Run 3



Run 4

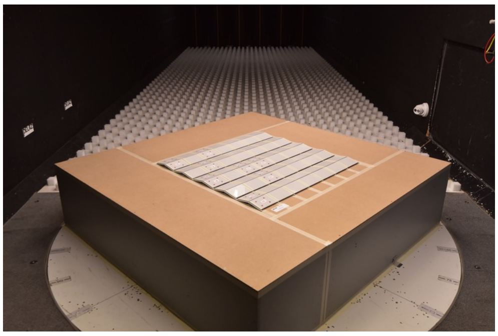


Run 5

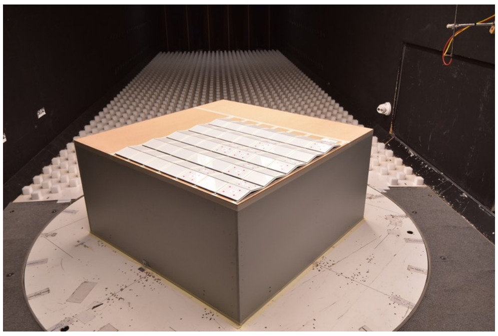


Run 6

Run 7



Run 8



2.4 Measurement system local pressures

The local pressures on the models of the MetaBuild Solar system with PV panels have been measured using SensorTechnics HCLA12X5TEB sensors. These sensors are read using National Instruments AD cards with a sample frequency of 200 Hz during 240 s per wind direction.

The micro manometers are connected with the pressure taps using special tubes, which are as much as possible incorporated in the model. The deformation of amplitude and phase of the signal by the tubes is corrected digitally. The correction is based on a comparison between measurement with tubes and measurements with a number of pressure transducers mounted directly in the facade of a test building and matches closely the findings of Irwin and others [9].

2.5 Extreme value analysis

Since the time in the wind tunnel is also scaled, it is necessary to compute this time scaling factor as follows:

$$\lambda_t = T_{WT} / T_{VS} = \lambda_g / \lambda_v \quad , \quad \lambda_g = L_{WT} / L_{VS} \quad \text{en} \quad \lambda_v = v_{WT} / v_{VS}$$

where T_{WT} [s] is the wind tunnel scaled time, T_{VS} [s] is the time at full scale, L_{WT} [m] the length scale in the wind tunnel, L_{VS} [m] the length scale at full scale, v_{WT} [m/s] the wind speed in the wind tunnel and v_{VS} [m/s] the wind speed at full scale.

In this study: λ_T = 1 : 5 (λ_g = 1 : 15 and λ_v = 8,5 : 27), i.e. 1 second in the wind tunnel corresponds to 5 seconds at full scale. The total measurement time per wind direction amounts to 4 minutes. Since the measurement for each wind direction has been split into 24 sub series, the measurement time per sub series is 15 s, which is approximately 50 s at full scale, which almost matches the value prescribed by the CUR-Recommendation. Each sub series has a sufficiently stationary signal in this manner.

This maximum hourly mean wind speed of 27 m/s used in the calculations, corresponds to a wind speed with an average repetition time of 50 years conforming to the NEN 7250:2021. The gusts will have values up to 45 m/s in this case. It matches a wind force of 10 Beaufort at a meteo station in area II in the Netherlands, at the standard height of 10 m for which weather data are generally provided.

The measurements are performed with a measurement sample frequency of 200 Hz. All relevant points (related to an object) are measured simultaneously. This is well above the desired minimum Nyquist frequency, which is depending on the goal of the measurements. For the local peak loads on PV panels, the minimum Nyquist frequency needed is $F = 1/T = 25$ Hz. With this frequency the local wind load on an element with a typical length scale of $L = 2$m is determined in this case. This frequency is based on the expected maximum gust speed for wind, $V = 45$ m/s, at roof height (based on the reference wind speed and the turbulence intensity) and the relation between gust duration and gust length as proposed by Cook [3] , the TVL formula, that has as well been thoroughly evaluated by, among others, Breeze [4].

$$T \cdot V = 4.5 \cdot L$$

The blockage of the cross section of the wind tunnel by the models is approximately 9 % for all wind directions. Using the equations of Melbourne [5] a correction for the blockage is made per wind direction and per measurement point, accounting the effects of the blocking on the total pressure and the pressure drop over the model.

The measured pressures are made non-dimensional using the peak reference speed (including turbulent gusts) and the density of air, and integrated over each panel resulting in a pressure coefficient C_p:

$$C_p = \frac{P_{WT}}{\frac{1}{2} \cdot \rho \cdot V_{ref}^2}$$

with P_{WT} measured pressure, ρ the density of air (= 1,25 kg·m^{-3}) and V_{ref} the reference speed in the wind tunnel (peak value 12,1 m/s at a height of 0.4 m, corresponding to a mean value of 7.7 m/s and turbulence intensity 19 %).

The presented loads have not yet been multiplied by the safety factors given in the NEN-EN 1990 (including $\boldsymbol{\gamma_{f,q} = 1.35}$ for local pressures and pressure differences and ***0,9*** for the self weight).

The net pressure coefficients that result from taking the difference over the top and the bottom of the panels, $c_{p,net}$, have to be multiplied by the panel area and the reference wind pressure in order to yield the forces discussed down here. This has been done in the XLSX spreadsheet that has been delivered.

2.6 Evaluation of pressure differences and lift and drag forces

The pre-standard NEN 7250:2014 prescribed three possible mechanisms for a possible failure of the system and for the determination of the ballast needed to prevent this: overturning of the system by a vertical wind load, for example wind suction at the top face, shifting of the system by the horizontal component of the wind load, the drag, and being lifted by the vertical wind load, for example wind suction at the top face. However, earlier wind tunnel studies, for several other parties, have shown that the drag force combined with the unfavorable effect of lift on the friction is determining for the ballast needed.

The fluctuating pressures, which have been measured simultaneously, have all been combined, taking into account the area that each pressure tap represents.

2.6.1 mechanism drag

The surface of each panel has been divided in two rows for the determination of the drag force as well. Per sample of the measured pressures at the top and the bottom of the panels as well as at both faces of the side plates, the difference is determined and multiplied by the vertical projection of the surface area. For the surface area, a unity value of 1 m^2 has been taken, so the values that result, have to be multiplied by the horizontally covered roof space of the setup in order to yield the proper forces.

With the extreme value analysis the representative peak values with the proper probability of exceedance have been determined from the combined signal of all pressure taps of each panel. Both positive and negative values are applicable with respect to the drag force.

Conforming to the pre-standard NEN 7250:2014 the ballast weight, $G_{ballast}$, to prevent drag is computed from:

$$F_{friction} > |F_{drag}|$$

$F_{friction}$ is determined from:

$$F_{friction} = \gamma F_{vert} f$$

and F_{vert} from:

$$F_{vert} = G_{total} - F_{lift}$$

So, the total weight per square meter horizontally covered roof space, needed to prevent drag is:

$$G_{total} = \gamma \left(|F_{drag}| + f F_{lift} \right) / f$$

The safety factors to be used are $\gamma_{f,q}$= 0.9 for favourable self-weight of the system and the ballast, G_{total}, as well as $\gamma_{f,q}$ = 1.35 for the wind forces F_{drag} and F_{lift} . The parameter f is the roof - solar support friction coefficient.

2.6.2 mechanism drag-lift combined

Since the maximum drag and lift do not always occur at the same time, because the wind panel and side plates have a different orientation, their simultaneous action has been researched as well.

For F_{lift} the value corresponding to the same sample as the simultaneously measurement of F_{drag} has been taken; i.e. they have been combined on a sample by sample basis. Upon combining these forces the absolute sample value of F_{drag} has been taken, since the direction of F_{drag} is not important, since in drag in all directions has to be prevented by applying sufficient ballast.

The term: $\left(\left|F_{drag}\right| + f\,F_{lift}\right)$

in the latter formula is called $F_{drag\text{-}lift}$ and has been computed on a sample by sample basis. The dimensionless values of it as well as those for the drag and the lift separately are entered into the delivered spreadsheet. The friction coefficient has values of ***f=0.3***, ***f=0.6*** and ***f=0.9*** in the calculations in the spreadsheet that has been delivered.

This has been done for single panels and for coupled groups. The definite number of coupled panels in a group has to be based upon lift tests, during which the tilt angle and height of south facing panels submitted to a lift force has to be determined with a crane equipped with a load cell.

The number of panels actually contributing to the redistribution and averaging of the lift and drag forces has to be determined by posing a maximum allowable tilting height of 5 cm conforming to the draft Standard NEN 7250:2021 Appendix D5. At the instant this has been reached, the total lift and drag force has been compared with the weight of the lifted and the surrounding panels to determine how many have contributed to the redistribution of the forces. After all, by subtracting the weight of the lifted panel from the force applied by the crane, the contribution of the neighbours to the load sharing is known.

The forces and the total weight needed for a coupled group, have to be multiplied by the panel size and the number of coupled panels in order to yield the forces acting at the group.

3 Results and discussion

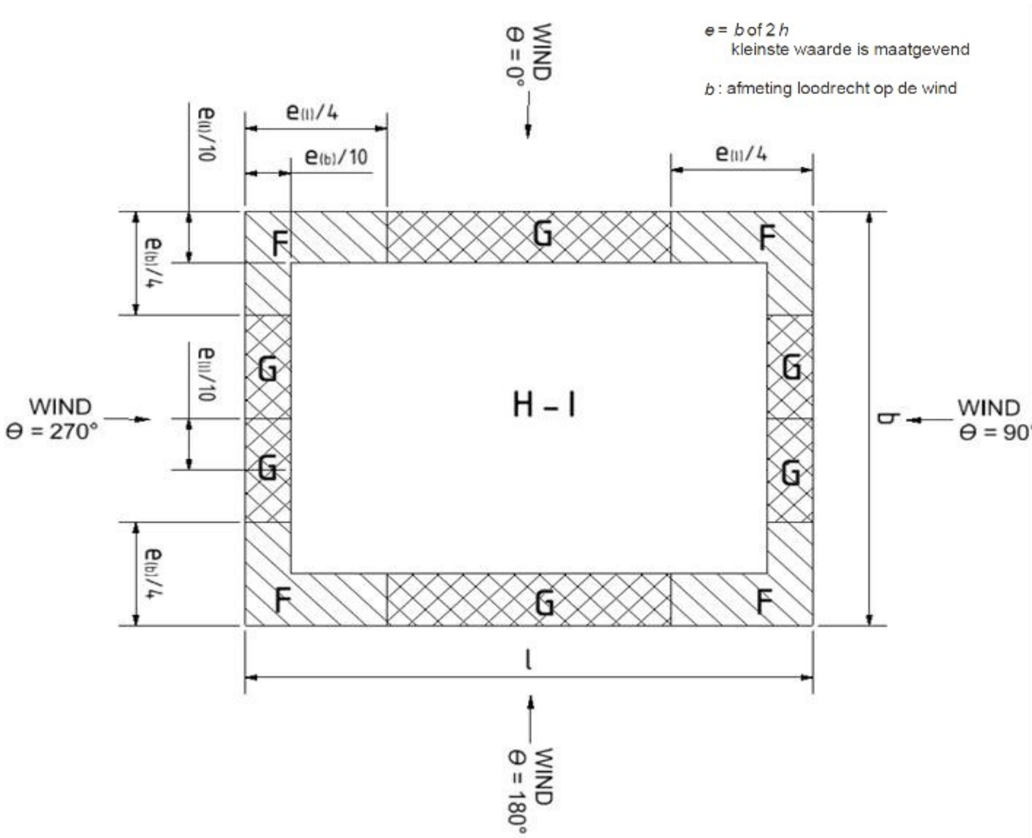
The results are laid down in the spreadsheets W 15616 EN1991-1-4-total-weight_FrictionCo -S=vs2.xlsx and W 15616 EN1991-1-4-total-weight_FrictionCo -EW-vs2.xlsx dated June 6th . 2024.

The numbers of the panels are presented in the plan views in the appendix to this report.

In the plan views in appendix, it is as well shown from which coupled group the shape factors must be selected, for each panel on the roof. These plots do as well indicate which panels have been assumed as coupled.

The results for the relation between drag and lift coefficient for a friction coefficient with values of ***f=0.3***, ***f=0,6*** and ***f=0.9*** are calculated. The definitions match those of the NEN-EN 1991-1-4:2011 figure 7.6. This figure shows the roof zones for one wind direction. It has been elaborated in this report for wind from any direction, so with roof edge zones all around the circumference of the roof, in the figure down here.

f3.1 Roof zones after figure 7.6 from the NEN-EN-1991-1-4:2011



The number of coupled panels in a group, see appendix 1, has been based upon lift tests conducted by MB Solar and Voxdale in April 2024, during which the tilt angle and height of south facing panels submitted to a lift force has been determined with a crane equipped with a load cell. This has been done for a large and small array of landscape systems. The results and interpretation have been reported by Voxdale in 1214-240430-Lift test report-MB solar-S RevB and 1214-240502-Lift test report-MB solar-EW of April 30th and may 2nd , 2024. Some photographs of their tests have been included down here.

f3.2 Lift tests coupled groups South landscape

f3.3 Lift tests coupled groups East-West landscape

The number of panels actually contributing to the redistribution and averaging of the lift and drag forces has been determined by posing a maximum allowable tilting height of 5 cm conforming to the draft Standard NEN 7250:2021 Appendix D5. At the instant this has been reached, the total lift and drag force has been compared with the weight of the lifted and the surrounding panels to determine how many have contributed to the redistribution of the forces. After all, by subtracting the weight of the lifted panel from the force applied by the crane, the contribution of the neighbours to the load sharing is known.

In appendix 1 the numbers of effectively coupled panels that has been determined in by the lift tests is depicted in an approximate manner. The above mentioned reports of Voxdale describe the coupling factors resulting from the lift tests. The exact weighting per panel that results from this has been elaborated in the Voxdale spreadsheet W15616-lift-factoren_2024-05-30.xlsx dated May 30th, 2024. Peutz bv has used those to elaborate the forces acting on the corresponding groups.

4 Conclusions and recommendations

MetaBuild Solar of Riemst, Belgium, has commissioned Peutz to perform additional wind tunnel tests on behalf of the development of their solar energy system for landscape and portrait panels on flat roofs. Photo-voltaic (PV) panels are placed on flat roofs for the sustainable production of electricity. They must be provided with sufficient ballast in order to keep them from moving or tilting during a storm. But, in order to save costs and to minimize the dead weight loads on the roof, the amount of ballast must be kept as low as possible.

The photograph at the cover of this report shows one of the wind tunnel tests, with panels fixed to prototype scale models of the supports from MetaBuild Solar, models which are made of a plastic by means of a 3D printer. The panels with pressure taps have been 3D printed too, in order to obtain a smooth surface without external tubes that might disturb the air flows.

Along the bottom and top of the solar supports, ventilation slits have been provided in order to enhance the pressure equalization between the top and the bottom of the panels.

In the test series different configurations have been tested for MetaBuild Solar. The panel size is approximately 1.1 m x 1.7 m. The panels are placed in 8 different lay-outs.

Measurements of the fluctuating pressures at the top and bottom of the panels as well as the backplates have been undertaken for 11 up to 16 panels, depending on the lay-out studied, on the flat roof of a rectangular building. From the fluctuating pressures the fluctuating lift force and drag force have been determined for the lay-outs.

The measurements have been carried out and been elaborated conforming to the Dutch CUR- Recommendation C103 ‘Wind tunnel studies of wind loads on (high rise) buildings’ [1] and the Dutch standard NEN 7250:2021 'Solar-energy systems – integration in roofs and façades – building aspects' [2]. They have been elaborated for the single panel pairs as well as coupled panels in groups of approximately 1,5 to 6 pieces, since this accounts for the favourable load sharing effect in which the pressure and suction peaks are averaged over the panels. The definite number of coupled panels in a group will be based upon lift tests to be conducted by MetaBuild Solar.

In this report, the results of the wind tunnel study are presented. In chapter 2, the approach of the wind tunnel and the measurement system and method are described. Finally, in chapter 3 the most important results and the conclusions of the study are given and some additional remarks are made regarding the interpretation of the results as well as some recommendations. The complete results have been delivered by means of an XLSX-spreadsheet.
For all presented results in tables and figures, an inaccuracy of 10 to 15 %[3][6] applies. This inaccuracy however can be seen as part of the safety factor $\gamma_{f,q}$, since this safety factor already takes into account an error of this order of magnitude.

Thus, the presented loads must be multiplied by the safety factors given in the NEN 1990 (including $\gamma_{f,q}$ =1.35 for local pressures and pressure differences and 0,9 for the self weight) and by the panel size and by the reference wind pressure at roof height, q_p. In the spreadsheet this has already been done. The roof-solar support friction coefficient has a value of ***f=0.3***, ***f=0,6*** and ***f=0.9*** in the calculations in the spreadsheets.

Two spreadsheets W 15616 EN1991-1-4-total-weight_FrictionCo -S-vs2.xlsx and W 15616 EN1991-1-4-total-weight_FrictionCo -EW-vs2.xlsx dated June 6th . 2024, have been delivered separately for different roof heights and other regions in the Netherlands and other countries as well as the above mentioned values for the roof-solar support friction factor.

Mook,

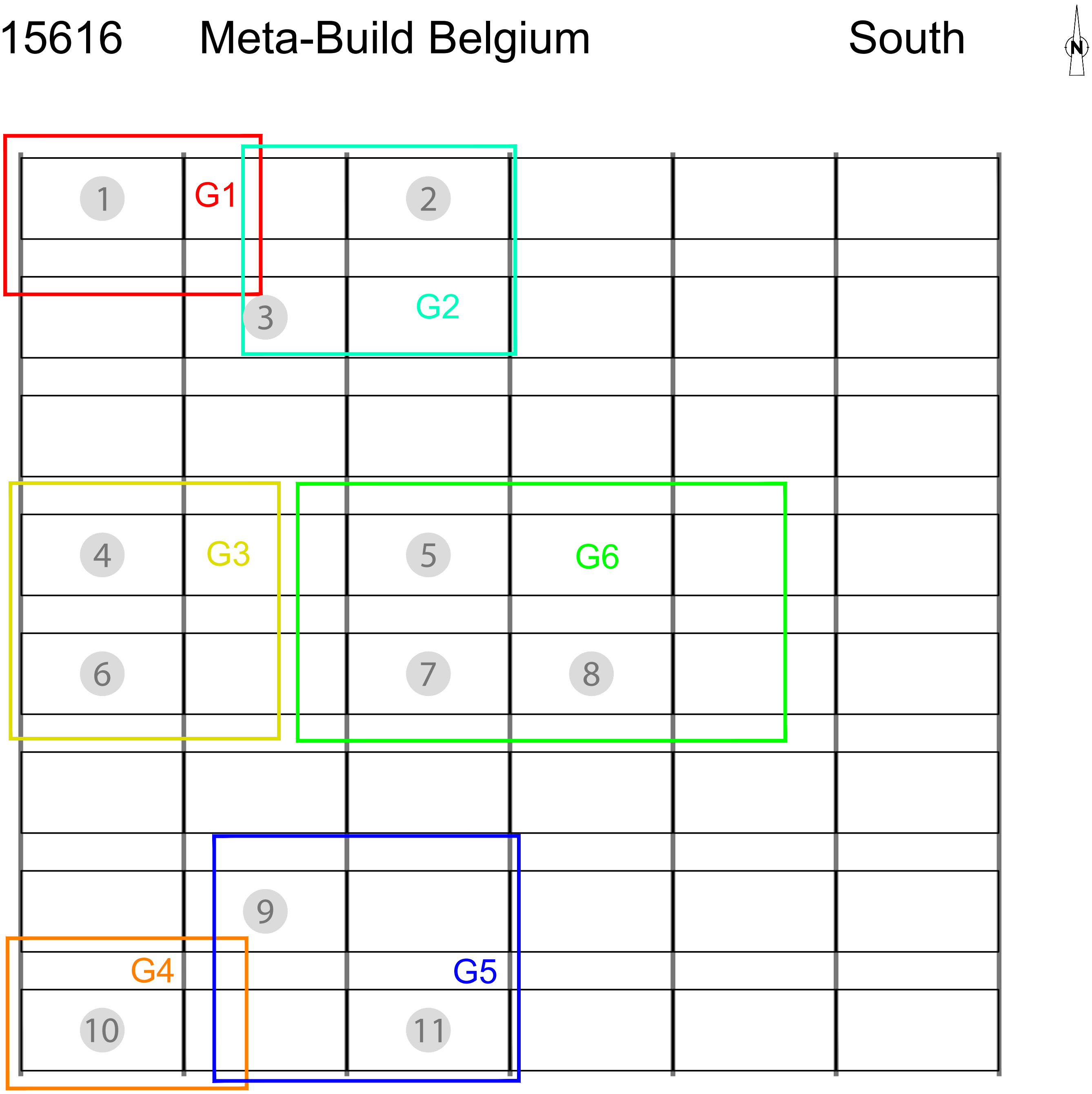
This report contains:
19 pages
1 appendix

5 Literature

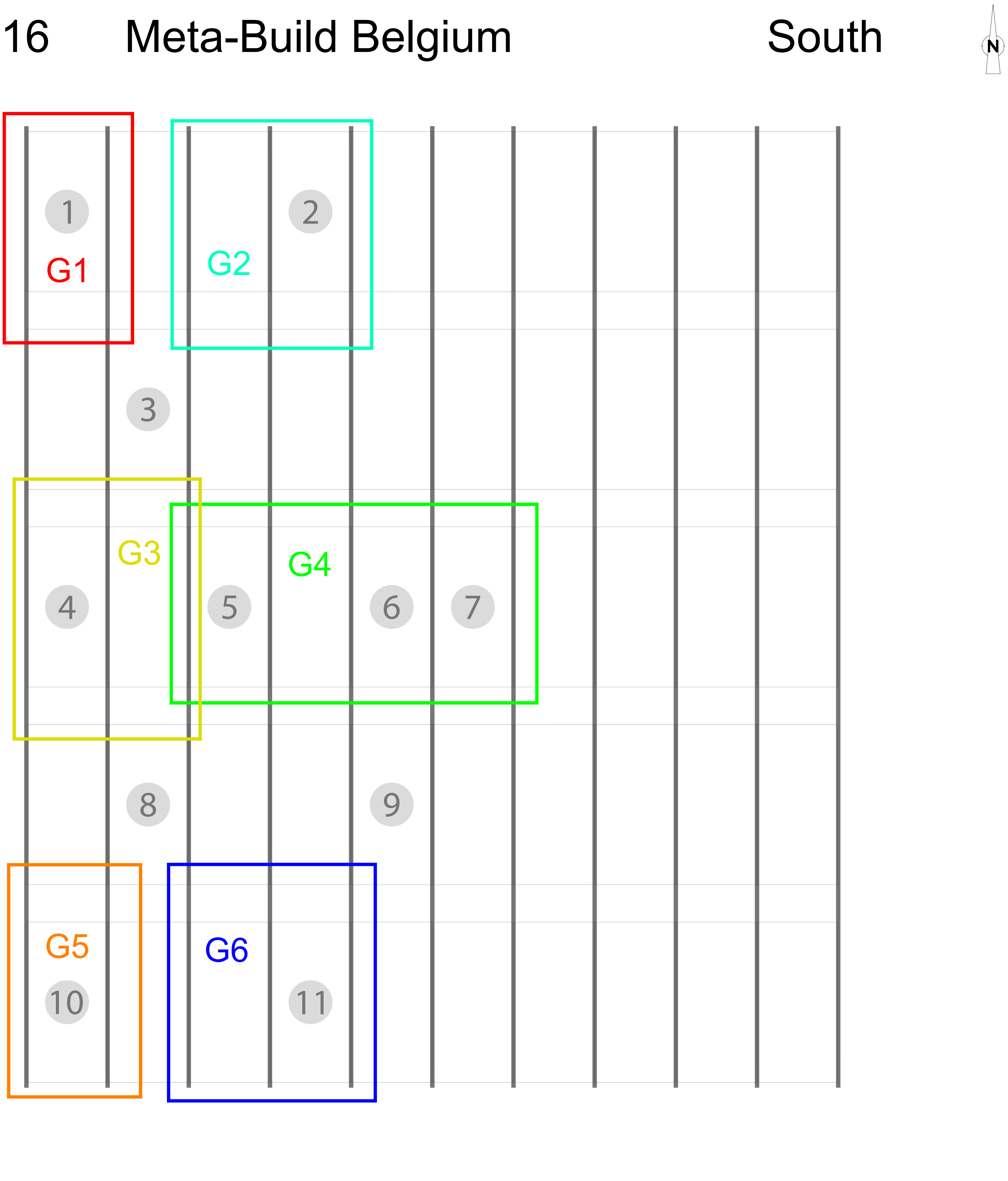
[1] Civieltechnisch Centrum Uitvoering Research en Regelgeving, CUR-Aanbeveling 103: Windtunnelonderzoek voor de bepaling van ontwerp-windbelastingen op (hoge) gebouwen en onderdelen ervan, 2005 (Dutch CUR- Recommendation C103 ‘Wind tunnel studies of wind loads on (high rise) buildings’)
[2] NEN 7250:2021, Solar-energy systems – integration in roofs and façades – building aspects
[3] N.J. Cook, The designer's guide to wind loading of building structures, 1990
[4] G. Breeze, Wind tunnel investigation upon the coherence of pressures measurements taken around a tall building in open site terrain, 1992
[5] W.H. Melbourne, Wind tunnel blockage effects and corrections, 1981
[6] C.P.W. Geurts, Wind-induced pressure fluctuations on building façades, 1997
[7] NEN-EN 1991-1-4:2011: Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions
[8] NEN 6702 (TGB): 2001: Technical principles for building structures – TGB 1990 – Loadings and deformations
[9] H.P.A.H. Irwin, K.R. Cooper and R. Girard, Correction of Distortion Effects Caused by Tubing Systems in Measurements of Fluctuating Pressures, Journal of Industrial Aerodynamics, 1979

Appendix 1 Panel and group numbering

W 15616 Meta-Build Belgium South



W 15616 Meta-Build Belgium South



W 15616 Meta-Build Belgium East/West