Project STA(CK)HOLM MARIEVIKStockholm, Sweden

Wind tunnel study conducted on the wind climate at walking level

Draft

Report number OA 15459-1E-RA d.d. 20 July 2015

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1 Introduction

By order of Förvaltningsbolaget Marievik HB c/o AMF Fastigheter AB at Stockholm, Sweden, a wind tunnel study was conducted on a scale model parts M15 and M22 of the project STA(CK)HOLM MARIEVIK including its direct surroundings in Stockholm, Sweden.

The scale model is based on the architectural drawings (see section 2.5). With respect to the built environment the architectural drawings received were used as well as the results from information gathered from Google Earth and the architect.

The objective of the wind tunnel study was to quantify the expected wind climate at the entrances of the different buildings of the projects, along the façades of the buildings, at the roof(terraces) of the towers, at the platforms and in the direct vicinity of the projects.

In chapter 2 of this report a description is given of the standard used and the set-up of the wind tunnel study. In chapter 3 a presentation and assessment of the measurement results are given. Finally in chapter 4 the conclusions are presented.

2 Standard and set-up of the wind tunnel investigation

2.1 NEN 8100

The assessment of the wind climate regarding wind nuisance and wind danger, is laid down in the Dutch standard NEN 8100:2006: "Windhinder en windgevaar in de gebouwde omgeving" ("Wind nuisance and wind danger in the built environment").
The measurements and the results have been performed and assessed as much as possible in accordance with this standard.

2.2 Wind nuisance and wind danger according to NEN 8100

In the standard NEN 8100 a distinction is made between wind nuisance and wind danger.

2.2.1 Wind nuisance

The sensitivity of humans with respect to wind nuisance (more or less strongly) depends on the activity they are engaged in. At a low activity level (for instance waiting at a bus stop, having lunch on a terrace, or something similar) lower wind speeds will be perceived as more unpleasant than in the case of a higher activity level (like walking at a normal pace). In the assessment of the wind climate, NEN 8100 makes a distinction for different activity levels.

Wind nuisance can not be totally prevented: during a storm high winds will cause a nuisance, whatever precautions have been taken. In the assessment of the wind climate the chance that wind nuisance occurs should therefore be kept within the limits for different activity levels.

With respect to wind nuisance an hourly averaged threshold value wind speed $V_{threshold;wind\ nuisance}$ = 5 m/s in accordance with NEN 8100 is used as a criterion wind speed at walking or residence level.

At this wind speed, certain "mechanical" effects occur like dust blown into the eyes or unwanted closing of car doors by the force of the wind, etc.

Based on the next table (from NEN 8100), an assessment is given of the expected level of wind nuisance.

t2.1 Table criteria wind nuisance according to NEN 8100.

Exceedance chance $P(V_{loc} > V_{threshold;wind\ nuisance})$ **In percentages of the number of hours per year**	**Quality level**	**Activity level**		
		I. Walking, normal pace	II. Walking leisurely strolling	III. Sitting longer time
< 2.5	A	Good	Good	Good
2.5 – 5	B	Good	Good	Moderate
5 – 10	C	Good	Moderate	Poor
10 – 20	D	Moderate	Poor	Poor
≥ 20	E	Poor	Poor	Poor

Activity level I : e.g. Parking areas and walking areas at normal pace.
Activity level II : e.g. Shopping areas, main entrances and terraces.
Activity level III: e.g. Terraces and benches in a park.

Concerning the categories good, moderate and poor the following can be noted:

Category good:
In principle no specific attention is necessary.
In general the wind climate within this category is acceptable.

Category moderate:
This means that some of the time the wind climate is uncomfortable.
When possible it is advised to improve the local wind climate with relatively simple mitigation measures, either in the landscape design or with wind preventing provisions like for example wind screens.
Preferably these measures are implemented during the design stage. However one can wait until the building is completed. If the local wind climate proves to be uncomfortable in daily use at a certain spot/area, as predicted by the wind tunnel investigation, measures have to be taken.

Category poor:
Regular wind disturbance occurs. In the category poor locations it is usually advised to take mitigation measures immediately, or to remove pedestrian paths from these positions.

2.2.2 Wind danger

At higher wind speeds dangerous situations can occur, for example loss of balance by people when they pass a corner of a building. With respect to wind danger an hourly averaged threshold value wind speed $V_{threshold;wind\ danger}$ = 15 m/s is used as the criterion for wind speed at walking or residence level. At this average wind speed, the wind speed during wind gusts will exceed 20-25 m/s. Measures for improvement are strongly advised.

Based on the next table (from NEN 8100), an assessment is given of the expected level of wind danger.

t2.2 Table criteria wind danger according to NEN 8100.

Exceedance chance $P(V_{loc} > V_{threshold;wind\ danger})$ in percentages of the number of hours per year	**Qualification**
$0.05 < p < 0.30$	Limited risk
$p \geq 0.30$	Dangerous

Situations with an exceedance percentage chance of $0.05 < p < 0.30$ should only be accepted if they fall within the activity class I (walking at normal pace). With respect to the activity classes II and III the exceeding percentage should be: $p \leq 0.05$.

Situations with an exceedance percentage of $p \geq 0.30$ are clearly dangerous and should be prevented at all time. The public shall not be exposed to this situation.

For every measurement location the exceedance of the danger criterion was also evaluated.

2.3 Wind climate on location

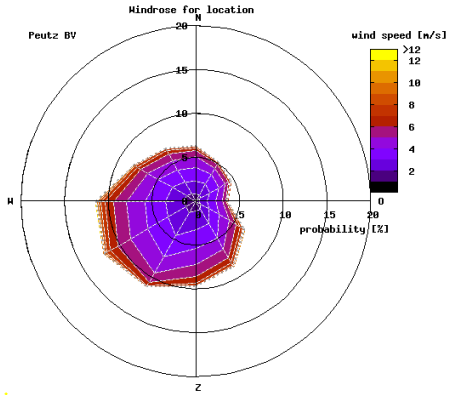
For the "translation" of the results of the measurements on a scale model in the wind tunnel to the real situation, local wind statistics are used.

The local wind climate can be characterised by the frequency distribution of the hourly averaged wind speed. For this situation the frequency distribution from the weather station near Stockholm Bromma Airport was used, which, given the location of the project, is the most representative. The wind statistics and the wind roses are presented below.

f1 *Weather station Stockholm Bromma Airport: distributive divided frequency of the hourly averaged wind velocity from 1984-2013.*

Wind			EAST			SOUTH	Wind direction		WEST			NORTH
speed [m/s]	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
0	8	6	4	10	13	13	13	14	21	16	13	8
1	68	49	30	49	85	95	126	102	107	93	76	66
2	133	117	86	101	181	190	281	221	191	181	139	136
3	115	113	95	123	171	200	263	247	216	167	151	147
4	78	75	66	121	137	175	196	214	195	129	117	109
5	46	42	35	89	99	127	109	152	140	83	79	66
6	20	18	14	53	62	64	41	88	86	47	41	31
7	7	7	5	26	32	28	12	47	48	25	19	13
8	3	3	1	12	15	10	3	20	28	12	8	5
9	1	1	0	7	6	4	1	9	13	6	3	2
10	0	0	0	3	3	1	0	3	5	4	1	0
11	0	0	0	1	1	0	0	1	1	2	1	0
12	0	0	0	0	0	0	0	0	1	1	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0
40	-	-	-	-	-	-	-	-	-	-	-	-
total	479	431	338	594	805	906	1046	1119	1053	766	647	584
average	3.5	3.6	3.7	4.3	4.0	3.9	3.5	4.1	4.2	3.8	3.8	3.7

f2 *Weather station Stockholm Bromma Airport: wind rose 1984-2013.*



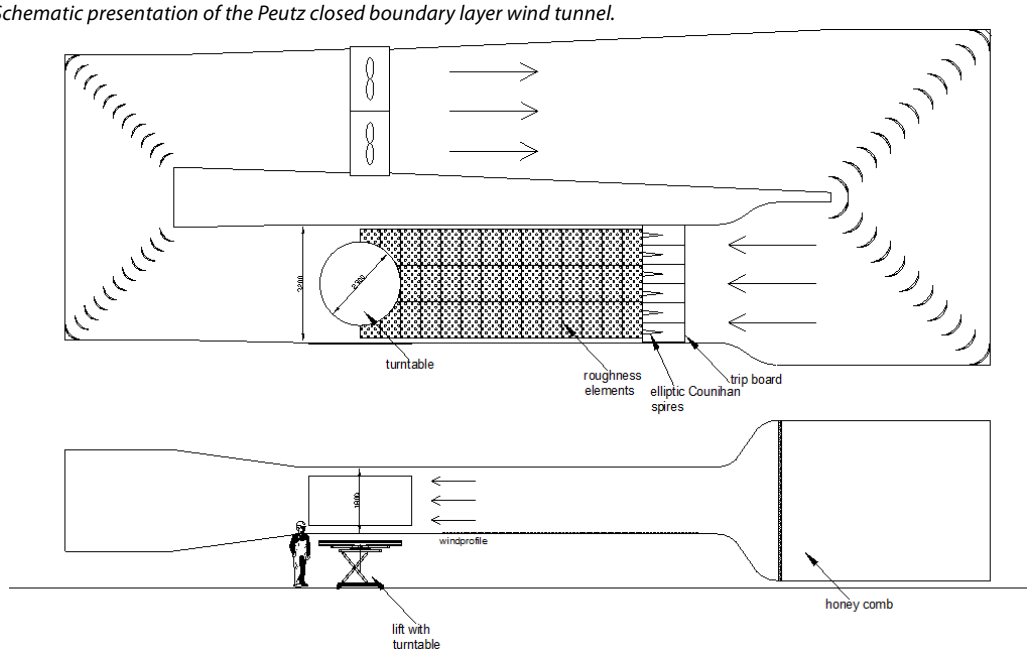
The wind statistics and the wind rose show that the prevailing wind directions are west to south.

Because of the distance between the location of the weather station and the building site there should not be any significant difference.

2.4 Simulation of wind speeds in the wind tunnel

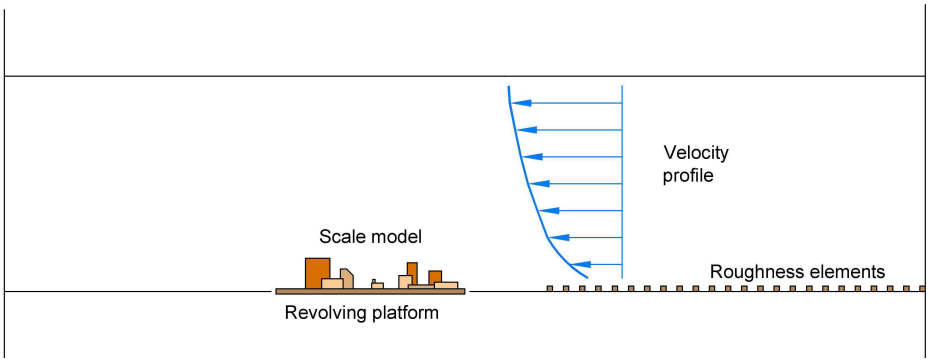
Wind tunnel investigations are performed in the Peutz wind tunnel at Mook, The Netherlands. The wind tunnel is a so-called closed boundary layer wind tunnel, specially designed for simulating an atmospheric boundary layer. A schematic presentation of the wind tunnel is given below.

f3 Schematic presentation of the Peutz closed boundary layer wind tunnel.



In the wind tunnel the boundary layer that occurs in practice (with a neutral stability with respect to the temperature profile) is generated on scale, therefore the right wind profile is "offered" at the measuring location (depending on the roughness of the terrain). Sophistication of the local wind profile occurs by adding, on the revolving platform, the buildings and vegetation in the direct vicinity to the scale model.

f4 Simulation of wind profile in wind tunnel.



2.5 Scale model

For the purpose of the wind tunnel investigation a 1:250 scale model was made based on the architectural drawings of M15 by SeArch architects, Amsterdam, The Netherlands, stage of development June 2015 and architectural drawings of M22 by Rotstein Arkitekter, Stockholm, stage of development June 2015. With respect to the built environment the drawings received were used, as well as the results of the data gathered from Google Earth and the architect. The model for the environment was made made for the purpose of an earlier wind tunnel investigation.
The scale model represents the built environment up to a distance of approx. 250 meters from the centre of the building plan. The difference in height at the building site and of the surrounding terrain has been modelled as accurate as possible.

2.6 Investigation in the wind tunnel

The measurements in the base situation include 171 locations at (elevated) ground level surrounding the present development and it's direct vicinity. Several measuring locations are placed on the (roof) terraces of the high rises T4, T5 and T6.

In these locations the hourly averaged wind speed at the level where people may be present, approximately 1.75 m above street, platform or roof level, is measured for 12 wind directions.

Taking the local statistic wind data into account, the measured wind velocities per wind direction are transformed into the chance that a certain wind speed ($V_{threshold}$) will be exceeded. The total probability of exceeding the threshold value is the sum of the probabilities per wind direction. In order to be able to evaluate the local wind climate these probablilities are, given the activity level in the area - "normal walking" area or "leisure walking - strolling" area -, compared with the probabilities as prescribed in section 2.2.1.

3 Presentation, results and evaluation of the measurement

3.1 Presentation of measurements

The evaluation of the wind climate is based on the results obtained from the wind tunnel measurements, the local wind statistics and the limits concerning wind nuisance and wind danger as described in chapter 2.2.
The measurement locations in front of the entrances of the buildings, as well as the locations at the (roof)terraces are evaluated as activity level II ("leisure"). Colour blue.
The other points are evaluated as walking area, activity level I. Colour orange.

An overview of the measuring locations and the category classification is given in figure 1 (base) and 3 (variant). The triangle measuring points are located on higher levels.

In figure 2 and 4 the measurement results are given using the following colour coding:

- Category good: green
- Category moderate: yellow
- Category poor: red
- Exceeding the danger criterion or slight risk: red underlined or red dotted underlined.

On the points with a green colour we expect a good wind climate. These need no further attention.
On the points with a yellow colour a reasonable/moderate wind climate has to be expected. This is acceptable if there are no simple mitigations to improve the wind climate.
On the points with a red colour a poor wind climate has to be expected. These points need attention.

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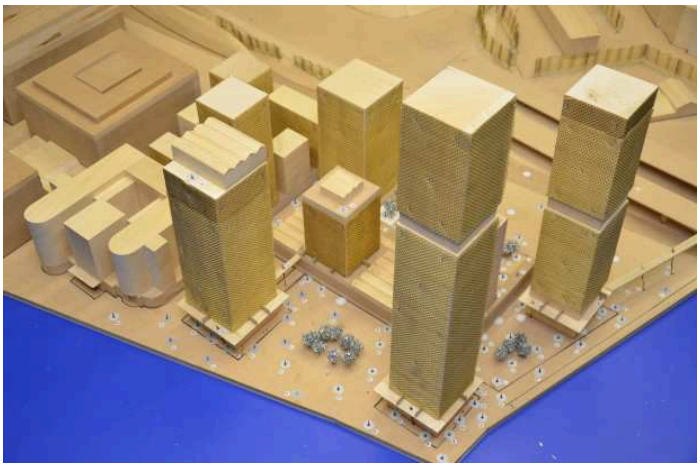
3.2 Results M15



f5 View of the scale model, planned built situation.

The results of the measurements on the scale model are given in figure 2 of appendix 2 (V_{thr}=5.0 m/sec.), the measuring points in figure 1.

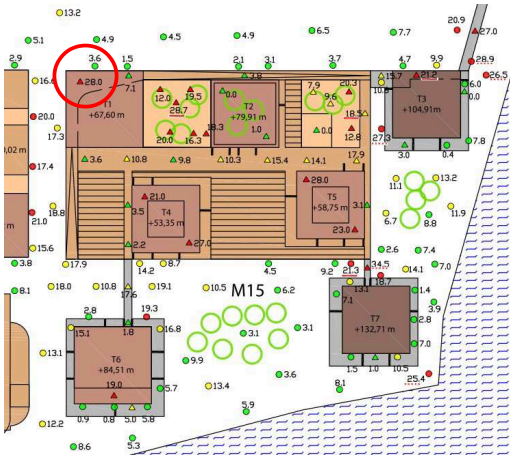
General:

In the base situation there are several points with a poor wind climate. Also there are a few points with wind danger.

North-west side and the south-east of the project the expected wind climate is mainly good

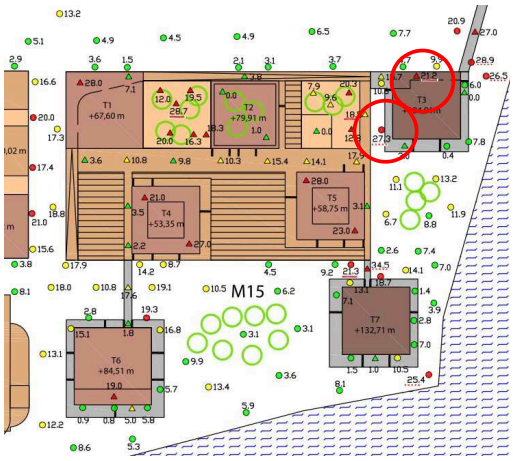
Tower T1:

The expected wind climate at the entrances of T1 is good. On the walking route towards the deck a poor wind climate is expected at the corner of T1. This poor wind climate is caused by wind from south-southwest to north-west. To improve the wind climate at this point a wind screen can be placed at the north-west side of the path.



Around T3:

Near the entrance at measuring point 114 the wind climate is poor. The wind climate at the entrance itself will be significantly better thanks to the planned set back. Since the point is located at the walking route from the bridge, it is advised to improve the wind climate at this point by placing wind screens. The expected wind climate at point 85 is poor. It is advised to improve the wind climate at this point by adding screens or bushes in this area. At both points there is also a (limited) risk on wind danger.

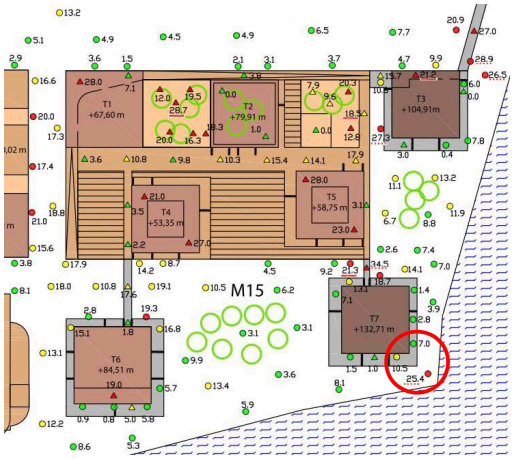


Between T5 and T7:

Between the high rise buildings T5 and T7 there will be a poor wind climate, with the possibility of wind danger at the measuring point 66 and a limited risk on point 116 (bridge). It is advised to place canopies and/or locating some screens or other wind disturbing elements at ground level. In order to protect the bridge a wind screen can be placed at at least the south-west side of the bridge.

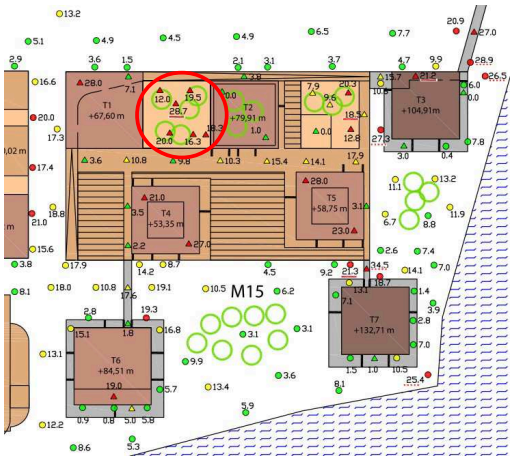
Along the quay:

At the measuring points 73 near the corner of T7 a poor wind climate for walking level is expected with a limited risk on wind danger. Maybe there is a possibility to put some more trees here or other vegetation to disturb the wind flow.



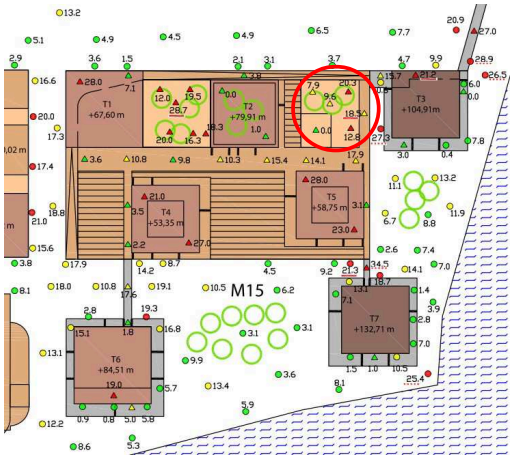
Between T1 and T2:

At the playground between T1 and T2 a poor wind climate is expected, with at one point a risk on wind danger. In order to improve the wind climate wind screens should be placed at both sides of the playground. Looking at the size of the playground and the fact that part of the problem is caused by down wash from T1 and T2, these screens should be combined with the trees as are now present in the plan.



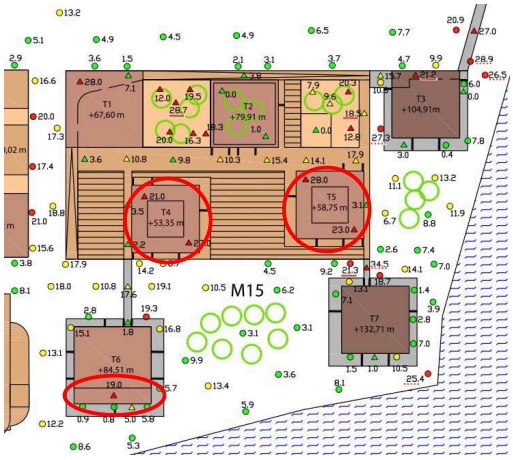
Between T2 and T3:

At the playground between T2 and T3 a moderate to poor wind climate is expected, with locally a probability on wind danger. Looking at the wind directions causing the nuisance, it is advised to add wind screens at the north-west, north-east and south-east side.

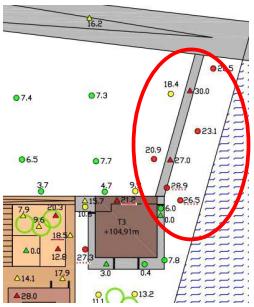


Roofs T4, T5 and T6:

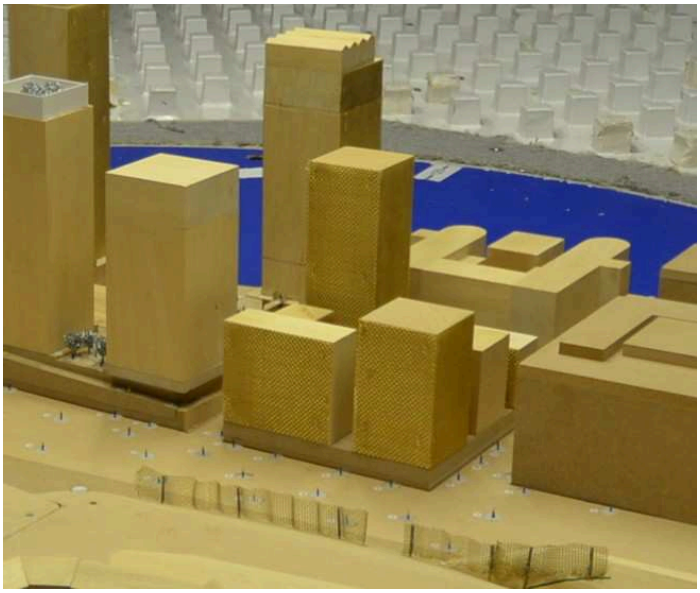
On the roofs of the high rise buildings T4, T5 and T6 there is a poor wind climate. It is only possible to make some roof terraces here with wind disturbing screens.



Bridge near T3:
Near the T3 high rise at several measuring point a poor wind climate is expected, with at two points a limited risk on wind danger. It is advised to place wind screens at at least the west side of the bridge and to place trees along the water side.



3.3 Results M22



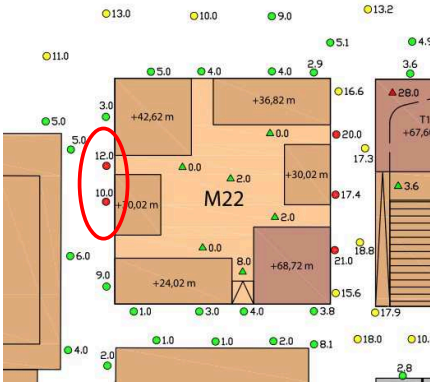
f6 View of the scale model, planned built situation.

The results of the measurements on the scale model are given in figure 2 of appendix 2 (V_{thr}=5.0 m/sec.), the measuring points in figure 1.

General:
In general the expected wind climate around M22 is good to moderate. There are however a few points with a poor wind climate. North-west of the project the expected wind climate is good to moderate. South east of the project at most points a good wind climate is expected. Around M22 no wind danger is expected.

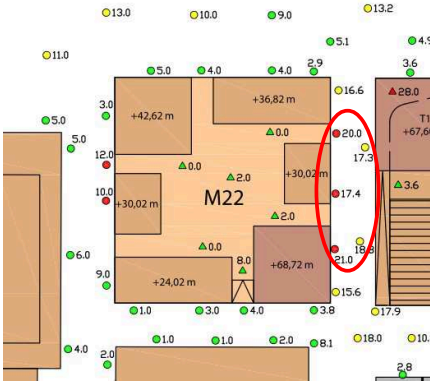
South-west side:

Near the entrances at the south-west side of the complex locally a for category II poor wind climate is expected. The wind climate can be improved by placing trees or other wind breaking structures in the street.



North-east side:

At the north-east side the wind climate is strongly influenced by tower T1 of M15, but also the tower at the east side of M22 plays a role. At three points a poor wind climate is expected, of which at two point also for category I. To improve the wind climate in the street, trees or other wind breaking structures can be placed. Beside that it could be considered to place the entrances in a recess.



4 Conclusions

By order of Förvaltningsbolaget Marievik HB c/o AMF Fastigheter AB at Stockholm, Sweden, a wind tunnel study was conducted on a scale model parts M15 and M22 of the project STA(CK)HOLM MARIEVIK including its direct surroundings in Stockholm, Sweden.

The objective of the wind tunnel study was to quantify the expected wind climate at the entrances of the different buildings of the projects, along the façades of the buildings, at the roof(terraces) of the towers, at the platforms and in the direct vicinity of the projects.

The conclusions of the results of the investigation are:

In the base situation there were several locations with a poor wind climate.

Around M15 these were:
- on the path towards the deck at the west corner of T1
- at several locations around T3
- in the area between T5 and T7
- along the quay near T7
- the pre school courtyards
- at the roof terraces of T4, T5 and T6.

On several points there also was slight risk or risk of dangerous wind situations.

Around M22 locally a poor wind climate is expected at the south-west and the north-east side of the plan. Around M22 no wind danger is expected.

If desired Peutz can comment on alternative provisions planned by the architect.

Mook,

This report contains 17 pages, 2 appendices

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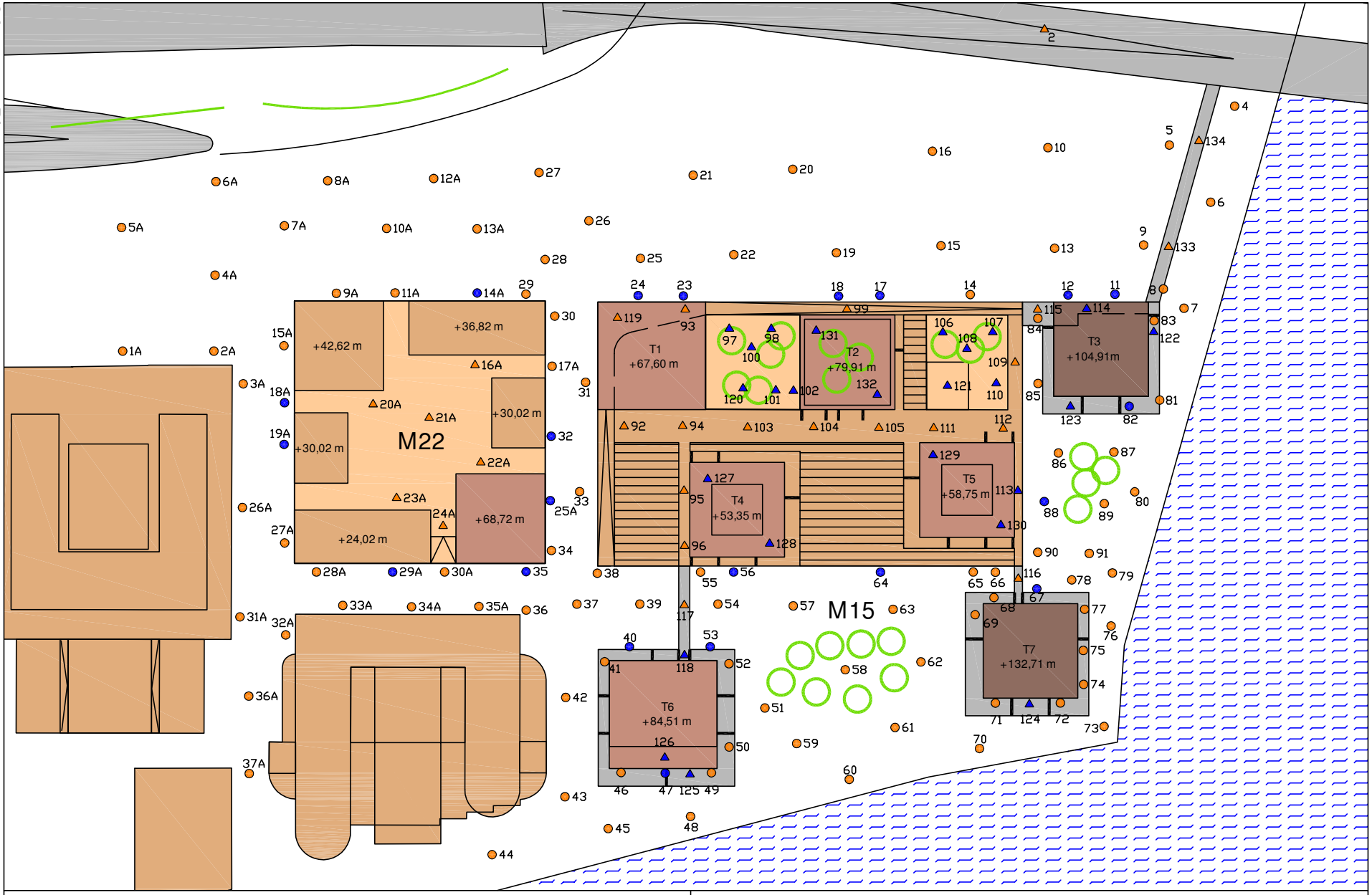
Appendix 1: **Technical insert wind tunnel simulation**

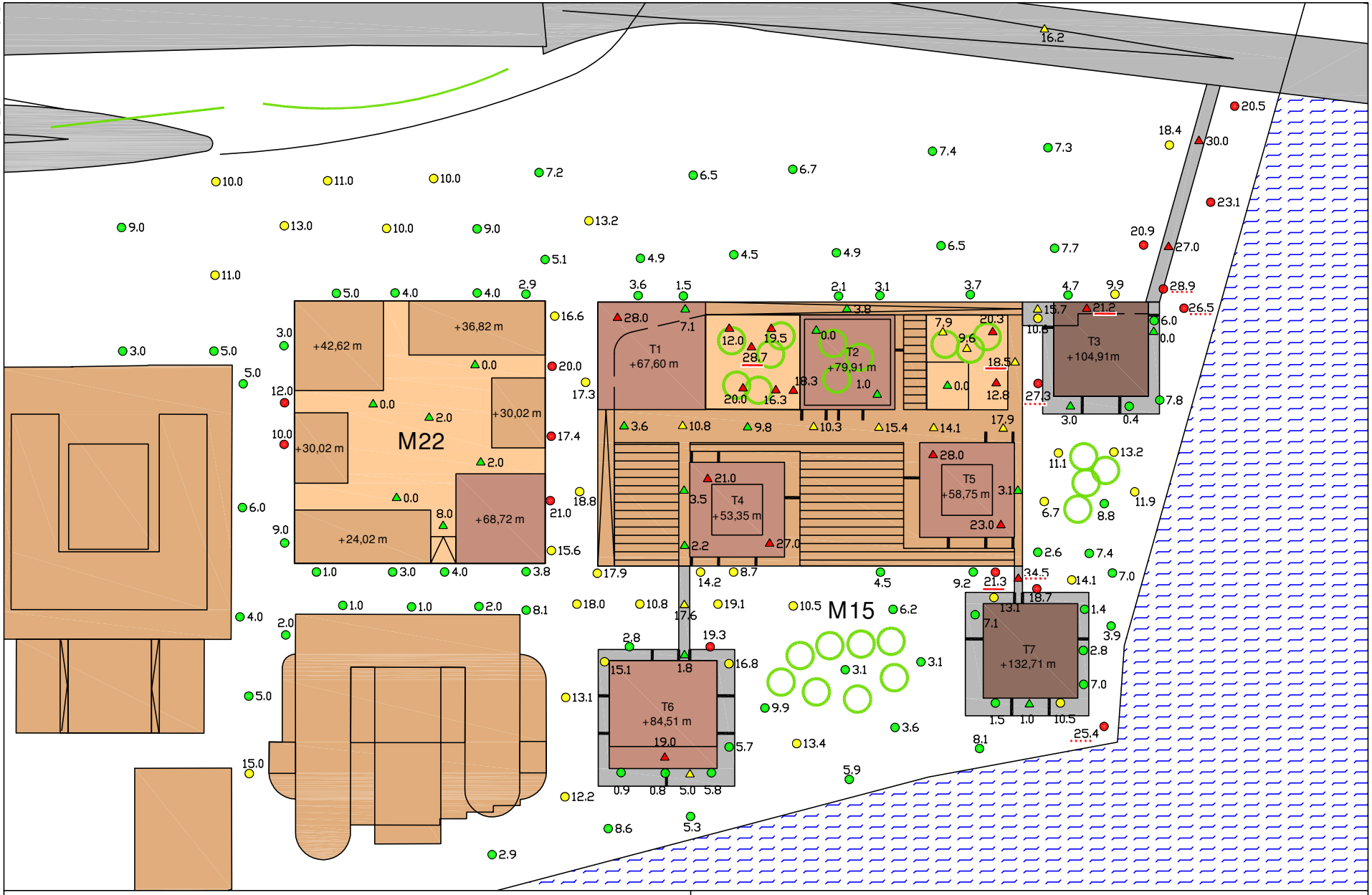
Project	**Project data**			
Project title	*STA(CK)HOLM MARIEVIK, Sweden*			
Principal	*Förvaltningsbolaget Marievik HB* *c/o AMF Fastigheter AB* *Stockholm SWEDEN*			
Project manager	*L. Aanen*			
Date	*July 27, 2015*			
Model	**General data concerning the model**			
Scale	*1:250*			
Amount of blocking	*< 5%*			
Scope of modelled area	*A circle with a radius of approx. 250 m*			
Central area	*The planned project*			
Surroundings	*Urban development*			
Modelled planting	*Annual averaged situation simulated with folded wire netting*			
Tested configurations	*Planned development*			
Measurement set-up	**Information concerning the measurement set-up**			
Simulated boundary layer – calibration date	*Urban building* *annually*			
Measuring locations and measuring height	*171 measurement locations at 1.75 m height above (elevated) ground level and at the (roof) terraces.*			
Tested wind direction	*12 (all around in steps of 30 degrees)*			
Wind speed control – calibration date – calibration authority	*Measuring equipment is checked annually and calibrated according to the quality system* *In house*			
Instruments – calibration date	*Measuring equipment is checked annually and calibrated according to the quality system*			
Data processing and assessment	**Information concerning location and assessment of wind climate**			
Coordinates of the location	*59.311608°N 18.031460°E*			
Applied requirements	V_{thr} m/s	Desired quality category	Exceedance chance %	Assessment
For comfort			$P(V_{loc}>V_{thr,n})$	
Walking (brisk)	5.0	≤ *D*	*<20*	≤ *moderate*
Walking (leisure)	5.0	≤ *C*	*<10*	≤ *moderate*
Sitting	5.0	≤ *B*	*<5*	≤ *moderate*
For danger			$P(V_{loc}>V_{thr,d})$	
	15	n.a.	$0.05 < p < 0.30$	Limited risk
	15	n.a.	$p \geq 0.30$	dangerous
Presented results	*Measurement results are presented as graphs*			
Meteorological data	*Wind statistic computed based on measurement at the meteorological station of Stockholm Bromma Airport, Sweden.*			



● = measuring points judged as category I (walking area)
● = measuring points judged as category II (entrances, terraces)
△ = measuring points at higher level
— = trees, vegetation

Sta(ck)holm Marievik Stockholm, Sweden
Measuring points

Figure 1



= good windclimate (category I: <10.0; category II: <5.0)
= reasonable / moderate windclimate (category I: 10.0 - 20.0; category II: 5.0 - 10.0)
= poor windclimate (category I: ≥20.0; category II: ≥10.0)
= slight risk category I
= exceeds danger criterion / slight risk category II

Sta(ck)holm Marievik Stockholm, Sweden
Exceedance percentage in accordance with NEN 8100
Base

Figure 2

PEUTZ