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Aspects of Using CFD for Wind Comfort Modeling Around Tall Buildings

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Abstract

The Light*House complex is investigated for uncomfortable wind climate and dangerous winds at pedestrian level. A CFD model is used for simulating the wind effect for 12 different directions and correlated to the wind statistics of a nearby meteorological station. Comparing to practical standards for safety and comfort, the results indicates that the building is safe for pedestrians. However, when designing surrounding builds, care shall be taken to avoid interaction between buildings.

Keywords: *CFD modelling; Wind climate; pedestrian Comfort.*

1 Introduction

Tall buildings create their own local wind climate. In certain circumstances this can result in amplification of both the mean wind velocity and of the turbulence. The challenge is to combine the vision of the architect with methods of the civil engineer. Traditional, wind engineering has been focused on the structure-wind interaction from a structural point of view. The work has been related to the wind loading on the building. Increasingly emphasis has been put on how tall buildings affect the surrounding wind climate. Here, the analysis is based on forces acting on different parts of the structure and the dynamical interaction between air and structure. For complex buildings, the forces can either be determined by wind tunnels test or by CFD models.

However, the effects of upstream and surrounding buildings can have a severe effect on the indoor ventilation, fire fighting, air pollution, odors and pedestrian safety and comfort. In the case of pedestrian safety and comfort, the results from a CFD model or measurements in a wind tunnel can be difficult to interpret into variables that confident can be translated into levels of comfort and safety.

In the case of the Light*House complex at Århus, Denmark (3XN, UNStudio, Gehl Architects, Keops Development, Frederiksberg Ejendomme, Grontmij, Carl Bro), a dominant 145 m. tower is planned to be located at the harbour edge, controlling much of the wind climate surrounding it. The Light*House project consists, besides the tower, of buildings for offices, hotel, restaurants, residential and apartments. The area where the Light*House is planned for is today an active harbour with container activity.

The municipality of Århus requires that all buildings with a height over 8 storages should be evaluated for wind climate effects at ground level.

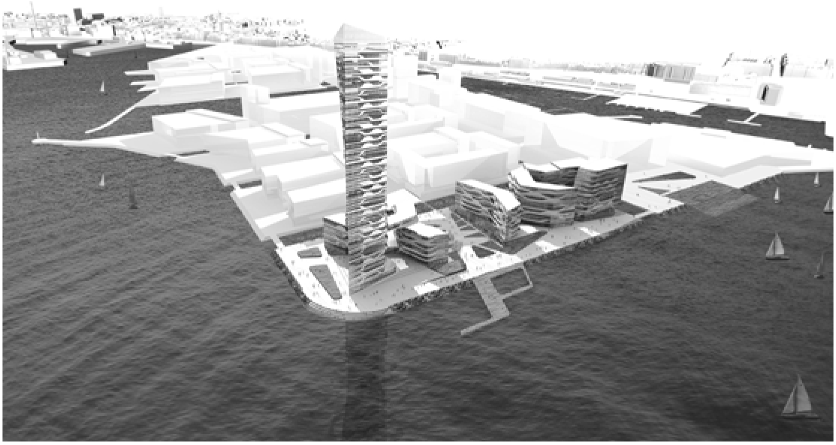

Figure 1. Overview of the complex.
(illustration:3XN, UNStudio and Gehl Architects)

The area between the buildings are planned to be used for public activities, culture, sports and small café areas. Due to the spectacular location and the height of the tower (the highest in Denmark) the area will attract many visitors to the open areas around the buildings. The buildings around the Light*House complex is not at this date planned in detail. Instead, the architects have illustrated possible buildings, which height and geometry is within the local planning regulations

The challenge is that the building is standing on the edge of the sea and that most of the area is exposed winds coming from the east. Fortunately, the predominant wind direction is more south-west.

2 Method

The method for evaluating the safety and comfort for pedestrian is to model both the buildings and a large part of the surrounding buildings and landscape. The wind pattern from 12 different directions is modeled. The amplification between wind velocity at 10 meter above ground level and pedestrian level is calculated by the CFD model. Wind velocities at pedestrian level (here defined at 1.75 over ground level) are then compared to criteria's for safety and comfort. Based on wind statistics for wind direction, speed and duration it is possible to calculate the average number of hours a given points exceeds the safety and comfort criteria.

2.1 Evaluation of safety and comfort

In the case of wind affecting pedestrians, the analysis is not straight forward. A clear separation between danger and comfort must be made. While the danger depends primarily on the wind and turbulence levels, the comfort is more a perceived parameter. The comfort can be a result of wind speed, air temperature, relative humidity and solar radiation (Stathopoulos et al., 2004).

Bottema (Bottema, 2000) performed a very comprehensible study of the different safety and comfort criteria used though the recent decades. The criteria in the present study are condensed to:

Comfort criteria:

$$U + \sigma_u > 6\ m/s\ , \quad P_{\max} = 15\% \qquad (1)$$

Safety criteria:

$$U + 3\sigma_u > 20\ m/s\ , \quad P_{\max} = 0{,}18\,\% \qquad (2)$$

Where U is the mean air velocity, σ_u is the standard deviation of the instantaneous air velocity (turbulence) and P_{max} is maximal exceedence probability. This yields that the comfort level can be exceed 1314 hours/year, while the safety level only can be exceed 16 hours/year.

The concept is that both safety and comfort is controlled by the mean velocity and the turbulence. It is significant that the turbulence plays a larger role when evaluating safety compared to comfort. This is caused by the very large directional shifts in direction which can be experienced in large scale turbulence. The human body cannot adapt to rapid directional changes when trying to keep the balance.

It is more complicated to evaluate the thermal effects of wind on pedestrians as no clear dependency on average air velocity or turbulences is identified (Bottema, 2000). It however seems reasonable that thermal comfort to some extent can be evaluated in the same manner as mechanical comfort (equation 1).

2.2 Wind statistics for the location

The nearest meteorological station where wind is measured continuously is Tirstrup airport, close to Århus. The wind gauge is located at 10 m above ground level. The statistics is generated on basis of 8 years of measurements. A two parameter Weibull distribution is developed for the 12 primary wind directions.

$$P\left(U > U_{critical}\right) = 100\% \cdot \exp\left(-\left(\frac{U_{critical}}{A}\right)^{k}\right) \qquad (3)$$

Where $U_{critical}$ is maximal exceedence velocity, A and k are Weibull parameters.

The Weibull parameters are dependent on the direction of the wind, table 1.

Table 1. Weibull parameters for Tirstrup airport, (Troen and Lundtang, 1989)

Sector	**Frequency**	***A***	***k***
0	4.6	4.2	1.49
30	4.8	4.3	1.51
60	5.6	5.0	1.63
90	6.9	5.2	1.72
120	9.1	4.9	1.69
150	7.8	3.7	1.40
180	8.8	3.5	1.47
210	10.9	3.8	1.66
240	13.0	4.2	1.77
270	15.0	5.6	1.75
300	9.6	5.7	1.63
330	4.1	3.5	1.22
total	100.0	4.6	1.56

In order to evaluate the safety and comfort levels, an estimate for the turbulences is also necessary to calculate the related turbulence level. An empirical investigation for a meteorological station is established (Larsen, 1999):

$$\sigma_{u,10} = 0.151 \cdot U_{10} + 0.119 \qquad (4)$$

Where 10 indicates that the relation is established for measurements in a height of 10 above ground level. It is in this context assumed that the turbulence level is following the same relation at pedestrian level.

2.3 Numerical model

The ANSYS CFX model is used for the simulation of the flow field around the buildings. The SST turbulence model is used for better prediction of both the boundary layer and the recirculation pattern around the tower.

The first step of the modeling process is to identify which of the surrounding buildings should be included in the model. The primary buildings within a 2 km. radius are digitized, using the digital city model of Århus. Figure 2 illustrates the geometry which is modeled by the CFD model. The 145 meter tower can be seen at the edge of the harbor area

Figure 2. Overview of the modeled area.

Unfortunately the digital model much more details than it will be possible to model. Therefore only the primary geometry is modeled and the physical properties of the buildings are accommodated by increasing the aerodynamic roughness of the building surfaces.

Figure 3. Surface structure of the Light*House building.
(illustration:3XN, UNStudio and Gehl Architects)

The sea in front of the complex is modeled with a roughness of 1 meter, while the surfaces of the buildings are assumed to have a roughness of 1.5 meter, figure 3. All the areas inland which are represented by buildings are modeled with a surface roughness of 5 meter.

The reason why so large an area is modeled is to achieve realistic wind profiles close to the investigated buildings. In order to connect the wind statistics to the CFD model, the boundary condition to the model is a velocity profile approximated to (Wang et al, 2004):

$$U = U_{10}\left(\frac{z}{10}\right)^{0.25} \tag{5}$$

Where *z* is the height above ground level.

An unstructured grid is generated around the building in a 2 km radius around the tower and to a height of 500 meter above ground level. The final grid uses structured grid close to the surface in order to improve the resolution of the boundary layer.

3 Results

The flow field is simulated for each of the 12 directions where statistics are available, table 1. The amplification factor is the ratio between the velocity in 10 meter at the boundary and the velocity in pedestrian level, figure 4. The figure illustrates that the wind is amplified very different depending on the position on the ground and the wind direction.

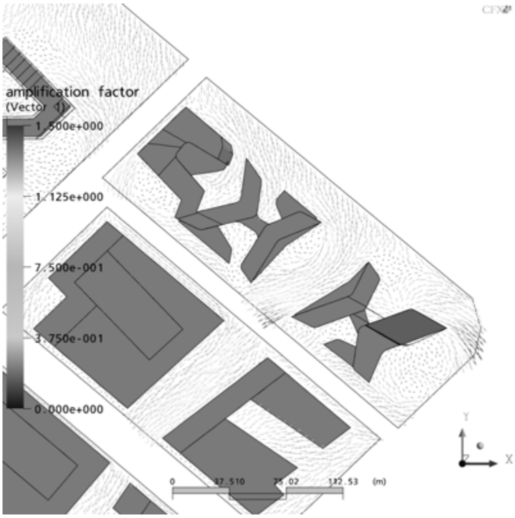

Figure 4. Vector plot of wind around the buildings at 1.75 above ground level. The wind is coming from north.

In order to evaluate the exceedence probability, 240 points are defined around the complex. The simulations reveal that there is no exceedence of the safety criteria, eq. 2. However 26 of the 240 points exceed the comfort criteria. This is illustrated in figure 5, where areas of uncomfortable are depicted as dark grey.

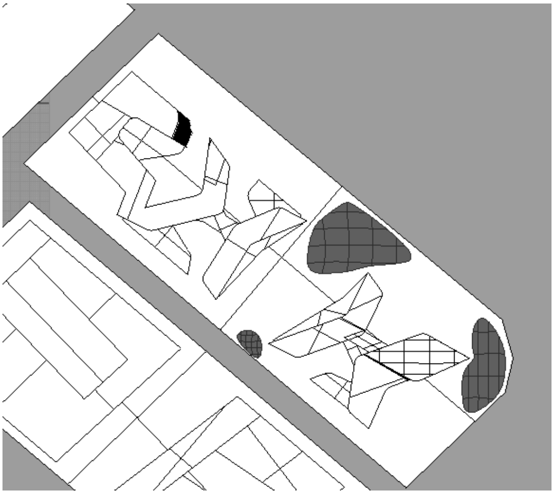

Figure 5. Areas where comfort levels are exceed.

The results indicate that the areas west and north-east of the tower are especially exposed to uncomfortable wind climate.

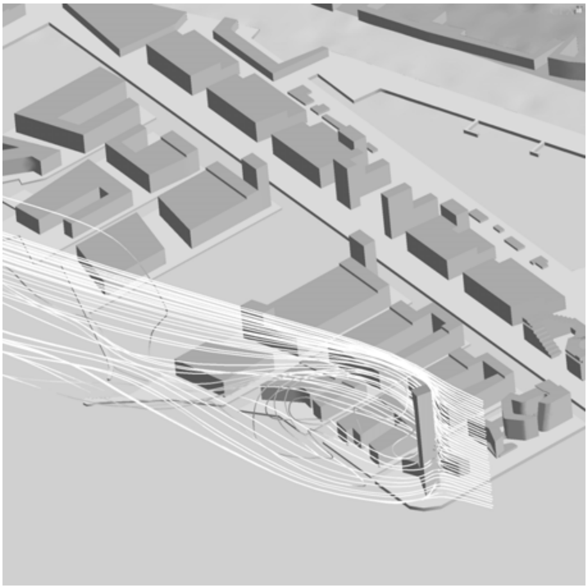

Figure 6. Streamlines around the Light*House tower.

For the area west of the tower, the reason is that the wind cannot in any significant way go above the tower. Most of the wind has to follow the facade around the tower. This area in front of the tower will certainly be one of the more attractive areas for visitors to stay, as it is on the edge of waterfront and close to the imposing tower. Using this area for say cafés would require extra attention to local wind barriers to lower the adverse affects of the wind. Also, the sharp separations behind the tower can at ground level create unpleasant gusts of wind and increase the turbulences in the area, figure 6.

At the north-east area, the reason for the unpleasant wind climate shall be found in the interaction with other buildings. The gap between the tower complex and the residential/business buildings to the north east is continued in the area south – east of the Light*House complex. This allows for the wind to escape between the buildings and not be forces upwards.

This emphasizes a point: When designing e new building in an area, where the surrounding buildings are not yet planned. The fictive building can be responsible for just as much unfavorable wind climate as the actual building which is investigated.

3 Conclusion

The simulations indicate that uncomfortable wind condition can appear at ground level around the complex in areas of public interest. However, the wind climate should not reach dangerous levels. Action should be taken to make wind barriers and integrate them into the area, if continuously occupation is wanted.

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