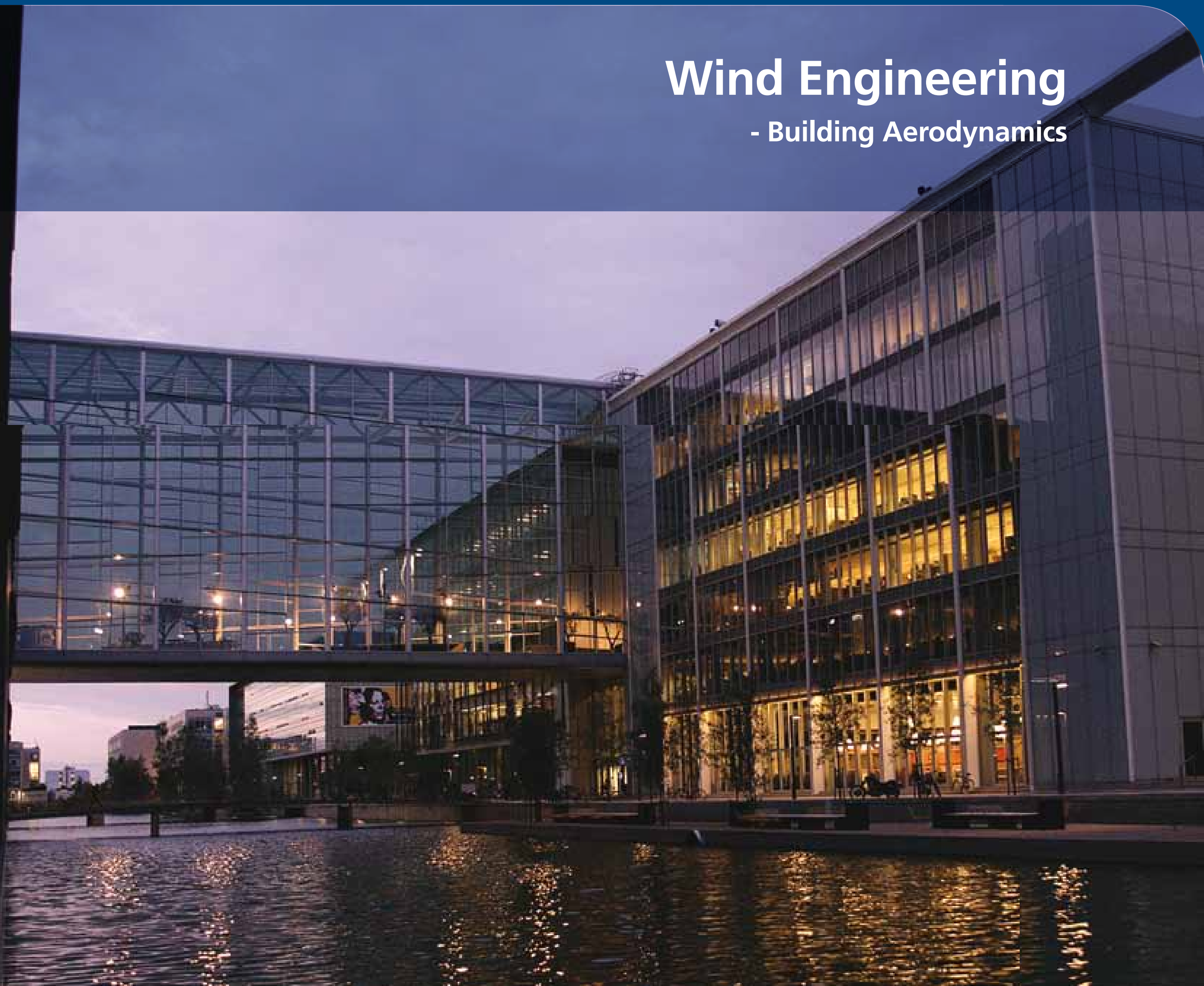
Wind Engineering

- Building Aerodynamics



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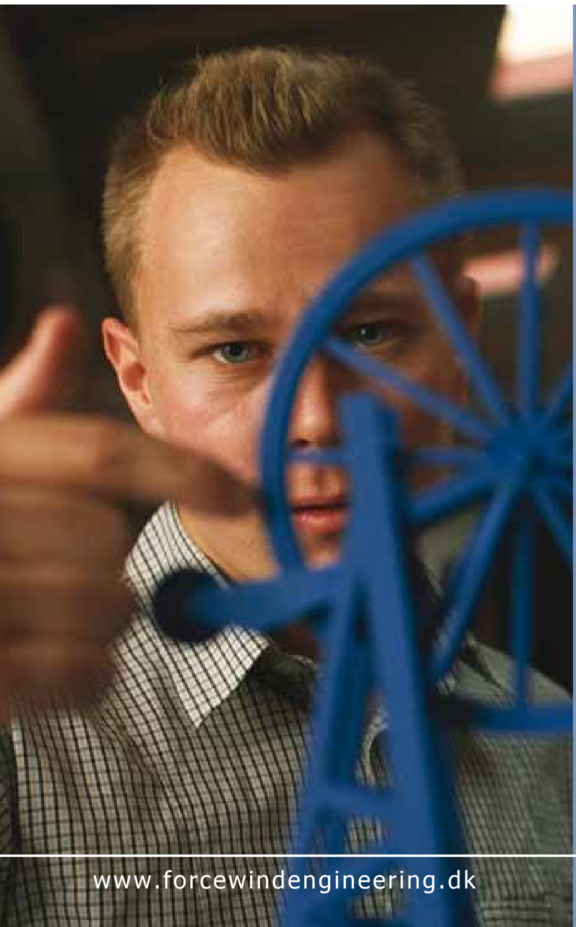

FORCE Technology offers knowledge that supports you in the engineering phase.

Our services cover:

- Building and bridge aerodynamics
- Design wind loads and forces
- Dynamic structural response to wind
- Wind related environmental issues, e.g. urban areas
- Wind conditions across landscapes
- Plume dispersion investigations

Your partner in wind engineering

Engineers and architects from around the world face the challenge of decreasing the impact of wind on structures and the surrounding environment. Questions arise, such as how should the building be placed?, what are the design-life wind loads? and how can wind-induced vibrations be alleviated? This can often be particularly challenging, as structures may have an architecturally unique shape and therefore are not covered by traditional design codes and standards.

Core competencies in building aerodynamics

To face the challenges you need to team up with a partner that understands your need for complex investigations on structural surfaces. Here you can rely on FORCE Technology's knowledge and expertise within wind engineering.

With over 50 years of experience in hydro- and aerodynamic engineering, we are recognised as one of the world's leading wind and water testing centers for industrial aerodynamics. Our highly qualified and trained staff uses state-of-the-art facilities and numerical simulation capabilities to solve the most challenging engineering problems. Our broad range of competencies and expertise place us in a unique position to offer you full engineering service packages for integrated solutions - from project concept to full completion. In other words - you can have confidence in FORCE Technology as your partner.

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About FORCE Technology

Division for Maritime Industry

At our Division for Maritime Industry we offer our customers extensive services and expertise within aerodynamic and hydrodynamic model testing, numerical fluid mechanics and computer-based simulations.

Within wind engineering, we specialise in bridge aerodynamics, building aerodynamics, ship aerodynamics, and offshore aerodynamics, as well as carry out consultancy and CWE.

FORCE Technology in brief

FORCE Technology is a leading technology, consulting and service company on the international market. We offer our expertise to a broad range of industries, such as the building and construction industry, offshore and maritime industry, pharmaceutical and food manufacturers and to the public sector.

We offer unique competitive advantages through the development of flexible, innovative and value-creating solutions that build on trust and close collaboration with our customers.

A full service package

We offer a comprehensive range of services to our customers ranging from initial desktop studies to wind-tunnel testing.

Expert advice and testimony

As your wind engineering consultants, FORCE Technology can advice you on the feasibility and the structural consequences of a proposed design, the effects of the structure on the built environment and the likelihood of pedestrian and occupancy comfort problems. Furthermore, we can advise you on corrective measures for existing wind-related problems that you may encounter during or after completion of your project. Additionally, our specialists provide expert testimony at legal proceedings.

Surface pressures

Surface pressures and cladding loads can be determined for even the most unusual structures using FORCE Technology's High-Frequency Pressure Acquisition System. Wind-tunnel testing of scaled models under simulated site-specific climatological conditions can provide both static and dynamic wind pressure loads and coefficients that can be used directly for structural design.

Structural wind loads

Structural wind loads can be determined using several tried and tested techniques or a combination of these. For this purpose, a dynamic 6-DOF Force Balance System with a lightweight model can be used to determine wind-induced structural base reactions such as overturning moments and shears. Additionally, acquired surface pressures can be integrated to provide both local and global structural loads. Comparisons with existing engineering codes may be undertaken simultaneously.

Aeroelastic and dynamic testing

Evaluating the fluid-dynamic interaction between wind and structure can often prove daunting. FORCE Technology offers the option of aeroelastic and/or section model testing of a structure or its components, in order to physically determine the dynamic behaviour of the structure due to this interaction. Using experimental testing equipment, e.g. High Reynolds Number Rig with simultaneous pressure acquisition and Vortex Induced Motion System (VIMS), we can offer you concrete explanations to your fluid-dynamic phenomena.

Dynamic analysis

With our state-of-the-art software and theoretical models, FORCE Technology can effectively determine the dynamic response of your structure and its subcomponents using known wind load models or acquired load time-histories. Using our in-house software and Finite Element packages, we can model the most complex structures and provide information on linear and non-linear response in both the frequency and the time-domains.

Wind environment

A pleasant wind environment around a structure or site can prove to be the key to its economic success and viability. Using sophisticated wind models and wind-tunnel testing, FORCE Technology can assess the wind comfort of a site for pedestrians, the dispersion of gases and plumes, the wind climate around buildings, stadiums and cafés and the dispersion of e.g. snow, pollen and rain.

Occupancy comfort and structural fatigue

Through dynamic analysis and/or testing, the vibrational characteristics of a structure can be determined. Using this information and well-established comfort criteria, FORCE Technology can assess the expected occupancy comfort of your structure. Additionally, we can address the undesirable short- or long-term consequences of structural vibrations, such as fatigue, and make suggestions for performance improvements.

Structural vibration control

With experience and state-of-the-art know-how in structural control, FORCE Technology can advise on design and implementation of the appropriate control strategy for your structural vibration problems. The selection of a passive, semi-active or active control system is made easier by our ability to simulate the effects of a particular control regime on your structure or structural subcomponent – both numerically and experimentally – using sophisticated software and testing equipment.

Structural optimisation

By examining the effects of wind on the overall performance of your structure, an assessment of the options for structural optimisation can be made. Obvious improvements include reductions of structural loads, construction cost savings and increased pedestrian and occupancy comfort. Beyond this, FORCE Technology can help optimise your structure for improved ventilation and internal flow, decreased heat loss, improved overall structural life expectancy and a reduction of noise levels.

Ventilation and internal flow

Through the use of reduced and full-scale mock-ups, Computational Fluid Dynamics (CFD) and pressure studies, FORCE Technology can help you with your internal flow and ventilation needs. Whether it is the quality of the air or the quantity of the flow, we can help you optimise your structure to meet your requirements.

Structural design checks for wind loading

Although we strive to provide you with a clear understanding of the wind that your structure may experience during its lifetime, we understand the periodic need for a verification of the application of those loads on your structure. Using dedicated structural design software and in-house expertise, FORCE Technology is in a position to verify your application through structured design checks.

On-site testing and monitoring
Structural health monitoring and testing is undertaken using the latest available in-house and commercial monitoring and testing equipment and technologies. Monitoring systems are developed for both short- and long-term applications and tailored specifically for your structural needs. Testing and monitoring are non-destructive and in most cases non-evasive.

Systems can include wind-monitoring stations, structural vibration measurements, integrated welding inspections and flow quality stations to name a few.

Wind-turbine siting
With one of the world’s largest environmental wind tunnels and the experience to match, FORCE Technology can help you in the financially decisive task of wind-turbine placement.

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With one of the world's largest environmental wind tunnels and the experience to match, FORCE Technology can help you in the financially decisive task of wind-turbine placement. Our experience, facilities and extensive CFD capabilities can help you utilise your wind-turbine potential to maximise overall electricity output.

Code application and development
The wind loads and extreme structural responses determined through wind-tunnel testing and numerical analysis are compatible with the format of national and international design codes for structures. FORCE Technology advises you which type of investigation suits your needs best and guides for a correct application of the reported results. Participating in several national and international research programs, FORCE Technology provides services based on state-of-the-art knowledge in the field of wind and structural engineering.

Choice of approach

In modern wind engineering, investigating wind loads, flow fields and pedestrian wind comfort can be approached using different methods. At FORCE Technology we offer three different methods dependent on the required detail-level and purpose of the study: desktop study, Computational Fluid Dynamics (CFD) calculations or wind-tunnel testing.

Desktop study

For simpler non life-critical structures and structural subcomponents, FORCE Technology can undertake budget-minded desktop wind-engineering studies with the intention of providing reliable estimates of expected structual loads, vibrations, fatigue life and comfort quality.

Usually, the basis of a desktop study is drawings provided by the client and meteorological data published by the local meteorological institute. From a professional point of view, this method is primarily indicative as it is entirely based on theoretical considerations. The advantage, on the other hand, is the low cost, and we recommend this method for projects that do not require a high level of precision, for example projects in the early planning phase.

Wind-tunnel testing or CFD analysis?

Wind-tunnel testing and CFD calculations are two methods at an almost equally detailing level but with different advantages and benefits for the customer. In general, there is not much difference in the cost of performing CFD calculations or wind tunnel tests, but as we offer both possibilities, you can be certain that your project is investigated in the most efficient manner according to purpose.

CFD calculations

One of the major benefits of CFD calculation is the possibility to obtain detailed information about the flow field as well as temperature and concentration fields within a large domain. For example, CFD calculations can be applied to predict the dispersion of gases or to determine temperature fields due to explosion and fire. The detailed information about the total flow, including pressure and velocity fields, provides a good basis for diagnostics and optimisation. CFD calculations provide information which is not readily obtained by physical modelling, i.e. simulation of structures dynamically influenced by fire. A numerical approach is also applied successfully in ventilation studies and analyses of internal flow within maritime applications.

Wind-tunnel testing

Applications where physical wind-tunnel tests are superior to CFD calculation include predictions of wind loads on civil engineering structures. These predictions are done on the basis of an accurate prediction of time-dependent pressure fluctuations as well as turbulence conditions. Wind-tunnel tests are also suitable for fast investigation of a large number of configurations. This is, for example, utilised in the analysis of smoke dispersion from smoke stacks where investigation of selected measuring points for different wind directions is carried out rapidly by application of a physical model.

New Air Traffic Control Tower at Copenhagen International Airport

The extent of a structure's wind-induced vibrations can often affect design decisions concerning acceptable occupancy comfort levels, the effects of structural fatigue and long-term maintenance costs.

Aerodynamic investigations

The design of the new 70 m tall Air Traffic Control Tower at Copenhagen International Airport required a range of aerodynamic investigative techniques. More specifically, both the varying wind pressure on the tower surface and the dynamic response of the tower to the wind were simulated at model scale. The aeroelastic model was designed to reflect the scaled stiffness, mass and damping distribution of the full-scale structure. FORCE Technology's experience of model design and production resulted in the accurate and efficient production of the final tower model.

Qualified design decisions

Detailed investigations of the tower provided a reliable prediction of design loads and extreme responses to the wind. This allowed the designers to adjust their design to fulfil the specifications demanded by the air traffic controllers and the airport authorities alike. The examination of the structure performance in the wind, prior to erection, contributed not only to air traffic safety, but also to the overall serviceability of the structure over its lifetime.

Aveiro City Stadium, Portugal

Limiting wind-induced roof vibrations

Large-span roofs such as those designed for sizable stadiums are typical examples of flexible structures subjected to potentially large wind loads and wind-induced vibrations.

As an integral part of the design process, Portugal's Aveiro Stadium engineers commissioned FORCE Technology to undertake the wind-tunnel studies of the stadium. The determination of the wind loading on the large flexible torus-shaped roof of the stadium required pressure measurements acquired simultaneously at a high sampling frequency over the whole surface of the roof. Typical considerations for the simulation and the measurement of the wind load at model scale are as follows:

A stadium roof is often constructed as a continuous structure covering the grand stand round. To determine the response of such structures, the time varying wind load on the roof must be measured simultaneously and at a high frequency over the entire roof area. The dynamic vibration of the roof structure may affect stay cables and other elastic or stiff supports of the roof. For these elements, additional wind analyses including dynamic vibration effects must be undertaken.

The large area of a stadium roof has to be sufficiently equipped with pressure sensors so as to accurately measure the distribution of the wind load on both sides of the roof.

Salle de Concert, Luxembourg

Considering the wind for load and comfort

As part of the ongoing development of the European Centre in Luxembourg, a new concert hall - the Salle de Concert Grande-Duchesse Joséphine Charlotte - has been erected on the Place de l'Europe adjacent to the European parliament building. Architect Christian de Portzamparc developed the particular architectural concept of the Salle de Concert with its 823 slender columns along the 20 m high glass faade.

FORCE Technology was commissioned to undertake the wind-tunnel testing of the concert hall, focusing on the wind load on the towering glass façade and the slender columns surrounding it. A detailed study of the wind-induced vibrations of the structural elements was performed using model tests.

Due to the cultural importance and the congressional nature of the concert hall, the wind comfort felt by pedestrians around the building was highly important. In order to assess the wind comfort near the entrances on the access way near the building, wind speed at ground level was measured.

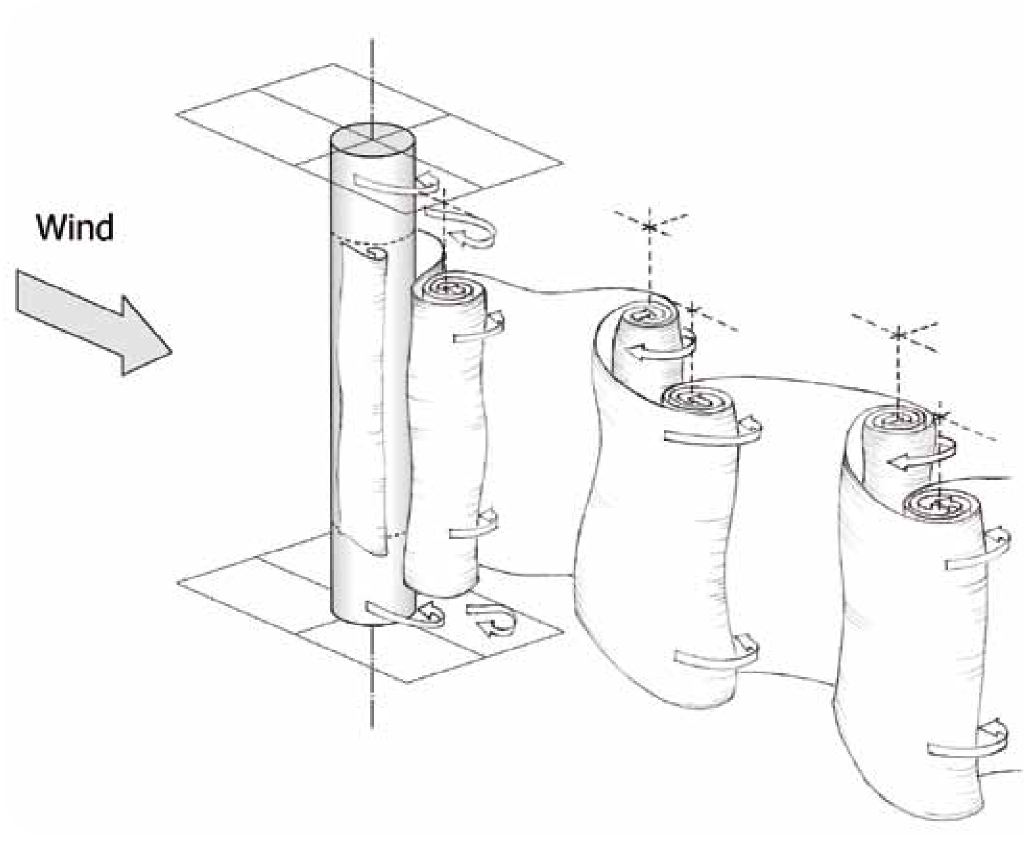
For the optimisation of the indoor climate, the lobby draught was examined. The measured wind pressures acting on doors and ventilation ducts were used to calculate the numerous draught scenarios and based on this, measures were taken to ensure an optimal indoor climate.

Engineering focus:
Column vibration

One of the main particulars of the architectural design is the vast number of columns surrounding the Salle de Concert along the façade perimeter. Predicting the aerodynamic effects and vortex-induced vibrations of circular cylindrical shapes is always a challenge. But when the arrangement of circular cylinders is in groups, the complexity of assessing the vibrational characteristics of the columns grows.

Based on FORCE Technology's flow measurements, the vibration of the columns was estimated through the application of theoretical models.
The results of the theoretical study, through application of the measured flow, were verified in cooperation with Gehl Jacoby & Associés by full-scale measurements on a mock-up of the column arrangement. The full-scale test results have been used for the structural design of the building.

By using the theoretical predictions and the experimental measurements, successful vibration reduction measures were developed and installed in all of the 823 columns. The high number of columns demanded an effective and cost-effective solution with long maintenance intervals.



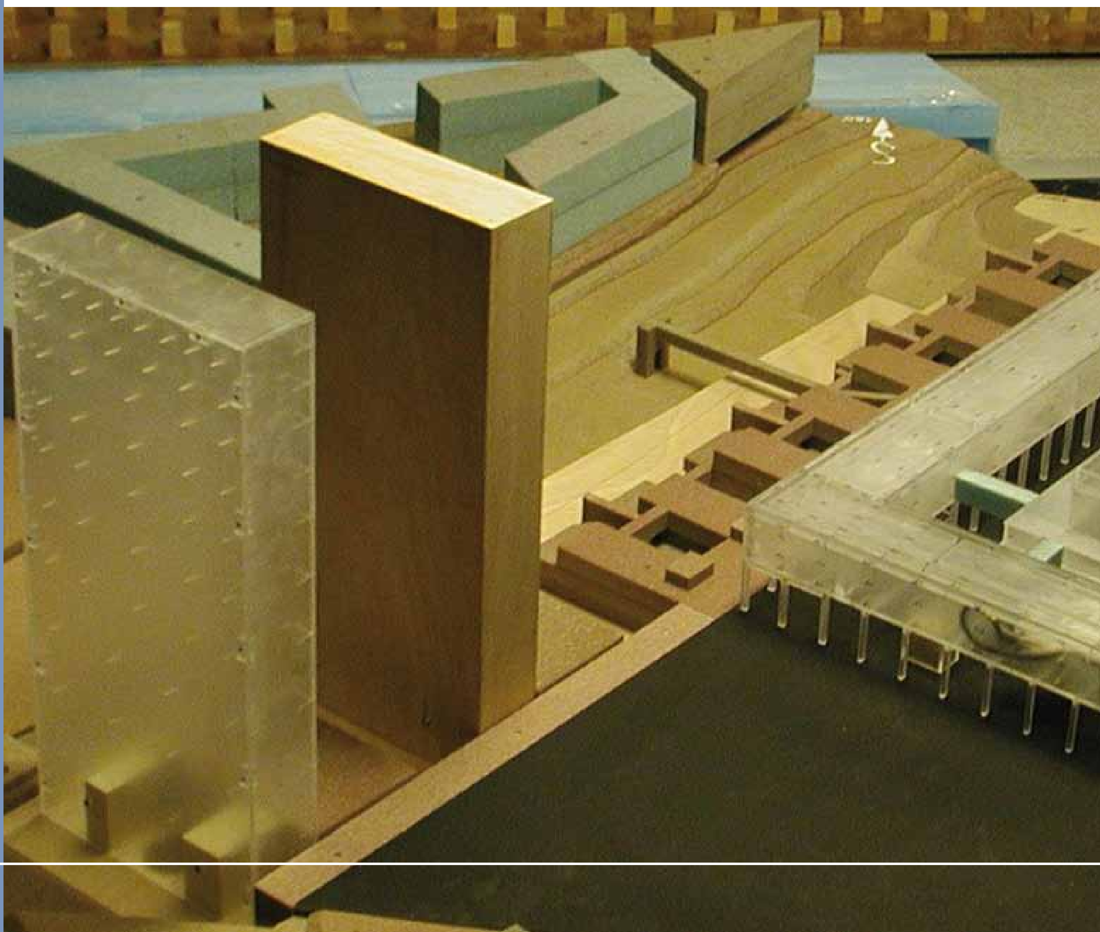
European Court of Justice, Luxembourg

Tower vibrations, unique landscape and local wind climate

As one of Europe's most important institutions, the European Court of Justice has to cope with an ever-growing level of activity. As a consequence, a new design and expansion of the institution, located on the Kirchberg Plateau in Luxembourg, was envisaged. Architects Dominique Perrault and engineers Gehl Jacoby & Associés have been responsible for the design of the buildings, while FORCE Technology was main provider of wind engineering and other specialist services.

For this building complex, the wind loading for facade design was determined. Furthermore, the wind field around the buildings was investigated as well as the level of pedestrian wind comfort and the dynamic structural response of the two 103 m high towers to wind load. It was particularly important to determine the tower occupancy comfort levels and their relation to tower accelerations. Measures to ensure the appropriate levels of occupancy comfort include the development and design of a unique Tuned Liquid Damper system.

For the wind-tunnel investigations, the local wind climate and the topography of the Kirchberg Plateau were carefully reproduced. Meteorological data measured at the nearby airport was used to adjust the wind-tunnel simulation considering the particularities of Luxembourg's unique landscape and wind climate.



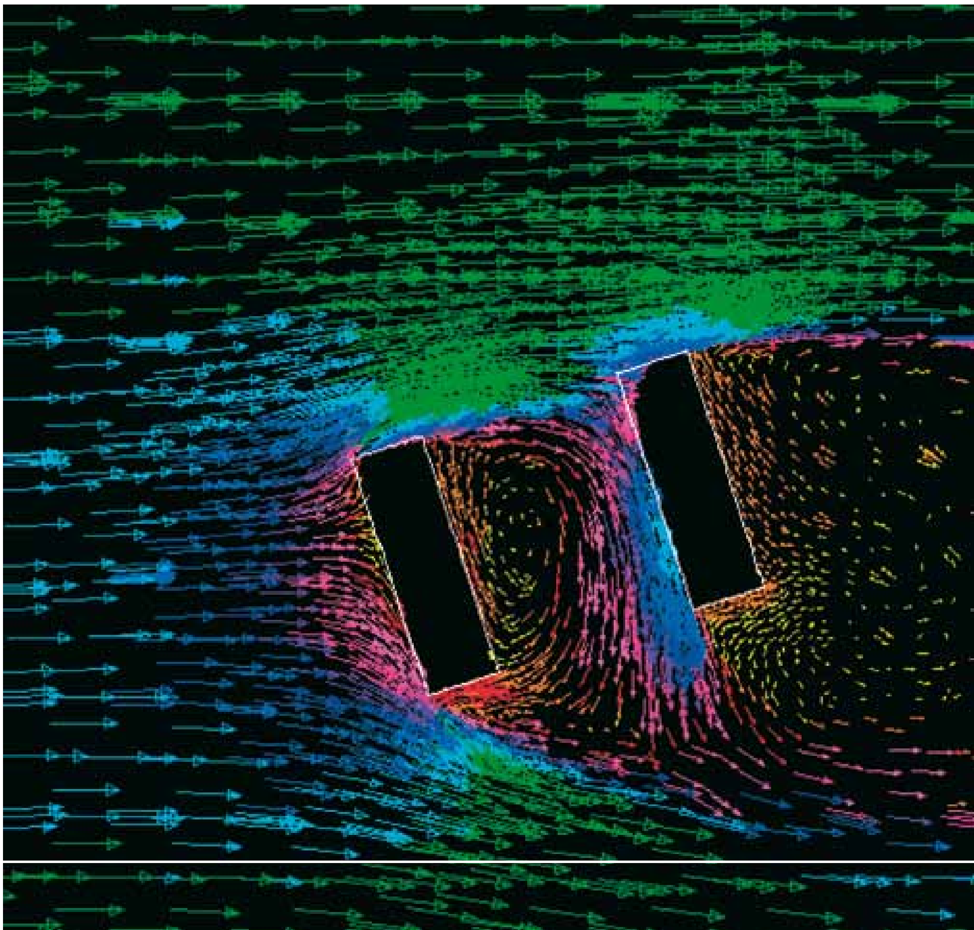
Engineering challenge: Structural vibration and control

The parallel arrangement of the two slender towers creates a unique interaction between the buildings in certain wind directions. Due to this, FORCE Technology found that accelerations in the towers were beyond acceptable levels. To identify the driving flow mechanism, additional numerical simulations of the airflow around the towers were performed using Computational Fluid Dynamics (CFD).

The established numerical model of the tower buildings combined with the measured wind load process was used to develop suitable remedial measures reducing the magnitude of structural vibrations. Through FORCE Technology's expertise, a cost-effective solution for the reduction of structural accelerations to acceptable levels was found in the form of a Tuned Liquid Damper system – located on the top floors of the towers.

Testing the concept

The theoretical design of the water tanks was verified by tests at reduced scale. A 1-D shaking table simulated the tower vibrations allowing for the evaluation of the effectiveness of the dampers. Once the towers are erected, the dampers will be tuned, tested and monitored to control and ensure the desired performance.



Multimedia Center and Copenhagen Concert Hall

Wind and architecture

South of Copenhagen, the Danish Broadcasting Corporation (DR) has built its new headquarters as part of a large city development project. The area will house several important institutions including parts of the University of Copenhagen and DR's new Multimedia Center and Concert Hall. Architects for the complex are Gotlieb Paludan, Nobel Architects, Ateliers Jean Nouvel and Dissing+Weitling.

The multimedia complex consists of four segments covering 130.000 m^2. Large glass façades, a central atrium and integrated gardens to regulate the indoor climate, give an open-spaced atmosphere. Furthermore, the Concert Hall is surrounded by a giant steel-frame that is covered by a special blue fabric to be used as a projection canvas.

Wind pressure and flow investigation

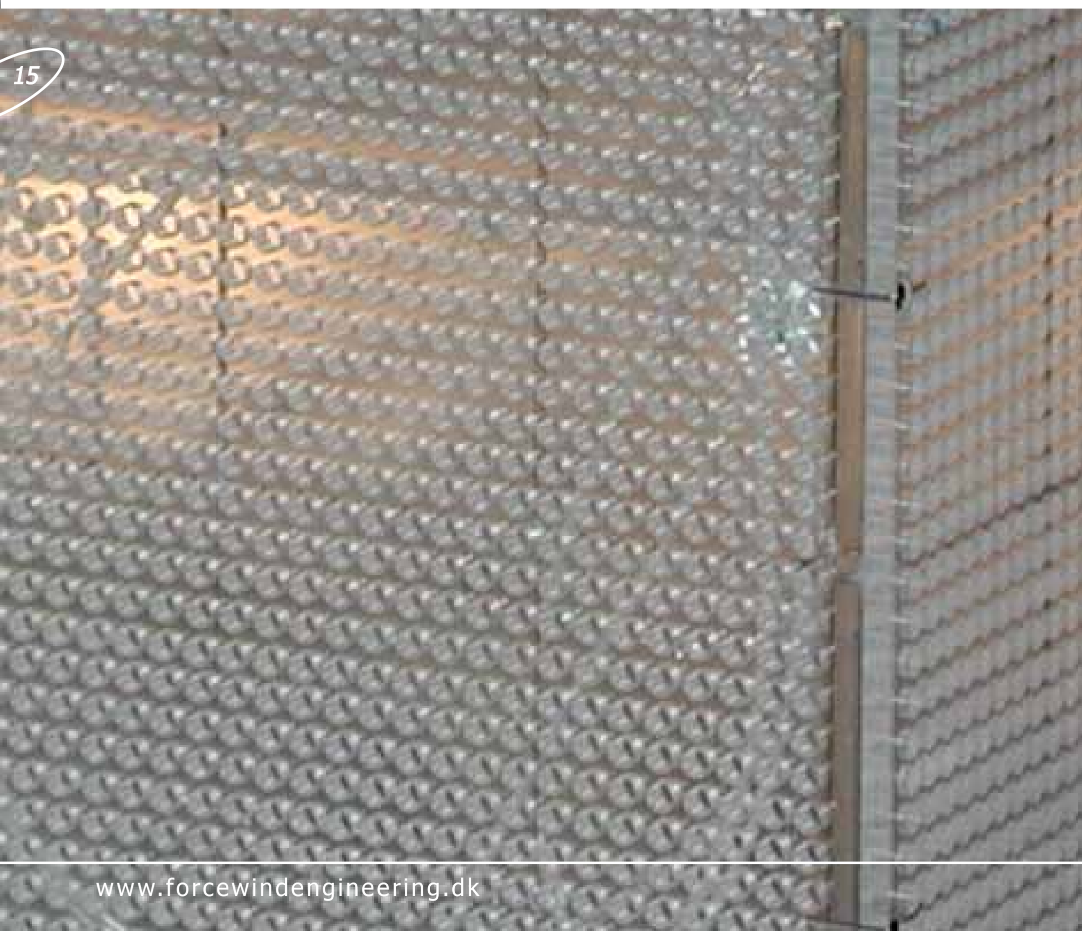
FORCE Technology assisted the designers through wind-tunnel experiments with comprehensive studies of the wind acting on and around the building. The wind field on top of the building was visualised in order to study possible adverse effects of the airflow on the sensitive antenna arrangements on the roof. The information on the flow around the building was also used for studies of the arrangement of ventilation openings and the calculation of zones of pedestrian comfort or discomfort. Wind pressures were measured with and without the simulated projection canvas and were determined even for the most complex parts of the structure which include an intricate arrangement of outer cladding shells on a futuristic "meteor like" Concert Hall roof surface.

Challenges in physical modeling

Apart from the measurements of the wind loads on the facades and roof and the evaluation of pedestrian wind comfort, the integrated wind load on the steel frame around "Segment One" was measured directly with a Force Balance System. To isolate the wind load on the steel frame, the filigree frame structure was modelled as a separate unit detached from the rest of the building. The elements of the steel frame were modeled to reflect the correct aerodynamic characteristics of the prototype.

Irregularly shaped flat plates resembling the jagged surface of a meteor form the outer surface of the Concert Hall roof. The arbitrary arrangement of the plates creates a ventilated second facade with openings of varying shapes and sizes. The difference between inner and outer pressure fields on the roof depends on the communicating system of these openings. The model design accounts for the unique arrangement of the Concert Hall roof.

A "box" of blue fabric, which forms one of the main architectural elements, surrounds the Concert Hall building. Since the permeable fabric is directly exposed to the wind, the prediction of the acting wind loads was undertaken assuming two different configurations: the buildings with and without the blue fabric. The model representation of the fabric was scaled according to the flow resistance through the covering. Pressure measurements on the model fabric surface in and outside the box were used to estimate the design wind load acting on the full-scale fabric.



COWI A/S
Engineering Consultants

"FORCE Technology helped us analyse the wind impact on the structures of the Concert Hall and also the landscape surrounding the entire DR city. Through the whole project, they were extremely well-prepared and shared all information about calculations and wind-tunnel studies with us".

Mr. Jan Bering Sørensen,
Project Manager

Marmormolen

Most often when FORCE Technology, Division for Maritime Industry, wins a contract, it only concerns one of the three departments within DMI. Therefore, the Marmormolen project was special as FORCE Technology was contracted with two assignments in relation to this development.

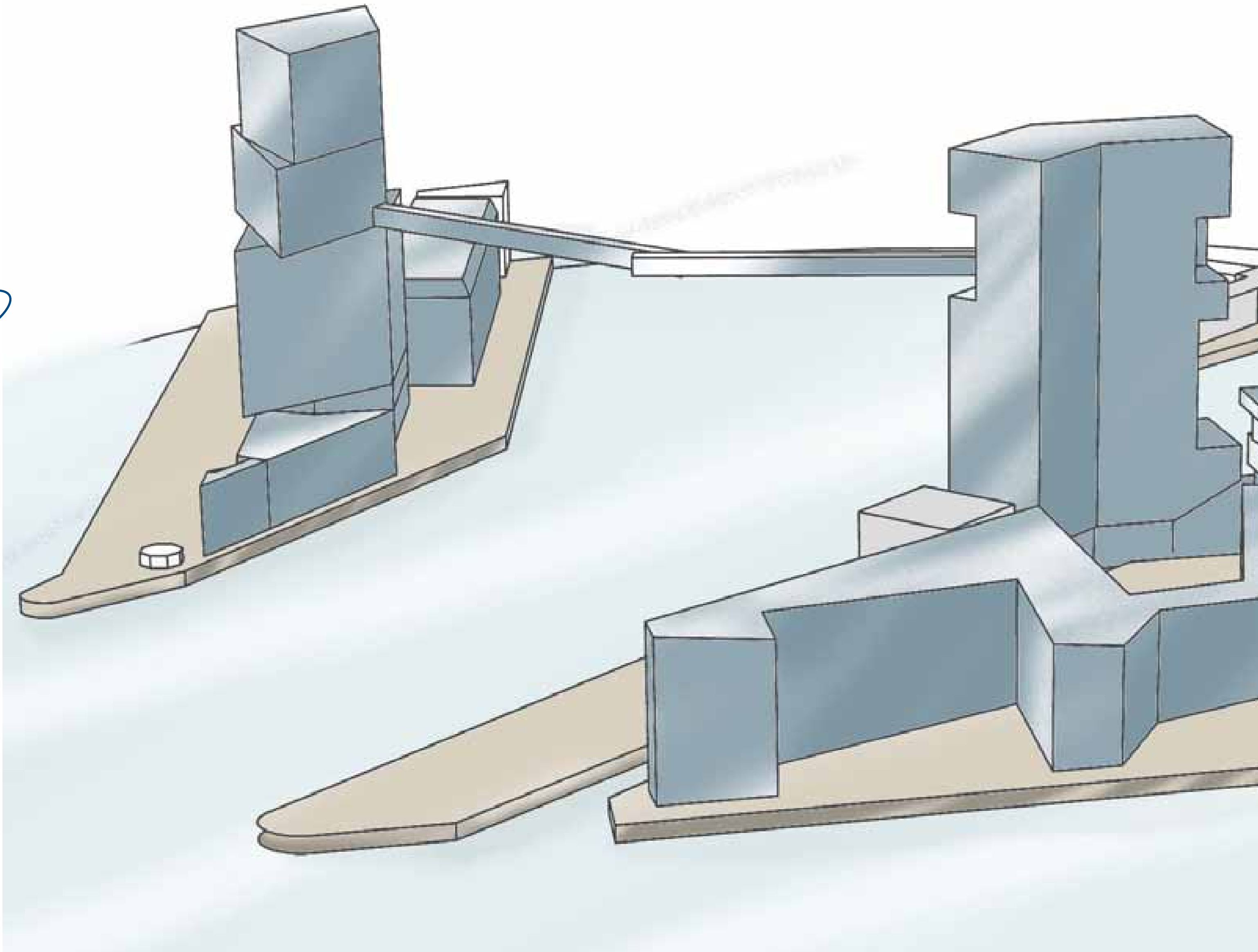
First, FORCE Technology was assigned to investigate the wind environment of the proposed layout of the two towers. This was done in the department for hydro- and aerodynamics using our large boundary-layer wind tunnel to determine how the wind will affect the pedestrian comfort in the access ways and the areas surrounding the two new high- rise buildings.

Silvia Geyer, project manager for the aerodynamic investigation, explains, "The investigations were performed with a model at a geometric scale of 1:250. The model was manufactured of high-density foam using drawings and pictures provided by the client, By & Havn. The investigations included erosion tests, flow visualisation tests and hot-wire measurements.

The advantage of combining these three methods is that you get a complete overview of the flow conditions in the area of interest. Thereby you obtain both a statistical evaluation of the wind comfort and a visual representation of the flow pattern around the buildings."

When the aerodynamic study was completed, our department for Ports, Training and Human Factors used the collected data to conduct a port study of how ships berthing in the harbour would be affected by the towers. The port study took place in our state-of-the-art 360° full-mission simulator where it was possible to evaluate the two towers' influence on the wind and the manoeuvring abilities at the ferry berths.

Niels Arndal, project manager for the port study, explains, "The main objective of the manoeuvring evaluation was to find the most suitable manoeuvring strategy for entering the ferry berths. This was important as the two towers would be placed at the critical area just before the small basin, and the towers would create some wind disturbance and wind lee in the area of operation."



The assessment of the wind comfort was based on wind statistics provided by Danish Metrological Institute's observation station at Copenhagen Airport.

What is Marmormolen:

Marmormolen is an area at the waterfront of Copenhagen opposite the Langelinie waterfront. The Marmormolen project involves the construction of a tower on each wharf connected by a pedestrian bridge on the 17th floor of the buildings – 65 metres above the water.

The towers will have 24 and 27 floors respectively and will be regarded as landmarks of the city, especially when coming from the sea.

Hannemannsparken, Copenhagen

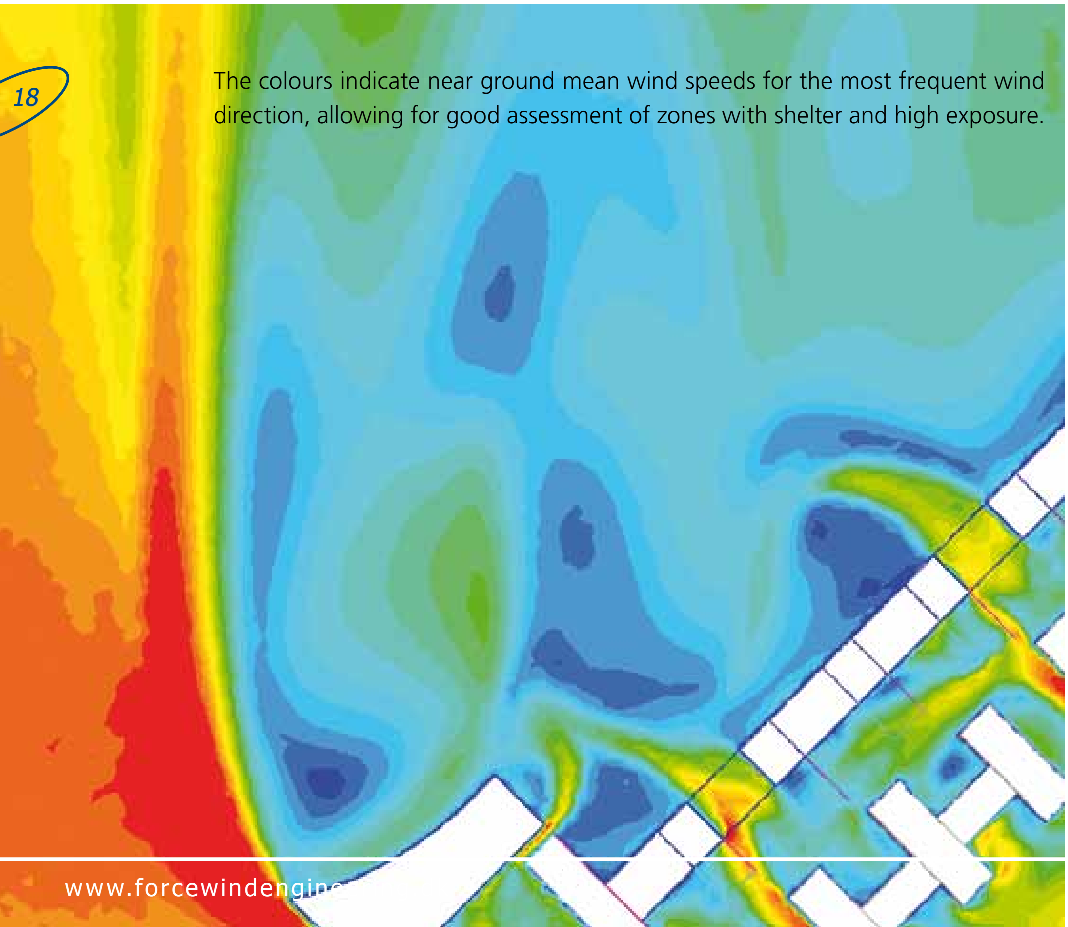
When building projects in urban areas are planned, questions regarding wind comfort are often raised at an early stage. Here, the use of Computational Fluid Dynamics (CFD) calculations can provide a good indication of the future wind field in the considered urban area.

One of the major benefits offered by CFD calculations is the possibility to obtain detailed information about the flow field as well as temperature and concentration fields within a large domain. The detailed information about the total flow, including pressure and velocity fields, provides a good basis for diagnostics and optimisation.

A good example of the use of CFD calculations in the early stages is seen at the Danish company White architects A/S, who use the results of FORCE Technology's CFD calculations in their quotations to document the wind effect on the proposed design.

Mette Boye, architect at White architects A/S, explains, "when giving tender, it is normally required to document the consequences on the surrounding environment. By using CFD results to determine airflow along buildings and wind speeds between buildings, we receive what we call "a qualified estimate" of future wind comfort which we use to determine the placement of the buildings. For us, using CFD calculations is an effective tool to provide knowledge and documentation in the design phase."

Using CFD is just one method to gain knowledge on air and wind flow – another is physical model tests. Depending on the specific case, physical model testing or CFD may be the most adequate method. In several cases, a combination of the two techniques will provide the client with the requested information in a fast and effective way.



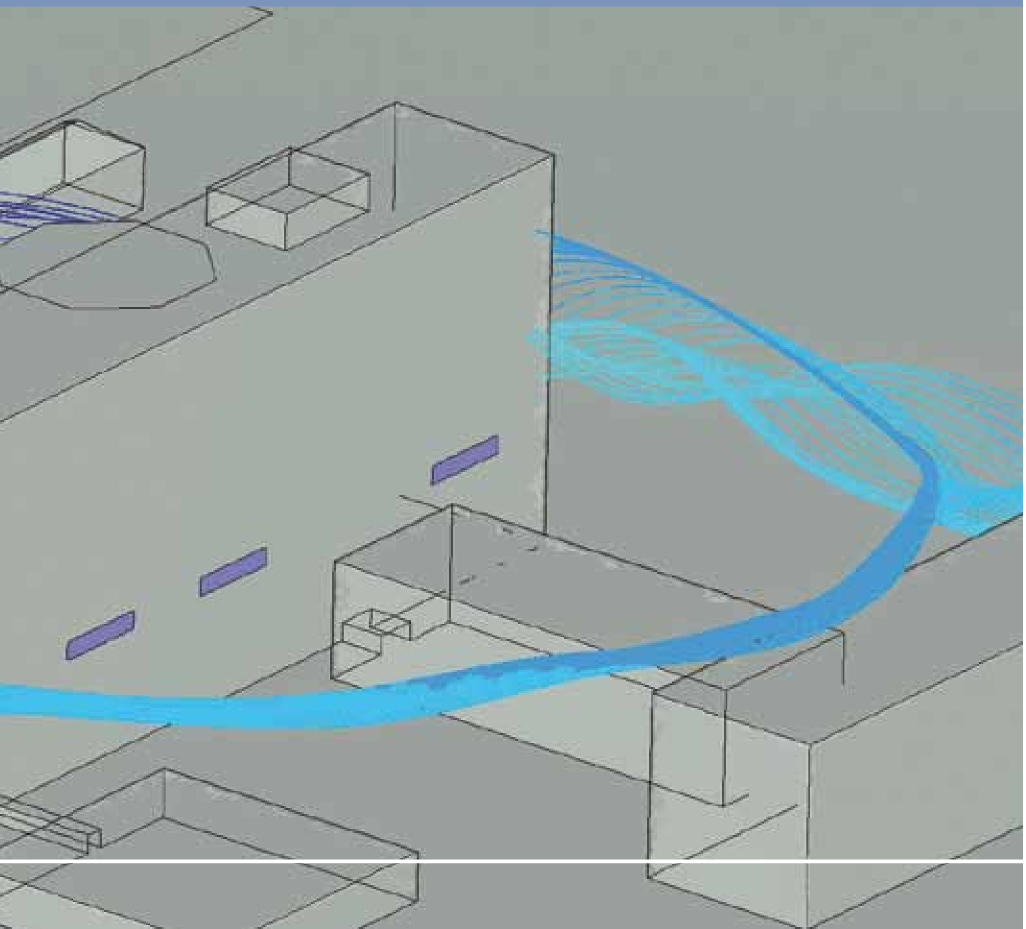
The colours indicate near ground mean wind speeds for the most frequent wind direction, allowing for good assessment of zones with shelter and high exposure.

Copenhagen University Hospital

To get as detailed and precise information about the smoke dispersal as possible, FORCE Technology constructed a 3D numerical model of the chimney, the hospital and the surroundings. The 3D numerical model was used in 9 CFD calculated scenarios with maximum exhaust from the chimney at different wind speeds and chimney heights. The numerical flow analysis was performed with the CFD program ANSYS FLUENT.

Thomas Ingvorsen, project manager at FORCE Technology, explains, "By performing CFD calculations in this kind of analysis, you get a detailed overview of how the smoke is dispersed after leaving the chimney. This is done in a cost-efficient way where it is shown how parameters such as wind speed, wind direction, the height and position of the chimney and the mixture of the exhaust gas affect the dispersal."

Besides being an efficient way of getting the needed information, the use of CFD calculations is an uncomplicated process for the customer as they only have to provide the most basic data. Mogens Thrane says, "for us it was very simple, we provided the CAD data of our buildings together with the exhaust data of the chimney. FORCE Technology then took care of the modelling and the CFD calculations. When they had done the calculations, they presented the results to us and we could start the construction of the chimney."



CFD and wind-tunnel testing

Wind plays an important role in the dispersal of pollutants and smoke from chimneys, smoke stacks, building exhaust outlets and automobile exhaust systems. The absence of wind, while pleasant for the pedestrian, creates stagnant and potentially dangerous areas by concentrating harmful gases.

On the other hand, certain flow conditions can result in the pollutants re-circulating into air intakes, deteriorating the internal air quality. Visualisation in the wind tunnel or numerical calculations for a range of wind directions and speeds and for various configurations of the outlet can help identify potential problems such as possible smoke recirculation. Once these areas are identified, measurements of actual concentrations of tracer gases using a hydro-carbon analyzer or numerical methods can be made.

A major advantage of applying CFD for this pollutant dispersal investigation was that detailed and precise information about the pollutant concentration was achieved in every part of the surroundings investigated. In this way, not only knowledge about the regions in focus, i.e. the intakes, was obtained, but it was also possible to identify and eliminate other potentially hazardous areas. Furthermore, the detailed information obtained about the flow field around the buildings provided a solid basis for evaluation of proposed design changes.

As the methods CFD and wind tunnel studies are rather supplementary in nature, the choice of method – CFD or wind tunnel investigation – depends on the specific problem and the outcome requested by the client. Consequently, the method is selected in close cooperation with the client.

Facilities overview

1 **Full-mission simulator, 360°**
Equipped with full size bridge consoles for control and monitoring. Real NACOS Radar, Conning and Ecdis system. Full HD visual system

2 **Full-mission simulator, 210°**
Equipped with full size bridge consoles for control and monitoring. Real NACOS Radar, Conning and Ecdis system. Full HD visual system

3 **Full-mission simulator, 210°**
Equipped with full size bridge consoles for control and monitoring. Real NACOS Radar, Conning and Ecdis system. Full HD visual system

4 **Part task simulator, 130°**
Full HD projection theatre. Real size bridge consoles. Single NACOS Radar system. Ideal for engineering studies

5 **Tug cubicles, 2 pcs**
Mini Tug bridges. Mostly used in conjunction with multi bridge setups, dealing with tug operations

6 **Full-mission tug simulator, 360°**
Control and monitoring from a real life tug boat. 2 X Full HD visual system with 52" LCD screens. Perfect for tug operations

7 **Closed circuit wind tunnel (WT1)**
Dimensions: Test section length x width x height: 2.60 x 1.00 x 0.70m
Max Flow Velocity: 70m/s.

8 **Boundary-layer wind tunnel (WT2)**
Dimensions: Test section length x width x height: 20.40 x 2.60 x 1.80 - 2.30m
Max Flow Velocity: 24m/s

9a **Wide boundary-layer wind tunnel (WT3)**
Dimensions: Test section length x width x height: 15.50 x 13.60 x 1.70m
Max Flow Velocity: 7.3 m/s

9b **Wide boundary-layer wind tunnel (WT4)**
Dimensions: Test section length x width x height: 9.00 x 7.50 x 1.70m
Max Flow Velocity: 12.0 m/s

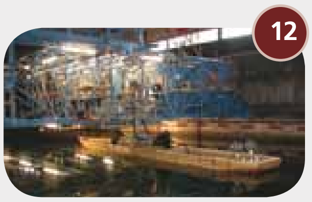
10 **Climatic wind tunnel (WT5)**
Dimensions: Test section length x width x height: 5.00 x 2.00 x 2.00m
Max Flow Velocity: 25.0 m/s. Temperature down to -5 degrees Celsius at maximum flow velocity

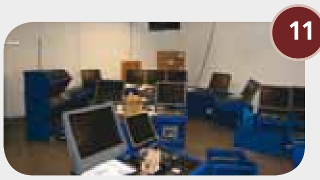
11 **Simulator assembly hall**

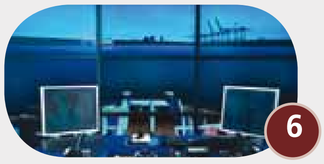
12 **Deep water towing tank**
Length x breadth x water depth: 240 x 12 x 5.5m.
Speed: From 0 to 14m/s, Accuracy: ± 0.2% of actual value
Maximum wave height: 0.9 m

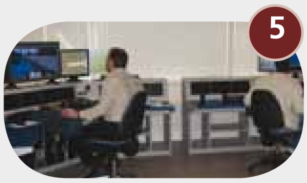
13 **Shallow water towing tank**
Length x breadth x water depth: 25 x 8 x 0 to 0.8m.
Speed: From 0 to 2 m/s, Accuracy: ± 0.2% of actual value

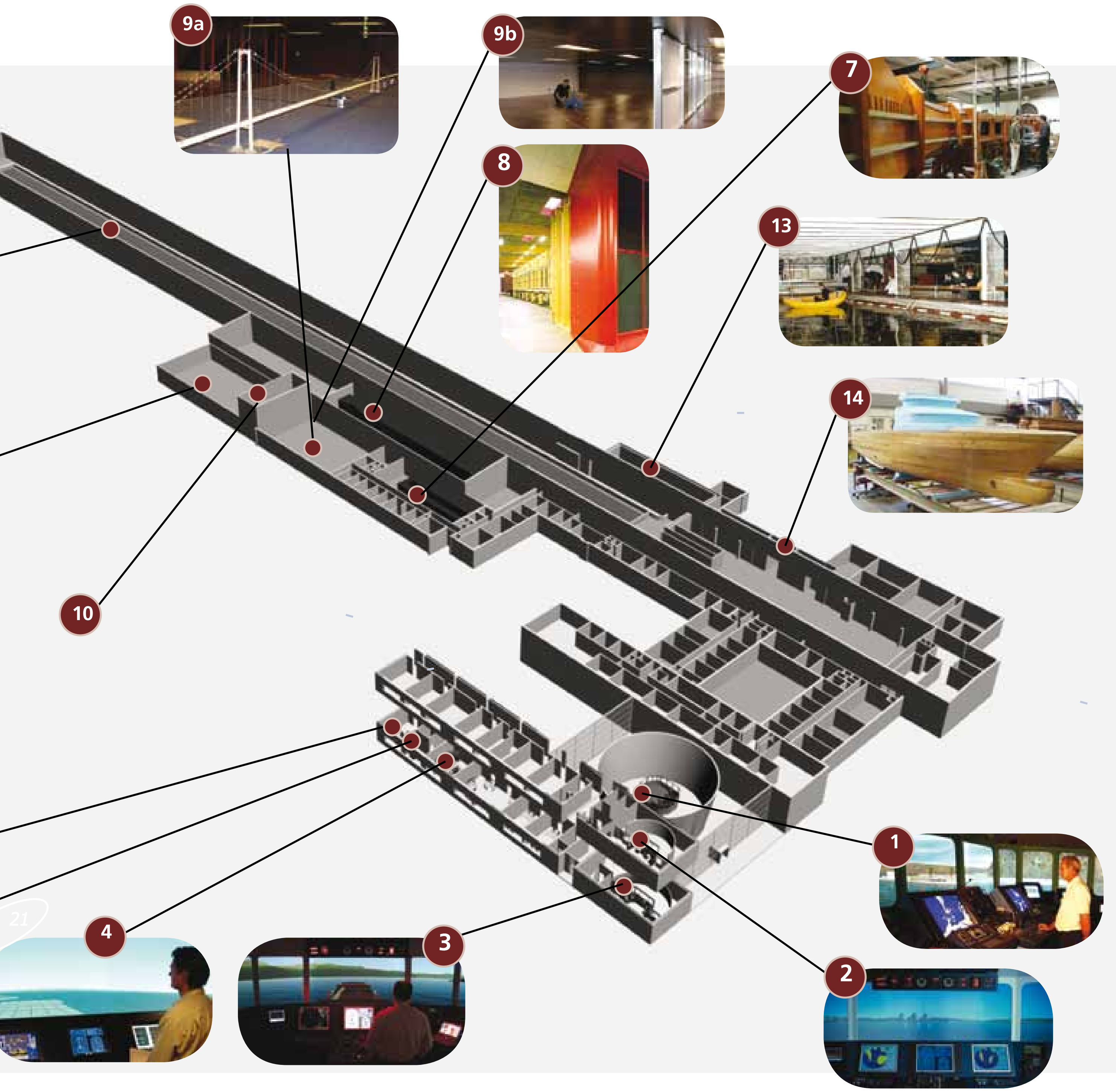
14 **Workshop**
Workshpfor construction of all types of models for towing tank and wind tunnel tests











Combining knowledge with technical supremacy

The strength of FORCE Technology is the unique combination of top-class know-how and facilities within hydro- and aerodynamics and state-of-the-art simulator and training facilities.

In our two towing tanks and five wind tunnels, we are testing and measuring everything related to ships and ports. The knowledge we gain from these facilities are used in our seven full-mission and part-task training simulators, where we simulate conditions and train captains, masters, navigators and pilots.

By choosing FORCE Technology you get market-leading knowledge from three different but equally important areas.

Wind tunnel facilities

Closed Circuit Wind Tunnel (WT1)

The Closed Circuit Wind Tunnel (WT1) is mainly used to perform aerodynamic evaluations in uniform flow. By installing special grids upstream of the working section, varying turbulence intensities can be created in the initially laminar flow. The high flow velocity of up to 70m/s enables the investigation of a variety of fluid dynamical problems at high Reynolds numbers. Small-scale models, section models or details, e.g. buildings and ships, are tested to identify forces, surface pressures or to observe the flow field around the respective body.

The working section is completely interchangeable and a number of different types are available.

Tunnel specifications:

Length:	2.60m
Width:	1.00m
Height:	0.70m
Max Flow Velocity:	70m/s

Boundary-Layer Wind Tunnel (WT2)

The Boundary-Layer Wind Tunnel (WT2) is designed for investigations of wind effects on building structures and the environment.

Its field of application spans a wide range of tasks from e.g. wind conditions in complex terrains to pressure measurements on engineered onshore and offshore structures. Model scales are typically between 1:100 and 1:500, but can be larger or smaller depending on the application.

The adjustable height of the ceiling makes it possible to investigate larger models which may cause undesirable blockage of the simulated wind. The tunnel has a variety of state-of-the-art instruments and rigs which include a Dynamic Section Model Rig, High Reynolds Number Section Model Rig, 1-DOF Forced Motion Rig and a 6-DOF Dynamic Force Balance.

Tunnel specifications:

Length:	20.40m
Width:	2.60m
Height (adjustable):	1.80 - 2.30m
Max Flow Velocity:	24m/s

Climatic Wind Tunnel (WT5)

FORCE Technology's newest wind tunnel (WT5) is a facility in which aerodynamic tests can be conducted under a number of climatic conditions including rain and ice. The climatic wind tunnel is a closed circuit wind tunnel with water nozzle system for simulation of rain and a cooling system for testing at subzero temperatures.

The aerodynamic behaviour of certain objects can drastically change if the object's surface becomes ice-covered. Also so-called water rivulets can be formed. Both these issues are of importance in cable-supported structures. The 4.00m long test section allows testing of inclined objects, e.g., hangers or stay cables for cable supported bridges.

Tunnel specifications:

Length:	5.00m
Width:	2.00m
Height:	2.00m
Max Flow Velocity:	25m/s

Testing in rain
Testing at temperatures down to -5°C
Creation of ice (e.g., cables)

Wide Boundary-Layer Wind Tunnel (WT3)

FORCE Technology’s 13.6m Wide Boundary-Layer Wind-Tunnel (WT3) has been built for aeroelastic and environmental model testing, e.g. large-scale landscapes and long suspension and cable-stayed bridges. The experimentally acquired data is applied for bridge design, optimisation of wind farm layouts and has also been used for aviation purposes.

Tunnel specifications:

Length:	15.50m
Width:	13.60m
Height:	1.70m
Max Flow Velocity:	7.30m/s

Truncated Wide Boundary-layer Wind Tunnel (WT4)

FORCE Technology's 7.5m wide boundary-layer wind tunnel (WT4) is designed to perform model tests of long suspension and cable-stayed bridges. Moreover, the wind tunnel is used for testing landscapes, bridge layouts, airports, building projects etc. The wind tunnel is established by implementing a contraction in WT3 thus obtaining higher wind speeds.

Tunnel specifications:

Length:	9.00m
Width:	7.50m
Height:	1.70m
Max Flow Velocity:	12m/s

Daewoo Shipbuilding & Marine Engineering Co. Ltd.

"We chose to work with FORCE Technology because we know their capabilities from previous collaboration and know that they deliver reliable results within the marine field. Also their wind tunnels and related equipment are extremely suited to perform yard typhoon studies".

Mr. Hyeok Lee,
Research Engineer

Cover photo by
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