WHITE PAPER

WHAT IS PEDESTRIAN WIND COMFORT (PWC)?

This paper addresses the topic of pedestrian wind comfort, from origin and definition to wind comfort analysis, criteria, and example case studies; all meant to form an in-depth understanding of the field.

SIMSCALE

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Origins of Pedestrian Wind Comfort

The year was 1902 and the world had just stepped through the threshold into the new millennium. New York was starting to test the boundaries of civil engineering with its skyscrapers—the innovative buildings that would dramatically alter the face of the city to what we know it to be today.

Technically, New York’s first skyscraper was The Tower Building in 1889; this status was not given so much for its height—of 11 stories—but for being the first building in the city to have a steel skeleton. Unfortunately we can now only see it in old pictures, as it was demolished in 1913. But our story starts with 1902, the year the next iconic skyscraper—which is still standing tall despite adversities of all kinds—was opened: the unmistakable Flatiron Building.

Origins of Pedestrian Wind Comfort

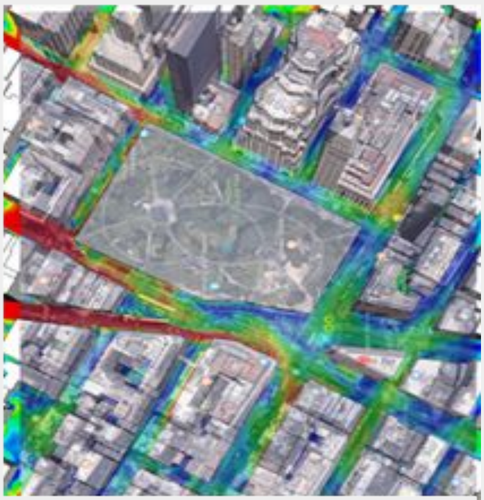
Located on 23rd Street at the intersection of Fifth Avenue and Broadway, the Flatiron Building had to withstand great social opprobrium, despite the commonly accepted idea that its engineering cleverness was outstanding. The Municipal Art Society declared it "unfit to be in the Center of the City," The New York Tribune described it as "A stingy piece of pie… the greatest inanimate troublemaker in New York," and The New York Times said it was a "monstrosity."

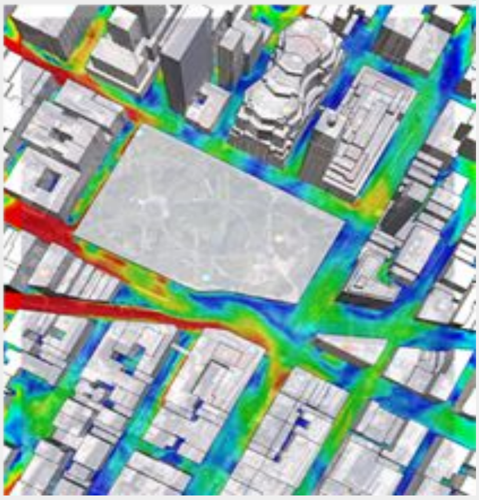
But the criticism didn't stop at aesthetics. When the building proved to cause such strong wind gusts that they would lift the skirts of women passing by, its bad reputation only grew stronger, this time with a touch of humor to it. **"One vast horror, facing Madison Square, is distinctly responsible for a new form of hurricane, which meets unsuspecting pedestrians as they reach the corner, causing them extreme discomfort. I suppose the wind is in some way intercepted by the towering height of the building, and forced down with fury into an unaccustomed channel. When its effects first became noticeable, a little rude crowd of loafers [...] used to congregate upon the curb to jeer at and gloat over the distress of ladies whose skirts were blown into their eyes as they rounded the treacherous corner. Hanging about this particular spot soon became a recognised and punishable offence [...]. A lawsuit is also at this moment pending against the owner of this building, brought by a neighbouring tradesman whose shop-window has twice been blown in by the newly created whirlwind.**" – Sir Phillip Burne-Jones, 1904

Origins of Pedestrian Wind Comfort

New Yorkers even placed bets on how far the debris would fly when the wind knocked it down. This was referred to as "Burnham's Folly," named after the building's architect, Daniel Burnham. Thanks to the steel bracing designed by engineer Corydon Purdy, however, the Flatiron building was here to stay, being able to withstand four times the typical wind loads in the area. While the building itself is safe, sometimes, when the wind blows from the North, not the same can be said about pedestrians. Due to its shape, as it can be seen in the simulation below, wind currents from the leading edge of the building move up and down in a vortex pattern.

Nowadays, a landmark quite loved by New Yorkers, the Flatiron Building stands proof of how important pedestrian wind comfort studies are in civil engineering. And fortunately, it is a new millennium, with plenty of technologies to help ensure it. (*Find sources here*)





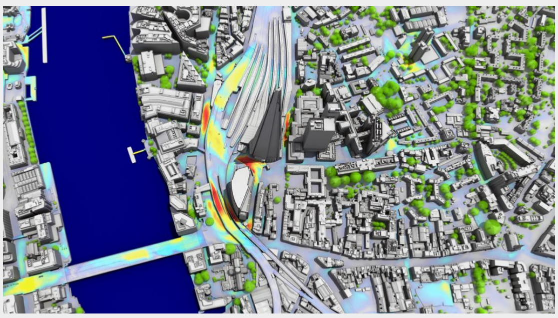
Origins of Pedestrian Wind Comfort

The 20 Fenchurch Street skyscraper in London, known as the 'Walkie Talkie' building, has also joined the ranks of infamous buildings to date. The tower has been accused of creating a wind tunnel with extreme gusts and posing a serious danger.

Using SimScale, we ran a CFD simulation online to investigate how significant were the wind effects. These simulation results showed higher wind velocities around the corners of some of the buildings. This phenomenon is called the 'cornering effect' and can have an even stronger impact when two opposite buildings are subject to it and the street is parallel to the wind direction. In fact, the simulation predicted this effect on the neighboring narrow streets.

In 2011 in Leeds, a northern UK city, accelerated wind speeds caused by the 110m-tall Bridgewater Place office and apartment building caused a truck to roll over, killing a pedestrian [3]. This tragedy, along with 25 incidents [4] prompted the reconsideration of construction standards across Great Britain.

These buildings are famous cases of dramatic changes occurring within urban microclimates caused by construction. Since then, laws and regulations have been passed, with many urban authorities requiring pedestrian wind comfort analysis results for granting building authorizations. Despite the progress made, the industry still has a long way ahead as PWC is a relatively new consideration.

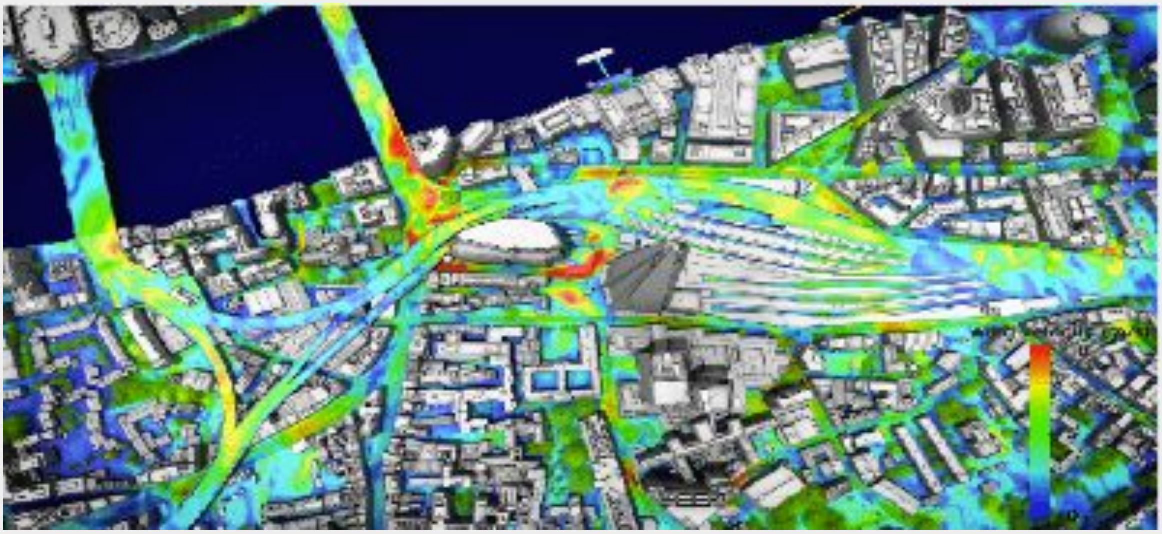


What is Pedestrian Wind Comfort (PWC)?

Pedestrian wind comfort is the branch of wind engineering dedicated to studying wind effects of the comfort and safety of pedestrians and cyclists—what causes them, how they develop, and how the urban environment can be designed to control them.

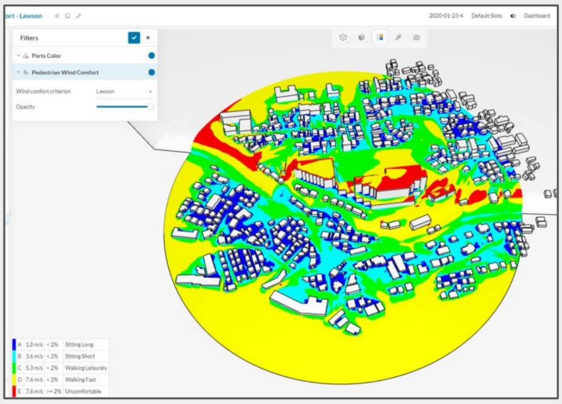
Urban microclimates affect more than the hustle and bustle of busy high streets. They can dictate everything from building energy performance and the implementation of renewable energy technologies to necessary safety precautions. To fully understand the concept, however, we need to dive a little deeper.

The construction of any building inevitably changes the microclimate in its vicinity; the changes become dramatic when it comes to skyscrapers. In these cases, the wind pushes against the surface of the skyscraper creating vortices and vortex shedding, which can cause the building to shake and vibrate, as well as causing discomfort for pedestrians. In engineering, the aim of any skyscraper design is not to make a smooth shape, but one that can break up the wind and prevent these vortices. For this, solutions include rounded or notched facade corners, open slots to let wind pass, planting trees, and more.



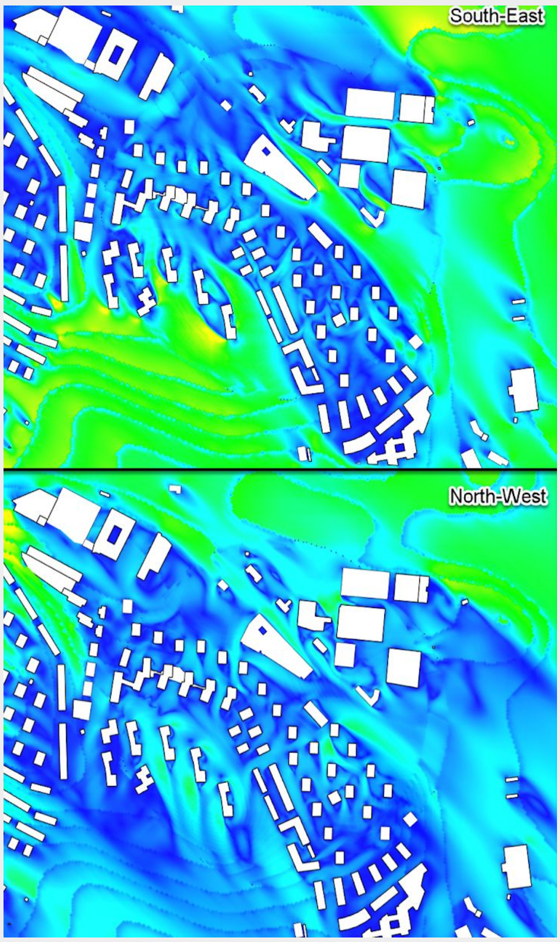
What are PWC Studies?

Pedestrian wind comfort studies take into consideration meteorological data, aerodynamics, and comfort criteria. The data regarding the latter two is provided by wind tunnel testing (physical experiments) and numerical simulation with computational fluid dynamics (CFD) software.



Simulation can digitally model the airflow over and around a building or urban area and is a faster and less costly approach than physical experiments, but it is not meant to exclude them. Both techniques are used together in a construction project in order to ensure all required data is provided and adequate testing ensured.

By assessing pedestrian wind comfort with CFD, urban master planners, civil engineers, and architects can predict the behavior of wind flow around buildings early, and benefit from an iterative design process. Wind speeds and other parameters can be calculated at pedestrian levels, and comfort can be evaluated based on given criteria.



Wind Comfort Criteria

As urbanization increases, more and more people live in and frequent city centers. This, in turn, creates a problem with how to create more space, becoming a housing issue. Many developers across the globe have begun opting for high-rise buildings. Examples of this can be seen in major cities across Europe such as the Stockholm Royal Seaport project in Sweden, as well as in America and across Asia.

Wind nuisance, or unfavorable wind conditions, are an important factor to consider for both zoning and construction plans, as these new high-rise buildings can create higher wind speeds at the pedestrian level. Yet, as high wind velocities are innately unpleasant, how does one determine the exact point at which it becomes bothersome? As people differ in height and wind tolerance, this turns into a taxing responsibility. Therefore, it is imperative to assess its impact on pedestrians, something broadly referred to as 'pedestrian wind comfort.'

Wind Comfort Criteria

There are many criteria and standards existing today to help assess the expected wind climate in the design stage, by providing parameters of what should be achieved to stay within favorable conditions. SimScale covers Lawson, Davenport, and NEN 8100 wind criteria.

These criteria address a wide range of activities, including "sitting/standing long," "sitting short," and "strolling." All three criteria consist of a threshold value of the wind speed and a maximum allowable exceedance probability of this threshold value.

Wind Comfort Criteria

Lawson Criteria

Lawson's criteria, named after the researcher T.V. Lawson and published in 1978, are a series of comfort criteria categories that quantify the worst wind conditions that most passersby will consider acceptable. Levels of pedestrian comfort strongly depend on individual activity. Therefore, the Lawson comfort criteria are defined for each activity in terms of a threshold wind speed which should not be exceeded for a given time throughout the year.

Pedestrian comfort criteria are assessed at 1.5m above ground level. In general, velocities at pedestrian level increase as you go higher from the ground. An assessment at 1.5m will usually be more onerous than one at 0.5m (wind velocity is always zero where it meets the ground). Lawson assumes that wind speeds exceed its average velocity of less than 5% of the time considered.

A	4 m/s	< 5%	Sitting
B	6 m/s	< 5%	Standing
C	8 m/s	< 5%	Strolling
D	10 m/s	< 5%	Business Walking
E	10 m/s	> 5%	Uncomfortable
S	15 m/s	> 0.023%	Unsafe frail
S	20 m/s	> 0.023%	Unsafe all

Lawson (2001) comfort criteria

The first group (pictured above) of comfort criteria groups wind speeds according to activities that an individual might conduct under those conditions. Someone sitting at a cafe will become uncomfortable at much lower wind speeds than someone walking briskly.

A	2.5 m/s	< 5%	Frequent Sitting
B	4 m/s	< 5%	Occasional Sitting
C	6 m/s	< 5%	Standing
D	8 m/s	< 5%	Walking
E	8 m/s	> 5%	Uncomfortable
S	15 m/s	> 0.022%	Unsafe

Lawson LDDC comfort criteria

Wind Comfort Criteria

The most famous of Lawson's criteria is the LDDC (London Docklands Development Corporation) method, which specifies a limit of 0.025%, using wind speeds of 20m/s for "General Public," and 15m/s for "Frail Person Or Cyclist."

Davenport Criteria

Davenport 's comfort criteria are the oldest of the group, as it was published in 1975, making it the first of its kind in pedestrian wind comfort standards. The standard applies a maximum exceedance probability of "one/week" for tolerability of wind climate for certain activities. The associated exceedance probability is said to be 1.5%, yet it is slightly unclear how this value was obtained. One hour a week would be 0.6% (1/168×100%), a value also used by Lawson when comparing his comfort criteria with Davenport's.

The Davenport criterion also uses the Beaufort scale like the wind speed threshold. However, the Beaufort scale contains an interval of values for wind speed. As a result, the exact value of the wind speed threshold is not clear.

A	3.6 m/s	< 1.5%	Sitting Long
B	5.3 m/s	< 1.5%	Sitting Short
C	7.6 m/s	< 1.5%	Walking Leisurely
D	9.8 m/s	< 1.5%	Walking Fast
E	9.8 m/s	>= 1.5%	Uncomfortable
S	15.1 m/s	>= 0.01%	Dangerous

Davenport comfort criteria

The Davenport criterion is essentially divided into specific activities and evaluates how comfortable it is to practice that activity at a certain location. The longer the average wind speeds exceed this limit, the more uncomfortable the activity is assumed to be.

NEN 8100 Criteria

The most recent of these standards is the Dutch wind nuisance standard (NEN 8100), and it applies a

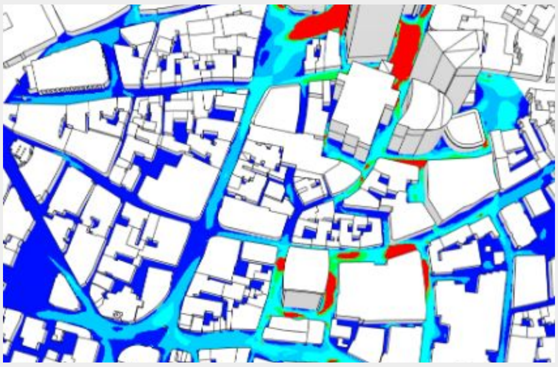
Wind Comfort Criteria

discomfort threshold for the hourly mean wind speed of 5 m/s for all types of activities. Depending on the exceedance probability of the threshold wind speed, the code defines five quality classes of wind comfort A–E (Table 1). This standard also advises on dangers caused by wind.

Results using Lawson (2001) comfort criteria

A	5 m/s	< 2.5%	Sitting Long
B	5 m/s	< 5%	Sitting Short
C	5 m/s	< 10%	Walking Leisurely
D	5 m/s	< 20%	Walking Fast
E	5 m/s	>= 20%	Uncomfortable

NEN 8100 comfort criteria



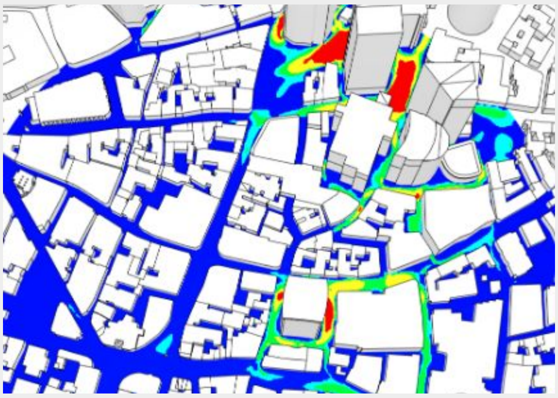
Results using Davenport comfort criteria

A	15 m/s	< 0.05%	No Risk
B	15 m/s	< 0.30%	Limited Risk
C	15 m/s	>= 0.30%	Dangerous

NEN 8100 safety criteria

Wind Comfort Criteria Examples

The following images show wind comfort simulation results around the 20 Fenchurch Street building.



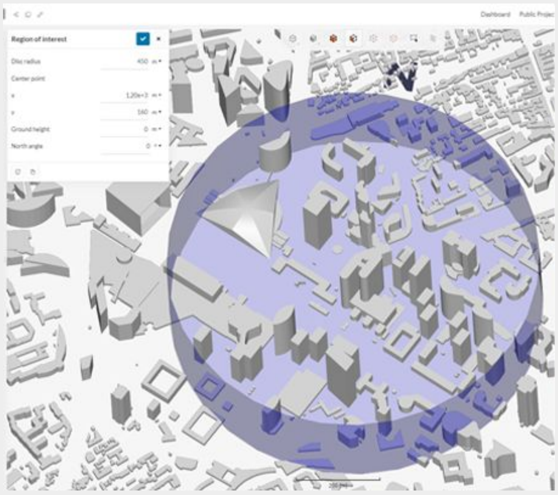
Results using NEN 8100 comfort criteria

Case Study: The District "La Défense" in Paris, France

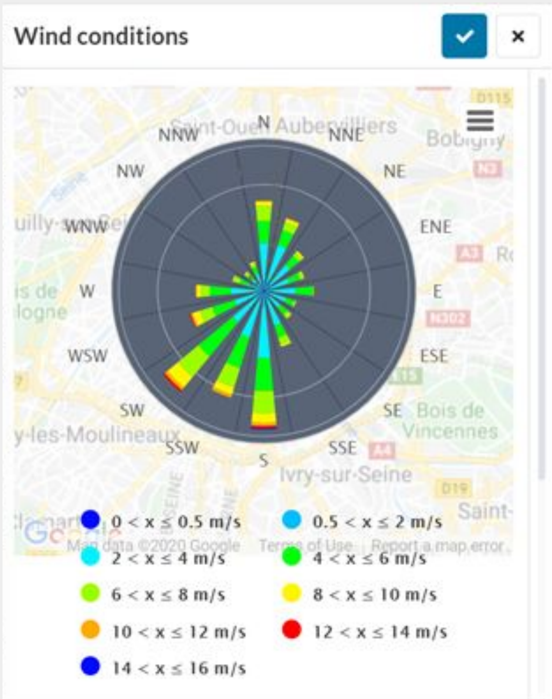
We will use the district of La Défense, in Paris, to assess the surrounding PWC. La Défense's layout is characterized by tall buildings that are very close in proximity, creating interesting flow phenomena. The goals of our simulation are to identify areas that are uncomfortable for designated activities, investigate the causes for uncomfortable zones, and discuss ways of relieving undesirable wind effects as well as ultimately making the environment safer.

Simulation Setup

At SimScale, our priority is making accurate analyses accessible to people worldwide, in an easy-to-use platform. The setup consists of (1) defining the region of interest, (2) defining wind rose, and (3) defining the pedestrian zones.



Setting up the wind comfort simulation using SimScale



Case Study: The District “La Défense” in Paris, France

Simulation Results

With the results from the simulation, it is possible to see the wind effects over this region of Paris. The areas in yellow represent the narrow passages between tall buildings that can become uncomfortable for pedestrians. This happens especially where these passages are aligned with the dominant wind directions, as shown on the meteorological data we’ve imported: South, South-South West, and South West.

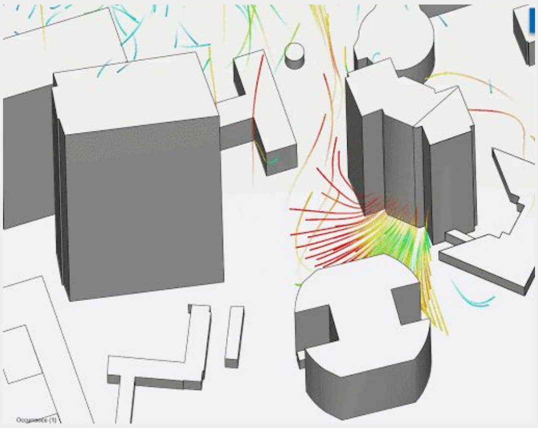
Wind directions are computed at once, so that regular wind patterns are accounted for. This allows users to run 36 wind directions at the same time, and the results will be shown for the pedestrian region. For this project, we see South, South-South West, and South West as the predominant wind directions. As the wind enters the region, it accelerates its way through the buildings, creating strong winds by the time it reaches the center.

Generated Wind Effects

There are three main wind effects created by buildings: downwashing, channeling, and corner acceleration. We will use our case to illustrate each one of them.

Downwashing

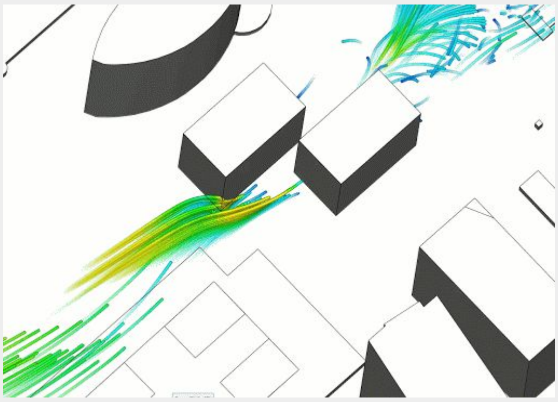
This effect happens when a tall building is surrounded by lower buildings. The tall building captures the wind at higher levels and redirects it towards the ground, causing downward air velocity. This effect often creates a large recirculation at the ground level, causing greater wind. With our case, we can see the airflow traveling downwards, and then increasing the wind velocity at lower levels.



Case Study: The District "La Défense" in Paris, France

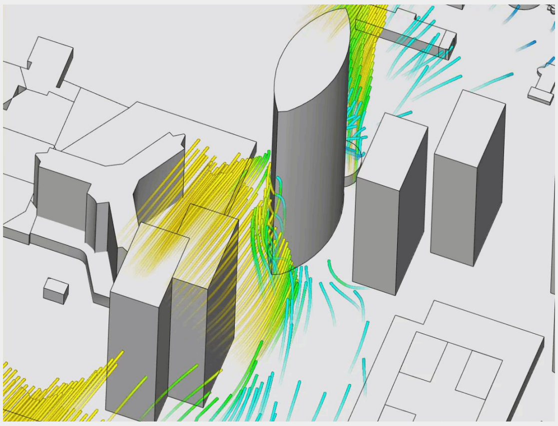
Channeling

Channeling (also known as Venturi) effect happens when buildings are located in close proximity to one another. The effect is perpetuated by a reduction of wind pressure, resulting in wind acceleration through the tight channel created between the buildings. This effect can create high winds that can even be unsafe for pedestrians. In our model, we can see this effect in action, as narrow passages increase wind velocity.



Corner Acceleration

Corner acceleration happens when the wind reaches the vertical edge of a tall building. This effect is mainly created from sharp building shapes, causing acceleration around the corners. In our example, the winds coming from the South West generate high corner acceleration as we can see below.

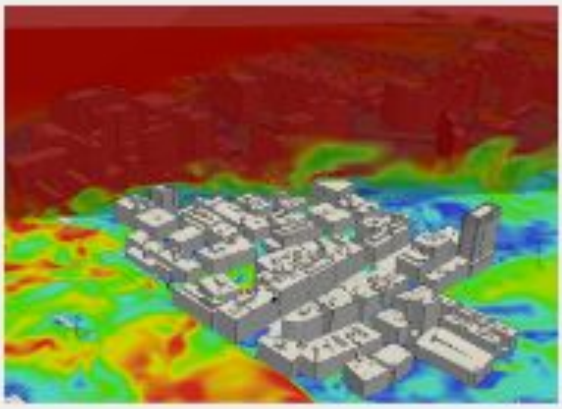


Conclusion: What Can We Do?

To reduce the impact of these effects, some measures can be taken dependent on the building stage. For example, canopies can be installed to counter the downwash effect. Entrances can be positioned away from corners, to avoid the corner acceleration effect. Planting trees can be used to shield specific areas and to diverge the wind, as well as urban furniture such as panels and fences, and to promote main streets angled with prevailing winds.

Case Study: Boston Waterfront in MA, USA

Waterfront cities are often confronted with windy weather. As they neighbor bodies of water, these areas can experience unusually high pedestrian discomfort due to powerful winds from the ocean and the subsequent Venturi effect caused by surrounding structures. This effect occurs when velocity increases, as fluid passes through a constriction of any kind. Buildings and other obstructions will then force an increase in wind speed through city streets and other unobstructed channels, leading to passerby-level discomfort.



Location and orientation can be optimized to minimize discomfort for waterfronts, if localized weather conditions are taken into account.

South Boston Weather

Boston, Massachusetts, experiences all four seasons in a year. The weather is constantly changing, to the extent that locals have taken to the expression, 'if you don't like the weather, wait five minutes'. With annual temperature averages ranging from -5.5 °C to 26.6°C, Boston experiences harsh winters, hot summers, and everything else.

Beaufort Wind Force Scale

In addition to these fluctuating weather patterns, Boston's Seaport experiences strong winds coming off the Atlantic Ocean. According to wind speed data from Logan Airport, for over 13% of the year, Boston at large is at a level 6 on the Boston Waterfront on the Beaufort Wind Force Scale, which is considered quite high. The Beaufort Wind Force Scale is used widely across the world for measuring wind speeds in all types of climates. In most cities, the wind force tends to fluctuate between 0 and 8.

Case Study: Boston Waterfront in MA, USA

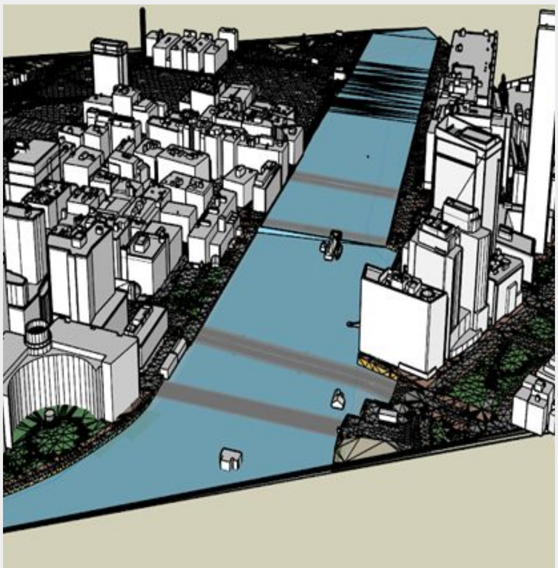
If you take into account that twice a day, thousands of pedestrians walk across Fort Point Channel between their offices and South Station Terminal alongside thousands of tourists, waterfront wind affects many people daily. This additionally influences the economic success of the surrounding stores. Outcomes could include shops being untenanted, parks being underutilized, and in extreme cases even personal injury. To avoid this, PWC must be employed in the planning process of Boston's continuous urbanization.

Our Focal Point: Seaport Boulevard

The objectives of this project were to simulate how wind from the harbor affects pedestrians, to pinpoint windy areas that have high foot traffic, and become familiar with SimScale and PWC analysis. Two questions are answered; Does the Venturi Effect increase wind speed and discomfort on the Fort Point Channel bridges? And what is the wind profile of this area?

Simulation Setup

A CAD model of Seaport Boston was created, and an atmospheric boundary layer obtained via spreadsheet calculations. The aerodynamic roughness was assumed to be 0.0002 (ocean), and the weather data assumed to be collected at 10 meters. The model was simulated with wind direction set to West-Southwest, 22.5° counter-clockwise at 14 m/s (or about a level 6 on the Beaufort Wind Force Scale). Check out the public project to determine the mesh refinements and other boundary conditions applied.



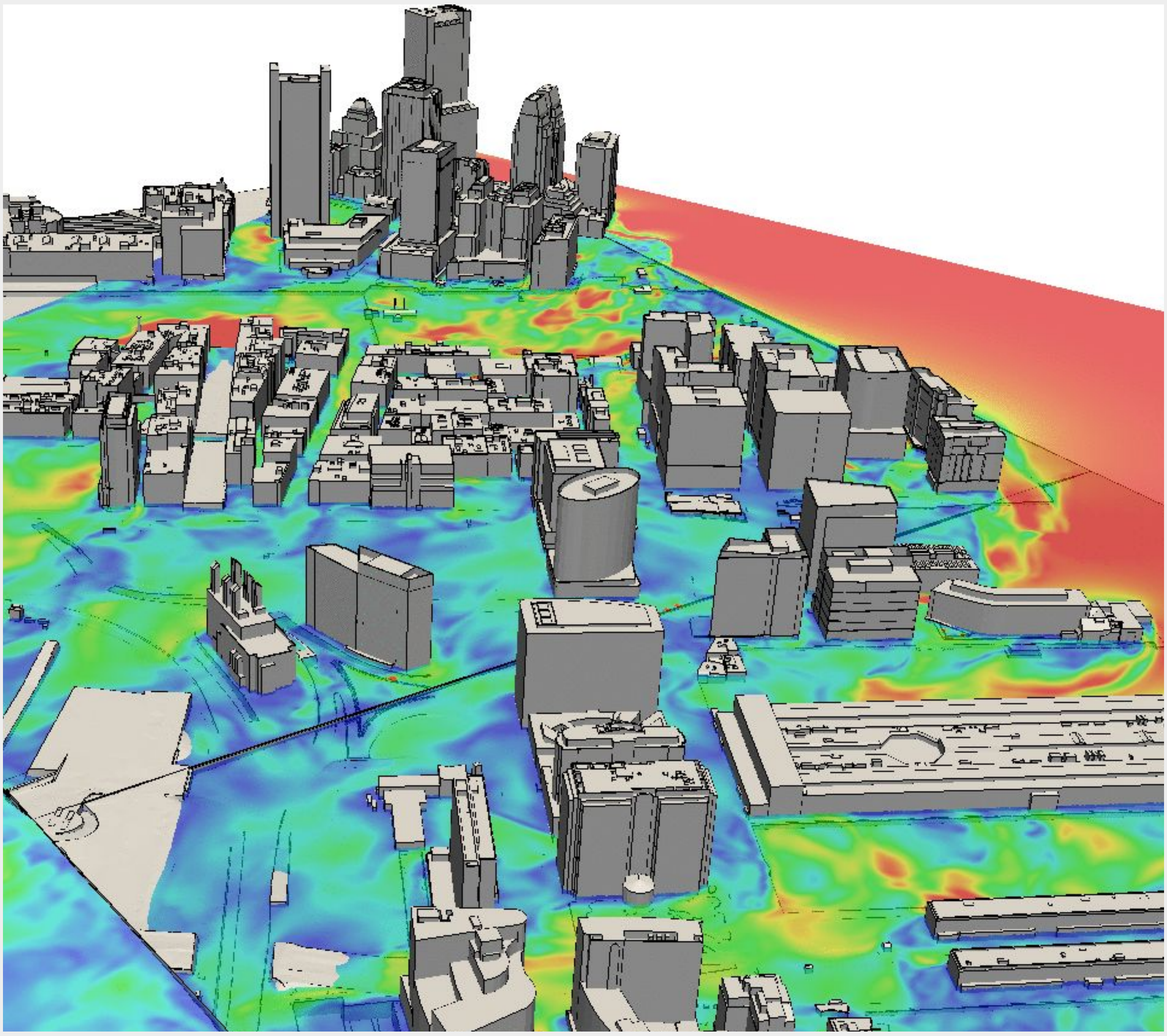
Case Study: Boston Waterfront in MA, USA

Simulation Results

As you can see in the results pictured below, the airflow enters the Seaport at 14 m/s (in red) and then fluctuates between this speed and 0 m/s (blue) as it gets further from the port.

Watch the full webinar here.

The LBM simulation revealed that certain buildings coupled with narrow pathways create the Venturi effect, forming a high and unsteady turbulent flow that proves to be uncomfortable for pedestrians, and inducing large wind velocity fluctuations.



About SimScale

Founded in 2012 with offices in Munich, New York, and Boston, **SimScale** is the world's first production-ready SaaS application for simulation. From any web browser, instantly access a full-fledged HPC-powered simulation platform, up to 96-core machines, plenty of simulation features, and learning resources.

By providing instant access to computational fluid dynamics (CFD) and finite element analysis (FEA), SimScale supports over 200,000 users (from beginners to experts) through a user-friendly cloud application accessible online via a subscription-based pricing model.

Why SimScale?

Zero hardware or maintenance investment. By leveraging the power of the cloud, SimScale helps you save on average $30K by cutting the cost of expensive hardware and software maintenance fees.

No installation. No maintenance
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Seamless collaboration
With SimScale, globally distributed design and engineering teams can easily share and collaborate on their projects in real time. No more hassle with data exchange or hidden costs.

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