

SIMSCALE

WHITE PAPER

Simulating Outdoor Thermal Comfort

Performing external comfort calculations using engineering simulation on the cloud

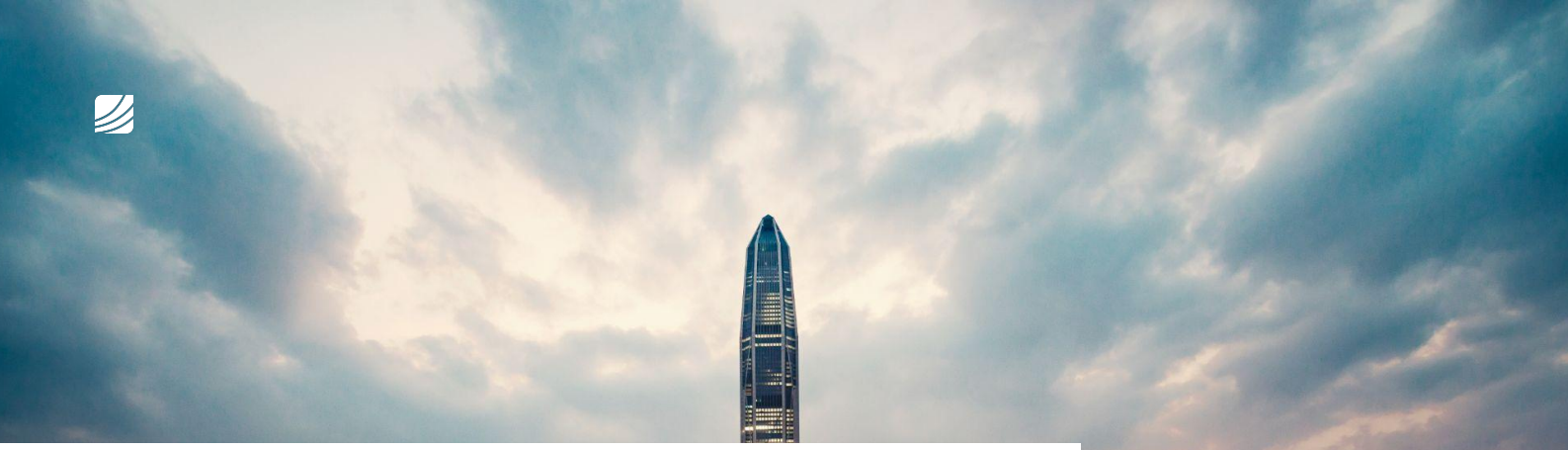
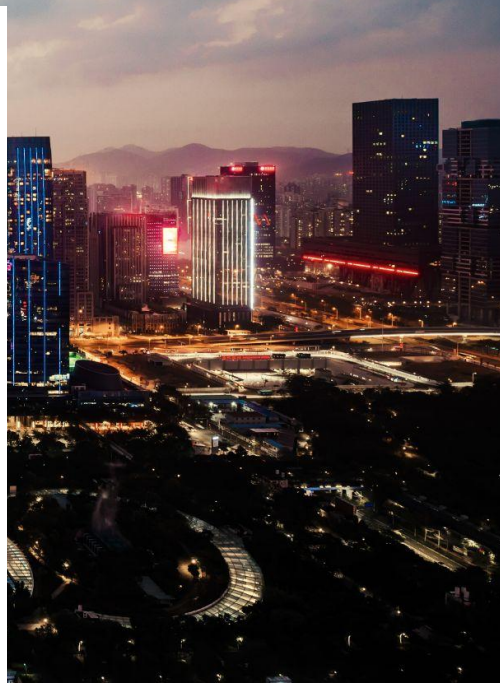


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What Is This White Paper?

Outdoor thermal comfort assessments are increasingly used in the design of buildings and cities. Traditionally, evaluating the wind component of the Universal Thermal Comfort Index (UTCI) is dependent on on-premise CFD software that takes days or weeks to simulate. This white paper describes how simulation on the cloud, using Graphic Processor Unit (GPU) accelerated physics is a leap forward in evaluating outdoor comfort and heat island reduction strategies for architects and engineers.



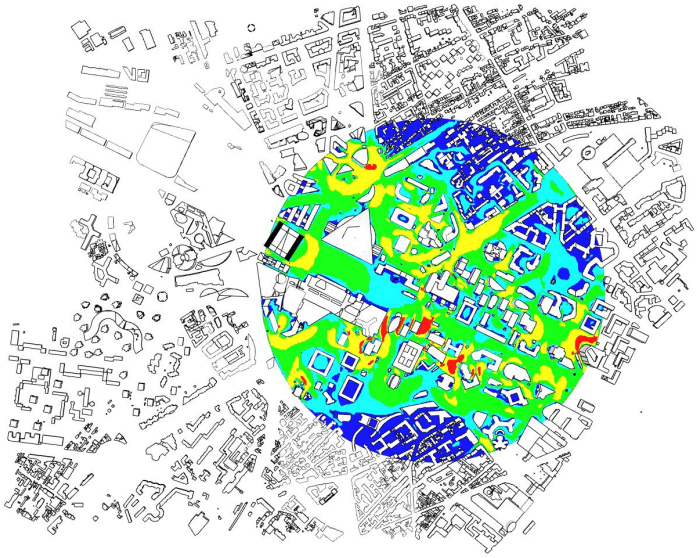
What is Outdoor Thermal Comfort?

An Urban heat island (UHI) is the adverse effect on outdoor thermal comfort caused by warmer temperatures observed in urban spaces. Thermal comfort is a concept most often applied to the indoor environment. Many types of buildings will have their thermal comfort calculated under various climatic and occupancy conditions during the design stage and, more increasingly, measured during a building's operation.

The concept of thermal comfort, however, is increasingly applied to the outdoor environment. Traditionally, pedestrian wind comfort and safety have been the dominant metrics for evaluating the suitability of outdoor spaces for people. Pedestrian wind comfort is a relatively well-understood parameter with several international standards and criteria used for assessment during the planning process. For example, the Lawson criteria is a commonly used system that has been adapted several times to quantify the wind-related comfort and safety characteristics of a site, for pedestrians and cyclists. This is, however, only a wind-related comfort parameter and ignores several key climatic variables that significantly influence the outdoor environment. The UHI also needs to be considered correctly when evaluating outdoor comfort and a combination of several physics based microclimate modeling tools are required to achieve the appropriate level of detail.

Consider city center squares surrounded by cafes or the immediate areas around shopping malls and sports stadiums, all of which are impacted by outdoor thermal comfort. Being outdoors in a city does not mean a person is free from man-made influence. Urban areas will have complex interactions between several environmental phenomena. A city will be subject to uneven heating and cooling as the sun rises and sets, depending on its built form and streetscape. Some areas will be shaded, whilst others are in full receipt of the heat gain from the sun. Wind-induced turbulence, solar shading, and long-wave radiation exchange from the copious amounts of heat-absorbing tarmac that cover our towns and cities, all need some form of simulation to capture their true effects on energy and environmental performance.

A combination of these factors is what gives rise to the urban heat island and, along with additional variables including temperature, humidity, and physiological influences — the concept of outdoor thermal comfort arises; just how comfortable is an outdoor space at different times of the year?



A pedestrian wind comfort (PWC) analysis of a city center using SimScale

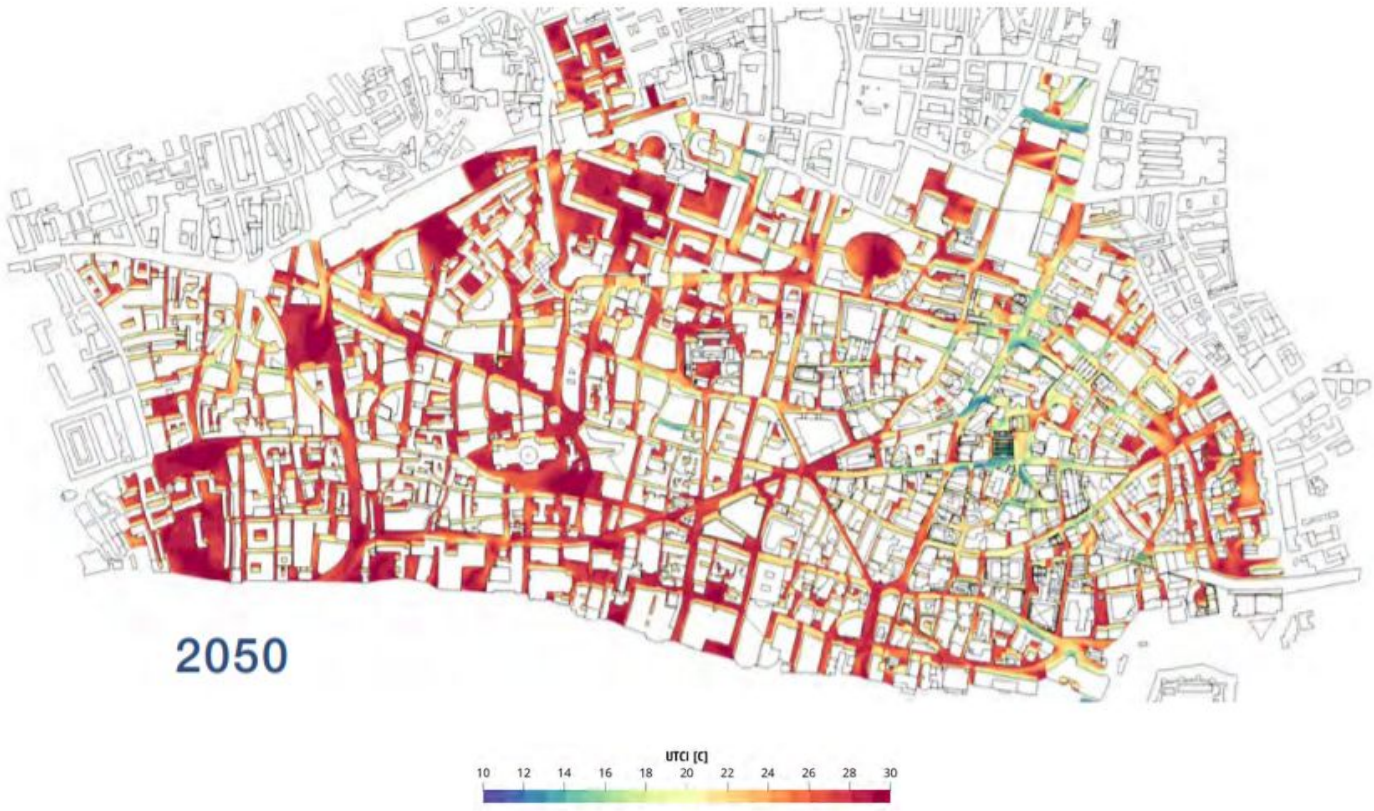
These factors tend to be transient phenomena and are difficult to predict. They require simulation and modeling to understand their behavior and interaction with the built environment.

Understanding UHI and outdoor thermal comfort means we need to capture the physical, climate, and physiological impacts, too. A commonly applied definition of outdoor thermal comfort is the Universal Thermal Comfort Index (UTCI) that accounts for wind, solar, temperature, and humidity to give an overall comfort score. The UTCI is an environmental physics construct that requires mathematical modeling and simulation to correctly calculate.

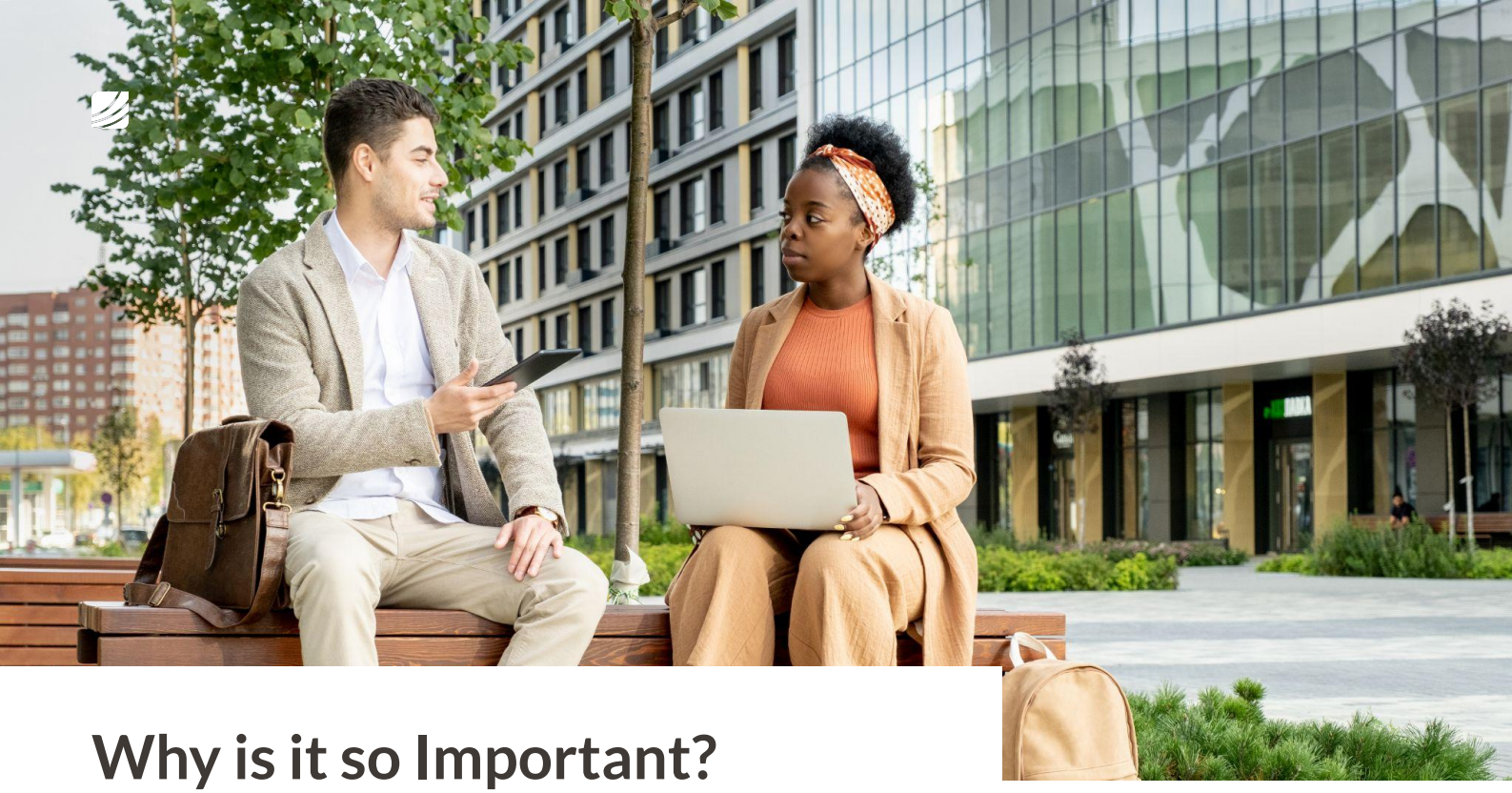
Simulating buildings and cities has historically required a high investment of both time and money to provide accurate results. Novel CFD solvers such as the lattice Boltzmann method (LBM)-based Pacefish® have reduced simulation times from weeks and days to hours and minutes. They offer a compelling value proposition for architects and engineers who can benefit from:

- Fast and accurate simulations
- GPU-accelerated computing on the cloud (no need for local hardware)
- Scalability–model buildings and entire cities
- Easy accessibility through any preferred web browser
- Online project collaboration
- Multiple-scenario analysis using parallel simulation capabilities

Ultimately, these developments mean that simulating outdoor thermal comfort in large city-scale projects is suited to working on the cloud using SimScale.



Climate change related heat risk prediction for the City of London using one possible climate scenario for 2050. Image courtesy of City of London



Why is it so Important?

Many architects and engineers are designing buildings and cities that will face adverse effects from a changing climate. The need to reduce energy and carbon emissions means we cannot mechanically condition outdoor spaces in any meaningful way as we do with indoor spaces. Passive environmental design features, therefore, become critical to optimizing design.

Assessing the outdoor environment at an early stage of the design process ensures that microclimate considerations are built into the design rather than being afterthoughts that need to be mitigated. The City of London Corporation, for example, adopted new guidelines to better understand the impact buildings will have on the thermal comfort of their surroundings and, to increase their resilience to the effects of climate change. These new Thermal Comfort Guidelines will see “data on wind, sunlight, temperature, and humidity analyzed on a seasonal level to predict how the microclimatic character of a place will feel to the public once a scheme is put in place.”

This means all major building projects and tall buildings will be required to calculate the outdoor thermal comfort impacts caused by the project at the early design stages. These new guidelines use the UTCI and also aim to assess the urban heat island effect.

The aim is to get better at quantifying and predicting the heat-stress-related risk to people, buildings, and services. "The new Thermal Comfort Guidelines show the City Corporation's dedication to considerate development, as we seek to understand and manage the impact of schemes on the local area at an early stage in the planning process.

By taking into account how a development will impact the wind, sunlight, temperature, and humidity of its neighboring properties and amenities we are ensuring the feel of our globally renowned landscape is maintained. These world-leading guidelines support our drive towards a greener future." (City of London Corporation).

Usage Category	% of hours with Acceptable UTCI	Description	Colour (HTML Colour Code)
All Season	≥90% in each season	Appropriate for use year-round (e.g. parks).	Green (#378c4b)
Seasonal	≥90% spring-autumn AND ≥70% winter	Appropriate for use during most of the year (e.g. outdoor dining).	Purple (#c86ebe)
Short-term	≥50% in all seasons	Appropriate for short duration and/or infrequent sedentary uses (e.g. unsheltered bus stops or entrances) year-round.	Cyan (#1effff)
Short-term Seasonal	≥50% spring-autumn AND ≥25% winter	Appropriate for short duration and/or infrequent sedentary uses during most of the year.	Orange (#fab92d)
Transient	<25% in winter OR <50% in any other season	Appropriate for public spaces where people are not expected to linger for extended period (e.g. pavements, cycle paths).	Red (#de2d26)

UTCI comfort plot categories in 'Thermal Comfort Guidelines for New Developments in the City of London'. Image courtesy of City of London



Simulating Outdoor Thermal Comfort

The UTCI is the international standard of outdoor temperature sensation. It is a widely accepted metric that accounts for thermo-physiological effects and covers a large range of thermal operating conditions applicable to most climate classifications. This means it is valid to apply the UTCI in all climates and seasons and is influenced by several environmental and physiological factors. “The UTCI’s inputs are fairly straightforward, requiring only four variables to be calculated: air temperature, radiant temperature, humidity, and wind speed. The model accounts for clothing using correlations derived from observations of human adaptive behaviour in the outdoors. All other personal factors such as age, height, and weight are averaged over the population” *(Mackey et. al 2017: Wind, Sun, Surface Temperature, and Heat Island: Critical Variables for High-Resolution Outdoor Thermal Comfort).*

UTCI uses these variables in a human energy balance model to give a temperature value that is indicative of the heat stress or cold stress felt by a human body, outdoors. A UTCI between 9°C-26°C indicates no thermal stress or comfortable conditions outdoors, for example.

In simple terms, the UTCI is the temperature of what the weather "feels like". The full guidelines can be seen in Table 1.

UTCI (°C) Range	Thermal Stress
0-9	Slight cold stress, comfortable for short periods of time
9-26	No thermal stress or comfortable conditions outdoors
26-32	Moderate heat stress, hot but not dangerous
32-38	Strong heat stress dangerous beyond short periods of time
38-46	Very strong to extreme heat stress very dangerous
>46	Extreme heat stress

Table 1: UTCI Thermal heat stress categories, adapted from http://www.utci.org/

The solar radiation, mean radiant temperature and humidity can be taken from climate files for a particular location and applied to building energy models; software tools that calculate temperatures and other outputs such as energy and loads. Wind simulation, however, is more complex. A wind speed and direction from a weather file is not necessarily the wind profile you will encounter in a city center location.

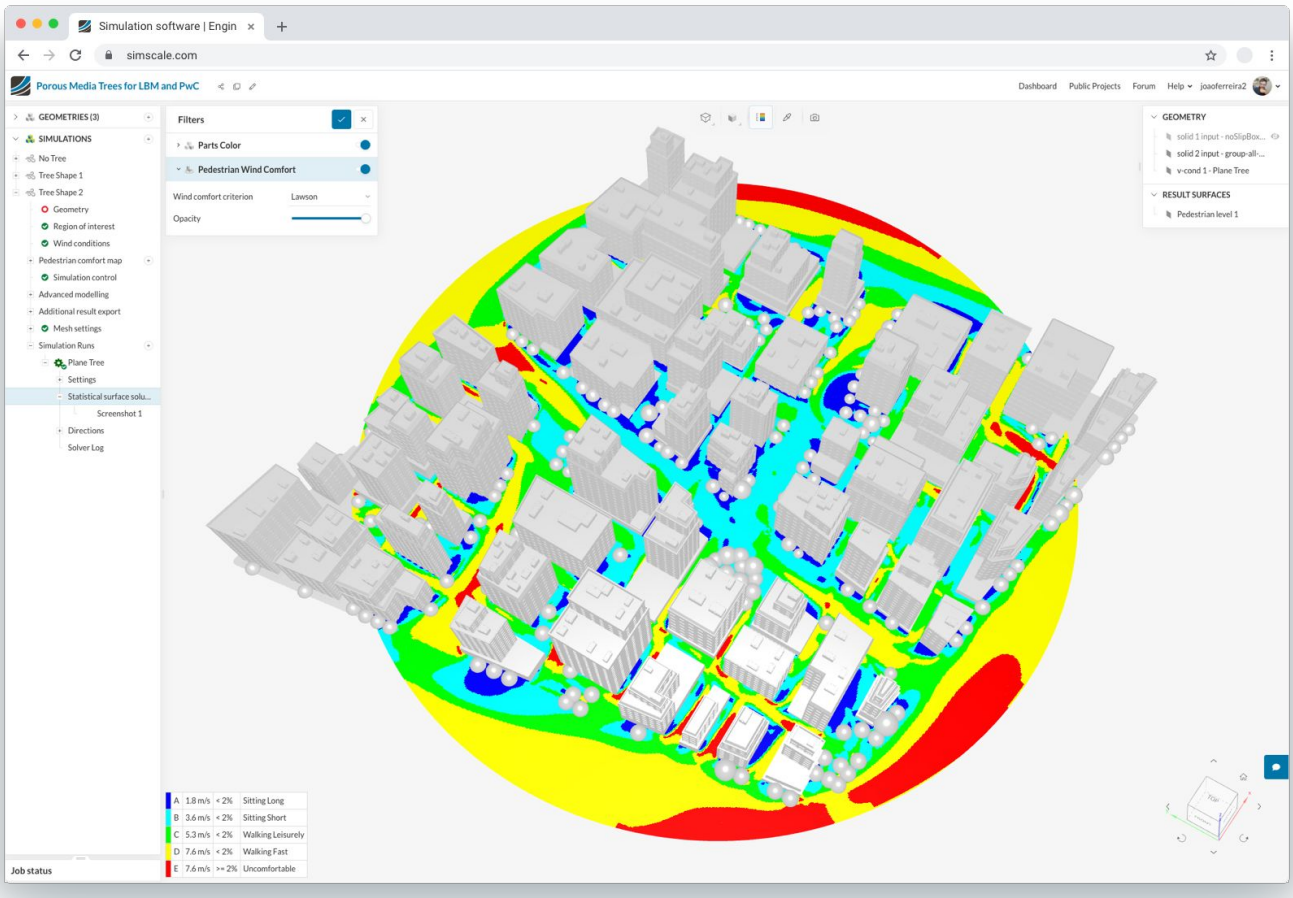
Multiple variables must be accounted for to give an accurate assessment of the wind's behavior including:

- The wind profile as it approaches an urban location of interest.
- Turbulence caused by the local topography—surrounding buildings, trees, urban layout, etc.
- The wind velocity at the point where UTCI is to be calculated—again, this will be impacted by the local topography.

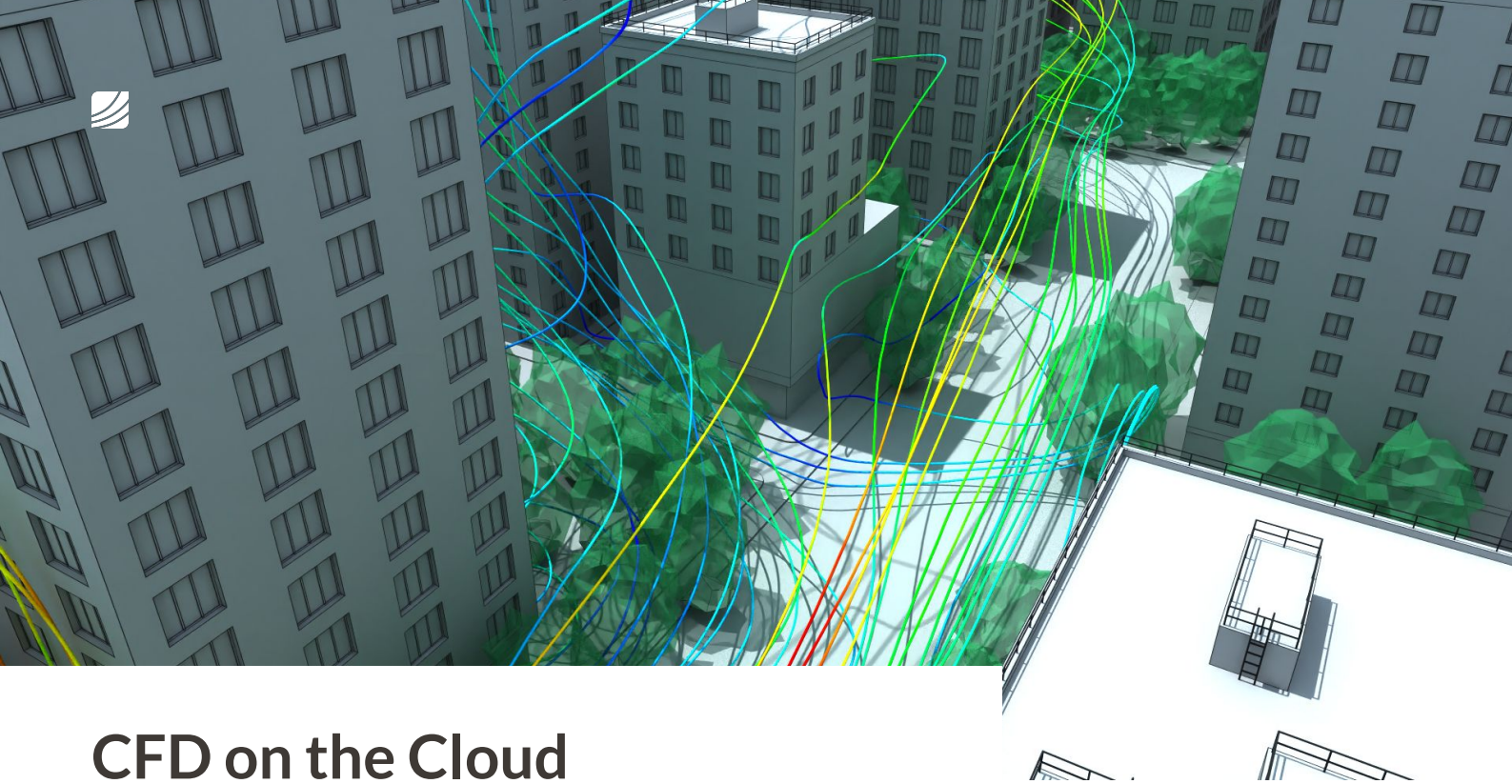
The number of wind directions that can adequately capture the annual wind rose of that location. A good guide is to use 16 wind directions or more. Simulating 16 wind directions to generate a wind comfort map of an area requires time and computational resources. A transient simulation is more accurate than a steady-state as it correctly accounts for the time-dependent effects induced by the wind—which are exacerbated by dense urban layouts.

Imagine an architect, at the early design stage of a new development wanting to calculate the UTCI—the bottleneck will almost always be the CFD wind simulation. Using traditional on-premises CFD solvers might take days, if not weeks, to converge on an acceptable solution. This time penalty effectively stifles early-stage design iteration and puts it out of reach of many users.

A better approach would be to have access to fast and accurate wind simulations using CFD on the cloud. This would significantly reduce the time taken to calculate UTCI and, allow more design iterations to be simulated and considered.



Wind simulations using the Pedestrian Wind Comfort tool in SimScale, accessed via any web browser.



CFD on the Cloud

Computational Fluid Dynamics (CFD) is the branch of CAE that simulates fluid motion and heat transfer using numerical methods. CFD acts as a virtual fluid dynamics simulator. SimScale GmbH has created the world's first cloud-based engineering simulation platform for CFD for the built environment. SimScale is accessed through a web browser and is hosted fully on the cloud.

A new generation of physics solvers based on LBM has been integrated into SimScale to offer transient simulations for buildings and cities at an order of magnitude greater than traditional CFD software. The LBM method is different from the common finite volume method (FVM) CFD tools, as it does not require CAD clean-up before importing into SimScale. The solver does not work by solving discretized small volumes of the 3D model, therefore the requirement for watertight geometry no longer applies.

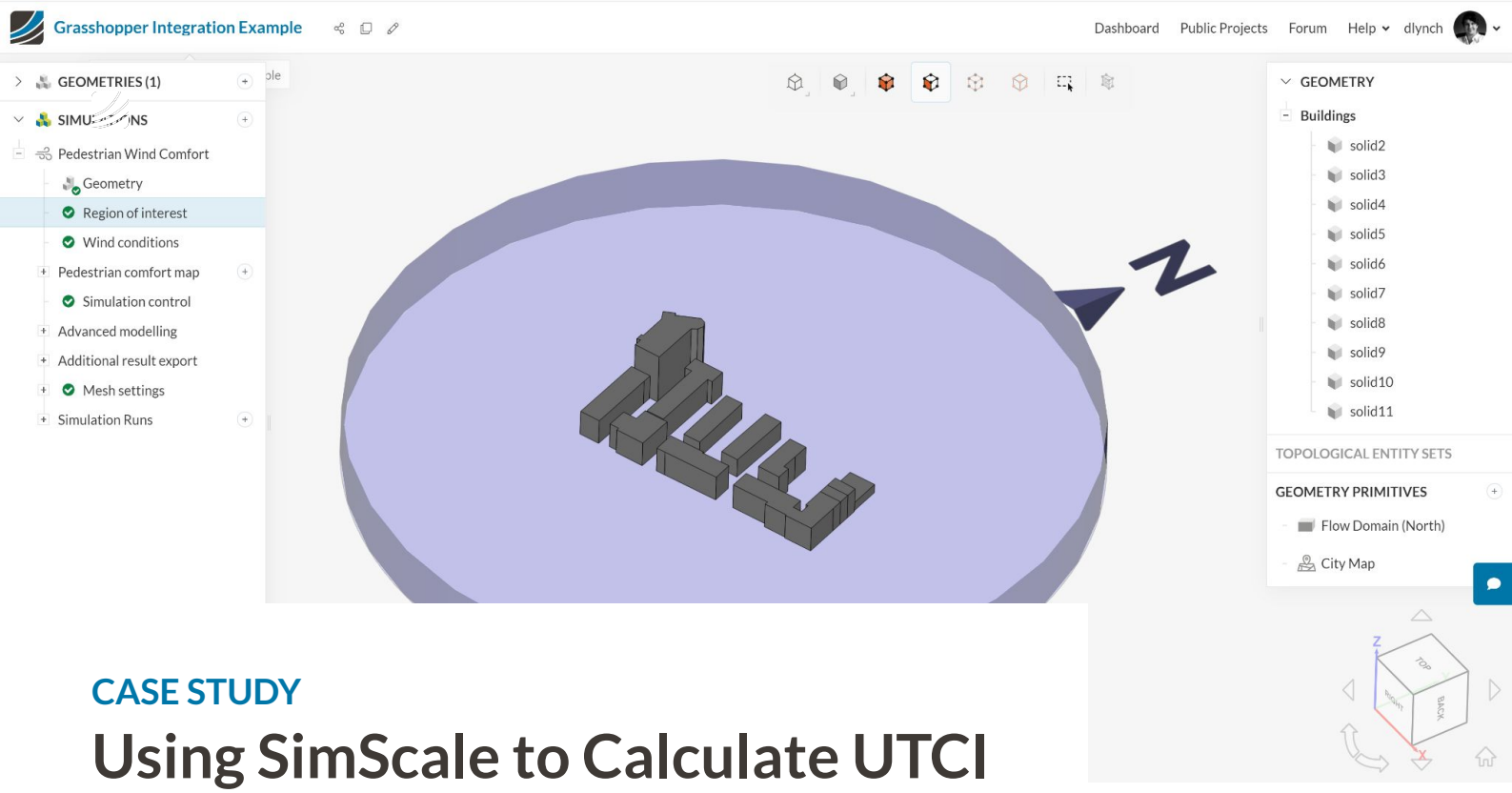
This means entire cities can be simulated for wind comfort, safety, wind loading, and general microclimate analyses, including outdoor thermal comfort in hours rather than days.

General-purpose CFD abilities for simulating the indoor environment are also widely available in SimScale. More importantly, SimScale now incorporates the two types of studies—indoor and

outdoor—to give a truer representation of real-world physics. SimScale's CFD software can analyze a range of problems related to laminar and turbulent flows, incompressible and compressible fluids, multiphase flows, and much more. With everything in the web browser, the barriers of limited computing power, accessibility, and high costs are eliminated.

Many traditional types of CFD software have been steady-state, in that they oversimplify and approximate turbulence effects. This is because the alternative— transient simulations, have historically required a high investment both in time and money to provide accurate results. SimScale has partnered with Numeric Systems GmbH to develop this innovative feature through their tool Pacefish® and has reduced running times for transient simulations from weeks and days to hours and minutes. Its ability to run on multiple GPUs in parallel enables turnaround times that are 20-30 times shorter than standard methods. Moreover, Pacefish® supports several turbulence modeling types such as Smagorinsky, SST-DDES, Hybrid SST-IDDES, and k-omega SST making it unique among other LBM solvers. An architect or engineer running a UTCI calculation requiring 16 wind directions might have to wait two hours for each wind direction to be solved in steady-state using traditional CFD software—the total wait time will be 32 hours and the PC or laptop will effectively be frozen. With SimScale on the cloud, all 16 directions are simulated in parallel, meaning the total simulation time is reduced to 2 hours. Because the simulations are taking place on the cloud, there is no resource limitation with computing power. SimScale also significantly simplifies the user experience for conducting CFD simulations.

Ordinarily cumbersome tasks such as meshing and post-processing of results are automated, whilst allowing the expert users to still use their CFD knowledge to alter key physics variables. The biggest advantage of the LBM method is its indifference to CAD models. Importing a Rhino or Revit model is easy as the software is not bothered by untidy geometry, meaning hours need not be spent on CAD cleanup.



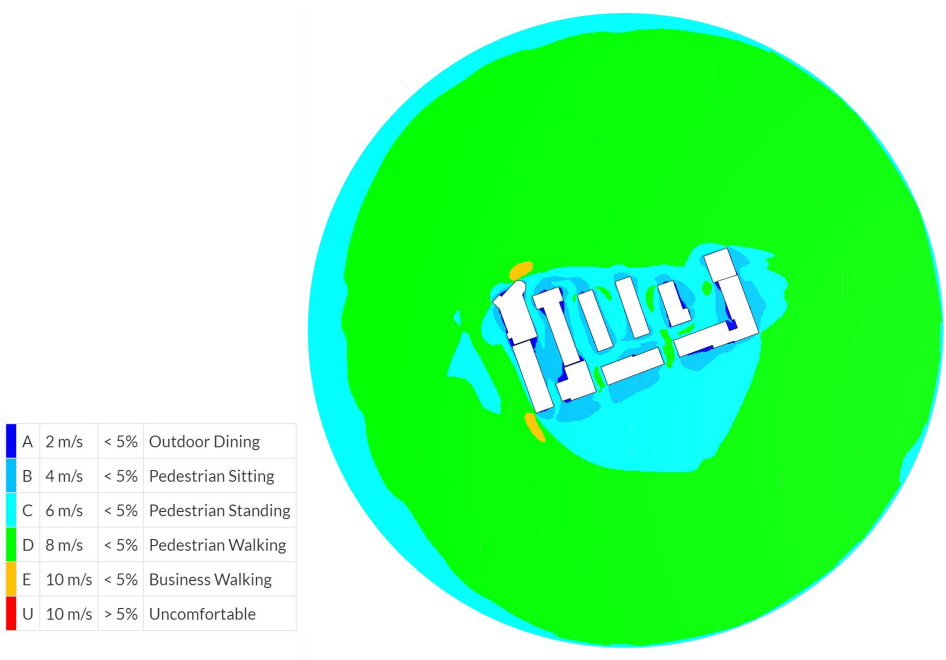
CASE STUDY

Using SimScale to Calculate UTCI

Step 1: A CAD model is imported into SimScale. The mesh is auto-generated and weather data selected.

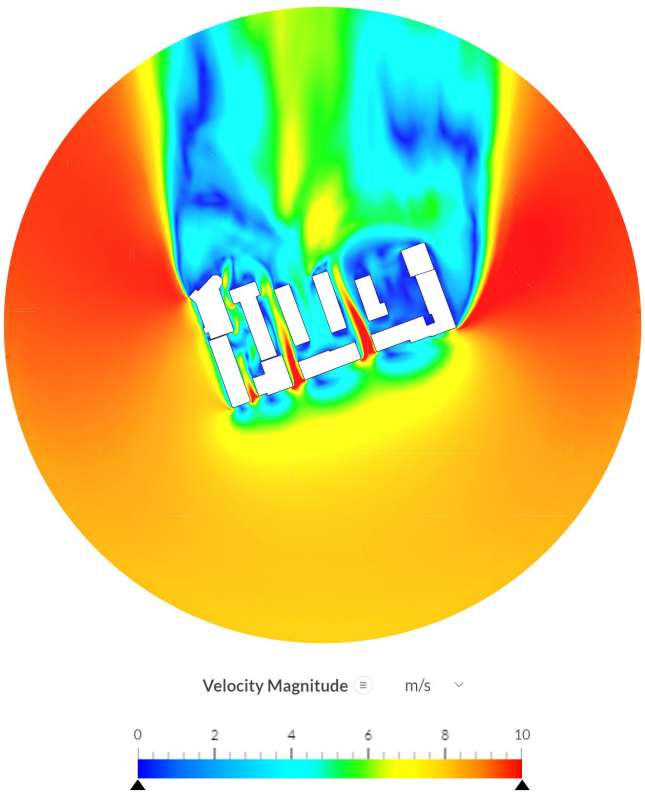
A set of buildings on a development are simulated for wind comfort and UTCI. The Pedestrian Wind Comfort tool in SimScale is used to evaluate 16 wind directions using a weather data set integrated into SimScale. Each wind direction is simulated and the results are statistically averaged to give annual average wind speeds that can then be scaled and imported into third party tools such as Ladybug. The simulated data can then be imported and integrated into the Rhino/Ladybug workflow for further calculation of UTCI using existing templates. The workflow can be summarized as follows:

1. Import a CAD model into SimScale and select weather data / location. The mesh is auto-generated.
2. Run a pedestrian wind comfort analysis to evaluate comfort criteria.
3. Evaluate the wind simulation data and iterate the design if needed. Download into CSV format.
4. Use Grasshopper and Ladybug to set up a UTCI script and import SimScale results (Sample scripts for both are available from SimScale). Wind speeds from SimScale should be scaled in Ladybug.
5. Use Ladybug to calculate Mean Radiant Temperature and the scaled wind speed results to produce the UTCI plots for specific times (such as the warmest week of the year) or as a percentage of the year. Customise images to show relevant data.



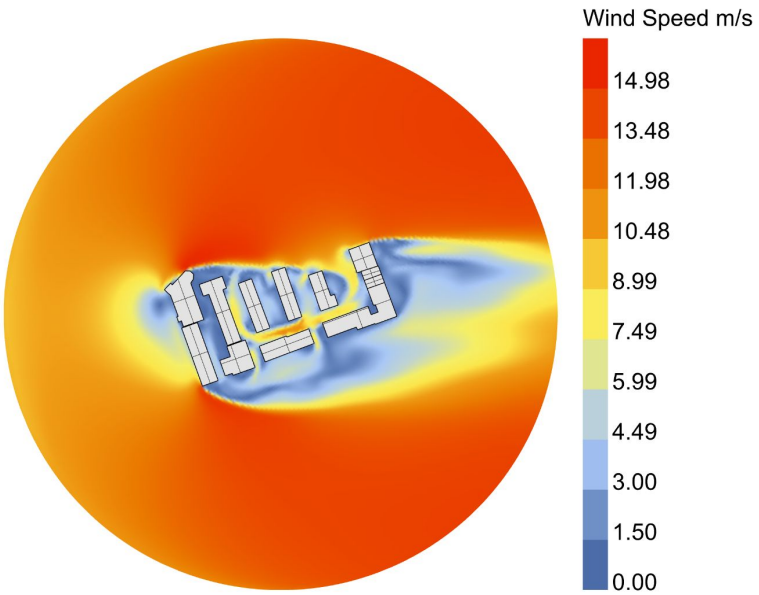
A	2 m/s	< 5%	Outdoor Dining
B	4 m/s	< 5%	Pedestrian Sitting
C	6 m/s	< 5%	Pedestrian Standing
D	8 m/s	< 5%	Pedestrian Walking
E	10 m/s	< 5%	Business Walking
U	10 m/s	> 5%	Uncomfortable

Step 2: Run a PWC analysis for multiple wind directions. In this example 16 wind directions have been simulated and the results are shown using the Lawson wind comfort criteria.

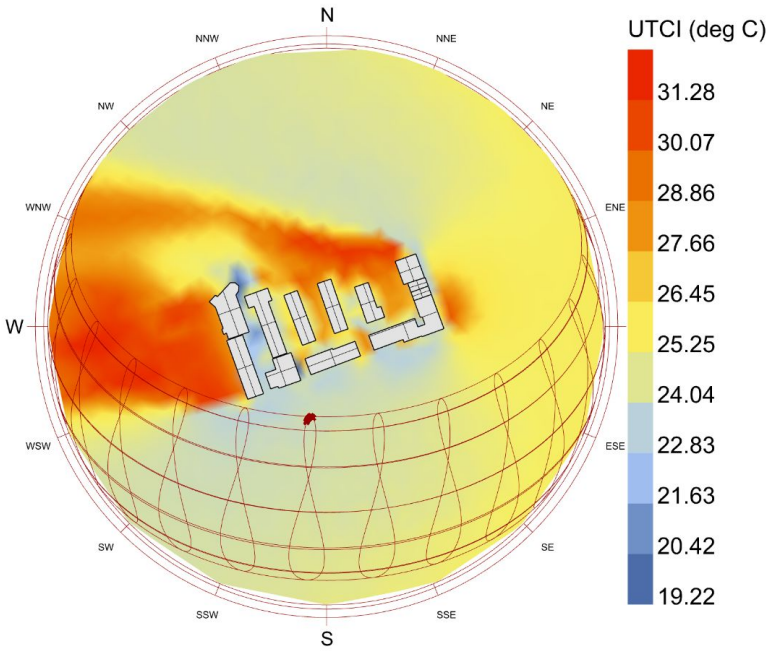


Step 3: Evaluate the wind simulation data and iterate the design if needed. Download into CSV format. This example shows the results of a southerly wind.

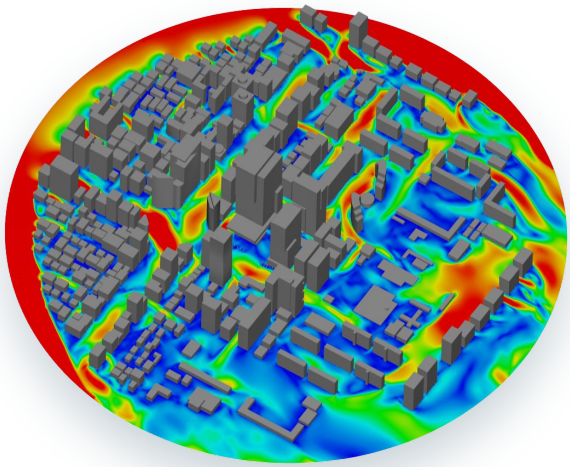
The images show results generated in Ladybug using CFD generated wind speeds for 16 directions from SimScale. Ladybug is then used to calculate the UTCI plot. Several existing scripts are available for Grasshopper and Ladybug to automate this process and available from SimScale.



Step 4: Use Grasshopper and Ladybug to set up a UTCI script and import SimScale results. This image shows scaled wind speeds in Ladybug.

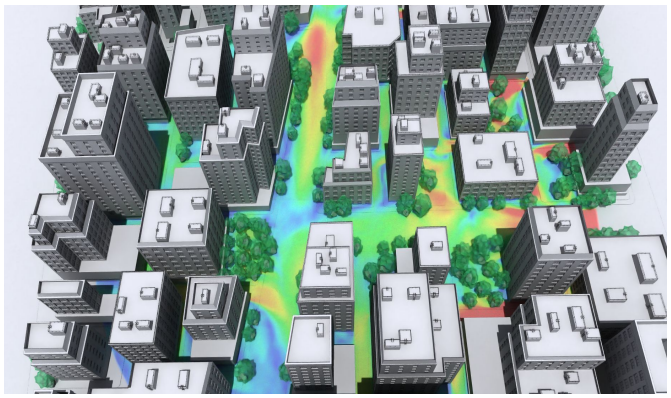


Step 5: UCTI plot in Ladybug using SimScale wind simulation results.



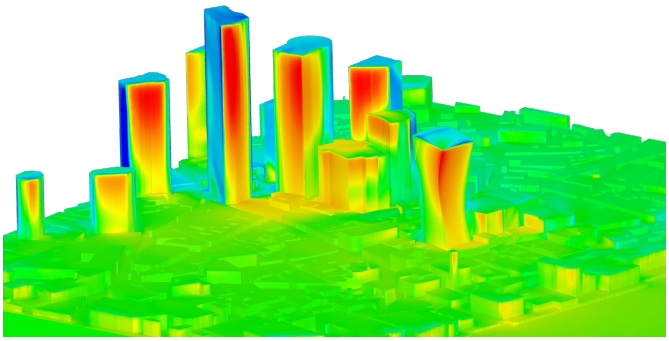
Pedestrian Wind Comfort

SimScale is used by architects and engineers to perform building aerodynamics and pedestrian wind comfort (PWC) studies. A designer can quickly iterate designs using the automated PWC tool that simplifies much of the modeling process. The new City of London Microclimate Guidelines and other standards are included.



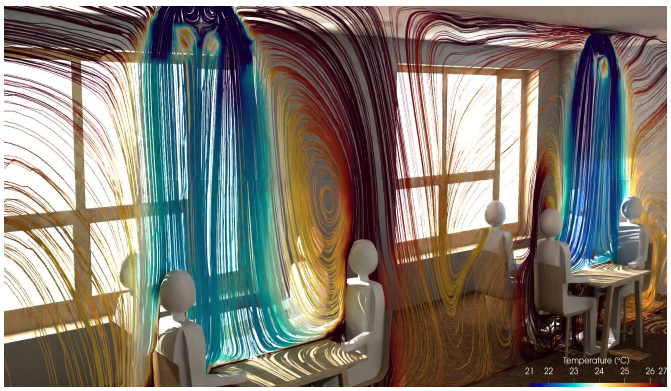
Greening Strategies

The same tools can be used to assess greening strategies by simulating trees, vegetation, landscaping and other urban features. Various tree species are integrated into SimScale and the user can evaluate the impact several different types of trees might have on the local wind speeds.



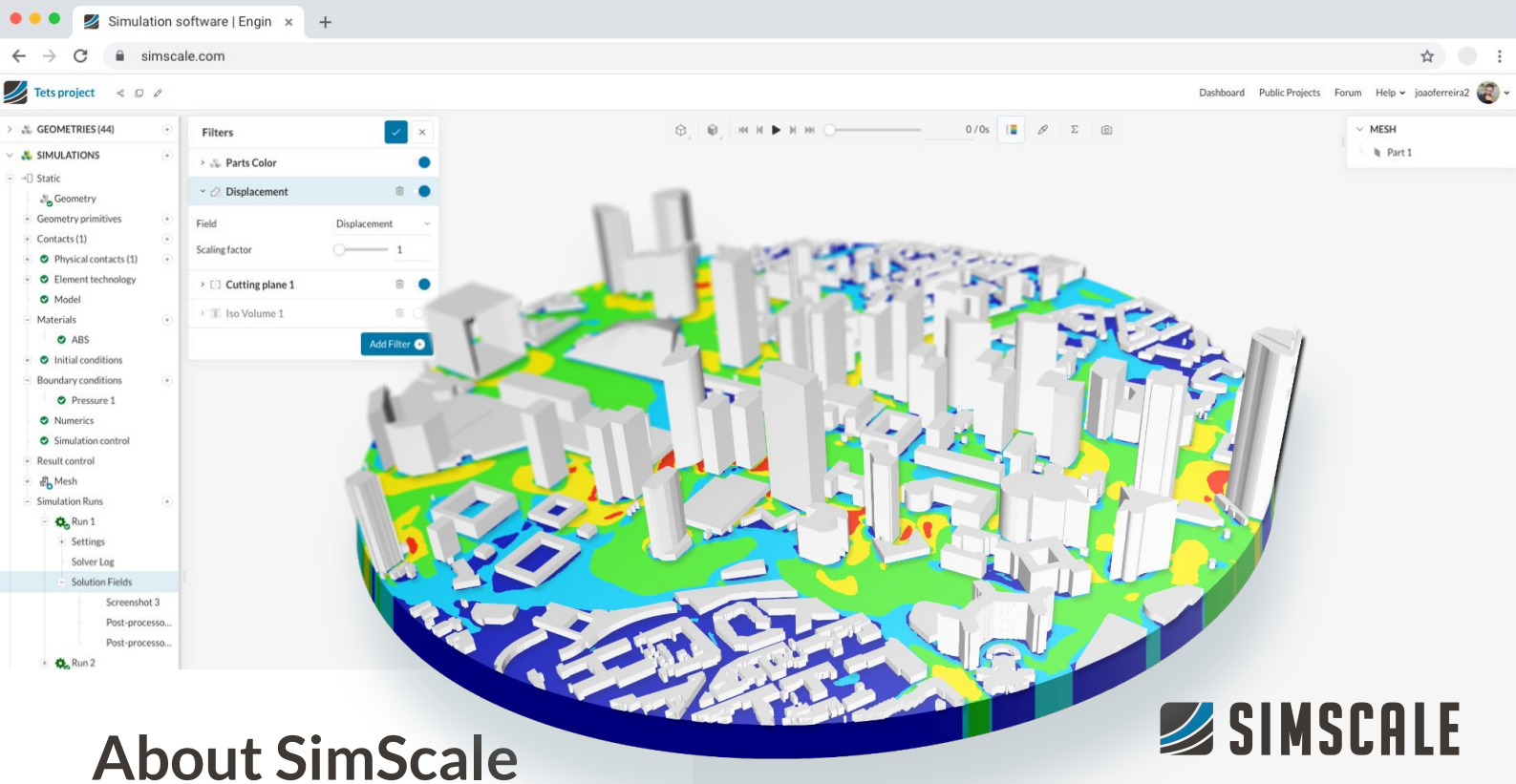
Wind Loading

SimScale is also used to calculate facade pressures and wind loading. Using this at the early design stages allows designers to visualise the impact of altering the building height, shape and orientation.



Indoor Air Quality

Understanding the impact of your designs on the indoor environment is critical. Use SimScale to model the indoor air quality, ventilation strategies, thermal comfort and more. Multiple design configurations can be run in parallel.



About SimScale

SimScale is a cloud simulation platform accessible via a web browser and has built the world's' first fully native cloud engineering simulation platform, now used by over 200,000 users globally.

SimScale is a pioneer of GPU-accelerated simulation for architects, engineers, and the construction industry, enabling a new generation of CFD solvers to significantly add value to buildings and cities.

Learn how leading architecture and engineering firms are leveraging the power of SimScale.

Why SimScale

Zero hardware or maintenance investment. By leveraging the power of the cloud, SimScale helps you save the cost of expensive hardware and software maintenance fees. No installation. No maintenance.

All you need is an internet connection to run demanding simulations on a laptop or PC of your choice.

With seamless collaboration through 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.

For more information visit www.simscale.com