# Scottish Opera New Rotterdam Wharf

## Wind Microclimate Analysis

**J7374-MXF-XX-XX-RP-Y-28001 P02**

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# 1.0 OVERVIEW

A wind microclimate assessment has been carried out for the proposed development. Guidance from the City of London has been used as a framework (*Wind Microclimate Guidelines, for Developments in the City of London, August 2019*). The Lawson criteria are the main metric indicated therein.

A summary overview of the *National Planning Framework (NPF4)* and of some planning applications to the Glasgow City Council has revealed that there are different approaches to wind microclimate reports. In our case, we have decided to focus on understanding the risk of worsening wind conditions in a reasonable worst-case scenario. This means that a full Lawson Criteria study has not been run, but we believe that our measures are fine enough to indicate and satisfactorily describe risk when it is present.

In particular, in isolating a reasonable worst-case scenario we have settled on a wind speed that is high enough to be undesirable but not so high as to be so rare that it is statistically insignificant. There is a further assumption that the behaviour of the wind (relative acceleration/deceleration) is independent enough of incoming wind speed in relevant scenarios as to make our model's results scalable. That is, we assume that if wind speeds are diminished enough in our reasonable worst-case scenario as to be acceptable, then they will be acceptable at lower incoming wind speeds too.

All in all, we deem this to be a reasonable approach given the nature of the project under consideration, which does not involve complicated geometries of intertwined narrow streets and tall buildings skirting each other (as is the case for example in the City of London).

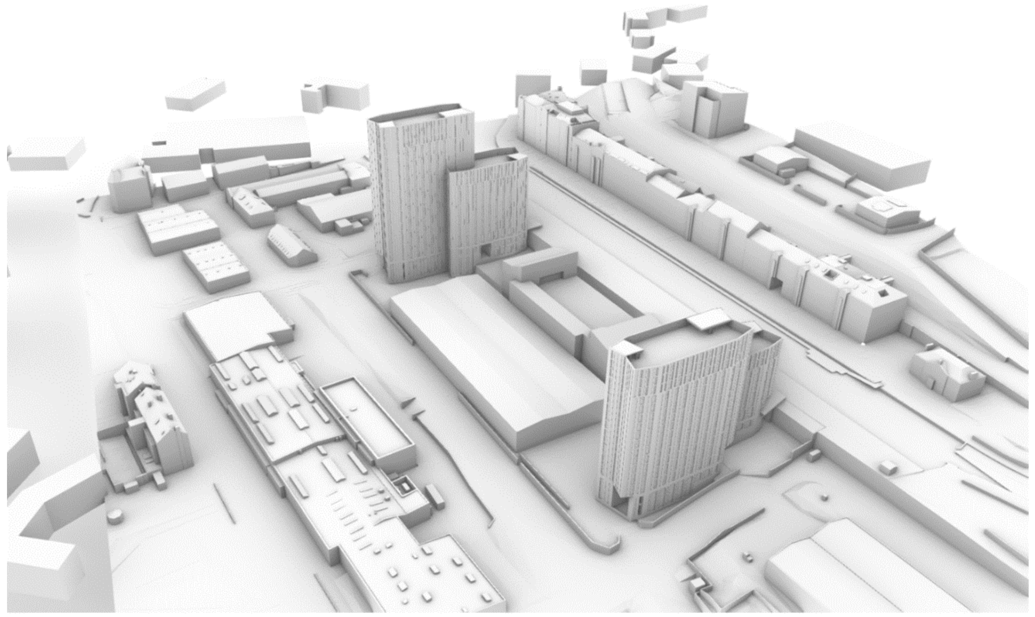
## 1.1 Conclusions

Overall, the development does not have an adverse effect on the surrounding area. In fact, it has a beneficial effect on Speirs Wharf. Furthermore, no downdraught effect was recorded in the model.

There is some channelling effect to the north-west of the development which might cause mild discomfort for passers-by in the reasonable worst-case scenario of strong wind from the south-west.

However, the potential issues in this area of the development can be substantially mitigated via careful landscaping. A further simulation has been run with a more careful rendition of the geometry of the area, which is stepped. As it is possible to see below, this is enough to considerably reduce wind speed in the area.

Considering that the complete landscaping will also include some soft elements, such as small trees, bushes, etc. we deem this to be sufficient to considerably reduce potential discomfort in this area.



# 2.0 CFD ANALYSIS

## 2.1 Overview

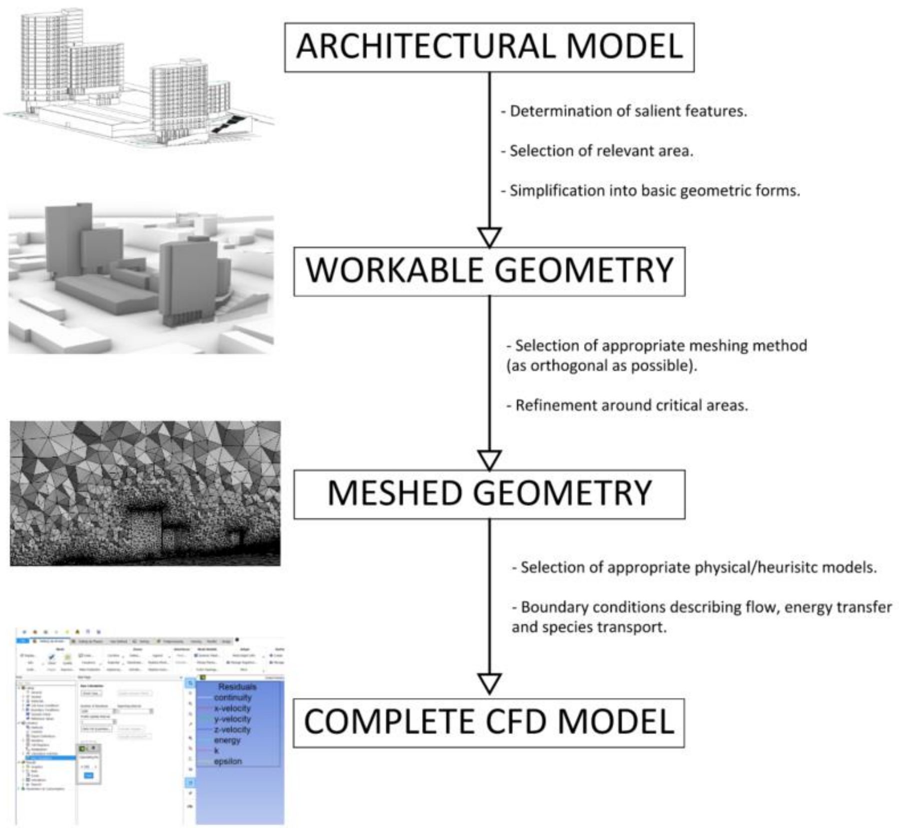
The aim of this study is to understand air comfort conditions in the surroundings of the Scottish Opera development in New Rotterdam Wharf.

Computational Fluid Dynamics (CFD) is an advanced simulation tool which allows us to build a detailed virtual model of the New Rotterdam Wharf development and relevant adjacent areas in order to understand air comfort conditions locally.

The basis for a CFD study is **a workable geometry**. A workable geometry is a model of the space under consideration satisfying the following requirements:

a. It is **representative** of the space: a workable geometry is first of all a representation of a real-world space. It represents the physical domain (enclosure) in which air flows. It should therefore include all of the salient features that constitute the space.

b. It is **reasonably simple**: a workable geometry is not an architectural model. It is a basis for brute force calculations (via more or less refined CFD algorithms) and as such needs to be as simple as possible, as to minimise approximation errors and reduce computational cost.




Once a workable geometry has been constructed in CAD, it needs to be **meshed.** A mesh is a discretised version of a workable geometry. The workable geometry is subdivided in simpler elements (which can be tetrahedrons, cubes, hexahedrons, or a mixture of these). The constitutive equations of fluid motion and energy transfer can be approximately solved in these finite elements via numerical algorithms with a high degree of accuracy.

Ideally, a good mesh is regular and simple, with element boundary surfaces at right angles to each other (orthogonality). It should be rougher where flow quantities are not expected to vary considerably and finer where more turbulent behaviour and steep gradients are expected.

Once a mesh has been produced, the **physical/heuristic laws** that best approximate the phenomenon are chosen. In addition to the basic constitutive equations describing the viscous-elastic properties of the medium, these include consideration of buoyancy effects, energy transfer, and the appropriate approximations of turbulent flow when applicable.

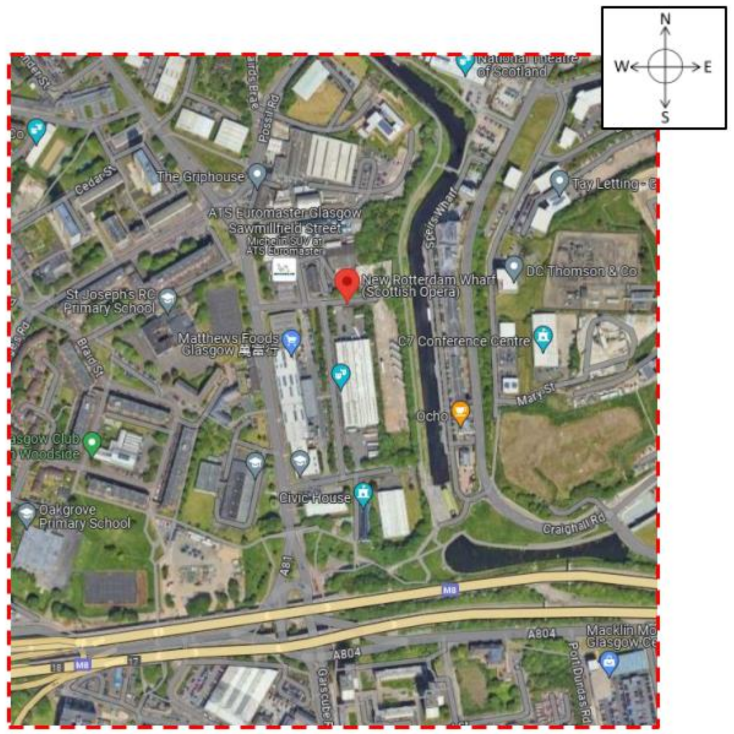
Finally, **boundary conditions** are inputted that accurately describe the physical starting conditions of an analysis. These may include:

a. **flow conditions**, describing air inlets and outlets with appropriate velocities/mass flow rates.

b. **energy transfer conditions**, describing transfer of energy, usually in the form of heat (sensible or latent) due to the presence of people, vegetation, solar radiation, equipment, etc.

c. **species transport conditions**, describing concentration/diffusion of relevant species (most typically water vapour, $CO_2$) at relevant boundaries.

In our specific case we **only include dynamical flow conditions** since wind is the main physical phenomenon under consideration.




## 2.2 Model Set-Up

### Geometry and Domain

The area analysed has been selected according to best practice guidelines and heuristic considerations about the topography and relevant features of the landscape.

A cylindrical domain has been chosen to reduce computational time and remove the need for re-meshing for every wind direction. The merits of using cylindrical domains for urban wind simulations are discussed in Kastner and Dogan (2020).

Every building in a radius of about 400 m from the centre of the development has been included in the model. This area is broader than usual for urban wind simulations. A larger radius has been selected to include the fly-over and some housing blocks to the south which were deemed to have a non-neglectable effect on wind flow.

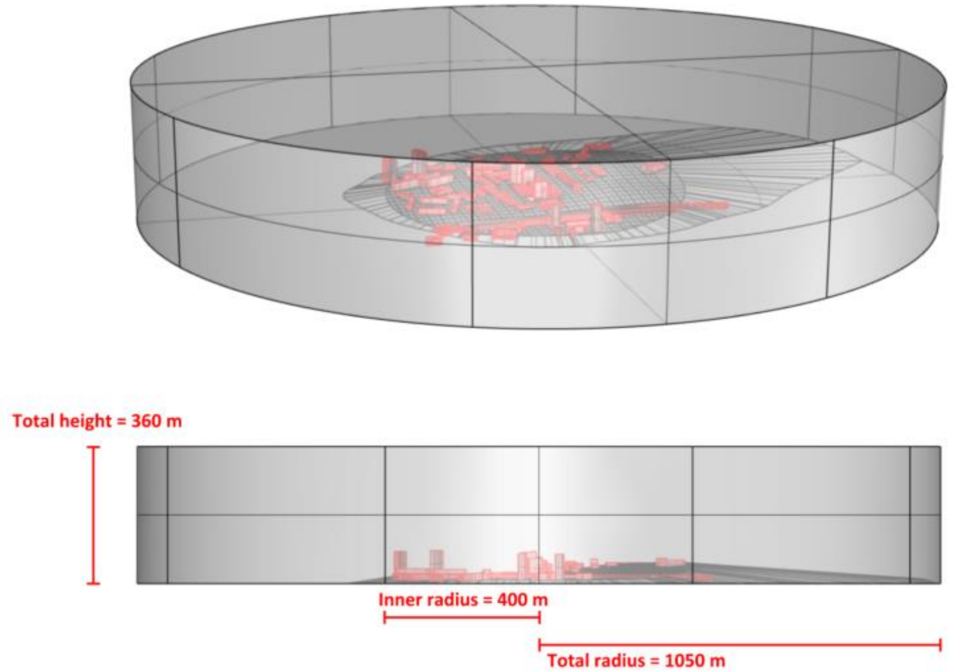
Franke (2006) suggests a total cylinder height of 6 times the height of the tallest building in the area and a total radius of about 15 times this height. Based on the observation that the tallest tower in the development has a height of about H = 65 m, we obtained a cylinder of about 360 m of height and 1050 m of radius.

The topography of the area has been taken into consideration when setting up the model. This was based on data obtained via Cadmapper.

Wind directions are obtained by slicing the perimeter surface of the cylinder in 8 sections of equal area (N, NE, E, SE, S, SW, W, NW).

### Meshing

The meshing is tetrahedral and finer around buildings in the area of interest. There are around 15 million cells.



### Physical Models

Air is modelled as a viscous compressible ideal gas. Viscosity is modelled via a realisable k-ε model, as per best practice.

### Boundary Conditions

Boundary conditions are set as follows:

1. **Landscape and buildings**: these are set as stationary no-slip walls.
2. **Vertical domain boundary (sky)**: this boundary is divided in 8 equal sections to model wind coming from different directions (N, NE, E, SE, S, SW, W, NW). These are managed as follows, depending on the wind conditions being simulated:
    a. The vertical boundary corresponding to the **incoming wind** direction is set as a velocity inlet with specified wind velocity magnitude, turbulent intensity and turbulent viscosity ratio.
    b. The vertical boundary diametrically opposite to this (**outgoing wind**) is set as a pressure outlet with static atmospheric pressure profile and backflow turbulence conditions consistent with the incoming wind.
    c. All other vertical boundaries are set to symmetry conditions. This is an appropriate model for a zero-shear slip wall in viscous flows.
3. **Horizontal domain boundary (sky)**: this is again set to symmetry conditions to model a zero-shear slip wall.

## 2.3 Analysis

### Scenarios

The scenario analysed is of prevalent wind. According to weather data (see wind rose below) this is south-westerly, as expected due to Glasgow's position and topography.

There has been a focus on understanding:

a. **Wind channelling effects in the development**: these happen when air flows between buildings that are in close proximity of each other (compared to the scale of wind flow). As a result, air undergoes acceleration. The higher air speed can cause discomfort. Downdraught from tall buildings can be categorised as type of wind channelling effect.

b. **The effect of the development on Speirs Wharf**: there is a worry that the development might have an adverse effect on Speirs Wharf because of channelling effects on the canal.

A reasonable worst-case scenario of 10 m/s wind speed has been taken into consideration in the investigation. There is an assumption that under lower speed conditions the channelling effects would be analogous (under appropriate scaling).

In order to clarify how the development affects air circulation in the area, two cases have been considered:

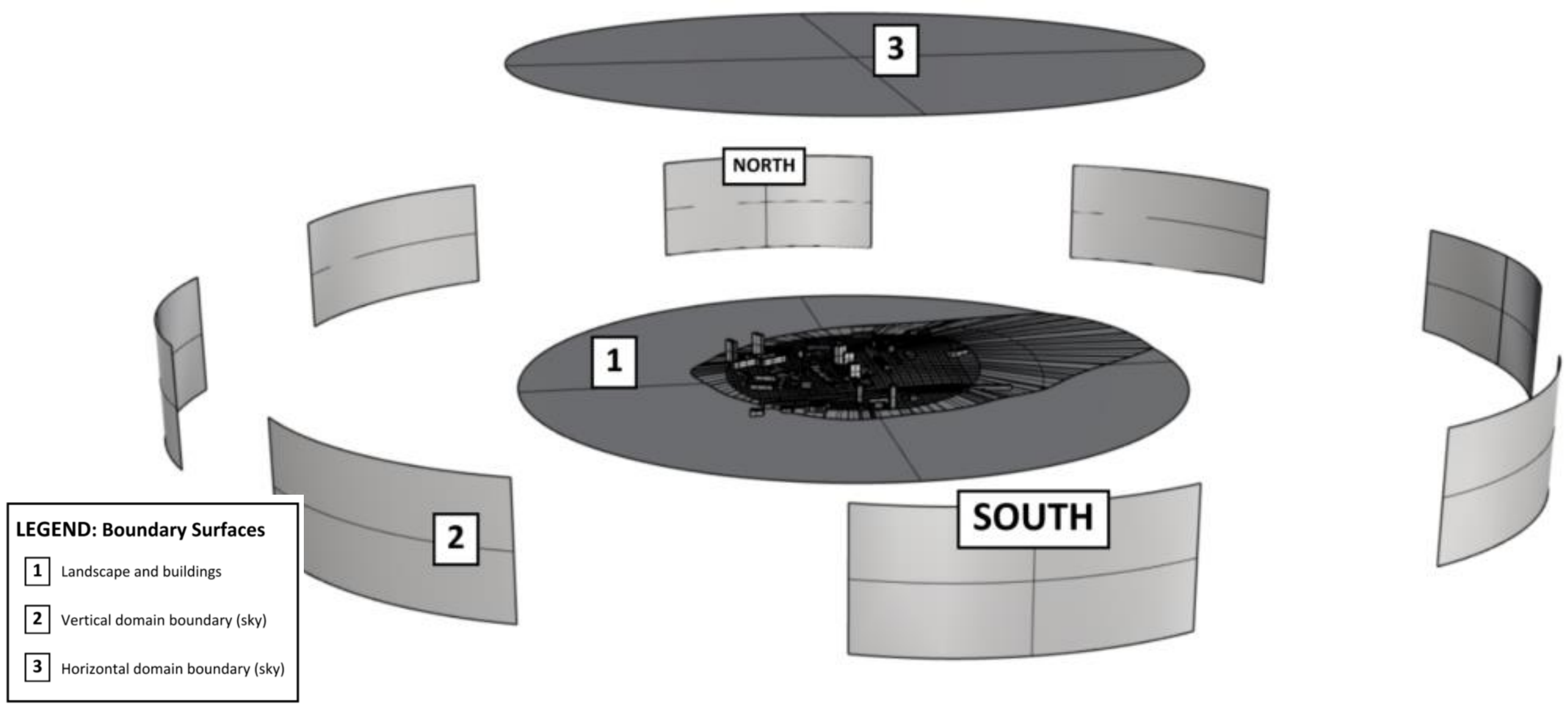
1. **Existing**: the area as it exists currently (without the new development) comprising of topography and pre-existing buildings and relevant landscape features.
2. **Proposed Design**: same base geometry as above, with the addition of the planned development.

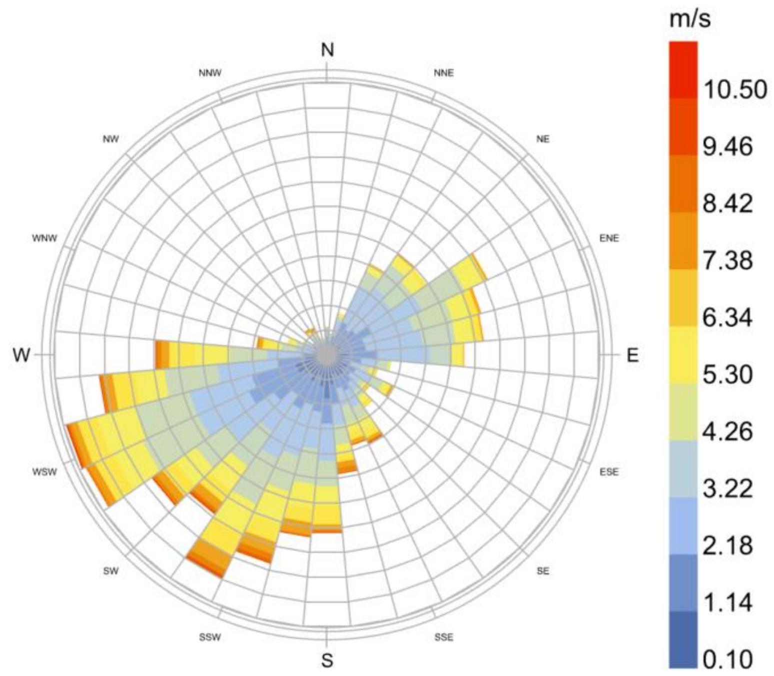
### Presentation of Results

Results are presented in the form of wind velocity plots on representative horizontal and vertical sections of the domain.

The top views are obtained by sampling the wind velocity at a fixed distance from the ground, at a height that is representative of the conditions experienced by a passer-by.

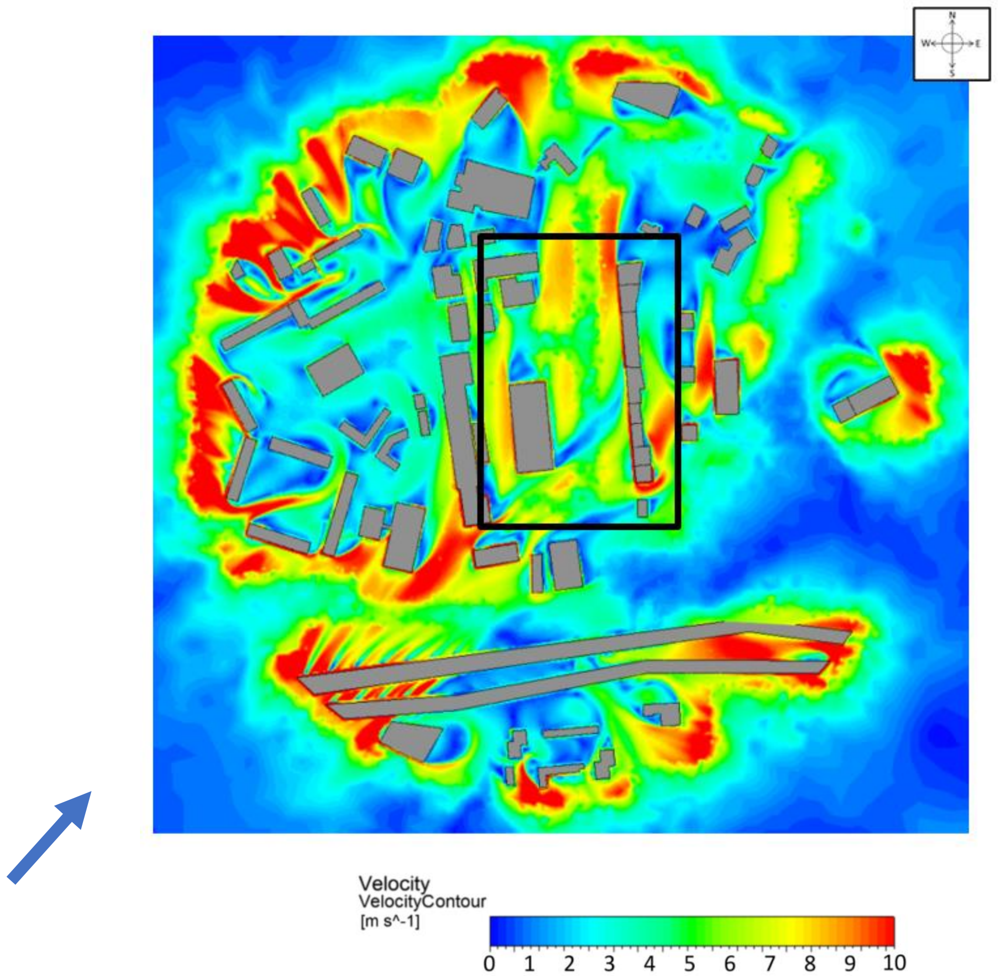
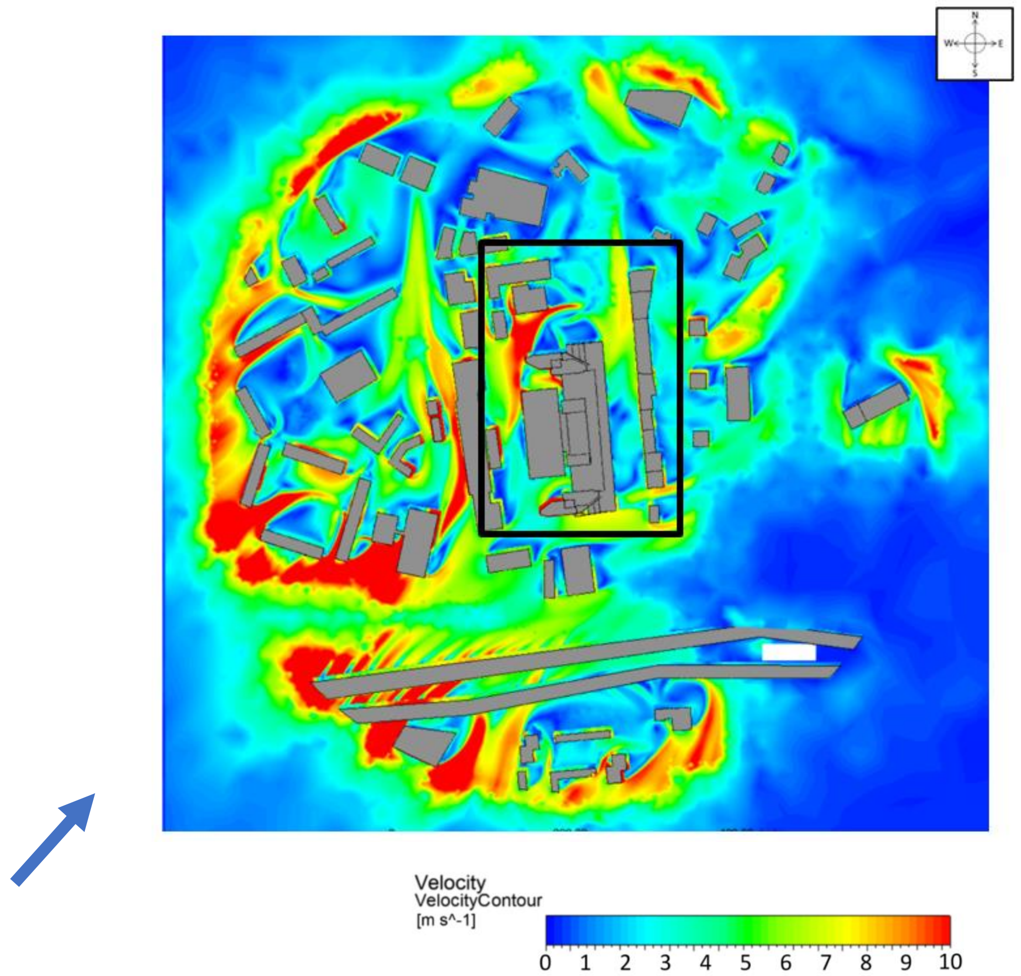
The vertical sections are cut at different levels of the development. The orientation and location of the sections are shown next to the plots for reference.




Wind Speed (m/s)
city: Glasgow.Wea.Center
country: GBR
time-zone: 0.0
source: SRC-TMYx
period: 1/1 to 12/31 between 0 and 23 @1
Calm for 5.08% of the time = 445 hours.
Each closed polyline shows frequency of 0.6% = 50 hours.

# Overview of Results (top view)

| Existing_Prevailing Wind | Proposed Design_Prevailing Wind |
| --- | --- |
|   |   |
| As it can be seen, the area to be subjected to development is protected enough by the surrounding buildings and the flyover to the south that it mainly experiences a reduction in wind speed. There is some minor channelling effect to the north and southeast of Speirs Wharf. | Overall, it can be appreciated that the development positively affects wind speed on the canal to the side of Speirs Wharf, as it has a shielding effect on south-westerly and westerly wind. However, there is a risk of channelling effects causing discomfort to the north-east of the development.<br><br>There is no discernible risk of downdraught from the towers. |

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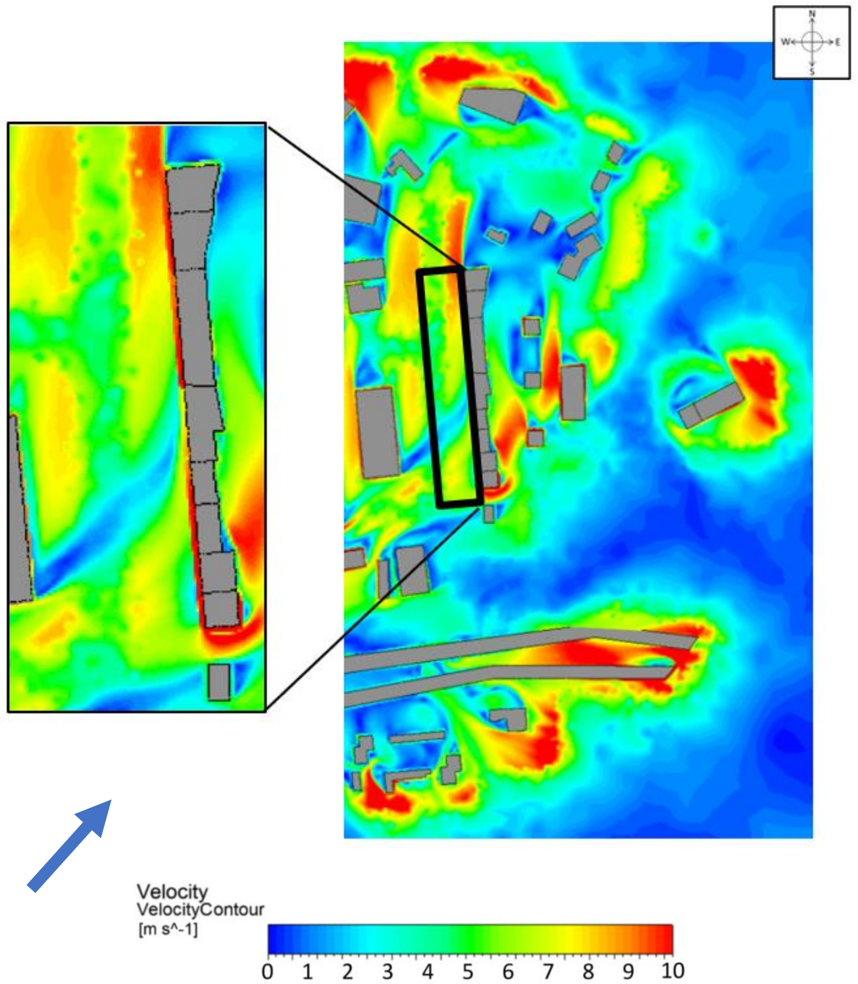
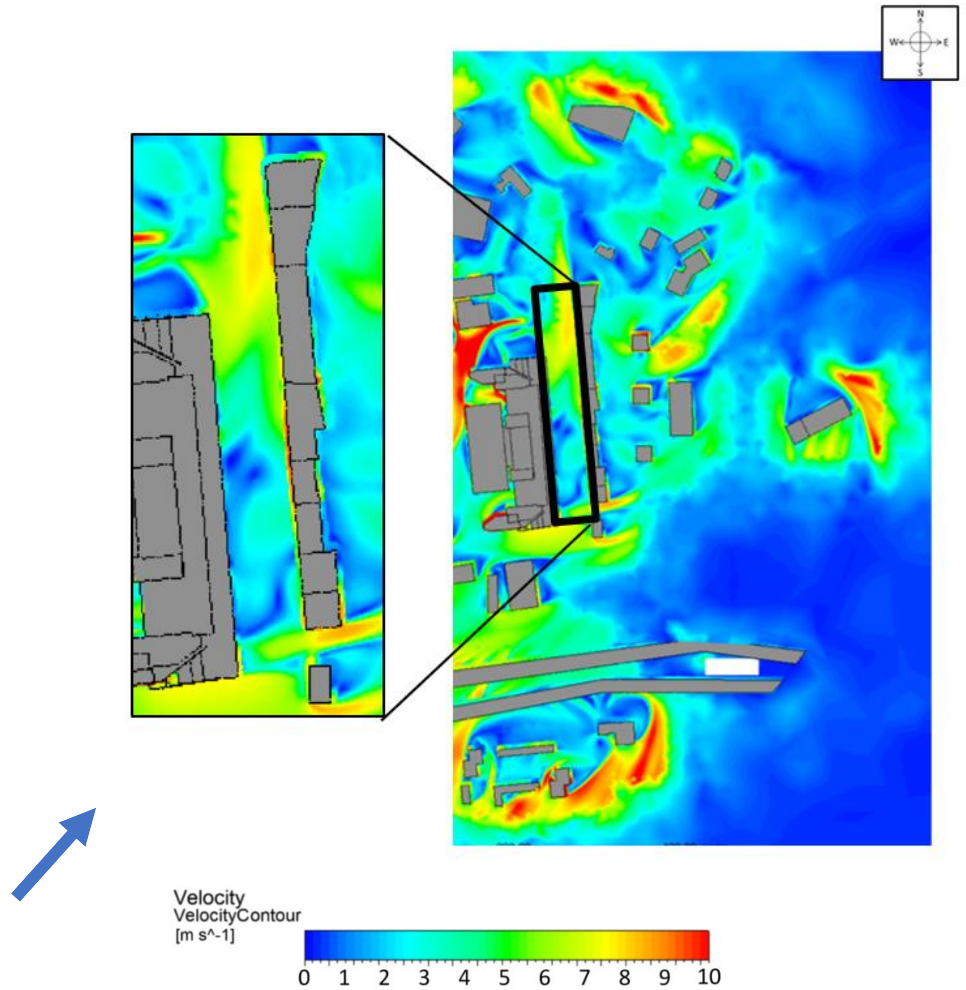
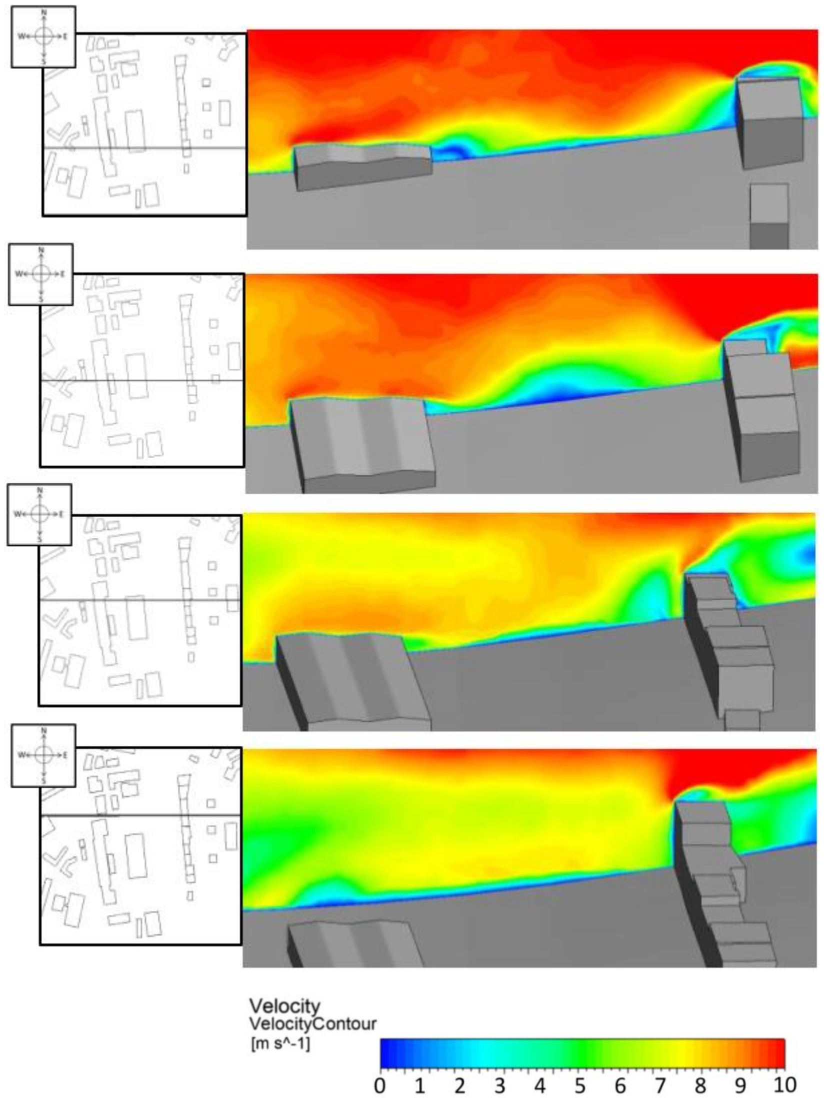
# Speirs Wharf (top view)

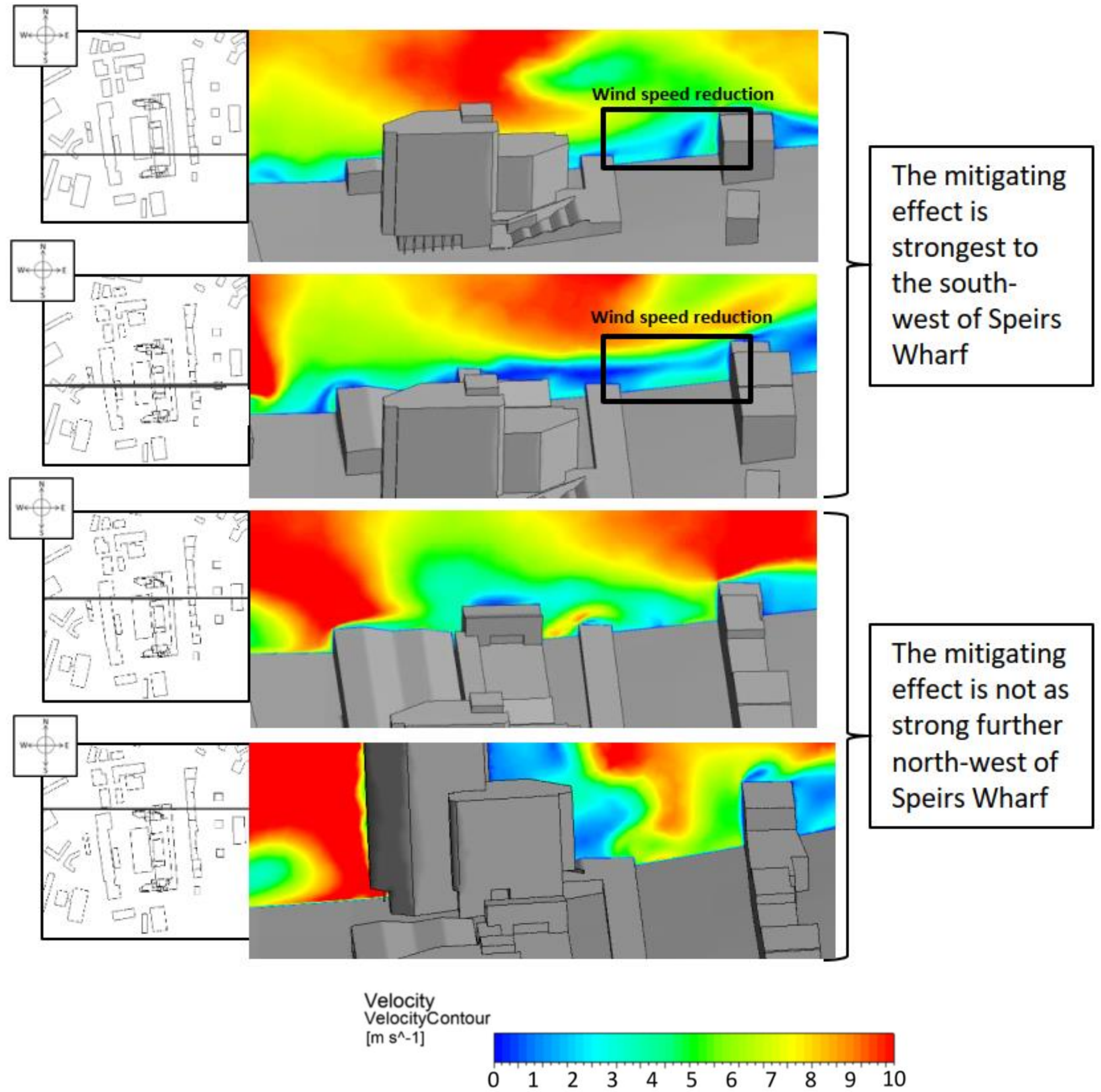
| Existing_Prevailing Wind | Proposed Design_Prevailing Wind |
| --- | --- |
|  |  |
| Without the planned development, there is a slight channelling effect to the north and south of Speirs Wharf, with speed increases of about 10% at most.<br><br>Overall, the canal is not subject to worrying air speeds in this reasonable worst-case scenario. A wind speed of 6-8 m/s is usually deemed comfortable for walking. | Overall, it can be appreciated that the development positively affects wind speed on the canal to the side of Speirs Wharf, as it has a shielding effect on south-westerly and westerly wind.<br><br>In particular, immediately to the east of the planned development wind speed is reduced to less than 4 m/s, which is in general deemed comfortable for sitting.<br><br>The beneficial effect is less pronounced to the north of Speirs Wharf. Here, the mitigating effect on the canal is counterbalanced by channelling to the north-west of the planned development. There is still a perceptible reduction of wind speed in this area. |

# Speirs Wharf (vertical sections)

## Existing_Prevailing Wind




## Proposed Design_Prevaling Wind




Looking at vertical section in more detail, it is clear that the average speed values close to the ground are of about 6-8 m/s. These are good values for walking pedestrians but are in general uncomfortable for sitting for an extended period of time.

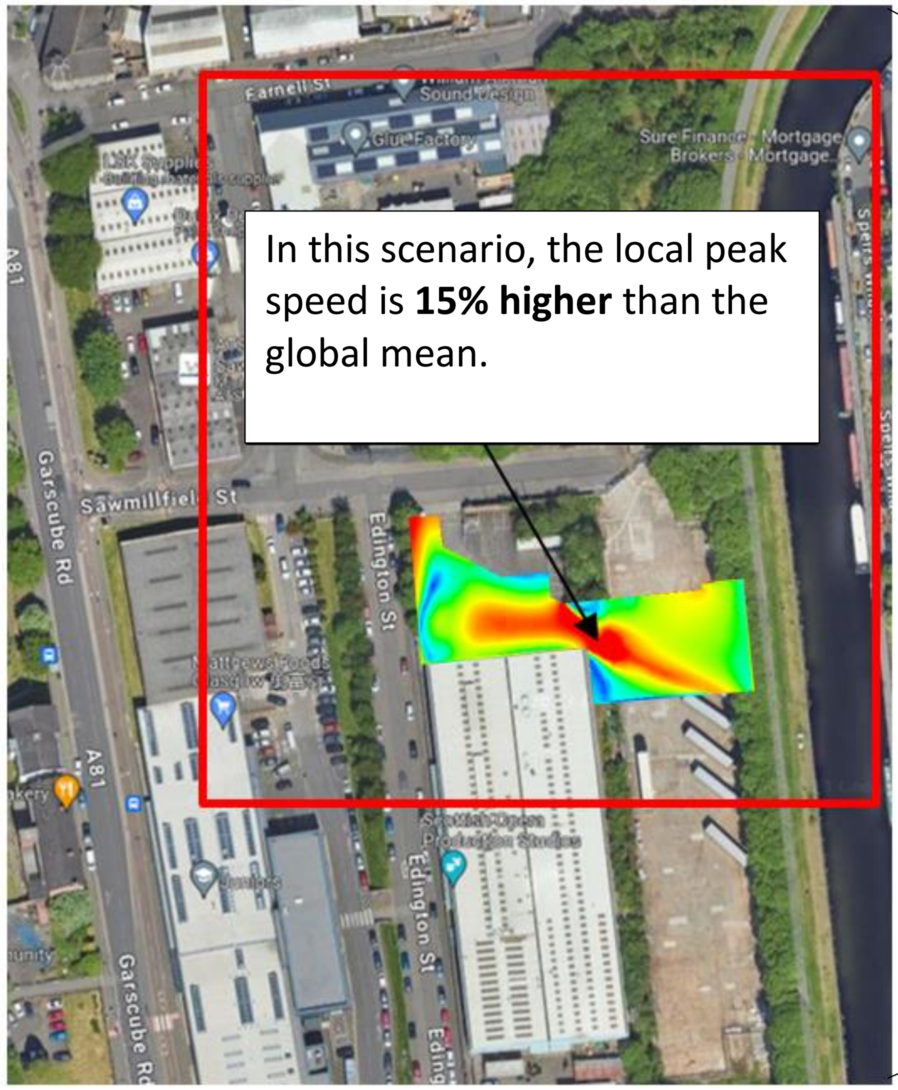
Introducing the planned development considerably reduces air speed in Speirs Wharf. The effect is most remarkable to the south of Speirs Wharf, where average air speeds are now comfortable for sitting for an extended period of time.

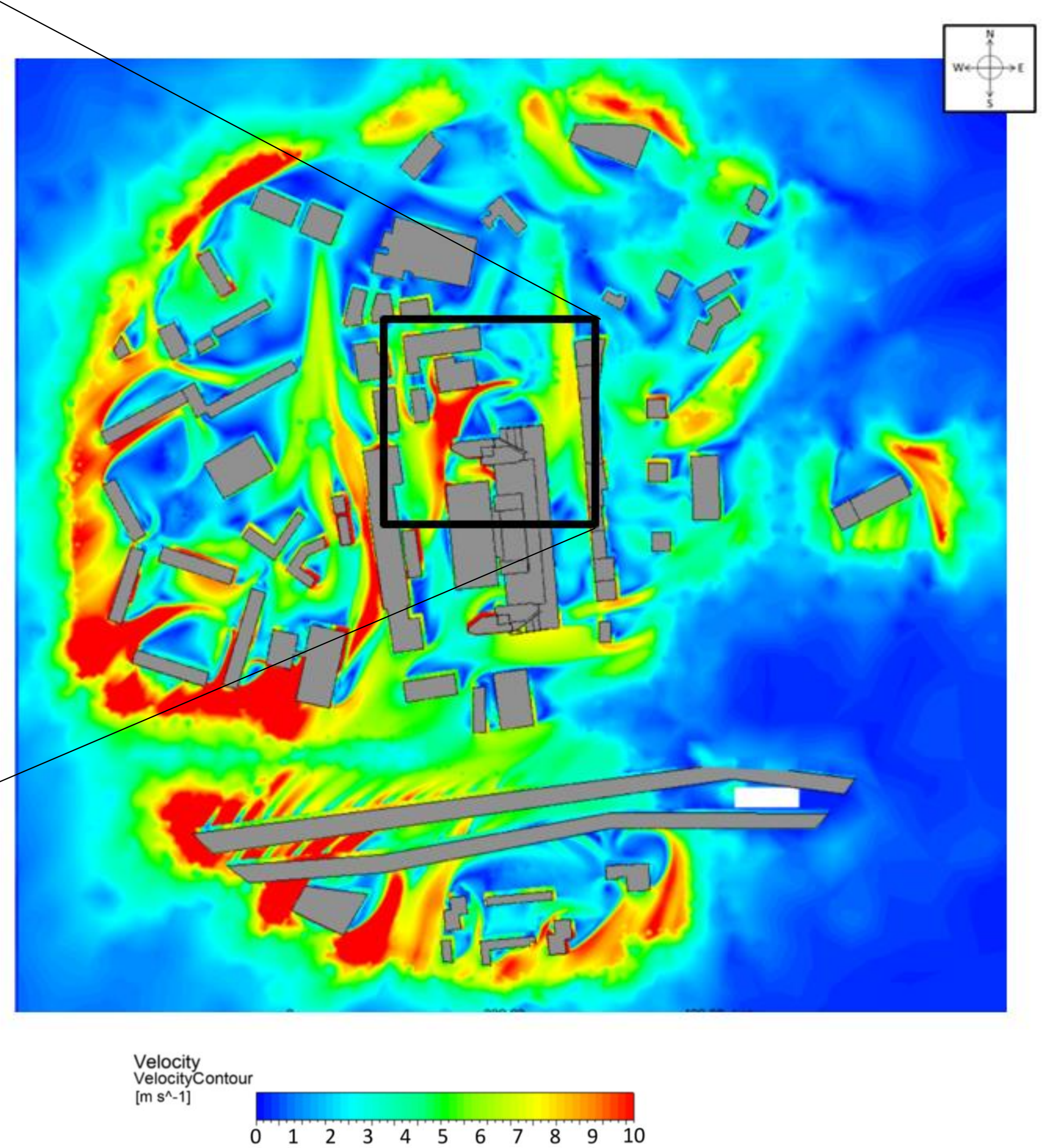
The mitigating effect is less noticeable to the north of Speirs Wharf, where speed reduction is nevertheless still perceptible.

Notice how there is no discernible risk of downdraught from the northern tower.

# Channelling Effects on the Development

## Proposed Design_Prevailing Wind




- As mentioned above, there is some channelling effect to the north-west of the development. This is mainly due to the narrowing of the air path due to the presence of the massing of the planned development.
- The increase in wind speed is of about 15% at worst in this area, for the scenario considered.

## 2.4 Conclusions

Overall, the development does not have an adverse effect on the surrounding area. In fact, it has a beneficial effect on Speirs Wharf. Furthermore, no downdraught effect was recorded in the model.

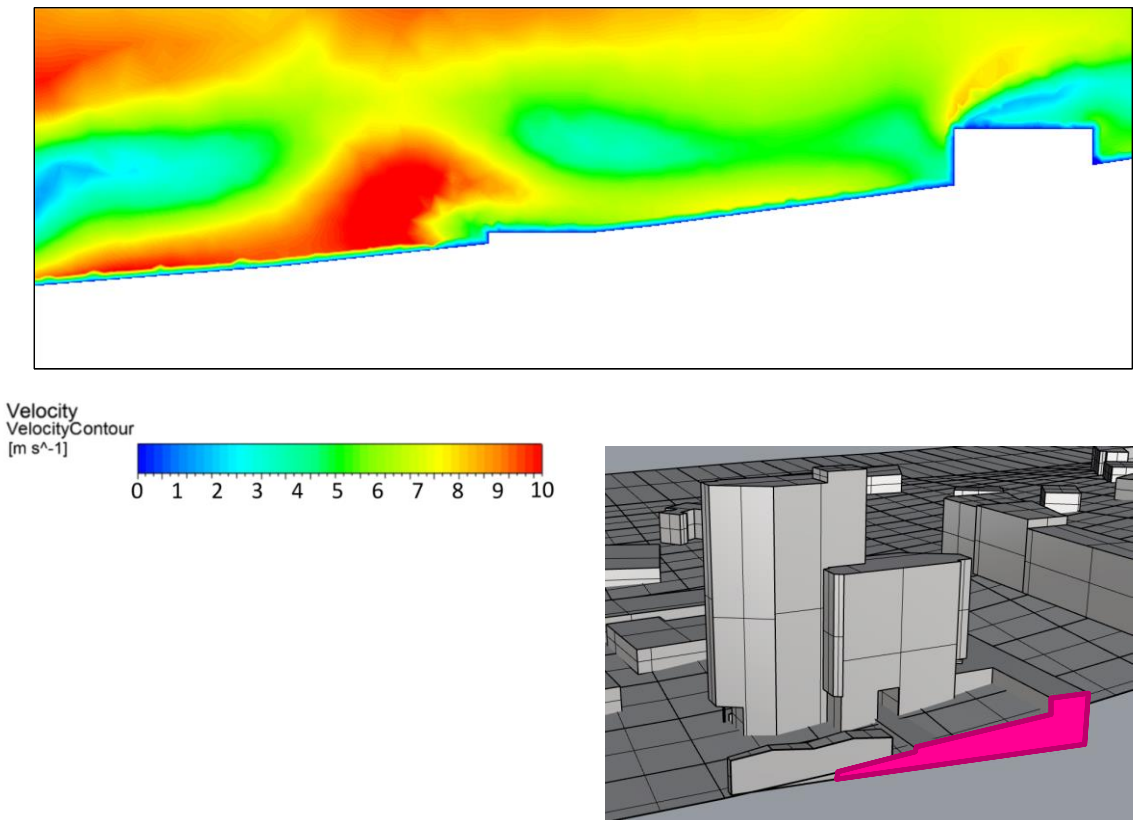
There is some channelling effect to the north-west of the development which might cause mild discomfort for passers-by in the reasonable worst-case scenario of strong wind from the south-west.

However, the potential issues in this area of the development can be substantially mitigated via careful landscaping. A further simulation has been run with a more careful rendition of the geometry of the area, which is stepped. As it is possible to see below, this is already enough to considerably reduce wind speed in the area.

Considering that the complete landscaping will also include some soft elements, such as small trees, bushes, etc. we deem this to be sufficient to considerably reduce potential discomfort in this area.

# Hard Landscaping (further studies)

## Smooth Slope (base case)




## Stepped (proposed improvement)