CLIMATE RESPONSIVE

ARCHITECTURE

Bachelorthesis
Jan Lukas Goldbach
Prof. Dipl.-Ing. Jürgen Reichardt
MSA I Münster School of Architecture
August 2019

urban

https://pixabay.com/de/photos/architektur-new-york-city-manhattan-1850129

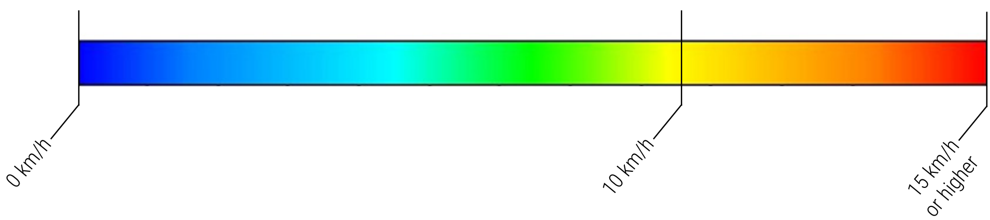
structure

CONTENT

Introduction

The climate change and the impact of higher temperatures in cities can be seen all over the world.
The use of natural ventilated buildings is an efficient and useful way to minimize this impact and forms comfortable climate in the places where people need it.
This use of natural ventilation is only effective, if you have enough air movement to use it. In my thesis I will analyse the behavior of urban structures in context of air movement and velocity and try to gain some knowledge and ideas of improvement. The analysed data should help to understand the air movement through cities and the ways architects can use it in different places to minimize the usage of additional building technology.

In the following study cases and visualisations the blue arrow will always show the direction in which the wind is blowing.



Every Autodesk CFD analysis will be shown with a colorchart like the one above. The first number from left to right will show the standing air with 0 km/h. The second number is the air velocity that is the basis for the corresponding analysis. It marks the speed which is set at the startpoint of the model. The last number shows a velocity that is reasonable in the consens of the analysis, so the results are clear and good to read out of the visualisation.

Thermal comfort in urban climate

The heat balance of human beings is also influenced by air movements or the air velocity in its immediate surroundings. Higher air velocities lead to higher heat transfer at areas of exposed skin and to local cooling of the skin, which is sensed as uncomfortable. At normal room temperatures (20 to 22 °C), acceptable air velocities of 0.1 to 0.2 m/s are given. Apart from the mean air velocity, also the frequency and amplitude of the velocity variations influence the comfort. At the same constant mean air velocity, airflows with high level of turbulence are sensed uncomfortable. In contrast, at high ambient air temperatures and humidity, high air velocities lead to better thermal comfort.

In the warm humid climate from our analyzed zones, the comfort zone would equal other air velocitys.
The proposed comfort zones show that subjects are comfortable up to 32 °C at still air condition (0 m/s–0.2 m/s) and up to 35 °C at higher speed (up to 1.5 m/s) in naturally ventilated buildings in the composite climate of India.[1]

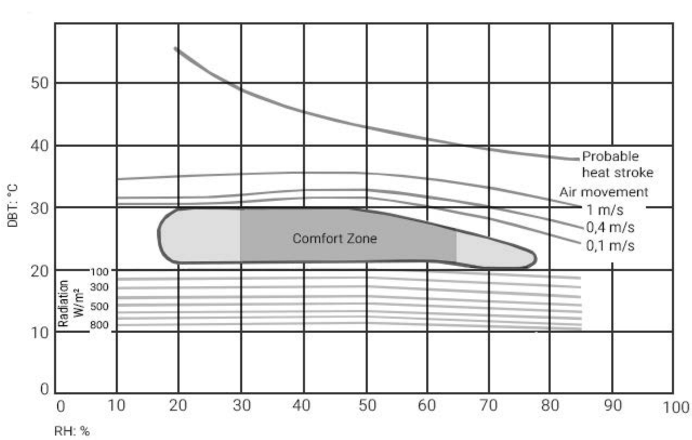


Fig.1: Bioclimatic chart for men at sendentary work, in warm climates [2]

[1] P. O. Fanger, McGraw Hille Book Company, (1973)
[2] Koenigsberger, O.H. et al, (1973)

Physical factors:

- air temperature,
- temperature of the surrounding surfaces,
- relative humidity,
- air movement in the vicinity of the body,
- heat resistance of the clothing.

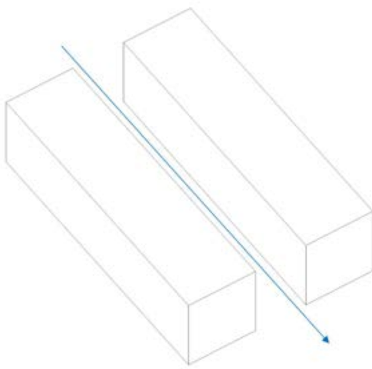
Physiologic factors:

- Weight and body height,
- Metabolism or heat production of the body, respectively. [3]

These informations are based on the thermal comfort zone in ventilated buildings. In an urban climate the physical and physiological factors will remain the same but the psychological factors will be different. So the thermal comfort air velocity at 35°C will rise up to 2.3 m/s (8,2 km/h).
In the urban climate the factors of the temperature of the surrounding surfaces will be much higher than in the buildings. Also the radiation heat of the sun will be a big factor in the feeling of the surrounding climate. [4]

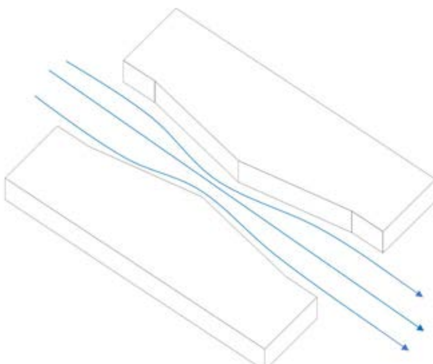
[3] Sanjay Kumar, et al, (2016)
[4] Hanqing Wu, John Zacharias (2006)

Flow effects of urban analysis



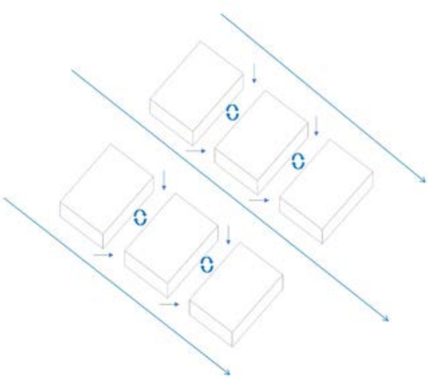
Steady flow

The wind is guided by surrounded buildings and doesn´t change its speed. If the street is only slightly angled it can guide the wind into another direction without building up turbulences.



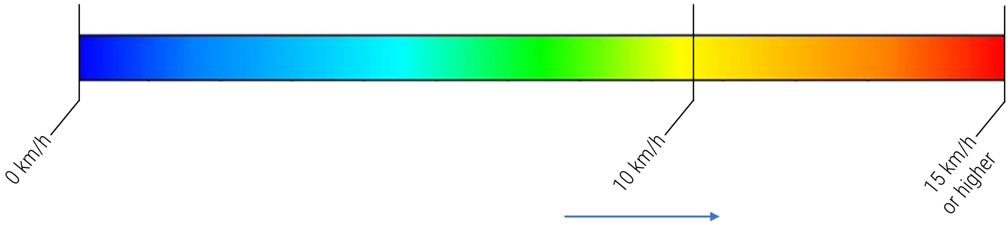
Compression (Venturi effect)

If the wind is guided through a more narrow part of a street, the pressure and speed is building up. After the narrow part the pressure goes down and the speed holds up.



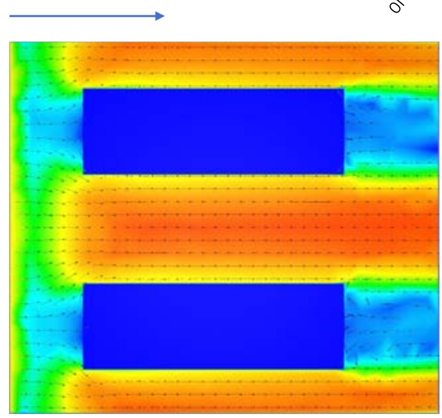
Dividing into streets

If the wind is guided through a main street and the smaller streets are perpendicular to the main street, the wind divides into the smaller streets because of the higher pressure of the moving air. If there is coming wind from the other side of the smaller street, turbulences build up between the buildings.



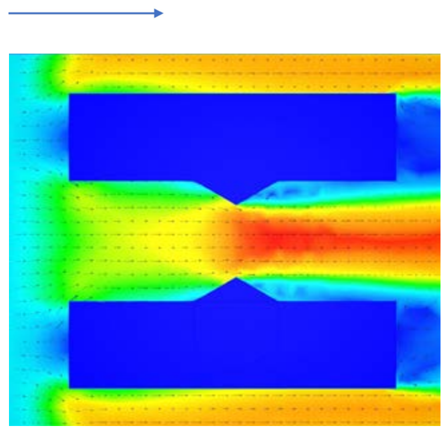
Autodesk CFD 2019

Air velocity : 10 km/h
Pressure at the end: 0 Pa



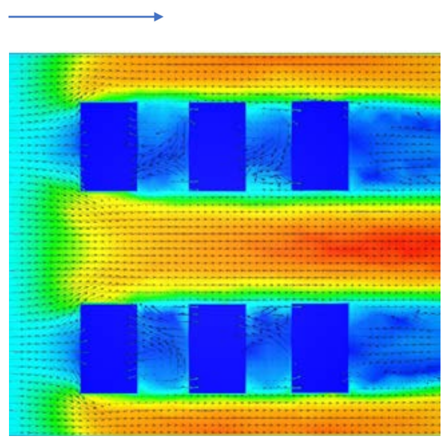
Autodesk CFD 2019

Air velocity : 10 km/h
Pressure at the end: 0 Pa

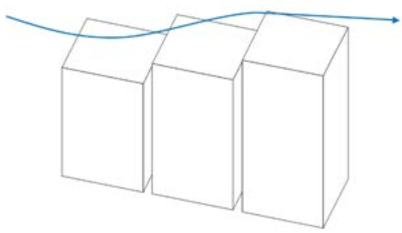


Autodesk CFD 2019

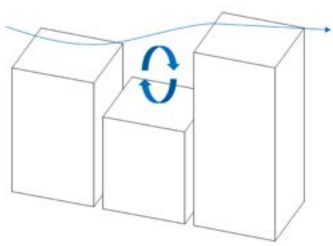
Air velocity : 10 km/h
Pressure at the end: 0 Pa



Flow effects of urban analysis



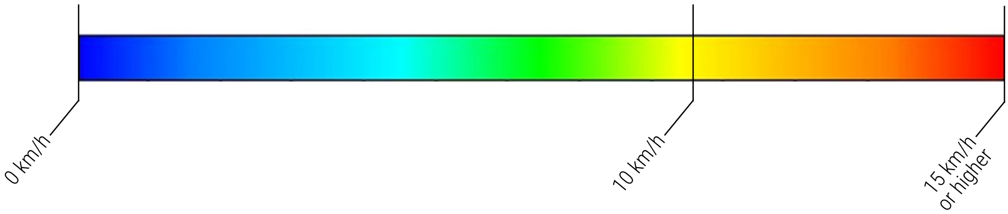
Stepping building structure
The wind is guided smoothly over the slowly rising buildings, if the difference between the buildings isn´t too high.

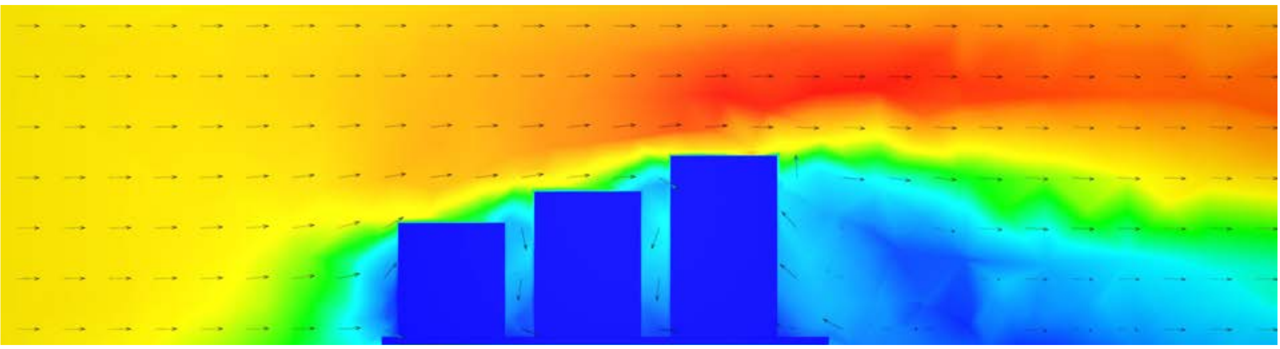


Turbulences between stepping building structure
If the stepping building structure is interrupted by a lower building, it slows down the air and builds up turbulences between the higher buildings.

Flow effects - analysis
The shown flow effects will be paired with the following city analysis so it is easy to compare the effects to city structures. The pictures of the flow effects will be used without their description.

Inspired by : City and Wind- CLIMATE AS AN ARCHITECTURAL INSTRUMENT-Basics 2014

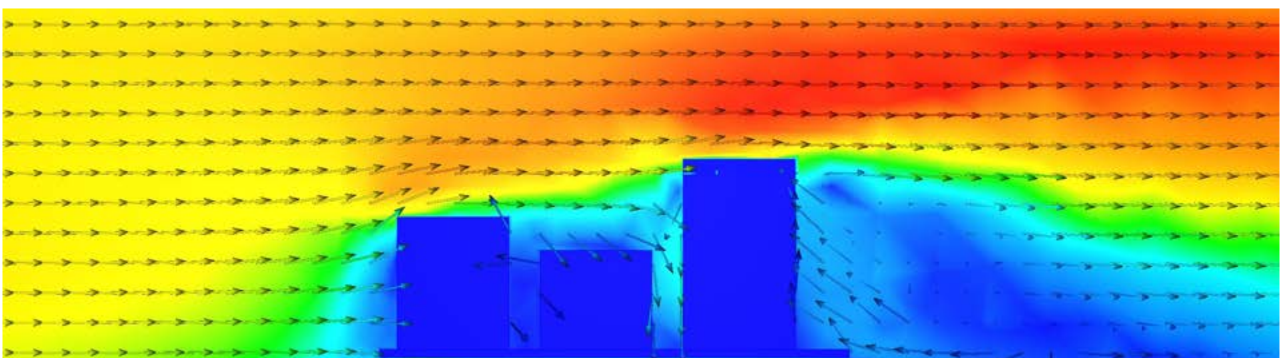




Cross-section of buildings

Autodesk CFD 2019

Air velocity : 10 km/h
Pressure at the end: 0 Pa



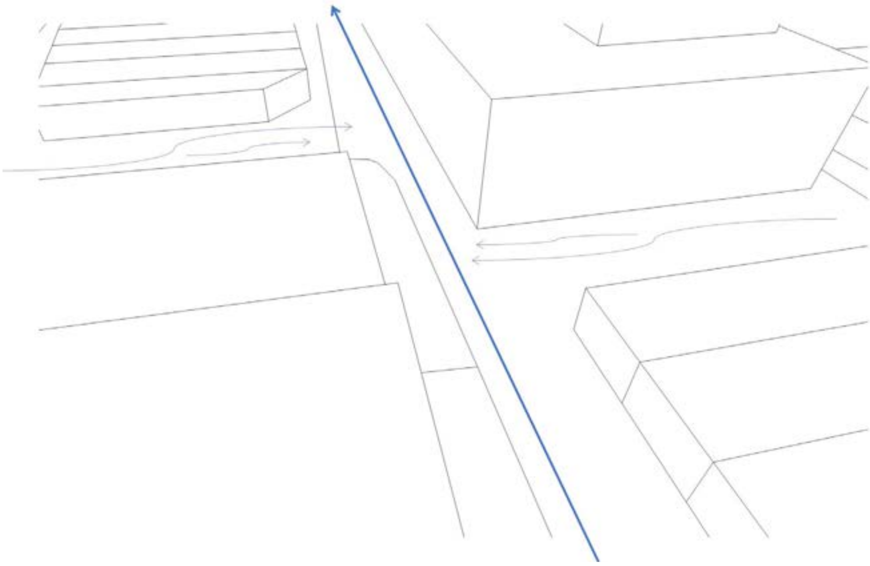
Cross-section of buildings

Autodesk CFD 2019

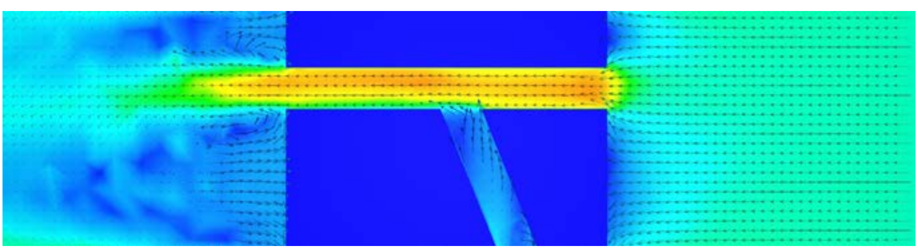
Air velocity : 10 km/h
Pressure at the end: 0 Pa

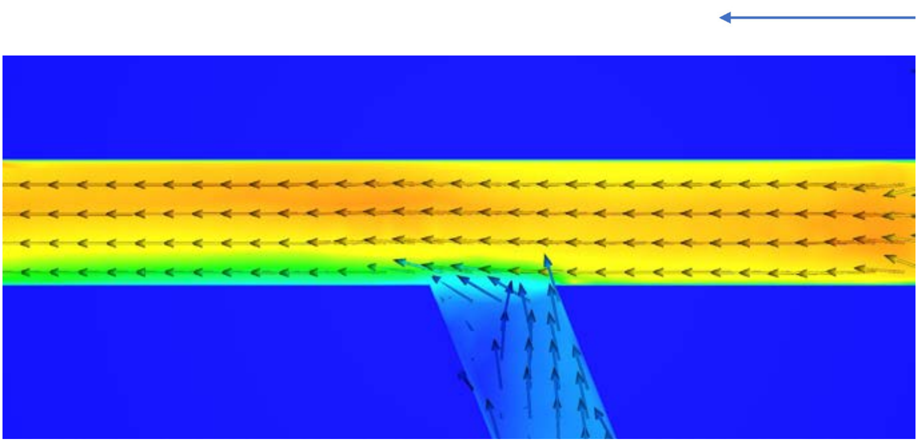
Bernouli effect

The Bernouli effect is the principle of high denser air traveling to regions with less denser air. A partion of standing air has a much higher density than a stream of fast travelling air. So a structural example could be, the stream of wind on a big main street, which is parallel to the wind direction, will suck air from slightly angled side streets that are connected to the main street.[5]



The same effect will create a suction to higher regions by the uprising warm air between high buildings. So the higher the temperatur between the buildings will get, the harder it is, to cool it down with ventilation, because the rising air will suck the cold wind with it to higher regions.

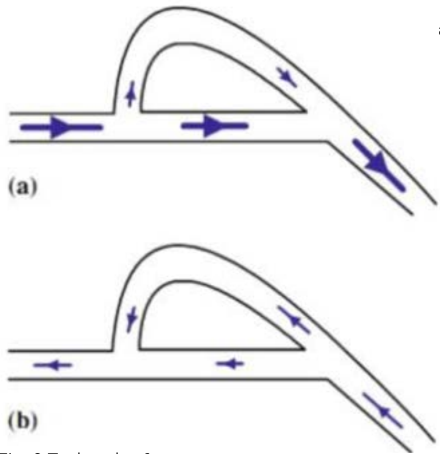




[5]Fluid Power Journal (2013)

Tesla valve

The Tesla valve is a device that Tesla patentet around 1920.



a) in the forward direction,

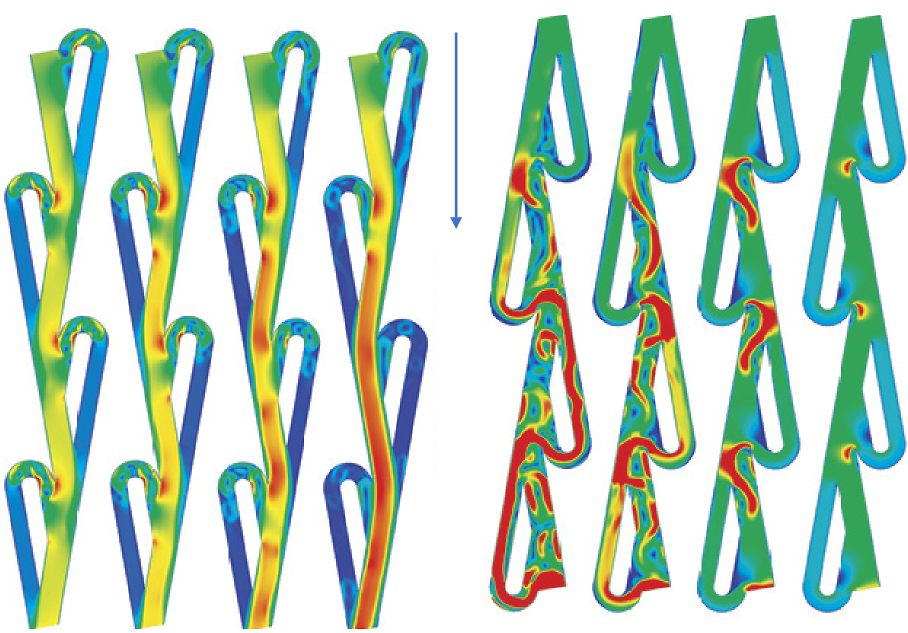
b) in the reverse direction

Fig. 2 Tesla valve [6]

The tesla valve uses the behaviour of a liquid or gas to slow itself down while creating turbulences. In the one direction the liquid or gas is going laminar through the device by using the path of least resistance. In the other direction the curves will create turbulences that flow against the direction of the main flow. This effect will increase with a higher velocity.

The effect of this device can be seen in a lot of urban structures. The tesla valve is a good example for understanding the context of corresponding streets and turbulences.

Same speed at the intake



b) in the forward direction - much higher speed of air at outlet

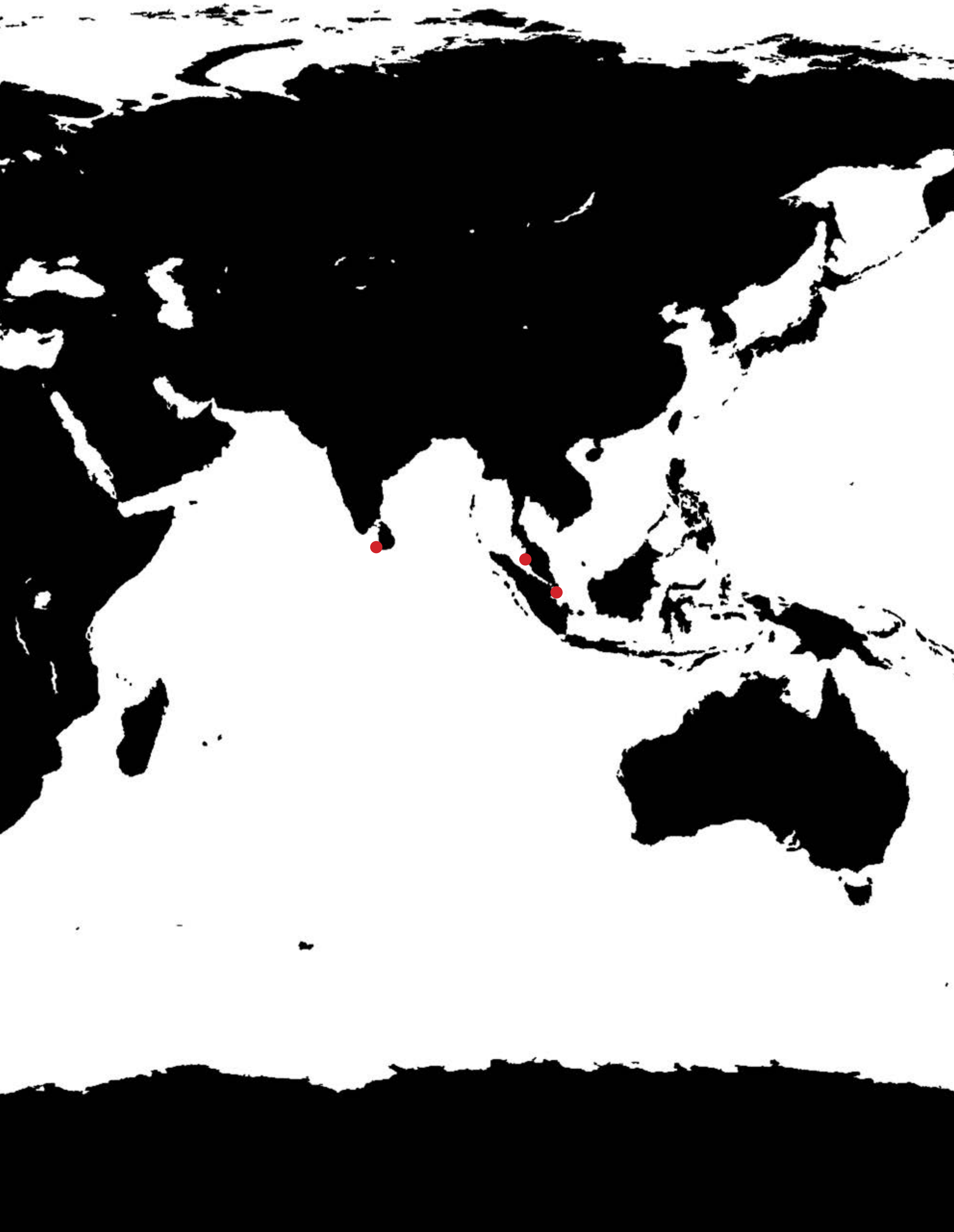
b) in the reverse direction - the turbulences at each valve slow down the air

Fig. 3 Tesla valve analysis [6]

[6] Liung Wang, et al, (2017)

Analysis

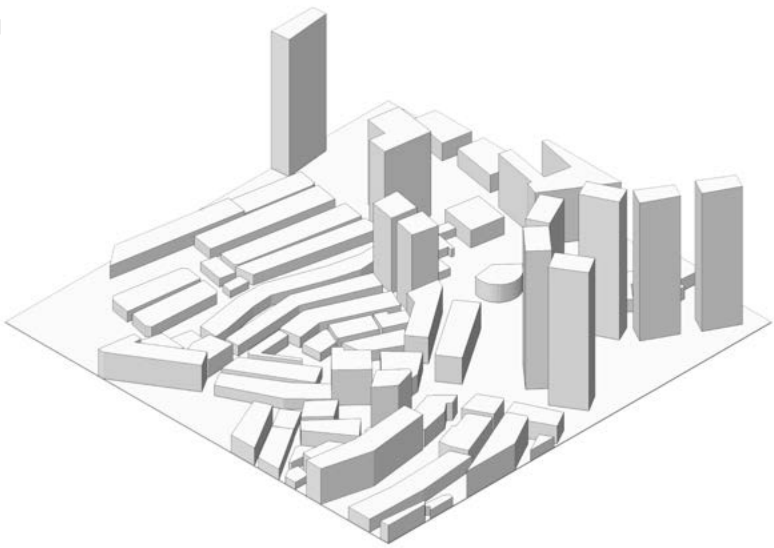
http://eumontage.dk/wp-content/uploads/2018/11/new-black-and-white-world-map-8.jpg (access : 22.07.2019)



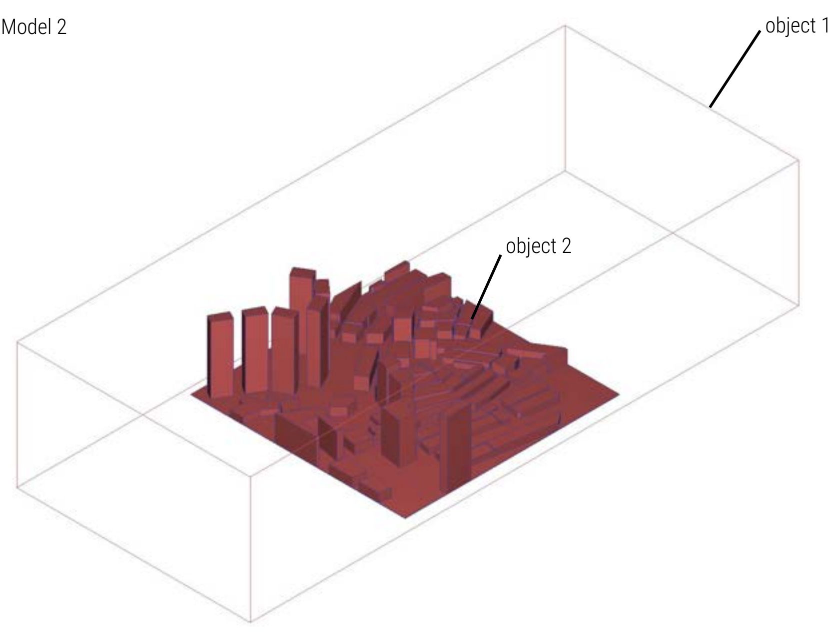
Analysis

The following part will analyse three typological different cities to their behaviour on temperature and wind. I used three dimensional data to rebuild a representative 500 m x 500 m square part of the city as an CAD model. I broke down the information to the relevant parameters I need to analyse the models in a computer assisted simulation program (Autodesk CFD 2019). The parameters given to the program are based on the average climate of 2018 in the analysed regions.

Model 1



Model 2



Model 1 shows the constructed 3D model from the analysis square. The informations for the model are collected from different sources to generate a accurate basis for the following steps. The sources I used are cadmapper.com in combination with Google maps and Schwarzplan.eu to create a exact representation of the groundfloor. For the 3 dimensional aspect I used information from google streetview, cadmapper.com and the information websites of some buildings.

Model 2 shows the input data for the analysis programm. Object 2 is the 3D modell I explained in the paragraph above which gets the information of the material and the behaviour of the material. Object 2 is a created body that gets the information of the surrounding air.
The pictures that show the analysed data will be cross-sections of the model or a horizontal cut that can be done in different hights to show the results.

Singapur

Temperature : 29 °C
Windspeed: 11 km/h [7]

Fig. 4 worldmap [9]

[7] WorldWeatherOnline.com (2018)
[8] dateandtime.info (2011-2019)
[9] EU Montage Danmark ApS (2019)

North-oriented plan
500 m x 500 m

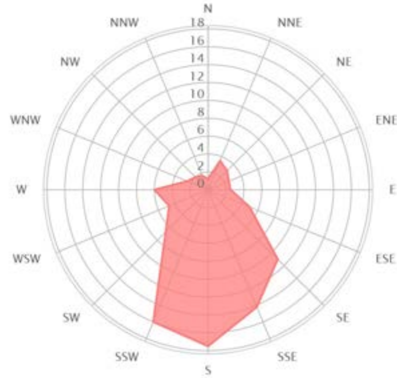


Fig. 5 Average wind direction 2018 [10]

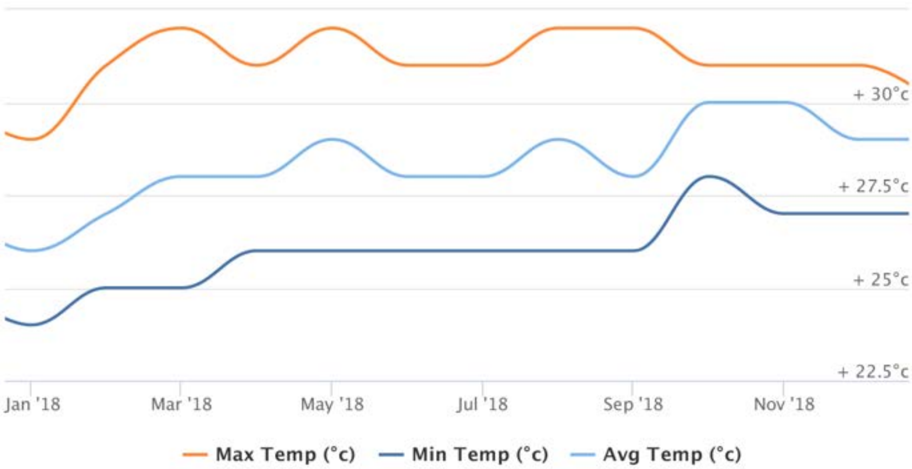


Fig. 6 Max, min and average temperature 2018 [11]

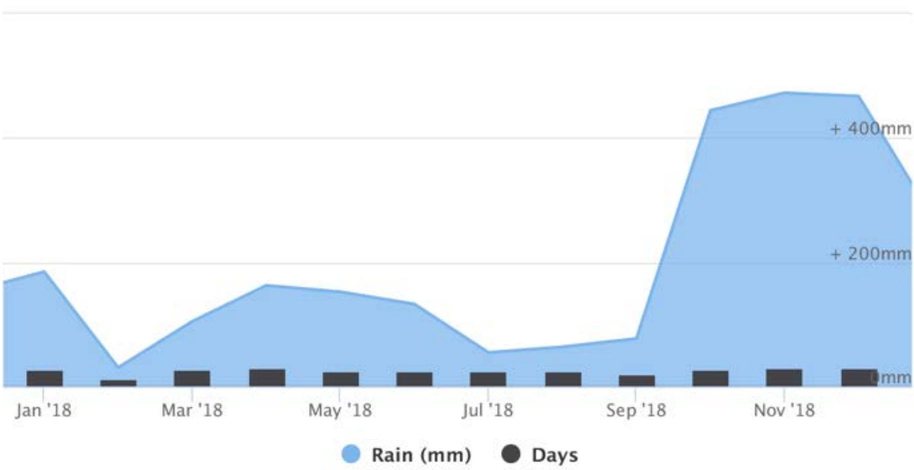
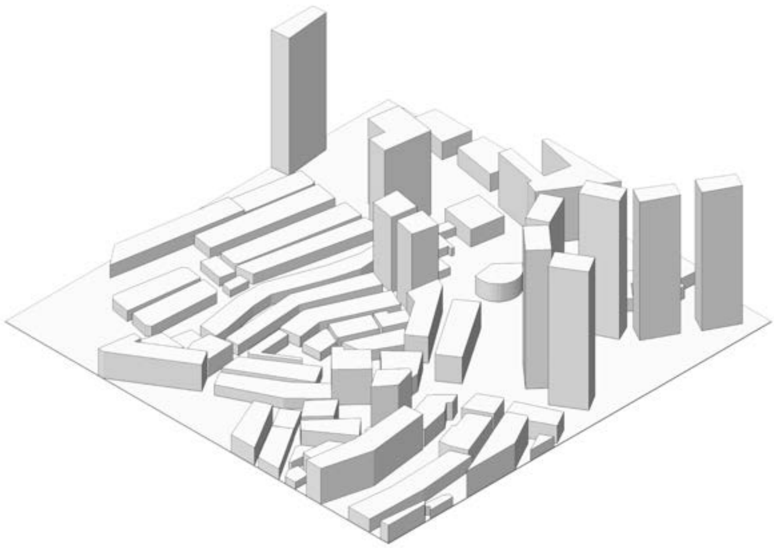


Fig. 7 Average rainfall and rainy days 2018 [11]

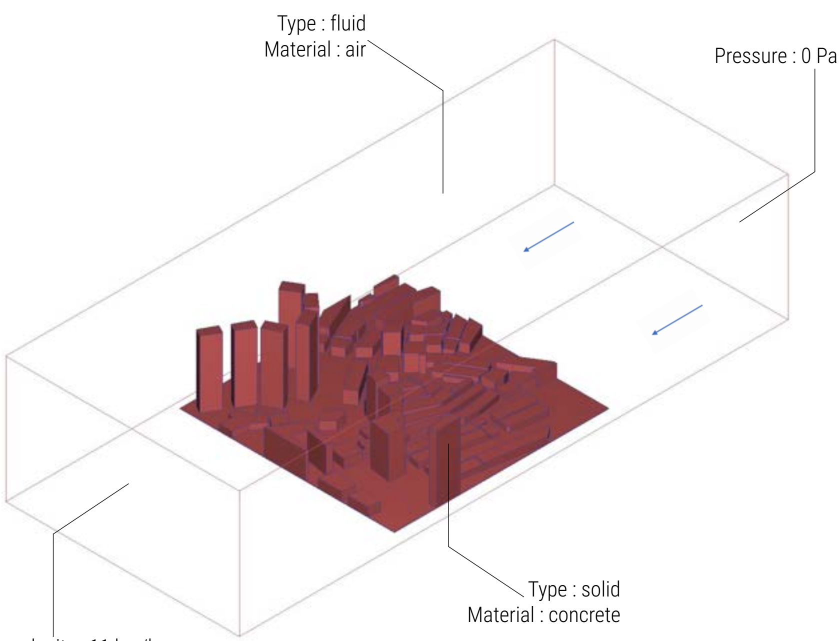
[10] WindFinder.com (2018)
[11] WorldWeatherOnline.com (2018)

500 m x 500 m analysis square



Colombo

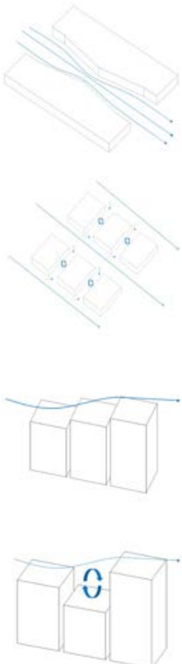
Teluk Bahang



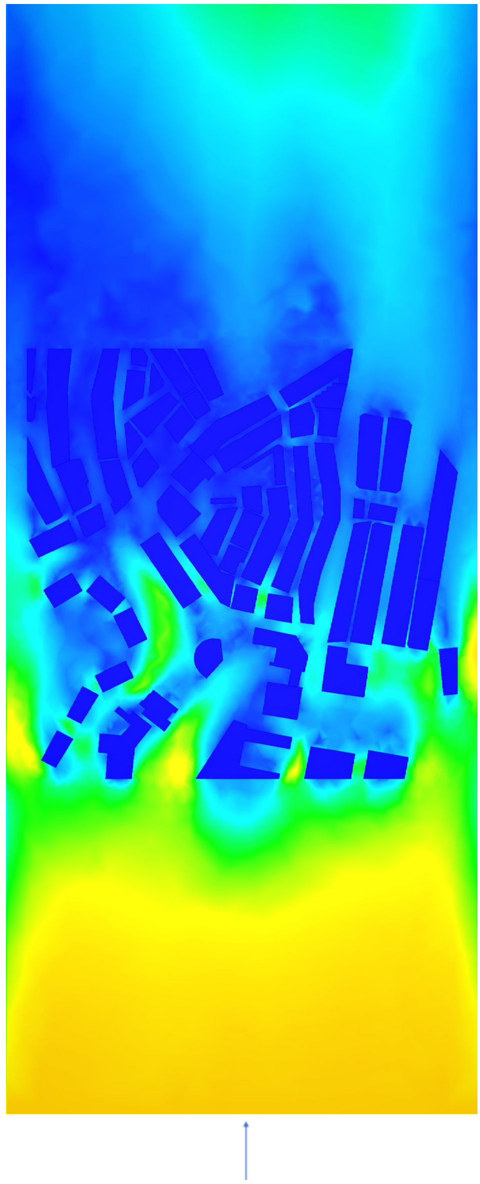
Information input for Autodesk CFD 2019

North-oriented analysis

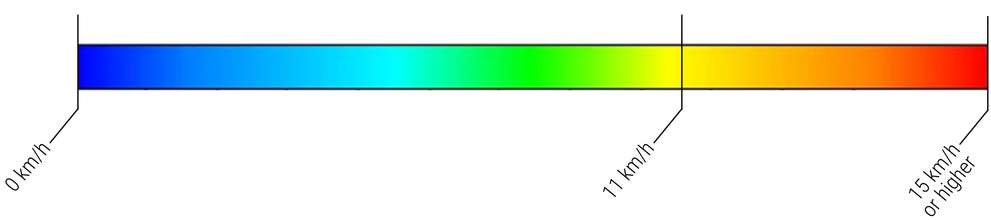
Analysed wind effects

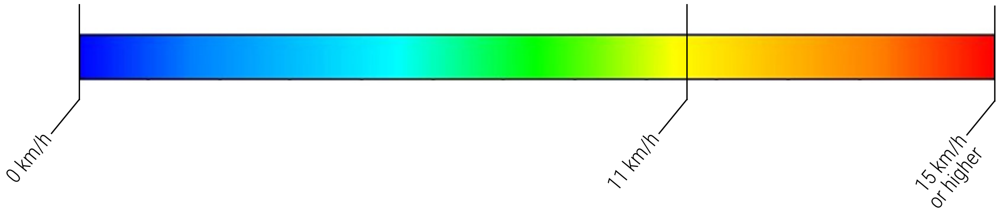


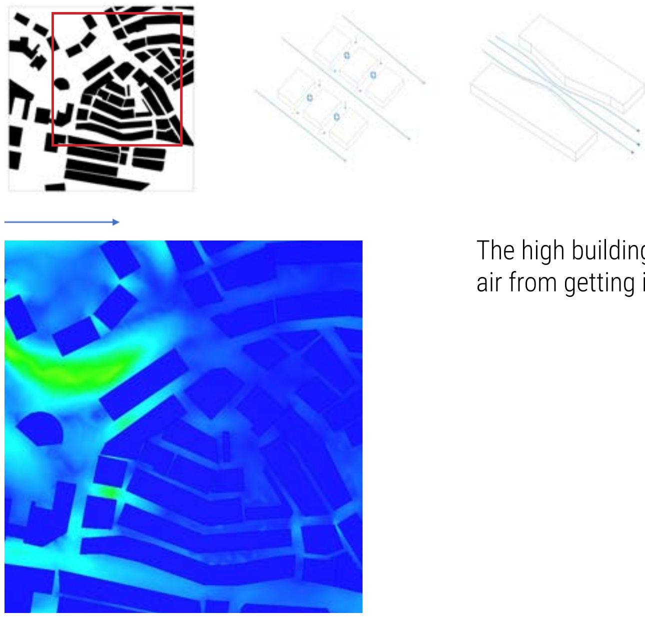
North-oriented analysis



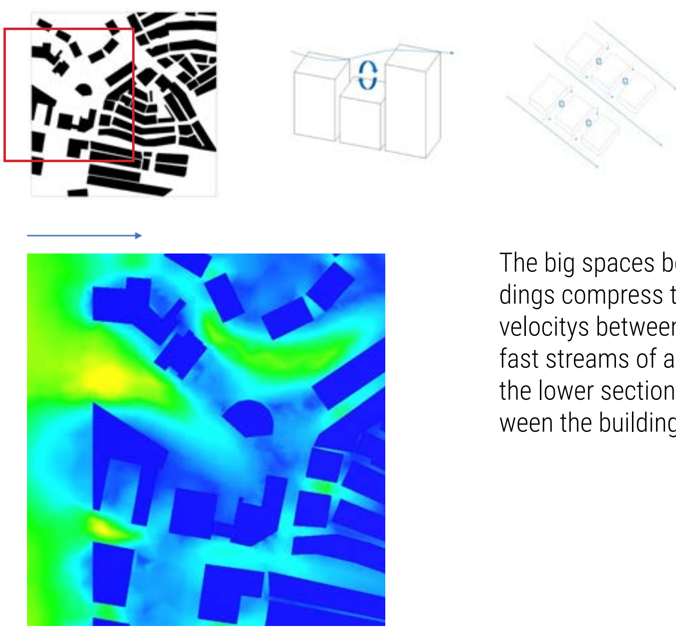
Air velocity : 11 km/h
From S



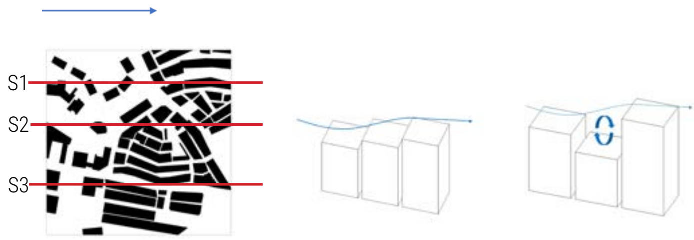




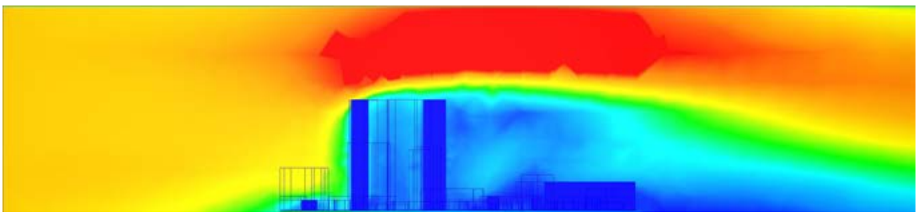
The high buildings in the front stop the air from getting into the smaller streets.



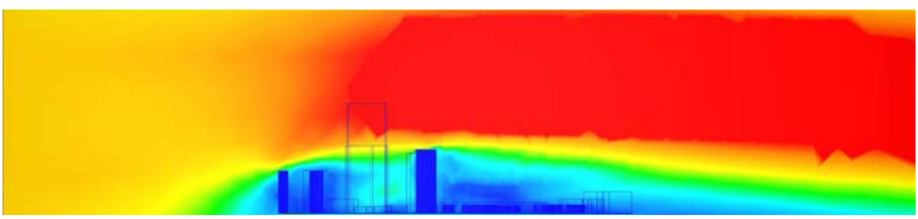
The big spaces between the high buildings compress the air streams to high velocitys between the buildings. These fast streams of air are not able to reach the lower sections. The difference between the building heights is to big.



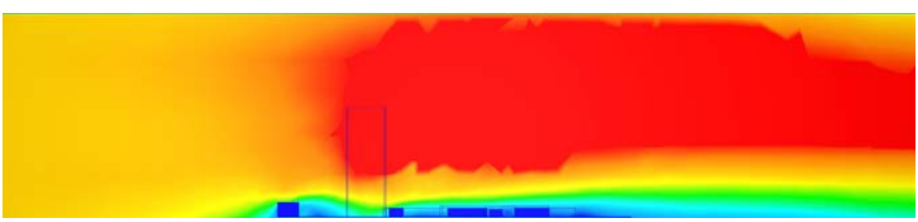
S1



S2

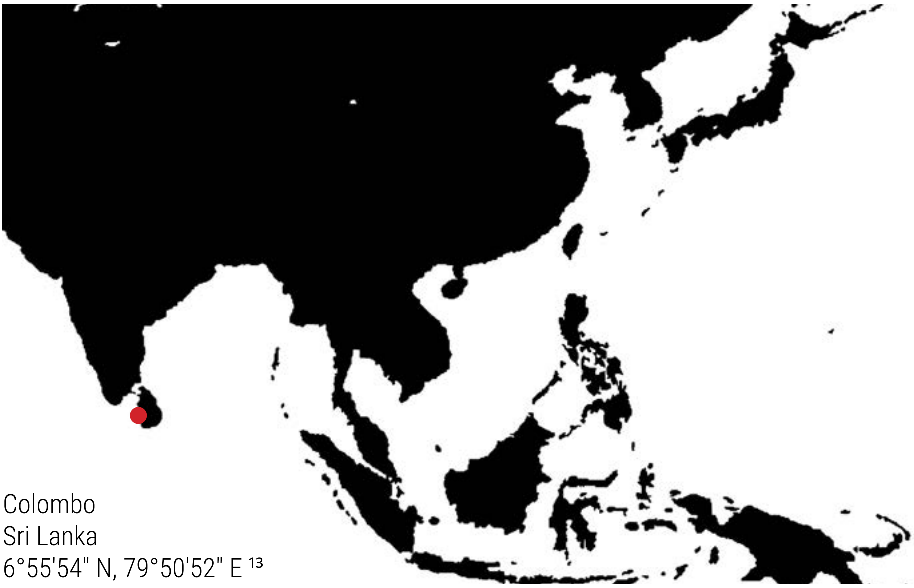


S3



Colombo

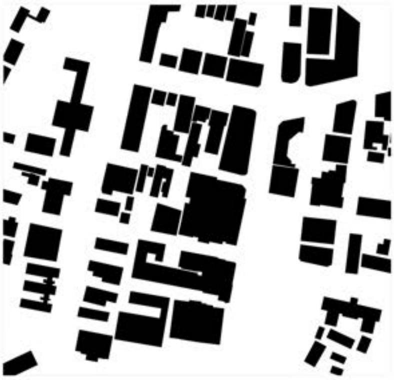
Temperature : 28 °C
Windspeed : 12 km/h [12]



Colombo
Sri Lanka
6°55'54" N, 79°50'52" E [13]

Fig.8 worldmap [14]

[12] WorldWeatherOnline.com
[13] dateandtime.info (2011-2019)
[14] EU Montage Danmark Aps (2019)



North-oriented plan
500 m x 500 m

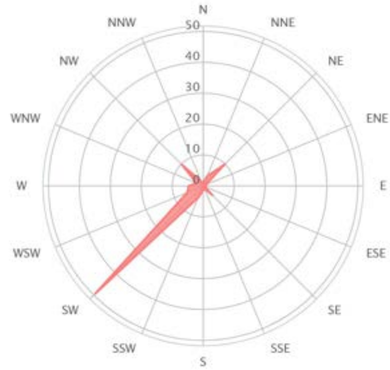


Fig. 9 Average wind direction 2018 [15]

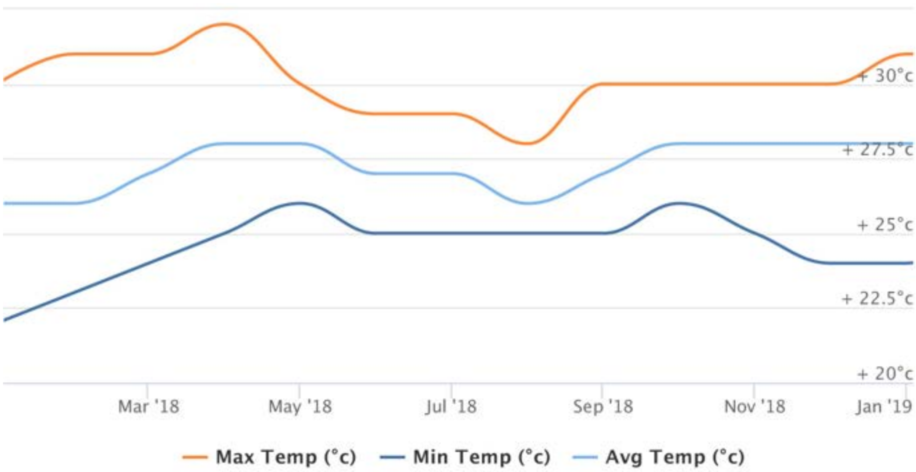


Fig. 10 Max, min and average temperature 2018 [16]

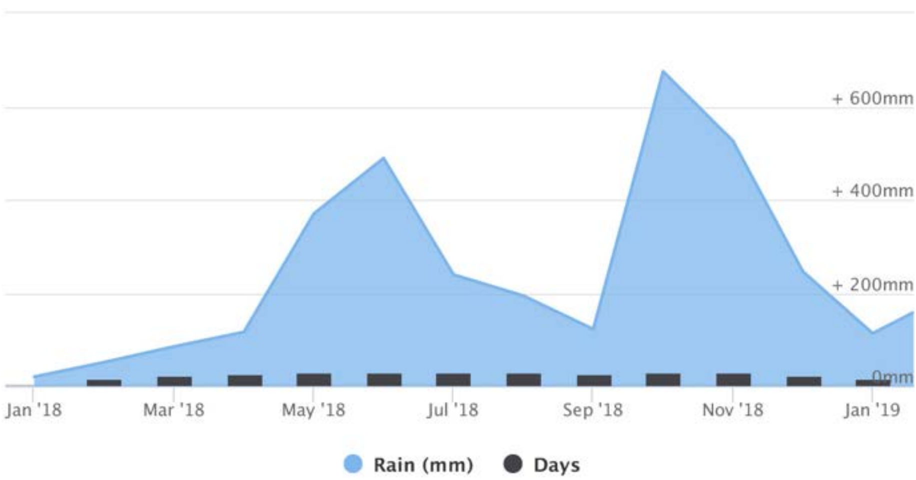
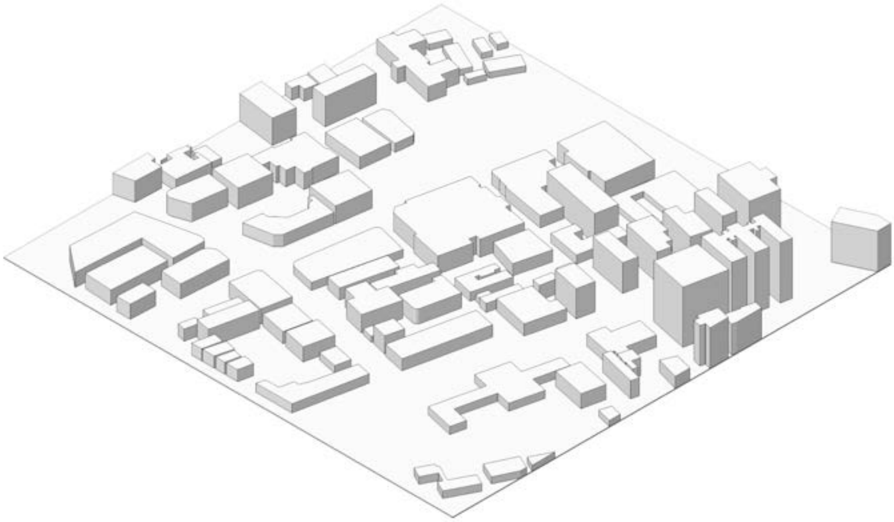


Fig. 11 Average rainfall and rainy days 2018 [16]

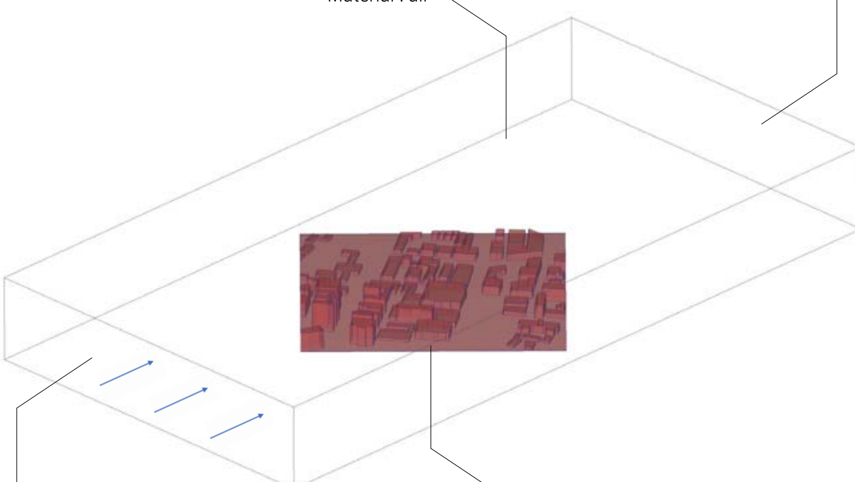
[15] WorldWeatherOnline.com (2018)
[16] WindFinder.com(2018)

500 m x 500 m analysis square



Singapur

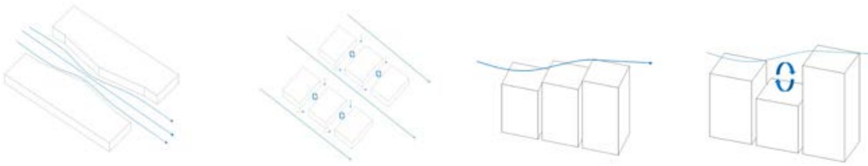
Teluk Bahang

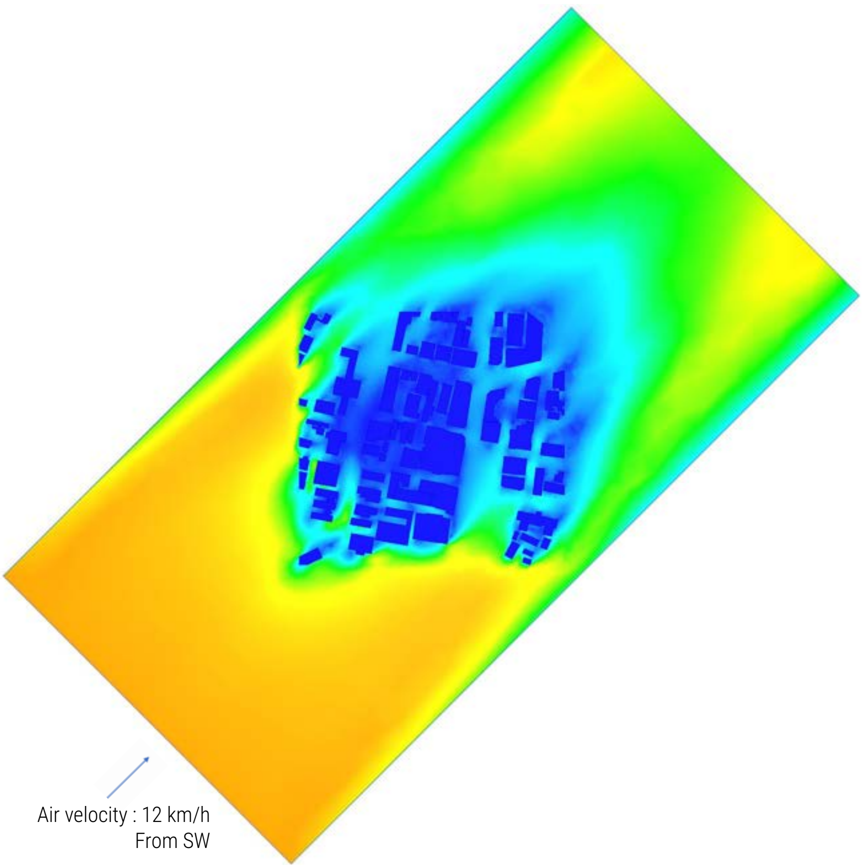


Information input for Autodesk CFD 2019

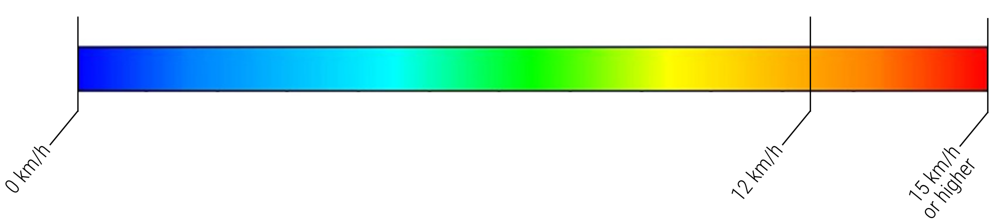
North-oriented analysis

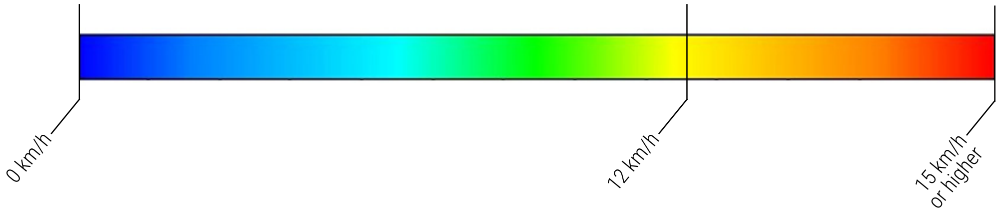
Analysed wind effects

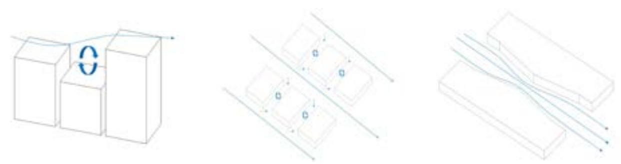


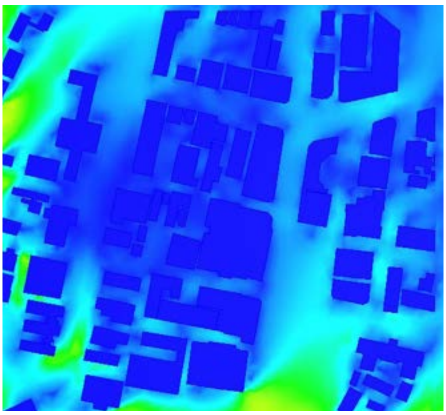


North-oriented analysis

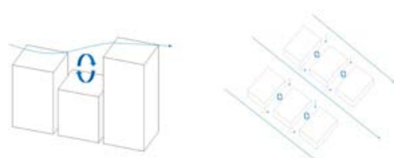


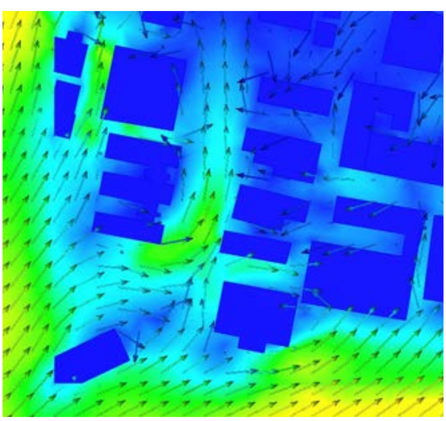




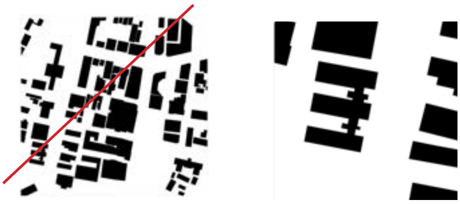


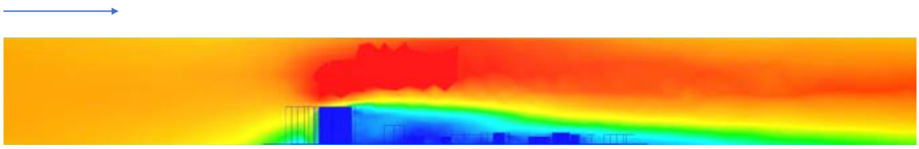
The wide street size, proportional to the building size allows some air movement between the buildings.



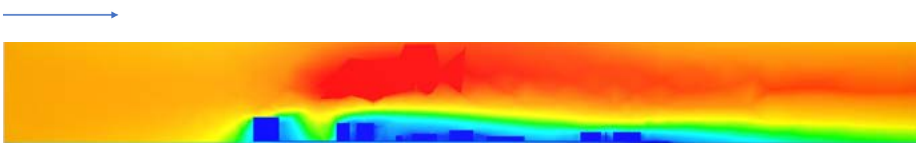


The street layout allows the air to flow through the streets, which are only slightly angled to the wind direction.



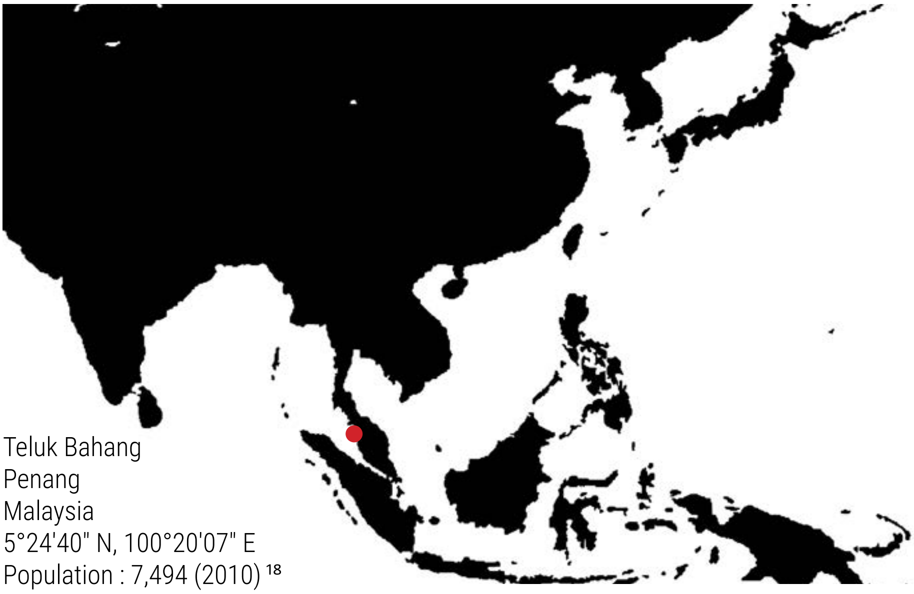


The form of the high building in the front of the square lets the air gain some speed after a relatively long distance behind the building.



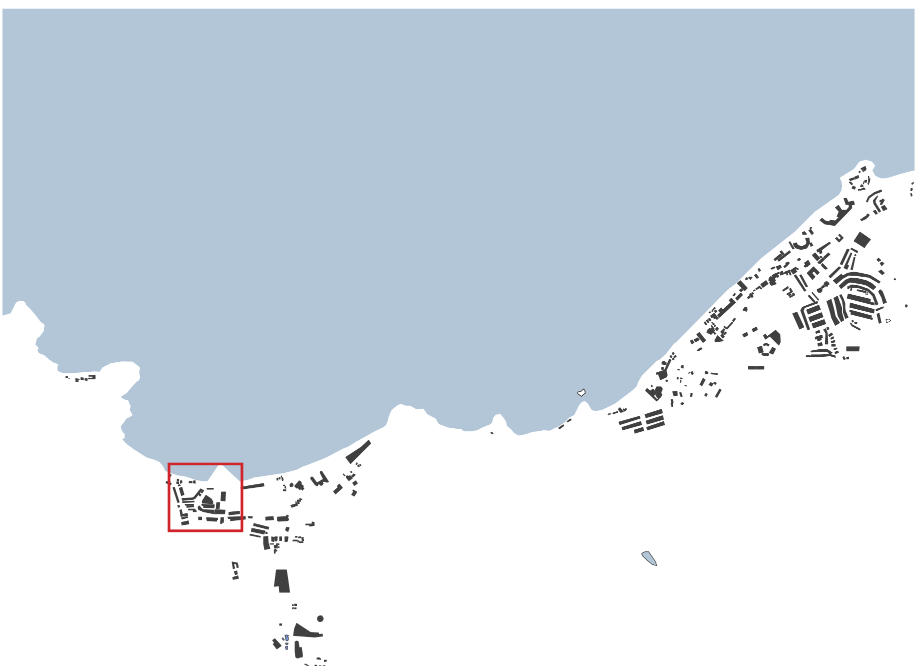
Teluk Bahang

Temperature : 28 °C
Windspeed : 10 km/h [17]



Teluk Bahang
Penang
Malaysia
5°24'40" N, 100°20'07" E
Population : 7,494 (2010) [18]

Fig.12 worlmap [19]



[17] WorldWeatherOnline.com (2018)
[18] dateandtime.info (2011-2019)
[19] EU Montage Danmark ApS (2019)

North-oriented plan
500 m x 500 m

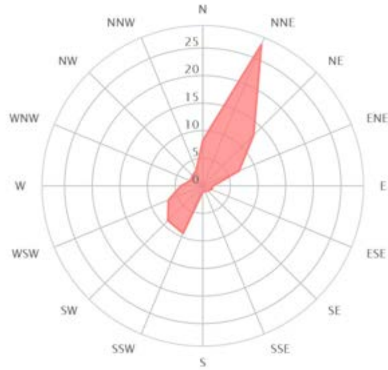


Fig.13 Average wind direction
2018 [20]

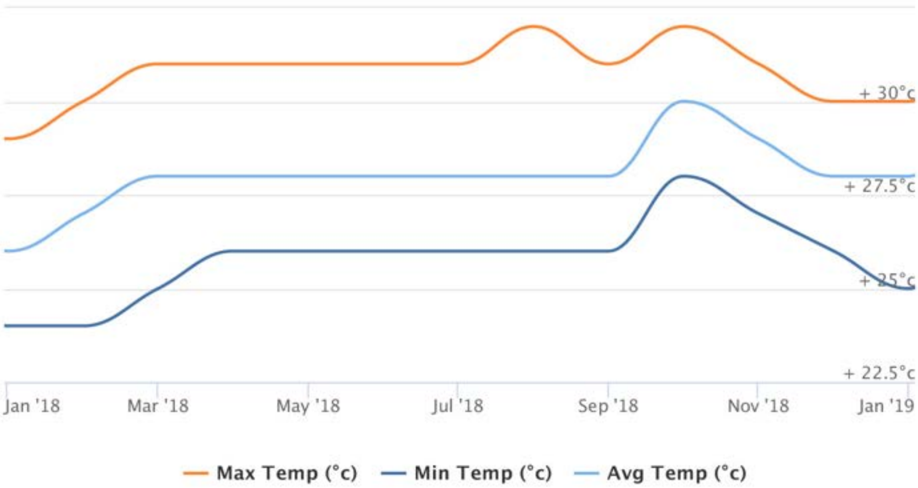


Fig. 14 Max, min and average temperature 2018 [21]

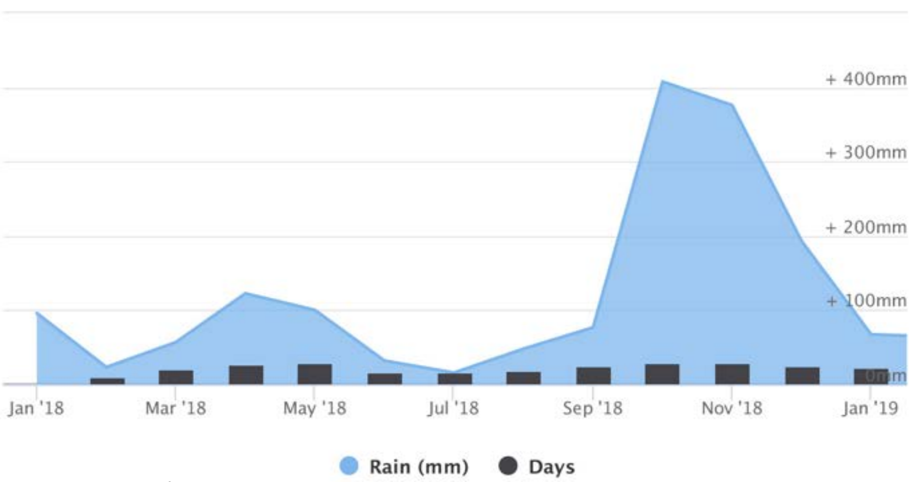
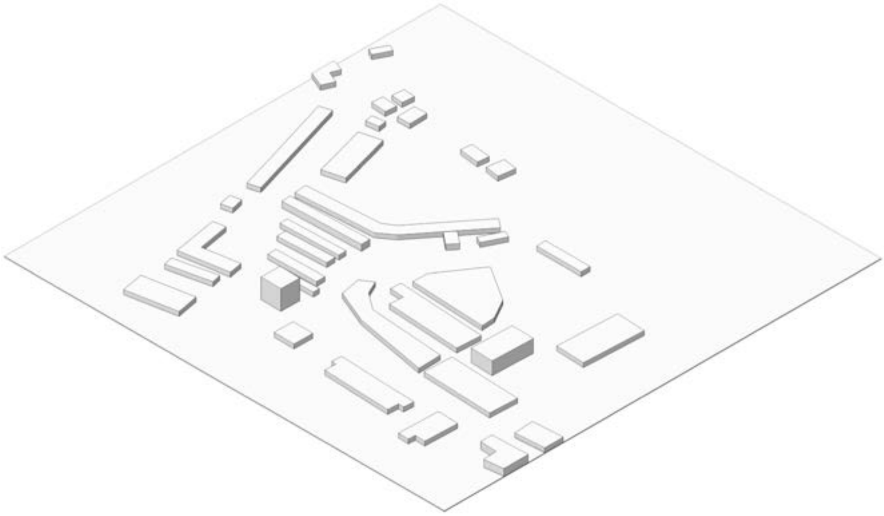


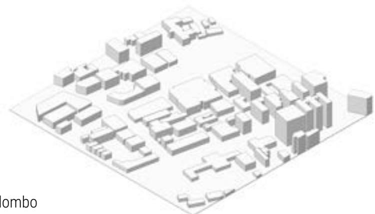
Fig. 15 Average rainfall and rainy days 2018 [21]

[20] WindFinder.com (2018)
[21] WorldWeatherOnline.com (2018)

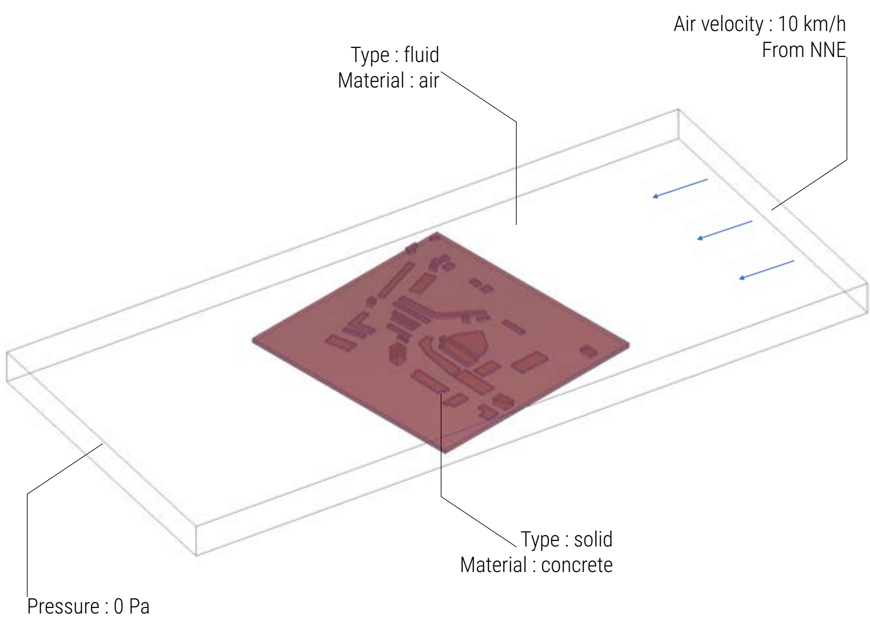
500 m x 500 m analysis square



Singapur



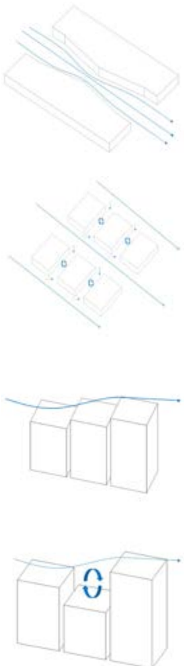
Colombo



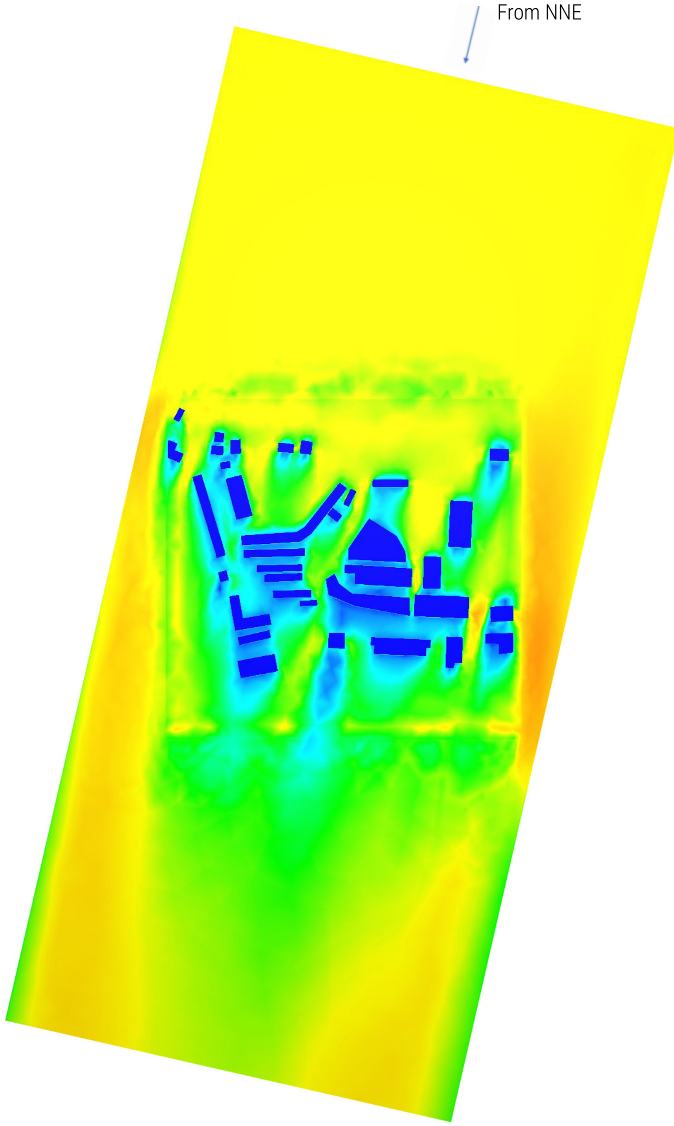
Information input for Autodesk CFD 2019

North-oriented analysis

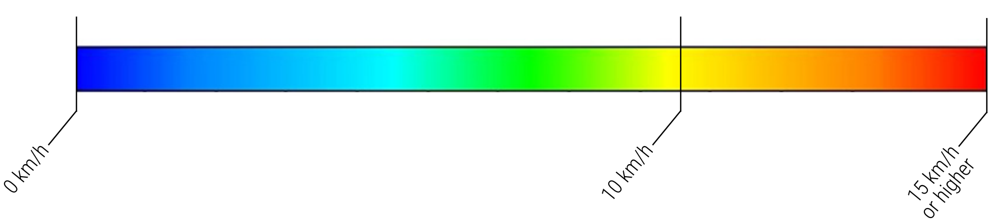
Analysed wind effects

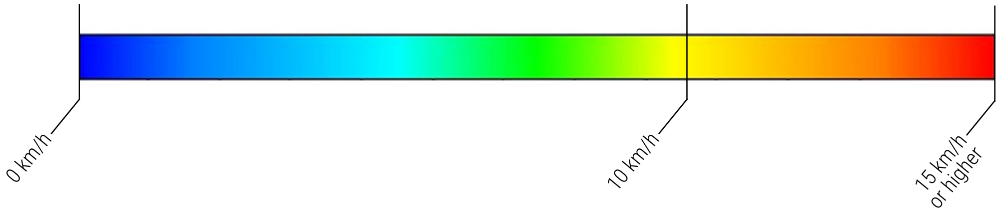


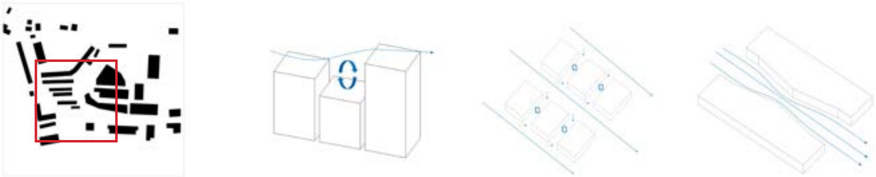
Air velocity : 10 km/h
From NNE

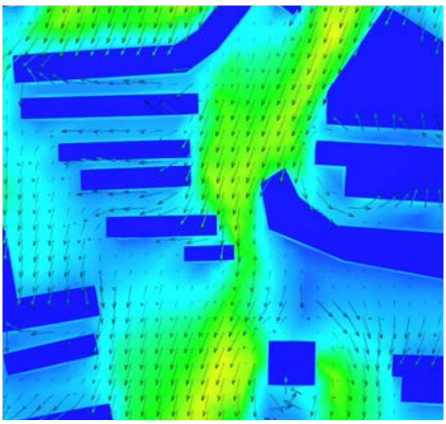


North-oriented analysis

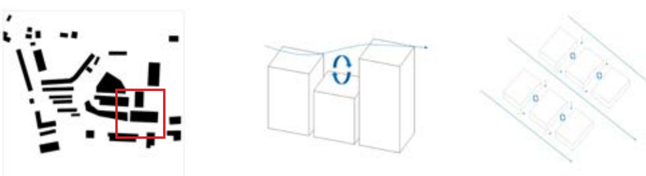


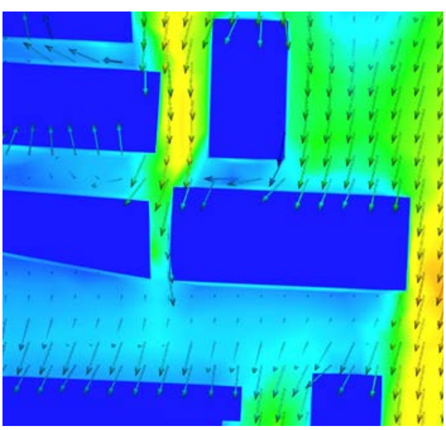




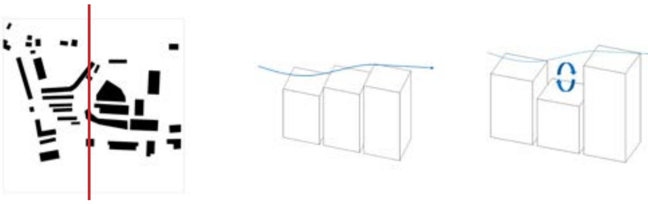


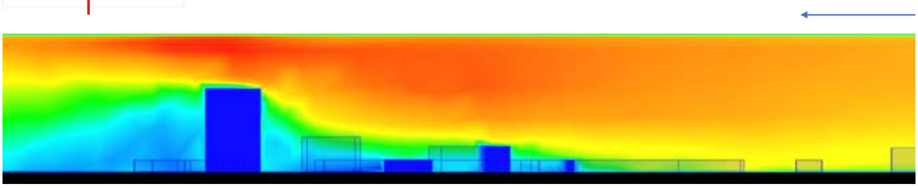
The building structures are opened to the wind direction, so the smaller side streets are able to collect a small amount of the wind.
Because of the wide opened spaces between some building groups the wind is able to flow in the regions of the lee side from the analysed square.

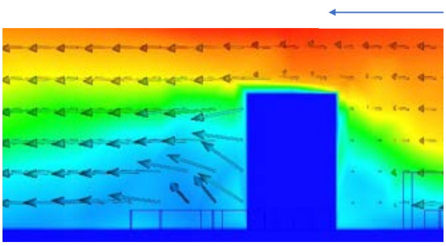




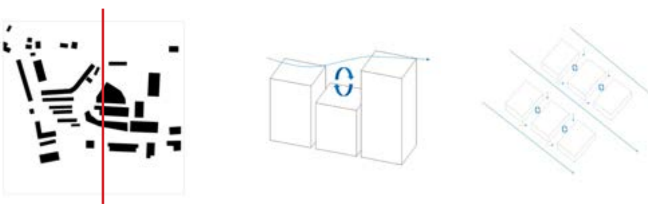
Because of the low profile of the buildings (see cross section analysis on the next side) turbulences are created behind the buildings. The turbulences create air movement in the orthogonal streets that are too long to benefit from the principle mentioned above.

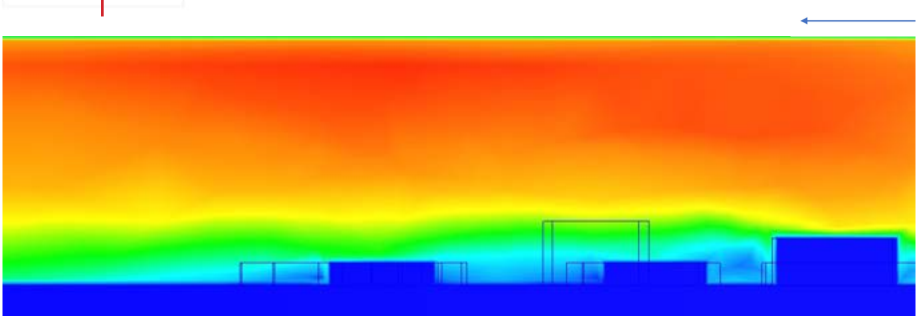






The low amount of high buildings gives the air the chance to speed up in a short distance after passing the higher structures. Paired with the high amount of low buildings this ensures a relatively high air velocity at the end of the analysed square.



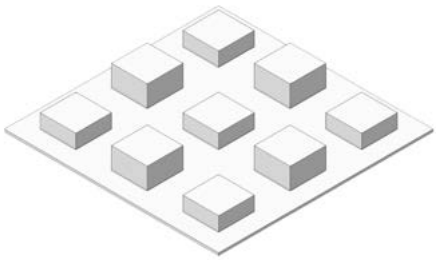


Because of the low profile of the buildings the turbulences create air movement in the orthogonal streets that are too long to benefit from the principle mentioned above. The average windspeed 2 meters above the ground has only dropped around 1,5 km/h after leaving the 500 m x 500 m analysis square.

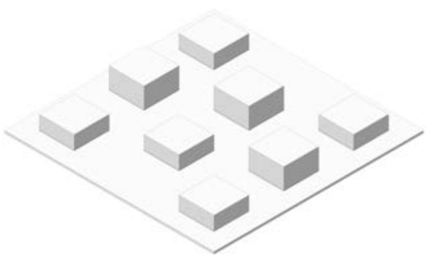
Structure basics

The following part will analyse some basic urban structures to develop basic information for building up a city plan which uses the analysed parameters to form a continuous airflow. The airflow will be able to stop the streets from heating up too much and allows a comfortable climate between the buildings.
The basic models can not be used to generate an exact way of thermal correct city planing and can not be compared to an analysis of a specific urban structure. But they can create some information to use as a basis for creating corresponding buildings. The direct analysis of the structure which is created will always be more efficient but if it follows basic rules it needs smaller adjustments to gain a better result in airflow.

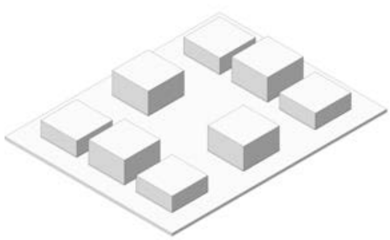
Living space



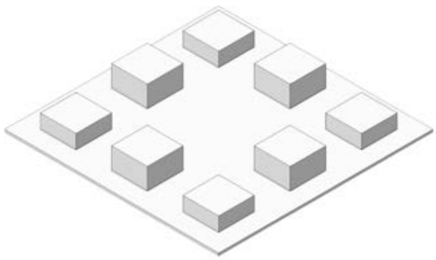
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.



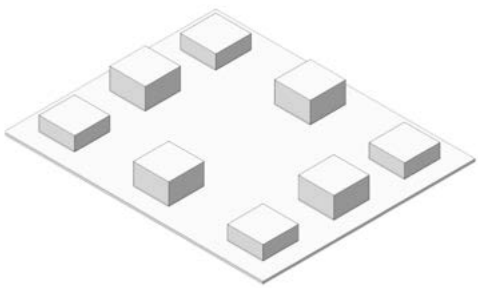
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
The second row of buildings is placed in between the buildings of the first and thrid row.



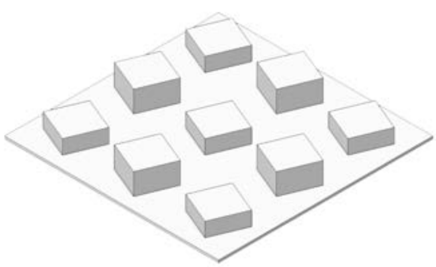
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
In the middle is a free section to mimic an area to gain some airspeed.
The section between the buildings is 25 meters.



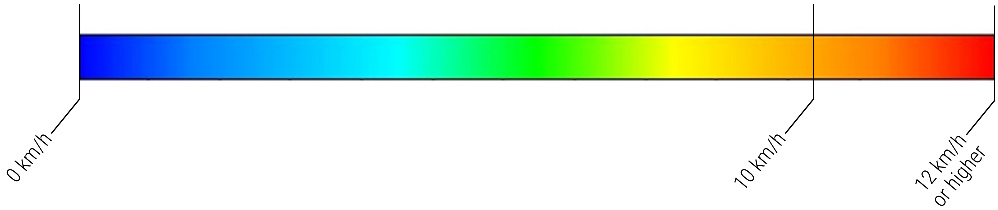
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
In the middle is a free section to mimic an area to gain some airspeed.
The section between the buildings is 45 meters.

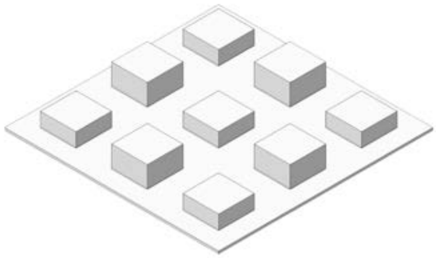


-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
In the middle is a free section to mimic an area to gain some airspeed.
The section between the buildings is 65 meters.

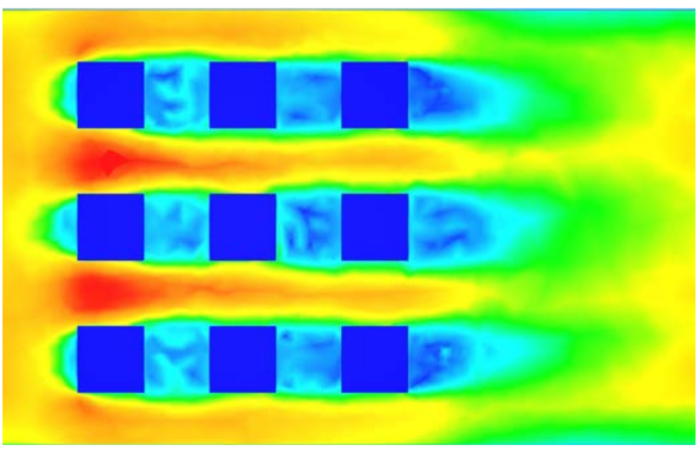


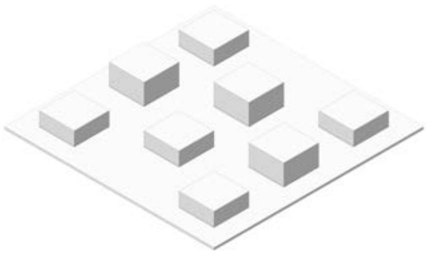
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
The floorplans are 22,5 ° tilted to compare the effect to the first structure.



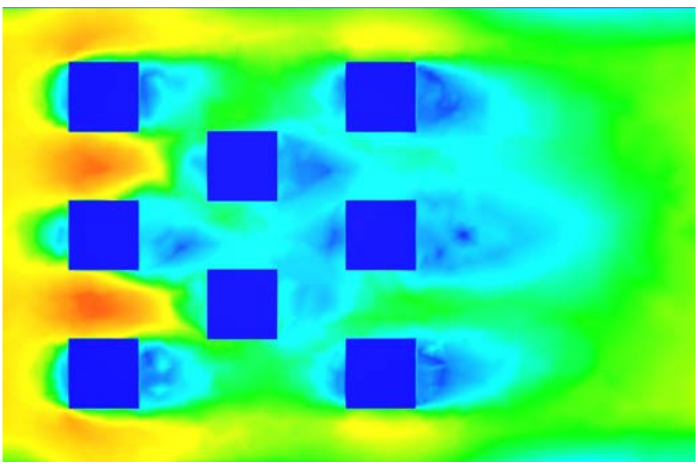


-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.

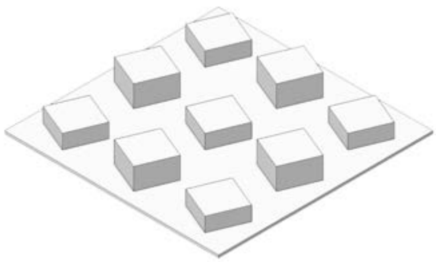




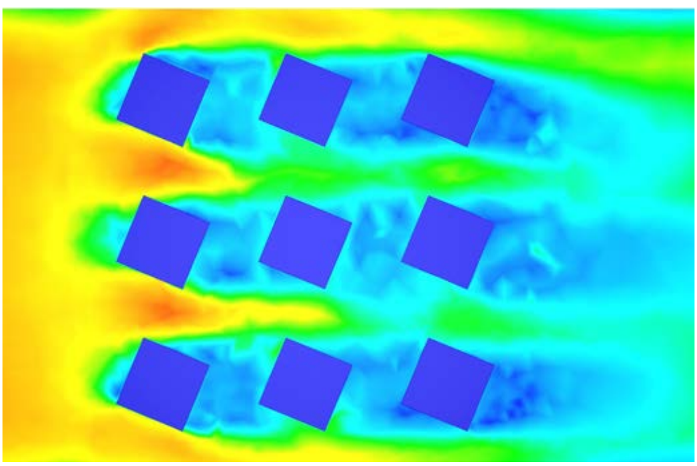
-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
The second row of buildings is placed in between the buildings of the first and thrid row.

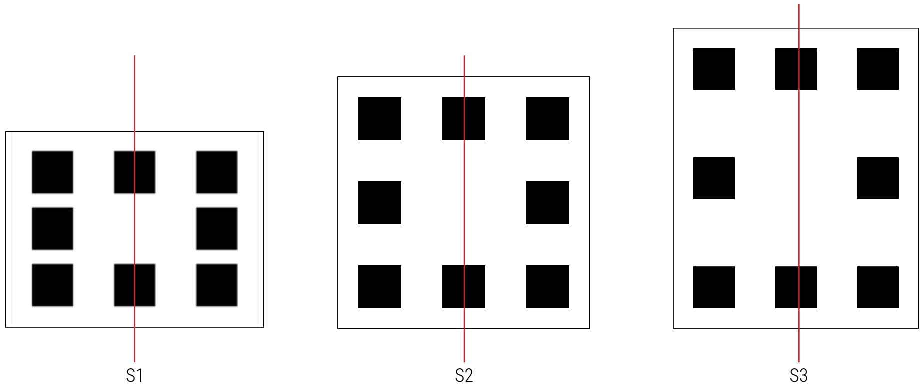


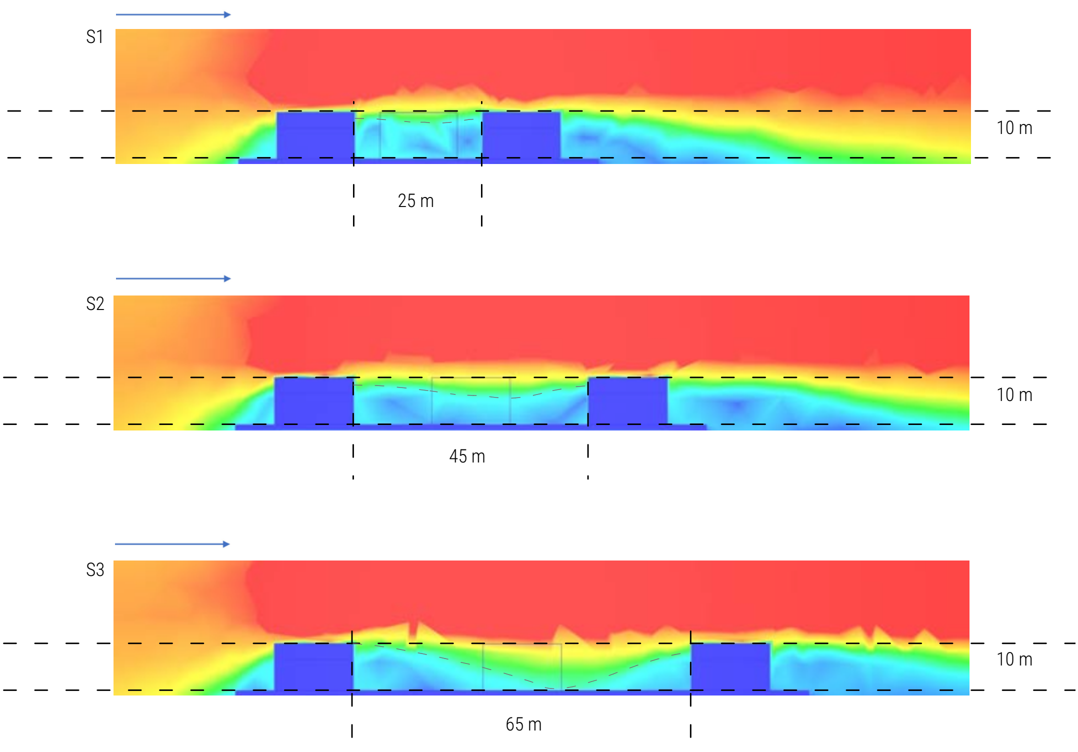
For the use of only two lines of buildings the second case would be more efficient to allow the wind to reach the second building and generate a good ventilation in the backyard. This could be used if you generate a space that allows the air to gain some speed for reaching other urban structures with a comfortable velocity after the first two rows of buildings. The first case is a better solution for the use of more than two buildings in a row. The continuous gap between the buildings allows the air to flow further through the arrangements and reach the buildings in the back with a higher velocity.



-Structure with 100 m x 100 m base and buildings with a 15 m x 15 m floorplan. The distance between the buildings is 10 meters.
The floorplans are 22,5 ° tilted to compare the effect to the first structure.

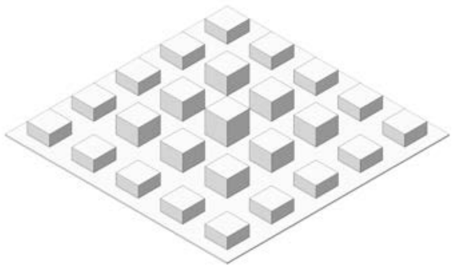




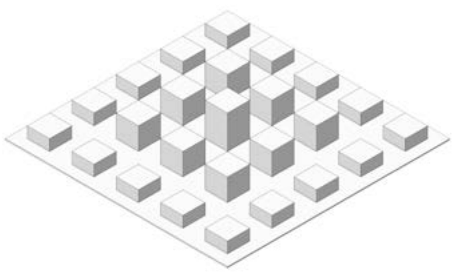


The free space between the buildings is used to generate some air movement between the buildings. With a thermal comfort zone of 8,2 km/h the distance should be 65 meters between buildings with a height of 10 meters. This distance is only needed to guarantee a perfectly comfortable place between the buildings.

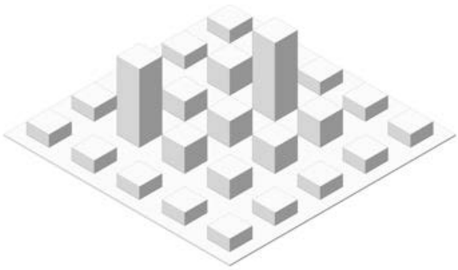
Commercial space



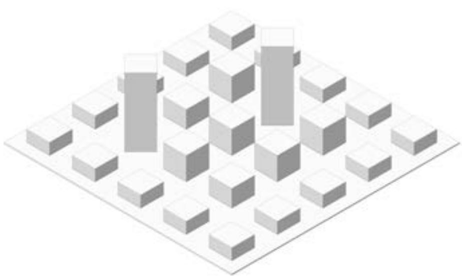
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan. The distance between the buildings is 20 m.
The building height steps up from 10 m to 20 m in the middle of the square.



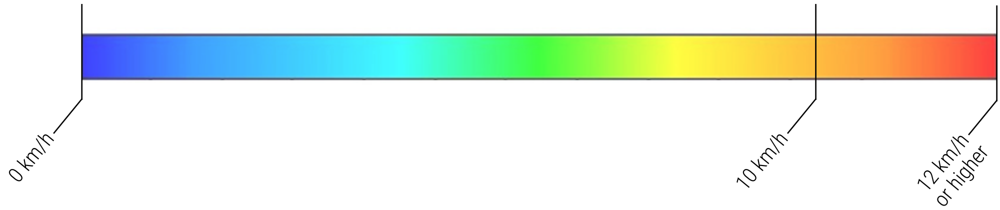
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan. The distance between the buildings is 20 m.
The building height steps up from 10 m to 30 m in the middle of the square.



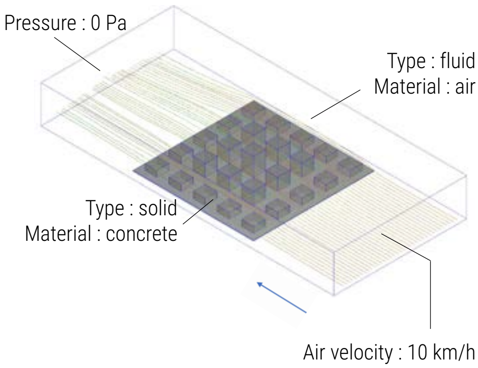
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan. The distance between the buildings is 20 m.
The building height equals the second pyramid structure but there are two buildings randomly placed in the grid that have a height of 60 m.



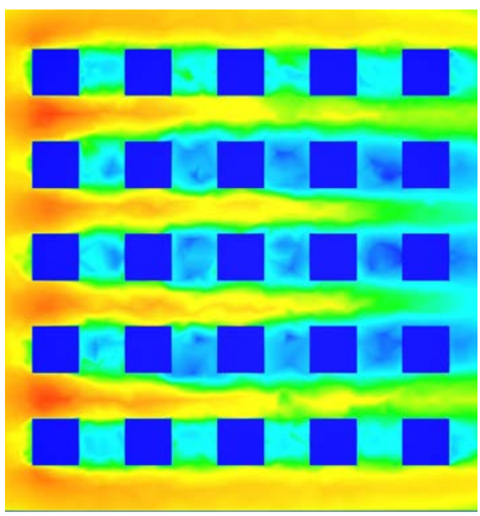
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan. The distance between the buildings is 20 m.
The building height equals the second pyramid structure but there are two buildings randomly placed in the grid that have a height of 60 m that are rotated by 45°.



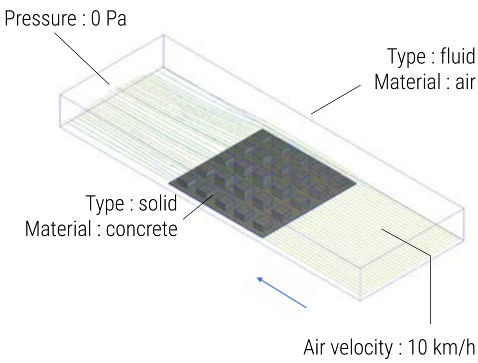
Information input for Autodesk CFD 2019



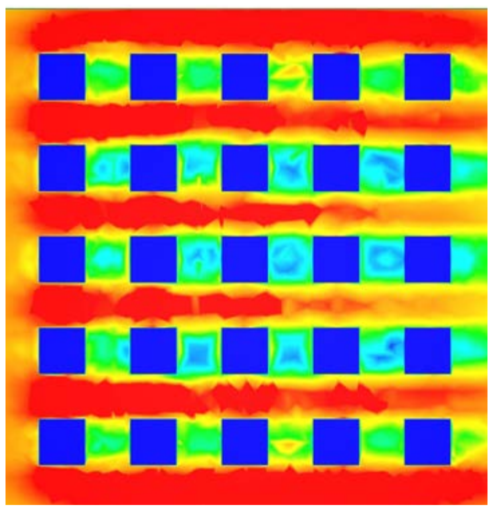
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan.
The distance between the buildings is 20 meters.
The building height steps up from 10m to 20 m in the middle of the square.



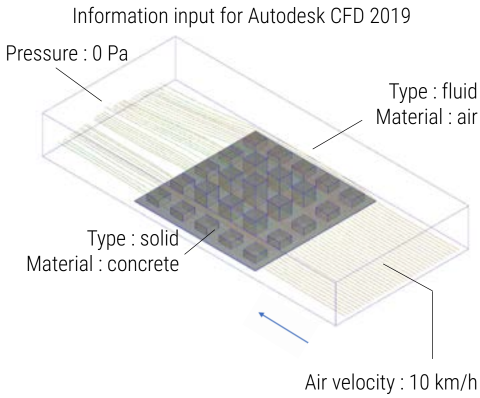
Information input for Autodesk CFD 2019

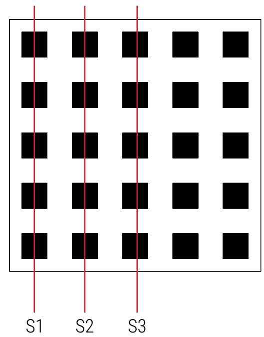


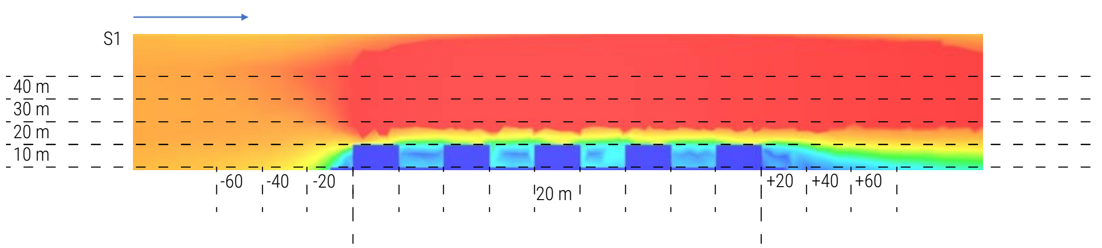
-Structure with 200 m x 200 m base and buildings with a 20 m x 20 m floorplan.
The distance between the buildings is 20 meters.
The building height steps up from 10m to 30 m in the middle of the square.

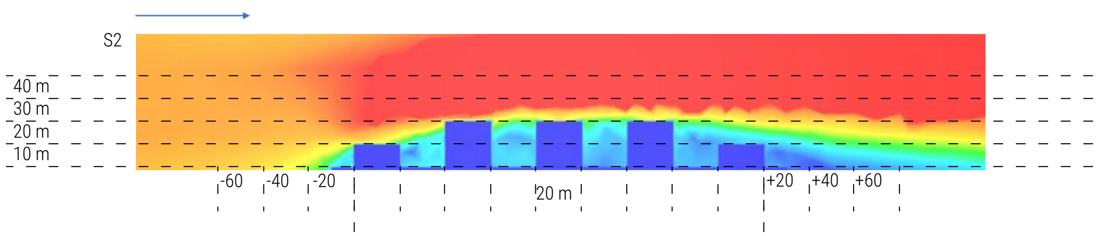


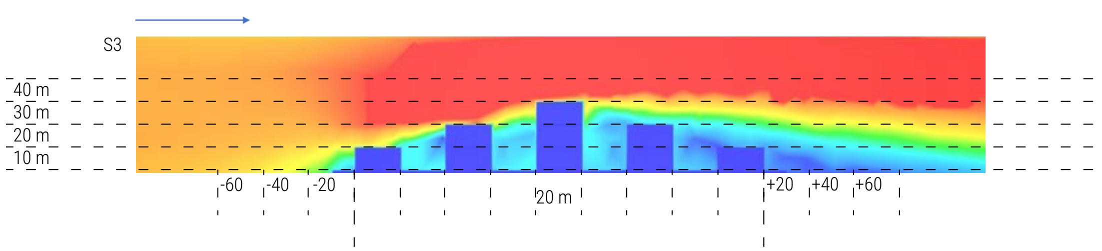
The height of the buildings has a high impact on the air velocity between the buildings. The higher the buildings are the slower the air 2 meters above the ground between them becomes.







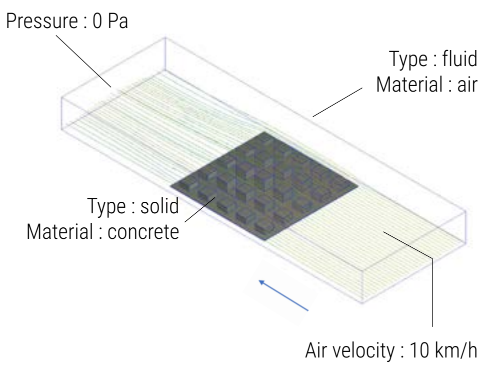


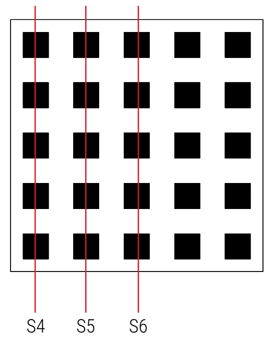


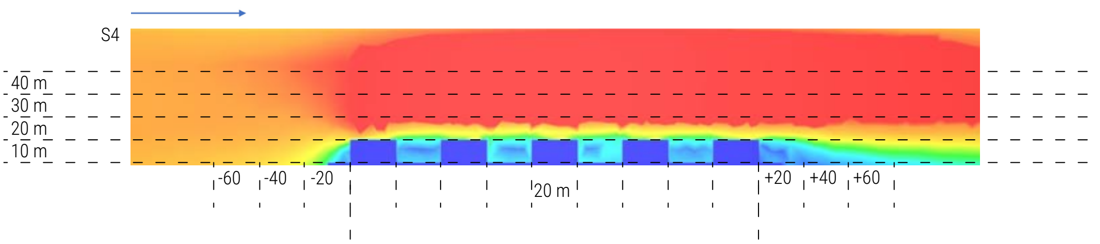
The 20 m x 20 m building complexes should symbolise a more dense urban structure. The spaces between the buildings are the same as the building itself.

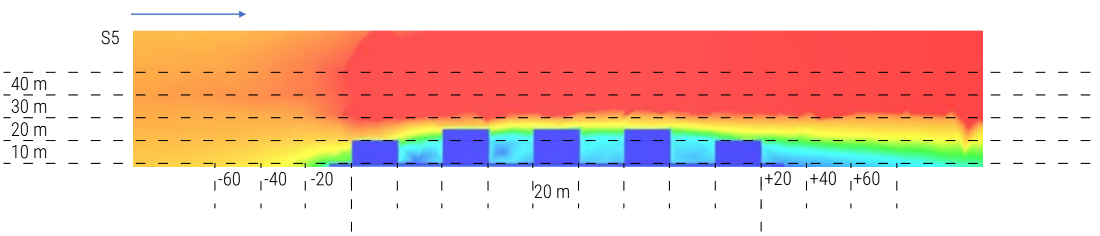
The building height steps up to the middle to allow the air to slowly rise without building up to much turbulences.
The air reaches a speed of 8 km/h around 1 m above the ground 100 m after the last building.

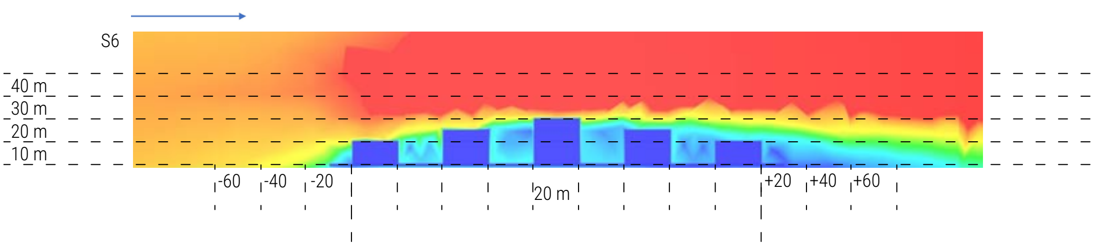
Information input for Autodesk CFD 2019



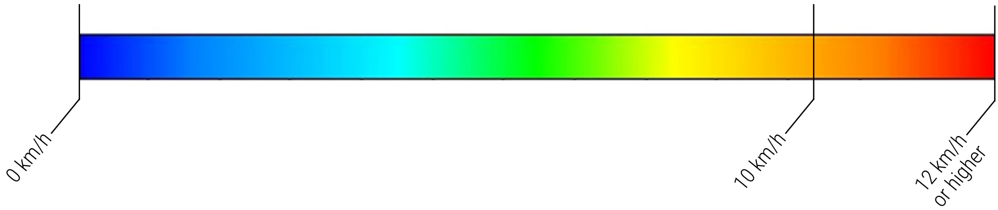




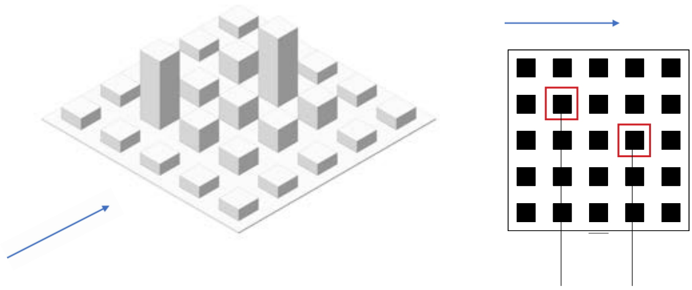




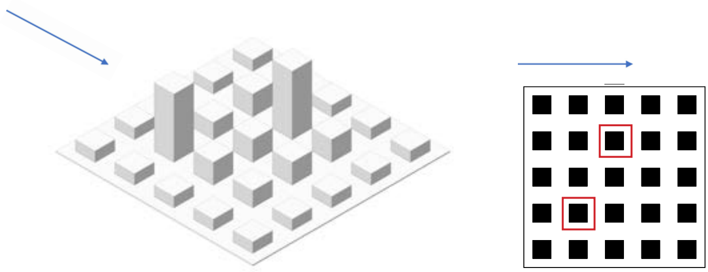
The same type of structures with the height only going up to 20 m at the highest building only needs 80 meters after the last building to reach an air velocity of 8 km/h 1 m above the ground.

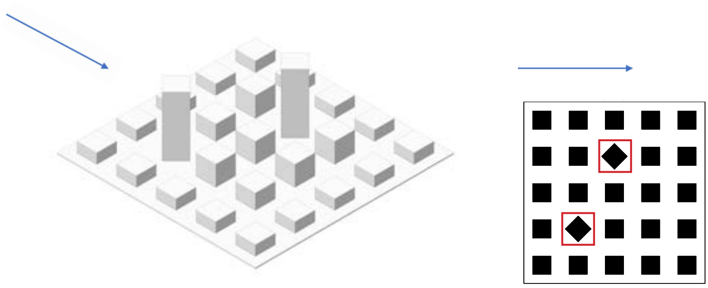


60 meter buildings



The air moving around the second building shortens the distance the air needs to speed up after the first building.

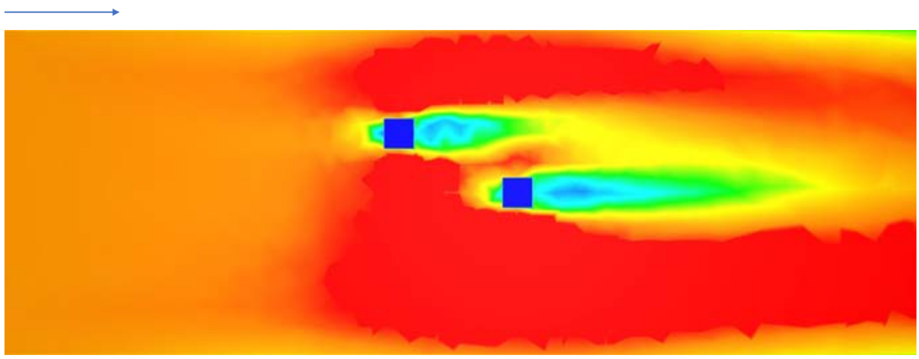


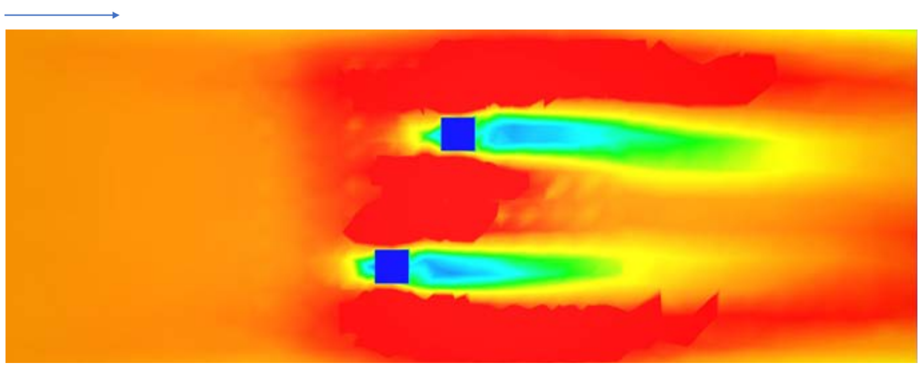


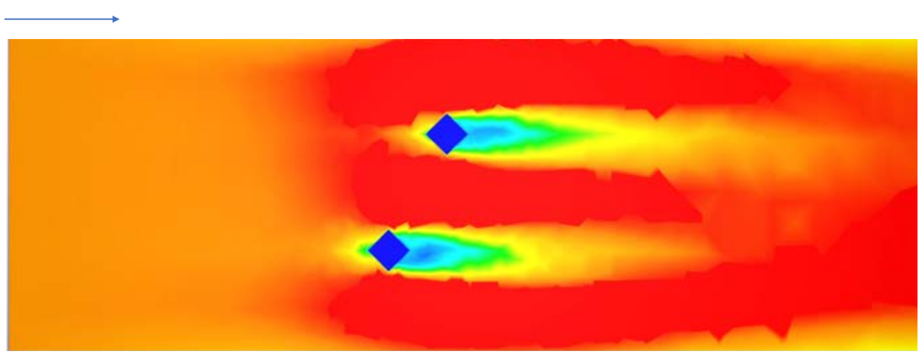
Air needs less distance to gain some velocity.

Autodesk CFD 2019

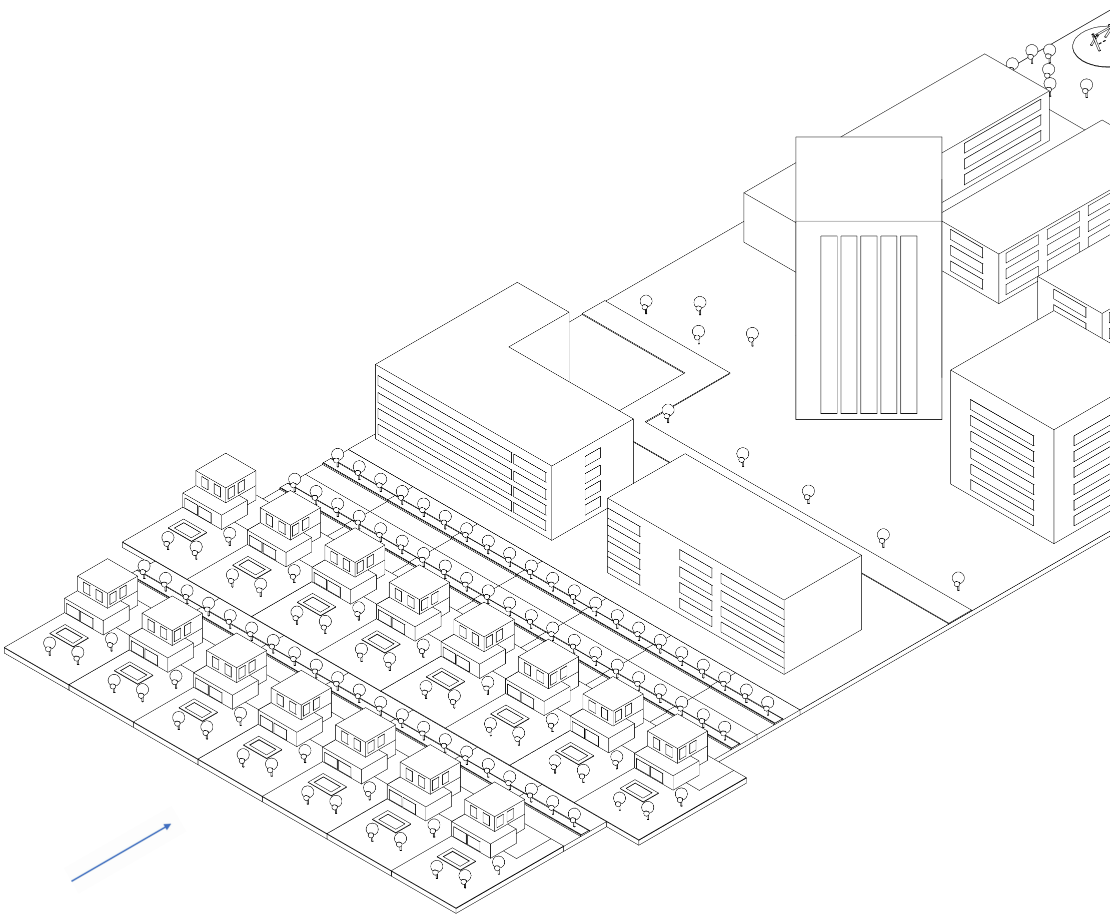
Air velocity : 10 km/h
Pressure at the end: 0 Pa

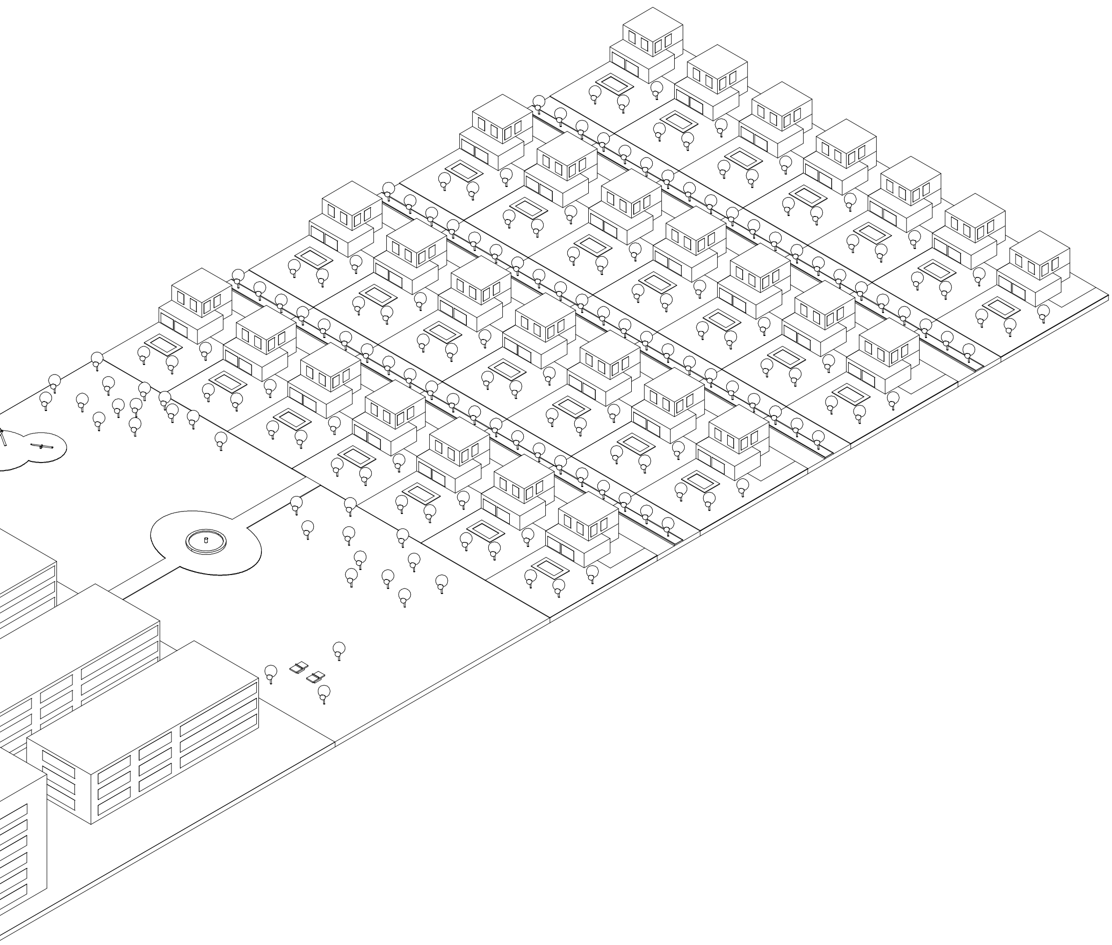


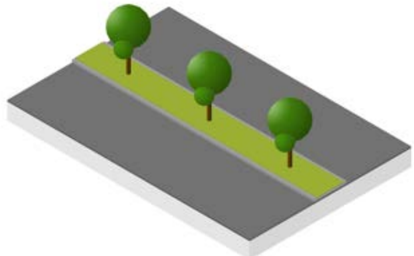


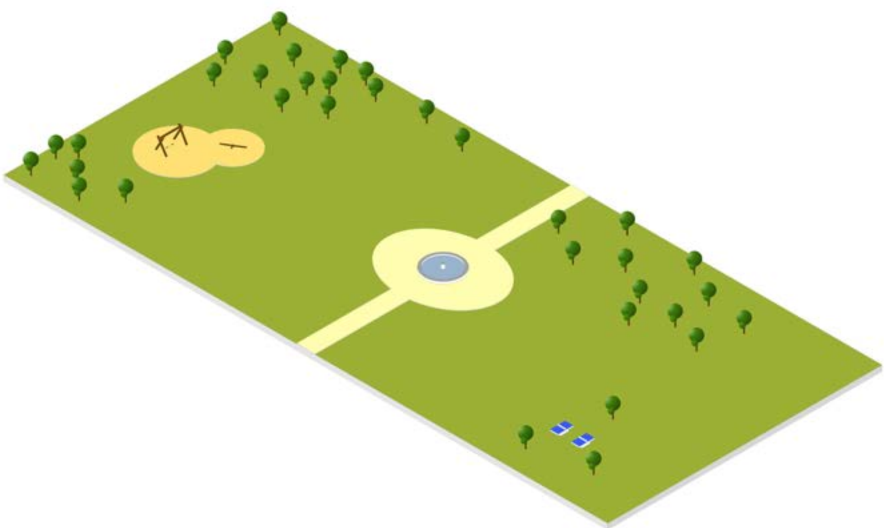


Conclusion



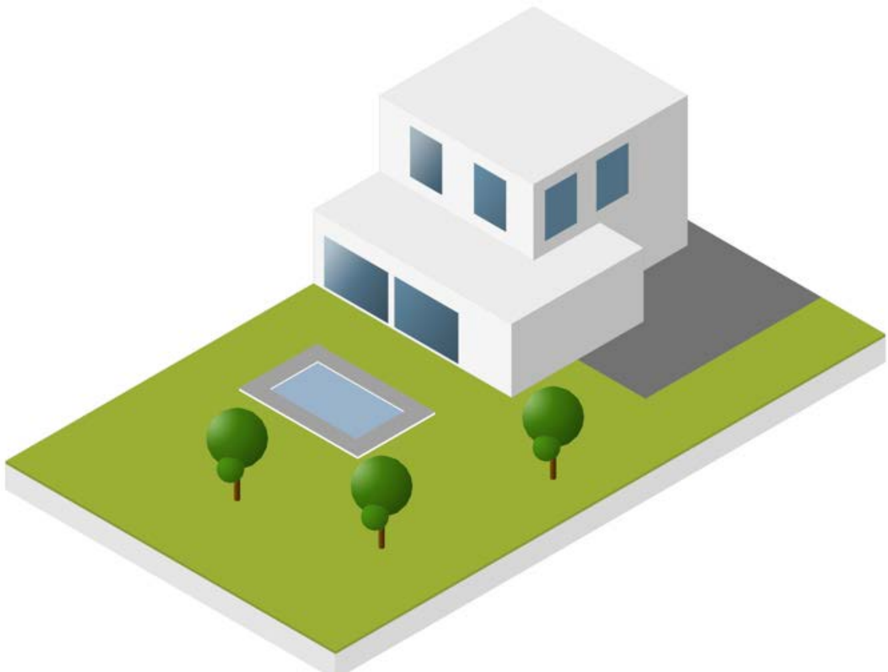






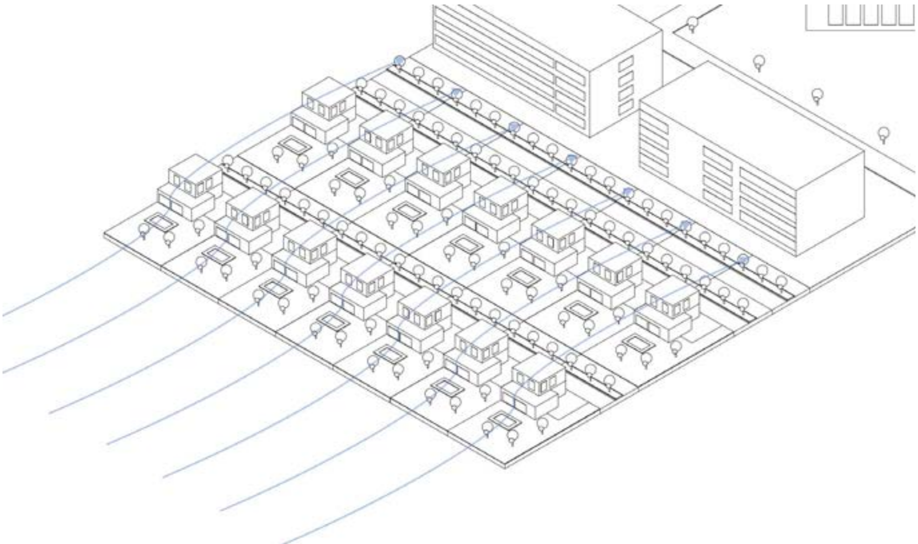
The following conclusion will summarize the researched facts and combine them into a construction kit like city planing. Each part will be able to be used in different parts of the city and it is able to arrange the different typologicaly structures to a combination, which will allow enough air to flow through the city. The following analysis of these structures will have the same input data as the previous city analysis. It will be based near the coast with warm humid climate and an air velocity of 10 km/h.

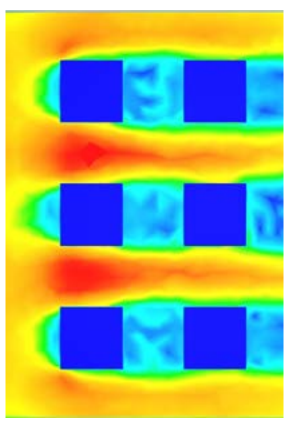
Living space

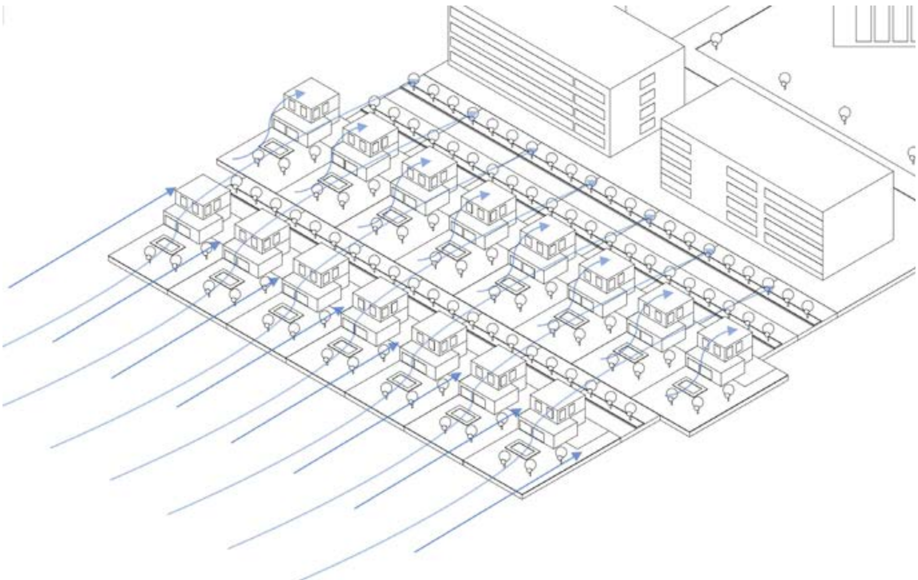


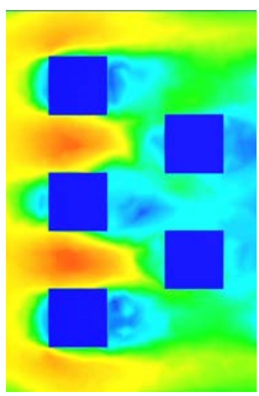
The model shows a exemplary building. The windows are not considered to ventilate this specific type of building, they are only exemplary for a building this size.

Example - beach houses - two lines



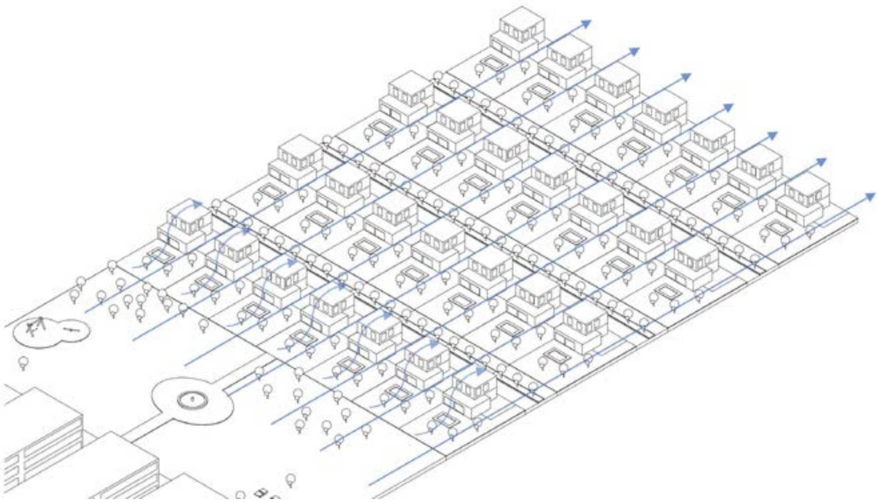


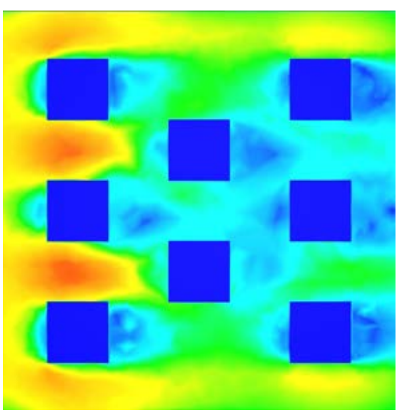


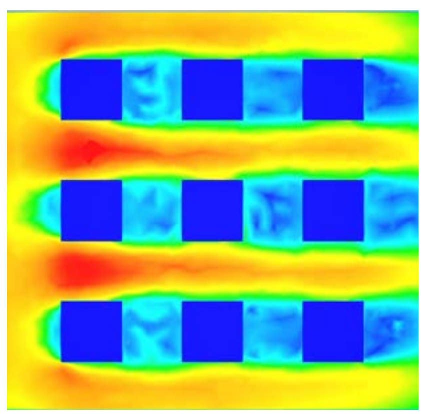


The building formations with the second row buildings placed in the gaps of the first row buildings guarantees air movement for both lines.

Example - houses - 3 lines or more





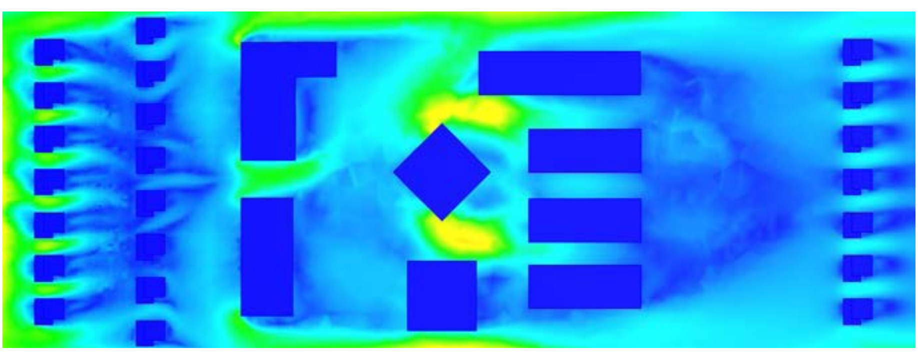


The building formations parallel to the wind direction allows the the air to reach the buildings in the back and create more air movement between structures.

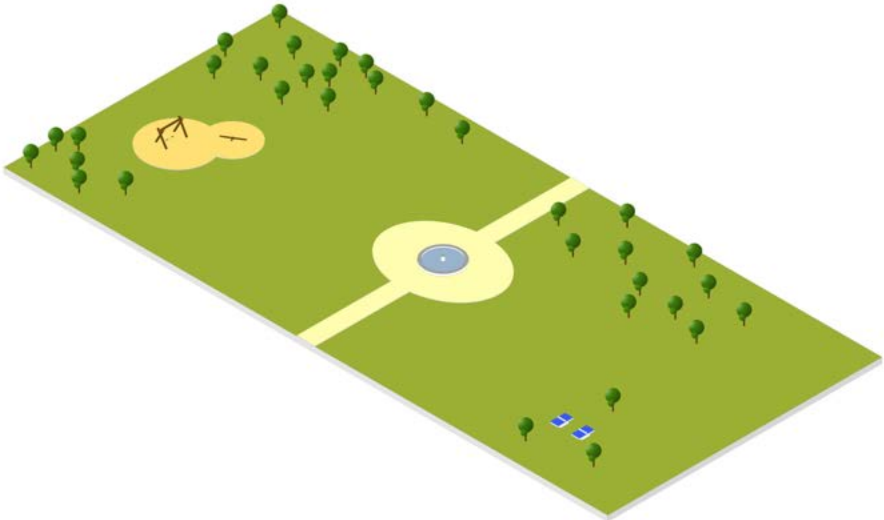
Commercial space

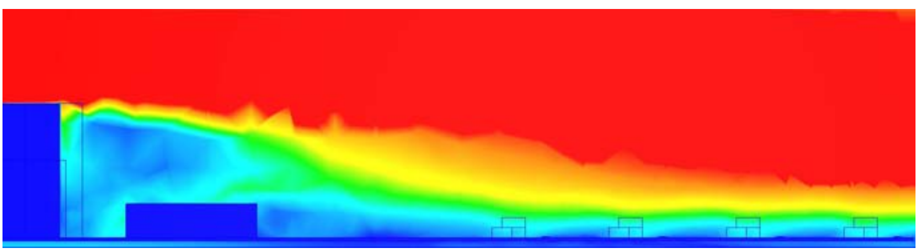
The model shows a exemplary building. The windows are not considered to ventilate this specific type of building, they are only exemplary for a building this size.

Todays usage of cities would not work without districts of higher densities and big complexes of hotels, workspaces and commercial uses. But also this part of the city could be designed to minimize the effect on the cities climate. If parking spaces are needed they should be under the ground level or integrated into some of the buildings. The use of asphalt on over the ground parking lots heats up the surrounding air much faster, which sucks the cold air up over the city. The higher buildings need to be designed so their shape slows down air as minimal as possible and the air is able to gain some speed shortly after passing the building. The use of stepping structures decreases the constitution of turbulences.



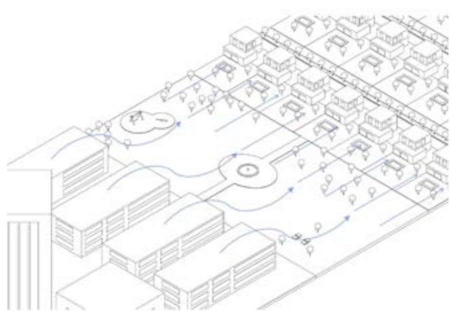
Regenerating space

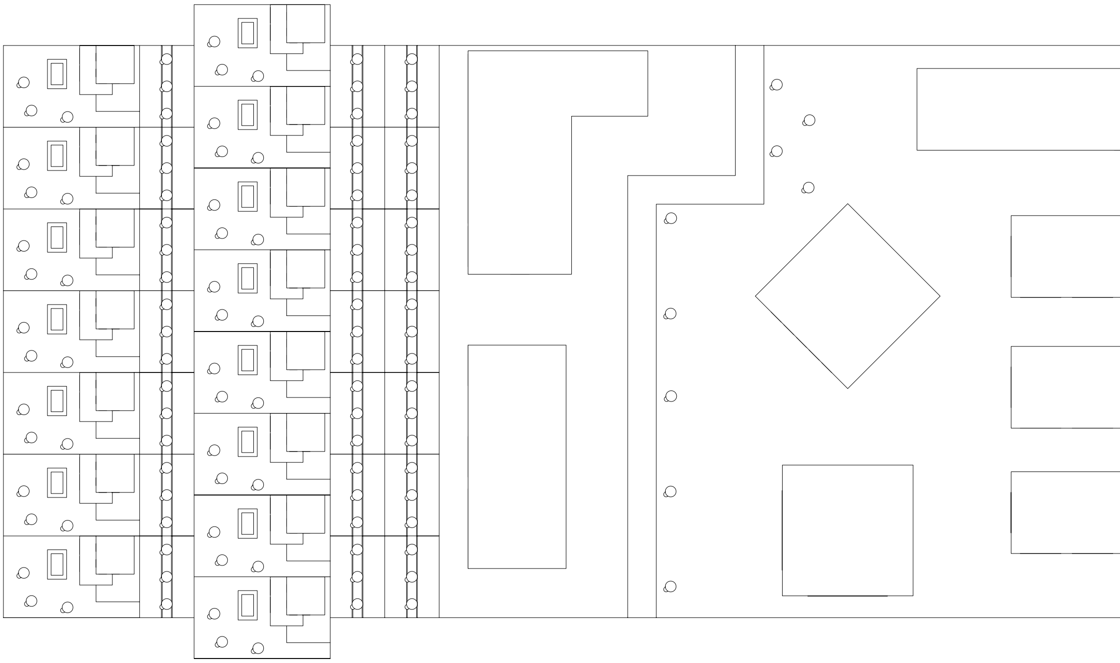


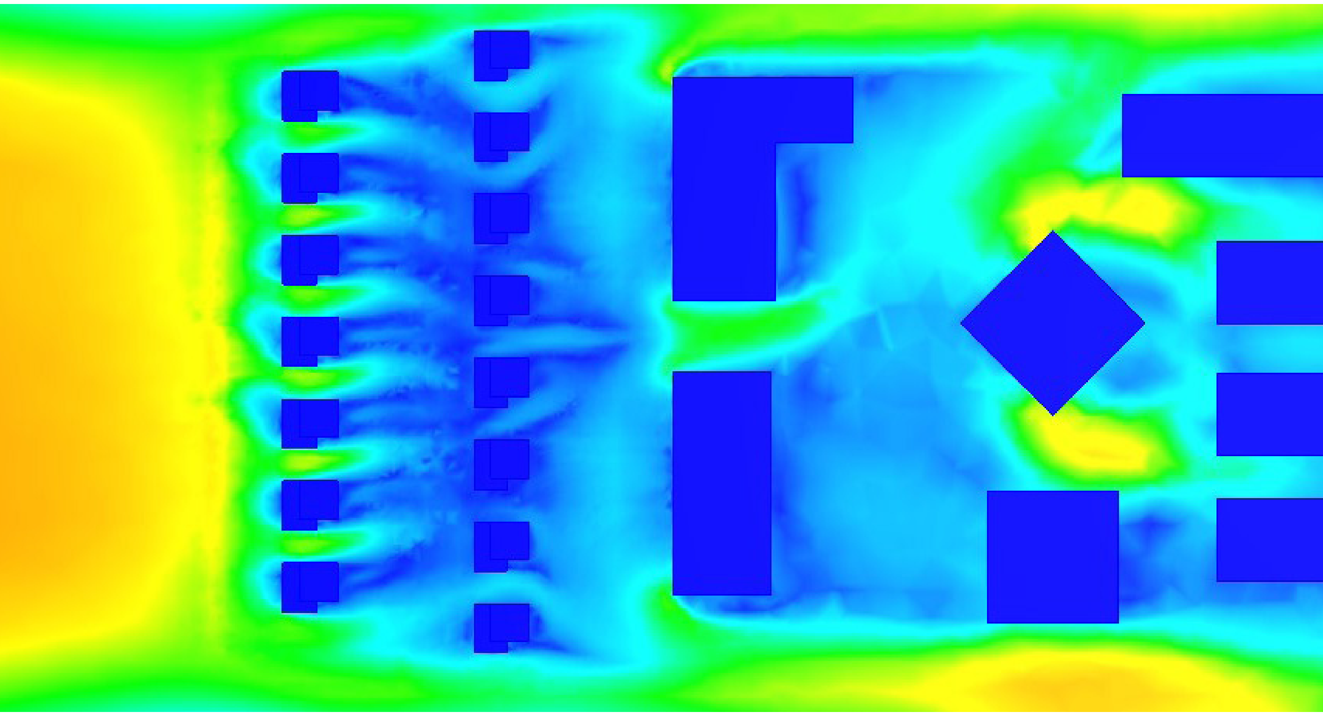


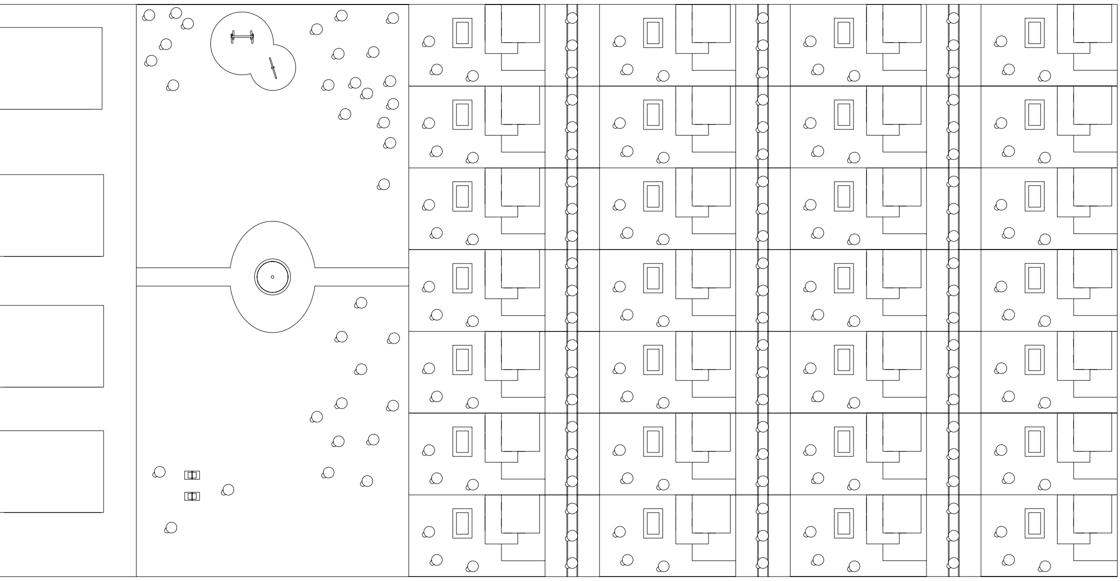
63

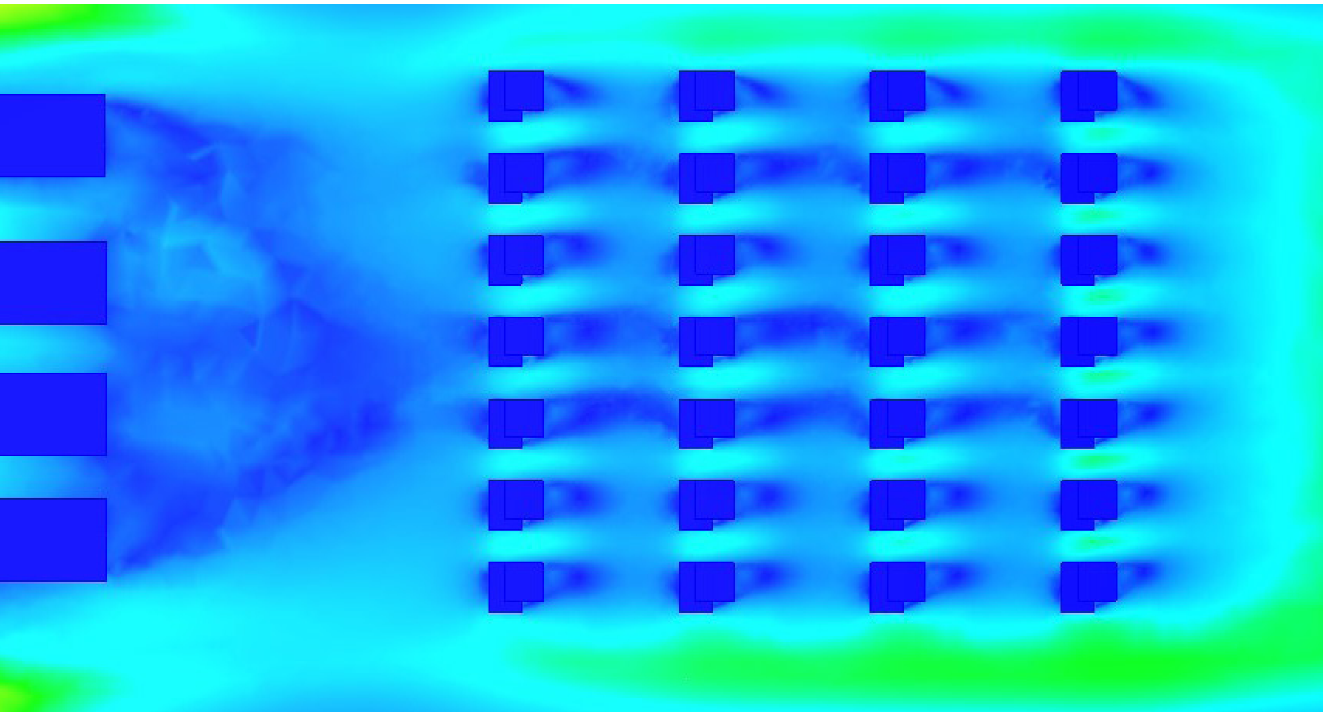
In the planing of cities it´s importand to use some spaces, where the air has the chance to gain some speed after the use of bigger structures. These spaces need to be placed after high impact areas to minimize their effect on the scale of the city. The use of green areas allows the air to cool down, which results in the ability of the air to stay near the ground level. It prevents the air from rising up over the buildings, which decreases the air velocity in the lee regions.



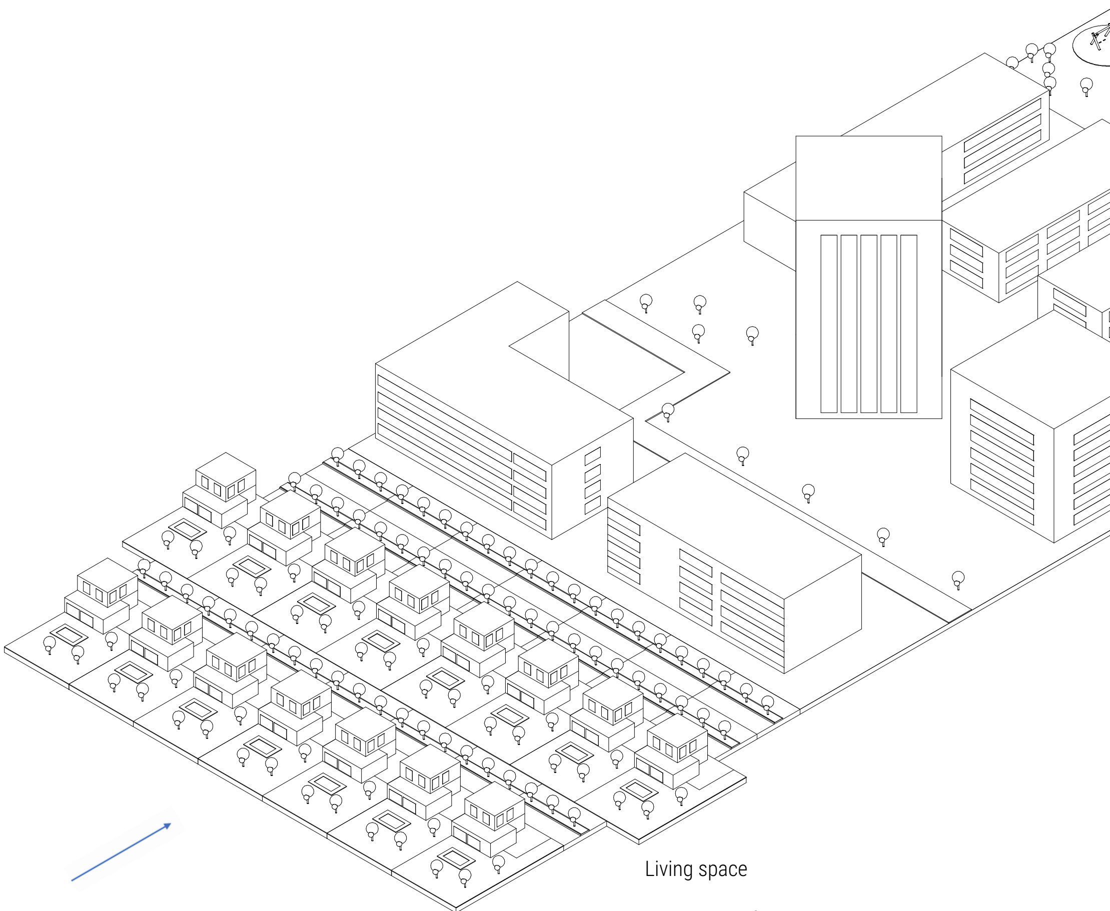






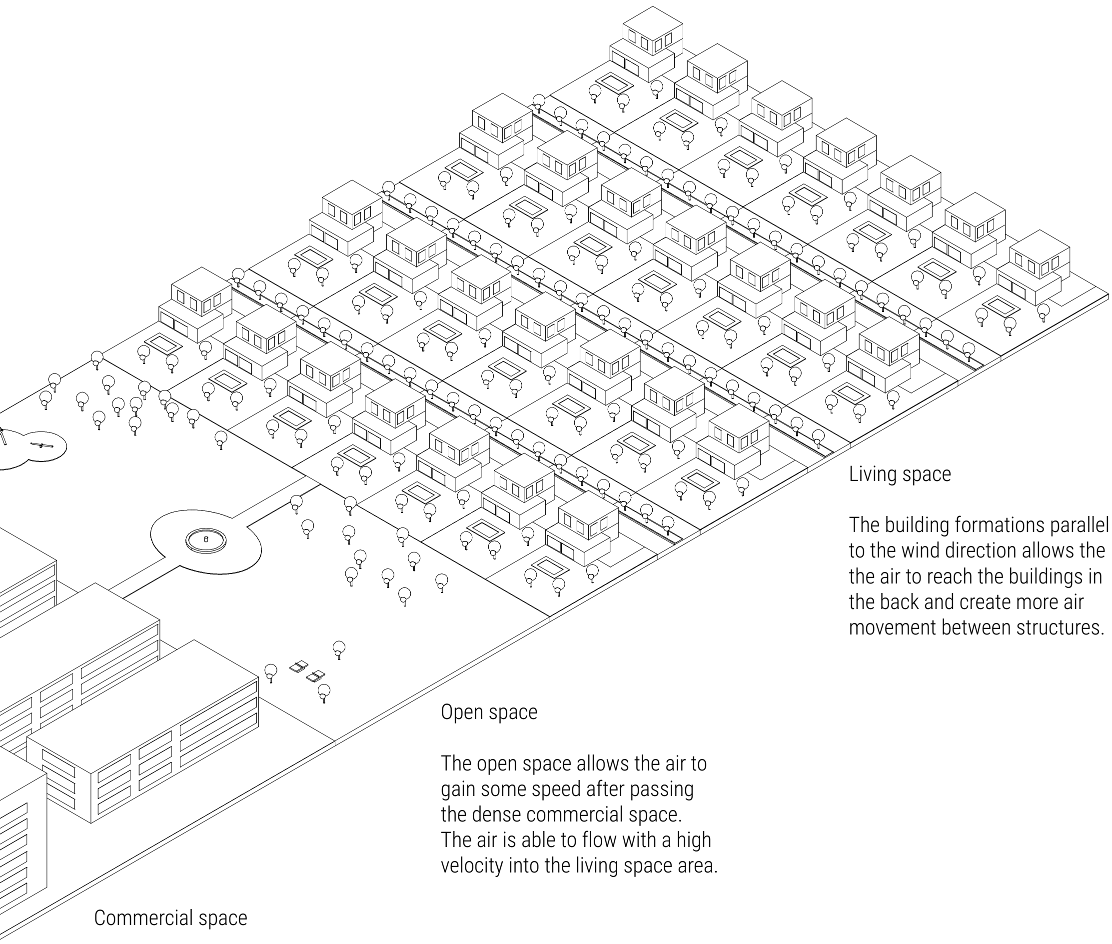


Conclusion



Living space

The building formations with the second row buildings placed in the gaps of the first row buildings guarantees air movement for both lines.



Living space

The building formations parallel to the wind direction allows the the air to reach the buildings in the back and create more air movement between structures.

Open space

The open space allows the air to gain some speed after passing the dense commercial space. The air is able to flow with a high velocity into the living space area.

Commercial space

The high building in the middle decreases its effect ow slowing down the air by its tilted ground-floor. The stepping from lower to higher buildings and back down prevents the air from building up turbulences.

Sources

-dateandtime.info (2011- 2019): Geographische Koordinaten von Singapore, Malaysia, http://dateandtime.info/de/citycoordinates.php?id=1735106 (access : 22.07.2019)

-dateandtime.info (2011- 2019): Geographische Koordinaten von Colombo, Sri Lanka, http://dateandtime.info/de/citycoordinates.php?id=1248991 (access : 22.07.2019)

-dateandtime.info (2011- 2019): Geographische Koordinaten von George Town, Malaysia, http://dateandtime.info/de/citycoordinates.php?id=1735106 (access : 22.07.2019)

-EU Montage Danmark ApS (2019): http://eumontage.dk/wp-content/uploads/2018/11/new-black-and-white-world-map-8.jpg
(access : 22.07.2019)

-Fluid Power Journal (2013): Tesla's Valvular Conduit, https://fluidpowerjournal.com/teslas-conduit/ (Access 10.07.2019)-Fluid Power Journal (2013): Tesla's Valvular Conduit, https://fluidpowerjournal.com/teslas-conduit/ (Access 10.07.2019)

-Hanqing Wu, John Zacharias (2006): Outdoor human comfort in an urban climate , https://www.researchgate.net/profile/John_Zacharias/publication/222781638_Outdoor_human_comfort_in_an_urban_climate/links/5c3faf3392851c22a37acca9/Outdoor-human-comfort-in-an-urban-climate.pdf?origin=publication_detail (Access 02.08.2019)

-Koenigsberger, O.H. et al, (1973): Manual of tropical housing and building- climatic design. London: Longman Group Ltd.

-Liung Wang, et al, (2017): Diodicity mechanism Tesla-typemicrovalves: a CFD study, https://mpra.ub.uni-muenchen.de/79746/1/MPRA_paper_79746.pdf (Access 10.07.2019)

-P. O. Fanger, McGraw Hille Book Company, (1973) : Thermal comfort , http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/5.htm (Access 02.08.2019)

-Sanjay Kumar, et al, (2016): An adaptive approach to define thermal comfort zones on psychrometric chart for naturally ventilated buildings in composite climate of India, https://www.sciencedirect.com/science/article/abs/pii/S0360132316303638 (Access 02.08.2019)

-WindFinder.com (2018): Wind- & Wetterstatistiken Colombo, https://de.windfinder.com/windstatistics/colombo
(access: 22.07.2019)

-WindFinder.com (2018): Wind- & Wetterstatistiken Penang bayan lepas Airport, https://de.windfinder.com/windstatistics/penang_airport_bayan_lepas (access : 22.07.2019)

-WindFinder.com (2018): Wind- & Wetterstatistiken Singapore Changi Airport, https://de.windfinder.com/windstatistics/singapore_changi (access : 22.07.2019)

-WorldWeatherOnline.com (2018): Colombo Monthly Climate Averages, https://www.worldweatheronline.com/colombo-weather-averages/western/lk.aspx (access : 22.07.2019)

-WorldWeatherOnline.com (2018): Penang Monthly Climate Averages, https://www.worldweatheronline.com/penang-weather-averages/pulau-pinang/my.aspx (access 22.07.2019)

-WorldWeatherOnline.com (2018): Singapore Monthly Climate Averages , https://www.worldweatheronline.com/singapore-weather-averages/sg.aspx (access 22.07.2019)