Sydney's Third City

Final report

LOW CARBON LIVING CRC

Authors	Project Leader: Prof. Mattheos Santamouris[1] Project team: S. Haddad[1], S. Garshasbi[1], C. Bartesaghi[1], R. Paolini[1] Sub-contractors: D. Kolokotsa[2], K. Gobakis[2], K. Lilli[2]
Title	Sydney's Third City
ISBN	
Date	May, 2019
Keywords	
Publisher	CRC for Low Carbon Living
Preferred citation	

1 Faculty of Built Environment, UNSW, Sydney, Australia

2 Technical University of Crete, Chania, Greece

Australian Government
Department of Industry, Innovation and Science
Business Cooperative Research Centres Programme

Acknowledgements

This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative

Disclaimer

Any opinions expressed in this document are those of the authors. They do not purport to reflect the opinions or views of the CRCLCL or its partners, agents or employees.

The CRCLCL gives no warranty or assurance, and makes no representation as to the accuracy or reliability of any information or advice contained in this document, or that it is suitable for any intended use. The CRCLCL, its partners, agents and employees, disclaim any and all liability for any errors or omissions or in respect of anything or the consequences of anything done or omitted to be done in reliance upon the whole or any part of this document.

Peer Review Statement

The CRCLCL recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

Table of Contents

LOW CARBON LIVING CRC

1. GLOSSARY OF TERMS

Glossary

Albedo: Albedo is a measure of reflectivity of a surface; i.e. the proportion of the incoming solar radiation that is reflected by the surface back into the atmosphere. It is determined by a value between 0 and 1.

Anthropogenic Heat Flux: is the heat flux resulting from vehicular emissions, space heating and cooling of buildings, industrial processing and the metabolic heat release by people.

Bureau of Meteorology (BoM) Stations: BoM weather stations that record a variety of weather phenomena.

Cooling Degree Days (CDD): Cooling degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature is above a certain level (base temperature). They are the summation (or integral) of the differences between outdoor temperatures and a defined base temperature. CDD are good indicator of the severity of the climate and the cooling needs of buildings.

Cool materials: materials (roofing and/or paving) that are characterized by high solar reflectance and high thermal emittance

Cool pavements: materials used in various surfaces of the urban fabric (e.g. roads, parking lots, sidewalks etc.) that are characterized by high solar reflectance and high thermal emittance.

Cool roofs: roofing materials that are characterized by high solar reflectance and high thermal emittance.

Correlation coefficient: is used in statistics to measure the strength of a relationship between two variables.

DesignBuilder: a whole building energy simulation program that models energy consumption and water use in buildings. More information can be found at: https://www.designbuilder.co.uk/. Design Builder was used to assess the effects of urban climate on the building energy consumption.

EnergyBus: it is UNSW mobile lab which is equipped to record the meteorological data.

ENVI-met: a three-dimensional microclimate model designed to simulate the surface, plant and air interactions in an urban environment. This computer program is an accurate tool to simulate the distribution of the main climatic parameters in the urban environment. More information can be found at: http://www.envi-met.com/

Global mitigation strategies: The global mitigation strategies for 2050 using mesoscale modelling include a combination of a) increased dwelling density based on future projections b) inclusion of new Urban Growth Areas c) increased anthropogenic Heat Flux d) planting of 2 million irrigated trees in the so called Third City and 3 million irrigated trees in the rest of Sydney e) increased albedo of urban impervious surfaces and f) Water in the landscape.

Heat Wave: A heat wave day is a period of excessively hot weather. In this report, the heat wave day in 2017 corresponds to the extreme condition (+10 °C above long-term average temperature).

Microscale climate model: is used to assess heat mitigation strategies based on micro-scale modelling with ENVI-met (Bruse and Fleer, 1998). This model works at the street or neighbourhood scale with higher resolution compared to mesoscale modelling. In this study, local heat mitigation strategies include: use of greenery, cool roofs and pavements, water-based technologies, and greenery. Result of microclimate simulations is used to generate weather data to compute building energy consumption and health impacts analysis.

New Weather File: Weather file that represents the weather profile of an area considering that a specific mitigation scenario has been implemented. The new weather files were developed by modifying the weather profiles given by the BoM station, considering the calculated mitigation factors, for each one of the mitigation scenarios under the present climate.

Outliers: An observation that seem to differ by a substantial amount from the rest of the data. For this study outliers are defined as points that are beyond the quartiles by one-and-a-half Interquartile Range (IQR), where the IQR is the difference between the between the upper quartile (Q3) and the lower quartile (Q1) (defined as the 25th and 75th percentiles).

Percentile: A percentile is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall. For example, the 25th percentile is the value (or score) below which 25% of the observations may be found.

Reference Case: it represents the existing situation, where no mitigation solutions have been considered. The terms reference case and unmitigated scenario are used interchangeably in the report.

Sensible cooling load: sensible cooling load is a measure of the amount of energy that must be removed from the air inside a building, in order to maintain a certain temperature. Sensible cooling load refers to “dry bulb temperature”.

Thermal comfort: is the condition of mind that expresses satisfaction with the thermal environment.

Total mitigation strategies: see global mitigation strategies

Urban Heat Island (UHI): It is a phenomenon in which urban areas exhibit higher temperatures than the surrounding rural areas. Urban Heat Island is the result of the positive thermal balance of cities caused mainly by the increased absorption of solar radiation and heat storage, high anthropogenic heat and reduced heat losses.

Urban heat island intensity (UHII): it is an important metric used in measuring Urban heat island (UHI) effect. The UHI magnitude is the temperature difference of an urban and rural area ($DT_{urban-rural}$)

Unmitigated Scenario: see Reference Case

Whisker-box plot diagrams: The box plot is a standardized way of displaying the distribution of data based on the five-number summary: minimum, first quartile, median, third quartile, and maximum. In the simplest box plot the central rectangle spans the first quartile to the third quartile (the interquartile range or IQR); the likely range of variation. A segment inside the rectangle shows the median and "whiskers" above and below the box show the minimum and maximum.

WRF (Weather Research and Forecasting) model: WRF is a next-generation mesoscale numerical weather prediction system developed by the National Center for Atmospheric Research (NCAR). It has been one of the world’s most widely used numerical weather prediction models. The WRF Model is an atmospheric model designed both research and numerical weather prediction (NWP).

LOW CARBON LIVING CRC

2. EXECUTIVE SUMMARY

Executive Summary

Overheating of cities is causing serious energy, environmental and health problems and it has a serious impact on the whole economic and cultural life of cities. To counterbalance the impact of high urban temperatures several mitigation technologies have been proposed, developed and implemented. Monitoring of several large-scale urban projects involving the application of mitigation technologies has demonstrated the possibility decreasing the peak ambient temperature of the precincts up to 2.5 °C.

Analysis reveals that the magnitude of the overheating depends on many parameters of which the more important are: The layout and the characteristics of the buildings and open spaces, the type of the materials used, the released anthropogenic heat, the land use, the climatic conditions, etc. Several studies have been performed to understand and evaluate the impact of some of the above parameters; however, detailed studies to investigate the impact of the precincts' layout and characteristics on the urban overheating are not widely available.

The present study aimed to provide answers to the following research questions:

Research Questions

1. What is the impact of building height, street width, aspect ratio, built area ratio, orientation and dimensions of open spaces to the distribution of the ambient and surface temperature as well as on thermal comfort conditions in open spaces?
2. What is the exact impact of the above parameters on the energy consumption of buildings in a precinct?
3. How is the cooling potential of the common mitigation technologies influenced by the layout and characteristics of precincts?
4. Is it possible to decrease the amplitude of urban overheating through the proper design of buildings and precincts and what is the exact cooling potential?

Methodology

To respond to the above research questions the methodology described below was followed:

1. A total of 14 residential typologies have been used to provide a logical categorisation of residential areas that can support micro-climatic and energy consumption analyses. The typologies are suggested by the Urban Taskforce Australia, and follows the approach applied by the Local Climates Zones (LCZs) proposed by Stewart and Oke, which is a standardised and widely applied scheme for analysis of urban overheating conditions within urban areas. Seven housing types were profiled for this study and for the Sydney metropolitan area (SMA) based on building height as per the building typologies defined by the Department of Planning and Environment New South Wales (NSW).

Figure 1 Selected 14 precincts in this study

2. Mesoscale climatic models have been used to simulate the climatic conditions in the Sydney area for the actual land use and climatic conditions, as well as for the future climate and land use in 2050. In parallel, the expected future climatic conditions in Sydney considering a full implementation of mitigation measures are simulated. Simulations have been performed for a full summer month on an hourly basis.

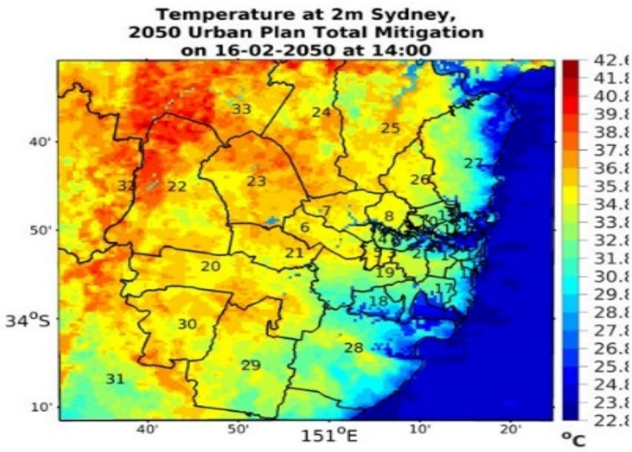


Figure 2 Air temperature at 2m, at 14:00 (16-02-2050)

3. Hourly climatic files for all the above climatic scenarios were prepared for use in energy and microscale climatic simulations.

4. Microscale simulations to predict the distribution of the main climatic parameters, ambient temperature, wind speed, surface temperature, outdoor thermal comfort, in the 14 different precincts were carried out for representative days of the summer period using the previously defined climatic data for the scenario of 2050 under non-mitigation and full mitigation conditions. Simulations were performed for two scenarios: a) Considering that mitigation technologies, greenery, evaporation, cool materials, are implemented everywhere in the precinct, and b) no mitigation measures are used in the precinct

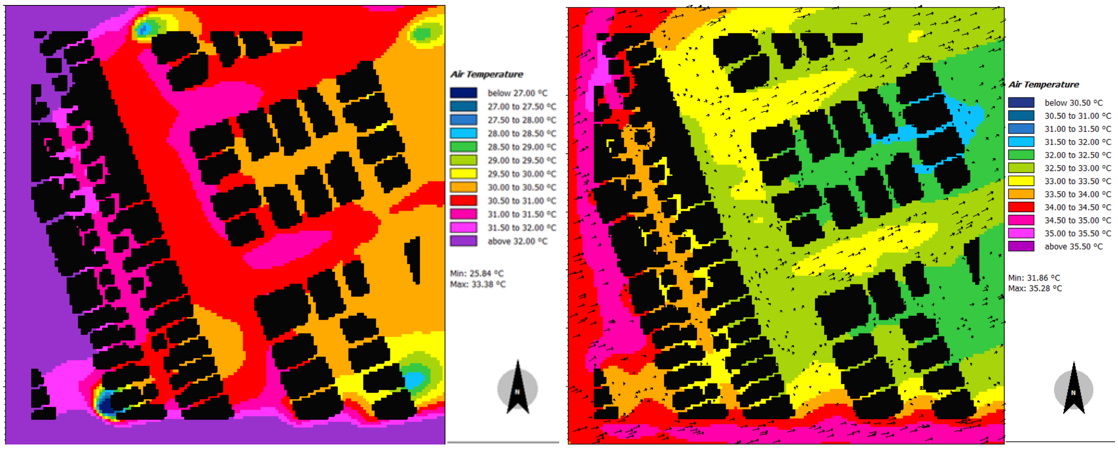


Figure 3 Temperature distribution in the mitigated (left) and non-mitigated (right): CT1

5. The results of the previously described simulations during the peak daytime temperature conditions, were thoroughly analysed and conclusions drawn regarding the distribution of the main climatic parameters and the outdoor thermal comfort, and the impact of the main parameters defined in the research questions.

6. The results of the microscale simulations for each precinct were used to prepare detailed climatic input files to be used in energy simulation models.

7. Detailed energy simulations were performed to identify the impact of the parameters defined in the research questions on the energy consumption of the buildings in a precinct.

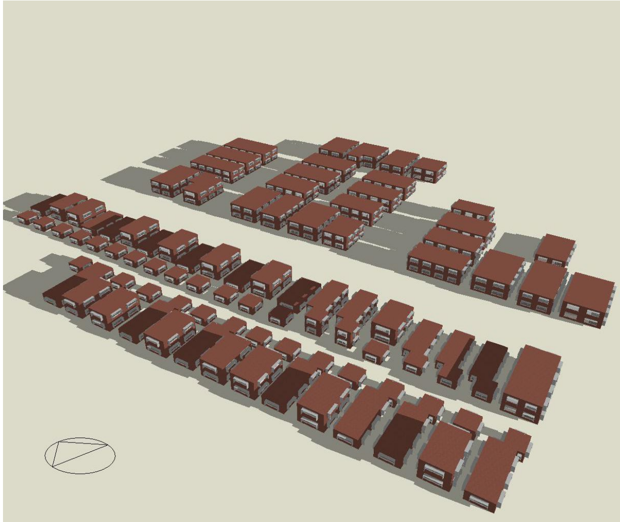


Figure 4 The precinct model for energy simulation: (CT1)

8. Conclusions were reached about the impact of the precincts' layout and characteristics of the defined precincts.

Results

Impact on the Climate of the Precincts

1. To evaluate the cooling potential of each of the 14 considered precincts, a new parameter called 'Gradient of the Temperature Decrease along the Precinct Axis', GTD, was developed. The parameter measures the average temperature decrease along the X or the Y axis of the canyon.

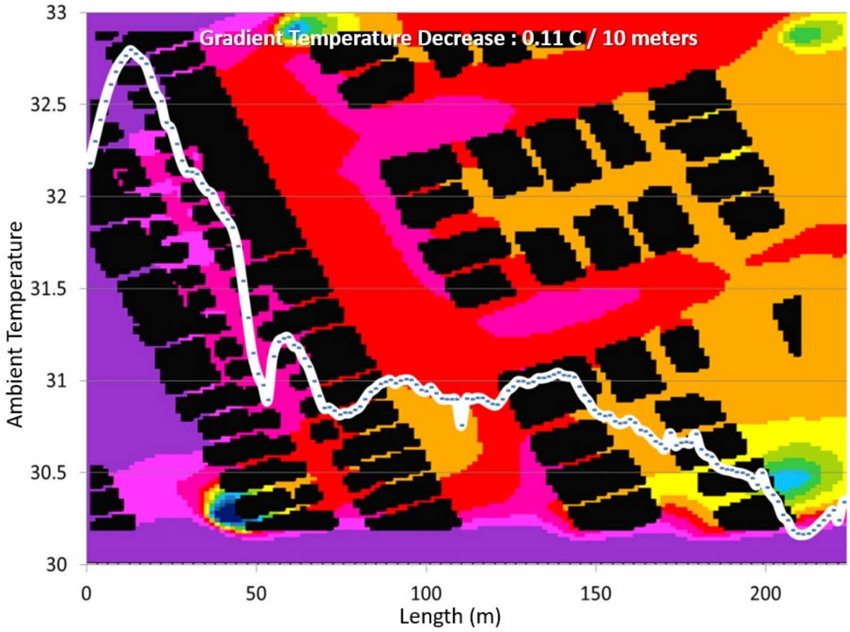


Figure 5 calculation of CTD and presentation of X or the Y axis of the canyon

2. In precincts with mitigation the Gradient of Temperature decrease, GTD, varies between 0.01 K/m to 0.004 K/m.

Figure 6 GTD values for all the precincts with mitigation

3. In precincts without mitigation, GTD varies between 0.0093 K/m to 0.0024 K/m.

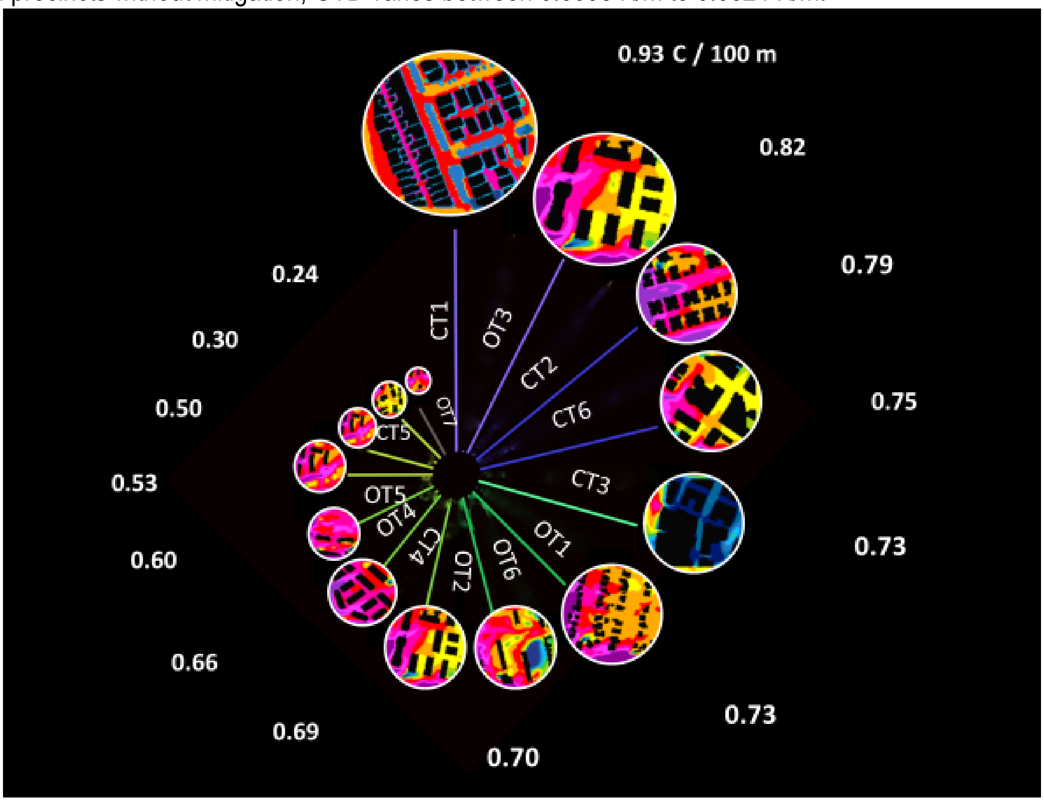


Figure 7 GTD values for all the precincts with no mitigation

4. The maximum expected temperature difference between precincts of about 40000 m^2, employing the same mitigation measures, caused by different layout and characteristics of the buildings and open spaces may be close to 0.9 °C for a reference ambient temperature of 32 °C, and a wind speed of about 2 m/sec.

5. The maximum expected temperature difference between precincts of about 40000 m^2, without any mitigation measure, is close to 1.5 °C, for a reference ambient temperature of 33 °C, and a wind speed of about 2 m/sec.

6. The cooling potential caused only because of the layout of the precincts is decreasing when mitigation technologies are used, compared with the cooling potential of the same precinct without mitigation, because the utilisability factor is lower.

7. Analysis of the results shown that advection is the major mechanism to transfer heat to the precincts and there is a strong relation between the flux of heat, because of the wind, and the GTD values.

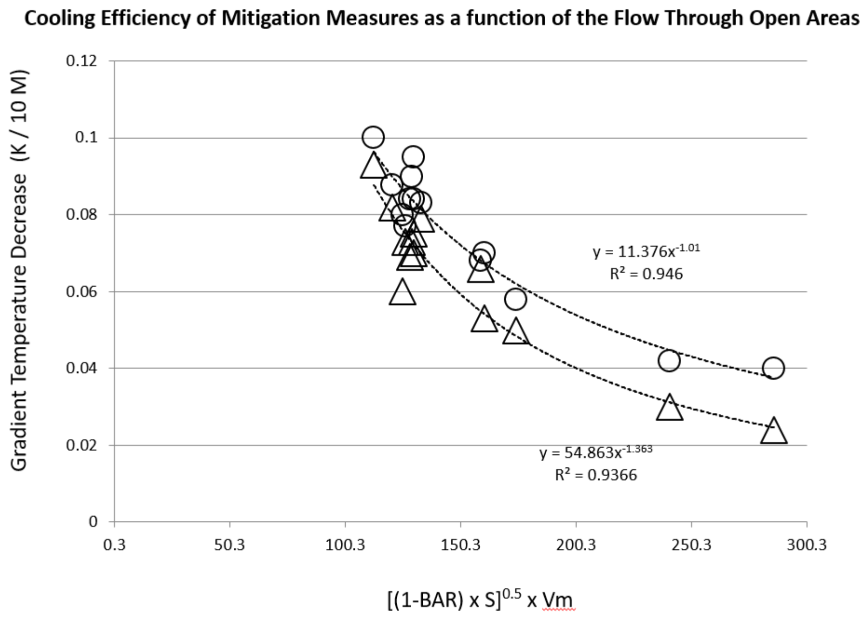


Figure 8 Cooling Efficiency of Mitigation Measures as a function of the Flow Through Open Areas

8. There is a strong correlation between the GTD of all the precincts with and without mitigation, and the corresponding average aspect ratio, (Height of buildings to Width of streets), of the precincts. The higher the aspect ratio of the precinct the lower the Cooling Capacity This is expected, as: a) the application of cool roofs in high rise buildings has a lower impact and b) wind speed in canyons of high aspect ratios is quite higher and corresponds to a much higher advection rate.

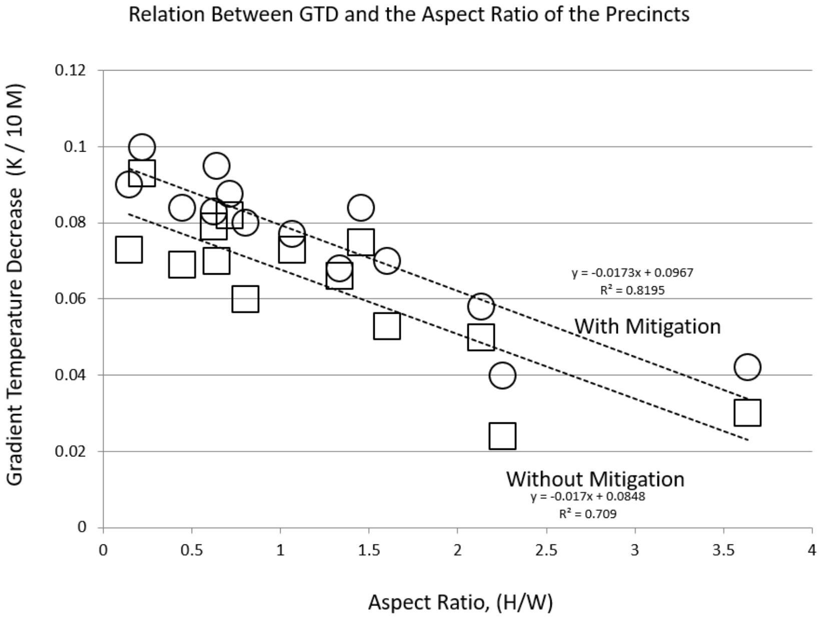


Figure 9 Relation Between GTD and the Aspect Ratio of the Precincts

9. The cooling contribution of the specific layout of the precincts is more important when advection to the precinct is low and decreases as advection is rising.
10. The higher the Built Area Ratio, the lower the contribution of the mitigation techniques to the cooling rate of the precincts. This is logical as less space is allocated to install mitigation measures

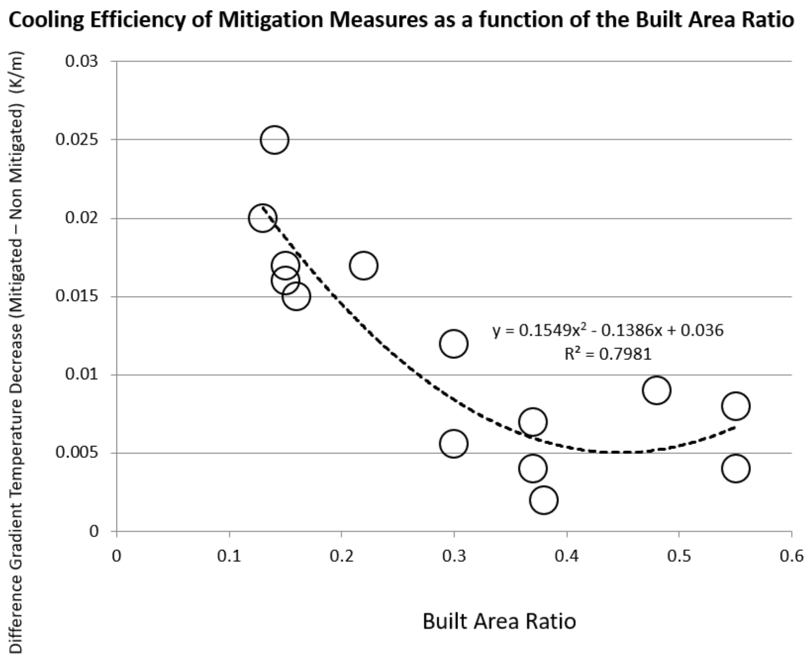


Figure 10 Cooling Efficiency of Mitigation Measures as a function of the Built Area Ratio

11. Two prediction methods of sufficient accuracy are proposed to calculate the GTD of the mitigated and non-mitigated precincts. The average relative prediction error of both methods for the mitigated precincts is close to 10 %. For the non-mitigated precincts, the average prediction error of the method based on the aspect ratio is close to 17 %, while the corresponding error of the method based on the estimation of the advection rate is close to 12 %.

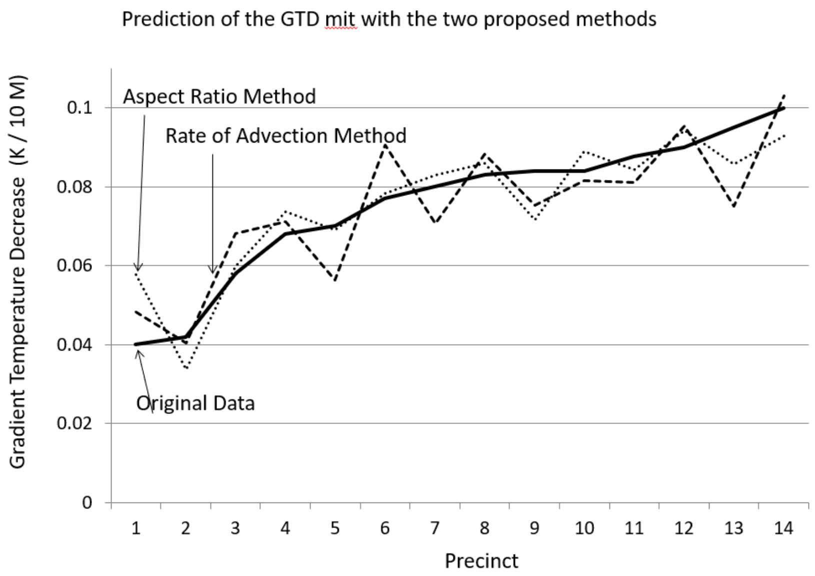


Figure 11 Prediction of the GTD mit with the two proposed methods

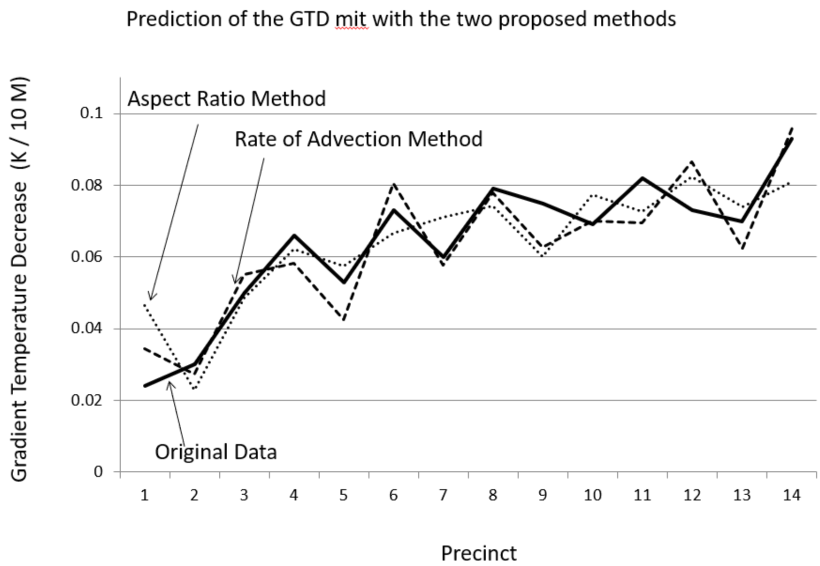


Figure 12 Prediction of the GTD mit with the two proposed methods

12. There is a strong correlation between the ratio of the average wind speed in the precinct, $V_{(average)}$, and the incident wind speed in the limits of the precinct, V_{inc}, with the average aspect ratio of the precinct, H/W.

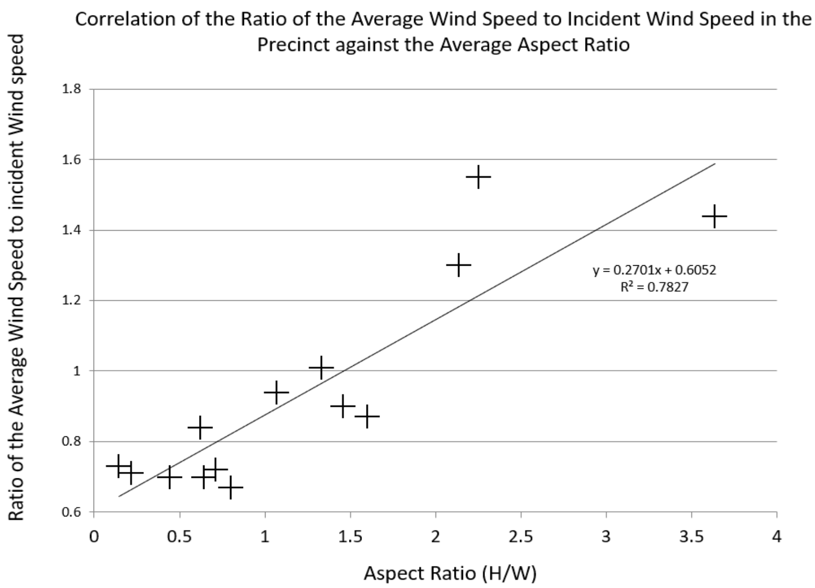


Figure 13 Correlation of the Ratio of the Average Wind Speed to Incident Wind Speed in the Precinct against the Average Aspect Ratio

13. The advection rate in the precincts depends highly on the orientation and the characteristics of its canyons. Canyons with an axis vertical or oblique to the wind direction may present a lower wind speed compared to the canyon with their axis parallel to the wind direction. This depends highly on the aspect ratio. For canyons vertical or oblique to the wind direction, a high h/w value > 0.8 signifies that the flow is under skimming regime and corresponds to a local vortex inside the canyon, and a bypass of the flowing air above the height of the buildings. For h/w values between 0.8 and 0.3, the flow is wake inference, and for lower values is isolated roughness.

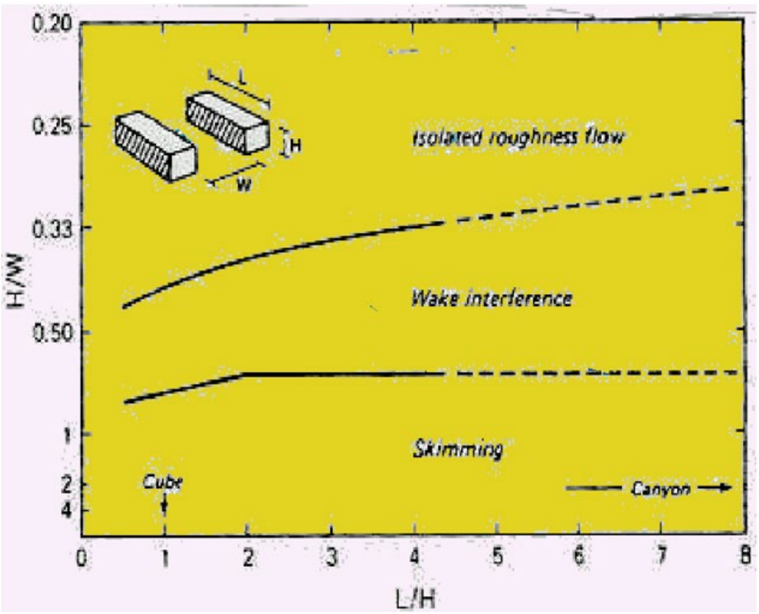


Figure 14 Air Flow Characteristics in Canyons with an axis vertical or slightly oblique to the wind direction; source: Oke

14. For all canyons of the precincts with an axis vertical or slightly oblique to the wind direction, a strong correlation of the average wind speed in the canyon, $V_{(veraverage)}$ and the aspect ratio, (h/w), is found.

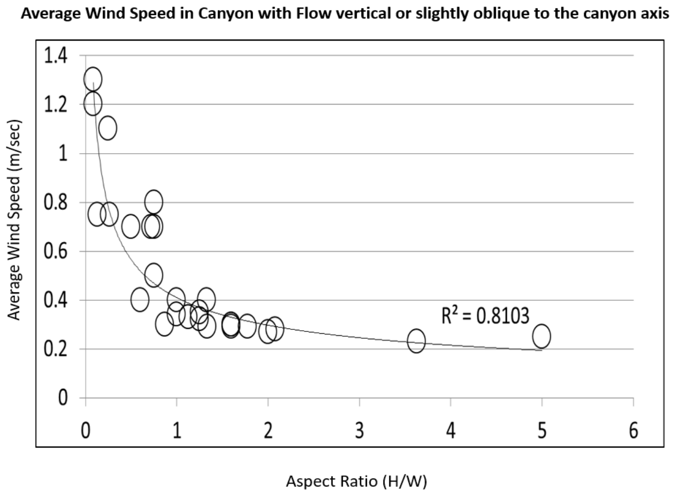


Figure 15 Average Wind Speed in Canyon with Flow vertical or slightly oblique to the canyon axis

15. For all canyon with their axis parallel to wind direction, a strong correlation is established between the length of the canyon and the product of the entry wind speed and width of the canyon as, well as with the product of the product of the exit wind speed with the width of the canyon.

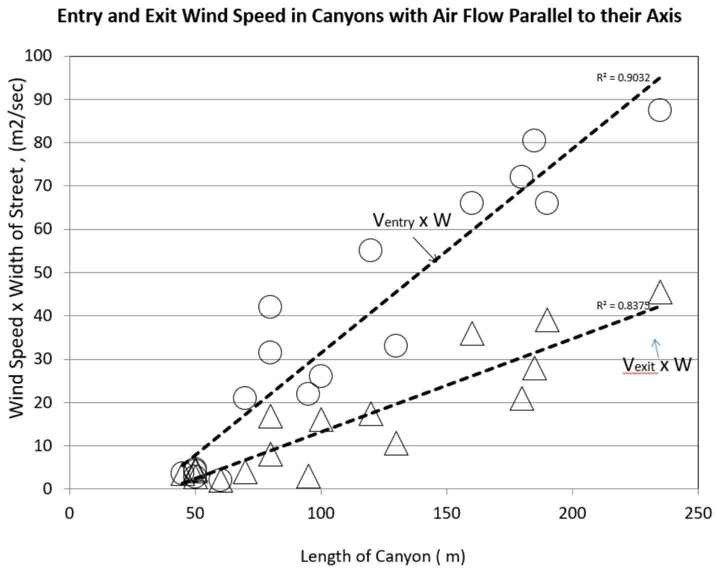


Figure 16 Entry and Exit Wind Speed in Canyons with Air Flow Parallel to their Axis

Impact on Energy

1. The layout and the characteristics of the precincts may affect the cooling energy consumption of a building of same orientation and same thermal and faced characteristics by up to 6 %.

2. The layout and the characteristics of the precincts may affect the total cooling energy consumption per square meter, of all buildings in a precinct, with different orientation and façade and thermal characteristics up to 53 % when buildings are extremely well shaded, or up to 93 % when the shading coefficient is average.

3. There is a general trend that the lower cooling energy consumption is presented in precincts with a lower aspect ratio, (H/W). This trend is stronger for the OT precincts than the CT precincts.

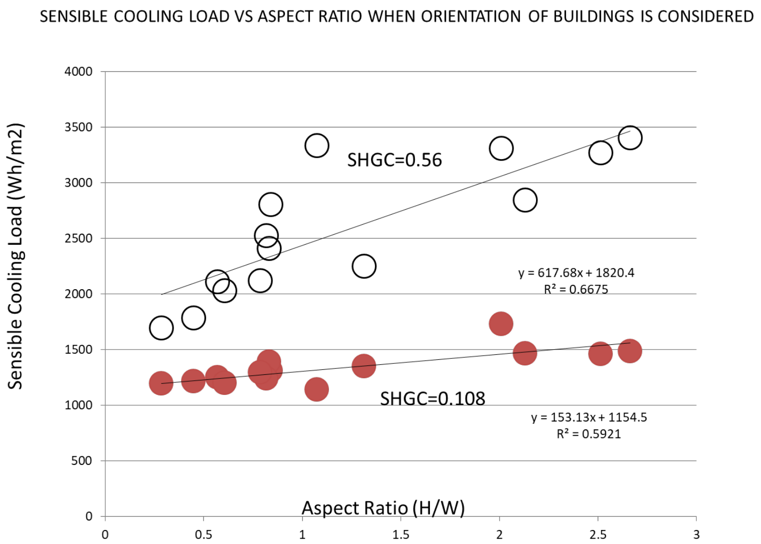


Figure 17 Sensible cooling load vs aspect ratio when orientation of buildings is considered

4. The global cooling energy consumption in a precinct may be up to 4800 % higher than in another precinct of the similar plot. This is of course very much influenced by the total built area, orientation, building characteristics, etc.

3. SIMULATION OF THE CURRENT AND FUTURE CLIMATIC SCENARIOS IN THE THIRD CITY OF SYDNEY

Model set-up

1. Model set-up

In the framework of this project, the WRF (Weather Research and Forecasting) model, Version 3.9.1 [1], was applied. The Mellor-Yamada-Janjić scheme (MYJ) [2-4] was used for the planetary boundary layer parameterization, combined with the Rapid Radiative Transfer Model for GCMs (Global Circulation Models) (RRTMG) scheme for longwave and shortwave radiation [5]. The land-surface model (LSM) Noah [6] was applied coupled with the single-layer urban canopy model UCM [7]. A surface-layer scheme by Janjić [8] based on the Monin-Obukhov similarity theory, as well as the Modified Tiedtke scheme [9-11] for cumulus parameterisation, were used. For microphysics, the scheme proposed by [12] was considered.

The simulation domain

The simulation domain was centered at the city of Sydney and three domains with a respective horizontal resolution of 4.5 km, 1.5 km and 0.5 km were used, where the two inner domains are two-way nested to their parent domain, as presented in Figure 18. The third inner-most domain covers an area between 150.205° to 151.491° East and -34.4202° to -33.4497° North. The output is provided every hour. On the vertical axis, 30 full sigma levels resolve the atmosphere up to 50 hPa (≈ 20 km above ground level (agl)), with a finer grid spacing near the surface.

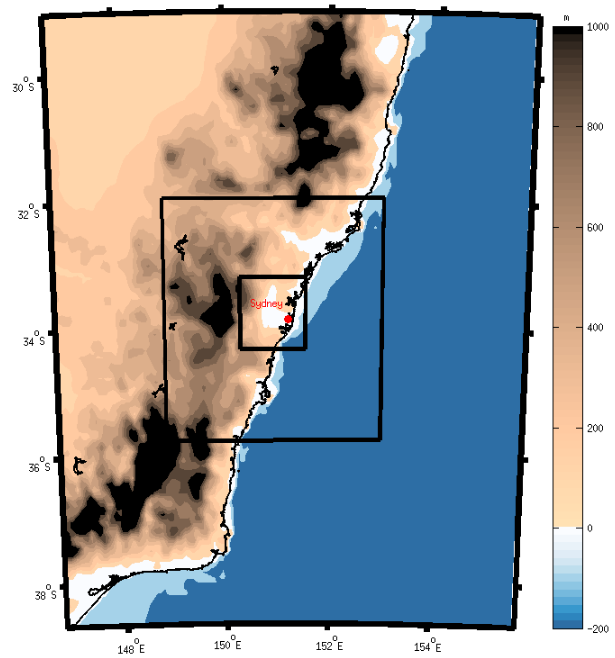


Figure 18 The three simulated domains.

Initial and lateral boundary conditions

1.1 <u>Initial and lateral boundary conditions</u>

1.1.a Present Climate

The initial and lateral boundary conditions, for the present climate, were derived from the National Center for Environmental Prediction (NCEP) Final (FNL) operational Global Data Assimilation System (GDAS) with 0.25° x 0.25° spatial resolution and were updated every 6 h. Regarding land use and soil types, the predefined datasets of Moderate Resolution Imaging Spectroradiometer (MODIS) with 21 land use classes were used. The urban land use was remapped by extracting land use zone data from a high-resolution spatial dataset (map) obtained from the NSW Department of Planning and Environment (DPE) Standard Instrument Local Environmental Plan - Land Zoning dataset: (https://datasets.seed.nsw.gov.au/dataset/standard-instrument-local-environmental-plan-land-zoning.

These data were then aggregated by the WRF pre-processor in order to assign a value to each grid cell (0.5×0.5 km), as presented in Figure 19, for the inner-most domain. Furthermore, urban canopy parameters and properties (e.g. building height, road width, urban fraction, albedo, roof layer thickness, emissivity, thermal conductivity, volumetric heat capacity) are configured for the simulations by combining information and data from literature [13-14] and imagery survey [15]. The following Table summarizes the basic values of the urban parameters configuration used for the base runs and mitigation simulations and Figure 20 the considered anthropogenic heat flux diurnal profile for present and future urban plan conditions.

Table 1 Basic Values of the urban canopy parameters configuration used for the base run and mitigation simulations.

Urban Canopy Model Parameters							
				Base run values		**Mitigation values**	
Urban Categories	Cat	Building Height	Urban Fraction	Roof Albedo	Road Albedo	Roof Albedo	Roof Albedo
Commercial Business Dist.	CBT	28	0.95	0.15	0.08	0.6	0.6
High Density	HD	13	0.66	0.15	0.08	0.6	0.6
Medium Density	MD	6	0.62	0.15	0.08	0.6	0.6
Low Density	LD	4	0.55	0.15	0.08	0.6	0.6
Industrial	IN	6	0.60	0.6	0.08	0.6	0.6

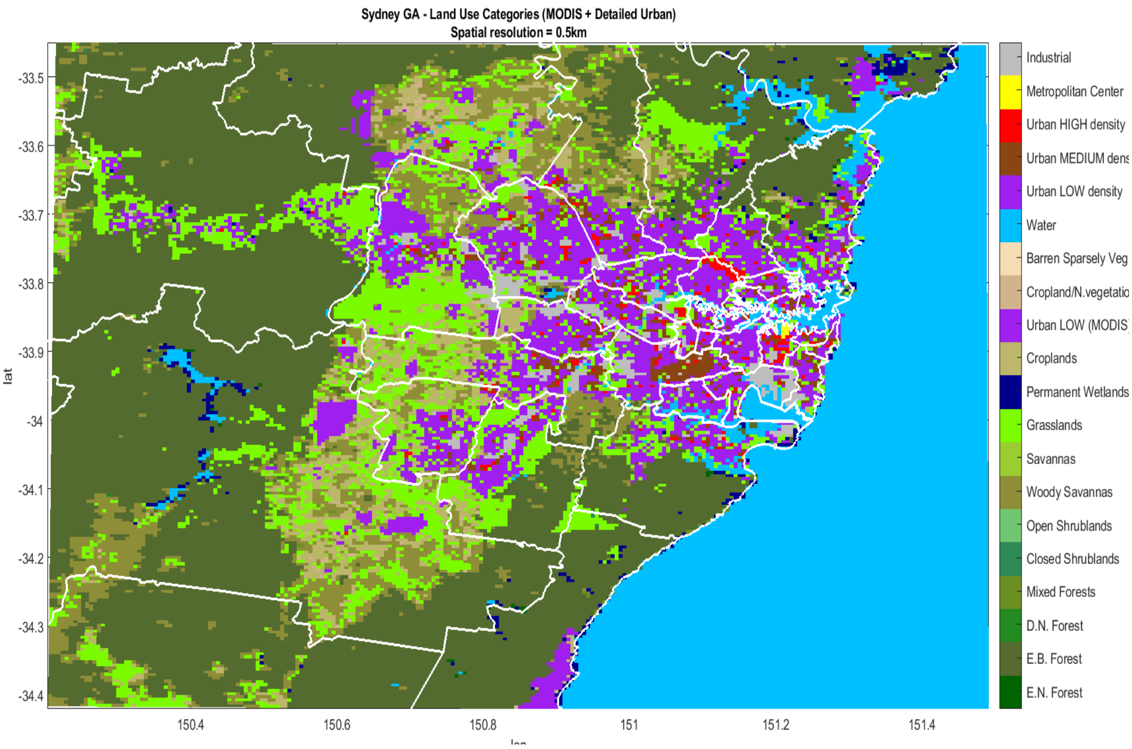
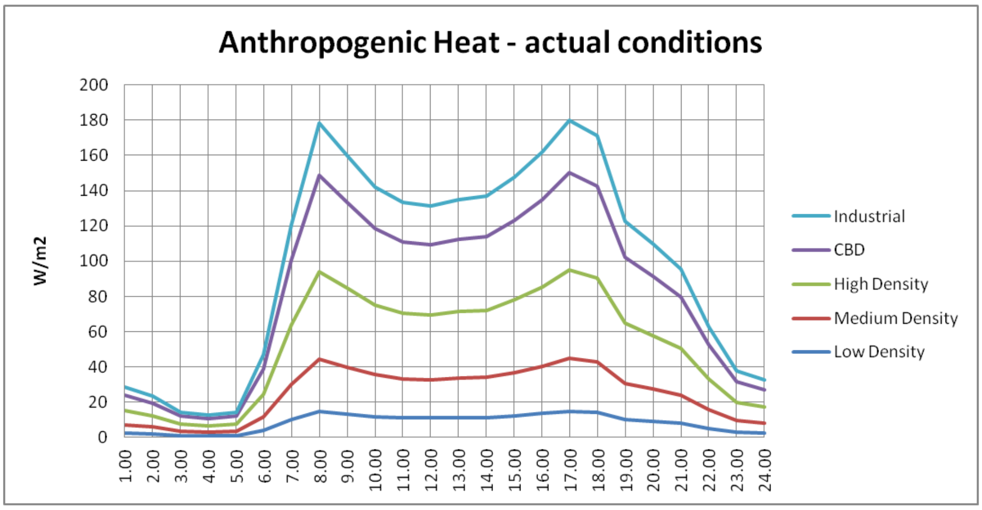


Figure 19 Land-use cover of the greater Sydney area (inner domain in Fig. 1) used as input for the WRF simulations. The white lines represent the municipalities' borders.

a



b

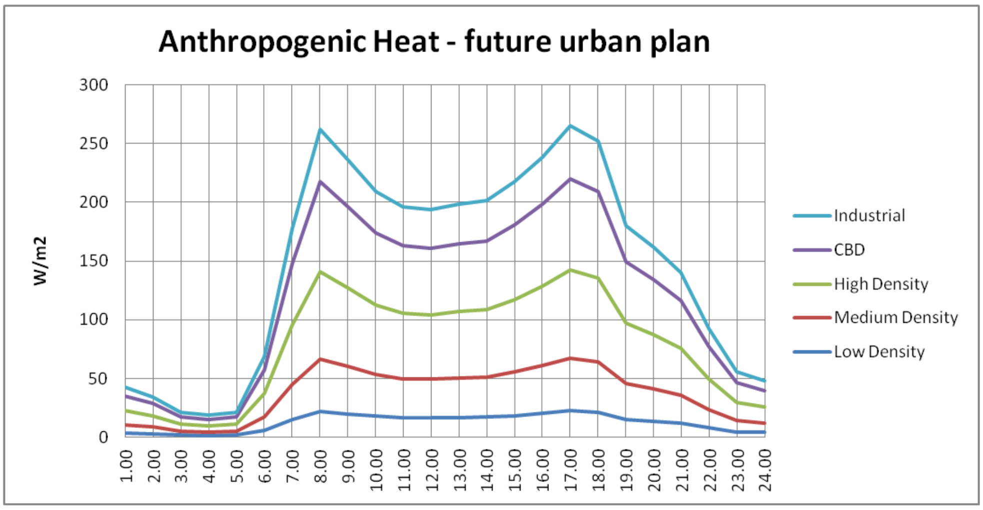


Figure 20 The considered anthropogenic heat flux diurnal profile at a) present and b) future urban plan conditions.

1.1 b. <u>Future Climate</u>

As far as the future climate scenarios are concerned, the input meteorological data were obtained from the NCAR CESM Global Bias-Corrected CMIP5 Output to Support WRF/MPAS Research dataset (https://rda.ucar.edu/datasets/ds316.1/#! description). This dataset includes global bias-corrected climate model output data from version 1 of NCAR's Community Earth System Model (CESM1) that participated in phase 5 of the Coupled Model Intercomparison Experiment (CMIP5), which supported the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5). The dataset contains all the variables needed for the initial and boundary conditions for simulations with the WRF or the Model for Prediction Across Scales (MPAS), provided in the Intermediate File Format specific to WRF and MPAS. The data are interpolated to 26 pressure levels and are provided in files at six hourly intervals. The variables have been bias-corrected using the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Reanalysis (ERA-Interim) fields for 1981-2005, following the method in [16]. Files are available for a 20th Century simulation (1951-2005) and three concomitant Representative Concentration Pathway (RCP) future scenarios (RCP4.5, RCP6.0 and RCP8.5) spanning 2006-2100.

For the Sydney future (2050) numerical simulations, the RCP4.5 Future Scenario dataset has been used. The land-use cover of the greater Sydney regarding the boundary conditions of the ‘Climatic conditions with future urbanization’ scenario is presented in Figure 21.

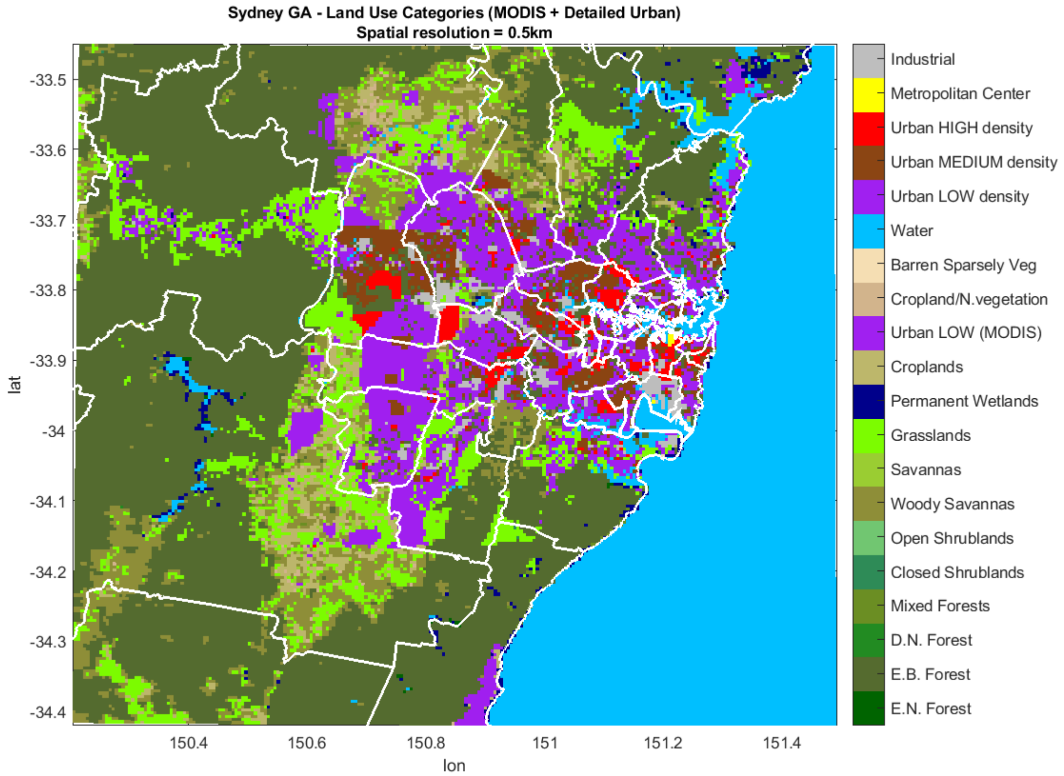


Figure 21 As in Fig. 2 but with increased dwelling density based on future projections and inclusion of new Urban Growth Areas for the 'Climatic conditions with future urbanization' scenario.

1.2 Simulation periods

According to BOM website, the Western Sydney area experienced a record of three days above 40 °C during February 2017, and several stations recorded their highest temperature on either the 10th or 11th of February. Furthermore, the mean maximum ambient condition was measured on the 9th February 2017. As a result, for the present conditions, the 9th and the 10th February 2017 were selected from the UNSW as representative days for 'Average maximum summer ambient temperature' and 'Heat Wave' respectively. Regarding the future climate scenarios, the numerical simulations were performed for the whole month of February 2050 and were compared with future mitigation and urbanization scenarios.

Model evaluation

2. Model evaluation

The model evaluation was performed for the two selected days (9th and 10th February 2017) and the simulated results were well compared with observations from the Olympic Park station (Figure 22 as presented in Figure 23 and Figure 24.

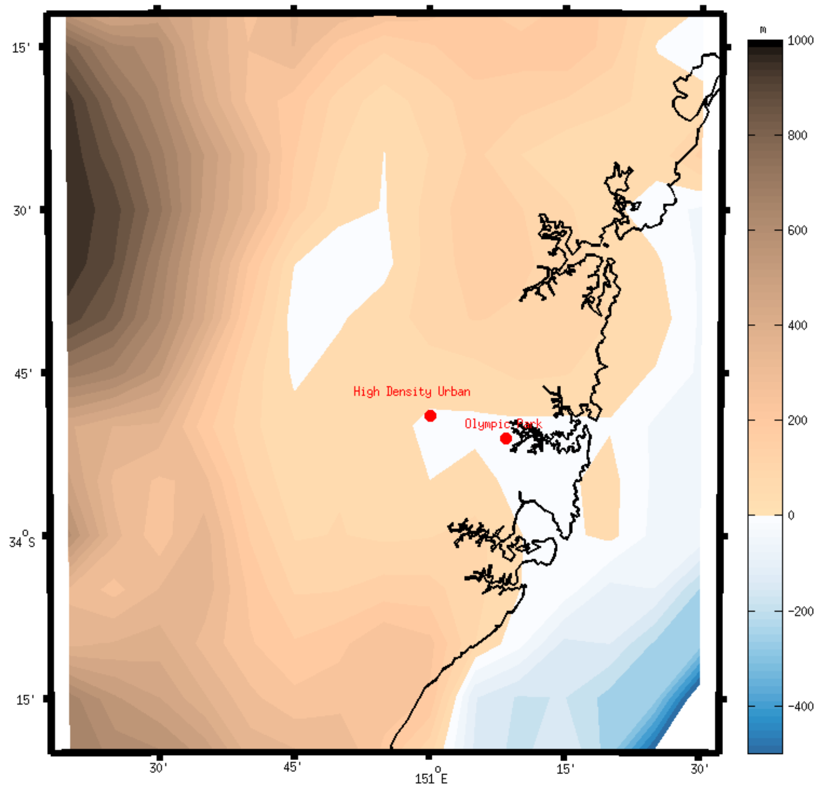


Figure 22 The location of the Olympic Park station and a selected high-density urban cell.

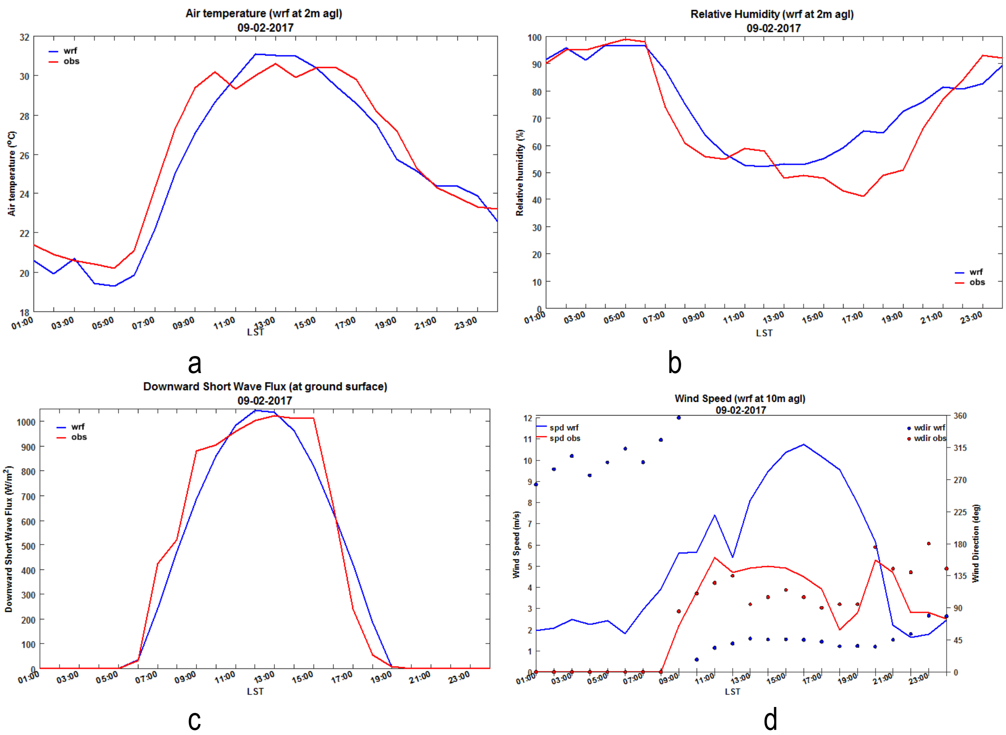


Figure 23 Timeseries of a) air temperature (at 2m agl) b) relative humidity c) downward short wave flux at ground surface and d) wind speed (at 10 m agl) as measured (red color) and simulated (blue color) on 09-02-2017 at the Olympic Park.

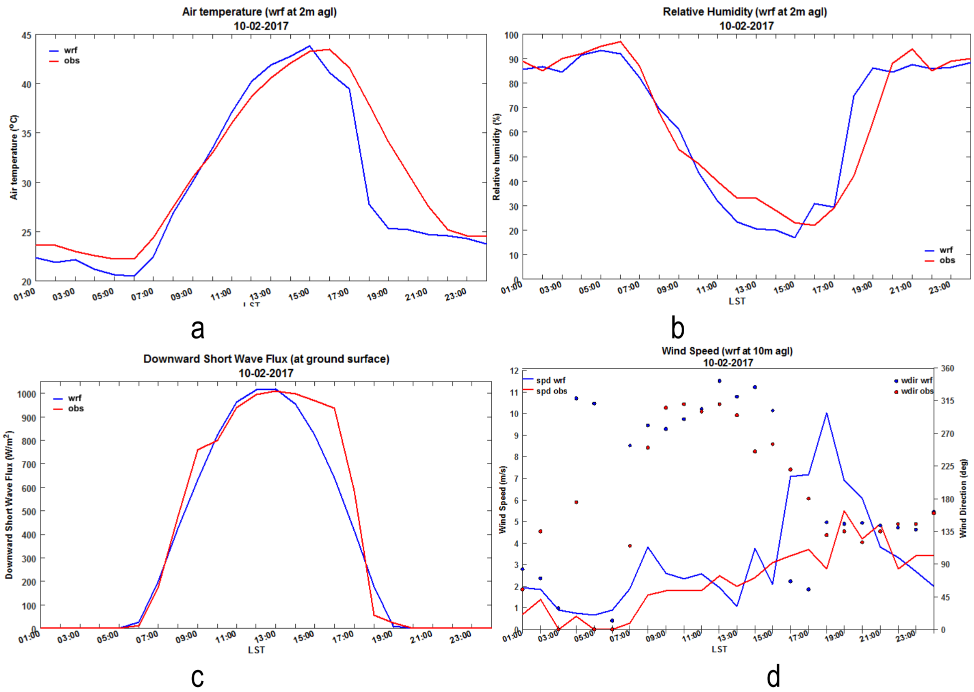


Figure 24 As in Fig. 9 but for 10-02-2017.

Activities

3. Activities

Specific simulations were performed in order to estimate the temperature spatial distribution. In particular, the simulations were performed under the following scenarios (boundary conditions):

1. Scenario 1: Average maximum summer ambient temperature using the actual urban layout: Mean maximum ambient condition for a warm summer day (Warm max Average Base Run: Use of the actual climate and land use. Mitigation technologies are not considered.

2. Scenarios 2-3: 2050 Climatic conditions with future urbanization: 2050 Urban Plan simulation, based on the RCP4.5 Future Scenario dataset, including a) increased dwelling density based on future projections b) inclusion of new Urban Growth Areas c) increased Anthropogenic Heat Flux.

3. Scenario 4: 2050 Climatic conditions with future urbanization and mitigation technologies: Urban Plan simulation is based on the RCP4.5 Future Scenario dataset and includes a) increased dwelling density based on future projections b) inclusion of new Urban Growth Areas c) increased anthropogenic Heat Flux d) planting of 2 million irrigated trees in the so called Third City and 3 million irrigated trees in the rest of Sydney e) increased albedo of urban impervious surfaces and f) Water in the landscape.

An example of the produced figures for a selected scenario (No 3) is given below in Figure 25.

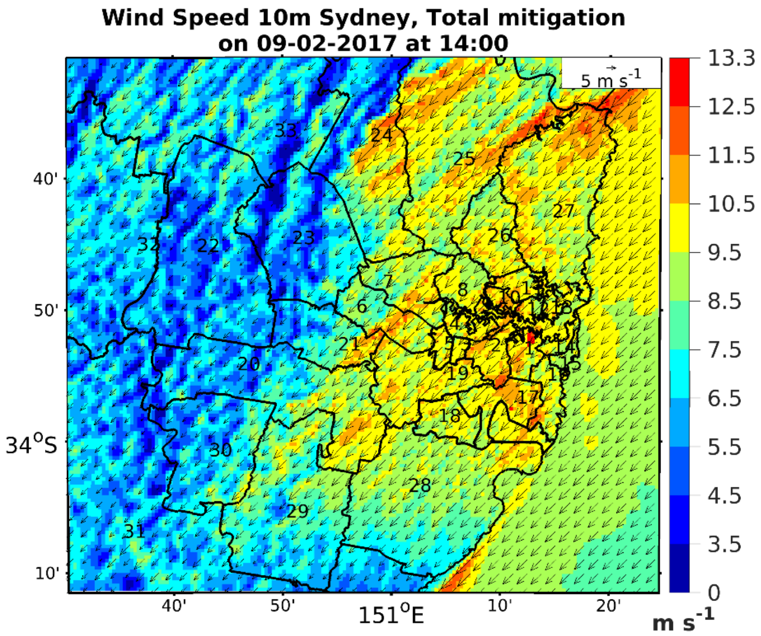


Figure 25 Surface wind speed fields (at 10m agl) on 09-02-2017 at 14:00 LST

Results

4. Results

Analysis of Scenario 1

Figure 26 to Figure 28 show the daily distribution of the wind speed and direction, the ambient temperature at 2 m height and the surface temperature. During the Midnight, the Wind flow from the ocean, (eastern or north eastern directions) is quite strong, and up to 10 m/sec. The sea breeze penetrates up to the western boundaries of the Sydney Municipality where the wind speed is 3-5 m/sec. In western parts of the Sydney Municipality, the wind speed is low and close to 1 m/sec and is flowing from Western and North Western directions. In the area of the Third City, the wind speed is close to 1 m/sec flowing from Western directions. An important wind penetration from Northern directions is observed in the area of Wollondilly, where wind speed may reach 6-7 m/sec. The ambient temperature in the Eastern suburbs and in all areas affected by the sea breeze is higher than in the rest of Sydney and varies between 22-26 °C. The ambient temperature western to the Municipality of Sydney is lower and vary between 18-23 °C. In the Third City zone, the ambient temperature is low and varies between 18-21 °C. Much lower ambient temperatures are observed in the area of the Blue Mountains and Wollondilly, 18-19 °C.

The distribution of the surface temperature follows the patterns of the ambient temperature. In the Eastern suburbs, the surface temperature varies between 22-26 °C, while in the western part of the city, it ranges between 18-22 °C. At 06:00, wind speed is flowing from Western and North Western directions in the whole Sydney area. In the Western part of the city, (Blue Mountains, Penrith), the wind speed can be as high as 6 m/sec. In the rest of the western Sydney area, the wind speed varies as a function of the ground relief and the specific local conditions. In most of the Western Sydney area, the wind speed is low and close to 1 m/sec. In the eastern suburbs, and close to the ocean front, wind speed is higher and may reach 5-6 m/sec. Ambient Temperature in Western Penrith is high and between 22-23 °C mainly because of the high advection caused by the warm western winds. In the rest of western Sydney area, the ambient temperature varies between 17 to 20 °C, while in the Eastern Suburbs the ambient temperature is slightly higher and varies between 19-22 °C, mainly because of the higher ambient temperature of the air above the ocean. The ambient temperature in the third City zone is close to 19 °C. The distribution of the surface temperature follows the patterns of the ambient temperature. In Western Penrith the surface temperature is influenced by the higher ambient temperature and is close to 22 °C. In the rest of the Western Sydney, it varies between 17-20 °C, while in the eastern suburbs it ranges between 21 to 22 °C.

Scenario 1 : Surface Wind (at 10 m agl)

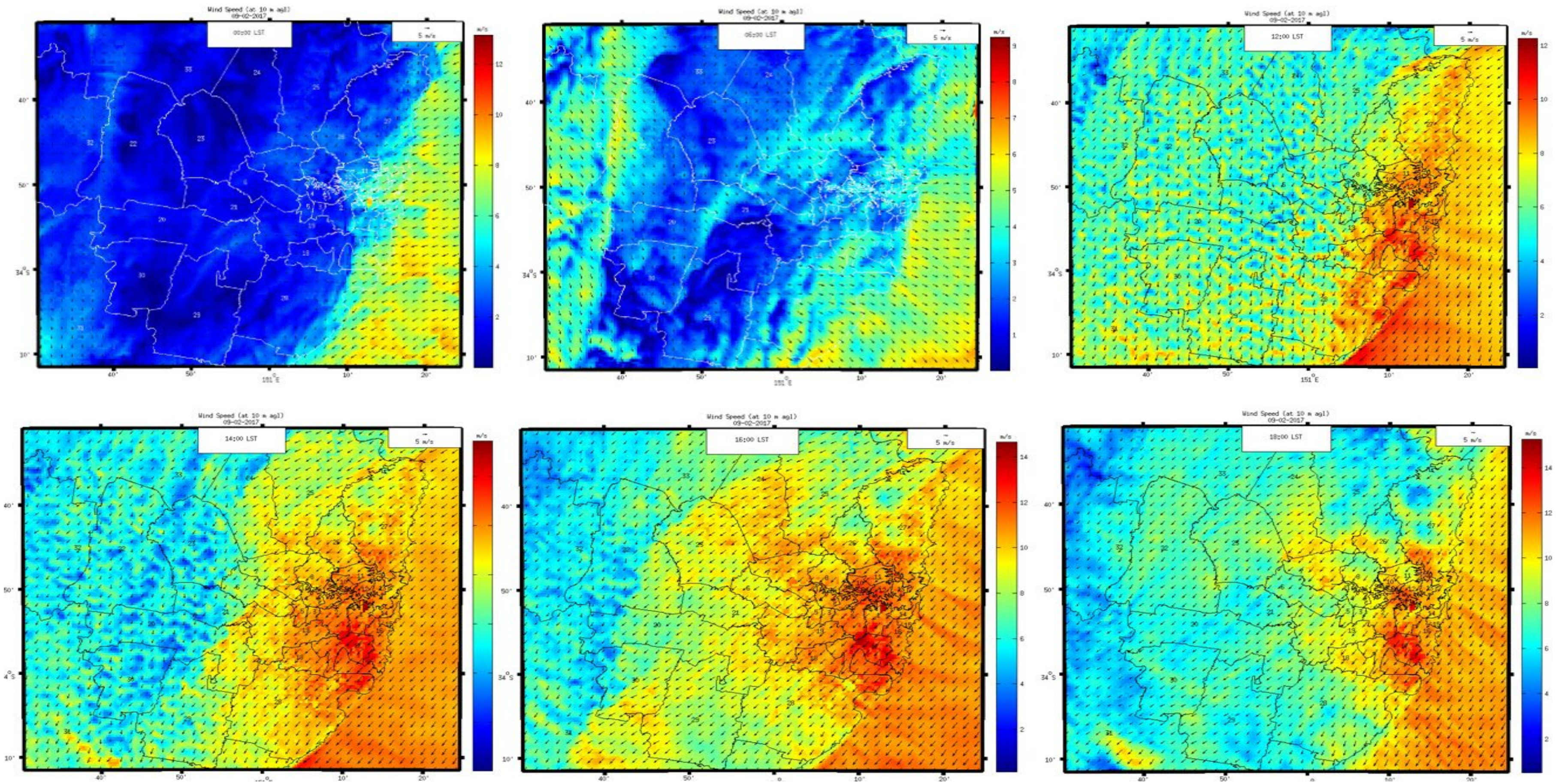


Figure 1 Distribution of the Wind Speed and Direction at 10 m (09/02/2017).

Scenario 1 : Distribution of the Mean Max Ambient Temperature - 09-2-2017

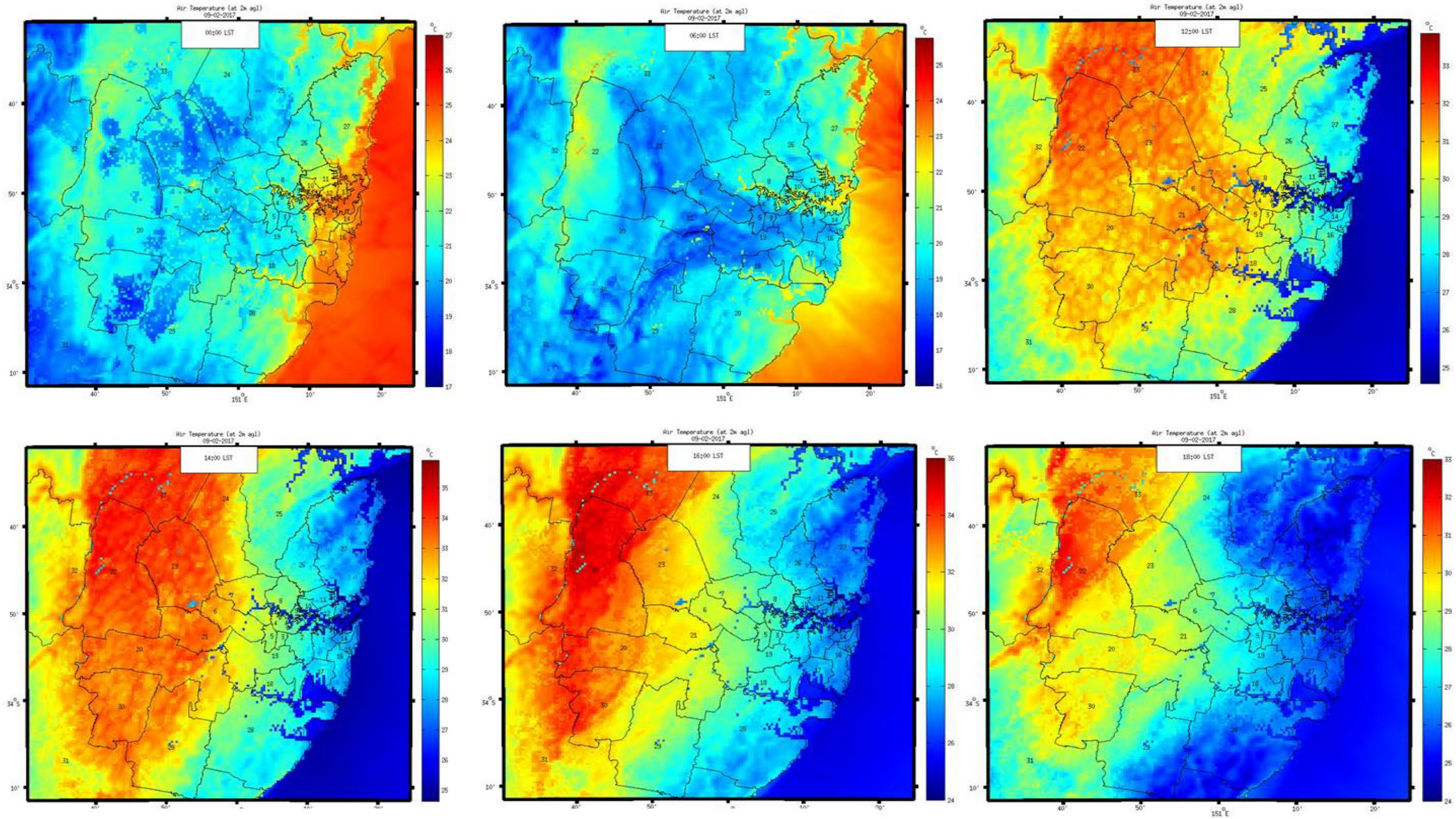


Figure 2 Distribution of the average maximum ambient temperature, 2m, (09/02/2017).

Scenario 1 : Surface Temperature

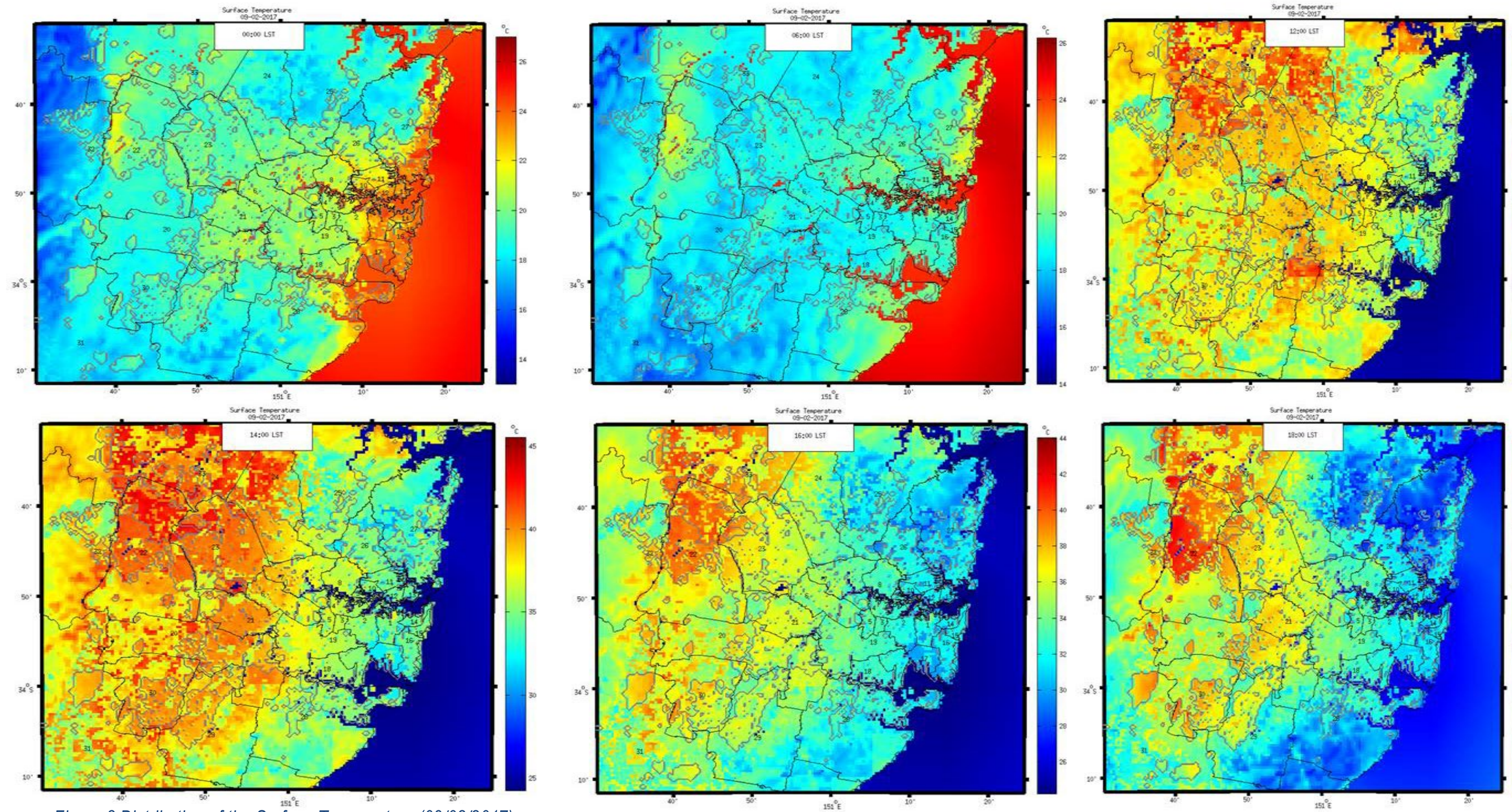


Figure 3 Distribution of the Surface Temperature (09/02/2017).

During the midday, the wind in the eastern suburbs is flowing from North Eastern directions. Wind speed varies between 5-10 m/sec. North – Eastern cool winds penetrate up to the western part of Ryde, Burwood and Georges River. The rest of the Western Sydney does not benefit from the cool sea breeze. Wind is mainly flowing from Northern directions with a speed between 2-7 m/sec depending on the local relief. Similar wind speed values are observed in the Third City area. As it concerns the temperature distribution, in the eastern suburbs present temperature is about 3 °C lower than in the rest of the Sydney area, mainly because of the impact of the refreshing sea breeze. Temperature in the eastern parts of Sydney varies between 27 to 29 °C, while in the western part it is between 30-32 °C, and in Penrith reaches 33 °C. In the South Creek area, the ambient temperature varies between 30,5 to 32 °C. It is distinctive that the refreshing winds penetrate much deeper in the Northern and Southern parts of Sydney than in the CBD area. This is mainly explained by the high density of the CBD zone in combination with the high-rise buildings which stop the penetration of the wind towards the western Sydney area. As a matter of fact, for the same longitudinal line, the northern and southern parts of the city present a lower ambient temperature than the central zone of the city. The surface temperature is mainly determined by the absorptivity of the materials in the earth surface and the ambient temperature and wind speed. In the eastern suburbs, the ambient temperature varies between 30-36 °C, in the western part between 33 to 40 °C, while some spots with high absorptivity may have a surface temperature close to 43 °C.

In the afternoon, the strength of the sea breeze is intensified. Refreshing north eastern winds may reach the western part of Cumberland or the eastern part of Liverpool. The wind speed in the eastern suburbs is high and varies between 7-12 m/sec. In the rest of the western Sydney the wind speed is low and is flowing from northern directions, 1-6 m/sec. Same wind speeds are observed in the Third City area. The distribution of the ambient temperature follows the wind patterns. All urban zones that benefit from the sea breeze present a much lower ambient temperature. In the eastern suburbs temperature varies between 29 to 31 °C, while in the rest of the western Sydney and the south creek area is between 33 to 35 °C. The ambient temperature in Penrith area is higher and close to 36 °C. As previously mentioned, the surface temperature is mainly determined by the absorptivity of the materials in the earth's surface, the ambient temperature and wind speed. In the eastern suburbs, the ambient temperature varies between 32-37 °C, in the western part between 35 to 43 °C, while some spots of high absorptivity may present a surface temperature close to 45 °C.

In the afternoon, the intensity of the sea breeze is increasing and penetrates up to eastern part of Penrith and Wollondilly. The intensity of the wind speed varies between 6-12 m/sec with higher wind speeds in the zone are calculated next to the coast. In the remaining part of western Sydney, the wind speed is low and is flowing from northern directions, 1-4 m/sec. Wind speed in the Third City varies between 6-8 m/sec. The ambient temperature is following the wind patterns. It is lower at the coastal area and is increasing gradually from eastern to western. In the eastern suburbs it varies between 26-28 °C, in the so called second city between 30-33°C, in the Western part between 32-34 °C, while in Penrith it reaches 36 °C. In the Third City area is between 31-33 °C.

At the late afternoon, the sea breeze penetrates in the whole Sydney area. Higher wind speeds are observed in the coastal area, 6-12 m/sec, while the wind speed is gradually decreasing and in the western part is close to 5 m/sec. As previously described, the ambient temperature follows the wind patterns. In the eastern suburbs it is varying between 24-27 °C, in the so called second city between 28 to 30 °C, while in the western part of Sydney is between 30-32 °C, and in Penrith it reaches 33 °C. Finally, the patterns of the surface temperature do not change considerably. In the eastern suburbs the surface temperature varies between 26-28 °C, in the so called second city between 28 -31 °C, while in the western part of Sydney it may reach 34 °C.

The distribution of the temperature during an average warm day of summer is almost completely determined by the wind patterns prevailing in the city. During the night time, the eastern suburbs may be up to 3 °C warmer than the western parts of the city. During the day time, cool eastern winds penetrate gradually in the city. The penetration depth is lower in the morning hours and is increasing gradually as the intensity of the breeze intensifies. At late afternoon sea breeze penetrates up to the eastern part of Pernith. Wind speed is much higher in the eastern parts of the city and gradually is losing its momentum moving towards the western parts. As a result, the ambient temperature in the eastern part is considerably lower than western parts. During the morning hours the temperature difference between the eastern and western parts can be as high as 3 °C, but it increases up to 6 °C in the late afternoon. The warmest part of the Sydney area is located in Penrith that may present up to 8 °C higher temperature than the eastern suburbs. The Third City area does not present any specific climatic characteristics and follow the patterns of Western Sydney.

Analysis of the Scenario 4

The distribution of the ambient temperature is given below in Figure 29. During the midnight period, wind in the eastern part of the city is flowing from northern directions. The wind speed in the coastal area is between 4-6 m/sec, while in the Northern Sydney it is higher and up to 10 m/sec. Northern winds penetrate the whole northern Sydney up to the level of Penrith and the northern boundaries of Ryde, Parramatta and Fairfield. In the southern part of this boundary, wind speed is very low and close to 1 m/sec. While the urban zones affected by the warmer northern winds, presented a temperature between 22-24 °C under Scenario 2, the application of mitigation technologies (scenario 4) decreases the temperature to a range of 18 – 24 °C. In the urban zones with low wind speed, mainly in western Sydney, the temperature under Scenario 2 and 3, was 19 to 23 °C, and 18-23 °C respectively, while under the scenario 4, the ambient temperature ranges between 18-23 °C. In the Third City area, the average temperature is 19 °C.

Early in the morning the wind characteristics in the coastal area are quite similar as previously described. In the Northern part of Sydney northern winds penetrate less than before and up to the limits of Hills Shire. In the rest of Sydney, the wind speed is very low and close to 1 m/sec. In the very western part of Sydney, Blue Mountains and Wollondilly, a strong frond of western winds starts to be developed. The ambient temperature in the area affected by the northern winds is varying between 18-21°C. In the remaining part of the western Sydney area, it is ranging between 15-21 °C, similar as in the scenario 3 and about 2 °C lower than that in the scenario 2 (17-23 °C). The ambient temperature in the Southern Creek area is between 16-18 °C. At midday, two wind fronds are observed over the Sydney area. In the eastern suburbs winds flows from eastern directions penetrating up to the western boundaries of Strathfield and Georges River. Wind speed varies between 5-9 m/sec. A second frond flown from the west enters the northern western part of Sydney at the level of Blue Mountains and Hawkesbury and flows in the northern part of Sydney towards the east. It is extended up to the southern boundaries of Hills Shire and Hornsby until is neutralised by the sea breeze at the level of Northern beaches. Wind Speed varies between 8 to 11 m/sec. In the west southern part of Sydney, Wollondilly a local western wind frond enters the city. The remaining part of Sydney exhibits very low wind speeds, close to 1 m/sec. The ambient temperature distribution in the city is determined by the wind patterns. All eastern areas affected by the sea breeze present much lower temperatures 27-34°C, while under the scenarios 3a and 2 it was ranging between 30-36 °C. The urban zones affected by the western winds exhibit much higher temperatures, 35-39 °C, while it was between 37-41 °C, about 1 °C higher than in the Scenario 2. The average temperature in the Third City is 36 °C, almost 3 °C lower than in the scenario 2. In Penrith the ambient temperature is 39 °C.

In the early afternoon, sea breeze dominates and eastern winds from the coast cover the whole Sydney area except of the North Western part of the city. Wind speed varies between 4 to 10 m/sec. The eastern suburbs present lower ambient temperatures mainly because of the impact of the sea breeze, 27.5-34°C. Lower ambient temperatures are observed in the less dense coastal areas while the higher temperature is in the CBD area. In the Western Sydney area, the ambient temperature is higher, 32-39 °C. In the Third City zone, the average ambient temperature is close to 35 °C. At late afternoon, sea breeze dominates and covers all the northern, central and part of the southern Sydney. In the Southern Western part of the city, strong western winds enter the city and are extended up to the eastern parts of Campbelltown and Camden and the western part of Liverpool. Temperature in the eastern part is varying between 24-29 °C. In the western part of Sydney, it varies between 29-31 °C. Temperature is 31 °C in the Third City and 32 °C in Penrith.

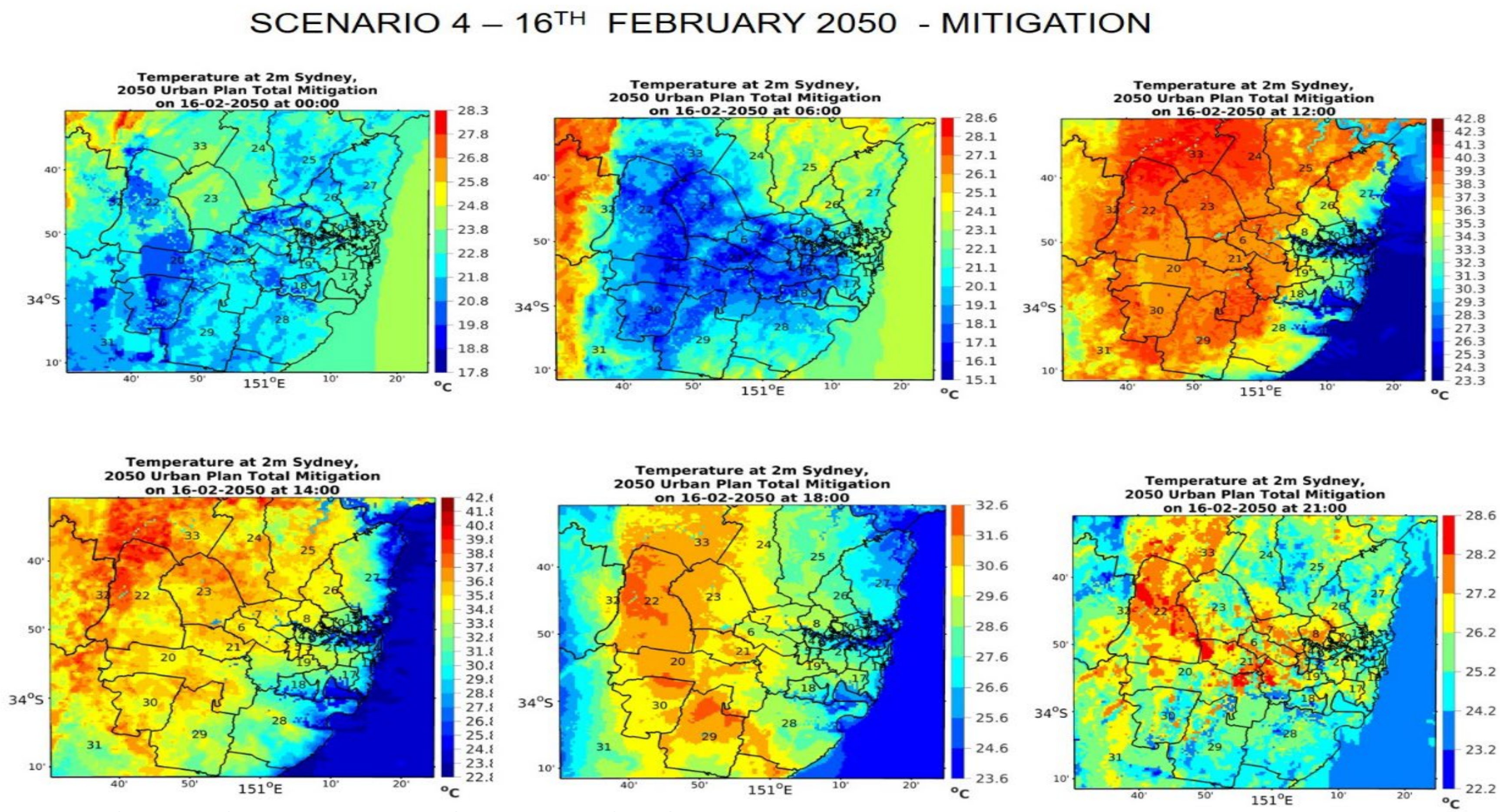


Figure 4 Distribution of the Ambient Temperature in Sydney as predicted for *the Scenario*

Under the 4th Scenario, the maximum temperatures in Eastern and Western Suburbs of Sydney are reduced by almost 1 °C to 3,5 °C. Thus, the application of global mitigation techniques in the Sydney area can counterbalance the impact of the additional precincts in Western Sydney and further decrease the ambient temperature up to 3,5 °C. The achieved reduction of the ambient temperature is varying between 1-5 °C, compared to scenario 2. The calculated day time temperature decrease, ranges between 3 to 3,5 °C.

References

[1] Skamarock W.C., Klemp J.B., Dudhia J., Gill D.O., Barker D.M., Duda M.G., Huang X.-Y., Wang W., Powers J.G., 2008: 'A description of the advanced research WRF version 3', NCAR TECHNICAL NOTE, NCAR/TN-475+STR, 113 pp

[2] Janjić Z.I., 1990: 'The step-mountain coordinate: physics package', Mon. Weather Rev., 118, 1429–1443

[3] Janjić Z.I., 1996: 'The surface layer in the NCEP Eta Model', Eleventh Con-Conference on Numerical Weather Prediction, 19–23 August, Norfolk, VA, American Meteorological Society, Boston, MA; 354–355

[4] Janjić Z.I., 2002: 'Nonsingular implementation of the Mellor–Yamada Level 2.5 scheme in the NCEP meso model', NCEP Office Note 437 (61 pp)

[5] Iacono M.J., Delamere J.S., Mlawer E.J., Shephard M.W., Clough S.A., Collins W.D., 2008: 'Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models', J. Geophys. Res., 113, D13103

[6] Chen F., Dudhia J., 2001: 'Coupling an advanced land surface–hydrology model with the Penn State–NCAR MM5 modeling system. Part I: Model implementation and sensitivity', Mon. Weather Rev., 129, 569–585

[7] Tewari M., Chen F., Kusaka H., Miao S., 2007: 'Coupled WRF/Unified Noah/urban-canopy modeling system', NCAR WRF Documentation, Boulder: NCAR., pp. 1–20

[8] Janjić, Z.I., 2001: 'Nonsingular implementation of the Mellor -Yamada level 2.5 scheme in the NCEP meso model', Office Note 437. pp 1-61

[9] Tiedtke M., 1989: 'A Comprehensive Mass Flux Scheme for Cumulus Parameterization in Large-Scale Models', Mon. Weather Rev., 117, 1779-1800.

[10] Nordeng T. E., 1995: 'Extended versions of the convective parameterization scheme at ECMWF and their impact on the mean and transient activity of the model in the Tropics', ECMWF Research Department Tech. Memo. 2006, 41 pp.

[11] Gregory D., Morcrette J.-J., Jakob C., Beljaars A. M., Stockdale, T, 2000: 'Revision of convection, radiation and cloud schemes in the ECMWF model', Q. J. R. Meteorol. Soc., 126, 1685–1710

[12] Thompson G., Field P.R., Rasmussen R.M., Hall W.D., 2008: 'Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization', Mon. Weather Rev., 136, 5095–5115

[13] Jackson T.L., Feddema J.J., Oleson K.W., Bonan G.B., Bauer J.T., 2010: 'Parameterization of Urban Characteristics for Global Climate Modeling', Annals of the Association of American Geographers, 100(4), 848-865

[14] Adams M., Duc H., Trieu T., 2015: 'Impacts of land-use change on Sydney's future temperatures', Published by: Office of Environment and Heritage, https://climatechange.environment.nsw.gov.au/~/media/28CBA38BB62E425E97650EE682728476.ashx

[15] Google Earth version 7.3.2, 2018. https://www.google.com/earth

[16] Bruyère C.L., Done J.M., Holland G.J., Fredrick S., 2014: 'Bias Corrections of Global Models for Regional Climate Simulations of High-Impact Weather', Clim. Dyn., 43, 1847-1856

4. DESCRIPTION OF THE SELECTED LAYOUTS

Building types

Seven housing types were profiled for this study and for Sydney metropolitan area (SMA) based on building height as per the building typologies defined by the Department of Planning and Environment New South Wales (NSW). These are described in detailed in the documentation prepared for the Sydenham to Bankstown Urban Renewal Corridor[1]. To understand the differences and characteristics that define each building type it was implemented a coding system. A brief description of these seven types is presented below and a comparative summary of characteristics is presented in Figure 30.

T1 Single dwellings
Single dwelling areas includes houses as well as terrace houses, dual occupancies and semi-detached dwellings between one and two storeys. In this type the average number of people per hectare ranges between 30 and 100. This type of buildings is typically found in suburban areas with local parks and distant shops in the vicinity.

T2 Low rise
Low rise housing typically involves residential townhouse/terrace housing or small-scale buildings between three and four storeys with street level retail shops and cafés at ground level and residential apartments above. In this type the average number of people per hectare ranges between 70 and 200. This type of buildings is typically found close to village centres and alongside transport corridors, with parks and shops in close vicinity.

T3 Low/medium rise
Low/medium rise housing involves residential apartment buildings of five to six storeys high, sometimes with cafes or small shops at the ground level. In this type the average number of people per hectare ranges between 150 and 300. This type of buildings is typically found close to town centres and urban renewal areas and possess amenities such as parks, shops and swimming pools.

T4 Medium rise
Medium rise housing involves residential apartment buildings of seven to eight storeys high, sometimes with cafes or medium shops at the ground level. In this type the average number of people per hectare ranges between 250 and 400. This type of buildings is typically found near urban corridors, urban renewal areas and city centres. Common amenities in close vicinity are parks, shops, gyms, child cares, swimming pools, buses, trains.

T5 Medium/High rise
Medium/high rise housing involves residential apartment buildings of nine to 12 storeys high, sometimes with retail, medium and large shops at the ground level. In this type the average number of people per hectare ranges between 300 and 400. This type of buildings is typically found near urban corridors, urban renewal areas, near railway stations. Common amenities in close vicinity are parks, supermarkets, gyms, child cares, swimming pools, buses, trains, theatres/cinemas.

T6 High rise 1
High rise housing 1 comprises both standalone apartment buildings and mixed-use buildings of 13 to 25 storeys high that incorporate retail shops and/or commercial uses on the lower levels. In this type the average number of people per hectare ranges between 400 and 800. This type of buildings is typically found near transport nodes, urban renewal areas, and city centres. Common amenities in close vicinity are parks, supermarkets, gyms, child cares, swimming pools, buses, trains, theatres/cinemas.

T7 high rise 2
High rise housing 1 comprises both standalone residential and mixed-use towers of more than 25 storeys that incorporate retail shops and/or commercial uses on the lower levels. In this type the average number of people per hectare ranges between 600 and 1200. This type of buildings is typically found in city centres and near railway stations. Common amenities in close vicinity are parks, jobs, supermarkets, gyms, clubs, swimming pools, buses, theatres/cinemas, major railway stations.

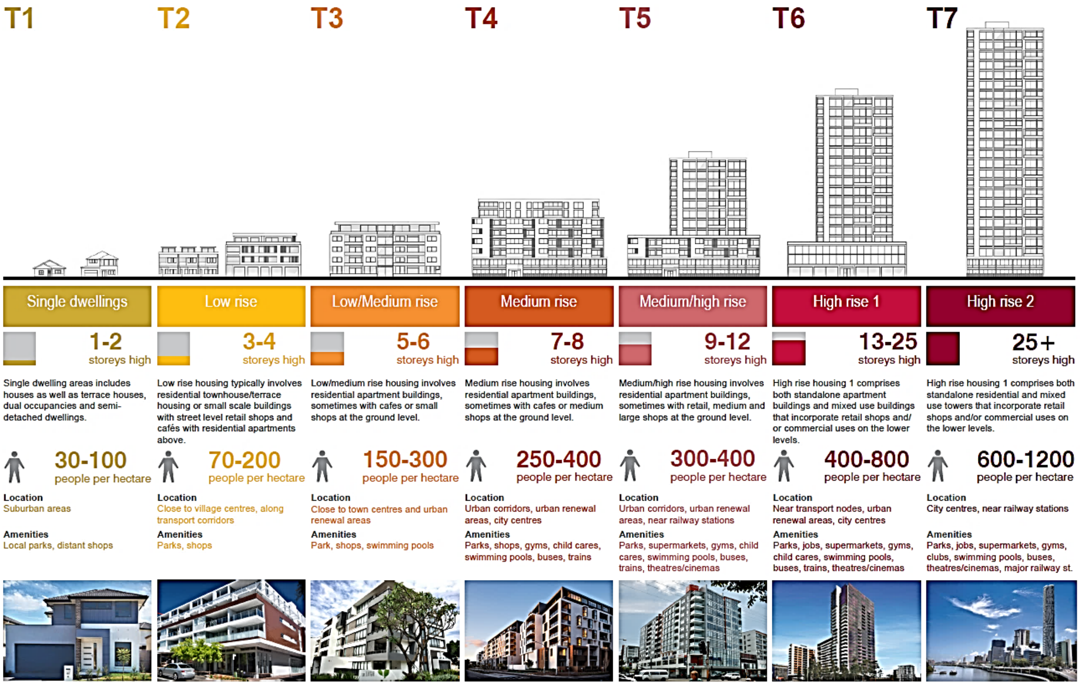


Figure 30. Comparison between the seven buildings types defined for the present study in accordance with the Department of Planning and Environment NSW.

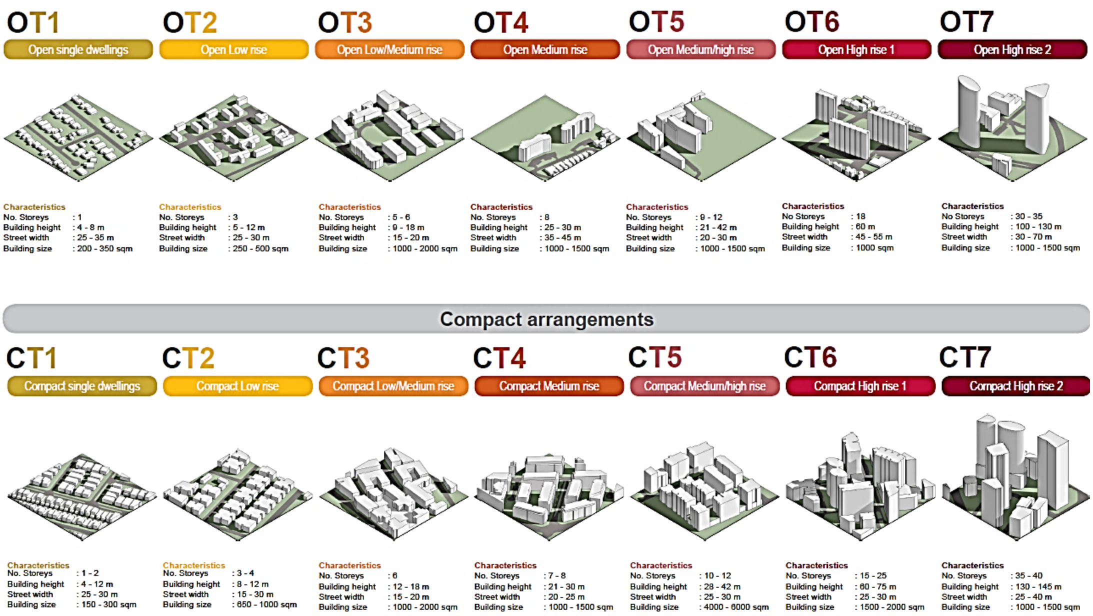


Figure 31. Summary of the 14 housing typologies proposed based on seven building types organised in open and compact arrangements.

---

[1] https://www.planning.nsw.gov.au/Plans-for-your-area/Priority-Growth-Areas-and-Precincts/Sydenham-to-Bankstown-Urban-Renewal-Corridor

As suggested by the Urban Taskforce Australia, most urban precincts are not completely homogenous, indeed, most developments have a mixture of building heights and distinct patterns and arrangements of buildings defined that provide different densities and open space solutions [2]. To respond to this, the seven typologies where additionally distinguished into two types of arrangements; open arrangement of buildings are represented by the letter 'O' while compact arrangement of buildings are represented by the letter 'C' (Figure 31).

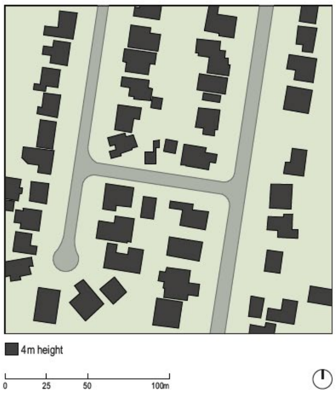
This division follows the approach applied by the Local Climates Zones (LCZs) proposed by Stewart and Oke (2012) which is a standardised and widely applied scheme for analysis of urban heat islands (UHI) conditions within urban areas. Accordingly, a total of 14 residential typologies have been proposed to provide a logical categorisation of residential areas that can support micro-climatic and energy consumption analyses. It is assumed that thermal and energy demand differences prevail among typologies due to the distinct morphological and surface properties exhibited by each typology. A detailed description of each residential typology identified for a particular location within SMA is presented below.

[2] http://www.ecodencity.com.au/building-types/

Description of residential typology

OT1: Open single dwellings

Size : 17.0 x 20.0m
Height : 4m
No. stories : 1
Orientation : East-West (length)
Glazing : Double
Location : Normanhurst, NSW (https://goo.gl/maps/vd3Bj6sDgUD2)
Building material : Variable
Total built area precinct : 8,850 sqm
Window spacing : 4.5m
Window height : 2.0m
Window to wall ratio : 35%
Built area ratio : 0.22 (22%)

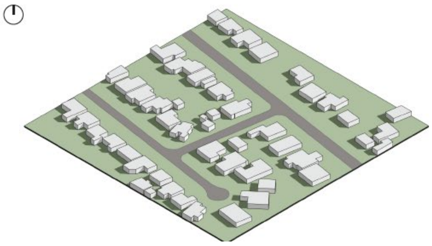



Figure 32. Typical characteristics of the typology OT1: Open single dwellings

CT1: Compact single dwellings

Size : 13.0 x 22.0m
Height : 8m
No. stories : 2
Orientation : North-South (length)
Glazing : Double
Location : Kellyville, NSW (https://goo.gl/maps/ULKg6dEeV2y)
Building material : Variable
Total built area precinct : 25,350 sqm
Window spacing : 3.5m
Window height : 1.5m
Window to wall ratio : 35%
Built area ratio : 0.372 (37%)

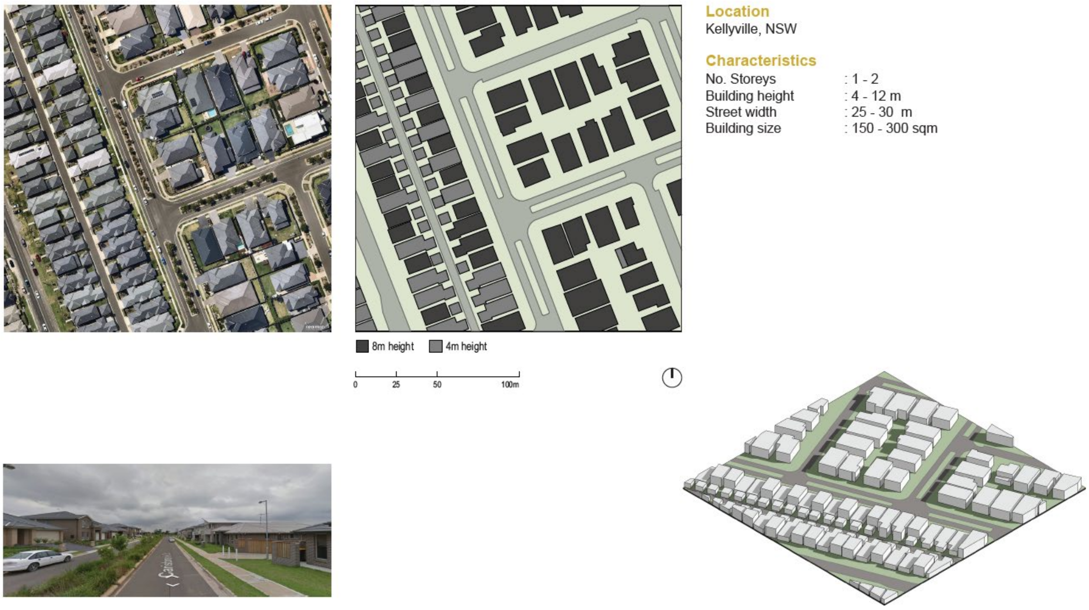


Figure 33. Typical characteristics of the typology CT1: Compact single dwellings.

OT2: Open low-rise housing

Size	**:** 40.0 x 10.0m
Height	**:** 10m
No. stories	**:** 3
Orientation	**:** North-South (length)
Glazing	**:** Double
Location	**:** Kooloora, NSW (https://goo.gl/maps/ee9sSLxS9zu)
Building material	**:** Variable
Total built area precinct	: 18,950 sqm
Window spacing	: 2.5m
Window height	: 1.7m
Window to wall ratio	: 30%
Built area ratio	: 0.158 (16%)

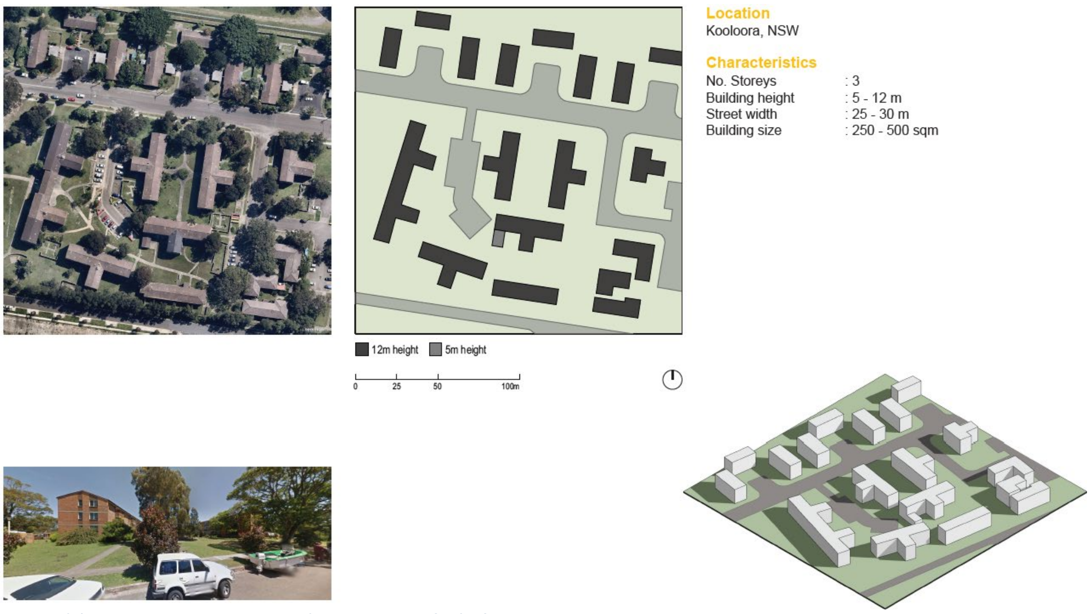


Figure 34. Typical characteristics of the typology OT2: Open low-rise housing.

CT2: Compact low-rise housing

Size : 32.0 x 35.0m
Height : 12m
No. stories : 4
Orientation : North-South (length)
Glazing : Double
Location : Epping, NSW (https://goo.gl/maps/GJFKv2N5fF72)
Building material : Variable
Total built area precinct : 55,550 sqm
Window spacing : 1.6m
Window height : 1.8m
Window to wall ratio : 35%
Built area ratio : 0.365 (37%)

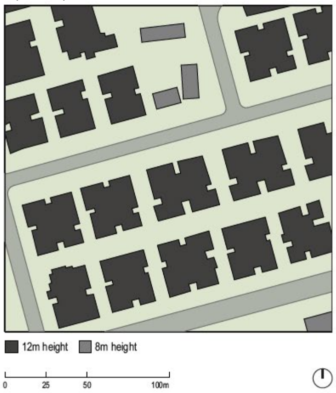


Figure 35. Typical characteristics of the typology CT2: Compact low-rise housing.

OT3: Open low/medium rise housing

Size : 60.0 x 20.0m
Height : 18m
No. stories : 6
Orientation : North-South (length)
Glazing : Double
Location : Rosebery, NSW (https://goo.gl/maps/ovzfXEPqW7D2)
Building material : Variable
Total built area precinct : 60,000 sqm
Window spacing : 2.1m
Window height : 1.5m
Window to wall ratio : 20%
Built area ratio : 0.295 (30%)

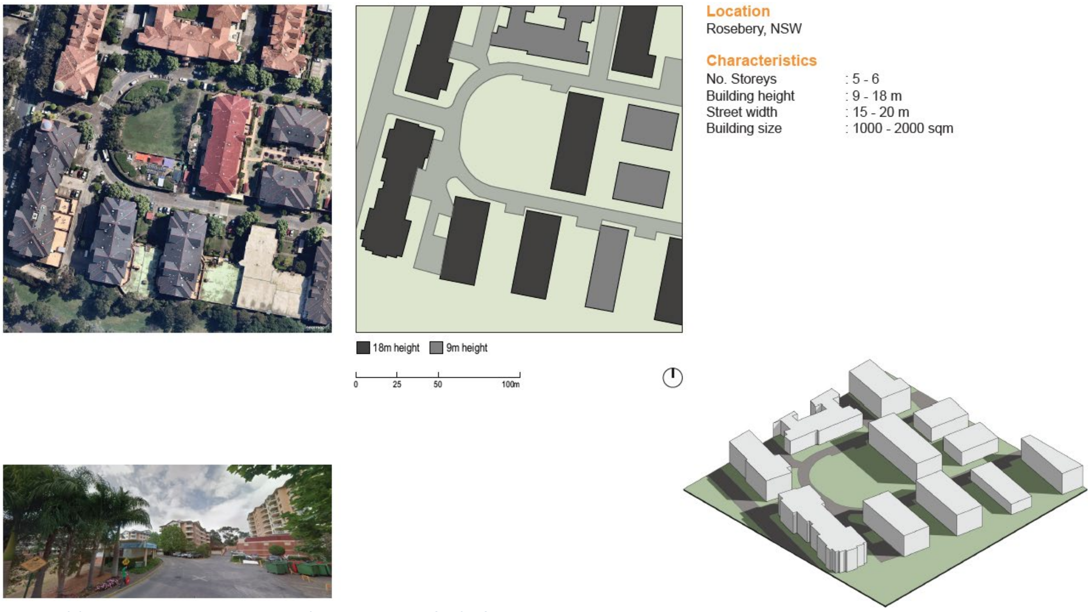


Figure 36. Typical characteristics of the typology OT3: Open low/medium rise housing.

CT3: Compact low/medium rise housing

Size	**:** 22.0 x 80.0m
Height	**:** 18m
No. stories	**:** 6
Orientation	**:** North-South (length)
Glazing	**:** Double
Location	**:** Meadowbank, NSW (https://goo.gl/maps/Rr4JqhhhLBJ2)
Building material	**:** Variable
Total built area precinct	: 112,300 sqm
Window spacing	: 3.2m
Window height	: 2.5m
Window to wall ratio	: 40%
Built area ratio	: 0.554 (55%)

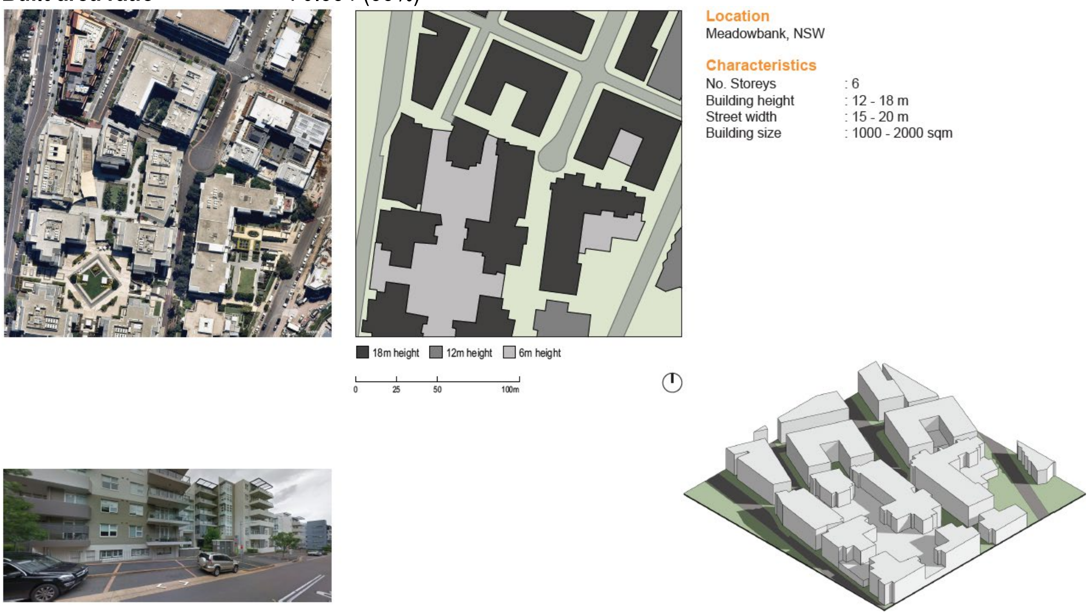


Figure 37. Typical characteristics of the typology CT3: Compact low/medium rise housing.

OT4: Open medium rise housing

Size : 75.0 x 20.0m
Height : 30m
No. stories : 8
Orientation : North-South (length)
Glazing : Double
Location : Raleigh Park, NSW (https://goo.gl/maps/Jbma3iGfcdK2)
Building material : Variable
Total built area precinct : 26,200 sqm
Window spacing : 2.0m
Window height : 1.5m
Window to wall ratio : 25%
Built area ratio : 5056.7/40000.0 = 0.126 (13%)

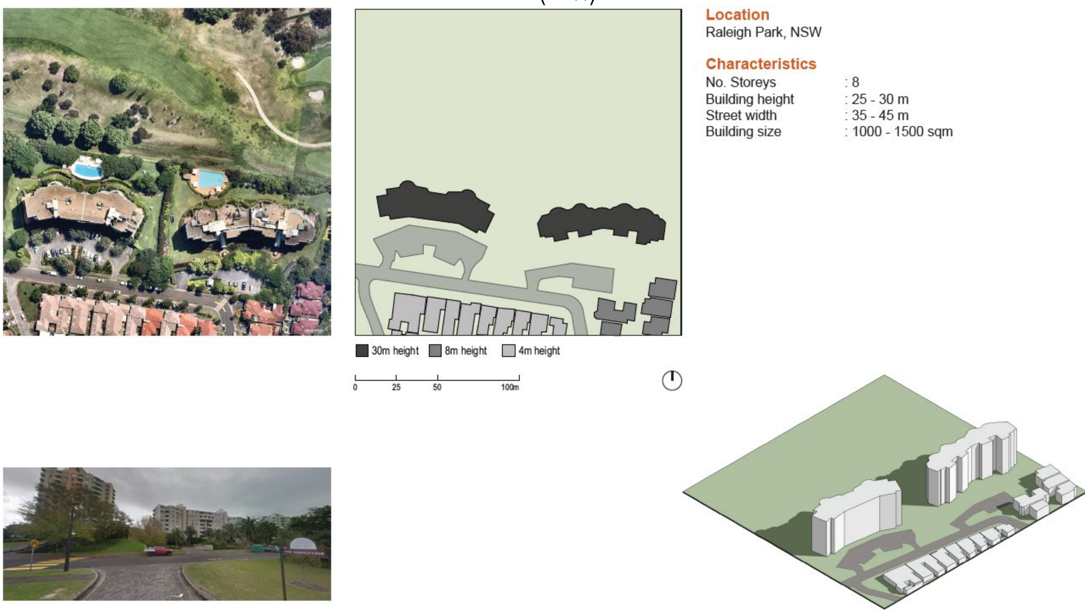


Figure 38. Typical characteristics of the typology OT4: Open medium rise housing.

CT4: Compact medium rise housing

Size : 65.0 x 20.0m
Height : 30m
No. stories : 8
Orientation : Northwest-Southeast (length)
Glazing : Double
Location : Harold Park, NSW (https://goo.gl/maps/sNsaw8UMFm22)
Building material : Variable
Total built area precinct : 104,250 sqm
Window spacing : 2.1m
Window height : 2.0m
Window to wall ratio : 45%
Built area ratio : 0.381 (38%)

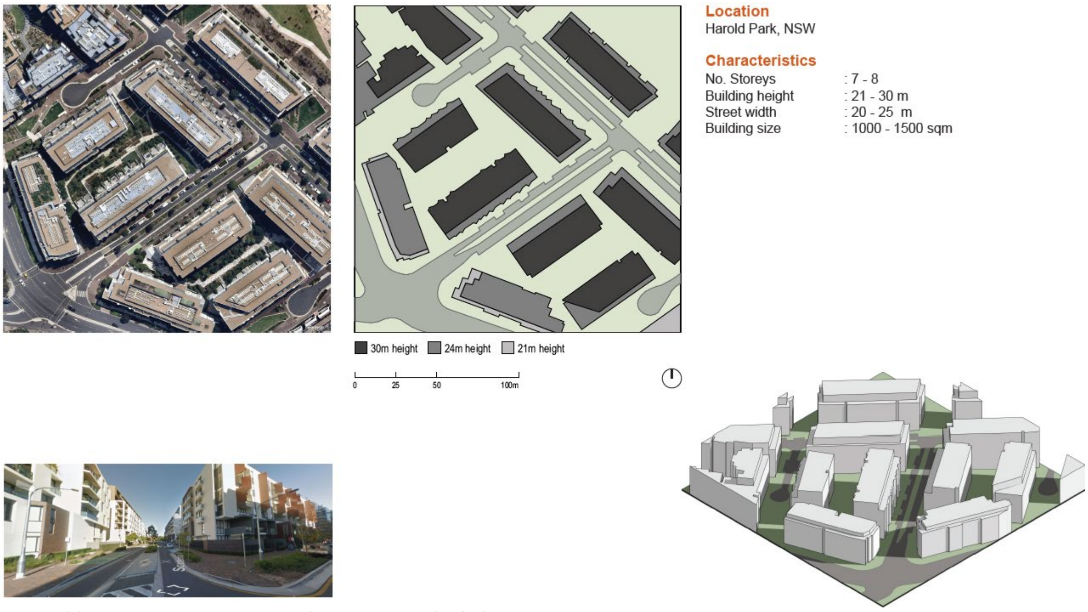


Figure 39. Typical characteristics of the typology CT4: Compact medium rise housing.

OT5: Open medium/high rise housing

Size	**:** 55.0 x 20.0m
Height	**:** 40m
No. stories	**:** 10
Orientation	**:** North-South (length)
Glazing	**:** Double
Location	**:** Parramatta, NSW (https://goo.gl/maps/Jt7fwke7oW62)
Building material	**:** Variable
Total built area precinct	: 54,500 sqm
Window spacing	: 2.0m
Window height	: 1.8m
Window to wall ratio	: 35%
Built area ratio	: 0.149 (15%)

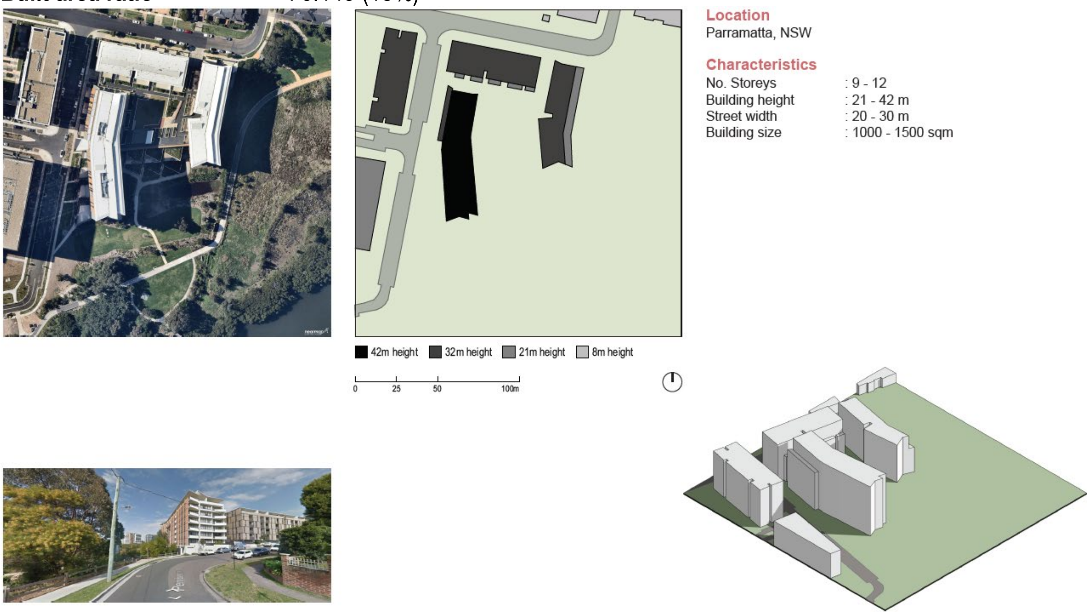


Figure 40. Typical characteristics of the typology OT5: Open medium/high rise housing.

CT5: Compact medium/high rise housing

Size : 85.0 x 25.0m
Height : 40m
No. stories : 12
Orientation : North-South (length)
Glazing : Double
Location : Mascot, NSW (https://goo.gl/maps/y8Rnqy2sfEL2)
Building material : Variable
Total built area precinct : 170,100 sqm
Window spacing : 1,5m
Window height : 2.1m
Window to wall ratio : 70%
Built area ratio : 0.55 (55%)

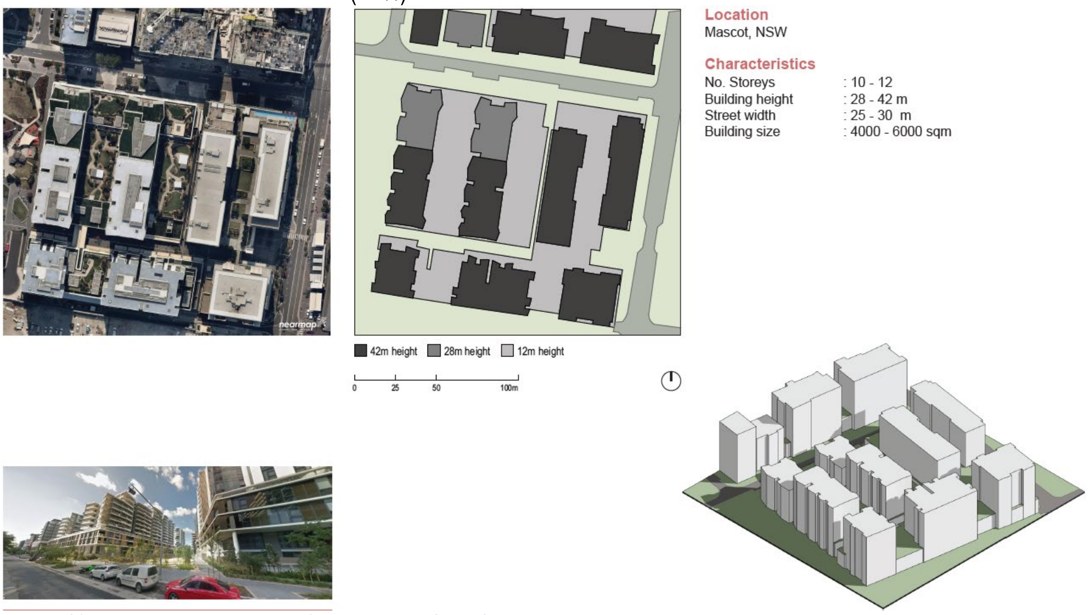


Figure 41. Typical characteristics of the typology CT5: Compact medium/high rise housing.

OT6: Open high-rise 1 housing

Size : 85.0 x 15.0m
Height : 60m
No. stories : 18
Orientation : Northwest-Southeast (length)
Glazing : Double
Location : Waterloo, NSW (https://goo.gl/maps/X6FXdEPiieT2)
Building material : Variable
Total built area precinct : 55,000 sqm
Window spacing : 1.0m
Window height : 1.0m
Window to wall ratio : 25%
Built area ratio : (14%)


Location
Waterloo, NSW

Characteristics

No. Storeys	: 18
Building height	: 60 m
Street width	: 45 - 55 m
Building size	: 1000 sqm

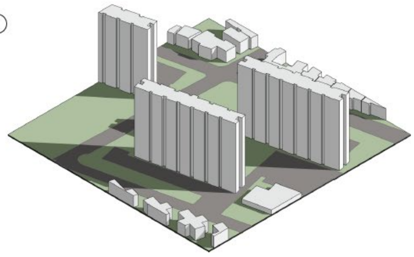
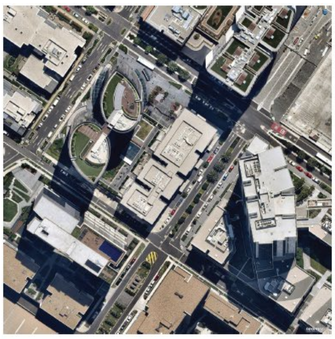
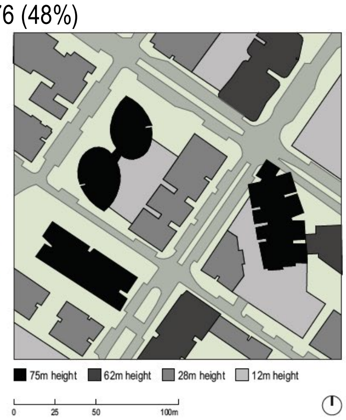



Figure 42. Typical characteristics of the typology OT6: Open high-rise 1 housing.

CT6: Compact high-rise 1 housing

Size	**:** 70.0 x 25.0m
Height	**:** 70m
No. stories	**:** 22
Orientation	**:** Northwest-Southeast (length)
Glazing	**:** Double
Location	**:** Wentworth Point, NSW (https://goo.gl/maps/xw2DoREU5712)
Building material	**:** Variable
Total built area precinct	: 200,000 sqm
Window spacing	: 2.0m
Window height	: 2.2m
Window to wall ratio	: 75%
Built area ratio	: 0.476 (48%)

Location
Wentworth Point, NSW

Characteristics

No. Storeys	: 15 - 25
Building height	: 60 - 75 m
Street width	: 25 - 30 m
Building size	: 1500 - 2000 sqm

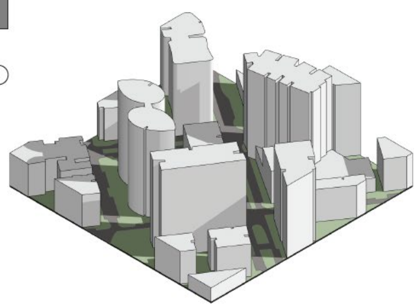



Figure 43. Typical characteristics of the typology CT6: Compact high-rise 1 housing.

OT7: Open high-rise 2 housing

Size : 60.0 x 25.0m
Height : 130m
No. stories : 35
Orientation : Northwest-Southeast (length)
Glazing : Double
Location : Sydney Olympic Park, NSW (https://goo.gl/maps/HBjK9Mu4LWL2)
Building material : Variable
Total built area precinct : 117,500 sqm
Window spacing : 0.5m
Window height : 2.1m
Window to wall ratio : 75%
Built area ratio : 0.146 (15%)

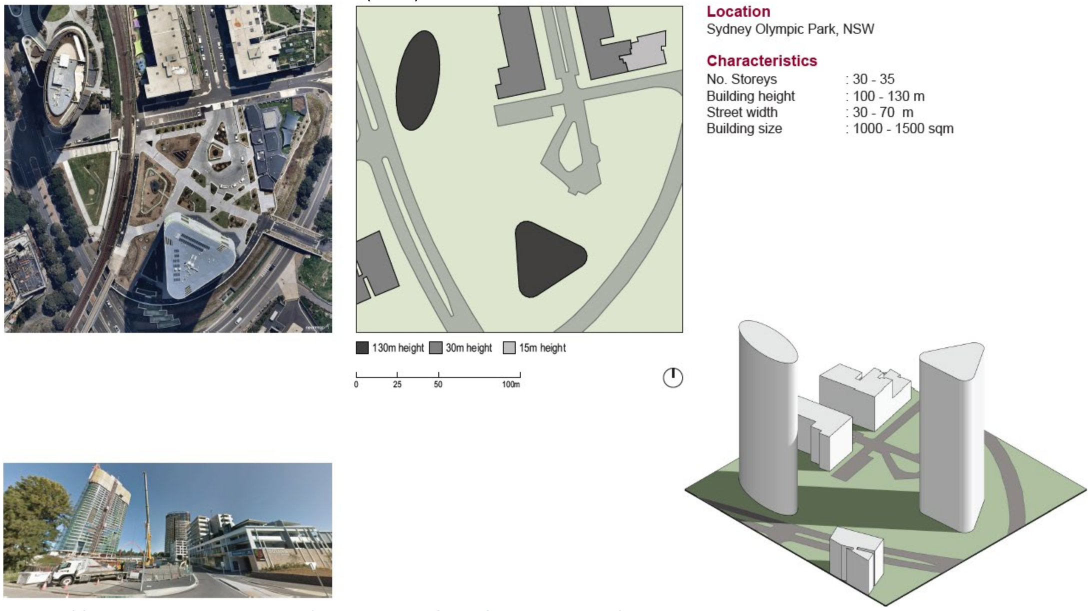


Figure 44. Typical characteristics of the typology OT7: Open high-rise 2 housing.

CT7: Compact high-rise 2 housing

Size : 50.0 x 30.0m
Height : 145m
No. stories : 40
Orientation : North-South (length)
Glazing : Double
Location : Chatswood, NSW (https://goo.gl/maps/mTHdULfhEyF2)
Building material : Variable
Total built area precinct : 290,000 sqm
Window spacing : 1.0m
Window height : 2.2m
Window to wall ratio : 75%
Built area ratio : 0.303 (30%)

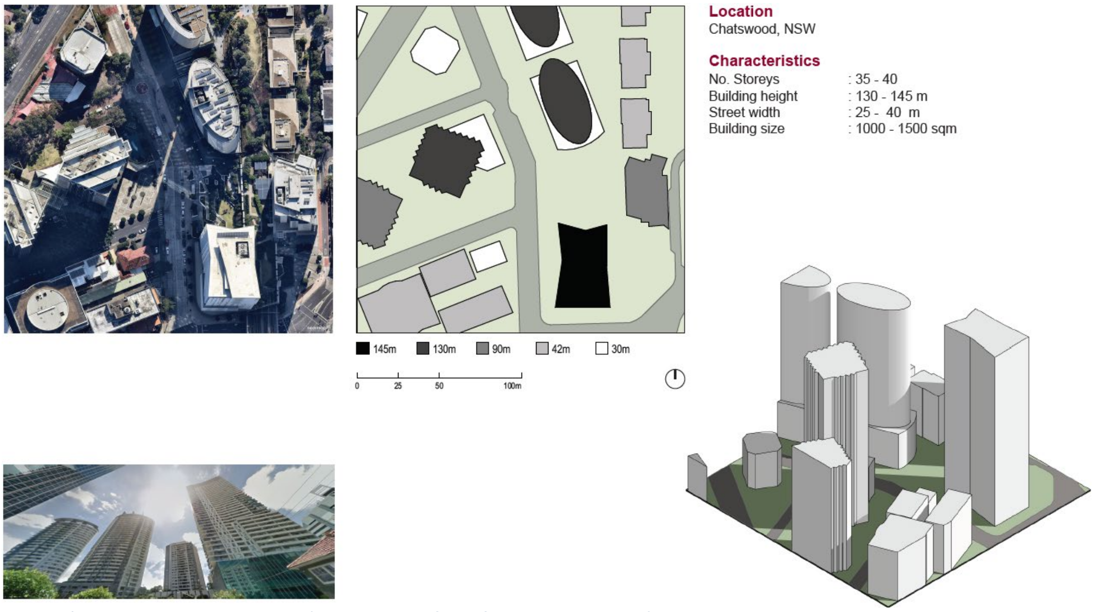


Figure 45. Typical characteristics of the typology CT7: Compact high-rise 2 housing.

LOW CARBON LIVING CRC

5. MICROCLIMATE SIMULATION RESULTS

Introduction

Urban heat island (UHI) and global warming increase the near surface ambient temperature in cities [1,2]. Urban heat island can affect the energy performance of buildings located in densely built areas as these buildings undergo several UHI effects such as higher external air temperatures, lower wind speeds and reduced energy losses during the night period. These effects have a significant impact especially on cooling energy consumption [1]. Research studies have identified and tested a wide range of counter measures to urban overheating, including the use of reflective materials, greenery [3]. The potential of mitigation technologies to lower ambient temperatures has been evaluated through a large number of mitigation projects from various parts of the world and various climatic conditions, demonstrating they can lower average peak temperatures by 2°C [4]. Lowering ambient temperatures by the large-scale use of UHI mitigation strategies such cool materials or greenery results in reducing the needs for cooling [5,6].

In this study, we performed simulations of the unmitigated and mitigated conditions based on future climate (2050) using the software ENVI-met V4.4.2. This program is a three-dimensional microclimate model designed to simulate the surface, plant and air interactions in an urban environment. This computer program is an accurate tool to simulate the distribution of the main climatic parameters in the urban environment. It is designed for microscale with a typical horizontal resolution from 0.5 to 5 metres and a typical time frame of 24 to 48 hours with a time step of 1 to 5 seconds. This resolution allows to analyse small-scale interactions between individual buildings, surfaces and plants. ENVI-met includes a full 3D Computational Fluid Dynamics (CFD) model. It solves the Reynolds-averaged non-hydrostatic Navier-Stokes equations for each grid in space and for each time step.

Method and Simulation settings

The spatial resolution used in the simulations is 1.5 m horizontally. The area has been rendered with a 150 × 150 × 30 (x-y-z) cells, with the following size: dx = 1.5 m, dy = 1.5 m, and base dz = 0.5 m. The grid at the z axis is telescopic with a thicker cell near the ground, allowing a better accuracy for edge effects. Mesoscale climatic predictions models, WRF, are used to simulate the future climatic conditions in the selected precincts in Greater Sydney. In this study, two approaches namely full forcing and simple forcing methods are used.

Simple Forcing: In the simple forcing method, the initial wind speed and direction were taken as 2.5m/s and 250°, respectively. The simulations started at 18:00 21/2/2050 and were performed for 34 hours. Figure 46 summarises the input climatic temperature. Output data derived for 22/2/2050 were extracted for analysis. Input climate data was derived from mesoscale modelling for 2050. The results of simulations based simple forcing method were used for creating weather file for energy impact analysis as described in the following chapters. Next section discusses the results of simulations based on the simple forcing approach.

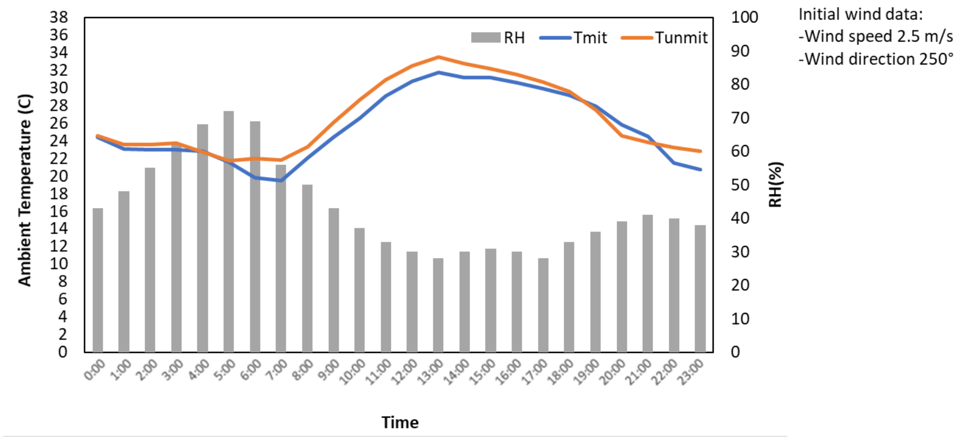


Figure 46 The input ambient temperature and humidity in the unmitigated and mitigated simulations

The simulations were performed for both mitigated and unmitigated conditions using simple forcing method (Figure 46). The unmitigated climate data was derived from WRF modelling based on the 2018 land use and the 2050 climatic conditions. The mitigated scenario is based on the 2050 land use and climate. It considers that a combination of mitigation technologies is implemented in the whole Sydney area (2050 Climatic conditions with future urbanization and mitigation technologies): Urban Plan simulation is based on the RCP4.5 Future Scenario dataset and includes a) increased dwelling density based on future projections b) inclusion of new Urban Growth Areas c) increased of the Anthropogenic Heat Flux d) planting of 2 million irrigated trees in the so called Third City and 3 million irrigated trees in the rest of Sydney e) increased albedo of urban impervious surfaces to 0.6 and f) Water in the landscape.

Full Forcing: In the full forcing method, the simulations were forced for the air temperature, relative humidity and solar radiation. With the new full forcing concept, it is now possible to set diurnal cycles of boundary conditions for various meteorological parameters such as radiation. This means that the diurnal variation of the atmospheric boundary conditions and the incoming radiation are defined in each simulation step when simulations were performed using full forcing method. The simulations of full forcing also were started at 18:00 on 21/2/2050 and run for 34 hours (the end time and date of simulation: 00:00 23/2/2050). The initial conditions for wind speed and direction are: Wind speed: 2.5m/s; Wind direction: 250°.The simulations with full forcing method run only based on the mitigated climate data (2050) and using implemented mitigation strategies in the precincts. Results of Full forcing simulations are provided in Appendix II.

Evaluation of comfort

Thermal comfort was assessed using ENVI-met BioMet to evaluate the effect of mitigation technologies on outdoor urban microclimate and examine thermal comfort at pedestrian level, calculate potential heat stress reduction with each microclimatic scenario, and identify the microclimatic zones where the mitigation technologies ameliorate the urban biometeorological conditions. For the evaluation of outdoor thermal comfort, we calculated two comfort indices using ENVI-met Biomet: Universal Thermal Climate Index (UTCI) and Physiological Equivalent Temperature (PET). For the thermo-physiological parameter of human body, we assumed a typical male (35 years old, 1.75 tall, weight 75) with clothing values of 0.5 (corresponding to summer business suits) and an activity level of 1.4 MET.

UTCI is a state-of-art human energy balance model that quantifies outdoor thermal comfort by integrating thermo-physiological effects of four environmental (air temperature (T_a), mean radiant temperature (MRT), relative humidity (RH), wind speed (v)), and two personal parameters, clothing insolation (clo), and activity (w). UTCI is a multi-node model of human thermoregulation [8] incorporating an adaptive clothing algorithm [9] related to outdoor thermal conditions. UTCI above 46 °C indicates extreme heat stress, values comprised between 38 °C and 46 °C identify very strong heat stress, moderate heat stress between 26 °C and 38 °C, and no heat stress between 9 °C and 26 °C. In ENVI-met, the calculation of UTCI is based on a 6^{th} order polynomial regression function estimating UTCI from wind speed, air temperature, mean radiant temperature and air vapour pressure. This approach has two limitations: 1) UTCI as used in the software is limited to a wind speed range of 0.5 to 17 m/s related to 10 m Height. 2) UTCI is related to wind speed at 10 m height while the biometeorological parameters are normally define between 1.5 and 2 m. Due to these restrictions, areas outside the official bounds of UTCI are not calculated by BioMet and marked with “No Data”. Thus, in urban areas the lower limit of 0.5 m/s can create a number of white “No Data” areas in the maps. UTCI in the regression-based version based on using pedestrian level wind speeds extrapolated to 10m. However, in a complex urban environment, wind speeds at pedestrian level are unique and cannot be related to some above-roof general quantity. Therefore, we also assessed comfort using the application of a pure physically-based approach (i.e. PET) as recommended.

The Physiological Equivalent Temperature (PET) is a thermal comfort index that is based on a prognostic model of the human energy balance that computes the skin temperature, the body core temperature, the sweat rate and the clothing temperature. It is generally based on the 2-node model proposed by Gagge et al. [10] and was compiled and extended by Höppe [11]. PET is defined as “the physiologically equivalent air temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of a human body is maintained with core and skin temperatures equal to those under the conditions being assessed” [11]. It corresponds to the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed [11]. PET expresses the thermal comfort of a human body using the skin and core temperature as reference indicators. Thus, all incoming and outgoing fluxes at the human body are defined, a skin and a core temperature, that matches all the calculated fluxes are calculated, the person is transposed into an indoor environment, then it reset all data that are not available in an indoor environment (direct solar radiation, forced wind movement), and search for an indoor air temperature (as only parameter) that results in the same skin temperature and core temperature as the outdoor setting. This theoretically calculated indoor temperature is called PET.

Simulation domain and settings

The buildings construction is tabulated in Table 2, and the material properties are included in Table 3.

Table 2. Buildings construction characteristics

		Construction		
Code	Name	Outside Layer	1st layer	2nd layer
000000	Default wall – moderate insulation	0100PL (1cm)	0100IN (11cm)	0100CO (6cm)
0100Q2	CoolRoof – moderate insulation	0100Q1 (1cm)	0100FE (11cm)	0100F3 (6cm)

Table 3. Building materials' properties

Code	Name	Absorption	Reflection	Emissivity	Specific heat (J/(kgK))	Thermal conductivity (w/(mK)	Density (kg/m³)
0100PL	Default Plaster	0.50	0.50	0.90	850	0.60	1500
0100Q1	CoolPaint	0.30	0.70	0.90	830	0.84	1856
0100IN	Default Insulation	0.50	0.50	0.90	1500	0.07	400
0100CO	Default Concrete	0.50	0.50	0.90	850	1.60	2220
0100F3	Moderate insulation	0.42	0.45	0.90	1033	1.00	1687

CT1

The CT1 topology (Compact Single Dwellings typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT1 topology in ENVI-met is depicted in Figure 47.

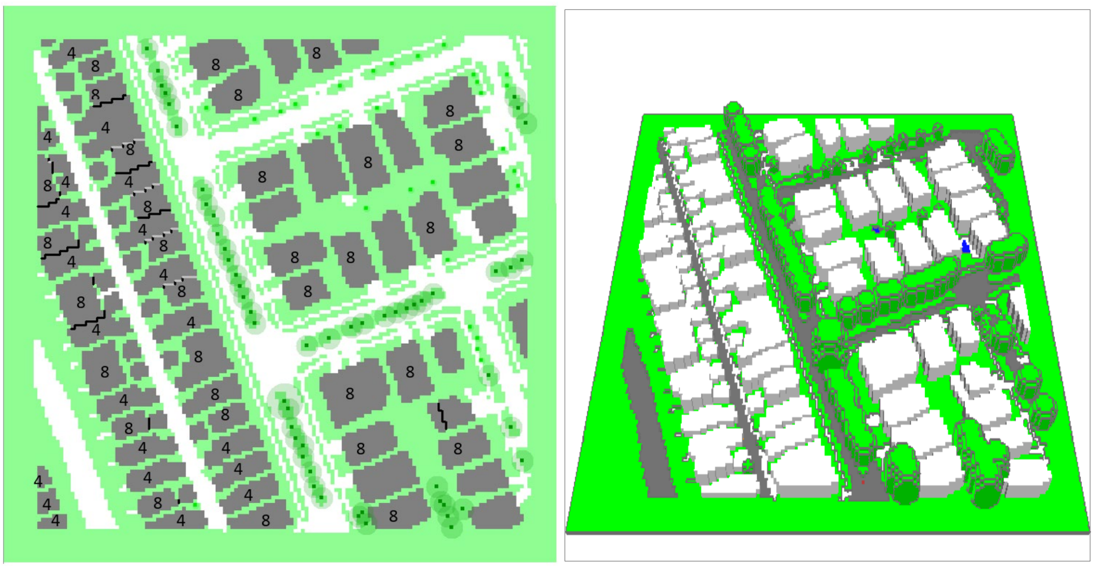


Figure 47 CT1 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The building construction and materials are tabulated in Table 2 and Table 3. The urban surface properties and vegetation types used in CT1 are provided in Table 4 and Table 5, respectively. In the simulation of mitigated CT1, we used 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 4. The CT1 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90
0100WW	Deep water (swimming pools)	0.00	0.96

Table 5. The CT1 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01CSDS	Cylindric, small trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

CT2

The CT2 topology (Compact low-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT2 topology in ENVI-met is depicted in Figure 48.

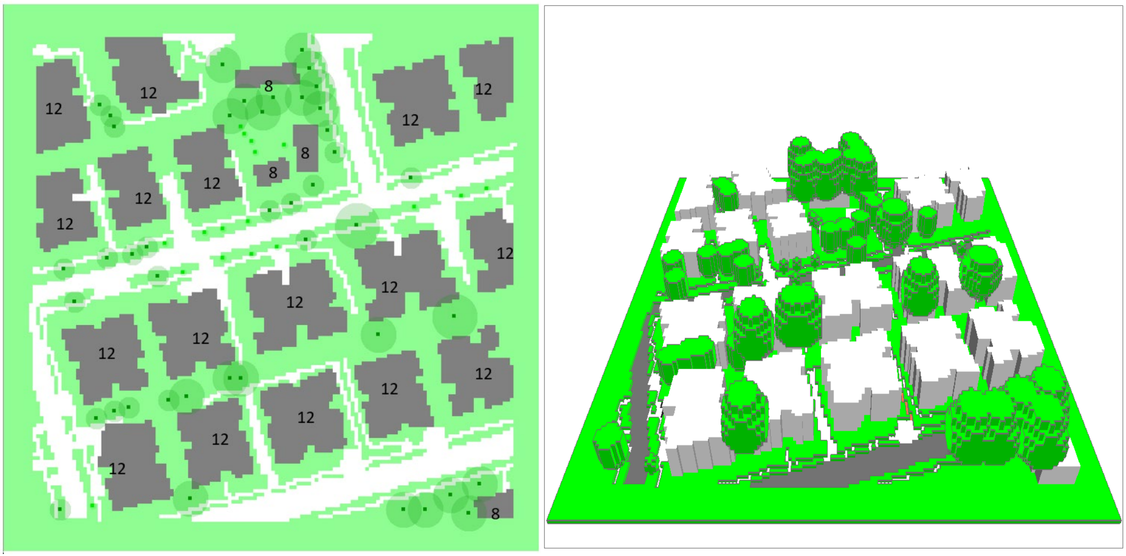


Figure 48 CT2 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction is tabulated in Table 2, while the materials coding is included in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 6 and Table 7, respectively. Consistent with other models, in the simulation of CT2 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 6. The CT2 urban surfaces albedo and emissivity.

Code	Name	Albedo	Emissivity
0100ST	Asphalt Road	0.9	0.20
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90
0100KK	Brick road (red stones)	0.9	0.30

Table 7. The CT2 vegetation characteristics.

Code	Name
0100XX	Grass 25cm aver. Dense
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01HLDL	Heart-shaped, large trunk, dense, large (25m)
01CLDL	Cylindric, large trunk, dense, large (25m)

CT3

The CT3 topology (Compact low/medium-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT3 topology in ENVI-met is depicted in Figure 49.

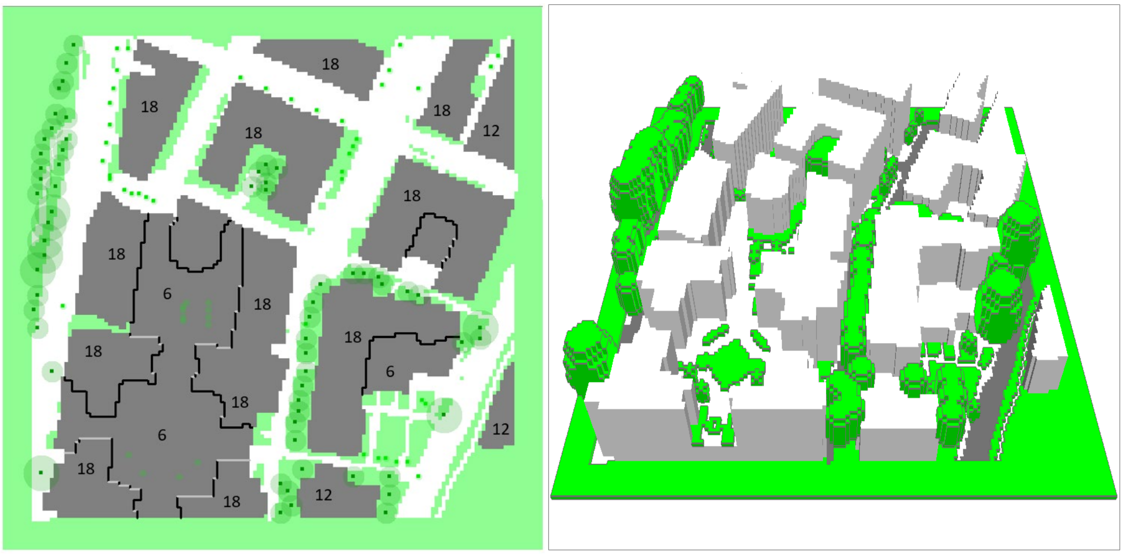


Figure 49 CT3 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction is tabulated in Table 2, while the materials coding is included in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 8 and Table 9, respectively. Consistent with other models, in the simulation of CT3 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 8. The CT3 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100GG	Dark Granit Pavement	0.90	0.30
0100Q5	Cool Asphalt Road	0.55	0.90
0100KK	Brick road (red stones)	0.90	0.30

Table 9. The CT3 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01PLDS	Palm, large trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)

CT4

The CT4 topology (Compact medium-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT4 topology in ENVI-met is depicted in Figure 50.

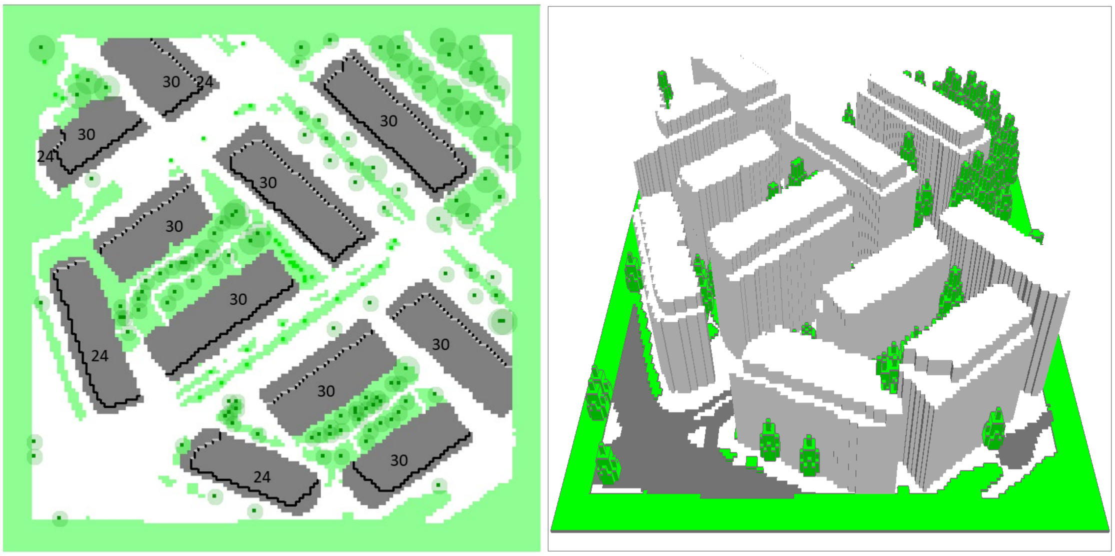


Figure 50 CT4 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction is tabulated in Table 2, while the materials coding is included in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 10 and, Table 11, respectively. Consistent with other models, in the simulation of CT4 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 10. The CT4 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 11. The CT4 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01ALDM	Conic, large trunk, dense, medium (15m)
01ALDL	Conic, large trunk, dense, large (25m)
01ALDS	Conic, large trunk, dense, small (5m)

CT5

The CT5 topology (Compact medium/high rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT5 topology in ENVI-met is depicted in Figure 61.

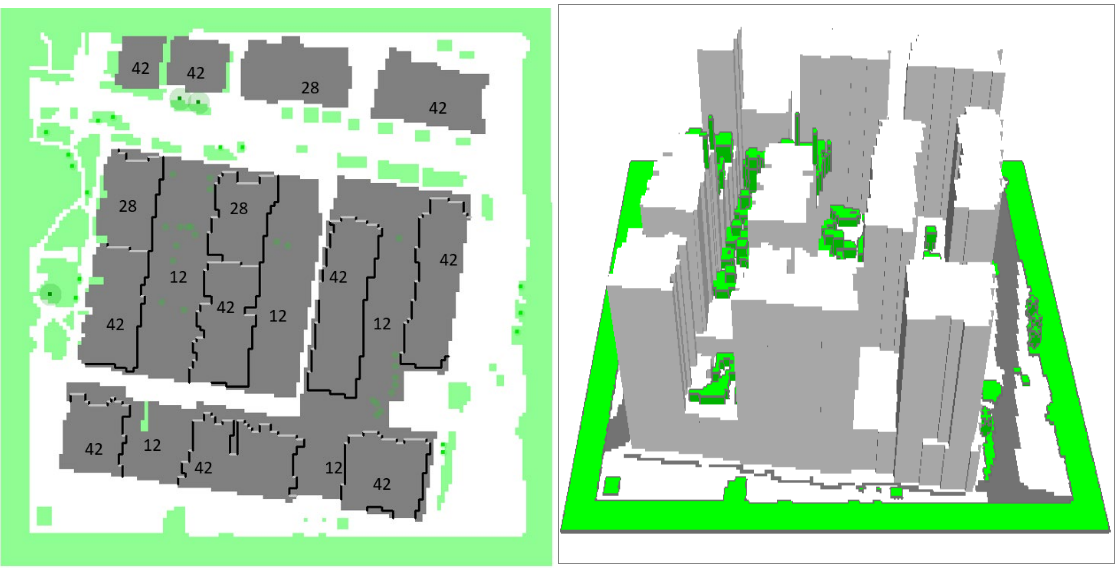


Figure 51 CT5 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in CT5 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 12 and Table 13, respectively. In the simulation of CT5 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 12. The CT5 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 13. The CT5 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01CMSS	Cylindric, medium trunk, sparse, small (5m)
01CSSS	Cylindric, small trunk, sparse, small (5m)
01CLSS	Cylindric, large trunk, sparse, small (5m)

CT6

The CT6 topology (Compact high-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT6 topology in ENVI-met is depicted in Figure 52.

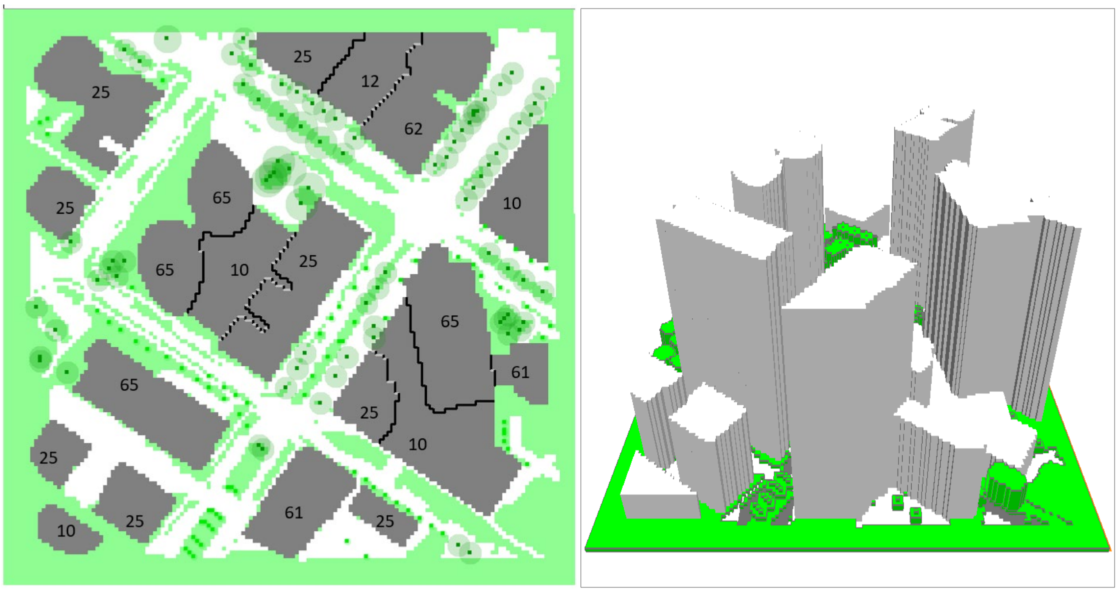


Figure 52 CT6 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in CT6 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 14 and Table 15, respectively. In the simulation of CT6 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 14. The CT6 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 15. The CT6 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01OLDL	Cylindric, large trunk, dense, large (25m)
01PLDM	Palm, large trunk, dense, medium (15m)
01OMDS	Cylindric, medium trunk, dense, small (5m)
01OLDM	Cylindric, large trunk, dense, medium (15m)
01PLDL	Palm, large trunk, dense, large (25m)
01OLDS	Cylindric, large trunk, dense, small (5m)

CT7

The CT6 topology (Compact high-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the CT6 topology in ENVI-met is depicted in Figure 53.

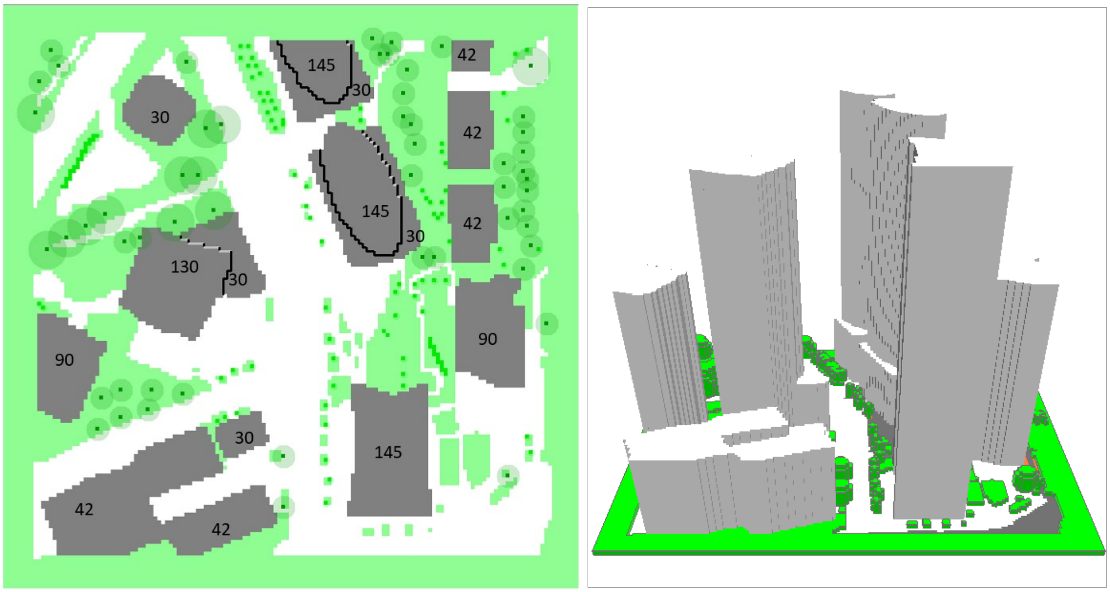


Figure 53 CT7 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in CT7 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 16 and Table 17, respectively. In the simulation of CT7 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 16. The CT7 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90
0100KK	Brick road (red stones)	0.90	0.30

Table 17. The CT7 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01PLDS	Palm, large trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01PLDM	Palm, large trunk, dense, medium (15m)
01PSDS	Palm, small trunk, dense, small (5m)
01CSDL	Cylindric, small trunk, dense, large (25m)

OT1

The OT1 topology (Open single dwellings typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT1 topology in ENVI-met is depicted in Figure 54.

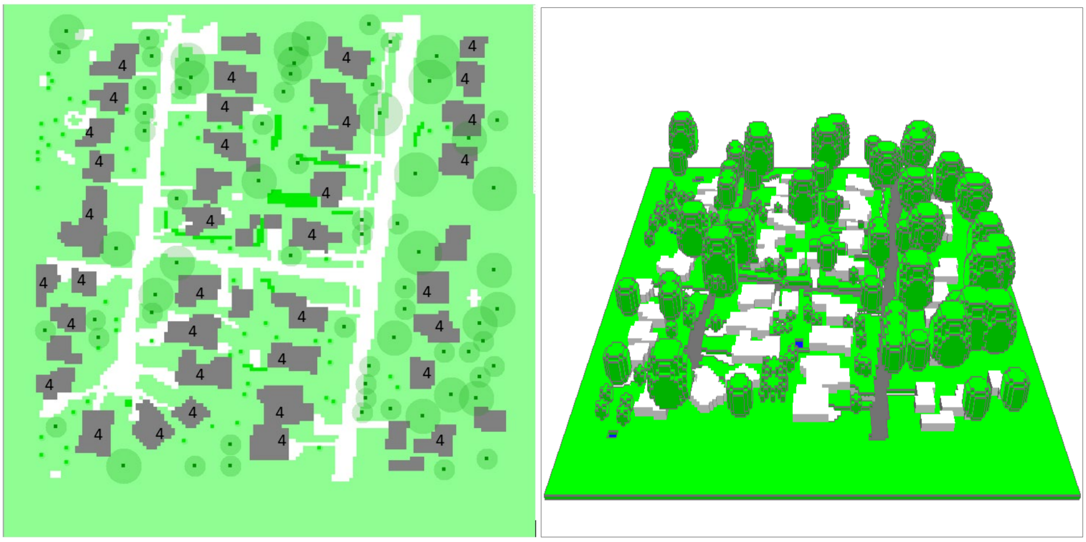


Figure 54 OT1 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT1 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 18 and Table 19, respectively. In the simulation of OT1 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 18. The OT1 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90
0100WW	Deep water (swimming pools)	0.00	0.96

Table 19. The OT1 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
0100H4	Hedge dense, 4m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01CMDM	Cylindric, medium trunk, dense, medium (15m)
01HLDL	Heart-shaped, large trunk, dense, large (25m)
01PSDS	Palm, small trunk, dense, small (5m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01PLDM	Palm, large trunk, dense, medium (15m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CMDL	Cylindric, medium trunk, dense, large (25m)

OT2

The OT3 topology (Open low-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT3 topology in ENVI-met is depicted in Figure 55.

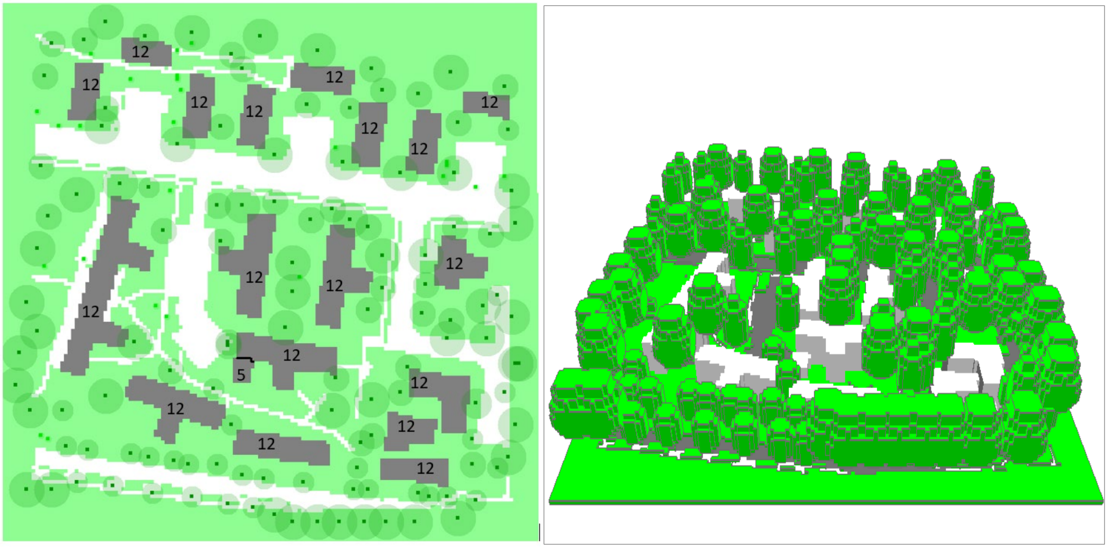


Figure 55 OT2 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT2 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 20 and Table 21, respectively. In the simulation of OT2 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 20. The OT2 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 21. The OT2 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01PLDS	Palm, large trunk, dense, small (5m)
01OLDS	Cylindric, large trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01OLDM	Cylindric, large trunk, dense, medium (15m)
01OLDL	Cylindric, large trunk, dense, large (25m)
01PLDL	Palm, large trunk, dense, large (25m)

OT3

The OT3 topology (Open low/ medium-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT3 topology in ENVI-met is depicted in Figure 56.

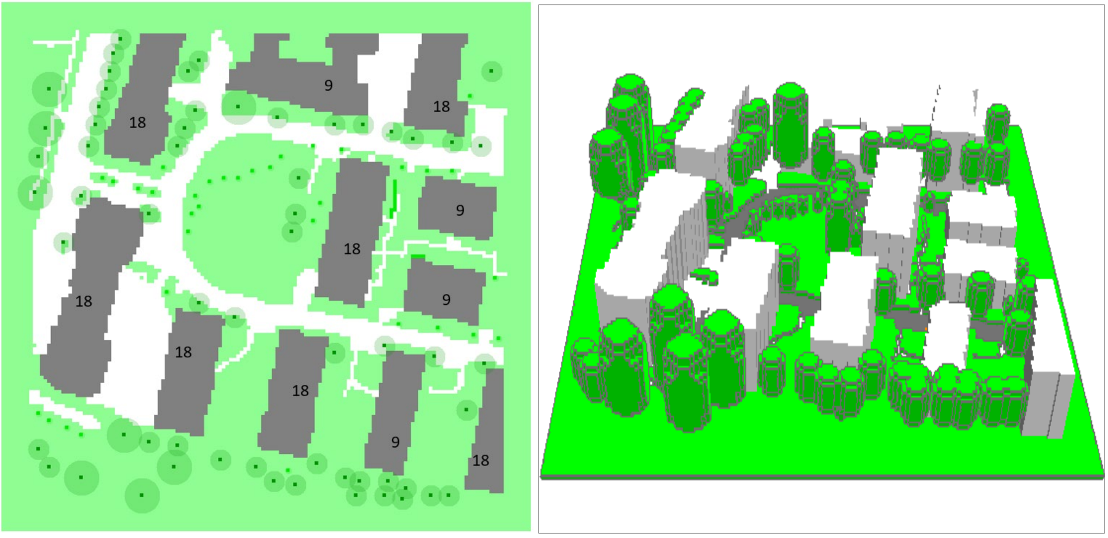


Figure 56 OT3 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT3 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 22 and Table 23, respectively. In the simulation of OT3 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 22. The OT3 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 23. The OT3 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01CMDL	Cylindric, medium trunk, dense, large (25m)
01CSDS	Cylindric, small trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

OT4

The OT4 topology (Open medium-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT4 topology in ENVI-met is depicted in Figure 57.

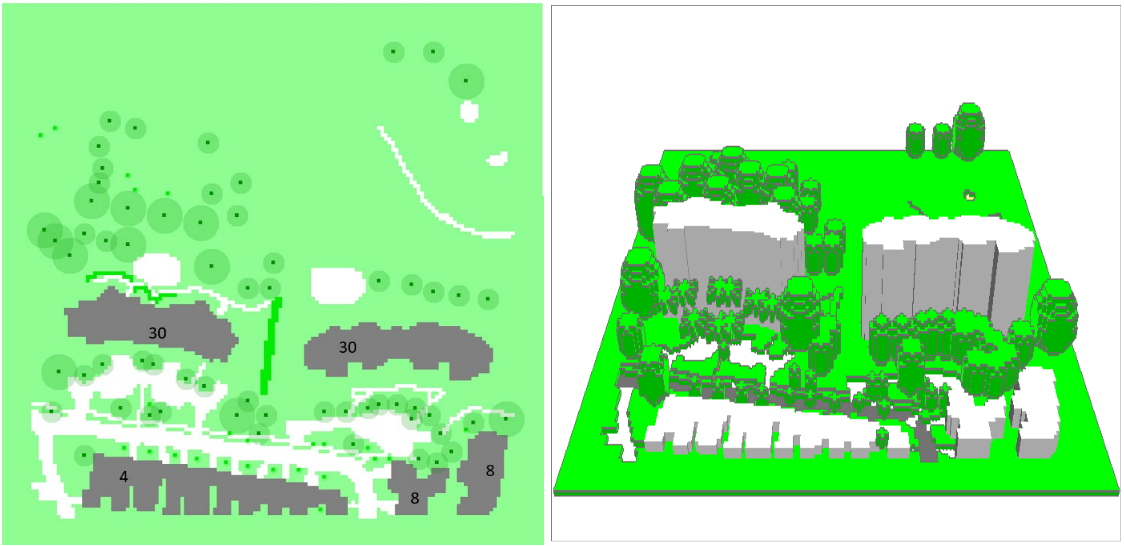


Figure 57 OT4 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT4 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 24 and Table 25, respectively. In the simulation of OT4 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 24. The OT4 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100SD			
0100KK			
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90
0100WW	Deep water (swimming pools)	0.00	0.96

Table 25. The OT4 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CLDS	Cylindric, large trunk, dense, small (5m)
01CSDS	Cylindric, small trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01PLDM	Palm, large trunk, dense, medium (15m)
01PLDS	Palm, large trunk, dense, small (5m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01CMDM	Cylindric, medium trunk, dense, medium (15m)
01CMDL	Cylindric, medium trunk, dense, large (25m)
01OLDM	Cylindric, large trunk, dense, medium (15m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

OT5

The OT5 topology (Open Medium/ high-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT5 topology in ENVI-met is depicted in Figure 58.

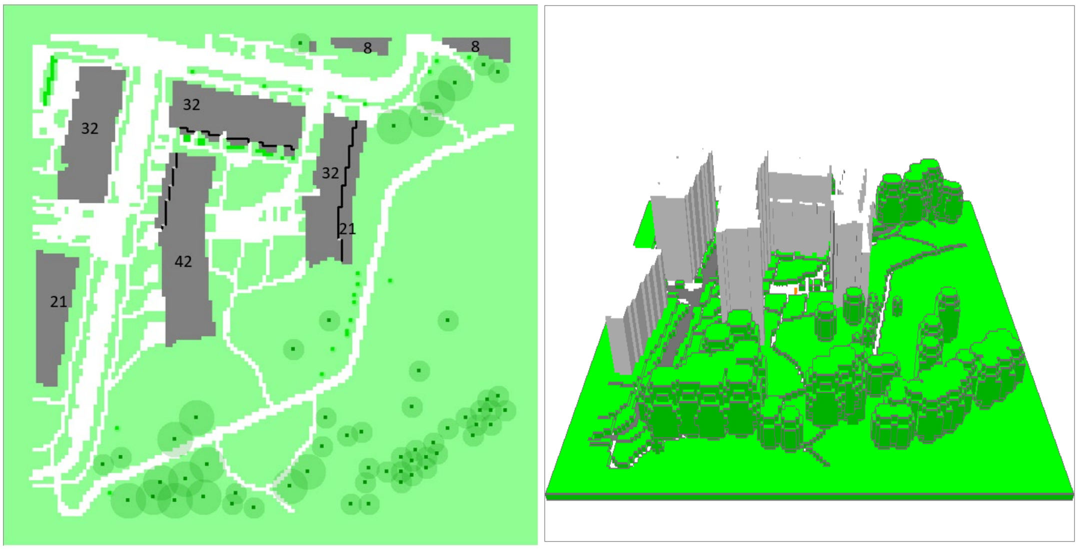


Figure 58 OT5 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT5 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 26 and Table 27, respectively. In the simulation of OT5 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 26. The OT5 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 27. The OT5 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CMDM	Cylindric, medium trunk, dense, medium (15m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01CLSL	Cylindric, large trunk, sparse, large (25m)
01CSDS	Cylindric, small trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

OT6

The OT6 topology (Open high-rise typology) is modelled in ENVI-met SPACES V4.4 (Figure 59).

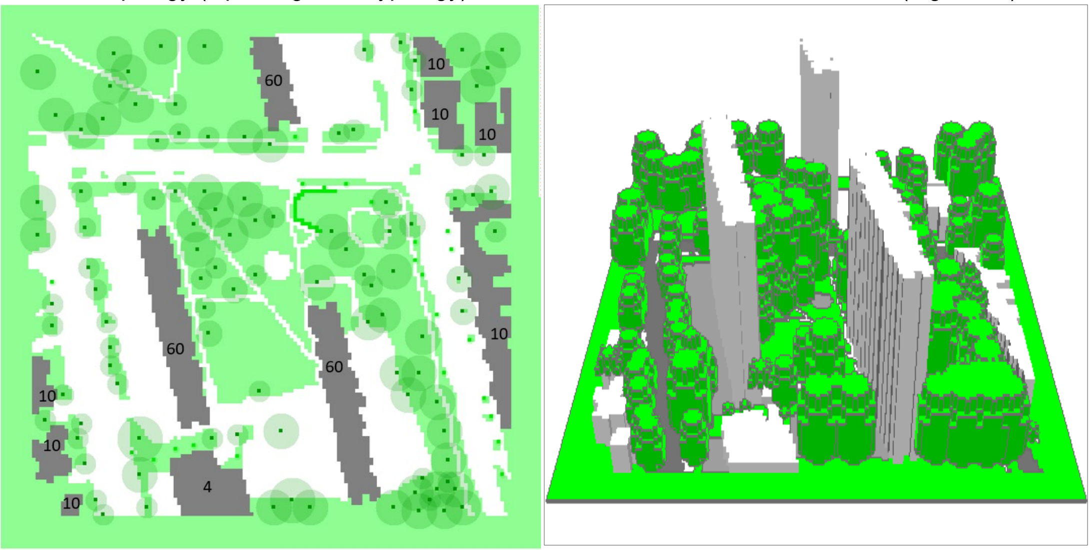


Figure 59 OT6 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction and the materials coding in OT6 are tabulated in Table 2 and Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 28 and Table 29, respectively. There are 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 28. The OT6 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 29. The OT6 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
0100H2	Hedge dense, 2m
01CLDM	Cylindric, large trunk, dense, medium (15m)
01CSSM	Cylindric, small trunk, sparse, medium (15m)
01PLDL	Palm, large trunk, dense, large (25m)
01PLDS	Palm, large trunk, dense, small (5m)
01SMDS	Spherical, medium trunk, dense, small (5m)
01CLSM	Cylindric, large trunk, sparse, medium (15m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01SMDM	Spherical, medium trunk, dense, medium (15m)
01CMSL	Cylindric, medium trunk, sparse, large (25m)
01SSSM	Spherical, small trunk, sparse, medium (15m)
01SMSL	Spherical, medium trunk, sparse, large (25m)
01CMDM	Cylindric, medium trunk, dense, medium (15m)
01CSDL	Cylindric, small trunk, dense, large (25m)
01CMDL	Cylindric, medium trunk, dense, large (25m)
01PLDM	Palm, large trunk, dense, medium (15m)
01SLDS	Spherical, large trunk, dense, small (5m)
01CMSM	Cylindric, medium trunk, sparse, medium (15m)
01CSDS	Cylindric, small trunk, dense, small (5m)
01CLDL	Cylindric, large trunk, dense, large (25m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

OT7

The OT7 topology (Open high-rise typology) is modelled in ENVI-met SPACES V4.4. The layout of the OT7 topology in ENVI-met is depicted in Figure 60.

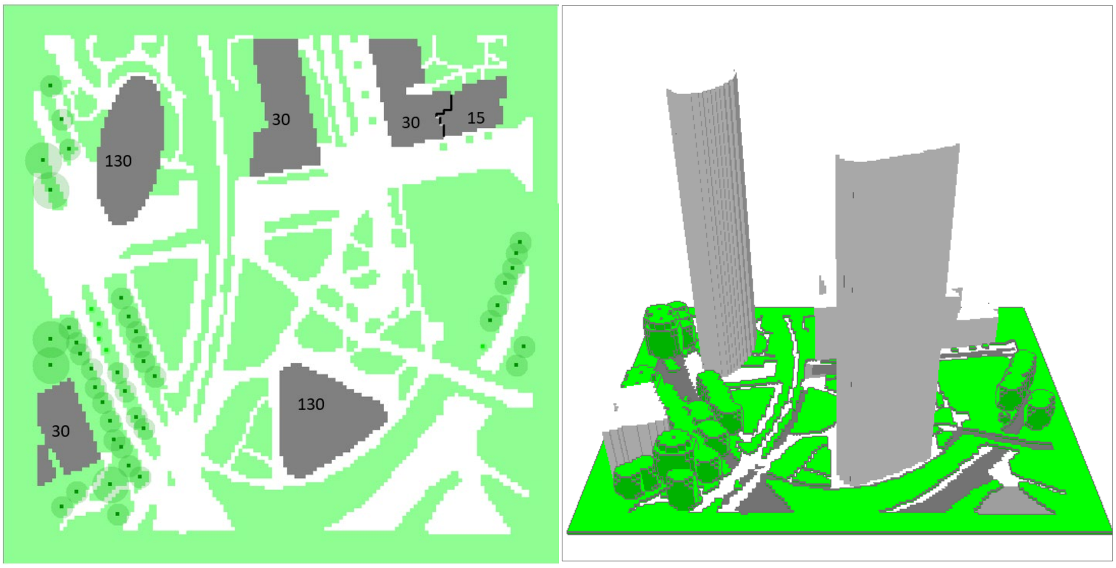


Figure 60 OT7 simulation domain: 2D view (left) with an overlay of building heights, 3D view (right)

The buildings construction in OT7 is tabulated in Table 2 and the materials coding is provided in Table 3. The urban surfaces albedo and emissivity and vegetation types used in the model are tabulated in Table 30 and Table 31, respectively. In the simulation of OT7 under mitigated condition, we implemented 4 misting systems with the size of 4.5m×4.5m and the height of 4m.

Table 30. The OT7 urban surfaces albedo and emissivity

Code	Name	Albedo	Emissivity
0100PD	Concrete Pavement Dark	0.20	0.90
0100PG	Concrete Pavement Gray	0.50	0.90
0100PL	Concrete Pavement Light	0.80	0.90
0100Q3	Cool Pavement	0.50	0.90
0100Q5	Cool Asphalt Road	0.55	0.90

Table 31. The OT7 vegetation characteristics

Code	Name
0100XX	Grass 25cm aver. Dense
01CMDM	Cylindric, medium trunk, dense, medium (15m)
01CMDS	Cylindric, medium trunk, dense, small (5m)
01CMDL	Cylindric, medium trunk, dense, large (25m)
01CMSL	Cylindric, medium trunk, sparse, large (25m)
01CMSM	Cylindric, medium trunk, sparse, medium (15m)
01CSDM	Cylindric, small trunk, dense, medium (15m)

Results of simple forcing (mitigated 2050 climate and mitigated precinct)

CT1 mitigated

CT1- Mitigated

Figure 61 shows the distribution of ambient temperature, wind speed and surface temperature in CT1.

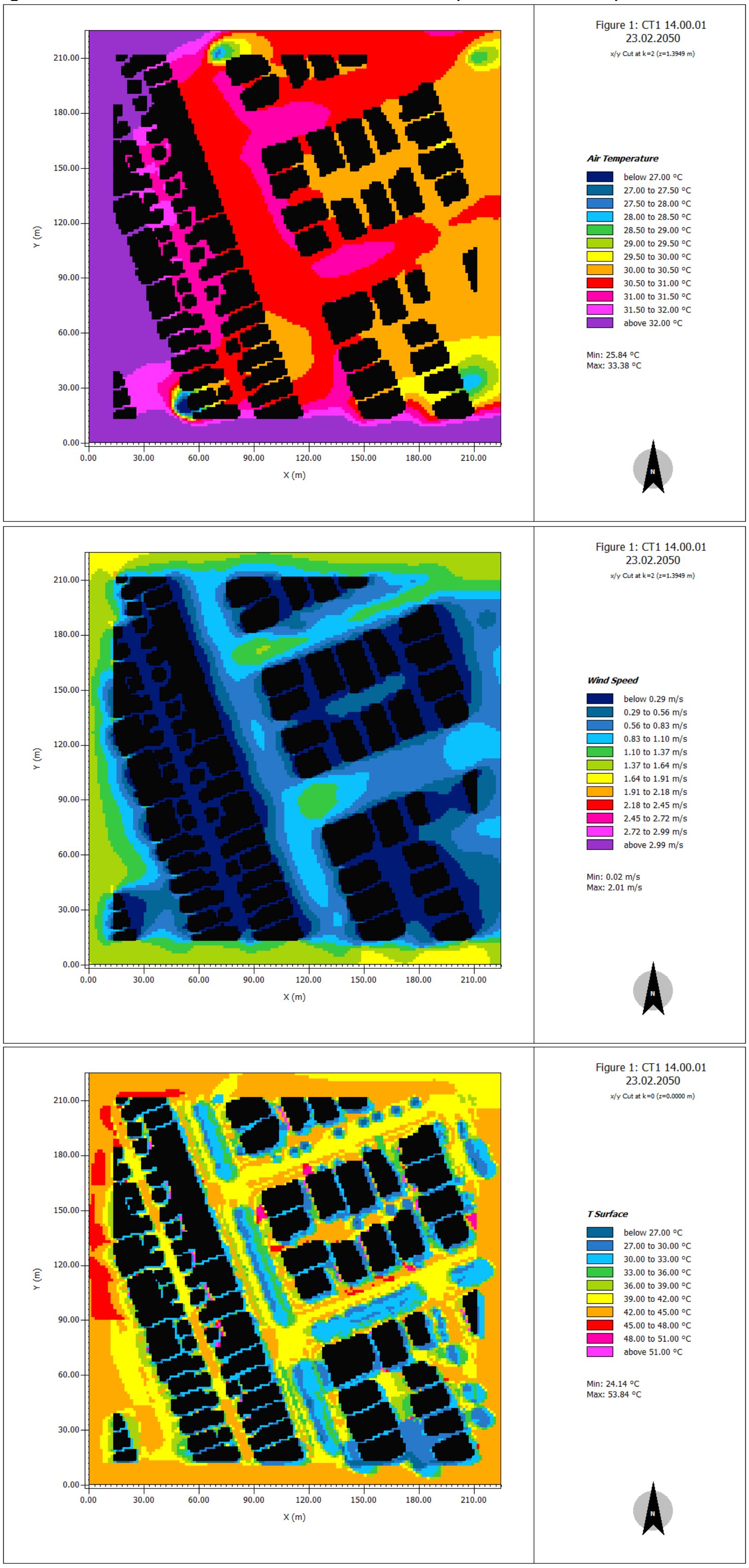


Figure 61 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT1

As shown above, ambient temperature ranges from 25.8 °C to 33.4 °C in CT1 at 14:00. The average temperature is 31.1°C at 14:00. The areas near water sprinklers present lower ambient temperatures and western part of the precinct is affected by the initial boundary condition. The wind speed at 14:00 reaches to 2 m/s. The areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.1 °C to 53.9 °C in CT1 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 62 shows the distribution of thermal comfort indices (PET, UTCI). CT1 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 31.9°C to 40°C. Thermal comfort is improved in the shaded areas and near water sprinklers.

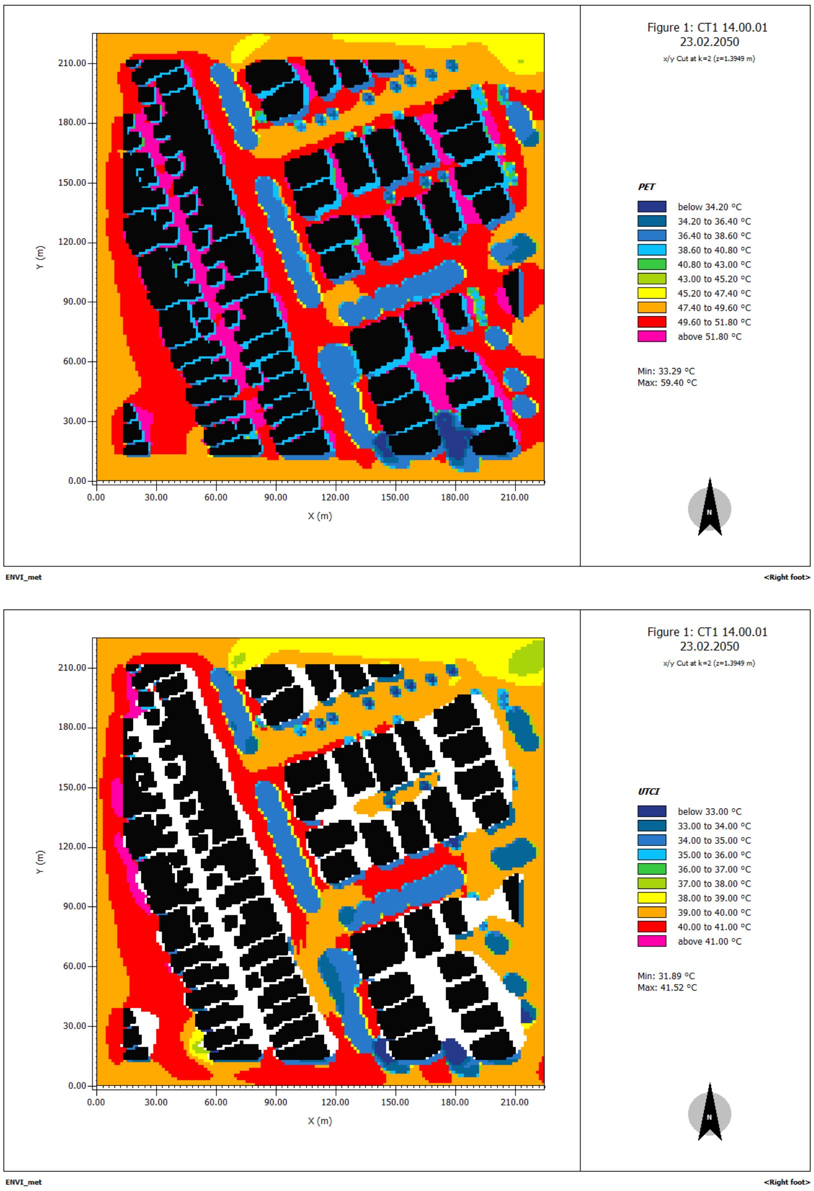


Figure 62 Distribution of thermal comfort in CT1; PET (top), UTCI (bottom)

CT2 mitigated

CT2- Mitigated

Figure 63 shows the distribution of ambient temperature, wind speed and surface temperature in CT2.

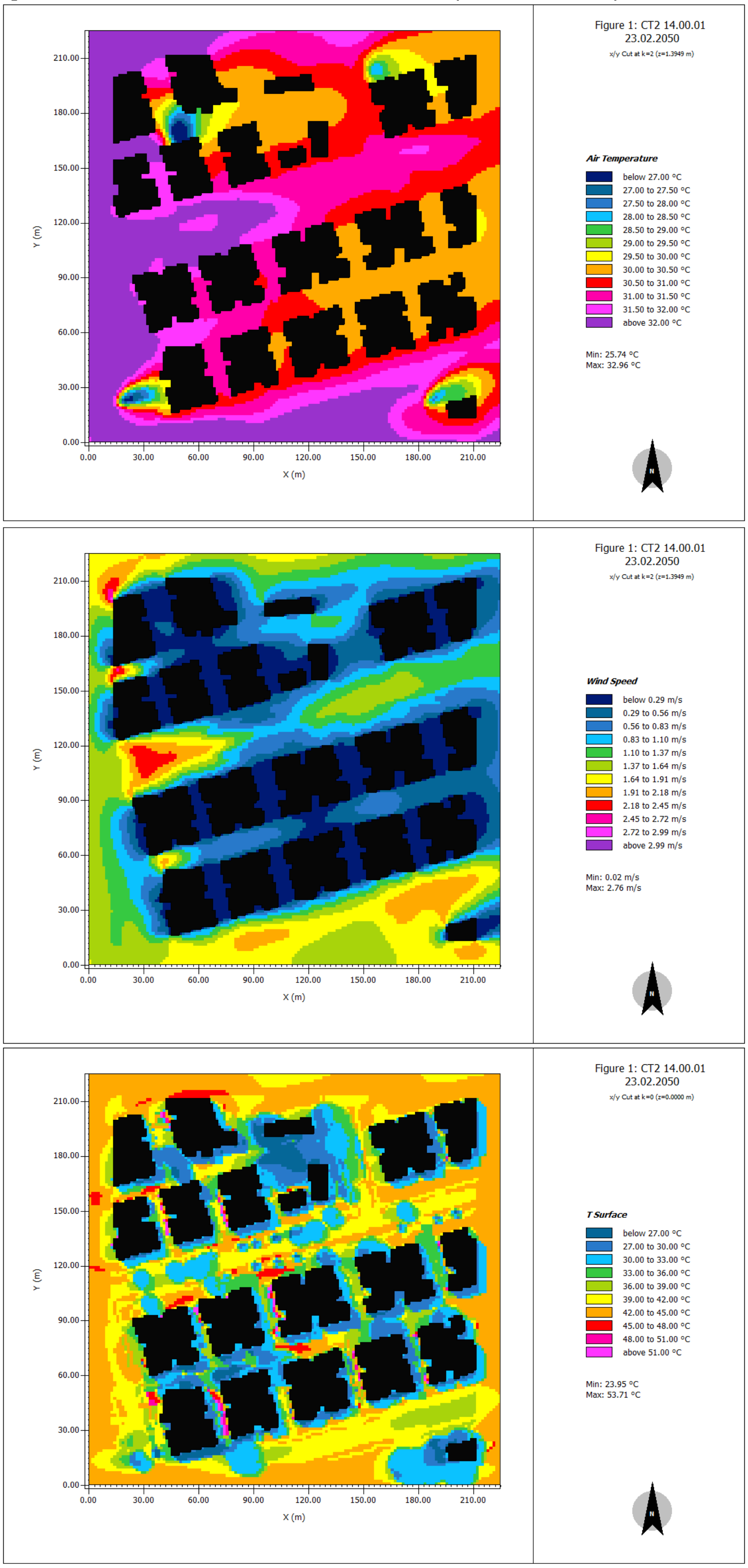


Figure 63 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT2

The ambient temperature ranges from 25.8 °C to 33.0 °C in CT2 at the peak time of the simulation day (14:00). The average temperature is 31.2°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.8 m/s. The areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.0 °C to 53.7 °C in CT2 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 64 shows the distribution of thermal comfort indices (PET, UTCI). CT2 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.2°C to 41.1°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

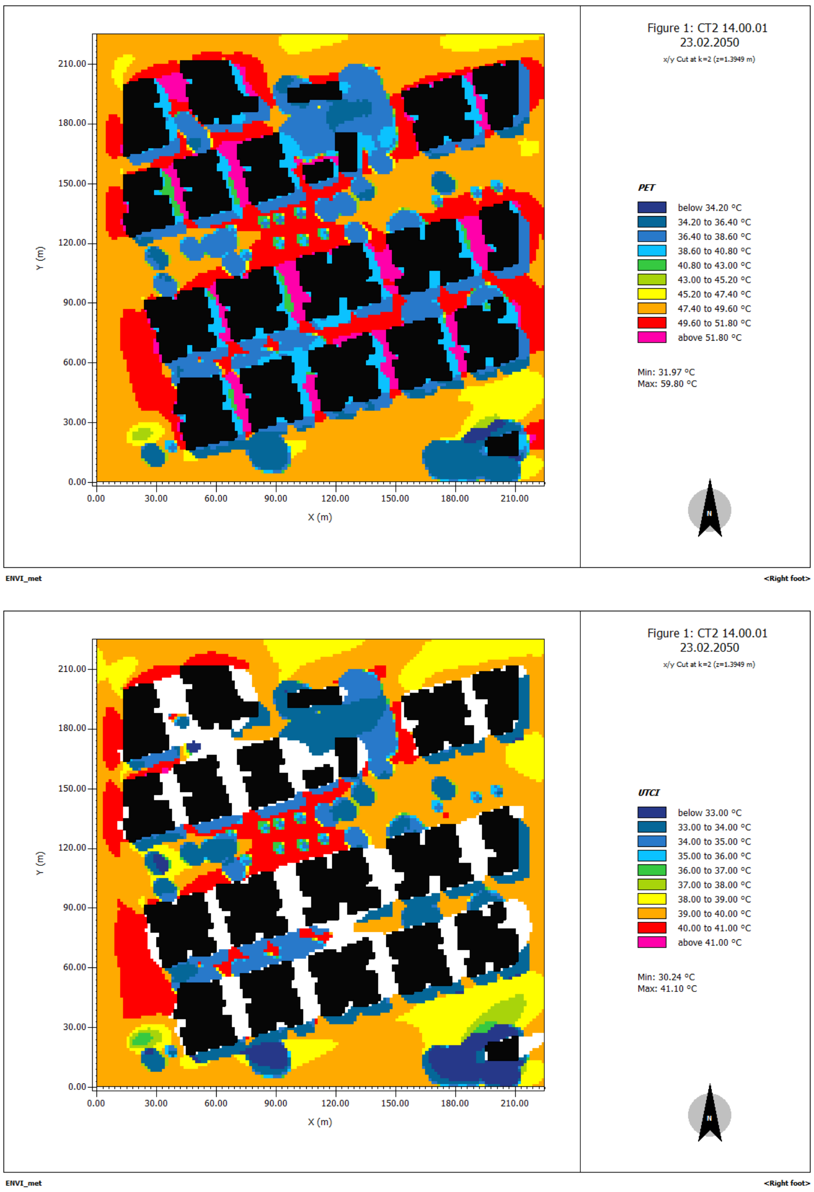


Figure 64 Distribution of thermal comfort in CT2; PET (top), UTCI (bottom)

CT3 mitigated

CT3- Mitigated

Figure 65 shows the distribution of ambient temperature, wind speed and surface temperature in CT3.

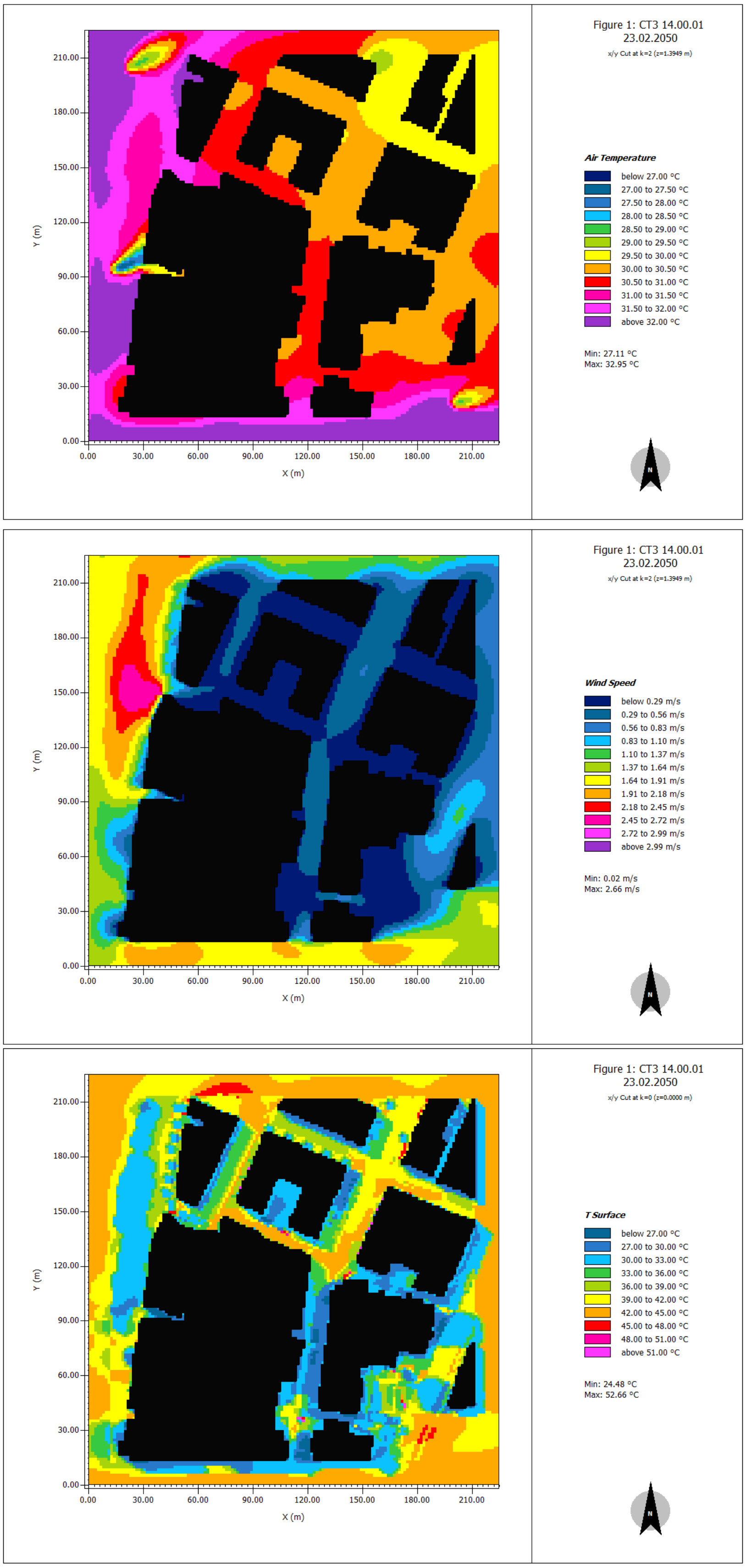


Figure 65 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT3

As depicted in Figure 65, the ambient temperature ranges from 27.1 °C to 33.0 °C in CT3 at the peak time of the simulation day (14:00). The average temperature is 31.2°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.7 m/s. The areas between the buildings present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.5 °C to 52.7 °C in CT3 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 66 shows the distribution of thermal comfort indices (PET, UTCI). CT3 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.2°C to 41.1°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

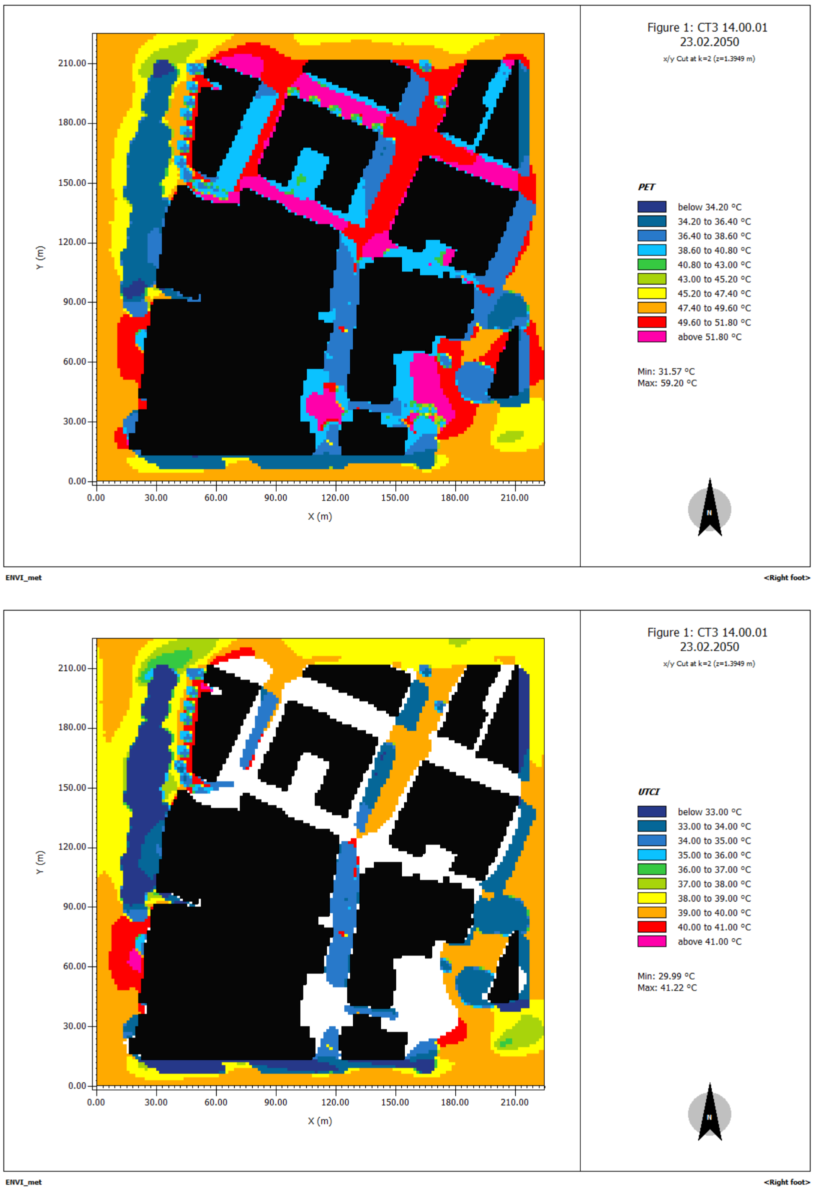


Figure 66 Distribution of thermal comfort in CT3; PET (top), UTCI (bottom)

CT4 mitigated

CT4- Mitigated

Figure 67 shows the distribution of ambient temperature, wind speed and surface temperature in CT4.

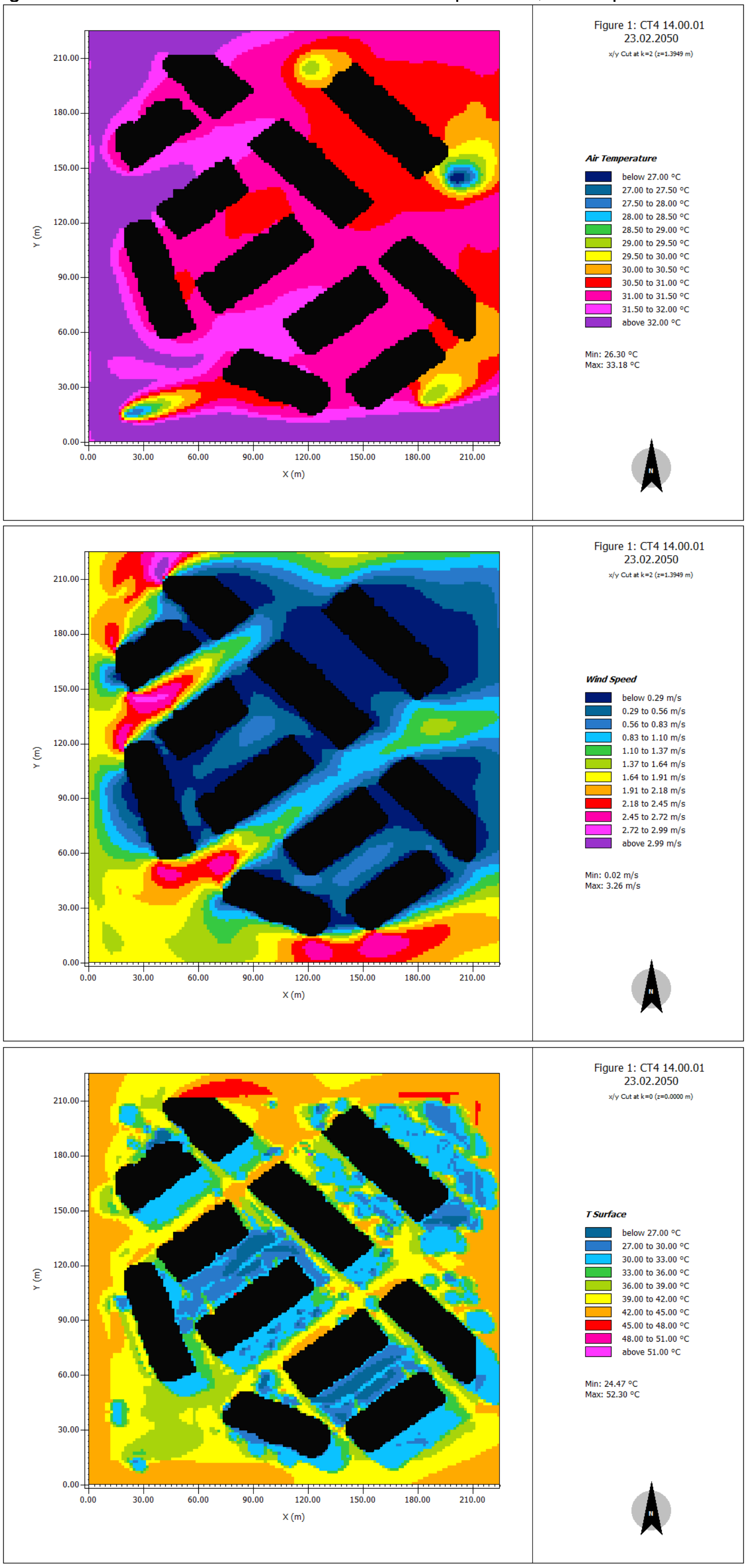


Figure 67 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT4

As depicted in Figure 67, the ambient temperature ranges from 26.3 °C to 33.2 °C in CT4 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.4°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 3.3 m/s. The areas between the buildings present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.5 °C to 52.3 °C in CT4 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 69 illustrates the distribution of thermal comfort indices (PET, UTCI). CT4 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.5°C to 41.0°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

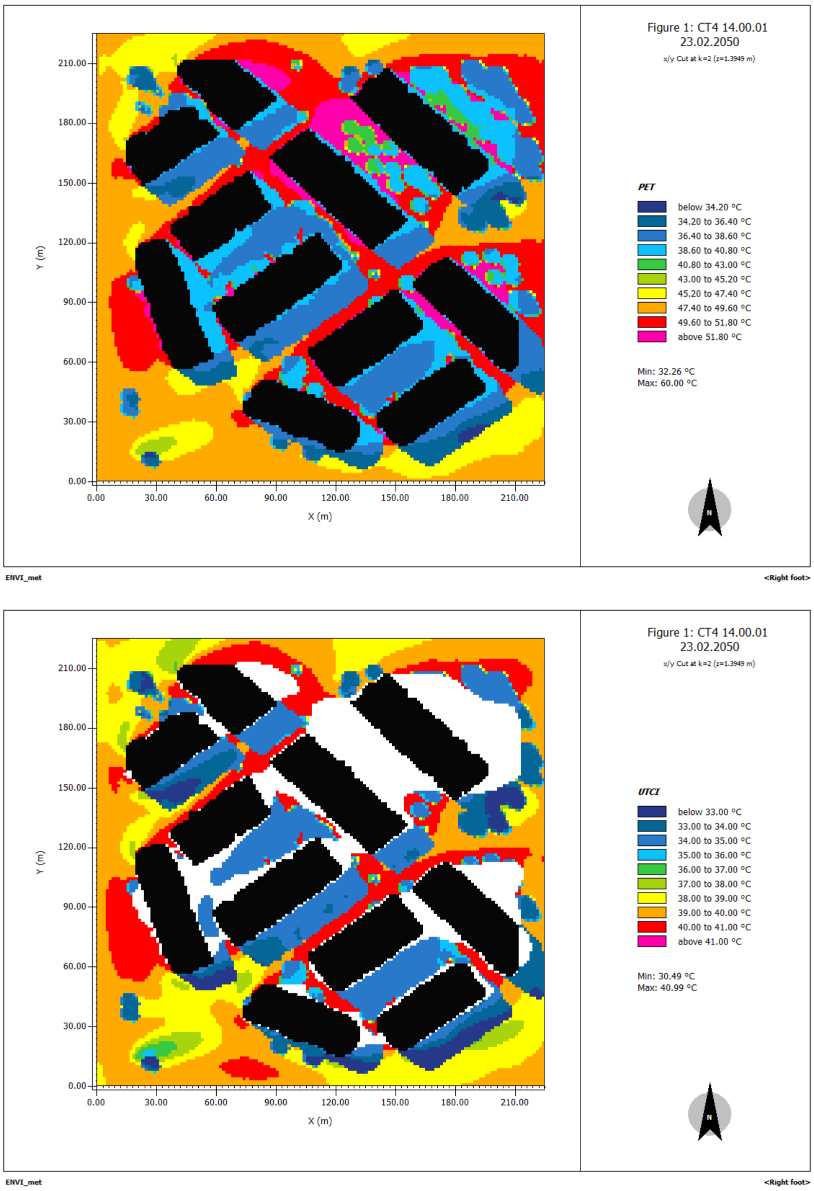


Figure 68 Distribution of thermal comfort in CT4; PET (top), UTCI (bottom)

CT5 mitigated

CT5- Mitigated

Figure 69 shows the distribution of ambient temperature, wind speed and surface temperature in CT5.

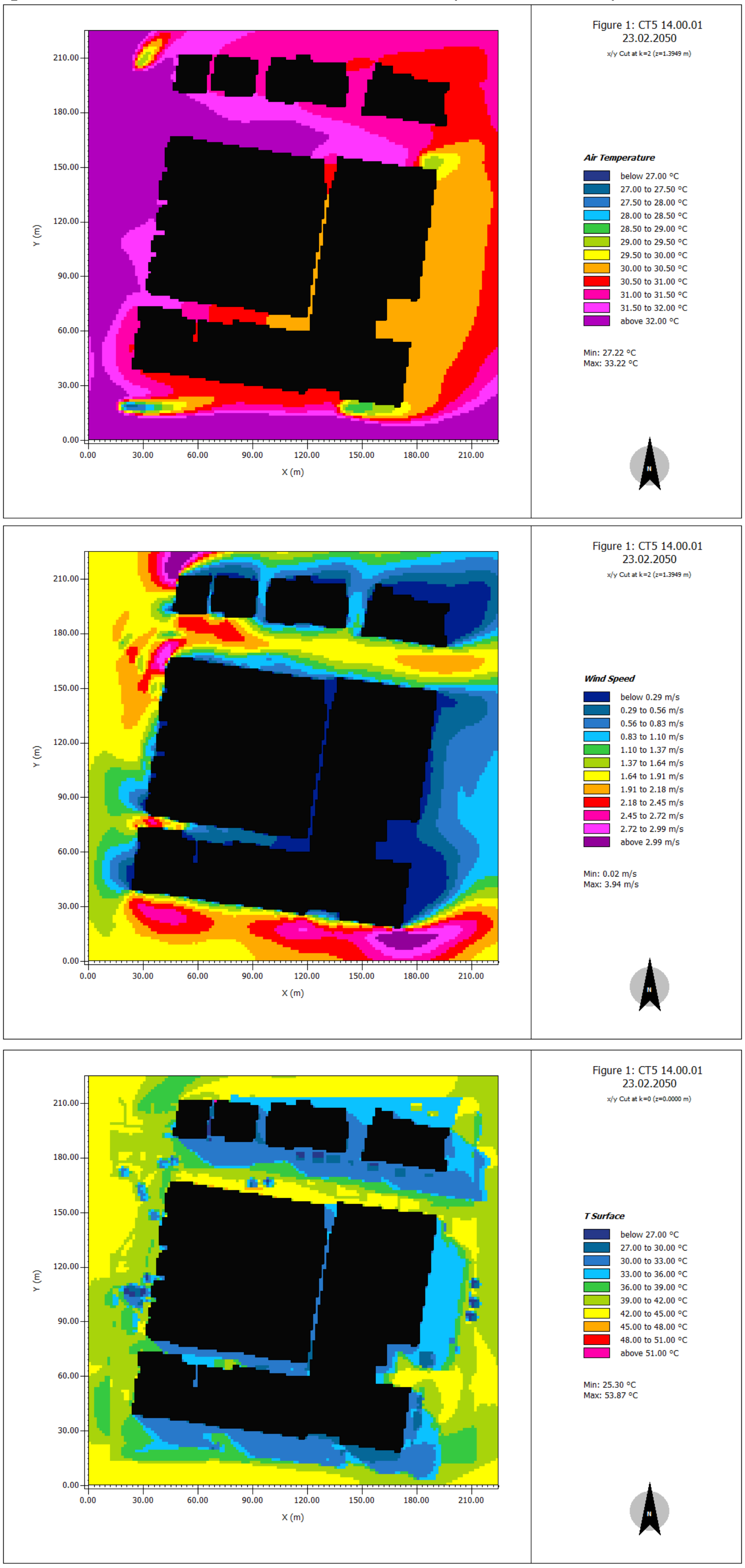


Figure 69 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT5

The ambient temperature ranges from 27.2 °C to 33.2 °C in CT5 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.5°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 3.9 m/s. The areas between the buildings present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.3 °C to 53.9 °C in CT5 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 70 illustrates the distribution of thermal comfort indices (PET, UTCI). CT5 in general indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.0°C to 42.12°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

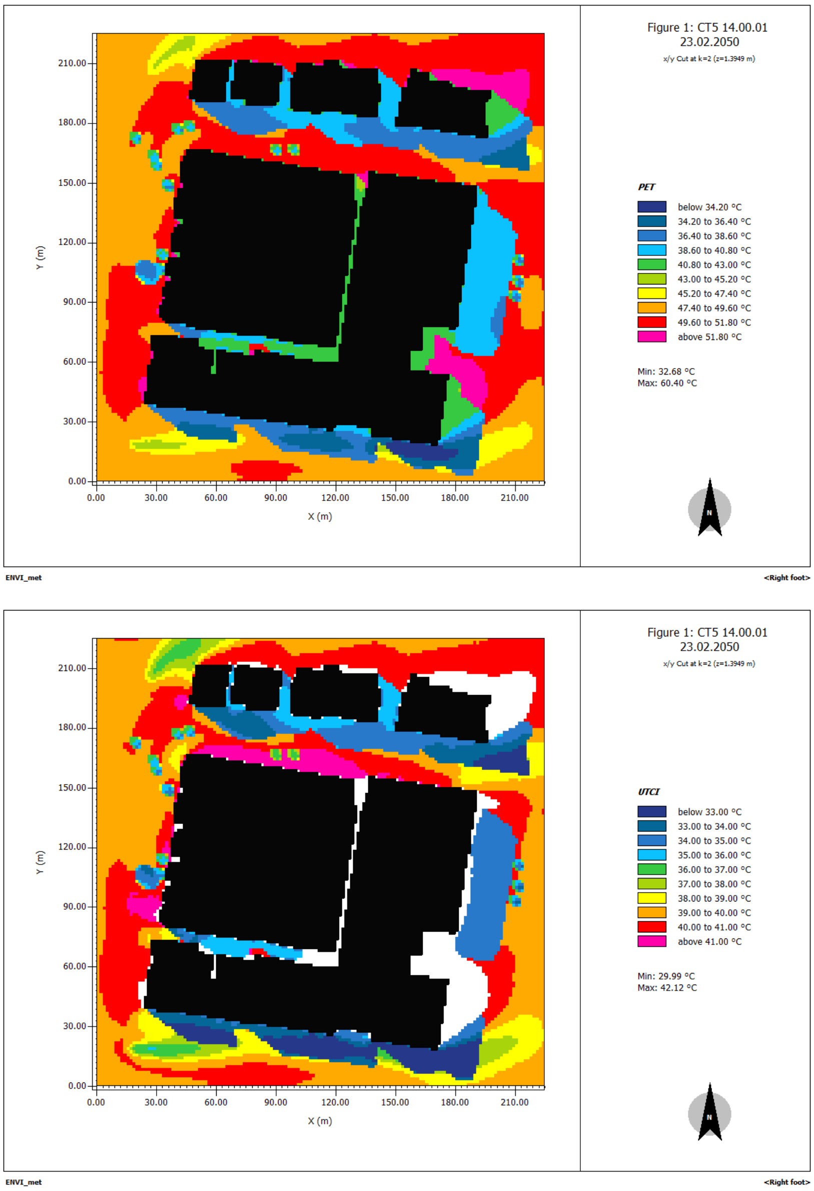


Figure 70 Distribution of thermal comfort in CT5; PET (top), UTCI (bottom)

CT6 mitigated

CT6- Mitigated

Figure 71 shows the distribution of ambient temperature, wind speed and surface temperature in CT6.

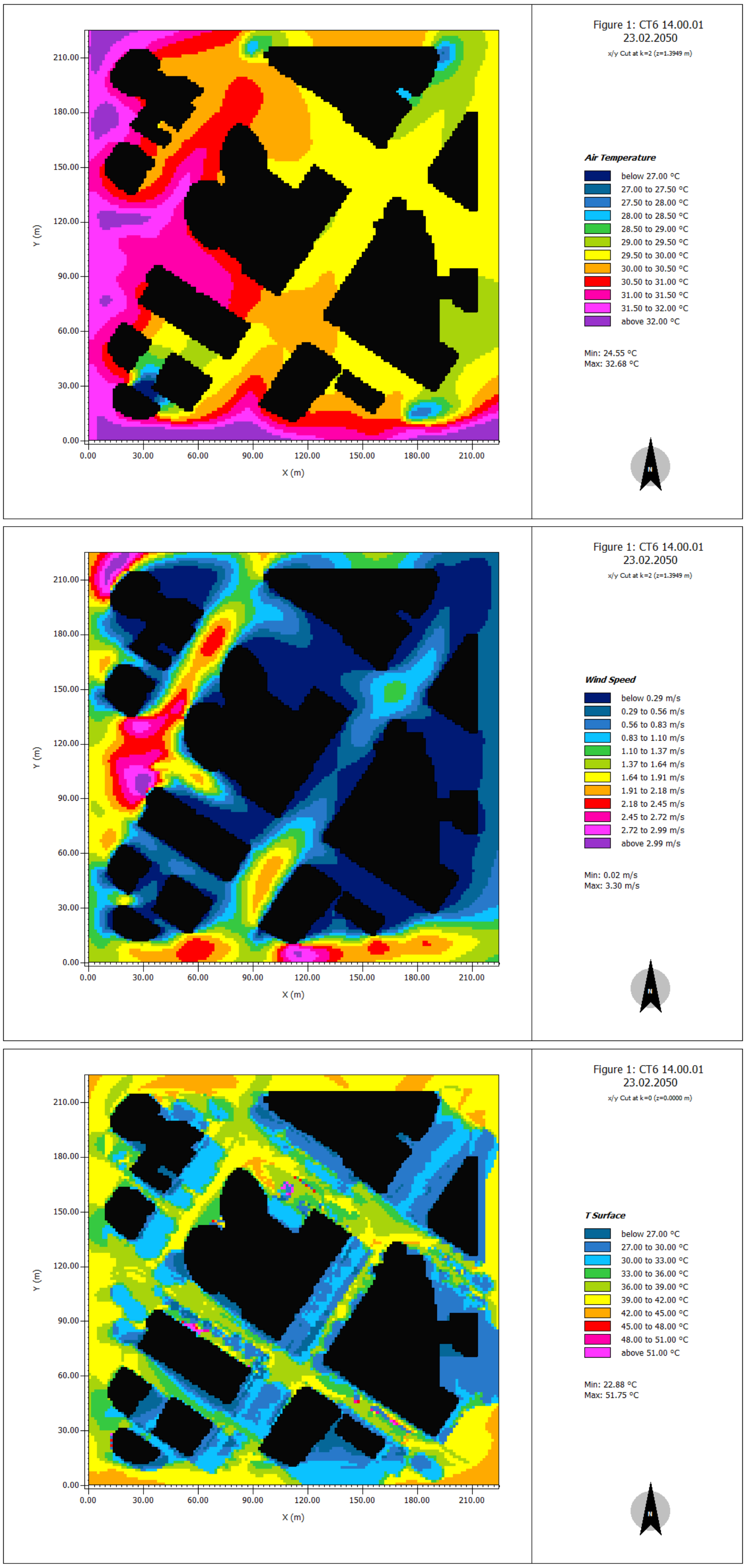


Figure 71 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT6

The ambient temperature ranges from 24.6 °C to 32.7 °C in CT6 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 30.4°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 3.3 m/s. The areas between the buildings present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 22.9 °C to 51.6 °C in CT6 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 72 illustrates the distribution of thermal comfort indices (PET, UTCI). CT6 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 28.9°C to 39.7°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

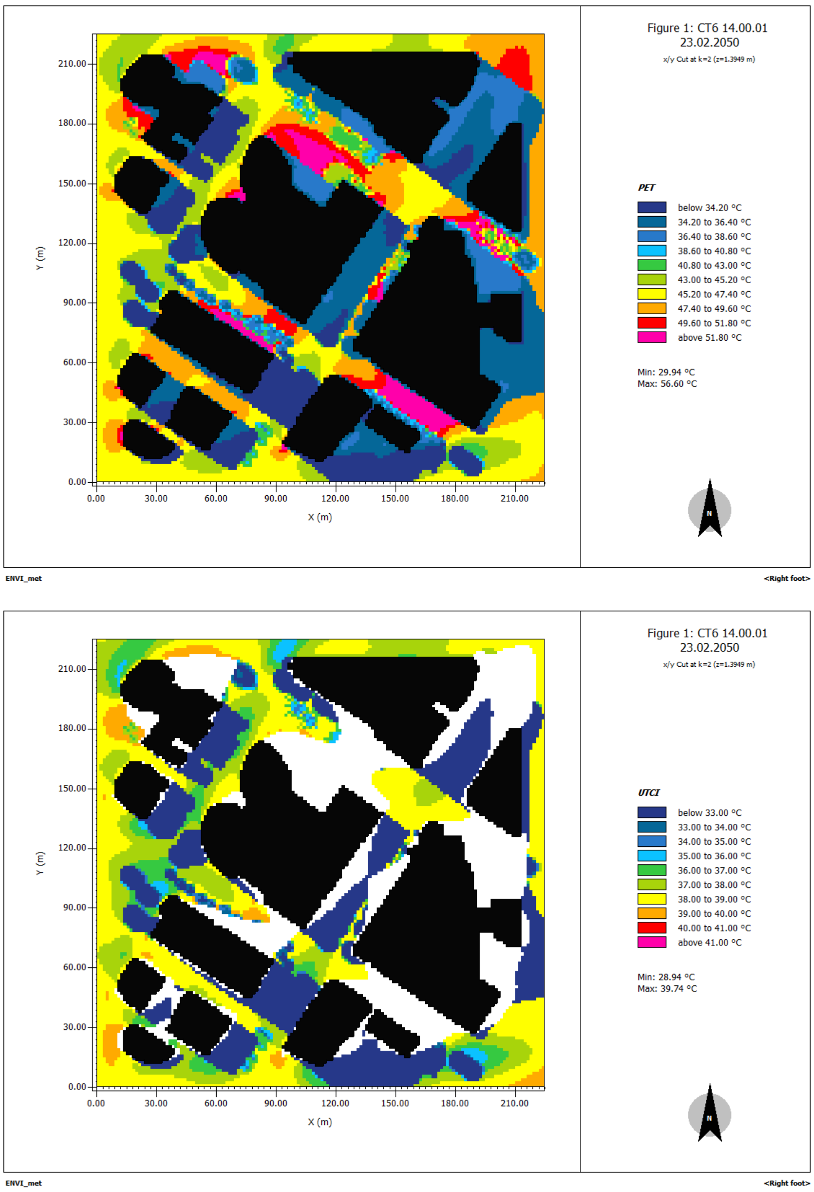


Figure 72 Distribution of thermal comfort in CT6; PET (top), UTCI (bottom)

CT7 mitigated

CT7- Mitigated

Figure 73 shows the distribution of ambient temperature, wind speed and surface temperature in CT7.

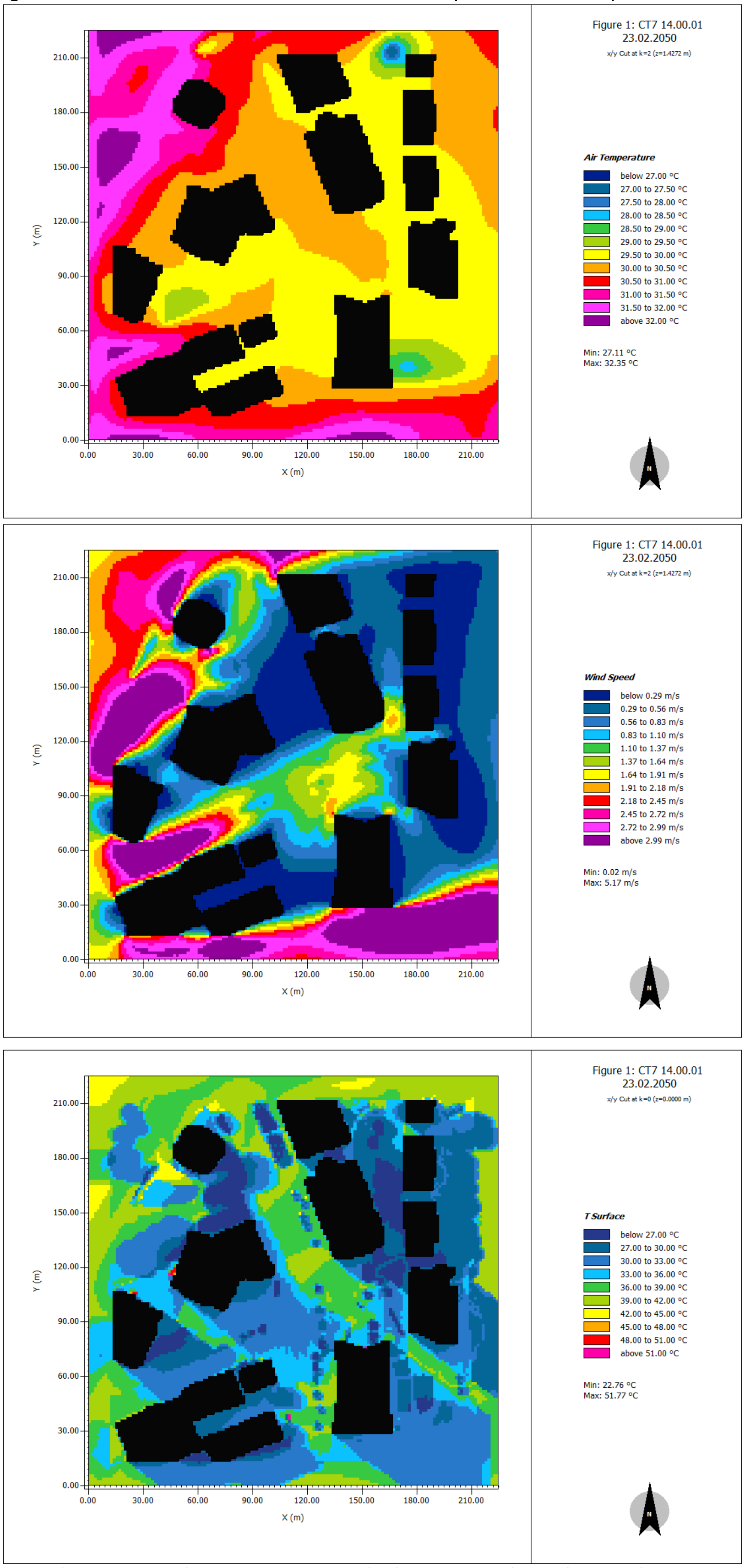


Figure 73 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in CT7

As shown in Figure 73, the ambient temperature ranges from 27.1 °C to 32.4 °C in CT7 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 30.4°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 5.2 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 22.8 °C to 51.8 °C in CT7 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

Figure 74 illustrates the distribution of thermal comfort indices (PET, UTCI). CT7 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 27.8°C to 39.3°C. Thermal comfort is improved in the shaded areas and near water sprinklers. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

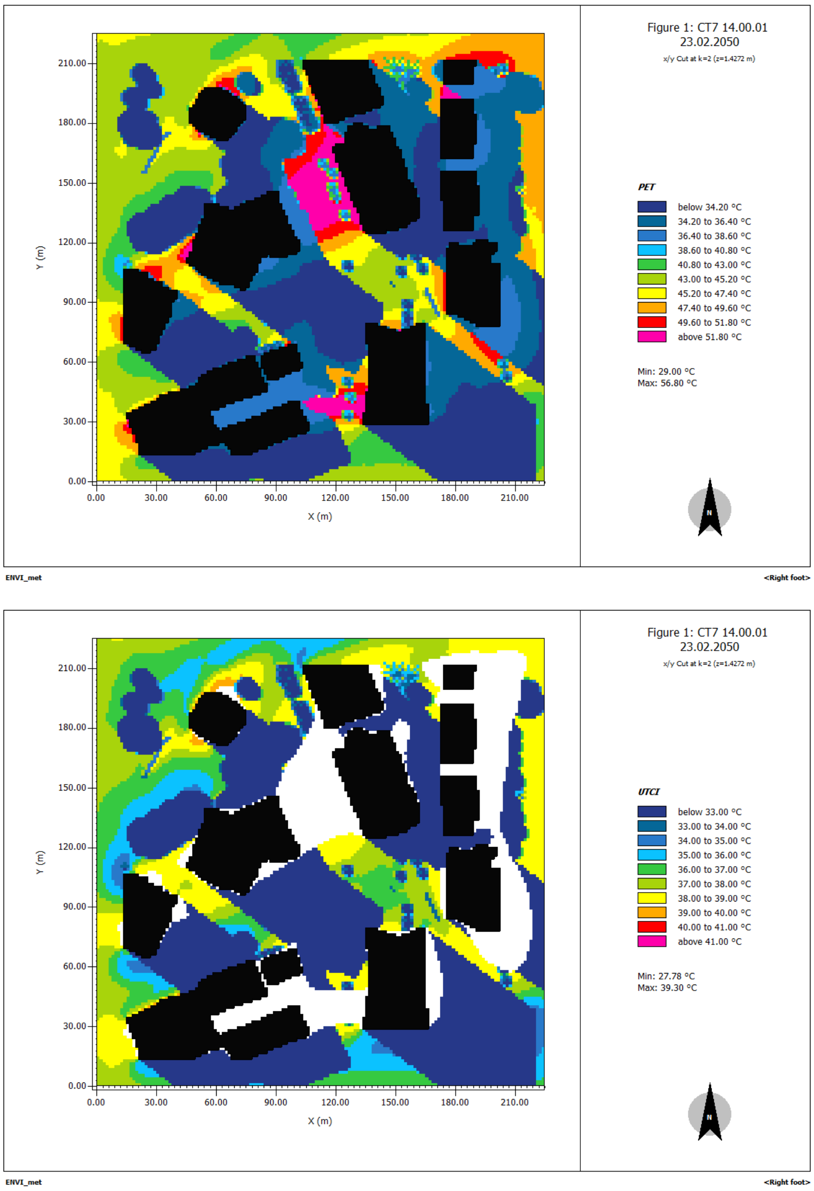


Figure 74 Distribution of thermal comfort in CT7; PET (top), UTCI (bottom)

OT1 mitigated

OT1- Mitigated

Figure 75 shows the distribution of ambient temperature, wind speed and surface temperature in OT1.

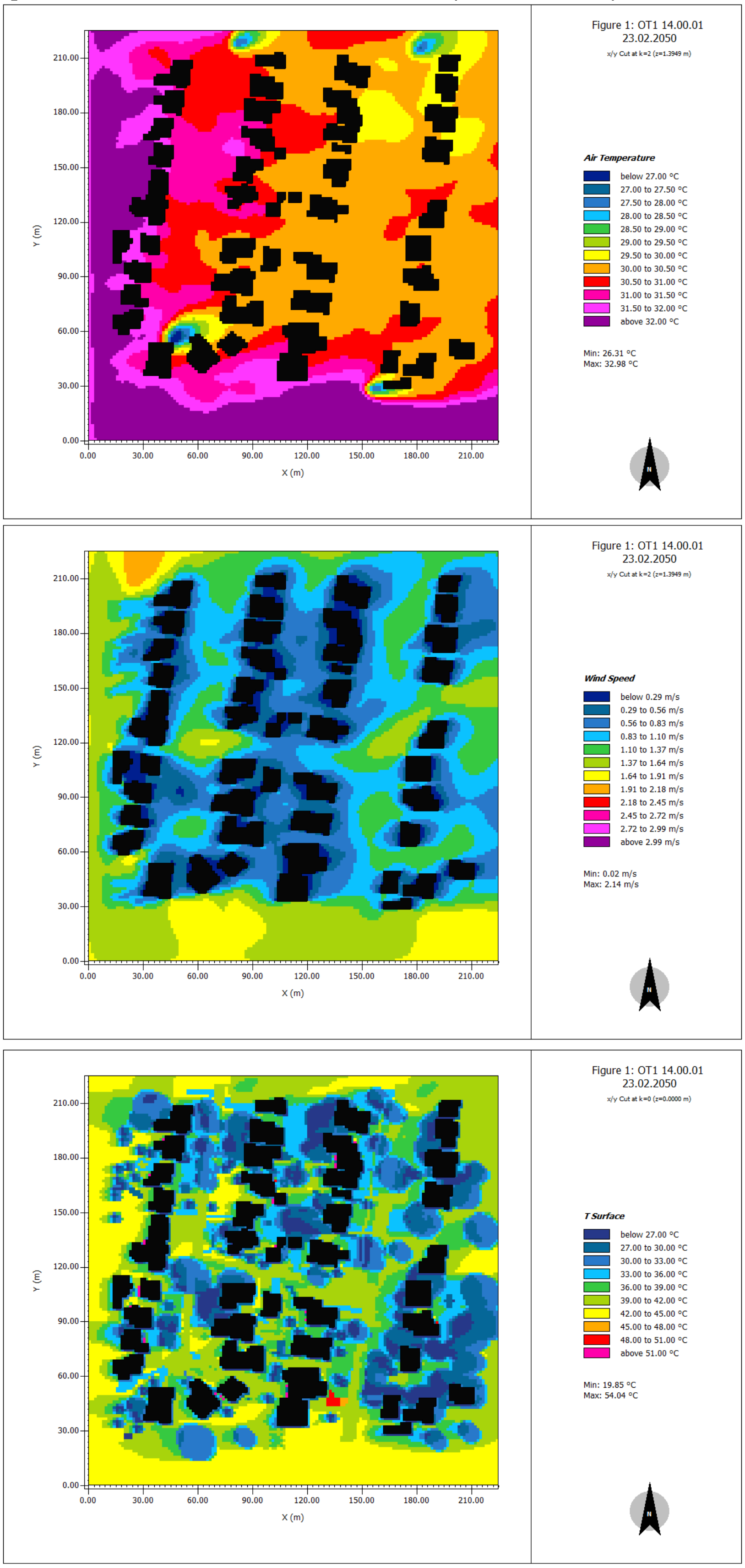
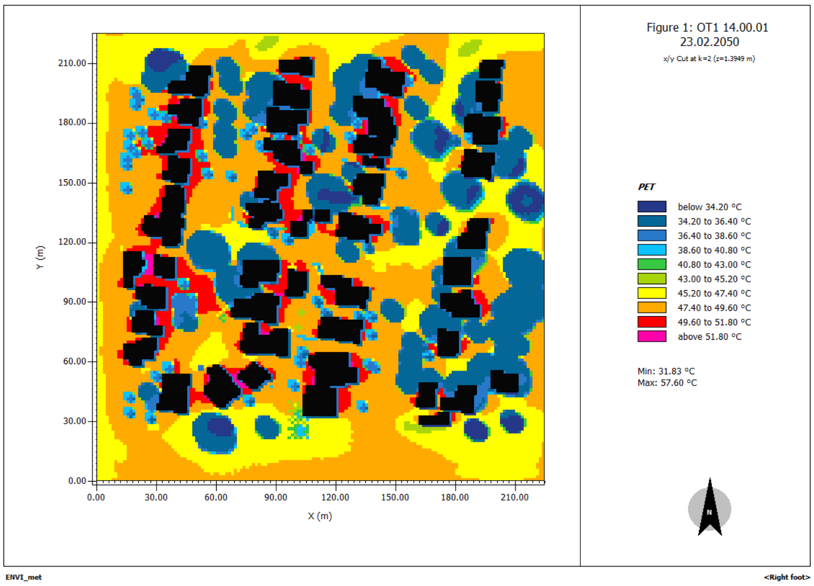


Figure 75 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT1

As shown in Figure 75, the ambient temperature ranges from 26.3 °C to 33.0 °C in OT1 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.0°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.1 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 20.0 °C to 54.0 °C in OT1 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 76. OT1 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.4°C to 40.6°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.



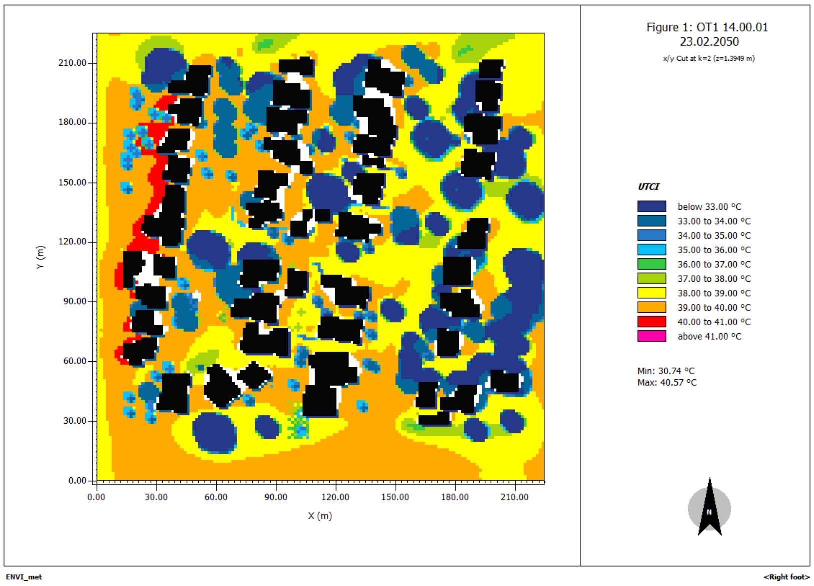


Figure 76 Distribution of thermal comfort in OT1; PET (top), UTCI (bottom)

OT2 mitigated

OT2- Mitigated

Figure 77 shows the distribution of ambient temperature, wind speed and surface temperature in OT2.

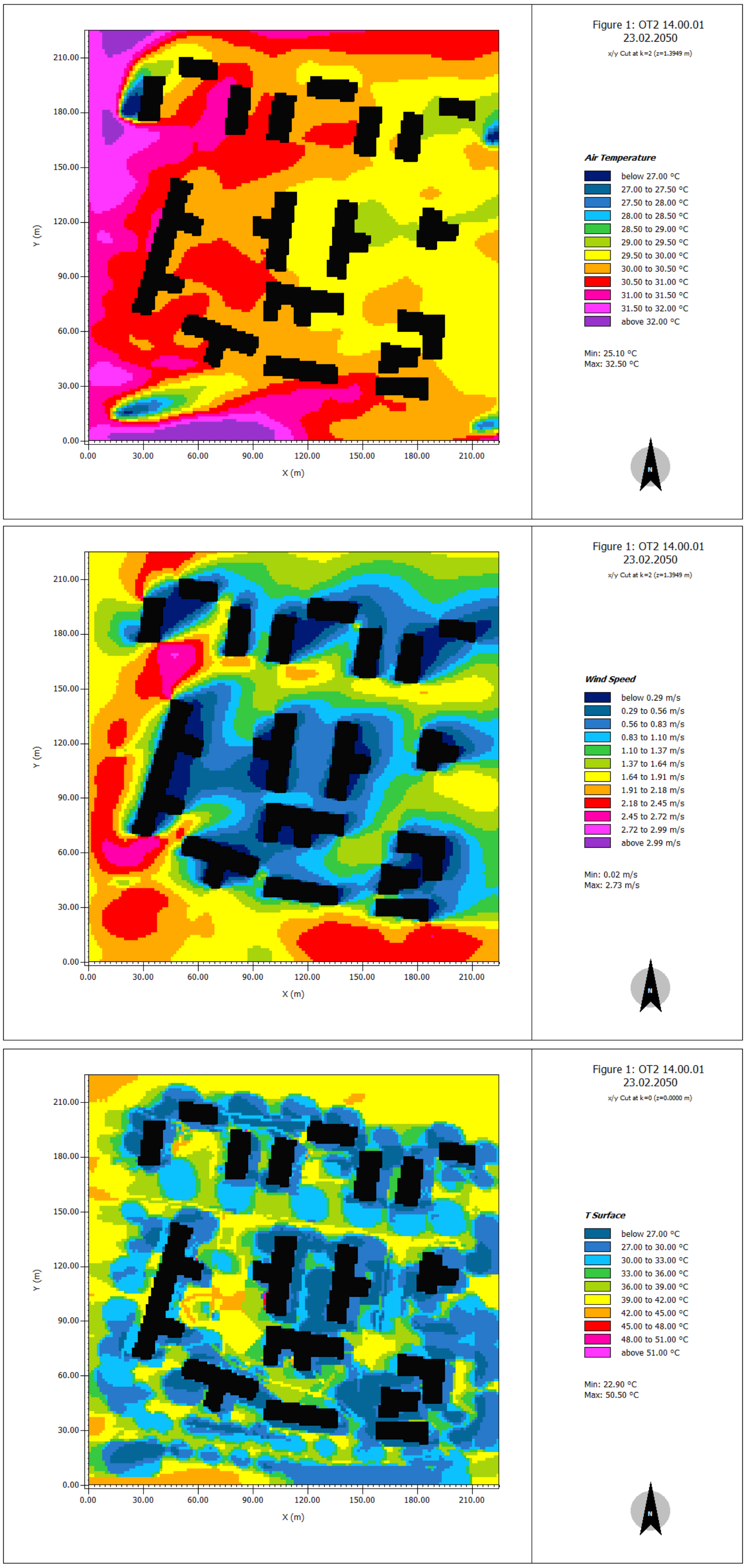


Figure 77 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT2

The ambient temperature ranges from 25.1 °C to 32.5 °C in OT2 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 30.4°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.7 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 22.9 °C to 50.5 °C in OT2 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 78. OT2 in general indicates low to moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 27.1°C to 38.9°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

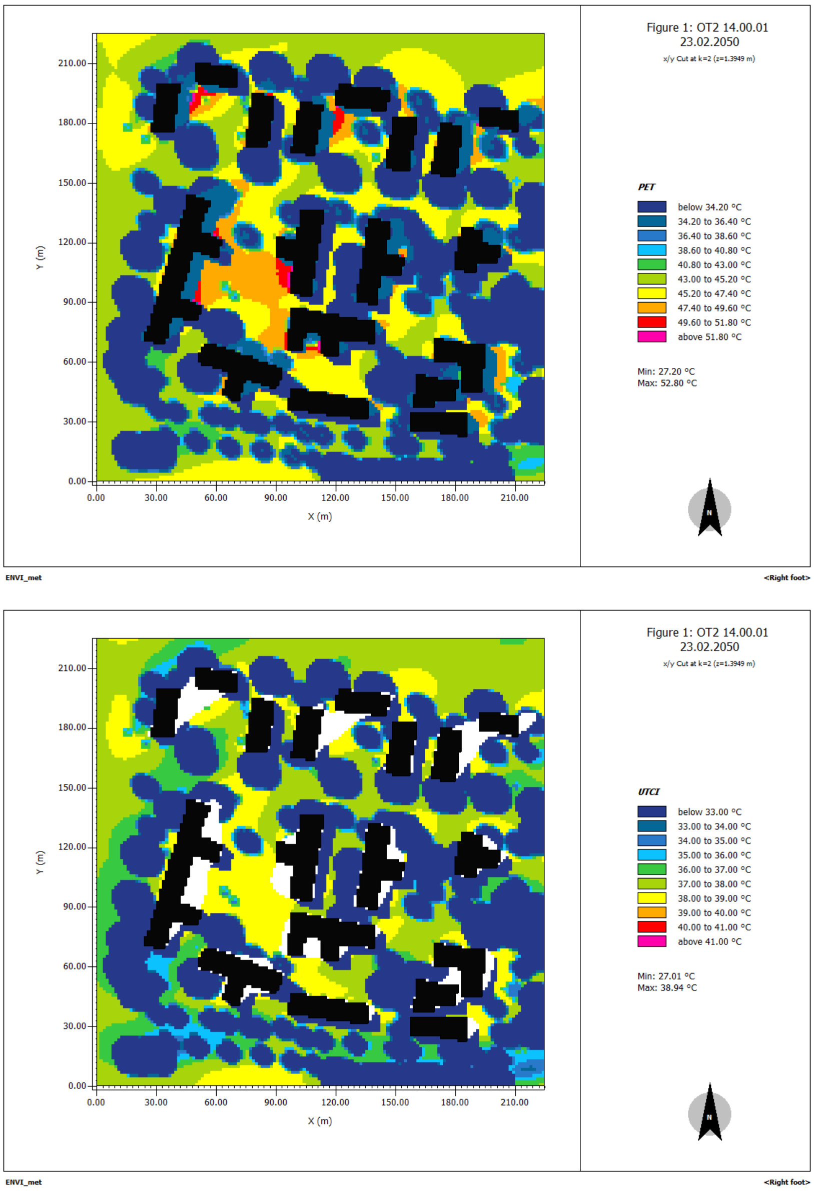


Figure 78 Distribution of thermal comfort in OT2; PET (top), UTCI (bottom)

OT3 mitigated

OT3- Mitigated

Figure 79 shows the distribution of ambient temperature, wind speed and surface temperature in OT3.

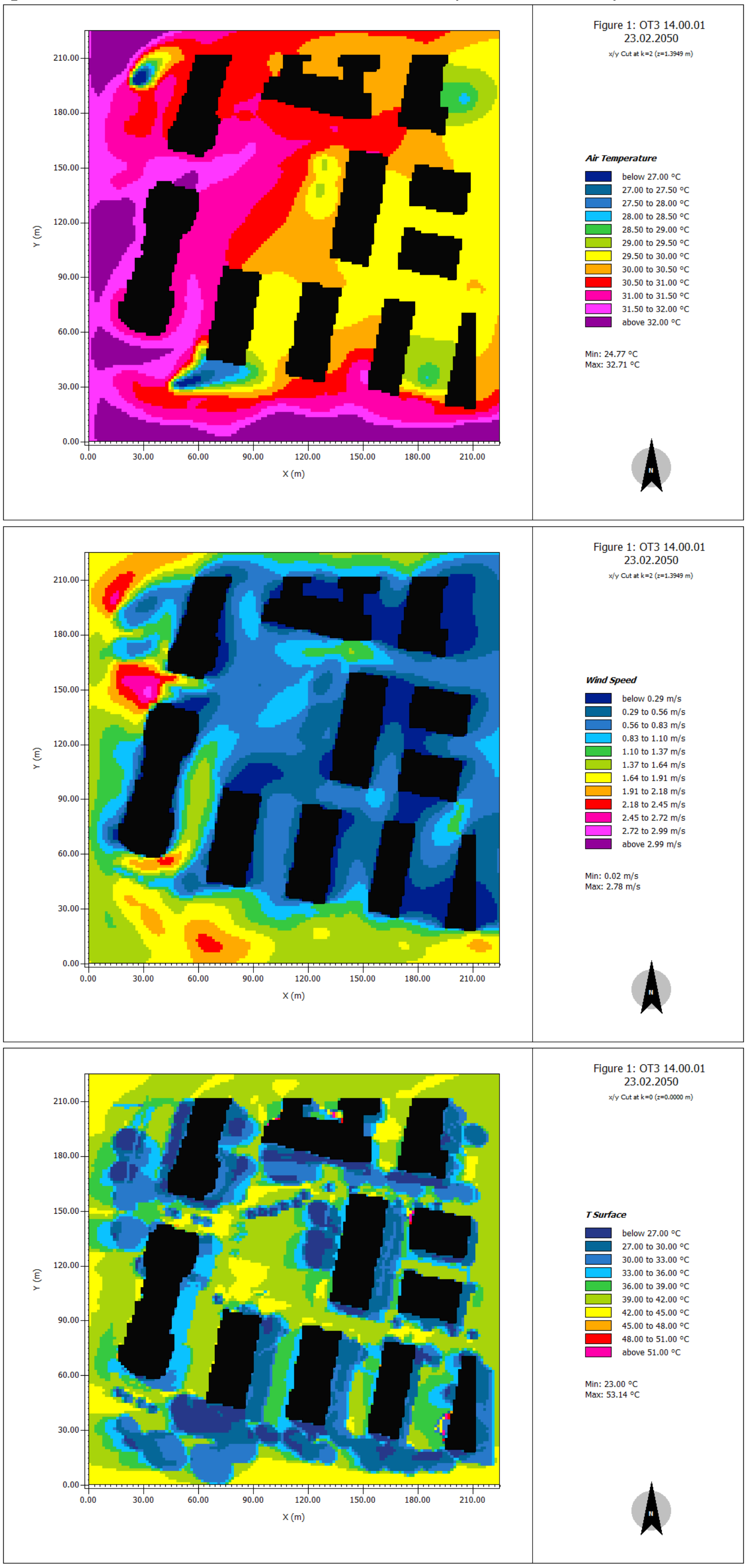


Figure 79 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT3

The ambient temperature ranges from 24.8 °C to 32.7 °C in OT3 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 30.8°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect, however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.8 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 23.0 °C to 53.1 °C in OT3 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 80. OT3 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 29.1°C to 40.9°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

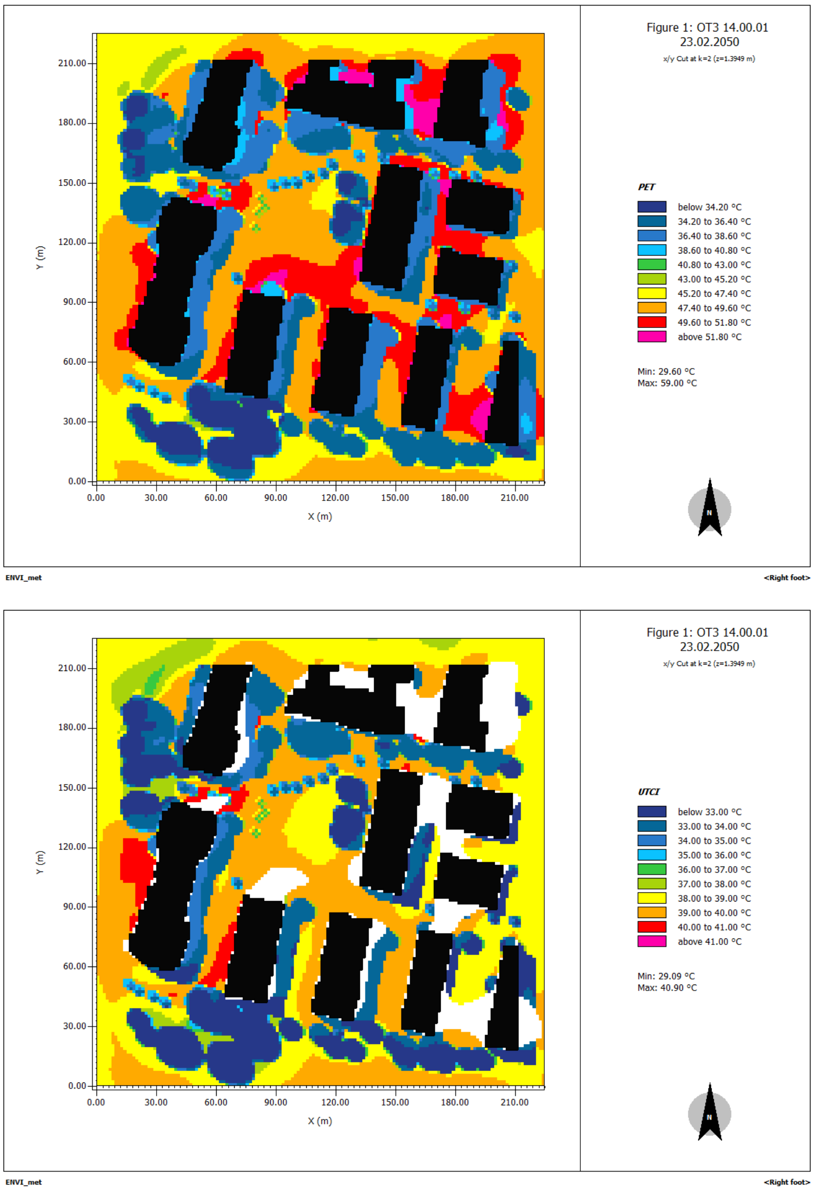


Figure 80 Distribution of thermal comfort in OT3; PET (top), UTCI (bottom)

OT4 mitigated

OT4- Mitigated

Figure 81 shows the distribution of ambient temperature, wind speed and surface temperature in OT4.

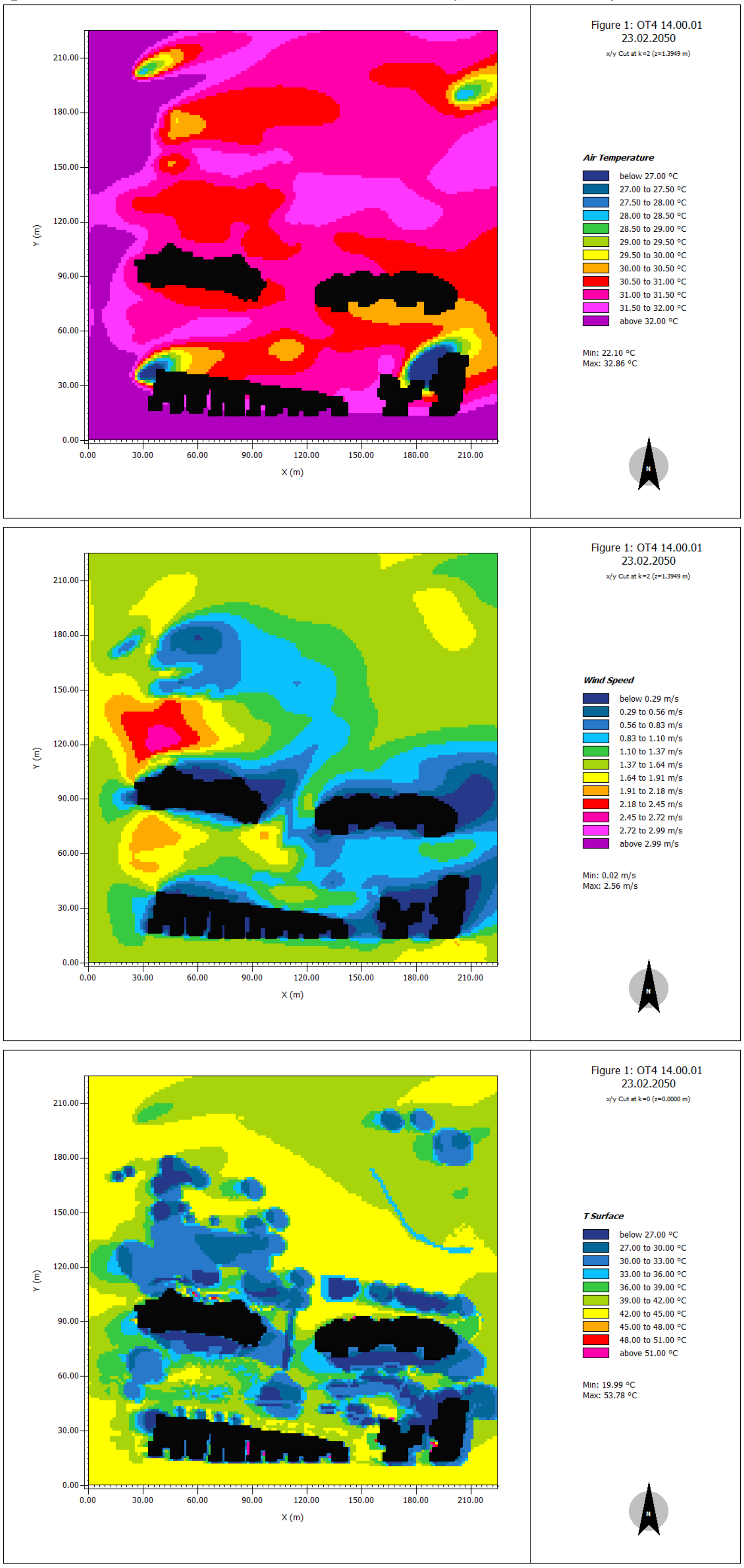


Figure 81 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT4

As depicted in Figure 81, the ambient temperature ranges from 22.1 °C to 32.9 °C in OT4 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.3°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect; however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 2.6 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 20.0 °C to 53.8 °C in OT4 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 82. OT4 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 29.5°C to 40.8°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

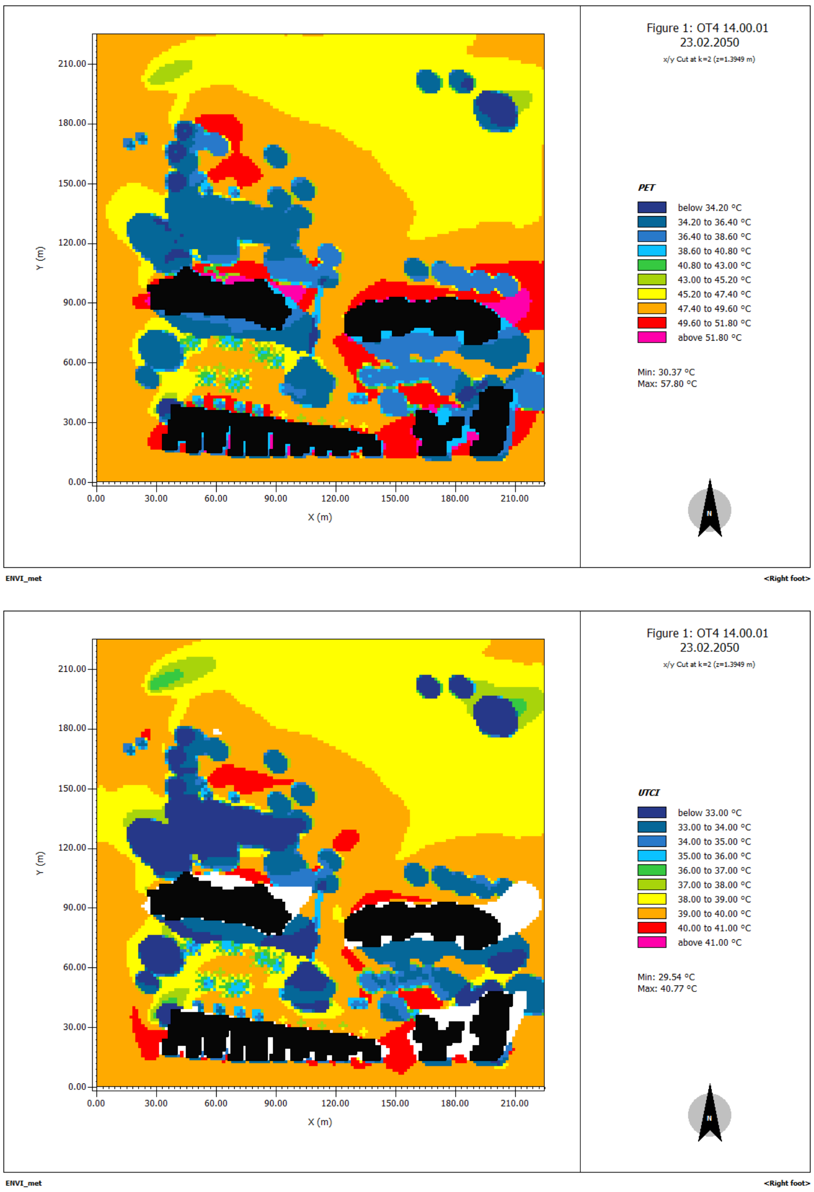


Figure 82 Distribution of thermal comfort in OT4; PET (top), UTCI (bottom)

OT5 mitigated

OT5- Mitigated

Figure 83 shows the distribution of ambient temperature, wind speed and surface temperature in OT5.

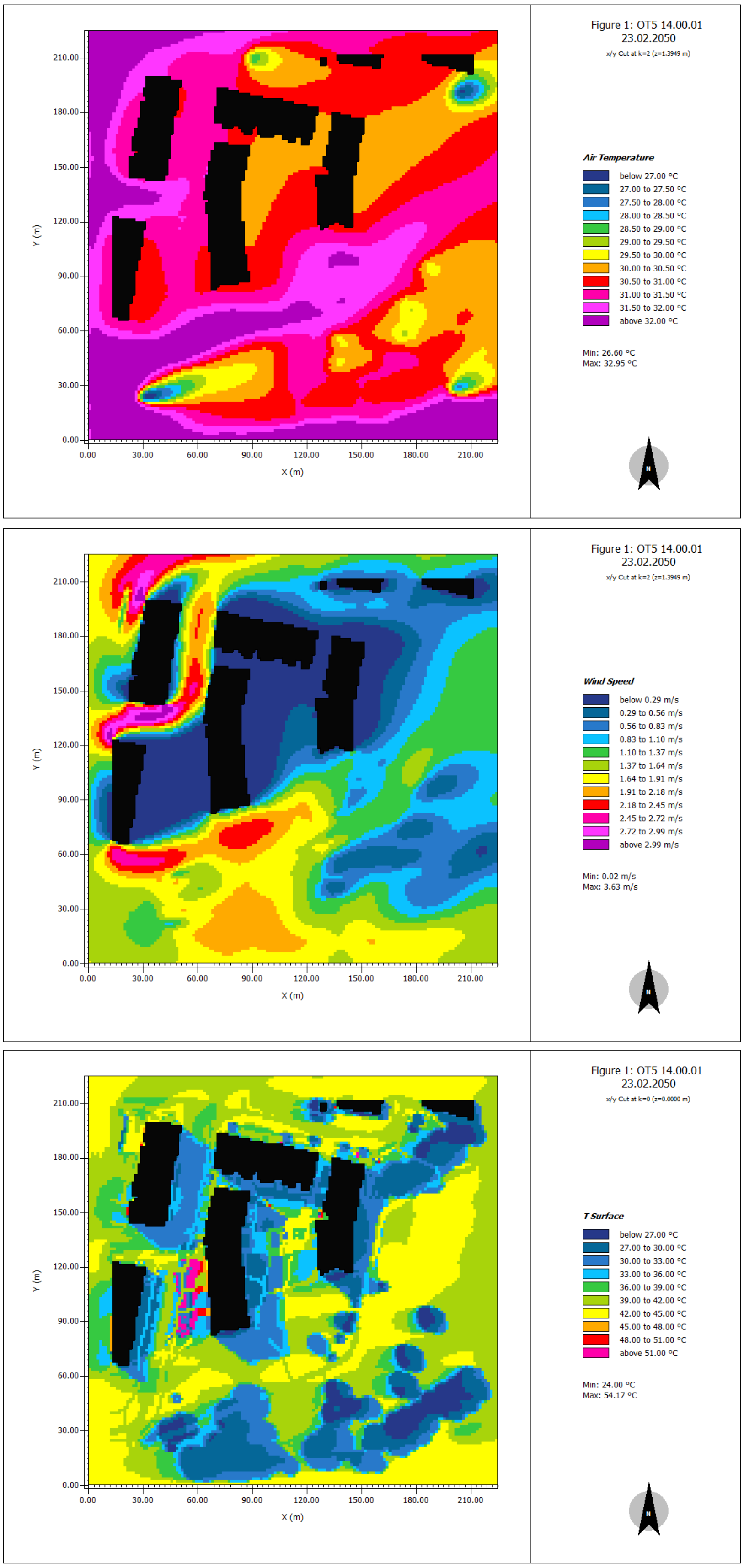


Figure 83 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT5

The ambient temperature ranges from 26.6 °C to 33.0 °C in OT5 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.1°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect; however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 3.6 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.0 °C to 54.2 °C in OT5 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 84. OT5 in general indicates moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 30.3°C to 40.9°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

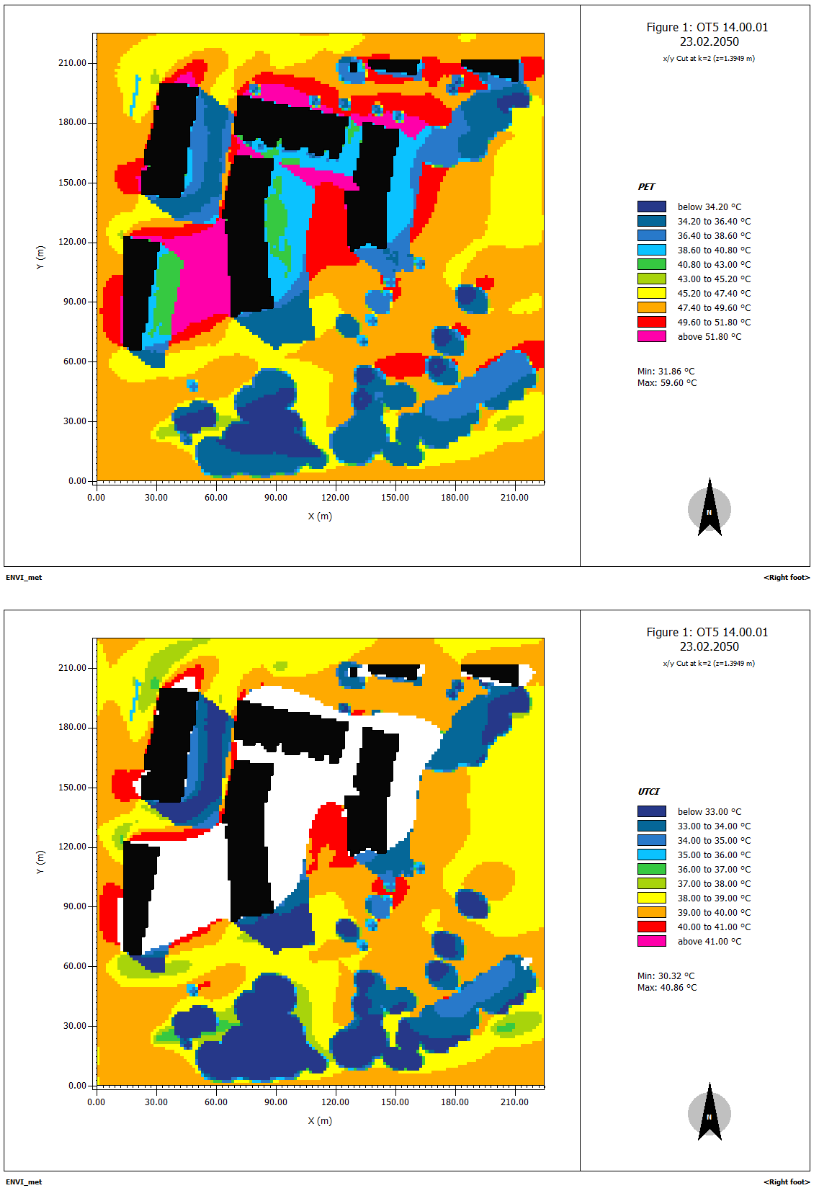


Figure 84 Distribution of thermal comfort in OT5; PET (top), UTCI (bottom)

OT6 mitigated

OT6- Mitigated

Figure 85 shows the distribution of ambient temperature, wind speed and surface temperature in OT6.

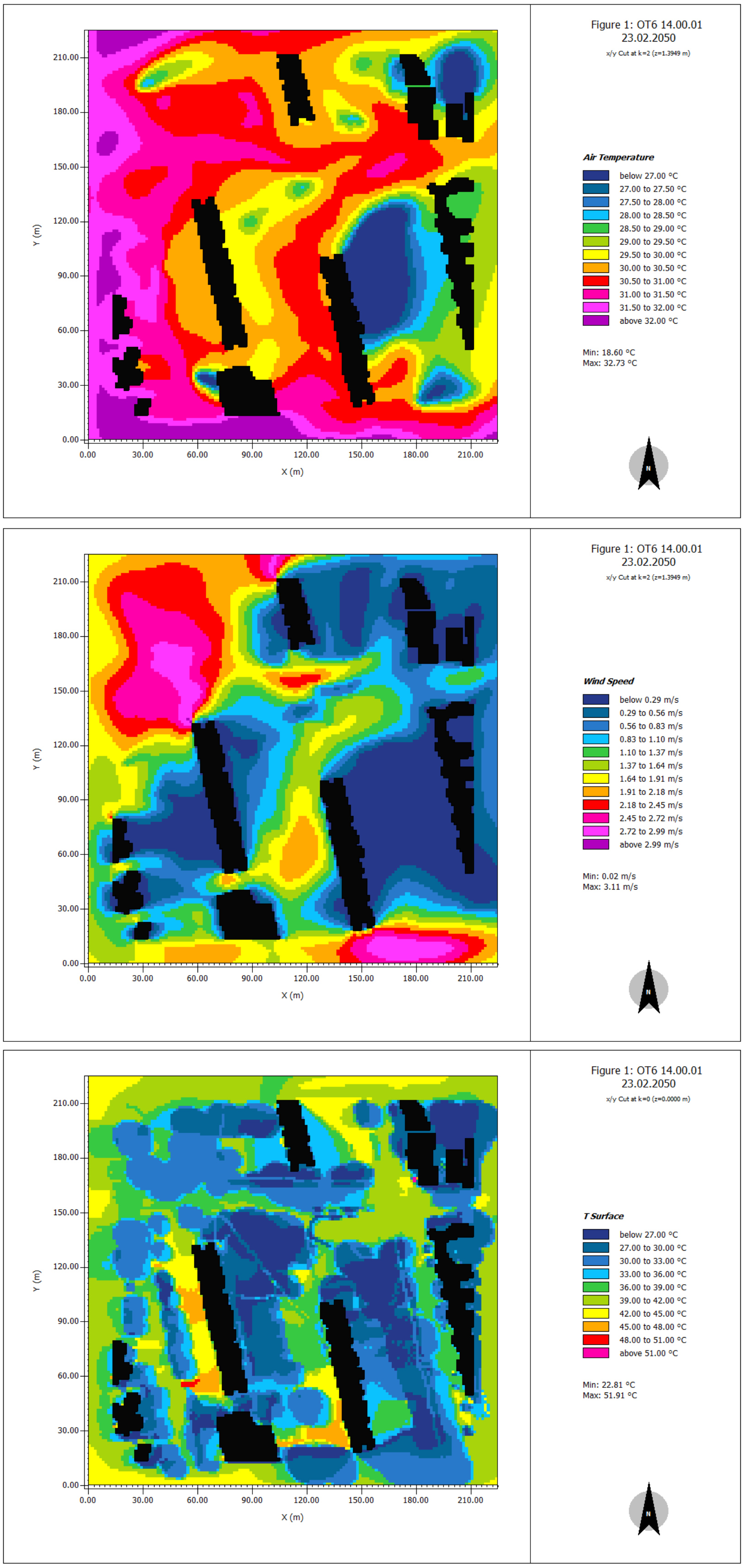


Figure 85 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT6

The ambient temperature ranges from 18.6 °C to 32.7 °C in OT6 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 30.2°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect; however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 3.1 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 22.8 °C to 51.9 °C in OT6 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 86. OT6 in general indicates low to moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 27.7°C to 39.6°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

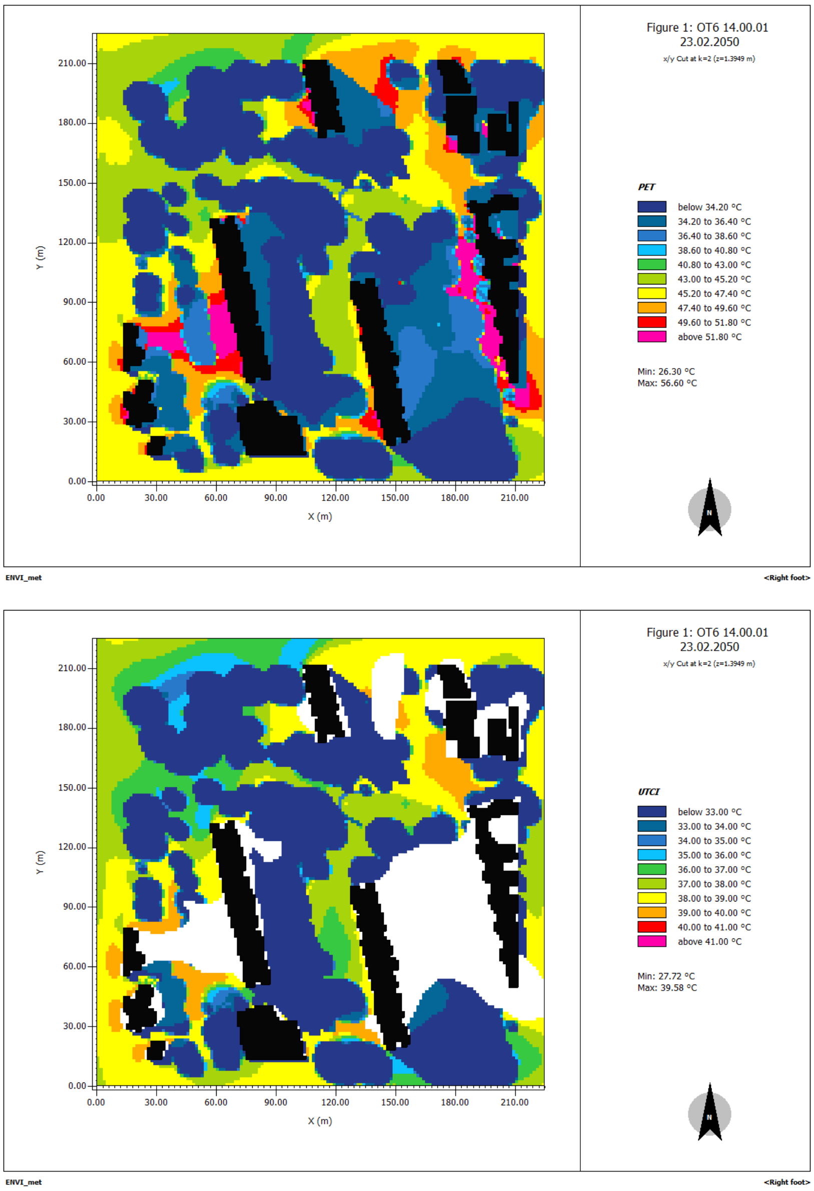


Figure 86 Distribution of thermal comfort in OT6; PET (top), UTCI (bottom)

OT7 mitigated

OT7- Mitigated

Figure 87 shows the distribution of ambient temperature, wind speed and surface temperature in OT7.

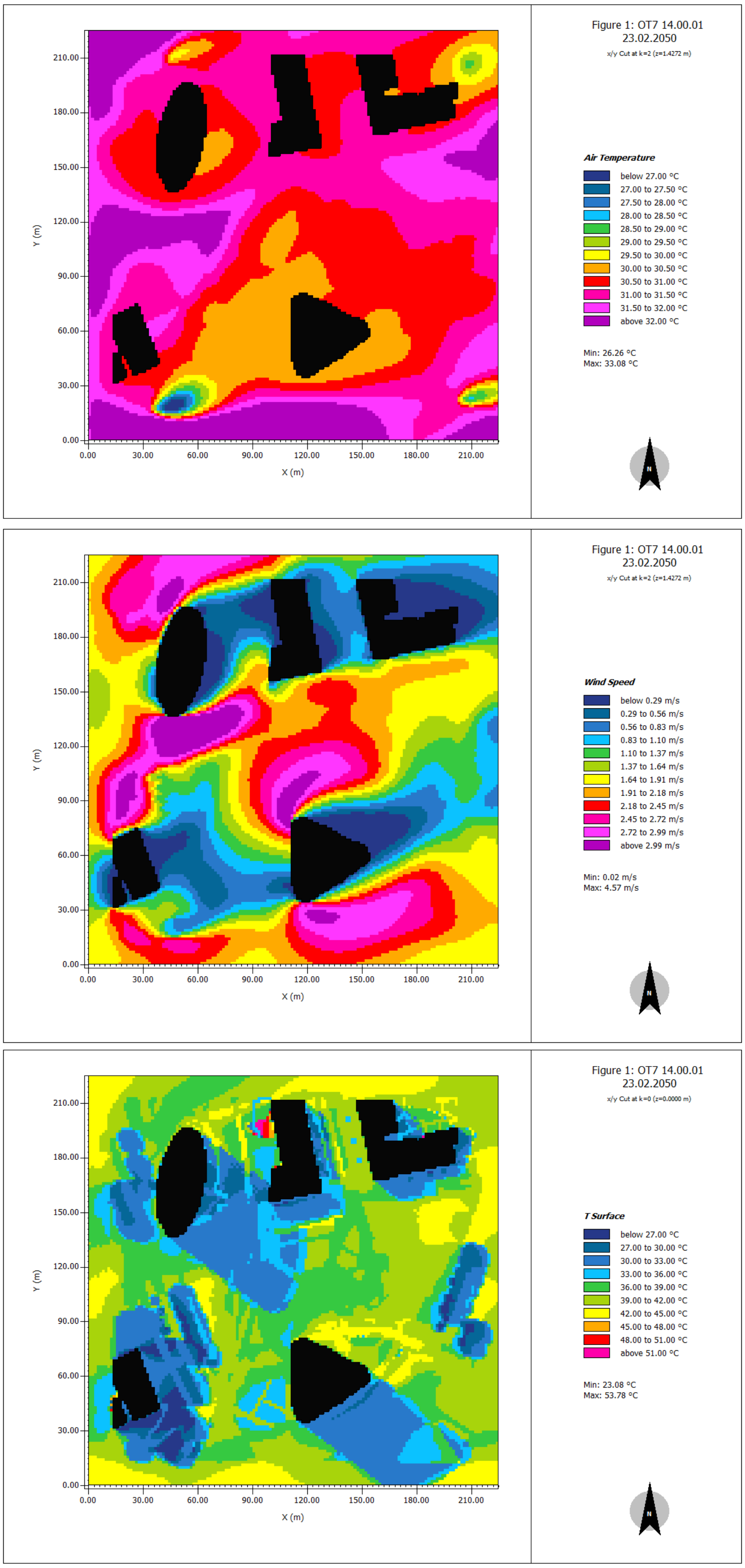


Figure 87 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in OT7

The ambient temperature ranges from 26.3 °C to 33.1 °C in OT7 at the peak time of the simulation day (14:00). The average temperature over the whole precinct is 31.2°C at 14:00. The areas near water sprinklers present lowest ambient temperatures. Misting systems have strong local cooling effect; however, it is affected by the advection. Western part of the precinct is affected by the initial boundary condition and south westerly wind. The wind speed at 14:00 reaches to 4.6 m/s. The areas between the buildings and leeward side present very low wind speed values. The surface temperature distribution map shows that surface temperature varies from 23.1 °C to 53.8 °C in OT7 at 14:00. The areas shaded by buildings and trees present lower surface temperatures.

The distribution of thermal comfort indices (PET, UTCI) is shown in Figure 88. OT7 in general indicates low to moderate heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 28.9°C to 40.8°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating comfortable zones and areas out of comfort range.

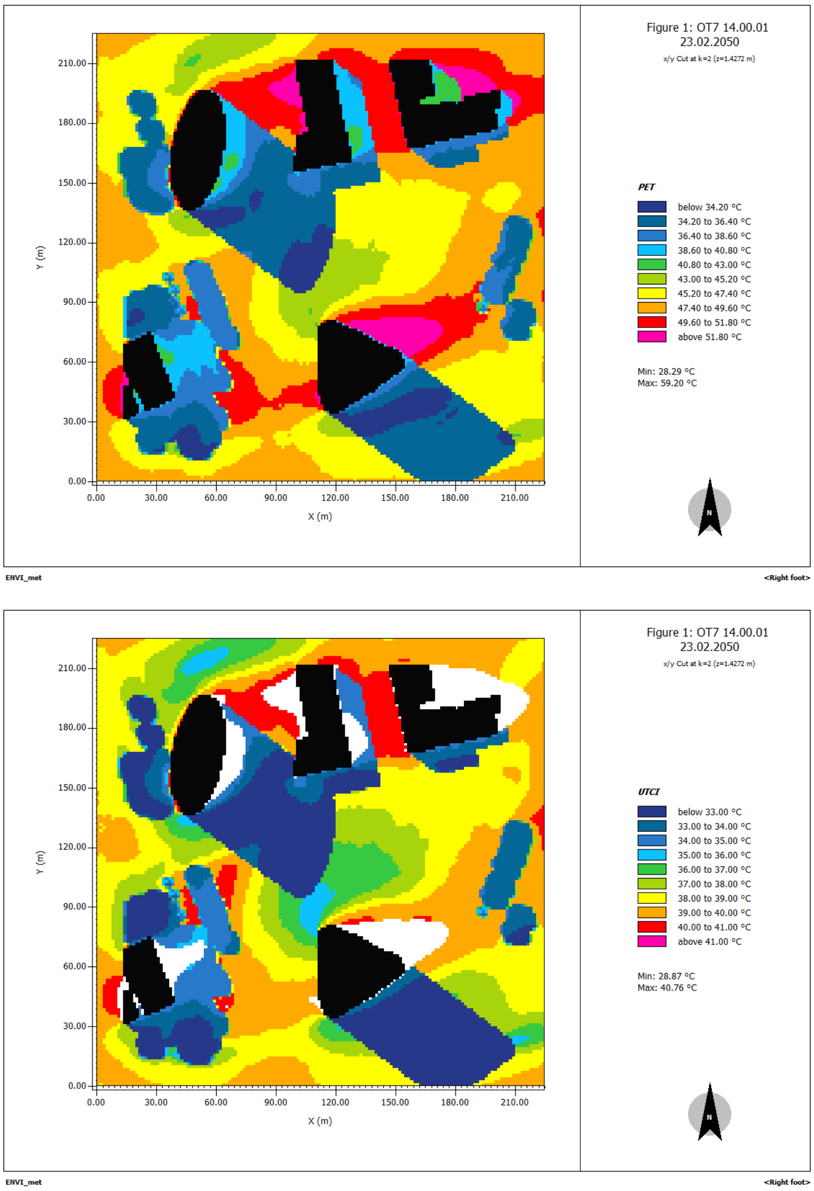


Figure 88 Distribution of thermal comfort in OT7; PET (top), UTCI (bottom)

Statistical summary of the results (24 hr)

The ambien temperature for 24 hours of the simlation day are presented in Table 32 and Table 33 for CT and OT precincts, respectibvely.

Table 32 Statistical summary of the results (average temperature over the whole precinct for 24h) for CT layouts

Temp	CT1	CT2	CT3	CT4	CT5	CT6	CT7
00:00	23.1	22.7	23.0	22.8	23.0	23.0	23.2
1:00	22.6	22.3	22.6	22.4	22.6	22.6	22.9
2:00	22.5	22.2	22.5	22.3	22.4	22.4	22.8
3:00	22.5	22.2	22.5	22.3	22.5	22.4	22.8
4:00	22.4	22.1	22.4	22.2	22.4	22.3	22.7
5:00	21.7	21.4	21.8	21.5	21.7	21.6	22.1
6:00	20.4	20.2	20.6	20.3	20.4	20.3	21.0
7:00	20.1	19.9	20.3	20.0	20.1	20.0	20.6
8:00	22.0	21.8	22.0	21.7	21.9	21.5	22.0
9:00	24.1	23.9	24.0	23.9	23.9	23.3	23.7
10:00	25.9	25.9	25.9	25.9	25.9	25.2	25.5
11:00	27.9	27.9	27.8	28.1	28.0	27.3	27.4
12:00	29.6	29.7	29.6	29.9	29.9	29.0	29.2
13:00	30.8	31.0	30.8	31.2	31.2	30.2	30.4
14:00	31.1	31.2	31.0	31.4	31.5	30.4	30.4
15:00	31.1	31.1	30.9	31.2	31.4	30.3	30.3
16:00	30.5	30.5	30.4	30.5	30.9	29.7	29.9
17:00	29.6	29.5	29.5	29.6	29.9	28.8	29.2
18:00	28.6	28.3	28.5	28.5	28.7	27.9	28.3
19:00	27.5	27.2	27.4	27.3	27.5	26.7	27.3
20:00	25.9	25.6	25.9	25.7	25.9	25.2	26.0
21:00	24.8	24.4	24.8	24.6	24.8	24.1	24.9
22:00	22.7	22.4	22.8	22.5	22.7	22.2	23.1
23:00	21.8	21.4	21.9	21.5	21.7	21.2	22.2

As shown in Table 32,Table 33 and Figure 89, the ambient temperature during peak hours is higher in CT4 and CT5 and lower in CT6 and CT7 compared to other CT layous. The ambient temperature is lower in OT2, while OT4 presents higher ambient temperaures compared to other OT layouts during peak hours of the day.

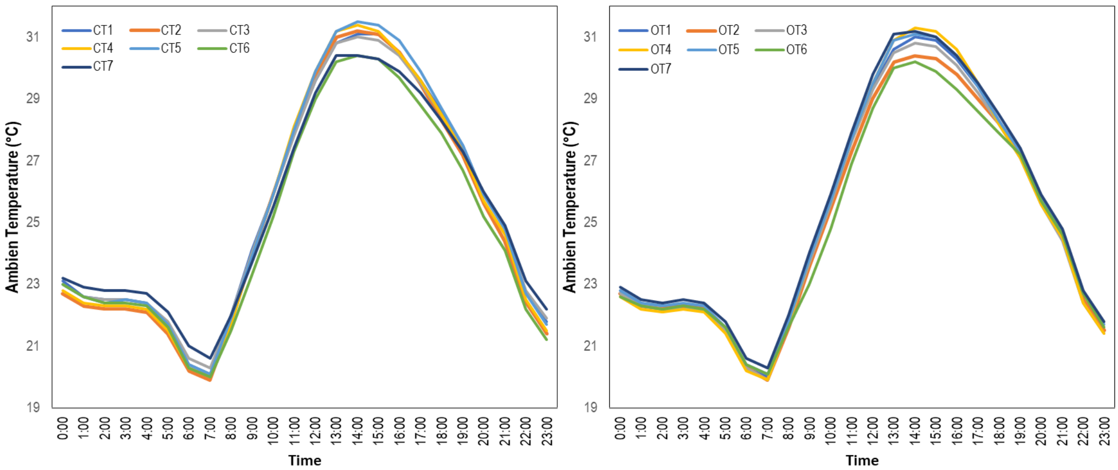


Figure 89 Temperature profile over 24 hours in CT layouts (left) and OT precincts (right)

Table 33 Statistical summary of the results (average temperature over the whole precinct for 24h) for OT layouts

Temp	OT1	OT2	OT3	OT4	OT5	OT6	OT7
00:00	22.8	22.7	22.7	22.6	22.8	22.6	22.9
1:00	22.4	22.3	22.3	22.2	22.4	22.3	22.5
2:00	22.3	22.2	22.2	22.1	22.3	22.2	22.4
3:00	22.3	22.3	22.2	22.2	22.4	22.3	22.5
4:00	22.3	22.2	22.2	22.1	22.3	22.2	22.4
5:00	21.5	21.5	21.5	21.4	21.6	21.6	21.8
6:00	20.3	20.3	20.3	20.2	20.4	20.4	20.6
7:00	20.0	19.9	19.9	19.9	20.1	20.1	20.3
8:00	21.8	21.6	21.7	21.7	21.8	21.6	22.0
9:00	23.9	23.6	23.7	23.8	23.8	23.0	24.0
10:00	25.8	25.4	25.6	25.7	25.7	24.8	25.9
11:00	27.7	27.3	27.6	27.7	27.7	26.9	27.9
12:00	29.4	29.0	29.3	29.5	29.5	28.7	29.8
13:00	30.6	30.2	30.5	30.9	30.9	30.0	31.1
14:00	31.0	30.4	30.8	31.3	31.1	30.2	31.2
15:00	30.9	30.3	30.7	31.2	31.0	29.9	31.0
16:00	30.3	29.8	30.1	30.6	30.4	29.3	30.4
17:00	29.4	29.0	29.2	29.5	29.4	28.6	29.5
18:00	28.3	28.2	28.2	28.2	28.3	27.9	28.5
19:00	27.2	27.2	27.1	27.1	27.3	27.2	27.4
20:00	25.7	25.7	25.6	25.6	25.8	25.7	25.9
21:00	24.6	24.6	24.4	24.5	24.7	24.6	24.8
22:00	22.5	22.5	22.4	22.4	22.7	22.7	22.8
23:00	21.5	21.5	21.4	21.4	21.7	21.6	21.8

Statistical summary of the results at 2pm

Table 34 shows the statistical summary of the ambient temperature at 14:00. The maximum ambient temperature is obtained in CT1 followed by CT4 and CT5. The minimum ambient temperature is 27.5 °C and is observed in CT6. The lowest 25th percentile of temperature data is 29.7°C and is occurred in CT6 and OT6, whereas the 95th percentile of data is 33.0 °C and is obtained in CT4. The average ambient temperature in CT layouts are higher than that in OT layouts.

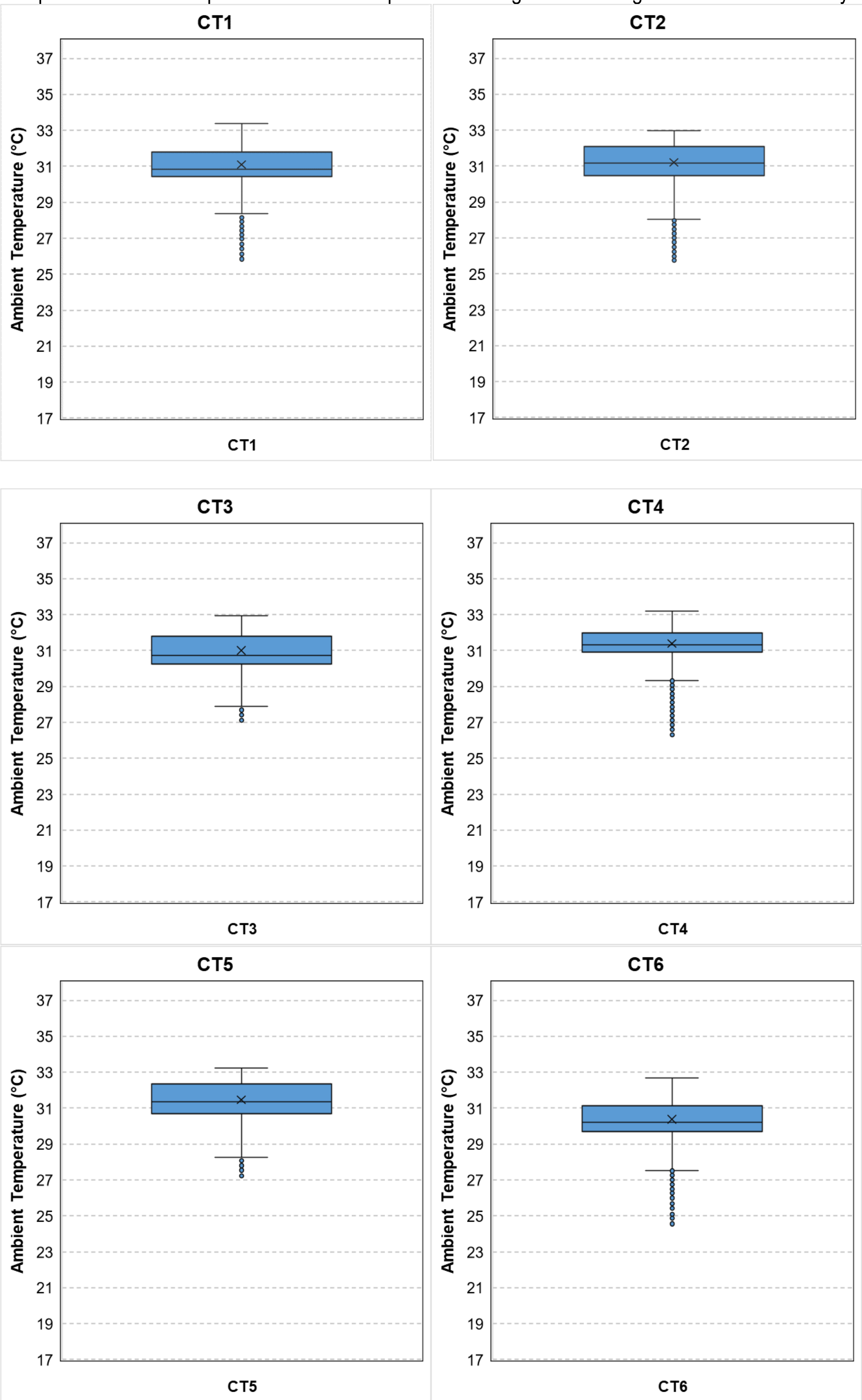
Table 34 Statistical summary of the results at 2pm

Layout	T_{Max}[1]	T_{Min}[1]	Mean	Median	Std.	T_{Max}[2]	T_{Min}[2]	Percentiles 25	50	75	90	95
OT1	33.0	27.9	31.0	30.6	0.9	33.0	26.3	30.3	30.6	31.8	32.4	32.5
OT2	32.2	28.5	30.4	30.3	0.8	32.5	25.1	29.9	30.3	30.8	31.4	31.8
OT3	32.7	27.7	30.8	30.8	1.0	32.7	24.8	30.0	30.8	31.5	32.1	32.4
OT4	32.7	29.8	31.3	31.3	0.9	32.9	22.1	30.9	31.3	31.6	32.4	32.6
OT5	32.9	28.8	31.1	31.0	0.8	32.9	26.6	30.5	31.0	31.7	32.3	32.6
OT6	32.7	27.7	30.2	30.5	1.7	32.7	18.6	29.7	30.5	31.1	31.8	32.0
OT7	33.0	29.2	31.2	31.1	0.8	33.1	26.3	30.7	31.1	31.6	32.2	32.5
CT1	33.4	28.4	31.1	30.8	1.0	33.4	25.8	30.4	30.8	31.8	32.7	32.8
CT2	33.0	28.0	31.2	31.2	1.0	33.0	25.7	30.5	31.2	32.1	32.5	32.6
CT3	32.9	27.9	31.0	30.7	0.9	32.9	27.1	30.2	30.7	31.8	32.4	32.7
CT4	33.2	29.3	31.4	31.3	0.8	33.2	26.3	30.9	31.3	32.0	32.5	32.7
CT5	33.2	28.3	31.5	31.3	1.0	33.2	27.2	30.7	31.3	32.3	32.8	33.0
CT6	32.7	27.5	30.4	30.2	1.0	32.7	24.5	29.7	30.2	31.1	31.8	32.0
CT7	32.4	28.2	30.4	30.2	0.8	32.4	27.1	29.8	30.2	31.0	31.6	31.9

[1]: The minimum and maximum excluding outliers as shown in the box plots below. [2]: The absolute minimum and maximum of temperature data.

Box plots of ambient temperature at 2pm

Box plots of ambient temperature at 14:00 are presented in Figure 90 and Figure 91 for CT and OT layouts.



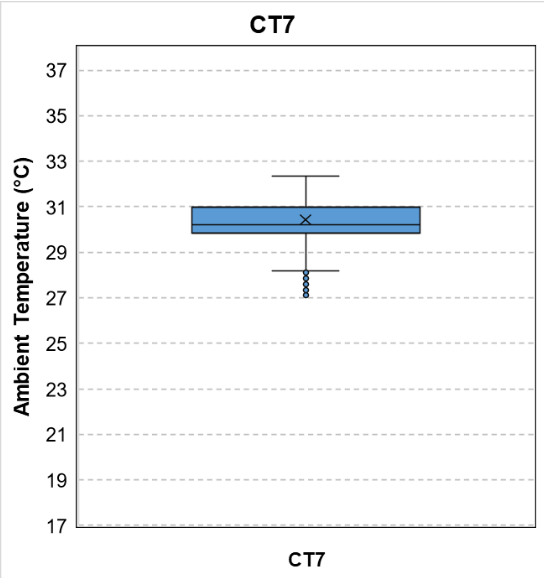
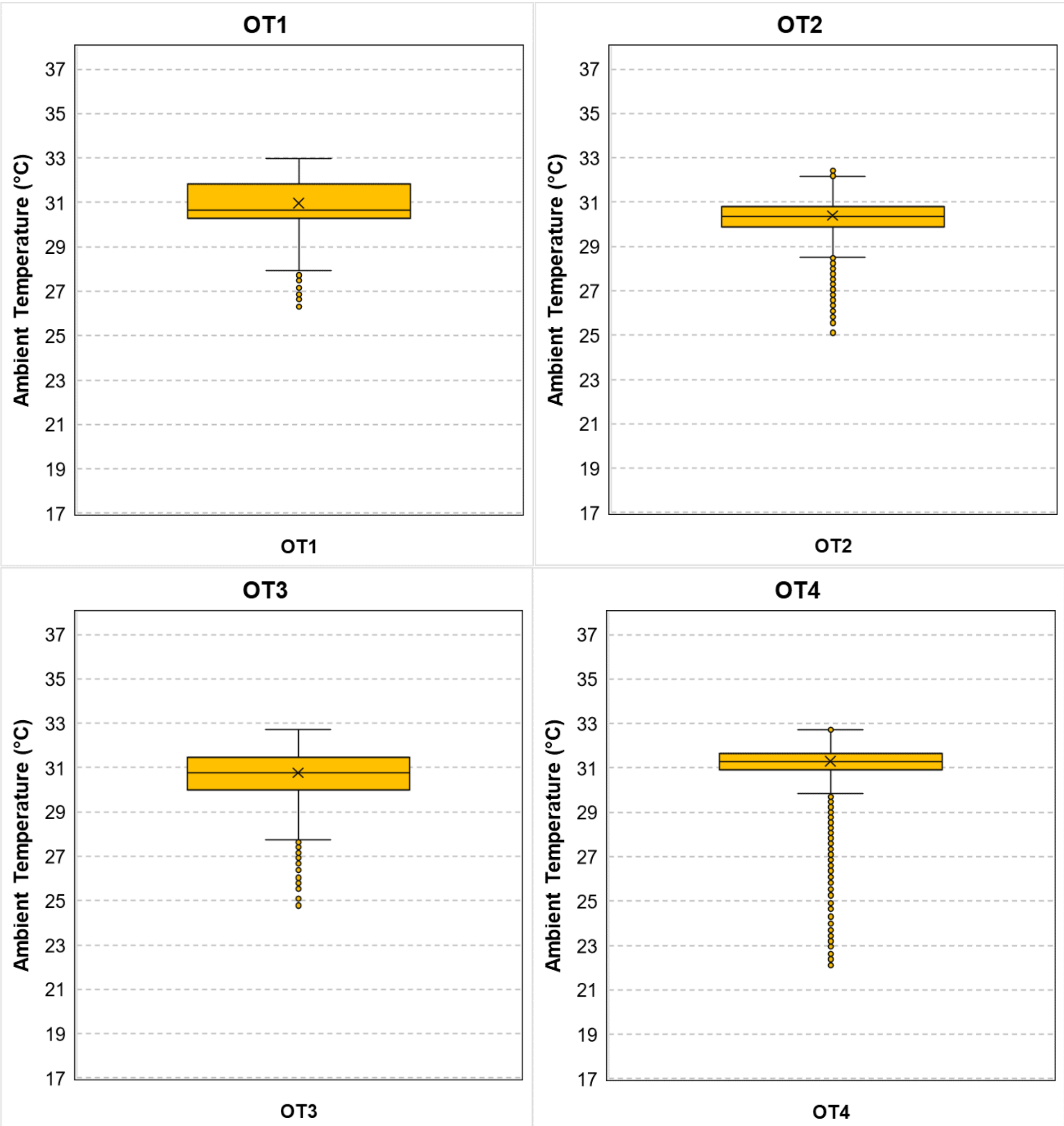


Figure 90 Box plots of ambient temperature in the mitigated scenarios – CT layouts



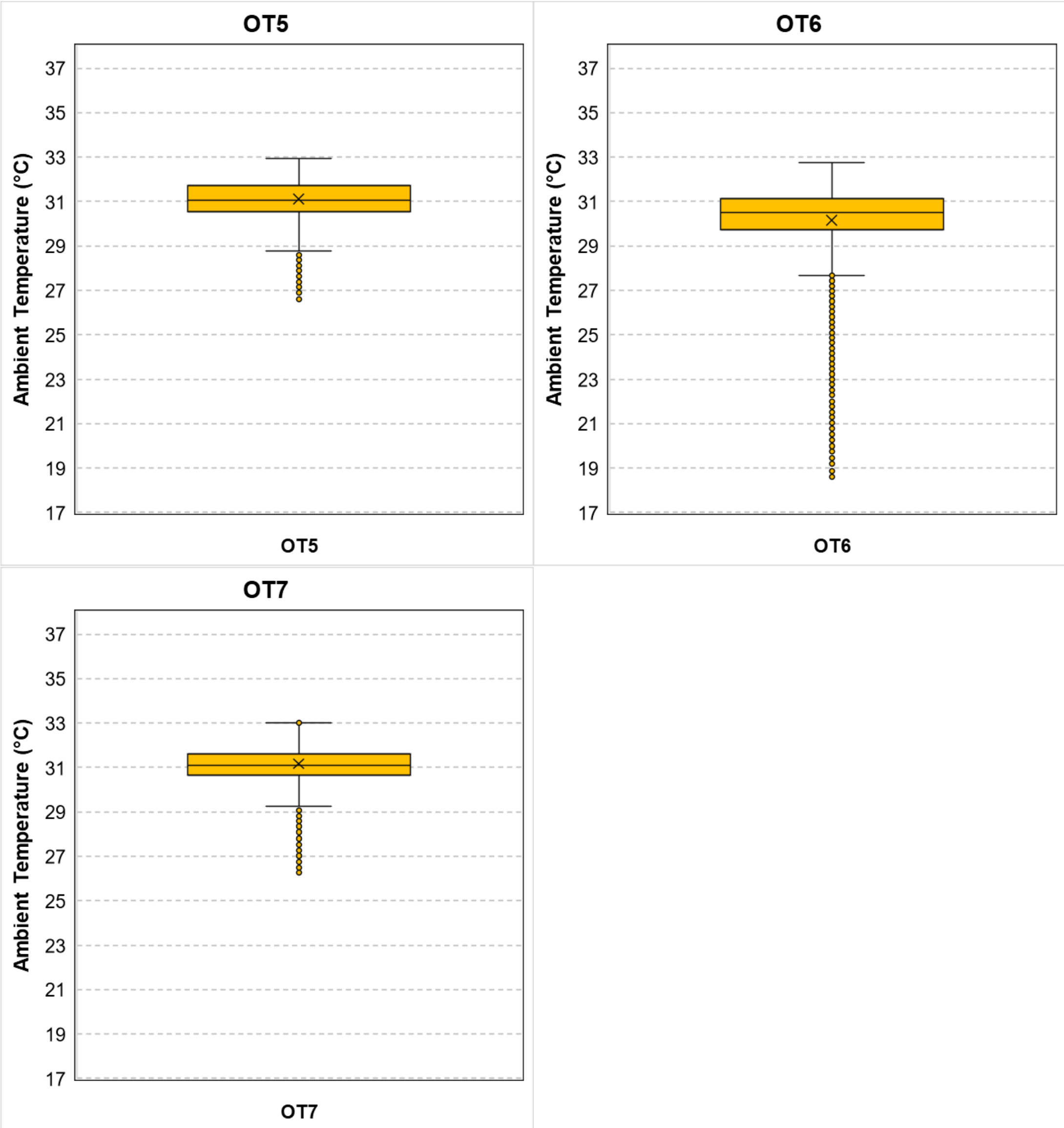


Figure 91 Box plots of ambient temperature in the mitigated scenarios – OT layouts

Effects of 'Wind Direction' in the mitigated scenarios

Changing Wind Direction in the mitigated scenarios

The initial wind direction (250°) has been changed to 340° and 70° to evaluate the effects of boundry condition and wind direction on the temperature and wind speed distribution of the precincts. The initial setting for the wind direction in the simulations described above was 250°. Two layouts with highest ambient temperature have been selected for analysis. The following section presents the results of simulations (CT4 and CT5) for three wind directions of 70, 250, and 340 degrees from north corresponding to north-east, south-west and northwest, respectively. Wind direction vectors are presented on the maps which indicate the wind direction in the precinct. The lenghth of the vector presents the wind speed magnitude. As shown in Figure 92 and Figure 94, changing the wind direction affects the pattern and distribution of the ambient tempetrure in CT4 and CT5 precincts. Figure 93 and Figure 95 present the wind speed distribution in these precincts.

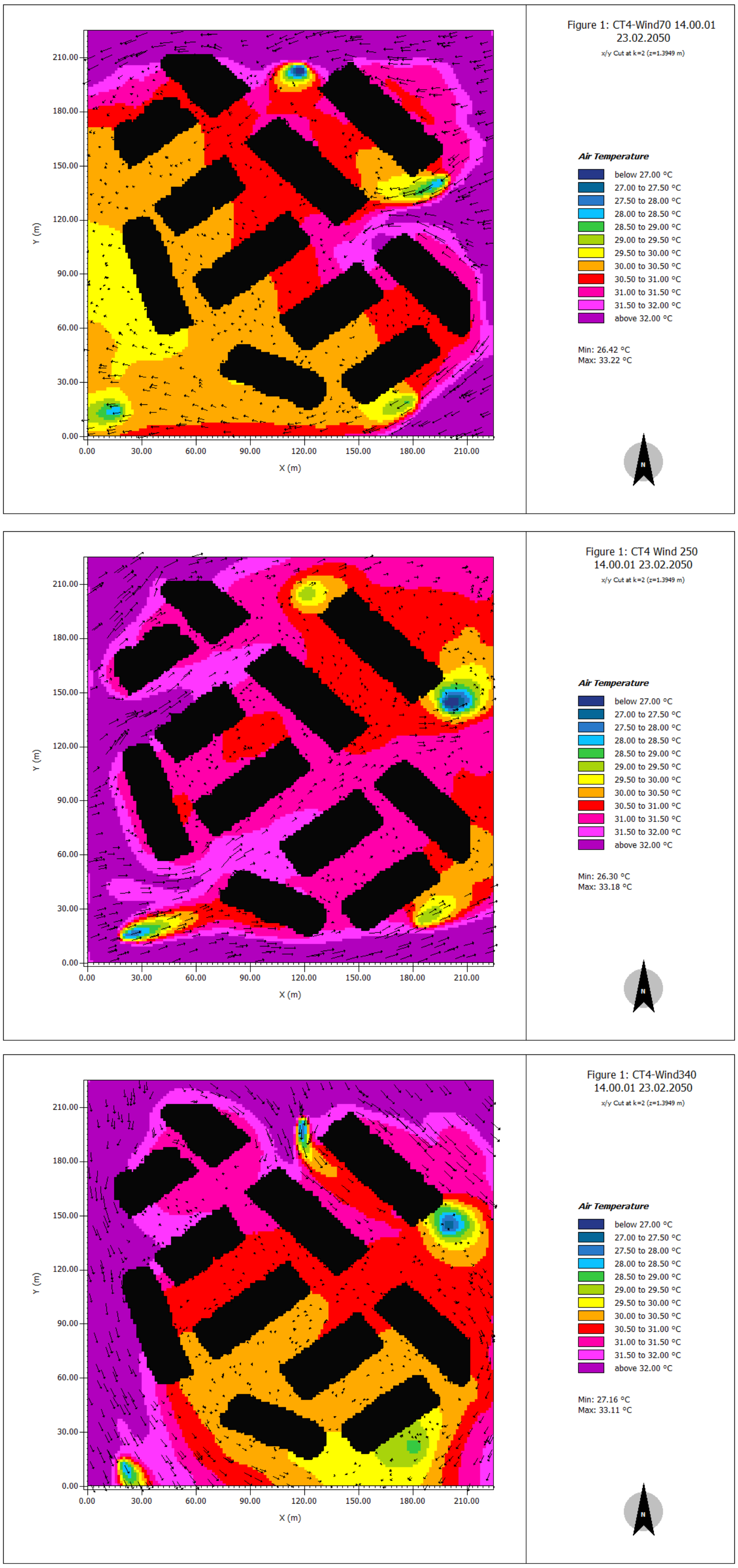


Figure 92 Temperature distribution in CT4 for the wind direction of 70 (top), 250 (middle) and 340 (bottom).

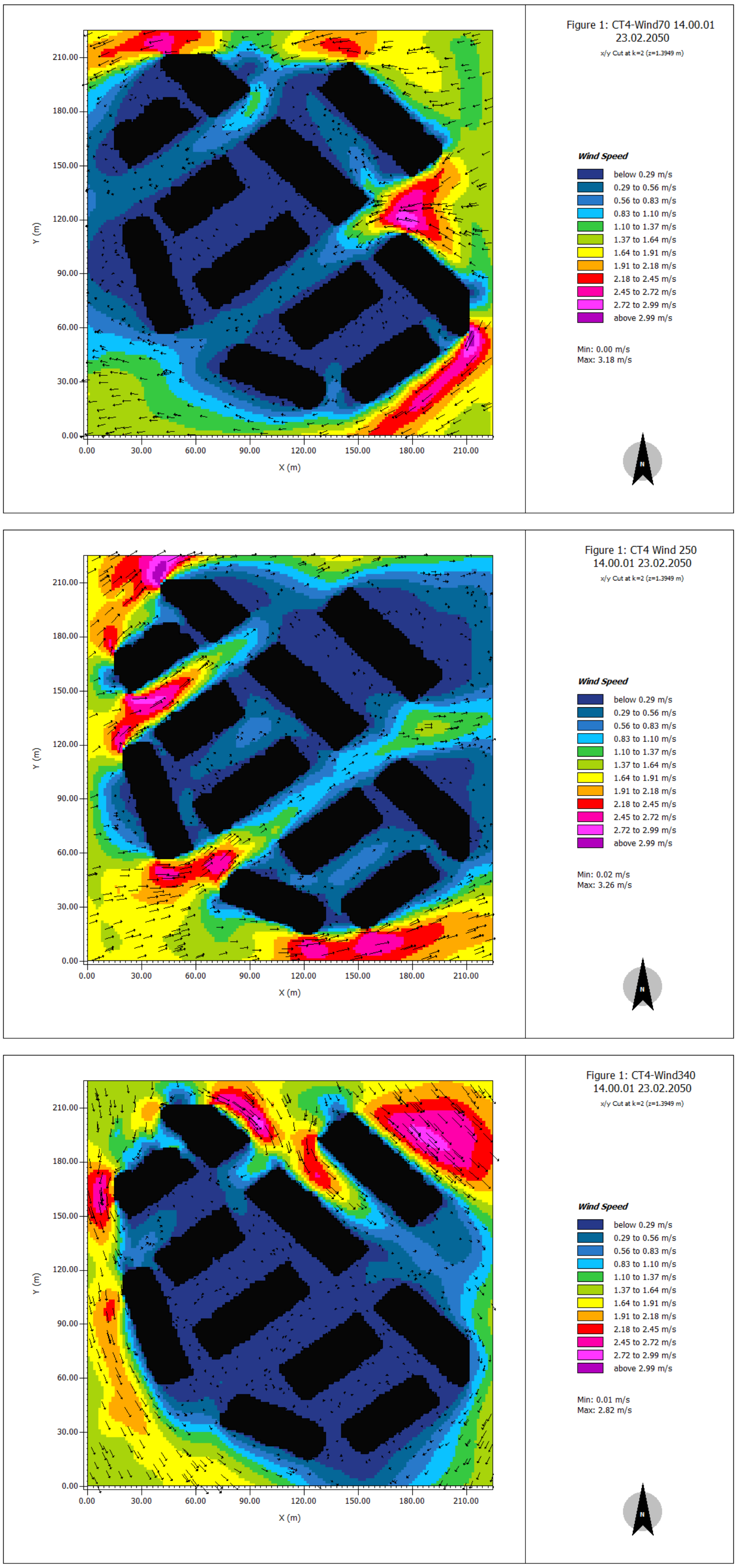
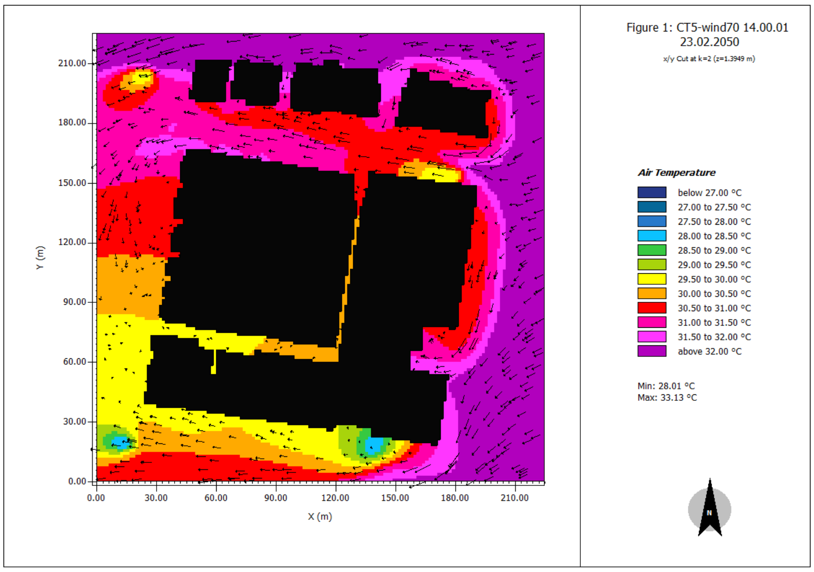
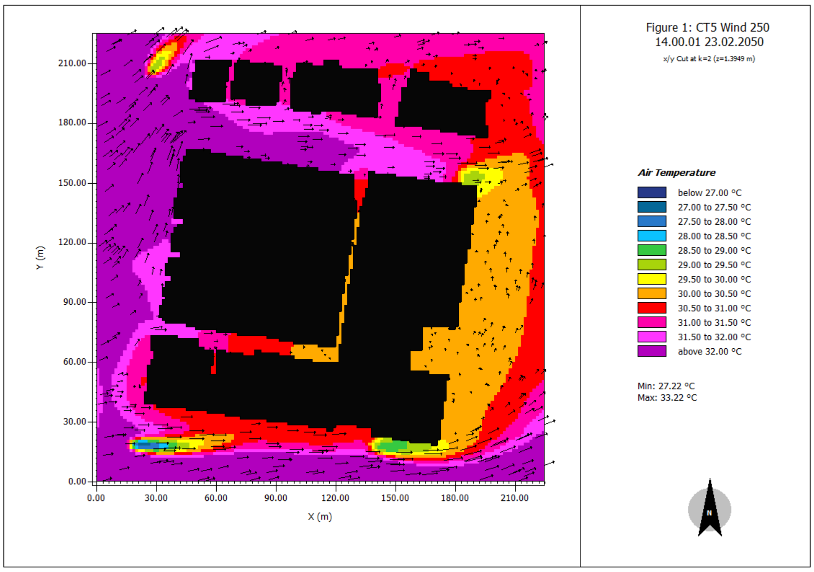


Figure 93 Wind speed distribution in CT4 for the wind direction of 70 (top), 250 (middle) and 340 (bottom).





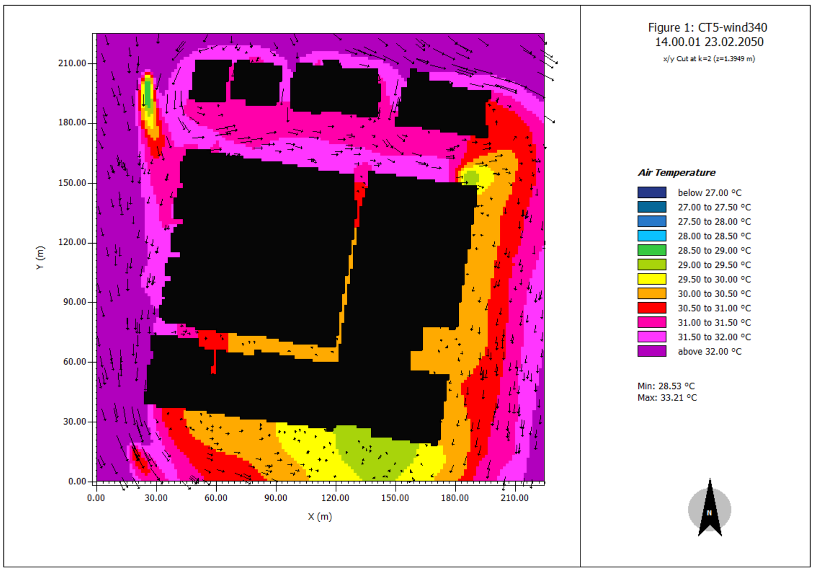


Figure 94 Temperature distribution in CT5 for the wind direction of 70 (top), 250 (middle) and 340 (bottom).

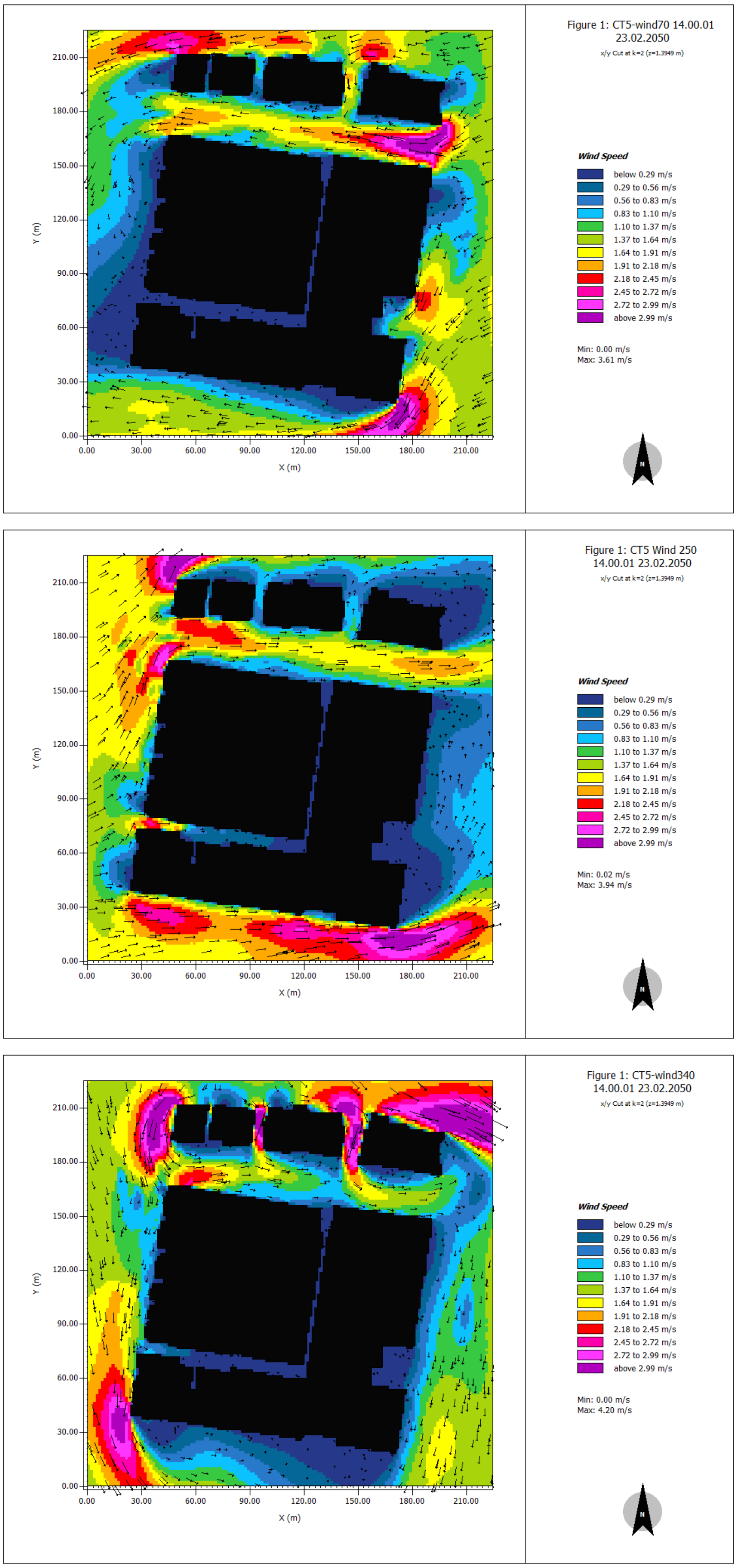


Figure 95 Wind speed distribution in CT5 for the wind direction of 70 (top), 250 (middle) and 340 (bottom).

Results of Unmitigated scenarios (unmitigated climate 2050 and unmitigated precinct)

CT1 unmitigated

CT1-unmitigated

Figure 96 shows the ambient temperauture and wind speed distribution in the unmitigated CT2.

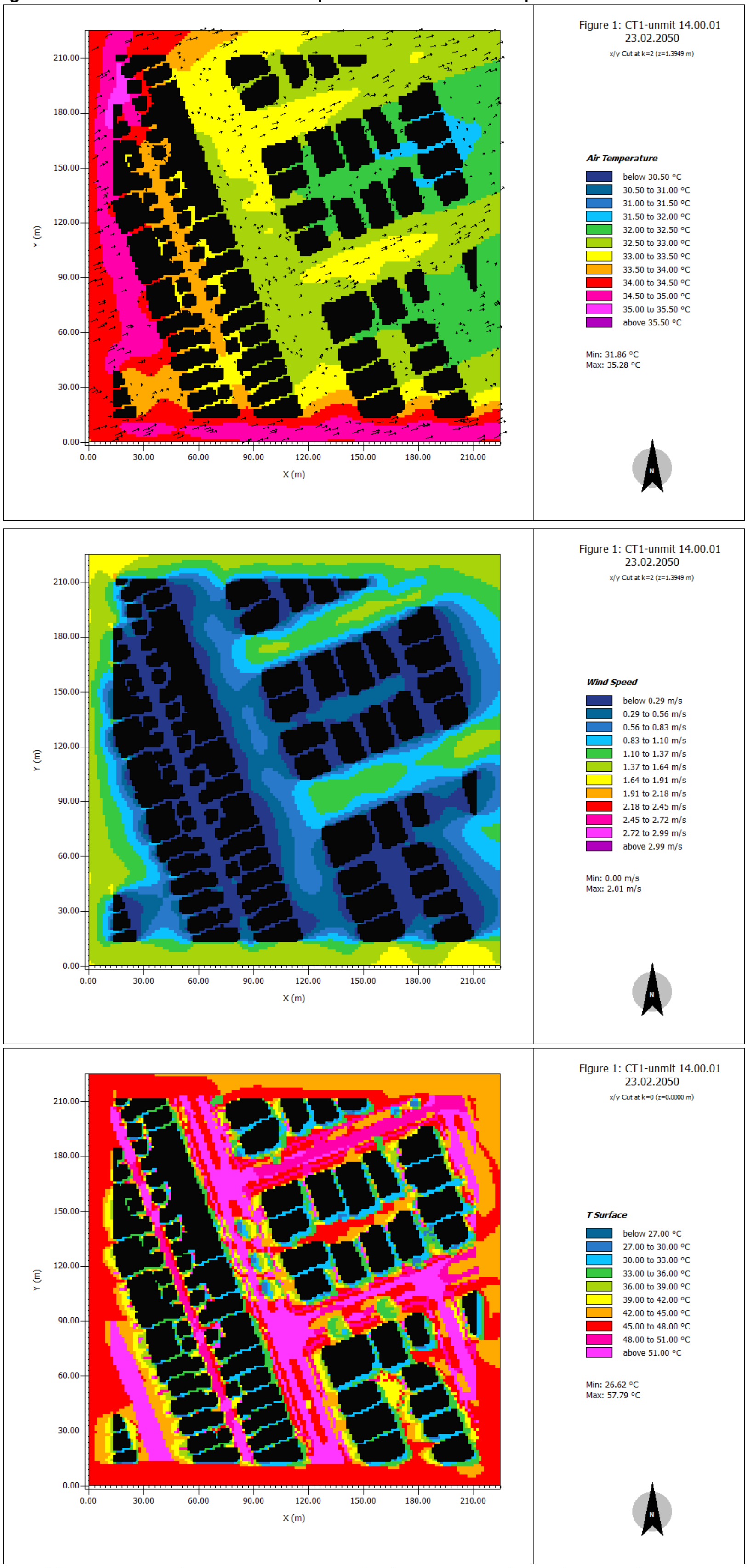
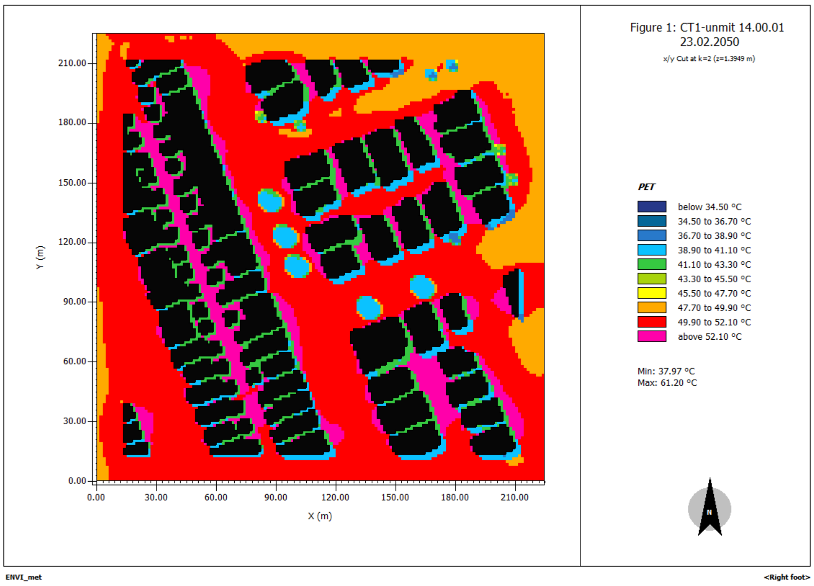


Figure 96 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in unmitigated CT1

Simulations have been performed using unmitigated climate 2050. Furthermore, the model setting in SPACES has been modified to the base case without any mitigation. The urban canopy properties (roof and roads albedo) and parameters (trees, water sprinklers) are modified for the simulations based on the model base run for 2050 (i.e., Road Albedo=0.08, Roof Albedo=0.15, limited number of trees and no water sprinklers in the precinct). These settings are consistent for all unmitigated simulations based on the model base run for 2050.

As shown here, the ambient temperature ranges between 31.9 °C to 35.3 °C in the unmitigated CT1. The maximum wind speed reaches to 2.0 m/s. The surface temperature distribution map shows that surface temperature varies from 26.6 °C to 57.8 °C in the unmitigated CT1 at 14:00. Figure 97 shows the distribution of thermal comfort indices (PET and UTCI). CT1 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 35.0°C to 43.6°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.



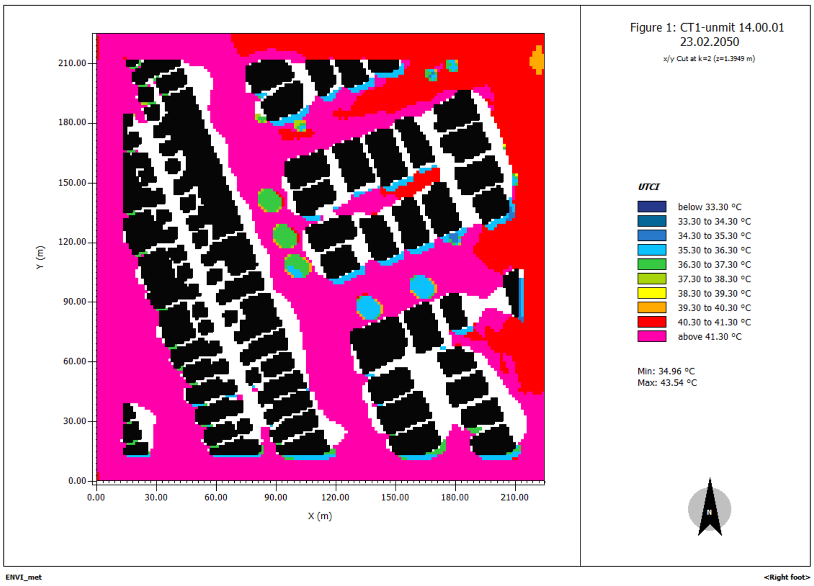


Figure 97 Distribution of thermal comfort in unmitigated CT1; PET (top), UTCI (bottom)

CT2- unmitigated

Figure 98 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT2.

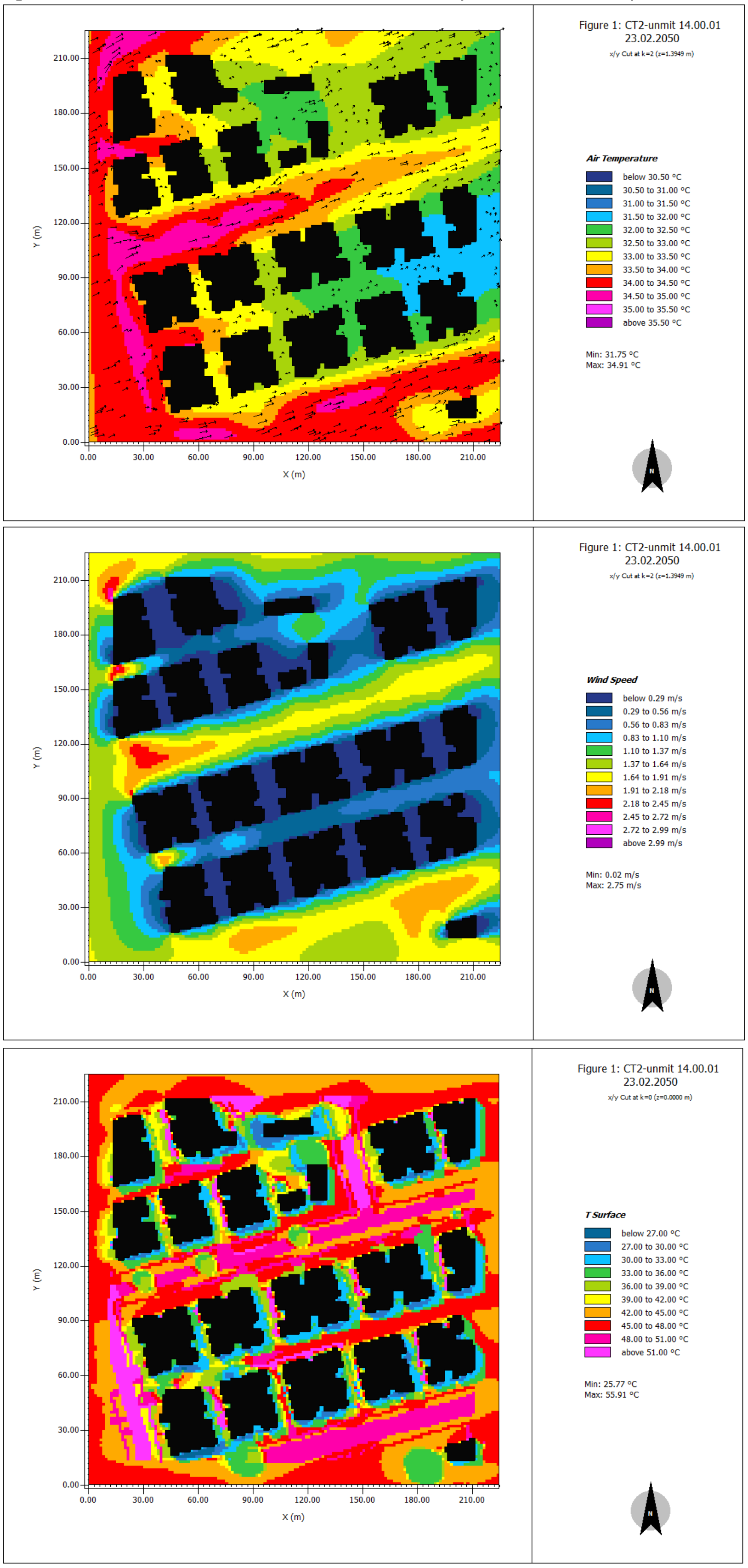


Figure 98 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in unmitigated CT2

The ambient temperature ranges between 31.8 °C to 34.9 °C in the unmitigated CT2. The maximum wind speed reaches to 2.8 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.8 °C to 55.9 °C in the unmitigated CT2 at 14:00.

Figure 99 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT2 indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.6°C to 43.2°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

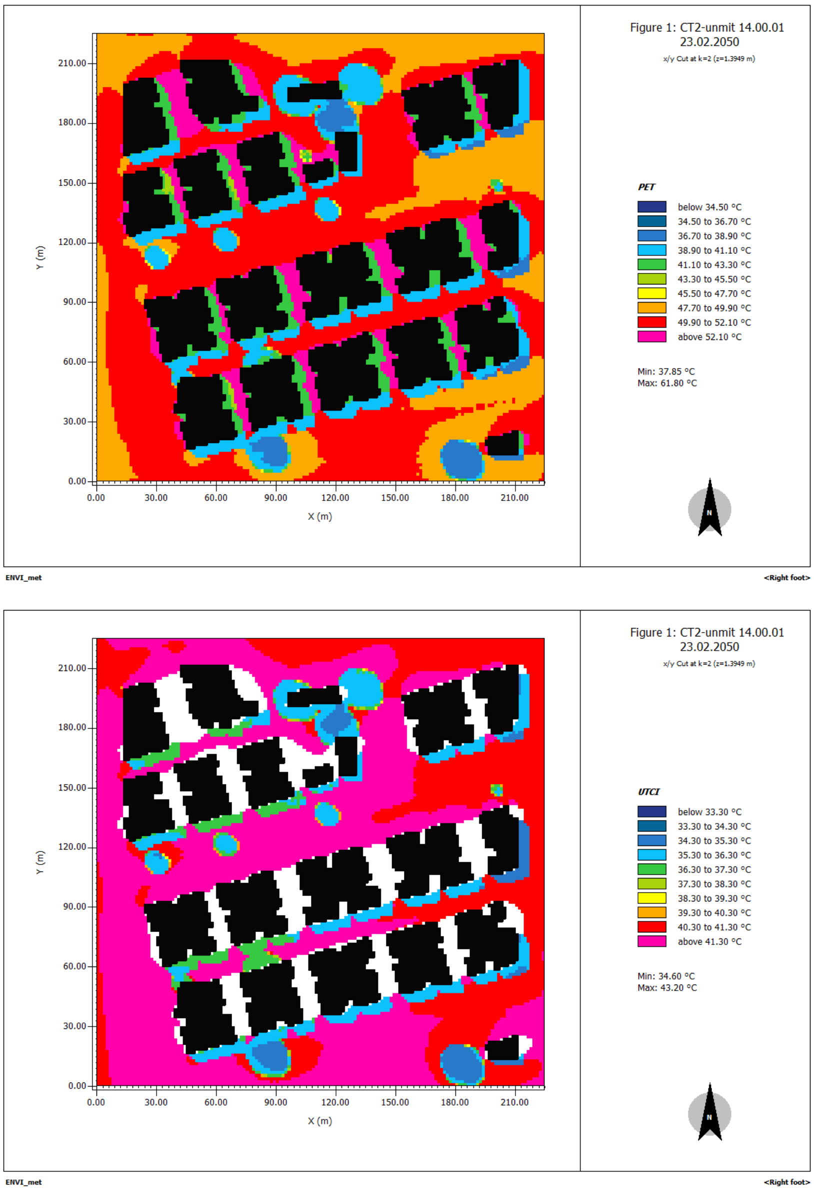


Figure 99 Distribution of thermal comfort in unmitigated CT2; PET (top), UTCI (bottom)

CT3 unmitigated

CT3- unmitigated

Figure 100 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT3.

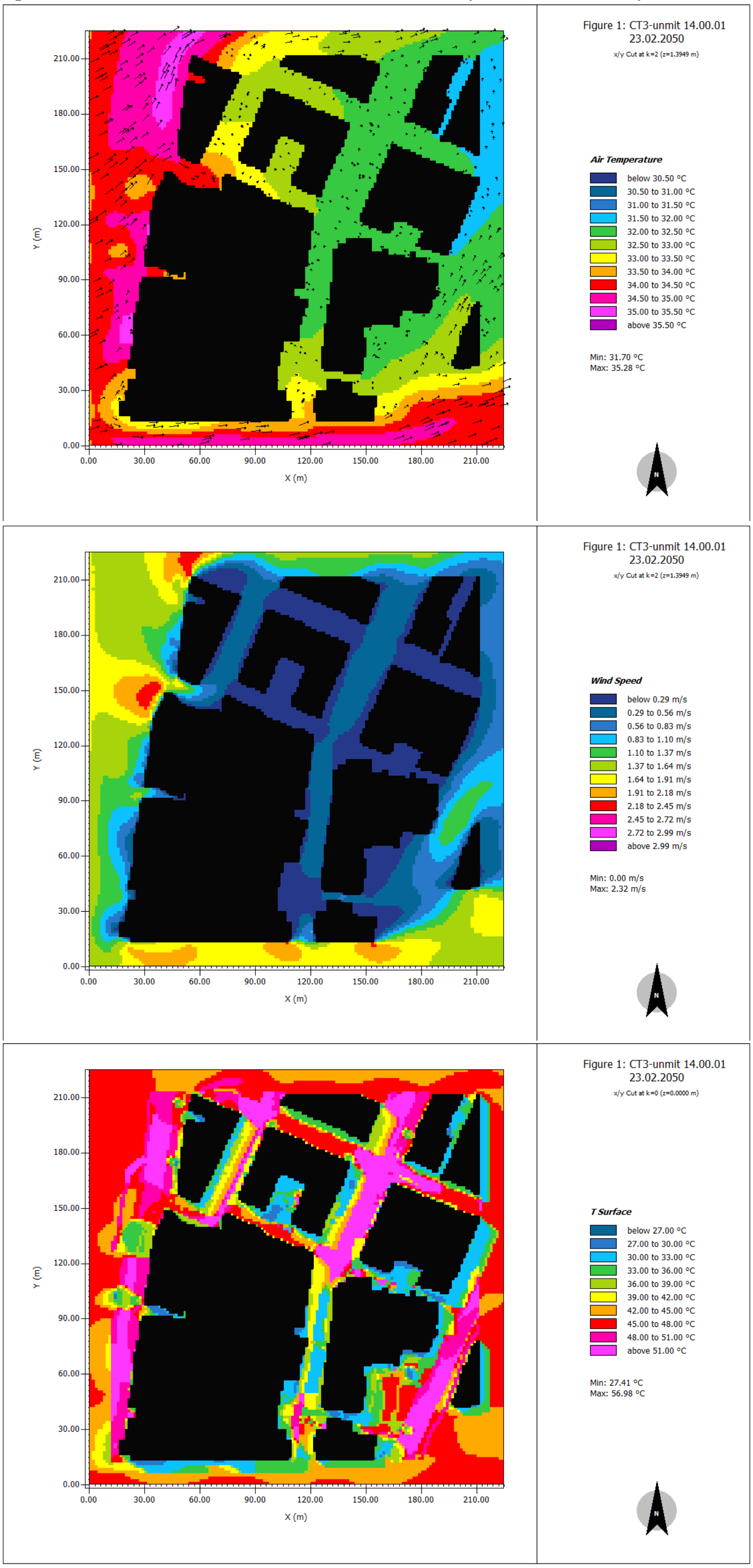
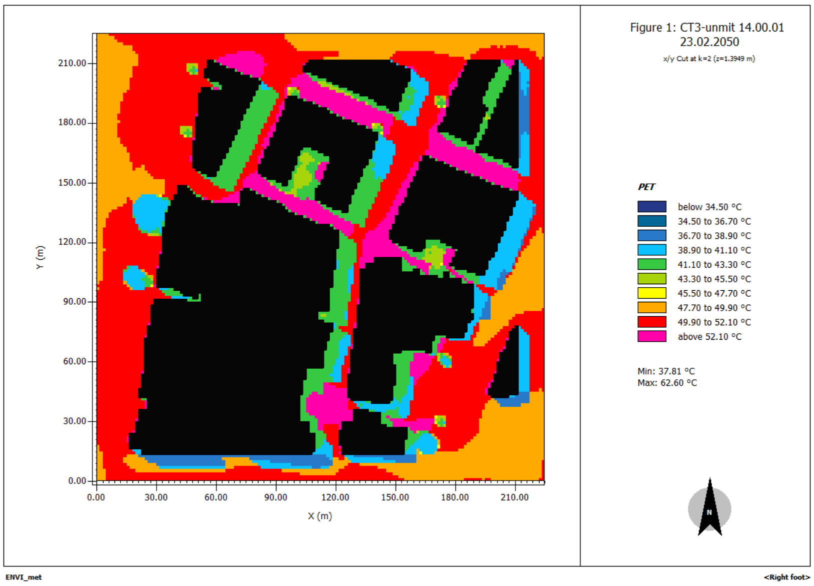


Figure 100 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated CT3

As depicted here, the ambient temperature ranges between 31.7 °C to 35.3 °C. The surface temperature distribution map shows that surface temperature varies from 27.4 °C to 57.0 °C in CT3 at 14:00. The maximum wind speed reaches to 2.3 m/s while the areas between the buildings present lower wind speed values.

Figure 101 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT3 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.5°C to 43.7°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.



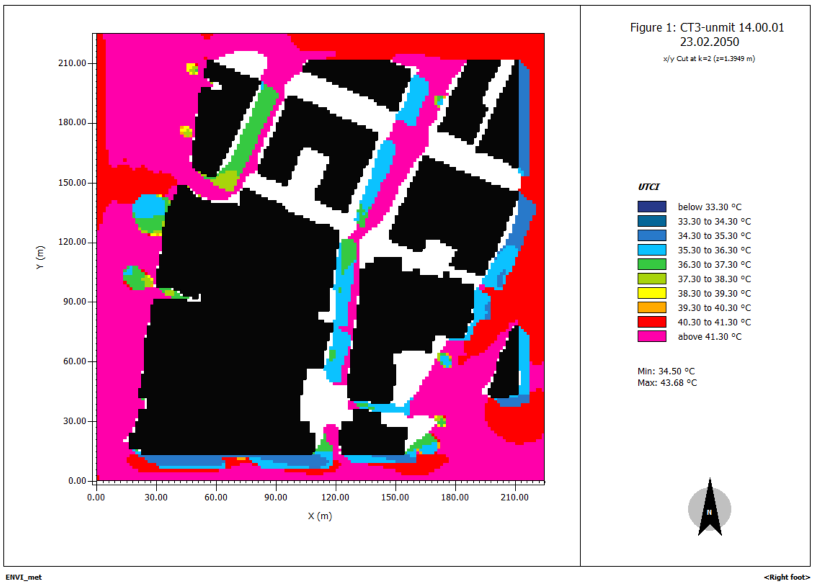


Figure 101 Distribution of thermal comfort in unmitigated CT3; PET (top), UTCI (bottom)

CT4 unmitigated

CT4-unmitigated

Figure 102 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT4.

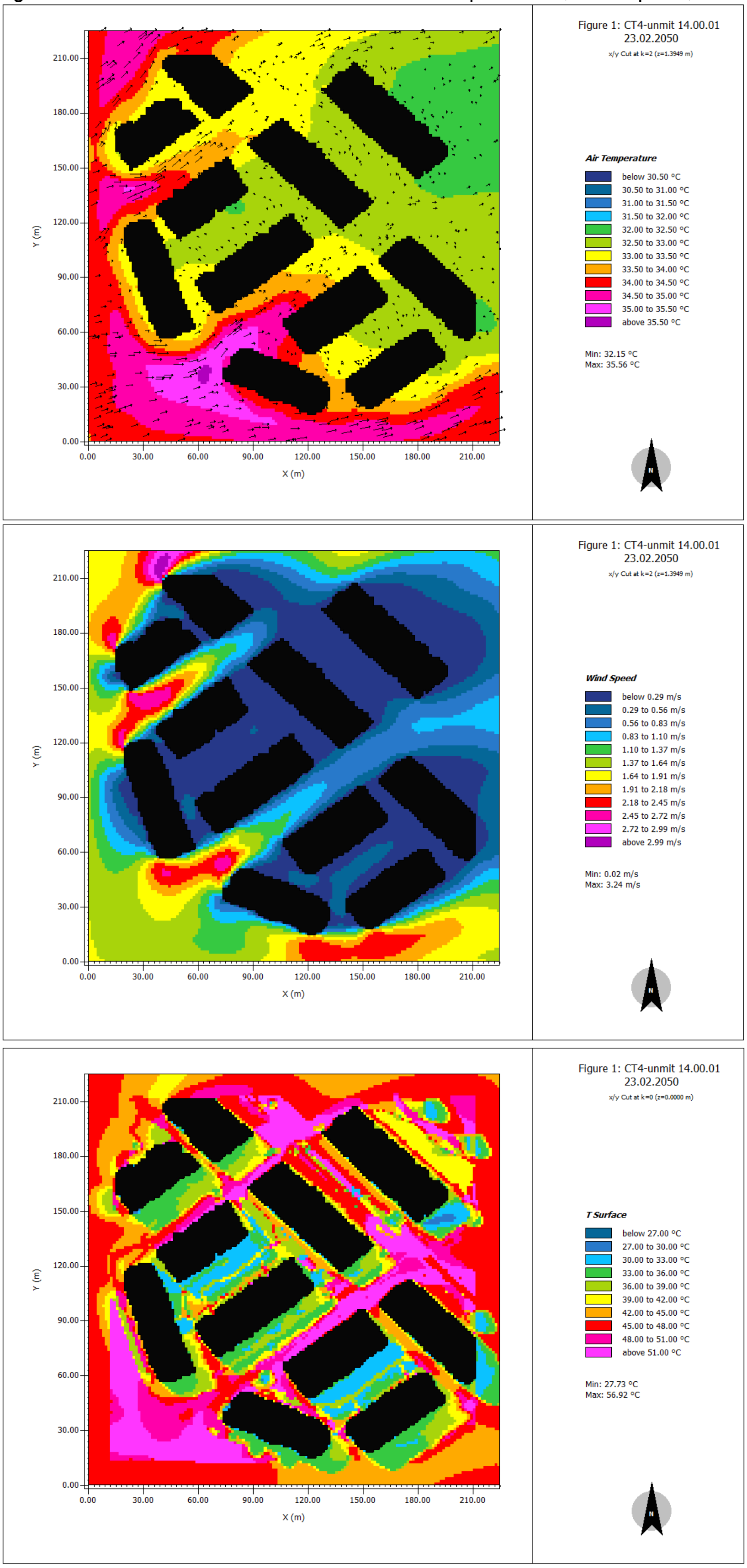


Figure 102 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated CT4

As shown here, the ambient temperature ranges between 32.2 °C to 35.6 °C. The maximum wind speed reaches to 3.2 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 27.7 °C to 57.0 °C in the unmitigated CT4 at 14:00.

Figure 103 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT4 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.5°C to 43.8°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

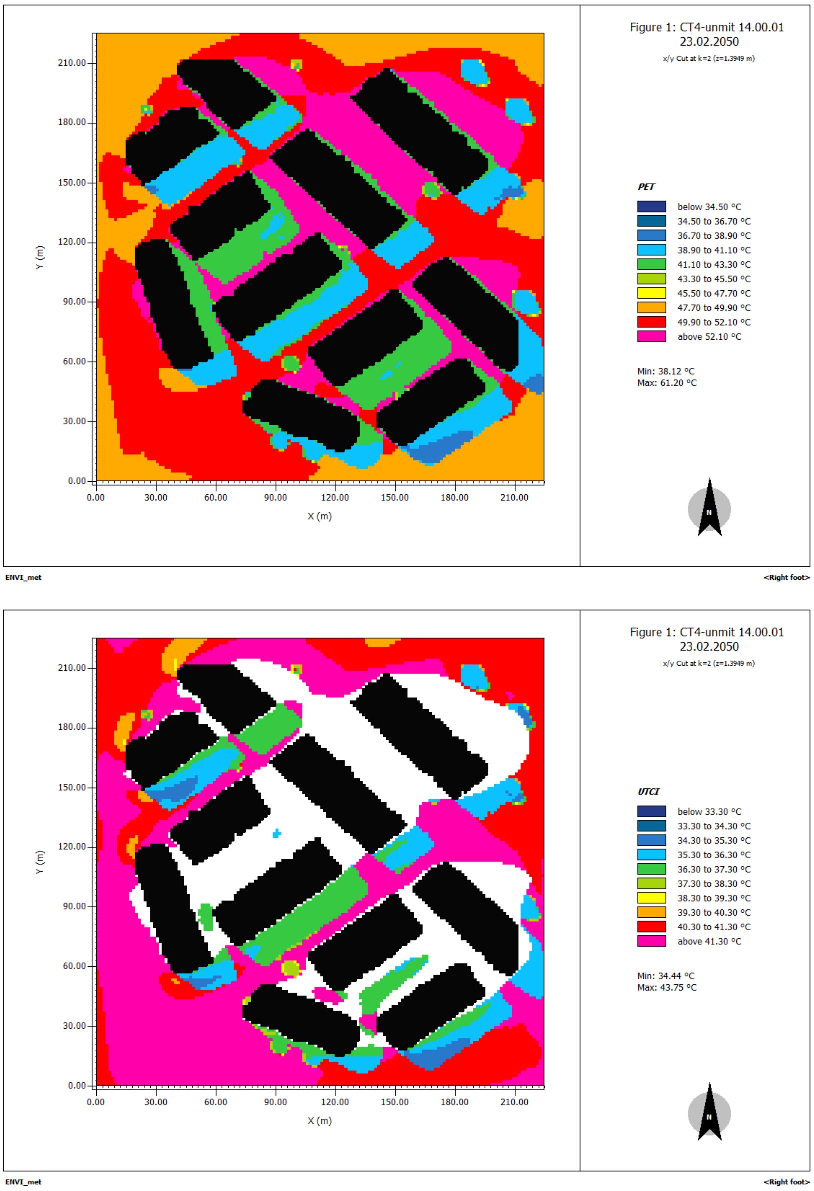


Figure 103 Distribution of thermal comfort in unmitigated CT4; PET (top), UTCI (bottom)

CT5 unmitigated

CT5-unmitigated

Figure 104 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT5.

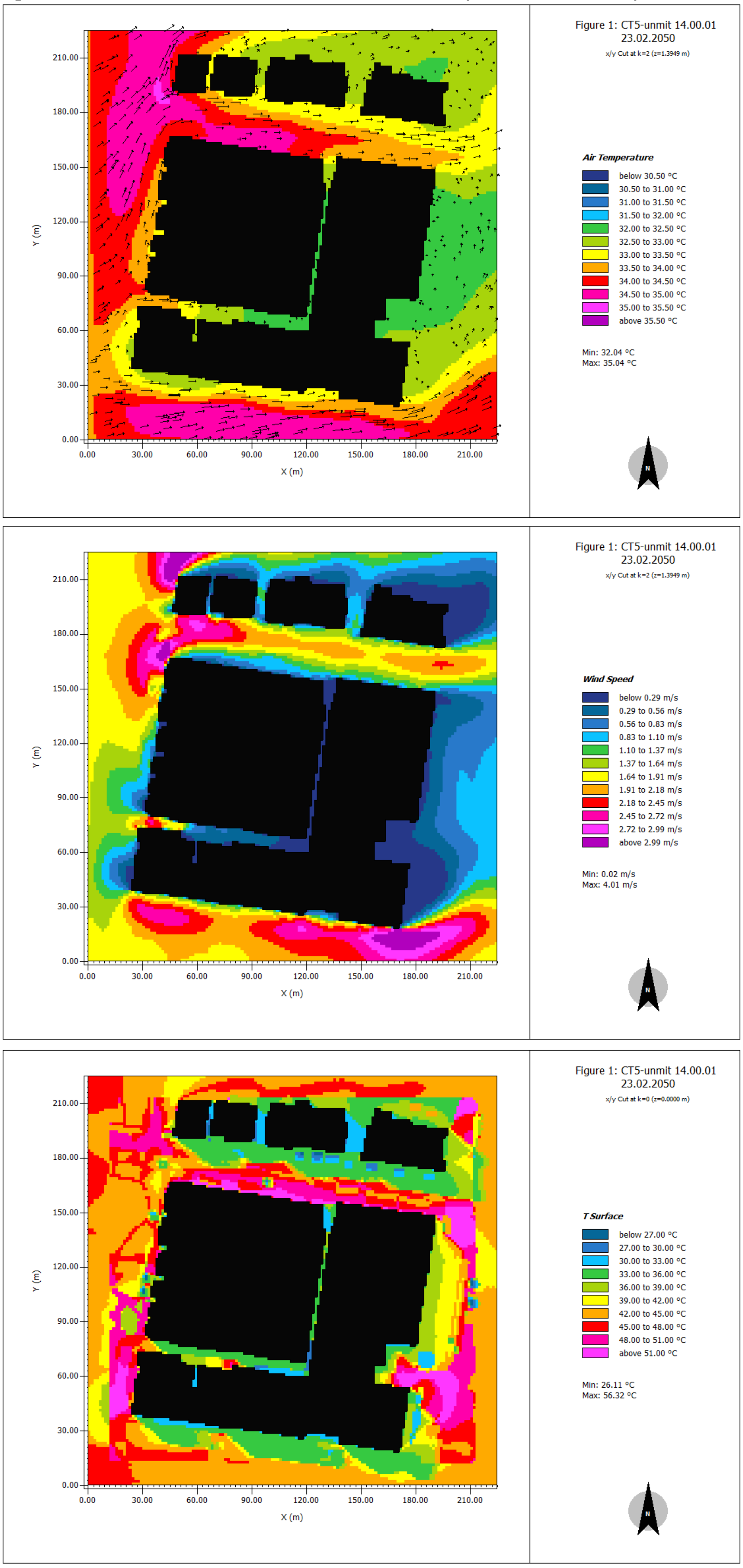


Figure 104 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated CT5

As shown in Figure 104, the ambient temperature ranges between 32.0 °C to 35.0 °C in the unmitigated CT5. The maximum wind speed reaches to 4.0 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 26.1 °C to 56.3 °C in the unmitigated CT5 at 14:00.

Figure 105 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT5 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 33.8°C to 43.4°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

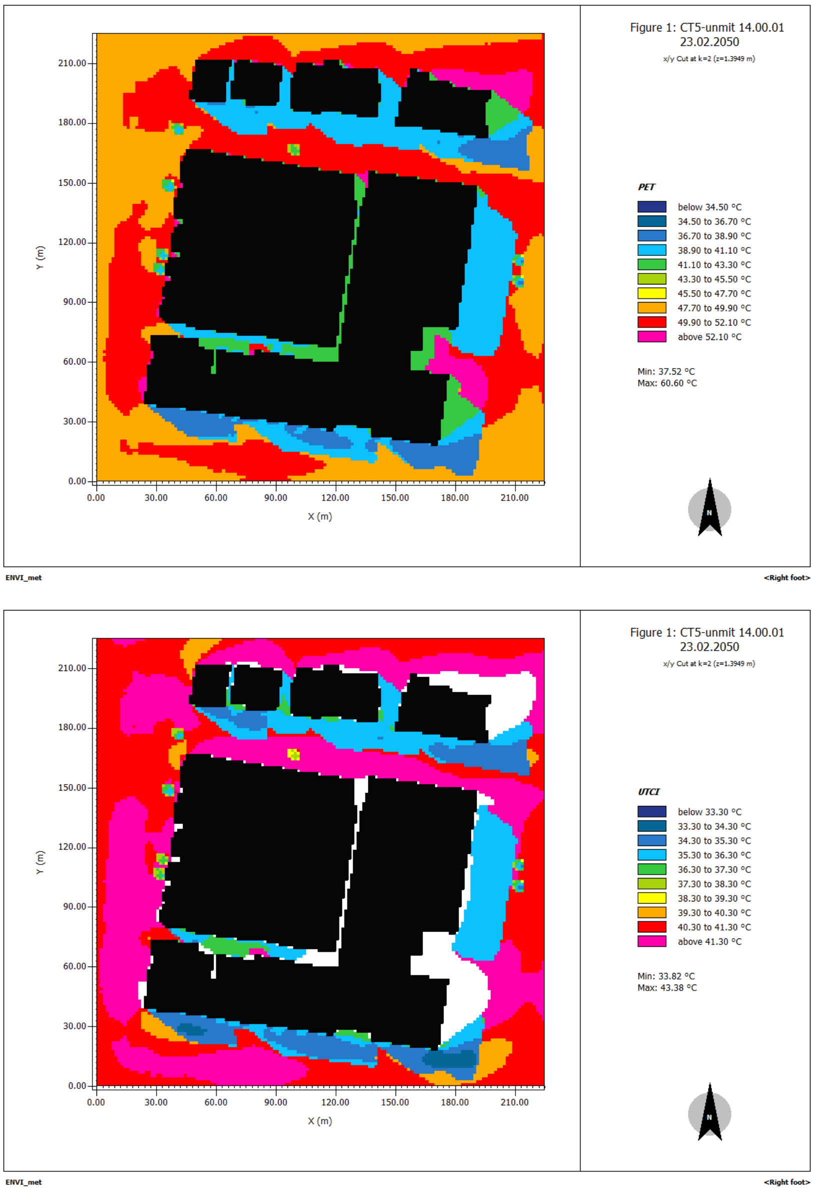


Figure 105 Distribution of thermal comfort in unmitigated CT5; PET (top), UTCI (bottom)

CT6 unmitigated

CT6-unmitigated

Figure 106 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT6.

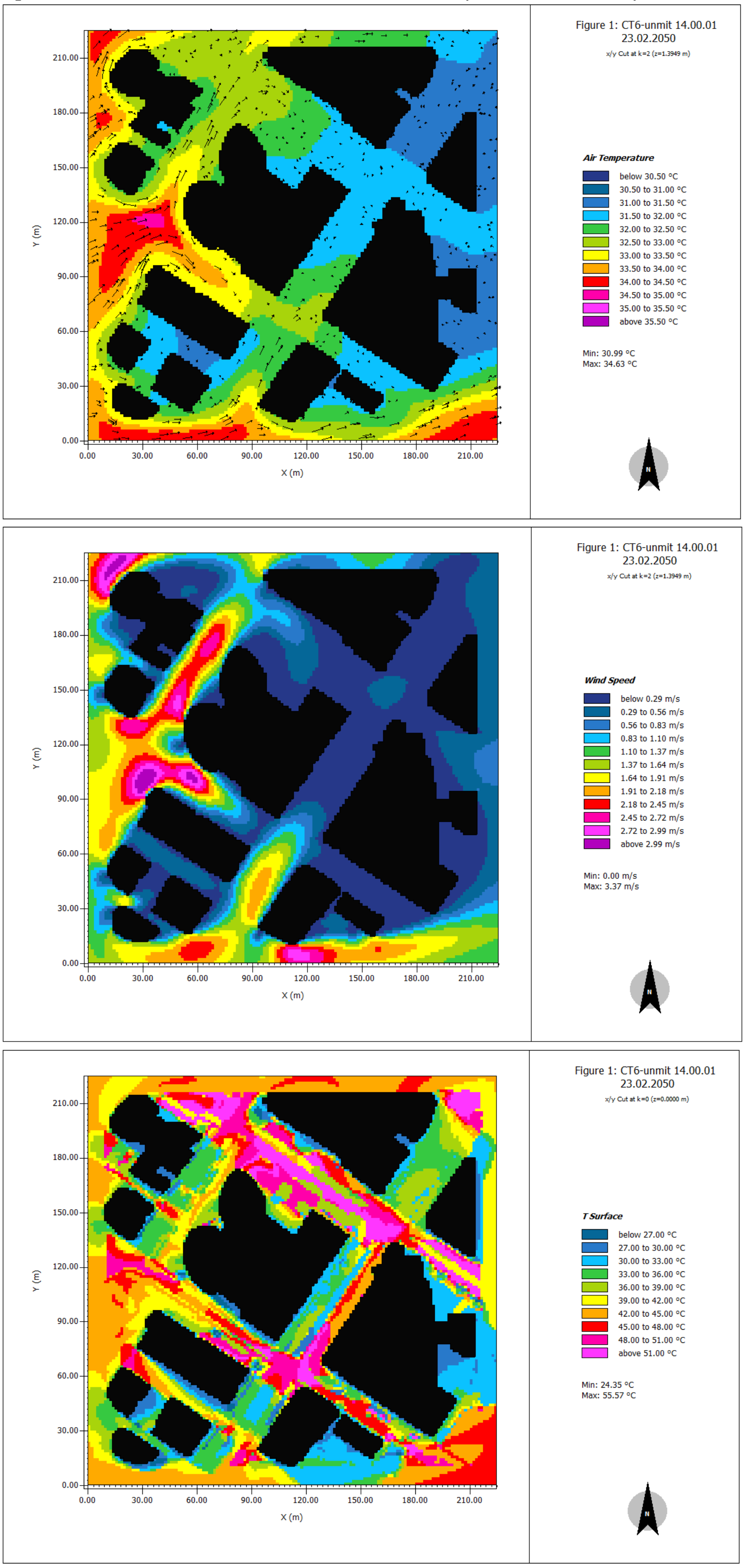


Figure 106 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated CT6

The ambient temperature ranges between 31.0 °C to 34.6 °C in the unmitigated CT6. The maximum wind speed reaches to 3.4 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.4 °C to 55.6 °C in the unmitigated CT6 at 14:00.

Figure 107 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT6 indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 31.9°C to 41.5°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

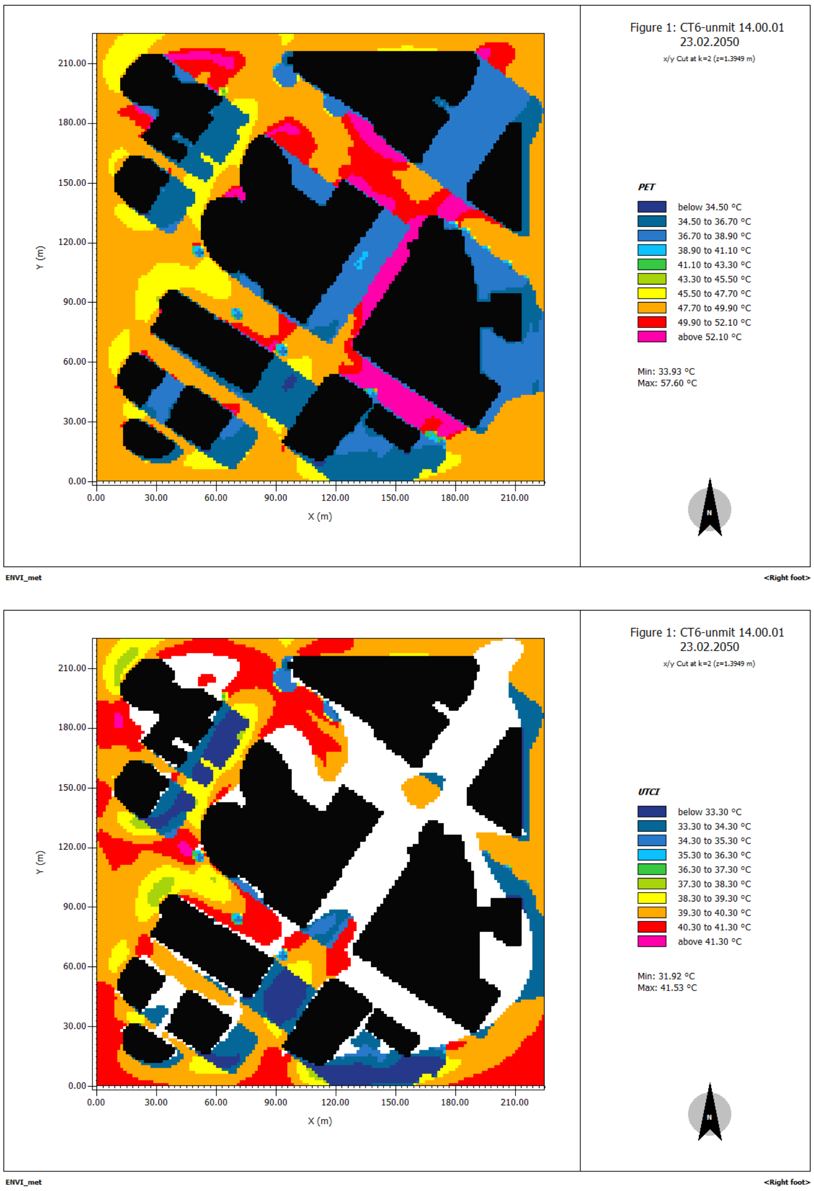


Figure 107 Distribution of thermal comfort in the unmitigated CT6; PET (top), UTCI (bottom)

CT7 unmitigated

CT7-unmitigated

Figure 108 shows the distribution of ambient temperauture, wind speed, and surface temperature in CT7.

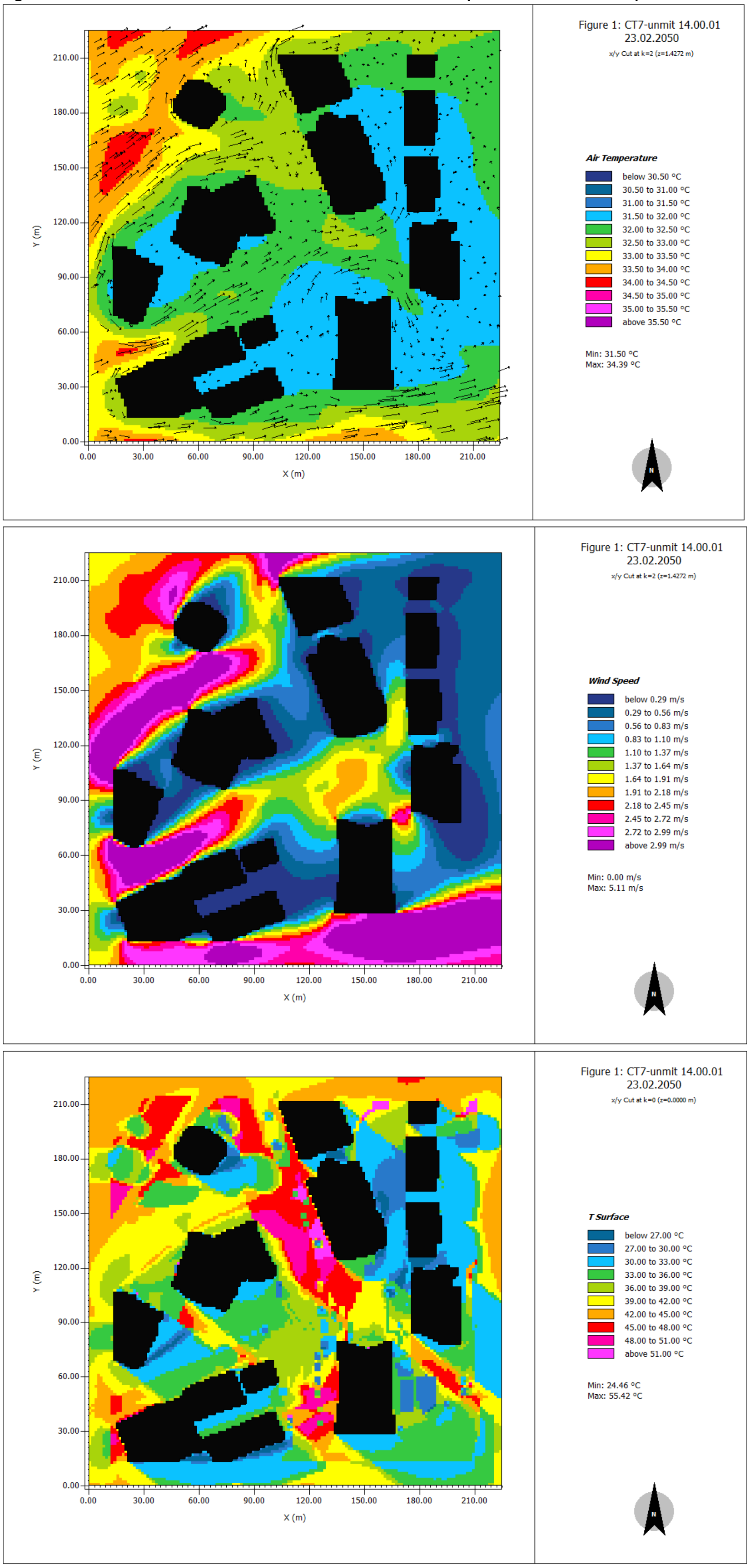


Figure 108 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated CT7

As shown here, the ambient temperature ranges between 31.5 °C to 34.4 °C. The maximum wind speed reaches to 5.1 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.5 °C to 55.4 °C in the unmitigated CT7 at 14:00.

Figure 109 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated CT7 indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 30.9°C to 41.5°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

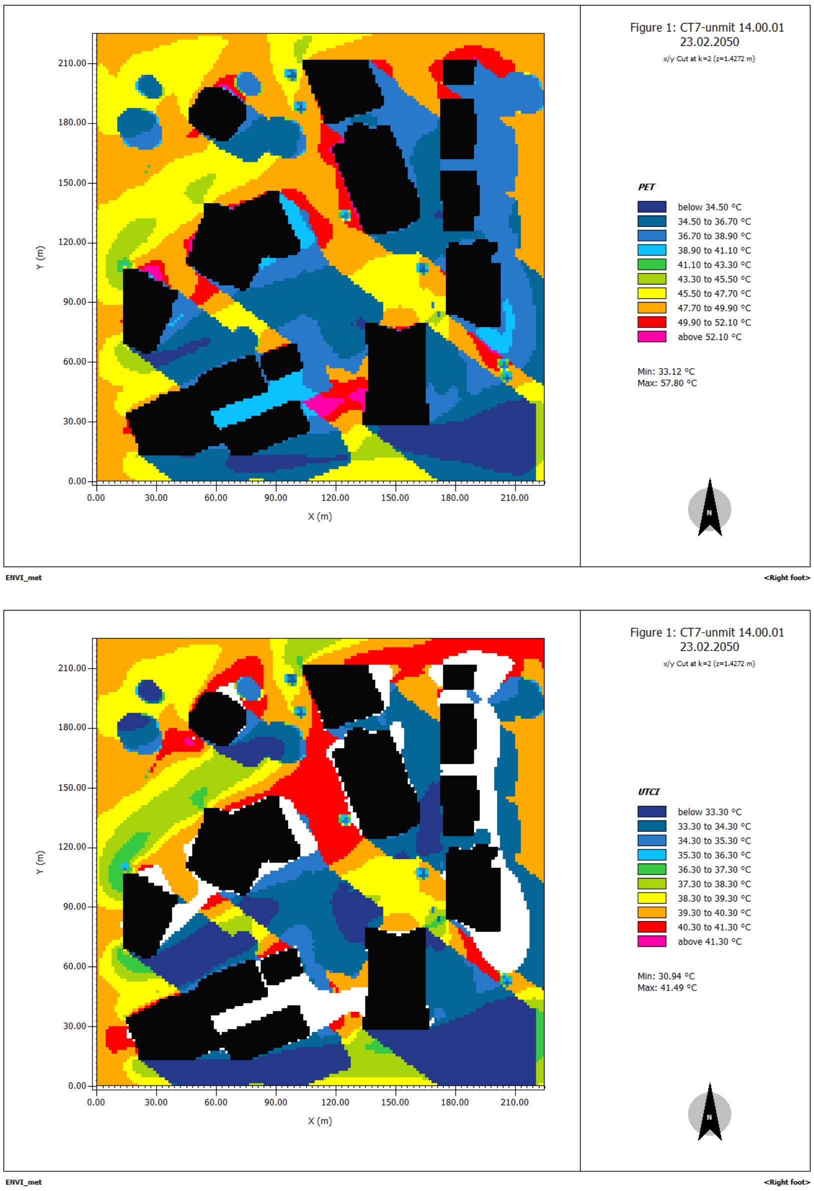


Figure 109 Distribution of thermal comfort in unmitigated CT7; PET (top), UTCI (bottom)

OT1 unmitigated

OT1-unmitigated

Figure 110 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT1.

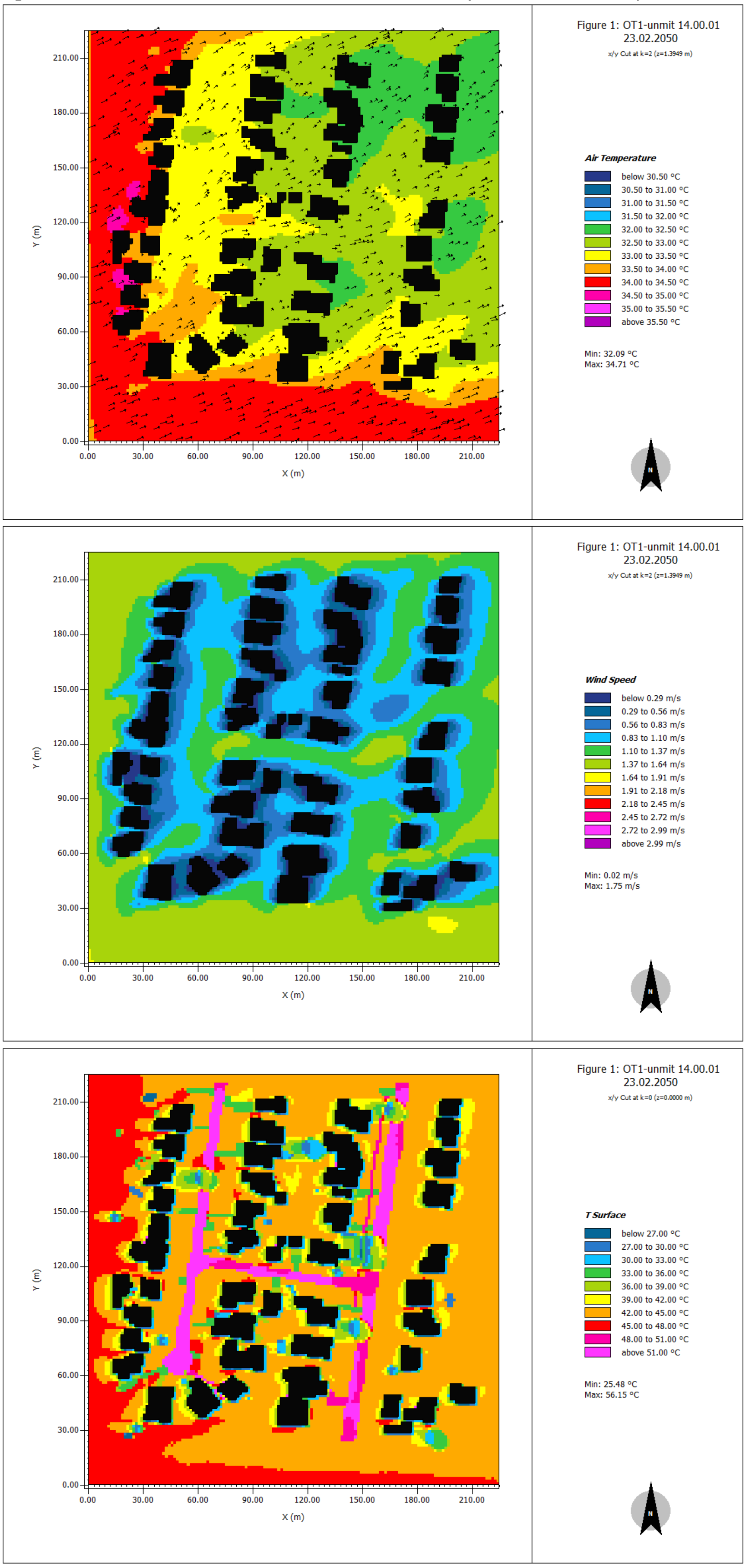


Figure 110 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT1

As shown here, the ambient temperature ranges between 32.1 °C to 34.7 °C. The maximum wind speed reaches to 1.8 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.5 °C to 56.2 °C in the unmitigated OT1 at 14:00.

Figure 111 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT1 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 35.2°C to 43.4°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

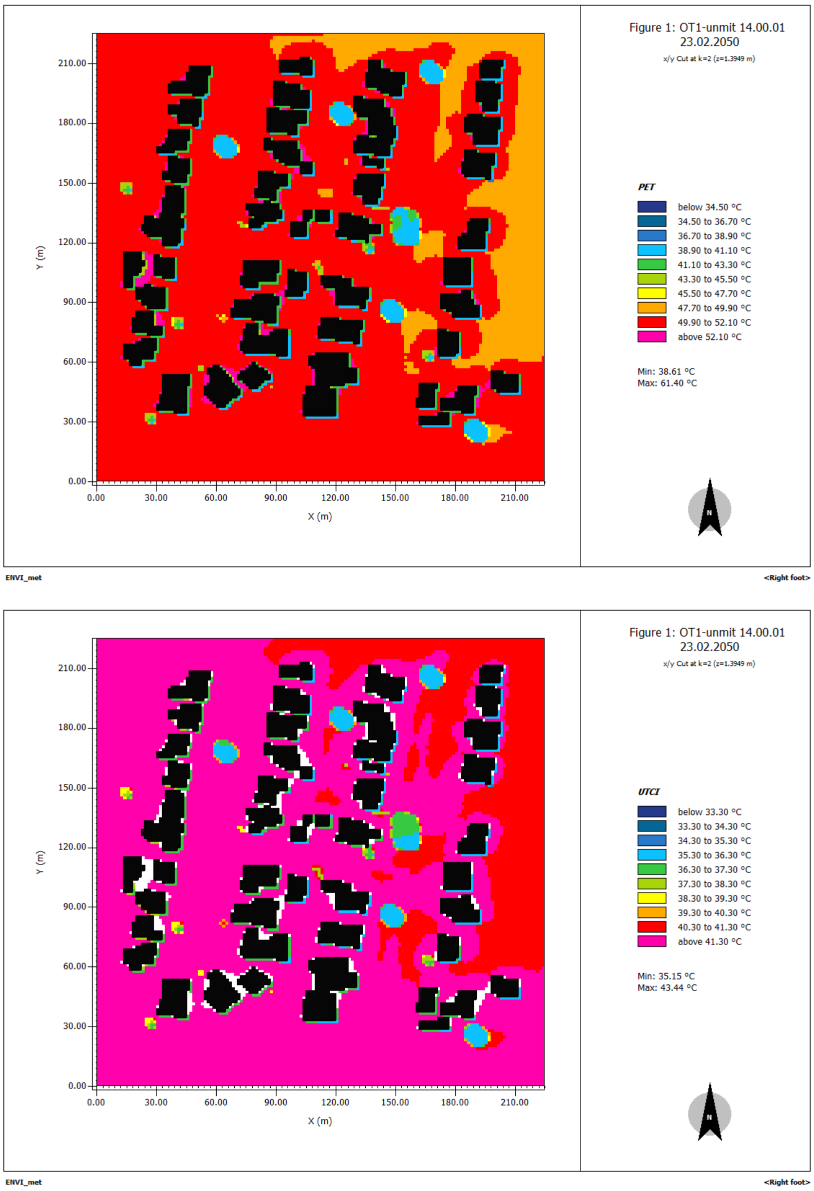


Figure 111 Distribution of thermal comfort in the unmitigated OT1; PET (top), UTCI (bottom)

OT2 unmitigated

OT 2-unmitigated

Figure 112 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT2.

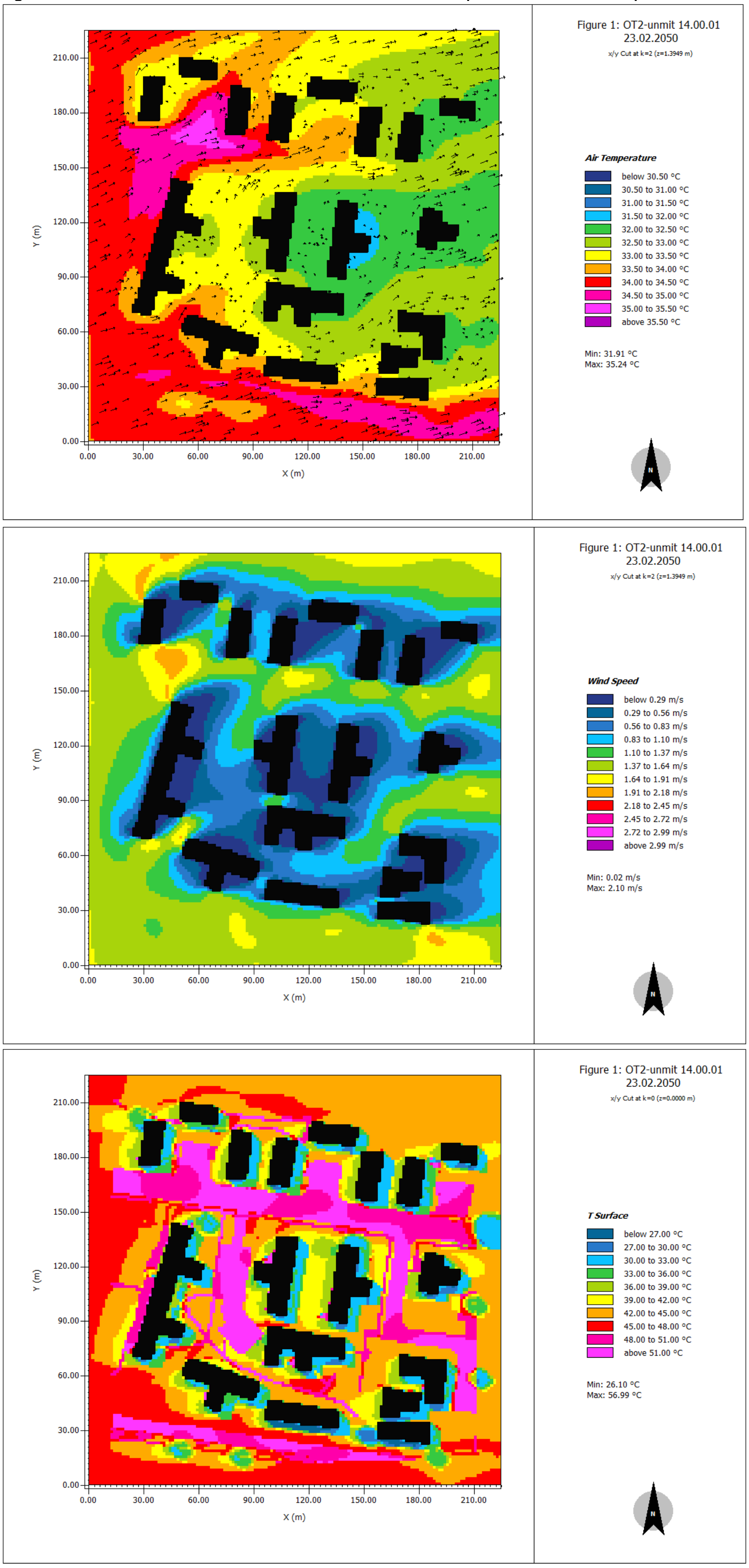


Figure 112 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT2

As shown here, the ambient temperature ranges between 31.9 °C to 35.2 °C. The maximum wind speed reaches to 2.1 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 26.1 °C to 57.0 °C in the unmitigated OT2 at 14:00.

Figure 113 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT2 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.4°C to 43.5°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

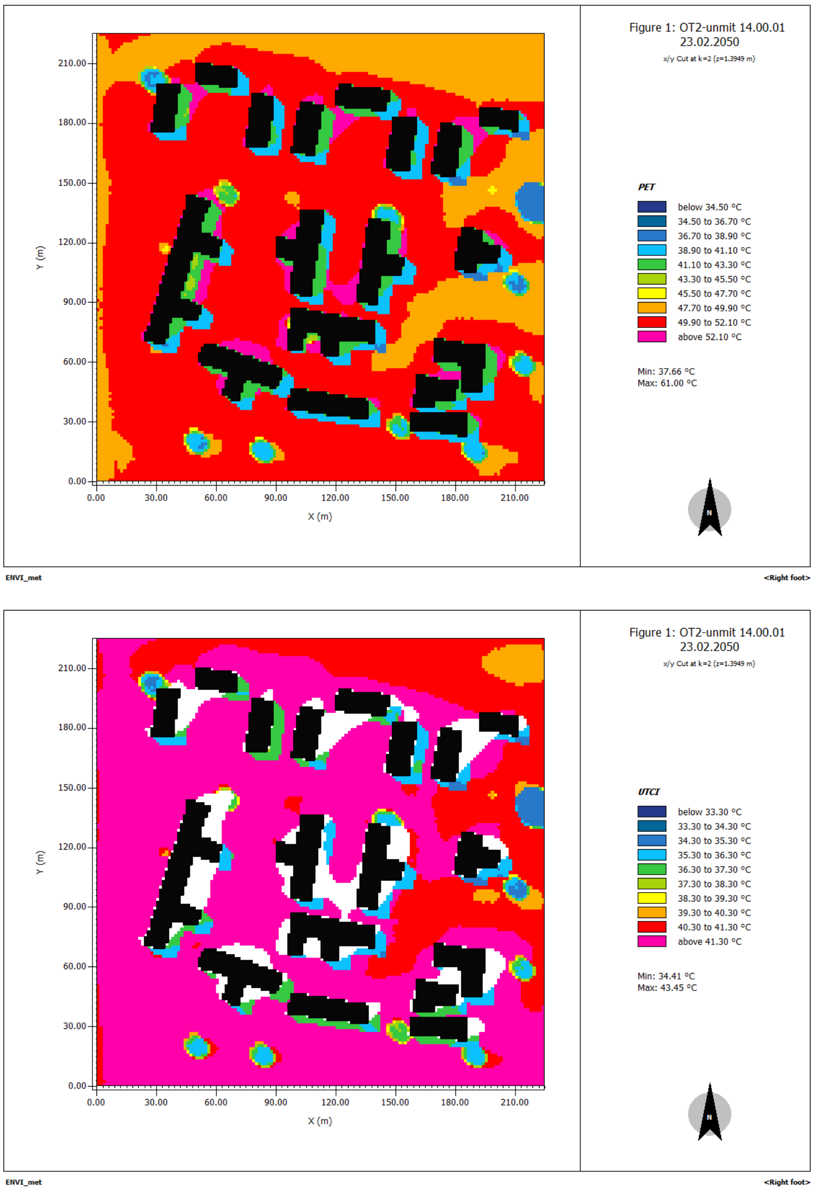


Figure 113 Distribution of thermal comfort in unmitigated OT2; PET (top), UTCI (bottom)

OT3 unmitigated

OT3-unmitigated

Figure 114 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT3.

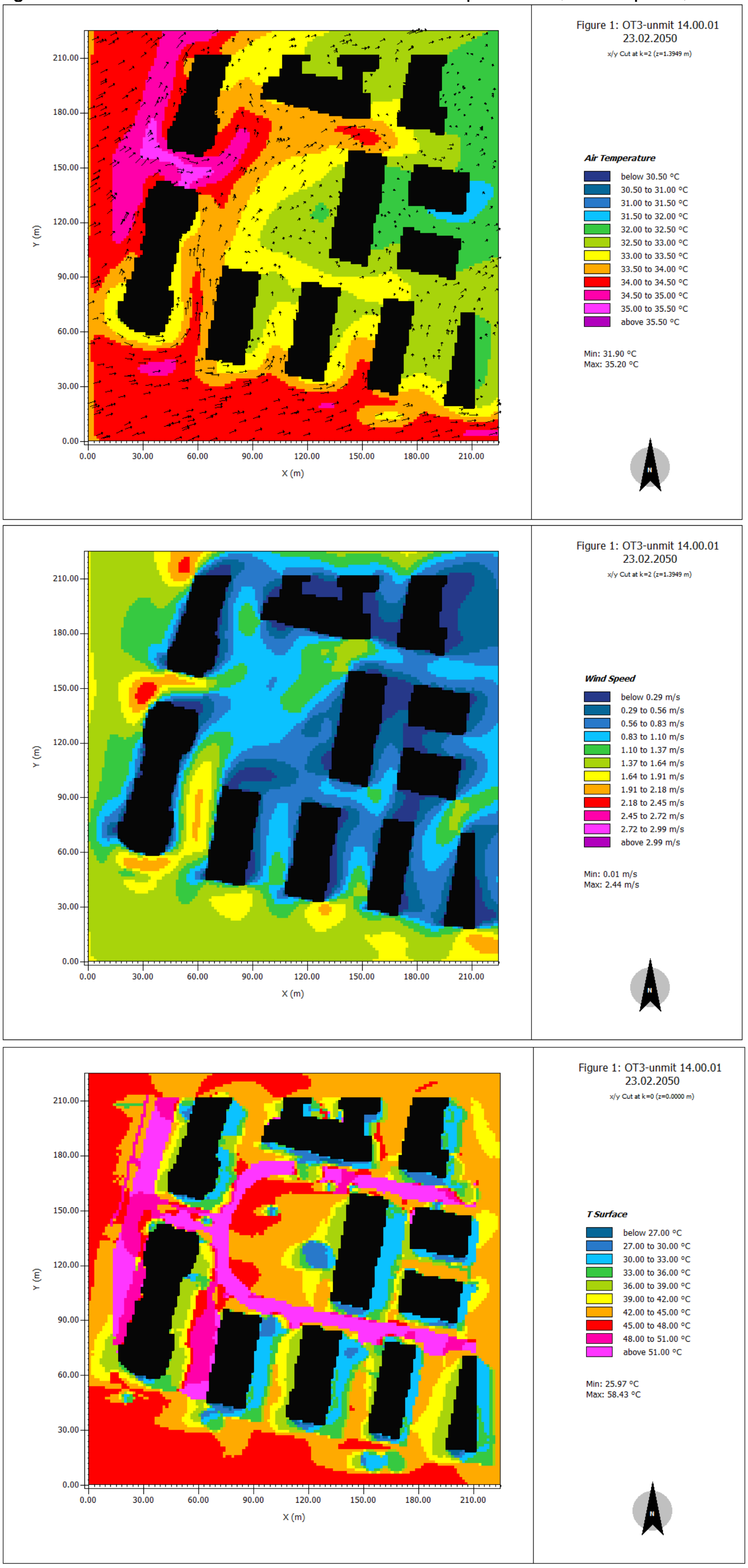


Figure 114 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT3

The ambient temperature ranges between 31.9 °C to 35.2 °C. The maximum wind speed reaches to 2.4 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 26.0 °C to 58.4 °C in the unmitigated OT3 at 14:00.

Figure 115 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT3 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is mostly ranging from 34.1°C to 44.0°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

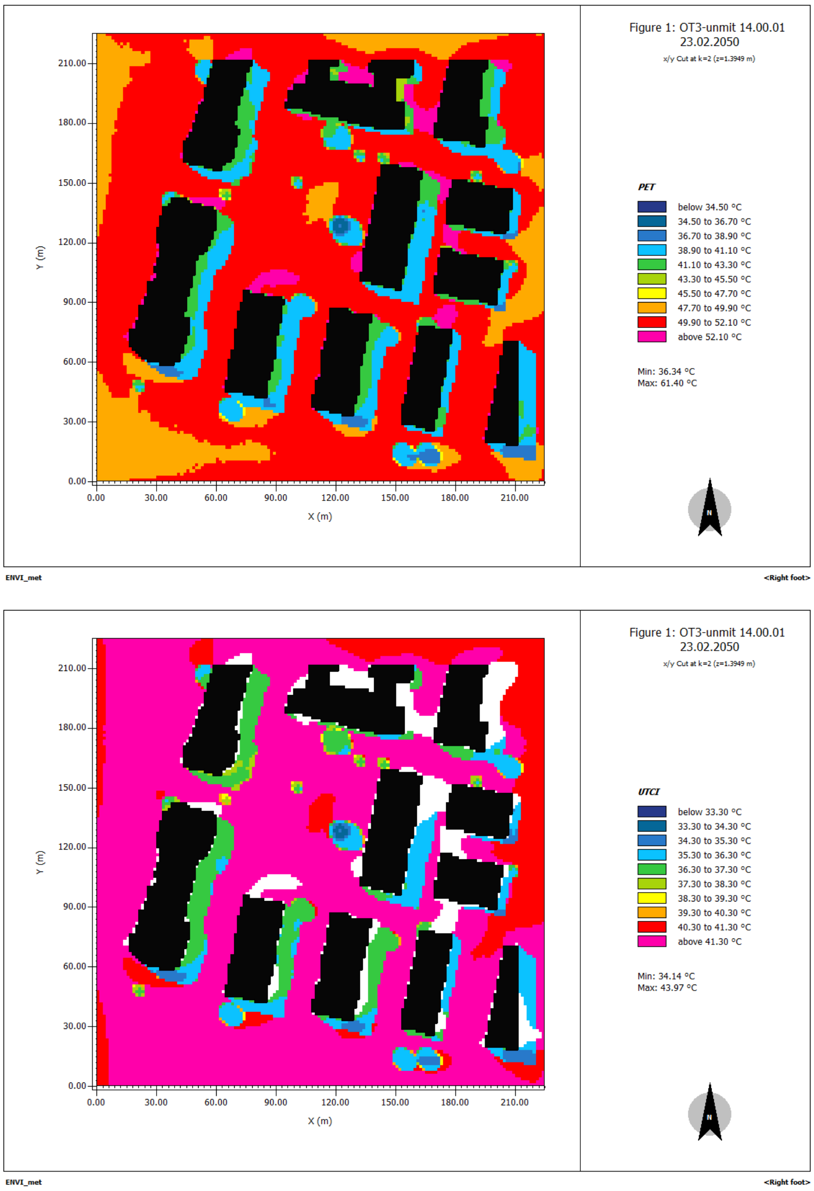


Figure 115 Distribution of thermal comfort in the unmitigated OT3; PET (top), UTCI (bottom)

OT4 unmitigated

OT4-unmitigated

Figure 116 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT4.

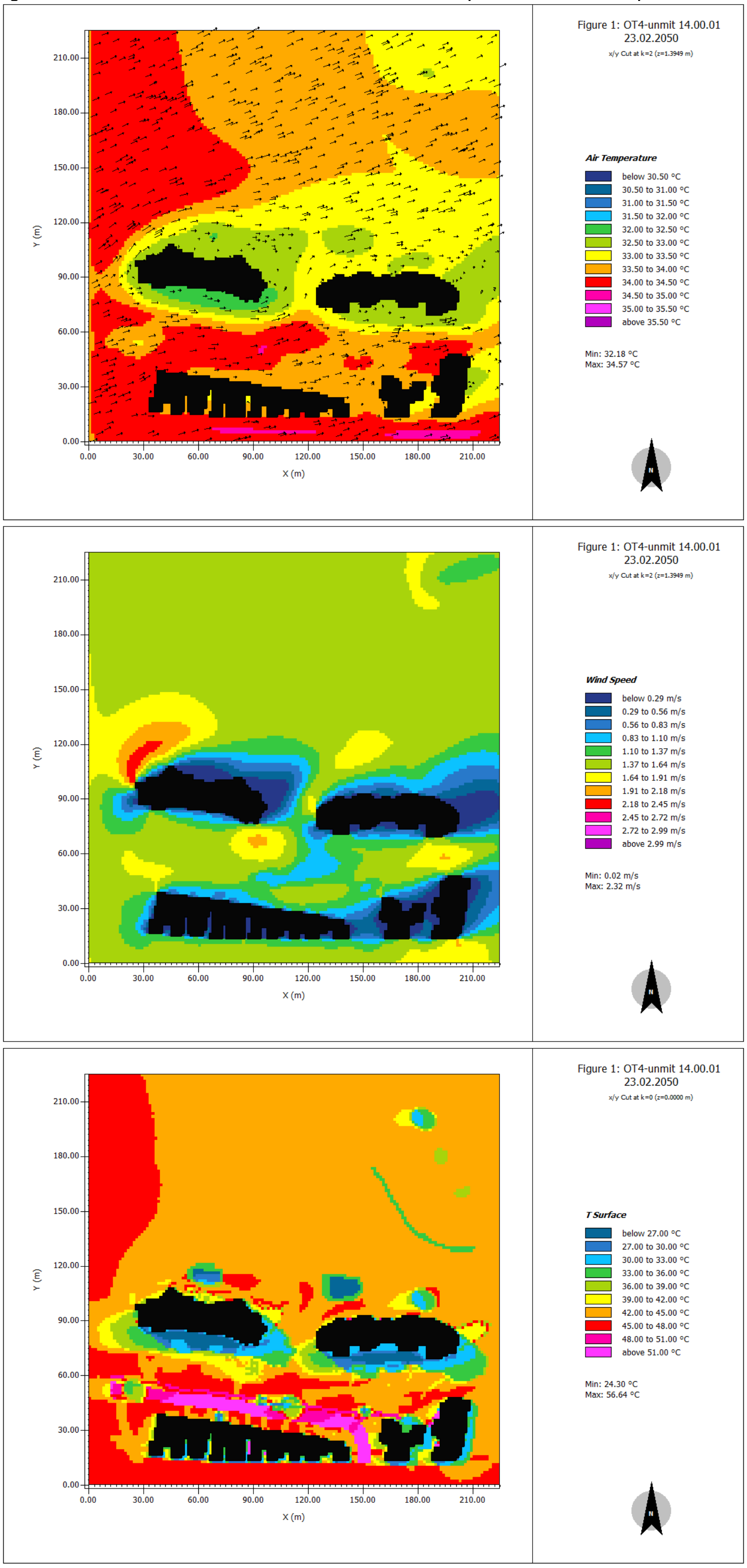


Figure 116 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT4

As shown here, the ambient temperature ranges between 32.2 °C to 34.6 °C. The maximum wind speed reaches to 2.3 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 24.3 °C to 56.6 °C in the unmitigated OT4 at 14:00.

Figure 117 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT4 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.9°C to 43.5°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

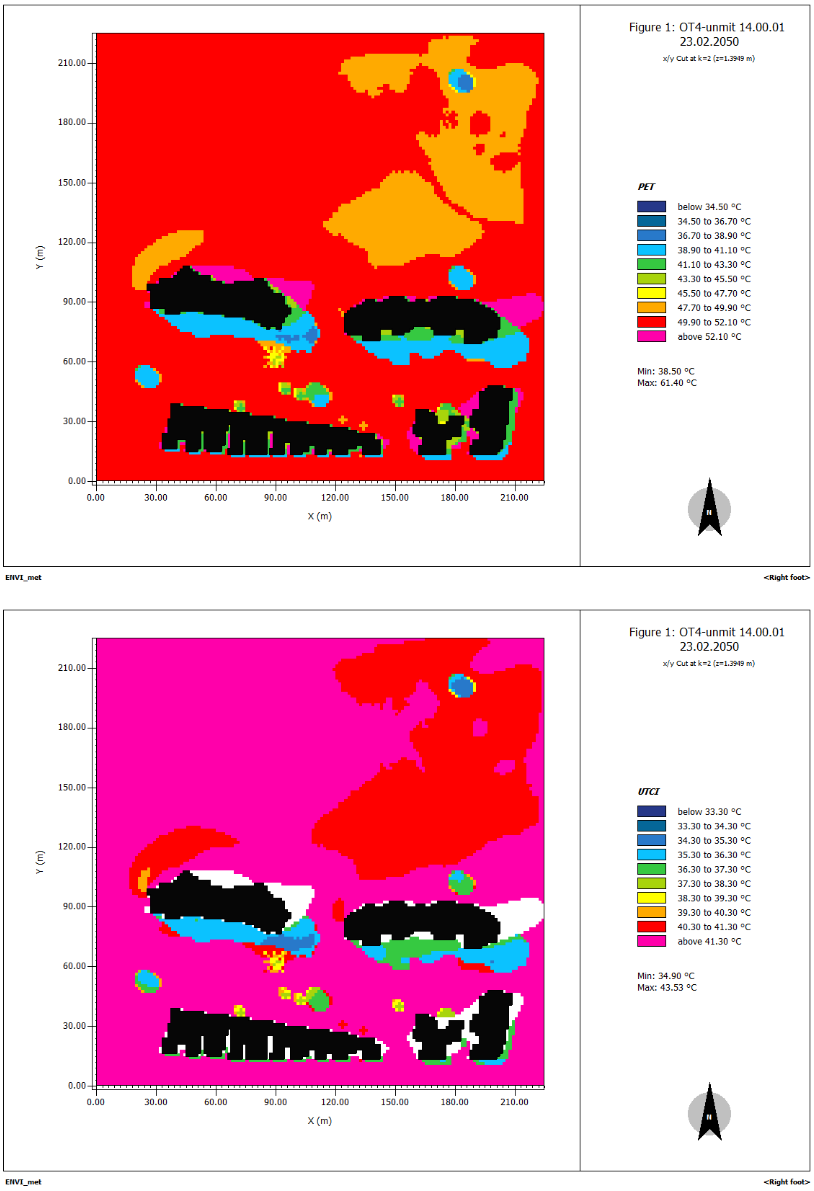


Figure 117 Distribution of thermal comfort in unmitigated OT4; PET (top), UTCI (bottom)

OT5 unmitigated

OT5-unmitigated

Figure 118 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT5.

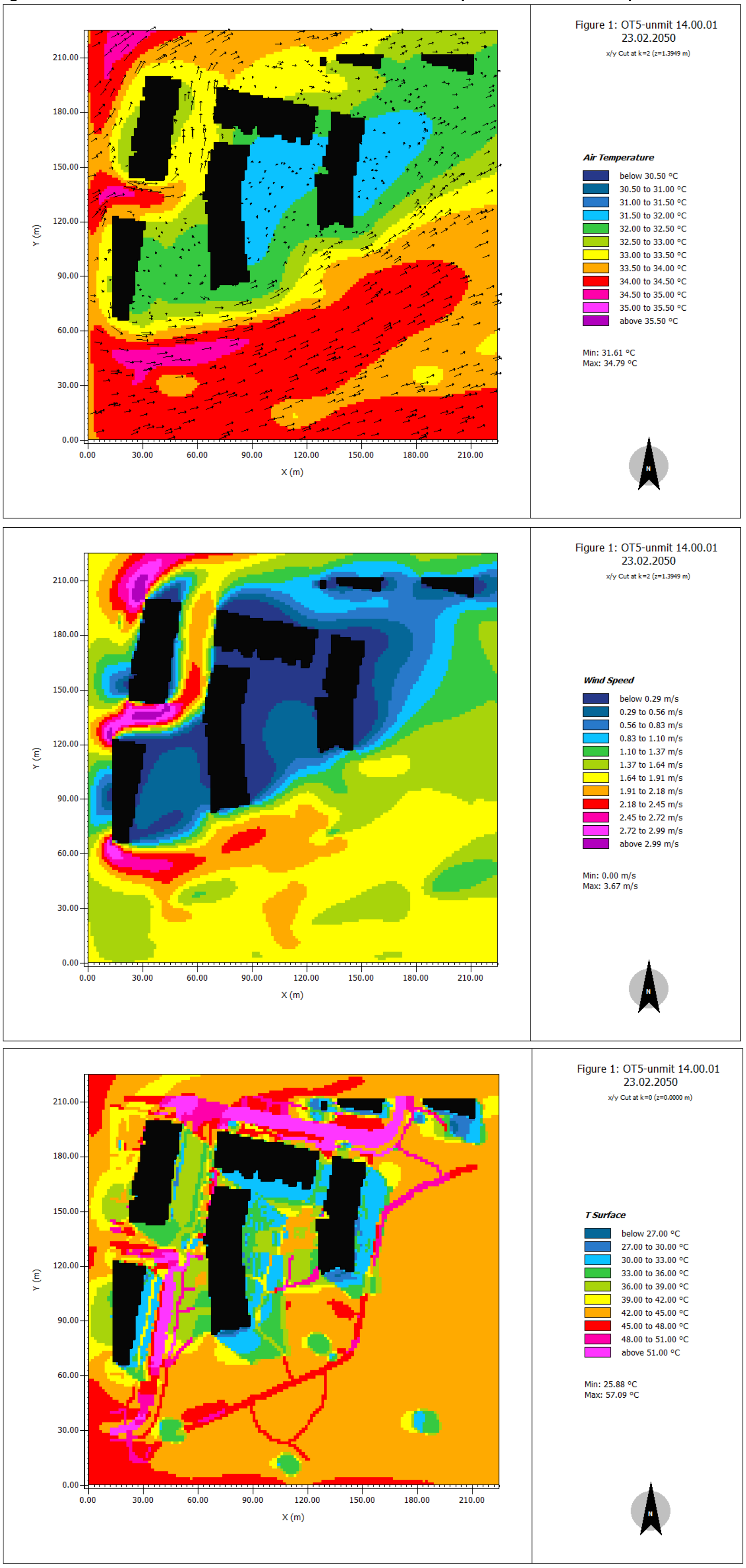


Figure 118 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT5

As shown here, the ambient temperature ranges between 31.6 °C to 34.8 °C. The maximum wind speed reaches to 3.7 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.9 °C to 57.1 °C in the unmitigated OT5 at 14:00.

Figure 119 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT5 indicates strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 34.0°C to 43.0°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

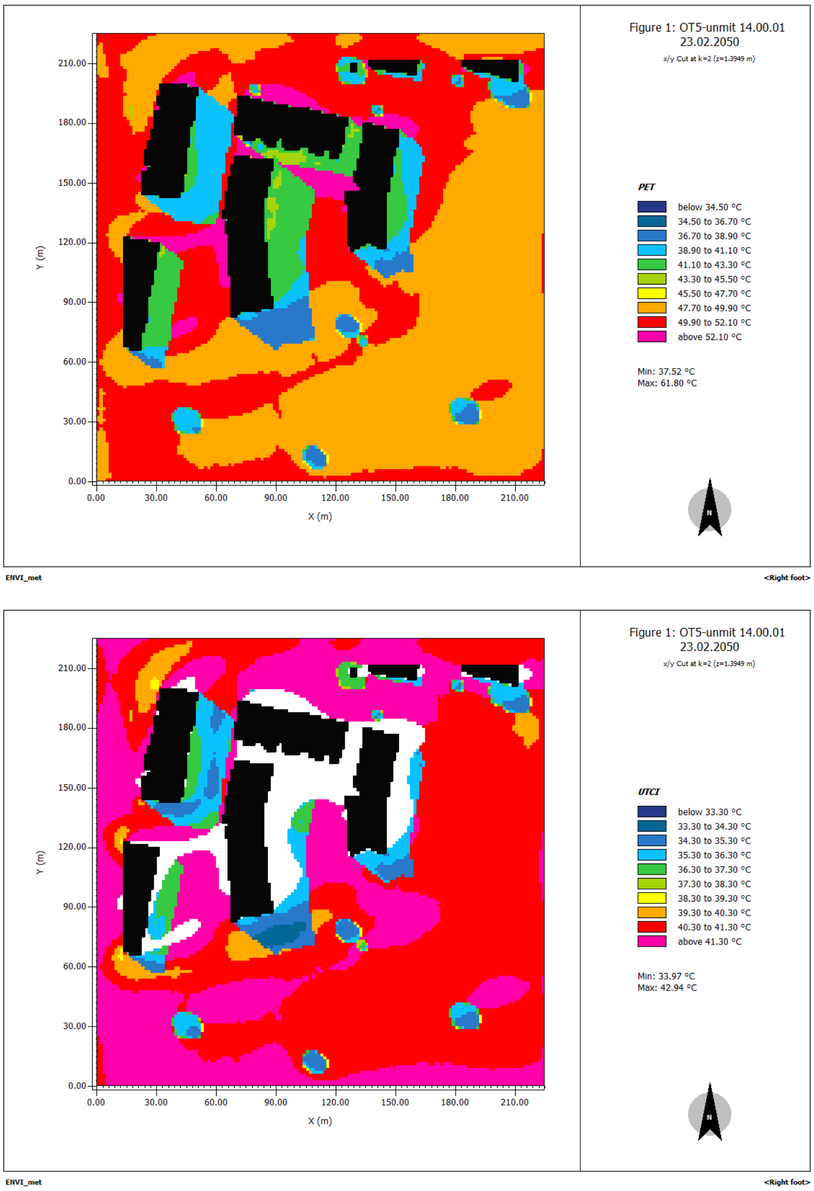


Figure 119 Distribution of thermal comfort in the unmitigated OT5; PET (top), UTCI (bottom)

OT6 unmitigated

OT6-unmitigated

Figure 120 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT6.

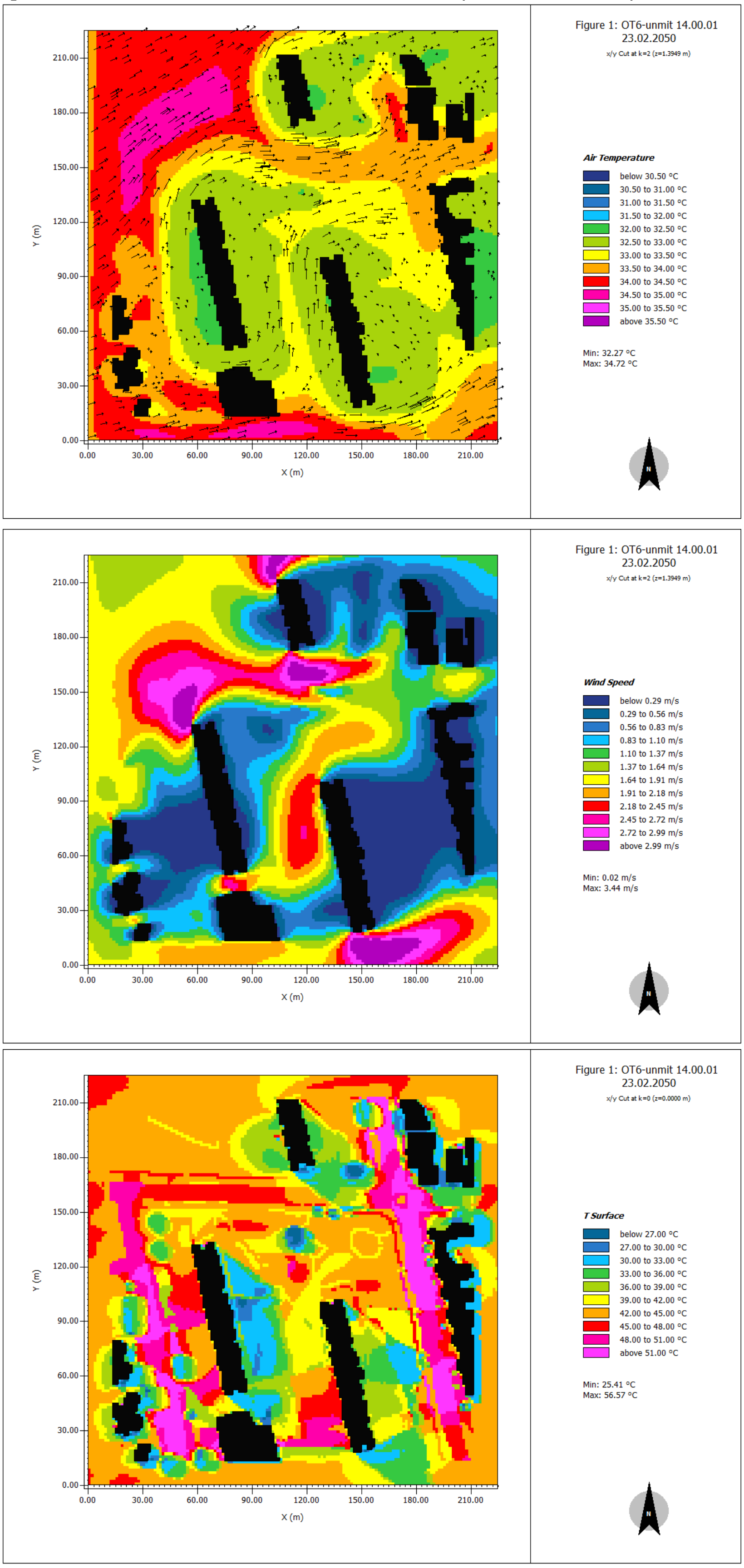


Figure 120 Distribution of air temperature (top), wind speed (middle) and surface temperature (bottom) in the unmitigated OT6

As shown here, the ambient temperature ranges between 32.3 °C to 34.7 °C. The maximum wind speed reaches to 3.4 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.4 °C to 56.6 °C in the unmitigated OT6 at 14:00.

Figure 121 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT6 indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 32.9°C to 42.9°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

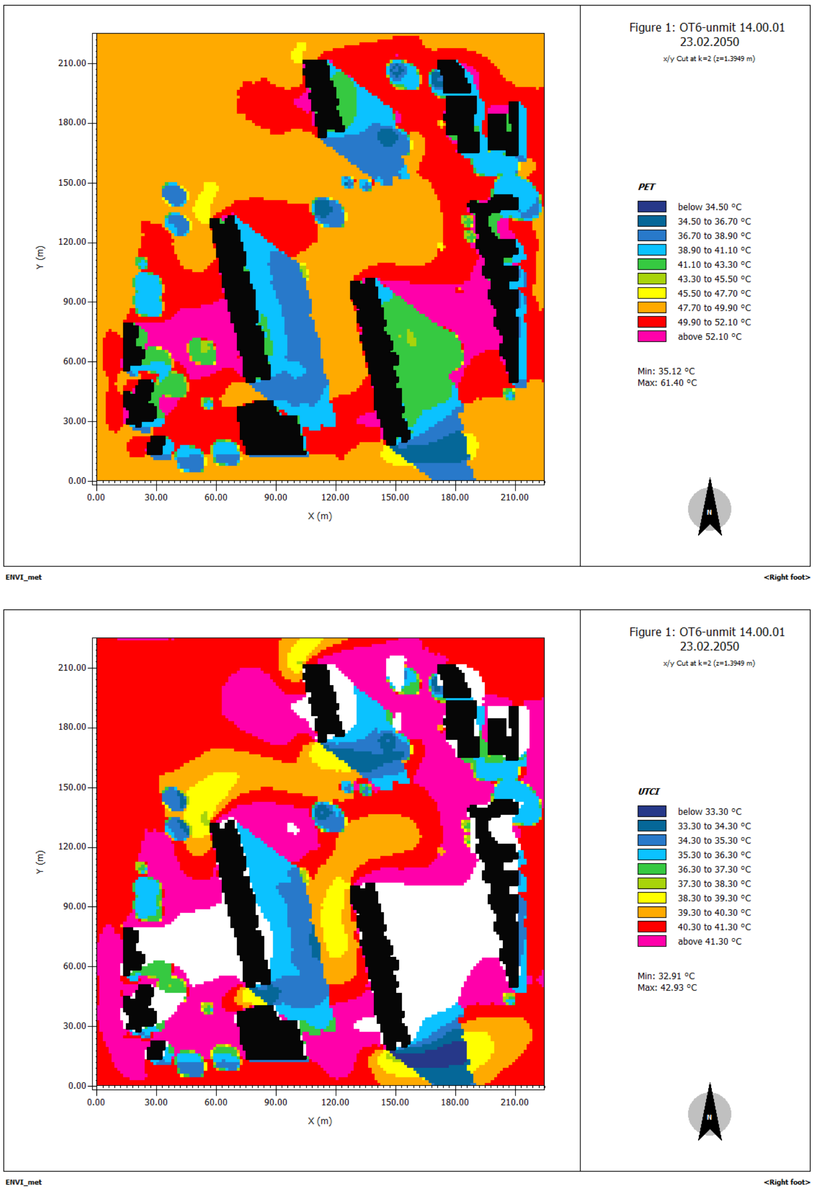


Figure 121 Distribution of thermal comfort in unmitigated OT6; PET (top), UTCI (bottom)

OT7 unmitigated

OT7-unmitigated

Figure 122 shows the distribution of ambient temperauture, wind speed, and surface temperature in OT7.

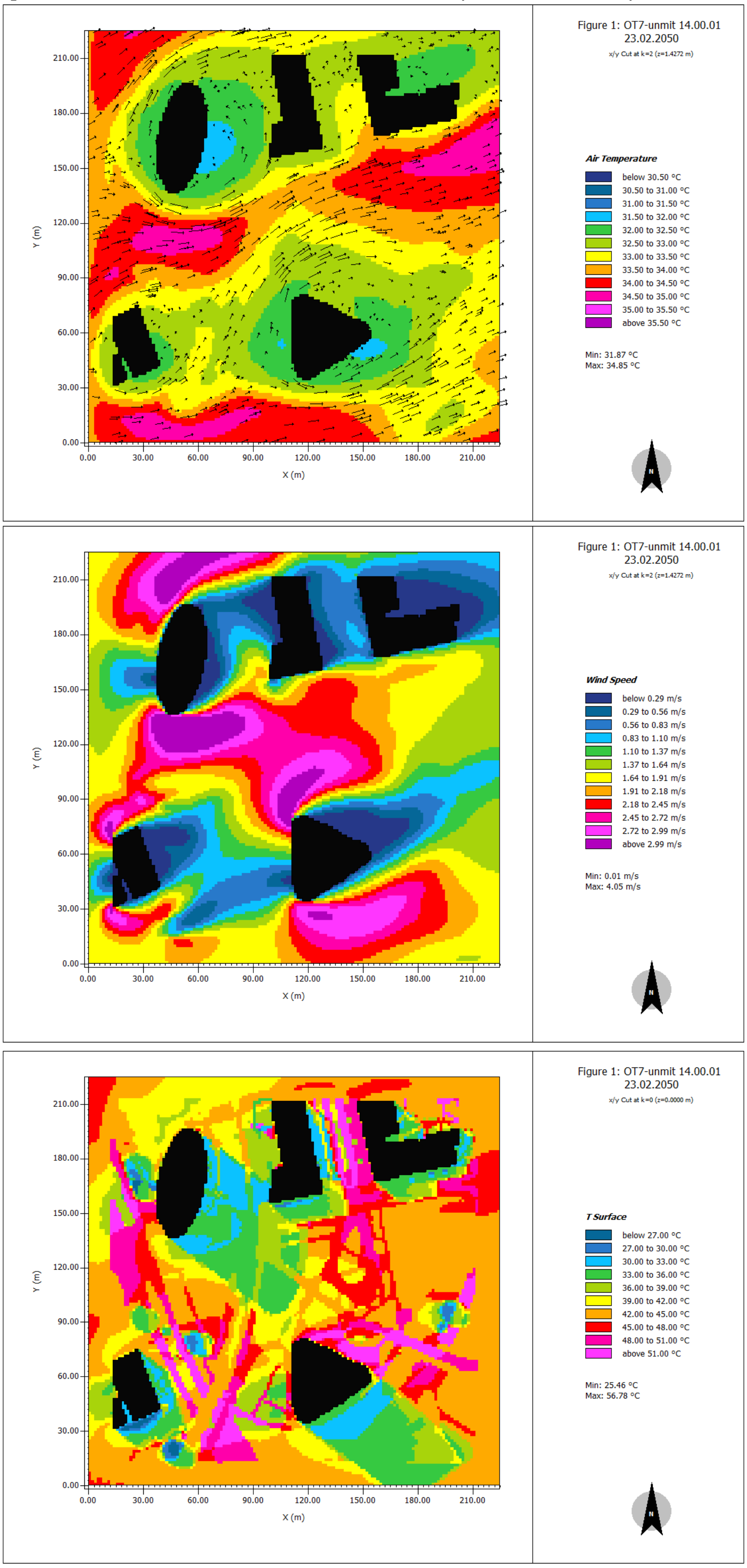


Figure 122 Distribution of ambient temperature (top), wind speed (middle) and surface temperature (bottom) in unmitigated OT7

As shown here, the ambient temperature ranges between 31.9 °C to 34.9 °C. The maximum wind speed reaches to 4.1 m/s while the areas between the buildings present lower wind speed values. The surface temperature distribution map shows that surface temperature varies from 25.5 °C to 56.8 °C in the unmitigated OT7 at 14:00.

Figure 123 shows the distribution of thermal comfort indices (PET and UTCI). The unmitigated OT7 indicates moderate to strong heat stress. The Universal Thermal Climate Index (UTCI) is ranging from 32.9°C to 42.6°C. Thermal comfort is mostly improved in the shaded areas. PET is consistent with UTCI indicating areas out of comfort range.

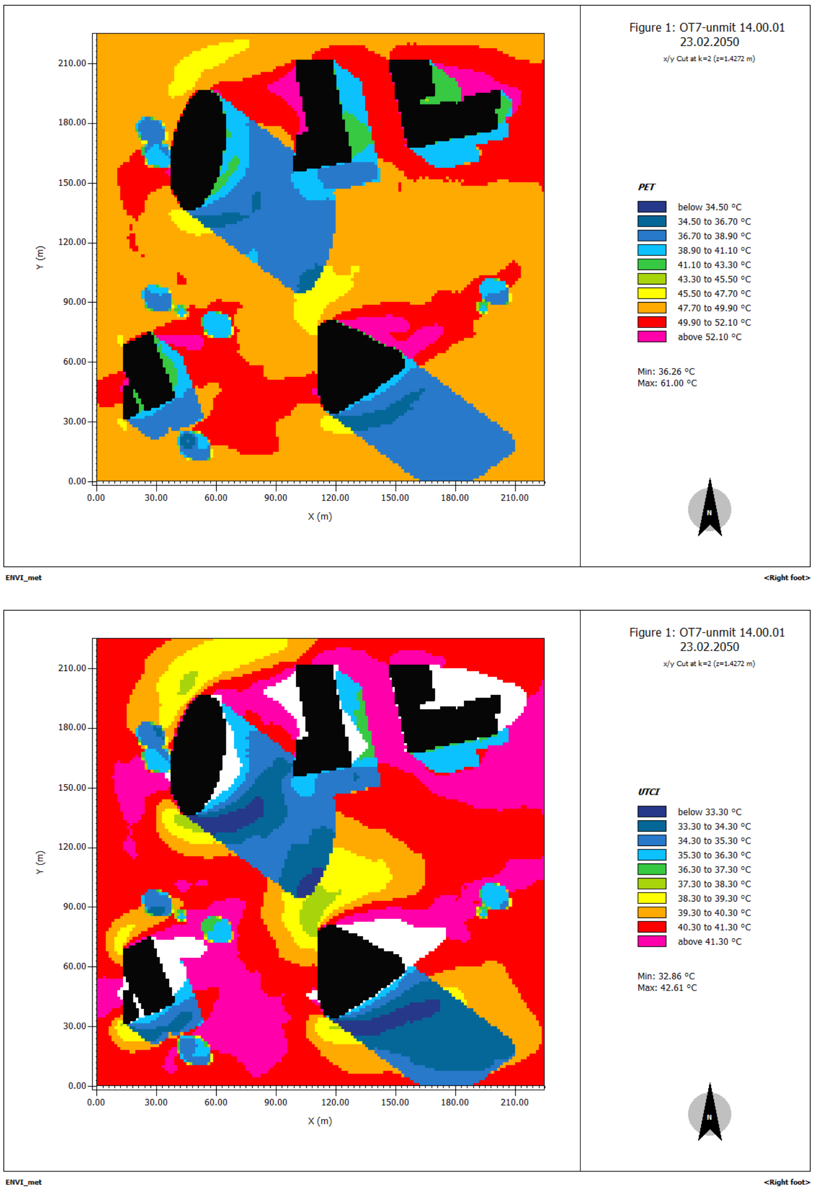


Figure 123 Distribution of thermal comfort in the unmitigated OT7; PET (top), UTCI (bottom)

Ambient temperature comparison maps

The results of ambient temperature in the mitigated simulations (mitigated 2050 climate and mitigated precinct) are compared with the base model run with 2050 climate and no mitigation strategy in the precinct. The difference between ambient temperature in each grid (1.5*1.5m) in the two simulations are obtained and results are reported in Table 35. The average reduction of ambient temperature ranges between 2.1 °C ±0.4 and 3.3 °C±1.5°C. The minimum reduction of ambient temperature is observed in CT7 and the maximum temperature drop is obtained in OT6.

Table 35 Statistical summary of temperature difference (Mean, Minimum and maximum temperature difference between mitigated and unmitigated simulations)

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	OT1	OT2	OT3	OT4	OT5	OT6	OT7
Mean	2.20	2.22	2.32	2.14	2.13	2.13	2.09	2.33	3.04	2.78	2.39	2.27	3.26	2.16
Std. Deviation	0.48	0.69	0.63	0.70	0.61	0.52	0.37	0.51	0.68	0.73	0.90	0.89	1.49	0.56
Minimum*	1.42	1.41	1.64	1.10	1.57	1.37	1.54	1.48	1.88	1.62	1.21	0.93	1.69	0.81
Maximum*	8.18	8.17	7.59	6.84	7.25	7.74	5.20	7.33	8.76	9.59	11.98	7.70	14.50	7.35

*: The maximum and minimum are presented in absolte term.

The ambient temperature, surface temperature and thermal comfort difference distribution maps are provided in Figure 124 to Figure 129.

Ambient temperature comparison maps

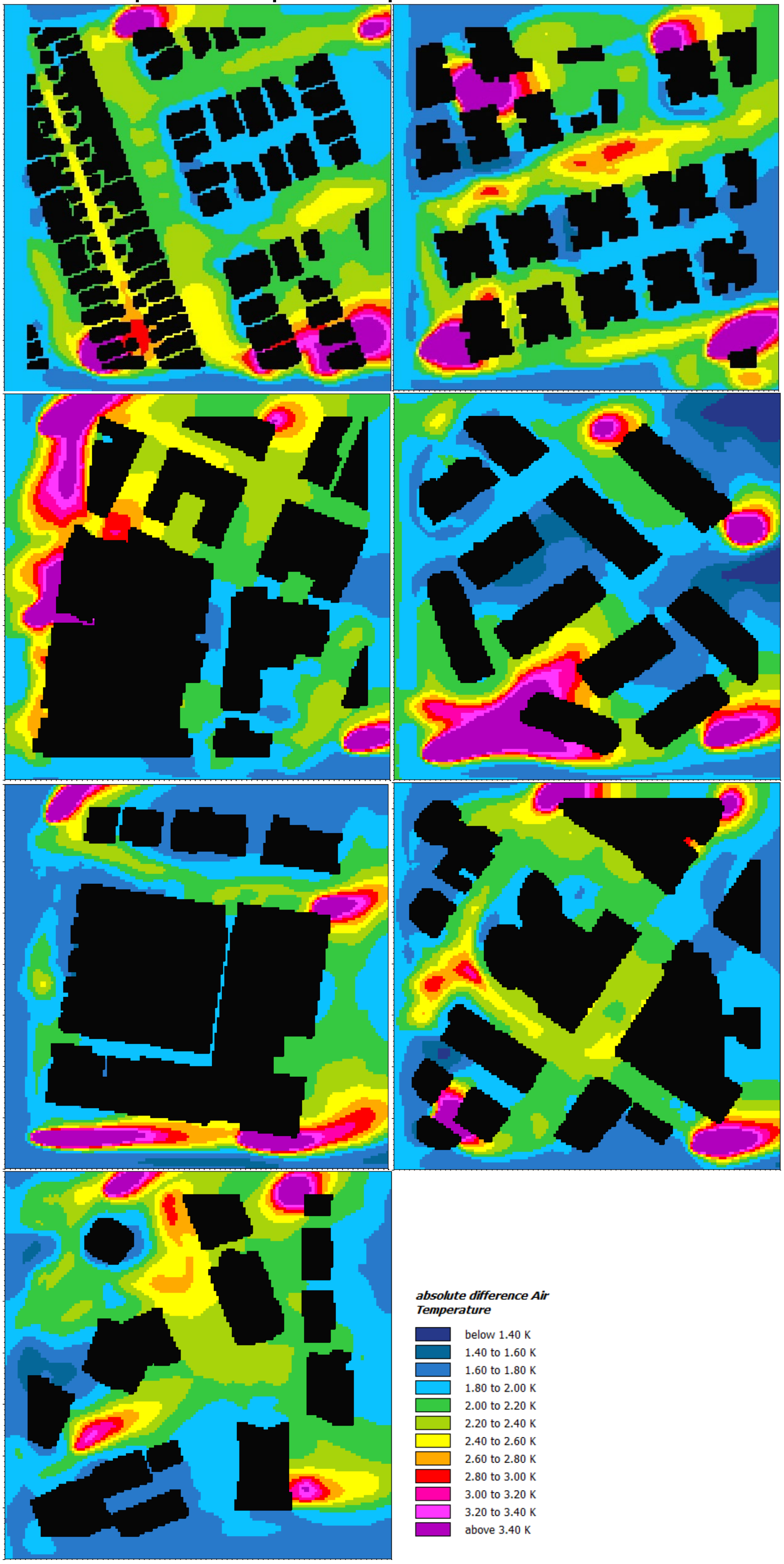


Figure 124 The ambient temperature difference distribution map in CT precincts

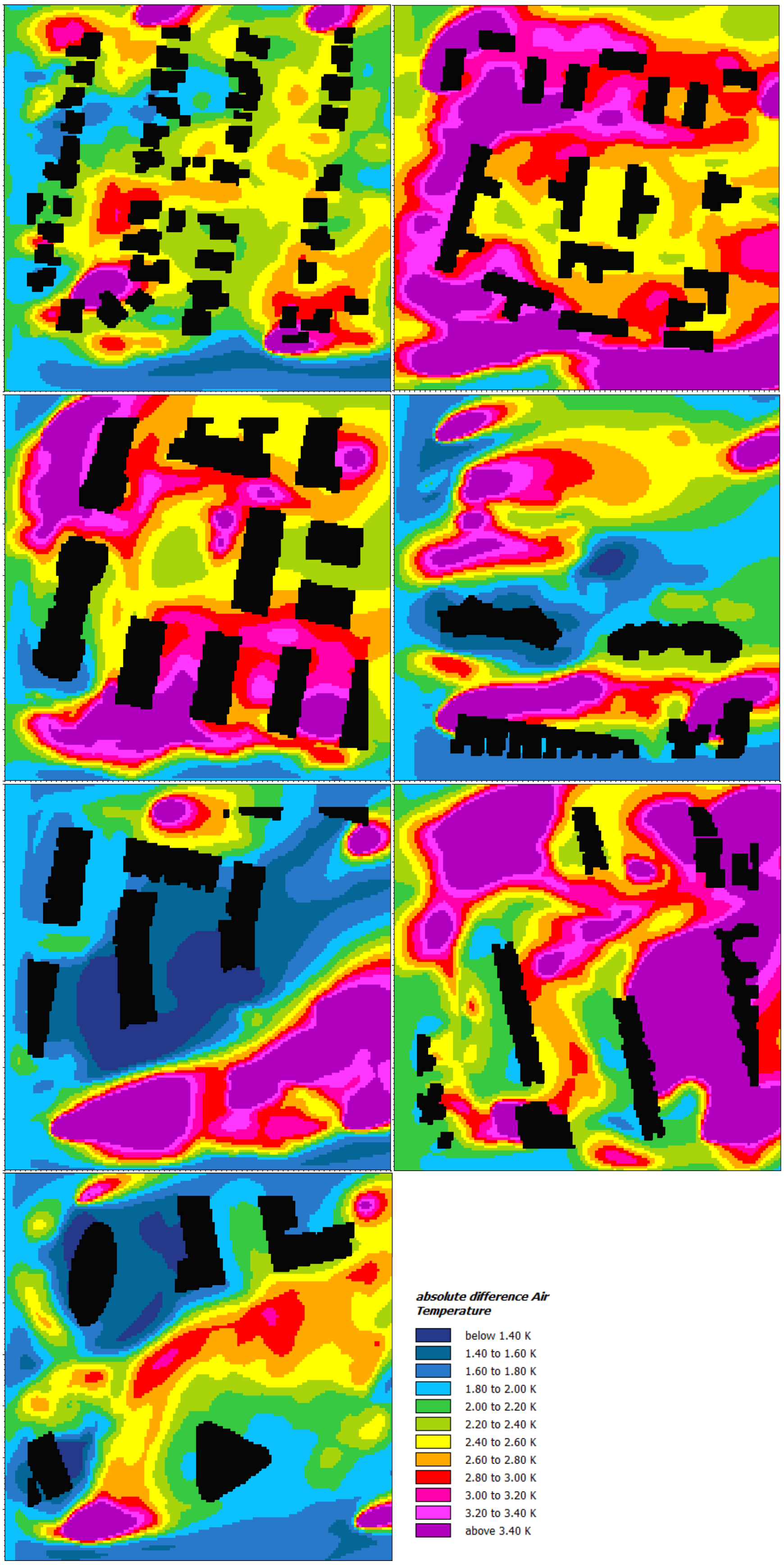


Figure 125 The ambient temperature difference distribution map in OT precincts

Surface temperature comparison maps

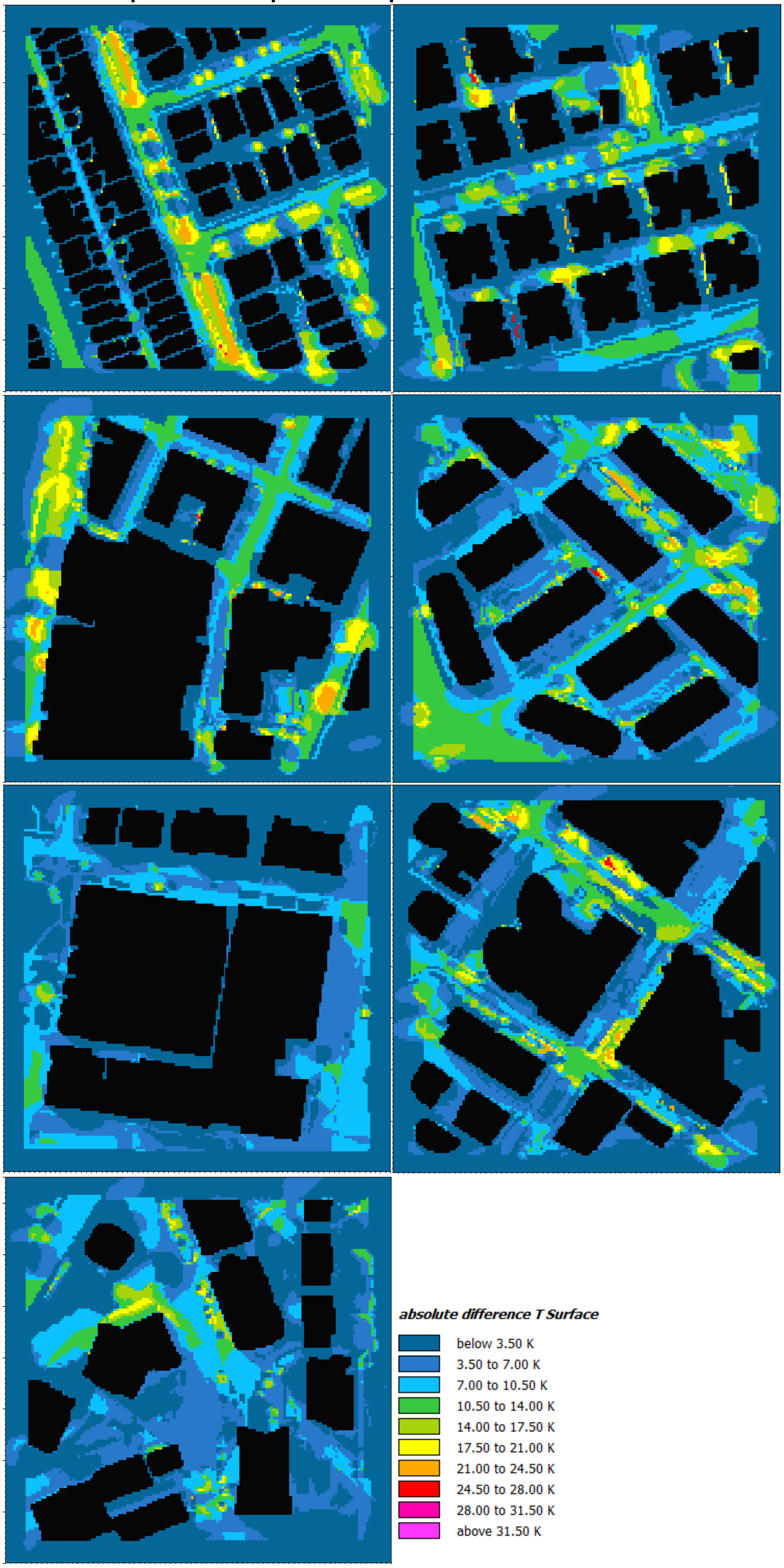


Figure 126 The surface temperature difference distribution map in CT precincts

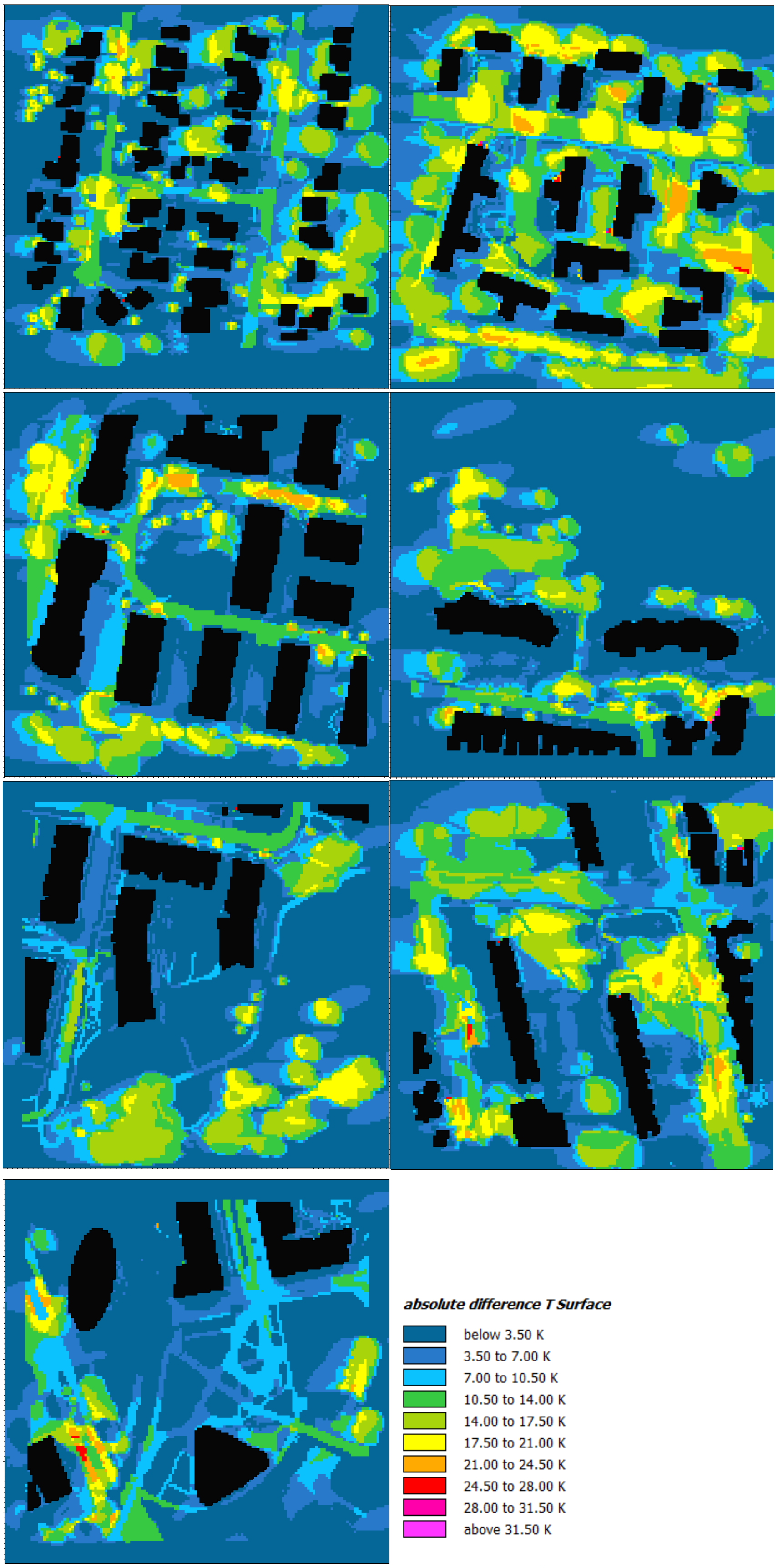


Figure 127 The surface temperature difference distribution map in OT precincts

PET comparison maps

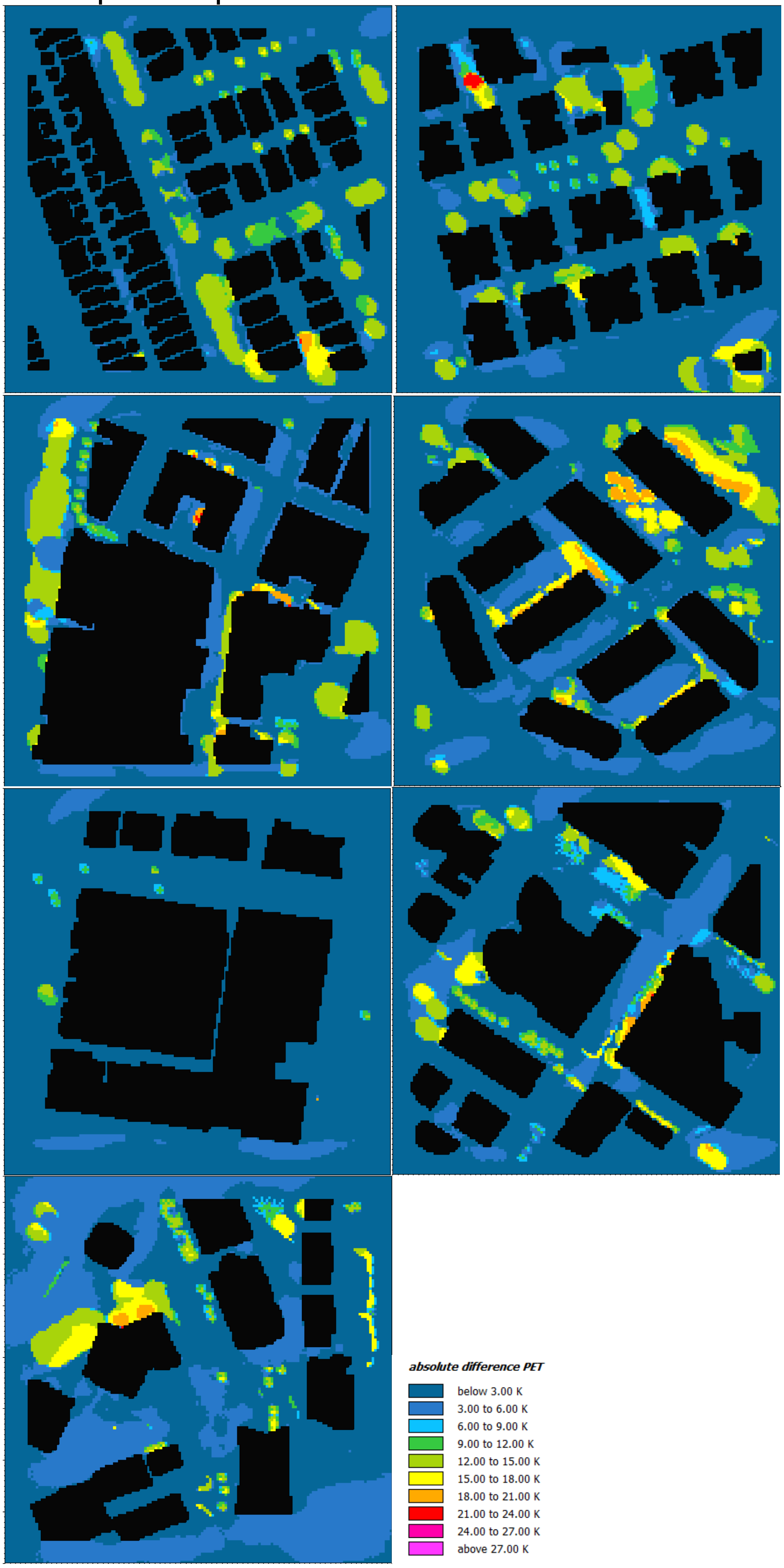


Figure 128 The thermal comfort (PET) difference distribution map in CT precincts

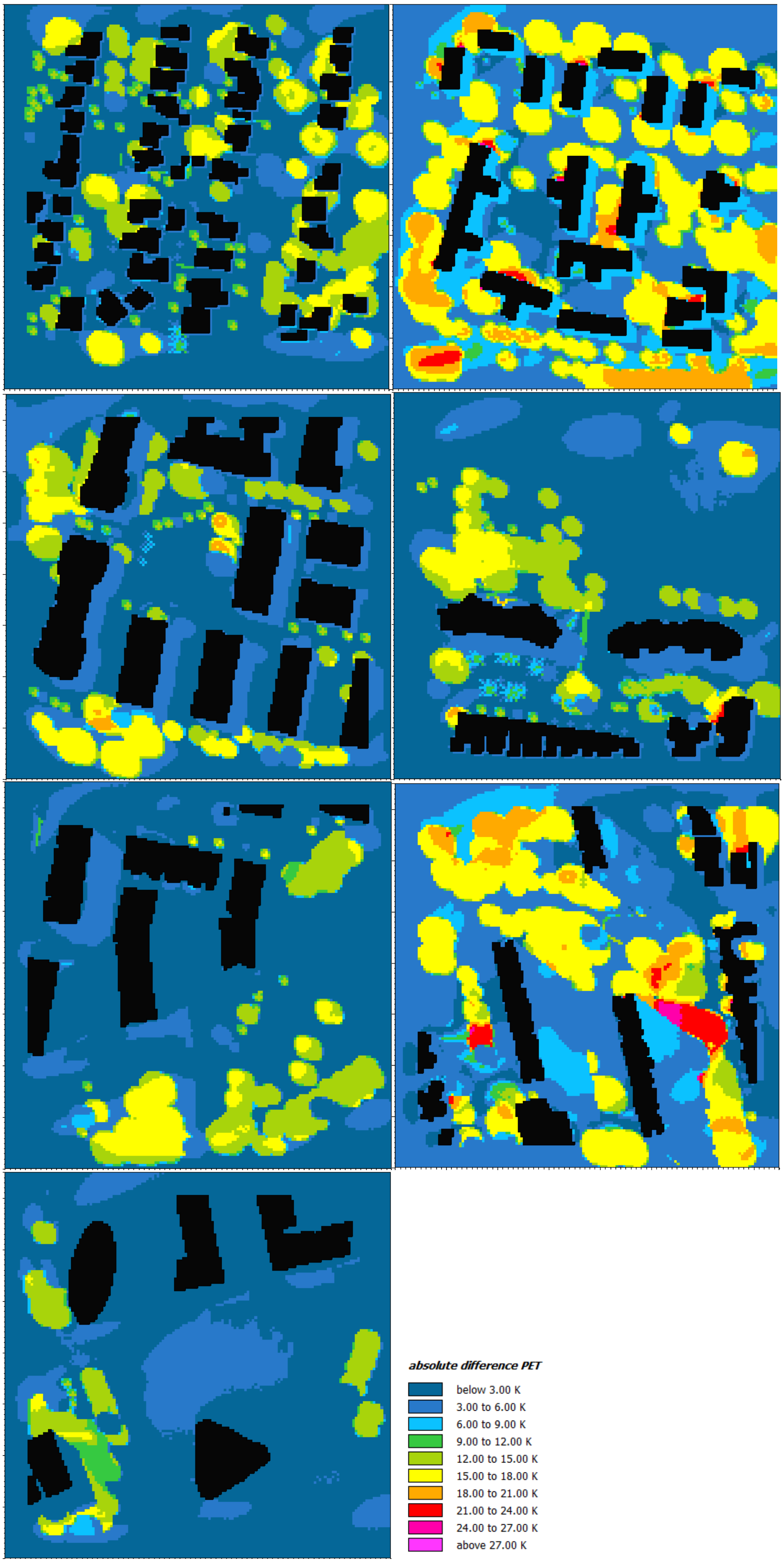


Figure 129 The thermal comfort (PET) difference distribution map in OT precincts

References

[1] Santamouris, M, (2014), On the energy impact of urban heat island and global warming on buildings, Energy and Buildings, Volume 82, pp. 100-113, ISSN 0378-7788

[2] Santamouris, M, (2015), Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions, Science of the Total Environment 512–513, pp.582–598

[3] Akbari, H. et al. (2015), Local climate change and urban heat island mitigation techniques – the state of the art. J. Civ. Eng. Manag. 22, pp.1–16

[4] M. Santamouris, L. Ding, F. Fiorito, P. Oldfield, P. Osmond, R. Paolini, D. Prasad, A. Synnefa (2016), Passive and active cooling for the outdoor built environment – Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects, Solar Energy, Available online 19 December 2016,

[5] Rosenfeld, A., J. J. Romm, H. Akbari, and M. Pomerantz, (1998), Cool communities: Strategies for heat islands mitigation and smog reduction. Energy Build., 28, 51–62

[6] Taha, H., S. Konopacki, and S. Gabersek, (1999), Impacts of large-scale surface modifications on meteorological conditions and energy use: A 10-region modeling study. Theor. Appl. Climatol., 62, 3–4. 175–185.

[8] Fiala, D., Havenith, G., Bröde, P., Kampmann, B., & Jendritzky, G. (2012). UTCI-Fiala multi-node model of human heat transfer and temperature regulation. International Journal of Biometeorology, 56(3), 429-441.

[9] Havenith, G., Fiala, D., Błazejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamaki, H., Benshabat, Y. and Jendritzky, G., (2012), The UTCI-clothing model. International journal of biometeorology, 56(3), pp.461-470.

[10] Gagge, A., Stolwijk, J., and Nishi, Y. (1971), An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Trans., 77(1):247–262.

[11] Höppe, P. (1999), The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. - International Journal of Biometeorology 43, 71-75.

[12] Fanger, P. O. (1982). Thermal Comfort. Analysis and Application in Environment Engineering. McGraw Hill Book Company, New York.

[13] Hossain, M. M., & Gu, M, (2016), Radiative cooling: Principles, progress, and potentials. Advanced Science, 3(7), 1500360.

LOW CARBON LIVING CRC

6. ANALYSIS

Introduction

This chapter provides detailed analysis of the temperature, wind speed and comfort along the precinct. To evaluate the cooling potential of each of the 14 considered precincts, a new parameter called 'Gradient of the Temperature Decrease along the Precinct Axis', GTD. The parameter measures the average temperature decrease along the X or the Y axis of the canyon, (Figure 130), closer to the wind direction. In the reference wind configuration used in the present study, the angle φ with the X axis is lower that the Θ angle with the Y axis, thus GTD is calculated along the X axis.

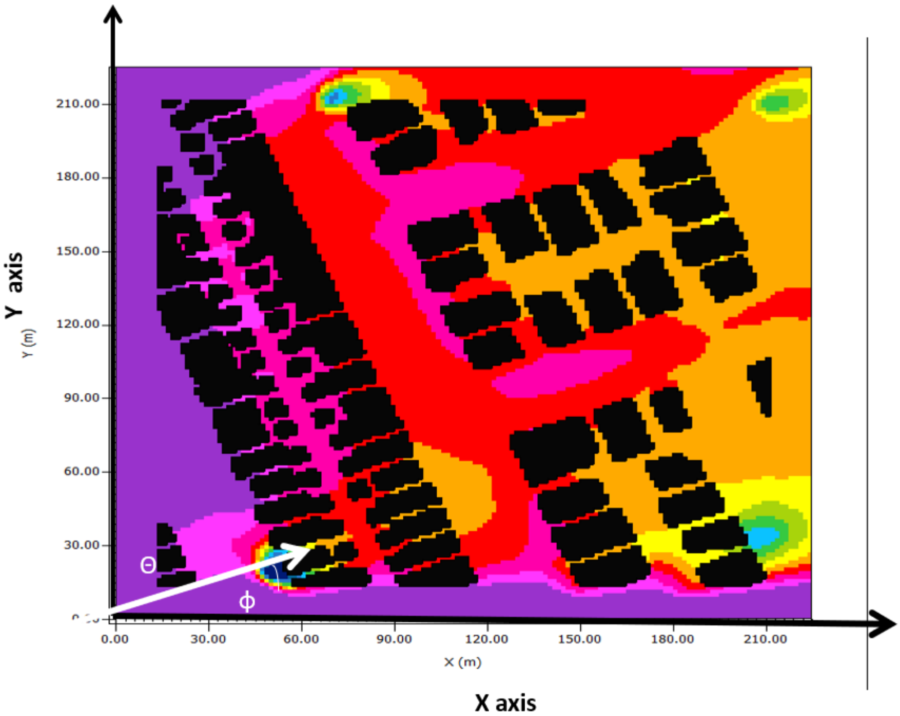


Figure 130 calculation of CTD and presentation of X or the Y axis of the canyon

Calculations of the climatic and other parameters for each precinct are performed for a grid of 224 x 224 Cells. For each parameter, W, its average value $W(Xi, Y_{1\text{-}224})$ corresponding to one X cell and all the 224 Y cells of the same X value is calculated. For example, for the cell X=3, the sum of the W values corresponding to cells with X=3 and Y = 1 to 224, is calculated, and divided by 224. In case cells did not include numerical values of the parameter W (because the area is covered by buildings), then the corresponding cells were not considered.

The GTD for the average distribution of ambient temperature, and wind speed, is calculated along the axis X. The GTD(x), is calculated as the average difference between the initial and the final value of the ambient temperature along the canyon axis:

$$GTD(x)= [T(_{average\ x=1}) - T(_{average\ x=224})] / 224$$

GTD(x) counts for the temperature decrease along the X axis per meter of length of the precinct and expresses the potential of the precinct to mitigate the ambient overheating along the axis closer to the wind direction.

The same procedure is followed considering that precincts with mitigation and without any mitigation.

CT1

Ambient temperature along the precinct of CT1 is shown in Figure 131 and Figure 132. The gradient of temperature decrease along the precinct is 0.10 °C / 10 meters.

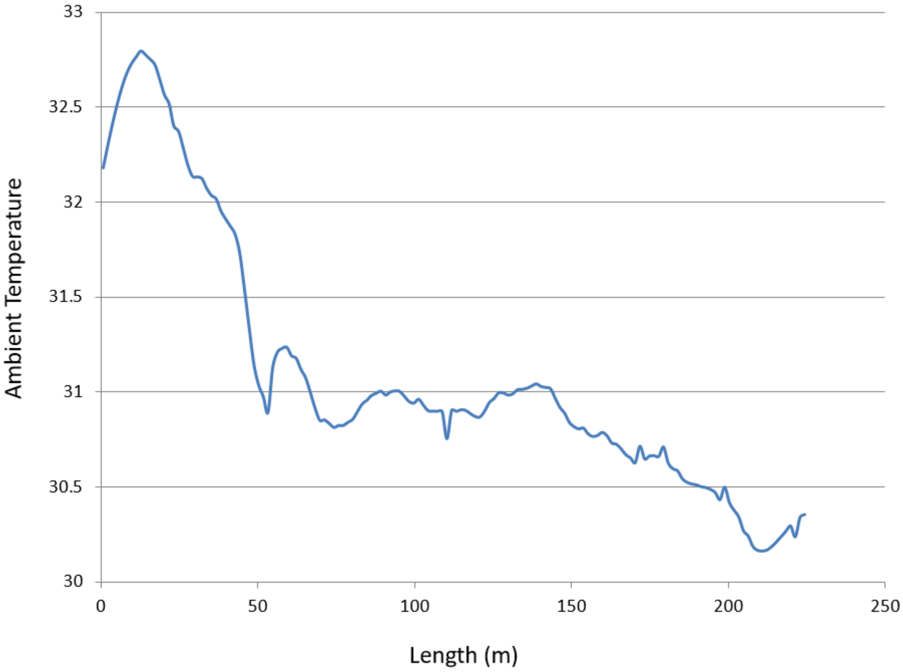


Figure 131 CT1 – Ambient Temperature Along the Precinct: Gradient Temperature Decrease: 0.11 °C / 10 meters

Figure 132 CT1 – Ambient Temperature Along the Precinct

Figure 133 and Figure 134 present the ambient temperature along the precinct plotted on the simulation domain and the temperature distribution map, respectively.

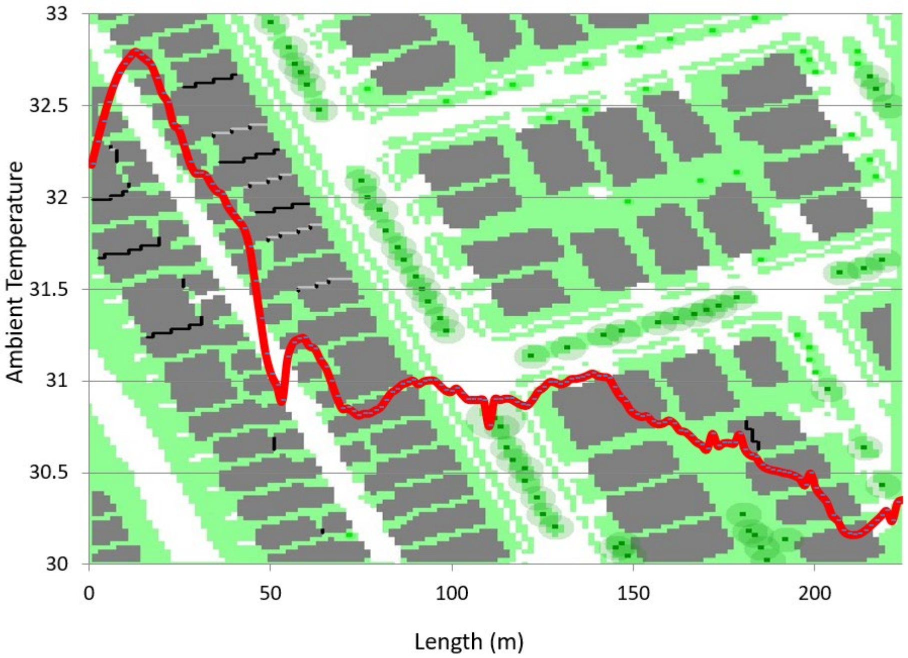


Figure 133 CT1 – Ambient Temperature Along the Precinct: plotted on the simulation domain

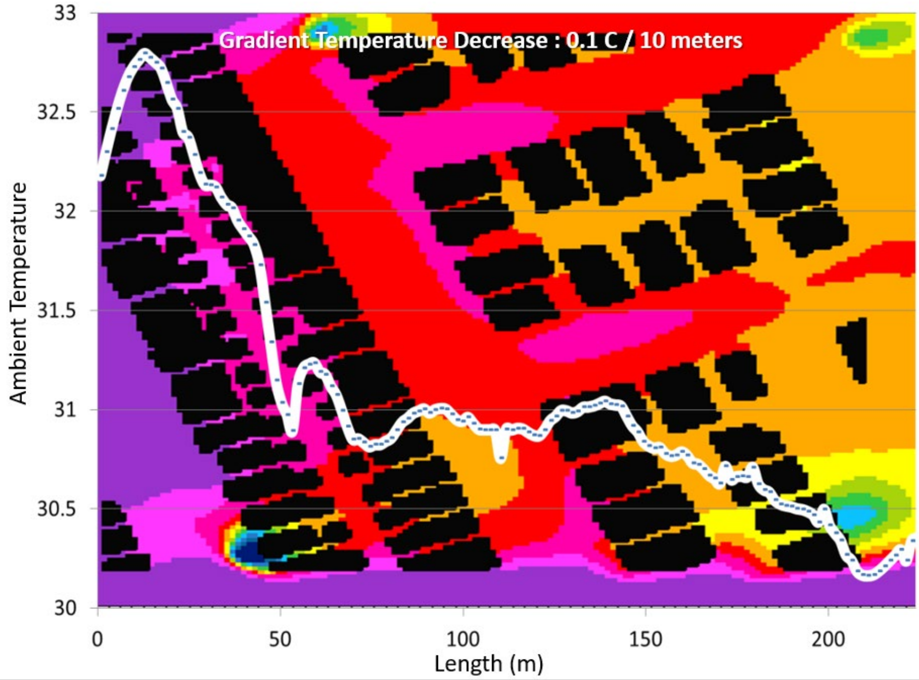


Figure 134 CT1 – Ambient Temperature Along the Precinct-Mitigated: plotted on the temperature distribution map

Figure 135 shows the temperature distribution in the mitigated and non-mitigated CT1 while Figure 136 compares the ambient temperature along the precinct in the mitigated and non-mitigated CT1.

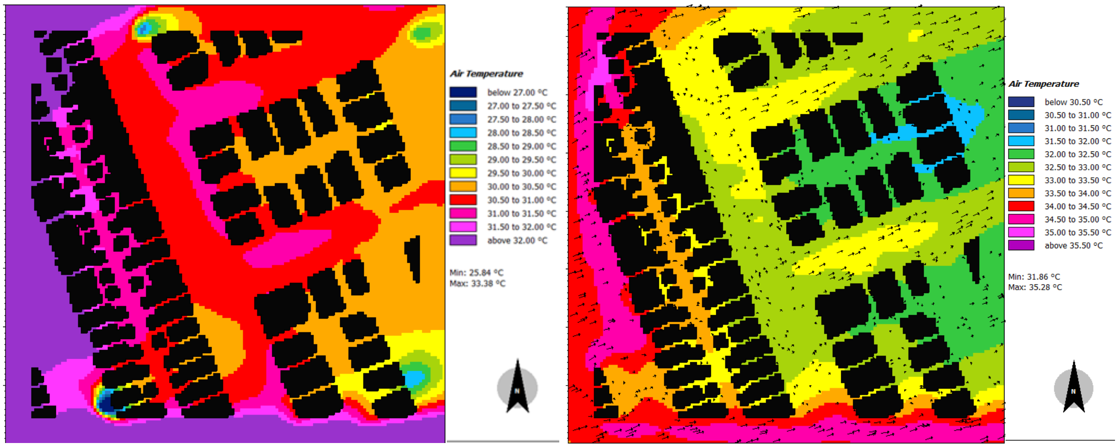


Figure 135 Temperature distribution in the mitigated (left) and non-mitigated (right) CT1

As shown here, the average gradient of the temperature decrease along the precinct is close to 0.10 °C/10m, while for the unmitigated case is lower, 0.093 °C/10m.

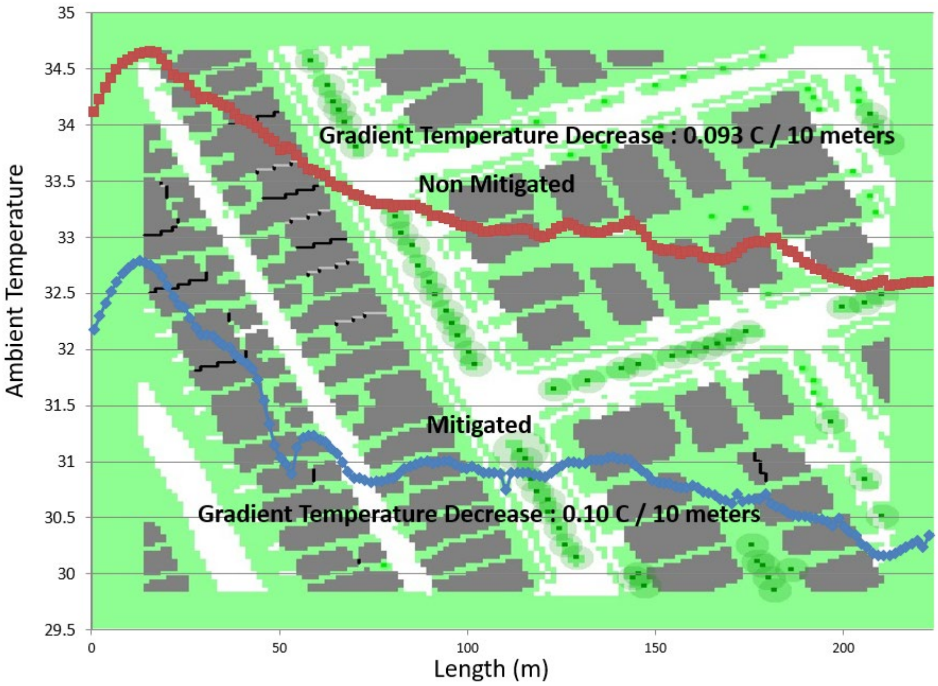


Figure 136 CT1 – Ambient Temperature Along the Precinct: comparison between mitigated and non-mitigated CT1

Figure 137 illustrates the ambient temperature difference distribution map.

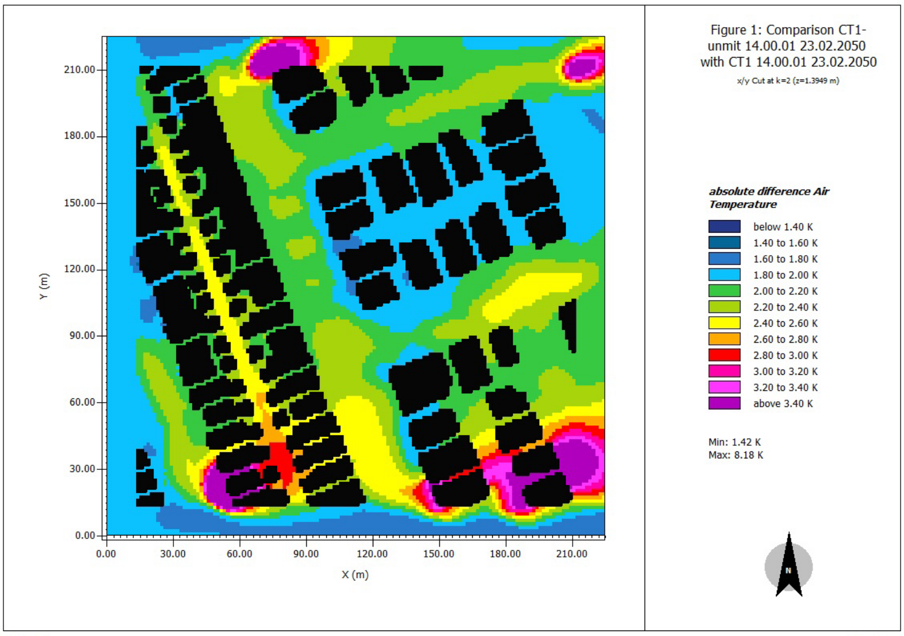


Figure 137 CT1 – Ambient Temperature Difference (Non-Mitigated – Mitigated) Along the Precinct

Figure 138 and Figure 139 present the wind speed and thermal comfort along the precinct plotted on the wind speed and thermal comfort (PET) distribution maps, respectively.

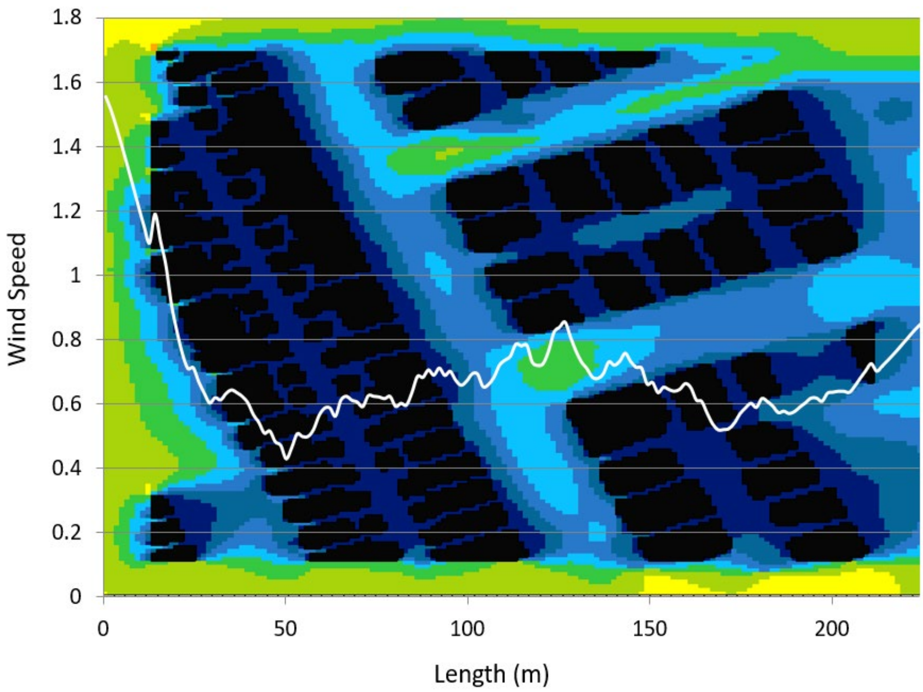


Figure 138 CT1 – Wind Speed Along the Precinct-Mitigated: plotted on the wind speed distribution map

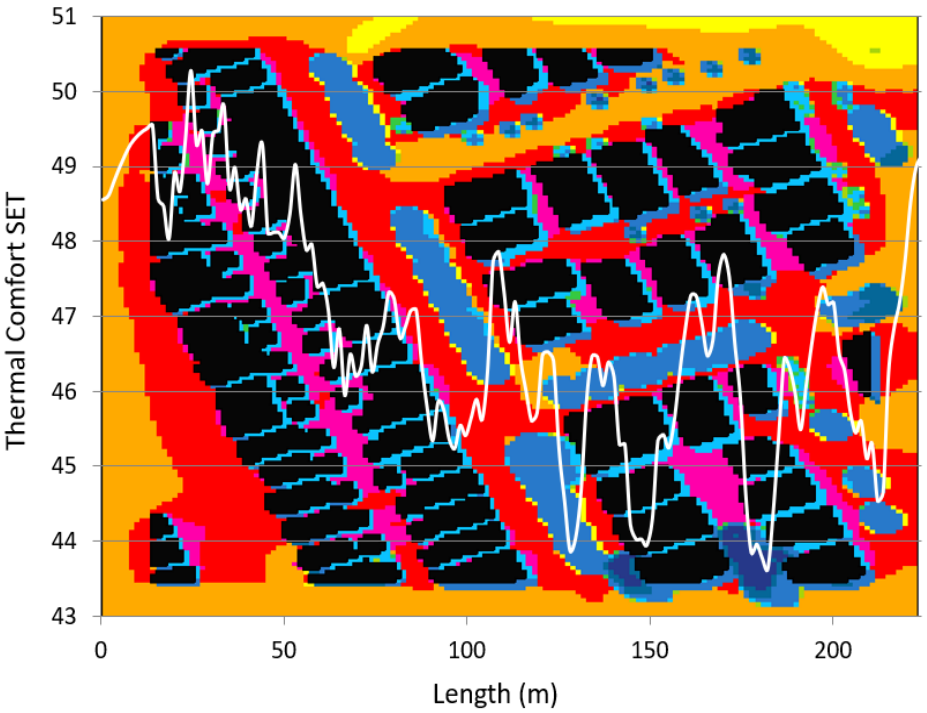


Figure 139 CT1 – Thermal Comfort Along the Precinct-Mitigated: plotted on the PET distribution map

Figure 140 shows the wind speed and temperature along the precinct (CT1).

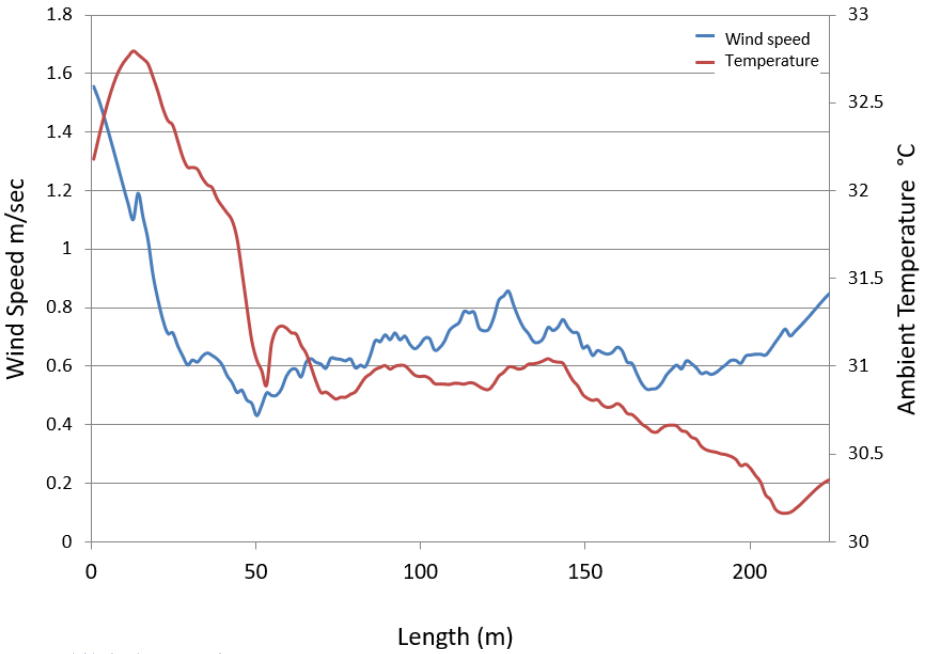


Figure 140 CT1 – Wind Speed and Temperature Along the Precinct-Mitigated

The climatic conditions in the CT1 precinct can be classified in four distinguished zones as depicted in Figure 141.

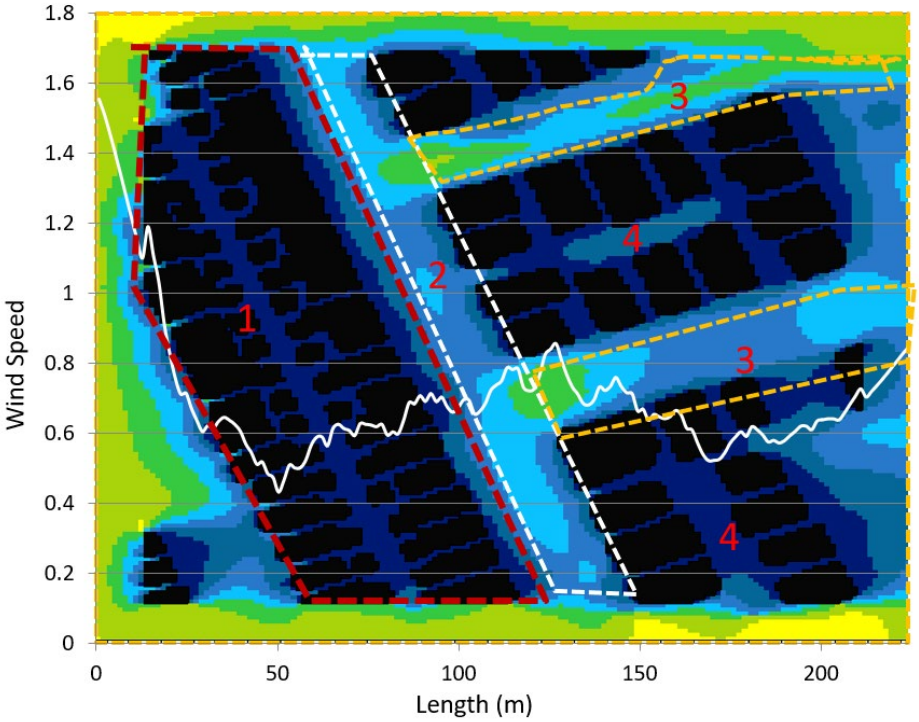


Figure 141 Four distinguished zones in CT1

Zone 1: Flow vertical to the axis of the canyon.

- Aspect ratio (h/w) =1.33 corresponds to skimming flow. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.29 m/sec. However, there is an advection of hot air in the small streets between the buildings.
- The average ambient temperature in the canyon is close to 31.5 °C which corresponds to a gradient of temperature decrease close to 0.019 °C /m.
- Because of the orientation of the canyon, and the low height of building, solar radiation reaches the ground of the canyon and the surface temperature is high and between 39 to 45 °C.
- Thermal Comfort is not at acceptable levels, PET above 52 °C.

Zone 2: Flow vertical to the axis of the canyon.

- h/w =0.27 corresponds to an isolated roughness flow. The ambient air flows reach the ground just after the leeward part of the eastern buildings. The average wind speed in the canyon is around 0.75 m/sec. Corner vortices of higher wind speed are developed in the intersections with the vertical streets
- The average ambient temperature in the canyon is between 30 to 30.5 °C while there is no temperature decrease across the street. The impact of trees on the ambient temperature is not apparent but compared against the non-mitigated case, trees extend the area of low temperature in almost all the surface of the canyon. On the contrary there is a slight increase because of the flow of warm air in windward façade of the western buildings
- Because of the orientation of the canyon, and the low height of building, solar radiation reaches the ground of the canyon and the surface temperature in the non-shaded part is high between 39 to 42°C. In the part shaded by the trees the surface temperature is much lower and between 27 to 30 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 38 °C, while in the non-shaded part is close to 51 °C.

Zone 3: Flow parallel to the axis of the canyon.

- h/w =0.37 and higher corresponds to a flow along the canyon axis. The average wind speed in the canyon is around 1.1 m/sec. Wind speed is higher at the middle of the road that close to the edges of the buildings
- The average ambient temperature in the canyons is between 31.5 to 30.5 °C while the average temperature decrease across the street is around 0.007 °C/m. The impact of trees on the ambient temperature quite clear.
- Because of the high aspect ratio of the canyons, solar radiation reaches the ground of the canyons and the surface temperature in the non-shaded part is high between 39 to 42 °C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 37 °C, while in the non-shaded part is between 47 to 51 °C.

Zone 4: Flow vertical to the axis of the small streets separating the buildings.

- h/w =1.6 corresponds to skimming flow. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.29 m/sec.
- The average ambient temperature in the canyon is between 30- 31 °C which corresponds to a gradient of temperature decrease close to 0.013 °C /m.
- Because of the low aspect ratio of the canyons and the corresponding shading by the buildings solar radiation is not reaching the ground of the canyon and the surface temperature is quite low and between 27 to 33 °C.
- Thermal comfort conditions in the low aspect ratio canyons is acceptable but it worsens once the aspect ratio is decreasing.

General Comments:

The average gradient of the temperature decrease along the precinct is close to 0.010 °C/m, while for the unmitigated case is lower, 0.0093 °C/m. This is the highest temperature decrease for all the studied precincts. This is mainly because of the very rapid decrease of the temperature at the 50 m of the precinct where the wind speed is tremendously reduced because of the low aspect ratio and the orientation perpendicular to the wind of the front canyons. Once the aspect ratio increases, and the flow is along the canyon axis, the decrease of the temperature is limited. In general, for the specific precinct, there is a quite strong relation of the wind speed with the ambient temperature. The higher the wind speed the higher the advection of heat and the higher the ambient temperature. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

CT2

The ambient temperature along the precinct of CT2 with mitigation is shown in Figure 142. The gradient of temperature decrease is 0.09 °C / 10 meters. Figure 143 and Figure 144 present the ambient temperature along the precinct (with mitigation) plotted on the simulation domain and temperature distribution map.

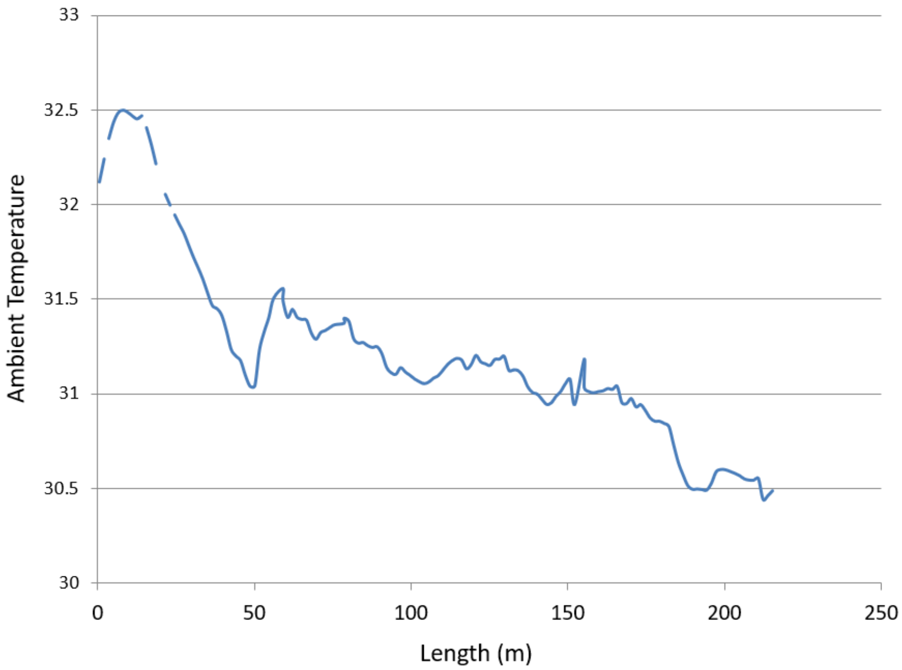


Figure 142 CT2 – Ambient Temperature Along the Precinct with Mitigation

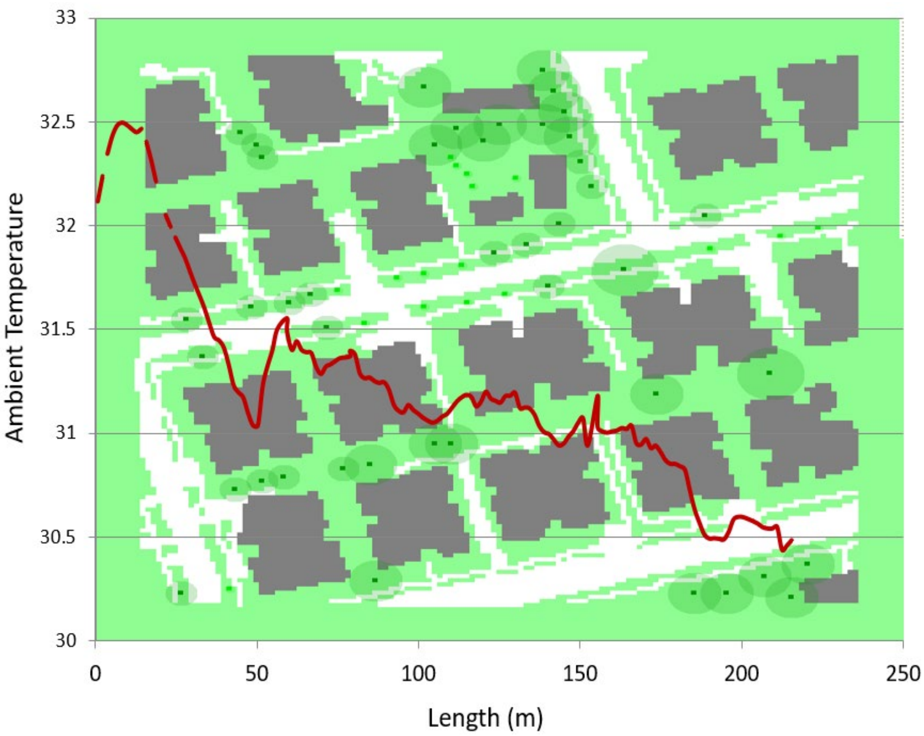


Figure 143 CT2 – Ambient Temperature Along the Precinct with Mitigation: plotted on the simulation domain

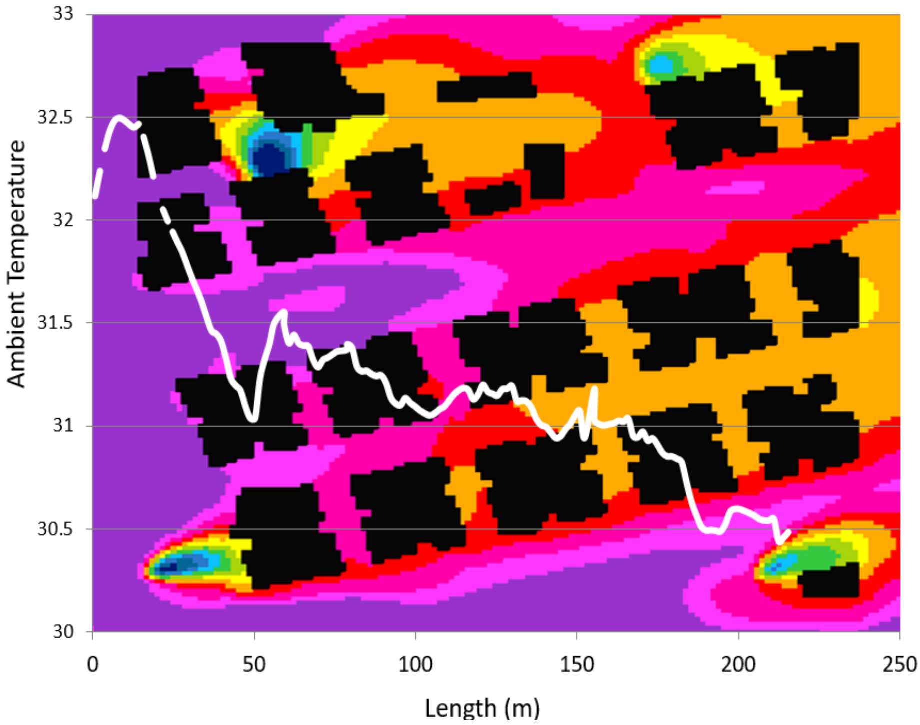


Figure 144 CT2 – Ambient Temperature Along the Precinct with Mitigation: plotted on the temperature distribution map

Figure 145 compares the ambient temperature along the precinct with and without mitigation.

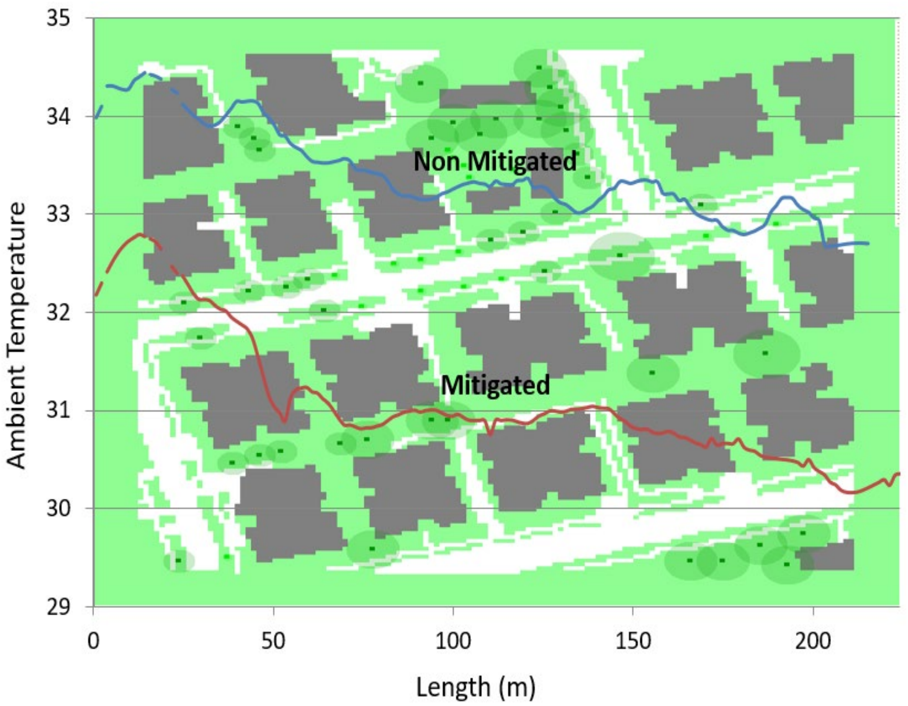


Figure 145 CT2 – Ambient Temperature Along the Precinct Mitigated and Non-Mitigated Scenarios

Figure 146 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

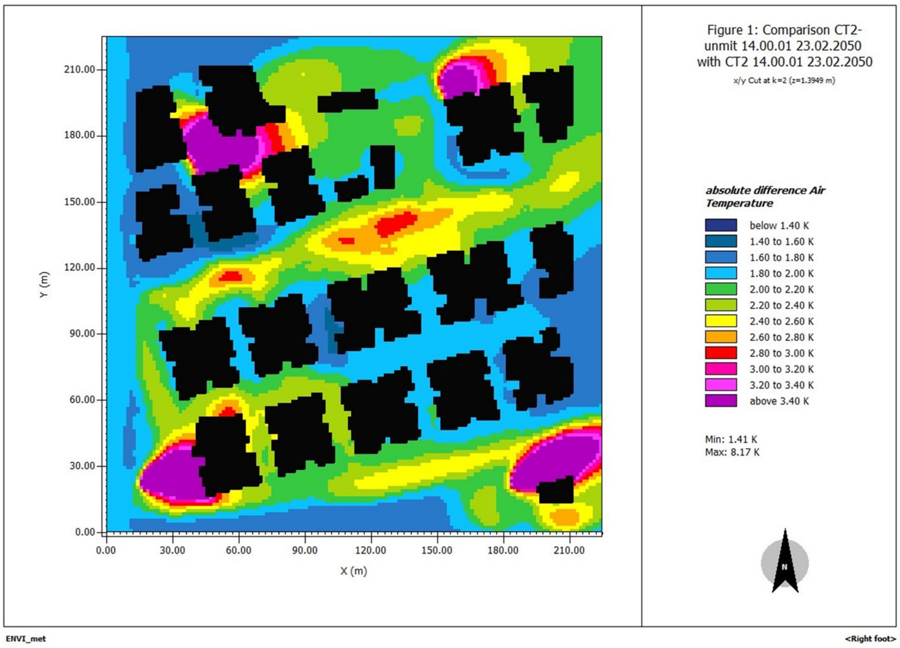


Figure 146 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 147 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

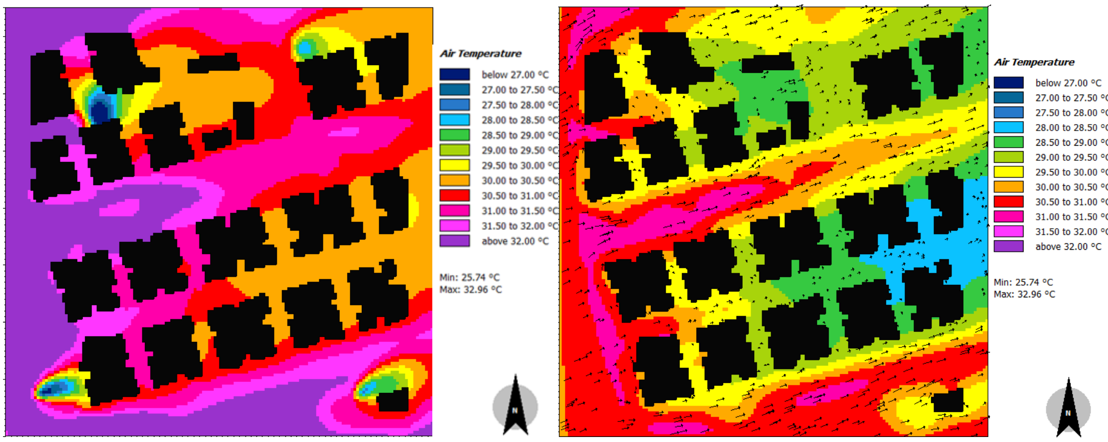


Figure 147 Temperature distribution in the mitigated (left) and non-mitigated (right) CT2

Figure 148 compares the ambient temperature along the precinct with and without mitigation.

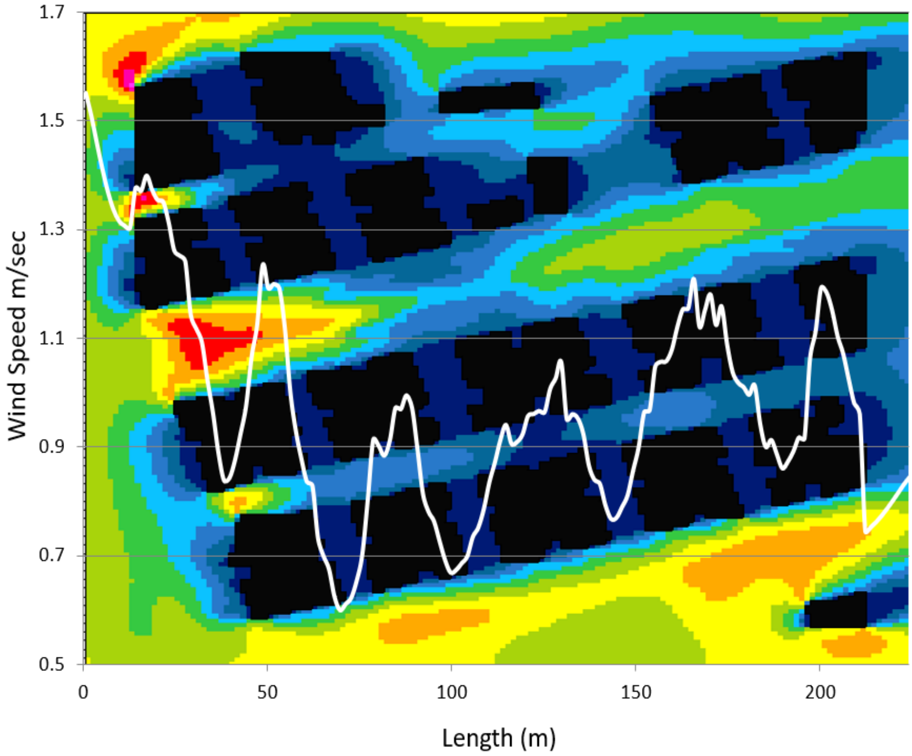


Figure 148 CT2 – Wind Speed Along the Precinct with Mitigation: plotted on the wind speed distribution map

Figure 149 shows the wind speed and temperature along the precinct (CT2).

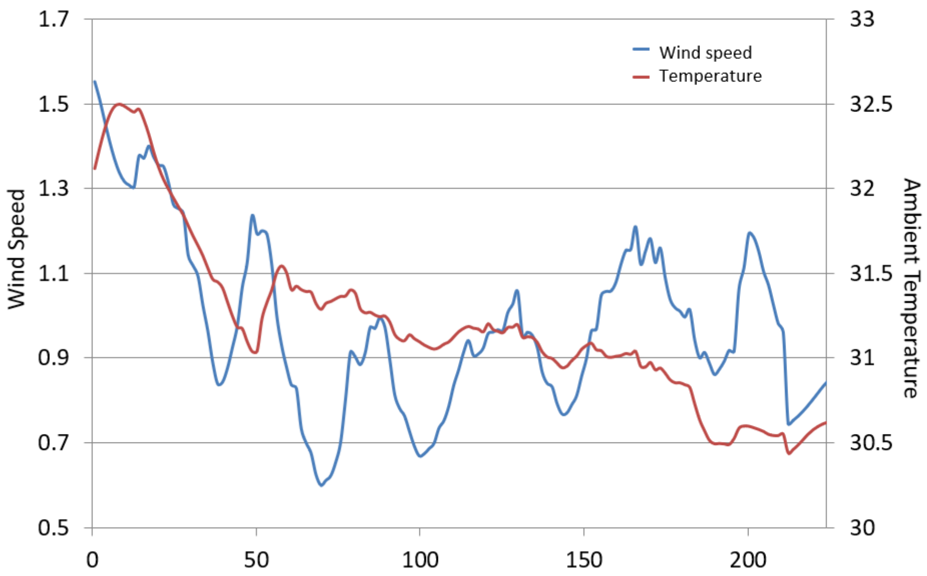


Figure 149 CT2 – Wind Speed and Temperature Along the Precinct with Mitigation

The climatic conditions in the precinct of CT2 can be classified in three distinguished zones as depicted in Figure 150.

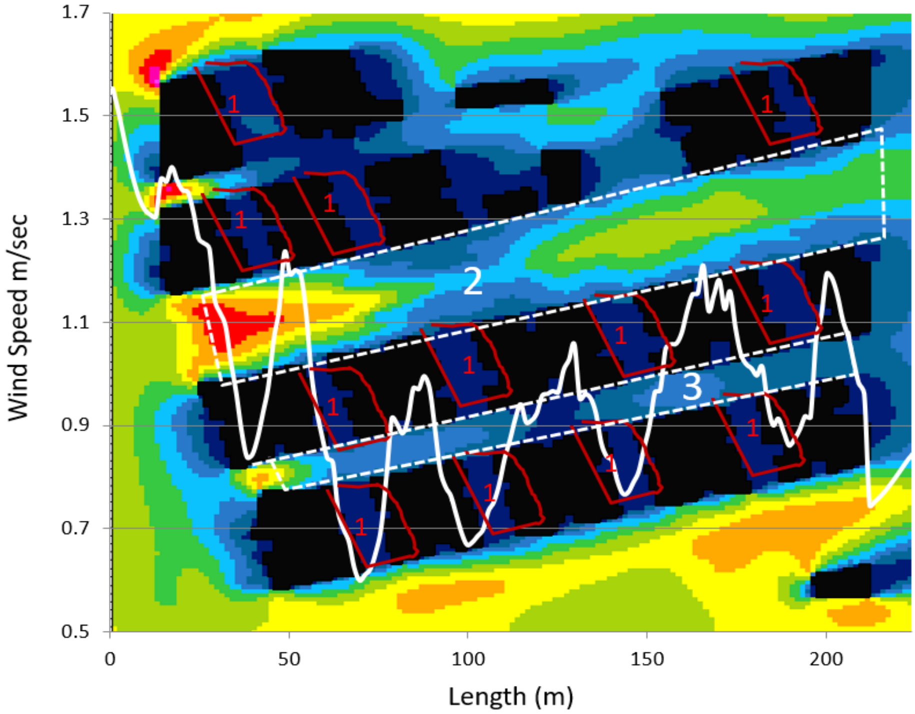


Figure 150 Three distinguished zones in CT2

Zone 1: Flow vertical to the axis of the canyon.

- h/w =1.77 corresponds to skimming flow. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.29 m/sec.
- The average ambient temperature in the canyons varies between 32 °C at the wind entry zone and decreases up to 30 °C at the end of the precinct. This corresponds to a cooling rate to 0.08 °C /m.
- Because of the orientation of the canyon, g, solar radiation reaches part of the ground of the canyons. In the shaded part of the canyons is close to 30 °C and increases up to 42 °C in the non-shaded parts.
- Thermal Comfort in the shaded parts is quite acceptable 39 °C, However, in the non-shaded part comfort levels are not acceptable PET=51 °C.

Zone 2: Flow parallel to the axis of the canyon.

- h/w =0.45 and higher corresponds to a flow along the canyon axis. The average wind speed in the canyon is around 1.4 m/sec. Wind speed is higher at the middle of the road that close to the edges of the buildings. An important increase of the speed is observed at the entry of the canyon.
- The average ambient temperature in the canyons is between 32 to 30.5 °C while the average temperature decrease across the street is around 0.007 °C/m. The impact of trees on the ambient temperature quite clear and contributes to the quite high cooling rate. Compared to the non-mitigation scenario, trees decrease the zone where high temperatures are penetrated into the canyon.
- Because of the high aspect ratio of the canyons, solar radiation reaches the ground of the canyons and the surface temperature in the non-shaded part is high between 39 to 42 °C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 37 °C, while in the non-shaded part is between 47 to 51 °C.

Zone 3: Flow parallel to the axis of the canyon.

- h/w =1,6 and higher corresponds to a quite weak flow along the canyon axis. The average wind speed in the canyon is around 1.4 m/sec. Wind speed is higher at the middle of the road that close to the edges of the buildings. An important increase of the speed is observed at the entry of the canyon.
- The average ambient temperature in the canyons is between 32 to 30 °C while the average temperature decrease across the street is around 0.008 C/m. The impact of trees on the ambient temperature quite clear.
- Because of the average aspect ratio of the canyon, solar radiation reaches part of the ground surface of the ground and the surface temperature in the non-shaded part is high between 39 to 45 °C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 35 °C, while in the non-shaded part is between 47 to 51 °C.

General Comments:

The average gradient of the temperature decrease along the precinct under the mitigation and non-mitigation scenarios are close to 0.0083 °C/m. and 0.0079 °C/m, respectively. The sections of the precinct of zone 1, contributes highly to increase the cooling gradient as they provide low advection and good solar protection. The zones 2 and 3 although are in parallel to the wind speed present a quite important cooling rate mainly because of the intensive planting considered. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

CT3

The ambient temperature along the precinct of CT3 with mitigation is shown in Figure 151. The gradient of temperature decrease is 0.077 °C / 10 meters.

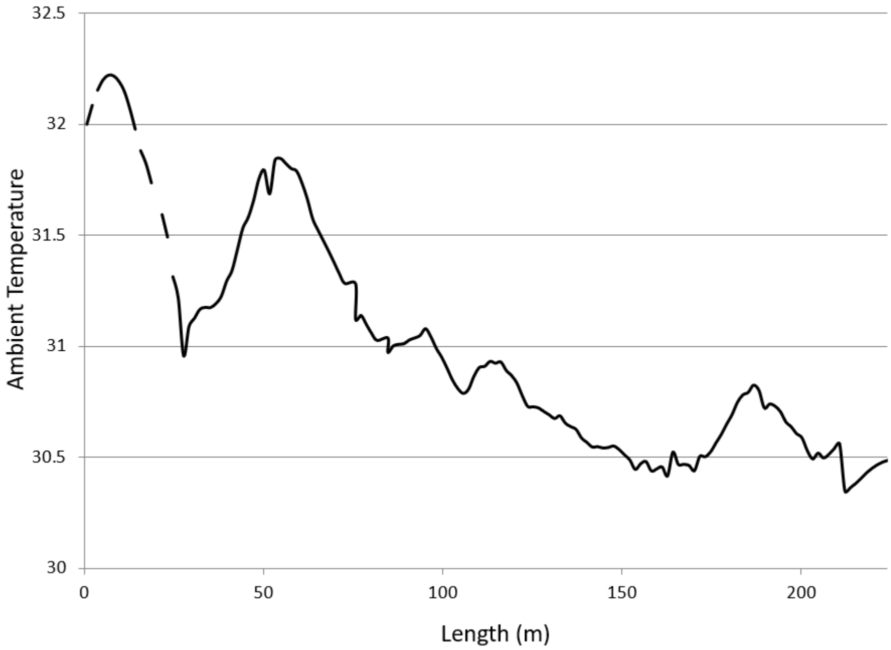


Figure 151 CT3 – Ambient Temperature Along the Precinct with Mitigation

Figure 152 and Figure 153 present the ambient temperature along the precinct plotted on the simulation domain and temperature distribution map.

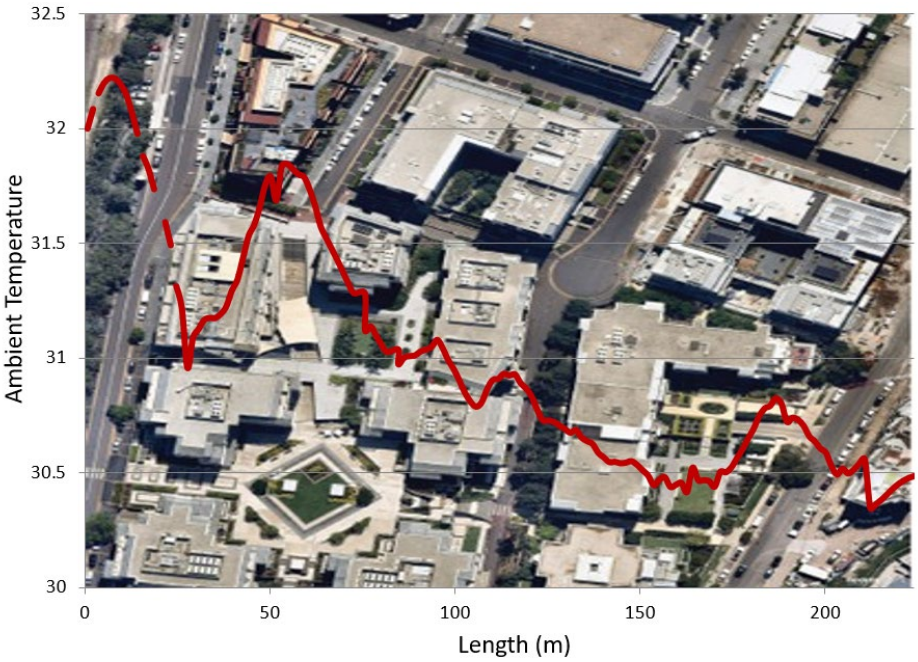


Figure 152 CT3 – Ambient Temperature Along the Precinct with Mitigation

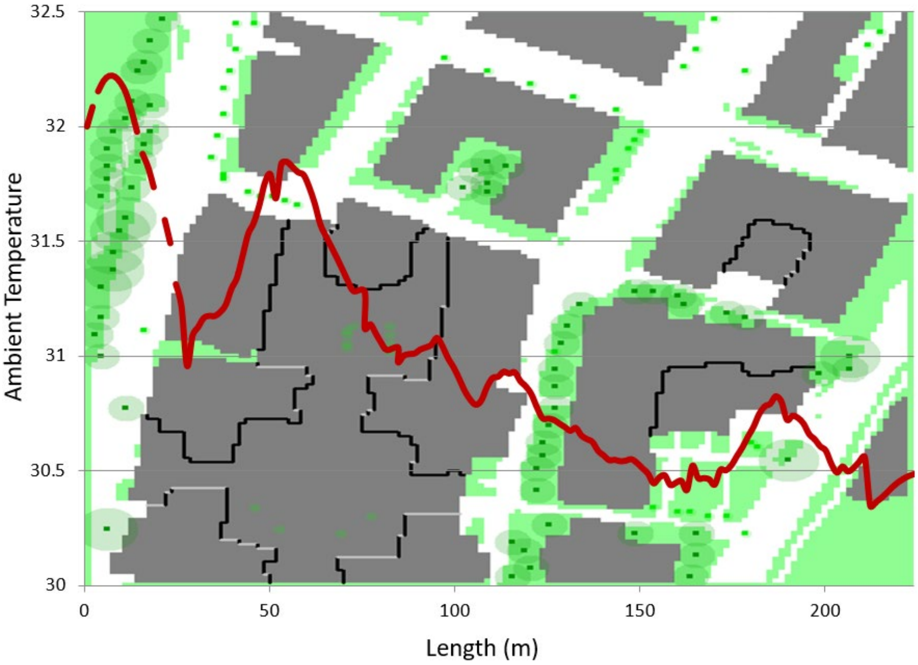


Figure 153 CT3 – Ambient Temperature Along the Precinct with Mitigation

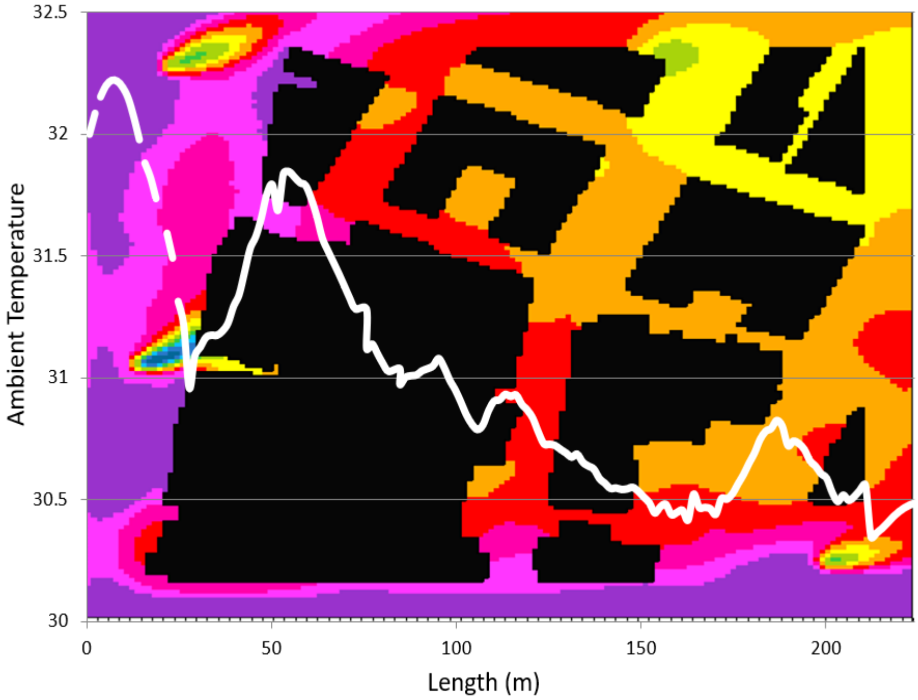


Figure 154 CT3 – Ambient Temperature Along the Precinct with Mitigation

Figure 155 compares the ambient temperature along the precinct with and without mitigation.

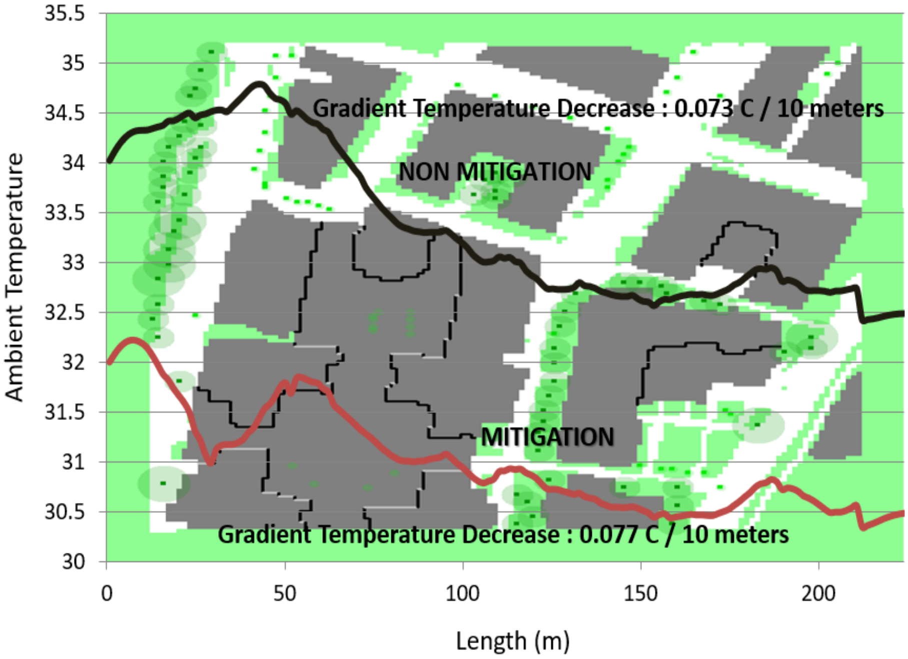


Figure 155 CT3 – Temperature Distribution along the precinct for the mitigation and non-mitigation Scenarios

Figure 156 illustrates the wind speed along the precinct with mitigation.

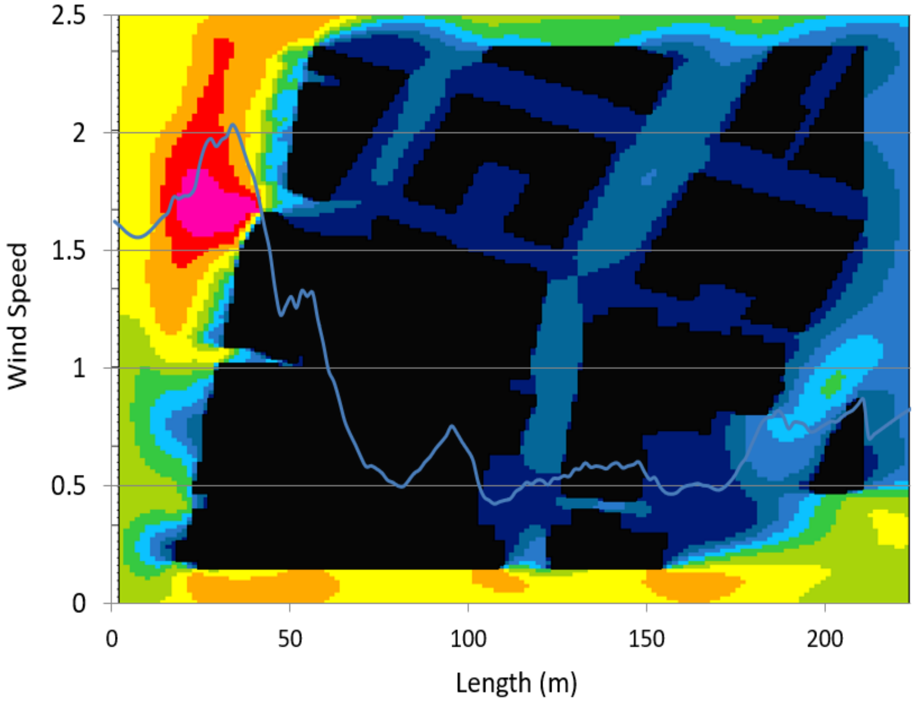


Figure 156 CT3 – Wind Speed Along the Precinct with Mitigation

Figure 157 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

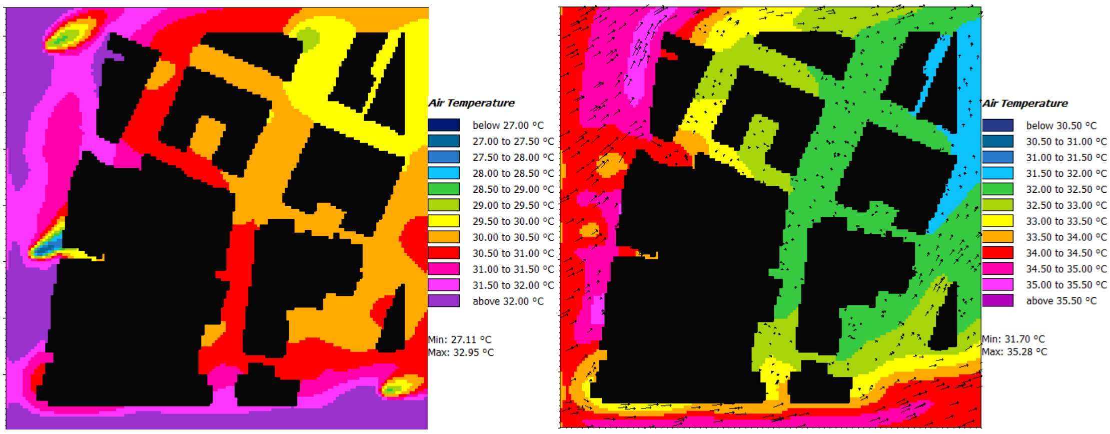


Figure 157 Temperature distribution in the mitigated (left) and non-mitigated (right) CT3

The climatic conditions in the CT3 precinct can be classified in two distinguished zones as depicted in Figure 158.

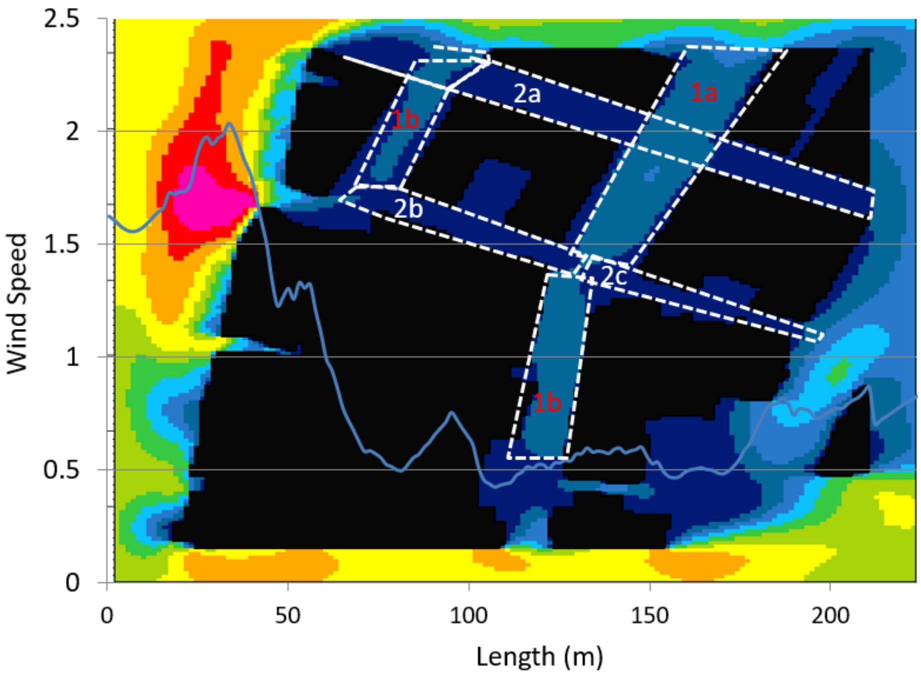


Figure 158 Two distinguished zones in CT3

Zone 1: Flow vertical to the axis of the canyon.

- The aspect ratio of zone 1a is equal to 1 and of the zone 1b is equal to 1.66 and the flow is skimming. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon 1a is close to 0.4 m/sec and in 1b is 0.3 m/sec.
- The average ambient temperature in the canyon 1a is varying between 29.5 °C and 30.5 °C to 31.5 °C, while in the canyon 1b is between 30-31 °C. Comparison against the non-mitigation scenario shows that trees contribute significantly to establish lower temperatures along the streets
- Because of the orientation of all the canyons, solar radiation reaches the ground of the canyon and the surface temperature in the non-shaded parts is high and close to 45 °C, while in the

shaded parts is below 30 °C. Thermal Comfort In the non-shaded parts is not acceptable PET=51 °C, and improves considerable PET=31 in the well shaded parts.

Zone 2: Flow parallel to the axis of the canyon.

- The aspect ratio in canyon 2a is 1.76, of 2b is 2.66 and of 2c is 2.7. The flow is along the canyon axis. The average wind speed in the canyons below 0.29 m/sec is around 1.1 m/sec. Wind speed is higher at the middle of the road that close to the edges of the buildings.
- The average ambient temperature in the canyons is between 31.0 to 30.0 °C while the average temperature decrease across the street is around 0.004 °C/m. The impact of trees on the ambient temperature quite clear.
- Because of the aspect ratio of the canyons, solar radiation reaches partly the ground of the canyons and the surface temperature in the non-shaded part is high between 39 to 45 °C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C. The canyon 2c is almost fully shaded because of the surrounding buildings. Thermal Comfort in the shaded zones improves considerably, PET around 35 °C, while in the non-shaded part is between 47 to 51 °C.

General Comments:

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.0077 °C/m. and 0.0073 °C/m. The sections of the precinct of zone 1, contributes highly to increase the cooling gradient as they provide low advection and good solar protection. The zone 2 although are in parallel to the wind speed present a low average wind speed and a quite significant cooling rate mainly because of the intensive planting considered. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

CT4

The ambient temperature along the precinct of CT4 with mitigation is shown in Figure 159 and Figure 160. The gradient of temperature decrease is 0.068 °C / 10 meters.

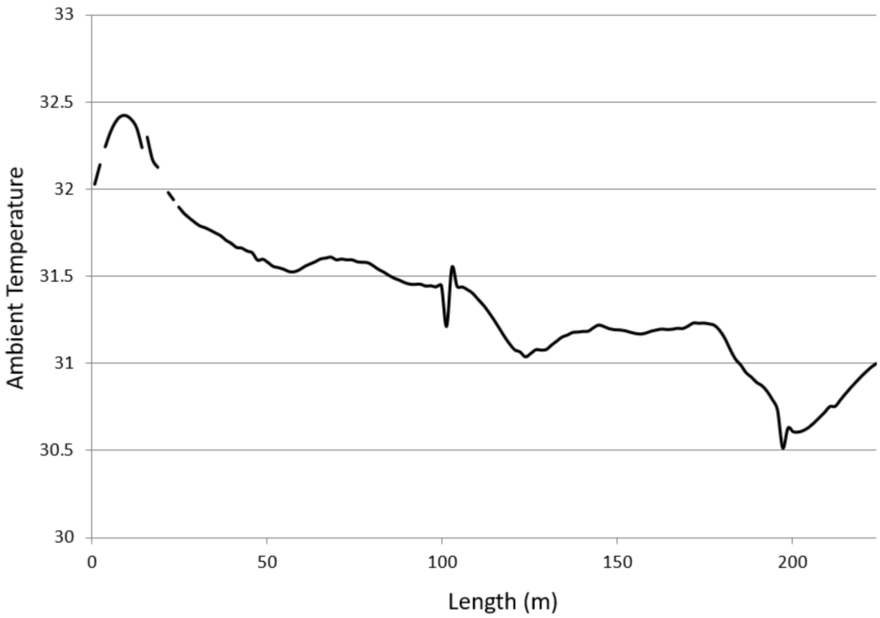


Figure 159 CT4 – Ambient Temperature Along the Precinct with Mitigation

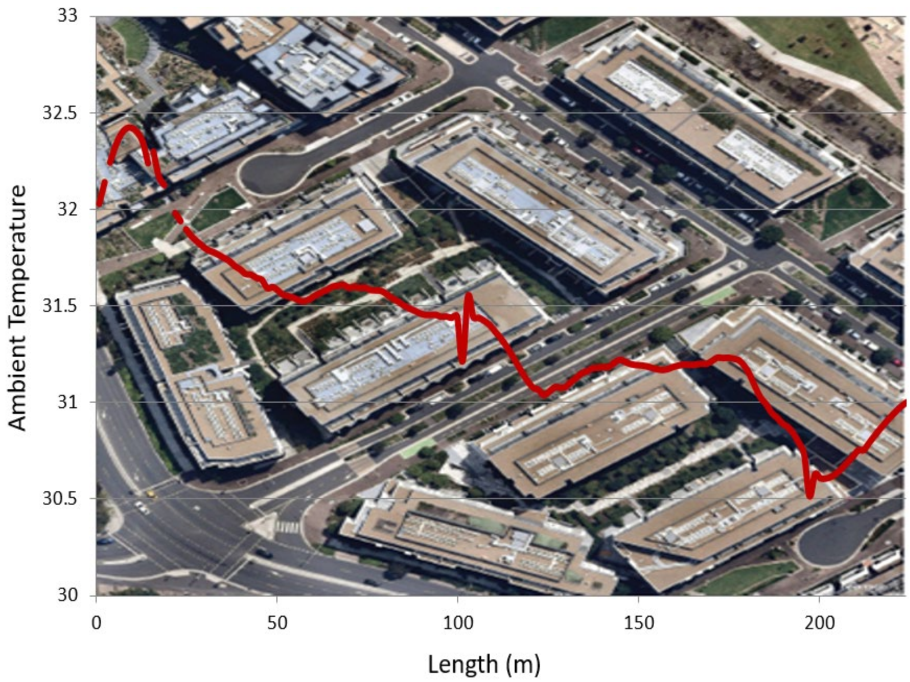


Figure 160 CT4 – Ambient Temperature Along the Precinct with Mitigation

Figure 161, Figure 162 and Figure 163 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

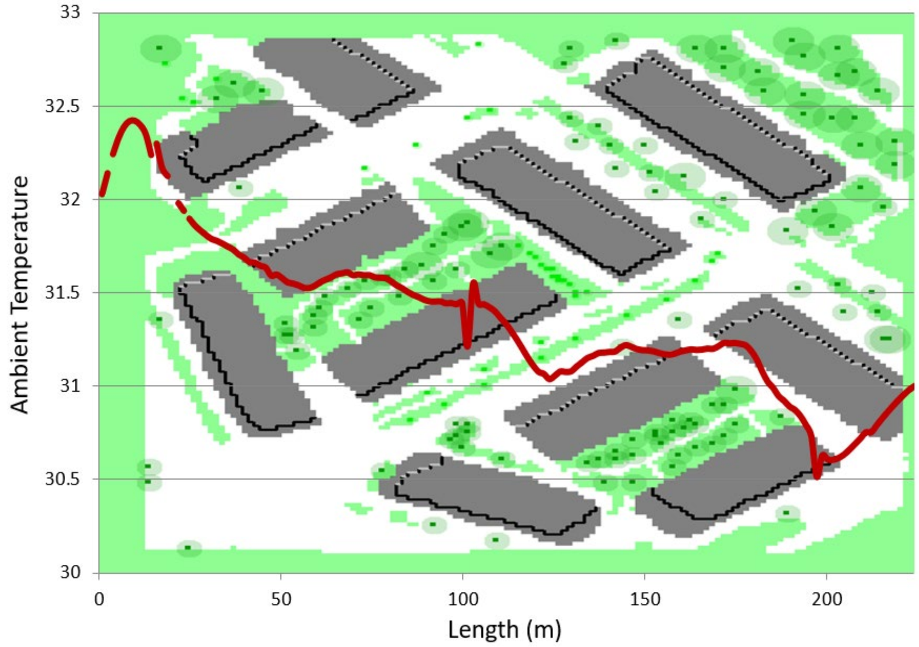


Figure 161 CT4 – Ambient Temperature Along the Precinct with Mitigation

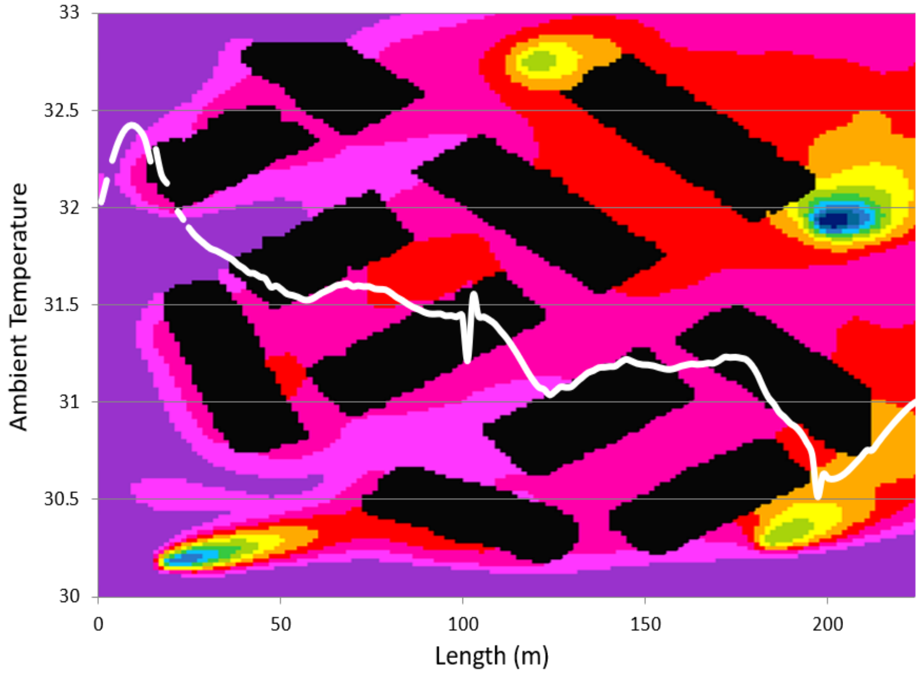


Figure 162 CT4 – Ambient Temperature Along the Precinct with Mitigation

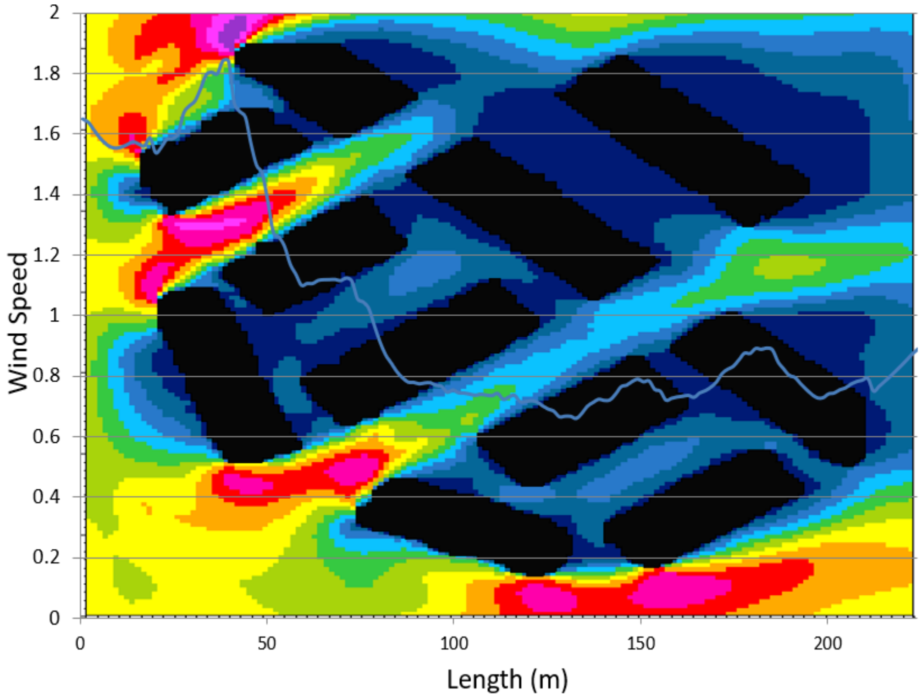


Figure 163 CT4 – Wind Speed Along the Precinct with Mitigation

Figure 164 compares the ambient temperature along the precinct with and without mitigation.

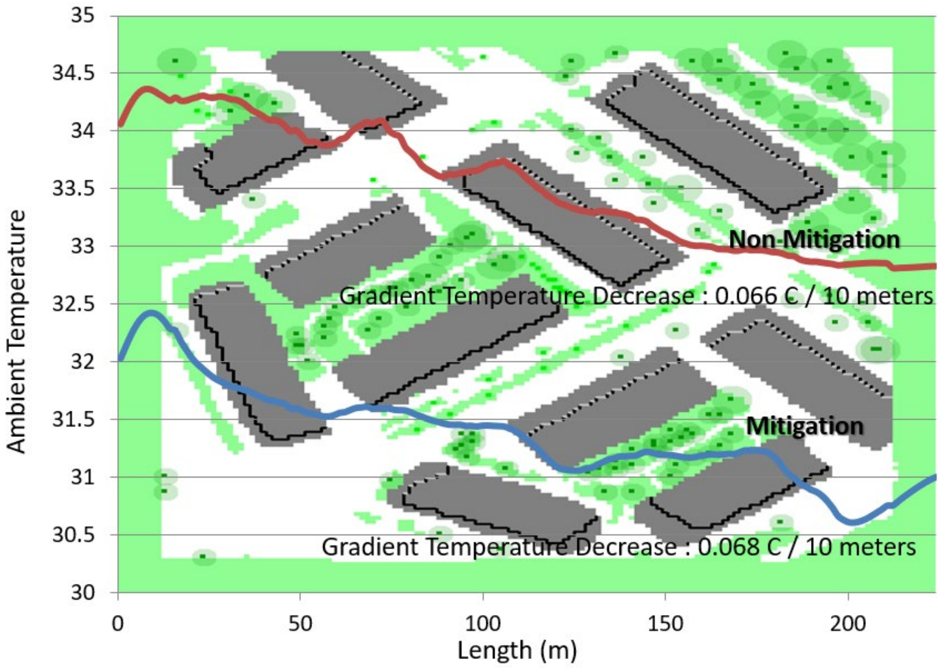


Figure 164 CT4 – Ambient Temperature Along the Precinct with and without Mitigation

Figure 165 shows the distribution of ambient temperature in CT4 with and without mitigation.

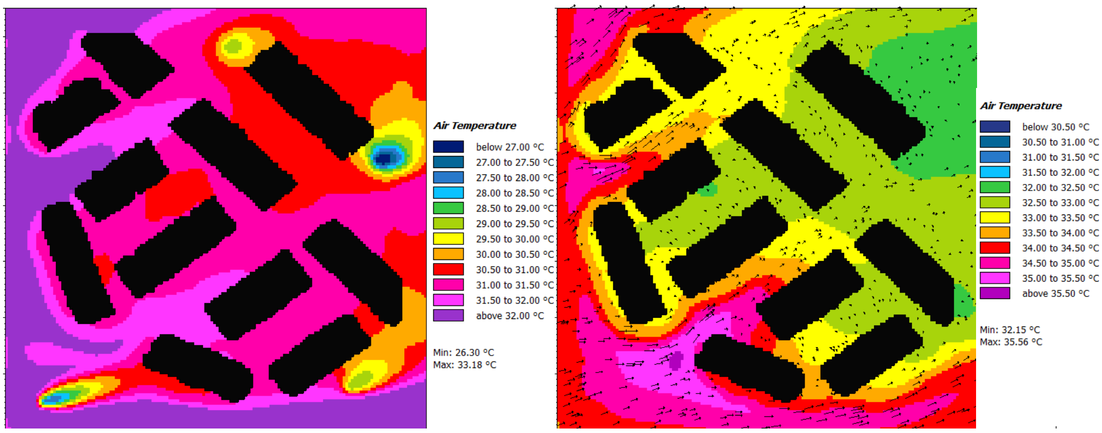


Figure 165 Temperature distribution in the mitigated (left) and non-mitigated (right) CT4

Figure 166 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

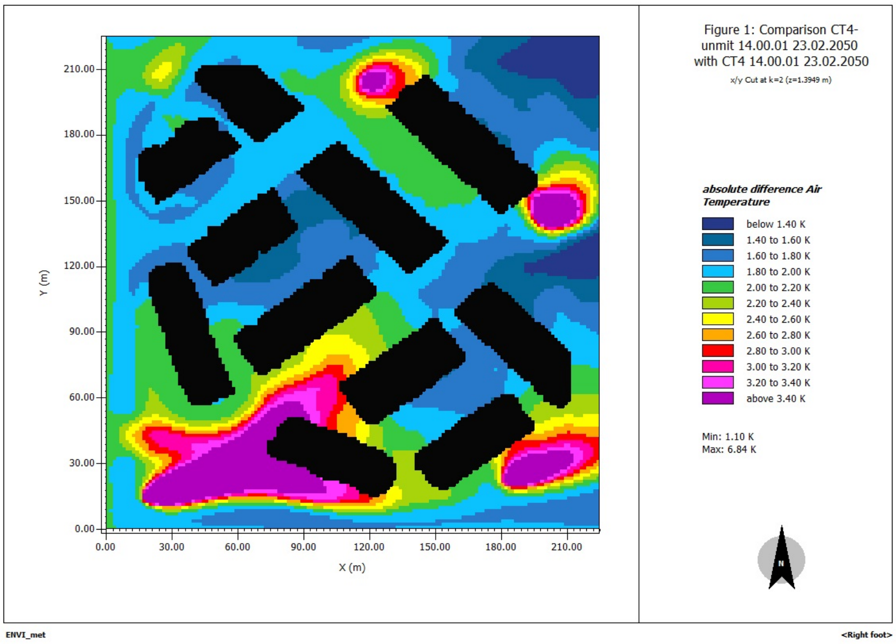


Figure 166 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

The climatic conditions in the CT4 precinct can be classified in two distinguished zones as depicted in Figure 167.

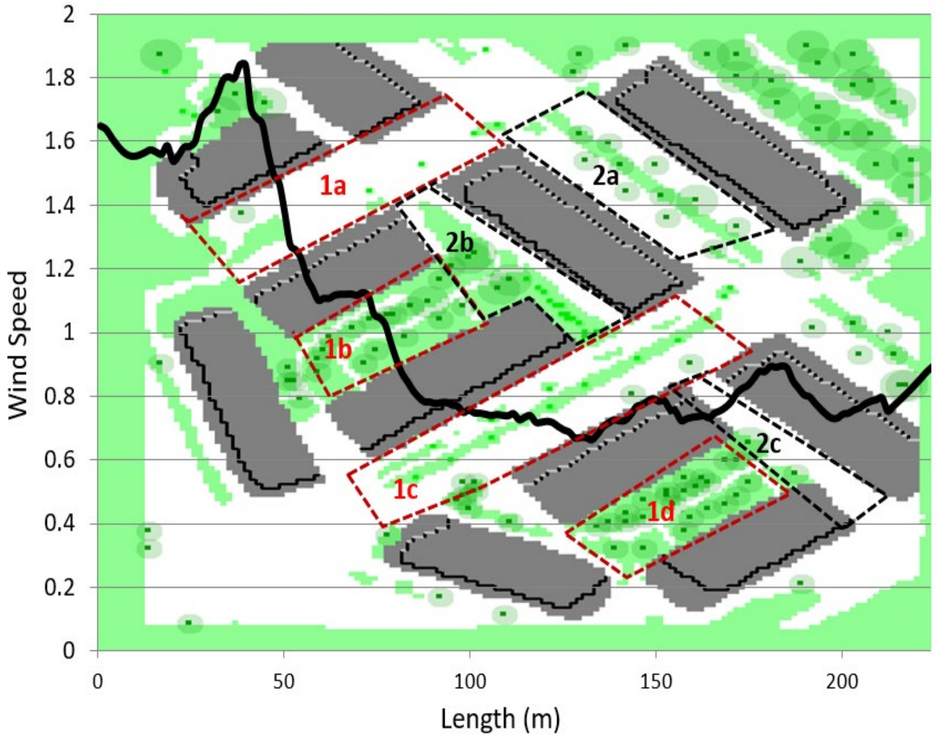


Figure 167 Two distinguished zones in CT4

Zone 1: Flow parallel to the axis of the canyon.

- The aspect ratios are 1.2, 1.6, 2.4 and 2 for the canyons 1a to 1d respectively. In all canyons the flow along the canyon axis. Canyons 1b and 1d present a much lower wind speed because their windward part is obstructed by buildings. The average wind speed in these canyons is around 0.6 m/sec. The wind speed in canyons 1a and 1c varies between 2.45 to 0.5 m/sec, with a much higher speed at the entry zone of the canyons.
- The average ambient temperature in the canyons is between 32 to 30.5 °C. Higher temperatures are observed in canyon 1a and the lower in canyon 1b. The impact of trees on the ambient temperature is quite clear in the canyons 1b and 1d.
- Solar radiation reaches only part of the ground of canyons 1a and 1c. Canyons 1b and 1d are fully shaded. The surface temperature in the non-shaded part is high between 39 to 45. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C. Thermal Comfort in the shaded zones improves considerably, PET around 37 °C, while in the non-shaded part is between 47 to 51 °C.

Zone 2: Flow vertical to the axis of the small streets separating the buildings.

- The aspect ratio of canyons 2a, 2b and 2c are 1, 1.6 and 2 respectively. In all canyons the air flow is under the skimming regime. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.29 m/sec.
- The average ambient temperature in the canyon is between 30- 31.5 °C with the minimum temperature in canyon 2a because of the present of trees.
- Because of the low aspect ratio of the canyons solar radiation is reaching the ground of the canyons and the surface temperature of the non-shaded by the trees part is close to 42 °C, while the corresponding temperature in the shaded part is close to 30 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is not acceptable but it improves in the shaded by the tree zones.

General Comments

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.0068 °C/m. and 0.0066 °C/m. The sections of the precinct of zone 1 and in particular canyon 1a and 1c, contributes highly to increase the temperature in the precinct as they provide high advection air flows. The zone 2 which is perpendicular to the to the wind speed present a low average wind speed and a quite significant cooling rate mainly because of the intensive planting considered. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

CT5

The ambient temperature along the precinct of CT5 with mitigation is shown in Figure 168 and Figure 169. The gradient of temperature decrease is 0.055°C / 10 meters.

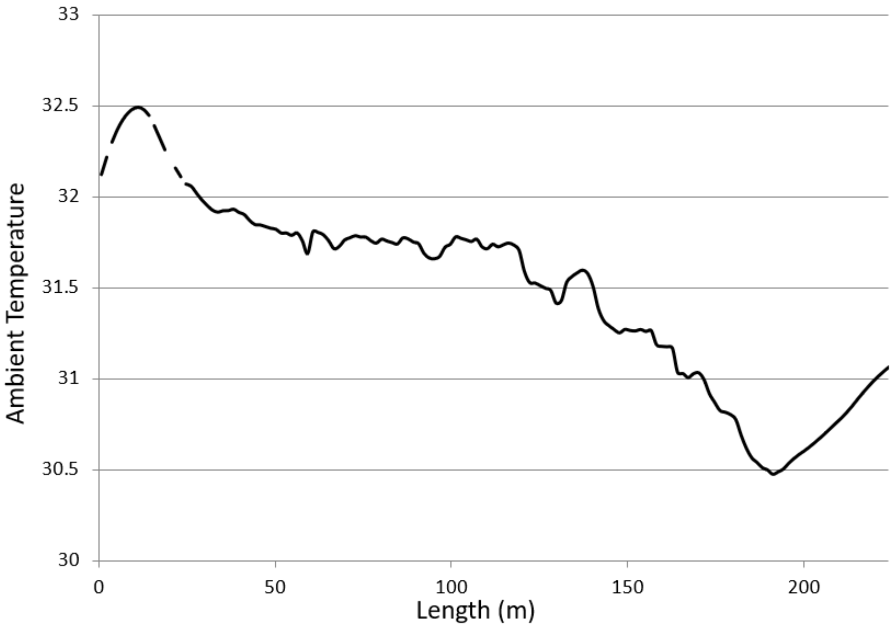


Figure 168 CT5– Ambient Temperature Along the Precinct with Mitigation

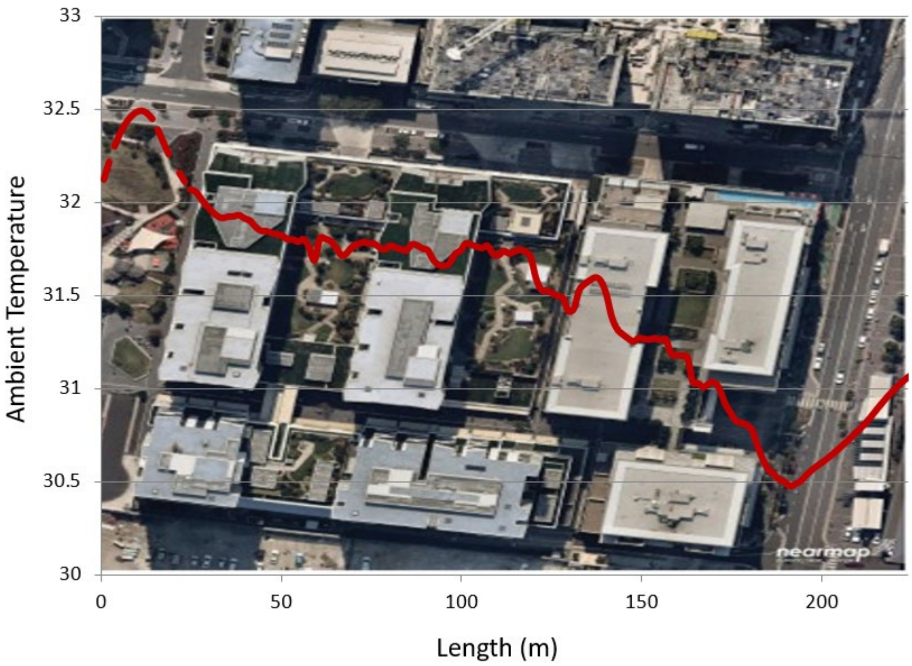


Figure 169 CT5– Ambient Temperature Along the Precinct with Mitigation

Figure 170, Figure 171, and Figure 172 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

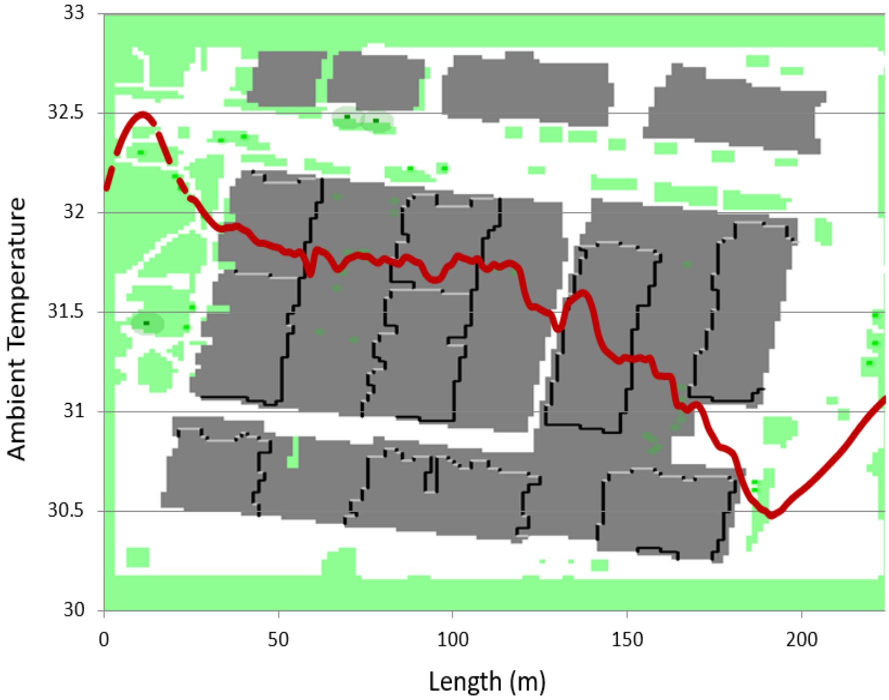


Figure 170 CT5– Ambient Temperature Along the Precinct with Mitigation

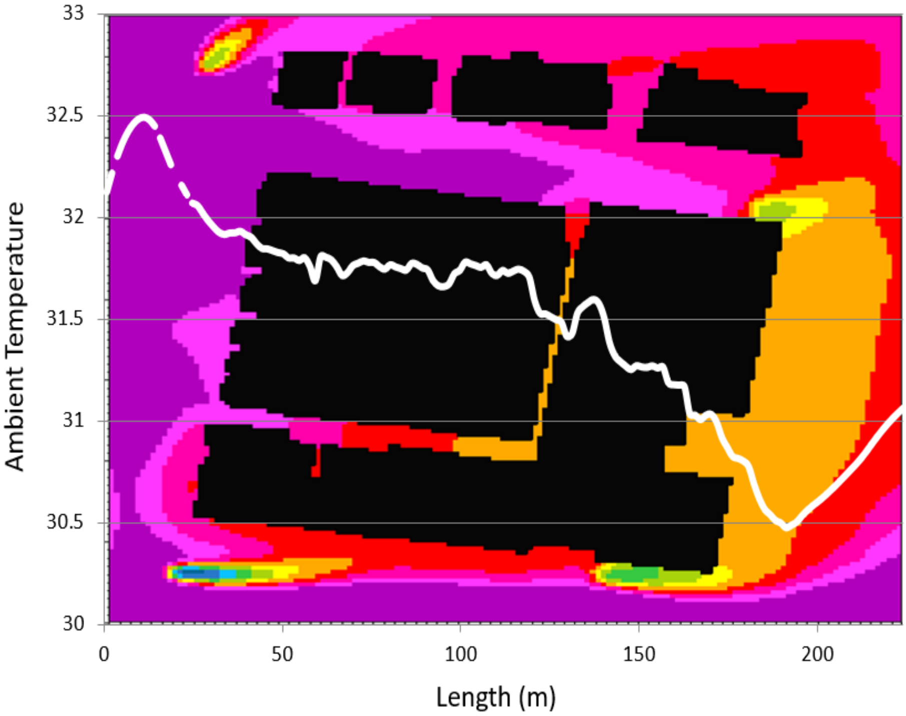


Figure 171 CT5– Ambient Temperature Along the Precinct with Mitigation

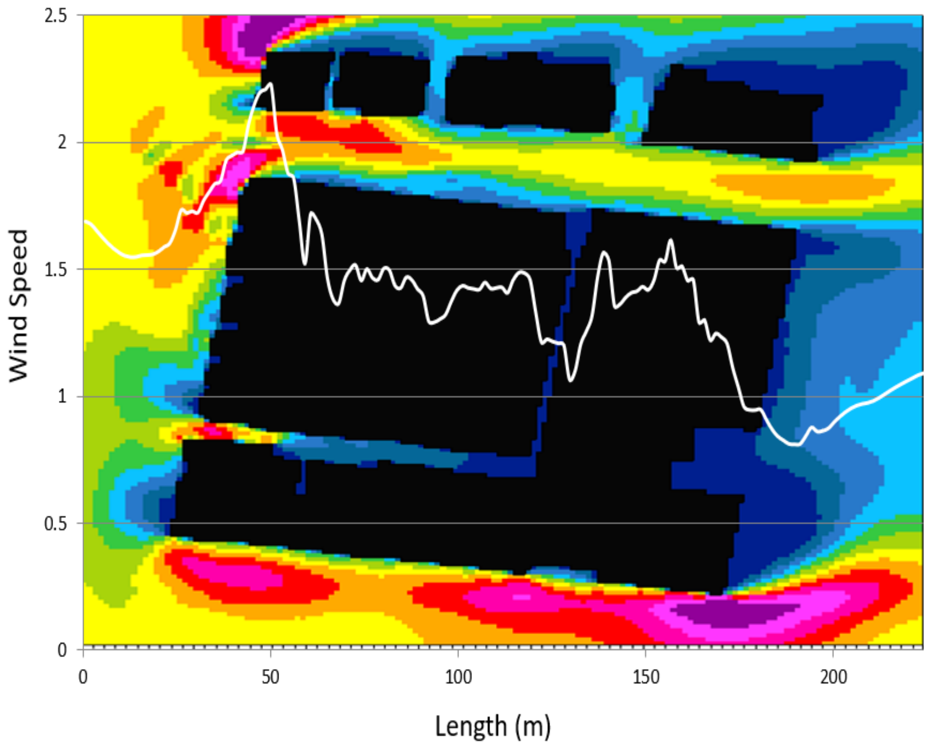


Figure 172   CT5– Wind speed Along the Precinct with Mitigation

Figure 173 compares the ambient temperature along the precinct with and without mitigation.

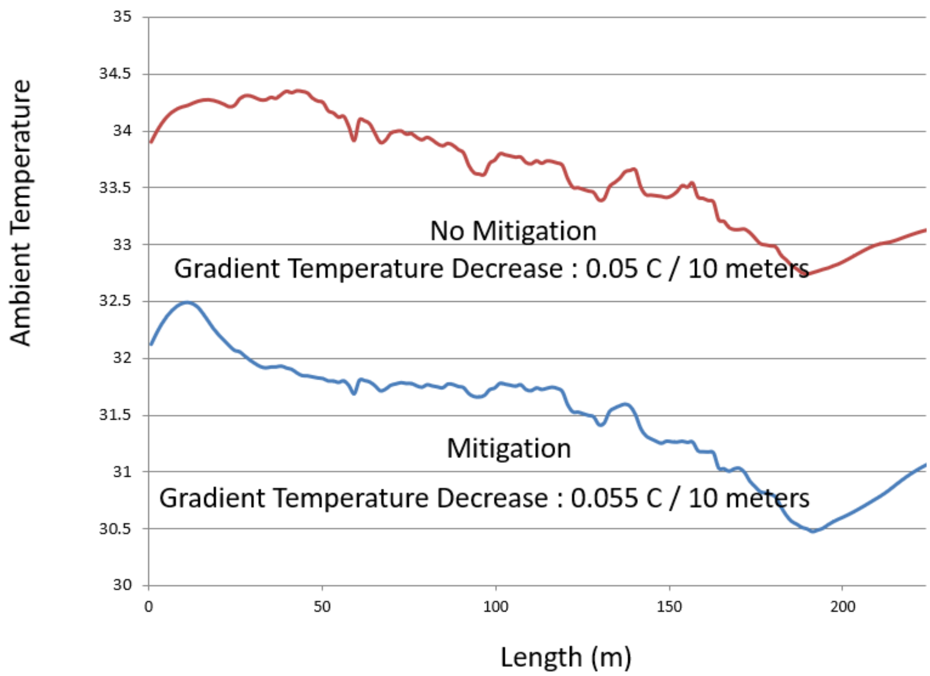


Figure 173   CT5– Ambient Temperature Along the Precinct with and Without Mitigation

Figure 174 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

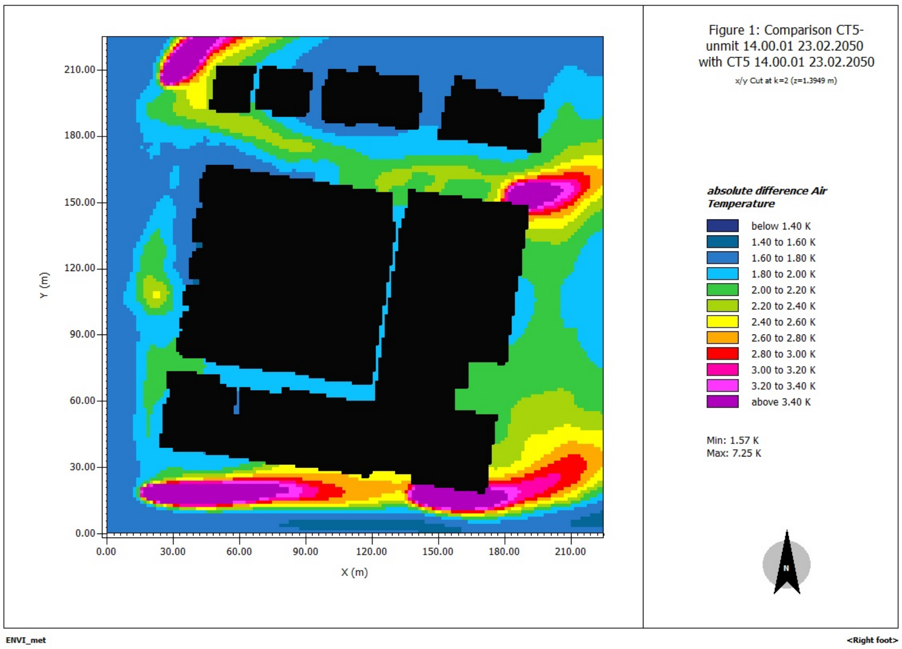


Figure 174 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

The climatic conditions in the CT5 precinct can be classified in two distinguished zones as depicted in Figure 175.

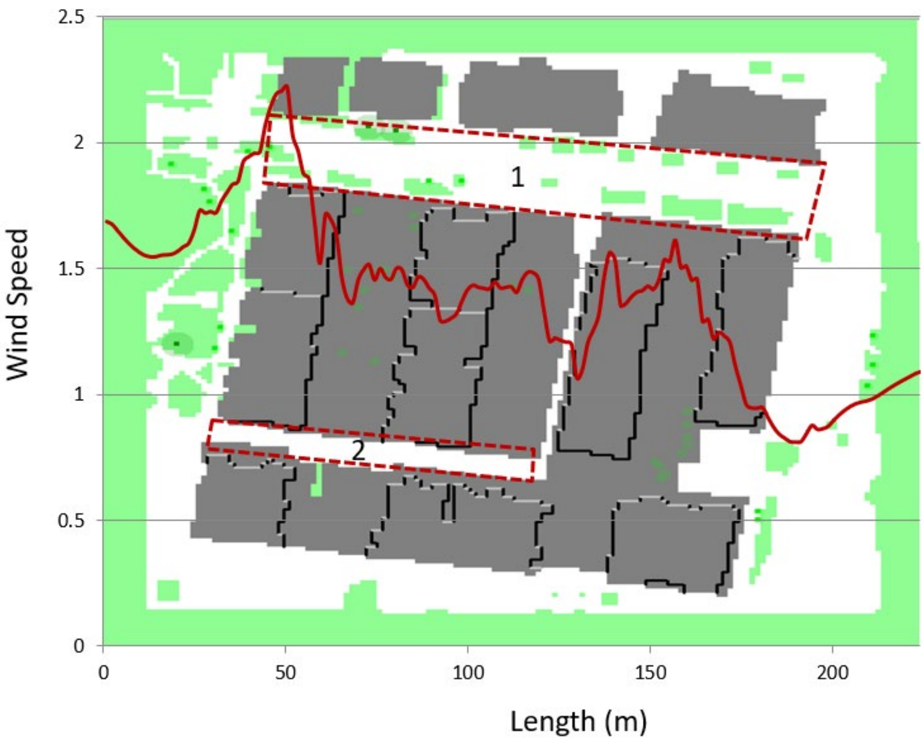


Figure 175 Two distinguished zones in CT5

Zone 1: Flow parallel to the axis of the canyon.

- h/w =5.6 and corresponds to a flow along the canyon axis. The wind speed in the canyon varies between 1.6 to 2.45 m/sec. Wind speed is higher at the middle of the road that close to the edges of the buildings

- The average ambient temperature in the canyons is between 32 to 31 °C The impact of trees on the ambient temperature is minimum.
- Because of the high aspect ratio of the canyons, solar radiation reaches the ground of the canyon in the south part and the surface temperature in the non-shaded part is high between 39 to 45 °C. In the shaded part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 30 °C, while in the non-shaded part is between 47 to 51 °C.

Zone 2: **Flow parallel to the axis of the canyon.**

- h/w =16.8 and higher corresponds to a flow along the canyon axis. The wind speed in the canyon varies between 2.2 to 0.3 m/sec. Higher speeds are developed in the entry zone of the canyon.
- The average ambient temperature in the canyons is between 31 to 30 °C.
- Because of the high aspect ratio of the canyons, solar radiation does not reach the ground of the canyon and the surface temperature is low, 27-30 °C.
- Thermal Comfort is at a level of PET = 40 °C.

General Comments

The average gradient of the temperature decreases along the precinct for the mitigation and the non-mitigation scenarios are to 0.0055 C/m. and 0.005 °C/m. Zone 1 contributes highly to increase the temperature in the precinct as it provides high advection air flows. The impact of zone 2 is negligible. This precinct is characterised by high rise buildings and high density. The use of trees is reduced, and the impact of cool roofs is minimal given the height of the buildings.

CT6

The ambient temperature along the precinct of CT6 with mitigation is shown in Figure 176 and Figure 177. The gradient of temperature decrease is 0.084°C / 10 meters.

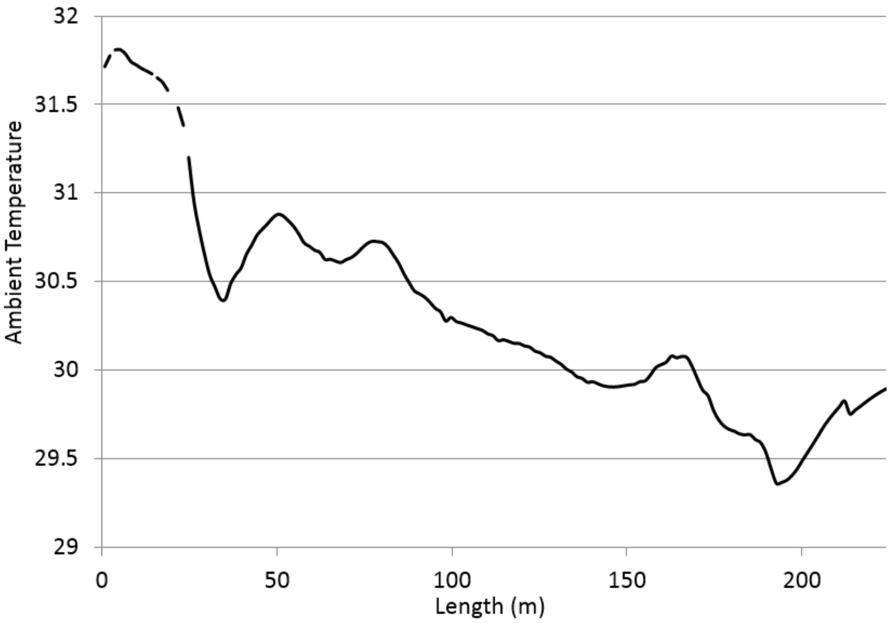


Figure 176 CT6– Ambient Temperature Along the Precinct with Mitigation

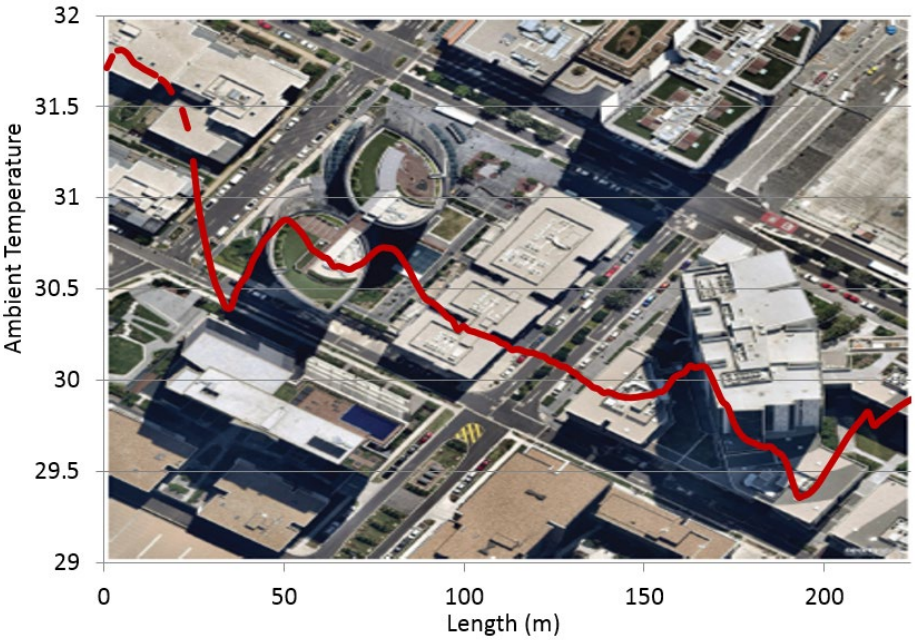


Figure 177 CT6– Ambient Temperature Along the Precinct with Mitigation

Figure 178, Figure 179 and Figure 180 present the ambient temperature and wind speed along the precinct (with mitigation) plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

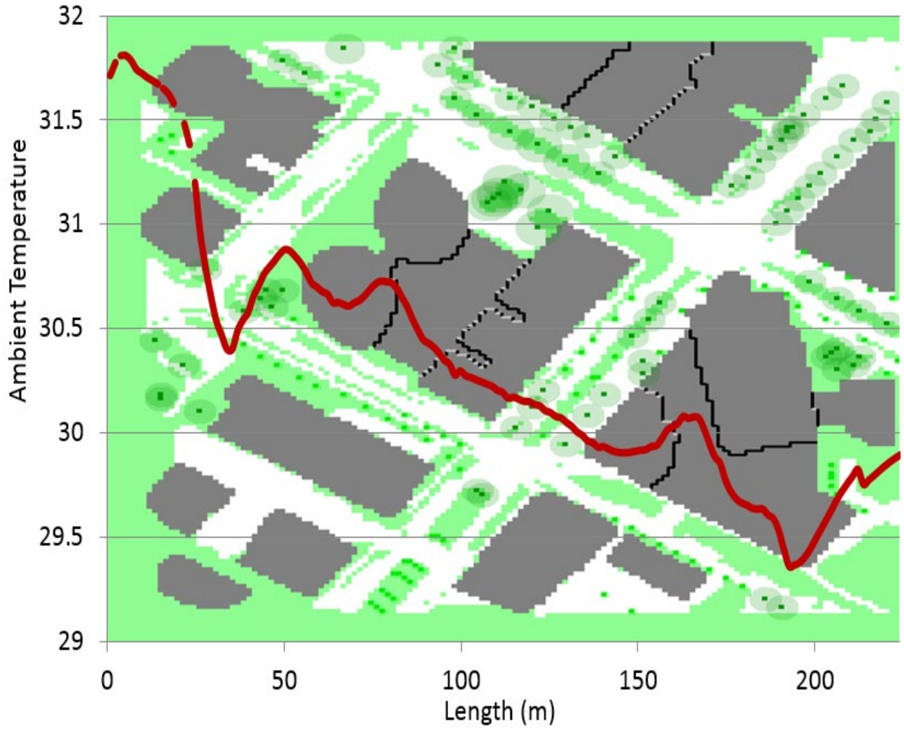


Figure 178 CT6– Ambient Temperature Along the Precinct with Mitigation

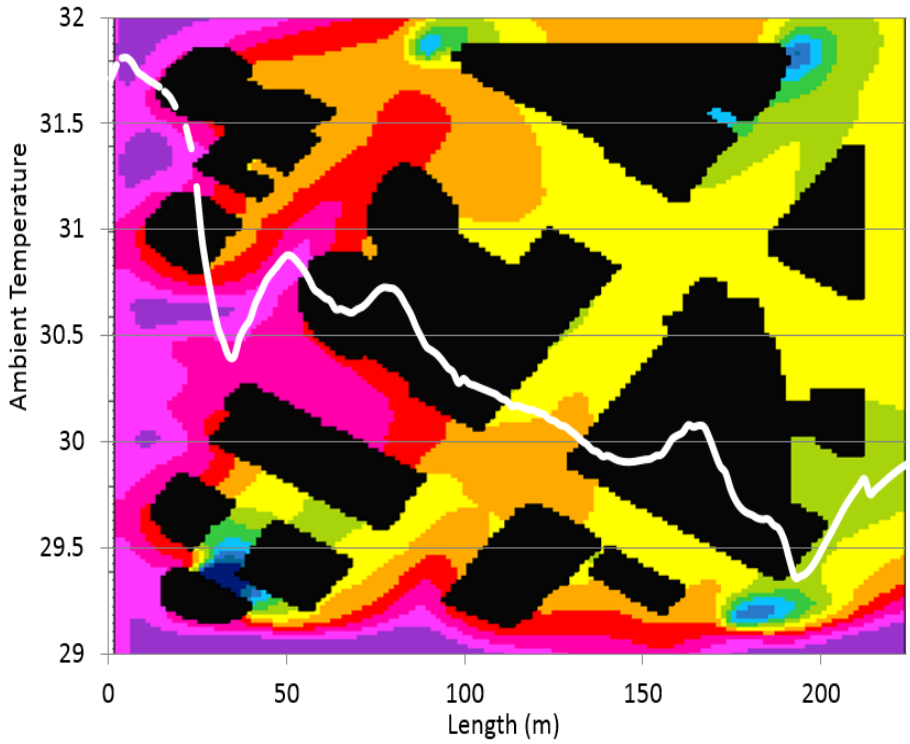


Figure 179 CT6– Ambient Temperature Along the Precinct with Mitigation

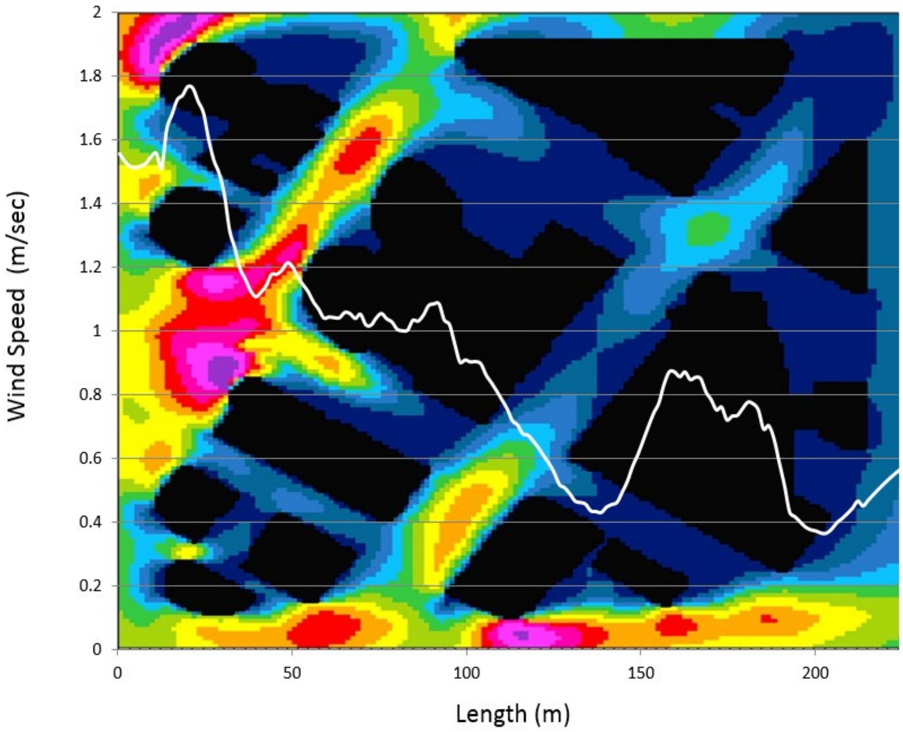


Figure 180 CT6– Ambient Temperature Along the Precinct with Mitigation

Figure 181 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

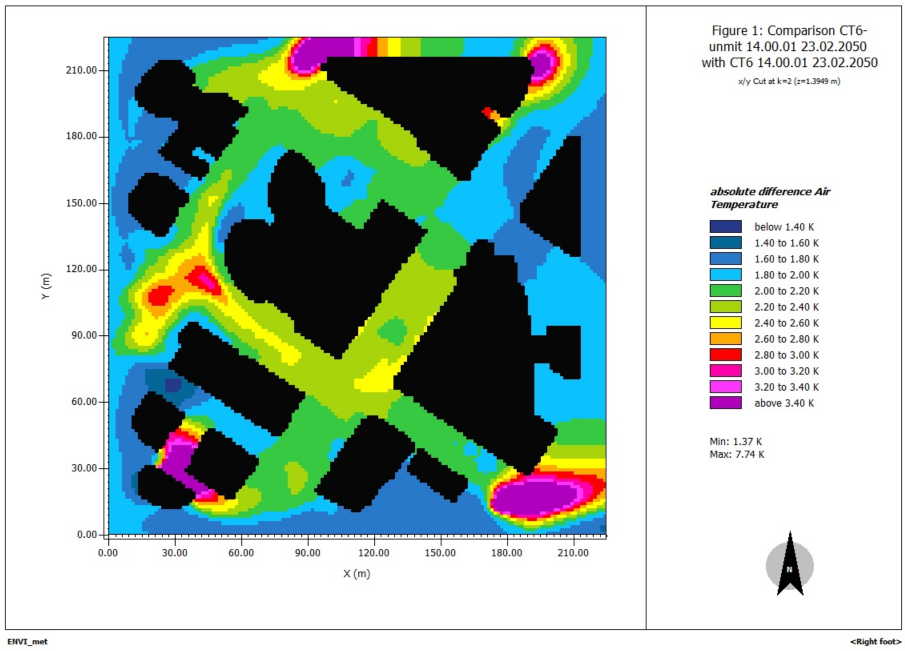


Figure 181 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 182 compares the ambient temperature along the precinct with and without mitigation.

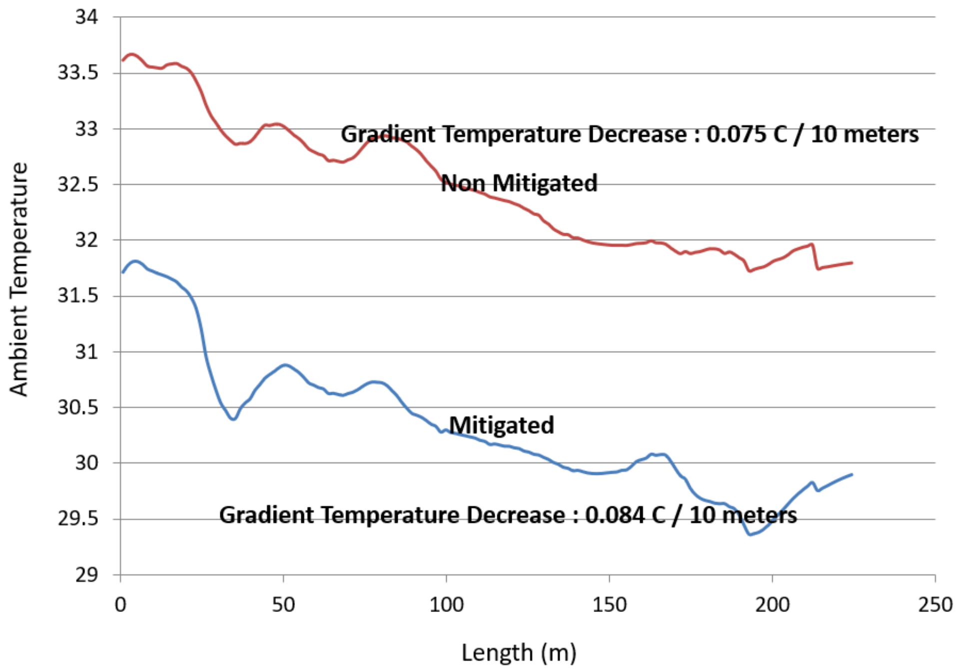


Figure 182 CT6– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the CT6 precinct can be classified in two distinguished zones as depicted in Figure 183.

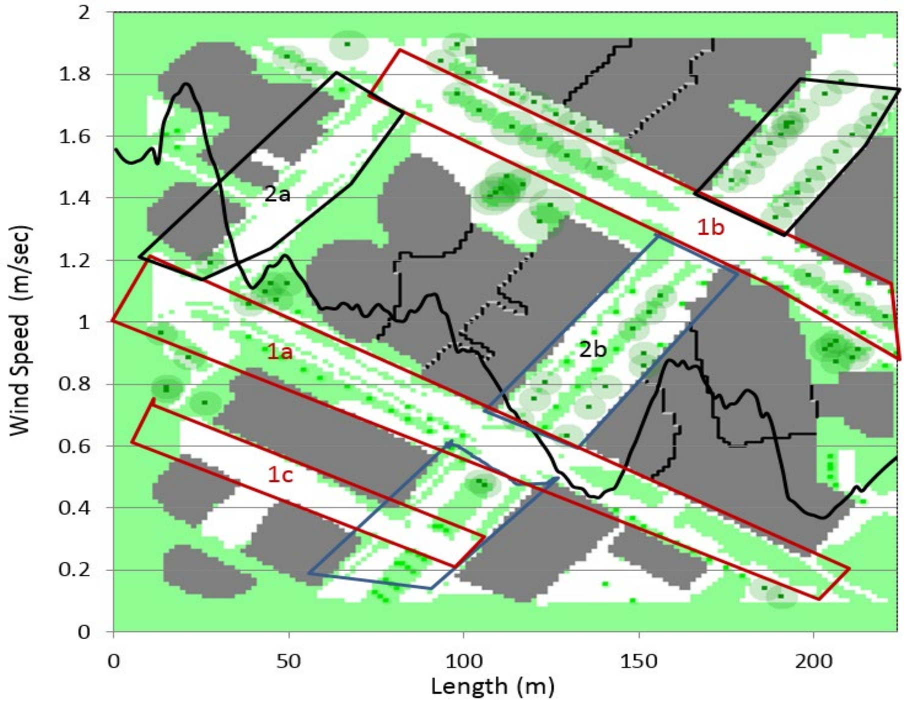


Figure 183 Two distinguished zones in CT6

Zone 1: Flow vertical to the axis of the streets.

- The aspect ratio of canyons 1a, 1b and 1c are 1.25, 1.25, and 2.08 respectively. In all canyons the air flow is under the skimming regime. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.3 m/sec.
- The average ambient temperature in the canyon is between 31.5 and 29 °C with the minimum temperature in canyon 1c and the highest in canyon 1a.
- Because of the orientation of the canyons solar radiation is reaching partly the ground of the canyons and the surface temperature of the non-shaded part is close to 42 °C, while the corresponding temperature in the shaded part is close to 27-30 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is not acceptable but it improves in the shaded by the trees zones.

Zone 2: Flow parallel to the axis of the canyon.

- The aspect ratios are 0.8 and 1 for the canyons 2a to 2b respectively. In all canyons the flow along the canyon axis. The wind speed in canyon 2a and 2b varies between 2.5 to 1.5 m/sec, with a much higher speed at the entry zone of the canyons, while in the canyon 2b varies between 2 to 0.5 m/sec
- The average ambient temperature in the canyon 2a is between 31.5 to 30. °C, and in the canyon 2b between 30.5 to 29.5 °C. The impact of trees on the ambient temperature is quite clear in the canyon 2b.
- Solar radiation reaches only part of the ground of canyons. The surface temperature in the non-shaded part is high between 39 to 45°C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 37 °C, while in the non-shaded part is between 47 to 51 °C.

General Comments

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.0084 °C/m. and 0.0075 °C/m. The sections of the precinct of zone 2 and in particular canyon 2a, contributes highly to increase the temperature in the precinct as they provide high advection air flows. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important

CT7

The ambient temperature along the precinct of CT7 with mitigation is shown in Figure 184 and Figure 185. The gradient of temperature decrease is 0.042°C / 10 meters.

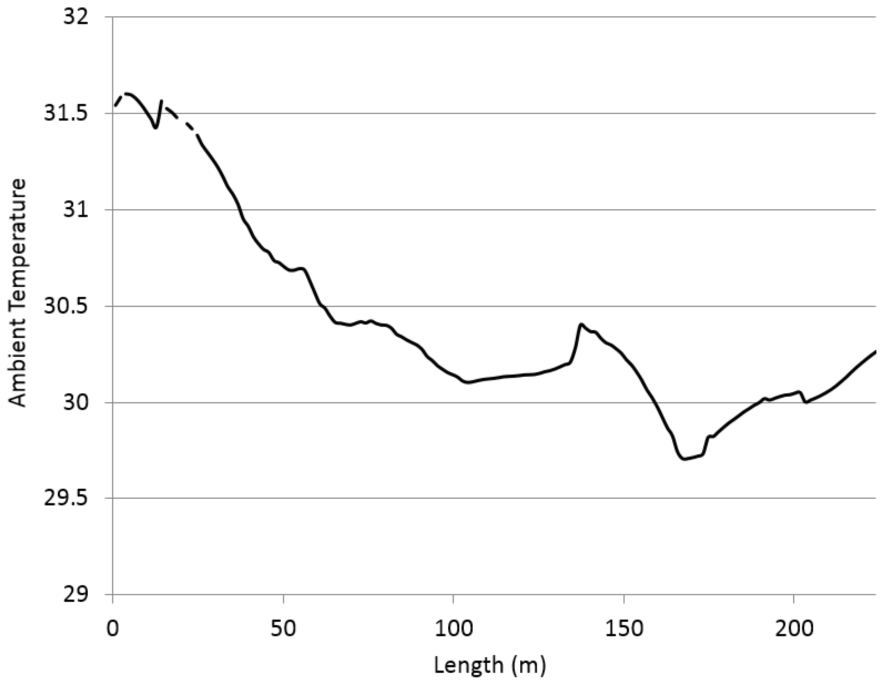


Figure 184 CT7– Ambient Temperature Along the Precinct with Mitigation

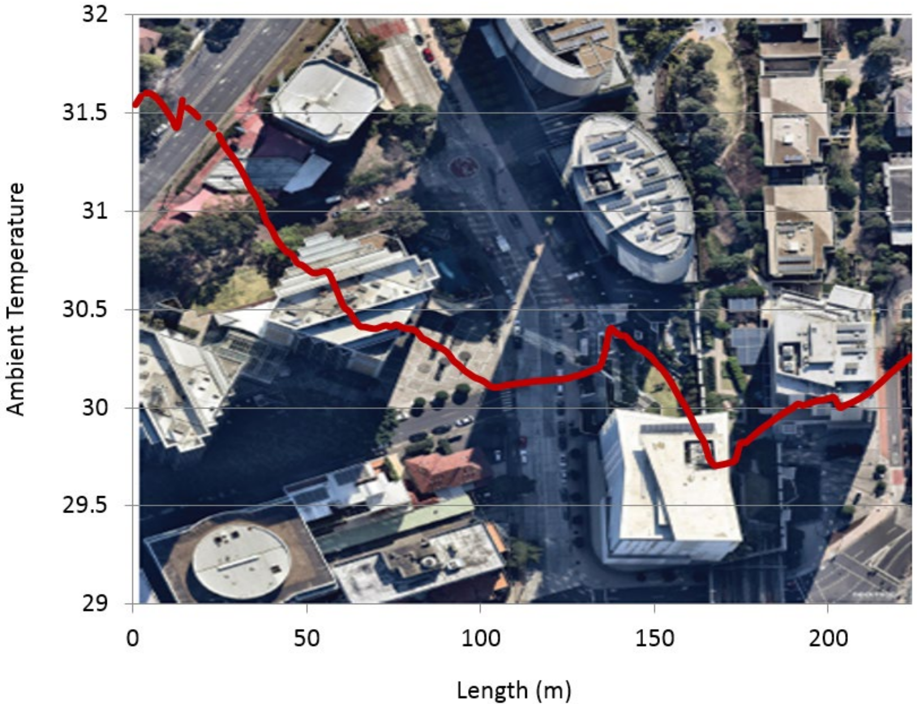


Figure 185 CT7– Ambient Temperature Along the Precinct with Mitigation

Figure 186, Figure 187 and Figure 188 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

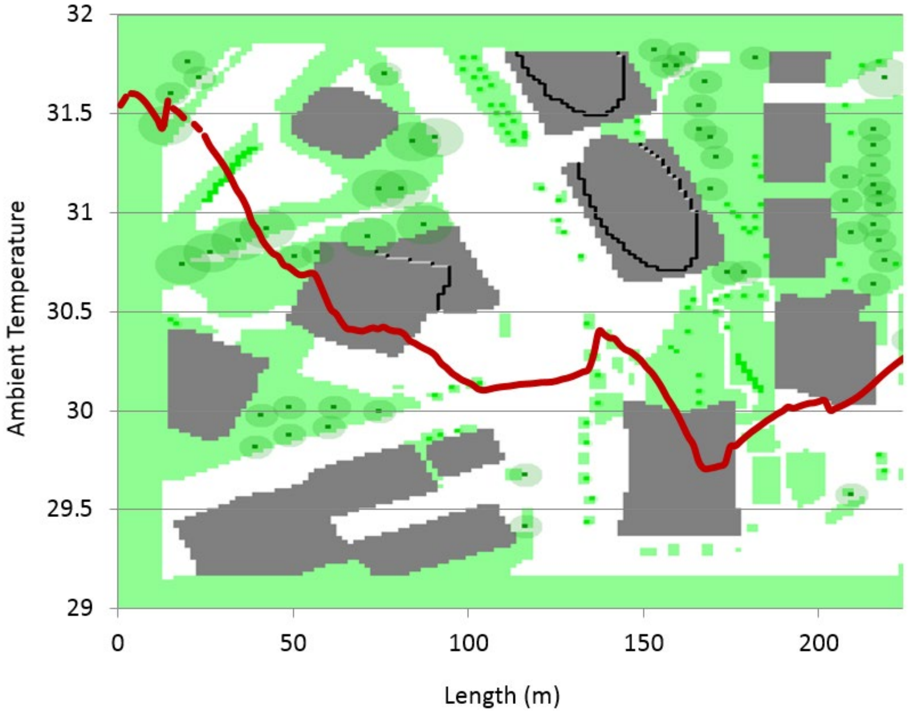


Figure 186 CT7– Ambient Temperature Along the Precinct with Mitigation

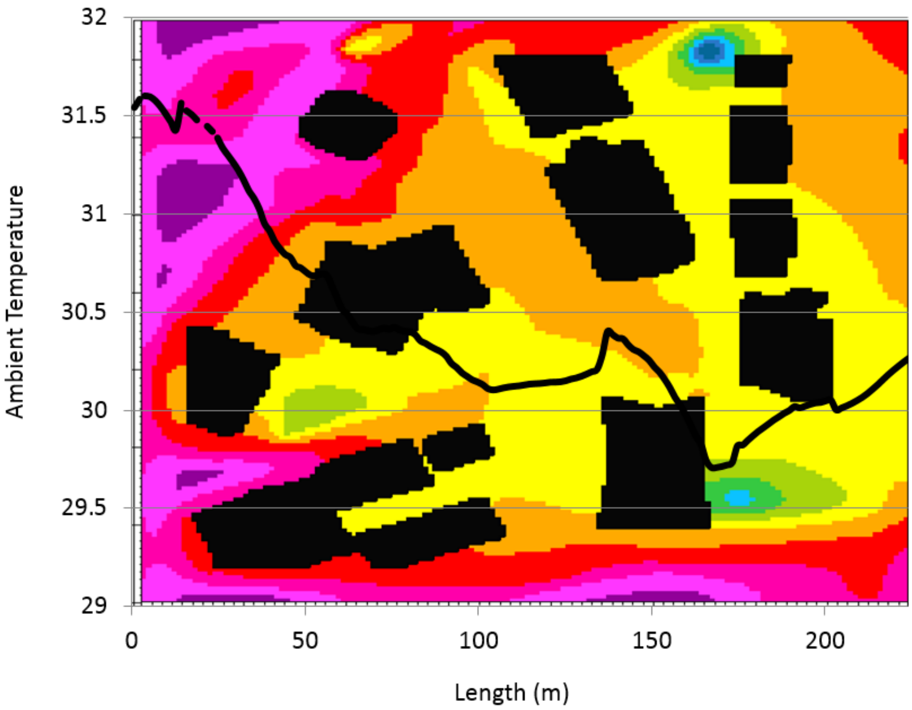


Figure 187 CT7– Ambient Temperature Along the Precinct with Mitigation

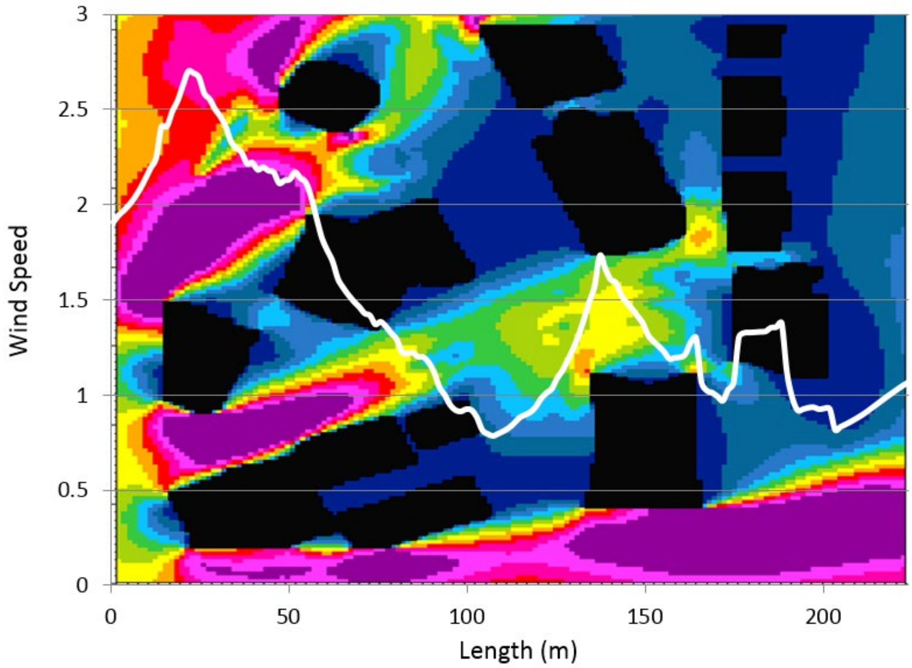


Figure 188 CT7– Wind speed Along the Precinct with Mitigation

Figure 189 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

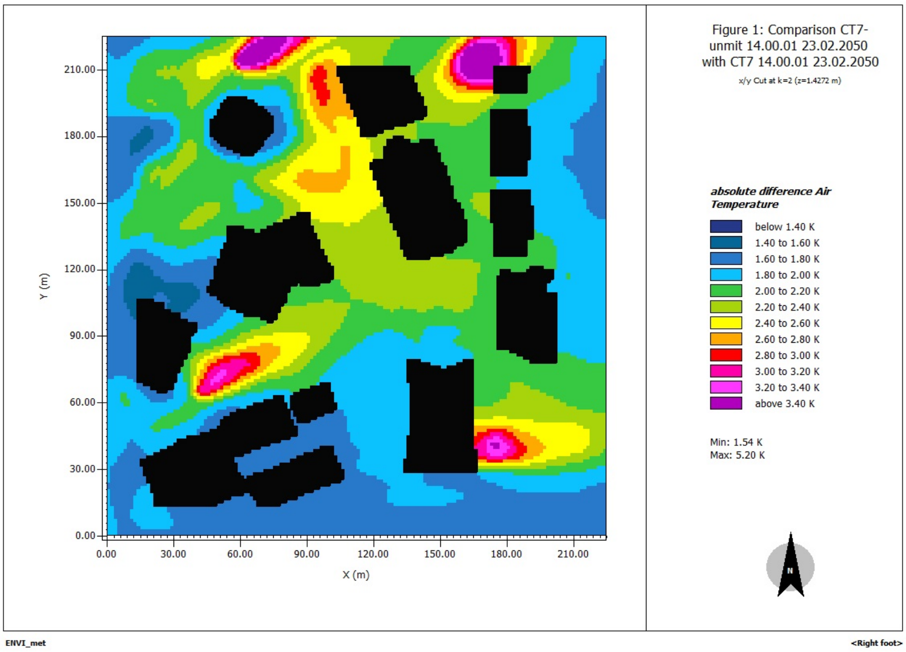


Figure 189 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 190 compares the ambient temperature along the precinct with and without mitigation.

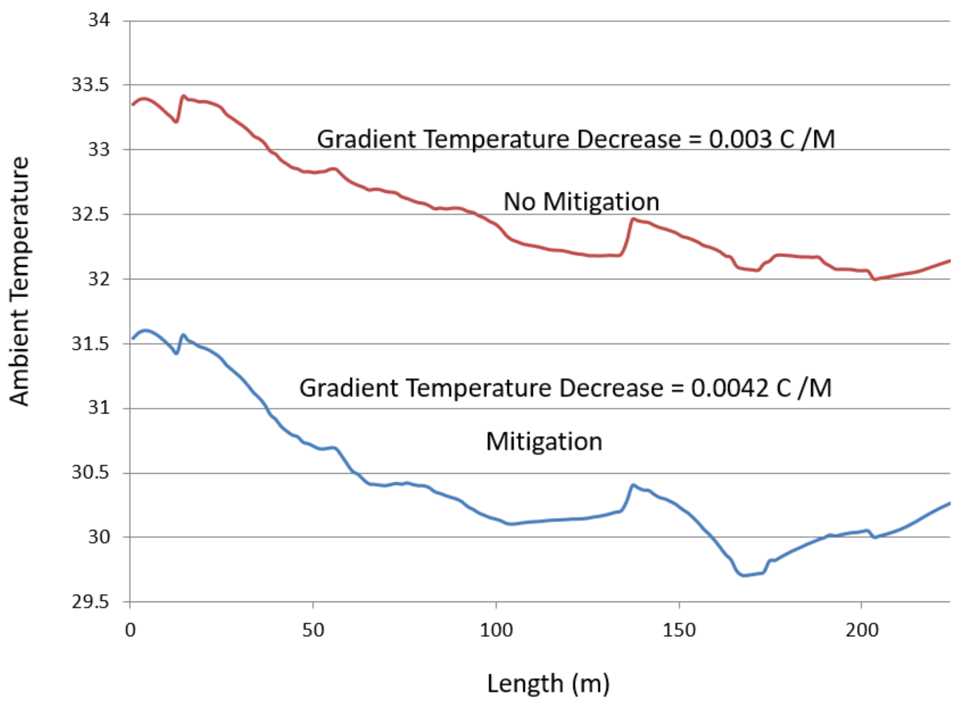


Figure 190 CT7– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the CT7 precinct can be classified in two distinguished zones as depicted in Figure 191.

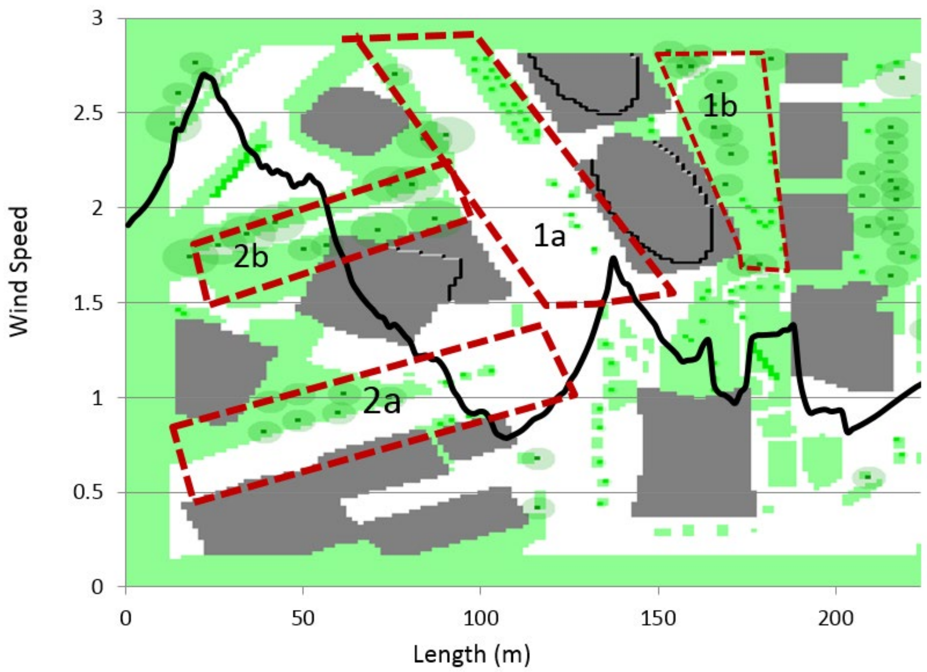


Figure 191 Two distinguished zones in CT7

Zone 1: Flow vertical to the axis of the street.

- The aspect ratio of canyon 1a is close to 3.5 and of canyon 1b is close to 5. The air flow is under the skimming regime. The ambient air flows above the buildings while between the buildings a vortex is created. The average wind speed in the canyon is below 0.3 m/sec. There is an important cornet vortex developed in the intersection with zone 2.

- The average ambient temperature in the canyon 1a is between 30.5 and 30 °C and in the canyon 1b is between 29.5 and 30 °C.
- Because of the orientation and the aspect ratio of the canyons solar radiation is reaching partly the ground of the canyon 1a and the surface temperature of the non-shaded part is close to 42 °C, while the corresponding temperature in the shaded part is close to 27-30 °C. The canyon 1b is fully shaded and the surface temperature is close to 27 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is not acceptable but it improves in the shaded by the trees zones.

Zone 2: Flow parallel to the axis of the canyon.

- The aspect ratio of both canyons is close to 2.85. In both canyons the flow along the canyon axis. The wind speed in canyon 2a and 2b varies between 3 to 1.5 m/sec, with a much higher speed at the entry zone of the canyons,
- The average ambient temperature in the canyons varies between 31.5 to 29.5 °C. Much higher temperatures are observed in the entry zone of the canyons where the advection of heat is very important.
- Because of the orientation of the canyon and the high rise of the buildings, solar radiation does not reach the ground and the surface temperature in the shaded parts is between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 36 °C.

General Comments

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.0042 °C/m. and 0.0030 °C/m. The sections of the precinct of zone 2 and in particular canyon 2a, contributes highly to increase the temperature in the precinct as they provide high advection air flows. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

OT1

The ambient temperature along the precinct of OT1 with mitigation is shown in Figure 192 to Figure 194. The gradient of temperature decrease is 0.073°C / 10 meters.

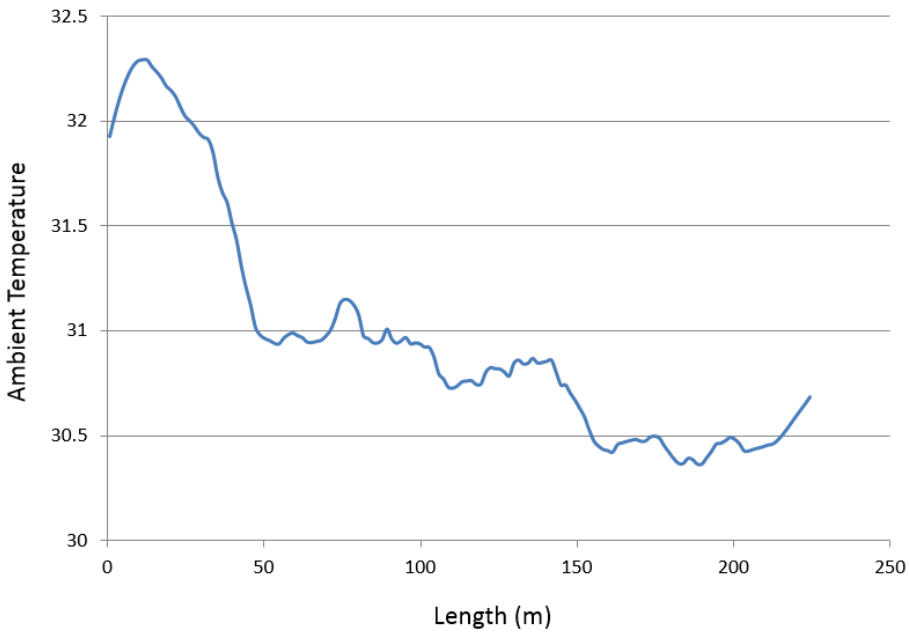


Figure 192 OT1 – Ambient Temperature along the Precinct

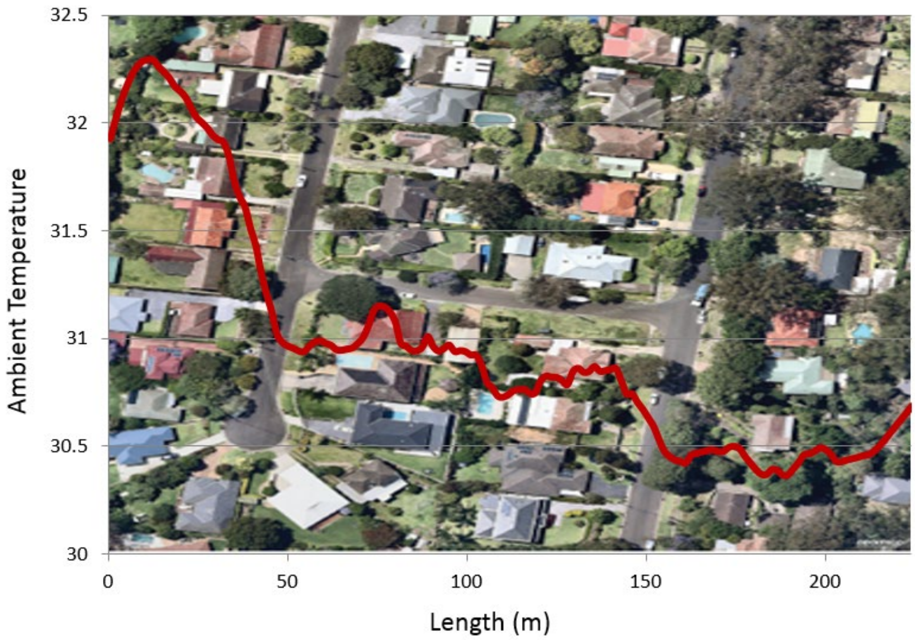


Figure 193 OT1 – Ambient Temperature along the Precinct

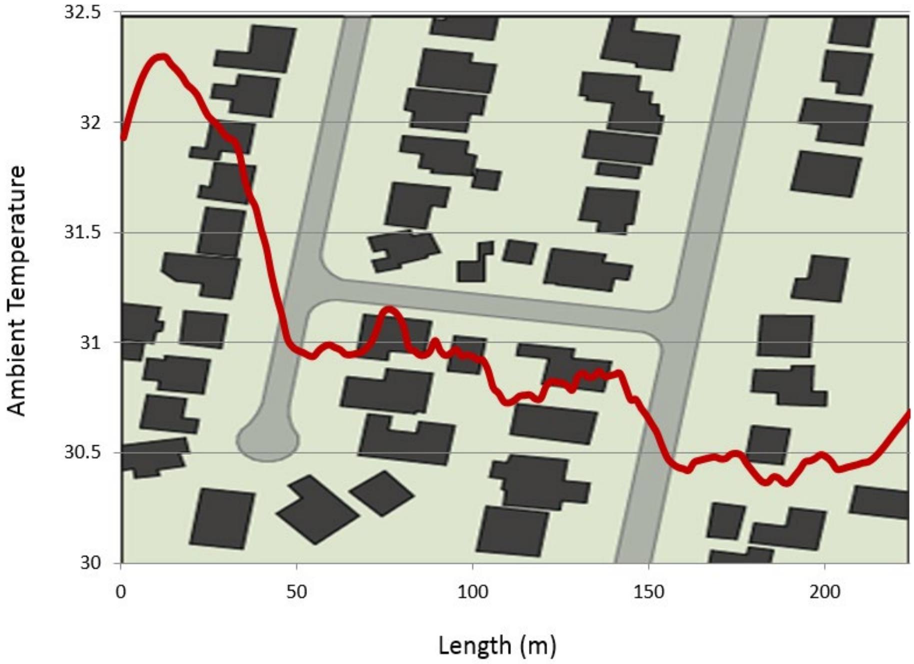


Figure 194 OT1 – Ambient Temperature along the Precinct

Figure 195 and Figure 196 present the ambient temperature and wind speed along the precinct with mitigation plotted on the temperature distribution and wind speed distribution maps, respectively.

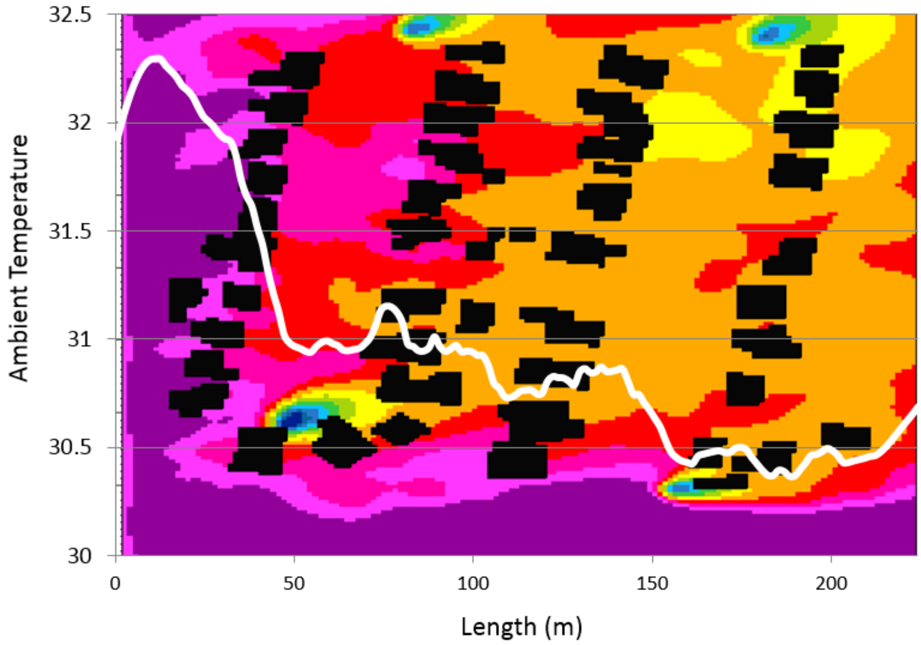


Figure 195 OT1 – Ambient Temperature along the Precinct

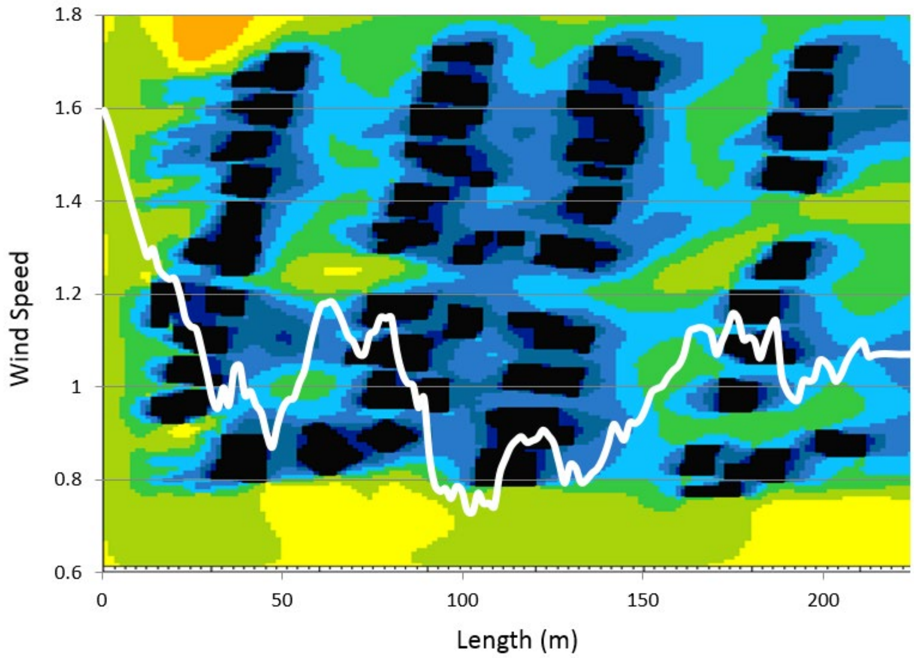


Figure 196 OT1 – Wind Speed along the Precinct

Figure 197 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

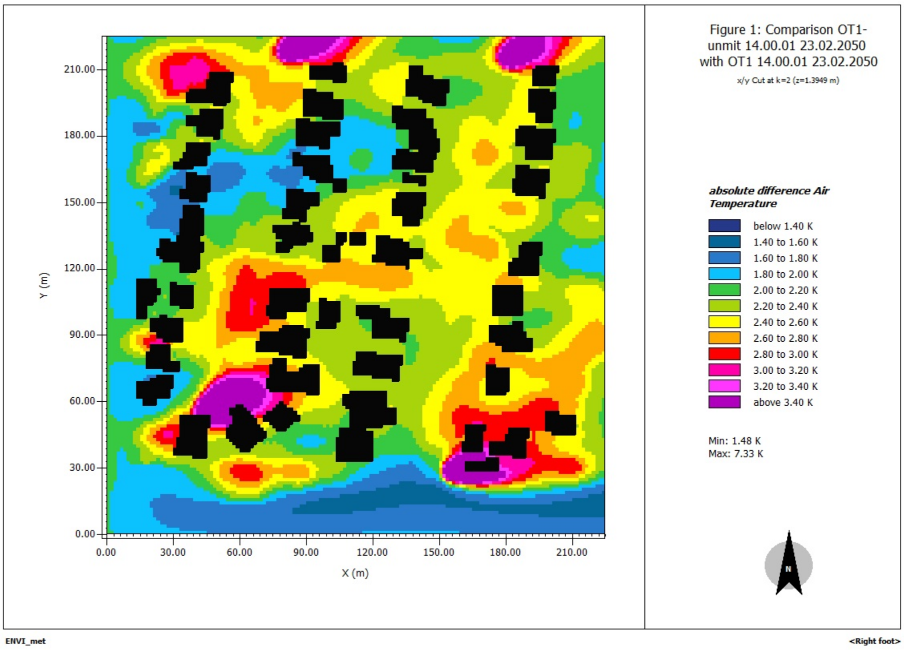


Figure 197 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 198 compares the ambient temperature along the precinct with and without mitigation.

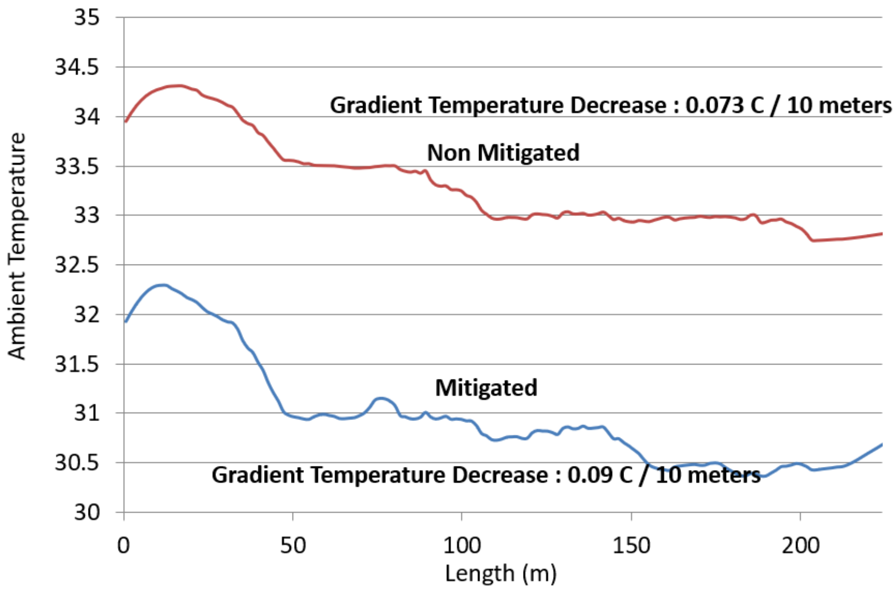


Figure 198 OT1– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT1 precinct can be classified in two distinguished zones as depicted in Figure 199.

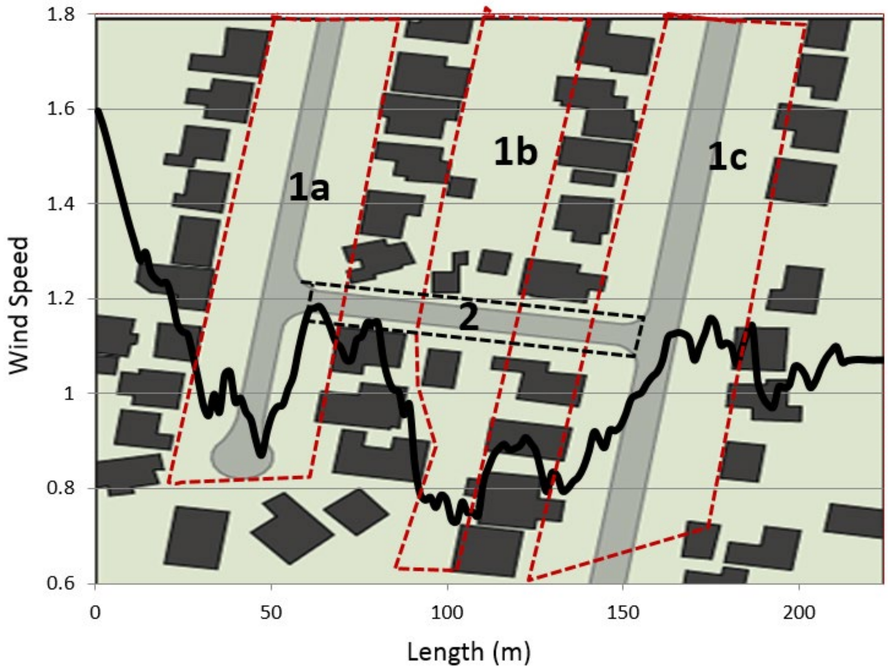


Figure 199 Two distinguished zones in OT1

Zone 1: Flow vertical to the axis of the streets.

- The aspect ratio of canyons 1a, 1b and 1c are 0.09,0.133,0.085 respectively. In all canyons the air flow is under the isolated roughness regime. The ambient air flows inside the canyons while there is an important advection through the spaces between the buildings. The average wind speed in the zone 1a is close to 1.2 m/sec, in zone 1b it is lower (0.78 m/sec), because of the pressure drop created by the buildings in the middle in the zone and in the intersection with zone 2, while in zone 1c is close to 1.3 m/sec.

- The average ambient temperature in the canyon is between 31.5 and 30 °C with the minimum temperature in canyon 1c and the highest in canyon 1a.
- Because of the orientation of the canyons solar radiation is reaching the ground of the canyons and the surface temperature of the non-shaded part is close to 45 °C, while the corresponding temperature in the shaded by the trees part is close to 27-30 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is not acceptable but it improves in the shaded by the trees zones.

Zone 2: Flow parallel to the axis of the canyon.

- The aspect ratio is 0.2 and the flow is along the canyon axis. The wind speed in the canyon varies between 1.9 to 0.5 m/sec, with a much higher speed at the entry zone of the canyon.
- The average ambient temperature in the canyon is between 31 to 30 °C.
- Solar radiation reaches only part of the ground of canyon. The surface temperature in the non-shaded part is high and close to 45°C. In the part shaded by the trees the surface temperature is much lower and between 27 to 32 °C.
- Thermal Comfort in the shaded zones improves considerably, PET around 37 °C, while in the non-shaded part is around 45 °C.

General Comments

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.009°C/m. and 0.0073 °C/m. The zones 1, contributes highly to increase the temperature in the precinct as they provide high advection air flows. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

OT2

The ambient temperature along the precinct of OT2 with mitigation is shown in Figure 200 and Figure 201. The gradient of temperature decrease is 0.084°C / 10 meters.

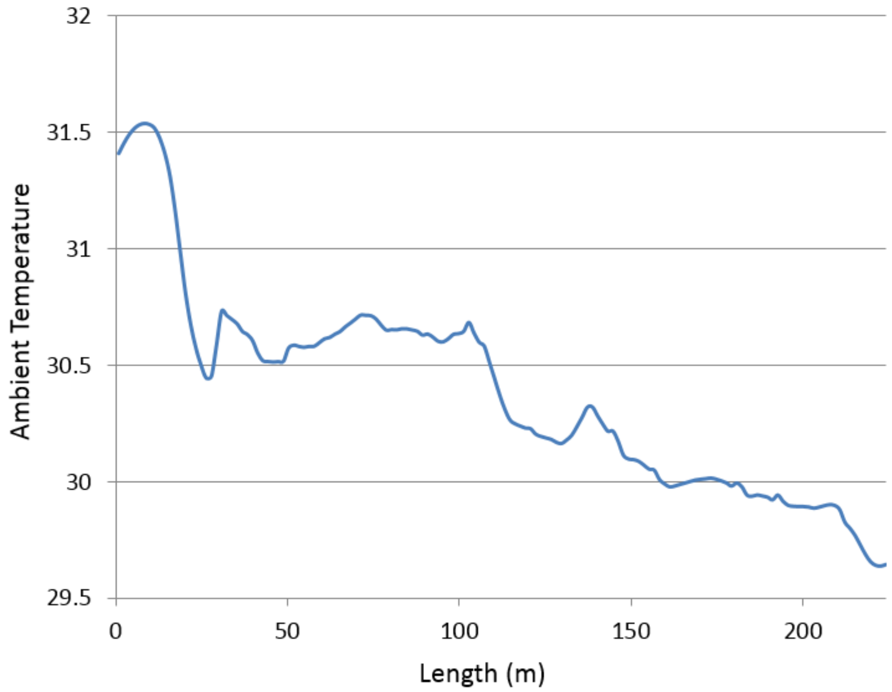


Figure 200   OT2– Ambient Temperature Along the Precinct with Mitigation

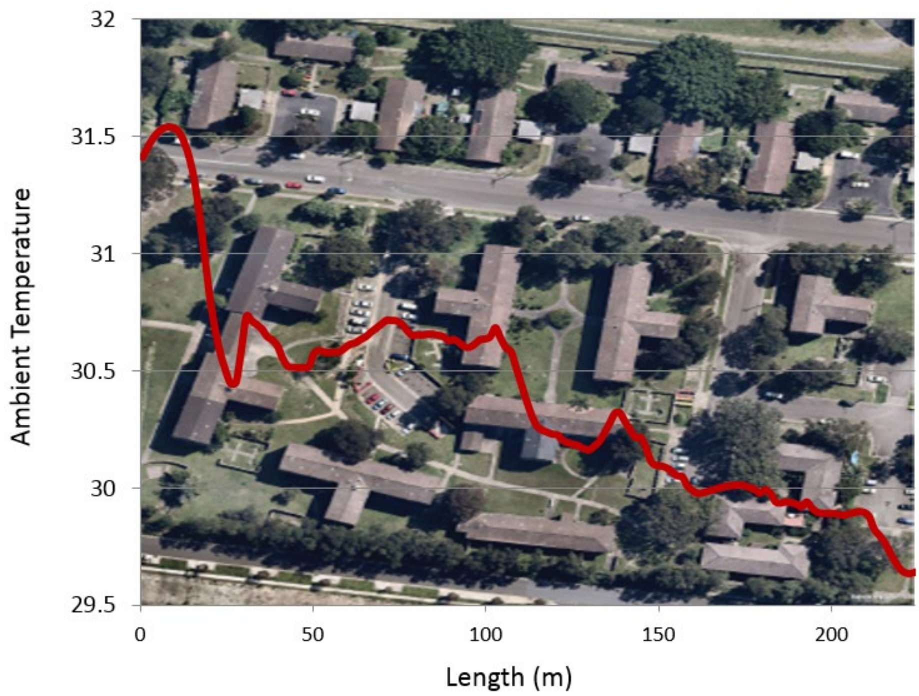


Figure 201   OT2– Ambient Temperature Along the Precinct with Mitigation

Figure 202, Figure 203, and Figure 204 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

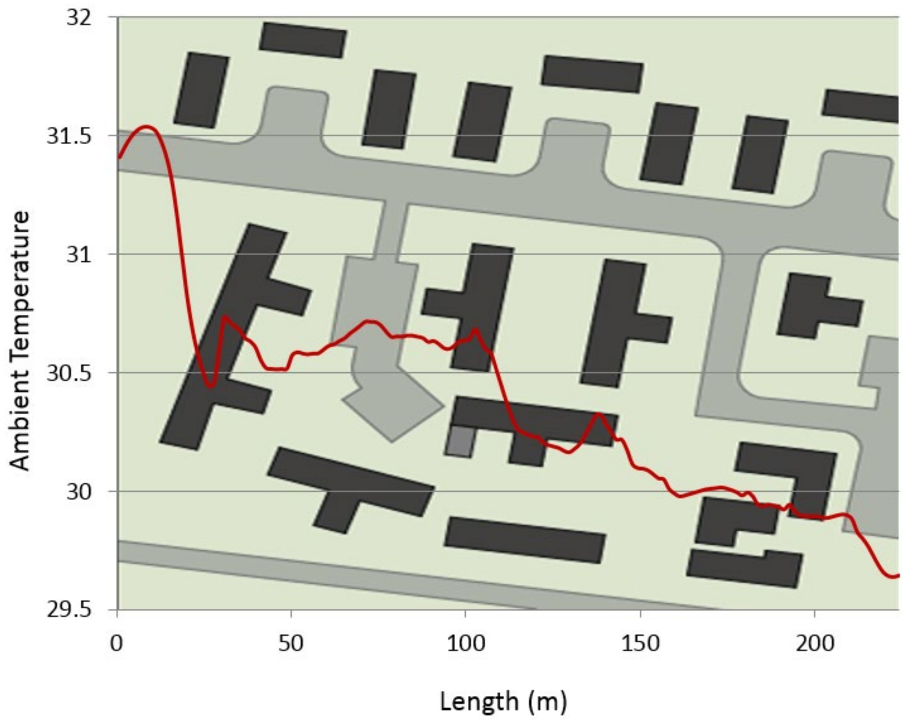


Figure 202 OT2– Ambient Temperature Along the Precinct with Mitigation

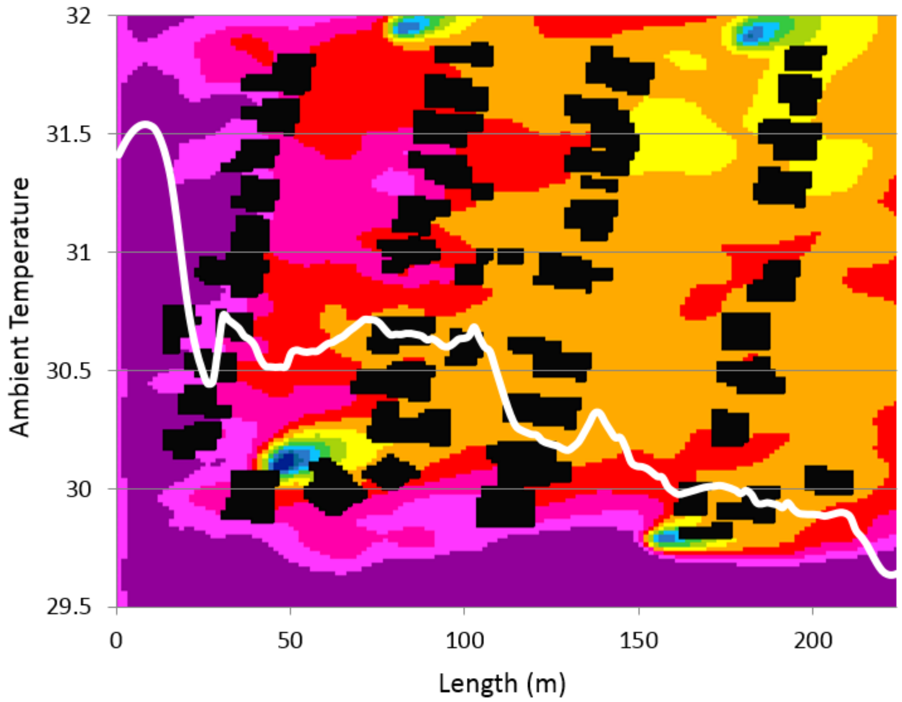


Figure 203 OT2– Ambient Temperature Along the Precinct with Mitigation

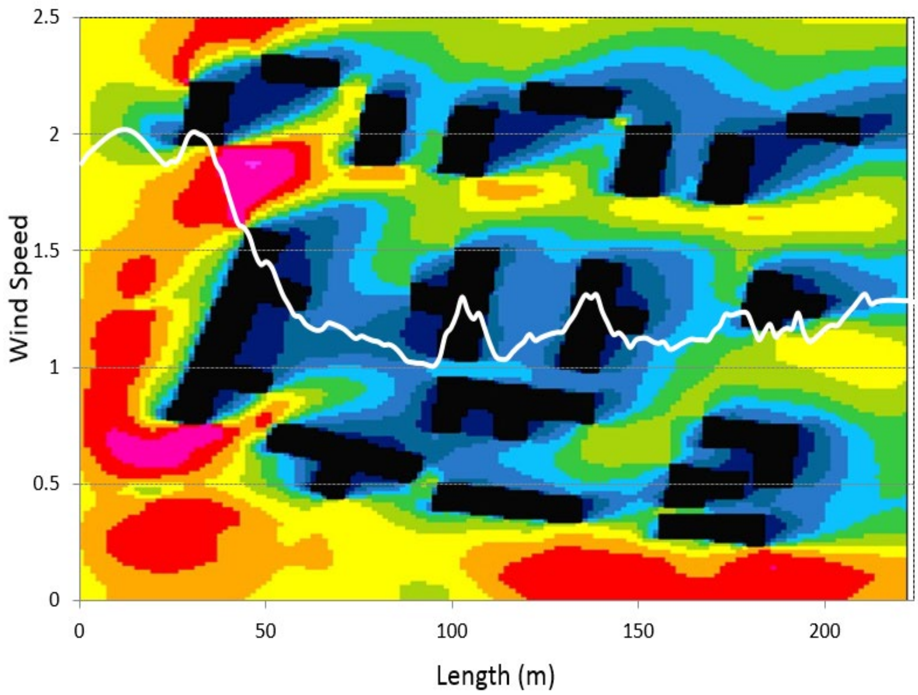


Figure 204 OT2– Wind speed Along the Precinct with Mitigation

Figure 205 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

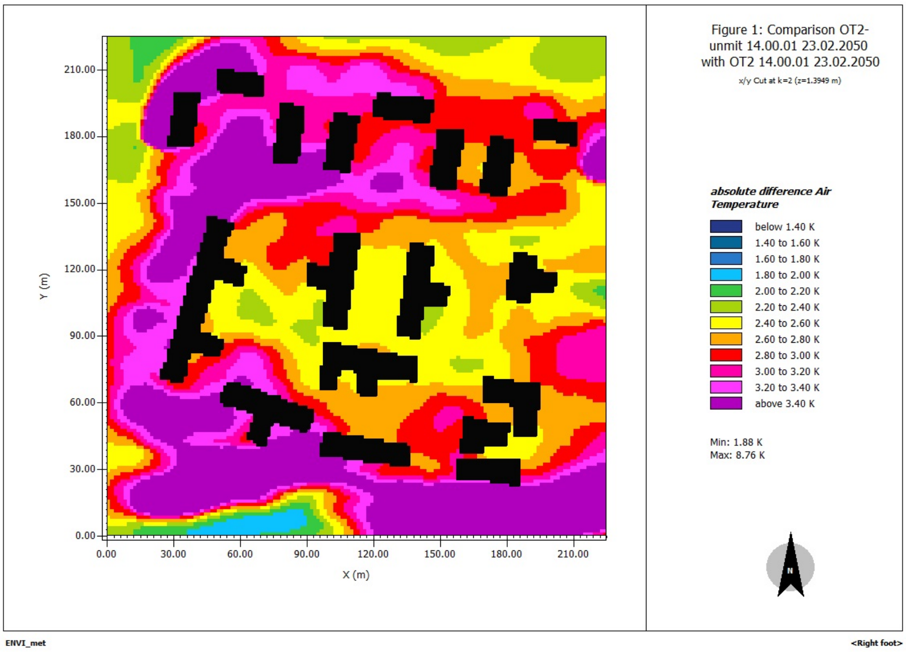


Figure 205 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 206 compares the ambient temperature along the precinct with and without mitigation.

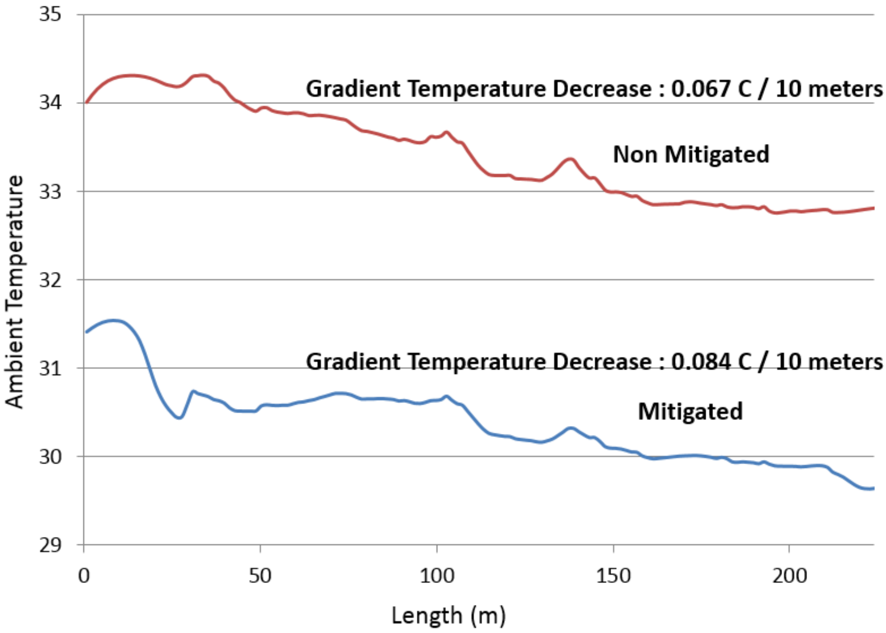


Figure 206 OT2– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT2 precinct can be classified in three distinguished zones as depicted in Figure 207.

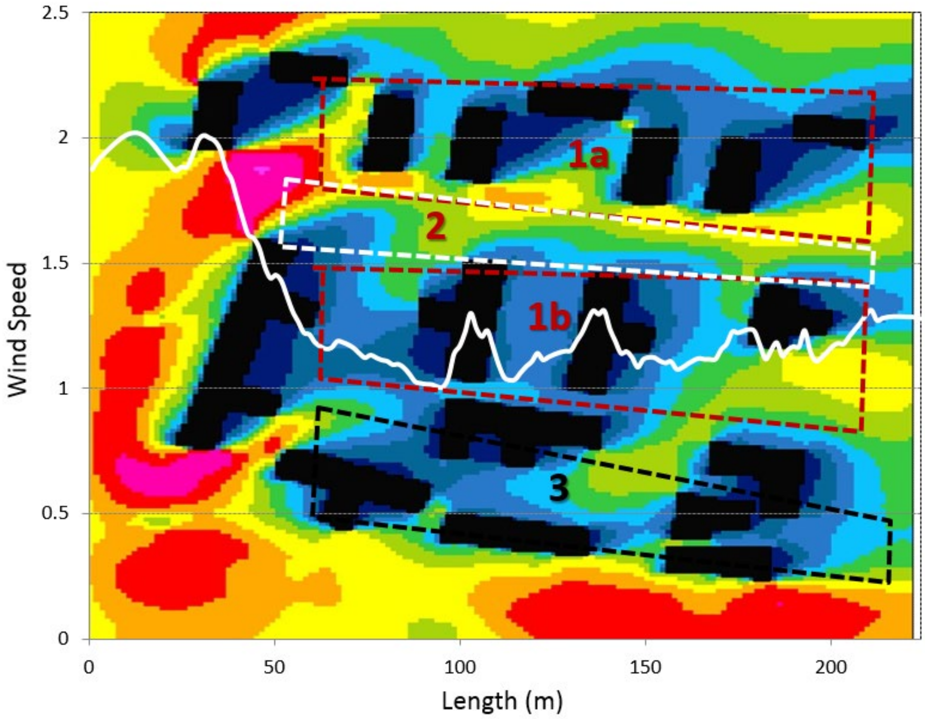


Figure 207 Three distinguished zones in OT2

<u>Zone 1a:</u> **Flow oblique to the axis of the streets.**

- The aspect ratio of the two small canyons is close to 0.75. In both canyons the air flow is under the wake interference regime. The average wind speed in the canyon is between 0.7 and 0.8 m/sec.
- The average ambient temperature in the canyon is between 31.5 and 29.5 °C.

- Because of the orientation of the canyons solar radiation is reaching partly the ground of the canyons and the surface temperature of the non-shaded part is close to 39 °C, while the corresponding temperature in the shaded part is close to 27 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is above the thresholds but it improves in the shaded by the trees zones.

Zone 1b: Flow oblique to the axis of the streets.

- The aspect ratio of the canyon in the middle of the zone is close to 0.5. The air flow is under the wake interference regime. The average wind speed in the canyon is close to 0.7.
- The average ambient temperature in the canyon is between 30 and 29.5 °C.
- Because of the orientation of the canyon and the presence of a building in the southern part, solar radiation is reaching a small part of the canyon ground and the surface temperature of the non-shaded part is close to 39 °C, while the corresponding temperature in the shaded part is close to 27 °C.
- Thermal comfort conditions in the non-shaded parts of the canyons is above the thresholds but it improves in the shaded by the trees zones.

Zone 2: Almost an open space.

- Wind speeds between 0.8 and 2 m/sec.
- Higher wind speeds in the windward façade of the buildings of zone 1a.
- Temperatures between 29.5 °C and 31°C.
- Low surface temperatures and acceptable thermal comfort conditions in the shaded parts of the zone.

Zone 3: Is more an open space than a canyon.

- Low wind speeds in the leeward part of the buildings that increases out of the wake.
- Temperatures 29.5 and 30.5 °C.
- High surface temperatures in the non-shaded parts, close to 42 °C.
- Acceptable thermal comfort conditions in the shaded zones.

General Comments

The average gradient of the temperature decreases along the precinct for the mitigation and the non-mitigation scenarios are to 0.0084 °C/m. and 0.0067 °C/m. Very good wind shading arrangement between the buildings decreases the wind speed and the heat advection. Shading is not optimised and surface temperatures in the non-shaded zones are quite high. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

OT3

The ambient temperature along the precinct of OT3 with mitigation is shown in Figure 208 and Figure 209. The gradient of temperature decrease is 0.087°C / 10 meters.

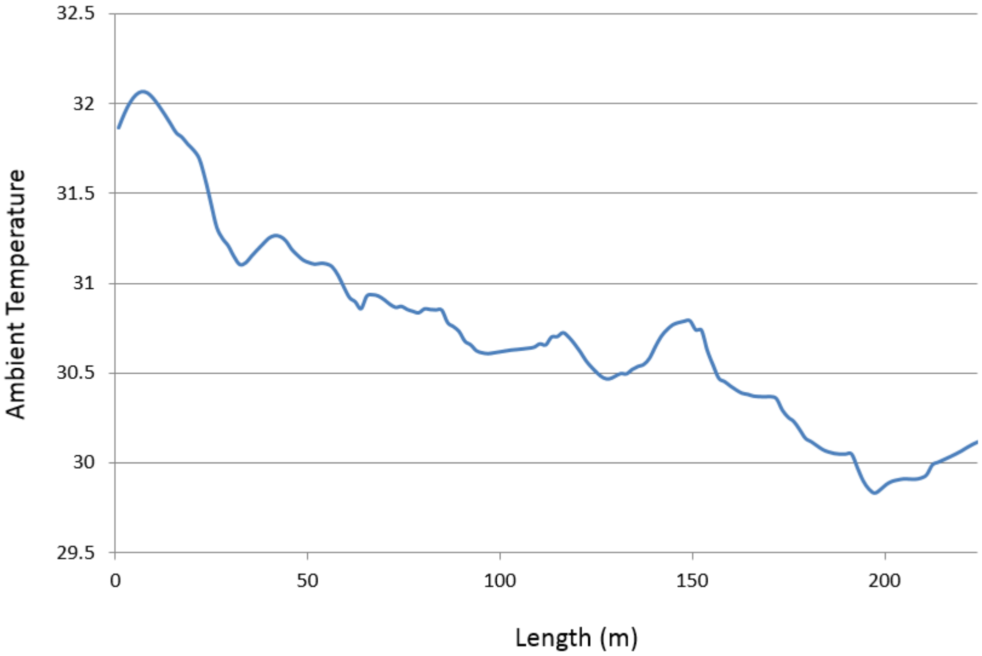


Figure 208 OT3– Ambient Temperature Along the Precinct with Mitigation

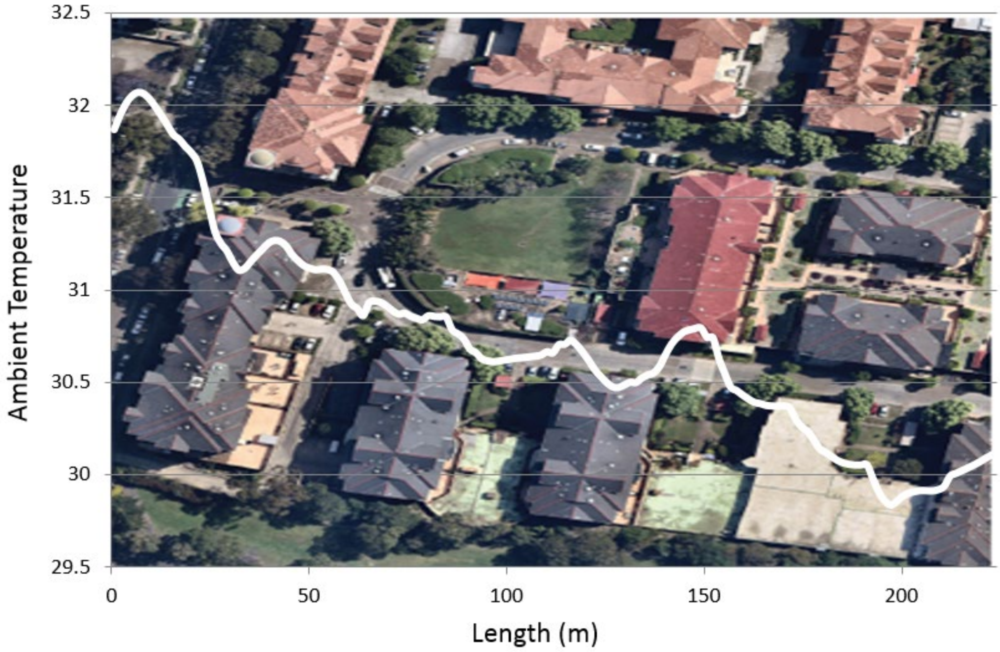


Figure 209 OT3– Ambient Temperature Along the Precinct with Mitigation

Figure 210, Figure 211 and Figure 212 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

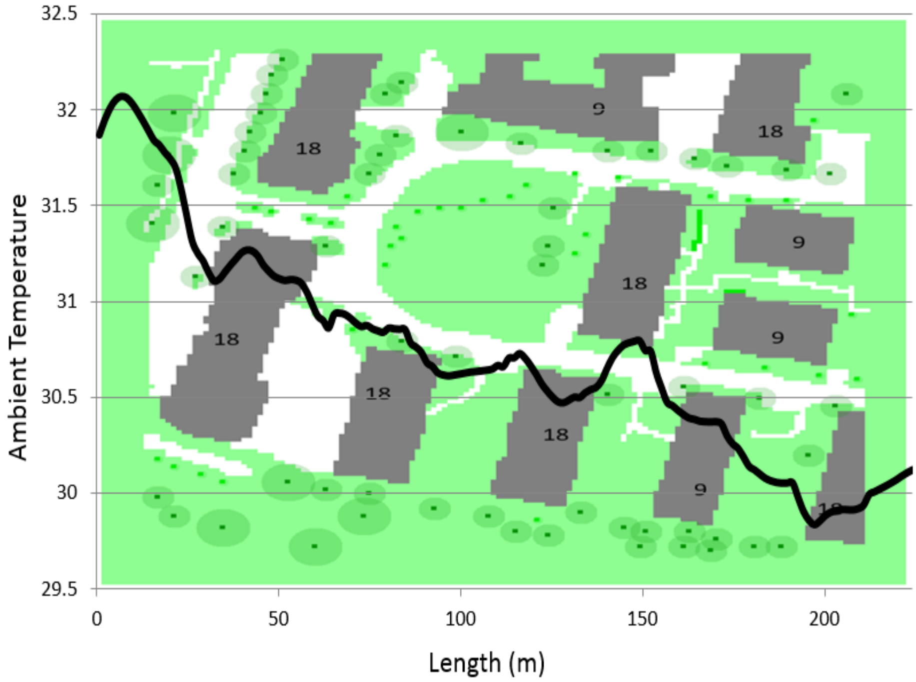


Figure 210   OT3– Ambient Temperature Along the Precinct with Mitigation

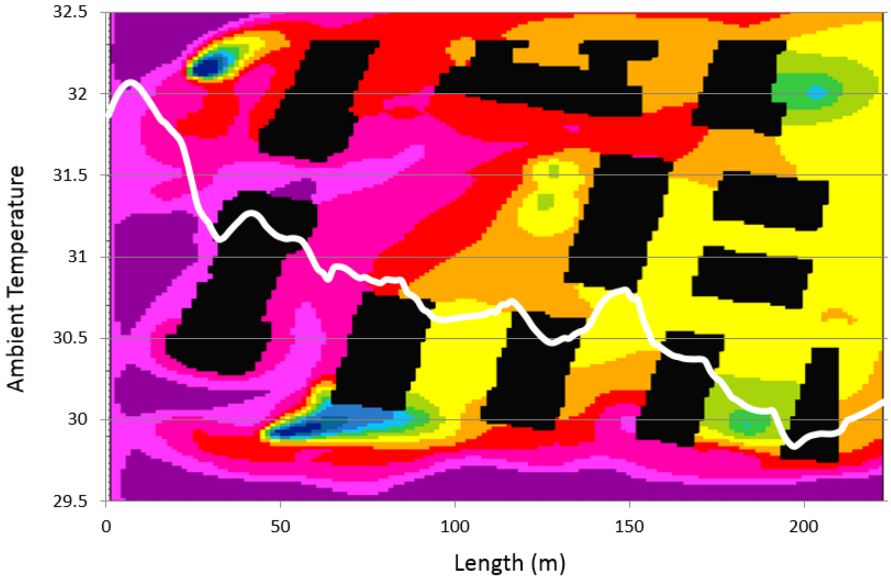


Figure 211   OT3– Ambient Temperature Along the Precinct with Mitigation

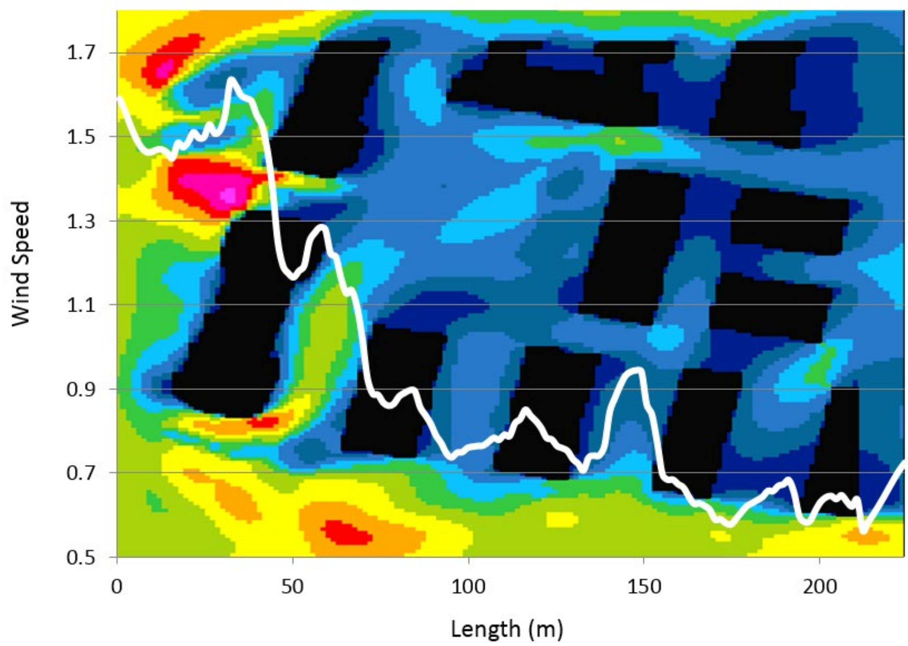


Figure 212   OT3– Wind Speed Along the Precinct with Mitigation

Figure 213 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

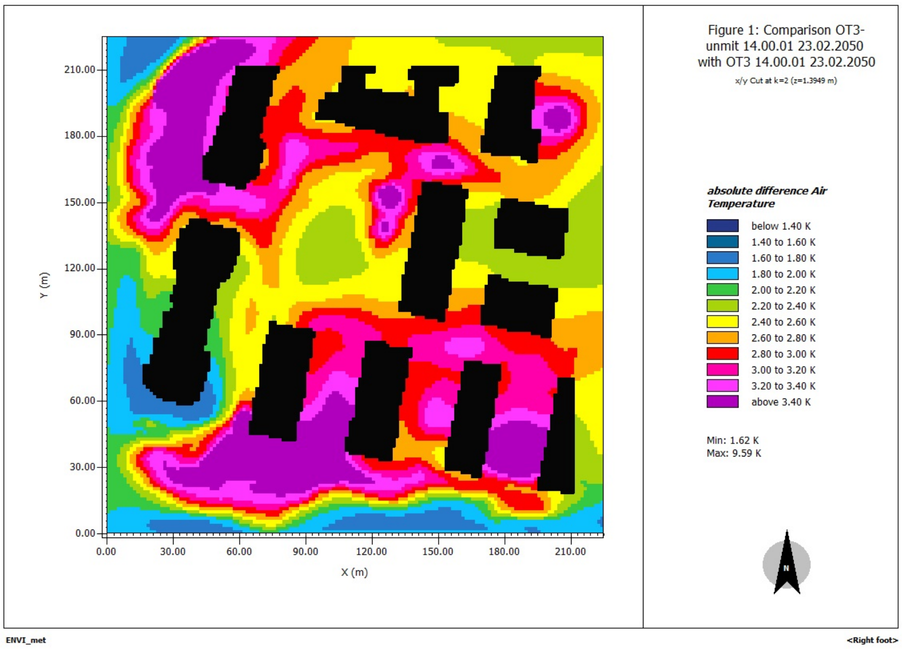


Figure 213 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 214 compares the ambient temperature along the precinct with and without mitigation.

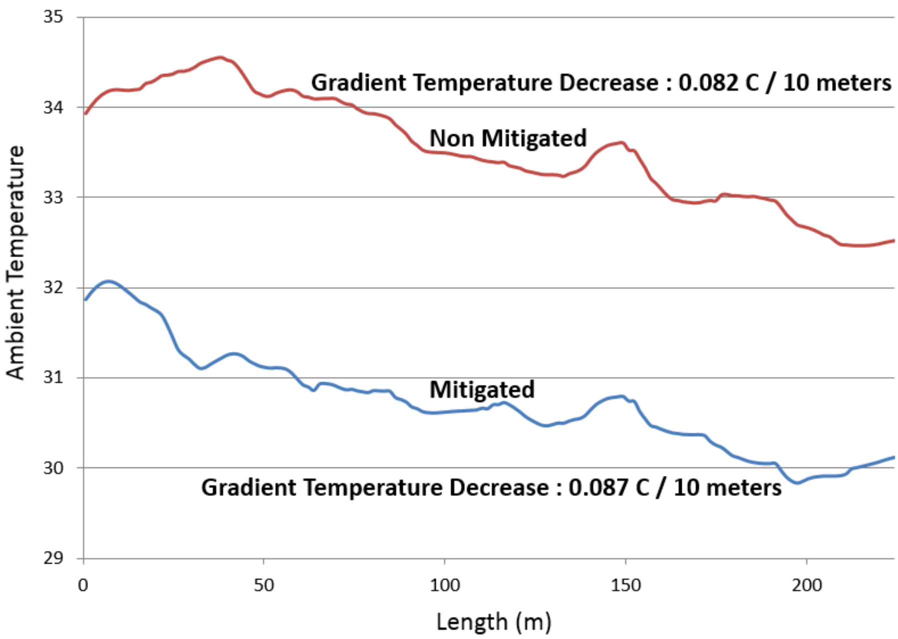


Figure 214 OT3– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT3 precinct can be classified in three distinguished zones as depicted in Figure 215.

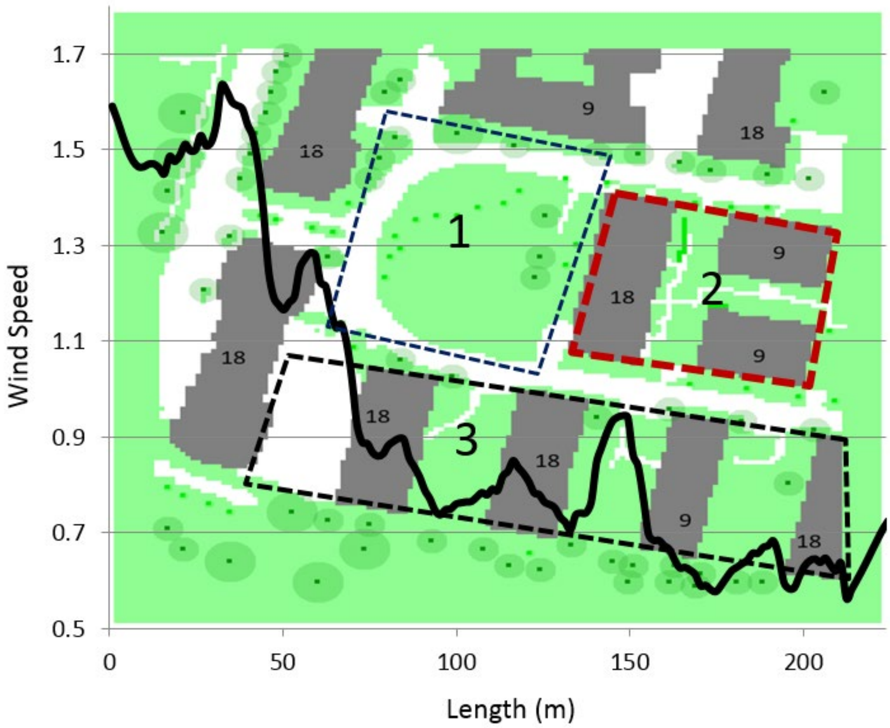


Figure 215 Three distinguished zones in OT3

Zone 1: An open space.

- Wind speeds between 0.5 and 1 m/sec. Significant decrease of the wind speed because of the 2 buildings in the windward zone.
- Temperatures between 29. °C to 31 °C.
- Low surface temperatures and acceptable thermal comfort conditions in the shaded parts of the zone.

Zone 2: It includes two perpendicular canyons.

- The long canyon has an aspect ratio close to 1,12 and an average wind speed close to 0.35. The flow is under skimming regime. The small perpendicular canyon has an aspect ratio close to 0.6 and an average wind speed close to 0.4.
- Temperature is between 29.5 °C and 30 °C.
- Most of the ground surface of the long canyon is shaded and presents low surface temperature and acceptable comfort conditions.
- On the contrary the small canyon presents high surface temperatures.

Zone 3: It includes four almost similar canyons.

- The aspect ratio is close to 0.7.
- The flow corresponds to wake interface regime. The average wind speed is close to 0.7.
- The ambient temperature varies between 29.5 to 31 °C.
- Most of the ground surface is not shaded and presents high surface temperature and high PET values.

General Comments

The average gradient of the temperature decrease along the precinct for the mitigation and the non-mitigation scenarios are to 0.0087 °C/m. and 0.0082 °C/m. Very good wind shading arrangement in zones 2 and 3 between the buildings decreases the wind speed and the heat advection. Shading is not optimised and surface temperatures in the non-shaded zones are quite high. Cool pavements and cool roofs in combination with vegetation contribute to decrease the ambient temperature significantly, while the impact of the tree shading is very important.

OT4

The ambient temperature along the precinct of OT4 with mitigation is shown in Figure 216 and Figure 217. The gradient of temperature decrease is 0.08°C / 10 meters.

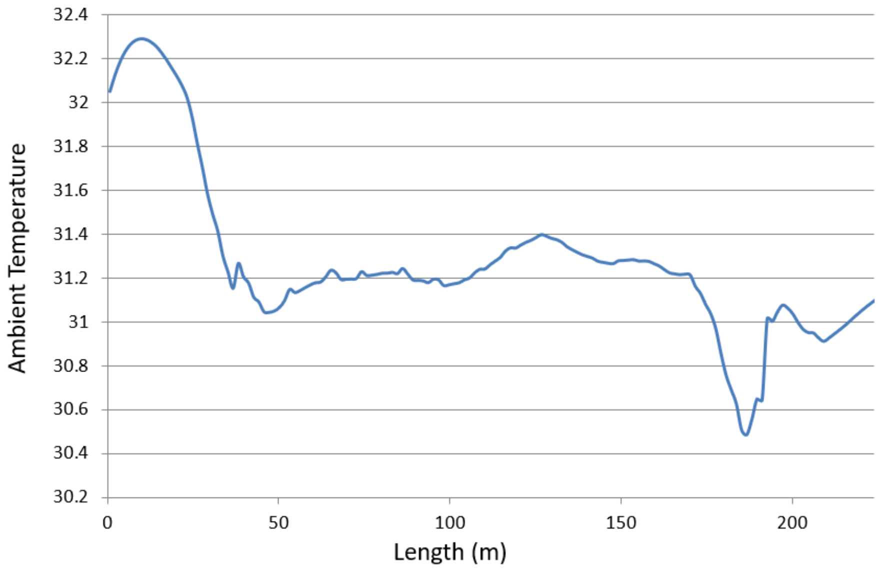


Figure 216 OT4– Ambient Temperature Along the Precinct with Mitigation

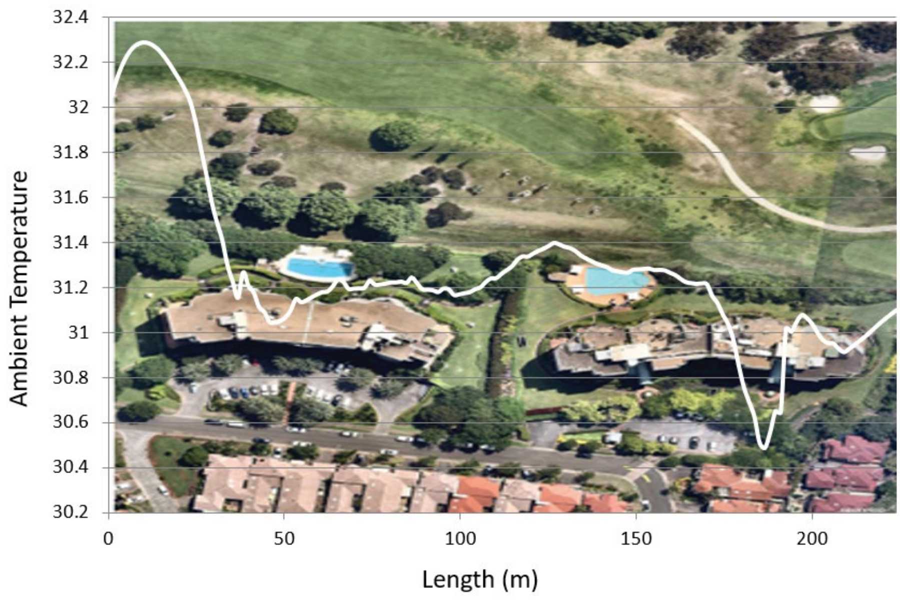


Figure 217 OT4– Ambient Temperature Along the Precinct with Mitigation

Figure 218, Figure 219, and Figure 220 present the ambient temperature and wind speed along the precinct (with mitigation) plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

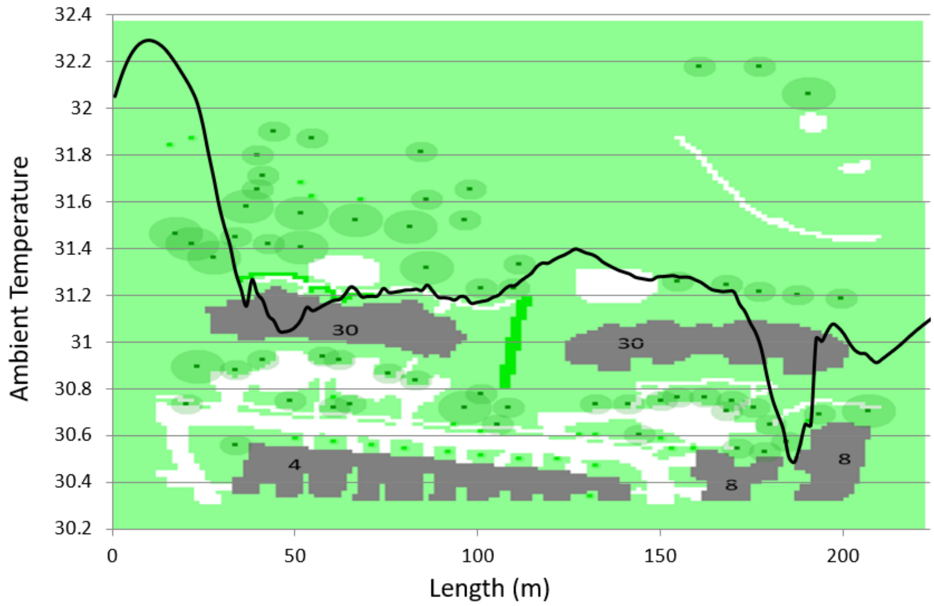


Figure 218 OT4– Ambient Temperature Along the Precinct with Mitigation

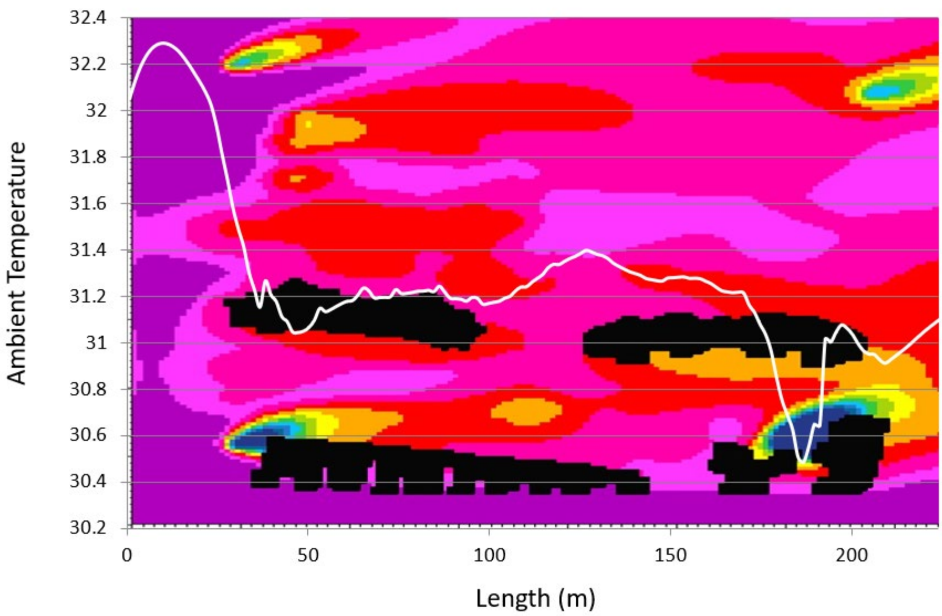


Figure 219 OT4– Ambient Temperature Along the Precinct with Mitigation

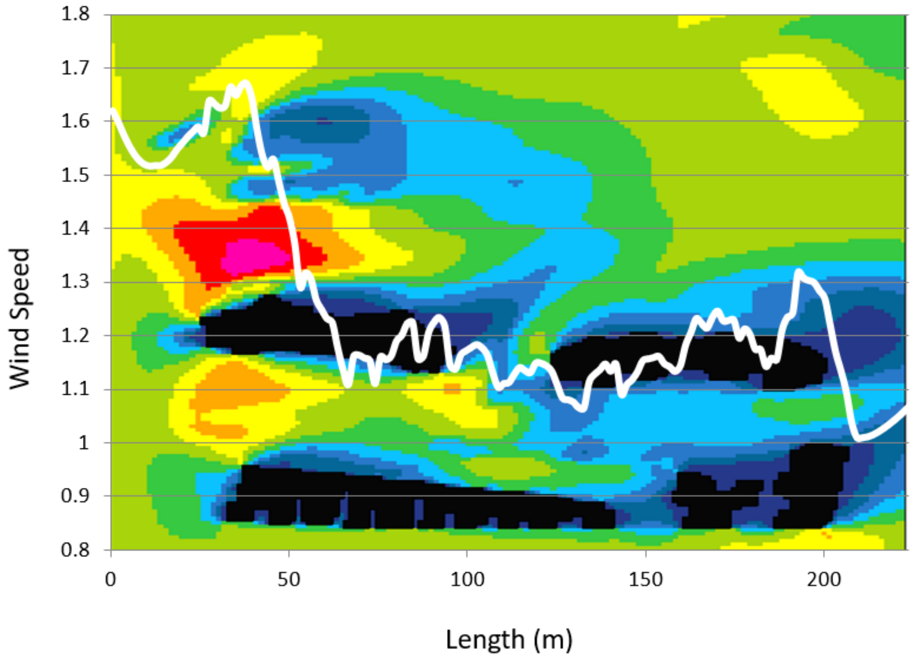


Figure 220 OT4– Wind speed Along the Precinct with Mitigation

Figure 221 compares the ambient temperature along the precinct with and without mitigation.

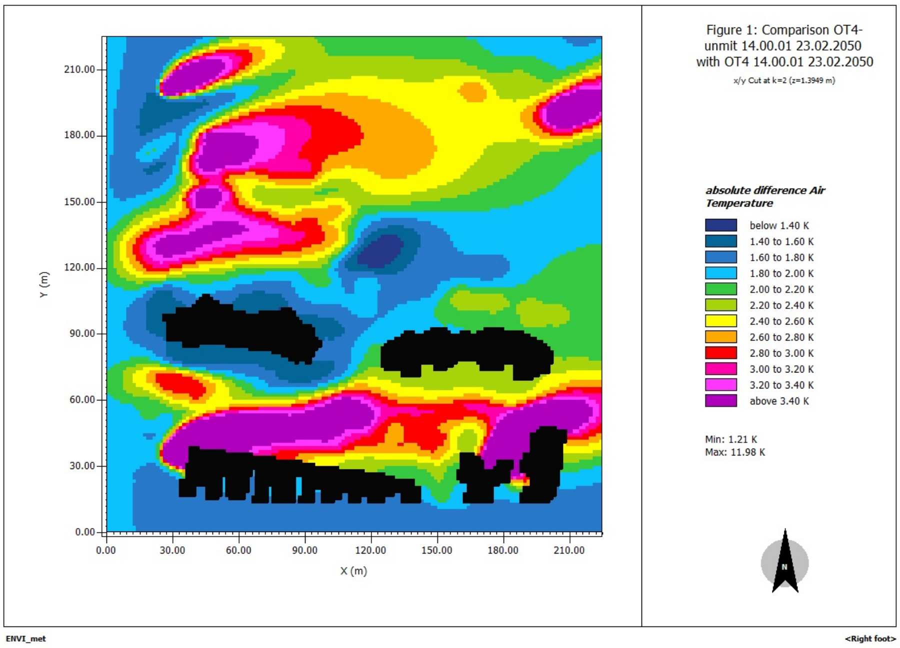


Figure 221 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

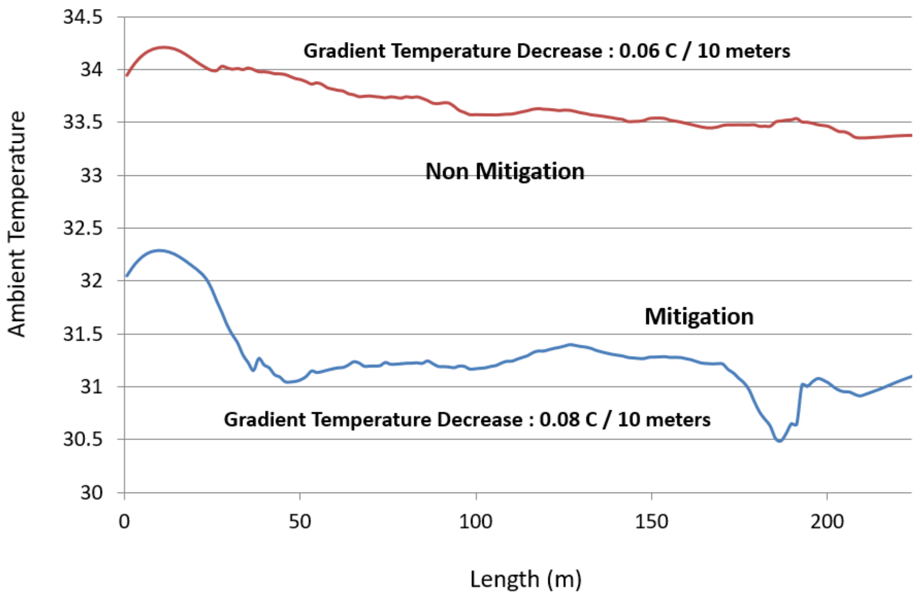


Figure 222 OT4– Ambient Temperature Along the Precinct with Mitigation

The climatic conditions in the OT4 precinct can be classified in two distinguished zones as depicted in Figure 223.

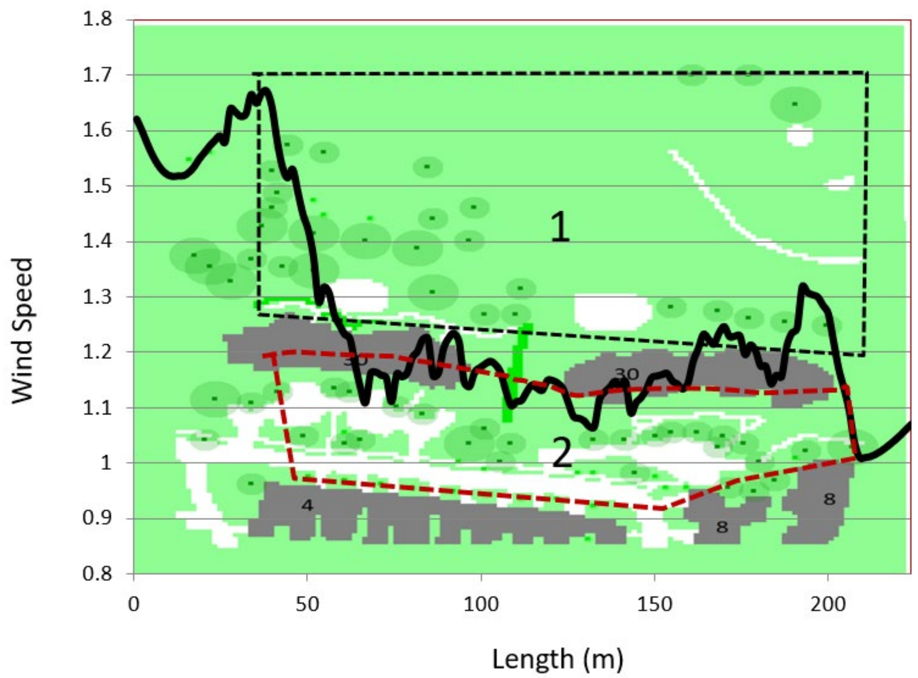


Figure 223 Two distinguished zones in OT4

Zone 1: An open space.

Wind speed varies between 2 to 1.2 m/sec. The ambient temperature varies between 32 to 31 °C. Part of the area is shaded by trees and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

Zone 2: It is almost open area.

Wind speeds varies between 2 m/sec to 0.8 m/sec. Ambient temperature varies between 31-32 °C. Part of the area is shaded by trees and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

General Comments

The average gradient of the temperature decreases along the habituated part of the precinct for the mitigation and the non-mitigation scenarios are to 0.008 °C/m. and 0.006 °C/m. The specific configuration does not benefit from any wind or solar shading and the decrease of the temperature along the canyon axis is because of the used mitigation techniques.

OT5

The ambient temperature along the precinct of OT5 with mitigation is shown in Figure 224 and Figure 225. The gradient of temperature decrease is 0.07°C / 10 meters.

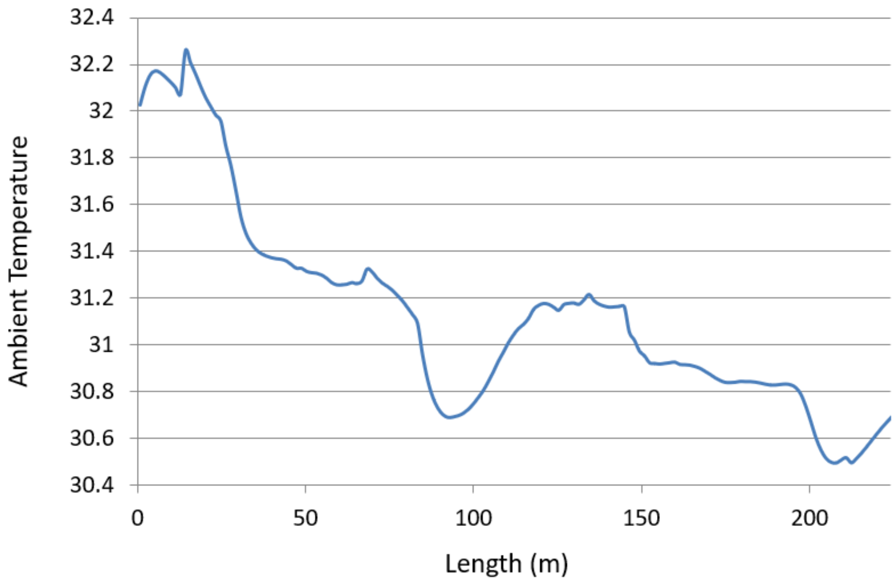


Figure 224 OT5– Ambient Temperature Along the Precinct with Mitigation

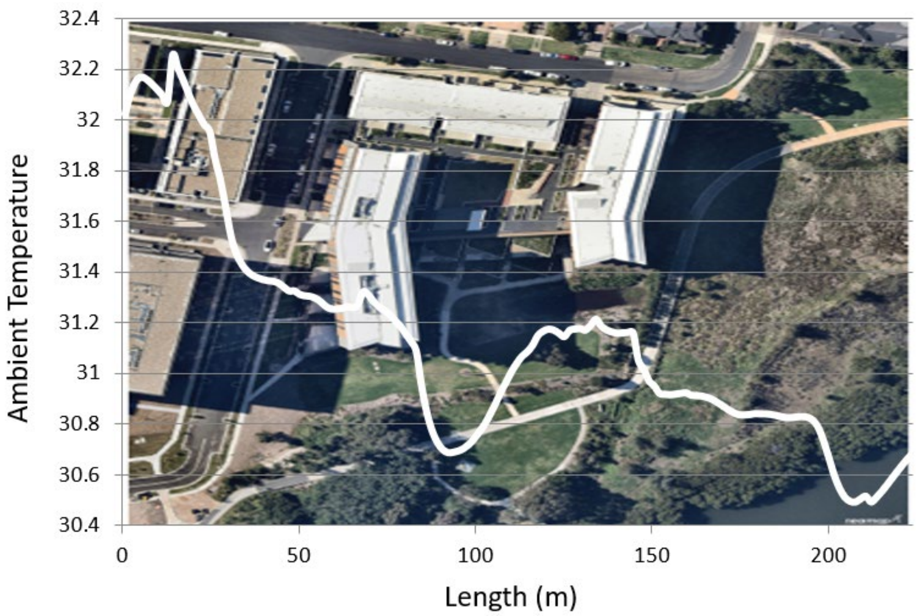


Figure 225 OT5– Ambient Temperature Along the Precinct with Mitigation

Figure 226, Figure 227, and Figure 228 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

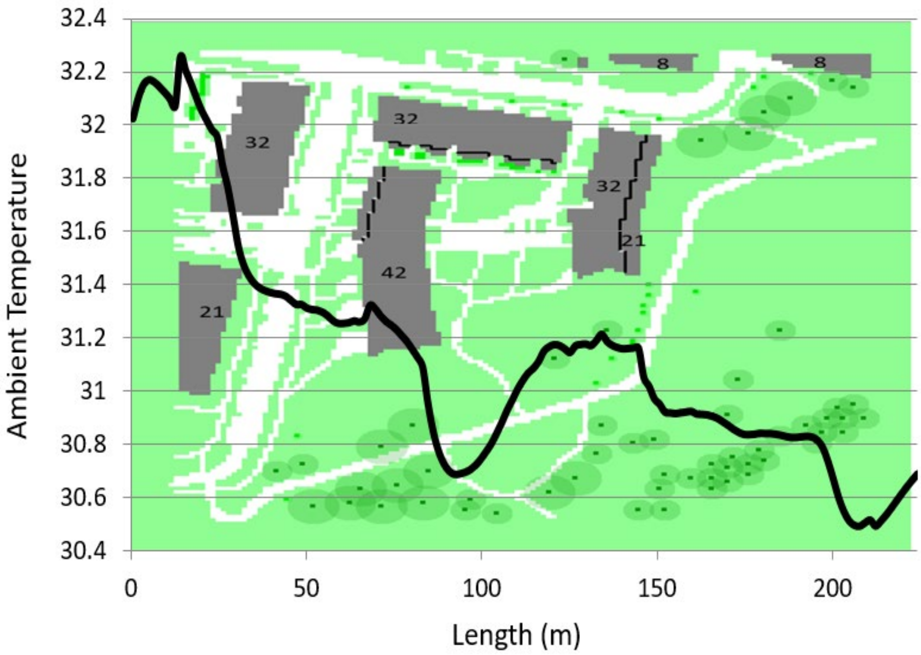


Figure 226 OT5– Ambient Temperature Along the Precinct with Mitigation

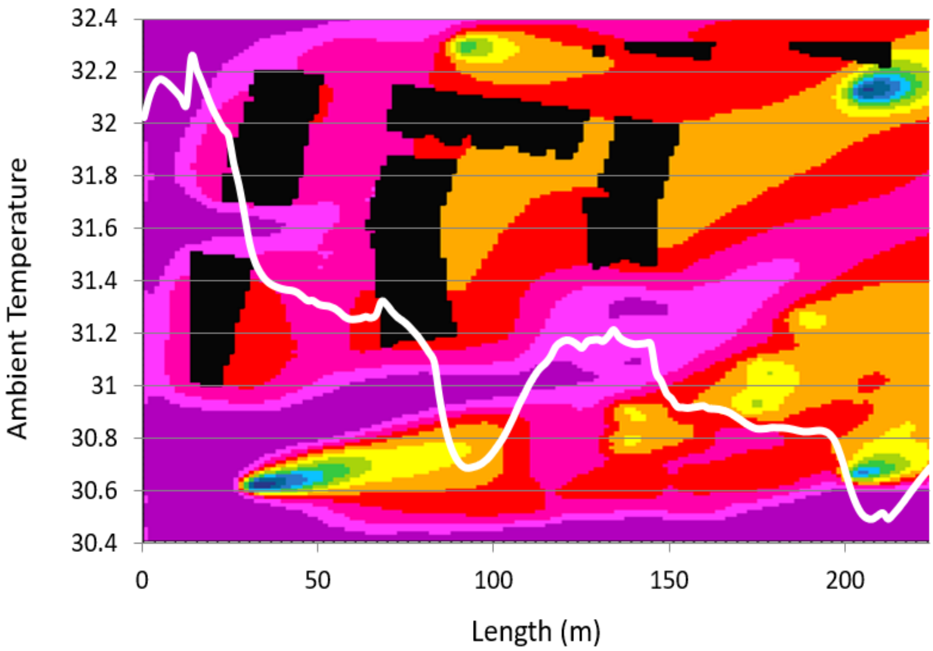


Figure 227 Ambient Temperature Along the Precinct with Mitigation

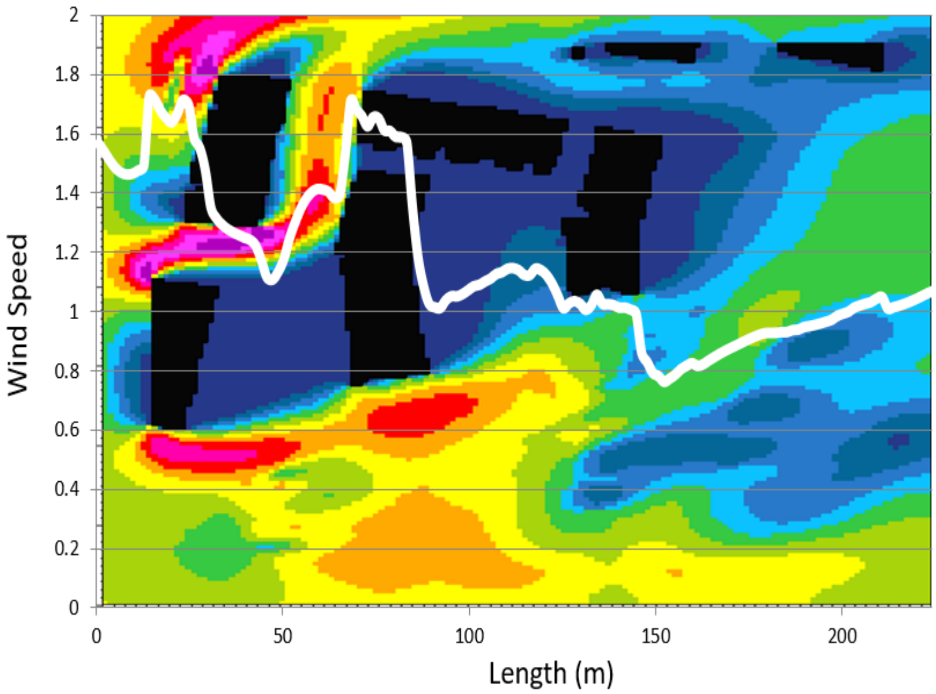


Figure 228 OT5– Wind speed Along the Precinct with Mitigation

Figure 229 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

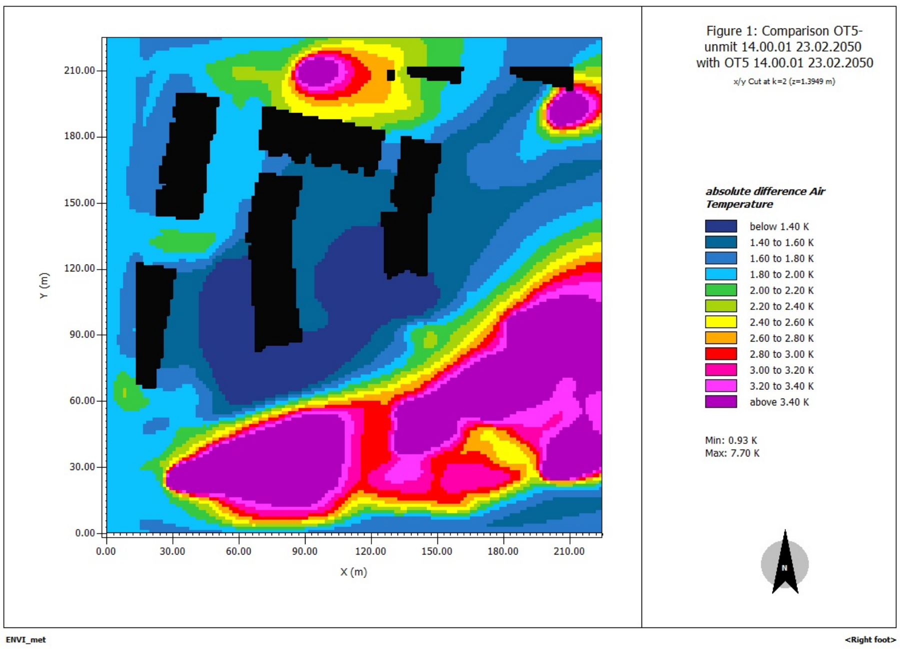


Figure 229 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 230 compares the ambient temperature along the precinct with and without mitigation.

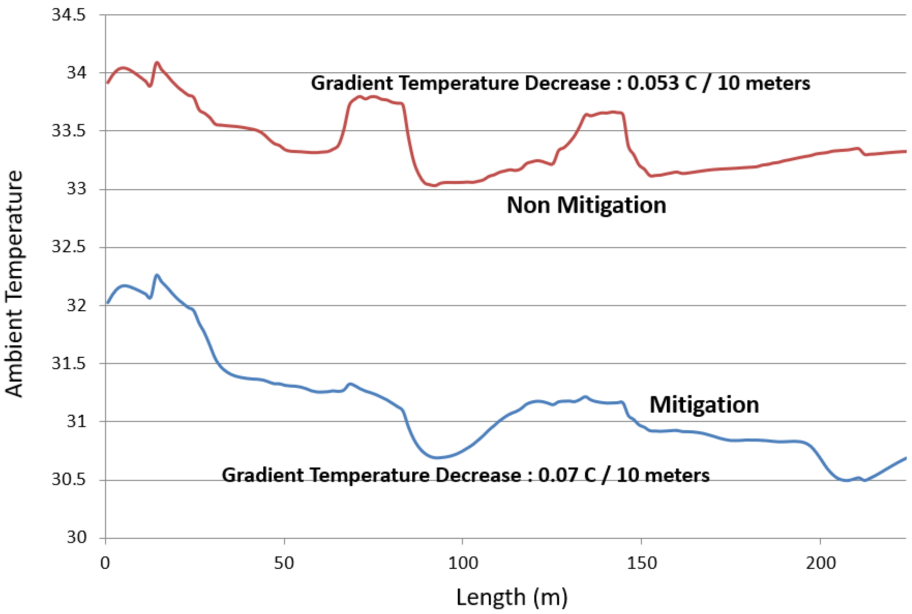


Figure 230 OT5– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT5 precinct can be classified in three distinguished zones as depicted in Figure 231.

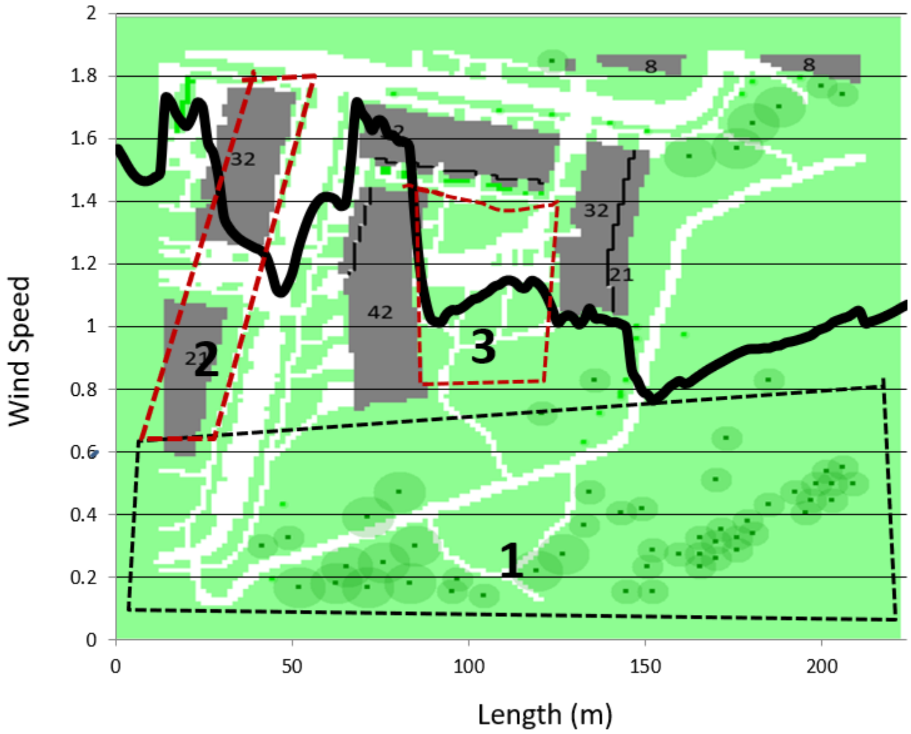


Figure 231 Three distinguished zones in OT5

Zone 1: An open space.

Wind speed varies between 2 to 1.2 m/sec. The ambient temperature varies between 32 to 30 °C. Part of the area is shaded by trees and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

Zone 2: **Air mainly enters through the gap between the two buildings.**

It flows from the gap towards the northern building. The wind speed close to the northern building is high > 2 m/sec, as a Bernoulli effect is created. Close to the southern building is quite low, 0.5 m/sec. Temperature is between 31 to 32 °C. Part of the area is shaded by trees and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

Zone 3: **It is an almost open area fully protected from wind.**

Wind speed is low, blow 0.3 m/sec, while the ambient temperature is varying between 30 to 31 °C. A high part of the zone is shaded and the surface temperature as well as thermal comfort are at acceptable levels.

General Comments

The average gradient of the temperature decrease along the habituated part of the precinct for the mitigation and the non-mitigation scenarios are to 0.007 °C/m. and 0.0055 °C/m. The specific configuration and in particular zone 3 is very well protected from the wind. This helps to reduce the wind speed and the ambient temperature. Solar shading is not optimised. The impact of the used mitigation techniques contributes highly to decrease the temperature along the canyon axis.

OT6

The ambient temperature along the precinct of OT6 with mitigation is shown in Figure 232 and Figure 233. The gradient of temperature decrease is 0.095°C / 10 meters.

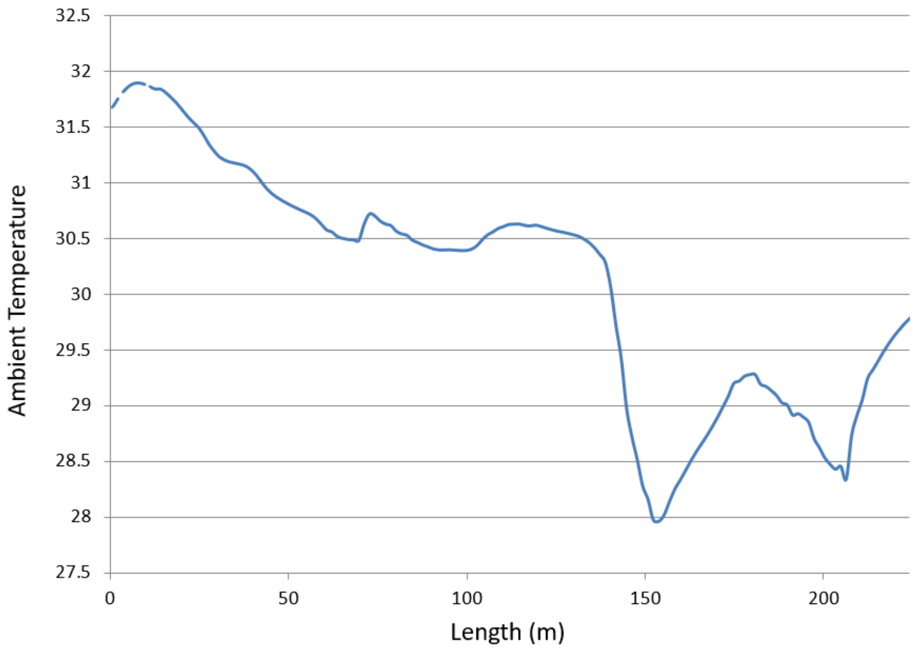


Figure 232 OT6– Ambient Temperature Along the Precinct with Mitigation

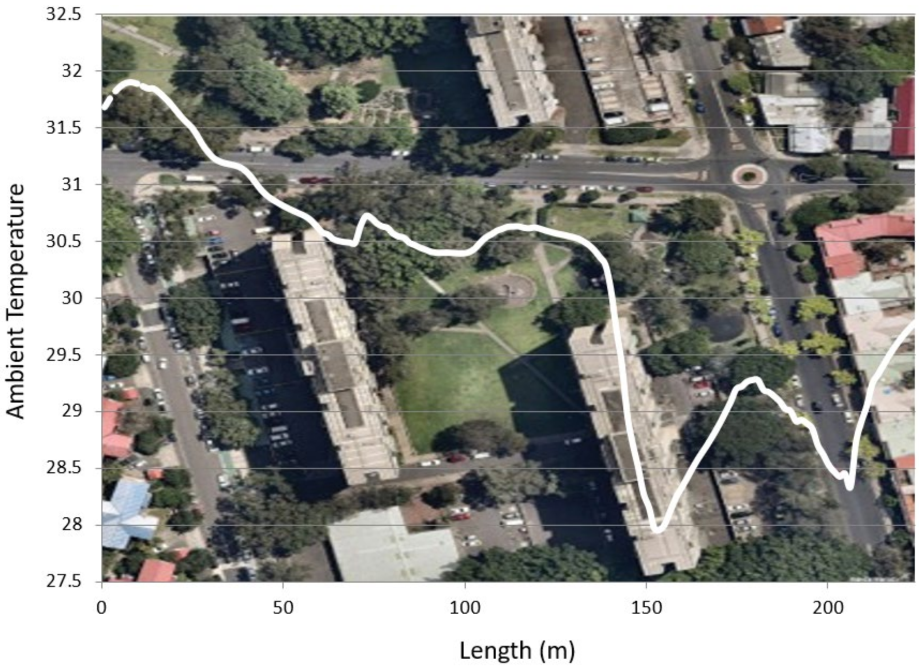


Figure 233 OT6– Ambient Temperature Along the Precinct with Mitigation

Figure 234, Figure 235, and Figure 236 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

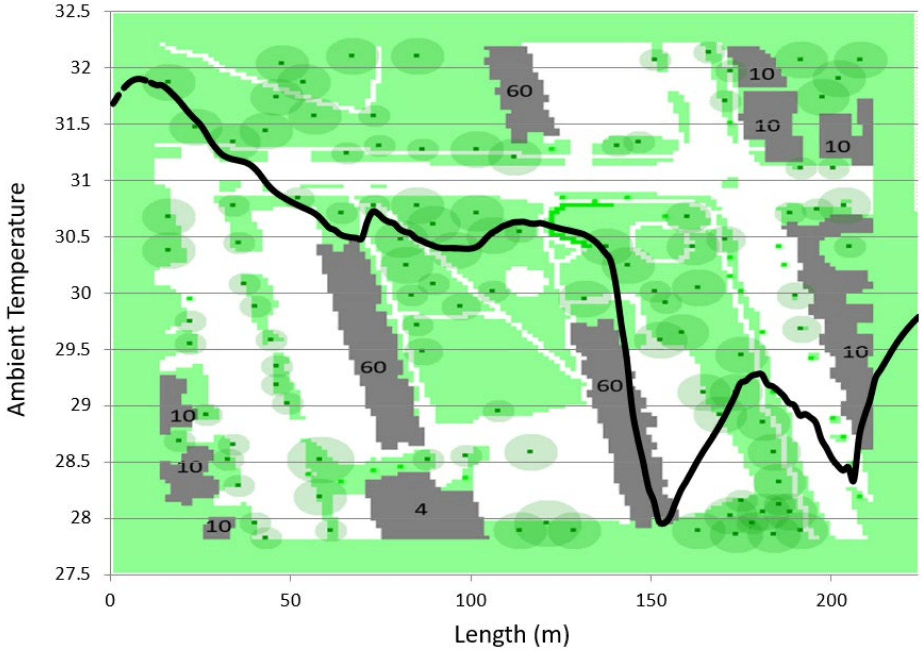


Figure 234 OT6– Ambient Temperature Along the Precinct with Mitigation

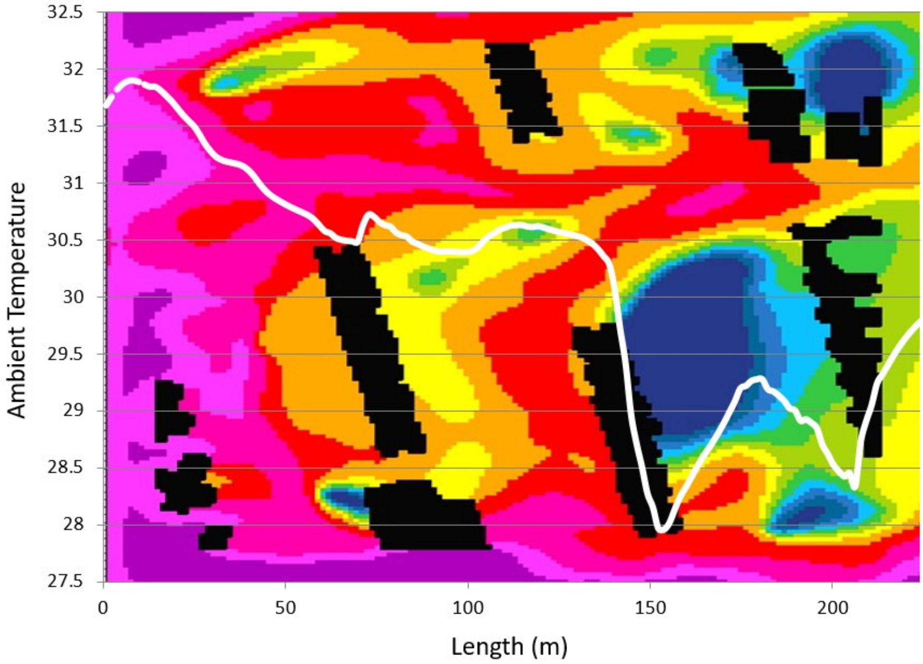


Figure 235 OT6– Ambient Temperature Along the Precinct with Mitigation

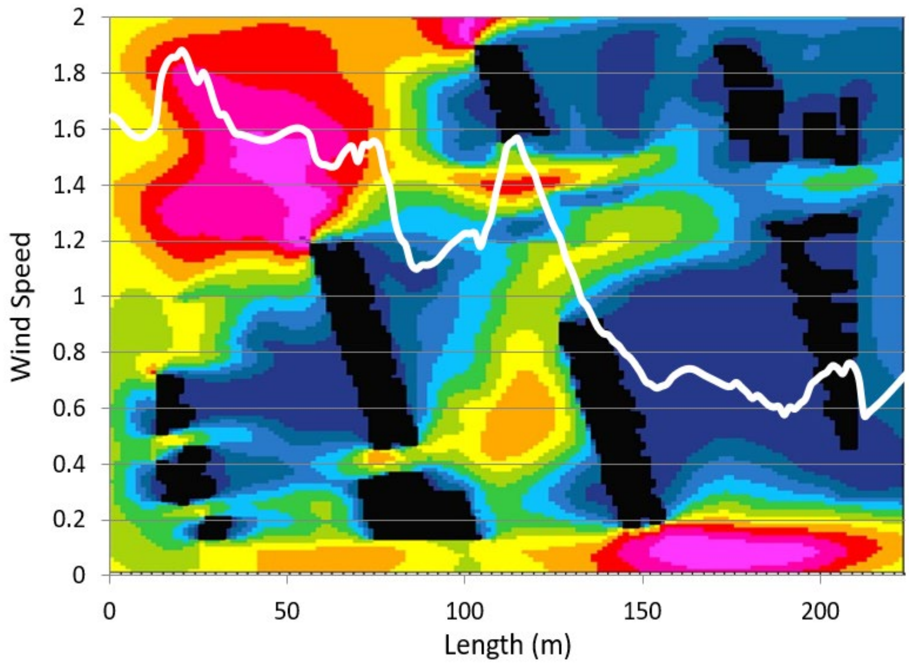


Figure 236 OT6– Wind Speed Along the Precinct with Mitigation

Figure 237 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

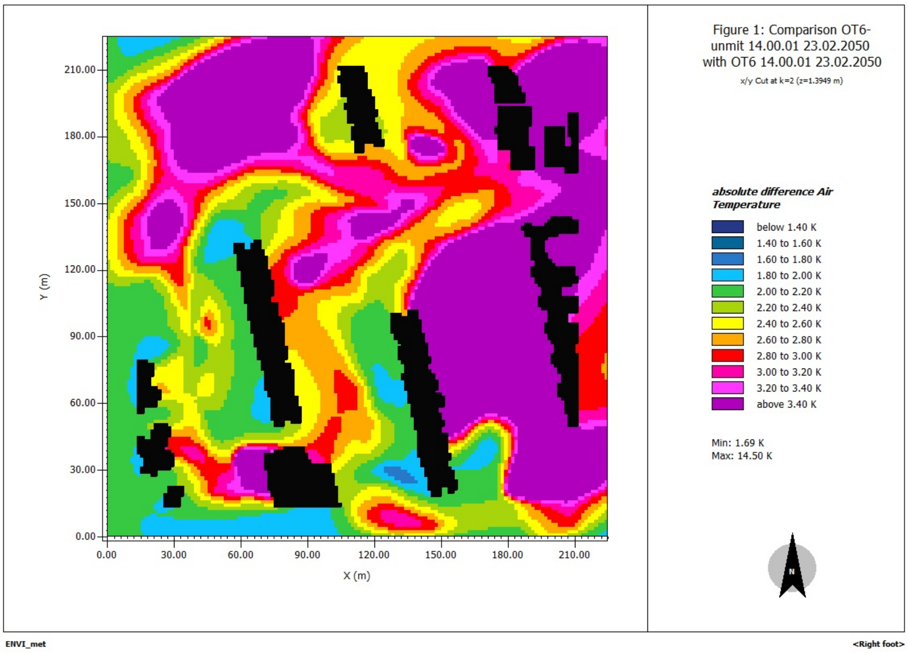


Figure 237 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 238 compares the ambient temperature along the precinct with and without mitigation.

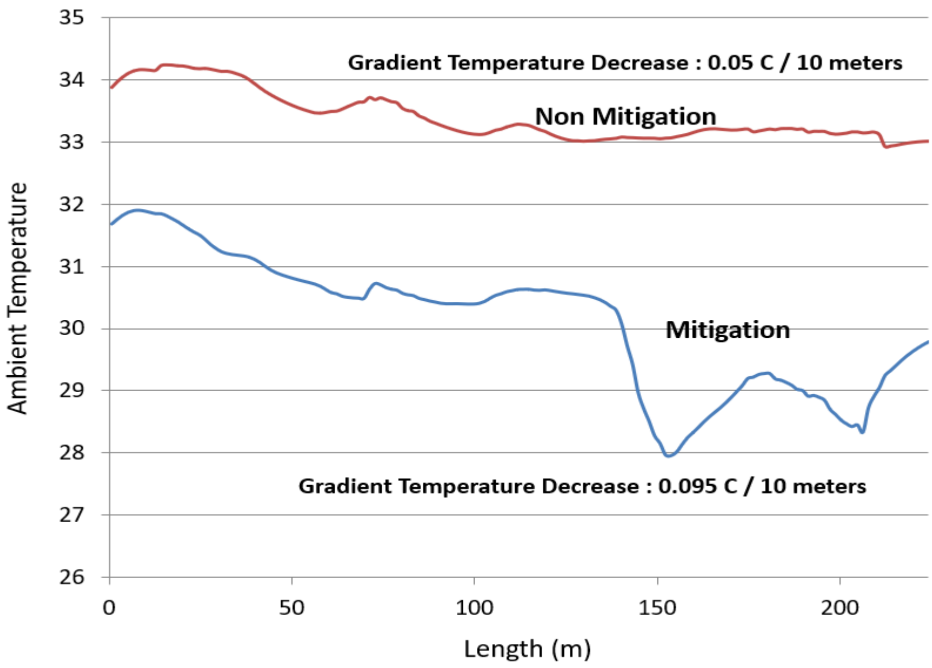


Figure 238 OT6– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT6 precinct can be classified in two distinguished zones as shown in Figure 239.

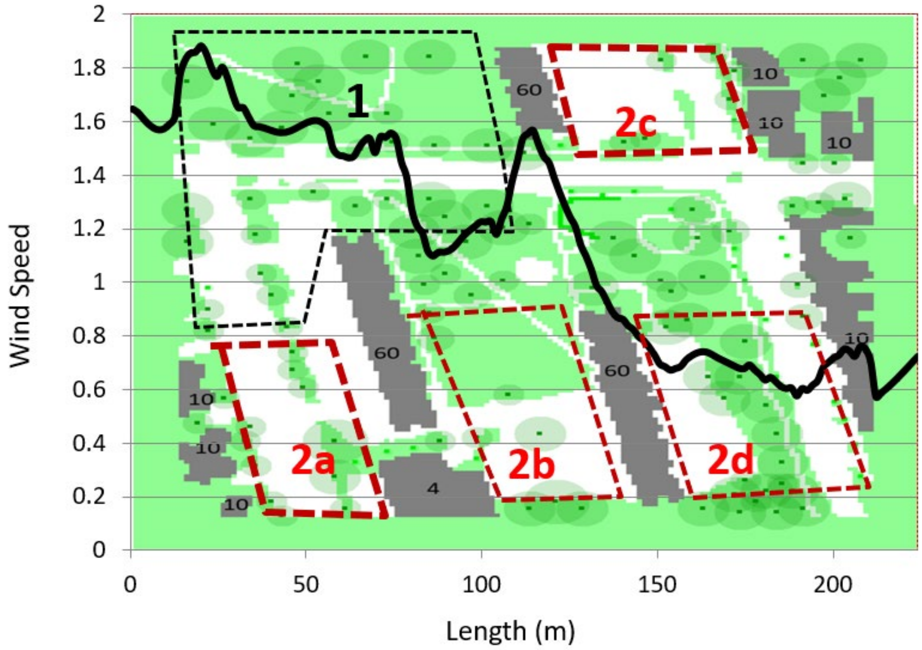


Figure 239 Two distinguished zones in OT6

Zone 1: An open space.

Wind speed varies between 2.5 to 0.7 m/sec. The ambient temperature varies between 32 to 30 °C. Part of the area is shaded by trees and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

Zone 2: It is composed by 4 canyons.

- Canyon 2a, has an aspect ratio close to 40 while the flow is undisturbed and under the isolated roughness regime. The average wind speed is higher than 1 m/sec. Temperature is between 31.5 to 30.5 °C. The part of the street that is shaded by the trees presents a relatively low surface temperature and a reasonable PET value.

- The canyon 2b has an aspect ratio close to 1.5 and the flow is managed by the advection from zone 2.a. The wind speed is quite high 1.5 m/sec, while in the leeward part of the buildings is much lower. Temperature is close to 31 °C in the middle of the canyon and decreases to 29.5 °C in the leeward part of the street.

- Canyon 2c has an aspect ratio close to 0.65 and the wind speed is around 0,6 m/sec, Temperature is close to 30 °C. Finally, canyon 2d, has an aspect ratio close to 0.87 and the wind speed is very low close to 0.3 m/sec. The shaded parts of the canyons have low surface temperatures and acceptable thermal comfort.

General comments:

The average gradient of the temperature decrease along the habituated part of the precinct for the mitigation and the non-mitigation scenarios are to 0.0095 °C/m. and 0.005 °C/m. Part of the specific configuration benefits from a wind shading. Solar shading by the trees is low. The decrease of the temperature along the precinct axis is because of the used mitigation techniques.

OT7

The ambient temperature along the precinct of OT7 with mitigation is shown in Figure 240 and Figure 241. The gradient of temperature decrease is 0.04°C / 10 meters.

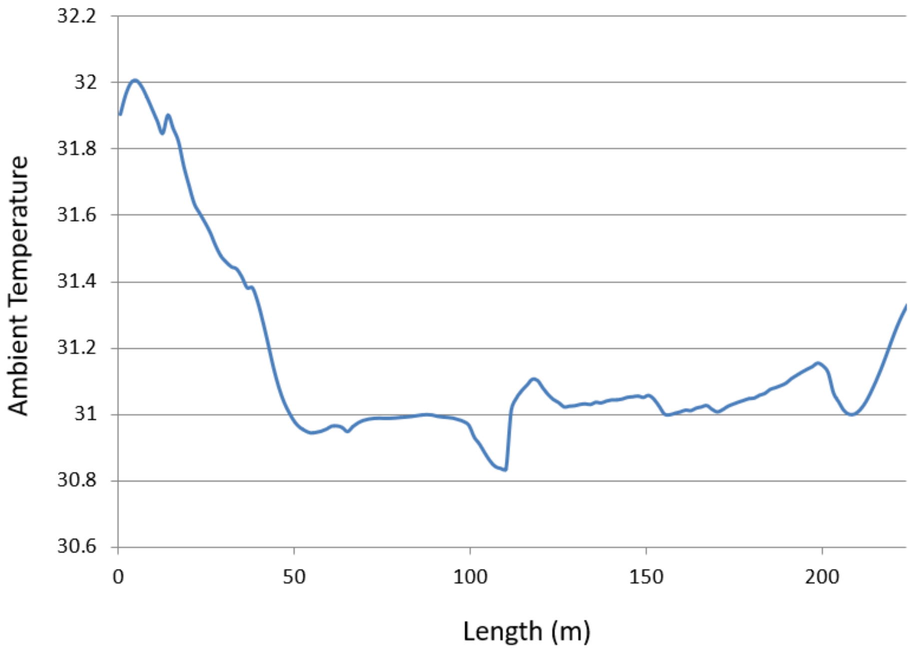


Figure 240 OT7– Ambient Temperature Along the Precinct with Mitigation

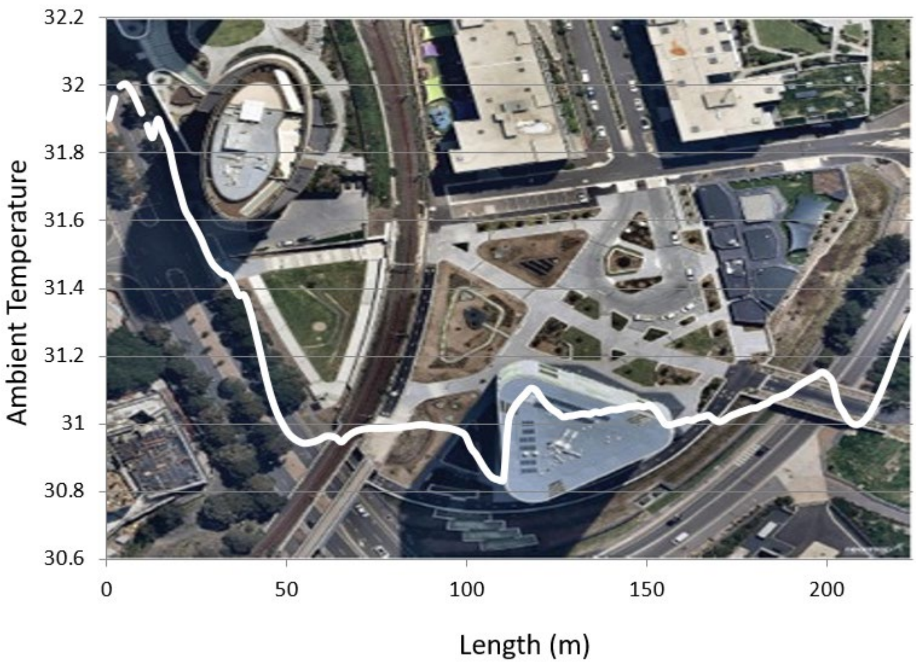


Figure 241 OT7– Ambient Temperature Along the Precinct with Mitigation

Figure 242, Figure 243 and Figure 244 present the ambient temperature and wind speed along the precinct with mitigation plotted on the simulation domain, temperature distribution and wind speed distribution maps, respectively.

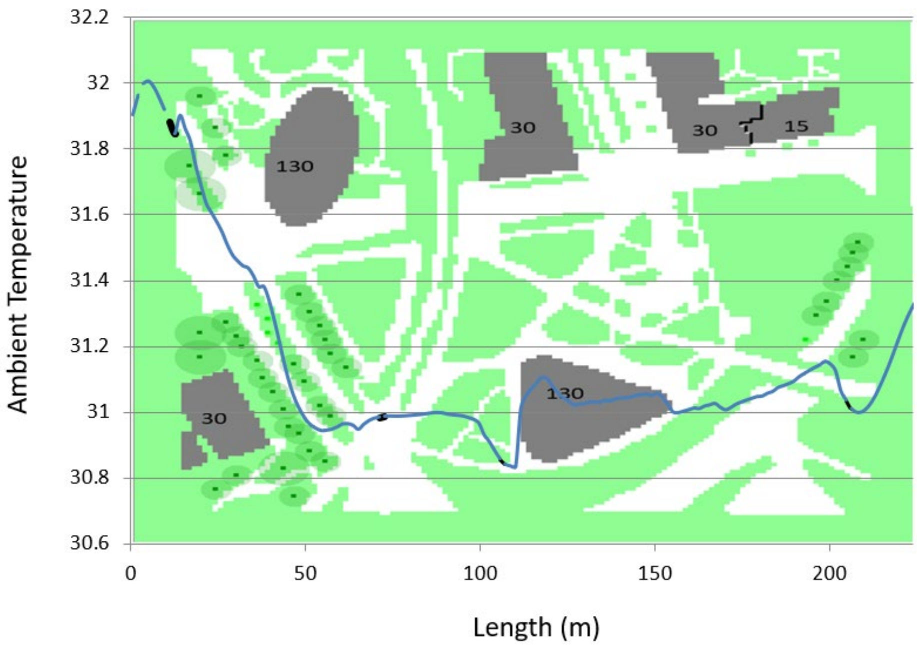


Figure 242 OT7– Ambient Temperature Along the Precinct with Mitigation

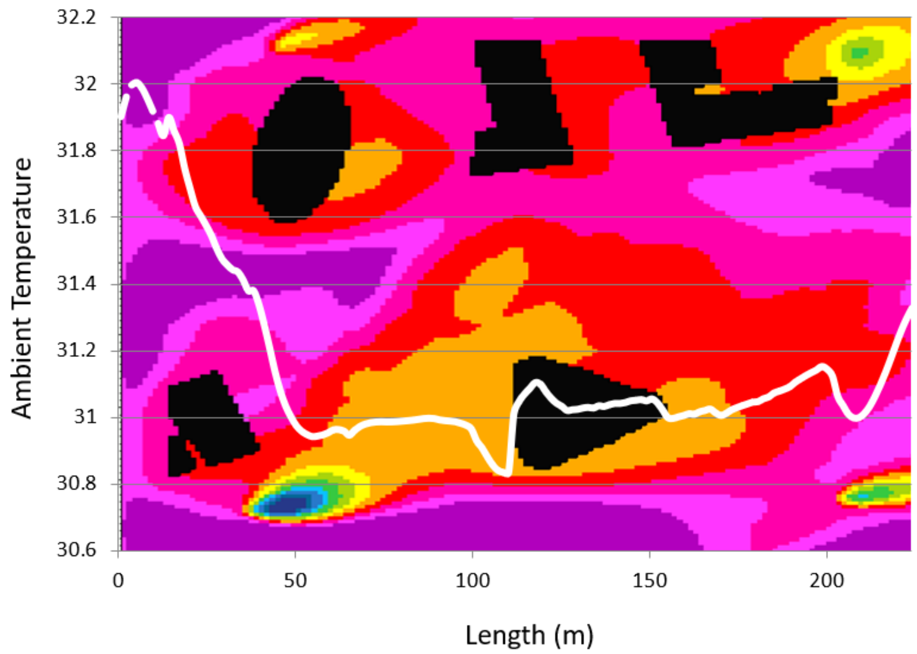


Figure 243 OT7– Ambient Temperature Along the Precinct with Mitigation

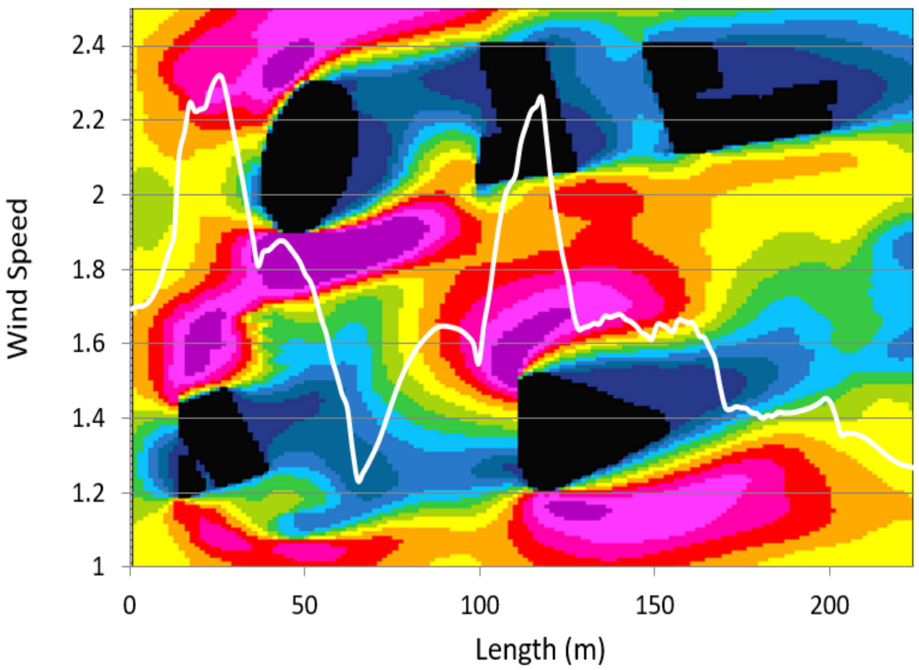


Figure 244 OT7– Wind speed Along the Precinct with Mitigation

Figure 245 shows the ambient temperature difference between the non-mitigated and mitigated precinct.

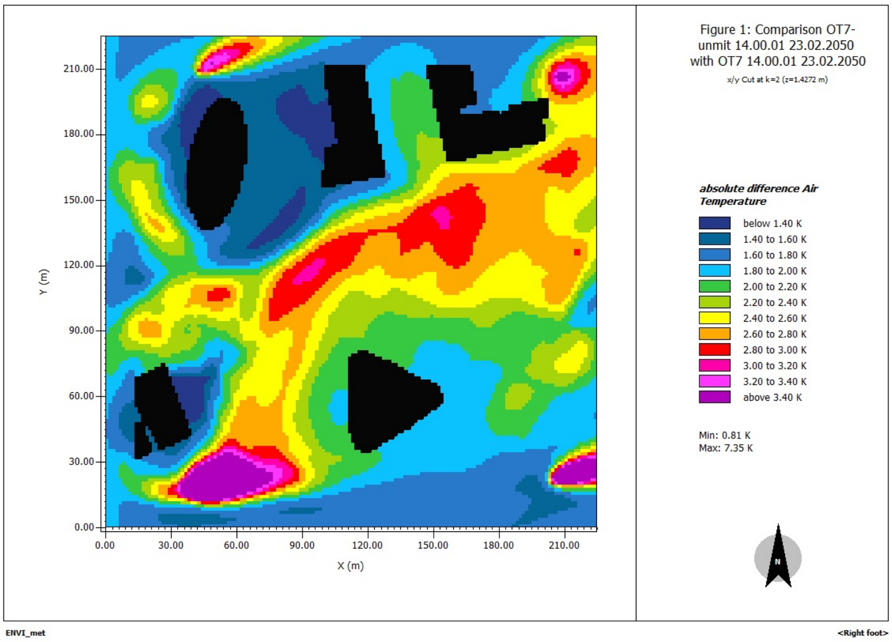


Figure 245 Temperature Difference between the Non-Mitigation and Mitigation Scenarios

Figure 246 compares the ambient temperature along the precinct with and without mitigation.

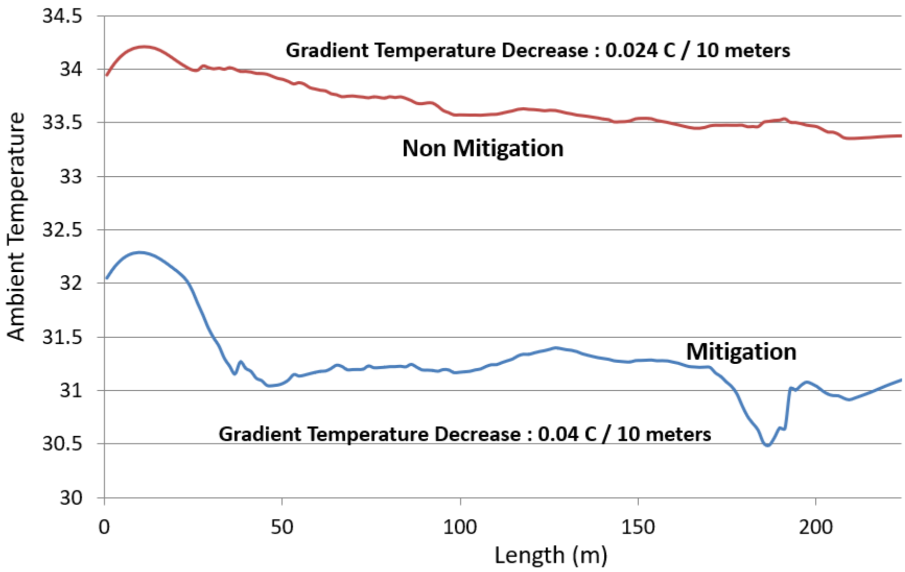


Figure 246 OT7– Ambient Temperature Along the Precinct with and Without Mitigation

The climatic conditions in the OT7 precinct can be classified in two distinguished zones as depicted in Figure 247.

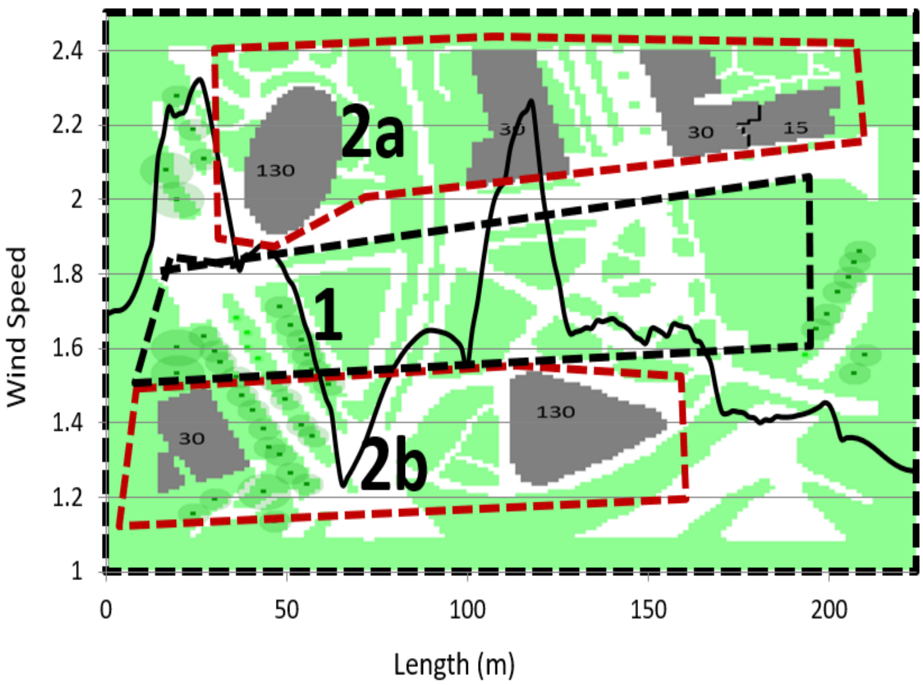


Figure 247 Two distinguished zones in OT3

Zone 1: An open space.

Wind speed varies between 2.5 to 1.5 m/sec. The ambient temperature varies between 32 to 30.5 °C. Part of the area is shaded by neighboring buildings and the surface temperature is between 27 to 30 °C, while thermal comfort is at acceptable levels.

Zone 2: It is an area characterised by the wake of the buildings.

The wind speed is low close to 0.4 m. Ambient temperature is about 0.5-1 °C lower than in zone 1. Part of the canyon surface is shaded by the neighboring buildings and present a quite low surface temperature and acceptable thermal comfort conditions.

General comments:

The average gradient of the temperature decrease along the habituated part of the precinct for the mitigation and the non-mitigation scenarios are to 0.004 °C/m. and 0.0024 °C/m. The specific configuration does not benefit from any wind or solar shading and the decrease of the temperature along the canyon axis is because of the used mitigation techniques.

7. ENERGY IMPACT

Methodology

This section describes the calculation of the cooling load for the selected precincts using dynamic thermal modelling for the mitigated 2050 climate. In order to calculate the cooling loads for the high performing reference building and precincts, a whole building simulation method has been developed which is based on a multi-zone energy model, dynamic simulation with a 8760 hours weather file, using DesignBuilder v6 software. DesignBuilder v6 is a powerful interface of EnergyPlus which is globally well-respected simulation engine capable of assessing the energy performance of buildings.

To estimate the impact of the different mitigation strategies on energy, the weather data given by WRF for 2050 mitigation have been modified considering the microclimate mitigation results. The future climate data predicted by Weather Forecast Modelling (WRF) for the mitigated 2050 was initially used as an input in the microclimate modelling (ENVI-met). Then, the hourly output data from the microclimate simulations was used to create a 24-hour profile for the simulation day. Thus, the EnergyPlus format (.epw) hourly weather data representing 2050 full mitigation was adjusted for the mitigated precinct considering the air temperature, relative humidity and dew point temperature derived from ENVI-met simulations for 10 consecutive days (from 22 February 2050 to 3 March 2050). The methodology that was followed in this section consists of the following steps:

- Development of new weather files (epw) representing the mitigated climate 2050.
- Adapting the new weather files (epw) developed for the mitigated climate 2050 (from the mesoscale modelling) based on the results of microclimate simulations for the mitigated precinct for 10 consecutive days from 22 February 2050 to 3 March 2050.
- Creating 14 new weather files for the mitigated 2050 for all precincts.
- Development of the building models and precincts in Design Builder simulation tool representing higher performing buildings.
- Calculation of the cooling load (total cooling load and sensible cooling load) for reference building and all precincts.
- Performing a sensitivity analysis of contributing factors on cooling energy needs.

Creating weather file

The Weather Research and Forecasting (WRF) Model has been used to quantitatively evaluate the impact of the developed mitigation scenarios and land use changes in terms of reducing ambient temperatures in comparison with the reference case which represents the actual situation in 2050. WRF is a next-generation mesoscale numerical weather prediction system. It has been one of the world's most widely used numerical weather prediction models. Mitigation scenario involving the combination of greenery, and water-based technologies, and increased albedo of urban impervious surfaces have been developed (Table 36). New weather data files for a whole calendar year (2050) have been developed for the simulation with Design Builder. The generated epw file for the mitigated 2050 were changed to represent mitigated precinct and then used for the simulation with Design Builder.

Table 36 Description of the reference (unmitigated) case and the defined mitigation scenario

Climate Scenario	Description
2050 Base case	2050 climate and 2018 land use
2050 mitigations	2050 climate, 2050 land use and full mitigations

Impact of mitigation strategies on air temperature

This section briefly analyses the impact of the considered mitigation scenarios on the ambient air temperature based on the developed 2050 weather data from WRF modelling. Table 37 presents statistical summary of the annual ambient air temperature based on the current climate and the considered scenarios for 2050 (non-mitigation and full mitigation). Figure 248 presents box plots of the ambient air temperature for the reference scenario in 2050 (non-mitigation) and the full mitigation scenarios. The box plots represent a statistical distribution of the air temperature. In each box plot, the median, lower (1st) and upper (3rd) quartile values are represented. The whiskers indicate variability outside the upper and lower quartiles, and any point outside those lines (whiskers) is considered an outlier. The 1st and 3rd quartile, and the median values for the non-mitigated 2050 is 13.3°C, 18°C, and 23°C. The application of mitigation strategies has a reduction effect of annual mean temperature between 0.8°C.

Table 37 Mean, median, maximum (Max), and minimum (Min), 99th and 1st percentile values for annual hourly air temperature (°C), T_{air}, for the reference case (non-mitigation) and the mitigation scenario in 2050 in Merrylands

T_{air}(°C)		2016-2017	T_unmit_ Merrylands	T_mit_ Merrylands
Mean		17.9	18.5	17.7
Median		17.8	18.0	17.2
Std. Deviation		6.5	7.3	7.0
Minimum		0.2	1.6	1.5
Maximum		43.4	44.1	41.8
Percentiles	1	4.5	5.2	4.9
	99	36	38.1	36.3

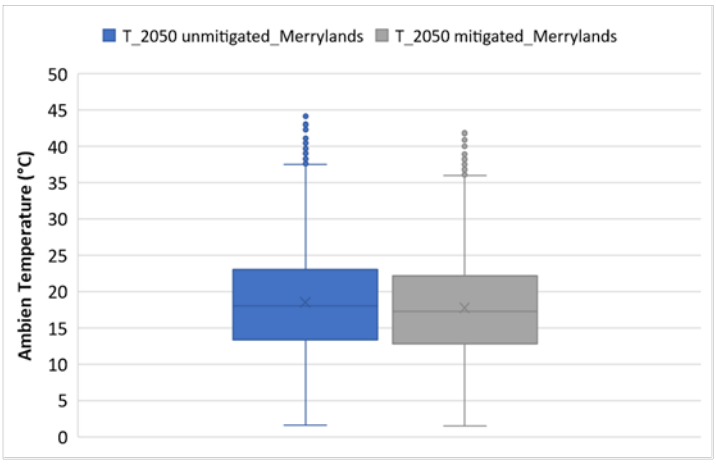


Figure 248 Statistical distribution of the air temperature (°C) for the reference case (unmitigated 2050) and the full mitigation scenario in 2050-Merrylands.

The main characteristics of the buildings are shown in Table 38. It presents the general specifications of the building energy simulations and design features considering the building energy conservation techniques.

Description of the representative buildings

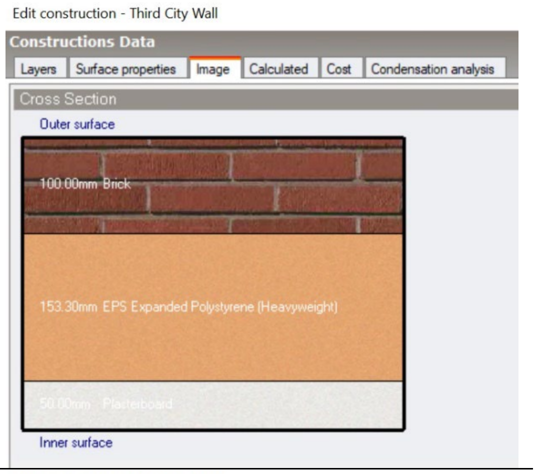
Table 38 Design features applied in the modelled buildings

Infiltration Rate	0.2 ac/h
Mechanical Ventilation	2 ac/h
Cooling Setpoint	26°C
Heating Setpoint	20°C
External walls	U-value: 0.2 W/m2K
Roof (Reflective Roof)	U-value: 0.1 W/m2K Solar Absorbance=0.25
Windows	Dbl LoE(e2=1) Clr 6mm/13mm Arg, U-value: 1.49 (W/m2-K), Solar heat gain coefficient (SHGC): 0.56
Shading	Overhang+Sidefins(1m Projection)
Internal gain	3.58 W/m2

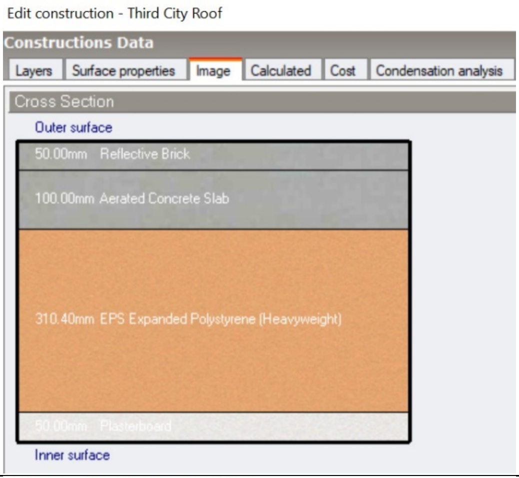
Table 39 shows the building construction details used in the building modelling and the energy simulations.

Table 39 building construction details used in the energy simulation

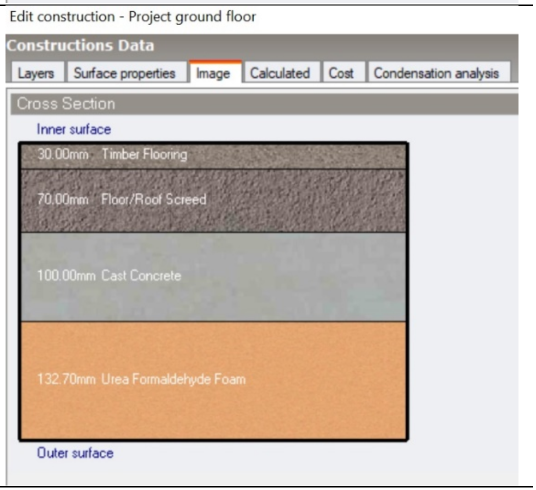
Walls



Roof



Floor



Calculation of the cooling load

This study introduces three analytical stages to evaluate the effects of different parameters in each precinct (e.g. outdoor climate and building configuration) on the energy performance.

- Stage 1 investigates the effects of precinct microclimate on building cooling energy needs,
- Stage 2 assesses the cooling energy need of each precinct as exists with two SHGC,
- Stage 3 performs a sensitivity analysis of contributing factors.

Stage 1

Stage 1: Calculation of the cooling load for a typical high-performing three-storey building based on the mitigated climate of each precinct.

The first stage of energy simulations evaluates the effects of the precinct climate on building cooling loads. A representative three-storey residential building, from OT2, (Figure 249) with a total floor area of 1200 m^2 is selected to perform the energy simulations. The building has a window to wall ratio of 30% and the window height is taken as 1.7m. The weather files developed for 14 different precincts are used in the building energy simulations to evaluate the cooling load of the representative building in different precincts. The total solar transmission (SHGC) is take as 0.568 (direct solar transmission: 0.47).

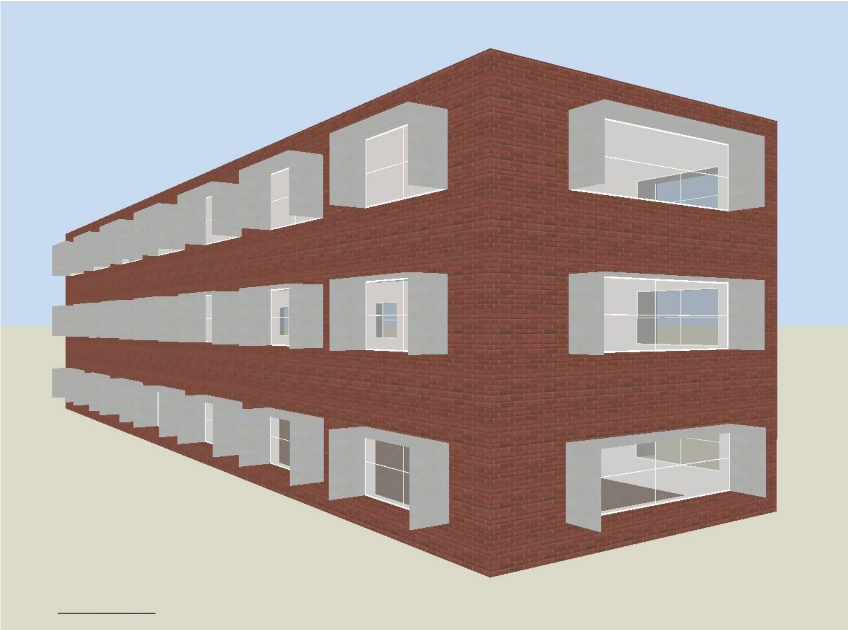


Figure 249 Representative residential building used in Stage 1 simulations

Table 40 provides a summary of design features used in stage 1.

Table 40 Design features applied in the modelled building in stage 1

General design features	
Infiltration Rate	0.2 ac/h
Mechanical Ventilation	2 ac/h
Cooling Setpoint	26°C
Heating Setpoint	20°C
External walls	U-value: 0.2 W/m2K
Roof (Reflective Roof)	U-value: 0.1 W/m2K Solar Absorbance=0.25
Windows	Dbl LoE(e2=1) Clr 6mm/13mm Arg, U-value: 1.49, SHGC: 0.56
Shading	Overhang+Sidefins(1m Projection)
Internal gain	3.58 W/m2
Design features in Stage 1	
Window to Wall Ratio	30%
Window Height	1.7 m
Building Dimensions	10 m*40 m
Number of Stories	3

Stage 2

Stage 2: Calculation of the cooling loads in 14 precincts based on the existing configuration and layout.

All building blocks in each precinct are modelled with design features as close as they exist. Building and canyon orientation, distance between the buildings, and building features (e.g., number of storeys, window to wall ratio, floor area) are derived from AutoCAD drawings of each precinct combined with features extracted from Google Street View.

General building construction and features in the buildings modelling are consistent with information given in Table 38 and Table 39. A typical window to wall ratio (WWR) in each precinct is used for all buildings within each precinct. Similarly, window height is considered for each precinct. Table 41 provides the selected window to wall ratio and window heights in each precinct. All simulations were performed for two shading coefficients: i.e., 0.56 and 0.108 (SHGC=0.108, U-value 1.33, direct solar transmission: 0.04). In total 28 simulations were performed.

Table 41 Window to wall ratio in each precinct.

Precinct		Window to wall ratio (%)	Window height (m)
OT	OT1	35%	2
	OT2	30%	1.7
	OT3	20%	1.5
	OT4	25%	1.5
	OT5	35%	1.8
	OT6	25%	1
	OT7	75%	2.1
CT	CT1	35%	1.5
	CT2	35%	1.8
	CT3	40%	2.5
	CT4	45%	2
	CT5	70%	2.1
	CT6	75%	2.2
	CT7	75%	2.2

Figure 250 and Figure 251 show the building blocks as modelled in DesignBuilder for CT and OT layouts, respectively. Table 42 summarises the built area ratio (total area of the buildings at ground level divided by the total area of the precinct: i.e., 40000m^2), and the total floor area of buildings in each precinct.

Table 42 Built area ratio and total floor area of each precinct

Precinct		Built area ratio (%)	Total floor area (m^2)
OT	OT1	22%	8,850
	OT2	16%	18,950
	OT3	30%	60,000
	OT4	13%	26,200
	OT5	15%	54,500
	OT6	14%	55,000
	OT7	15%	117,500
CT	CT1	37%	25,350
	CT2	37%	55,550
	CT3	55%	112,300
	CT4	38%	104,250
	CT5	55%	170,100
	CT6	48%	200,000
	CT7	30%	290,000

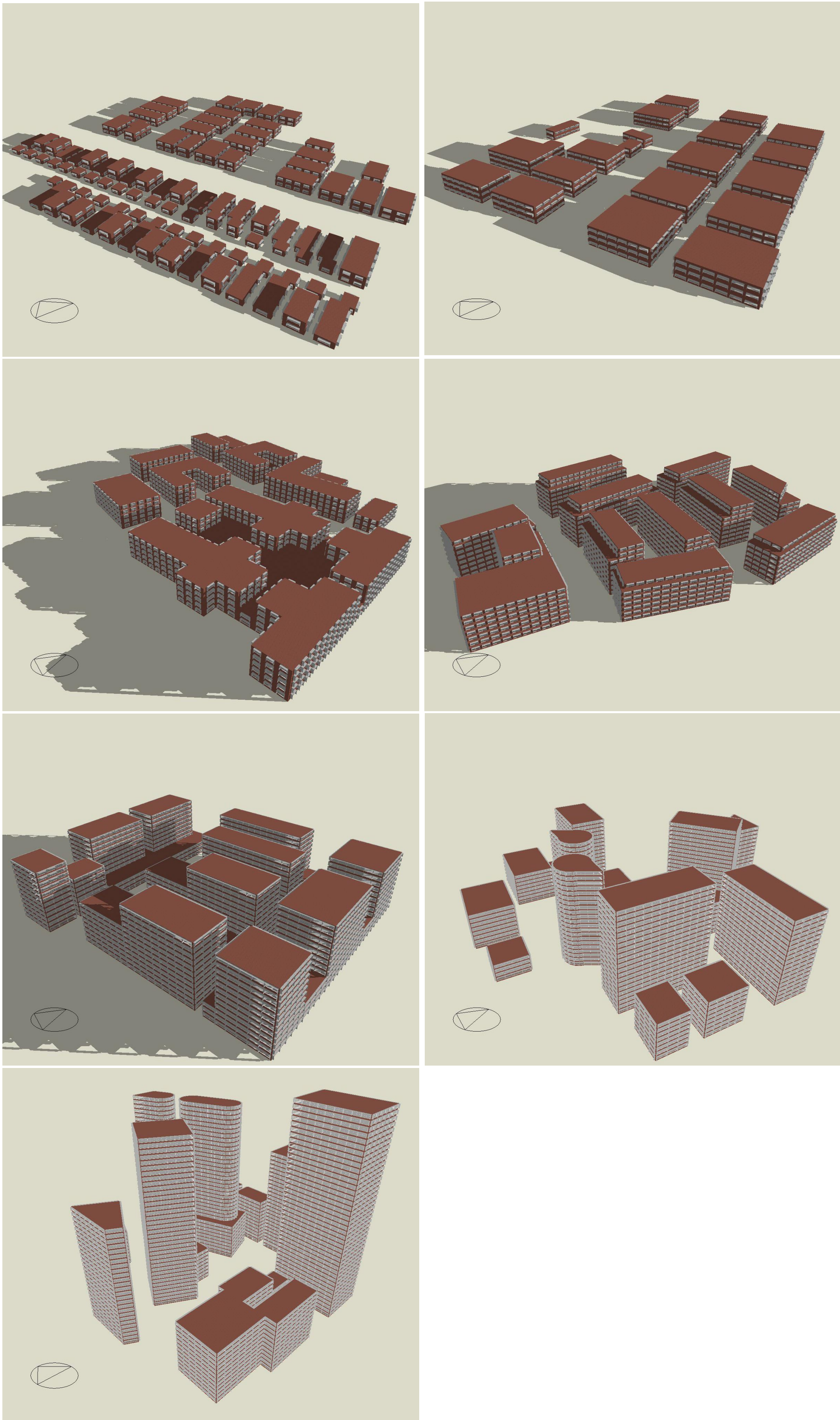


Figure 250 Building blocks as modelled in DesignBuilder for CT layouts

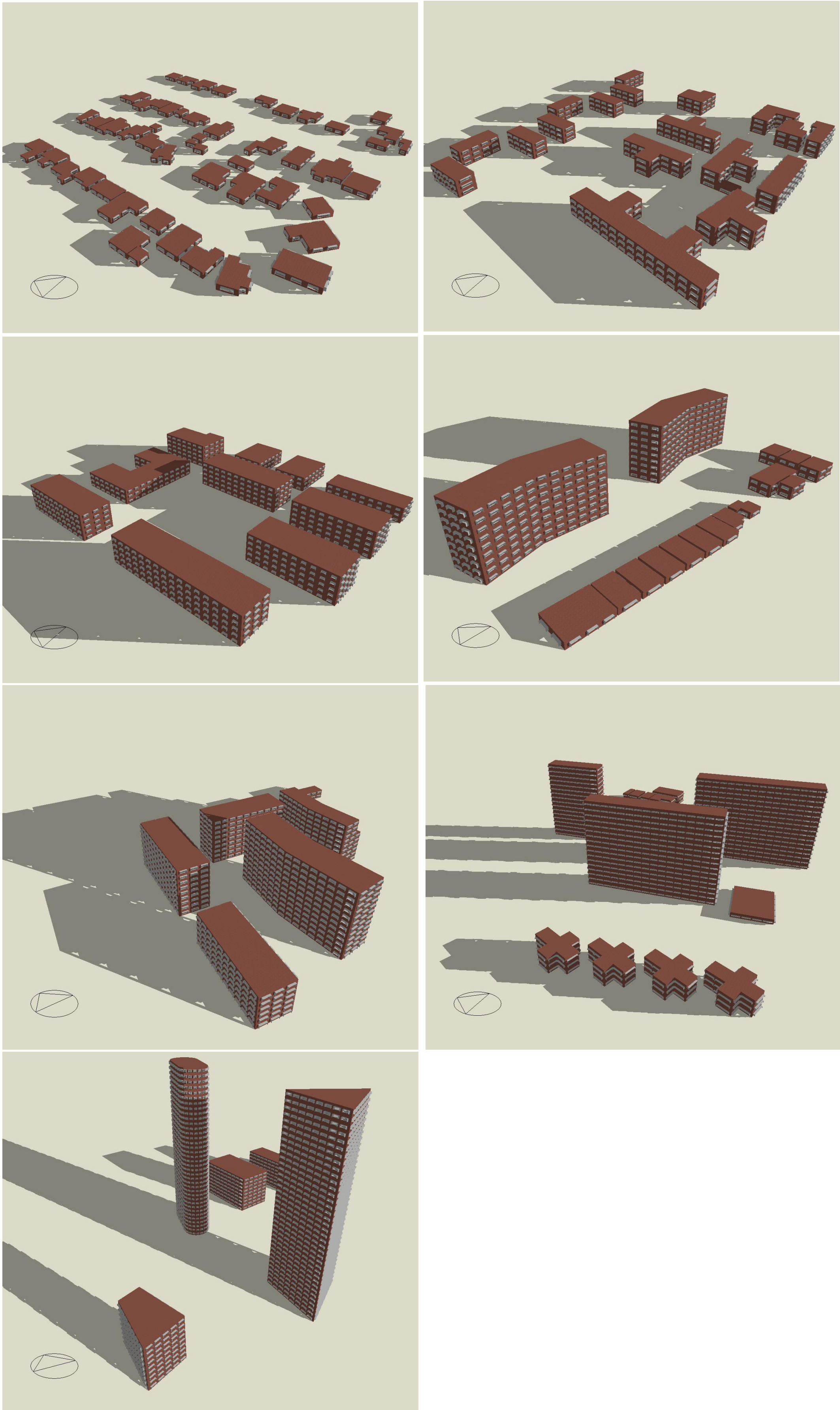


Figure 251 Building blocks as modelled in DesignBuilder for OT layouts

Stage 3

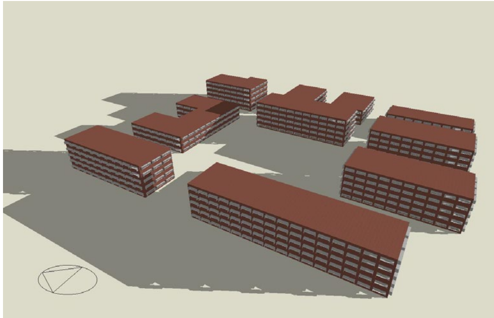
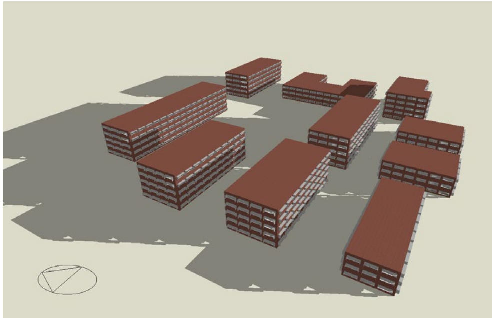
Stage 3- Sensitivity analysis of the contributing factors in cooling energy demand.

The sensitivity analysis involves five assessment and interventions. Building on the original OT3, CT3 and OT5 precincts described above, models are modified for the purpose of sensitivity analysis. The new OT3 is used as a reference layout for the analysis. It features, 3-5 storey buildings, window to wall ratio of 35%, and has East-West orientation. The SHGC in this analysis is 0.56. All building construction details and materials are kept unchanged as described earlier. All parameters are shown in Figure 252 and described in Table 43.

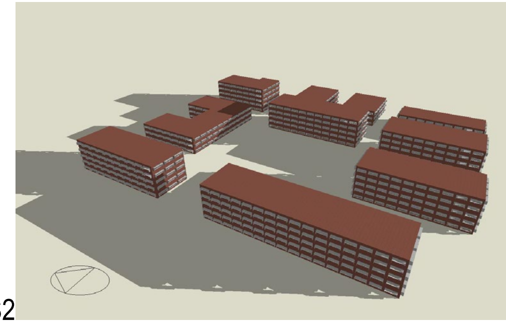
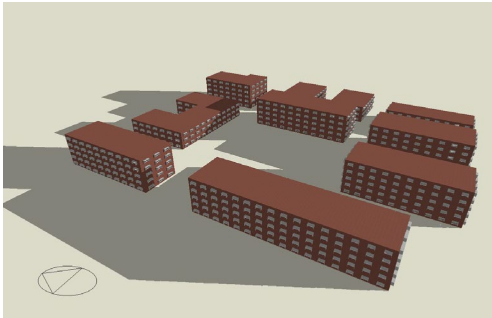
1. **Orientation (OT3):** The new OT3 ($OT3_{ref}$) is used a reference layout for the analysis. Simulations are performed for two different orientations: 1) East-West orientation ($OT3_{ref}$) and 2) South-North orientation. For South-West orientation, all buildings are rotated. All other parameters are kept unchanged.
2. **Window to Wall Ratio (OT3 precinct):** All parameters in the new OT3 are kept constant as shown in Table 43 except window-to-wall ratio. Simulations are performed for two different window-to-wall ratios in OT3 layout: 1) $OT3_{ref}$ where window-wall ratio=35% and 2) window-to-wall ratio=20%.
3. **Number of Storeys (OT3 typical building):** All parameters in the reference OT3 are kept constant as shown in Table 43 (including orientation and window to wall ratio). Simulations are performed to compare $OT3_{ref}$ typical building with 3-5 storeys with that when the number of storeys is changed to 12.
4. **Shading (OT3 and OT5 typical building Vs. precinct):** Simulations are performed to analyse the effect of shading provided by the adjacent buildings in the precinct. OT5 layout is compared with OT5 typical building. The shading from adjacent buildings is apparent in OT5 layout, while there is no shading effect in OT5 typical building. Similarly, the effects of shading in $OT3_{ref}$ layout can be compared with OT3 typical building. The typical buildings in OT3 and OT5 are selected from the new $OT3_{ref}$ and OT5 with the same window to wall ratio and orientation.

Table 43 Description of new precincts used for the sensitivity analysis

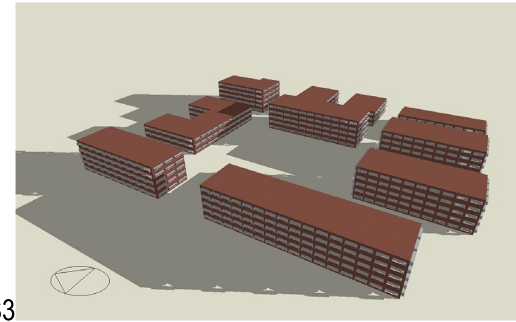
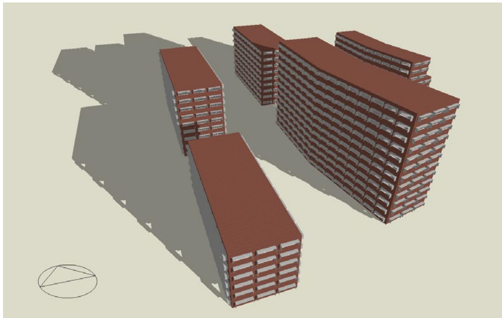
Sensitivity	Precinct	Built area ratio	Total area	WWR	Orientation	Layout/Typical Building
REF: 1,2,3,4	OT3	30%	60,000	35%	East-West	Layout
1	OT3	30%	60,000	35%	North-South	Layout
2	OT3	30%	60,000	20%	East-West	Layout
3	OT3	30%	60,000	35%	East-West	Layout and typical building with 12 storeys
4	OT5	15%	54,500	35%	East-West	Layout
4	OT5	15%	54,500	35%	East-West	Typical Building
4	OT3	30%	60,000	35%	East-West	Typical Building

S1



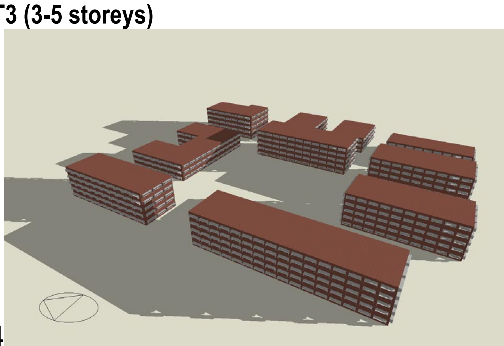
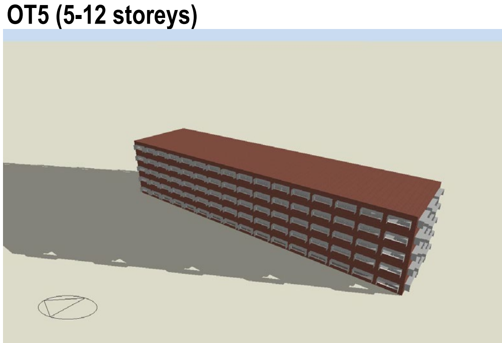
OT3: East-west | **OT3: North-south**

S2



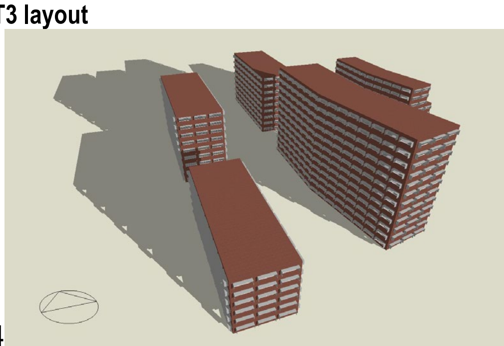
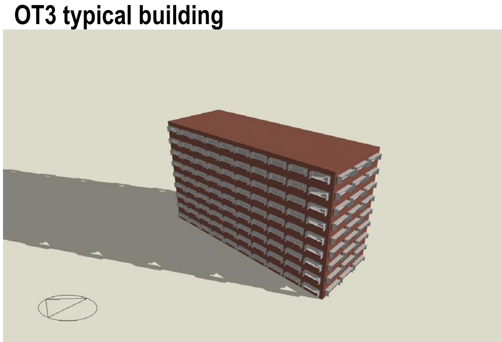
OT3: WWR: 35% | **OT3: WWR: 20%**

S3



OT3 (3-5 storeys) | **OT5 (5-12 storeys)**

S4



OT3 layout | **OT3 typical building**

S4



OT5 layout | **OT5 typical building**

Figure 252 Building models used for the sensitivity analysis

Calculation of the cooling loads

Stage 1 results

This section presents the calculation and the results for the cooling loads over 10 days in February 2050 for 2050 mitigated climate. In order to calculate the cooling loads of the buildings when the mitigation strategies are applied in 2050, the new climatic files developed for each precinct (as described in earlier) have been used.

The results for the total and sensible cooling loads for the representative three-story building based on the microclimate of each precinct are included in Table 44. Sensible cooling load is a measure of the amount of energy that must be removed from the air inside a building, in order to maintain a certain temperature. Sensible cooling load refers to “dry bulb temperature”. Latent cooling load refers to the “wet bulb temperature” and is a measure of the amount of energy that is necessary to dehumidify the air in a building. It specifies the cooling capacity of a cooling system needs to be able to dehumidify a building to a desired level of humidity. As shown in Table 44 and Figure 253, there are slight difference between the precincts. However, the microclimate of CT6 and OT6 lead to lower sensible cooling loads in these precincts; 2459.8 Wh/m^2 and 2471.3 Wh/m^2, respectively. On the contrary, the microclimate of CT5 layout shows the highest sensible cooling loads among the investigated precincts.

Table 44 The total and sensible cooling load (Wh/m^2) for the reference building based on each precinct microclimate

Precinct		CDH (26°C)	Total cooling load over 10 days (Wh/m^2)	Sensible cooling load over 10 days (Wh/m^2)	Latent cooling load over 10 days (Wh/m^2)
OT	OT1	30.8	2687.6	2539.3	148.3
	OT2	27.5	2649.5	2492.1	157.4
	OT3	29.5	2677.5	2511.3	166.1
	OT4	32.1	2686.6	2533.5	153.1
	OT5	31.6	2695.7	2554.5	141.2
	OT6	24.7	2710.2	2459.8	250.4
	OT7	32.7	2722.4	2586.0	136.4
CT	CT1	32.6	2720.6	2584.0	136.6
	CT2	32.3	2700.8	2543.2	157.6
	CT3	31.9	2723.7	2580.8	142.9
	CT4	33.6	2731.0	2567.2	163.8
	CT5	35.0	2718.6	2601.0	117.6
	CT6	26.3	2601.3	2471.3	130.0
	CT7	28.4	2696.1	2568.6	127.5

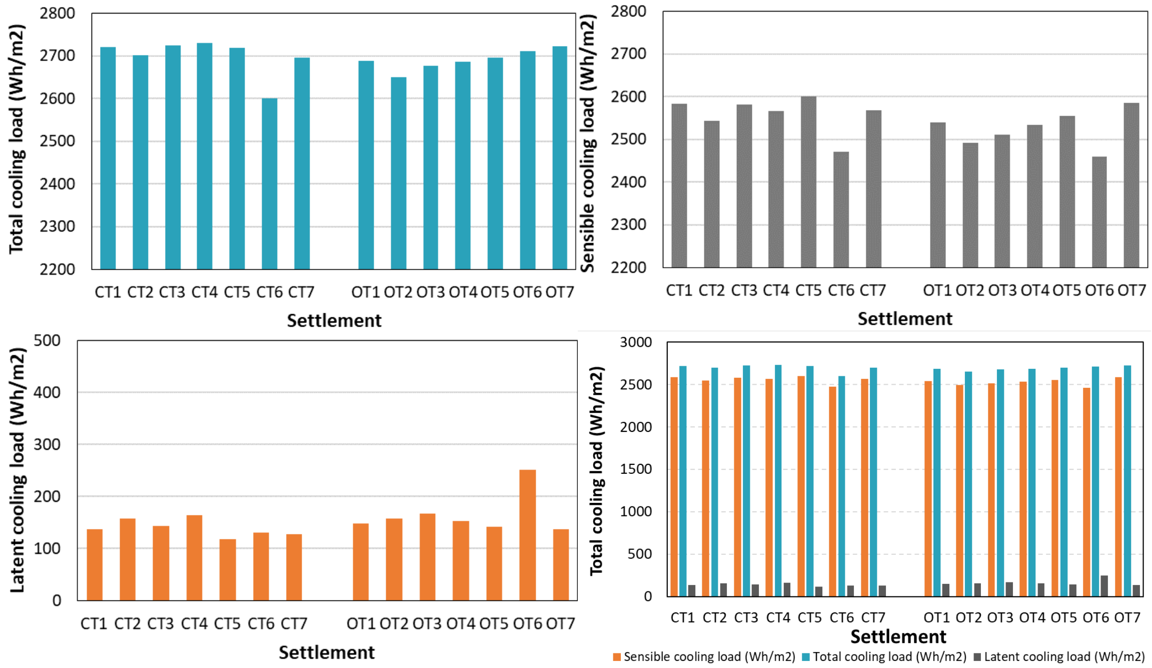


Figure 253 Total, sensible and latent (Wh/m^2) cooling loads calculated for the reference building (OT2)

Figure 254 shows bar graphs of Cooling Degree Hours (CDH-set point: 26°C), mean outdoor air temperature (24 average over the simulation day), and mean dew point temperature for the simulation day, and built area ratio for each precinct. As depicted here, the trend of sensible cooling load is consistent with the average ambient temperature in each precinct. Similarly, dew point temperature is consistent with the calculated latent heat load. CT6 and OT6 present the lowest CDH and mean ambient temperature among the precincts.

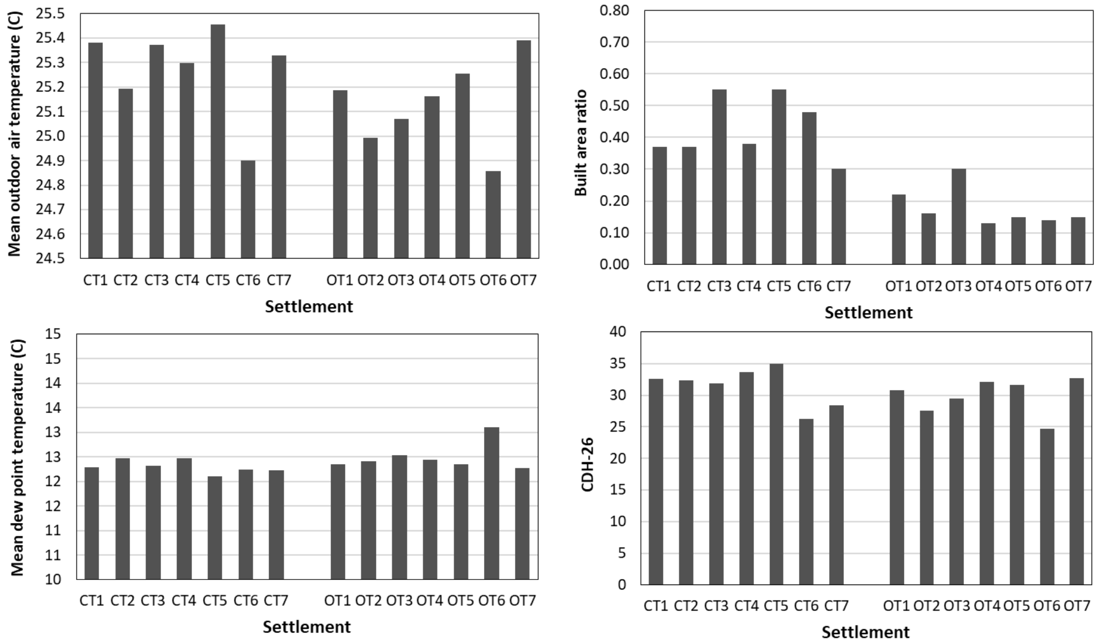


Figure 254 Cooling Degree Hours (CDH-set point: 26°C), mean outdoor air temperature, and mean dew point temperature for the simulation day, and built area ratio for each precinct.

The correlation between the calculated sensible cooling load over 10 days against the mean ambient temperature, and CDH (set points of 0°C, 24°C, and 26°C) in each precinct is shown in Figure 255. In general, there is a strong linear relationship between all climate-related parameter and sensible cooling load. The correlation between ambient temperature of the precinct and the sensible cooling load is very strong and significant (R^2=0.99, P<0.00).

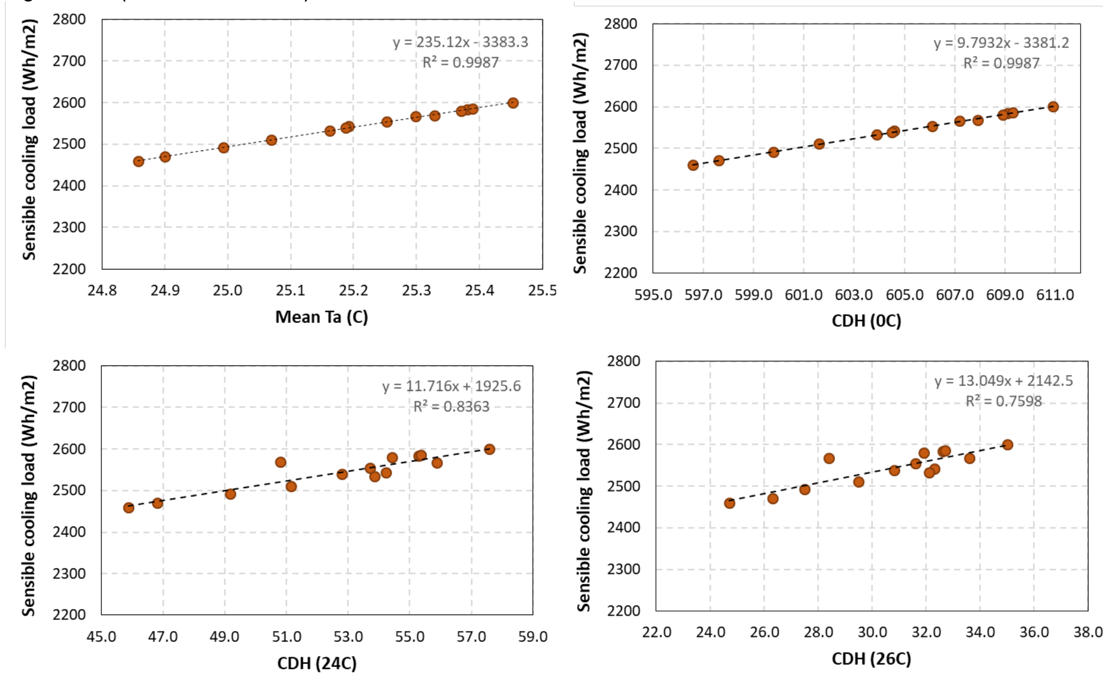


Figure 255 Correlation between sensible cooling load (over 10 days) and mean ambient temperature, and Cooling Degree Hour (set points of 0°C, 24°C, and 26 °C) in each precinct.

Stage 2 results

In stage 2, all buildings in each precinct have been modelled in DesignBuilder with specific WWR, window height and with two solar heat gain coefficients of 0.56 and 0.108. for each precinct relevant climatic file has been used. Table 45 and Table 46 show the total and sensible cooling load for each precinct. This analysis is performed to understand the cooling energy demand of each precinct as exist. Selected values of SHGC refer to high and low solar gain which indicate the solar energy transmittance of windows.

Table 45 Sensible and total cooling load (in Wh/m² and kWh) per precinct over 10 days when SHGC=0.56

Layout	Built area ratio	Total area (m²)	WWR	Sensible cooling load (Wh/m²)	Total cooling load (Wh/m²)	Sensible cooling (kWh)	Total cooling (kWh)
OT1	22%	8,850	35%	3337.9	3512.3	25830.7	27180.0
OT2	16%	18,950	30%	2806.4	2971.6	50031.1	52975.3
OT3	30%	60,000	20%	1699.2	1837.6	78990.4	85429.4
OT4	13%	26,200	25%	1787.4	1916.5	43837.8	47002.4
OT5	15%	54,500	35%	2410.1	2549.9	122620.3	129641.5
OT6	14%	55,000	25%	2113.0	2410.8	109712.0	125174.8
OT7	15%	117,500	75%	3309.4	3460.4	300917.0	314620.5
CT1	37%	25,350	35%	2526.9	2665.1	56202.9	59271.8
CT2	37%	55,550	35%	2031.2	2176.9	89831.6	96273.1
CT3	55%	112,300	40%	2123.6	2251.8	208330.9	220904.3
CT4	38%	104,250	45%	2250.1	2404.5	284620.8	304150.8
CT5	55%	170,100	70%	2844.6	2964.5	496666.6	517613.6
CT6	48%	200,000	75%	3271.1	3416.9	641617.5	670233.9
CT7	30%	290,000	75%	3405.4	3550.6	987571.8	1029665.3

Sensible and total cooling loads presented in Table 45 and Table 46 in two forms: normalised for total built area and cooling loads for the whole precinct. As shown here, CT layouts present a significantly higher cooling loads compared to OT layouts. This is apparent in the calculations with both SHGC.

Table 46 Sensible and total cooling load (in Wh/m² and kWh) per precinct over 10 days when SHGC=0.108

Layout	Built area ratio	Total area (m²)	WWR	Sensible cooling load (Wh/m²)	Total cooling load (Wh/m²)	Sensible cooling (kWh)	Total cooling (kWh)
OT1	22%	8,850	35%	1142.9	1201.4	8844.1	9296.7
OT2	16%	18,950	30%	1309.6	1404.6	23346.7	25040.1
OT3	30%	60,000	20%	1195.4	1293.7	55132.6	59673.4
OT4	13%	26,200	25%	1216.0	1307.5	29820.7	32065.0
OT5	15%	54,500	35%	1389.8	1487.2	70709.4	75666.3
OT6	14%	55,000	25%	1250.3	1490.4	64913.4	77384.9
OT7	15%	117,500	75%	1730.9	1842.0	157362.0	167458.6
CT1	37%	25,350	35%	1241.6	1304.8	27618.9	29026.1
CT2	37%	55,550	35%	1202.7	1285.3	53192.5	56845.0
CT3	55%	112,300	40%	1299.3	1385.4	127465.6	135911.5
CT4	38%	104,250	45%	1354.1	1464.3	171280.2	185208.9
CT5	55%	170,100	70%	1467.1	1544.5	256163.6	269679.3
CT6	48%	200,000	75%	1461.1	1553.7	286591.1	304756.8
CT7	30%	290,000	75%	1488.5	1577.6	431667.9	457477.9

Since different parameters are changing in each precinct, we performed a liner regression analysis to understand the correlation between solar radiation and sensible cooling load (kWh) calculated per precinct with SHGC of 0.56 and 0.108 (Figure 256). The Solar Gains Exterior Windows - (used to be called 'Transmitted solar gains') refers to short-wave solar radiation transmission through all external windows. Figure 256 suggests a very strong correlation between the precinct sensible cooling load (kWh) and solar radiation for all windows. The correlation coefficients are 0.98 and 0.93 for SHGC of 0.56 and 0.108, respectively. The same correlation coefficient is obtained when data over 10-days is analysed.

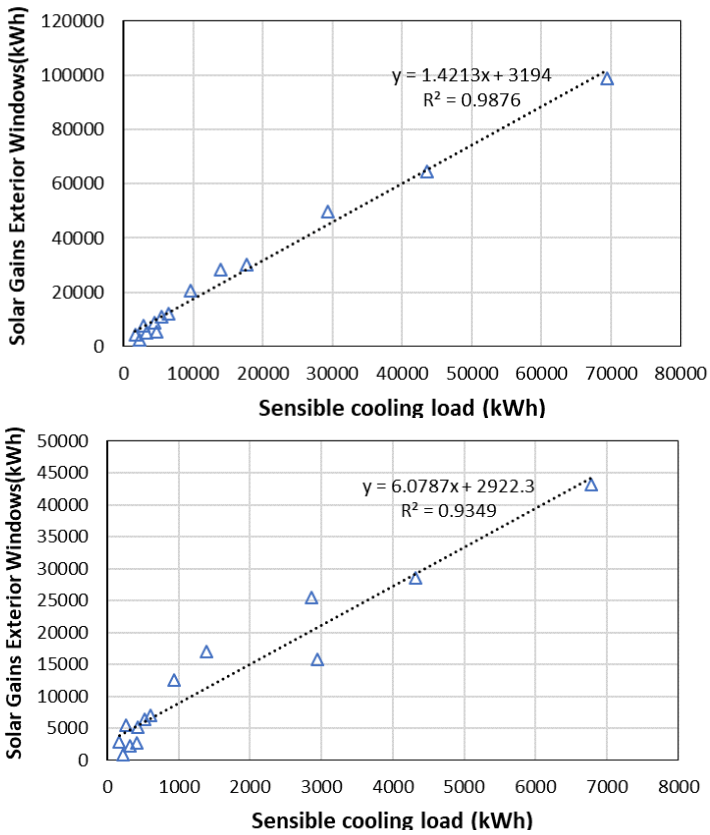


Figure 256 Correlation between solar radiation and sensible cooling load (kWh) calculated per precinct with SHGC of 0.56 (top) and SHGC of 0.108 (bottom): data refer to 1-day simulation (22-February 2050).

Figure 257 shows the percentage of decrease in the total Solar Gains Exterior Windows (kWh) of CT against the corresponding OT layouts. It reveals that changing compact layouts (CT) to open layout (OT) lead to 26-88% reduction in Solar Gains Exterior Windows (kWh) of the whole precinct.

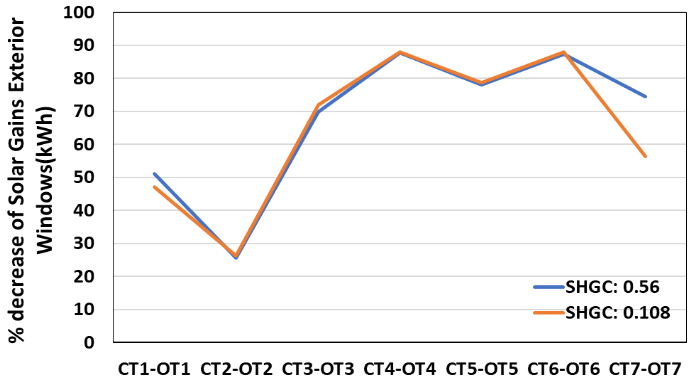


Figure 257 Percentage decrease of total Solar Gains Exterior Windows(kWh) when CT layouts is compared against OT layouts

Figure 258 and Figure 259 illustrate the sensible and total cooling load (in Wh/m^2 and kWh) for each precinct when SHGC is 0.56 and 0.108. The corresponding solar radiation at the exterior widow is also presented in the graphs. There is a consistent trend between the solar radiation (exterior windows) and the sensible cooling load (Figure 258) when SHGC is 0.56. The total Solar Gains Exterior Windows and cooling loads (sensible and total) in CT precincts are generally higher than OT layouts when the cooling load is calculated for the precinct (kWh). When cooling load per m^2 is presented CT7, OT1, CT6, and OT7 show higher, while

OT3 and OT4 present lower sensible and total cooling loads compared to other precincts. Figure 259 shows similar results when SHGC is 0.108.

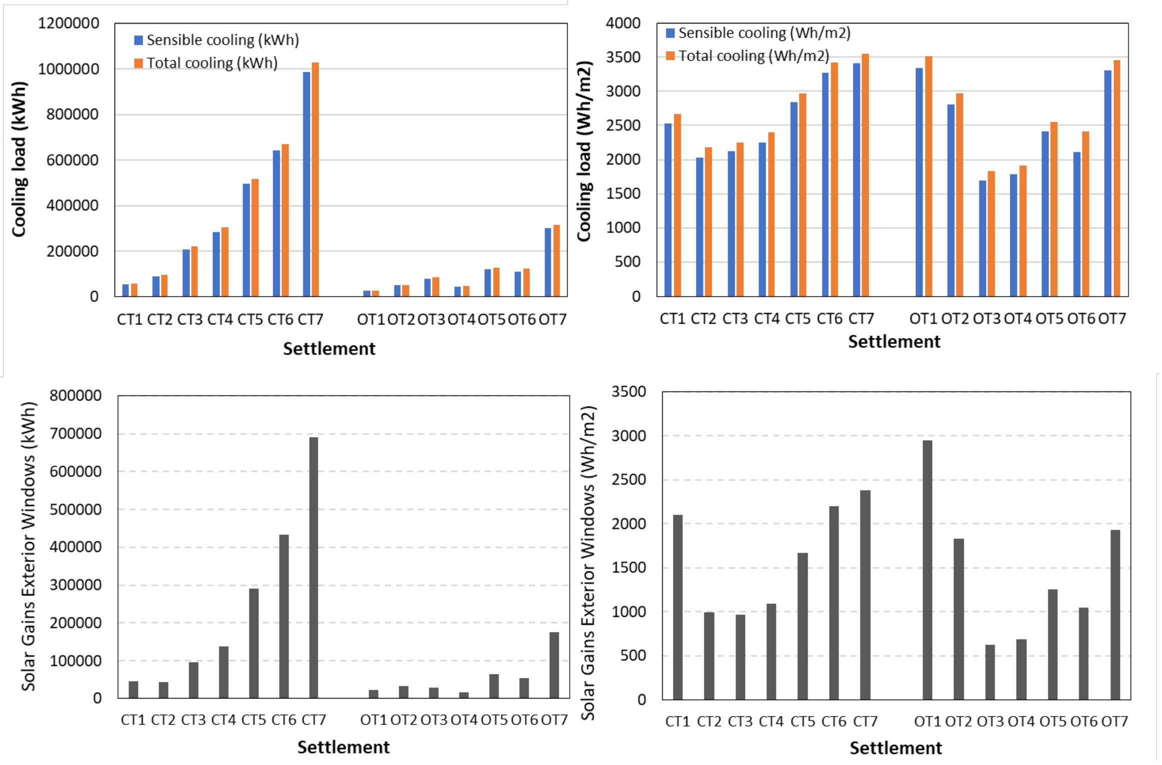


Figure 258 Sensible and total cooling load (Wh/m^2) and (kWh) for each precinct when shading coefficient is 0.56

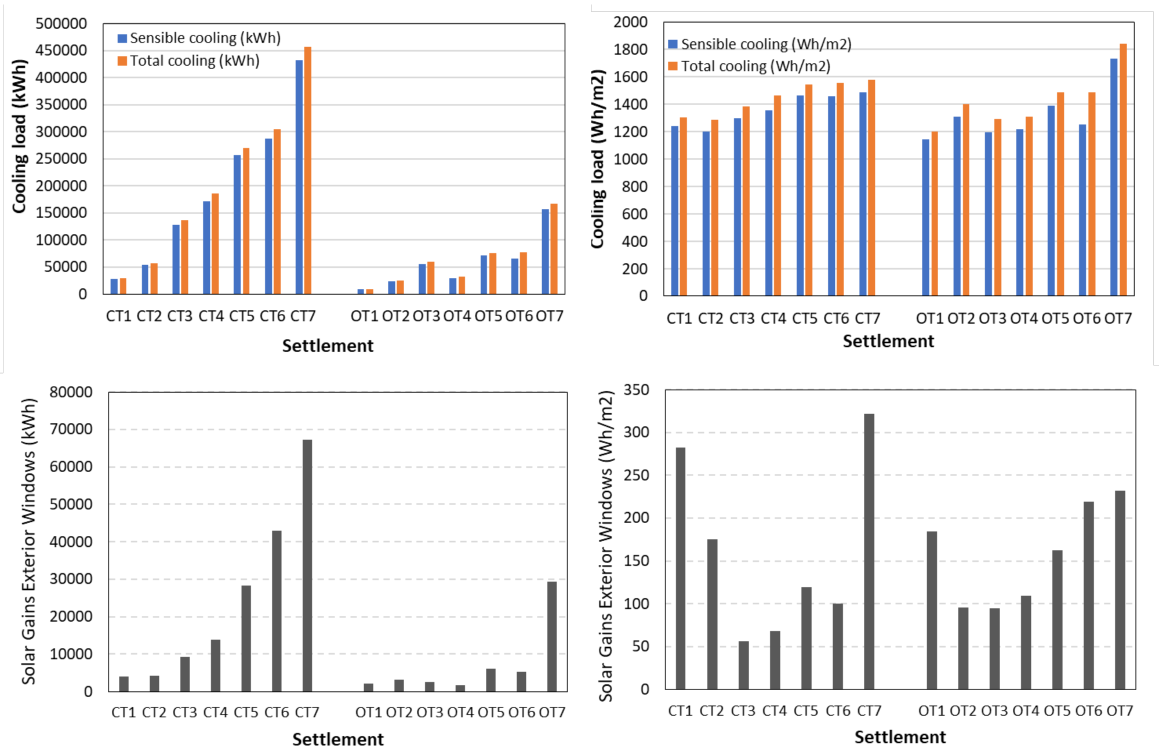


Figure 259 Sensible and total cooling load (Wh/m^2) and (kWh) for each precinct when shading coefficient is 0.108

Figure 260 shows the difference between cooling load of CT and corresponding OT layouts (e.g., CT1-OT1). It reveals that changing compact layouts (CT) to open layout (OT) lead to 44-85% and 56-83% reduction in sensible cooling load of the whole precinct (kWh) with SHGC of 0.58 and 0.108, respectively. Figure 261 illustrates the correlation between sensible cooling load (Wh/m²) and climate related parameters and building and precinct features when SHGC is 0.56. As shown in this figure, there is an upward trend between the mean ambient temperature and the sensible cooling load; however, the correlation is not significant. The sensible cooling loads show a linear relationship with the building features including window to wall ratio and window height. Similarly, the size of the precinct is a contributing factor in cooling demand of buildings.

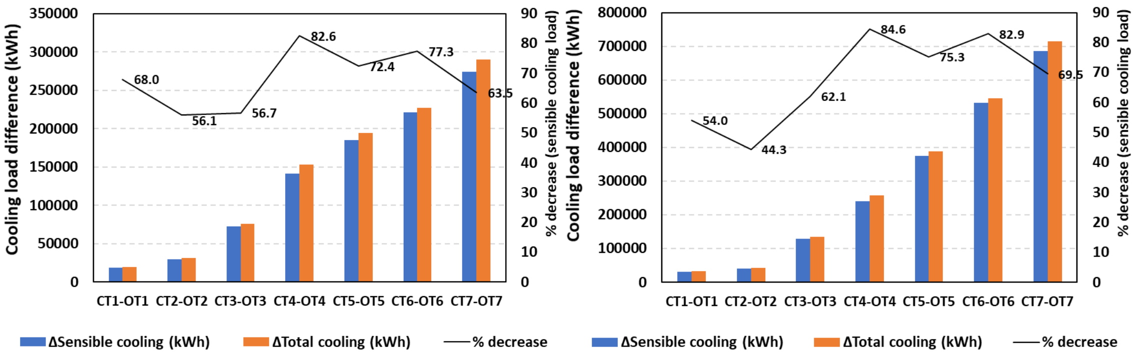


Figure 260 The cooling load difference between CT and OT layouts when SHGC is 0.108 (left) and 0.58 (right).

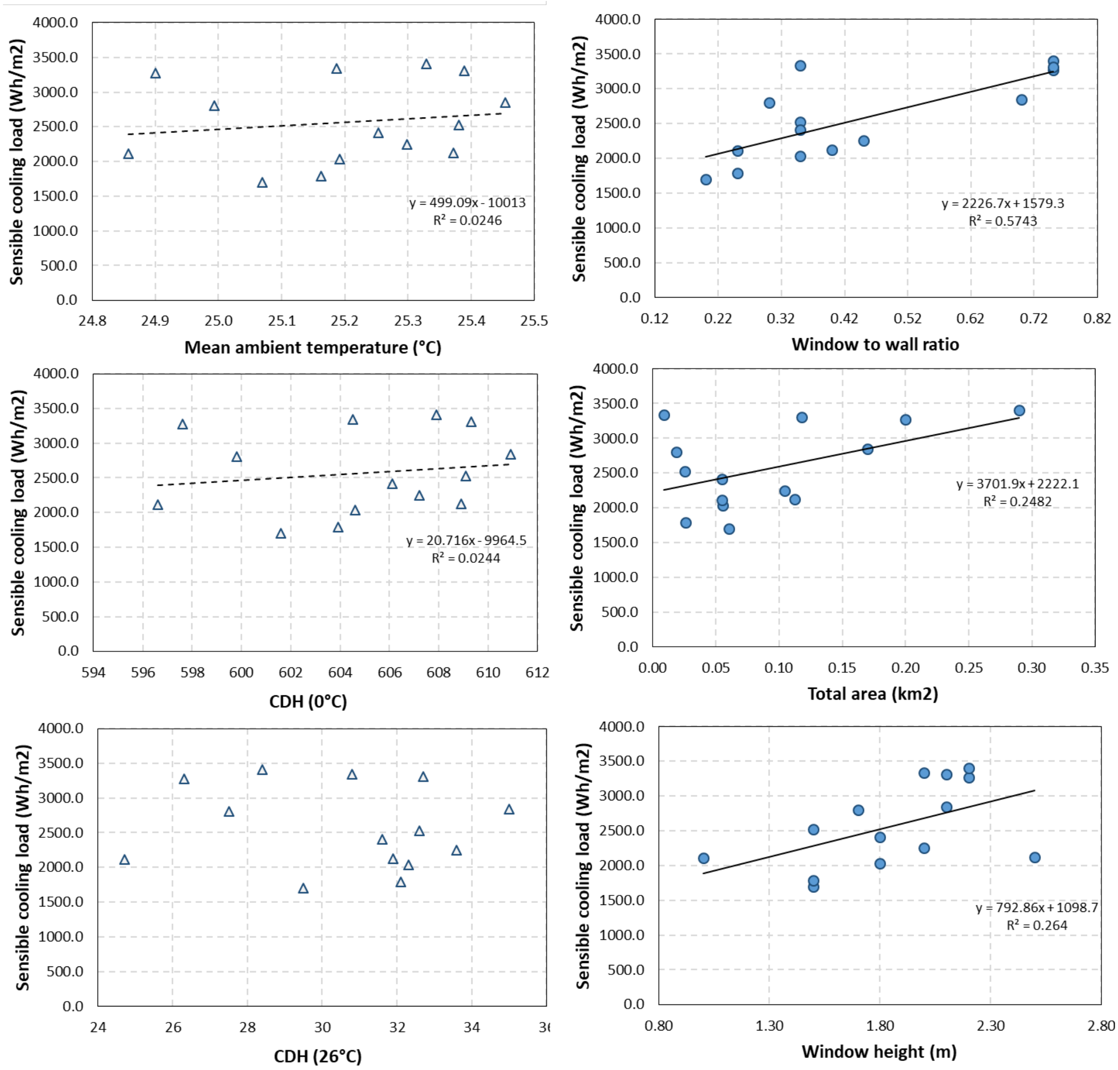


Figure 261 Correlation of Sensible cooling load (Wh/m²) per precinct with mean ambient temperature, Cooling Degree Hour (CDH), window to wall ratio, total floor area, and window height in each precinct and when SHGC is 0.56 (bottom)

Figure 262 depicts the correlation between sensible cooling load (Wh/m^2) and climate related parameters and building and precinct features when SHGC is 0.108. There is an upward trend between the mean ambient temperature of each precinct and the corresponding sensible cooling load; however, the correlation is not statistically significant. The sensible cooling loads show a linear strong relationship with the building features including window to wall ratio. The size of the precinct (total built area) is also shown to be a contributing factor in cooling demand of buildings and precincts. The correlation between sensible cooling load and window height is weak; however, there is a clear pattern between be two parameters.

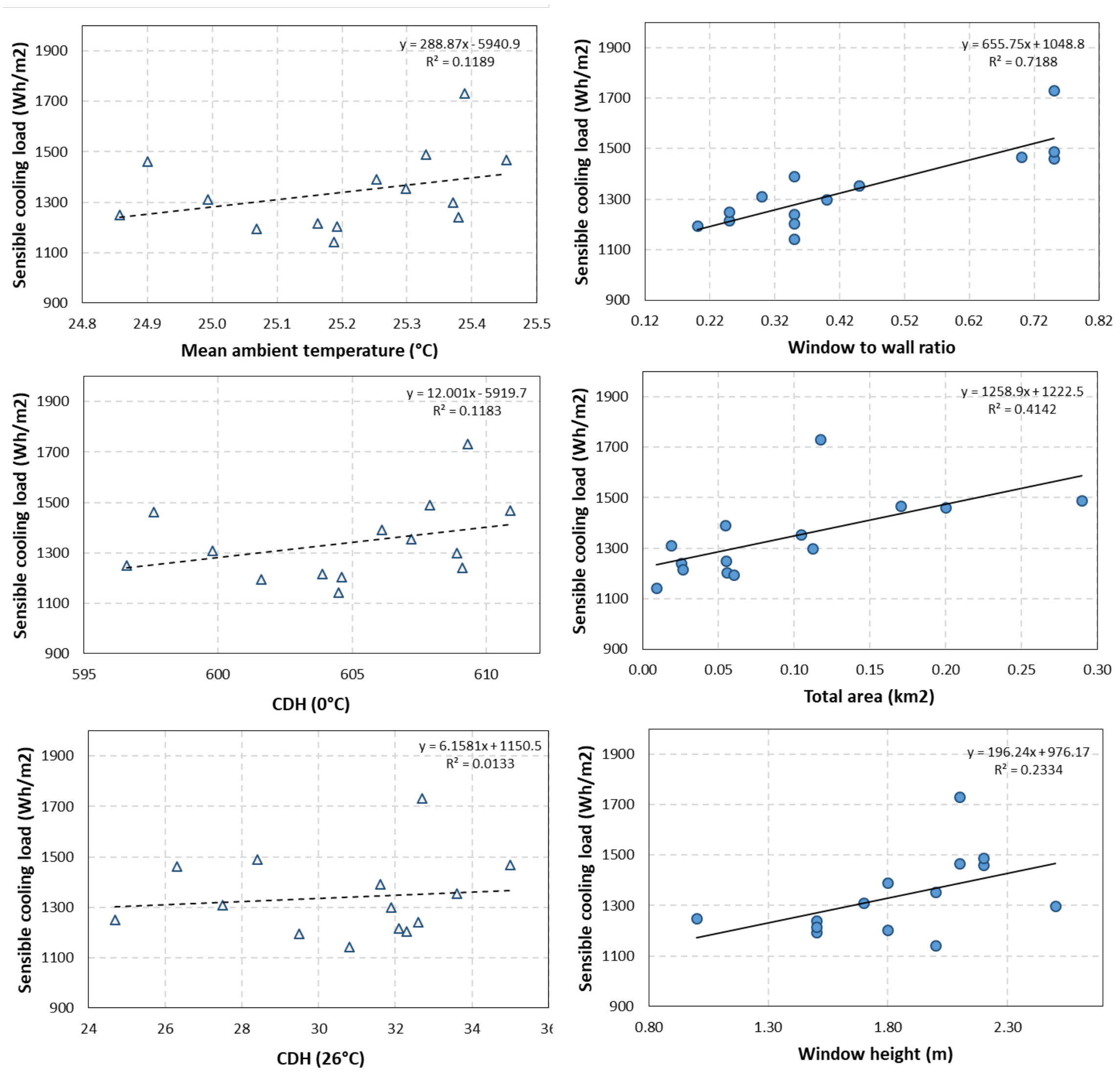


Figure 262 Correlation of Sensible cooling load (Wh/m^2) per precinct with mean ambient temperature, Cooling Degree Hour (CDH), window to wall ratio, total floor area, and window height in each precinct and when shading coefficient is 0.108 (bottom)

Stage 3 results

The results of sensitivity are illustrated in Figure 263. Results of sensitivity analysis shows that the orientation of buildings in each precinct, window to wall ratio, and number of storeys affect the cooling loads of the buildings. As depicted in Figure 263, the sensible and total cooling load of $OT3_{ref}$ building is reduced by 12% to 11% when the orientation of buildings is changed to North-South compared to East-West. Reducing the window to wall ratio in $OT3_{ref}$ from 35% to 20% also reduces the sensible and total cooling load by 23%. Number of storeys may also impact the cooling demand of buildings. When $OT3_{ref}$ with 3-5 storeys is changed to a 12-storey building, the cooling load (Wh/m^2) is increased by 3%. In the 4th scenario of the sensitivity analysis, we compared the cooling load (Wh/m^2) of a typical building against the precinct to see if interaction between the buildings (e.g. shading) affects the results. As shown here, the reported cooling load for the selected typical building (Wh/m^2) in OT3 and OT5 is increased by 12% when it is compared with the corresponding precinct.

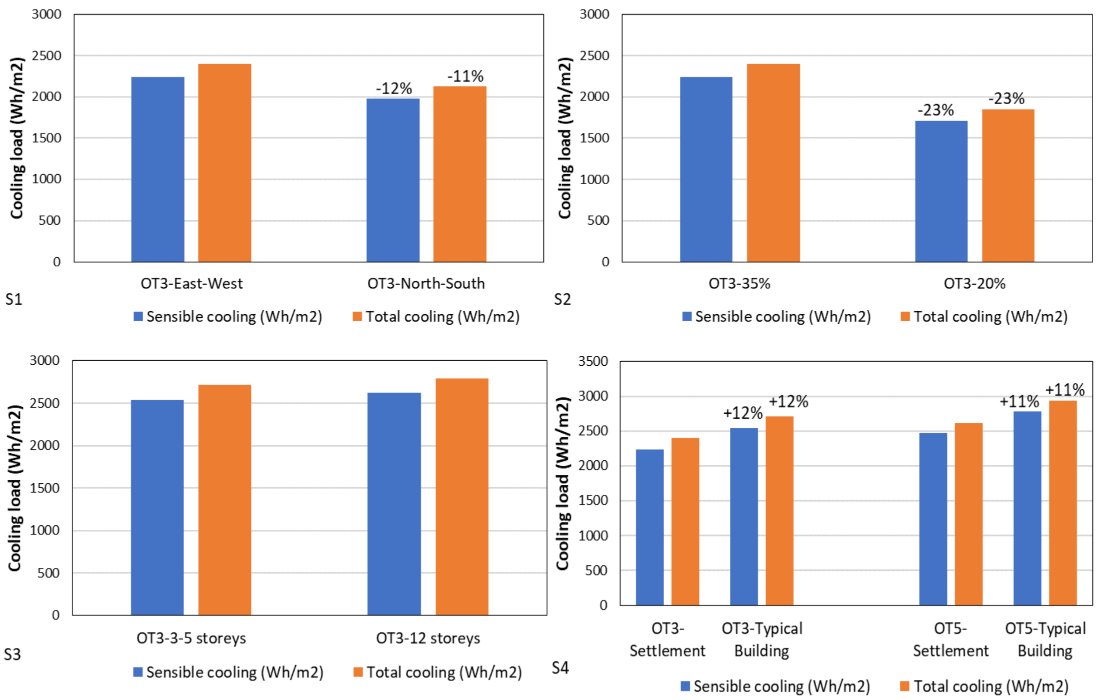


Figure 263 Sensible and total cooling load (Wh/m^2) for each of the sensitivity analysis; percentage of decrease or increase of cooling load is presented on the graph.

<u>Concluding remarks:</u>

A typical building with different climate of precincts:

- For a typical building there is a strong linear relationship between climate-related parameters and sensible cooling load. The correlation between ambient temperature of the precinct and the sensible cooling load of the typical building is very strong and significant (R^2=0.99, $P<0.00$).

Different precincts and corresponding climate:

- When the whole precinct energy consumption is evaluated, there is a very strong correlation between the precinct sensible cooling load (kWh) and the total solar radiation calculated for all windows. The correlation coefficients are 0.98 and 0.93 for SHGC of 0.56 and 0.108, respectively.
- The total Solar Gains Exterior Windows (kWh) and cooling loads (sensible and total) in CT precincts are generally higher than OT layouts when the cooling load is calculated for the precinct (kWh).
- The sensible cooling loads expressed in Wh/m^2 show a linear relationship with the building features including window to wall ratio and window height.
- Changing compact layouts (CT) to open layout (OT) lead to 44-85% and 56-83% reduction in sensible cooling load of the whole precinct (kWh) with SHGC of 0.58 and 0.108, respectively.

Sensitivity analysis

- Results of sensitivity analysis indicates that that the orientation of buildings in each precinct, window to wall ratio, and number of storeys contribute to the energy consumption and cooling load of the buildings and precincts. The calculated cooling load (Wh/m^2) for the selected typical building is higher than that calculated for the corresponding precinct.

- The layout and the characteristics of the precincts may affect the cooling energy consumption of a building of same orientation and same thermal and faced characteristics up to 6 %.

- The layout and the characteristics of the precincts may affect the total cooling energy consumption per square meter, of all buildings in a precinct, with different orientation and façade and thermal characteristics up to 53 % when buildings are extremely well shaded, or up to 93 % when the shading coefficient is average.

- There is a general trend that the lower cooling energy consumption is presented in precincts with a lower aspect ratio, (H/W). This trend is stronger for the OT precincts than the CT precincts.

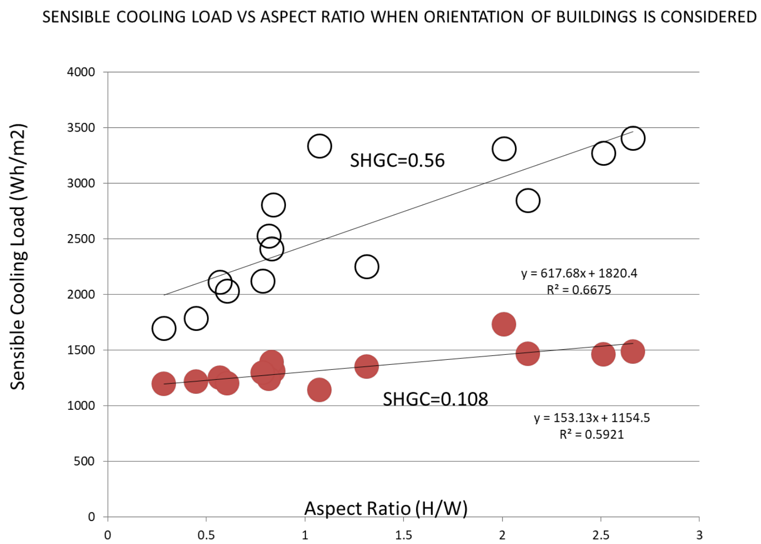


Figure 264 Sensible cooling load vs aspect ratio when orientation of buildings is considered

- The global cooling energy consumption in a precinct may be up to 4800 % higher than in another precinct of the similar plot. This is of course very much influenced by the total built area, orientation, building characteristics, etc.

LOW CARBON LIVING CRC

8. CONCLUSIONS

Concluding remarks

Conclusions – Further Remarks

To evaluate the cooling potential of each of the 14 considered precincts, a new parameter called 'Gradient of the Temperature Decrease along the Precinct Axis', GTD is used. The parameter measures the average temperature decrease along the X or the Y axis of the canyon, (Figure 265), closer to the wind direction. In the reference wind configuration used in the present study, the angle φ with the X axis is lower that the Θ angle with the Y axis, thus GTD is calculated along the X axis.

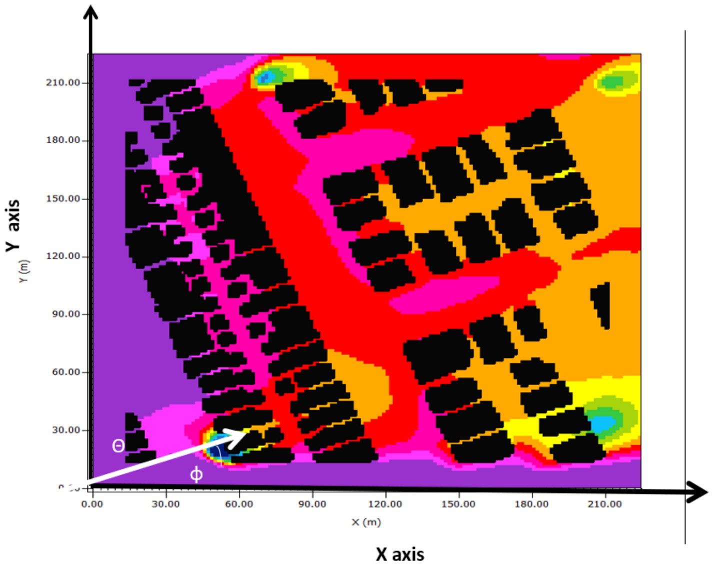


Figure 265 calculation of CTD and presentation of X or the Y axis of the canyon

To calculate the GTD(x) value for each of the 14 considered precincts, the following methodology is followed:

1. Calculations of the climatic and other parameters for each precinct are performed for a grid of 224 x 224 Cells. For each parameter, W, its average value $W(Xi, Y_{1\text{-}224})$ corresponding to one X cell and all the 224 Y cells of the same X value is calculated. For example, for the cell X=3, the sum of the W values corresponding to cells with X=3 and Y = 1 to 224, is calculated, and divided by 224. In case cells did not include numerical values of the parameter W, because the area is covered by buildings, then the corresponding cells were not considered.
2. The GTD for the average distribution of ambient temperature, and wind speed, is calculated along the axis X, as shown in Figure 266.

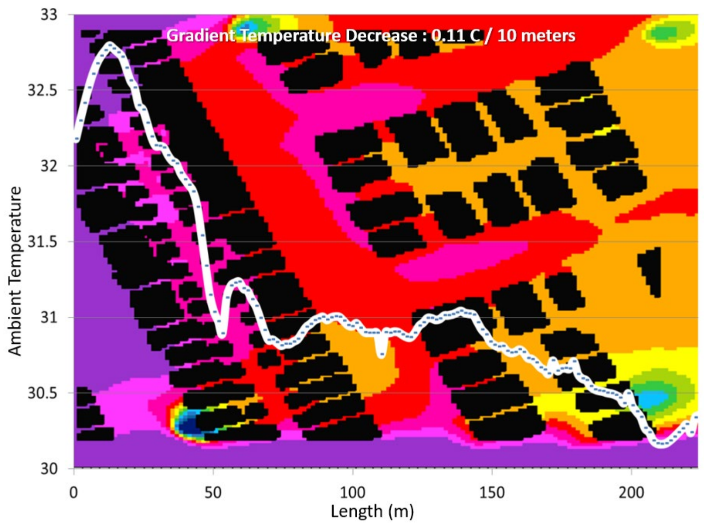


Figure 266 An example of the GTD calculation along the x-axis

3. The GTD(x), is calculated as the average difference between the initial and the final value of the ambient temperature along the canyon axis

   $GTD(x) = [T(_{average\ x=1}) - T(_{average\ x=224})] / 224$

   GTD(x) counts for the temperature decrease along the X axis per meter of length of the precinct and expresses the potential of the precinct to mitigate the ambient overheating along the axis closer to the wind direction.

4. The same procedure is followed considering that precincts with mitigation and without any mitigation.
5. The calculated GTD values for all the precincts with mitigation are given in Figure 267, while the corresponding values for the precincts without mitigation are given in Figure 268.

Figure 267 GTD values for all the precincts with mitigation

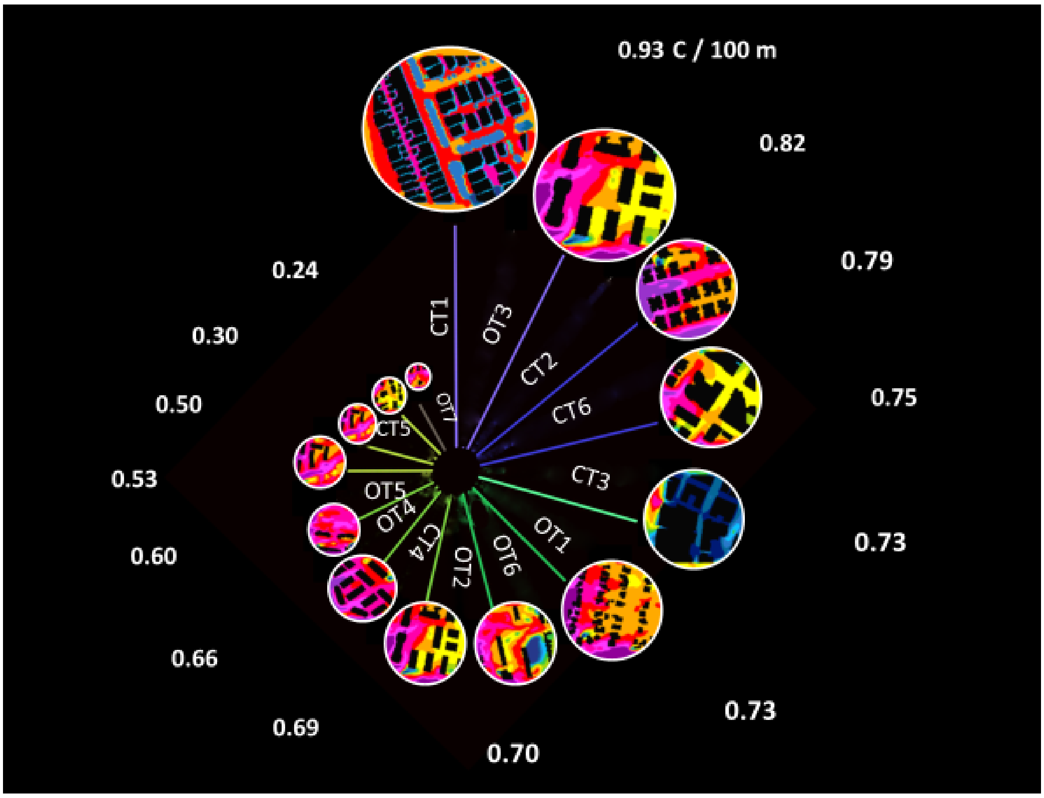


Figure 268 GTD values for all the precincts with no mitigation

6. For the scenarios including mitigation GTD, varies between 0.01 K/m to 0.004 K/m.
7. For the scenarios without mitigation GTD, varies between 0.0093 K/m to 0.0024 K/m.
8. The maximum expected temperature difference between precincts of about 40,000 m^2, employing the same mitigation measures, caused by different layout and characteristics of the buildings and open spaces, may be close to 0.9 °C for a reference ambient temperature of 32 °C, and a wind speed of about 2 m/sec.
9. The maximum expected temperature difference between precincts of about 40,000 m^2, without any mitigation measure, is close to 1.5 °C, for a reference ambient temperature of 33 °C, and a wind speed of about 2 m/sec.
10. The cooling potential caused by an appropriate layout of the precincts is decreasing when mitigation technologies are used, compared to the cooling potential of the same precinct without mitigation, because the utilisability factor.
11. Analysis of the results shows that advection is the major mechanism to transfer heat to the precincts. There is a strong relation between the flux of heat because of the wind and the GTD values.
12. The advected heat to the precincts is a function of the open spaces across the precinct where wind can flow and of the corresponding wind speed. Given that the considered precincts are of square form, an average cross section, $S_{(average)}$, is calculated as:

$$S_{(average)} = [(1 - BAR) \times A]^{0.5} \quad (1)$$

Where BAR is the Built Area Ratio of each precinct and A the total area of the precinct
Then the average wind speed is calculated for the whole area of the precinct, $V_{(average)}$.
The average advected heat, ($Q_{average}$), to each precinct is then approximated using the following expression,

$Q_{(average)} = S_{(average)} \times V_{(average)}$ (2)

13. It is found that the GTD value of each precinct correlates strongly with the corresponding $Q_{(average)}$ for both the mitigated and non-mitigated precincts, Figure 269.

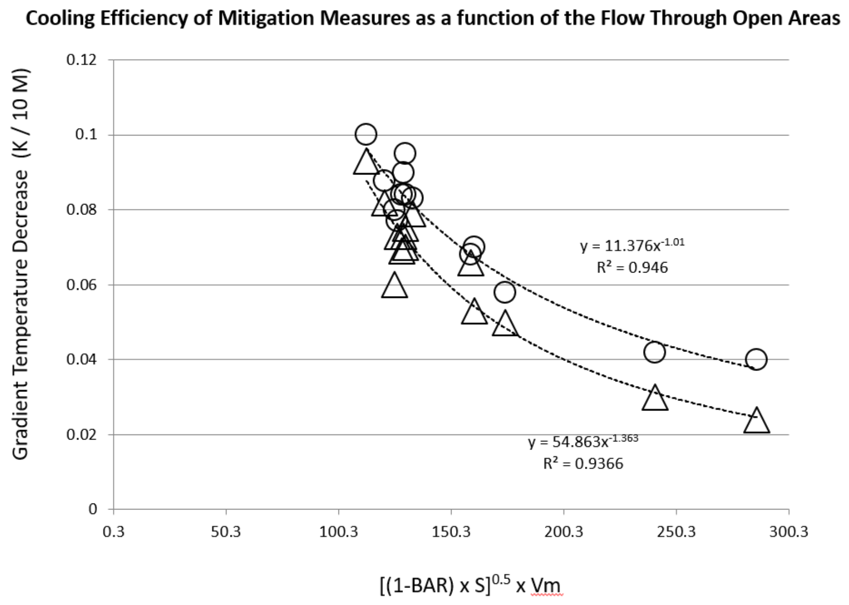


Figure 269 Cooling Efficiency of Mitigation Measures as a function of the Flow Through Open Areas

14. The correlation has the form:

    $GTD\ (i) = A \times Q_{(average)}{}^{b}$ (3)
    The corresponding R^2 for both the mitigation and non- mitigation scenarios are very high and close to 0.9.
    The correlation shows clearly that the lower the advection of heat to the precinct the higher the GTD, i.e., the higher the protection against the overheating.

15. A quite strong correlation is found between the ratio of the average wind speed in the precinct, $V_{(average)}$, and the incident wind speed in the limits of the precinct, V_{inc}, with the average aspect ratio of the precinct, H/W. H stands for the average height of the buildings and W the average width of the streets, Figure 270. The relation has the form:

    $V_{(average)} / V_{inc} = a1 + b1\ (H/W)$ (4)

    The parameters a1 and b1 can be taken from Figure 270.

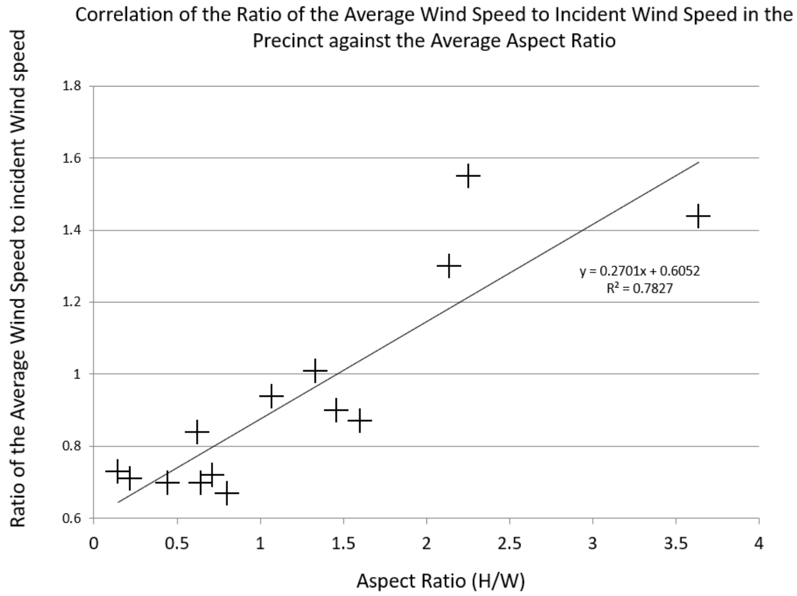


Figure 270 Correlation of the Ratio of the Average Wind Speed to Incident Wind Speed in the Precinct against the Average Aspect Ratio

16. Given that the aspect ratio and the parameter, S($_{average}$), of a precinct as well as the incident wind angle are known, the average wind speed in the precinct, V($_{average}$), can be calculated from equation 4, and the average advection rate, Q($_{average}$), can be estimated from equation 2. Finally, the expected decrease of the temperature in the precinct GTD(i), can be calculated from equation 3.
17. Comparison of the corresponding GTD relations for the mitigated and non-mitigated scenarios, shows clearly that the presence of mitigation systems, (vegetation, evaporation and cool materials), increases significantly the GTD value of the precincts and increases their cooling capacity. The increase of the GTD is lower for small advection values, Q($_{average}$), and increases significantly as the advection flow increases.
18. In precincts with mitigation measures, the total GTD($_{total,\ mit}$) may be attributed in two specific reasons: a) The existence of the mitigation measures and b) The layout of the precinct. In this case it can be written that:

    $GTD(_{total\ mit}) = GTD(_{mitigation}) + GTD(_{layout})$ (5)

    For a given advection rate Q($_{average}$), can be calculated from the corresponding expression of equation 3, and then the specific contribution of the mitigation may be estimated as

    $GTD(_{mitigation}) = GTD(_{total,\ mit}) - GTD(_{layout})$ (6)

    For a Q($_{average}$) =100 then GTD($_{mitigation}$)=0.006 K/m and counts for about the 6 % of the total GTD. However, once Q($_{average}$) increases, the contribution of mitigation measures becomes more important. For a Q($_{average}$) =300 then GTD($_{mitigation}$)=0.014 K/m and counts for about the 25 % of the total GTD. Thus, it can be concluded that the cooling contribution of the specific layout of the precincts is more important when advection is low and decreases as advection is rising.
19. A quite strong correlation between the GTD($_{mitigation}$) and the Built Area Ratio is found, (Figure 271). As shown, the higher the Built Area Ratio, the lower the contribution of the mitigation techniques to the cooling rate of the precincts. This is logical as less space is allocated to install mitigation measures.

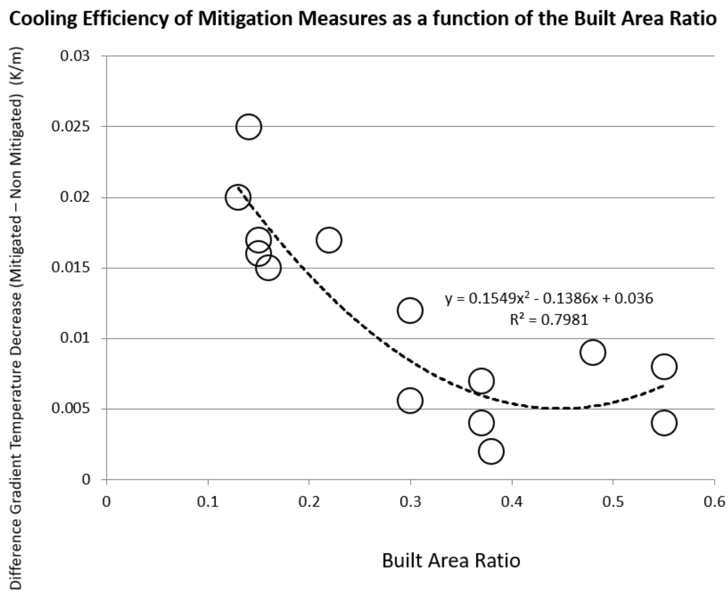


Figure 271 Cooling Efficiency of Mitigation Measures as a function of the Built Area Ratio

20. A clear and quite strong correlation is found between the GTD of all the precincts with and without mitigation, and the corresponding average aspect ratio, (Height of buildings to Width of streets), of the precincts, (Figure 272). The relation is:

    GTD(i)= a2+b2 x (H/D) (7)

    Where a2 and b2 are coefficients given in Figure 271.

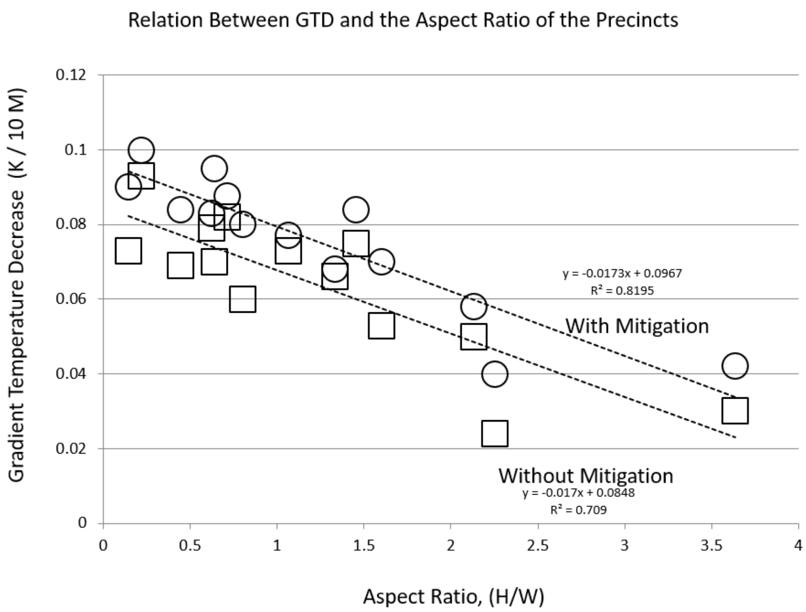


Figure 272 Relation Between GTD and the Aspect Ratio of the Precincts

21. As shown in Figure 272, the higher the aspect ratio of a precinct the lower the cooling potential and GTD. This is expected, as: a) the application of cool roofs in high rise buildings has a lower impact and b) wind speed in canyons of high aspect ratios is quite higher and corresponds to a much higher advection rate.

22. Both prediction methods proposed to calculate the GTD of the mitigated and non-mitigated precincts, are of sufficient accuracy. Figure 273 and Figure 274 compare the predicted GTD values by the two methods against the original data for the mitigated and the non-mitigated precincts. The average relative prediction error of both methods for the mitigated precincts is close to 10 %. For the non-mitigated precincts, the average prediction error of the method based in the aspect ratio is close to 17 %, while the corresponding error of the method based on the estimation of the advection rate is close to 12 %.

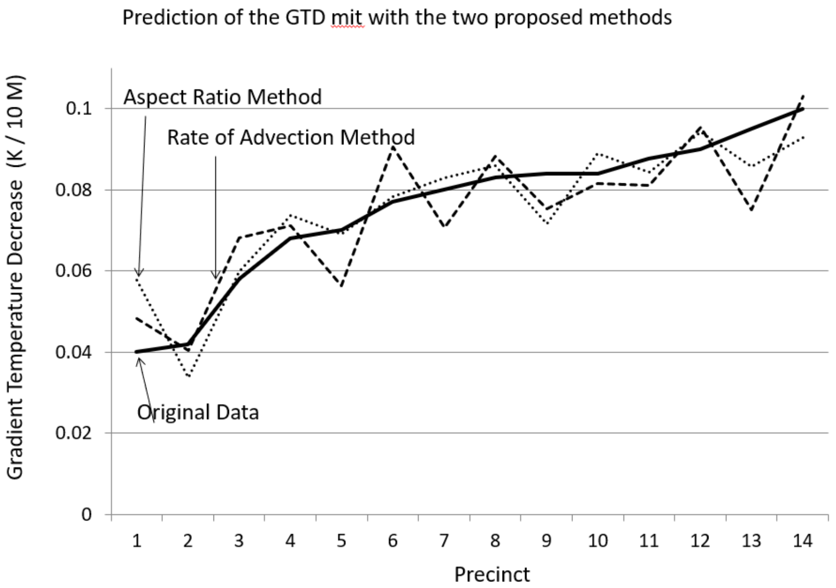


Figure 273 Prediction of the GTD mit with the two proposed methods

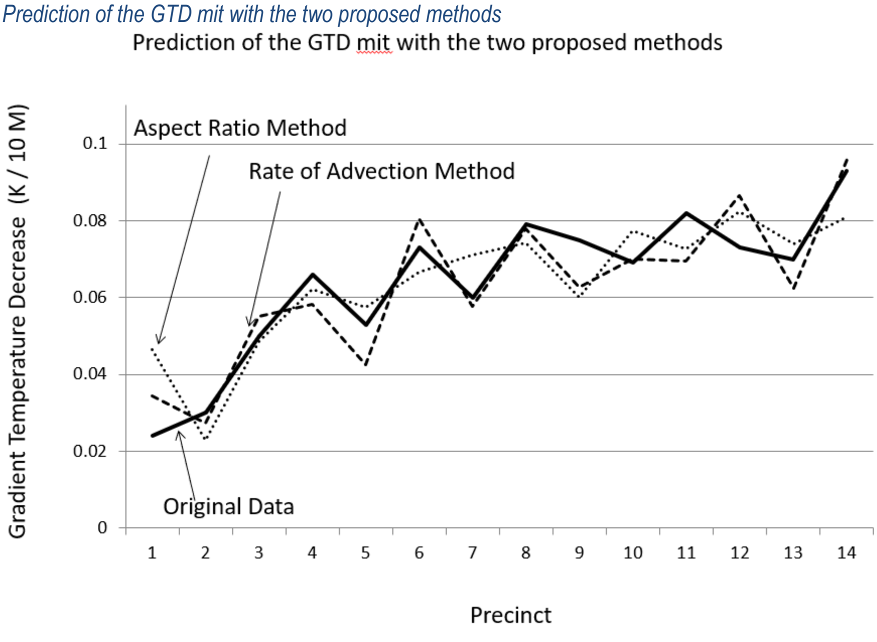


Figure 274 Prediction of the GTD mit with the two proposed methods

23. The advection rate in the precincts is highly dependent on the orientation and the characteristics of its canyons. Canyons having their axis vertical or oblique to the wind direction may present a lower wind speed compared to the canyon with their axis parallel to the wind direction. This depends highly on the aspect ratio, (h/w), of the canyons, Figure 275. For canyons vertical or

oblique to the wind direction, a high h/w value > 0.8 signifies that the flow is under skimming regime and corresponds to a local vortex inside the canyon, and a bypass of the flowing air above the height of the buildings. For h/w values between 0.8 and 0.3, the flow is wake interface, and for low r values is isolated roughness. The specific characteristics of the flow are shown in Figure 276.

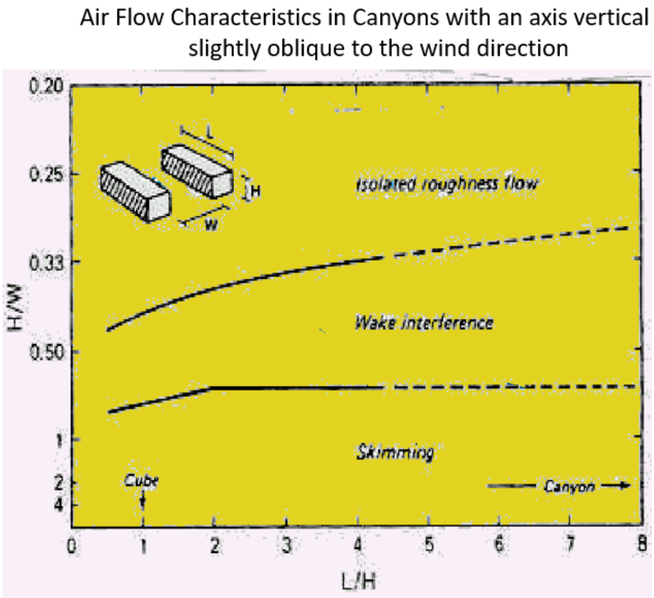


Figure 275 Air Flow Characteristics in Canyons with an axis vertical or slightly oblique to the wind direction; source: Oke

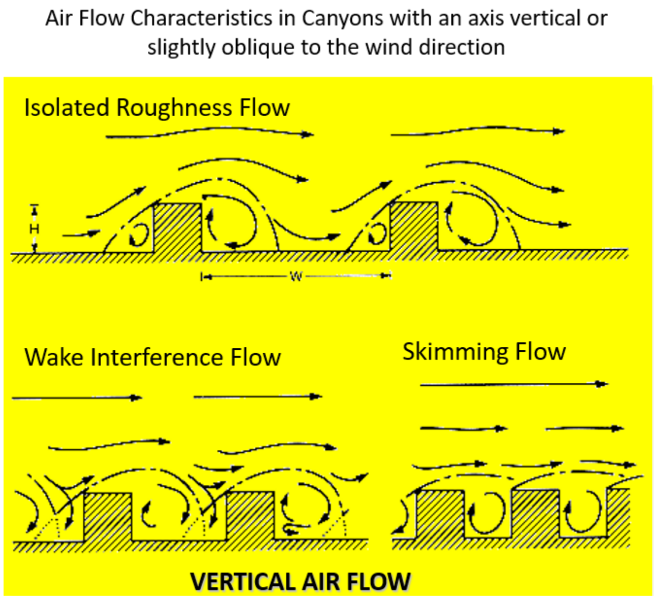


Figure 276 Air Flow Characteristics in Canyons with an axis vertical or slightly oblique to the wind direction; source: Oke

24. For all canyons of the precincts having their axis vertical or slightly oblique to the wind direction, a strong correlation of the average wind speed in the canyon, $V_{(veraverage)}$ and the aspect ratio, (h/w), is found, Figure 277. The relation has the form:

$V_{(veraverage)}$=0.2046 x $(h/w)^{-1.745}$ (8)

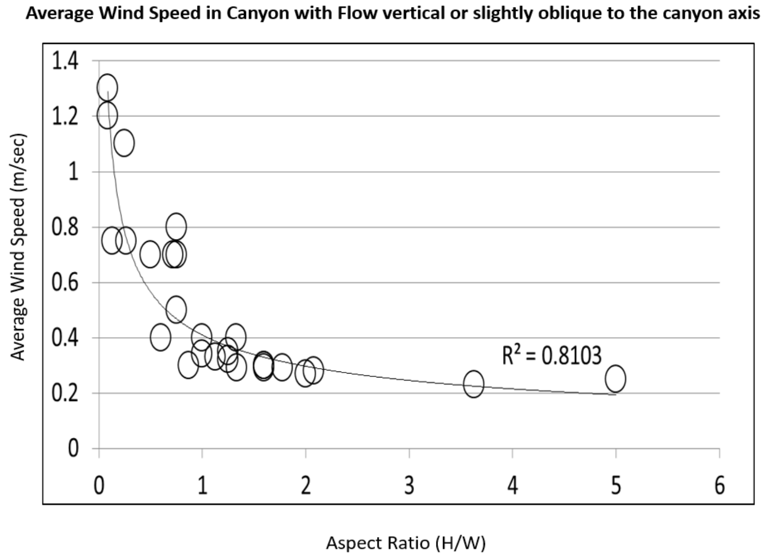


Figure 277 Average Wind Speed in Canyon with Flow vertical or slightly oblique to the canyon axis

25. In parallel, for all canyons having their axis parallel to wind direction, a strong correlation is established between the length of the canyon and the product of the entry wind speed and width of the canyon as well as with the product of the exit wind speed with the width of the canyon (Figure 278).

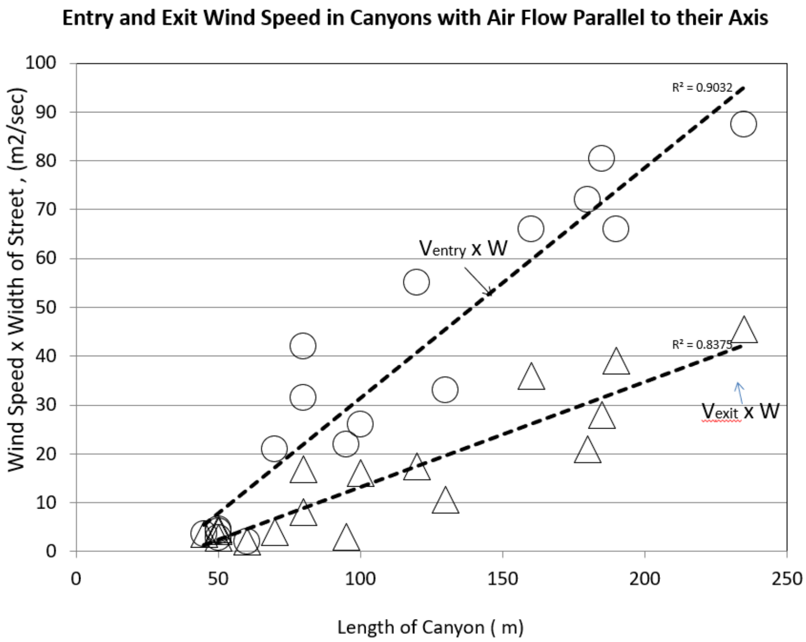


Figure 278 Entry and Exit Wind Speed in Canyons with Air Flow Parallel to their Axis

<u>Impact on Energy</u>

1. The layout and the characteristics of the precincts may affect the cooling energy consumption of a building of same orientation and same thermal characteristics up to 6 %.

2. The layout and the characteristics of the precincts may affect the total cooling energy consumption per square meter, of all buildings in a precinct, with different orientation and façade and thermal characteristics up to 53 % when buildings are extremely well shaded, or up to 93 % when the shading coefficient is average.
3. There is a general trend that the lower cooling energy consumption is presented in precincts with a lower aspect ratio, (H/W). This trend is stronger for the OT precincts than the CT precincts.

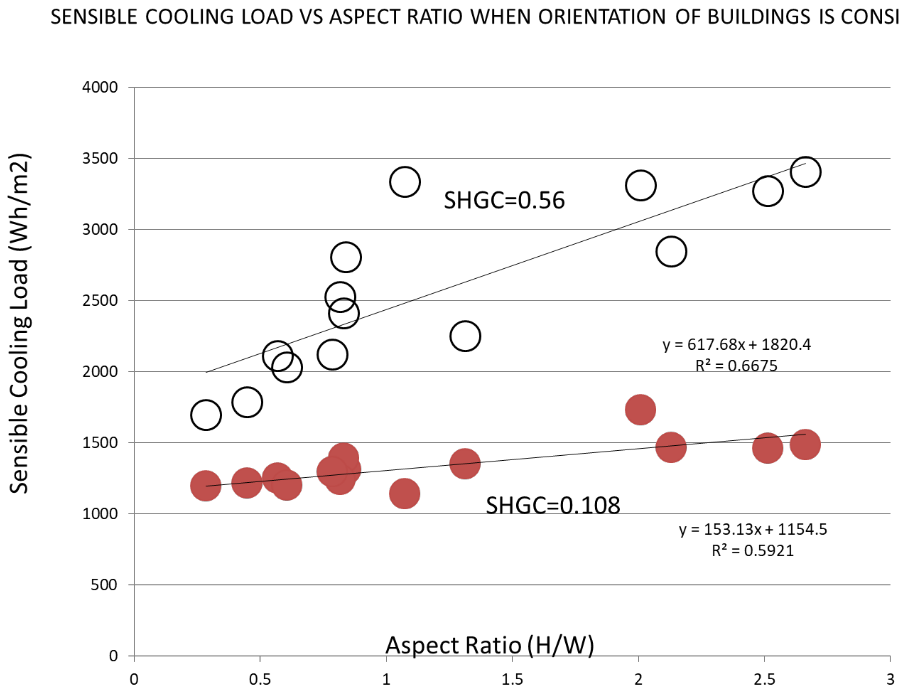


Figure 279 Sensible cooling load vs aspect ratio when orientation of buildings is considered

4. The global cooling energy consumption in a precinct may be up to 4800 % higher than in another precinct of the similar plot. This is of course very much influenced by the total built area, orientation, building characteristics, etc.

Acknowledgement

We acknowledge the Cooperative Research Centre (CRC) For Low Carbon Living for supporting this project.

9. APPENDIX

I: MATLAB CODE to prepare database

The script below was developed to prepare a database of climatic data for Sydney based on WRF simulations. The values are extended over a grid size of (86.4*97.2) km with a grid resolution of 1.2 km. For each variable there are 72 grid points in the west-east direction and 81 in the north-south direction. The number of hours is 673 so the total size of matrix in each case is 72*81*673. The parameters include Ambient temperature, Relative humidity, wind speed, Wind direction, latent heat flux, sensible heat flux, and surface pressure.

```
A=readtable ('C:\latentheatflux.xlsx');
Q=readtable ('C:\sensibleheatflux.xlsx');
W=readtable ('C:\surfacepressure.xlsx');
E=readtable ('C:\surfacetemperature.xlsx');
R=readtable ('C:\2mTemperature.xlsx');
T=readtable ('C:\winddirection.xlsx');
Y=readtable ('C:\windspeed.xlsx');
D=readtable ('C:\RH2_MUGHAL.xlsx'); %Humidity
A=table2array(A);
Q=table2array(Q);
W=table2array(W);
E=table2array(E);
R=table2array(R);
T=table2array(T);
Y=table2array(Y);
D=table2array(D);
m=1;
i=4;
hh=1;
while hh<=81
j=hh;
while j<54432
s(m)=(A(j,i));
z(m)=(Q(j,i));
x(m)=(W(j,i));
c(m)=(E(j,i));
v(m)=(R(j,i));
b(m)=(T(j,i));
n(m)=(Y(j,i));
k(m)=(D(j,i));
m=m+1;
j=j+81;
end
s=transpose(s);
z=transpose(z);
x=transpose(x);
c=transpose(c);
v=transpose(v);
b=transpose(b);
n=transpose(n);
k=transpose(k);
co1=(A(hh,3));
co2=xlsread('C:\latentheatflux.xlsx', 'D1:D1');
filename=strcat(num2str(co1),strcat(num2str(co2)),'.xlsx');
xlswrite(filename,{'latentheatflux'},'sheet1','C1');
xlswrite(filename,{'sensibleheatflux'},'sheet1','D1');
```

```
xlswrite(filename,{'surfacepressure'},'sheet1','E1');
xlswrite(filename,{'surfacetemperature'},'sheet1','F1');
xlswrite(filename,{'2mTemperature'},'sheet1','G1');
xlswrite(filename,{'winddirection'},'sheet1','H1');
xlswrite(filename,{'windspeed'},'sheet1','I1');
xlswrite(filename,{'humidity'},'sheet1','J1');
xlswrite(filename,s,'sheet1','C2');
xlswrite(filename,z,'sheet1','D2');
xlswrite(filename,x,'sheet1','E2');
xlswrite(filename,c,'sheet1','F2');
xlswrite(filename,v,'sheet1','G2');
xlswrite(filename,b,'sheet1','H2');
xlswrite(filename,n,'sheet1','I2');
xlswrite(filename,k,'sheet1','J2');
clear s
clear z
clear x
clear c
clear v
clear b
clear n
clear m
clear k
m=1;
hh=hh+1;
end
clear m
clear i
clear hh
clear j
clear s
clear z
clear x
clear c
clear v
clear b
clear n
clear k
clear filename
```

Since there are 72 columns in each input file, the script is extended to “i=75”. Further, to name each output file based on corresponding coordinate, the script is adjusted to write from the relevant geographical coordinate. For instance, when i=4 “co2=xlsread('C:\latentheatflux.xlsx', 'D1:D1')” is changed to “co2=xlsread('C:\latentheatflux.xlsx', 'E1:E1')” for i=5.

II: Results of full forcing

CT1-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 280 and Figure 281 respectively. The maximum air temperature at 14:00 is equal to 34.24°C, the minimum is equal to 28.35°C and average is equal to 33.35°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (49.50m, 19.50m) (210.50m, 34.50m) (210.00m, 210.00m) and (69.00m, 211.5m) of the terrain. The maximum air temperature at 15:00 is equal to 34.06 °C, the minimum is equal to 28.08 °C and average is equal to 32.21°C. The temperature is also considerably decreased to the regions of water sprays.

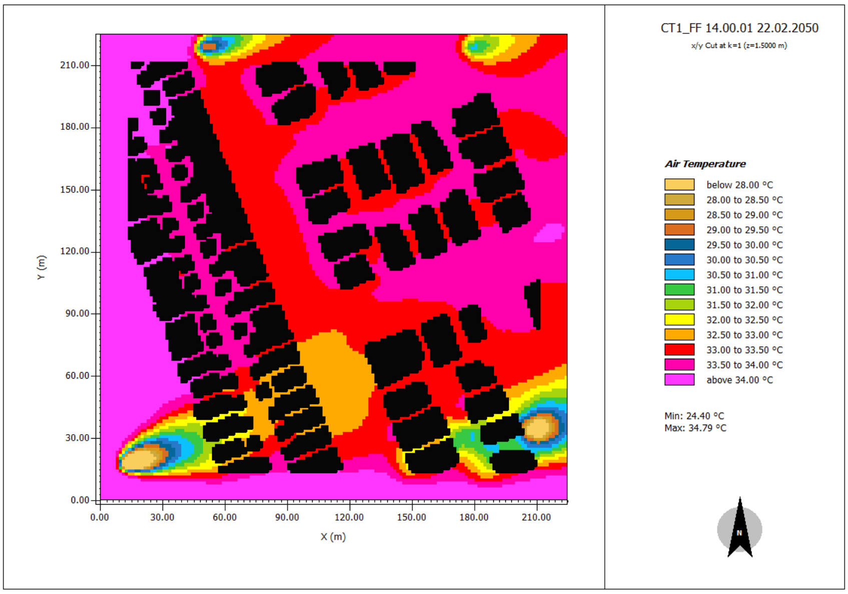


Figure 280. The air temperature of CT1 at 14:00

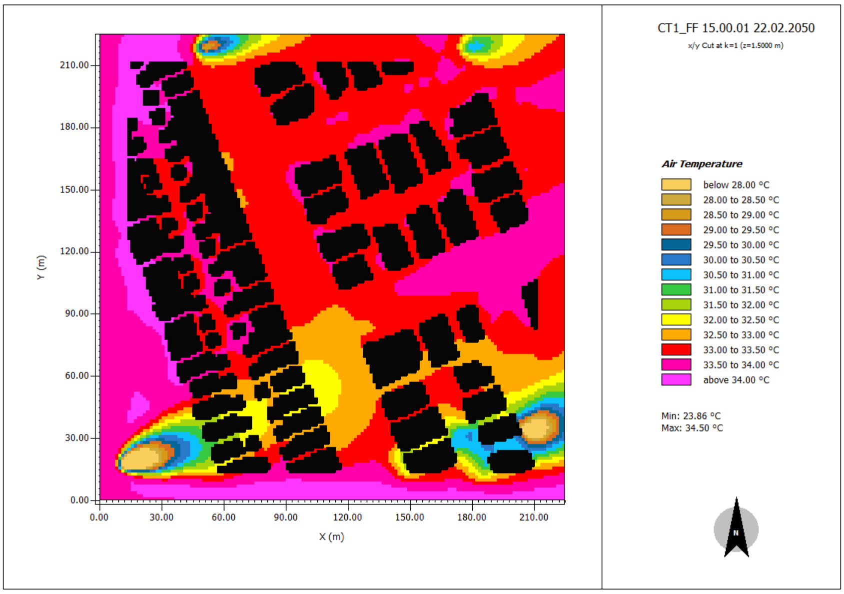


Figure 281. The air temperature of CT1 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 282, Figure 283, Figure 284 respectively. The same points are used for the statistical analysis of surface temperature.

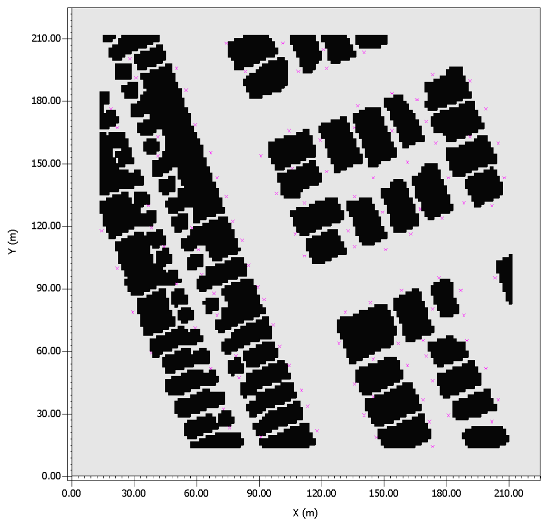


Figure 282. Points for the analysis of the air temperature close to houses

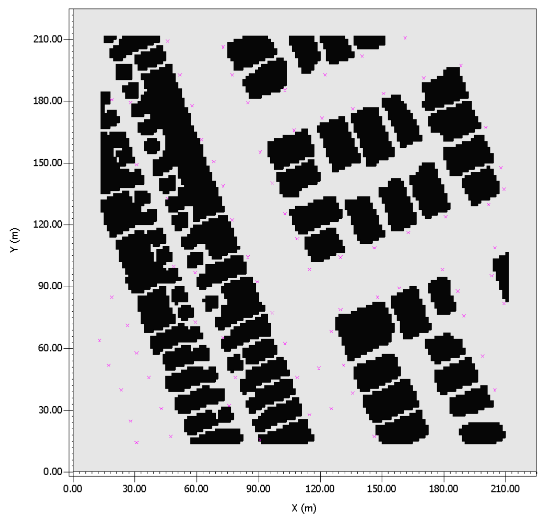


Figure 283. Points for the analysis of the air temperature close to pavements

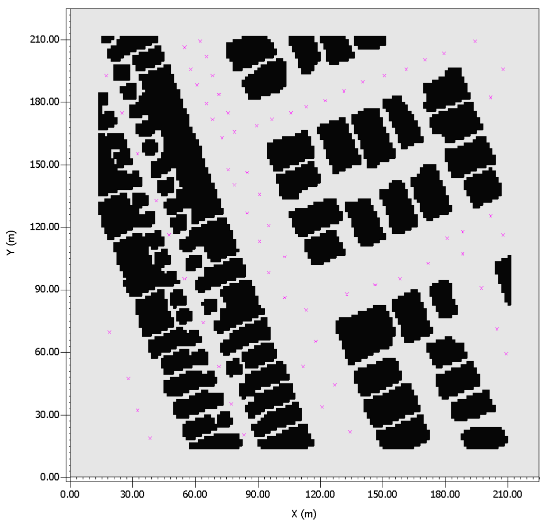


Figure 284. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 285. Statistical analysis of simulation results for all simulation hours is tabulated in Table 47.

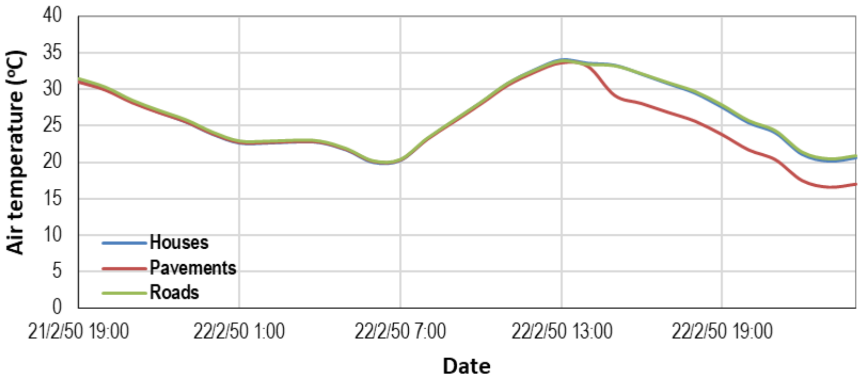


Figure 285. Air temperature versus time for the various points

Table 47. The CT1 statistical analysis of air temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	26.36	33.95	20.04
Roads	26.52	33.86	20.2
Pavements	25.03	33.66	16.53

Wind speed

The wind speed simulation results for CT1 and for 14:00 and 15:00 are depicted in Figure 286 and Figure 287 respectively. The maximum wind speed at 14:00 is 1.79 m/s close to the open area and the minimum is 0.02 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.79 m/s and the minimum wind speed is 0.02 m/s.

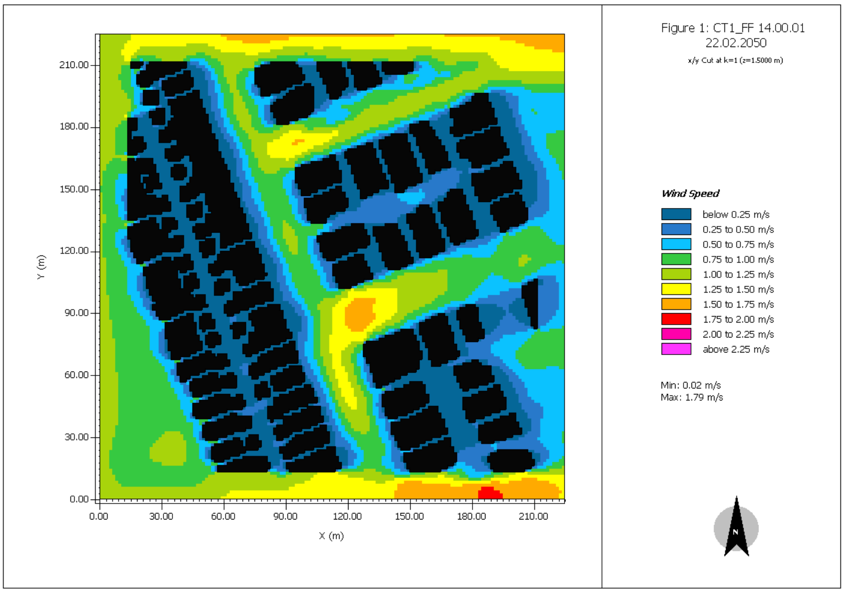


Figure 286. The wind speed of CT1 at 14:00

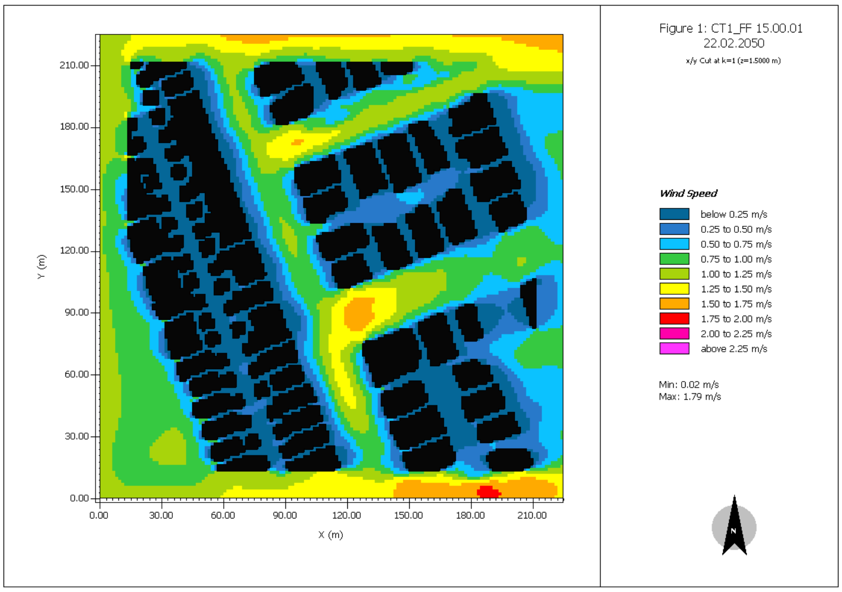


Figure 287. The wind speed of CT1 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 288 and Figure 289 respectively. The maximum surface temperature at 14:00 is equal to 54.04 °C, the minimum is equal to 25.87 °C and average is equal to 38.27°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (49.50m, 19.50m) (210.50m, 34.50m) (210.00m, 210.00m) and (69.00m, 211.5m) of the terrain. The maximum surface temperature at 15:00 is equal to 50.61 °C, the minimum is equal to 26.21 °C and average is equal to 36.71°C. The temperature is also considerably decreased to the regions of water sprays.

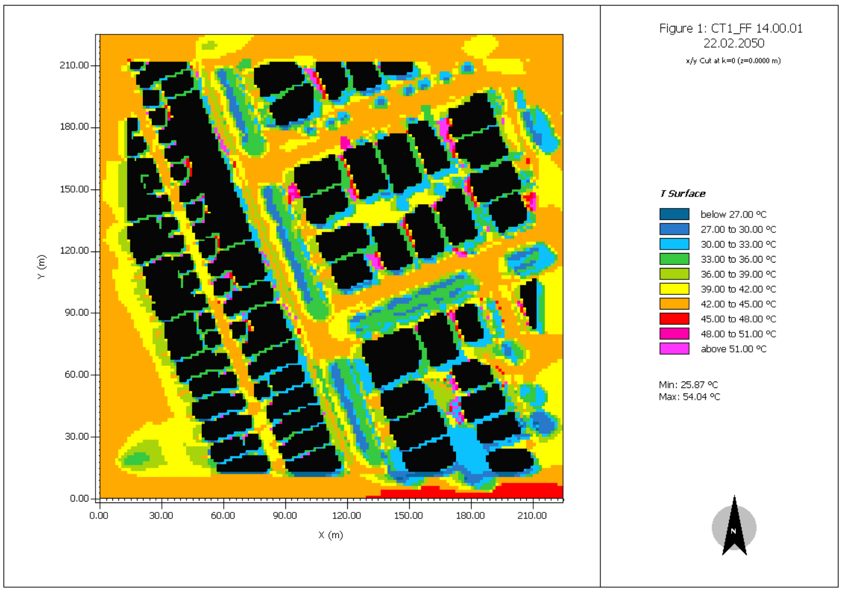


Figure 288. The surface temperature of CT1 at 14:00

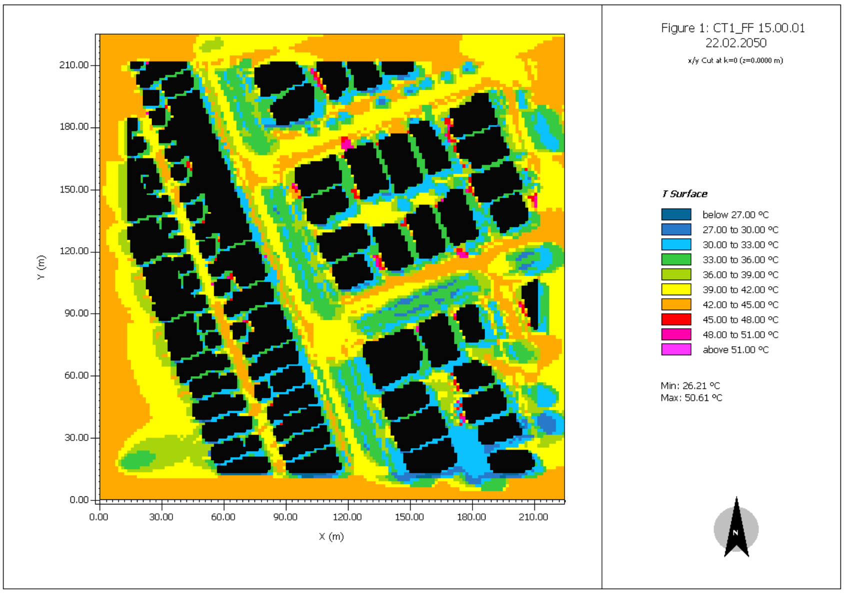


Figure 289. The surface temperature of CT1 at 15:00

The statistical results of all points versus time is depicted in Figure 290. Statistical analysis of simulation results for all simulation hours is tabulated in Table 48.

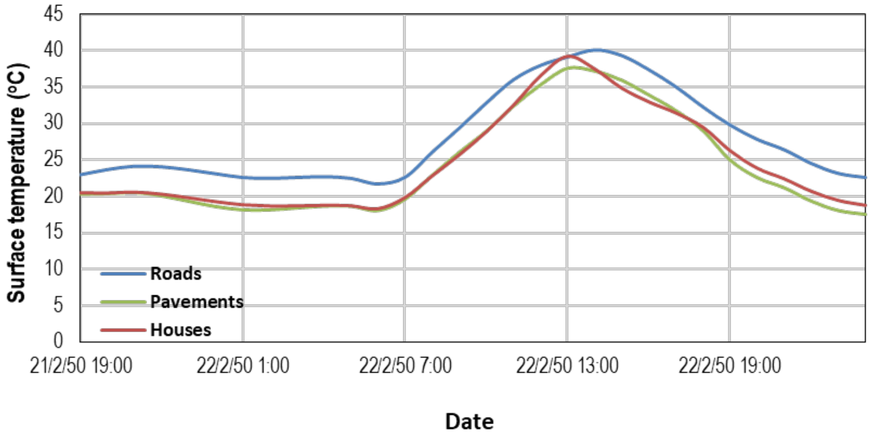


Figure 290. Surface temperature versus time for the various points

Table 48. The CT1 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	24.51	39.2	18.27
Roads	27.99	40.12	21.77
Pavements	24.15	37.59	17.56

CT2-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 291 and Figure 292 respectively. The maximum air temperature at 14:00 is equal to 35.12°C, the minimum is equal to 23.8°C and average is equal to 33.78°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (18.00m, 22.50m) (186.00m, 22.50m) (1560.00m, 204.00m) and (22.50m, 204.00m) of the terrain. The maximum air temperature at 15:00 is equal to 34.80 °C, the minimum is equal to 23.43 °C and average is equal to 33.44°C. The temperature is also considerably decreased to the regions of water sprays.

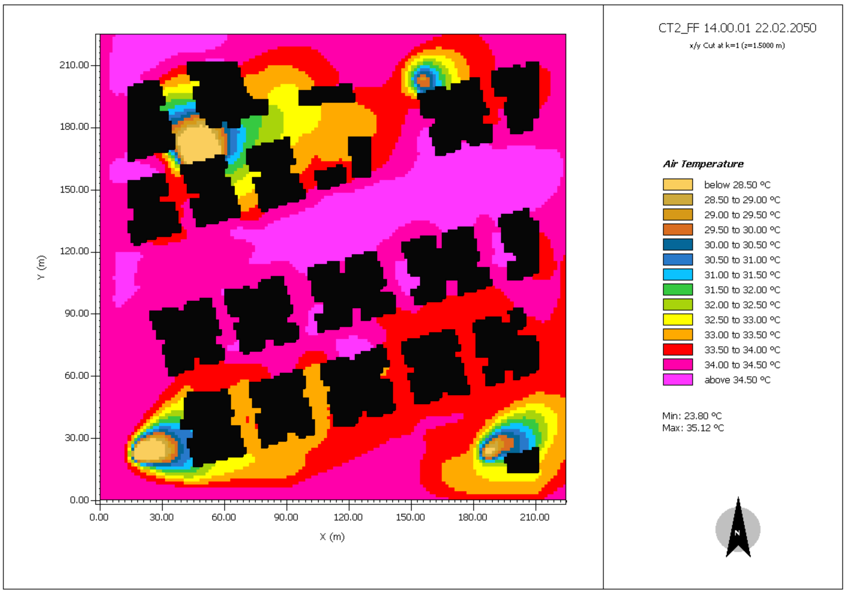


Figure 291. The air temperature of CT2 at 14:00

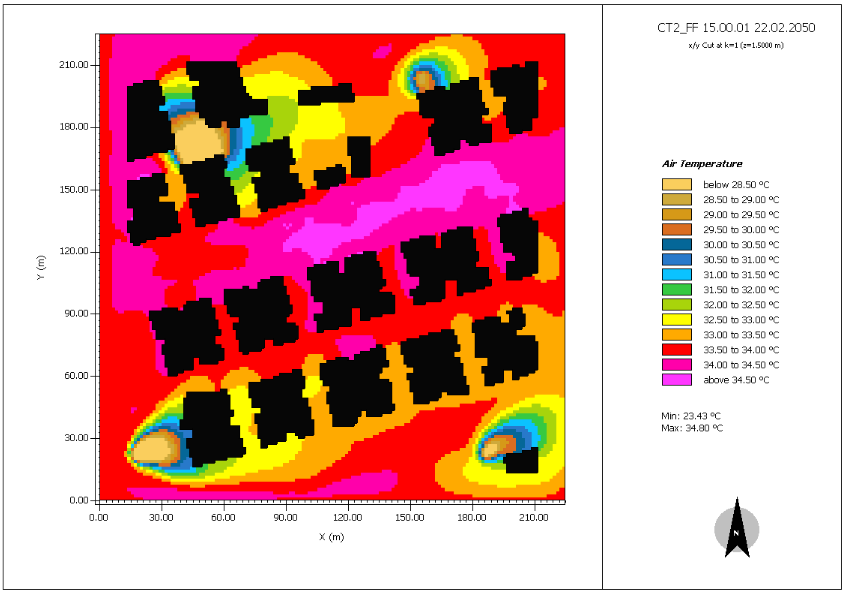


Figure 292. The air temperature of CT2 at 15:00.

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 293, Figure 294, Figure 295 respectively. The same points are used for the statistical analysis of surface temperature.

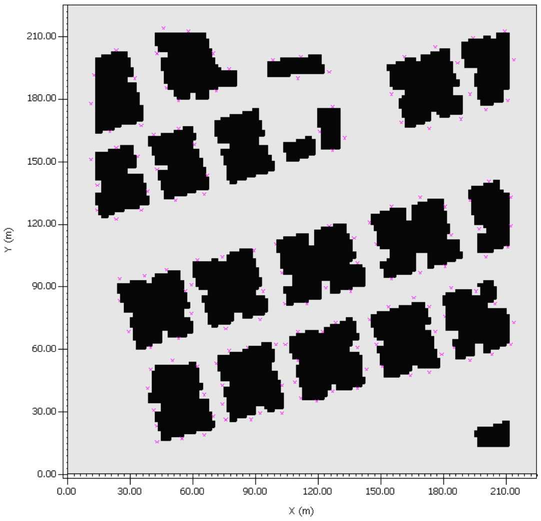


Figure 293. Points for the analysis of the air temperature close to houses

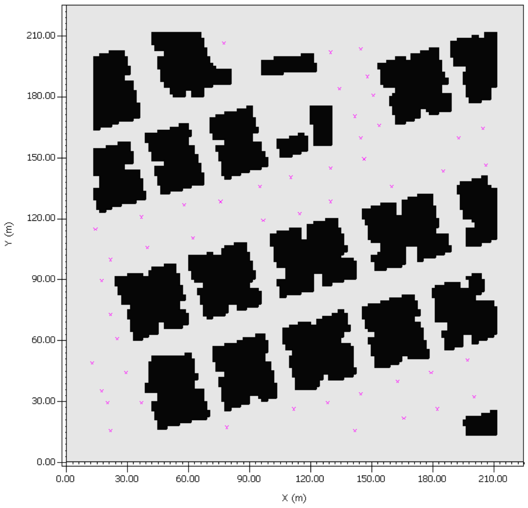


Figure 294. Points for the analysis of the air temperature close to pavements

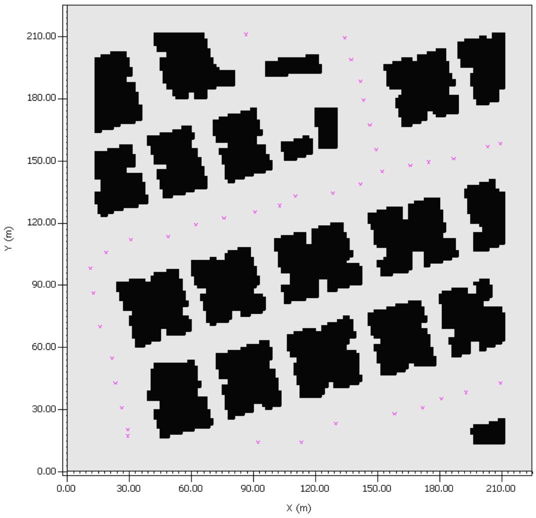


Figure 295. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 296. Statistical analysis of simulation results for all simulation hours is tabulated in Table 49.

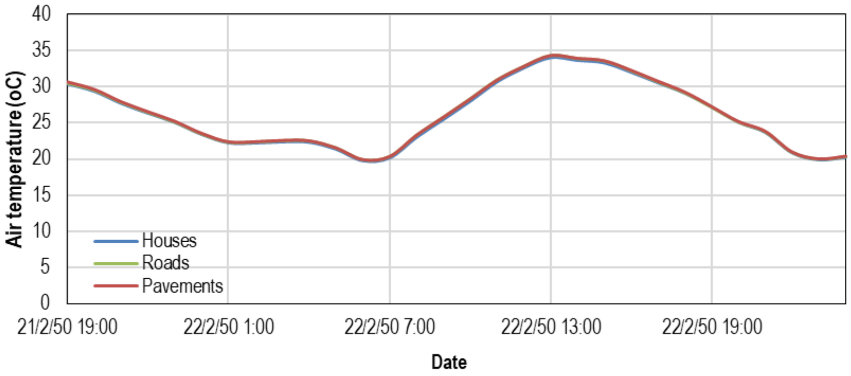


Figure 296. Air temperature versus time for the various points

Table 49. The CT2 statistical analysis of air temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	26.03	33.99	19.73
Roads	26.26	34.28	19.93
Pavements	26.21	34.27	19.93

Wind speed

The wind speed simulation results for CT2 and for 14:00 and 15:00 are depicted in Figure 297 and Figure 298 respectively. The maximum wind speed at 14:00 is 1.77 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.78 m/s and the minimum is 0.00 m/s.

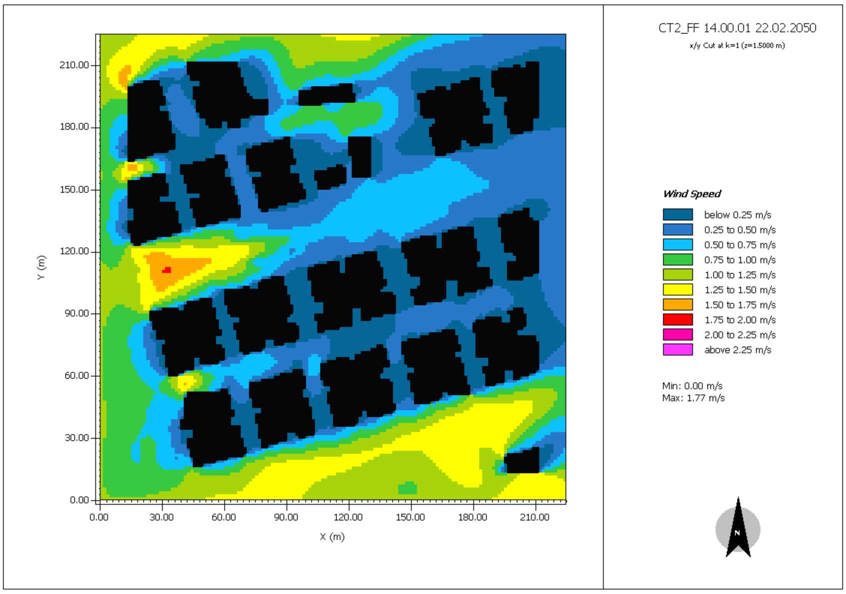


Figure 297. The wind speed of CT2 at 14:00

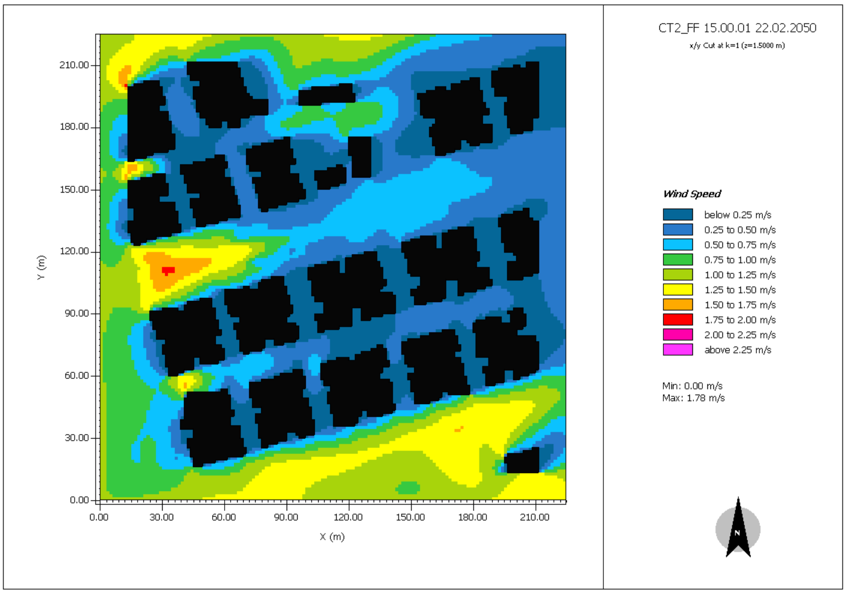


Figure 298. The wind speed of CT2 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 299 and Figure 300 respectively. The maximum surface temperature at 14:00 is equal to 53.86 °C, the minimum is equal to 24.77 °C and average is equal to 38.27°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (18.00m, 22.50m) (186.00m, 22.50m) (1560.00m, 204.00m) and (22.50m, 204.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 48.77 °C, the minimum is equal to 26.30 °C and average is equal to 38.46°C. The temperature is also considerably decreased to the regions of water sprays.

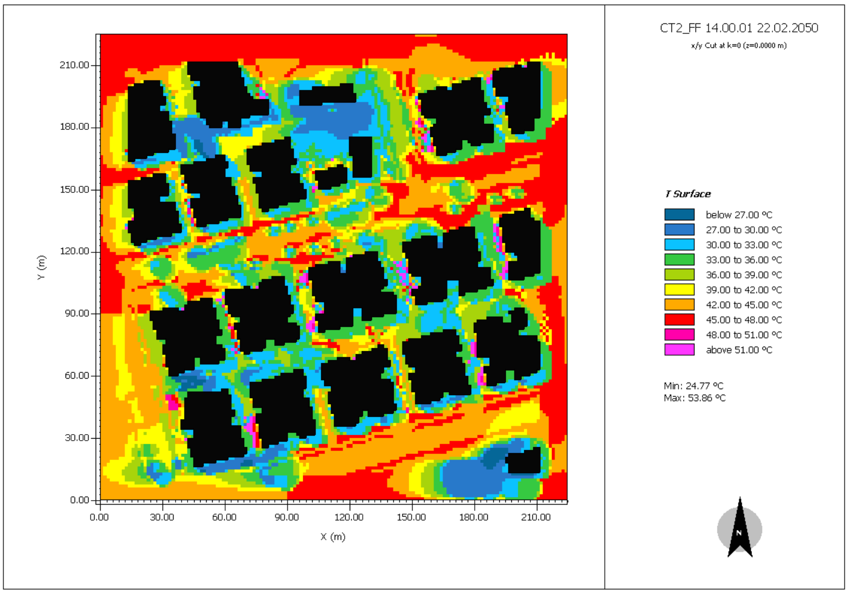


Figure 299. The surface temperature of CT2 at 14:00

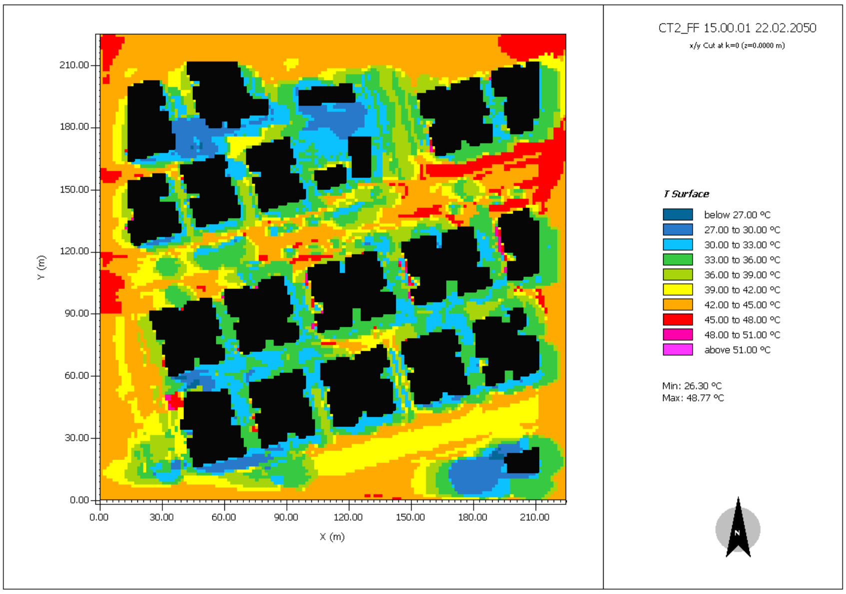


Figure 300. The surface temperature of CT2 at 15:00

The statistical results of all points versus time is depicted in Figure 301. Statistical analysis of simulation results for all simulation hours is tabulated in Table 50.

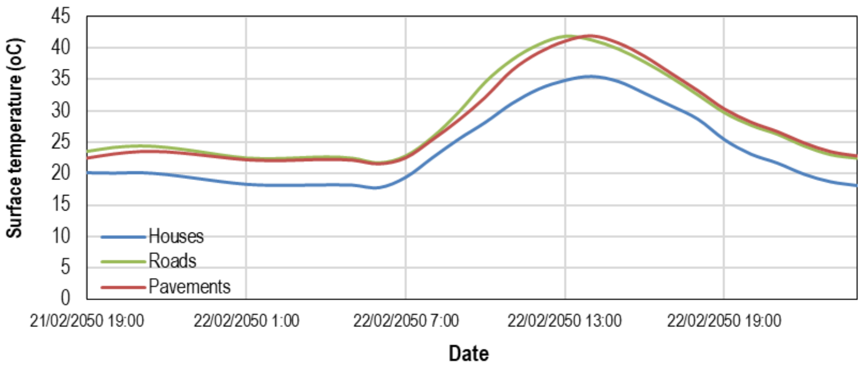


Figure 301. Surface temperature versus time for the various points

Table 50. The CT2 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	23.77	35.54	17.83
Roads	28.16	41.97	21.63
Pavements	28.33	41.81	21.69

CT3-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 302 and Figure 303 respectively. The maximum air temperature at 14:00 is equal to 34.86°C, the minimum is equal to 25.57°C and average is equal to 33.78°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (15.00m, 94.50m) (201.00m, 21.00m) (159.00m, 210.00m) and (22.50m, 204.00m) of the terrain.
The maximum air temperature at 15:00 is equal to 34.42 °C, the minimum is equal to 25.22 °C and average is equal to 33.44°C. The temperature is also considerably decreased to the regions of water sprays.

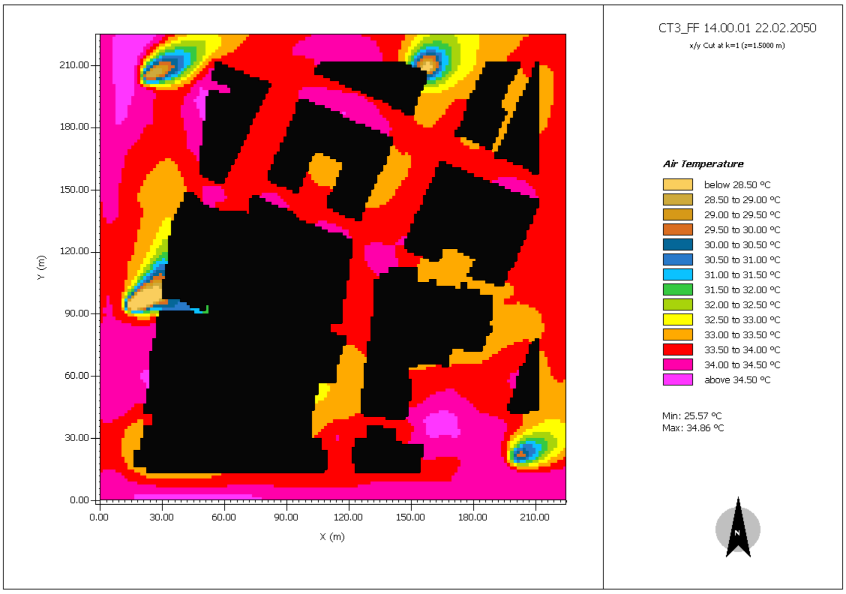


Figure 302. The air temperature of CT3 at 14:00

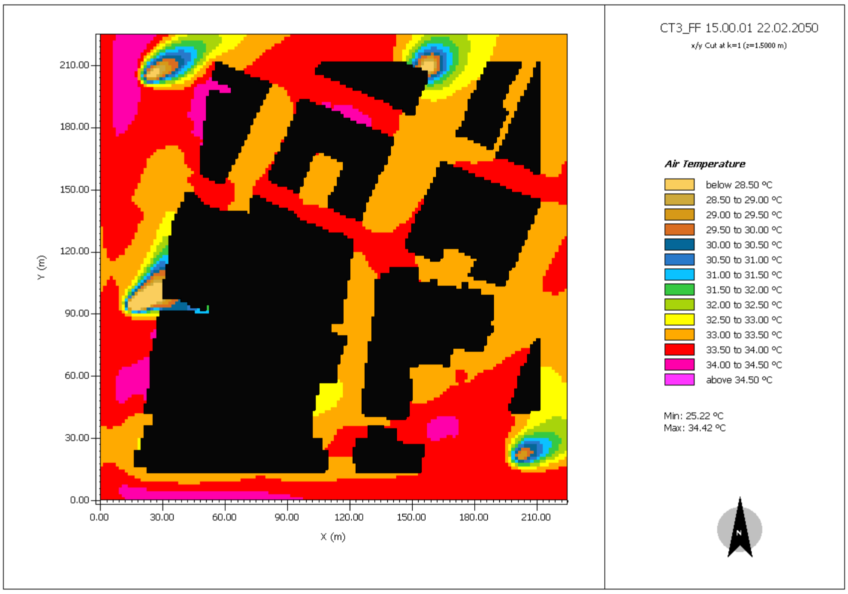


Figure 303. The air temperature of CT3 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 304, Figure 305, Figure 306 respectively. The same points are used for the statistical analysis of surface temperature.

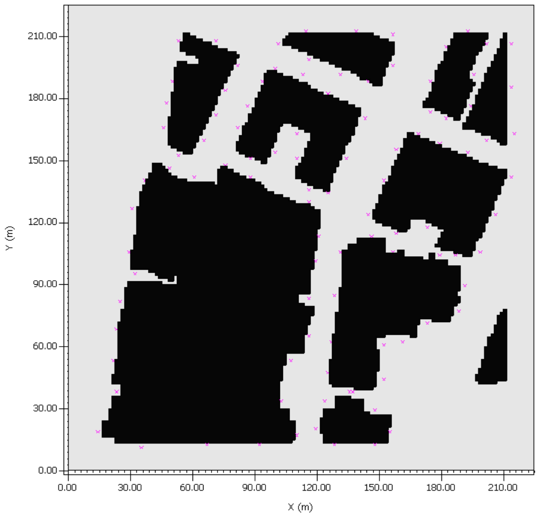


Figure 304. Points for the analysis of the air temperature close to houses

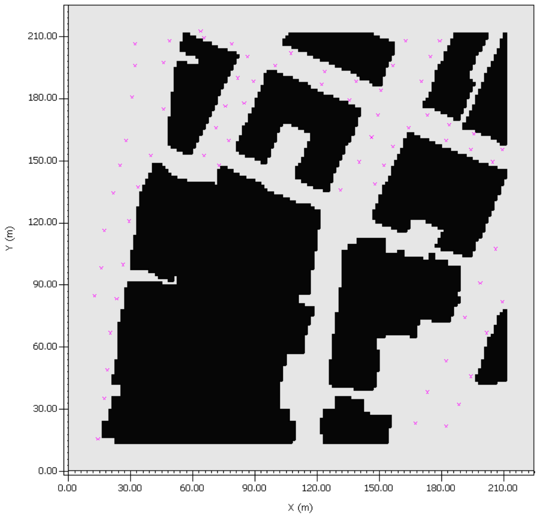


Figure 305. Points for the analysis of the air temperature close to pavements

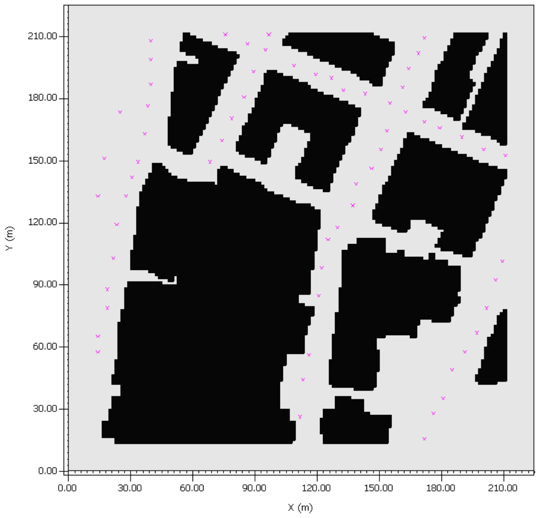


Figure 306. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 307. Statistical analysis of simulation results for all simulation hours is tabulated in Table 51.

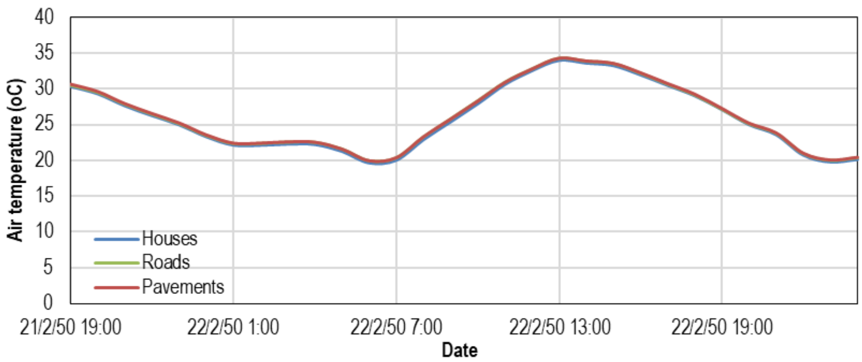


Figure 307. Air temperature versus time for the various points

Table 51. The CT3 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.03	33.99	19.73
Roads	26.26	34.28	19.93
Pavements	26.21	34.27	19.93

Wind speed

The wind speed simulation results for CT3 and for 14:00 and 15:00 are depicted in Figure 308 and Figure 309. The maximum wind speed at 14:00 is 1.98 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.98 m/s and the minimum is 0.00 m/s.

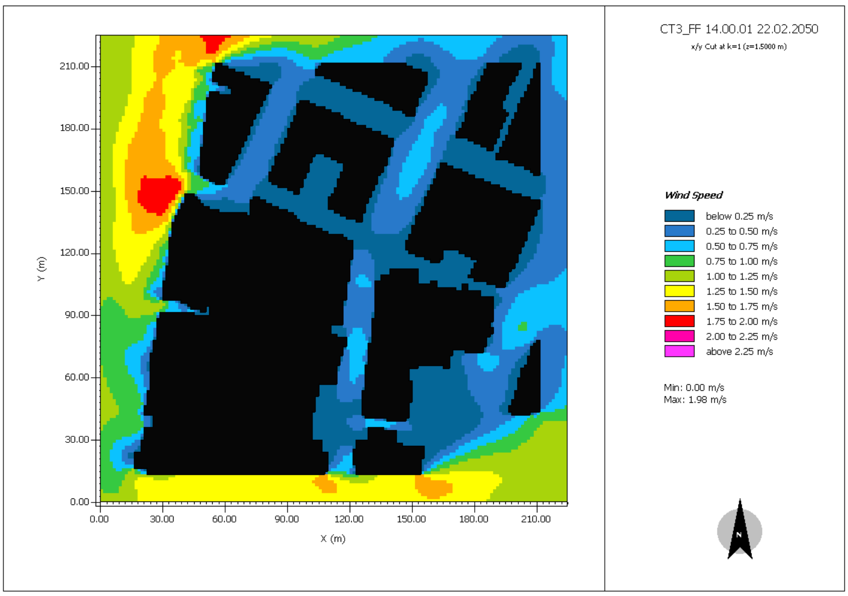


Figure 308. The wind speed of CT3 at 14:00

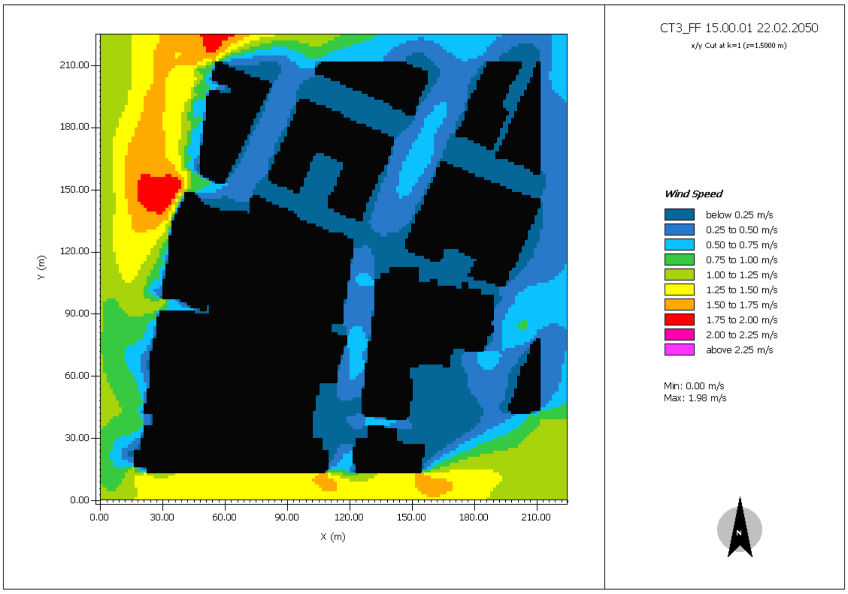


Figure 309. The wind speed of CT3 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 310 and Figure 311 respectively. The maximum surface temperature at 14:00 is equal to 53.61 °C, the minimum is equal to 25.58 °C and average is equal to 39.57°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (15.00m, 94.50m) (201.00m, 21.00m) (159.00m, 210.00m) and (22.50m, 204.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 48.48 °C, the minimum is equal to 26.18 °C and average is equal to 38.46°C. The temperature is also considerably decreased to the regions of water sprays.

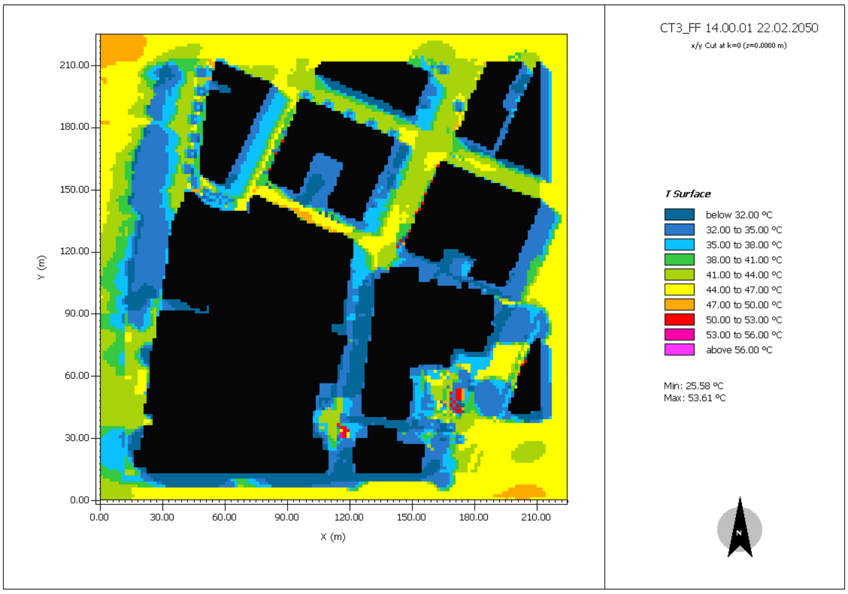


Figure 310. The surface temperature of CT3 at 14:00

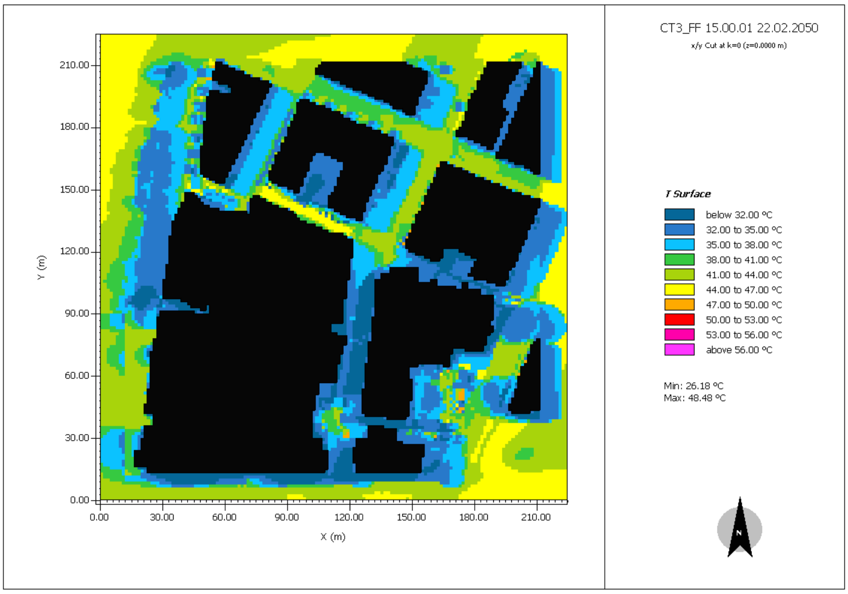


Figure 311. The surface temperature of CT3 at 15:00

The statistical results of all points versus time is depicted in Figure 312. Statistical analysis of simulation results for all simulation hours is tabulated in Table 52.

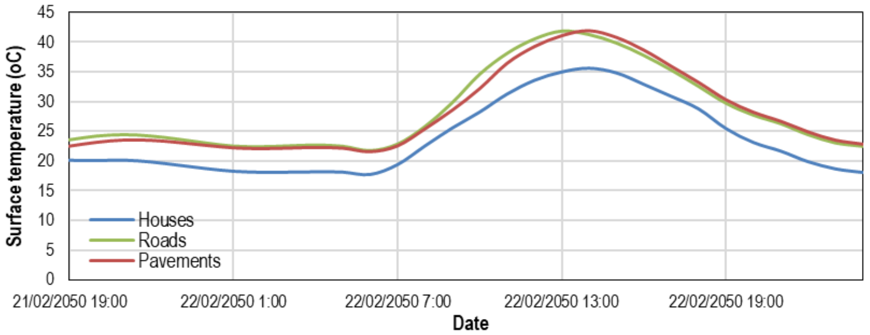


Figure 312. Surface temperature versus time for the various points

Table 52. The CT3 statistical analysis of surface temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	23.77	35.54	17.83
Roads	28.16	41.97	21.63
Pavements	28.33	41.81	21.69

CT4-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in
The maximum air temperature at 14:00 is equal to 36.37°C, the minimum is equal to 24.24°C and average is equal to 33.76°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (19.50m, 15.00m) (183.00m, 22.50m) (199.50m, 144.00m) and (120.00m, 204.00m) of the terrain.
The maximum air temperature at 15:00 is equal to 35.46 °C, the minimum is equal to 23.58 °C and average is equal to 33.29°C. The temperature is also considerably decreased to the regions of water sprays.

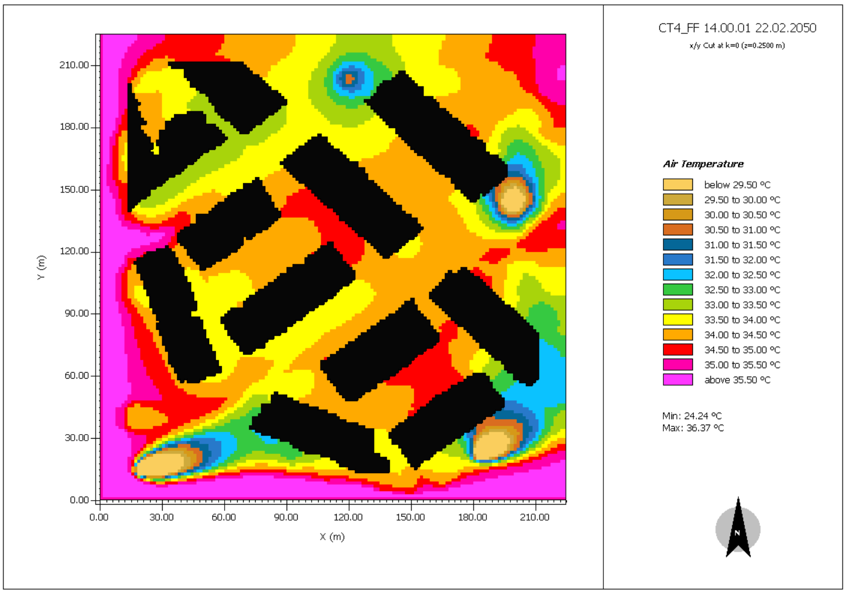


Figure 313. The air temperature of CT4 at 14:00

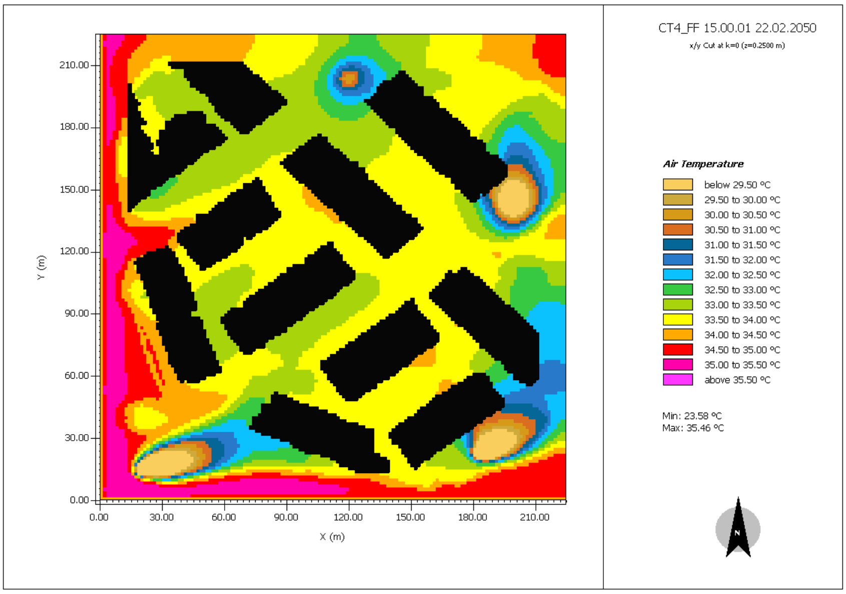


Figure 314. The air temperature of CT4 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 315, Figure 316 and Figure 317 respectively. The same points are used for the statistical analysis of surface temperature.

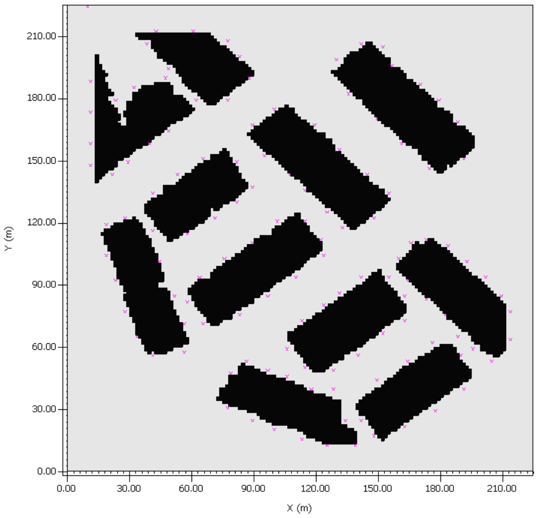


Figure 315. Points for the analysis of the air temperature close to houses

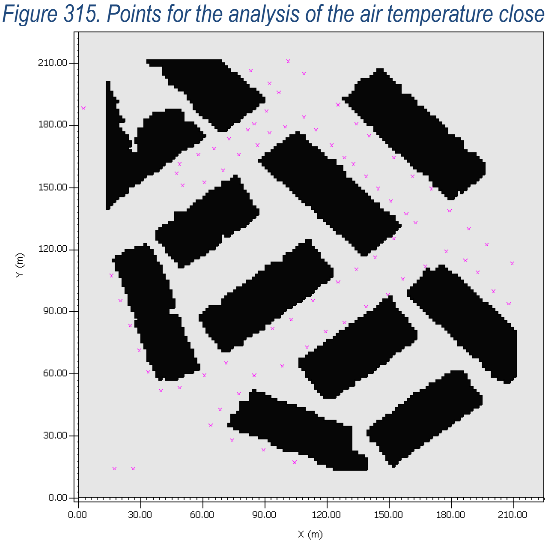


Figure 316. Points for the analysis of the air temperature close to pavements

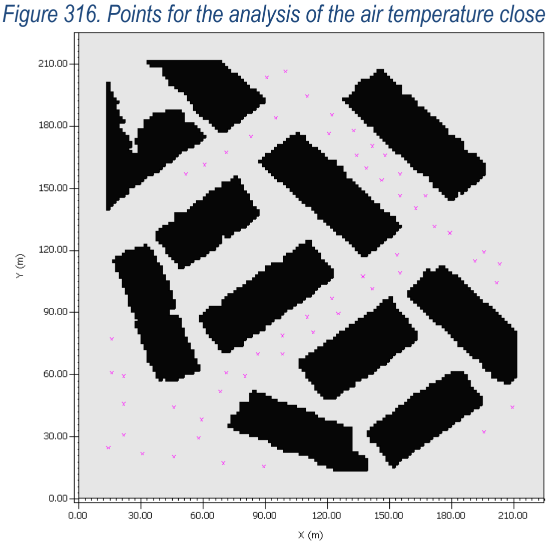


Figure 317. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 318. Statistical analysis of simulation results for all simulation hours is tabulated in Table 53.

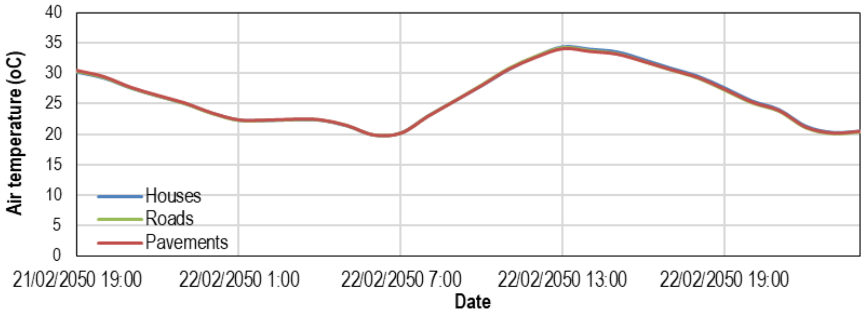


Figure 318. Air temperature versus time for the various points

Table 53. The CT4 statistical analysis of air temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	26.18	34.29	19.88
Roads	26.19	34.15	19.87
Pavements	26.05	34.21	19.76

Wind speed

The wind speed simulation results for CT4 and for 14:00 and 15:00 are depicted in Figure 319 and Figure 320 respectively. The maximum wind speed at 14:00 is 3.88 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 3.92 m/s and the minimum is 0.00 m/s.

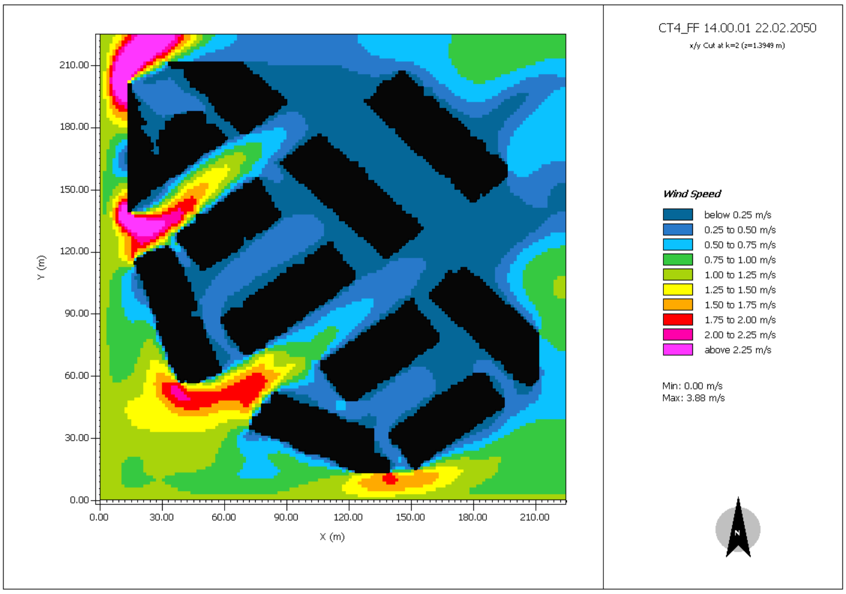


Figure 319. The wind speed of CT4 at 14:00

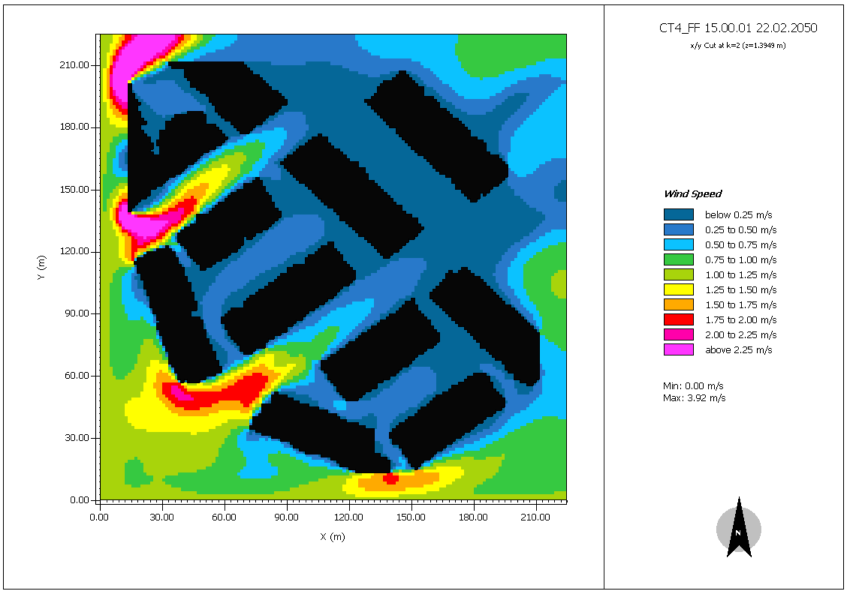


Figure 320. The wind speed of CT4 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 321 and Figure 322. The maximum surface temperature at 14:00 is equal to 51.02 °C, the minimum is equal to 25.51 °C and average is equal to 38.14°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (19.50m, 15.00m) (183.00m, 22.50m) (199.50m, 144.00m) and (120.00m, 204.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 48.16 °C, the minimum is equal to 25.60 °C and average is equal to 37.17°C. The temperature is also considerably decreased to the regions of water sprays.

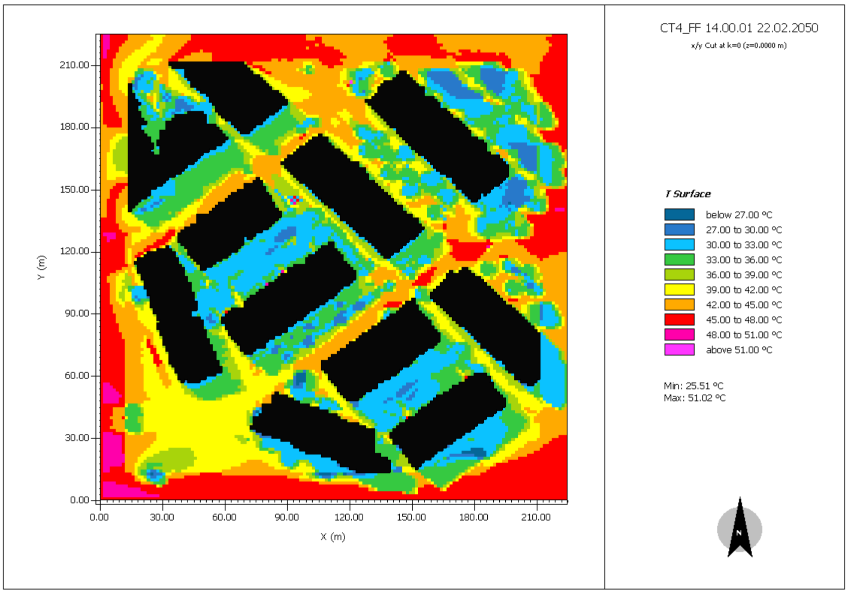


Figure 321. The surface temperature of CT4 at 14:00

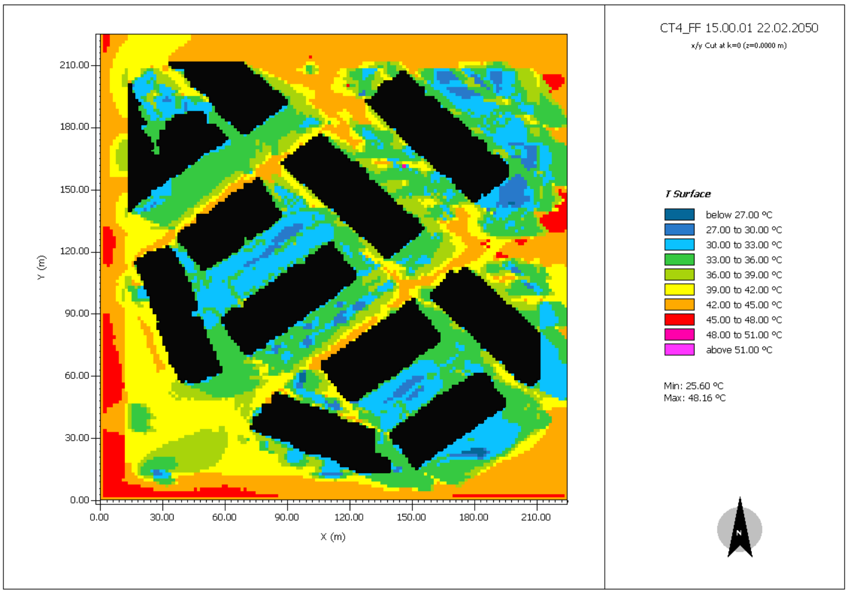


Figure 322. The surface temperature of CT4 at 15:00

The statistical results of all points versus time is depicted in Figure 323. Statistical analysis of simulation results for all simulation hours is tabulated in Table 54.

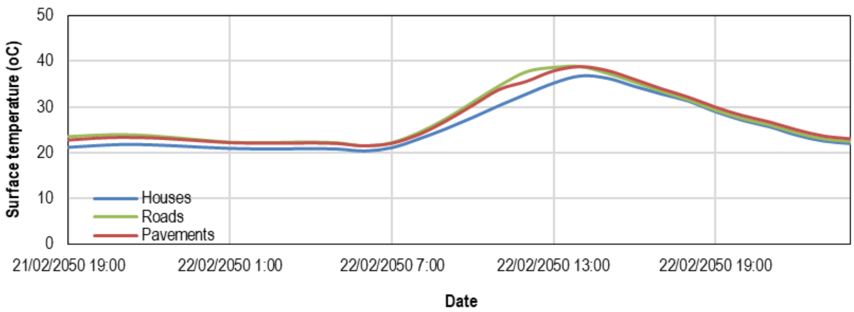


Figure 323. Surface temperature versus time for the various points

Table 54. The CT4 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	25.63	36.78	20.28
Roads	27.09	38.73	21.36
Pavements	27.26	38.91	21.39

CT5-Full forcing

Air temperature for CT5

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 324 and Figure 325 respectively. The maximum air temperature at 14:00 is equal to 35.73 °C, the minimum is equal to 24.66 °C and average is equal to 33.09°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (18.00m, 19.50m) (139.5m, 18.00m) (184.5m, 159.50m) and (18.00m, 174.00m) of the terrain. The maximum air temperature at 15:00 is equal to 35.16 °C, the minimum is equal to 24.22 °C and average is equal to 32.79°C. The temperature is also considerably decreased to the regions of water sprays.

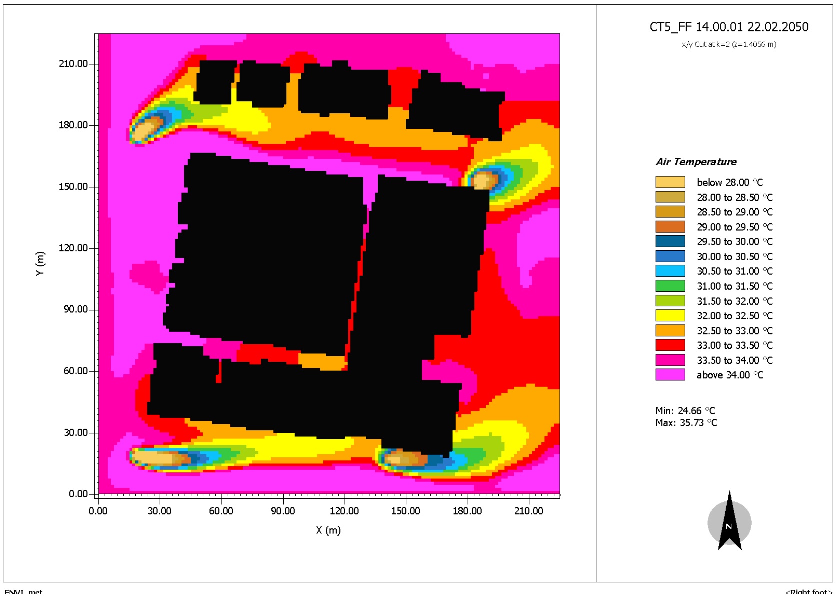


Figure 324. The air temperature of CT5 at 14:00

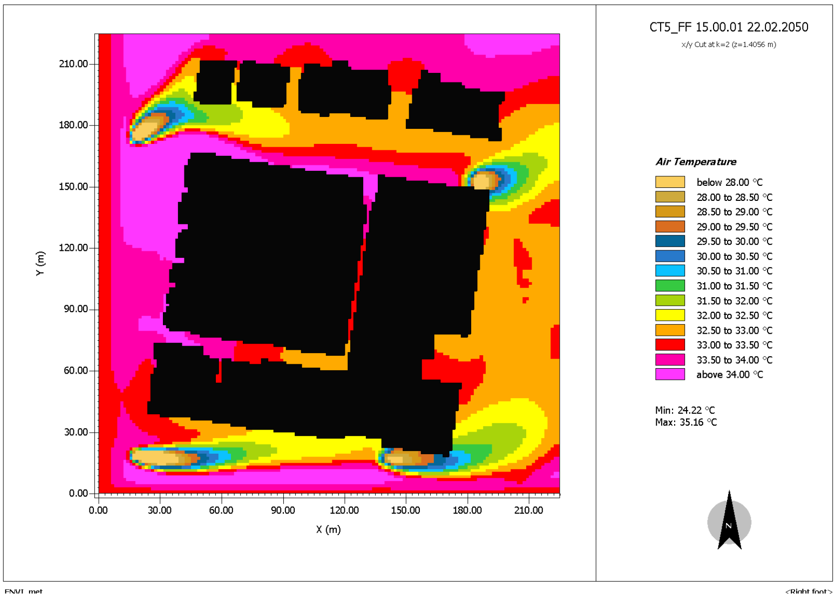


Figure 325. The air temperature of CT5 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements and roads are depicted in Figure 326, Figure 327, Figure 328 respectively. The same points are used for the statistical analysis of surface temperature.

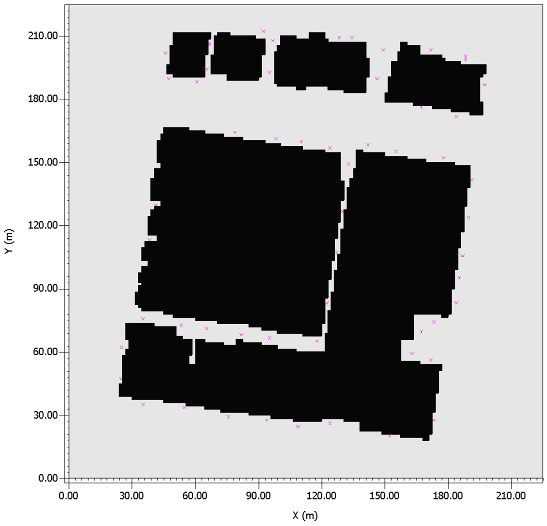


Figure 326. Points for the analysis of the air temperature close to houses

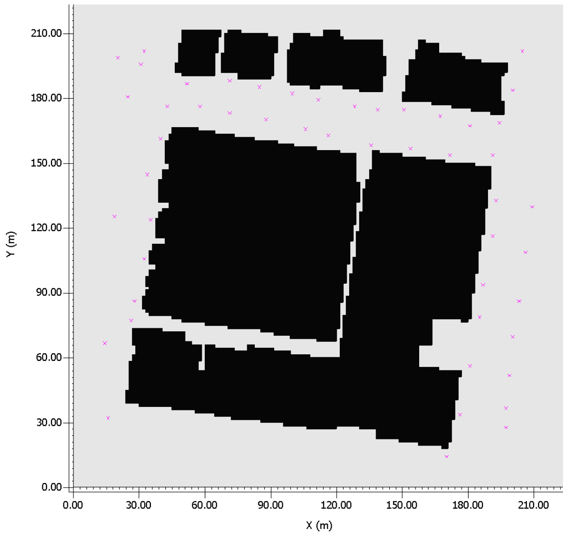


Figure 327. Points for the analysis of the air temperature close to pavements

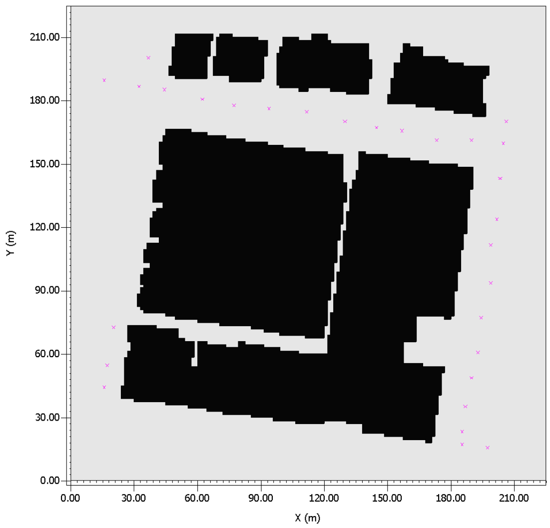


Figure 328. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 329. Statistical analysis of simulation results for all simulation hours is tabulated in Table 55.

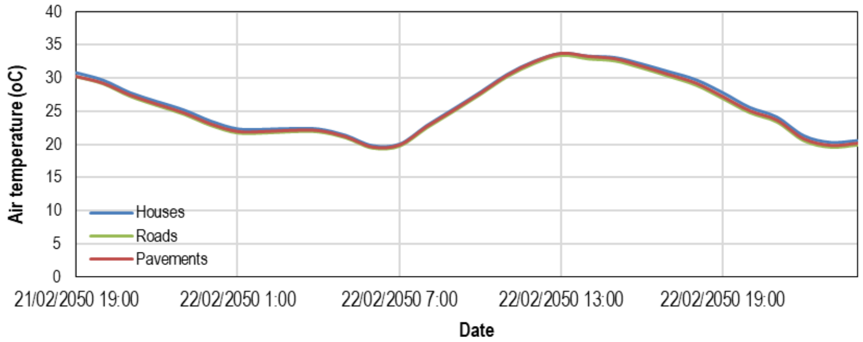


Figure 329. Air temperature versus time for the various points

Table 55. The CT5 statistical analysis of air temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	26.18	33.72	19.81
Roads	25.91	33.75	19.63
Pavements	25.59	33.37	19.39

Wind speed for CT5

The wind speed simulation results for CT5 and for 14:00 and 15:00 are depicted in Figure 330 and Figure 331 respectively. The maximum wind speed at 14:00 is 2.55 m/s close to the open area and the minimum is 0.02 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.58 m/s and the minimum is 0.02 m/s.

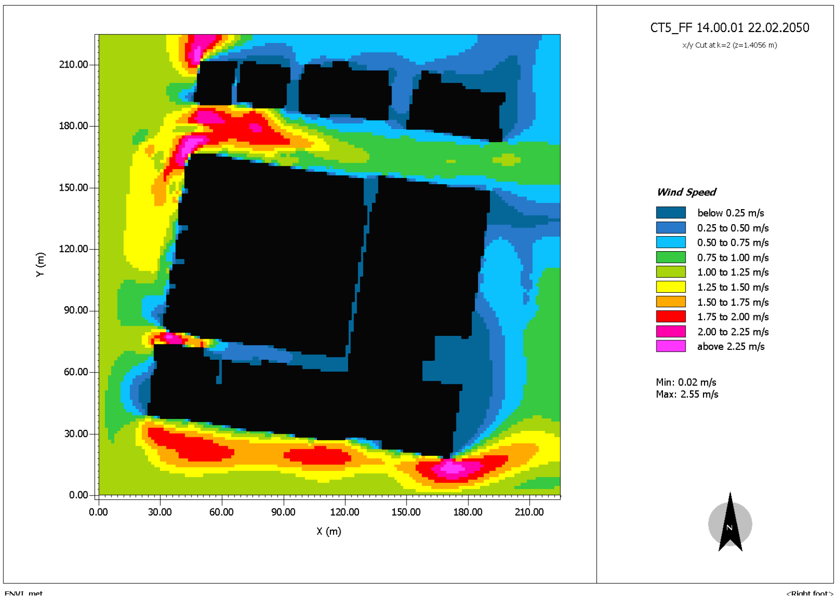


Figure 330. The wind speed of CT5 at 14:00

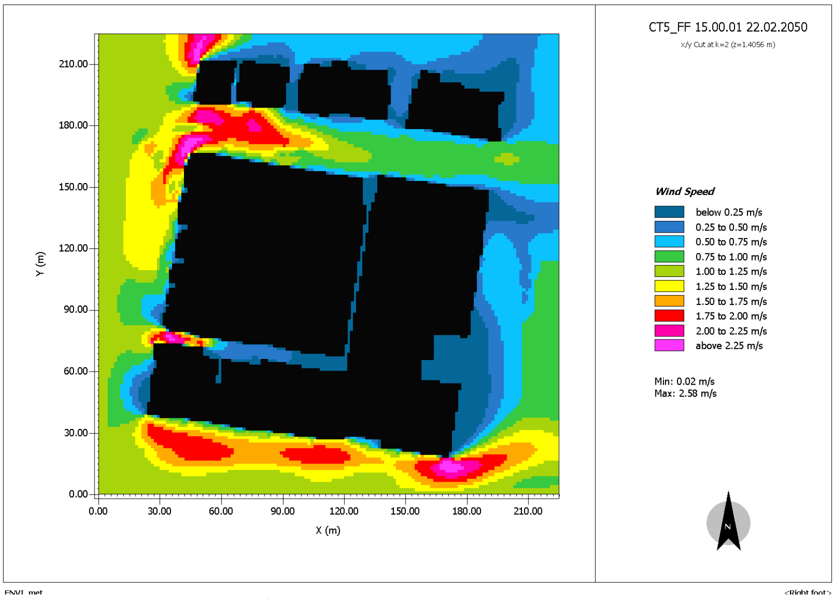


Figure 331. The wind speed of CT5 at 15:00

Surface temperature for CT5

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 332 and Figure 333 respectively. The maximum surface temperature at 14:00 is equal to 54.05 °C, the minimum is equal to 24.97 °C and average is equal to 37.01°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (18.00m, 19.50m) (139.5m, 18.00m) (184.5m, 159.50m) and (18.00m, 174.00m) of the terrain. The maximum air temperature at 15:00 is equal to 47.93 °C, the minimum is equal to 25.87 °C and average is equal to 36.66°C. The temperature is also considerably decreased to the regions of water sprays.

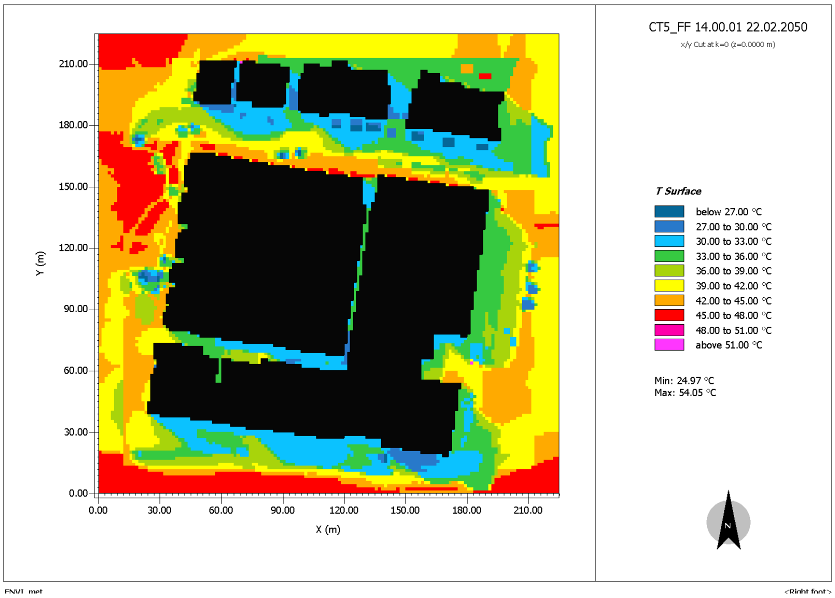


Figure 332. The surface temperature of CT5 at 14:00

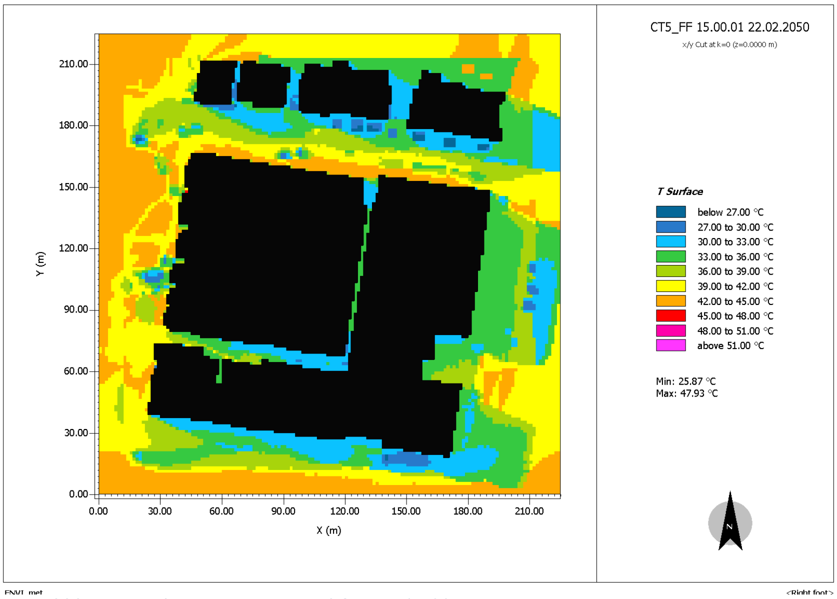


Figure 333. The surface temperature of CT5 at 15:00

The statistical results of all points versus time is depicted in Figure 334. Statistical analysis of simulation results for all simulation hours is tabulated in Table 56.

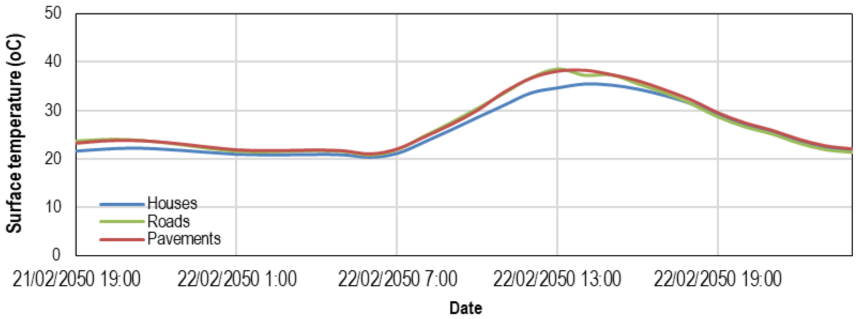


Figure 334. Surface temperature versus time for the various points

Table 56. The CT5 statistical analysis of surface temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	25.80	35.45	20.39
Roads	26.98	38.28	20.93
Pavements	26.83	38.63	20.81

CT6-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 335 and Figure 336 respectively. The maximum air temperature at 14:00 is equal to 35.44°C, the minimum is equal to 22.37°C and average is equal to 33.50°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (28.50m, 30.00m) (175.50m, 13.50m) (196.50m, 213.00m) and (88.50m, 213.00m) of the terrain.
The maximum air temperature at 15:00 is equal to 34.77 °C, the minimum is equal to 22.02 °C and average is equal to 31.99°C. The temperature is also considerably decreased to the regions of water sprays.

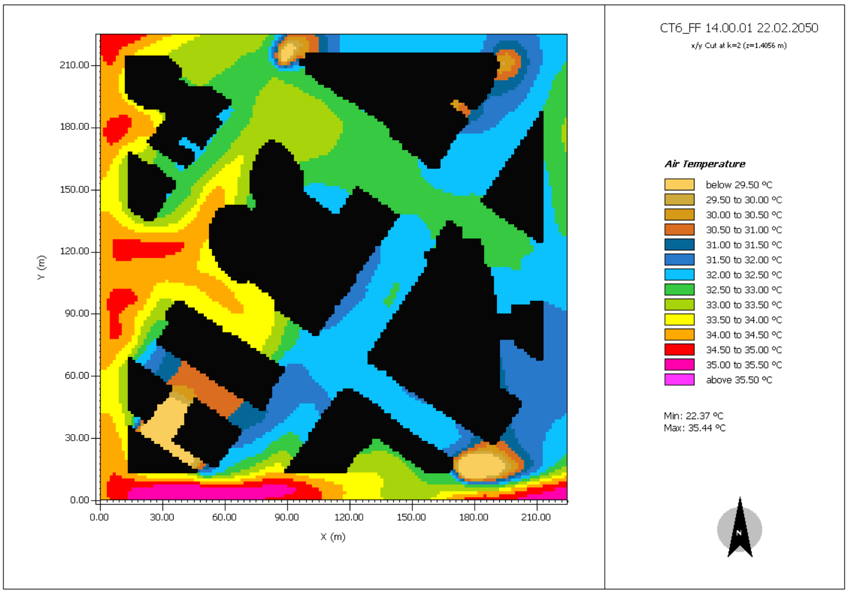


Figure 335. The air temperature of CT6 at 14:00

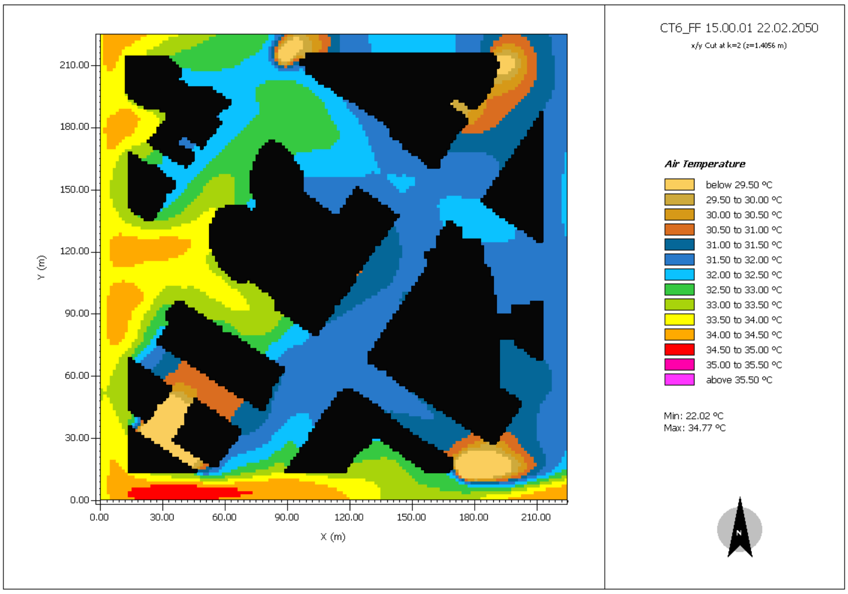


Figure 336. The air temperature of CT6 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 337, Figure 338 and Figure 339. The same points are used for the statistical analysis of surface temperature.

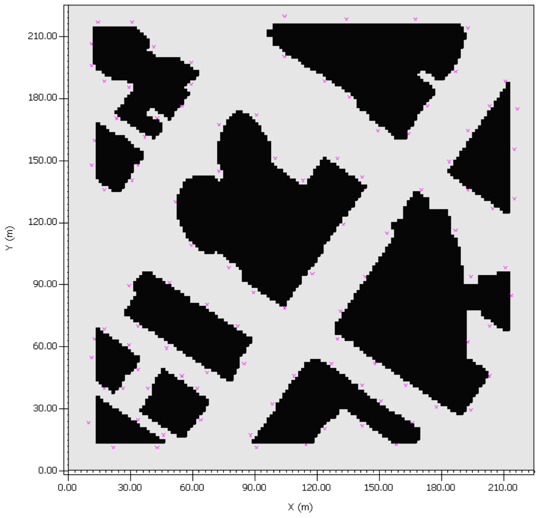


Figure 337. Points for the analysis of the air temperature close to houses

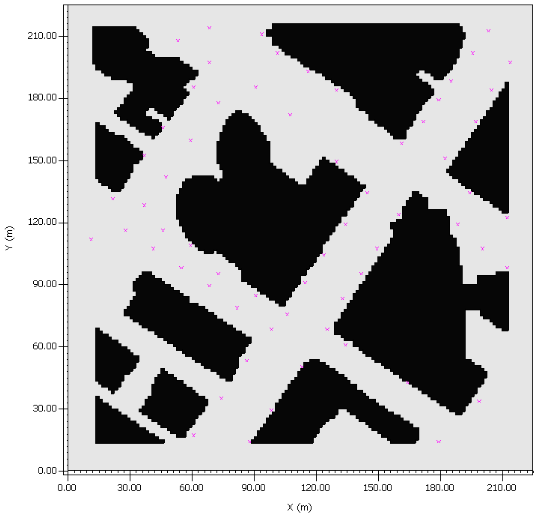


Figure 338. Points for the analysis of the air temperature close to pavements

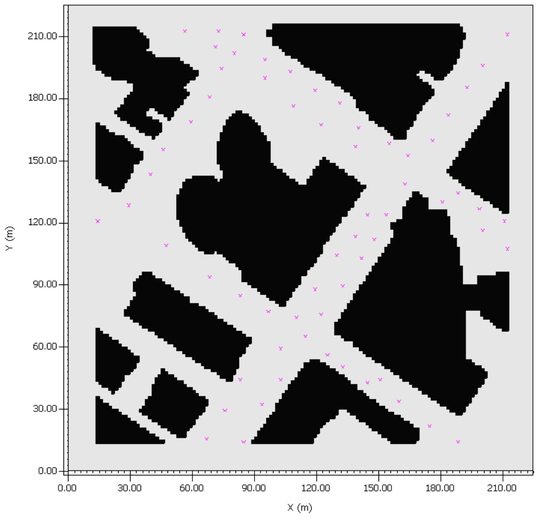


Figure 339. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 340. Statistical analysis of simulation results for all simulation hours is tabulated in Table 57.

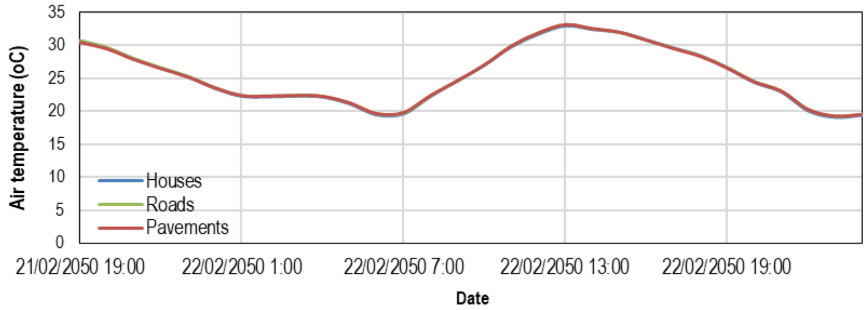


Figure 340. Air temperature versus time for the various points

Table 57. The CT6 statistical analysis of air temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	25.56	32.91	19.14
Roads	25.63	33.20	19.24
Pavements	25.67	33.14	19.29

Wind speed

The wind speed simulation results for CT6 and for 14:00 and 15:00 are depicted in Figure 341 and Figure 342. The maximum wind speed at 14:00 is 3.13 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 3.14 m/s and the minimum is 0.00 m/s.

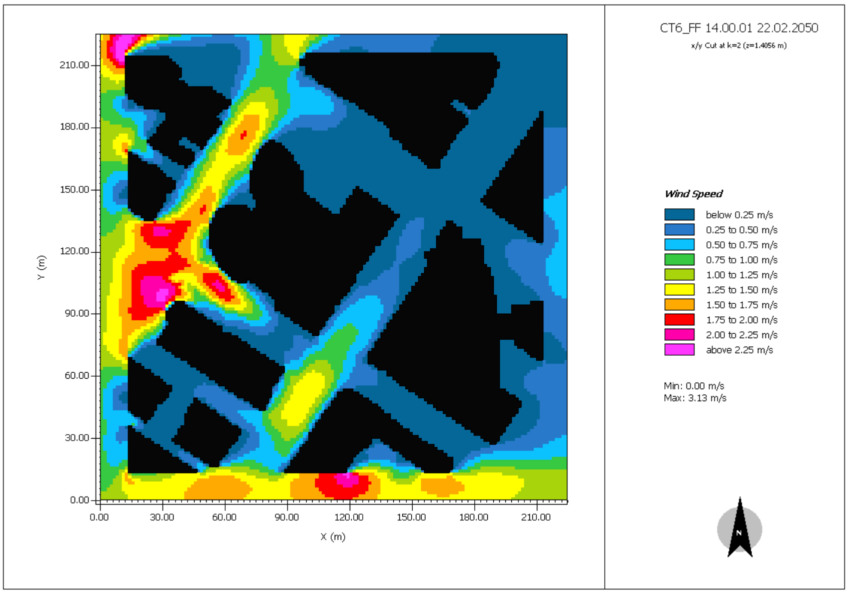


Figure 341. The wind speed of CT6 at 14:00

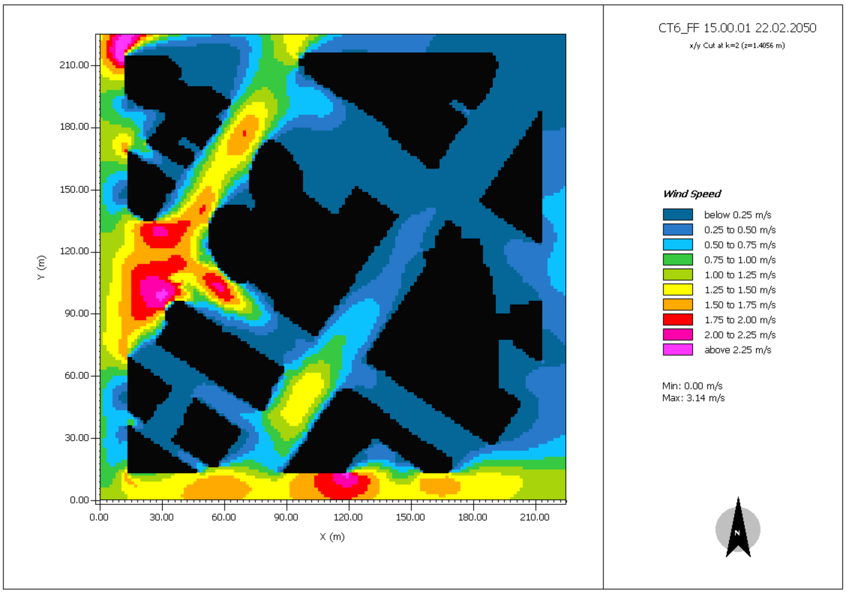


Figure 342. The wind speed of CT6 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 343 and Figure 344. The maximum surface temperature at 14:00 is equal to 52.74 °C, the minimum is equal to 22.21 °C and average is equal to 34.68°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (28.50m, 30.00m) (175.50m, 13.50m) (196.50m, 213.00m) and (88.50m, 213.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 45.88 °C, the minimum is equal to 22.07 °C and average is equal to 34.13°C. The temperature is also considerably decreased to the regions of water sprays.

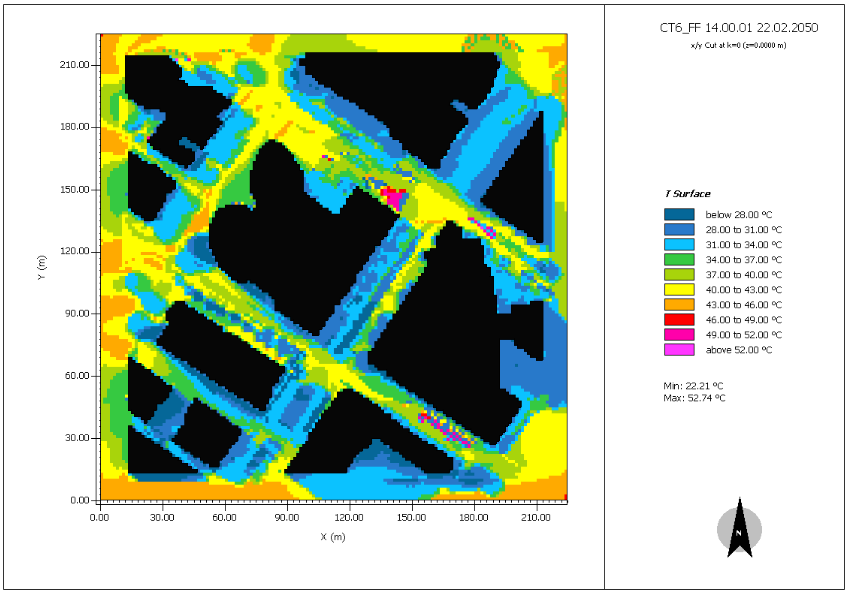


Figure 343. The surface temperature of CT6 at 14:00

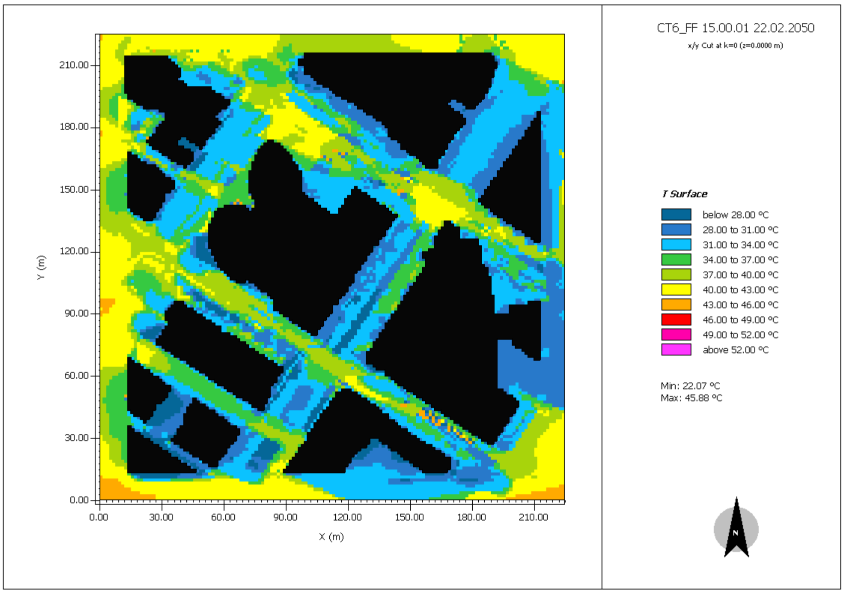


Figure 344. The surface temperature of CT6 at 15:00

The statistical results of all points versus time is depicted in Figure 345. Statistical analysis of simulation results for all simulation hours is tabulated in Table 58.

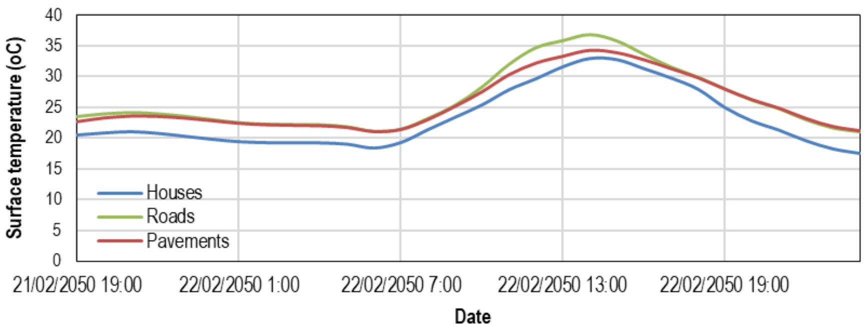


Figure 345. Surface temperature versus time for the various points

Table 58. The CT6 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	23.24	32.95	17.59
Roads	25.66	34.28	21.02
Pavements	26.21	36.81	20.97

CT7-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 346 and Figure 347 respectively. The maximum air temperature at 14:00 is equal to 34.28°C, the minimum is equal to 27.34°C and average is equal to 32.48°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (40.50m, 64.50m) (175.50m, 43.50m) (166.50m, 213.00m) and (60.00m, 217.00m) of the terrain. The maximum air temperature at 15:00 is equal to 33.89 °C, the minimum is equal to 26.91 °C and average is equal to 32.32°C. The temperature is also considerably decreased to the regions of water sprays.

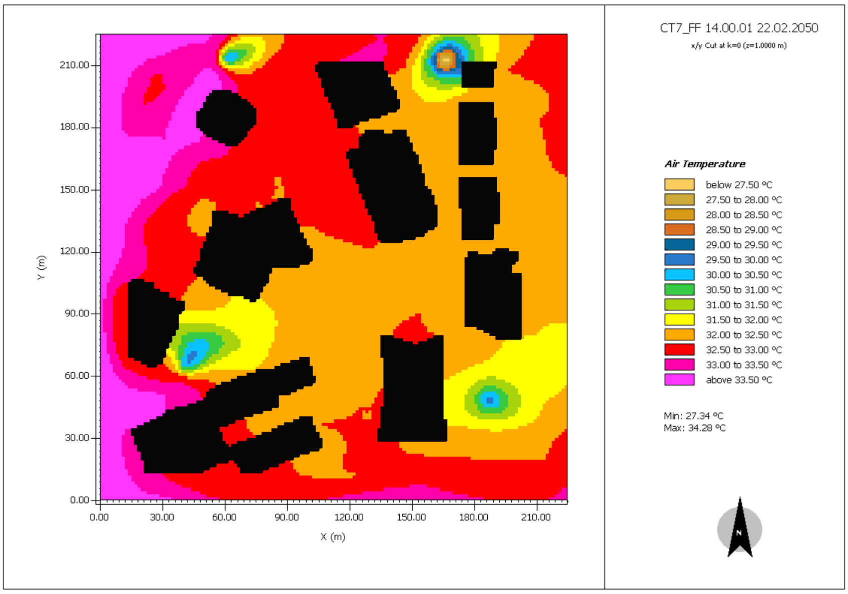


Figure 346. The air temperature of CT7 at 14:00

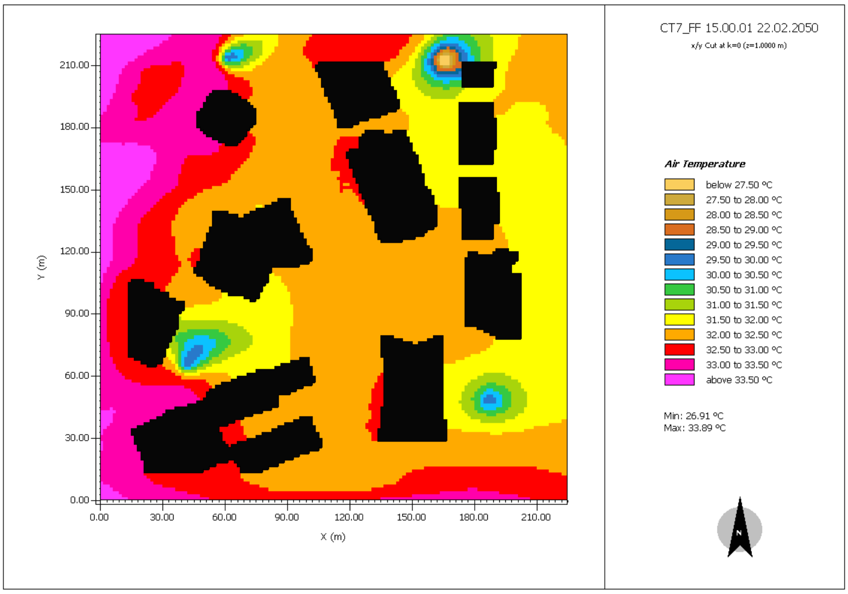


Figure 347. The air temperature of CT7 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 348, Figure 349 and Figure 350. The same points are used for the statistical analysis of surface temperature.

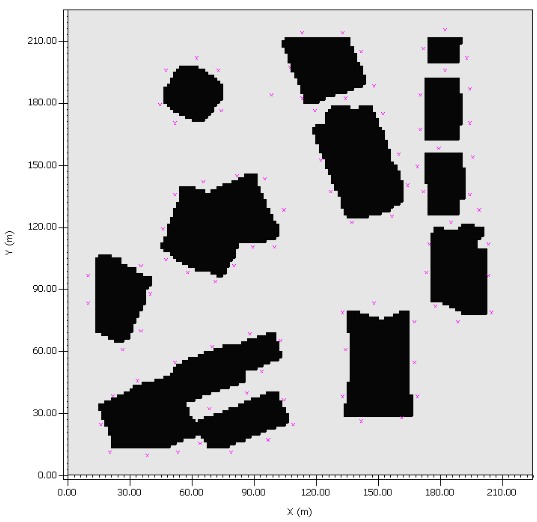


Figure 348. Points for the analysis of the air temperature close to houses

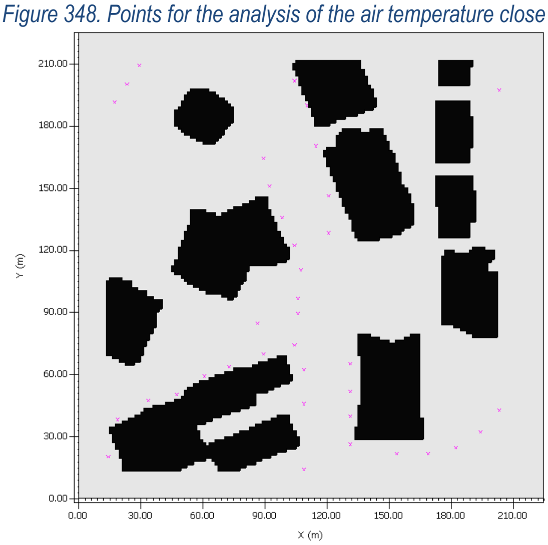


Figure 349. Points for the analysis of the air temperature close to pavements

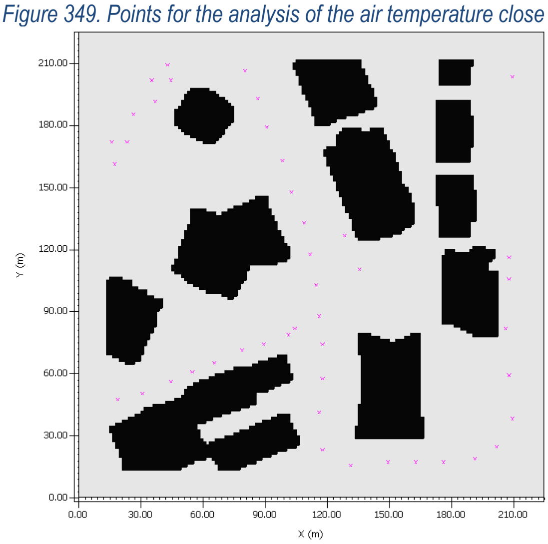


Figure 350. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 351. Statistical analysis of simulation results for all simulation hours is tabulated in Table 59.

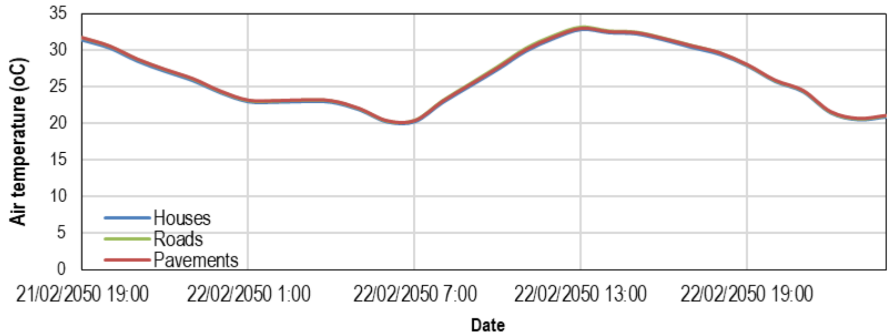


Figure 351. Air temperature versus time for the various points

Table 59. The CT7 statistical analysis of air temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	26.27	32.84	20.24
Roads	26.41	32.95	20.33
Pavements	26.43	33.09	20.31

Wind speed

The wind speed simulation results for CT7 and for 14:00 and 15:00 are depicted in Figure 352 and Figure 353 respectively. The maximum wind speed at 14:00 is 2.80 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.81 m/s and the minimum is 0.00 m/s.

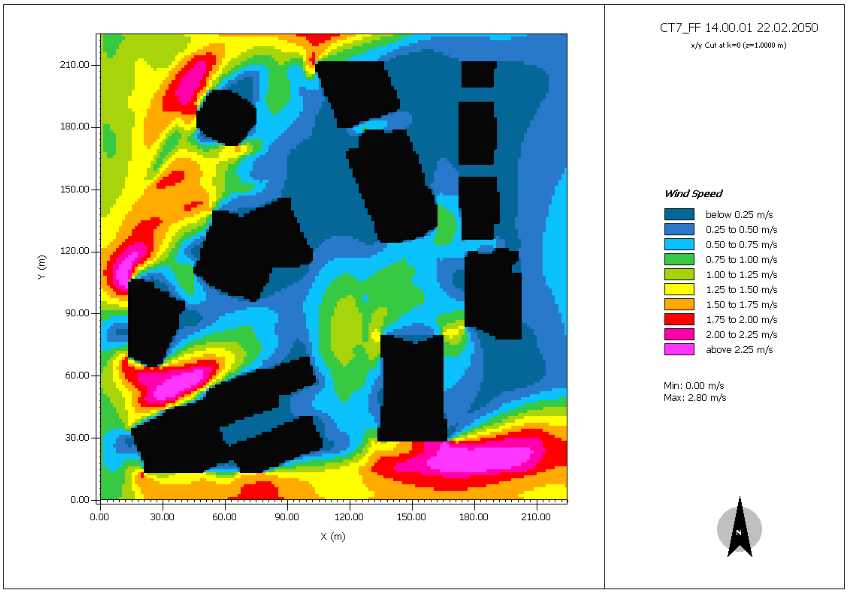


Figure 352. The wind speed of CT7 at 14:00

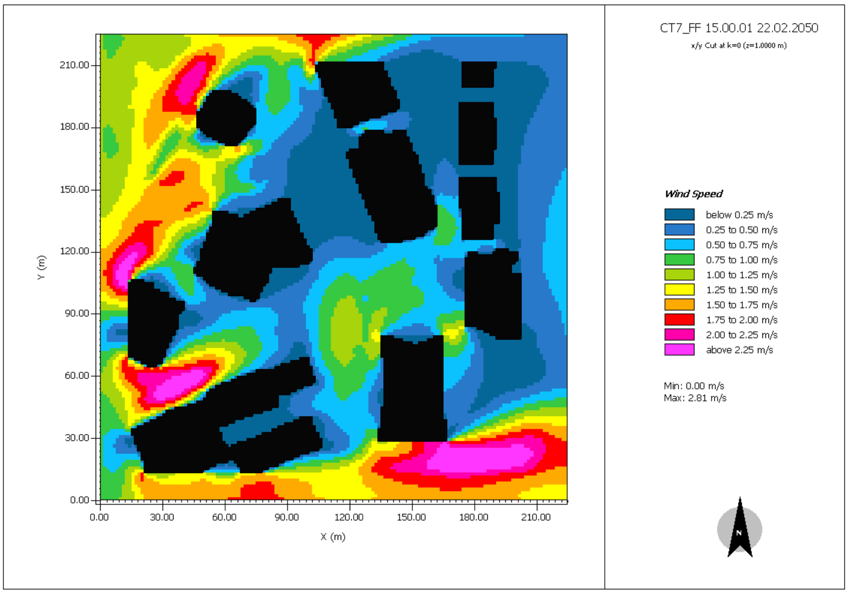


Figure 353. The wind speed of CT7 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 354 and Figure 355. The maximum surface temperature at 14:00 is equal to 51.43 °C, the minimum is equal to 23.91 °C and average is equal to 35.57°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (40.50m, 64.50m) (175.50m, 43.50m) (166.50m, 213.00m) and (60.00m, 217.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 47.43 °C, the minimum is equal to 24.25 °C and average is equal to 35.41°C. The temperature is also considerably decreased to the regions of water sprays.

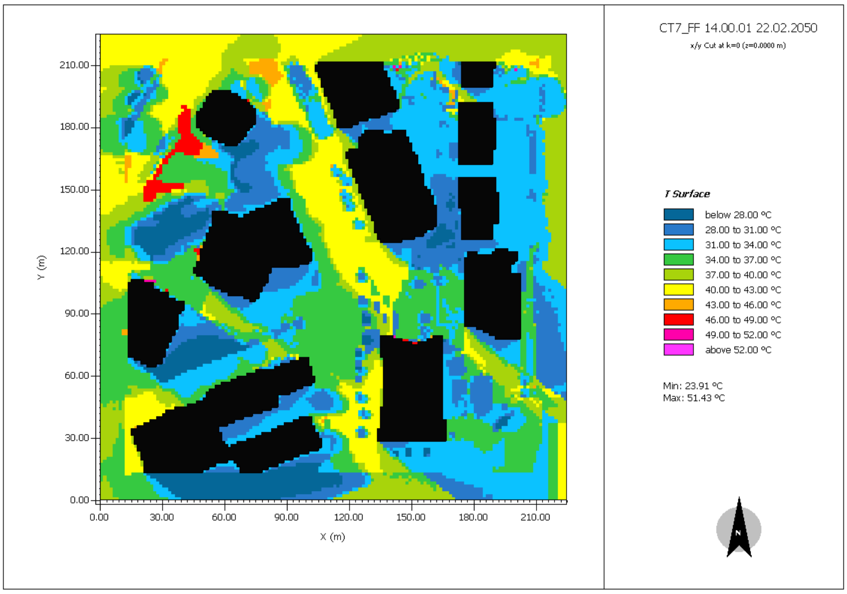


Figure 354. The surface temperature of CT7 at 14:00

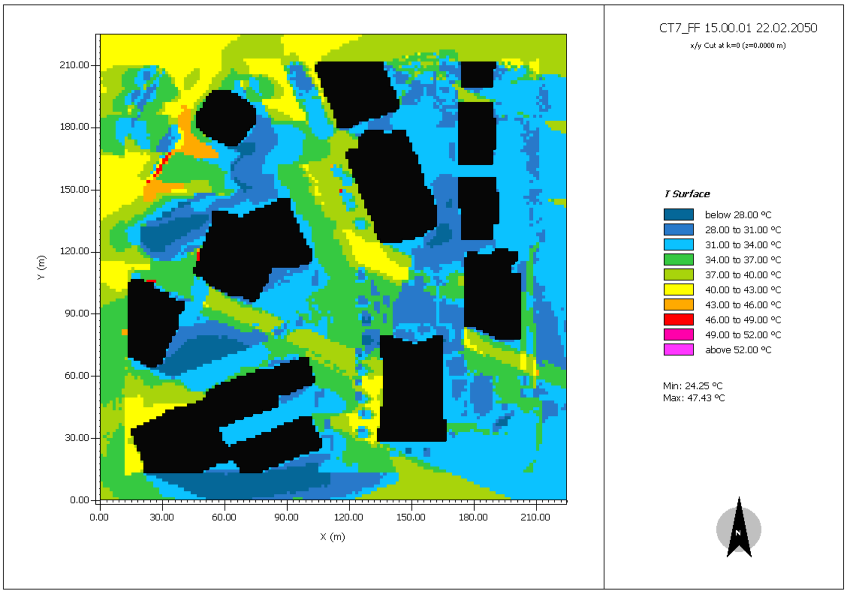


Figure 355. The surface temperature of CT7 at 15:00

The statistical results of all points versus time is depicted in Figure 356. Statistical analysis of simulation results for all simulation hours is tabulated in Table 60.

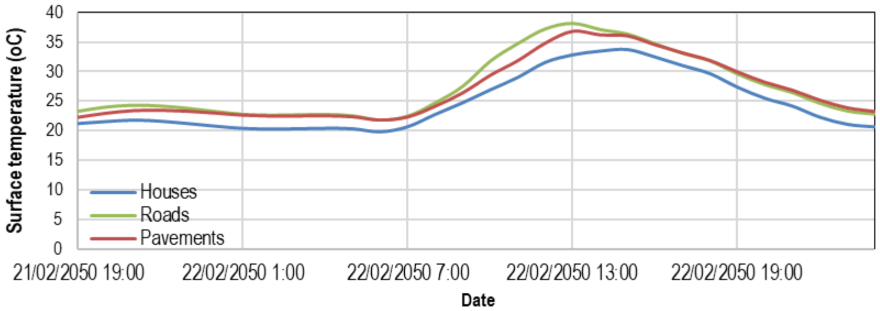


Figure 356. Surface temperature versus time for the various points

Table 60. The CT7 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	24.69	33.68	19.90
Roads	26.99	36.87	21.89
Pavements	27.37	38.08	21.79

OT1-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 357 and Figure 358 respectively. The maximum air temperature at 14:00 is equal to 34.77°C, the minimum is equal to 27.31°C and average is equal to 33.54°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (48.00m, 57.00m) (159.50m, 28.50m) (181.50m, 214.50m) and (81.00m, 217.50m) of the terrain. The maximum air temperature at 15:00 is equal to 34.67 °C, the minimum is equal to 28.82 °C and average is equal to 33.38°C. The temperature is also considerably decreased to the regions of water sprays.

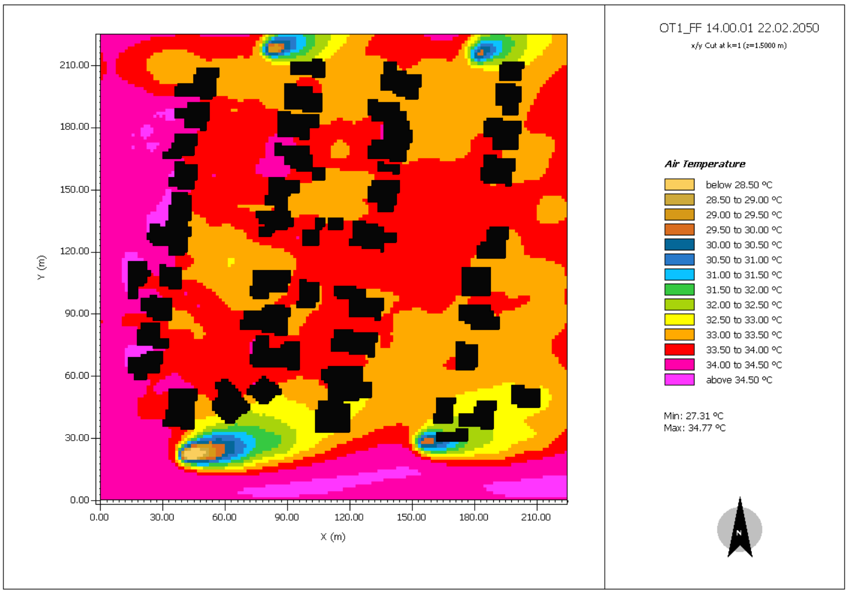


Figure 357. The air temperature of OT1 at 14:00

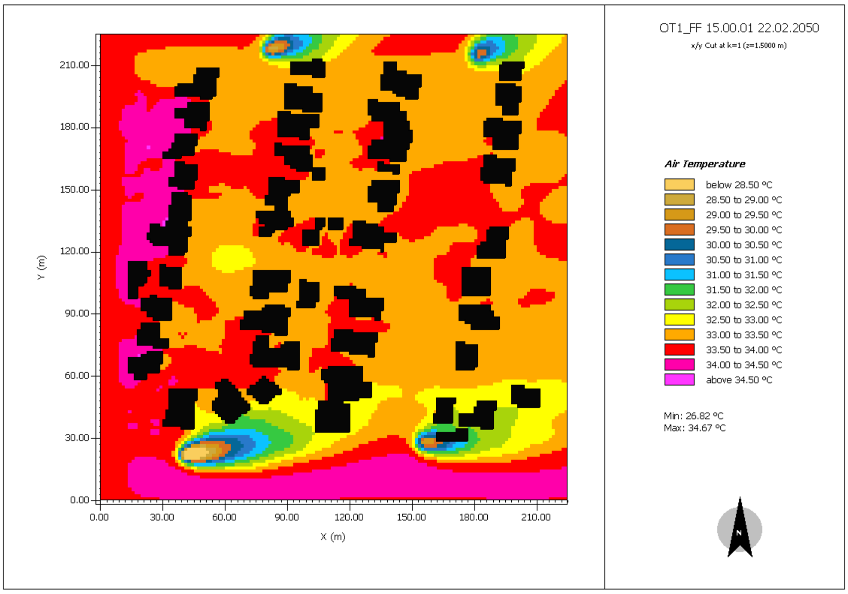


Figure 358. The air temperature of OT1 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 359, Figure 360 and Figure 361 respectively. The same points are used for the statistical analysis of surface temperature.

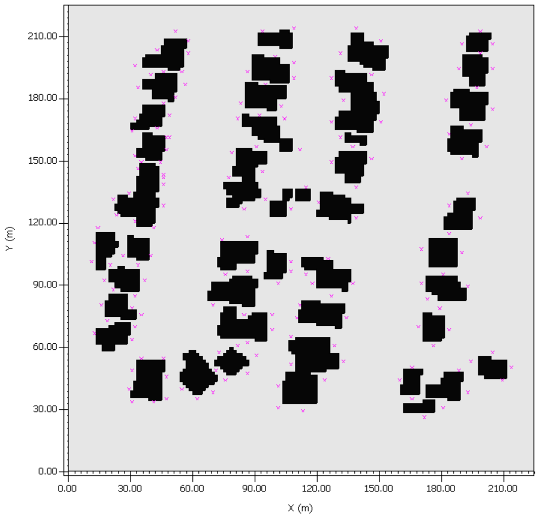


Figure 359. Points for the analysis of the air temperature close to houses

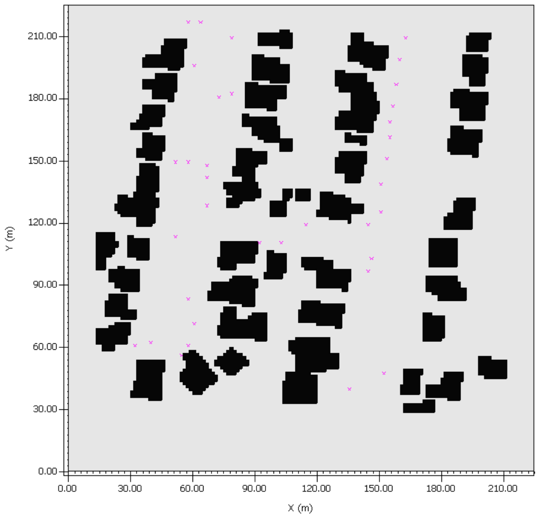


Figure 360. Points for the analysis of the air temperature close to pavements

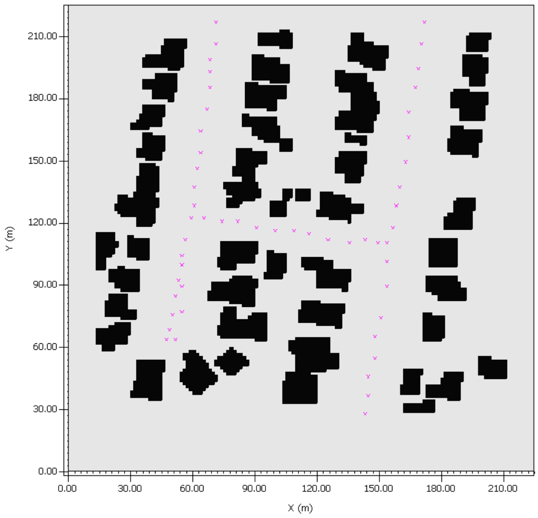


Figure 361. Points for the analysis of the air temperature close to road

The statistical results of all points versus time is depicted in Figure 362. Statistical analysis of simulation results for all simulation hours is tabulated in Table 61.

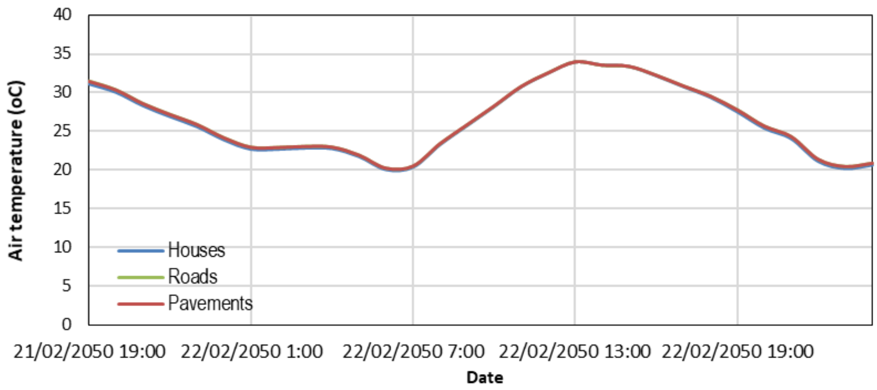


Figure 362. Air temperature versus time for the various points

Table 61. The OT1 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.42	33.96	20.11
Roads	26.61	33.98	20.31
Pavements	26.62	33.97	20.32

Wind speed

The wind speed simulation results for OT1 and for 14:00 and 15:00 are depicted in Figure 363 and Figure 364. The maximum wind speed at 14:00 is 1.81 m/s close to the open area and the minimum is 0.01 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.81 m/s and the minimum is 0.01 m/s.

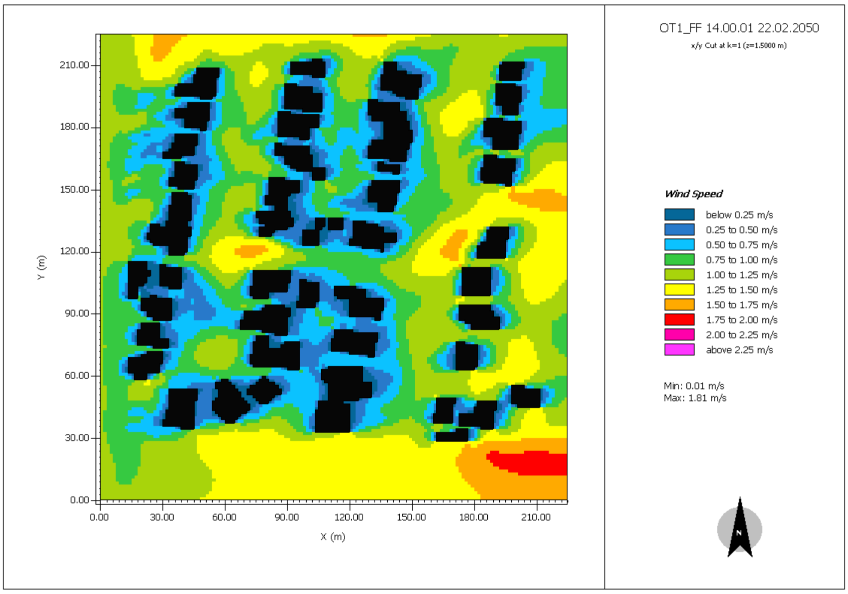


Figure 363. The wind speed of OT1 at 14:00

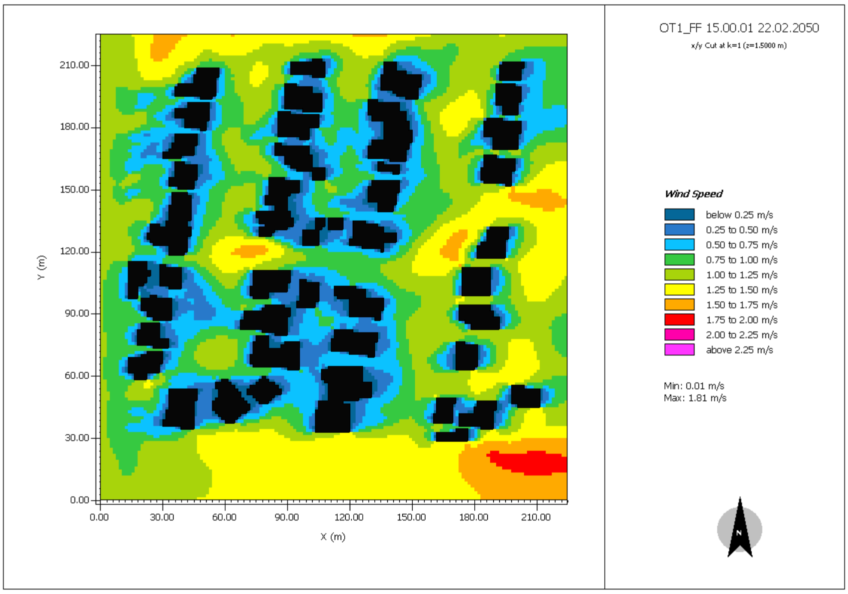


Figure 364. The wind speed of OT1 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 365 and Figure 366 respectively. The maximum surface temperature at 14:00 is equal to 49.36 °C, the minimum is equal to 21.37 °C and average is equal to 38.43°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (48.00m, 57.00m) (159.50m, 28.50m) (181.50m, 214.50m) and (81.00m, 217.50m) of the terrain. The maximum surface temperature at 15:00 is equal to 53.78 °C, the minimum is equal to 21.17 °C and average is equal to 37.28°C. The temperature is also considerably decreased to the regions of water sprays.

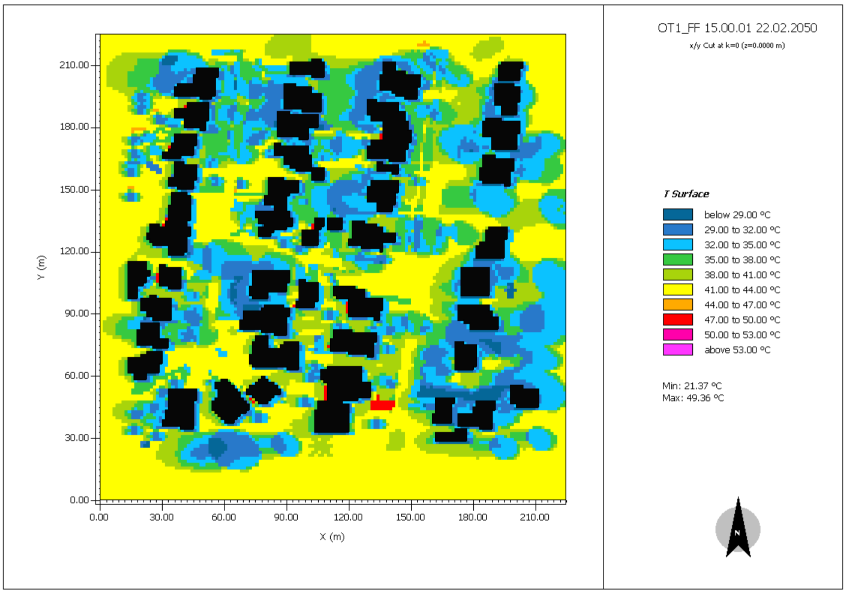


Figure 365. The surface temperature of OT1 at 14:00

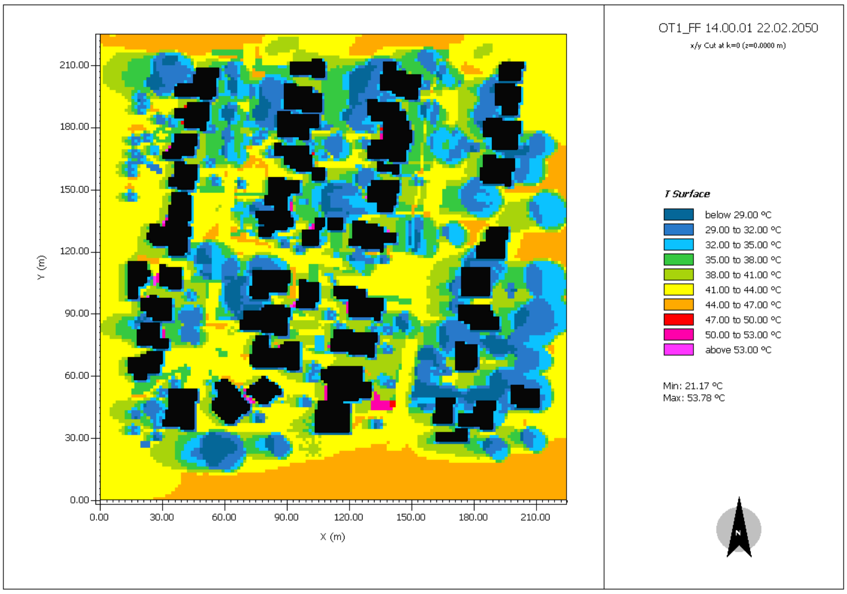


Figure 366. The surface temperature of OT1 at 15:00

The statistical results of all points versus time is depicted in Figure 367. Statistical analysis of simulation results for all simulation hours is tabulated in Table 62.

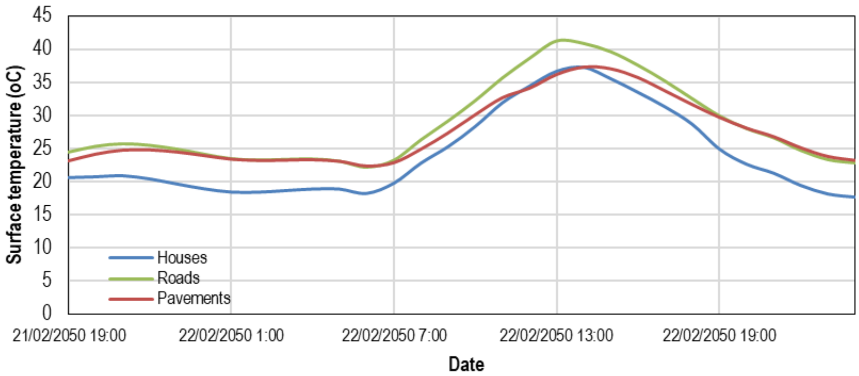


Figure 367. Surface temperature versus time for the various points

Table 62. The OT1 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	24.03	37.21	17.62
Roads	27.43	37.28	22.31
Pavements	28.52	41.21	22.17

OT2-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 368 and Figure 369 respectively. The maximum air temperature at 14:00 is equal to 34.49°C, the minimum is equal to 24.16°C and average is equal to 33.20°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (15.00m, 15.00m) (211.50m, 7.50m) (219.00m, 165.50m) and (18.00m, 180.00m) of the terrain. The maximum air temperature at 15:00 is equal to 34.11 °C, the minimum is equal to 28.08 °C and average is equal to 23.66°C. The temperature is also considerably decreased to the regions of water sprays.

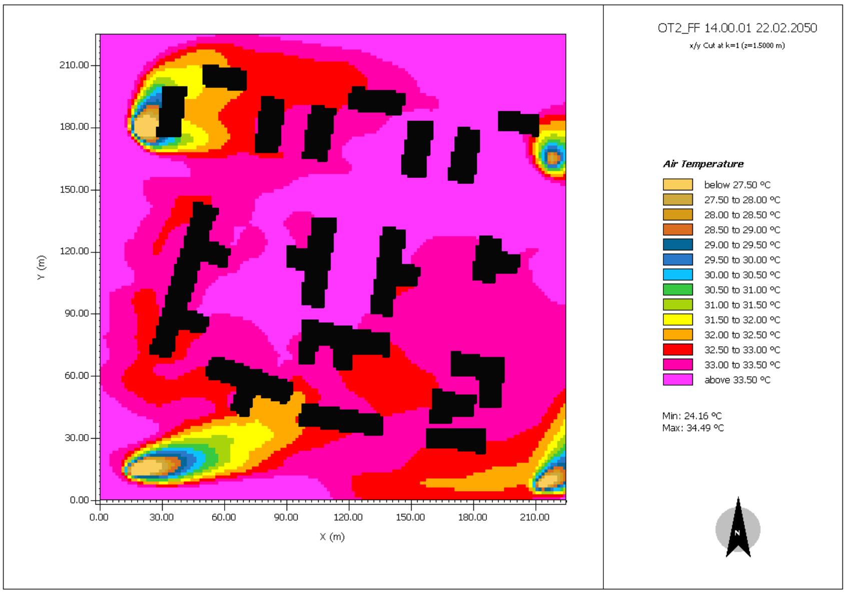


Figure 368. The air temperature of OT2 at 14:00

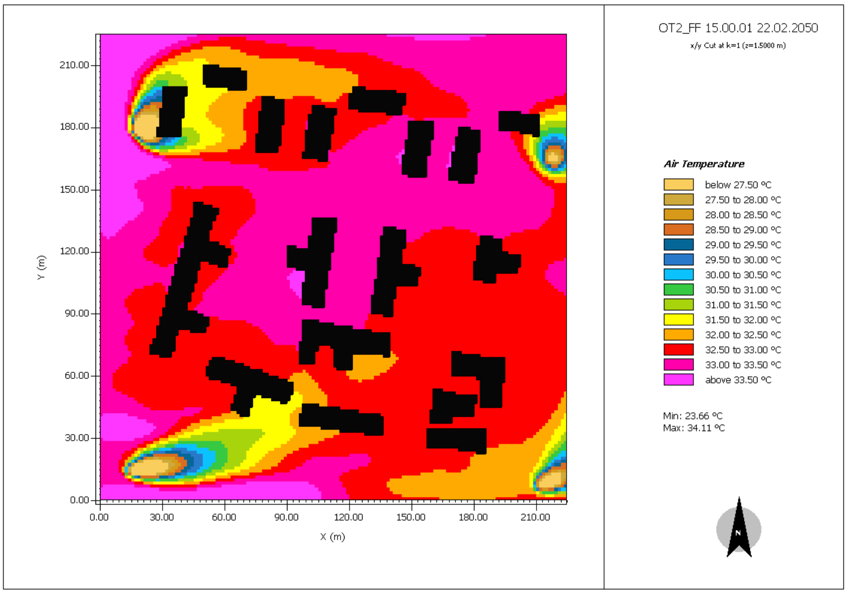


Figure 369. The air temperature of OT2 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 370, Figure 371, Figure 372 respectively. The same points are used for the statistical analysis of surface temperature.

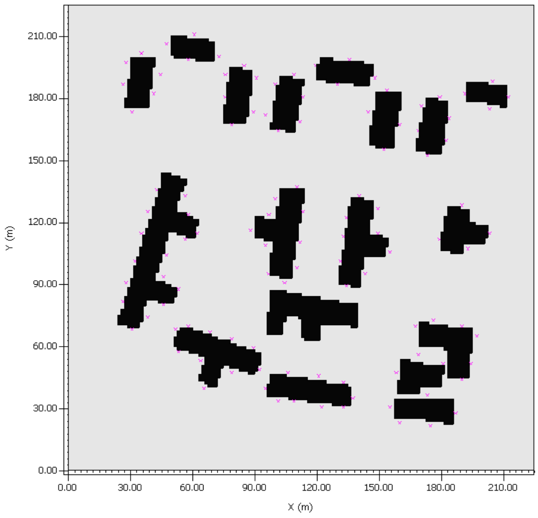


Figure 370. Points for the analysis of the air temperature close to houses

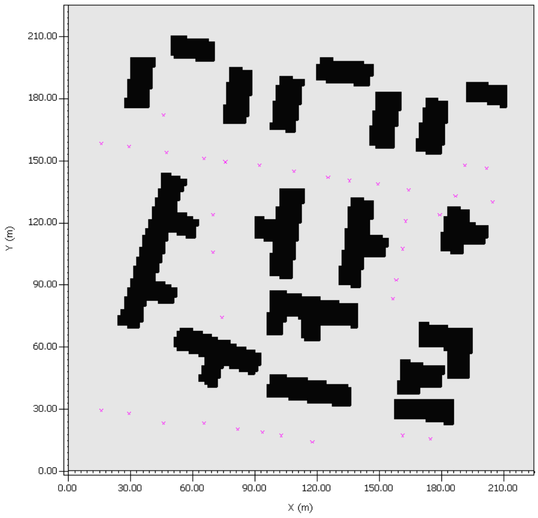


Figure 371. Points for the analysis of the air temperature close to pavements

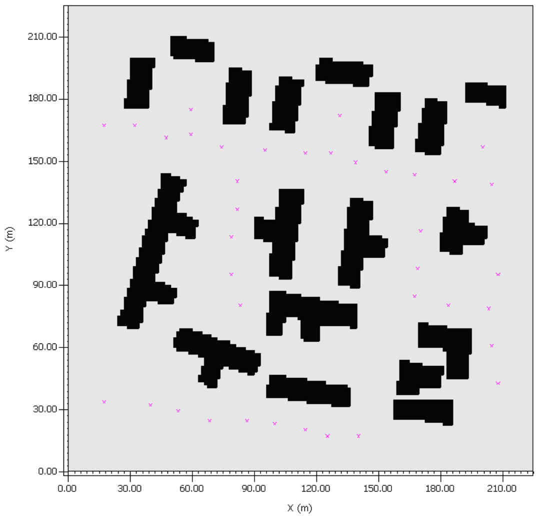


Figure 372. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 373. Statistical analysis of simulation results for all simulation hours is tabulated in Table 63.

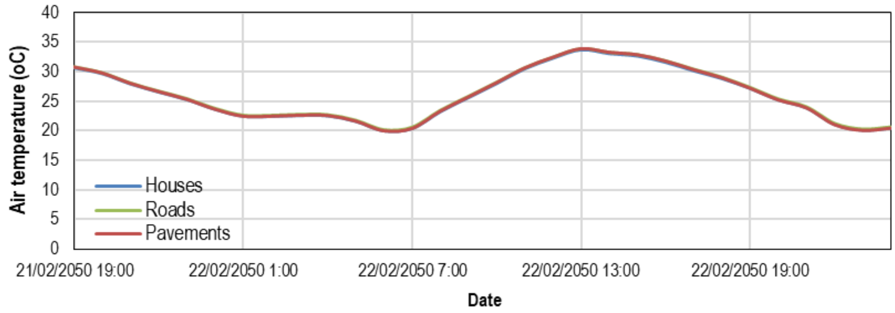


Figure 373. Air temperature versus time for the various points

Table 63. The OT2 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.11	33.73	19.98
Roads	26.18	33.84	20.03
Pavements	26.27	33.94	20.09

Wind speed

The wind speed simulation results for OT2 and for 14:00 and 15:00 are depicted in Figure 374 and Figure 375 respectively. The maximum wind speed at 14:00 is 1.95 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.93 m/s and the minimum is 0.00 m/s.

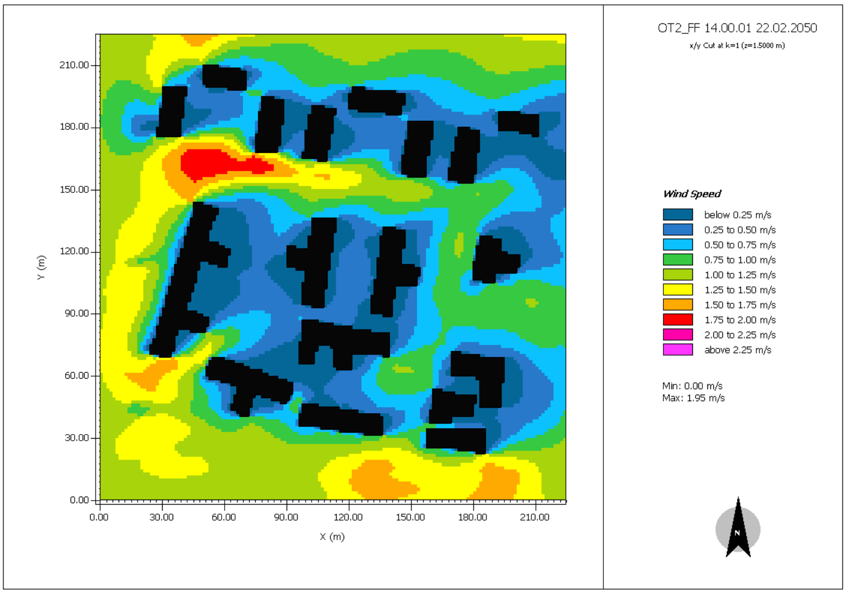


Figure 374. The wind speed of OT2 at 14:00

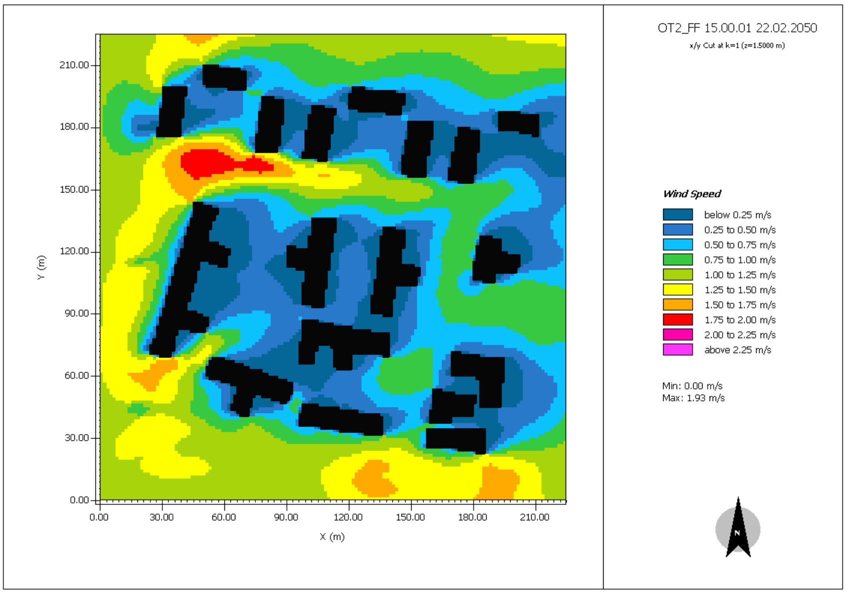


Figure 375. The wind speed of OT2 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 376 and Figure 377 respectively. The maximum surface temperature at 14:00 is equal to 53.25 °C, the minimum is equal to 23.65 °C and average is equal to 37.16°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (15.00m, 15.00m) (211.50m, 7.50m) (219.00m, 165.50m) and (18.00m, 180.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 47.58 °C, the minimum is equal to 24.09 °C and average is equal to 36.43°C. The temperature is also considerably decreased to the regions of water sprays.

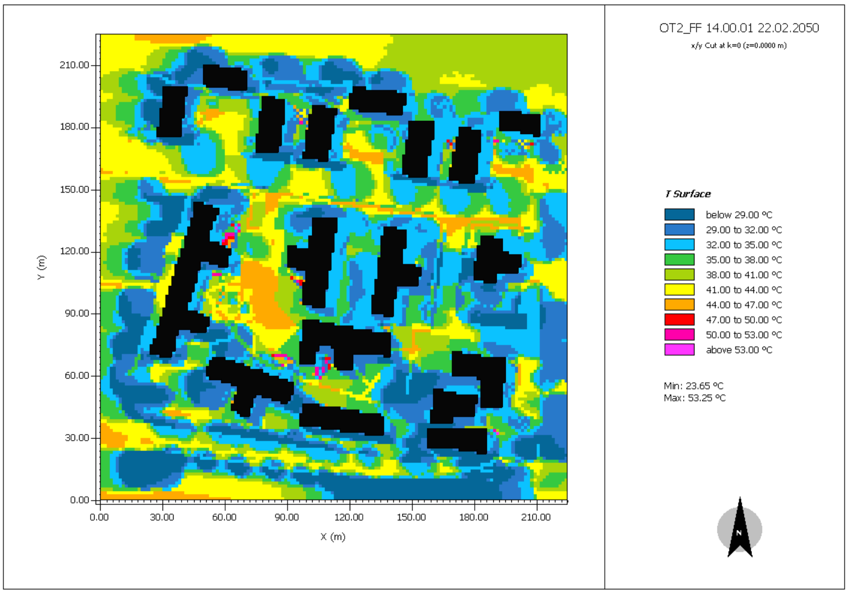


Figure 376. The surface temperature of OT2 at 14:00

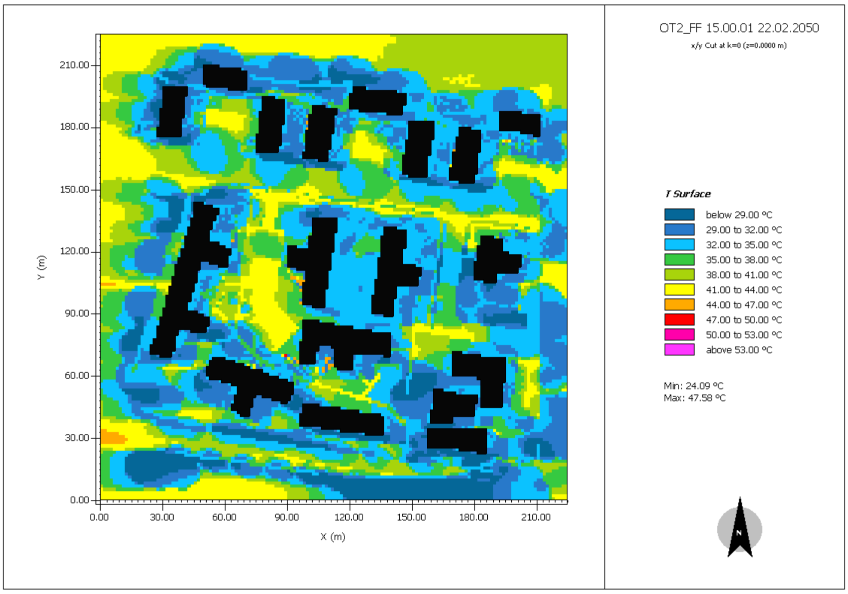


Figure 377. The surface temperature of OT2 at 15:00

The statistical results of all points versus time is depicted in Figure 378. Statistical analysis of simulation results for all simulation hours is tabulated in Table 64.

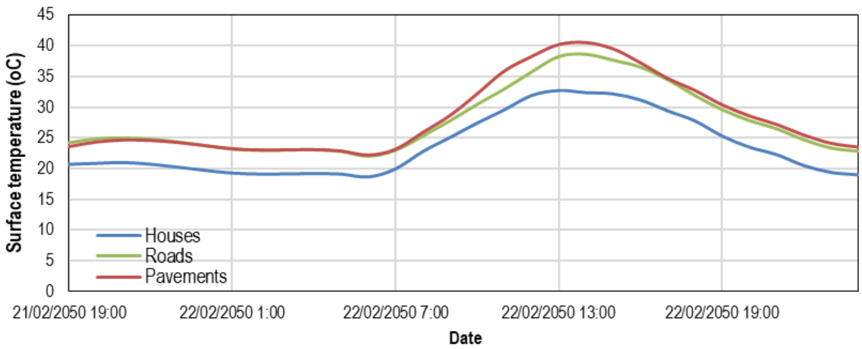


Figure 378. Surface temperature versus time for the various points

Table 64. The OT2 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	23.65	32.73	18.62
Roads	28.36	40.48	22.23
Pavements	27.77	38.63	22.10

OT3-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 379 and Figure 380 respectively. The maximum air temperature at 14:00 is equal to 34.5 °C, the minimum is equal to 24.45 °C and average is equal to 33.39°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (46.50m, 30.00m) (186.00m, 36.00m) (208.50m, 187.50m and (25.50m, 198.00m) of the terrain. The maximum air temperature at 15:00 is equal to 34.3 °C, the minimum is equal to 24.18 °C and average is equal to 33.11°C. The temperature is also considerably decreased to the regions of water sprays.

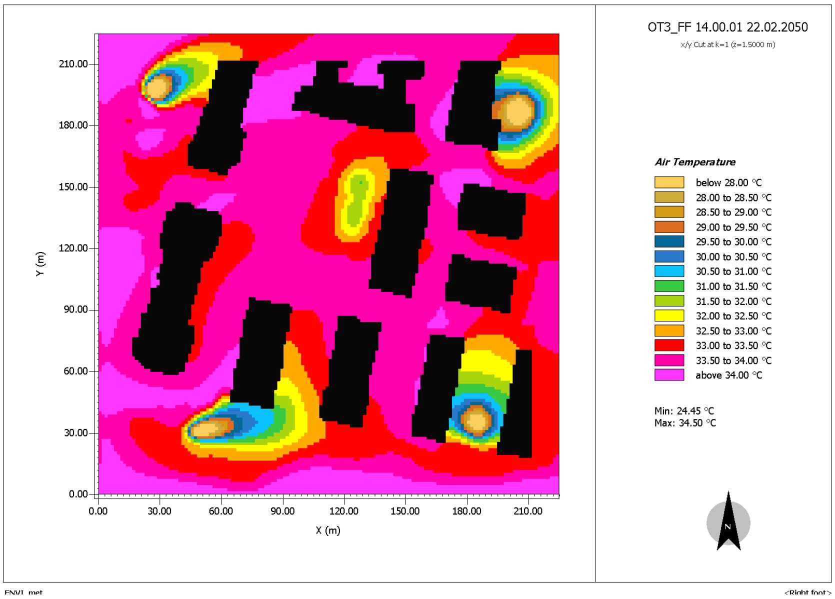


Figure 379. The air temperature of OT3 at 14:00

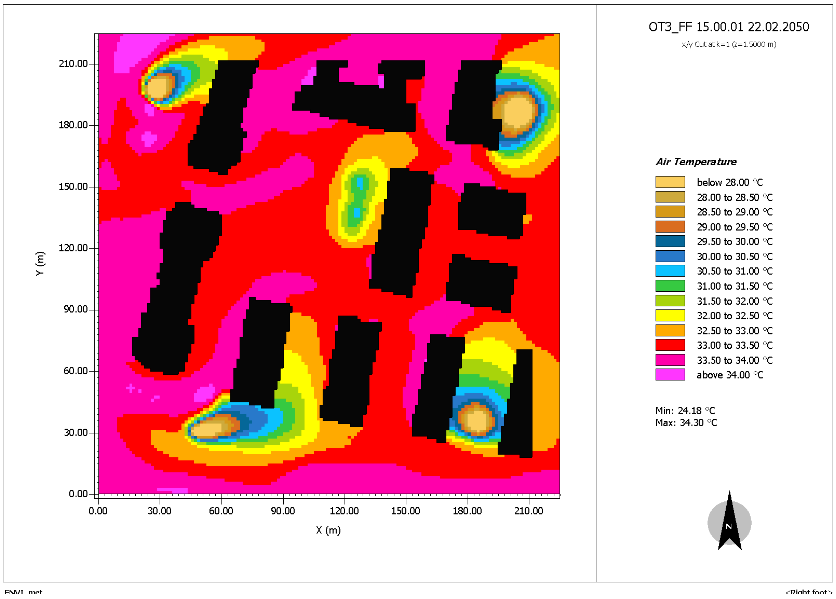


Figure 380. The air temperature of OT3 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements and roads are depicted in Figure 381, Figure 382, Figure 383 respectively. The same points are used for the statistical analysis of surface temperature.

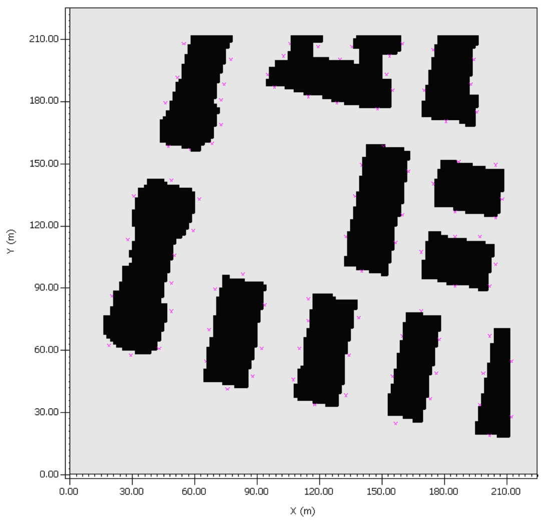


Figure 381. Points for the analysis of the air temperature close to houses

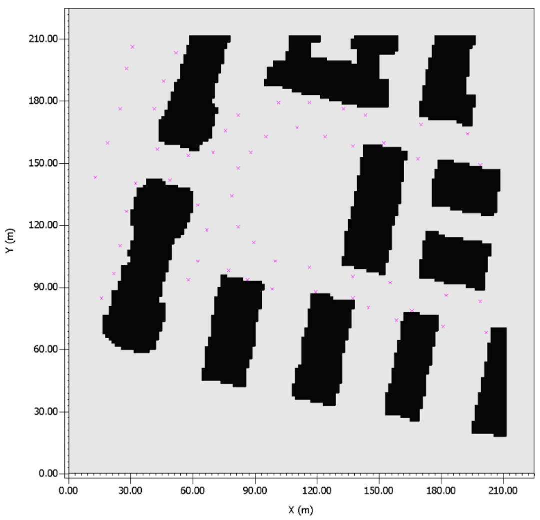


Figure 382. Points for the analysis of the air temperature close to pavements

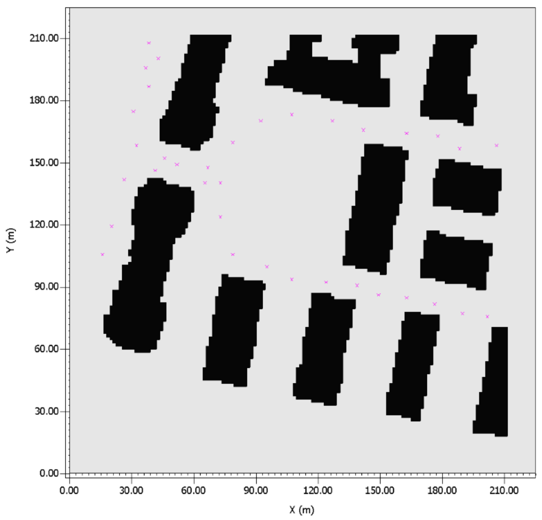


Figure 383. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 384. Statistical analysis of simulation results for all simulation hours is tabulated in Table 65.

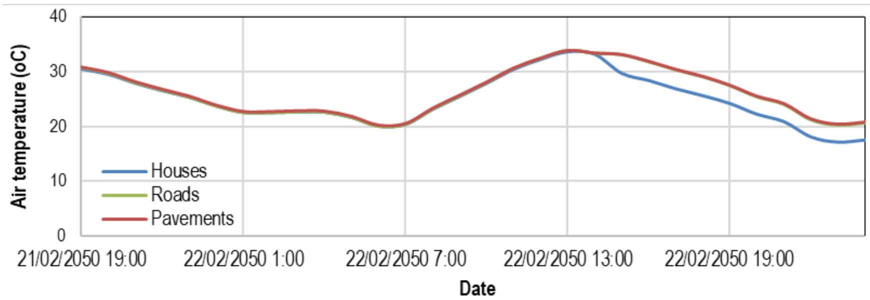


Figure 384. Air temperature versus time for the various points

Table 65. The OT3 statistical analysis of air temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	25.04	33.65	17.07
Roads	26.29	33.87	20.13
Pavements	26.28	33.91	20.09

Wind speed

The wind speed simulation results for OT3 and for 14:00 and 15:00 are depicted in Figure 385 and Figure 386 respectively. The maximum wind speed at 14:00 is 2.14 m/s close to the open area and the minimum is 0.02 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.14 m/s and the minimum is 0.02 m/s.

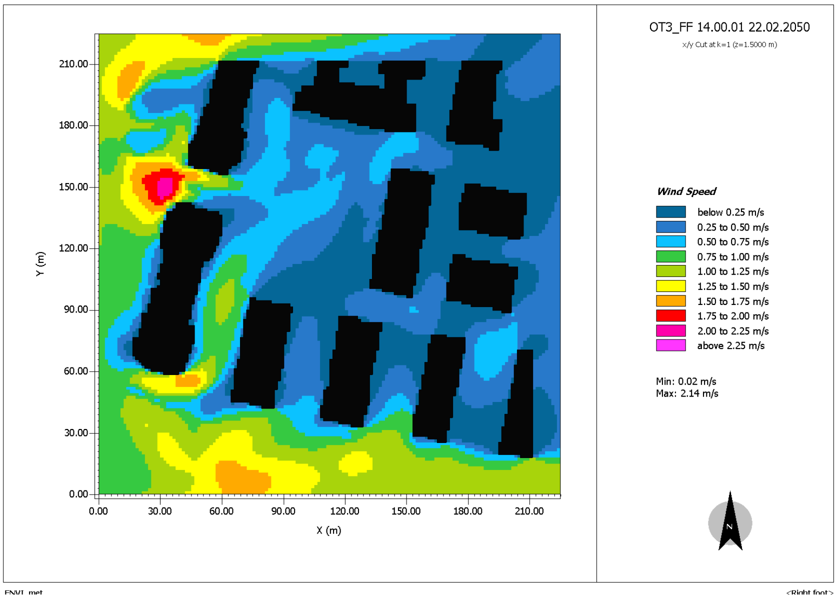


Figure 385. The wind speed of OT3 at 14:00

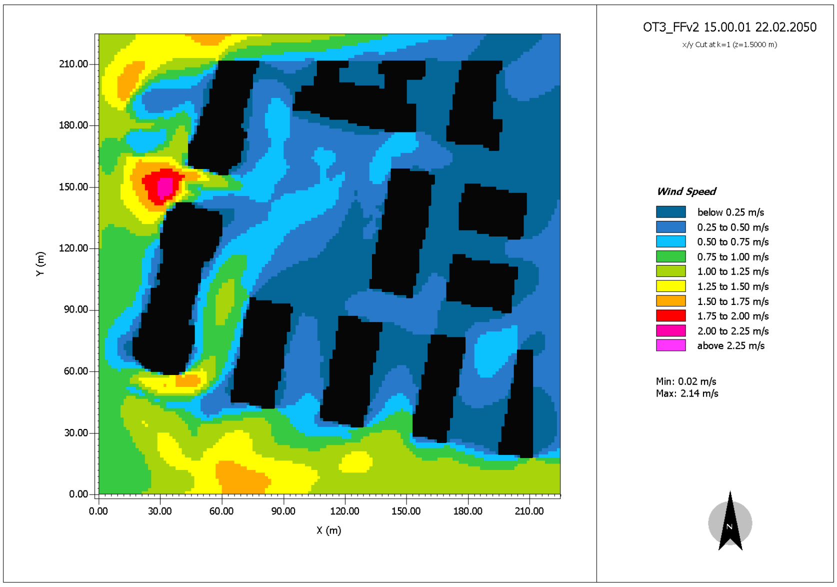


Figure 386. The wind speed of OT3 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 387 and Figure 388 respectively. The maximum surface temperature at 14:00 is equal to 54.31 °C, the minimum is equal to 24.41 °C and average is equal to 37.46°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (46.50m, 30.00m) (186.00m, 36.00m) (208.50m, 187.50m and (25.50m, 198.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 49.05 °C, the minimum is equal to 25.07 °C and average is equal to 36.58°C. The temperature is also considerably decreased to the regions of water sprays.

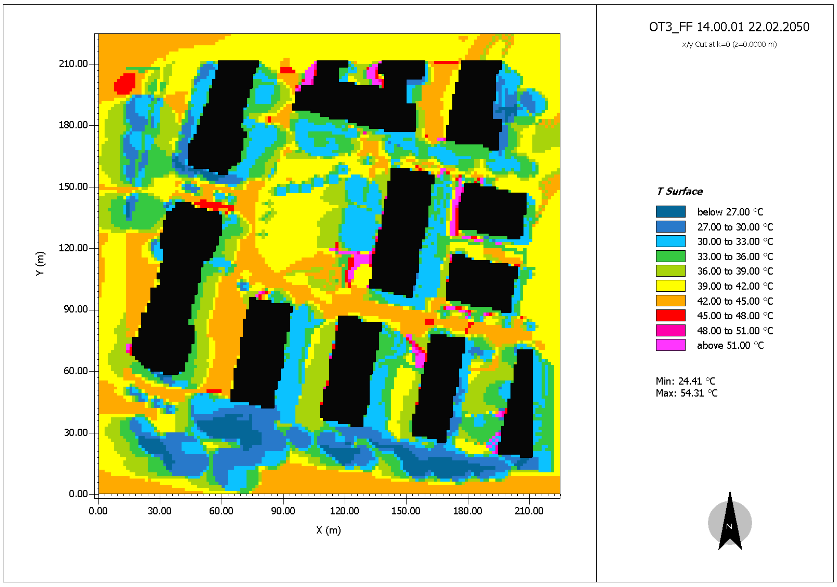


Figure 387. The surface temperature of OT3 at 14:00

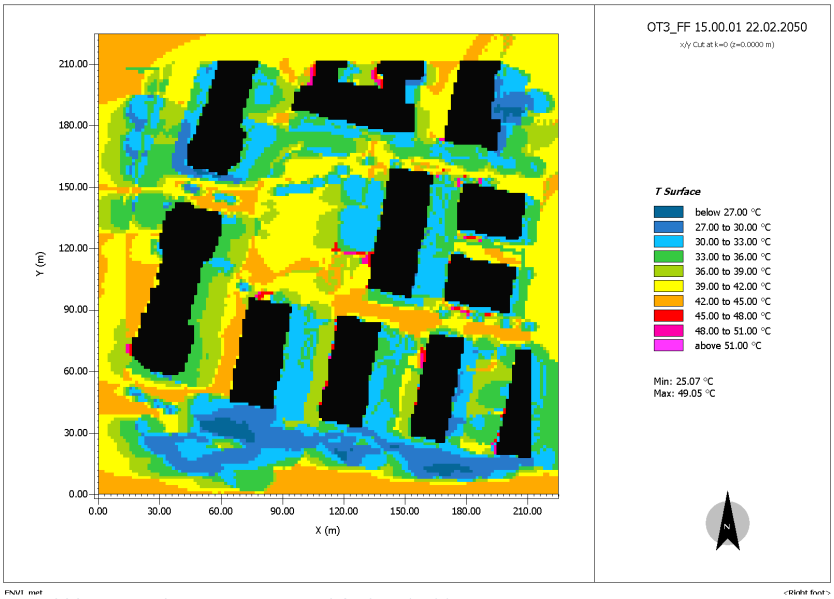


Figure 388. The surface temperature of OT3 at 15:00

The statistical results of all points versus time is depicted in Figure 389. Statistical analysis of simulation results for all simulation hours is tabulated in Table 66.

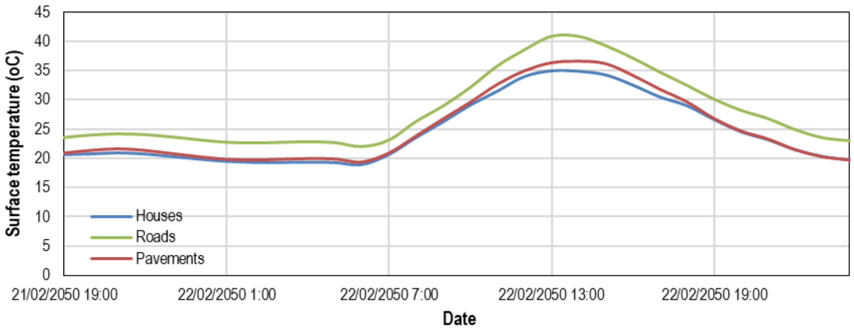


Figure 389. Surface temperature versus time for the various points

Table 66. The OT3 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	24.56	34.97	18.96
Roads	25.21	36.64	19.44
Pavements	28.11	40.83	21.96

OT4-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 390 and Figure 391 respectively. The maximum air temperature at 14:00 is equal to 34.50°C, the minimum is equal to 24.61°C and average is equal to 33.16°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (28.50m, 36.00m) (180.00m, 40.50m) (202.50m, 89.00m) and (27.00m, 201.00m) of the terrain. The maximum air temperature at 15:00 is equal to 34.37 °C, the minimum is equal to 24.41 °C and average is equal to 32.88°C. The temperature is also considerably decreased to the regions of water sprays.

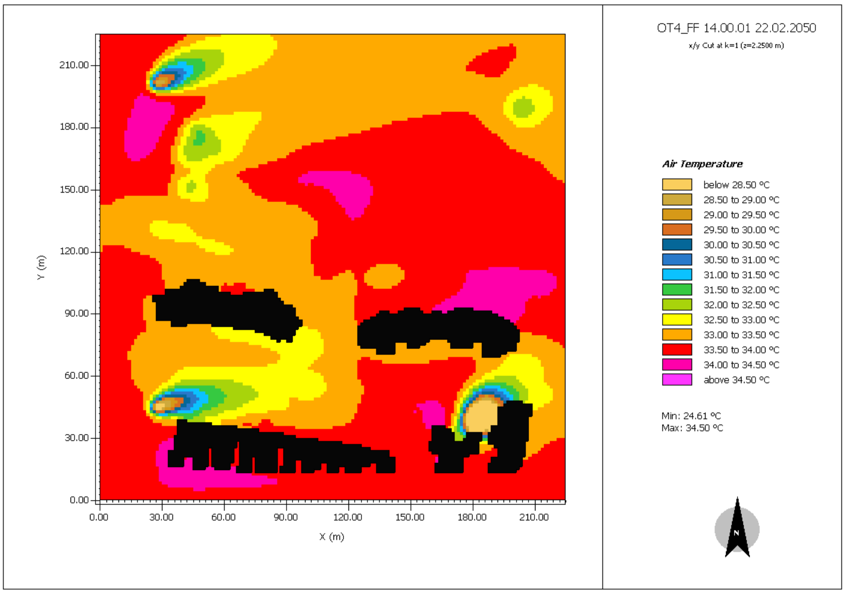


Figure 390. The air temperature of OT4 at 14:00

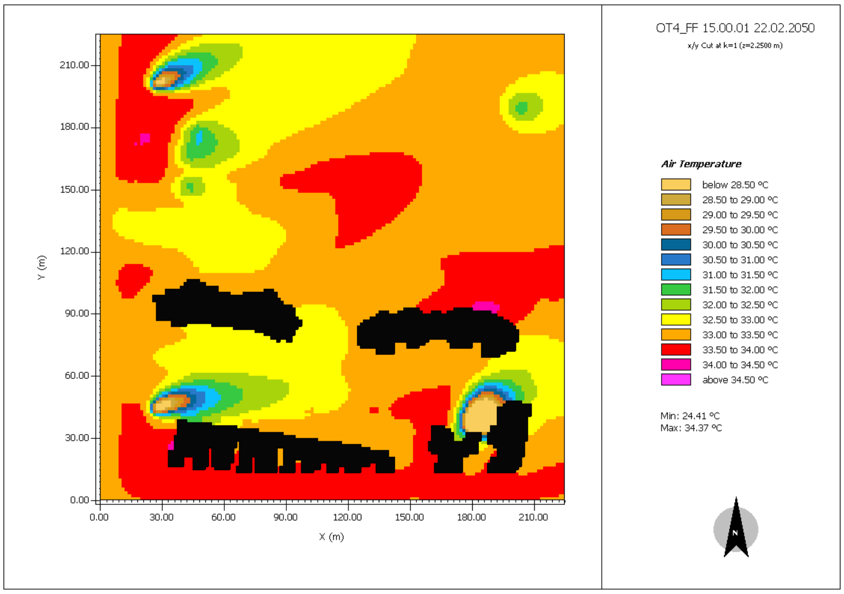


Figure 391. The air temperature of OT4 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 392, Figure 393 and Figure 394 respectively. The same points are used for the statistical analysis of surface temperature.

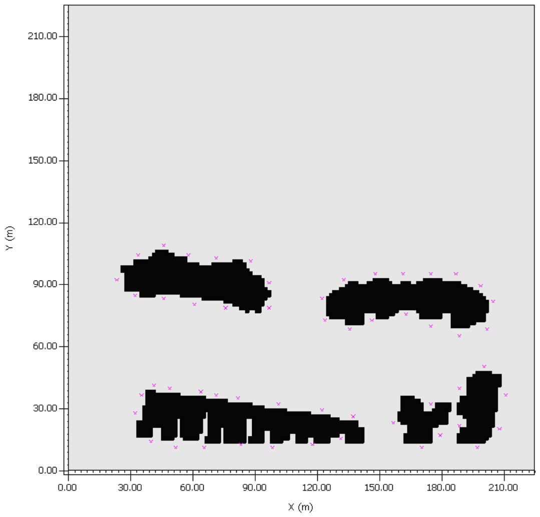


Figure 392. Points for the analysis of the air temperature close to houses

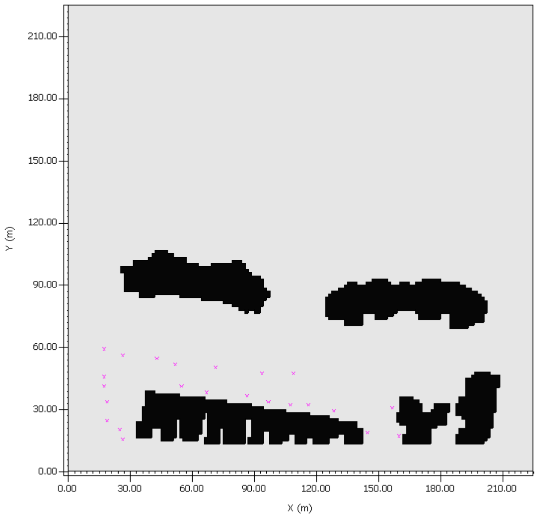


Figure 393. Points for the analysis of the air temperature close to pavements

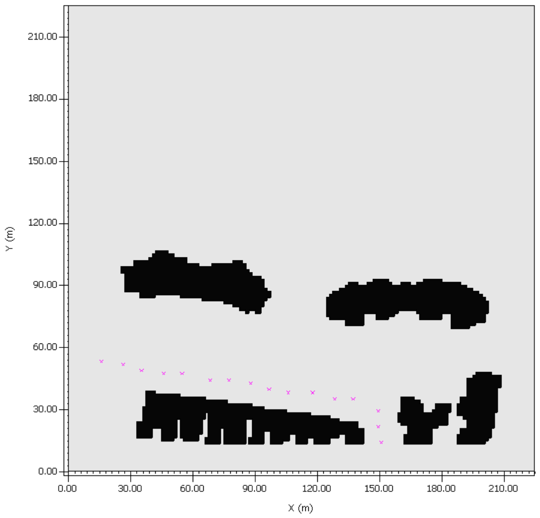


Figure 394. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 395. Statistical analysis of simulation results for all simulation hours is tabulated in Table 67.

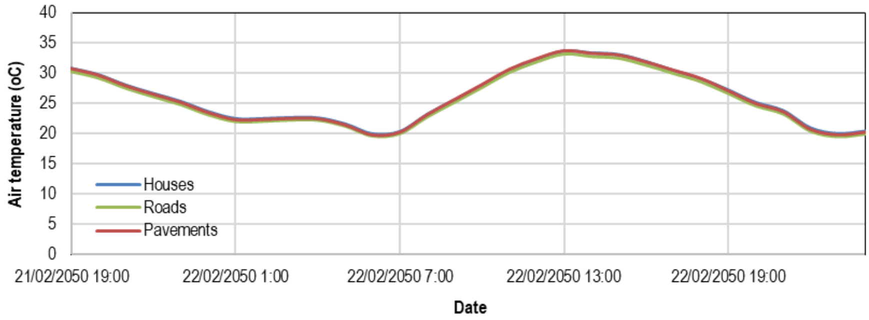


Figure 395. Air temperature versus time for the various points

Table 67. The OT4 statistical analysis of air temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	26.12	33.67	19.90
Roads	26.13	33.77	19.82
Pavements	25.73	33.26	19.50

Wind speed

The wind speed simulation results for OT1 and for 14:00 and 15:00 are depicted in Figure 396 and Figure 397 respectively. The maximum wind speed at 14:00 is 1.87 m/s close to the open area and the minimum is 0.01 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 1.88 m/s and the minimum is 0.01 m/s.

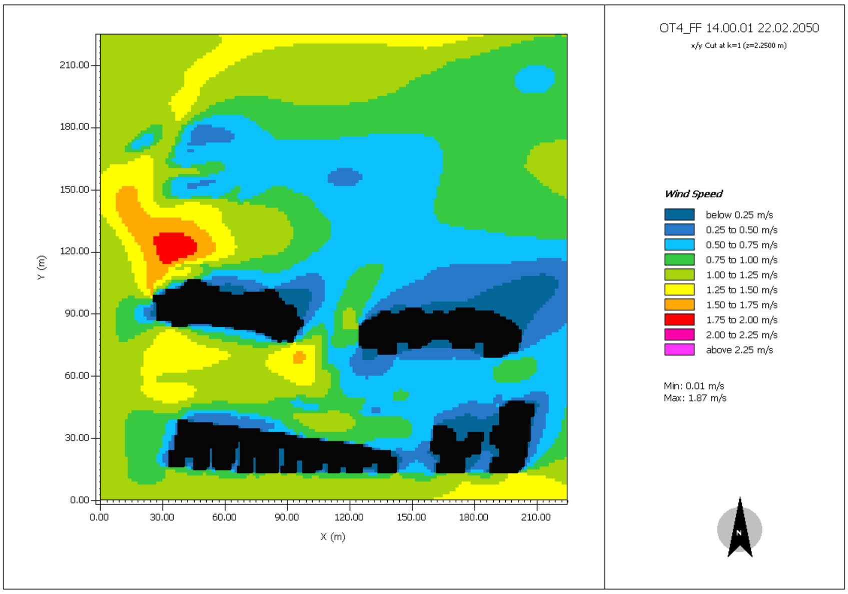


Figure 396. The wind speed of OT4 at 14:00

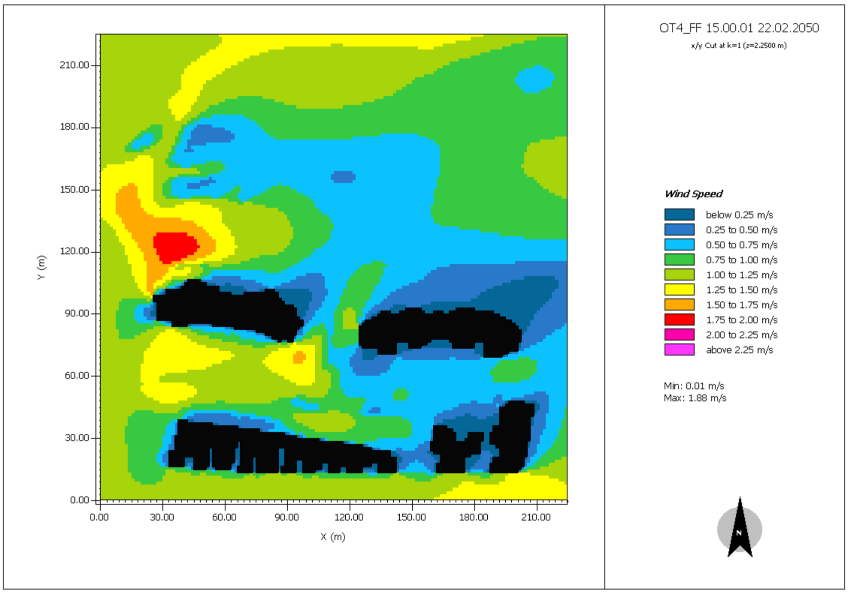


Figure 397. The wind speed of OT4 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 398 and Figure 399 respectively. The maximum surface temperature at 14:00 is equal to 53.77 °C, the minimum is equal to 23.65 °C and average is equal to 39.28°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (28.50m, 36.00m) (180.00m, 40.50m) (202.50m, 89.00m) and (27.00m, 201.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 48.85 °C, the minimum is equal to 23.74 °C and average is equal to 38.36°C. The temperature is also considerably decreased to the regions of water sprays.

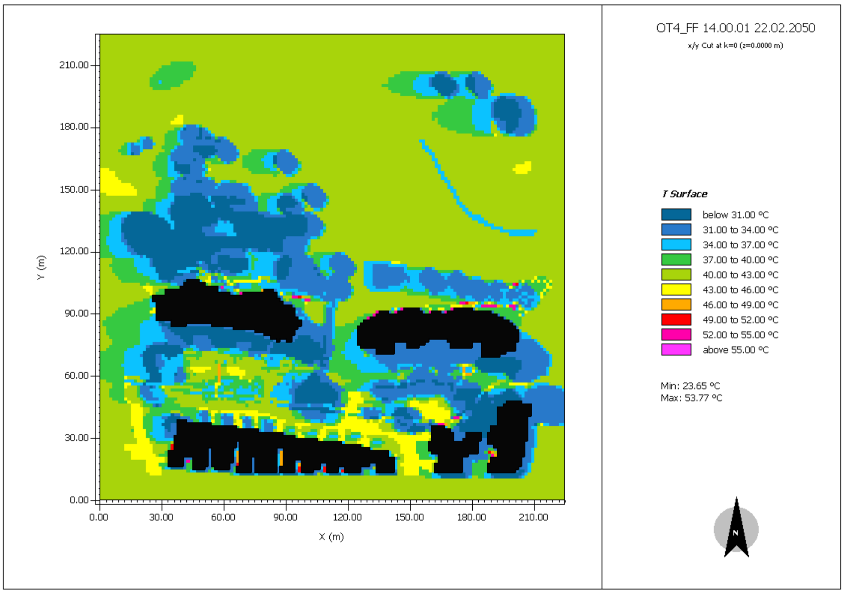


Figure 398. The surface temperature of OT4 at 14:00

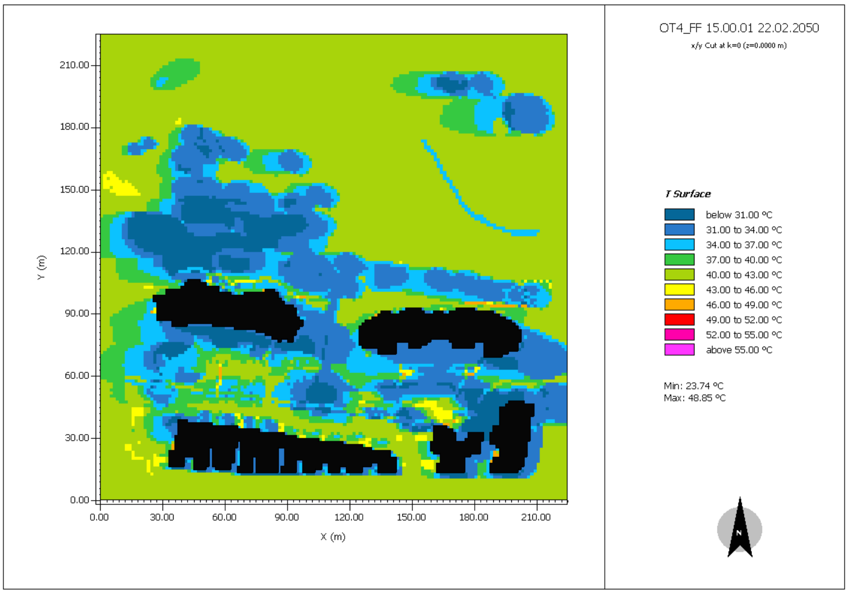


Figure 399. The surface temperature of OT4 at 15:00

The statistical results of all points versus time is depicted in Figure 400. Statistical analysis of simulation results for all simulation hours is tabulated in Table 68.

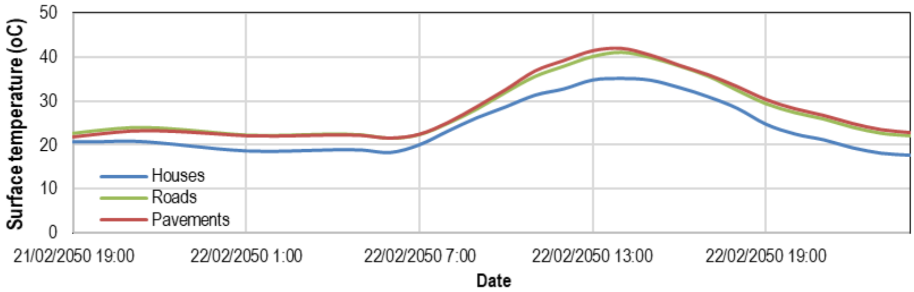


Figure 400. Surface temperature versus time for the various points

Table 68. The OT4 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	23.96	35.23	17.73
Roads	28.11	41.88	21.71
Pavements	27.81	41.04	21.62

OT5-Full forcing

Air temperature

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 401 and Figure 402 respectively. The maximum air temperature at 14:00 is equal to 35.27°C, the minimum is equal to 25.22°C and average is equal to 33.29°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (30.00m, 24.00m) (201.00m, 28.50m) (205.50m, 190.50m) and (90.00m, 204.00m) of the terrain. The maximum air temperature at 15:00 is equal to 34.63 °C, the minimum is equal to 24.55 °C and average is equal to 33.07°C. The temperature is also considerably decreased to the regions of water sprays.

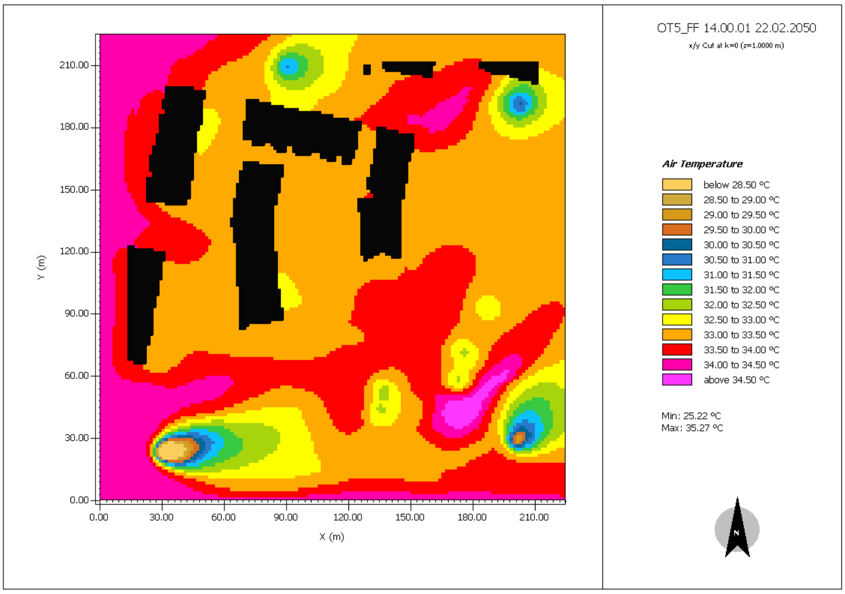


Figure 401. The air temperature of OT5 at 14:00

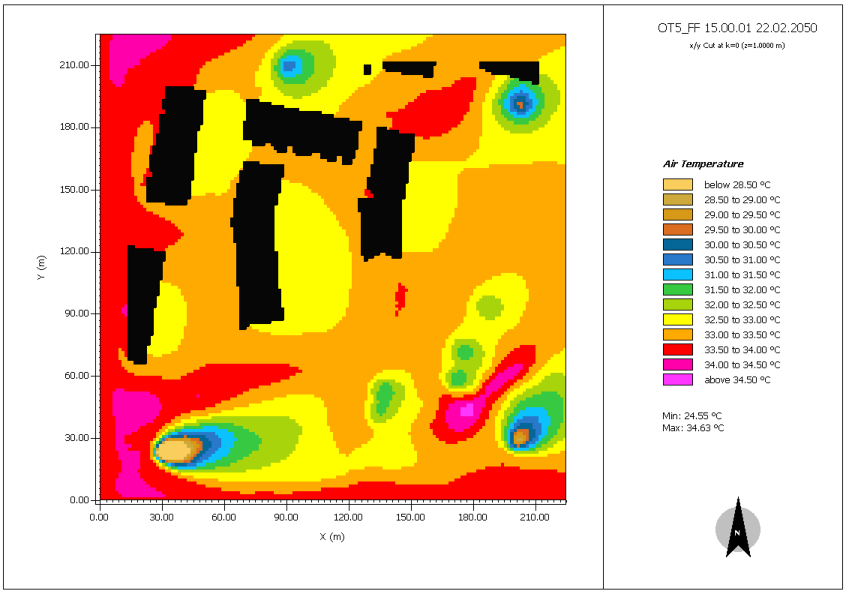


Figure 402. The air temperature of OT5 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 403, Figure 404, Figure 405 respectively. The same points are used for the statistical analysis of surface temperature.

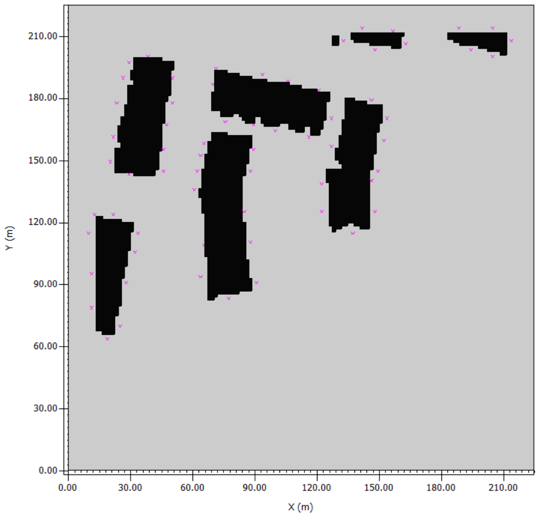


Figure 403. Points for the analysis of the air temperature close to houses

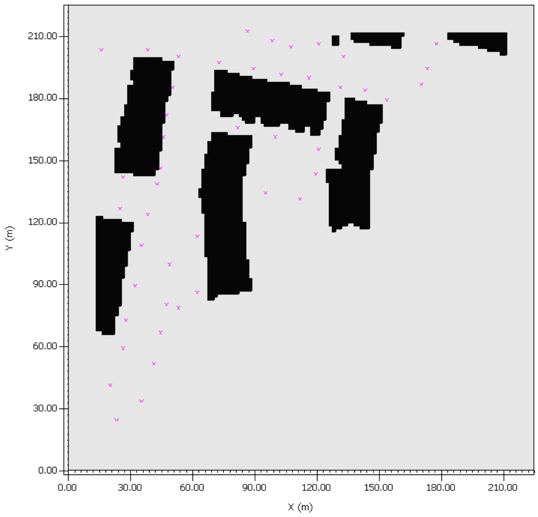


Figure 404. Points for the analysis of the air temperature close to pavements

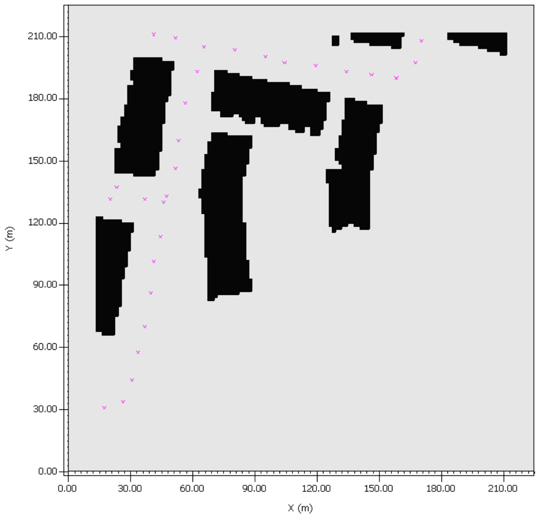


Figure 405. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 406. Statistical analysis of simulation results for all simulation hours is tabulated in Table 69.

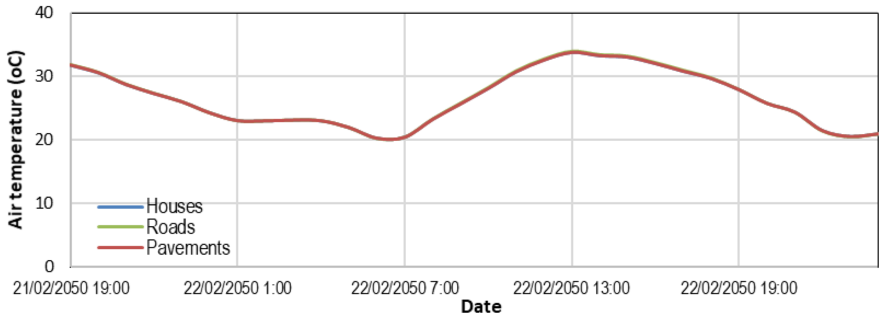


Figure 406. Air temperature versus time for the various points

Table 69. The OT5 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.58	33.79	20.27
Roads	26.56	33.76	20.24
Pavements	26.61	33.89	20.26

Wind speed

The wind speed simulation results for OT5 and for 14:00 and 15:00 are depicted in Figure 407 and Figure 408 respectively. The maximum wind speed at 14:00 is 2.21 m/s close to the open area and the minimum is 0.01 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.23 m/s and the minimum is 0.01 m/s.

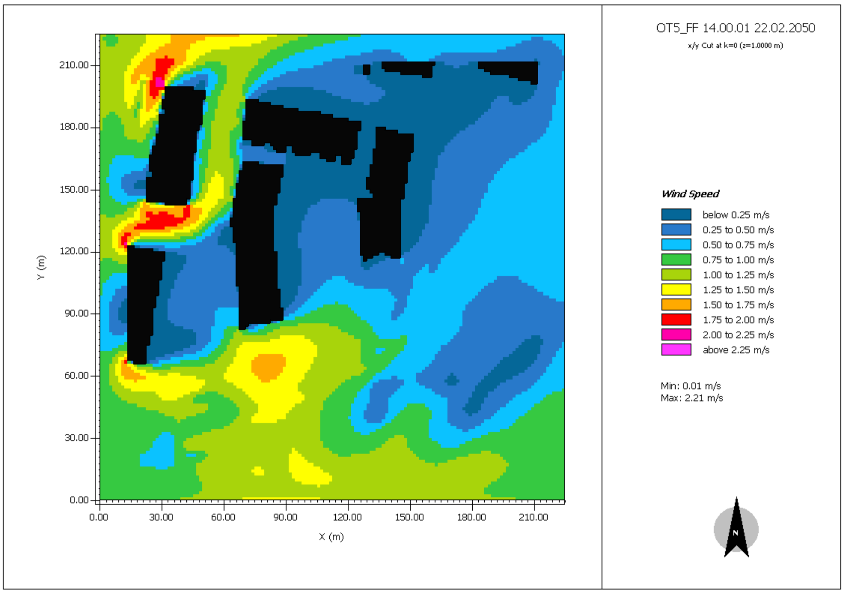


Figure 407. The wind speed of OT5 at 14:00

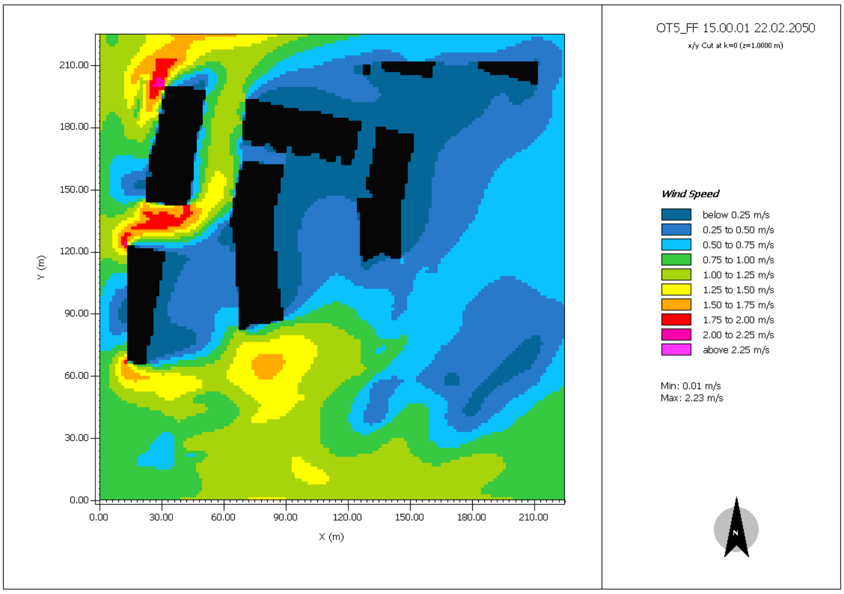


Figure 408. The wind speed of OT5 at 15:00

Surface temperature

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 409 and Figure 410 respectively. The maximum surface temperature at 14:00 is equal to 54.50 °C, the minimum is equal to 26.43 °C and average is equal to 39.24°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (30.00m, 24.00m) (201.00m, 28.50m) (205.50m, 190.50m) and (90.00m, 204.00m) of the terrain. The maximum surface temperature at 15:00 is equal to 50.41 °C, the minimum is equal to 27.50 °C and average is equal to 38.28°C. The temperature is also considerably decreased to the regions of water sprays.

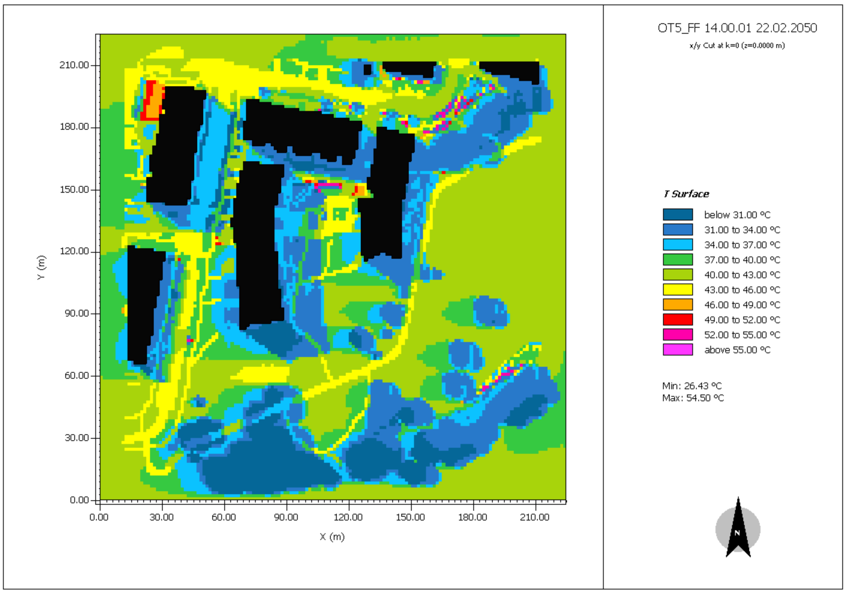


Figure 409. The surface temperature of OT5 at 14:00

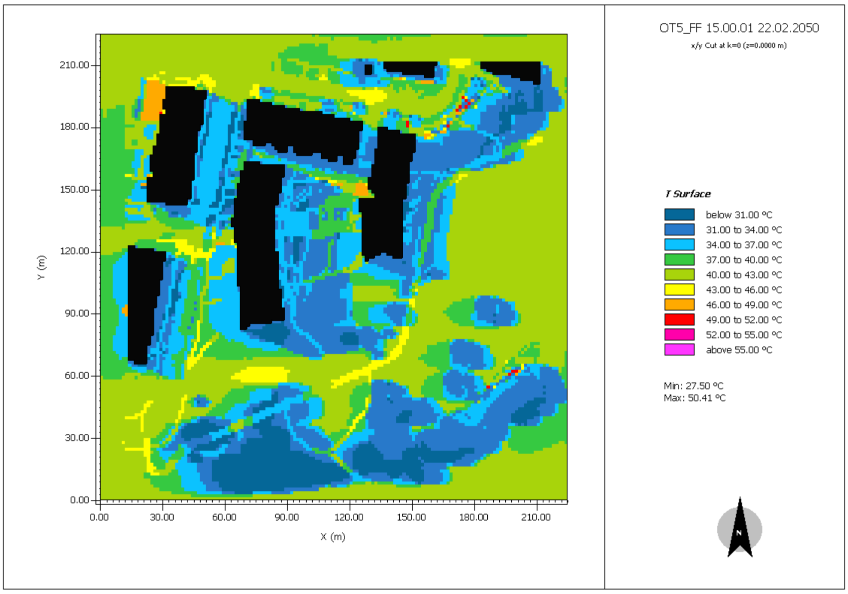


Figure 410. The surface temperature of OT5 at 15:00

The statistical results of all points versus time is depicted in Figure 411. Statistical analysis of simulation results for all simulation hours is tabulated in Table 70.

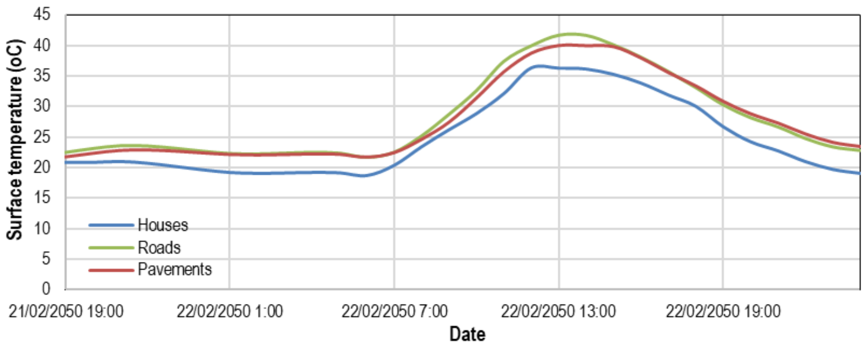


Figure 411. Surface temperature versus time for the various points

Table 70. The OT5 statistical analysis of surface temperature

Location	Average (oC)	Max (oC)	Min (oC)
Houses	24.76	36.27	18.77
Roads	27.83	39.99	21.73
Pavements	28.21	41.72	21.74

OT6-Full forcing

Air temperature for OT6

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 412 and Figure 413 respectively. The maximum air temperature at 14:00 is equal to 34.05°C, the minimum is equal to 27.77°C and average is equal to 33.06°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (61.50m, 36.00m) (81.50m, 21.00m) (204.00m, 190.50m) and (28.50m, 193.50m) of the terrain.

The maximum air temperature at 15:00 is equal to 33.90°C, the minimum is equal to 27.35°C and average is equal to 32.76°C. The temperature is also considerably decreased to the regions of water sprays.

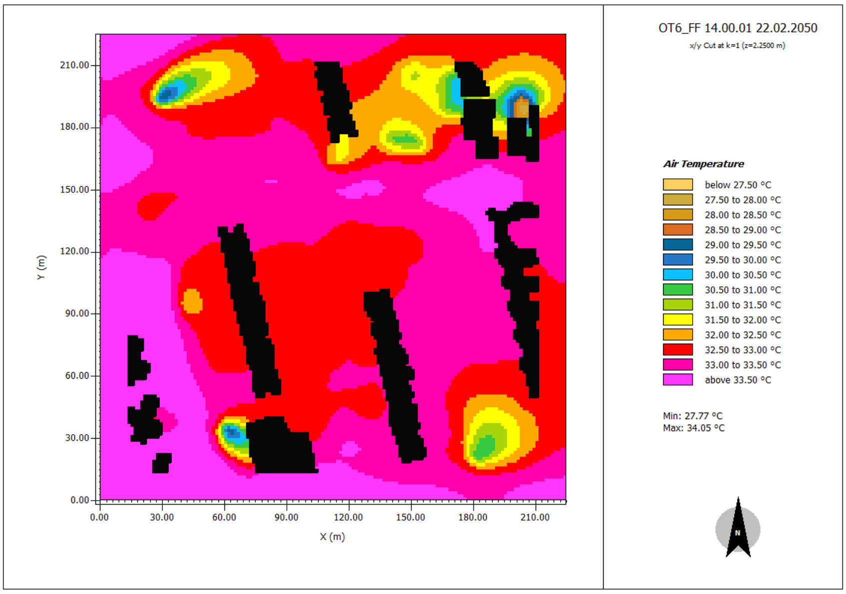


Figure 412. The air temperature of OT6 at 14:00

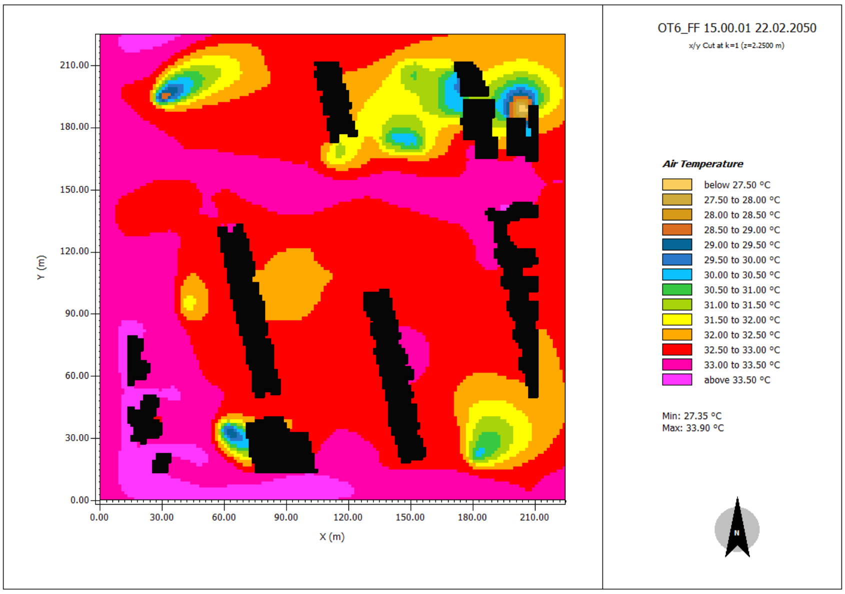


Figure 413. The air temperature of OT6 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 414, Figure 415, Figure 416 respectively. The same points are used for the statistical analysis of surface temperature.

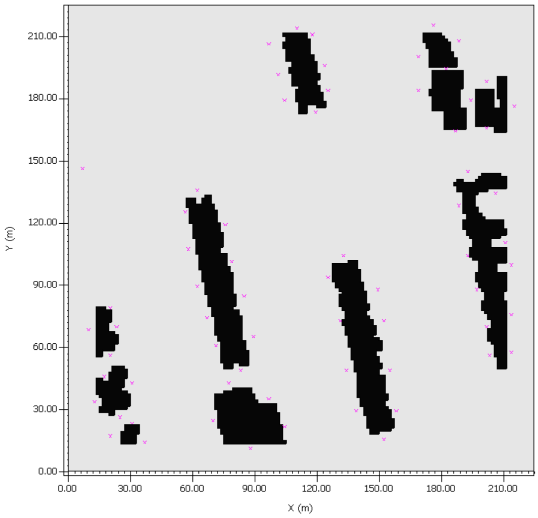


Figure 414. Points for the analysis of the air temperature close to houses

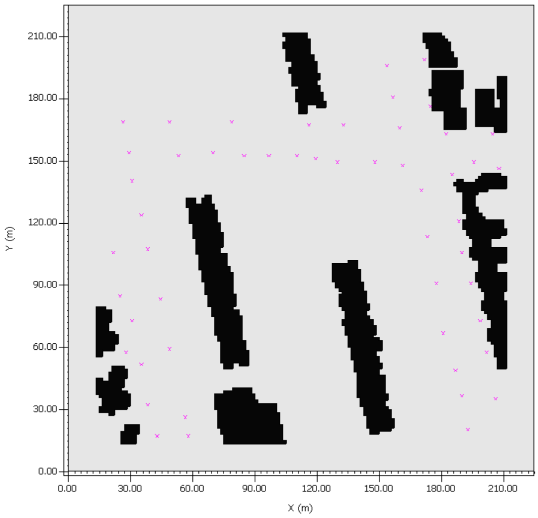


Figure 415. Points for the analysis of the air temperature close to pavements

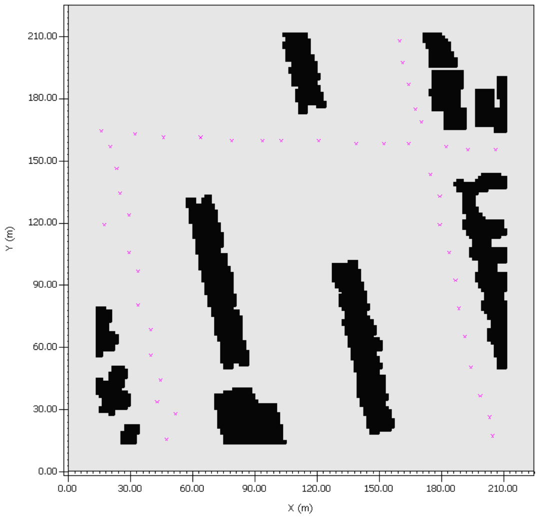


Figure 416. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 417. Statistical analysis of simulation results for all simulation hours is tabulated in Table 71.

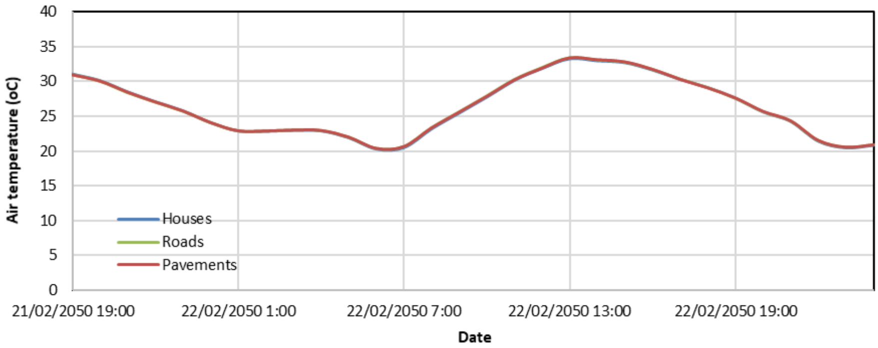


Figure 417. Air temperature versus time for the various points

Table 71. The OT6 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.29	33.21	20.29
Roads	26.37	33.36	20.40
Pavements	26.42	33.49	20.40

Wind speed for OT6

The wind speed simulation results for OT6 and for 14:00 and 15:00 are depicted in Figure 418 and Figure 419 respectively. The maximum wind speed at 14:00 is 2.07 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.06 m/s and the minimum is 0.00 m/s.

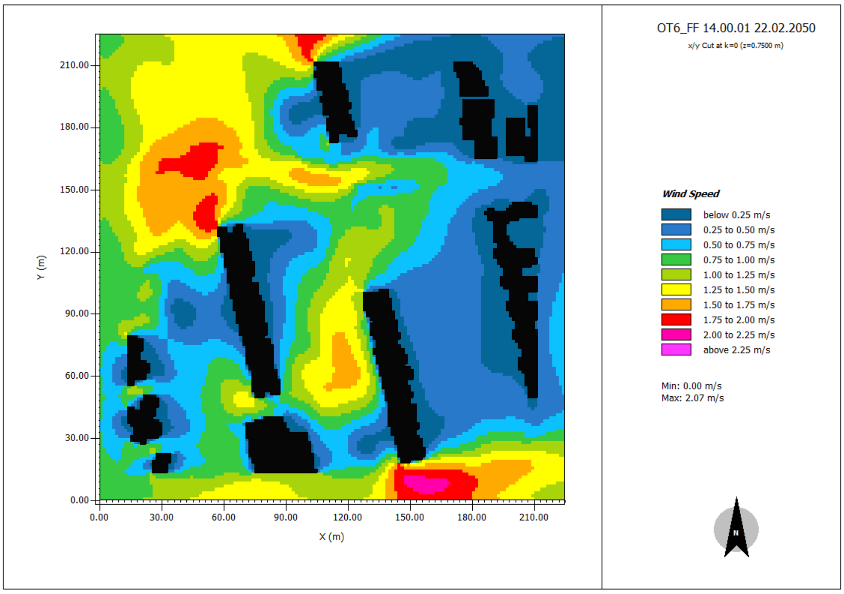


Figure 418. The wind speed of OT6 at 14:00

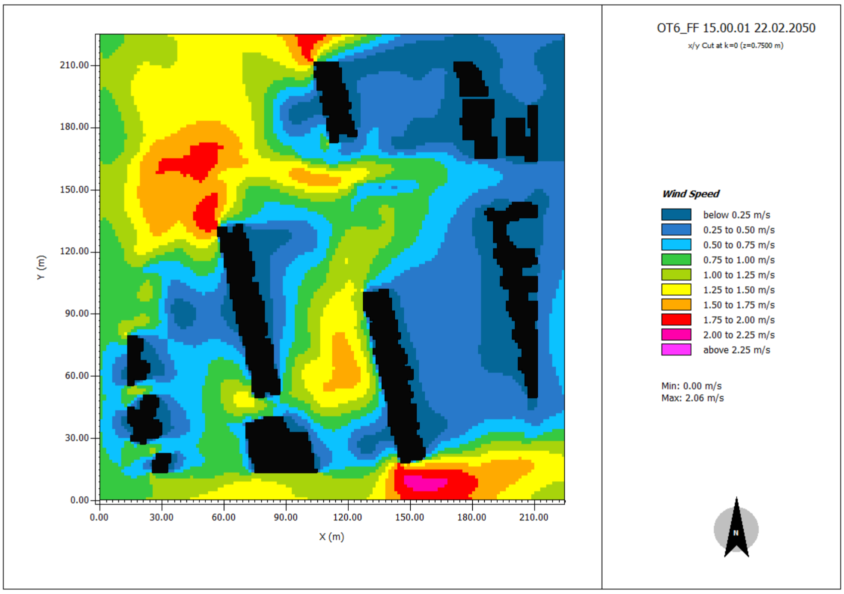


Figure 419. The wind speed of OT6 at 15:00

Surface temperature for OT6

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 420 and Figure 421 respectively. The maximum surface temperature at 14:00 is equal to 52.55 °C, the minimum is equal to 19.85°C and average is equal to 37.64°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (61.50m, 36.00m) (81.50m, 21.00m) (204.00m, 190.50m) and (28.50m, 193.50m) of the terrain. The maximum surface temperature at 15:00 is equal to 49.27°C, the minimum is equal to 19.85 °C and average is equal to 36.81°C. The temperature is also considerably decreased to the regions of water sprays.

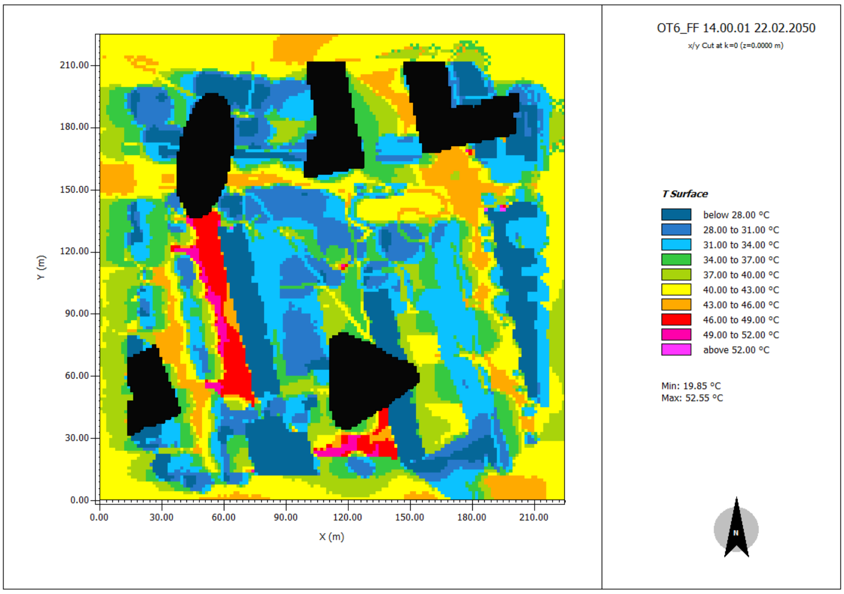


Figure 420. The surface temperature of OT6 at 14:00

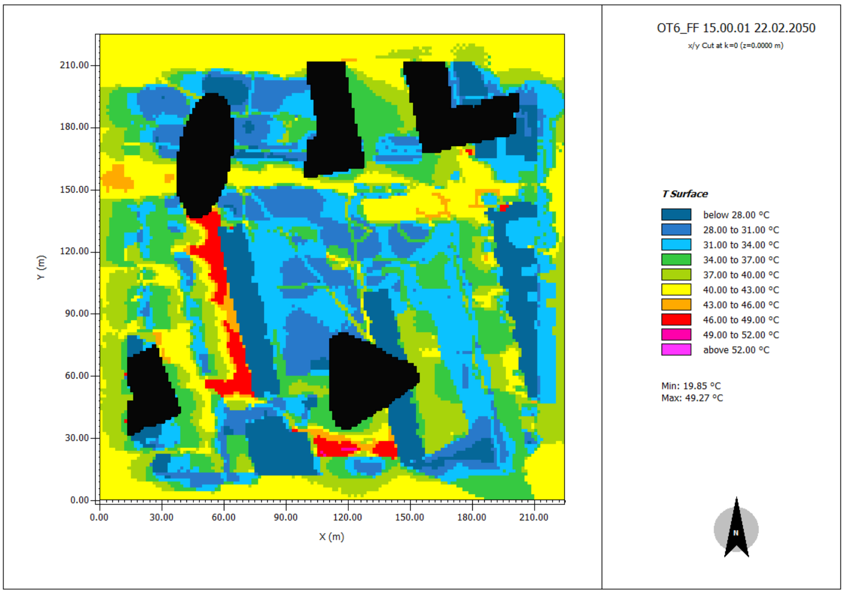


Figure 421. The surface temperature of OT6 at 15:00

The statistical results of all points versus time is depicted in Figure 422. Statistical analysis of simulation results for all simulation hours is tabulated in Table 72.

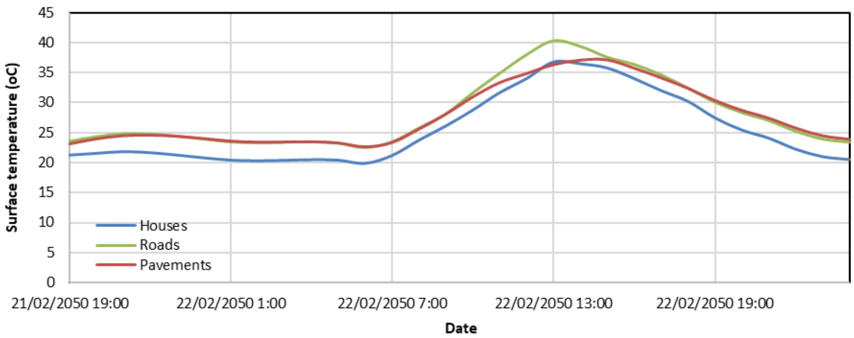


Figure 422. Surface temperature versus time for the various points

Table 72. The OT6 statistical analysis of surface temperature

Location	Average (ºC)	Max (ºC)	Min (ºC)
Houses	25.46	36.81	19.96
Roads	27.74	37.10	22.57
Pavements	28.13	40.27	22.43

OT7-Full forcing

Air temperature for OT7

The simulation results for the air temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 423 and Figure 424 respectively. The maximum air temperature at 14:00 is equal to 34.81°C, the minimum is equal to 29.29°C and average is equal to 33.19°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (37.50m, 38.00m) (205.50m, 22.50m) (208.50m, 207.0m) and (43.50m, 208.50m) of the terrain.

The maximum air temperature at 15:00 is equal to 34.29 °C, the minimum is equal to 28.79 °C and average is equal to 32.93°C. The temperature is also considerably decreased to the regions of water sprays.

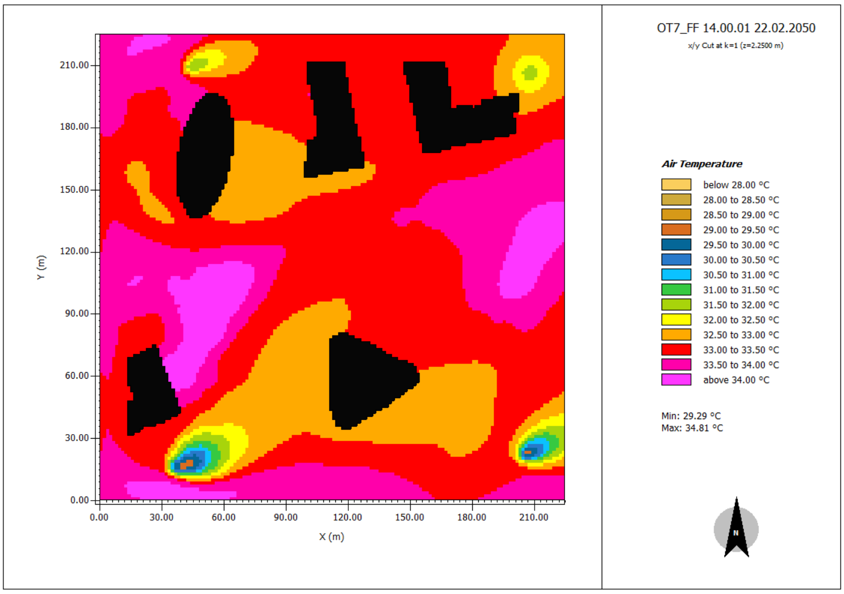


Figure 423. The air temperature of OT7 at 14:00

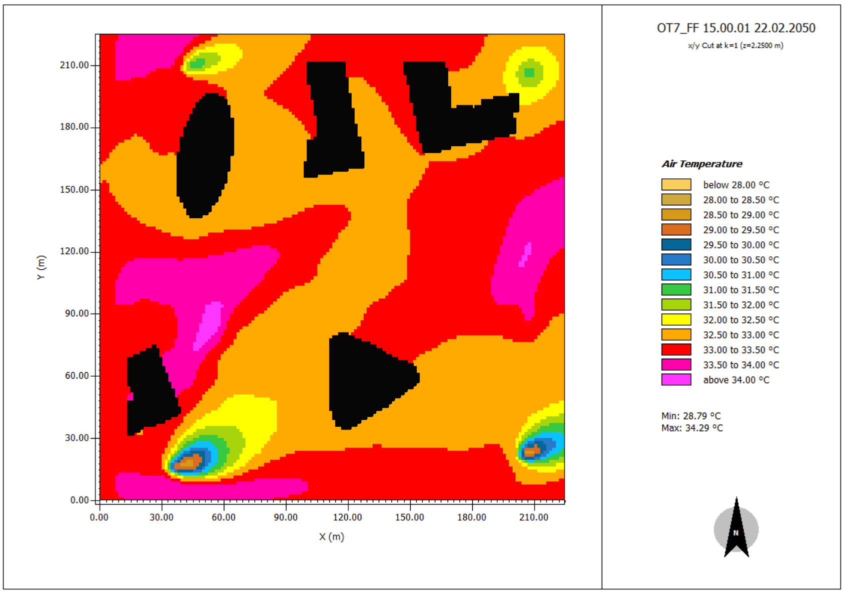


Figure 424. The air temperature of OT7 at 15:00

A statistical analysis is performed to the various areas. The points analysed for near houses, pavements, and roads are depicted in Figure 425, Figure 426 and Figure 427 respectively. The same points are used for the statistical analysis of surface temperature.

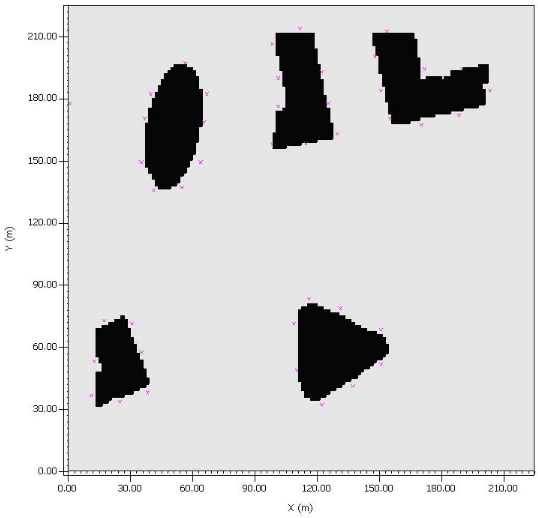


Figure 425. Points for the analysis of the air temperature close to houses

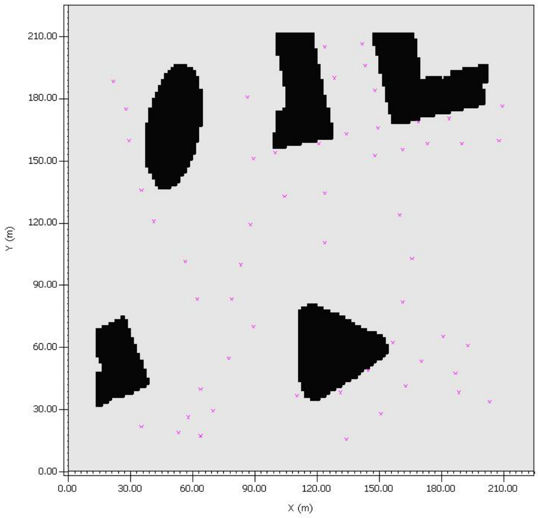


Figure 426. Points for the analysis of the air temperature close to pavements

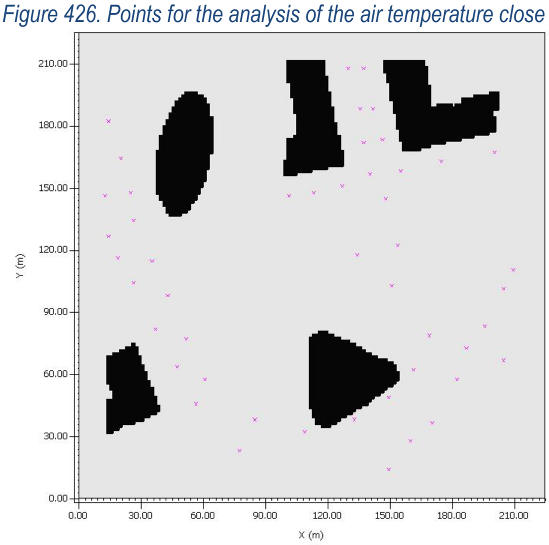


Figure 427. Points for the analysis of the air temperature close to roads

The statistical results of all points versus time is depicted in Figure 428. Statistical analysis of simulation results for all simulation hours is tabulated in Table 73.

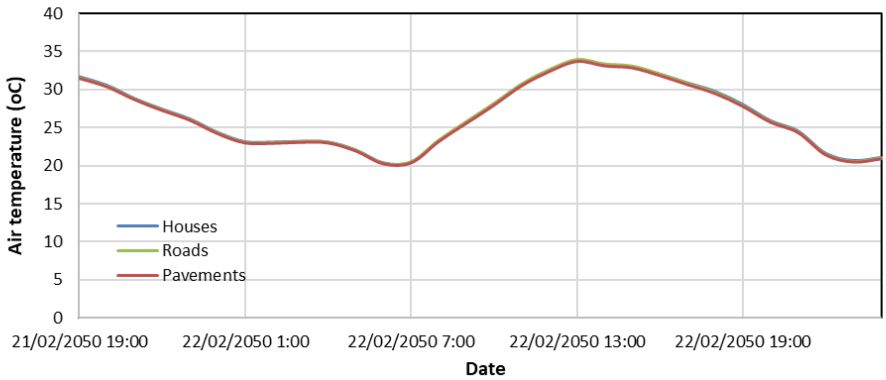


Figure 428. Points for the analysis of the air temperature close to roads

Table 73. The OT7 statistical analysis of air temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	26.61	33.77	20.34
Roads	26.48	33.65	20.28
Pavements	26.59	33.90	20.34

Wind speed for OT7

The wind speed simulation results for OT7 and for 14:00 and 15:00 are depicted in Figure 429 and Figure 430 respectively. The maximum wind speed at 14:00 is 2.89 m/s close to the open area and the minimum is 0.00 m/s among the buildings and the narrow streets. The maximum wind speed at 15:00 is 2.89 m/s and the minimum is 0.00 m/s.

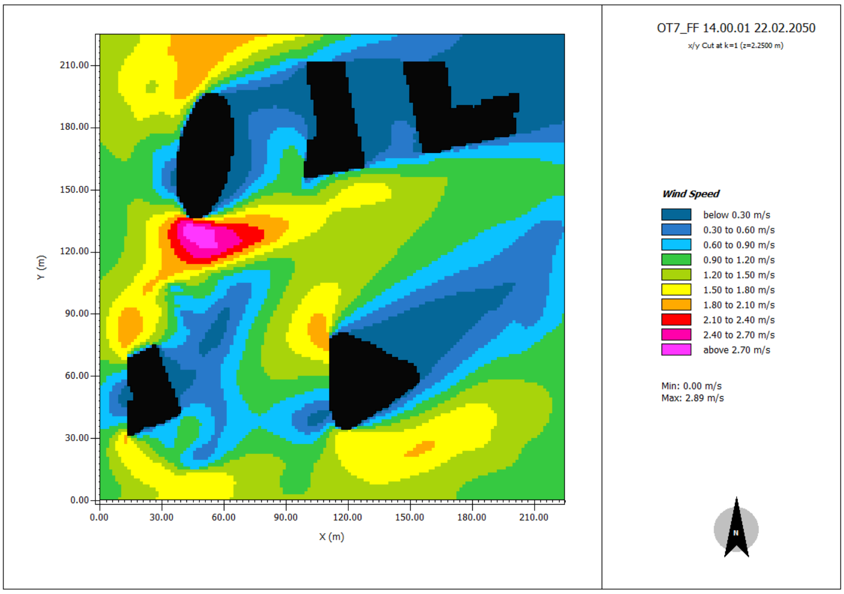


Figure 429. The wind speed of OT7 at 14:00

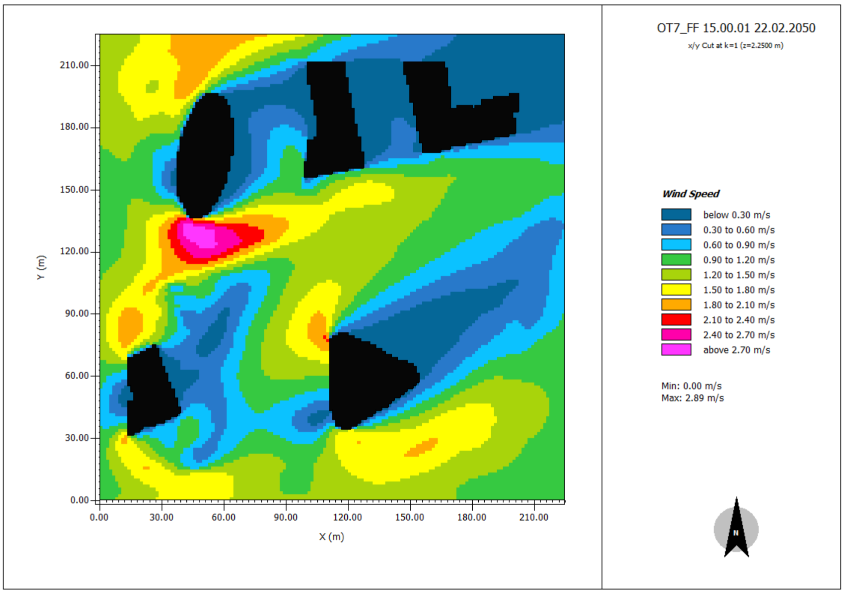


Figure 430. The wind speed of OT7 at 15:00

Surface temperature for OT7

The simulation results for the surface temperature on 22/2/2050 14:00 and 15:00 are depicted in Figure 431 and Figure 432 respectively. The maximum surface temperature at 14:00 is equal to 53.61 °C, the minimum is equal to 25.41 °C and average is equal to 38.53°C. We notice that the temperature is considerably decreased to the regions of water sprays which corresponds to (x, y) = (37.50m, 38.00m) (205.50m, 22.50m) (208.50m, 207.0m) and (43.50m, 208.50m) of the terrain. The maximum surface temperature at 15:00 is equal to 47.88 °C, the minimum is equal to 25.93 °C and average is equal to 37.25°C. The temperature is also considerably decreased to the regions of water sprays.

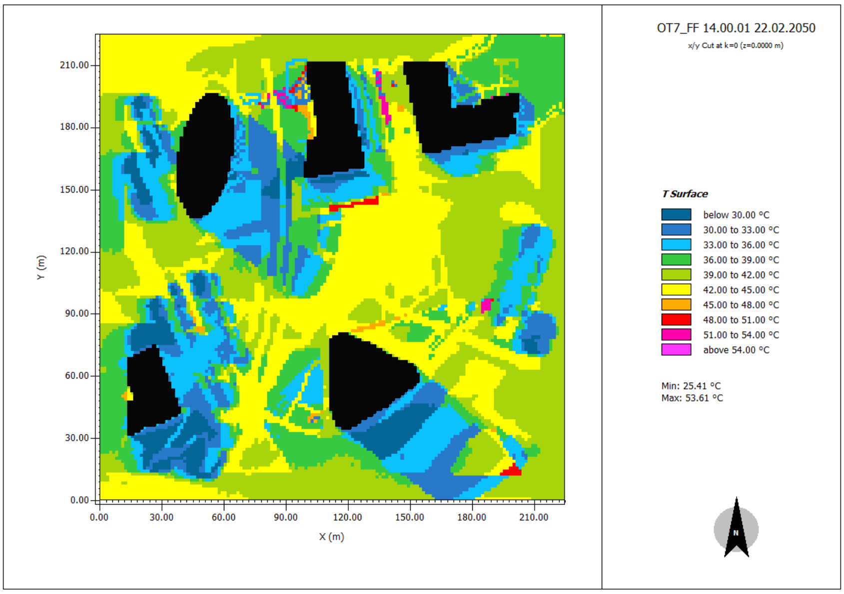


Figure 431. The surface temperature of OT7 at 14:00

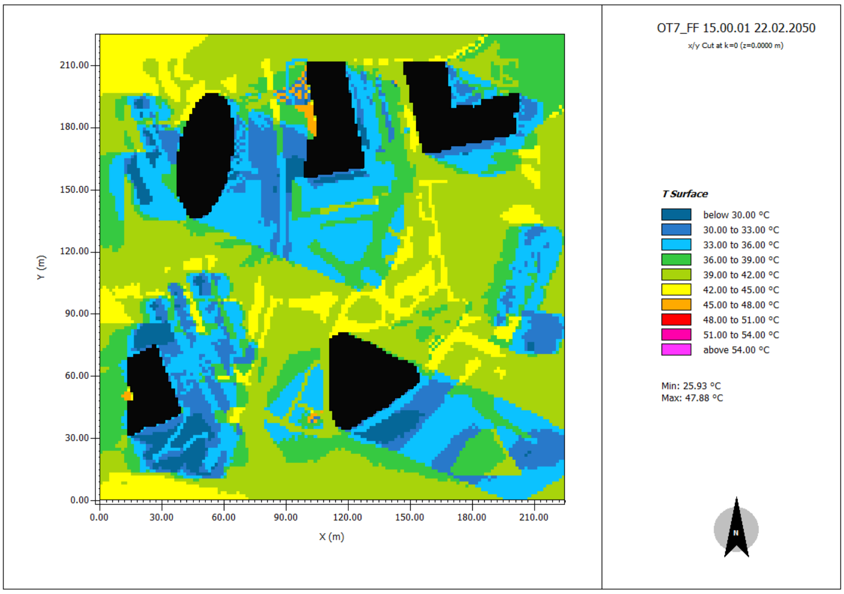


Figure 432. The surface temperature of OT7 at 15:00

The statistical results of all points versus time is depicted in Figure 433. Statistical analysis of simulation results for all simulation hours is tabulated in Table 74.

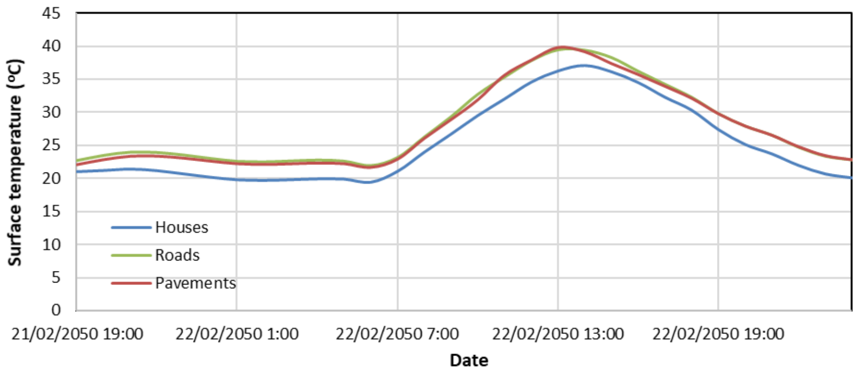


Figure 433. Surface temperature versus time for the various points

Table 74. The OT7 statistical analysis of surface temperature

Location	Average (°C)	Max (°C)	Min (°C)
Houses	25.29	37.05	19.50
Roads	27.61	39.84	21.73
Pavements	27.83	39.42	21.94