Enhancing Outdoor Thermal Comfort and Optimizing Indoor Energy Consumption Performance of an Existing Urban Community, Dubai, UAE

تعزيز الراحة الحرارية الخارجية وتحسين أداء استهلاك الطاقة في الأماكن الداخلية في مجتمع حضري قائم ، دبي ، الإمارات العربية المتحدة.

by

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Dissertation submitted in fulfilment

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ABSTRACT - ENGLISH

An attempt at enhancing outdoor environmental conditions by simulating passive design strategies to study the effect it will have on the energy consumption of an existing villa located in Dubai, United Arab Emirates. The significance of this research is based on the following issues that need urgent addressing: the UAE is at the top of the list of countries with the highest ecological footprint; residential energy consumption accounts for 57% of the total energy consumed, and targeting this group may have greater benefits in shorter time.

A mixed methodology was adapted, with simulation programs including ENVI-met and IES VE. The simulations are of cumulative nature and consist of thirteen simulations divided into five stages. Passive design strategies include orientation, coverage materials, greenery, and waterbodies, with the evaluating parameters consisting of air temperature, wind speed, and relative humidity. Energy consumption models are validated with DEWA's statistical data. Significant findings include a total reduction of 16.6 degrees Celsius in air temperature through the introduction of passive design strategies. The changes in the environment resulted in a total saving in energy consumption of 2,091 MWh per year for this villa. This cost saving of 624,6 AED for the year amounts 4,5% saving on the total consumption.

ABSTRACT - ARABIC

ملخص

هذا البحث هو محاولة لتحسين الظروف البيئية في الخارج من خلال استخدام نماذج المحاكاة الحاسوبية لدراسة تأثير استراتيجيات التصميم الشمسي السالب على استهلاك الطاقة في المباني، اختارت الدراسة فيلا موجودة في دبي في الامارات العربية المتحدة لتكون محور الدراسة. البحث يسلط الضوء على عدة قضايا بيئية مهمة في دولة الإمارات والتي تعتبر على رأس قائمة البلدان ذات أثر إيكولوجي عالي. يمثل استهلاك الطاقة السكنية 57٪ من إجمالي الطاقة المستهلكة، لذلك استهدفت المباني السكنية للدراسة لما لها من فوائد أكبر وفي وقت أقصر.

تم استخدام منهجية مختلطة في هذا البحث، بالإضافة الى استخدام برامج المحاكاة بما في ذلك ENVI-met و IES VE. تكون المحاكاة ذات طبيعة تراكمية وتتكون من ثلاث عشرة عملية محاكاة مقسمة إلى خمس مراحل. تتضمن استراتيجيات التصميم السلبية إعادة توجيه المبنى للجهة الأفضل بيئياً، ومواد التغطية، والمساحات الخضراء، والمجسمات المائية، مع تحديد عوامل تقييم تتكون من درجة حرارة الهواء وسرعة الرياح والرطوبة النسبية. تم التحقق من صحة نماذج استهلاك الطاقة من خلال البيانات الإحصائية لهيئة كهرباء ومياه دبي. وتشمل النتائج الهامة انخفاضاً كلياً قدره 16.6 درجة مئوية في درجة حرارة الهواء من خلال إدخال استراتيجيات التصميم السلبية. حيث أدت التغيرات في البيئة إلى توفير في استهلاك الطاقة يبلغ 2،091 ميغاوات في السنة لهذه الفيلا. هذا الادخار في التكاليف من 624،6 درهم للسنة يساوي 4.4 ٪ توفير على الاستهلاك الكلي، يجدر الإشارة أنه وبرغم أن هذا البحث كان في دولة الامارات، إلا أن نتائج هذا البحث يمكن أن تشمل الدول المجاورة والتي تتشارك مع الامارات في نفس الظروف البيئية.

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First and foremost, thank you to my supervisor Dr. H. Taleb. The door to Dr. Hanan's office was always open whenever I ran into a troubled spot or had a question about the research or writing. Thank you for believing not only in the topic, but also in me and my ability to achieve it. Thank you for always encouraging everyone that come across your path and thank you dearly for the time and effort you are willing to spend on more reserved students like myself. You have made a significant change in my life and I will forever be grateful.

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And last but not least, I would like to thank G.B. du Toit, without whom none of this would be possible. Thank you for your unfailing support, believing in my vision and motivating me throughout the entire master's degree program. Gratitude!

Warm regards,

Cheri Schreiber

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% - percentage

°C - Degrees Celsius

AAEA - African American Environmentalist Association

AT - Air temperature

ASCE - American Society of Civil Engineers

Bldg. - building

BREEAM - Building Research Establishment Environmental Assessment Method

c/c - center to center

CFSSD - Committee on Food Security and Sustainable Development

cm - Centimeters

Deg. - degrees

DEWA - Dubai Electricity and Water Authority

ECOSOC - United Nations Economic and Social Council

ENVI-met - ENVI_MET V4

EXPO - EXPO 2020 World Fair

FAO - Food and Agriculture Organization of the United Nations

g/kg - grams per one kilogram

gCO2eq/kWh - grams of carbon dioxide equivalent per kilowatt-hour of electricity generated

GCC - Gulf Cooperation Council

GCR - Green Coverage Ratio

gha - Global hectares

h:d - height to distance ratio

Ha - Hectares

HIE - Heat island effect

HOA - Home Owners Association

IES VE - Integrated Environmental Solutions Virtual Environment

IIEC - International Institute for Energy Conservation

IIED - International Institute for Environment and Development

ILO - International Labour Organization

IPCC - Intergovernmental Panel on Climate

km - Kilometers

km2 - Kilometer squared

kWh - Kilowatt hour

LEED - Leadership in Energy and Environmental Design m - Meters

m/s - Meters per second

m2 - Meter squared

MENA - Middle East and North Africa

NB - important

NCSE - National Council for Science and the Environment

OAS - Organization of American States

OECD - Green Growth and Sustainable Development

OECD - Organization for Economic Cooperation and Development

RH - Relative humidity

ROW - right of way

SEPP - Science & Environmental Policy Project

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Spot 1 - Location of measurements taken on spot at front of yard

Spot 2 - Location of measurements taken on spot at back of yard

Spot 3 - Location of measurements taken on spot at road surface

Spot 4 - Location of measurements taken on spot at open space

Str. - strategy

ST - Surface temperature

UAE - United Arab Emirates

UIA - International Union of Architects

UK - United Kingdom

UN - United Nations

UNEP - United Nations Environment Programme

UNESCO - United Nations Educational, Scientific, and Cultural Organization

UNRISD - United Nations Research Institute for Social Development

US - United States

USGBC - US Green Building Council

WASD World Association for Sustainable Development

WCA - World Congress of Architects

WMO - World Meteorological Organization

WS - Wind speed

CHAPTER 1

INTRODUCTION

1.1 Overview

An overview of the concept of sustainability. It provides information on the topics of ecological footprint, bio-capacity and give an indication of status on a global and on local level. Knowledge obtained through the overview of the document will include the familiarity with the subtleties, philosophies and notions of sustainability; identifying the community-, scientific- and environmental factor influences on sustainability; mindfulness of principal research, innovation and instances of sustainable strategies; key issues in sustainable development and stewardship. To understand the affiliation between systems, patterns, environments, and sustainability. To learn to apply strategies to maintain a balance between developments and system and resources. To identify the limitations involved in applying the concepts of sustainability into practice. The major concept is to understand sustainability in context. This include the current state of earth and its ecosystem regarding its services and functionality, the country's ecological footprint, to define what sustainability is in the context of this research and to determine the need for it, to understand the concept of sustainable development, to understand what impacts given buildings have on the environment and familiarizing and educating the community on the local and international laws regarding the environment. The first recorded instance of the term sustainability was in the 1800's in Germany where the forestry manager, G. L. Hartig, stated (translation from German) that:

> *"Every wise forest director has to have evaluated the forest stands without losing time, to utilize them to the greatest possible extent, but still in a way that future generations will have at least as much benefit as the living generation"*

Source: Schmutzenhofer (1992)

The definition of sustainability has changed over the past decades to suit each industry, but the bare basic concept of it has shown to still run throughout. According to Dr C. Weisser at the Penn State University, a basic definition of sustainability in general terms is the capacity or ability to bear or to remain or to continue. In today's time, sustainability focuses on energy and resource preservation by omitting depletion for the sake of satisfying short term needs. When looking at the themes of the congresses throughout the decades, it is evident that environment became an important factor to address at the International Union of Architects' 14th congress in 1981, Warsaw, with the title "Architecture, Man, Environment". Educational and social notion have been addressed as early as 1965. As stated at the 18th World Congress of Architects, 1993, in Chicago with the title "Architecture at the Crossroads - Designing for a Sustainable Future" sustainability is:

> *'Meeting the needs of current generation without compromising the ability of future generations to meet their own needs'.*

Source: Uia-architectes.org (2018).

The International Union of Architects (UIA, founded in 1948, France) has held 26 congresses since 1948 and the next will be in Rio de Janeiro in 2020 with the title "All Worlds. One World. Architecture in the 21st Century", after which the topic of sustainability will be yet again addressed in the 2023 congress in Copenhagen with the title "Design for a Sustainable Future".

1.2 Global Status Review

Ecological footprint refers to the measured process of how fast resources are consumed and waste generated by us humans; this, compared to the speed of the waste absorption ability of the environment and to generate new resources, Ec.europa.eu (2018). The current stance of the earth is that the measured yearly consumption has overshot the generated new resources by 1.7 times. Since 2000 to last year the date of Overshoot Day have moved from late September to 2nd of August. This information, nonetheless the reduction, means that ability of the environment to absorb our waste and to generate new resources for the year to come, has been surpassed. In layman's terms it means that we have already consumed the yearly supply by beginning of August. As soon as we have consumed the supply available for the year, we start using next year's supply, moving evermore into a deficit, or in other words, debt. The date will continue to move earlier at the current rate that it is going and the strain we put on the environment is projected to surpass the earth's capability on the overshoot day of 2020 by as much as 75% and by 2030 the strain will be twice as much than earth can handle with world Overshoot Day at the end of June. If carbon emissions are reduced by as much as 30%, Ec.europa.eu (2018), the strain could be reduced to an overshoot of 50% by 2030 as shown in image below. This mean that Overshoot Day could be pushed back to mid-September, drawing closer to reaching breakeven again. According to a figure by Global Footprint Network (2018), the sum of carbon footprint and non-carbon footprint exceed the biological capacity of the Earth. The sum of the two is referred to as ecological footprint. See figures below,

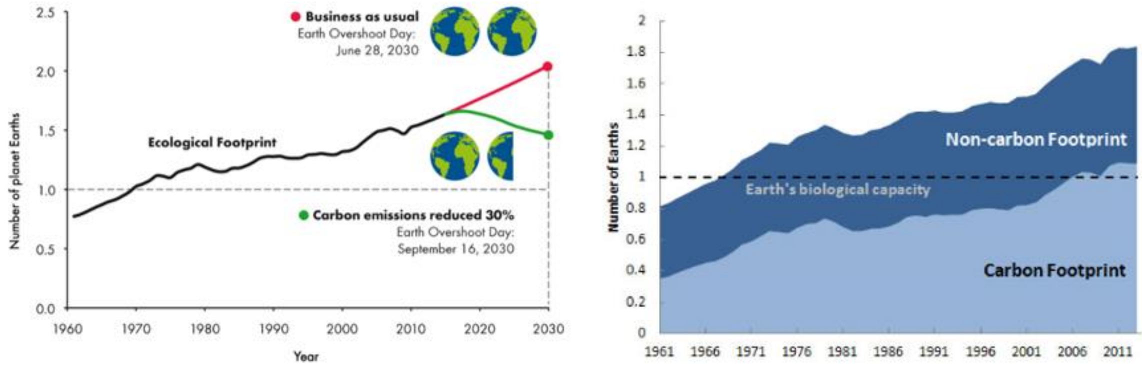


Figure 1.1 - Global ecological footprint status and projection (Source: Ec.europa.eu, 2018: Global Footprint Network, 2018)

Referring back to the quoted text from Schmutzenhofer (1992), "to utilize them to the greatest possible extent, but still in a way that future generations will have at least as much benefit" means to at peak break even with the biological capacity of the earth, but ideally to consume less so that the earth would have a buffer to reproduce and grow. It is crucial, according to the 18th World Congress of Architects, 1993, to go about life "without compromising", which refers to the surpassing of earths capacity. Without compromising means to not exceed, to avoid depletion. In layman's terms, it takes the earth one year and nine months to generate enough resources hat us humans consume in a year's time. If we can reduce the overshoot to 50% by the year 2030, as shown in figure above, then the time it will take 18 months to regenerate the resources consumed in a year.

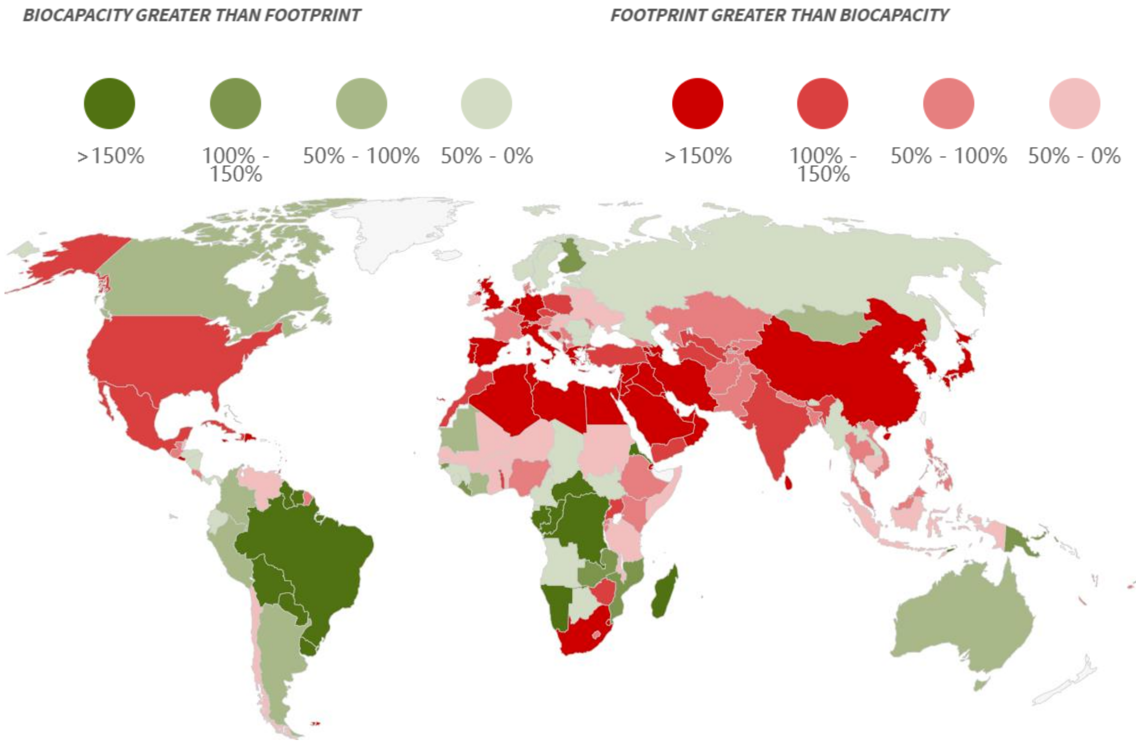


Figure 1.2 - Earth's biological capacity (Source: Data.footprintnetwork.org., 2018)

The figure above by Data.footprintnetwork.org (2018), illustrates the status of earth's biological capacity, also referred to as bio-capacity, with its consumption of each country and whether the capacity is greater than the footprint or not. Green represents the countries that possess bio-capacity reserve, which is measured by the percentage that bio-capacity exceeds the ecological footprint, which is what countries should aim for and achieve. Red represents the countries that have a bio-capacity deficit, which is measured by the percentage that ecological footprint exceeds the bio-capacity, which is what countries should aim to avoid. It means that countries are using the recourses that is meant for future generations. Depleting faster than the process to replenish takes. According to Data.footprintnetwork.org. (2018), the current top ten of countries with bio-capacity reserve include, at number one, French Guiana, Suriname, Guyana, Gabon, Congo, Central African Republic, Bolivia, Democratic Republic of Congo, Uruguay and in tenth place, Namibia.

Currently the top ten of countries with bio-capacity deficit include, at number one, Singapore, Bermuda, Reunion, Barbados, Cayman Islands, United Arab Emirates, Israel, Bahrain, Saudi Arabia and in tenth place, Cyprus. Factors that affect this rating include the area of the country in m^2, the amount of resources available, the type of resource and the population density in hectares per person. Other that South Africa, Zimbabwe in the south and Canada in the north, all the countries on and around the equator seem to have a deficit. This occurrence have to be caused by certain factors.

1.3 UAE Status Review

Factors that affect ones ecological footprint include the area of the country in m^2, the amount of resources available, the type of resource and the population density in hectares per person. This is calculated by taking the bio-capacity per person in gha, minus the ecological footprint per person, also in gha. According to the Ministry of Environment and Water (2015) the reported ecological footprint of the UAE was at 11.68 hectares per person in 2006. The reported ecological footprint of the UAE was at 8.4 hectares per person in 2012. According to The National (2018), the Ministry of Environment and Water reported the ecological footprint of the UAE was reduced to 7.75 hectares per person in 2014. According to footprintnetwork.org. (2018), the 2014 reading for United Arab Emirates: bio-capacity per person at 0.6gha minus the ecological footprint per person at 9.7gha showed a bio-capacity deficit of 9.1gha. Other readings also showed the population was at 9,086,139 people with a GDP of $39,034 per person.

The World Wide Fund for Nature (WWF) have produce a global ecological footprint report every two years, namely the ‘Living Planet Report.’ The first publishing of this report appeared in 1998 and results show the following patterns of data communication (indicators) for the UAE:

Table 1.1 - WWF global ecological footprint report (1998-2016)

The World Wide Fund for Nature (WWF) global ecological footprint report	**Population**	**CO^2 emissions**	**Consumption pressure**	**Ecological footprint**	**Energy footprint**	**Biological capacity**	**National ecological deficit**
1998 - UAE national and regional consumption per person per year: (1995 data)	2.38 mil	29.67 tons	2.61				
2000 - UAE national and regional consumption per person per year: (1996 data)	2.26 mil	13.58 tons		15.99		0.68	15.31
2002 - UAE national and regional consumption per person per year: (1999 data)	2.6 mil			10.13 gha/p	7.74 gha/p	1.26 gha/p	8.88 gha/p
2004 - UAE national and regional consumption per person per year: (2001 data)	2.3 mil			9.9 gha/p	7.5 gha/p	1.0 gha/p	8.9 gha/p
2006 - UAE national and regional consumption per person per year: (2003 data)	3.0 mil			11.9 gha/p	9.06 gha/p	0.8 gha/p	11.0 gha/p
2008 - UAE national and regional consumption per person per year: (2005 data)	4.5 mil			9.5 gha/p	7.82 gha/p	1.1 gha/p	8.4 gha/p
2010 - UAE national and regional consumption per person per year: (2007 data)	6.04 mil			10.7 gha/p	8.0 gha/p	0.6 gha/p	10.1 gha/p
2012 - UAE national and regional consumption per person per year: (2009 data)	7.67 mil			10.7 gha/p	5.9 gha/p	0.4 gha/p	10.3 gha/p
2014 - UAE national and regional consumption per person per year: (2010 data)	8.264 mil			7.8 gha/p	5.8 gha/p	0.4 gha/p	7.4 gha/p

2016 - UAE national and regional consumption per person per year: (2013 data)	9.01 mil			larger than 7.0 gha/p	5.8 gha/p	≤ 10 mil/ 9.01mil = ≤1.1 gha/p estimated biocapacity per person	+- 5.9 gha/p
*First table to be included to initiate the understanding and correlation between the supply and the demand within the topic of biocapacity, THE WORLD'S ECOLOGICAL FOOTPRINT AND BIOCAPACITY, 1999. Global Biocapacity supply is 1.9 gha/person and the demand is 2.28 gha/person.							

Source: Author; The World Wide Fund for Nature (WWF) Living Planet Report (1998-2016)

1998 - UAE national and regional consumption per person per year: (1995 data)

Population 2.38 mil, CO^2 emissions annually 29.67 tons, Consumption pressure - average consumer equivalent 2.61. This was the first attempt at producing a worldwide status report on how large countries' footprints are and factors that effect it within the chosen parameters.

2000 - UAE national and regional consumption per person per year: (1997 data)

Population 2.26 mil, CO^2 footprint 13.58 tons , Ecological footprint per area units per person 15.99, Biological capacity per area units per person 0.68, National ecological deficit per area units per person 15.31. The year 2000's report shaped the structure of organized parameters that effect the ecological footprint. A more comprehensive output of data collected, to set the standard measurements for evaluation. As from this publication the consumption pressure measure fell away and more detailed evaluation measures were put in place, namely, the ecological footprint, bio-capacity and the reserve or deficit indicator.

2002 - UAE national and regional consumption per person per year: (1999 data)

Population 2.6 mil, Ecological footprint 10.13 gha/p, Energy footprint 7.74 gha/p, Biological capacity 1.26 gha/p, National ecological deficit 8.88 gha/p. The year 2002's report was written on the same structure laid out in 2000's report but a small change was made to introduce the measure of energy footprint, which included the CO^2 emissions from fossil fuels, but was coupled with the fuelwood, nuclear and hydro to give a total energy footprint. **First table to be included to initiate the understanding and correlation between the supply and the demand within the topic of bio-capacity, THE WORLD'S ECOLOGICAL FOOTPRINT AND BIO-CAPACITY, 1999. Global Bio-capacity supply is 1.9 gha/person and the demand is 2.28 gha/person.

2004 - UAE national and regional consumption per person per year: (2001 data)

Population 2.3 mil, Ecological footprint 9.9 gha/p, Energy footprint 7.5 gha/p, Biological capacity 1.0 gha/p, National ecological deficit 8.9 gha/p. Structure of evaluating indicators and parameters was steady.

2006 - UAE national and regional consumption per person per year: (2003 data)

Population 3.0 mil, Ecological footprint 11.9 gha/p, Energy footprint 9.06 gha/p, Biological capacity 0.8 gha/p, National ecological deficit 11.0 gha/p. Structure of evaluating indicators and parameters was steady.

2008 - UAE national and regional consumption per person per year: (2005 data)

Population 4.5 mil, Ecological footprint 9.5 gha/p, Energy footprint 7.82 gha/p, Biological capacity 1.1 gha/p, National ecological deficit 8.4 gha/p. Structure of evaluating indicators and parameters was steady. **Increase in bio-capacity was due to a natural resource that was discovered in the form of oil.

2010 - UAE national and regional consumption per person per year: (2007 data)

Population 6.04 mil, Ecological footprint 10.7 gha/p, Energy footprint 8.0 gha/p, Biological capacity 0.6 gha/p, National ecological deficit 10.1 gha/p. Structure of evaluating indicators and parameters was steady.

2012 - UAE national and regional consumption per person per year: (2009 data)

Population 7.67 mil, Ecological footprint 10.7 gha/p, Energy footprint 5.9 gha/p, Biological capacity 0.4 gha/p, National ecological deficit 10.3 gha/p. The last report the structure of evaluating indicators and parameters was steady.

2014 - UAE national and regional consumption per person per year: (2010 data)

Population 8.264 mil, Ecological footprint 7.8 gha/p, Energy footprint 5.8 gha/p, Biological capacity 0.4 gha/p, National ecological deficit 7.4 gha/p. Structure of evaluating indicators and parameters changed in terms of illustrating the data and the table format of data disappeared and more graphs were used. Attention moved away from hard data reporting to real time case studies of countries and industries. It became more focused on the distribution and percentages of each subcategory, for example, what percentage of energy is consumed by which sector. This gave a weight to the included sector and by dividing the overall energy footprint into sectors, it made it easier to target the culprit and to evaluate what effect the implementations made in the sector.

2016 - UAE national and regional consumption per person per year: (2013 data)

Population 9.01 mil, Ecological footprint larger than 7.0 gha/p, Energy footprint 5.8 gha/p, Biological capacity per country is smaller than 10 mil/ 9.01mil = smaller than 1.1 gha/p estimated bio-capacity per person, National ecological deficit 5.9 gha/p. The 2016 report proved to be generalized data on a global scale. Not giving specific data per country anymore, but more focused on how to address the deficit and to reduce consumption and the rate of depletion. It focuses on how to increase renewable resources and to protect the diminishing of habitat of endangered species. It focuses on efficiency and policy making and standard and goals to reach to reduce the world overshoot percentage.

Although the report gives crucial insights on the global stance, this style of reporting does entail significant shortcomings. According to Ec.europa.eu. (2018) the list include:

1. The methodology. It needs to be improved and developed as it currently shows a perception of scored points for weaknesses.
2. It calls for a more robust message in terms of policy; the choice and the weighing of input variables need to be modified as it might give a different impression of the message that is indicated.
3. Diverse elements. ‘The fact that a single figure is obtained does not guarantee that its interpretation is straightforward.’ An estimation of demand or consumption of bio-capacity is expressed which include a variety of sub-components that do not necessarily correlate.

4. Limited scope. This concept is not a holistic representation of the environmental problems. Segregation need to be made between the capacities of non-regenerative resources and that which can be classified as biologically productive.
5. Data quality reliability. Input variables of the environmental database need to be of high and reliable quality on which the analysis rely. This statistical input data need to be a completed set of values. The missing values need a reliable estimation method and unified standard to minimize the error margin.
6. Total transparency of the judgements (due to lack of documentation), the assumptions (due to lack of documentation) and the selection on each of the decision making stages to compile the conglomerated values of what is included in the input factors and variables. Also transparency on point 5.
7. Weight factors should be scientifically justified. The calculation of it should include an environmental pressure coefficient.

It should be viewed as a worthy attempt at a standardized evaluation metric of the status of each country and it should be used as a platform for policy makers to develop a set of standardized guidelines, which include methodologies for validations and on attributions. It should contribute to the standardization of local and international environmental laws and standards.

1.4 Research motivations/ drivers:

Popular topics and trends which are drawing more focus and is of interest for researchers to explore:

- This part of the region has a very strong sustainability vision in place where every ministry has a drive or push towards sustainable design.

- Due to the stewardship from the government to push towards sustainable design, the reducing in energy consumption also comes into focus.
- There is a focus on the performance of outdoor thermal comfort of existing communities in Dubai, UAE.
- There is a focus on the performance of indoor thermal comfort of existing buildings in Dubai, UAE.
- There is a focus on the energy consumption of existing buildings in Dubai, UAE. The region has one of the highest consumption of energy rates, thus the need to reduce energy consumption.
- Although there are strong guidelines regarding energy consumption of buildings, the focus will be on residential buildings due to the sector's high consumption rate.
- There is a need for sustainability.
- There is a call to stop the use of fossil fuels for energy and going into renewable energy resources.
- There are sustainability checklists, like LEED and Estidama
- There is a need for more improvement and a need to carry out more research in the area in order to improve for optimization.

1.5 Aim and Objectives

1. The aim of this research is to investigate potential solutions to enhance the macro and micro climatic performance of outdoor thermal comfort of an existing community in Dubai, UAE and hopefully include the reduction in the energy consumption at building (villa) level by analyzing data against the DEWA bills in summer, peak load.

Objectives

2. To review and assess the current status of the existing conditions in communities in the UAE. General, all communities. Status to obtain a better understanding of the strategies and methodologies used in UAE.

3. To select a case study, existing urban community in the UAE to act as a main case study for this research.

4. To identify urban sustainable strategies by literature review combined with a questionnaire / survey that will help to enhance macro and micro climatic performance for thermal comfort.

5. To run the simulation for base case and revised cases to find an optimized case regarding each proposed strategy in terms of outdoor thermal comfort conditions.

6. To conduct a comparison of the sustainable strategy results against the base case model to see/ assess the success level.

7. To input the optimized outdoor conditions into the building level simulation

8. To analyze the effects that the outdoor optimization has on the energy consumption of the building (villa).

9. To draw future recommendations

The overall aim of the study is to enhance the thermal comfort of outdoor conditions to reduce the energy consumption of residential developments/ communities in Dubai, UAE. It is very important that the parameters proposed in the research document reflect the strategies which will help in achieving the aim.

1.6 Research outline

Listed and stated what are to be covered in the chapters.

The introduction chapter of the dissertation provides an overview of the concept of sustainability. It provides information on the topics of ecological footprint, bio-capacity and gives indications of status on a global and on local level.

Chapter 2, the literature review chapter, is a thorough revision of the importance of sustainability, outdoor thermal comfort factors of urban communities and of what is going on in the realm of academia focused on these topics. It consists of a critically evaluated analysis of published research papers which was collected through an academically accepted platform. It is communicated in a conglomerated manner to surely understand the level of complexity of which the research topic has reached. It is to give a clear review on the background of the research, where the gap in the research is, and what this dissertation aims to achieve.

Chapter 3, the Methodology chapter, highlights the importance of the methodologies available and will address the implementation effects. This is not only to illustrate a detailed layout of how the research is to be conducted, but also include a thorough analysis of past, present and possible future techniques and tools used in the area of study. This chapter illustrates a step by step guide of the processes that will be included in the study and to serve the reader with validated justifications of method choice and reasoning for a clear understanding of the thought processes.

Chapter 4, the Site selection and Simulation chapter, introduces the environmental and building criteria. It covers the site visits, synopsis, and climatic profile of the region and area. From the second, third and fourth chapters, strong emerging strategies are identified and discussed. The validation process, and the model setup of the simulation, conclude chapter 4, before moving on to the simulation run, results and discussion section.

Chapter 5, the Analysis and Discussion chapter, cover the in-depth discussions of the thirteen different simulations that were run and to compare and conclude the evaluating parameters' results and finding, before concluding the research.

Chapter 6, the Conclusion and Future Recommendations chapter, follows on the section discussing the findings of the simulation. It consists of cross-referencing the findings with the initial (and revised) aim and objectives to determine what was achieved by the dissertation study, what was not covered nor included, and also consists of posing recommendations for future studies to be conducted which may tie in with and contribute to the research in the field.

1.7 Projected timeline of the Dissertation

Starting date: 15 November 2017 as per The British University in Dubai schedule. Part time 8 months (34 weeks), Full time 4 months (17 weeks).

Literature review: weeks 1 and 2. Research, gathering of data and the development of the different strategies and inputs for the models: weeks 3, 4 and 5. Determining the most efficient/ optimized case layout together with floorplans: weeks 6, 7 and 8. Simulations of the models: weeks 9, 10, 11 and 12. Analysis of the data outputs and findings: weeks 13 and 14. Compilation of the dissertation writing and formatting: weeks 15, 16 and 17. (In the case of full time, weeks allocated to each section x2).

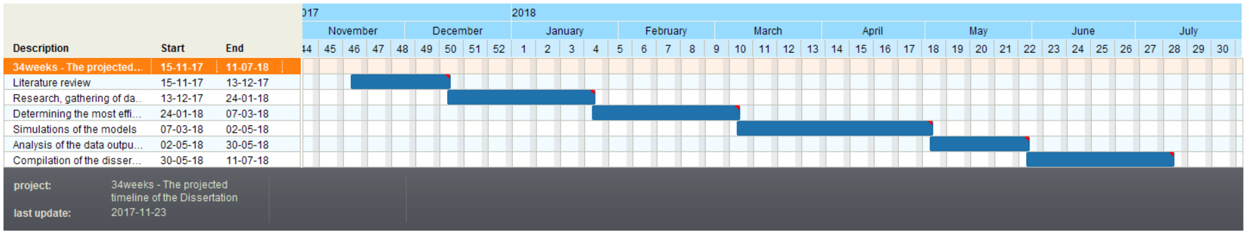


Figure 1.3 - Projected timeline chart (Source: Ganttify, 2017)

CHAPTER 2

LITERATURE REVIEW

Introduction to Chapter 2

The literature review chapter is a thorough revision of the importance of sustainability, outdoor thermal comfort factors of urban communities and of what is going on in the realm of academia focused on these topics. It consists of a critically evaluated analysis of published research papers which was collected through an academically accepted platform. It is communicated in a conglomerated manner to surely understand the level of complexity of which the research topic has reached. It is to give a clear review on the background of the research, where the gap in the research is, and what this dissertation aim to achieve. The literature review include some definitions but is focused on process of data collection, analysis and critical thinking. After having a clear objective for the literature review the following chapters will highlight the importance of the parameter and will address the implementation effects.

The topic of sustainability has sparked a lot of interest on the global platform, which is open for discussions and involvement to address the issue. Such meetings include forums, conferences, webinars and institutions that are actively increasing the focus of research within the environment. Intergovernmental Organizations that are on the forefront of sustainable sector include United Nations (UN) which have various agencies for environmental efforts such as United Nations Environment Programme (UNEP), United Nations Economic and Social Council (ECOSOC), Committee on Food Security and Sustainable Development (CFSSD), Food and Agriculture Organization of the United Nations (FAO), Sustainability Pathways, UNESCO (United Nations Educational, Scientific, and Cultural Organization and lastly Science for a Sustainable Future (UNESCO). Other international agencies include Green Growth and Sustainable

Development (OECD), Intergovernmental Panel on Climate Change (IPCC), International Labour Organization (ILO), Sustainable Development (ILO), OECD (Organization for Economic Cooperation and Development), Organization of American States (OAS), Sustainable Development (OAS), United Nations Development Programme, United Nations Development Programme Evaluation Resource Centre, AccessUNDP, United Nations Research Institute for Social Development (UNRISD), UN-WIDER, The World Bank, World Bank Projects and Operations, Sustainable Development (World Bank) and lastly Worldwatch Institute. Such meetings or forums focus on social, economic, and environmental perspectives.

Figure 2.1 - The four defining pillars of the successful 21st century organization (Source: Lombardi, 2018)

Non-governmental Organizations include African American Environmentalist Association (AAEA), Sustainability American Society of Civil Engineers (ASCE), American Solar Energy Society, Climate Institute, Environmental Defense Fund, Global Green USA, Greenpeace International, International Institute for Energy Conservation (IIEC), International Institute for Environment and Development (IIED), National Council for Science and the Environment (NCSE), Natural Resources Defense Council, Resources for the Future, Science & Environmental Policy Project (SEPP), Sustainable Buildings Industry Council, Union of Concerned Scientists, US Green Building Council {USGBC), The Water Page and lastly World Association for Sustainable Development (WASD).

2.1 The Importance of Sustainability in Urban Communities/ Developments

One of the more recent important topics in sustainable development and urban planning has to be the phenomenon of cities' rapid urbanization. Rapid urbanization refers to the process of a fast-moving shift of the population from the rural areas into urban areas. The ratio increase of the quantity of people living in urban areas, related to the quantity of people living in rural areas. This phenomenon frequently lead to undesirable environmental impacts within the urban microclimate, and a reduction in vegetation and an increase in pollution. The negative changes in the microclimate directly affects the outdoor climatic conditions and more importantly the outdoor thermal comfort. The Intergovernmental Panel on Climate Change IPCC. (2018) estimates the increase in temperature at least 0.2 degrees Celsius per decade. This means that extreme weather events will become more frequent in the near future, especially stronger and longer lasting heat waves in hot regions which will result in increased manifestations of heat stress and other heat-related diseases. This scenario coupled with the high level of pollution in urban areas tend to have a detrimental effect human performance and comfort and show an increase in pollution related illnesses and human mortality rate in these conditions. The impact of this in urban areas are a fraction more intense as the heat-island effect also play a role in the increased ambient outdoor air temperature of the outdoor environment. The physical environmental factors affecting the microclimatic conditions are fabric density, materials, mass, height of buildings, distance between buildings (also referred to as right of way/ ROW) and land coverage/ land use budget. Climatic parameters affecting the outdoor thermal comfort are solar radiation and reflectance, wind direction and speed, relative humidity, etc.

Challenges of the urban environment/ fabric are on the governance of the industry. Due to the fact that buildings are usually individually designed and the only way to control this is very strict regulations from council. These urban and architectural regulations are put in place to steward development in a given time frame. The usual regulations include instructions on area zoning, public urban spaces and parks, roads and public transportation networks, building height and footprint, ROW, etc. Thus it can be concluded that the city council regulations play an enormous part in the urban environment and is directly related to the formation of the microclimatic conditions of a given city. It is crucial for the parties involved within the built industry to be not only knowledgeable about the impact on climatic conditions, but to actively incorporating the knowledge into strategies within the planning and design phases to ensure optimal outdoor thermal conditions. Challenges, Solutions, Success Rate,

2.2 Urban communities: outdoor thermal comfort.

Many studies focus on indoor thermal comfort and only in the last decade have outdoor thermal comfort became an area of interest. Most studies focus on indoor and thus resulting in a need to research and contribute to the outdoor thermal comfort studies. The limitation that the industry face is that designs are based on the climate profile of a region and little to no research and measurements are done on the existing neighborhood's microclimatic condition. It is evident that there is a pressing need for more weather stations that are strategically placed within smaller urban areas/ neighborhoods to determine a more accurate microclimatic profile to be used for design in the designated area. In the meantime simulation modelling software are to be used to determine the best case scenario, by testing theories and strategies. According to Thani et al. (2013), the ease of participating in outdoor community activities, and the promotion of wellbeing of individuals within the community, is reliant of the outdoor thermal comfort. According to Chen & Ng (2012), the discomfort of outdoor thermal conditions impairs the everyday functionality of the individual in the given urban community and may render them completely incapable in some or most instances during certain seasons. According to Boumaraf & Tacherift, (2012), the UK and US have made various efforts to enhance the outdoor environmental conditions for participation in recreational activities to relieve stress and promote wellbeing of the highly stressed working class. These spaces include green areas and promote physical activity, and relaxation. It is found that high stress levels, coupled with family separation, can impair an individual's performance and wellbeing, thus these strategies and implementations aid as a rehabilitation form of the previous conditions and add on the argument of importance of outdoor condition. With the focus on microclimates and specializing in outdoor thermal comfort, the parameters/ strategies believed to contribute in enhancing the outdoor thermal comfort in hot arid climates are courtyards, open spaces, height to width ratio, orientation, landscaping such as vegetation types and placement, water features and fountains and outdoor floor materials. A study done by Achour-Younsi & Kharrat (2016) focused on outdoor thermal comfort of urban street canyons and the effect of urban morphology has on it, in this case in specific the effect of the geometry. It consists of a comparative study including three different city fabrics. The street scape is seen as a transitional space between building scale and urban scale and the connection to communicate each to the other. Factors affecting microclimatic conditions include the following: Height of buildings, Relative humidity, Sky View Factor, Air Temperature, Mean radiant temperature, Universal Thermal Climate Index, Wind speed and Width of street. Achour-Younsi & Kharrat (2016) agrees that the area of study is recent and that most studies in the past have focused mostly on indoor conditions. The complexity of the outdoor thermal comfort studies lie in the fact that there are much more factors affecting the outdoor environment, less control and little information available on how these factor interact with each other. The three classifications of these factors are climatic factors, personal factors and contributing factors. As the climatic factors can be safely measured and forecasted, it is suggested that it be the one studies focus on when dealing with thermal comfort. With the study focus on height to width ratio and the similarities of one of the chosen sites to the base case of study, it should be an interesting comparison of the results and outcomes. Most papers sited draw emphasis that outdoor thermal comfort is highly complex and that the physical, psychology, and social factors all interact. There is a sense of adaptability to a certain extend regarding the behavior of humans when they are exposed to sensory influences within the outdoor environment.

Determining what parameter will be applicable for the case of UAE will be is most important for the study and will be discussed in depth under the following headings:

2.2.1 Orientation

According to Sustainabilityworkshop.autodesk.com (2018), orientation together with building mass is the most important factors with regards to visual and thermal comfort. Focusing on the outdoor thermal comfort by optimizing orientation and keeping the mass as is in the base case. Orientation is the angle that the long façade of the building is facing and is measured by azimuth.

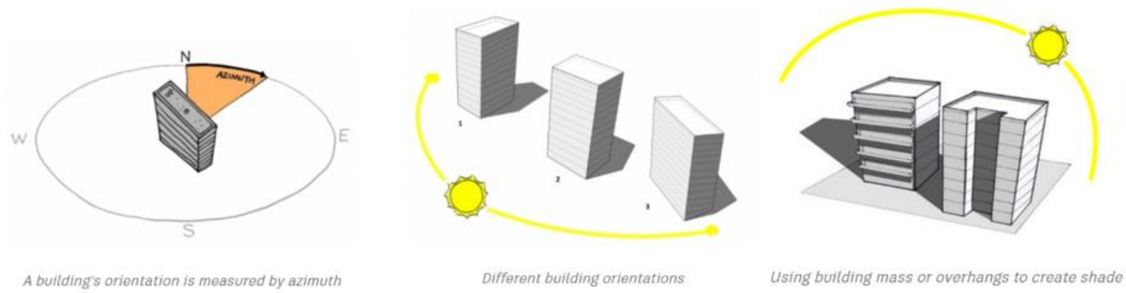


Figure 2.2 - Building orientation (Source: Sustainabilityworkshop.autodesk.com, 2018)

Successful orientation also contributes to good ventilation, self-shading, daylighting and to the social interactive aspects. Visually it is preferred to be East-West orientation. This results in good daylighting factor, controlled glare at sunrise and sunset times. Maximize the % of North and South walls by cutouts on east and west façade to provide self-shading, according to Sustainabilityworkshop.autodesk.com (2018).

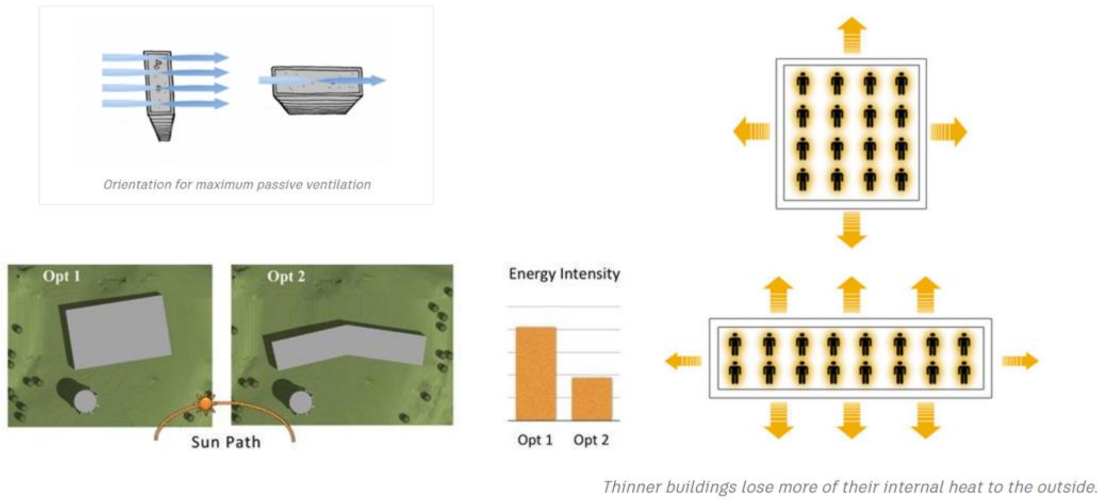


Figure 2.3 - Building form (Source: Sustainabilityworkshop.autodesk.com, 2018)

Thermally the orientation of thermal comfort is the same as daylighting, BUT optimizing daylighting also increase heat gain. Orientation of daylighting from North, avoiding direct solar and control glare. The West facing walls for heat storing. Ventilation aimed at the wind rose diagram/ Wind wheel. Yearly for optimal orientation, and monthly for crisis months (July, August). Very important for building in arid climates where cooling is required to have courtyards that are orientated at 45 degrees from the prevailing winds. This will optimize wind at courtyard and the cross-ventilation throughout the entire building. Orientation and massing is NB early on in the design. Massing for energy and program density regarding cooling - a thinner floorplan results in a less energy intensive building design as the main heat gain is on the east-west axis. Advantages for the building to have a thinner floorplan regarding program will result in better daylighting and thermal and visual comfort according to Sustainabilityworkshop.autodesk.com (2018).

According to Greenpassivesolar.com (2018), building orientation should be within 5 degree orientation of true south, but studies have shown that anything within 15 degrees will function just as well. According to Nachi.org. (2018) orientation can be adjusted by up to 20 degrees to accommodate external factors. Building orientation is considered to be one of the factors that is crucial for the holistic study of the environment. Orientation can also refer to the process of educating and introducing knowledge to urban communities, which are used to address the resistance of urban transformation. Passive urban configuration parameters include orientation and the study of height to width ratio. It has been found that the correct and optimal orientation tend to have an advantageous effect on solar heat gain and to offer self-shading to control direct solar exposure. Orientation refers to the sitting of a building not only on the site but also in the context and with relation to north. A Building or development is orientated for solar design. Not only the building materials, but also the orientation of the building are used to minimize solar gain and to optimize daylighting. The ideal site orientation are situated along the east to west axis and performance studies have shown little changes within 15 degrees swivel at this placing. Building orientation studies have been done and these studies include construction materials used in the process and the quantity of greenery that were introduced and at end to measure the air temperature and ventilation. According Pakzad and Salari (2018), the article has measured them if the morphological characteristics blocks by comparing the existing situation to the principles of sustainable development of urban form and evaluating the results. Apart from orientation the main morphological characteristics also include block size and configuration and at best referring to the block length and the urban fabric/ grain. Morello et al. (2009) recommends that the block orientated along the east west axis. The reason for this is that the energy consumption allocated for lighting surpasses the consumption for space heating. After extensive research and data grouping the authors have concluded that there were previously no clear set out principals regarding the topic of urban blocks. The site that had been studied do not possess a determined optimal block orientation and is best to aim for a neutral orientation to avoid undesirability. According to Shen et al. (2018), adapting a proper development orientation can be viewed as an adequate method used to promote the economic and social aspects of rural underdeveloped areas and at end will have a direct positive correlation to the attractiveness regarding the investment. It was found that previous studies do not provide or suggest valuable methods for existing rural townships to adopt regarding improvement on the development orientation to attract investments and this is exactly what the paper aimed to address. The models that were adopted show limitation with respect to the factor resource endowment available and strongly suggest that agritourist is the way to go in these situations to optimize the attractiveness of investments.

The gap in the information available and where there are little to no information available in the industry is on the evaluation of the different layouts of building orientations of not only the buildings itself, but also of the urban communities as a whole and the effect it has on outdoor and indoor thermal comfort.

2.2.2 Coverage construction materials

According to a study done by Cook et al. (2013) the importance of material colors were stressed and experiment results showed that lighter colors' thermal performance were more positive than the darker colored material cover. Measurements also showed favorable results related to the surface temperature, especially when compared to materials such as asphalt. An experiment on the different paving materials were done by Yang & Zhao

(2015), using the method of water exposure with a duration of 10minutes. Results of the strategy of reducing surface temperature were successful, so successful that the reading of the surface temperature dropped below the reading of the outdoor air temperature, supporting the argument of introducing evaporative cooling as strategy for regulating outdoor thermal environments. Clay tiles, however did not perform so well with the evaporative cooling strategy as signs of dampness were evident the duration of the day, this moisture coupled with high humidity can be troublesome and are one of the scenarios to monitor when introducing the strategy. According to a study by Ali-toudert and Mayer (2006), the paving material application of thick 100mm earth contacted concrete slabs contain the properties of thermal storage and delays, which cool in the evenings. The delay consists of at least an hour in the morning time and optimal placement of the material is in the shade. According to Yang & Zhao (2015), this type of paving does not perform as well in direct solar exposure, stressing the importance of outdoor coverage material choices and the effect it has on the outdoor environment. Mathew et al. (2017) found that natural soil tend to heat up and cool down more rapidly than the conventional paving and road surface materials and when covered with these paving's it has an effect on the behavior of the surface temperature. The replacing of natural soil or vegetation by impermeable paving or road materials reduces the rate of success of evaporative cooling, thus contributing to the heat island effect in cities. The study resulted in reading where vegetation was at least 11 degrees Celsius less than that of soil, concrete, concrete block and roads. In summer time the surface temperature showed a 17 degrees Celsius difference with vegetation the most successful. The study showed daytime readings of the surface soil to surpass the temperature reading of concrete and cement and cover materials alike, but at night time the soil cooled down much faster as the thermal storage capacity and conductivity differ. The occurrence of soil temperature to be higher than cover materials are only seen up to 3pm. The plotted curve of surface temperature readings also show that vegetation as ground cover are more stable in the sense that the fluctuation in surface temperature is more compact. Erell et al. (2014) found that for mitigating temperature in urban areas, large quantities of high-albedo materials should be used. Studies show a reduction in air temperature, but in heavily dense urban fabric areas it will not be sufficient to lighten the thermal load. This at end will affect pedestrian thermal outdoor comfort in a negative manner. It is evident that cities contain large quantity coverage with impermeable materials and there are many studies that support the use of high-albedo materials or cool pavements in such instances, that the urban planners have incorporated this knowledge into the city regulation to improve the thermal environment and to mitigate thermal gain. Studies have found that the application of these materials in urban areas had a temperature reduction of 1.5 degrees Celsius in the peak summer times. The study show that when introducing this material on external wall surfaces and ground it not only has a reduction in surface temperature and long-wave emissions, but also may have a negative effect of pedestrians as it increases the solar radiation reflection. The application on roofs show to be favorable. It is suggested that it will be successful when applied in large quantities vertically and horizontally and at fullest cover. According to a study done by Meng et al. (2016), the use of retro-reflective materials can have a reduction of 10 degrees Celsius on the outdoor surface temperature. High-reflective materials are also referred to as cooling materials. Properties of this materials are in correlation to statements made by Erell et al. (2014). The study also supports findings related to urban heat gain with increase solar radiation reflection and surface temperature long-wave emittance. How this retro-reflective material works is when solar radiation contacts the material, it is not reflected at right angle, but is reflected to the opposite side back to its source by the aid of a thin film. The study include a comparative model where one model is without retro-reflective material and the other has the application. Results show that outside air temperature show a slight reduction in daytime with the application of the retro-reflective film but are the same during night time. A significant reduction is found regarding the indoor temperature with a fluctuation of 8-10 degrees Celsius.

2.2.3 Greenery

Mathew et al. (2017) found that natural soil tend to heat up and cool down more rapidly than the conventional paving and road surface materials and when covered with these paving's it has an effect on the behavior of the surface temperature. The replacing of natural soil or vegetation by impermeable paving or road materials reduces the rate of success of evaporative cooling, thus contributing to the heat island effect in cities. The study resulted in reading where vegetation was at least 11 degrees Celsius less than that of soil, concrete, concrete block and roads. In summer time the surface temperature showed a 17 degrees Celsius difference with vegetation the most successful. The study showed daytime readings of the surface soil to surpass the temperature reading of concrete and cement and cover materials alike, but at night time the soil cooled down much faster as the thermal storage capacity and conductivity differ. The occurrence of soil temperature to be higher than cover materials are only seen up to 3pm. The plotted curve of surface temperature readings also show that vegetation as ground cover are more stable in the sense that the fluctuation in surface temperature is more compact. Morakinyo et al (2018) conducted a study on thermal comfort and saving energy by simulating the most common tree species on a typical summer's day to see to what extent the outdoor temperature could be regulated. Significant findings were observed when studying the base case, current case and optimized case. Optimized case had 30% GCR (greenery coverage ratio) and had a temperature decrease of between 0.5-1.0 degrees Celsius with an energy saving of 1900-3000kWh. The success of the results came down to species specific application and stressed the importance of the tree species that are to be chosen when designing a site that is climate sensitive. The most important factor of the selection of tree species is leaf area index, followed by the height of the trunk, the height of the tree and the diameter of the crown. Various studies on thermal comfort have been conducted and focus included materials, morphology and insulation and none show the beneficial extend that the introduction of greenery and green spaces show. It positively affects the ambient temperature, thermal comfort and energy consumption by providing evapotranspiration and shading. By the provision of shading the ground surface temperature, soil temperature, air temperature and sensible heat gain are reduced. The mean radiant temperature is the key measure of outdoor thermal comfort and in this case the thermal comfort is more desirable in the shade. The dissipation of water vapor from the leaves' stomata also has a cooling effect not only on the leave surface but also on the immediate surrounding environment. The study also included an exploration of the urban morphology and flow angles. The introduction of trees to low density urban areas prove to be highly beneficial, and tend to be the opposite in the reversed case (high density areas) due to wind and air flow restriction and obstruction, thus the need for the study on morphology and flow angles to determine if there can be exceptions to the rule in the case of high density areas. When referring to greenery, there are usually three categories which are included namely grasses, shrubs and trees. It is found that of the three different plant species trees are the most efficient in reducing outdoor microclimatic temperatures. This is regarded as results on urban scale and not site specific. It is found that greenery reduces the dry-bulb temperature of the outdoor conditions by evapotranspiration as is regarded as a strategy for urban heat island mitigation. Result indicate reduction of ambient temperatures of up to 4 degree Celsius, QIU et al. (2013). Zhang et al. (2018) ran a simulation on ENVI-met software to determine which the most efficient combination of species and configuration of vegetation trees species are. The most efficient case found that height-to-distance ratio of trees should be less than 2 to have an impact on temperature reduction of environmental conditions. Prioritize tall trees with a large diameter and be wary of evergreen trees as it obstructs wind flow which is necessary for natural ventilation and cooling. The building layout and materials, roofs, pavement and landscaping are considered to be effective methods to mitigate high temperatures. Again the author supports the efficiency of trees to reduce outdoor temperatures above that of shrubs and grasses, mainly due to shade provision. As found in this section, the landscapes affect and Importance are of high value regarding the 17 degree drop in surface temperature, the up to 4 degree drop in outdoor air temperature and as much as 1900-3000kWh cooling load energy saving. The strategy aim is recommended to enhance the amount of greenery around the units and throughout the community. Previous studies rated it as the most important point when dealing with healthy environment in urban communities. Tolba (2015), states that or arid climates, landscaping and vegetation ought to be used for shading to ease the intense solar radiation throughout the summer time. Overheating is particularly due to the heat storage of sunlit surfaces. In these climatic regions there's a poor performance of evapotranspiration, due to the soil's deficiency of H2O. Specialists in the discipline stipulated that carefully positioned vegetation placed within the urban fabric to provide shading is excellent for dry and hot climate. In cold climates, vegetation and landscaping acts more suitably as a guard from prevailing winds, and climatologists recommend that densely spaced vegetation ought to be positioned on the urban edges.

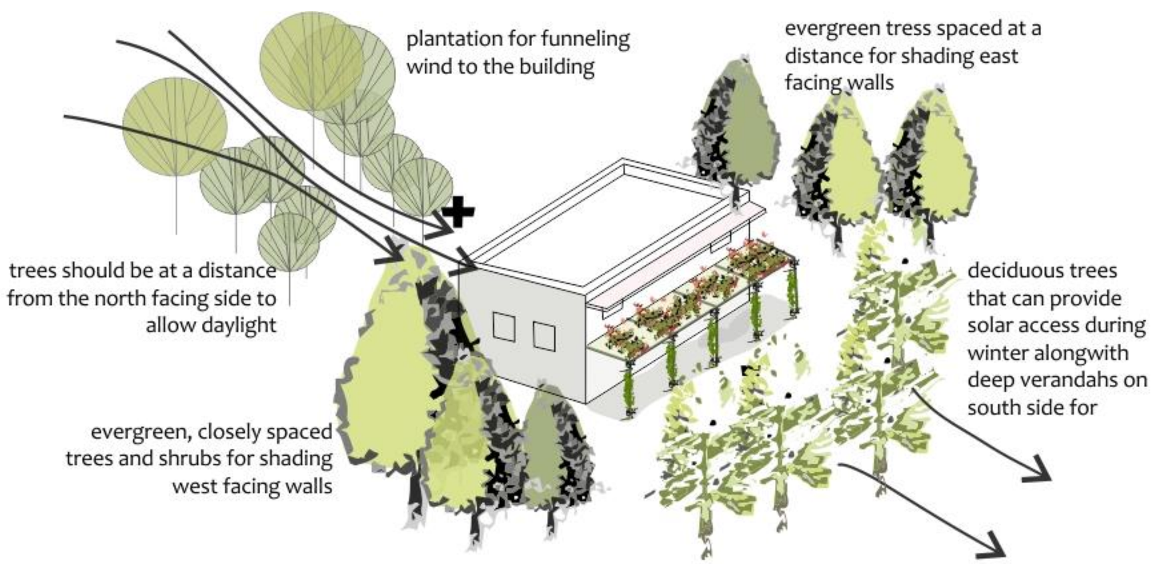


Figure 2.4 - Plantation control, achieving cooling and shading (Source: Tolba, 2015)

Zhao et al (2018), conducted a study in the arid region of Phoenix where the different configurations of tree placements were studied. The effect vegetation has on the microclimatic conditions were tested by clustered tree groupings, trees placed at equal intervals, and dispersed throughout the area of study. The arrangement of two trees at equal arrangements were most successful with a reduction of 1-1.5 degree Celsius and had the same effect as one tree in the center of the front yard would have. This is followed by clusters with overlapping crowns.

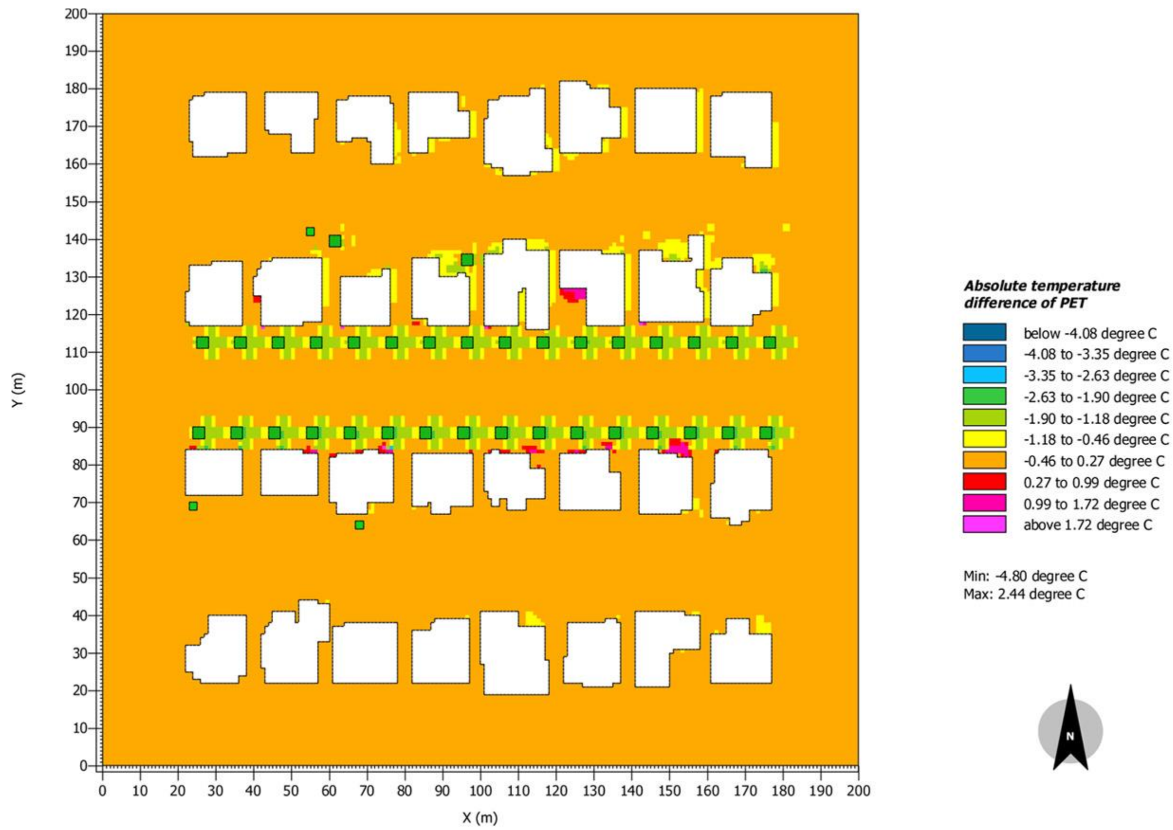


Figure 2.5 - Equal interval tree arrangement compared to no trees (Source: Zhao et al, 2018)

The most effective tree plan will couple the shading benefits and the efficient air flow conditions for adequate ventilation of the area of study, especially in hot humid climate. It is important to note that the proposed successful arrangements may not behave the same nor have the same results in a different climate and configuration. It is recommended that stewardship be taken by HOAs (home owners association) of given developments to ensure adequate climatic conditions throughout the developments.

2.2.4 Waterbodies

Water features are used to not only enhance the ambiance and visually pleasing public and private outdoor areas allocated for human use, but also to enhance the outdoor thermal comfort of the people utilizing these spaces. An experiment on the effect of water exposure on the different paving materials were done by Yang & Zhao (2015), as stated in the coverage materials section. The method of water exposure was done with a duration of 10minutes. Results of the strategy of reducing surface temperature were so successful that the reading of the surface temperature dropped below the reading of the outdoor air temperature, supporting the argument of introducing evaporative cooling as strategy for regulating outdoor thermal environments in hot climates. Clay tiles, however did not perform so well with the evaporative cooling strategy as signs of dampness were evident the duration of the day, this moisture coupled with high humidity can be troublesome and are one of the scenarios to monitor when introducing the strategy. Instead of continuous water exposure on paving materials it is recommended to introduce water features, still standing and with a spray to act as evaporative cooling strategy to cool the outdoor air temperature and to add moisture to the air as humidity conditions may be too dry for human thermal comfort conditions. The vegetation section explains the effect evapotranspiration has on outdoor thermal conditions which is also related to moisture content of the immediate environment. Morris et al. (2016) conducted a study on the effects that vegetation and waterbodies have on the urban microclimate of the city under focus. Vegetation, waterbodies and urban fabric were interchanged to see the effect. The results showed that waterbodies in the urban fabric with no vegetation performed poorly and had a negative effect on the thermal comfort, but coupled with vegetation it had the most efficient performance when reducing the urban heat island effect. Waterbodies boosted the performance of thermal reduction, compared to only vegetation introduced to the urban fabric. This is evident that when introducing the strategy of waterbodies, it should most probably be coupled with vegetation, the research aims to determine if this is the general case or only site specific. Results concluded a reductions of between 0.5-2 degrees Celsius. According to Amani-Beni et al. (2018), the study found that introducing waterbodies will have a positive effect on the outdoor thermal comfort and reduction in climatic temperature conditions and to enhance the comfort of relative humidity in China. It is noted that air temperature reduction can vary significantly due to the wind speed that flows over the water. The reduction in wind speed is due to obstructions in the area. Waterbodies that are clear in the open can reduce the temperature by 0.5 degrees Celsius. In this particular case where obstructions reduced the wind speed, the reduction in air temperature was hardly notable at 0.08 degree Celsius and caused the vast increase in humidity at 4.76% that made it more beneficial to only introduce vegetation and to keep large waterbodies to a minimum. It was suggested rather to make use of irrigation to aid vegetation cooling at grass level by up to 5 degrees Celsius compared to dry grass. Grass loose evapotranspiration effects earlier in the daytime and water need to be replenished for this effects to continue throughout the day. The reduction in wind speed equals an increase in humidity, thus the importance of wind speed as an influencer when conduction the study. In the case of hot humid regions this may result in negative effects and may increase discomfort with regards to the humidity reading. In these climatic regions the tree shading is most efficient. Taleghani, M. (2018) supports the notion of irrigation to aid vegetation with water replenishment for longer lasting evapotranspiration effects. According to a study done by Xue, S. & Xiao, Y. (2016), the effects of water in a moving form such as rivers or fountains have a more successful effect on the reduction of thermal temperature than that of still standing waterbodies. It was also found that even though the temperature reading where similar in situation with and without surrounding water feature, the participants showed a positive psychologically perceived comfort in conditions where waterbodies were present, especially when coupled with shading and vegetation. According to a study done by Karakounos, Dimoudi, A. & Zoras, S. (2018), the introduction of waterbodies in the form of a small lake resulted in a decrease in temperature of 1.6 degrees Celsius, but showed an increase in relative humidity by 6%. In the journals studied, the simulation readings were taken at 1.5m, 1.8m or at 2m above ground.

Evaporative cooling in hot arid climate. It is believed that evaporative cooling could work especially due to the fact that the community is not situated on the coastline, which means that humidity is not that big of a problem. Climatic conditions of coastal region is high humidity according to this study, but the inland has less humidity.

2.3 Emerged Research Questions

Based on the extensive literature review that has been conducted, the following concepts ad themes have been understood. The concept of sustainability and its origin have been covered. Information on the current status of the global and the local ecological footprint, bio-capacity and deficit have been covered and the results are bleak. Popular topics and trends regarding sustainability are surfacing and are growing not only more interest from the industry, but the topic is also growing more urgent. The importance and urgency of adopting sustainable living habits and mannerism to attempt to close the gap of supply and demand in terms of the bio-capacity of earth cannot be reiterated enough. The most logical approach would be to reduce demand to such an extent that the regenerative resources can stabilize and return to its producing cycle to start building up a biological reserve. This, however, will take generations to turn given the current stance and projections for the next few decades, thus it is our duty to push the ball to a roll immediately. Here is the list of questions related to the objectives previously stated that this research will try to answer:

- Are there any existing and/ or potential solutions, which could be adopted, to enhance the climatic performance of outdoor thermal comfort of an existing community in Dubai, UAE?
- What are the available solutions' effect on the evaluating parameters?
- Do these adopted solutions have a correlation with the performance of indoor thermal comfort?
- What is the effect on the performance of indoor thermal comfort?
- Will/ could this have an effect on the energy consumption of the unit?
- What is the effect on the energy consumption at building (villa) level?
- Can the correlation between outdoor thermal changes and the energy consumption of a unit be made?
- If any, what are the numbers with regards to DEWA bills?
- Are there any findings that could contribute in compiling a checklist/ index/ guidelines?

2.4 Revised objective

The problem: the extreme climatic conditions of the region and the effect it has on the cooling loads within residential buildings, may it be apartments or villas.

The revised objective of this research is to enhance the macro and micro climatic performance for outdoor thermal comfort of an existing community in Dubai, UAE, on an urban level, through applying different sustainable strategies to study the effect it has on the energy consumption at building (villa) level by analyzing data against the DEWA bills in summer, peak load.

The research will attempt understand what will happen to the energy consumption of residential developments/ communities if the environment is manipulated, by introducing variables that effect the outdoor thermal conditions.

2.5 Research limitations and focus

Upon the review of the literature that was collected and analyzed in the form of journals, various articles and information provided by organization which specialize on the topic under microscopic study focus, the following have been extracted and identified to be implemented into the study framework:

- Limitation regarding sustainability pillars: social, economic and environmental. Focus is on environmental pillar due to time constraints and limitation of the duration of the dissertation. Focus of environmental aspect of sustainability of an existing community in the case of UAE. The environmental pillar will have an effect on the other two as you cannot have one without the other.
- Limitations regarding weather conditions input should be set to the most extreme condition of summer time, ideally with heat gain at its highest, wind speed at its lowest, relative humidity at its lowest and peak load at its highest. These condition are unlikely to all be at the extreme at the same time, so the conditions of the day closest to the

worst combination should be modeled. This day was determined to be on 19 July 2017. Erell et al. (2014) aimed to improve the thermal environment and to mitigate thermal gain. The simulation was ran in critical conditions with peak summer time condition as input.

- The focus is on the residential developments, because the UAE footprint by demand sector indicates that residential households account for 57% energy consumption in the UAE, according to Footprintnetwork.org (2015), compared to 30% demand for business and industry sector and 12% demand for government.
- Focus on an existing community. Accessibility to UAE, to Dubai, to Al Waha community, to the site regarding approval to be on site, by proximity, by ease, and representative of a new developments in size and location expanding on the eastern outskirts of Dubailand. Access to the drawings in the form of a masterplan and floorplan of the unit's layout. Access to the site is crucial for site visits, site measurement and photographic evidence of community's architectural, urban and landscape fabric observations. Needed for validation of the software programs to be used in the simulation.
- Existing fabric in terms of form, proximity and relation of the adjacent structures should not be modified in this study as the focus will be on the existing outdoor urban environment and the changes in thermal conditions by implementing passive design strategies and decisions. By changing the built fabric, too many variables will be introduced, thus uncertainty of which variables caused fluctuations.
- Limitation placed on identified evaluating parameters, based on previous studies, include:

- air temperature, Yang & Zhao (2015) with a study moisture exposure;
- wind speed, Amani-Beni et al. (2018) with a study on the introduction of waterbodies;
- relative humidity, Achour-Younsi & Kharrat (2016) referring to influencing factors of microclimatic conditions;
- These are the most important and interconnected indicators and cannot be viewed without one of them. This is crucial to have a holistic understanding of the changes in environmental conditions.

2.6 Hypothesis

- Changes in the urban outdoor thermal condition can be partially achieved by the aid of passive strategies
- of passive strategies can produce favorable results in a reduction of the thermal temperatures (which means increased outdoor thermal comfort)
- The outdoor conditions will effect of the Indoor conditions
- Reducing the difference of the outdoor conditions with regards to the indoor thermal conditions should result in less strain on the cooling load
- Less strain on the cooling load of the unit should result in less energy consumption of the residence
- If the optimization can be applied on development or community level it has the potential impact on a far larger scale.

Summary of Chapter 2

Table 2.1 - Literature Review Summary: significant academic findings

Section of Literature : Orientation		
Findings	Author	Year of Publication
Block orientated along the east west axis.	Morello et al.	(2009)
Discomfort of outdoor thermal conditions impair the everyday functionality.	Chen & Ng	(2012)
UK and US have made various efforts to enhance the outdoor environmental conditions.	Boumaraf & Tacherift	(2012)
Factors affecting microclimatic conditions include the following: Height of buildings, Relative humidity, Sky View Factor, Air Temperature, Mean radiant temperature, Universal Thermal Climate Index, Wind speed and Width of street.	Achour-Younsi & Kharrat	(2016)

Complexity of the outdoor thermal comfort studies and that the physical, psychology, and social factors all interact.	Achour-Younsi & Kharrat	(2016)
Estimated increase in temperature at least 0.2 degrees Celsius per decade.	The Intergovernmental Panel on Climate Change IPCC.	(2018)
Courtyards that are orientated at 45 degrees from the prevailing winds. Optimize wind at courtyard and the cross-ventilation throughout the building.	Sustainabilityworkshop. autodesk.com	(2018)
Building orientation should be within 5 degree orientation of true south.	Greenpassivesolar.com	(2018)
Orientation can be adjusted by up to 20 degrees to accommodate external factors.	Nachi.org.	(2018)
Section of Literature : Coverage materials		
Findings	Author	Year of Publication
Lighter colors' thermal performance were more positive than the darker	Cook et al.	(2013)

colored material cover, also regarding the surface temperature measurement readings.		
Water exposure for evaporative cooling on paving materials successfully reducing surface temperature lower that outdoor air temperature, but this is not the case for clay tiled paving.	Yang & Zhao	(2015)
Natural soil tend to heat up and cool down more rapidly than the conventional paving and vegetation was at least 11 degrees Celsius less than that of soil, concrete, concrete block and roads - soil temperature to be higher than cover materials.	Mathew et al. (2017)	(2017)
Section of Literature : Greenery		
Findings	Author	Year of Publication
Trees are the most efficient in reducing outdoor microclimatic temperatures. It reduces the dry-bulb temperature of the outdoor	QIU et al.	(2013)

conditions by evapotranspiration as is regarded as a strategy for urban heat island mitigation. Result indicate reduction of ambient temperatures of up to 4 degree Celsius.		
Natural soil tend to heat up and cool down more rapidly than the conventional paving and vegetation was at least 11 degrees Celsius less than that of soil, concrete, concrete block and roads - soil temperature to be higher than cover materials - vegetation as ground cover are more stable in the sense that the fluctuation in surface temperature is more compact.	Mathew et al. (2017)	(2017)
Study of the most common tree species on a typical summer's day - 30% GCR (greenery coverage ratio) and had a temperature decrease of between 0.5-1.0 degrees Celsius with an energy saving of 1900-3000kWh -	Morakinyo et al	(2018)

stressed the importance of the tree species: leaf area index, followed by the height of the trunk, the height of the tree and the diameter of the crown. It positively affects the ambient temperature, thermal comfort and energy consumption by providing evapotranspiration and shading.		
Trees height-to-distance ratio of trees should be less than 2. Tall trees with a large diameter. Efficiency of trees to reduce outdoor temperatures above that of shrubs and grasses, mainly due to shade provision. High value regarding the 17 degree drop in surface temperature, the up to 4 degree drop in outdoor air temperature and as much as 1900-3000kWh cooling load energy saving.	Zhang et al.	(2018)
Study of clustered tree groupings, trees placed at equal intervals, and	Zhao et al.	(2018)

dispersed throughout the area. Arrangement of two trees at equal arrangements were most successful with a reduction of 1-1.5 degree Celsius and had the same effect as one tree in the center of the front yard.		
Section of Literature : Waterbodies		
Findings	Author	Year of Publication
Water features, still standing and with a spray to act as evaporative cooling strategy to cool the outdoor air temperature and to add moisture to the air as humidity conditions may be too dry for human thermal comfort conditions.	Yang & Zhao	(2015)
Water in a moving form such as rivers or fountains have a more successful effect on the reduction of thermal temperature than that of still standing waterbodies.	Xue, S. & Xiao, Y.	(2016)

Waterbodies in the urban fabric with no vegetation performed poorly and had a negative effect on the thermal comfort, but coupled with vegetation it had the most efficient performance when reducing the urban heat island effect - reductions of between 0.5-2 degrees Celsius.	Morris et al.	(2016)
Air temperature reduction can vary significantly due to the wind speed that flows over the water. The reduction in wind speed is due to obstructions in the area. Waterbodies that are clear in the open can reduce the temperature by 0.5 degrees Celsius. Obstructions reduced the wind speed, the reduction in air temperature was hardly notable at 0.08 degree Celsius and caused the vast increase in humidity at 4.76%, thus better to only introduce vegetation. The use of irrigation to aid vegetation cooling at grass level	Amani-Beni et al.	(2018)

by up to 5 degrees Celsius compared to dry grass.		
Supports the notion of irrigation to aid vegetation with water replenishment for longer lasting evapotranspiration effects.	Taleghani, M.	(2018)
Small lake resulted in a decrease in temperature of 1.6 degrees Celsius, but showed an increase in relative humidity by 6%.	Karakounos, Dimoudi, A. & Zoras, S.	(2018)

This table is to be used in conjunction with results discussion to determine the validity of the results. Is to be refered to in the Analysis and Discussion and the Conclusion chapter.

CHAPTER 3

METHODOLOGY

Introduction to Chapter 3

After having a clear objective of the literature review, this chapter will highlight the importance of the methodologies and will address the implementation effects. This is not only to illustrate a detailed layout of how the research is to be conducted, but also include a thorough analysis of past and present possible techniques and tools used in the area of study. This chapter will illustrate a step by step guide of the processes that will be included in the study and serve the reader with validated justifications of the method choice that is adapted. It is to provide reasoning for a clear understanding of the thought processes.

The research papers that were collected are related to the research in question and are similar to the character of the study conducted. The data collection include published research papers with the area of study similar to that of this document and similar scope covered.

The literature review above illustrates that several methodologies can be used in a given study, due to the complex nature of the external parameters and the effect it has on the microclimatic environmental conditions with regards to the outdoor thermal comfort of urban areas and communities. Due to the complex nature, it is important to collaborate and combine a variety of identified and justified research based methods, techniques and tools to ensure the validity of the information produced.

More professionals are turning to intelligent computational modeling techniques to avoid the trial and error method of doing things to cut time and costs related to studying the outdoor environment. Past studies tend to only focus on interior condition of structures, but the shift to study the external environmental thermal performance is crucial for the industry in terms of optimization and efficiency.

A quick review of the previous studies that have been used e.g., Experiments, Simulation, Statistics. To state the nature of the study to determine similarities when collecting papers for reference: The study and field are of a complex nature, due to the dynamic variables directly related to microclimatic conditions of a site specific profile. Generalization of a climatic profile will result in uninformed design decision-making and performance lag and inefficient consumption of energy resources.

First instance of method collection should be related to climatic data profiling, field measurements and validation of the data.

Second instance of method collection should be based on the observational and analytical method of the morphology of the urban fabric of the study field.

Third instance of method collection should be based on the projected aim and objectives of the study, which refers to the optimization of the environmental conditions.

Fourth instance of method collection should be related to energy consumption.

Fifth instance of method collection should be related to the usability of the results: communicating specific precautions, approaches and decisions in terms of project profile, stewardship, governance and regulatory guidelines for future projects of a similar nature.

3.1 Quantitative approach

Quantitative research approach is used as a research method generating numerical data and facts. It employs the statistical, logical and mathematical techniques. It is quantifying a given problem by generating numerical data or generating facts that can be converted into serviceable statistics. It is used to quantify defined variables such as people's opinions, behaviors, and attitudes. Results are generalized from a larger sample population. In other words this approach takes measurable data and formulates and uncover patterns. The manner of data collection is of a more structured nature compared to that of qualitative research approach. The data collection process include numerous types of surveys, structured interviews such as face-to-face, telephone, online interviews and systematic observational studies. It also includes the viewing and reviewing of documents and records to formulate numerical information, statistics and provides observed effects as interpreted by the researchers on the given problem or situation across a large number of cases. Accuracy and reliability of the measurements mainly depend on device or instrument used. More time spent on the planning phases of the research, compared to the time spent to do the analysis. It is a more broad general approach. The approach summarizes and compares the generalized characteristics that was found across the cases studied to determine the correlation or relationship between them.

3.1.1 Field observation and measurement

In conjunction with the main method of choice for the research to be done, field measurements are used in almost all journal papers, either for readings regarding input data or to validate results and findings. Input data readings include atmospheric temperature, relative humidity, wind speed, surface temperature and air pressure and light flux levels according to what was studied. Field measurements can be used in conjunction with other methods and is crucial in validating simulation software, input data and to validate results, thus can be seen as a complementary tool to include in any research if applicable, Pakzad and Salari (2018). Relating back to where it has been used in the literature: What the conditions were when taking the measurements, and the position and the specific precautions to consider when taking field measurements. Include the limitations when taking measurements, such as weather conditions, construction and obstructions. The field measurements are used in the validation of theories in the field studies. The accuracy of this method relies not only on the reliability of the tools, but also on the workmanship of the reader. It is crucial for the tools to be reliable and calibrated to precision. Measuring tool to be used is the General Tools DLAF8000C 4 in 1 Environmental Meter for Air-Flow, Temperature, Humidity, and Light Meter. The ideal set of measurements should stretch over a full year at established times to ensure continuity and consistency. Due to the time constraints of the dissertation, climatic data will be taken from reliable sources and be validated by field measurements, when the instruments are also available. The measurement taking process is fairly straight forward and easy to do. Anyone can do it but should take the correct precautions as previously mentioned. Measurements should be taken in intervals of one hour or every two hours, thus this is a timely process a lot of the time. The extensive time span is essential/ crucial for the reliability of the readings as variables in outdoor conditions are always certain to influence the readings, thus it is important to understand the variables at play and what effects it may have. Generally when conducting studies on thermal conditions the research method include field measurements for validation of data sets, coupled with surveys and simulations for testing different variables and documenting the results of the changes.

3.1.2 Questionnaire and survey

Surveys and questionnaires are often used due to the usual cost efficiency, ease and accessibility of information. This method of data collection is highly popular in conducting market research and is a well-known and accepted form of data collection used to evaluate and analyze trends, pat. This form of data collection can give the researcher valuable information of done correctly and if not, the information collected will not be of any use and money spent are waste. Accuracy of 100% can never be achieved due to the focus on opinions and trends. Human behavior has proven that opinions and even decision-making changes with moods, thus this should be taken in consideration when data is analyzed. The importance of survey taking is the source and the audience of population targeted. Care should be taken to provide a genuine representation of the cross-section of the population under scope, so that the survey results are not manipulated by sifting the responses to support an argument or point reflecting distorted information. Despite the dependency on integrity and honesty, when done correctly, surveys can give valuable insights on topics, thus making it the easiest, most accessible and cost effective research tool. Research scope covered in the survey should not stretch too broad and have too many questions as subject may lose focus and ramble through the rest of the question giving answers that are not truly representational of the honest opinion, nor the opposite as it will carry any value.

Determining Your Sample Group is critical and depend on accuracy, broad range of people base covered, quantity, and to pick the participant in correlation with the applicability of the participant in relation to the question. Should correlate and be related. Size of sample should be directly correlated with statistical data if possible. Set the number and the type of responses needed for validity and to avoid inaccuracy. When analyzing the data the researcher should be self-critical to avoid bias results. Transparency is key and should reflect the true process, the sample size and highlight any discrepancies that occurred during the study.

3.2 Qualitative approach

Qualitative research approach is used as a method of inquiry. Understanding the concept of human and social sciences, to determine the patterns in which people think and what they feel. The research method is exploratory in nature in order to gain knowledge of the motivations for the findings which include opinions and the underlying reasons. It is to obtain insights into the issue by developing ideas and hypothesis for the quantifiable section of the methodology. It is not only to identify trends and patterns but also to explore the problem on a deeper, more intuitive level. Some of the methods used include focus groups and group discussions, participation/observation experiments and individual interviews. The sample size is usually quite small and subjects/ participants are selected to fulfil a purpose/ question. Methods are mostly focused on in-depth interviews, focus groups, reviewing of documents to identify recurring themes. It approaches the issue descriptively to communicate the experience of the lay user to the researcher or reader in order to emphasize the personal perception and perspective of the individual, rather than to generalize and give a percentage value. It is text-based. It is a deeper study and understanding into fewer cases compared to the amount of cases to be used in the quantitative methodological approach. It is an un-structured or semi-structured, explorative process. It does not include statistical or standardized tests or results. Accuracy and reliability of the research mainly depend on skills, education and personal professionalism of the researcher conducting the study. More time spent to do the analysis, compared to the time spent on the planning phases of the research. It is a more n-depth approach to describe a phenomenon. The approach does not summarize nor give generalized characteristics. It studies the cases individually on a more complex comprehensive level and manner examining influencing variables and configurations to reach the phenomenon. It gives more weight to the personal views of the participants. It is entailed via phenomenology, grounded theory, historical happenings, ethnography and case studies.

3.2.1 Case study

A case study focus on an in depth study of a particular condition, scenario or case rather than generalized, statistical information. It is case specific and do not focus on trends and patterns of a large group of conditions. It is descriptive in nature, text based, rather that number based. It is a popular research method to analyze specific questions within the limitations of a detailed environment, organization and/ or situation. The three different case study profiles are descriptive, explanatory and exploratory. The main attraction to case study as research methodology is that the data collection and analysis is done within the context of a certain phenomenon. It consists of the integration of quantitative and qualitative methods and analysis. It possesses the capability to capture and identify intricacies of the real-life scenarios so that the matter can be studied in a greater depth. This is also considered to be a disadvantage when choosing a methodology for a study as a case study do not allow for generalized conclusions or generalization of the finding of a particular case. A case study is especially useful for testing theoretical models in real world conditions to find the success rate of the theory or hypothesis. Case study research cover such a narrow field and usually only one case at a time that the results cannot be extrapolated to fit an entire question. It might answer only a few of the uncertainties and should in many cases be accompanied by other methodologies in the study. A case study focus is based on the same or a similar nature of research conducted.

3.2.2 Focus group interview

Focus groups are a common techniques used in research regarding marketing purposes. The condensed nature of the focus groups ensure that he process is not time consuming and that the researcher gains honest, thoughtful insights to the statements made. Participants are numbered and only need about 10 people, usually around 6-12 people, which fall within the target market. The group is brought together in one space and usually led by a moderator to guide the discussions and topics to suit the outcome. It falls within qualitative research methodology because it does not have a closed-ended answer to a question. It consists of an open-ended response discussion which convey the feelings, perceptions and thoughts of the participant's complete perspective on the topic. Focus groups target a few participants within the market of the topic to have a better understanding of how the lager group would possible interpret the issue or situation. It is representative of the market under study or scrutiny. Care is to be taken by the moderator not to lead the group to think through a predesigned path of thought for a desired outcome, but to be especially careful to ensure the group's thoughts flow are determined by the participants and that the response is insightful and honest. Focus groups are used in situations where the results of a study is unpredictable and in need for a workshop or brainstorm session to create a forum for open feedback, rather than quantifiable results which can be compared. It usually revolves around a topic that does not have a reference point for preferred results. It is free-flowing in nature and comments from other member can be used to stimulate remembrance. The main concern when conducting such sessions are that there might be possibility of groupthink, where members are seen as alpha figures and the rest do not give their own inputs, but only agrees to whatever perception and commentary that the dominant participant seem to convey. These influential group member might distort the true expression of the other members of the group. One of the drawbacks or disadvantages of focus groups are that participants show higher levels of reluctance regarding negative feedback, than that of a more indirect, non-face-to-face setup, especially when participants are aware that the feedback is for research purposes.

3.2.3 Analytical/ descriptive

Pakzad and Salari (2018), did a study - Measuring sustainability of urban blocks: The case of Dowlatabad, Kermanshah city. They studied morphological characteristics of blocks by comparing the existing situation to the principles of sustainable development of urban form. The scope of the neighborhood consists of a population of around 44000, 129Ha and is built up 48% building in relation to circulation routes dividing the neighborhood in 8 distinct blocks. Two sections are covered in the journal paper, research approach and data resources. His research show that there are interpretative approaches and scientific approaches used within the realm of the built industry, and found that the scientific approach are most widely used in the case of architects and urban planners. Studies of this nature attempt to find correlations between measured factors of the environment to analyze the relationship between them. The paper' methodology is descriptive-analytic research based with data collection. This method distinct between idea-theory and the practiced-theory regarding the design. The French school assessed similarities and differences between what was said to be built compared to what was actually built. Focus group interviews have been applied within the data collection.

Precautions that need to be taken are:

- Settlement blocks that were compared were analyzed more than once, (three times).
- Settlement blocks were observed the equal amount of times.
- Information and irregularities were noted: block shape, orientation, narrow cracks, are the blocks structural or nonstructural.
- Include direct and indirect occupants for focus group interviews. Residence and old estate agents for objectivity.

Significant findings and notes include:

- The journal addressed gaps which exist within the theoretical urban block literature.
- Some results contradict what has been said by past research papers.

Shortcomings include:

- There are no set of regulatory principles for sustainable urban blocks.
- There is no recipe for the analytic assessment/ measurement of urban blocks regarding sustainability.

In conjunction with observation method, field measurements was used in most journal paper, either for readings regarding input data or to validate results. This can be used in conjunction with other methods and is crucial in validating data and results, thus can be seen as a complementary tool to include in any research if applicable.

3.2.4 Simulation

As stated in the book of Anderson (2014), it is necessary to establish the appropriate questions/ aims/ outcomes in order to choose the correct simulation software as there are no holistic program to model all and every aspect of the design. It is the responsibility of the researcher to ensure the software is compatible and applicable to the study.

Ways simulations have changed over the past years:

- User friendly – Software is designed to be used by professionals within the field/ industry such as architects and planner and not only for the specialized professionals anymore.
- Quick learning – less time to learn how to use the software, more efficient regarding time usage by readily available data files (for example weather files and basic construction types), which can be loaded into the modeling software/ simulation program as a default setting.
- Graphical interface
- Various types of simulations that can be run
- Modeling programs to be able to create 3D geometry
- Outputs which are able to map the results of the graphical data onto the 3D models

Software accuracy and validation depend on these key aspects:

- Development of graphical simulation software
- Design simulation software elements

ENVI-met environmental software to determine external urban factors and the influence of various strategies to optimize outdoor thermal conditions according to the outdoor thermal comfort of humans. Methods explored in the journals researched on the related topic all include simulations on ENVI-met software program and some are coupled with other methods, as follows: Four of the journals, Wu and Chen (2017), Morakinyo and Lam (2016), Sun et al. (2017) and Hofman et al. (2016), were focused on vegetation, which included alternative methods such as RayMan, on-site measurements, statistical analysis and LiDAR. One journal, Jin, Shao and Zhang (2017), focused on waterbodies, which only included ENVI-met software simulations. One journal, Wang, Akbari and Chen (2016) focused on urban geometry, which only used ENVI-met software simulations. Three journals, Battista and Pastore (2017), Alchapar and Correa (2016) and Taleghani and Berardi (2017), focused on pavements and materials which only included ENVI-met software simulations. Two journal, Barakat, Ayad and El-Sayed (2017) and Schwede and Sheng (2017), focused on energy demand and efficiency which the latter included methods such as TRNSYS, algorithms and calculations. The remainder journals, Perini et al. (2017), Huang et al. (2016), Gaspari and Fabbri (2017), Naboni et al. (2017), Evola et al. (2017), Li, Wang and Wong (2016) and Zhao and Fong (2017), focused on urban outdoor thermal comfort, which used ENVI-met with only one combining the methodology with numerical analysis.

In conjunction with simulation method, field measurements was used in almost all journal paper of this nature, either for readings regarding input data or to validate results. Input data readings include atmospheric temperature, relative humidity, wind speed, surface temperature and air pressure and light flux levels according to what was studied. Field measurements can be used in conjunction with other methods and is crucial in validating simulation software, input data and to validate results, thus can be seen as a complementary tool to include in any research if applicable.

An ideal research considers both methods, working together.

3.3 Research approaches summary table

Table 3.1 - Methodology Summary: significant academic findings

Publication	Journal title	Year of publication	Authors	Topic	Methods
Energy and Buildings , 152, pp.373-384.	Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper	2017	Perini et al.		
Energy Procedia , 104, pp.177-182.	The Ecological City: Considering Outdoor Thermal Environment	2016	Huang et al.		
Energy Procedia , 122, pp.1111-1116.	A Study on the Use of Outdoor Microclimate Map to Address Design Solutions for Urban Regeneration	2017	Gaspari and Fabbri		
Energy Procedia , 122, pp.1111-1116.	An overview of simulation tools for predicting the mean radiant temperature in an outdoor space	2017	Naboni et al.		
Energy Procedia, 134, pp.692-701.	UHI effects and strategies to improve outdoor thermal comfort in dense and old neighbourhoods	2017	Evola et al.		
Procedia Engineering , 169, pp.88-99.	Urban Micro-climate Research in High Density Cities: Case Study in Nanjing	2016	Li, Wang and Wong		
Sustainable Cities and Society , 32, pp.523-531.	Characterization of different heat mitigation strategies in landscape to fight against heat island and improve thermal comfort in hot–humid climate (Part I): Measurement and modelling	2017	Zhao and Fong	urban outdoor thermal comfort	only used ENVI-met software simulations.
Procedia Engineering , 169, pp.308-315.	Urban Geometry and Environmental Urban Policy Development	2016	Wang, Akbari and Chen	urban geometry	only used ENVI-met software simulations.
Energy Procedia , 134, pp.256-265.	Effect of water body forms on microclimate of residential district	2017	Jin, Shao and Zhang	waterbodies	only included ENVI-met software simulations
Alexandria Engineering Journal .	Urban design in favor of human thermal comfort for hot arid climate using advanced simulation methods	2017	Barakat, Ayad and El-Sayed		ENVI-met software simulation and the latter included TRNSYS, algorithms and
Procedia Engineering , 198, pp.305-312.	Assessment of the Annual Energy Demand for Cooling of Buildings in their Urban Context in 26 Cities in China	2017	Schwede and Sheng	energy demand and efficiency	
Energy Procedia , 113, pp.98-103.	Using Cool Pavements to Mitigate Urban Temperatures in a Case Study of Rome (Italy)	2017	Battista and Pastore		
Sustainable Cities and Society , 27, pp.1-14.	The use of reflective materials as a strategy for urban cooling in an arid "OASIS" city	2016	Alchapar and Correa	on pavements and materials	only included ENVI-met software simulations
Landscape and Urban Planning , 167, pp.463-472.	Optimizing the spatial arrangement of trees in residential neighborhoods for better cooling effects: Integrating modeling with in-situ measurements	2017	Wu and Chen		
Building and Environment , 103, pp.262-275.	Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort	2016	Morakinyo and Lam		
Building and Environment , 123, pp.277-288.	Evaluating the impact of urban green space and landscape design parameters on thermal comfort in hot summer by numerical simulation	2017	Sun et al.		
Urban Forestry & Urban Greening , 20, pp.265-276.	Influence of tree crown characteristics on the local PM 10 distribution inside an urban street canyon in Antwerp (Belgium): A model and experimental approach	2016	Hofman et al.	vegetation	ENVI-met software simulations and included alternative methods such as RayMan, on-site measurements, statistical analysis and LiDAR

The table included shows journal papers that were collected with similar scope, topic or method. These will be considered in the process of deciding on a method(s).

3.4 Methodology adapted and Justification

The focus is on elevating the achievement of the thermal comfort in the outdoor environmental conditions and relating it to the thermal comfort of indoor conditions to measure the energy consumption of urban communities. This will be done through the implementation of various passive built and landscape materials. The key concepts and finding is communicated with the use of a case study. The case study will act as a reference point after which conclusions can be extrapolated and possibly be applicable within future urban communities.

Method choice for the dissertation will be a mixed methodology, incorporating the literature review for thorough understanding of the scale, time and feasibility; observational approach of field measurements for validation of data collected (and calibration section); case study of development and the computational simulation models on ENVI-met and IES VE software.

Simulation: The two tools to be used in the simulation phase of the research will be ENVI-met and IES VE. It will be to simulate or to create the real-time evaluation scenario of the existing fabric, and the proposed scenario to be able to measure the effects that the proposed strategies will have of the area of study.

- The existing base case on building villa level will be done via IES VE depending on availability of licensing at the time of simulation phase.
- The existing base case on urban development level will be done via ENVI-met depending on availability of licensing at the time of simulation phase.

- The strategy implementation will be built upon the base case on urban development level in the ENVI-met program.
- The differences/ results/ outcomes of the outdoor conditions in the ENVI-met simulation scenario will be used as the manual input into the existing base case on building villa level in the IES VE program.
- Estimation of the effects on the indoor conditions will not be determined in this study.
- Estimation of the effect on the energy consumption will be determined.
- Determined connotation between outdoor and indoor comfort conditions and link between outdoor conditions and energy consumption of residential developments.

The scientific or descriptive-analytical method of research that is to be used is based on previous researchers' efforts at resolving and studying a similar field and conducting research.

3.5 Research approach

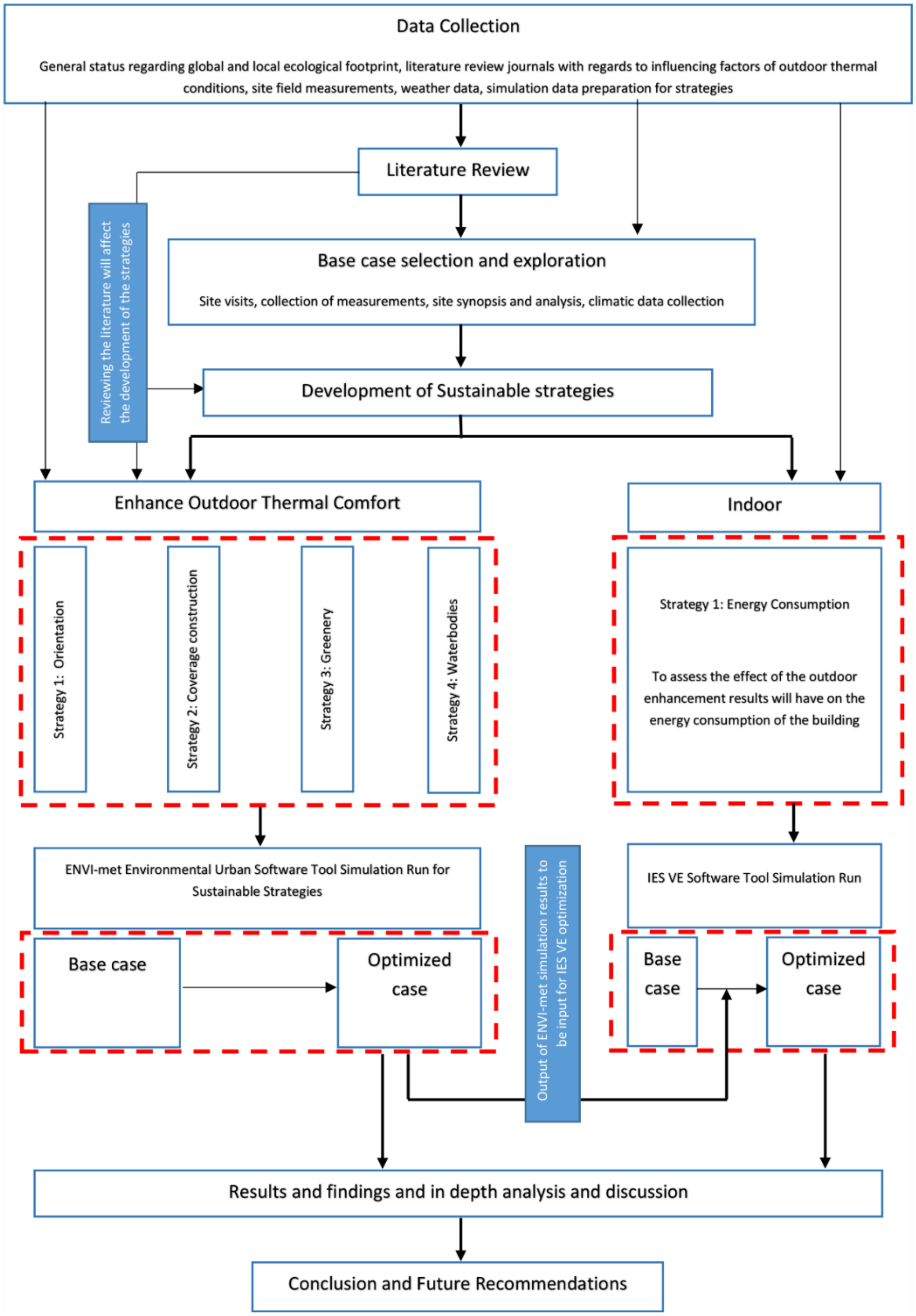


Figure 3.1 - Methodological map of research approach Source: Author (2018).

Summary of Chapter 3

Stating the nature of the study to determine similarities when collecting papers for reference: The study and field are of a complex nature, due to the dynamic variables directly related to microclimatic conditions of a site specific profile. The main research focus is on elevating the achievement of the thermal comfort in the outdoor environmental conditions and relating it to the thermal comfort of indoor conditions to at end measure the energy consumption of villas in urban communities.

Methods explored in the journals researched on the related topic all include simulations on ENVI-met software program and some are coupled with other methods. In conjunction with simulation method, field measurements was used in almost all journal paper of this nature, either for readings regarding input data or to validate results. Field measurements can be used in conjunction with other methods and is crucial in validating simulation software, input data and to validate results, thus can be seen as a complementary tool to include in any research if applicable.

Method choice for the dissertation will be a mixed methodology, incorporating field measurements for validation of data collected and to calibrate the error of computational simulation models on ENVI-met and IES VE. It is important to identify what the conditions were when taking the measurements, and the position and the specific precautions to consider when taking field measurements. Generally when conducting studies on thermal conditions the research method include field measurements for validation of data sets, coupled with surveys and simulations for testing different variables and documenting the results of the changes.

CHAPTER 4

SITE SELECTION AND SIMULATION

Introduction to Chapter 4

Introducing the environmental- and the building-criteria. Covering the site visits, synopsis, and climatic profile of the area. From the second, third and fourth chapters, strong emerging strategies are identified and discussed. The validation process, and the model setup of the simulation, conclude this chapter, before moving on to the results and discussion section.

4.1 Case study Selection

Site selection criteria include the following: As mentioned in the limitation section, the focus is on existing residential developments, because the UAE footprint by demand sector indicates that residential households account for 57% energy consumption in the UAE, according to Footprintnetwork.org (2015). The developments should be located in close proximity of an area currently under construction or prone for development in the near future. This is located on the outskirts of Dubai on the E611, Emirates Road, previously known as the Bypass Road. A densely residential built up and well known area on the E611 is Dubailand, which consists of a conglomeration of residential developments. Adjacent developments include Dubai Sustainable City, Layan Community on the west side and Serena community, of which he latter is currently under construction, on the north of Al Waha.

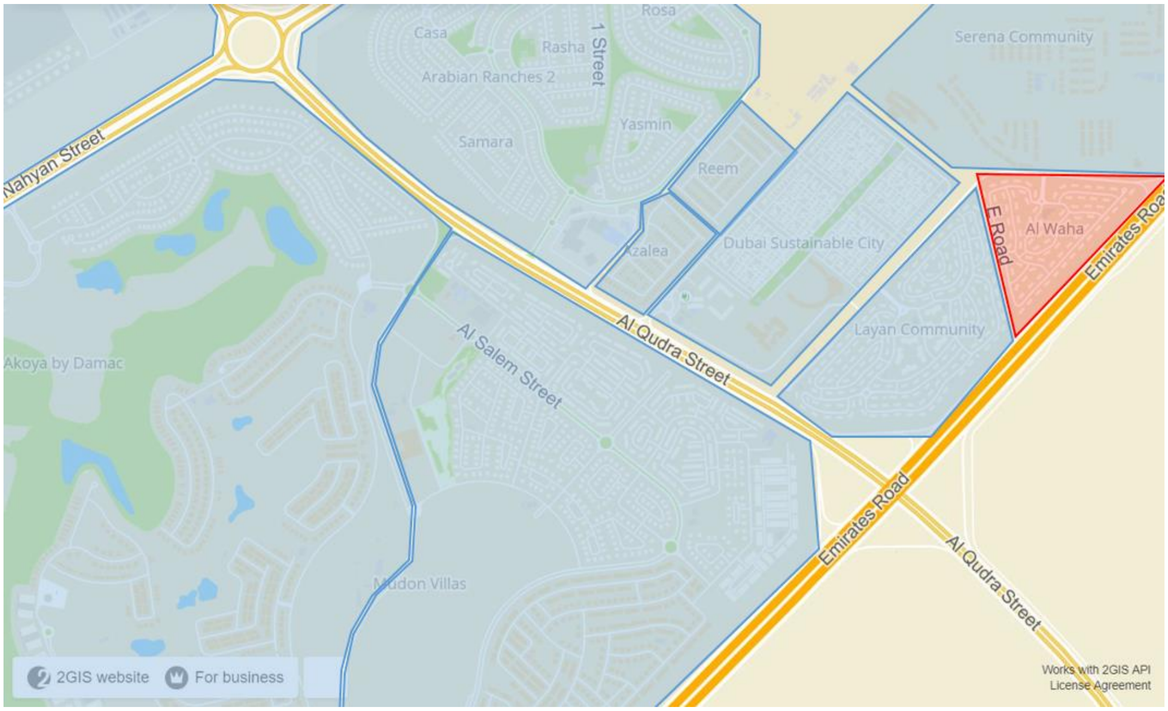


Figure 4.1 - Map location of Al Waha (Source: Author, 2018)

Accessibility through a contact person was made possible to the Al Waha community, situated on the E611, which is representative of new developments in terms of size and location, expanding into the desert on the eastern outskirts. Access to the site is crucial for site visits, site measurement and photographic evidence of community's architectural, urban and landscape fabric observations. This is to be used as the base case study in the research. Al Waha consists of 260 villas (including townhouses) development by Dubai Properties and is one of the mature communities in the area. Construction was completed in 2010 and the quality classification is seen as a mid-end property type.

Figure 4.2 - Map of road network around Al Waha (Source: Author, 2018)

The main arterial road, known as primary traffic movement road that is shown in red is Emirates Road/ E611, secondary traffic movement roads are shown in orange and are Al Qudra Street and the main road running through Mudon community, and tertiary traffic movement roads are shown in yellow. Entrance to residential developments are also shown in red. Emirates Road/ E611. Ease of access from major arteries enhance the value of the location. Numbered from 1 to 4, the entrances are for Mudon community, Arabian Ranches 2, Sustainable City and Al Waha community. Major landmarks include DWC Al Maktoum International Airport which is 22 minutes' drive from Al Waha, Dubai Miracle Garden, Al Barsha South 3 which is 10 minutes' drive, Dubai Autodrome on Sheikh Mohammed Bin Zayed Rd which is 9 minutes' drive, Palm Jumeirah which is 26 minutes' drive, Jumeirah Beach Residence which is 24 minutes' drive, Burj Al Arab Jumeirah which is 19 minutes' drive, Mall of The Emirates which is 19 minutes' drive and Dubai International Airport which is 32 minutes' drive. The closest form of public transportation is about a 23 minutes, 1.9 km walk to the nearest bus station which is located at entrance 3, Sustainable City that puts you on the F32 route every 35 min (8 stops) heading to Mall Of Emirates Metro Bus Station.

Neighborhoods zoning areas are residential developments with allocated shopping centers in a few of the communities. Most communities have facilities like a grocer market for day to day food and household shopping, restaurants, cafes, public swimming pools and might even have a gym, a nursery or even a school situated inside the development. Existing site conditions within Al Waha community is classified as completed, thus the community infrastructure and building construction is completed, although it is evident that the vegetation lack from what was proposed. On the left is the proposal and on the right is the current conditions shown on satellite imagery. An estimate of 50% of the proposed green footprint have been achieved to date. Public green parks show almost no vegetation.

Figure 4.3 - Visual comparison of vegetation proposed vs reality in Al Waha (Source: Author, 2018)

Main movement pattern layout is of organic nature with no clear structure. Sites are back to back orientated towards the street and such is the villas. 56 out of the 260 villas are orientated on the correct direction on the east-west axis with the living area situated on the northern side of the structure. This only accounts for 21.5% of the structures are orientated for minimizing heat gain. A further 58 villas are also orientated on this axis but are living out on the southern side of the structure, which account for another 22.3%. Total of villas orientated correctly amounts to 43.8%. Given the nature of the chosen approach for landscaping and services layout, it is nearly impossible to conform the orientation throughout the entire development.

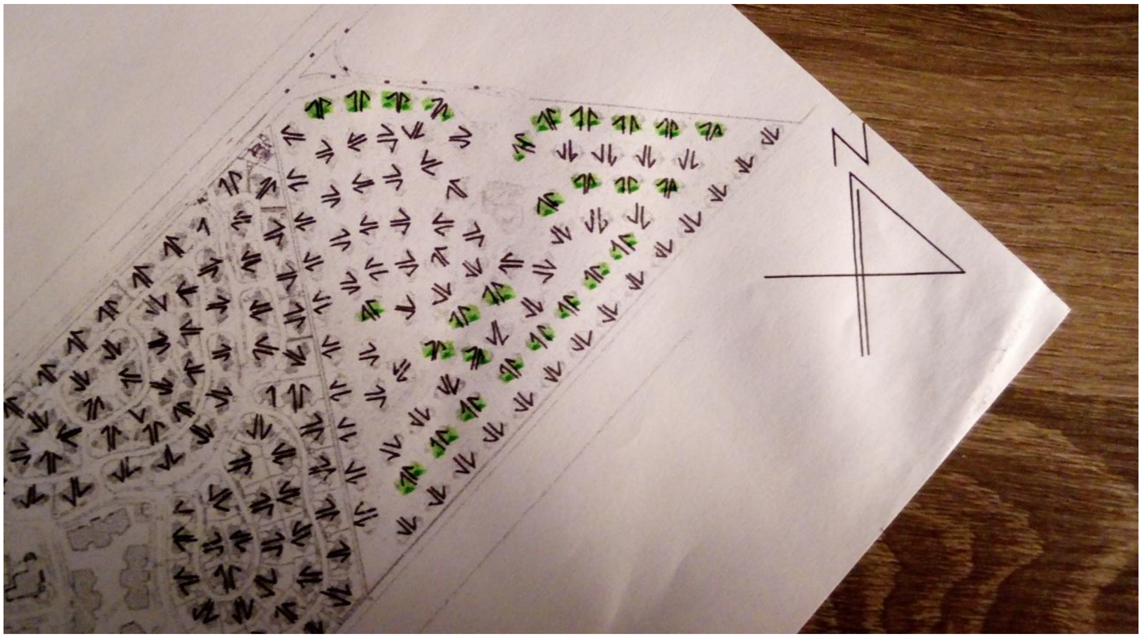


Figure 4.4 - Visual indication of villas orientation in Al Waha (Source: Author, 2018)

Figure 4.5 - vehicular and pedestrian movement provision in Al Waha (Source: Author, 2018)

Grey and red paved streets and driveways with no obstructions. Little to no on street parking with only space for one visitor's vehicle to Double Park the owner. Double open garages per unit allow for at least two vehicles to be parked comfortably at any given time. No street lighting nor street furniture nor allocated areas to store garbage effectively that is visually pleasing. Garbage bins stand on the street front. Current sidewalks only on one side of the street obstructed by garbage bin. The sidewalk is separated from the traffic by means of vegetation barrier.

Figure 4.6 - Pedestrian movement provision in Al Waha (Source: Author, 2018)

Some places do not have sidewalks for pedestrian circulation and movement usually happens in the street boundary. It has to be said that the speed limit of the community has been reduced to 20 to 40 km/h and traffic calming techniques like speed bumps have been implemented to keep pedestrians safe.

Figure 4.7 - Community upgrades near the main facilities in Al Waha (Source: Author, 2018)

The landscaping closer to the main community facilities have seen an upgrade regarding the quality of pedestrian movement provision, street lights for visual safety and short stub lights allocated specifically for the sidewalk. The area also seem to enjoy a greater number of trees although the sandy areas are still bountiful.

Figure 4.8 - Community facilities and public parks in Al Waha (Source: Author, 2018)

This illustration shows that the community facilities (blue square) are situated at the entrance (indicated with the yellow arrow) of the community. There are two park (blue ovals) in the community which are situated in close proximity to the facilities.

Figure 4.9 - Vegetation status in community public parks in Al Waha (Source: Author, 2018)

Upon closer investigation of the public parks or green spaces, it is evident that the vegetation is scares with bountiful sandy areas.

Figure 4.10 - Perimeter boundary of Al Waha community (Source: Author, 2018)

Current perimeter boundary consist of a 2 meter high wall with column spacing of 3 meters c/c. This is to secure the perimeter and protect the residence' privacy.

The chosen method of construction within the area is concrete foundations and slabs with precast concrete walls and joints. This is done to speed up construction process and avoid human error on site. Mass produced precast sections reduce the initial cost of the materials and construction.

4.2 Climate data

Weather: Sun path, Sky coverage, Temperature range, Wind velocity

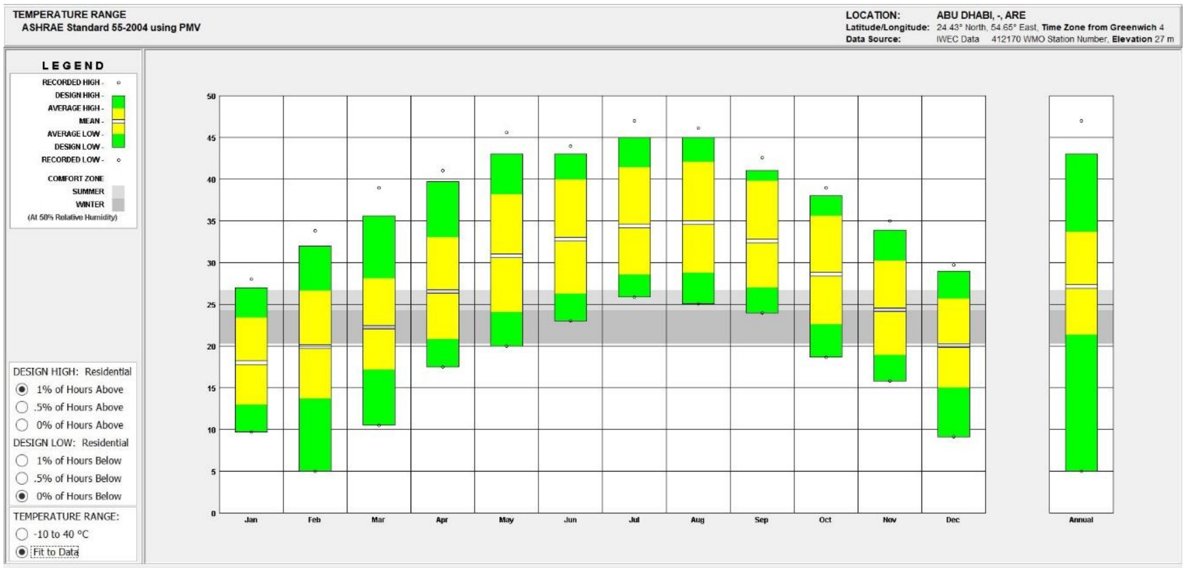


Figure 4.11 - Temperature range, Abu Dhabi (Source: Climate Consultant and EnergyPlus, 2018)

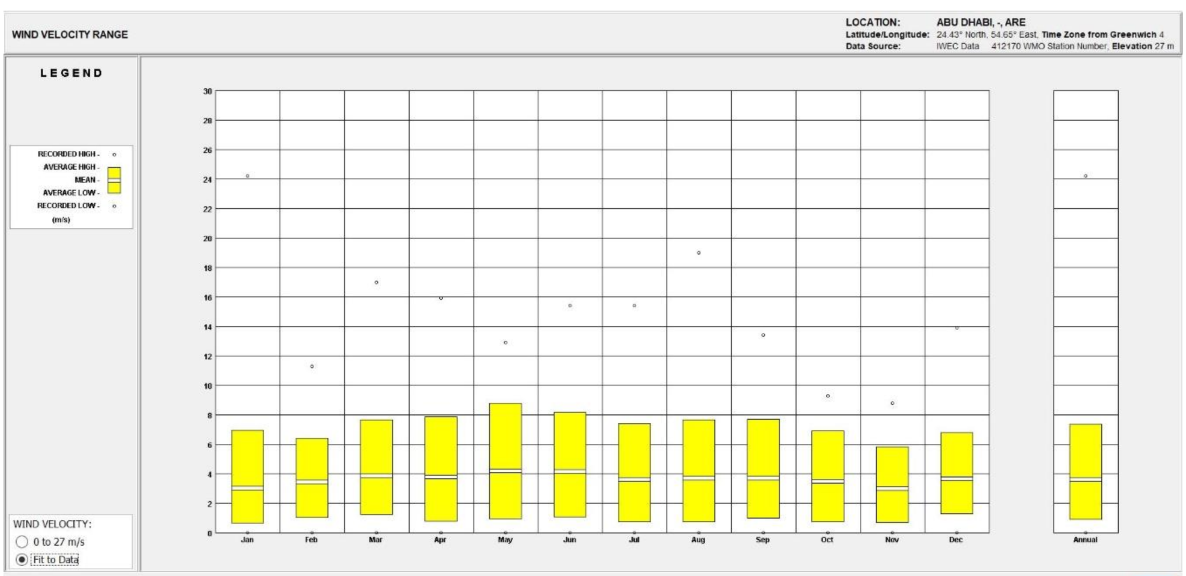


Figure 4.12 - Wind velocity range, Abu Dhabi (Source: Climate Consultant and EnergyPlus, 2018)

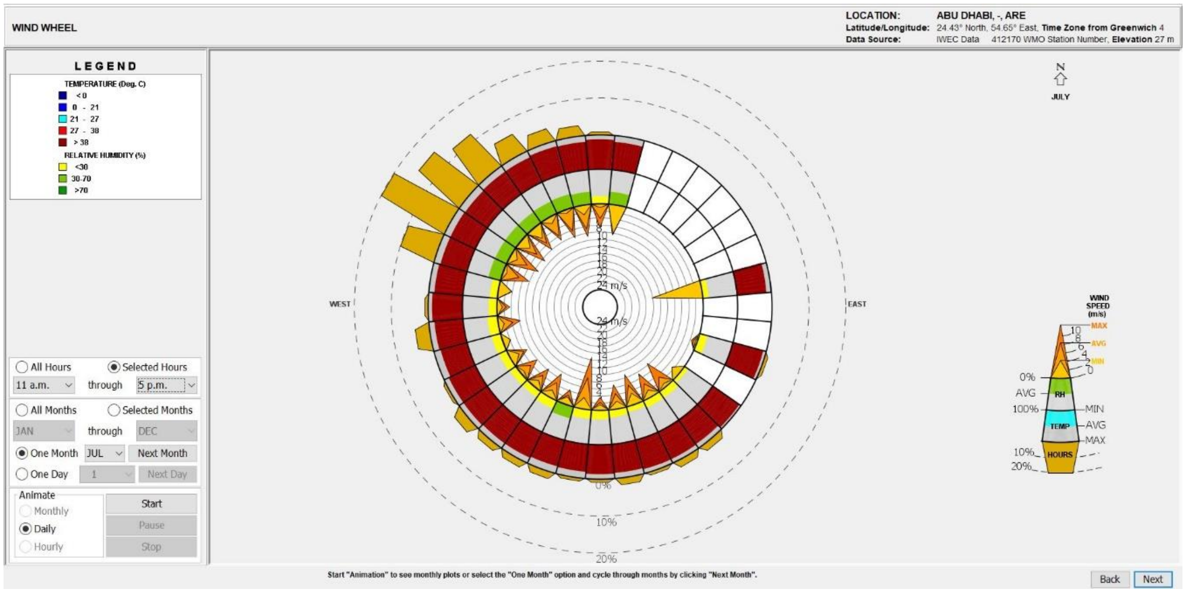


Figure 4.13 - Wind velocity chart for July, Abu Dhabi (Source: Climate Consultant and EnergyPlus, 2018)

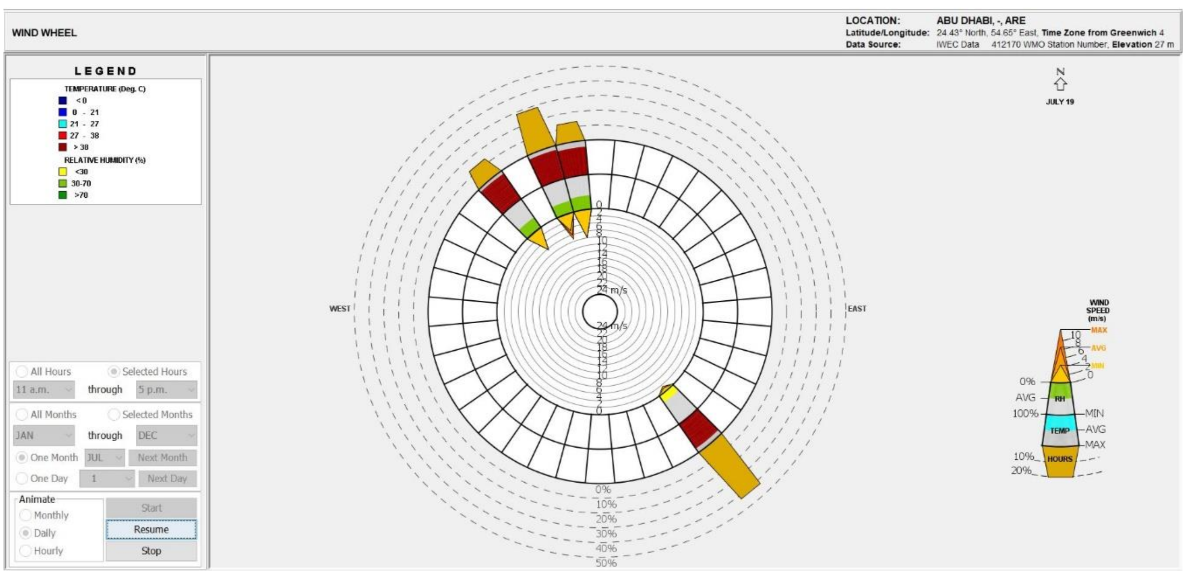


Figure 4.14 - Wind velocity chart for 19th of July, Abu Dhabi (Source: Climate Consultant and EnergyPlus, 2018)

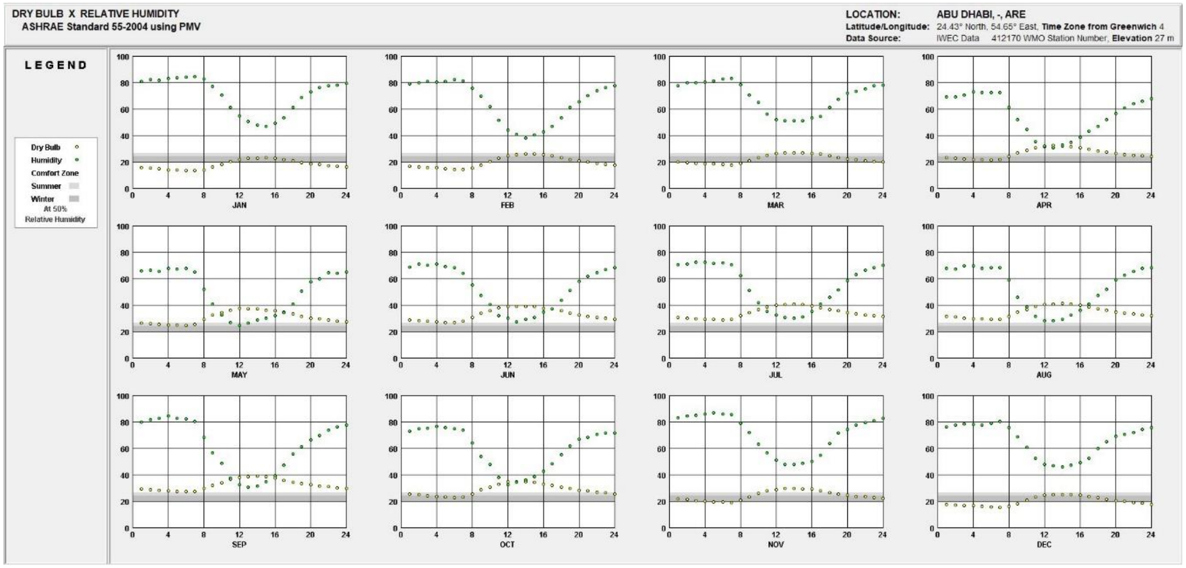


Figure 4.15 - Dry bulb and relative humidity plots for the year, Abu Dhabi (Source: Climate Consultant and EnergyPlus, 2018)

Climate consultant weather data file. Asia WMO Region 2 - United Arab Emirates – Abu Dhabi epw file used for weather data of Dubai as it is the closest proximity to the site and chosen development. Validation of weather data to be compared with the local weather stations at the main airports. The use of Climate Consultant 6.0 (build 12) September 22, 2017 most recent release.

4.3 Validation and Calibration

The main idea behind the validation process is to calibrate the simulation model. This process is done during the model set up stage to ensure accurate simulation results. Simulation as methodology is becoming more popular as it aids the decision making process in terms of time efficiency and accuracy. Simulations are what the name entails and can only project the anticipated outcome with means of input results. The verification and validation of the simulation models are done by means of weather data statistics and site measurements. Simulations are as close as we can get to real time data and is used to imitate real life scenarios with a set of assumptions to keep the model as accurate as possible. There might be some variations to the programmed inputs into the existing software, but can also be easily manipulated manually by means of real-time or optimized weather data inputs. This is a representation of what the model would do and how it would act if respective parameters were to be introduced. Validation is achieved by calibration of the model to accurately represent the actual/ real system. The verification process works in iterations. Take the initial model and compare it to the reality, then revise the model in terms of inputs and compare it to reality, this can be redone several times to ensure the accuracy of the model, as it is needed. Build the model, validate the assumptions or the inputs of the model parameters and then compare the input and output data transformations to real system measurements. Assumptions are to be based on reliable data and measurements to validate assumptions are to be taken several times during peak hour temperatures. If the marginal error is within 5% of the actual data readings, the model is considered to be calibrated. If there is an error of greater than 5%, it means that there is something wrong with the weather data of the simulation program and needs to be revisited.

4.3.1. Calibration of climate models

Calibration indicators of climate models include air temperature, relative humidity and wind speed. Weather data calibrated to National Centre for Meteorology and Seismology.

Table 4.1 - Temperature calibration (Source: Author, 2018)

					temperature							
Data source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
design builder 5%	24.8	27.1	30.7	35	38.8	39.9	41.1	41.1	38.8	35.5	31.2	27.1
design builder 10%	23.2	25.2	28.7	33.1	37.1	38.4	39.8	39.9	37.2	34.2	30.1	26
IES	27	32	36	39	43	43	45	45	41	38	34	28
Field measurement/ timeanddate	24	26	28	33	38	40	41	41	39	36	31	26
Envi-met	24.8	27.1	30.7	35	38.8	39.9	41.1	41.1	38.8	35.5	31.2	27.1
Climate Consultant Abu Dhabi/ IES VE	27	32	36	39	43	43	45	45	41	38	34	28
Weather underground	25.5	24.3	29.3	35.5	37.8	41.4	43.7	42.5	40.3	36.5	31.1	26.6
Accuweather	26	24	30	36	39	42	44	43	41	37	31	26
timeanddate, Dubai airport	24	26	28	33	38	40	41	41	39	36	31	26
National center of meteorology mean max	24.2	25.5	28.6	33.2	37.8	39.7	41.2	41.4	39.2	35.6	30.7	26.3

The table above and the chart below illustrate a conglomeration of various climate models used for calibration purposes against data obtained from NCMS.

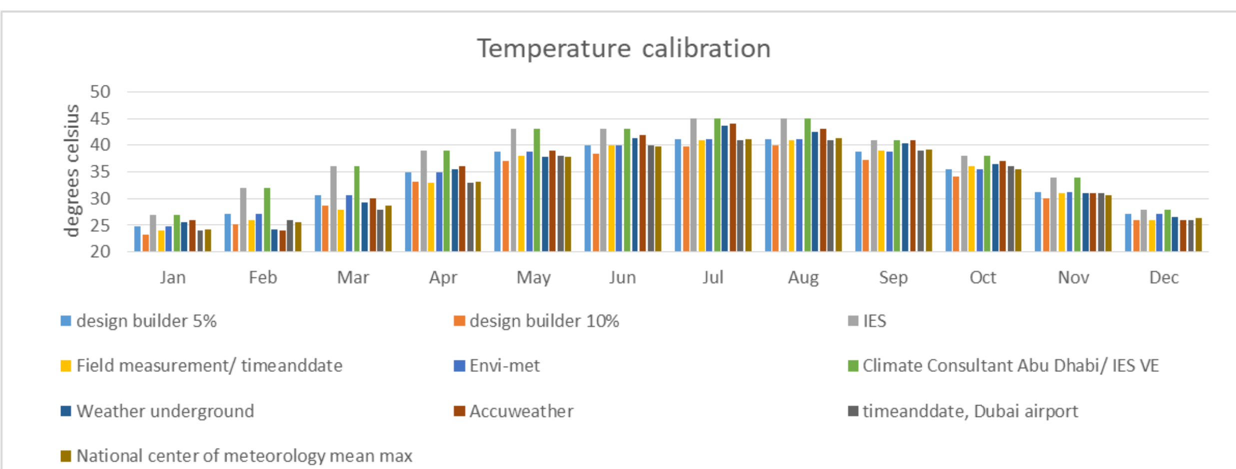


Figure 4.16 - Temperature calibration chart (Source: Author, 2018)

Table 4.2 - Temperature discrepancy (Source: Author, 2018)

	temperature												
Data source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
design builder 5%	2.41935484	5.90405904	6.84039088	5.14285714	2.57731959	0.50125313	-0.243309	-0.729927	-1.0309278	-0.2816901	1.6025641	2.95202952	2.137831
design builder 10%	-4.3103448	-1.1904762	0.34843206	-0.3021148	-1.8867925	-3.3854167	-3.5175879	-3.7593985	-5.3763441	-4.0935673	-1.9933555	-1.1538462	-2.55173
IES	10.3703704	20.3125	20.5555556	14.8717949	12.0930233	7.6744186	8.44444444	8	4.3902439	6.31578947	9.70588235	6.07142857	10.73379
Field measurement/ timeanddate	-0.8333333	1.92307692	-2.1428571	-0.6060606	0.52631579	0.75	-0.4878049	-0.9756098	-0.5128205	1.11111111	0.96774194	-1.1538462	-0.11951
Envi-met	2.41935484	5.90405904	6.84039088	5.14285714	2.57731959	0.50125313	-0.243309	-0.729927	-1.0309278	-0.2816901	1.6025641	2.95202952	2.137831
Climate Consultant Abu Dhabi	10.3703704	20.3125	20.5555556	14.8717949	12.0930233	7.6744186	8.44444444	8	4.3902439	6.31578947	9.70588235	6.07142857	10.73379
Weather underground	5.09803922	-4.9382716	2.3890785	6.47887324	0	4.10628019	5.7208238	2.58823529	2.72952854	2.46575342	1.28617363	1.12781955	2.421028
Accuweather	6.92307692	-6.25	4.66666667	7.77777778	3.07692308	5.47619048	6.36363636	3.72093023	4.3902439	3.78378378	0.96774194	-1.1538462	3.311927
timeanddate, Dubai airport	-0.8333333	1.92307692	-2.1428571	-0.6060606	0.52631579	0.75	-0.4878049	-0.9756098	-0.5128205	1.11111111	0.96774194	-1.1538462	-0.11951
National center of meteorology mean max	0	0	0	0	0	0	0	0	0	0	0	0	0

The table above and the chart below illustrate the discrepancies between these various climate models against data obtained from NCMS.

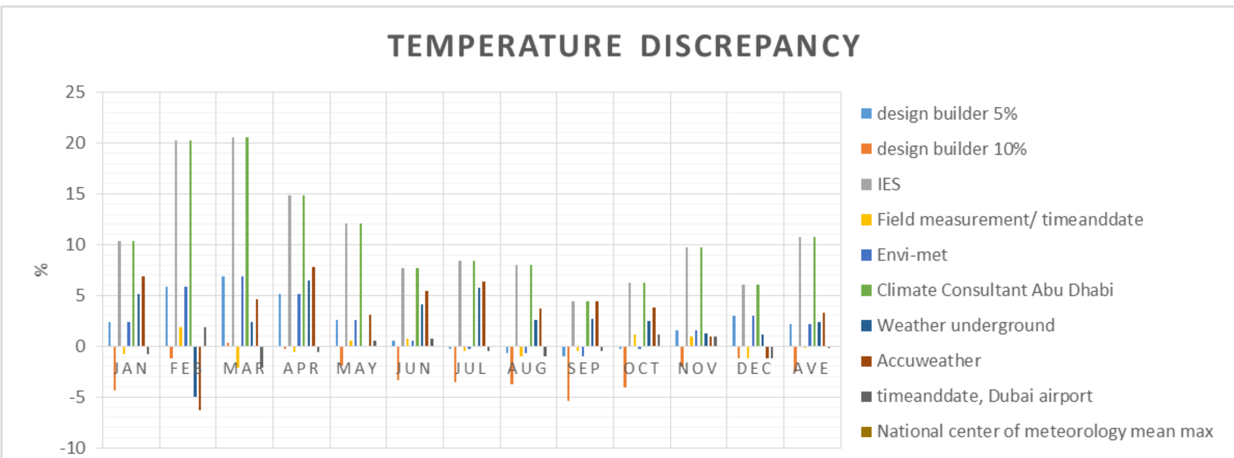


Figure 4.17 - Temperature discrepancy chart (Source: Author, 2018)

Average discrepancy for the following case are acceptable:

- Design builder 5%,
- Design builder 10%,
- Field measurements, Timeanddate
- ENVI-met

- Weather underground
- Accuweather and
- Dubai Airport Weather station, due to it being under 5%.

Average discrepancy for the following case are not acceptable:

- IES VE and
- Climate consultant, Abu Dhabi, due to it not being under 5%.

Table 4.3 - Wind speed calibration (Source: Author, 2018)

					wind							
Data source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IES	3	3.5	3.9	3.9	4	4	3.8	3.8	3.8	3.5	3	3.8
Field measurement/ timeanddate	3	4	4	4	4	4	4	4	4	3	3	3
Envi-met	3	4	4	4	4	4	4	4	4	3	3	3
Climate Consultant Abu Dhabi	3	3.5	3.9	3.9	4	4	3.8	3.8	3.8	3.5	3	3.8
Weather underground	2.9	3.9	3.6	3	3.3	3.3	3.3	3.5	3	3	3.2	2.9
National center of meteorology mean	3.3	3.6	3.75	3.6	3.8	3.8	3.8	3.7	3.4	3.1	3.1	3.1

The table above and the chart below illustrate a conglomeration of various climate models used for calibration purposes against data obtained from NCMS.

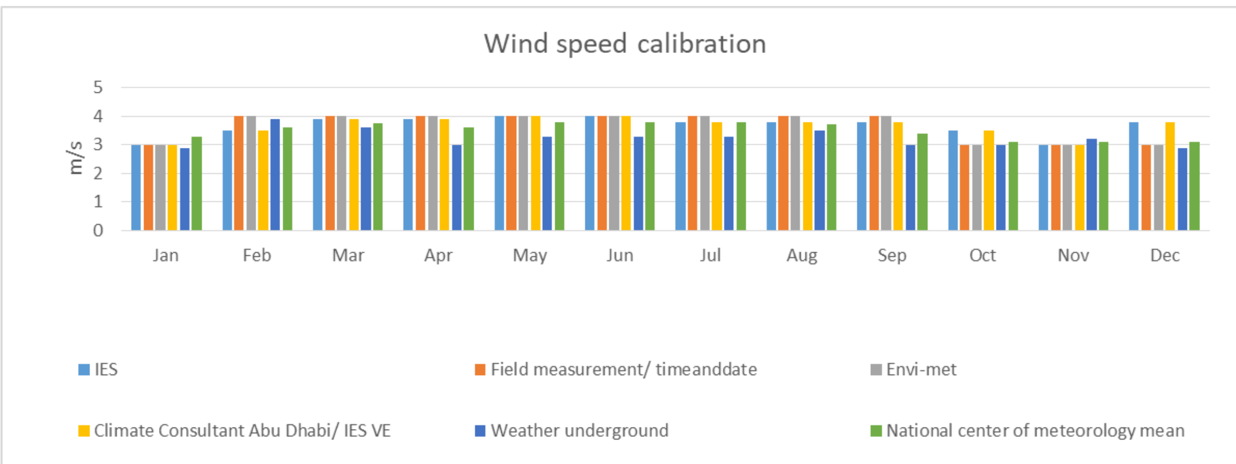


Figure 4.18 - Wind speed calibration chart (Source: Author, 2018)

Table 4.4 - Wind speed discrepancy (Source: Author, 2018)

						wind							
Data source	January	February	March	April	May	June	July	August	September	October	November	December	Ave
IES	-10	-2.8571429	3.84615385	7.69230769	5	5	0	2.63157895	10.5263158	11.4285714	-3.3333333	18.4210526	4.029625
Field measurement/ timeanddate	-10	10	6.25	10	5	5	5	7.5	15	-3.3333333	-3.3333333	-3.3333333	3.645833
Envi-met	-10	10	6.25	10	5	5	5	7.5	15	-3.3333333	-3.3333333	-3.3333333	3.645833
Climate Consultant Abu Dhabi	-10	-2.8571429	3.84615385	7.69230769	5	5	0	2.63157895	10.5263158	11.4285714	-3.3333333	18.4210526	4.029625
Weather underground	-13.793103	7.69230769	-4.1666667	-20	-15.151515	-15.151515	-15.151515	-5.7142857	-13.333333	-3.3333333	3.125	-6.8965517	-8.48954
National center of meteorology mean	0	0	0	0	0	0	0	0	0	0	0	0	0

The table above and the chart below illustrate the discrepancies between these various climate models against data obtained from NCMS.

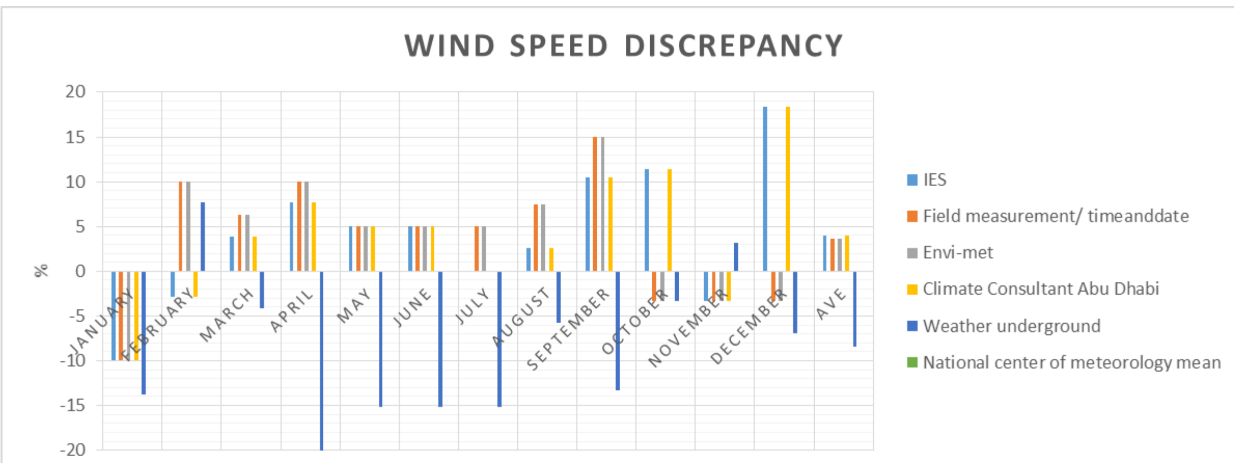


Figure 4.19 - Wind speed discrepancy chart (Source: Author, 2018)

Average discrepancy for the following case are acceptable:

- IES VE,
- Field measurements, Timeanddate, Dubai Airport
- ENVI-met
- Climate consultant, Abu Dhabi, due to it being under 5%.

Average discrepancy for the following case are not acceptable:

- Weather underground, due to it not being under 5%.

Table 4.5 - Relative humidity calibration (Source: Author, 2018)

	relative humidity											
Data source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IES	70	64	69	55	49	52	54	53	61	59	70	65
Field measurement/ timeanddate	63	62	59	51	46	53	52	51	57	58	59	63
Envi-met	63	62	59	51	46	53	52	51	57	58	59	63
Climate Consultant Abu Dhabi	70	64	69	55	49	52	54	53	61	59	70	65
Weather underground	73.9	72.1	72.8	56.7	63.6	67.4	56.5	63.3	71.5	79	64.5	72.9
National center of meteorology mean max	65	64	61	53	49	55	54	53	58	60	60	70

The table above and the chart below illustrate a conglomeration of various climate models used for calibration purposes against data obtained from National Centre for Meteorology and Seismology (NCMS).

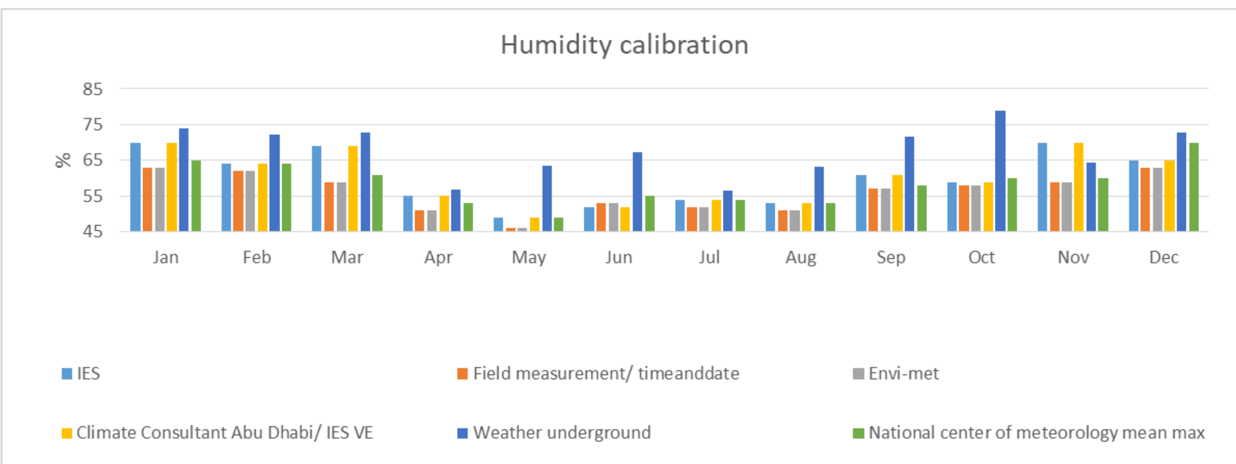


Figure 4.20 - Relative humidity calibration chart (Source: Author, 2018)

Table 4.6 - Relative humidity discrepancy (Source: Author, 2018)

relative humidity													
Data source	January	February	March	April	May	June	July	August	September	October	November	December	Ave
IES	-7.6923077	0	-13.114754	-3.7735849	0	5.45454545	0	0	-5.1724138	1.66666667	-16.666667	7.14285714	-2.67964
Field measurement/ timeanddate	3.07692308	3.125	3.27868852	3.77358491	6.12244898	3.63636364	3.7037037	3.77358491	1.72413793	3.33333333	1.66666667	10	3.934536
Envi-met	3.07692308	3.125	3.27868852	3.77358491	6.12244898	3.63636364	3.7037037	3.77358491	1.72413793	3.33333333	1.66666667	10	3.934536
Climate Consultant Abu Dhabi	-7.6923077	0	-13.114754	-3.7735849	0	5.45454545	0	0	-5.1724138	1.66666667	-16.666667	7.14285714	-2.67964
Weather underground	-13.692308	-12.65625	-19.344262	-6.9811321	-29.795918	-22.545455	-4.6296296	-19.433962	-23.275862	-31.666667	-7.5	-4.1428571	-16.3054
National center of meteorology mean max	0	0	0	0	0	0	0	0	0	0	0	0	0

The table above and the chart below illustrate the discrepancies between these various climate models against data obtained from NCMS.

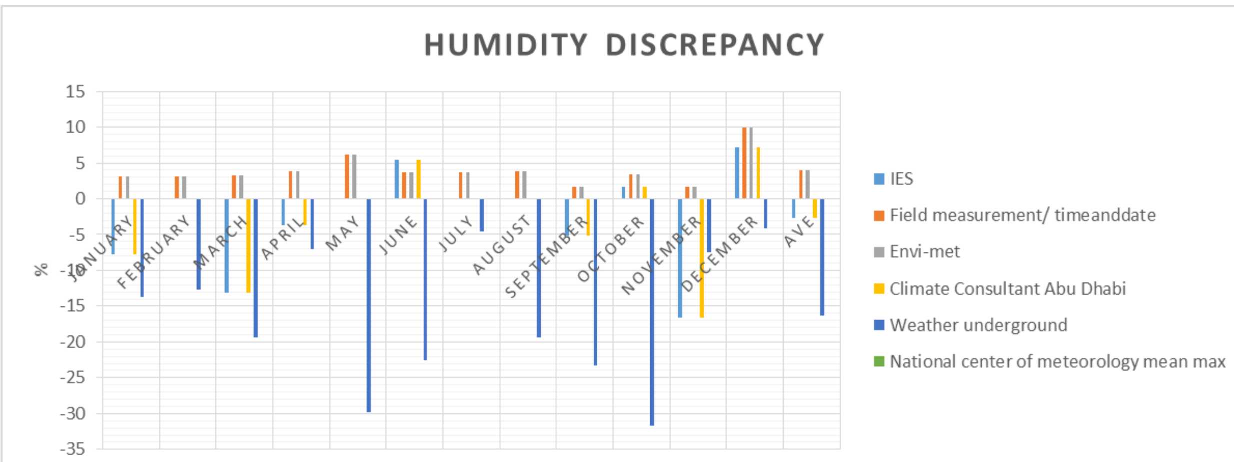


Figure 4.21 - Relative humidity discrepancy chart (Source: Author, 2018)

Average discrepancy for the following case are acceptable:

- IES VE,
- Field measurements, Timeanddate, Dubai Airport
- ENVI-met
- Climate consultant, Abu Dhabi, due to it being under 5%.

Average discrepancy for the following case are not acceptable:

- Weather underground, due to it not being under 5%.

ENVI-met simulation tool calibrated successfully with air temperature, wind speed and relative humidity. IES VE simulation tool calibrated successfully with wind speed and relative humidity, but showed a discrepancy of above 5% for the air temperature. Given that the simulation will only be run on one day due to time constraints, and that the simulation model allows for the input of climate data to be force fed into the project, this program is estimated to work successfully for the purpose of this study.

4.3.2. Calibration of energy models

Calibration of energy models include MWh for each month for the entire year.

Table 4.7 - Energy calibration (Source: Author, 2018)

Energy													
Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption Base case MWh	3.4	3.2	3.9	4.5	5.3	5.5	5.9	5.9	5.4	4.9	4.1	3.6	55.6
Energy consumption actual villa MWh	3.5	3.6	4.3	4.7	5.1	5.8	6.1	6.2	5.1	5	4.2	3.4	57

The table above and the chart below illustrate the energy model used for calibration purposes against data obtained of the actual villa under scope.

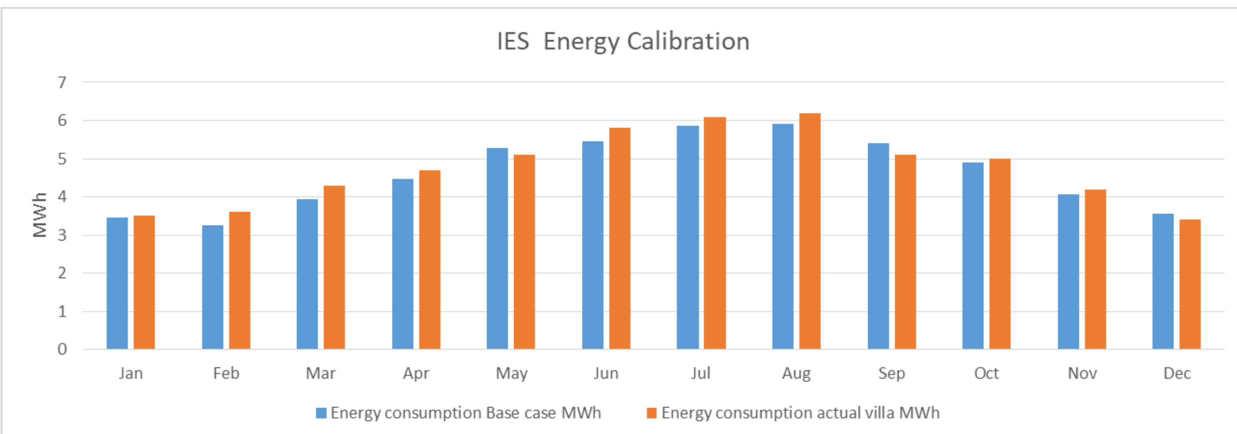


Figure 4.22 - Energy calibration chart (Source: Author, 2018)

Figure 4.8 - Energy discrepancy (Source: Author, 2018)

Energy													
Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption Base case MWh	3.4	3.2	3.9	4.5	5.3	5.5	5.9	5.9	5.4	4.9	4.1	3.6	55.6
Energy consumption actual villa MWh	3.5	3.6	4.3	4.7	5.1	5.8	6.1	6.2	5.1	5	4.2	3.4	57
Discrepancy percentage	2.9	11.1	9.3	4.3	-3.9	5.2	3.3	4.8	-5.9	2.0	2.4	-5.9	2.5

The table above and the chart below illustrate the discrepancy in data reading of the energy model used for calibration purposes against data obtained of the actual villa under scope.

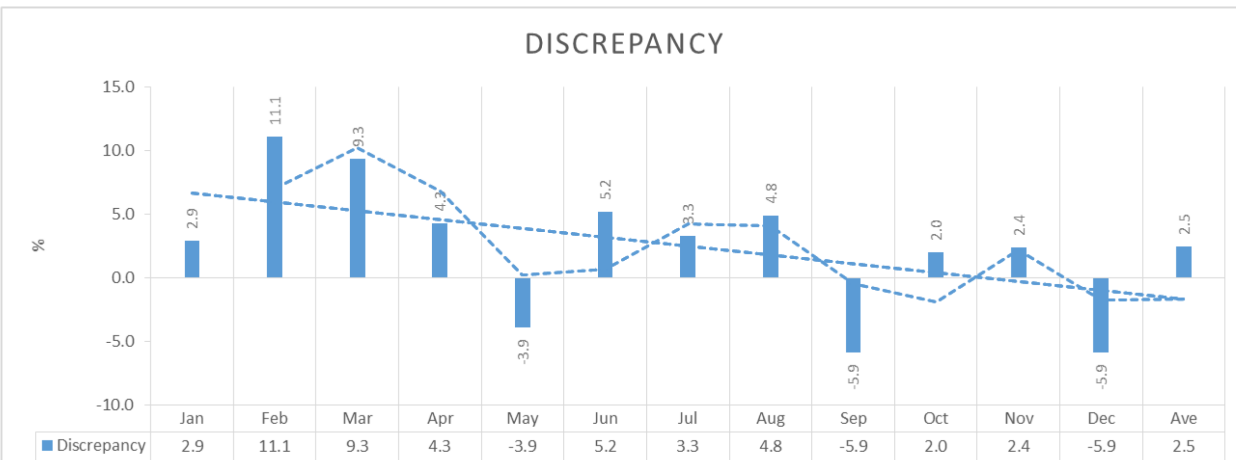


Figure 4.23 - Energy discrepancy chart (Source: Author, 2018)

With the discrepancy averaging at 2.5%, the IES VE model is successfully calibrated for energy consumption simulations due to it being under 5%.

4.3.3. Validation of climate and energy models

In this process the pattern of energy consumption will be visually compared to validate the expectant accuracy of the models.

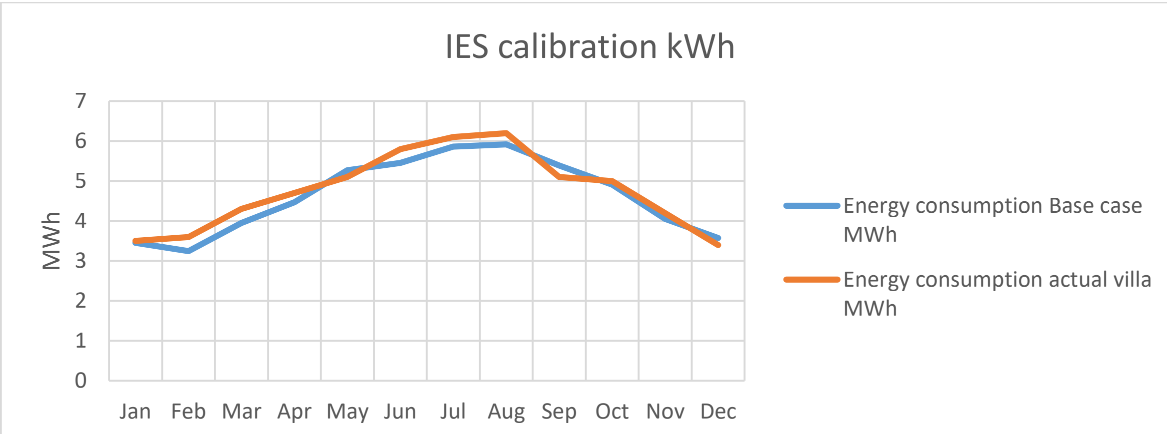


Figure 4.24 - Plotted Energy consumption pattern chart (Source: Author, 2018)

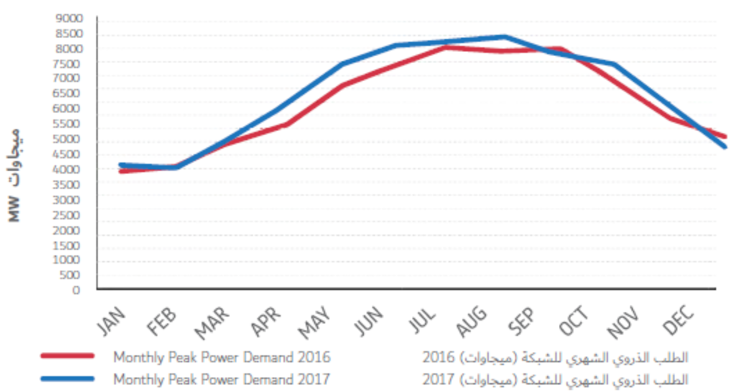


Figure 4.25 - Plotted Energy consumption pattern chart (Source: DEWA, 2018)

Consistent pattern can be found when comparing these two graphs. Firstly, the minimum and the maximum months correlate in both graphs. Secondly, the increase in energy consumption in both cases correlate via the similar angle of growth. Thirdly, the maximum in both cases amount to about double the minimum. Thus, the minimum, the maximum, the angle and the ratio of increase correlate.

4.4 Model Setup

As stated in the book of Anderson (2014), it is necessary to establish the appropriate questions/ aims/ outcomes in order to choose the correct simulation software as there are no holistic program to model all and every aspect of the design. It is the responsibility of the researcher to ensure the software is compatible and applicable to the study.

Ways simulations have changed over the past years:

- User friendly – Software is designed to be used by professionals within the field/ industry such as architects and planner and not only for the specialized professionals anymore.
- Quick learning – less time to learn how to use the software, more efficient regarding time usage by readily available data files (for example weather files and basic construction types), which can be loaded into the modeling software/ simulation program as a default setting.
- Graphical interface
- Various types of simulations that can be run
- Modeling programs to be able to create 3D geometry
- Outputs which are able to map the results of the graphical data onto the 3D models

Software accuracy and validation depend on these key aspects namely the development of graphical simulation software, and design simulation software elements

ENVI-met environmental software to determine external urban factors and the influence of various strategies to optimize outdoor thermal conditions according to the outdoor thermal comfort of humans. Models are set-up so that the inputs of the simulation model and the changes thereof will at end answer the questions raised/ posed. It is the minimum tie cost, complexity and size/ extent. This will put the researcher in a position to be able to compare the actual performance against the predicted performance and thus enable the analysis which will lead to identifying areas for optimization.

4.4.1. ENVI-met

Model initialization for simulations: July 19, 2018, were simulated to embody the typical hot summers day, as it was the most extreme conditions of the year 2017. The climatic data for this day was obtained from a combination of weather profiles to ensure reliable data. This was also used to calibrate and validate the simulation data information and will be used again in the analysis section of the document. The models were simulated for 5 hours, from 11:00hrs, with the first reading clocking in at 12:00 and extending to 16:00. Reason for the choice of this timeframe is to simulate the most extreme conditions of the day, as design decisions are to be taken on the extreme condition. Data from the simulation models were documented every hour in the form of graphic graph illustrations that are to be read correctly and compared in a good way. The mesh of a 60×60 grid was arranged over the site area and to also include a block/ row of houses on each side of the chosen villa. This will give analysis information on building urban level for the ground coverage, roads, vegetation and water features. Thus the model will stretch 120mX120m with horizontal resolution of 2 m per square block, resulting in a total area of 14400m^2. Vertical analysis is set to 1m height to ensure lay user comfort conditions. Building are set at 10m height to represent the 2 levels and extruding parapets of the flat roofs to ensure the reading are correct with regards to wind obstruction and self-shading. Changing and creating model domain for simulation model set up: Model type: concept design. Main model area layout: X-grids = 60, Y-grids = 60, Z-grids = 30. Nesting grids around main area is set at 0. Soil profiles for nesting grid is set on [LO] Loamy soil for Soil set A and set for Soil set B. Grid size and structure in the main area consist settings of size of grid cell at dx = 2meters, dy = 2meters, dz = 2meters base height. The method of vertical grid generation is set on equidistant which means that all dz are equal except lowest grid box. Default wall and roof properties are set [00] Concrete slab, Hollow block, Geographic Properties, base case set to 0 degrees of model rotation out of grid north. Modeled with North on 0degrees. Location on earth set on Dubai/UAE, Position on earth latitude (deg., +N, -S) 25.25, longitude (deg., -W, +E) 55.33, reference time zone GMT+4 and reference longitude 60.00. Georeferenced co-ordinate of lower left grid set at 0 for both x-value and y-value, reference system set to PLANE, and reference level above sea level for DEM=0 at 0.00. (The maximum model size is 100x100x40 in ENVI-met BASIC.)

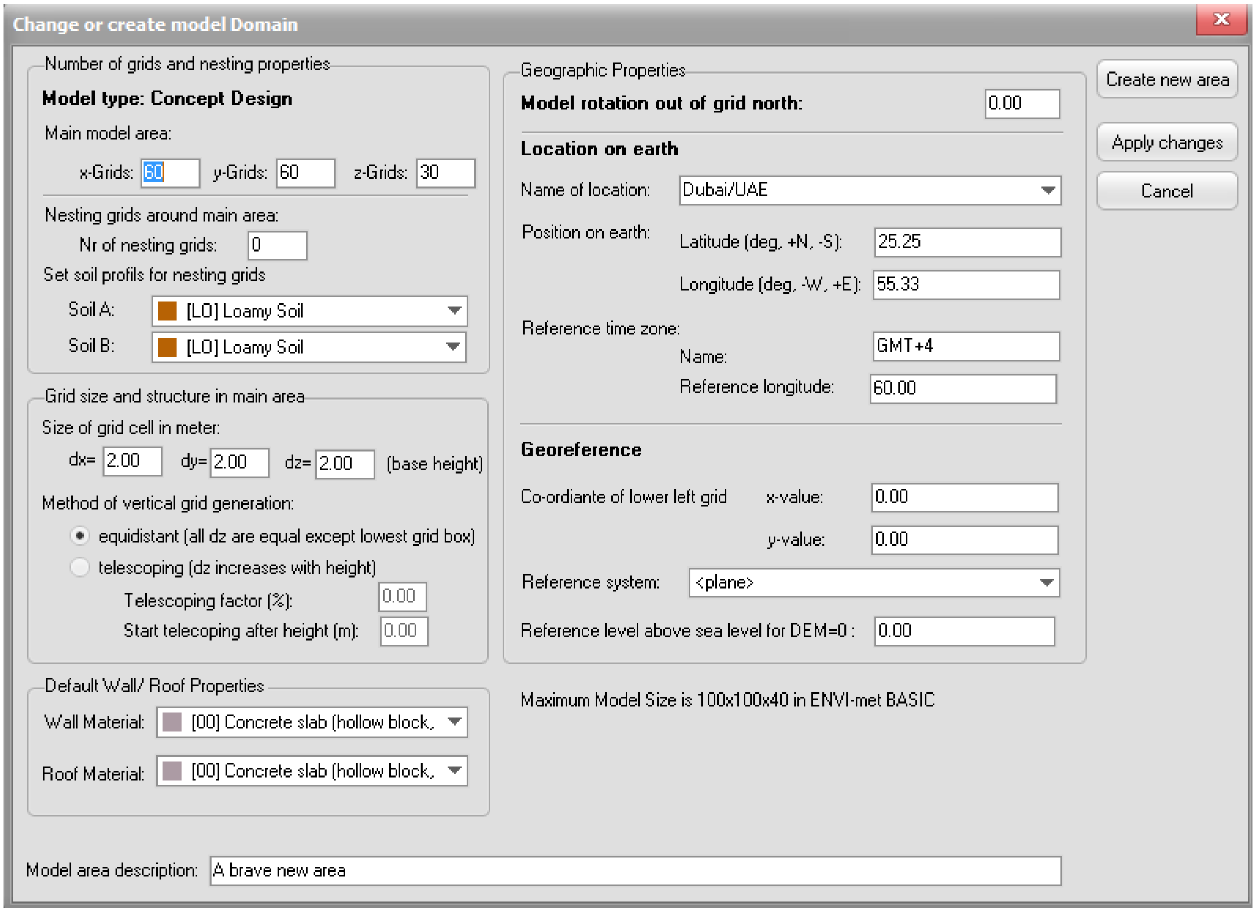


Figure 4.26 - Input model set up (Source: ENVI-met, 2018)

The Base Case include the simulation of villas, road surfaces and driveways and the rest is seen as [SD] Sandy Soil ground coverage. It was done in this way to separate the elements and to make informed decisions as to whether or not these parameters contribute positively or negatively on the external conditions. The community is done by Dubai properties and is categorized as a mature community that was completed in 2010 and has the finishes of mid-end property classifications. At present the community has about only 50% of the initially proposed vegetation as it was advertised and illustrated on the masterplan, thus the decision to simulate the base case with sandy soil.

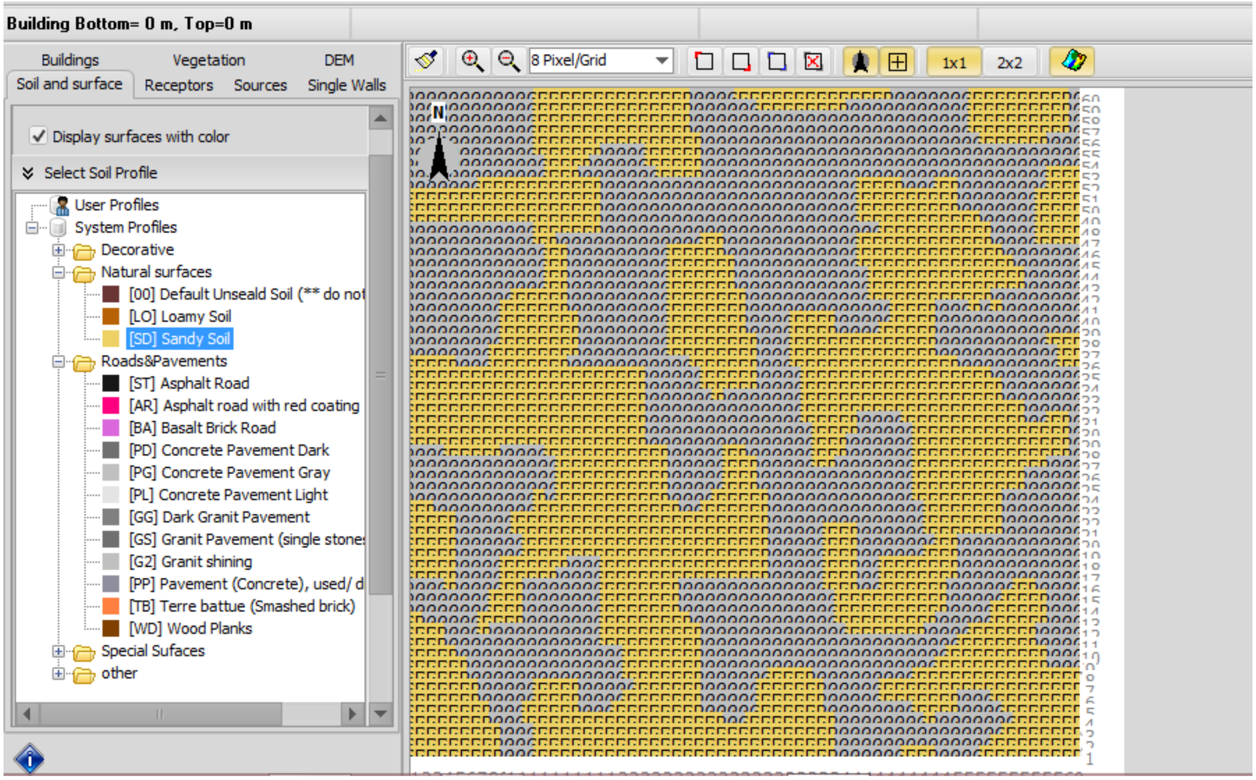


Figure 4.27 - Base case soil input (Source: ENVI-met, 2018)

Time and date output settings on 19-07-2017, 11:00:00, total of five hours simulation time. Output setting: output interval for files: receptors and buildings (min) at 340 and all other files (min) at 60. Meteorology: basic settings are to define the basic meteorological framework for the simulation. Initial meteorological conditions for wind set at 3.3m/s measured in 10m height, Wind direction (deg.) set at 315 degrees (if 0=North…180=from south…), the roughness length at measurement site set at 0.01. The temperature T settings set at 49.3 degrees Celsius of initial temperature of atmosphere which is calculated when forcing is used. The humidity (q) settings are set at 7.0g/kg, 2500m, at the model top and relative humidity set at 50% in 2m. **Important note:** A general residential block without vegetation in the base case was simulated to analyze the true effects of orientation, ground covering, vegetation tree height and the effects water has on the environment in these conditions.

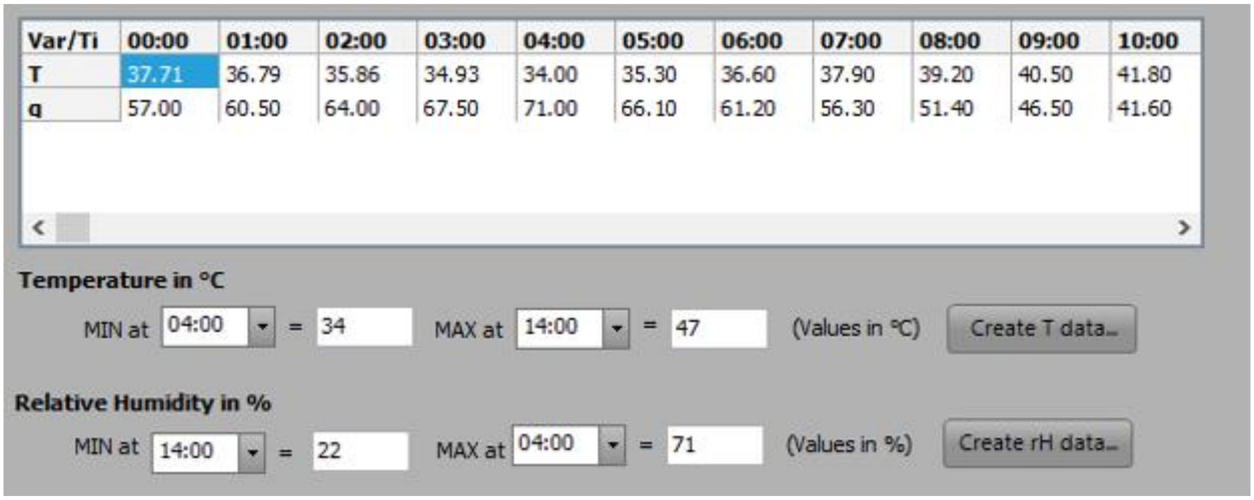


Figure 4.28 - Base case climate input (Source: ENVI-met, 2018)

Development of Sustainable strategies to Enhance Outdoor Thermal Comfort

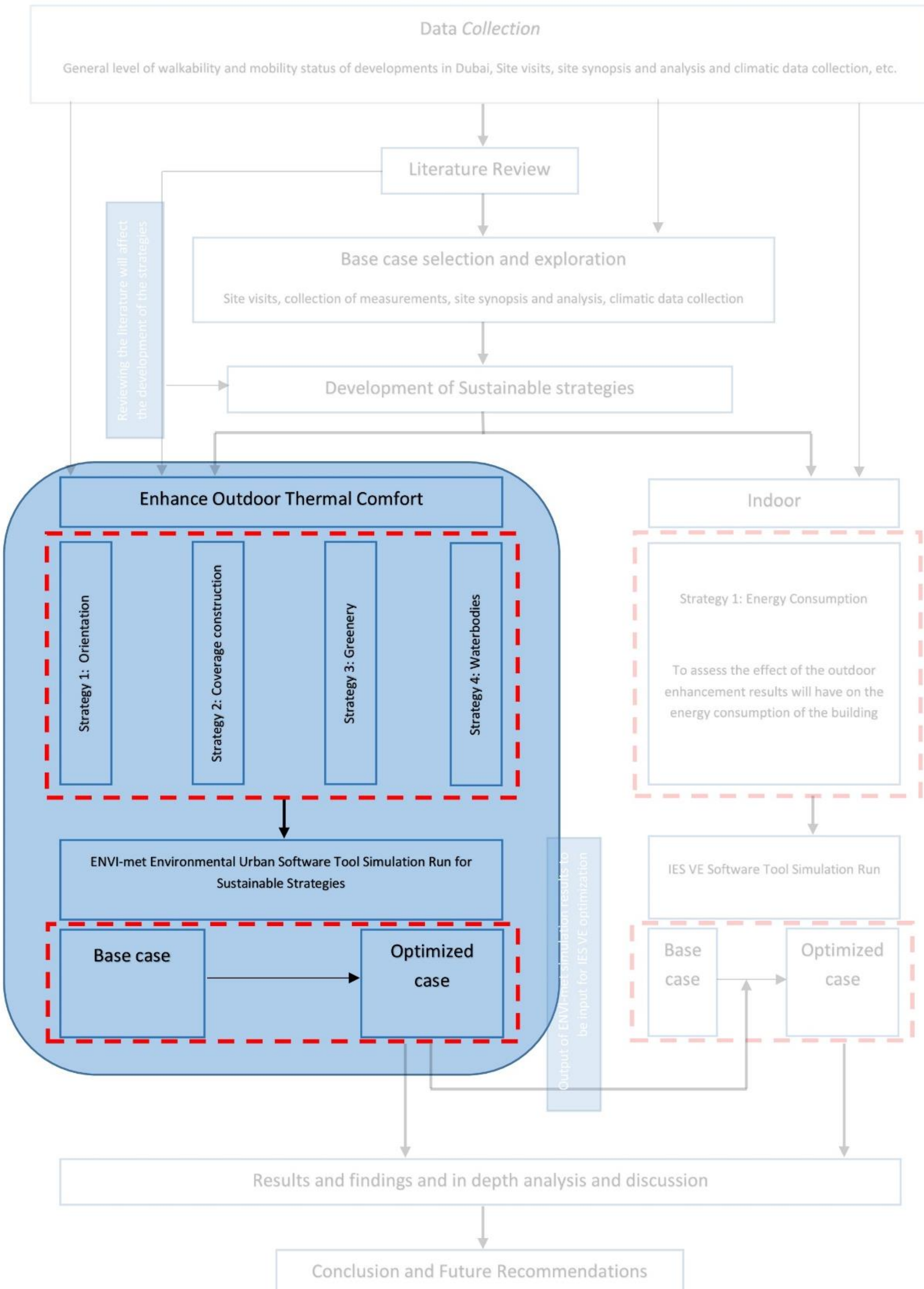


Figure 4.29 - Sectional map illustrating simulations covered in ENVI-met (Source: Author, 2018)

Conceptual strategy design development. Finalizing the processes to be evaluated with the main focus on the highlighted section of the methodological mapping of the study to enhance the outdoor thermal comfort of the immediate environment of human movement around the perimeter of the structure.

Strategy 1: orientation.

Base case information: Only things modeled are buildings as specified at 10m height, sandy soil and roads set as Concrete Pavement Grey as is the in reality.

Simulation run 1: Orientation of the area at 0 degrees=north as such in the base case.

Simulation run 2: Orientation of the area at 270 degrees=north.

Simulation run 3: Orientation of the area at 180 degrees=north.

Simulation run 4: Orientation of the area at 90 degrees=north.

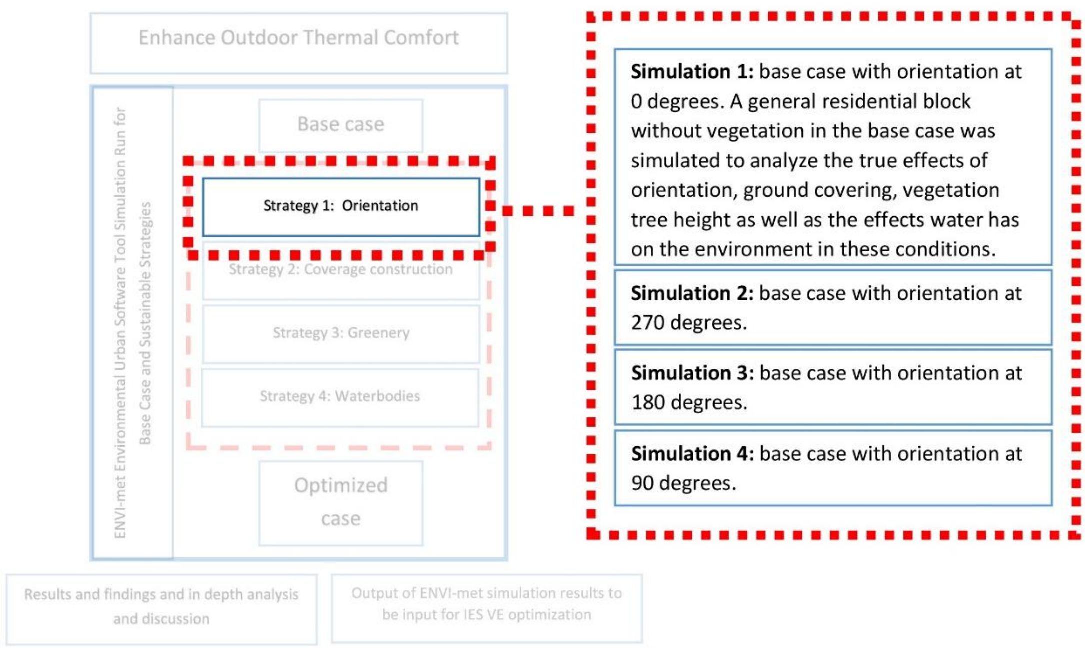


Figure 4.30 - Sectional map illustrating simulations covered in Strategy 1 (Source: Author, 2018)

NB: determine from the run simulations which orientation of the area of study is most efficient and use that as the base case for strategy 2.

Strategy 2: Coverage material.

Simulations of the first simulation phase which tested the orientation of the area of study and determined the most efficient case which is used as an input model for start of strategy 2.

Simulation run 5: Coverage materials as in the base case, but changes made to the paving material and color to determine if the is any changes.

First scenario: Roads are covered with Concrete Pavement Light (PL).

Simulation run 6: Second scenario: Roads are covered with Granite Shining (G2).

Vegetation is to be introduced gradually to determine the effects the different vegetation coverage will have in the external environmental factors and conditions. Sandy soil is to be replaced by grass type 1 or 2.

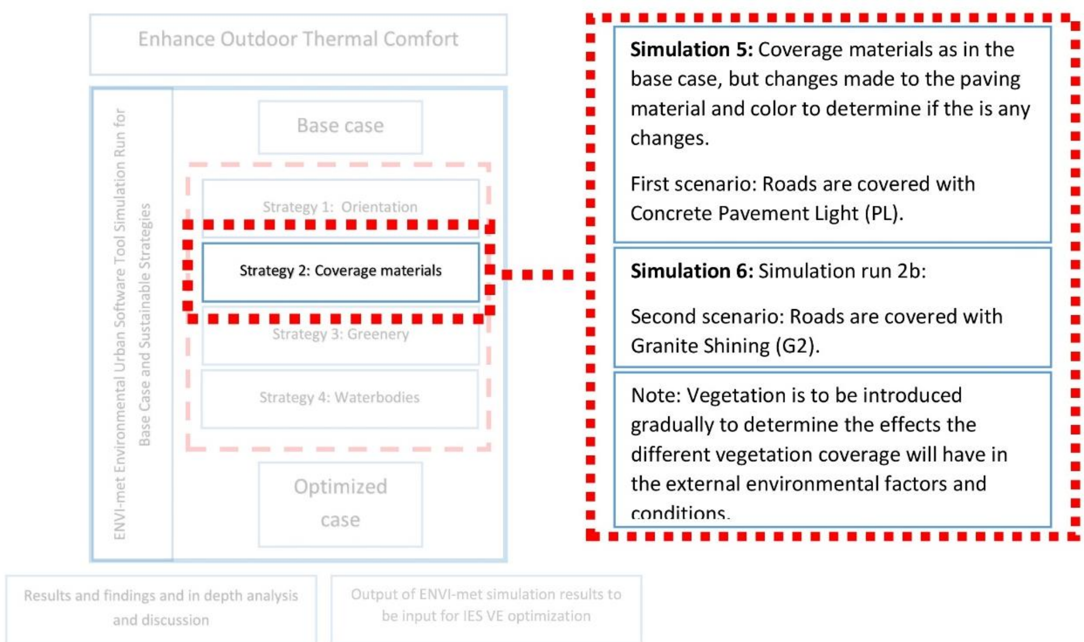


Figure 4.31 - Sectional map illustrating simulations covered in Strategy 2 (Source: Author, 2018)

NB: determine from the run simulations which coverage materials of the area of study is most efficient and use that as the base case for strategy 3.

Strategy 3: Greenery.

Simulations of the second simulation phase which tested the coverage materials of the area of study and determined the most efficient case which is used as an input model for start of strategy 3.

Simulation run 7: Most efficient case of phase 2 and then with the introduction of greenery via trees. First scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 10m height.

Simulation run 8: Second scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 15m height.

Simulation run 9: Third scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 20m height.

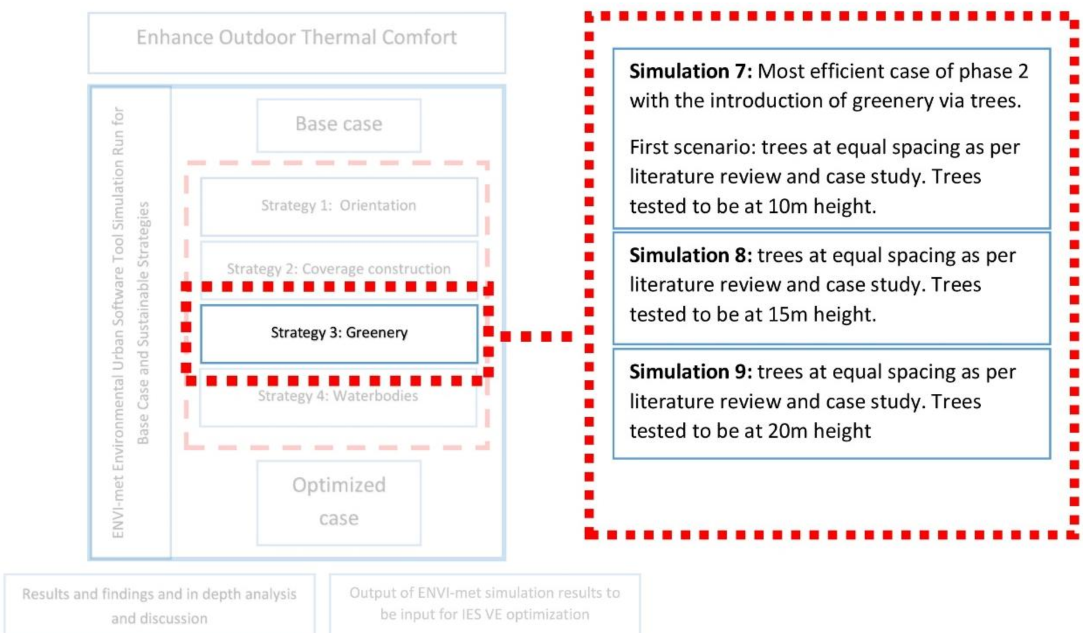


Figure 4.32 - Sectional map illustrating simulations covered in Strategy 3 (Source: Author, 2018)

NB: determine from the run simulations which greenery of the area of study is most efficient and use that as the base case for strategy 4.

Strategy 4: Waterbodies.

Simulations of the third simulation phase which tested the introduction of greenery and vegetation of the area of study and determined the most efficient case which is used as an input model for start of strategy 4.

Simulation run 10: Most efficient case of phase 3 and then with the introduction of waterbodies with various depths. Waterbodies introduces at front of yard and back of yard. The different variables that will be introduced will be the same coverage, but will differ in depth and will in some cases include spray. Swimming pools and spraying fountains. First scenario: Swimming pool with a depth of 1 to 2m.

Simulation run 11: Second scenario: fountain with a spray of 4m height for evaporating cooling and to test the effects of the humidity in the afternoon time.

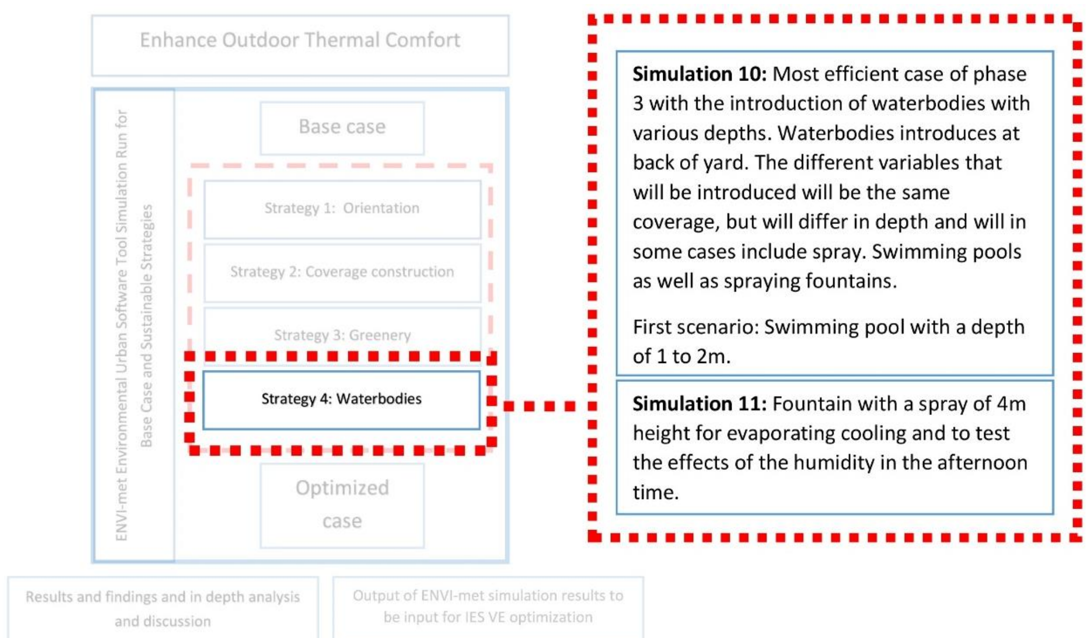


Figure 4.33 - Sectional map illustrating simulations covered in Strategy 4 (Source: Author, 2018)

NB: determine from the run simulations which waterbodies of the area of study is most efficient. The optimized results reading will act as an input for simulation run 13 in the IES VE simulation phase.

Environmental parameters

Using ENVI-met software, simulations of the Base case and the Optimized cases, with respect to the environmental parameters, were done. Scenarios have been simulated based on different selections of orientation, materials, and vegetation and water features, to determine the best possible configuration for the community.

The environmental objectives:

- Reduction of the atmospheric temperature,
- Decreasing the reduction/ obstruction of the wind flow speed,
- Increasing the humidity so that the minimum fall in the comfortable range which is minimum 50%, and ensure that the maximum humidity do not surpass 70%.

Areas targeted are front of yard, back of yard, roadside/ circulation route and green open spaces.

4.4.2. IES VE

Energy Consumption - To assess the effect of the outdoor enhancement results will have on the energy consumption of the building - via Energy plus Engine for Indoor Thermal Comfort Conditions. State period of simulation, will be at peak temperature in summertime due to energy consumption being at capacity.

Model initialization for simulations:

Base case as is in the current community. Done on a building scale to include only the villa and the environmental factors that will influence the parameters tested.

Simulation 12: First scenario: Base case villa. Reading for temperature and lighting and the energy consumption of the particular villa. It needs to be compared to real time data collected from the energy consumption of the modeled villa which is obtained from the owners themselves.

Simulation 13: Second scenario: Base case villa with the external environmental changes from the most efficient case of simulation done on ENVI-met used as input. Reading for the energy consumption of the particular villa will be modeled. It needs to be compared to real time data collected from the energy consumption of the modeled villa and the modeled base case in simulation 12 to determine the differences in reading and energy consumption.

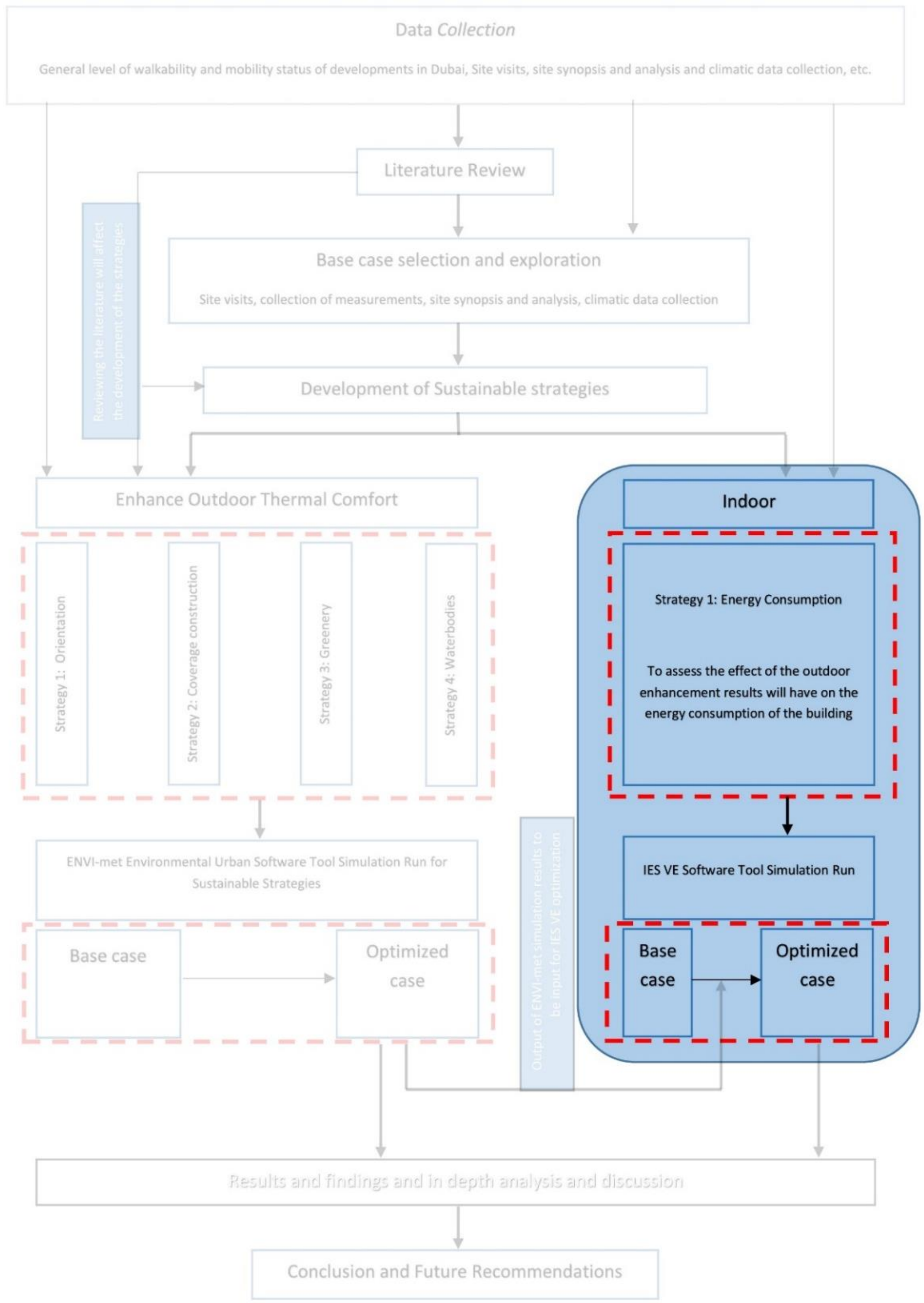


Figure 4.34 - Sectional map illustrating simulations covered in IES VE (Source: Author, 2018)

Conceptual strategy design development. Finalizing the processes to be evaluated with the main focus on the highlighted section of the methodological mapping of the study to assess the effect that the outdoor thermal conditions (after optimization strategies are simulated) have on energy consumption within the perimeter of the structure.

Strategy 5: energy consumption.

Simulation run 12: Base case on building level done of a single villa. As is.

Simulation run 13: the only variables to be used as inputs into the model are the optimized climatic changes that occurred in the ENVI-met modelling phases and concluded from the optimal results of phase 4.

Base case information: Only things modeled are buildings as specified at 10m height, sandy soil and roads set as Concrete Pavement Grey as is the in reality.

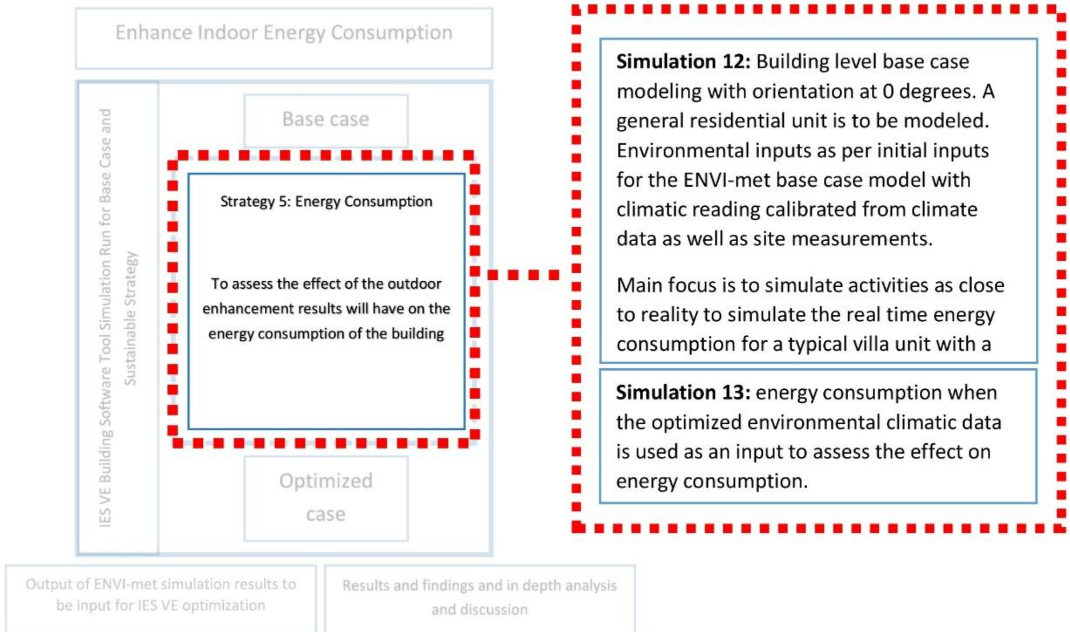


Figure 4.35 - Sectional map illustrating simulations covered in Strategy 5 (Source: Author, 2018)

Environmental parameters

Using IES VE software, simulations of the Base case and the Optimized case, with respect to the energy consumption, were done. Scenarios have been simulated based on the base case environment and the results of outdoor simulation phases (orientation, coverage materials, vegetation and water features) to determine the effect the changes in outdoor environmental conditions will pose on the energy consumption of the typical unit villa.

The energy consumption output:

- Reduced energy consumption, MWh
- Reduced cost, AED
- Reduced carbon footprint, gCO2eq/kWh, metric tons of carbon dioxide emissions

Area targeted is the overall yearly energy consumption of the unit and the monthly.

Summary of Chapter 4

Covered in this chapter are the site data analysis and climatic profile of the area. Simulation models ENVI-met and IES VE were calibrated successfully with promising resources emerging. Model set ups were done thoroughly, with missing data programmed at default.

CHAPTER 5

ANALYSIS AND DISCUSSION

Introduction to Chapter 5

Chapter 5, the Analysis and Discussion chapter, cover the in-depth discussions of the thirteen different simulations that were run which are compared against each other to conclude significant findings.

5.1 Orientation - ENVI-met

Important note: A general residential block without vegetation in the base case was simulated to analyze the true effects of orientation has on the environment in these conditions.

Base case info: Only things modeled are buildings as specified at 10m height, sandy soil and roads set as Concrete Pavement Grey as is the in reality.

Simulation run 1: Orientation of the area at 0 degrees=north as such in the base case.

Simulation run 2: Orientation of the area at 270 degrees=north.

Simulation run 3: Orientation of the area at 180 degrees=north.

Simulation run 4: Orientation of the area at 90 degrees=north.

The most sought after readings are the lowest temperature reading, coupled with the highest velocity wind speed with a relative humidity that falls within the comfort range.

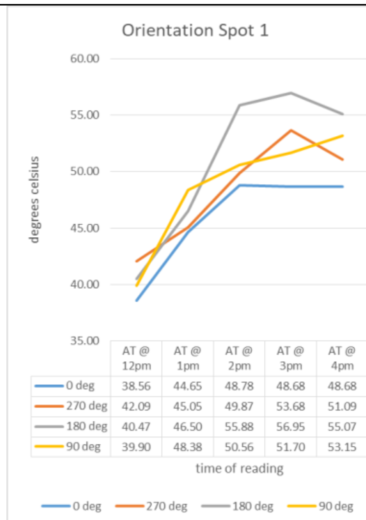
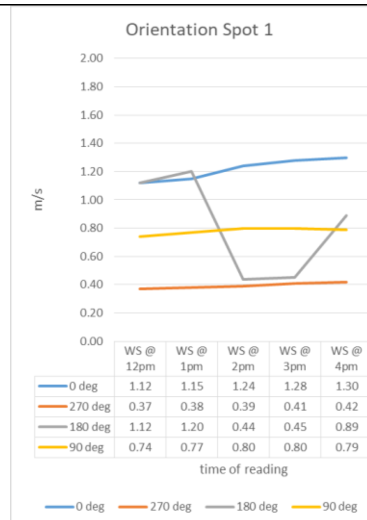
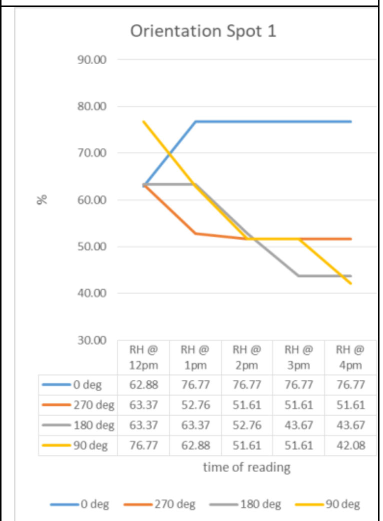
<table>
<tr><td colspan="4">Table 5.1: Orientation - Comparison of Simulations 1,2,3,4 (Measurement Spot 1)</td></tr>
<tr><td>ENVI
-met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 1</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.1 presents the readings of the measures taken on the five hours at Spot 1 in the front of the yard. The best readings of air temperature and wind speed lean toward orientation option 0 degrees, as with the base case. Relative humidity fall within the comfort zone at 1pm-2pm in all orientations, but one, and at 3pm with orientation option 270 degree and 90 degree with 180 degree falling below the comfort range and 0 degree above.

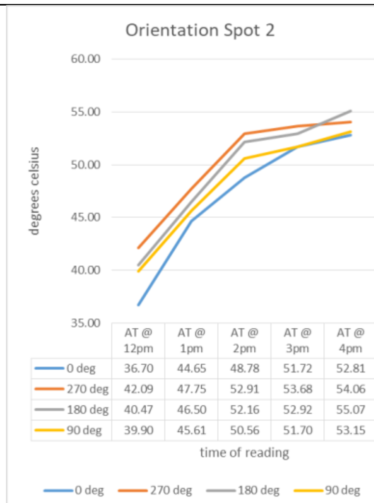
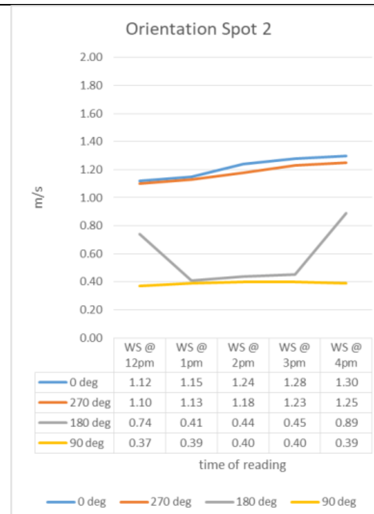
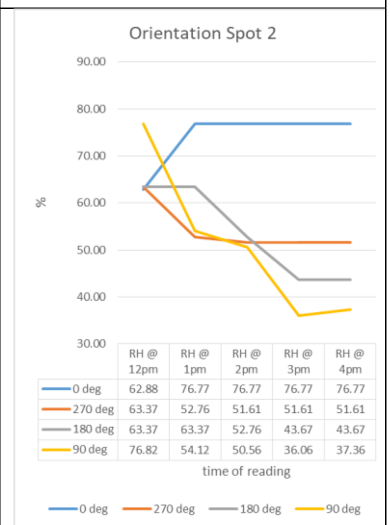
<table>
<tr><td colspan="4">Table 5.2: Orientation - Comparison of Simulations 1,2,3,4 (Measurement Spot 2)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 2</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.2 presents the readings of the measures taken on the five hours at spot 2 in the back of the yard. The best readings of air temperature and wind speed lean toward orientation option 0 degree, as with the base case. Relative humidity fall within the comfort zone at 1pm-2pm in all orientations, but one, and at 3pm with orientation option 270 degree and 90 degree with 180 degree falling below the comfort range and 0 degree above.

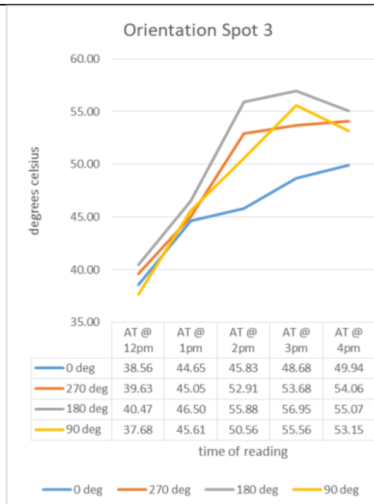
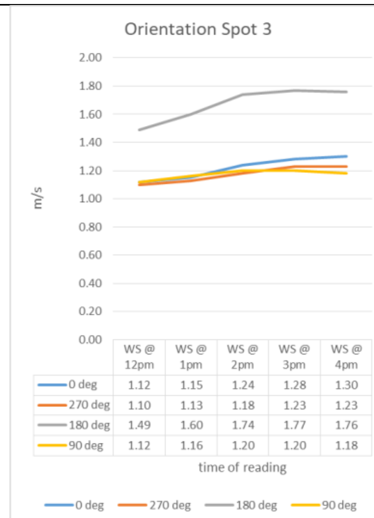
Table 5.3: Orientation - Comparison of Simulations 1,2,3,4 (Measurement Spot 3)			
EN VI- met	Air Temperature	Wind Speed	Relative Humidity
Measurement Spot 3			

Table 5.3 presents the readings of the measures taken on the five hours at spot 3 in the front of the yard on the road surface area. The best readings of air temperature lean toward orientation option 0 degree, as with the base case. The best readings of wind speed lean toward orientation option 180 degree. Relative humidity fall within the comfort zone at 1pm in all orientations and only at 2pm with orientation option 90 degree. Relative humidity fall within the comfort zone at 12pm in all orientations, but one, and at 1-2pm with orientation option 270 degree, 180 degree and 90 degree. After 3pm 180 degree and 90 degree falling below the comfort range and 0 degree above.

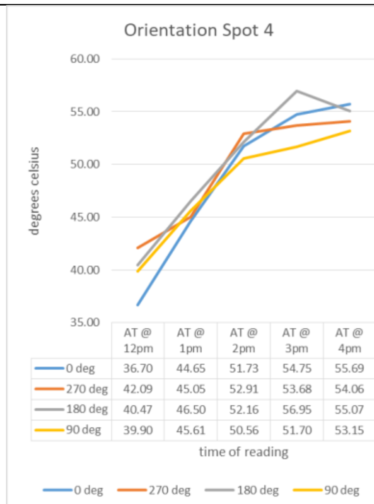
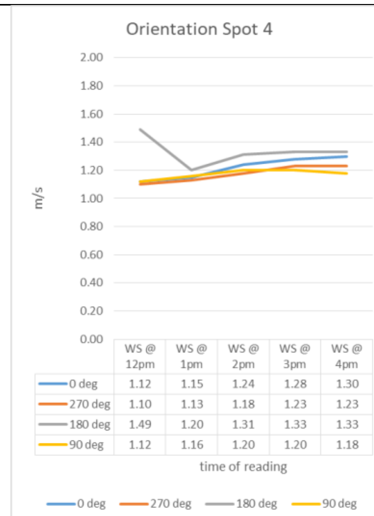
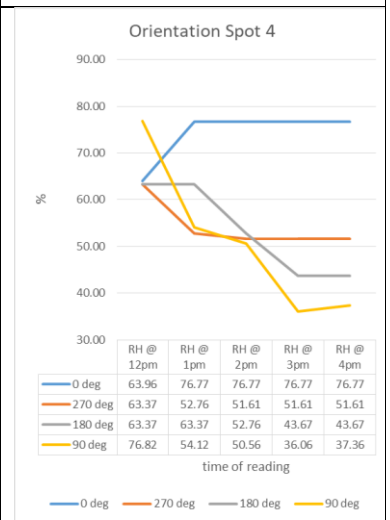
<table>
<tr><td colspan="4">Table 5.4: Orientation - Comparison of Simulations 1,2,3,4 (Measurement Spot 4)</td></tr>
<tr><td>EN VI- met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 4</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.4 presents the readings of the measures taken on the five hours at spot 4 in the back side of the yard on the open space area. The best readings of air temperature and wind speed lean toward orientation option 0 degree, as with the base case. Relative humidity fall within the comfort zone at 1pm in all orientations and only at 2pm with orientation option 1d. Relative humidity fall within the comfort zone at 12pm in all orientations, but one, and at 1-2pm with orientation option 270 degree, 180 degree and 90 degree. After 3pm 180 degree and 90 degree falling below the comfort range and 0 degree above.

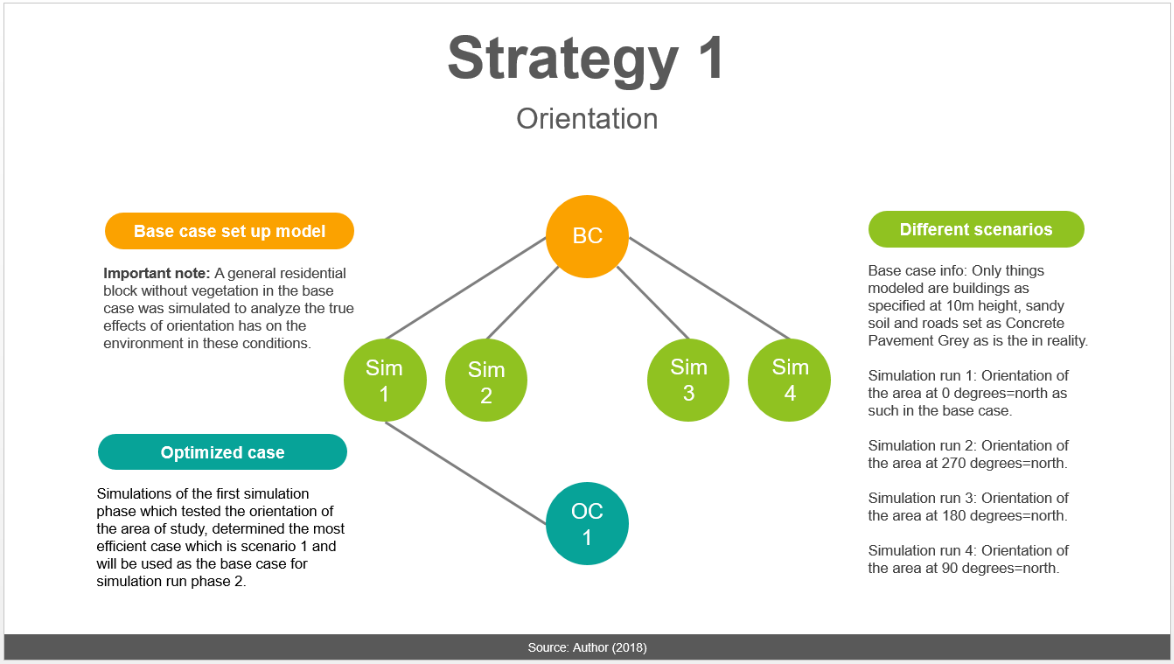


Figure 5.1 - Summary of strategy 1 (Source: Author, 2018)

- Most crucial first decision is the orientation which is included in simulation 1 through 4. If done correctly, this can result in benefits in the average temperature profile around the villa of 3.6 degrees Celsius, wind speed difference of 0.34 m/s.

5.2 Coverage materials - ENVI-met

Simulations of the first simulation phase which tested the orientation of the area of study, determined the most efficient case which is simulation 1 and will be used as the base case for simulation run strategy 2.

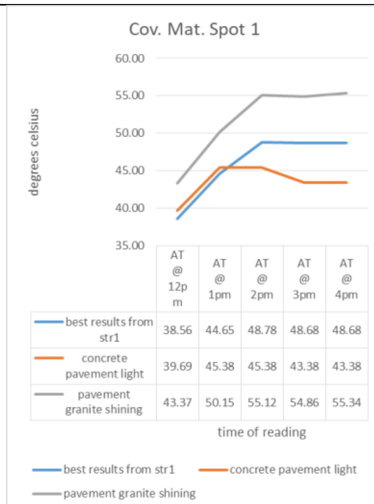
Simulation run 5: Coverage materials as in the base case, but changes made to the paving material and color to determine if the is any changes.

First scenario: Roads are covered with Concrete Pavement Light (PL).

Simulation run 6: Second scenario: Roads are covered with Granite Shining (G2).

Vegetation is to be introduced gradually to determine the effects the different vegetation coverage will have in the external environmental factors and conditions.

The most sought after readings are the lowest temperature reading, coupled with the highest velocity wind speed with a relative humidity that falls within the comfort range.

<table>
<tr><td colspan="4">Table 5.5: Coverage - Comparison of Simulations 1,5,6 (Measurement Spot 1)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 1</td>
<td>
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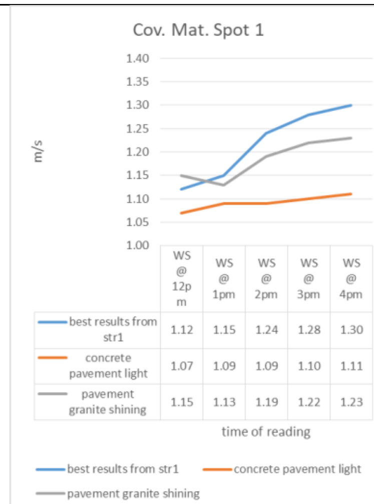
<td>
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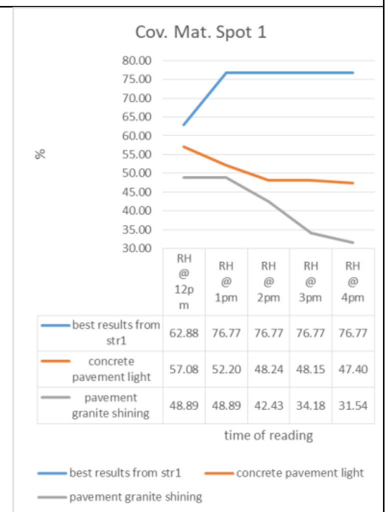
<td>
</td></tr>
</table>

Table 5.5 presents the readings of the measures taken on the five hours at spot 1 in the front side of the yard. The best readings of air temperature lean toward coverage material option 5. The best readings of wind speed lean toward coverage material option 6, but only by fractions of a second. Relative humidity at 12pm fall within the comfort zone in all the readings, but one. Relative humidity after 1pm surpass the range of human comfort for 1 and fall below the human comfort range for 5 and 6.

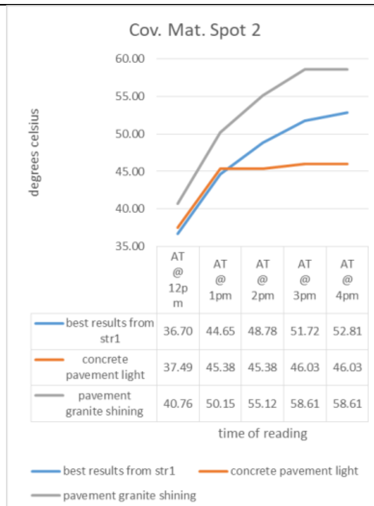
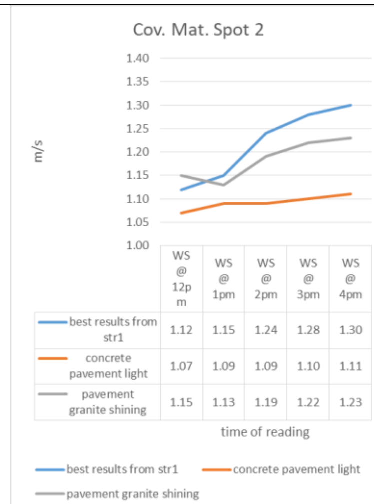
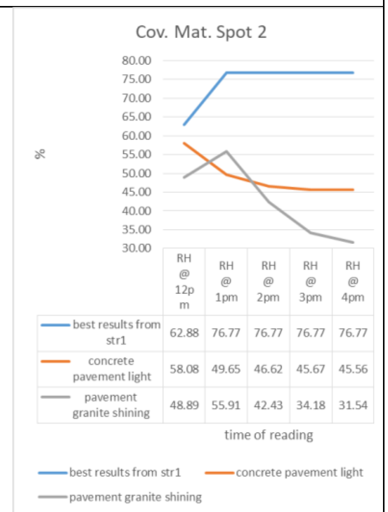
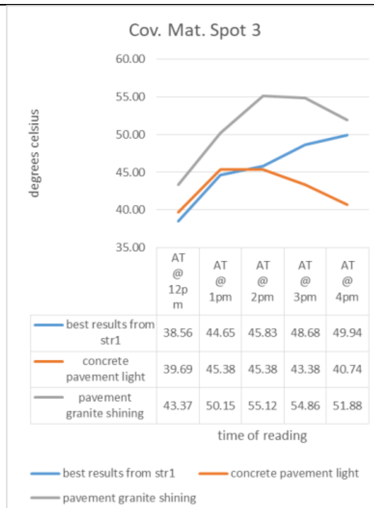
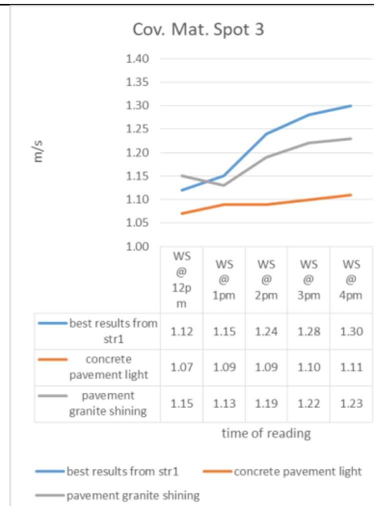
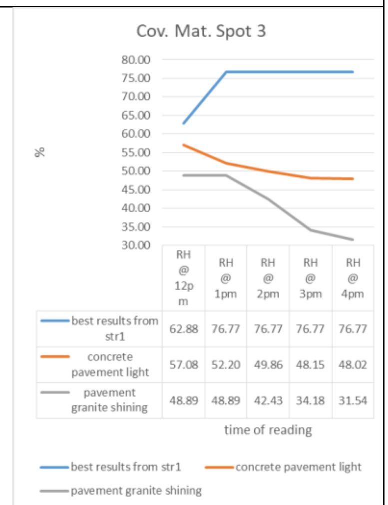
<table>
<tr><td colspan="4">Table 5.6: Coverage - Comparison of Simulations 1,5,6 (Measurement Spot 2)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 2</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.6 presents the readings of the measures taken on the five hours at spot 2 in the back side of the yard. The best readings of air temperature lean toward coverage material option 5. The best readings of wind speed lean toward coverage material option 6, but only by fractions of a second. Relative humidity at 12pm fall within the comfort zone in all the readings, but one. Relative humidity after 1pm surpass the range of human comfort for 1 and fall below the human comfort range for 5 and 6.

<table>
<tr><td colspan="4">Table 5.7: Coverage - Comparison of Simulations 1,5,6 (Measurement Spot 3)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 3</td><td>
</td><td>
</td><td>
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</table>

Table 5.7 presents the readings of the measures taken on the five hours at spot 3 in the front of the yard on the road surface area. The best readings of wind speed lean toward coverage material option 6, but only by fractions of a second. Relative humidity at 12pm fall within the comfort zone in all the readings, but one. Relative humidity after 1pm surpass the range of human comfort for 1 and fall below the human comfort range for 5 and 6.

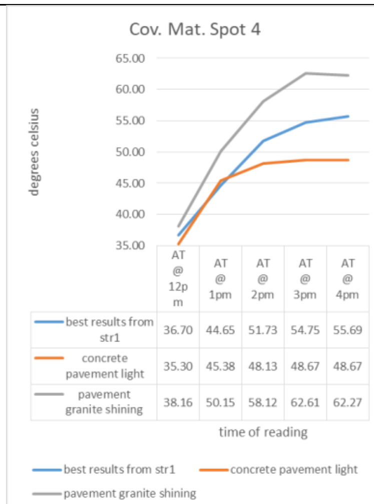
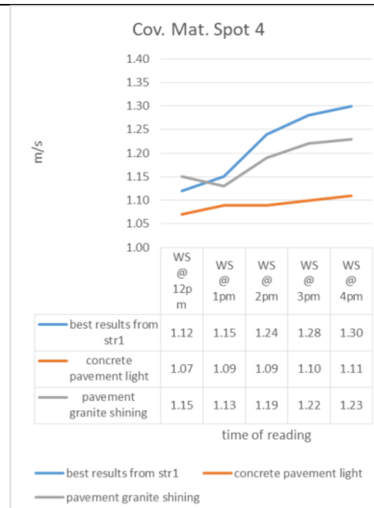
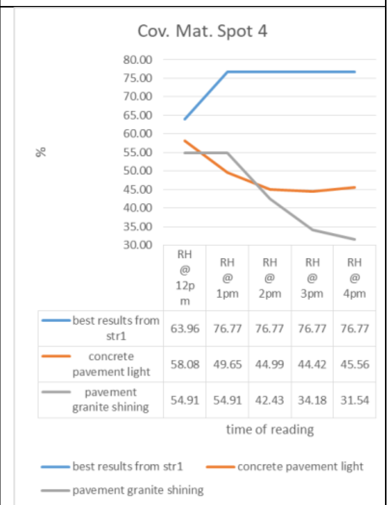
<table>
<tr><td colspan="4">Table 5.8: Coverage - Comparison of Simulations 1,5,6 (Measurement Spot 4)</td></tr>
<tr><td>EN VI- met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 4</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.8 presents the readings of the measures taken on the five hours at spot 4 in the back side of the yard on the open area. The best readings of wind speed lean toward coverage material option 6, but only by fractions of a second. Relative humidity at 12pm fall within the comfort zone in all the readings. Relative humidity after 1pm surpass the range of human comfort for 1 and fall below the human comfort range for 5 and 6.

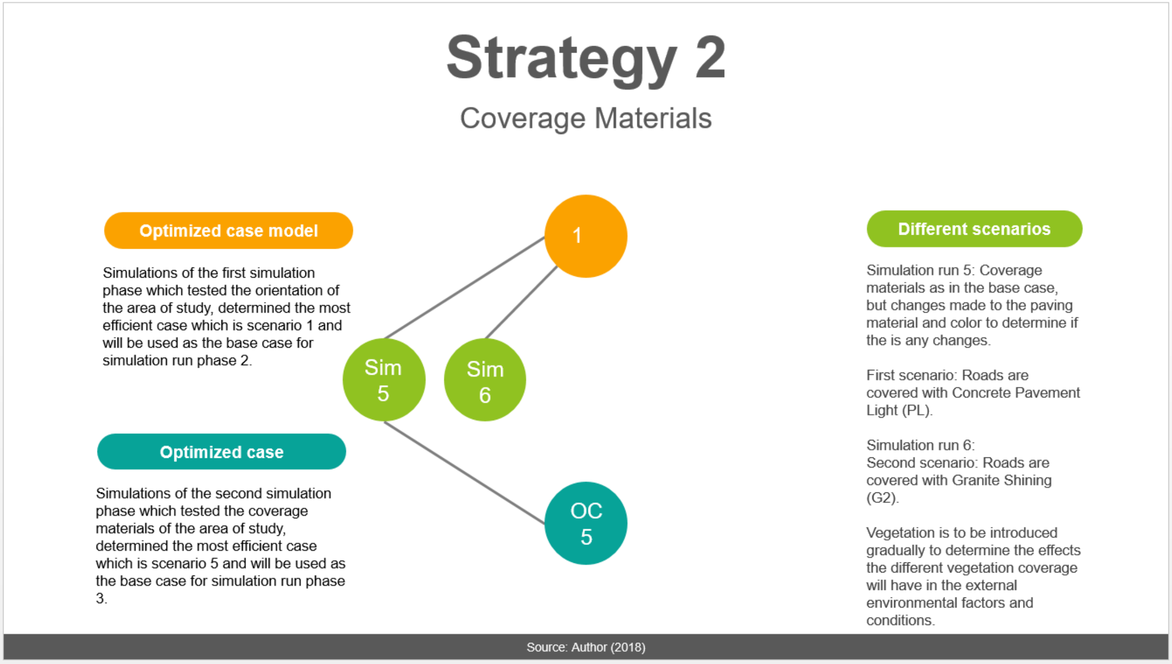


Figure 5.2 - Summary of strategy 2 (Source: Author, 2018)

- Coverage materials which is included in simulation 5 and 6 play a significant role in the outdoor thermal comfort and can result in a difference of 2.9 degrees Celsius just by choosing a lighter shade of pavement.

5.3 Greenery - ENVI-met

Simulations of the second simulation phase which tested the coverage materials of the area of study, determined the most efficient case which is simulation 5 and will be used as the base case for simulation run strategy 3.

Simulation run 7: Most efficient case of phase 2 is 5…and then with the introduction of greenery via trees.

First scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 10m height.

Simulation run 8: Second scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 15m height.

Simulation run 9: Third scenario: trees at equal spacing as per literature review and case study. Trees tested to be at 20m height.

The most sought after readings are the lowest temperature reading, coupled with the highest velocity wind speed with a relative humidity that falls within the comfort range.

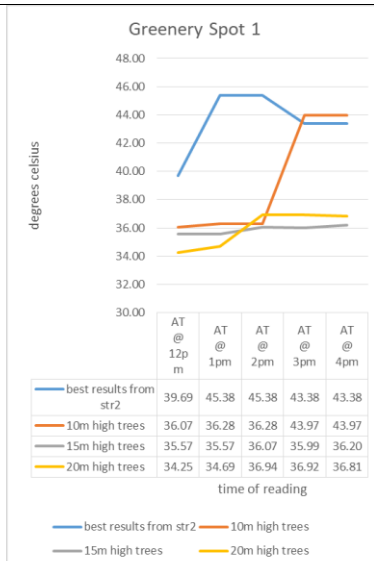
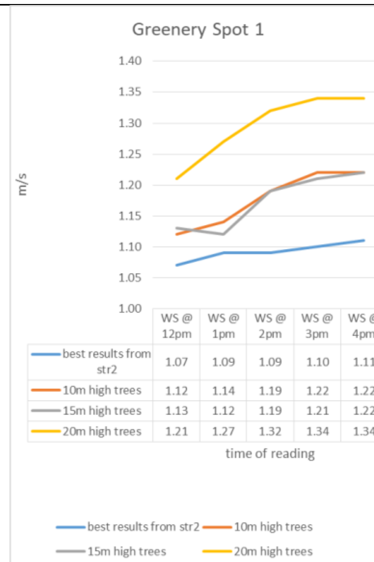
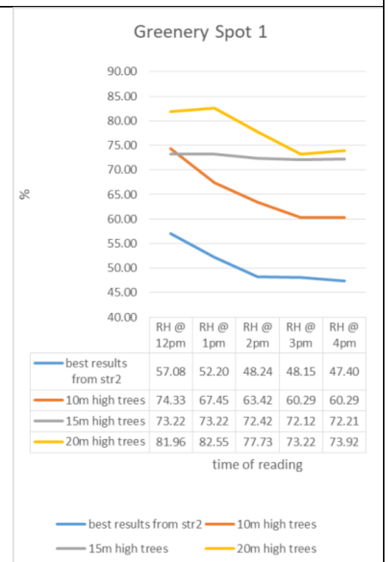
Table 5.9: Greenery - Comparison of Simulations 5,7,8,9 (Measurement Spot 1)			
ENVI-met	Air Temperature	Wind Speed	Relative Humidity
Measurement Spot 1			

Table 5.9 presents the readings of the measures taken on the five hours at spot 1 in the front side of the yard. The best readings of air temperature and wind speed lean toward greenery option 9. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

Table 5.10: Greenery - Comparison of Simulations 5,7,8,9 (Measurement Spot 2)

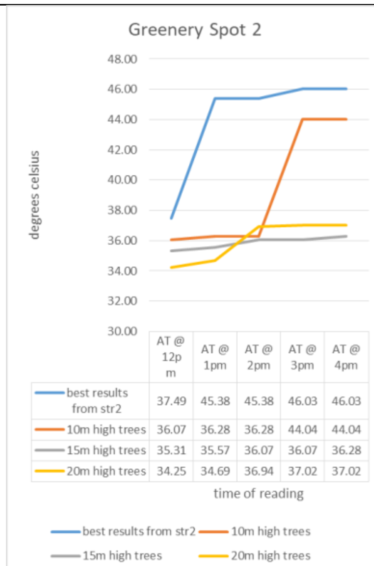
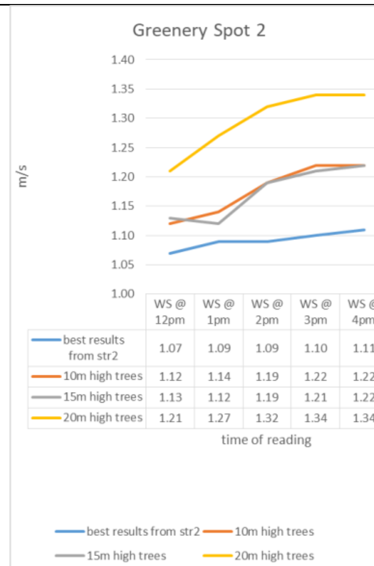
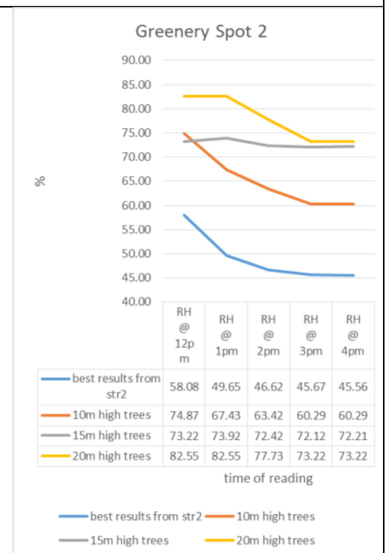
<table>
<tr><td>EN VI- met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 2</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.10 presents the readings of the measures taken on the five hours at spot 2 in the back side of the yard. The best readings of air temperature and wind speed lean toward greenery option 9. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

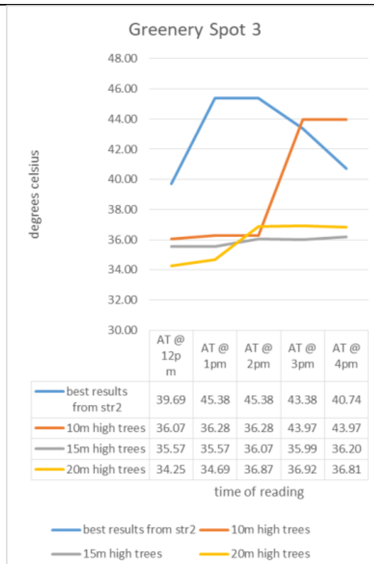
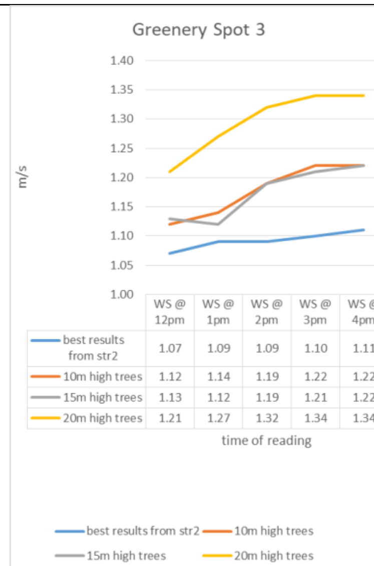
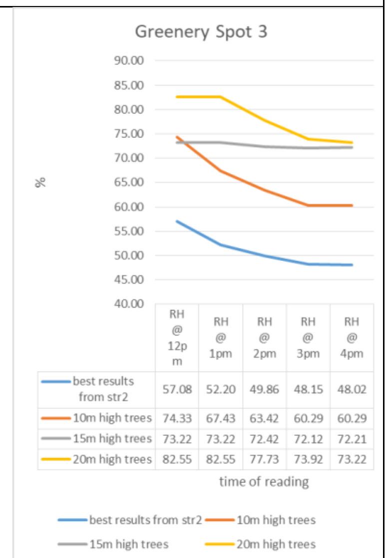
<table>
<tr><td colspan="4">Table 5.11: Greenery - Comparison of Simulations 5,7,8,9 (Measurement Spot 3)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 3</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.11 presents the readings of the measures taken on the five hours at spot 3 in the front of the yard on the road surface area. The best readings of air temperature and wind speed lean toward greenery option 9. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

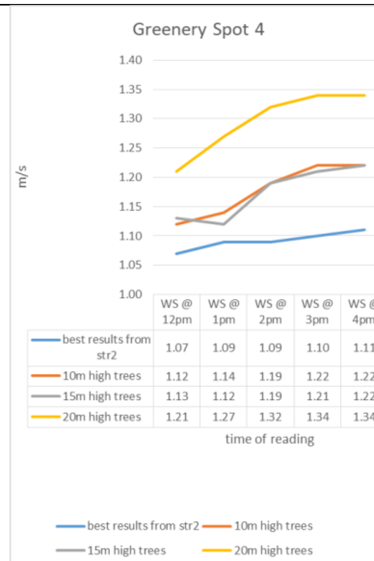
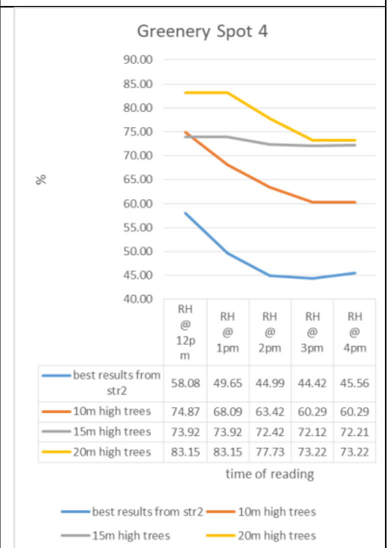
<table>
<tr><td colspan="4">Table 5.12: Greenery - Comparison of Simulations 5,7,8,9 (Measurement Spot 4)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 4</td><td>
</td><td>
</td><td>
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Table 5.12 presents the readings of the measures taken on the five hours at spot 4 in the back side of the yard on the open area. The best readings of air temperature and wind speed lean toward greenery option 9. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

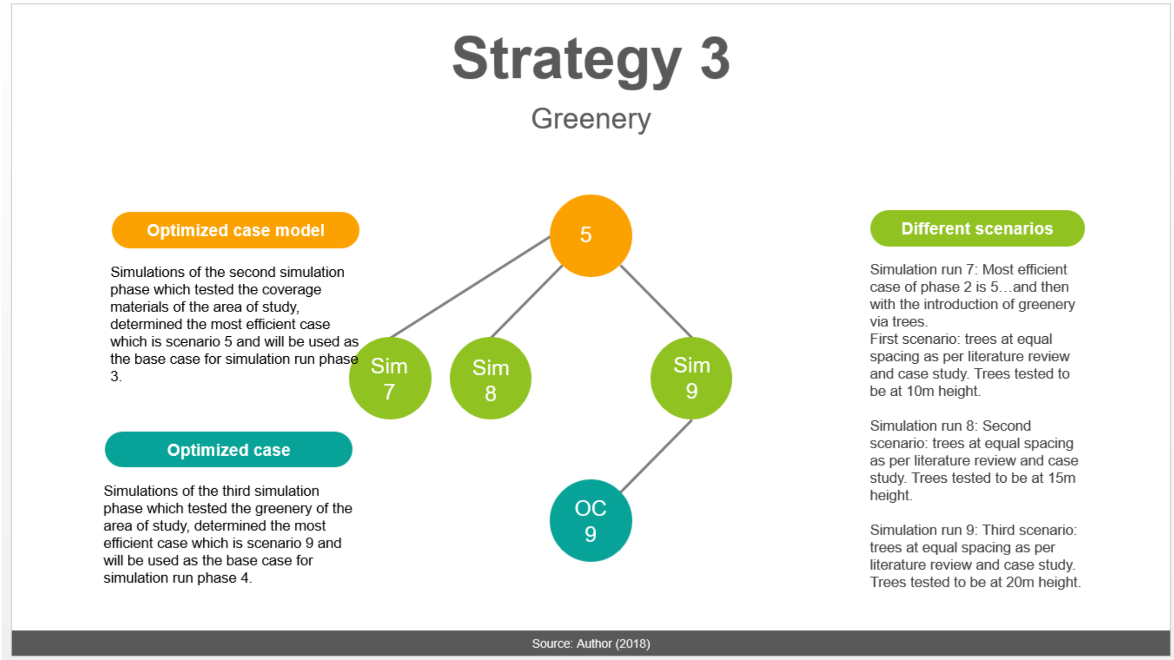


Figure 5.3 - Summary of strategy 3 (Source: Author, 2018)

- Greenery which is included in simulation 7 through 9 play a significant role in the outdoor thermal comfort and can result in a massive difference of 7.9 degrees Celsius just by introducing grass where the sand is and two trees per site at equal spacing to maintain the wind speed conditions. This strategy is very effective in maintaining a good level of relative humidity in residential areas and also affect the wind speed in a positive manner by 0.2 m/s.

5.4 Waterbodies - ENVI-met

Simulations of the third simulation phase which tested the greenery of the area of study, determined the most efficient case which is scenario 9 and will be used as the base case for simulation run phase 4.

Simulation run 10: Most efficient case of phase 3 is 9 and then with the introduction of waterbodies with various depths. Waterbodies introduces at front of yard as well as back of yard. The different variables that will be introduced will be the same coverage, but will differ in depth and will in some cases include spray. Ponds, swimming pools as well as spraying fountains.

First scenario: Swimming pool with a depth of 1 to 2m.

Simulation run 11: Second scenario: fountain with a spray of 4m height for evaporating cooling and to test the effects of the humidity in the afternoon time.

The most sought after readings are the lowest temperature reading, coupled with the highest velocity wind speed with a relative humidity that falls within the comfort range.

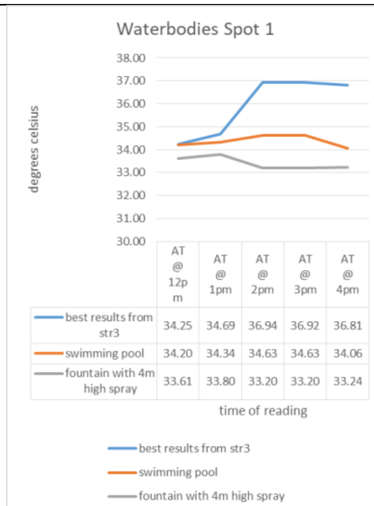
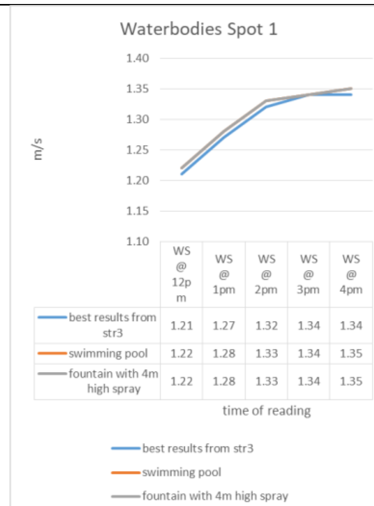
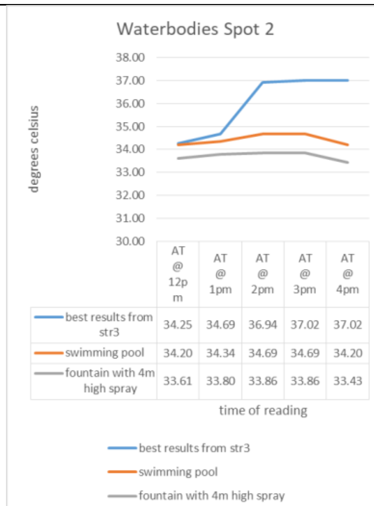
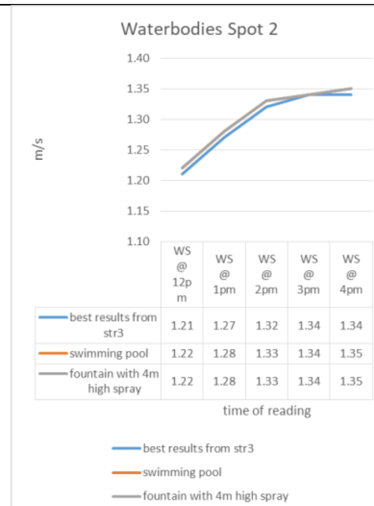
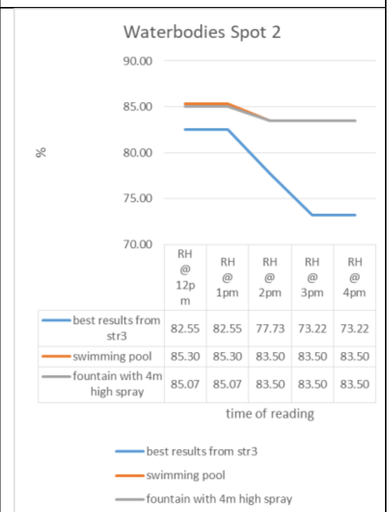
<table>
<tr><td colspan="4">Table 5.13: Waterbodies - Comparison of Simulations 9,10,11 (Measurement Spot 1)</td></tr>
<tr><td>EN
VI-
met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 1</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 5.13 presents the readings of the measures taken on the five hours at spot 1 in the front side of the yard. The best readings of air temperature and wind speed lean toward waterbodies option 11. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

<table>
<tr><td colspan="4">Table 5.14: Waterbodies - Comparison of Simulations 9,10,11 (Measurement Spot 2)</td></tr>
<tr><td>ENVI-met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 2</td><td>
</td><td>
</td><td>
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</table>

Table 5.14 presents the readings of the measures taken on the five hours at spot 2 in the back side of the yard. The best readings of air temperature and wind speed lean toward waterbodies option 11. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

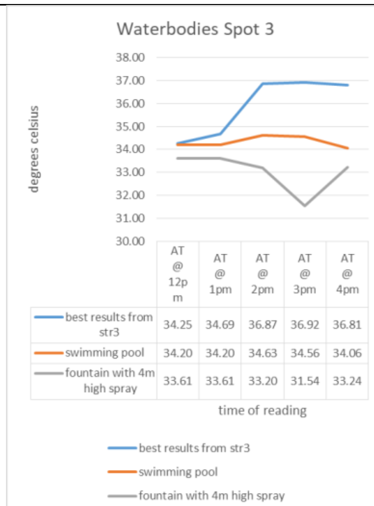
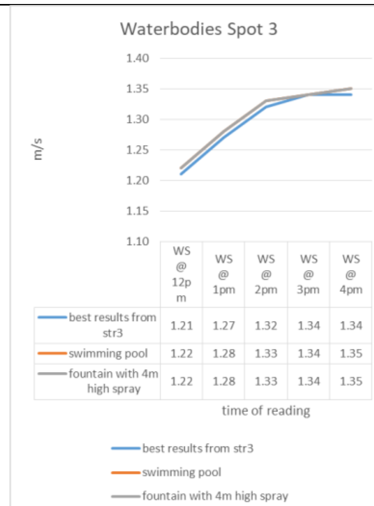
Table 5.15: Waterbodies - Comparison of Simulations 9,10,11 (Measurement Spot 3)			
EN VI- met	Air Temperature	Wind Speed	Relative Humidity
Measurement Spot 3			

Table 5.15 presents the readings of the measures taken on the five hours at spot 3 in the front of the yard on the road surface area. The best readings of air temperature and wind speed lean toward waterbodies option 11. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

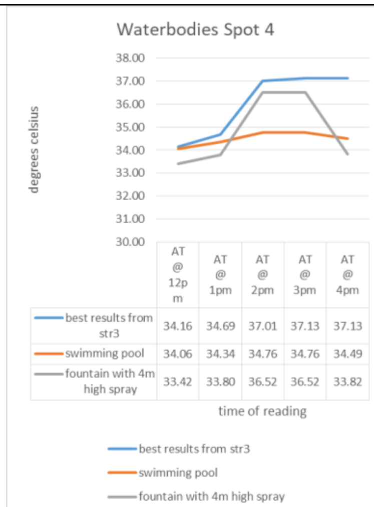
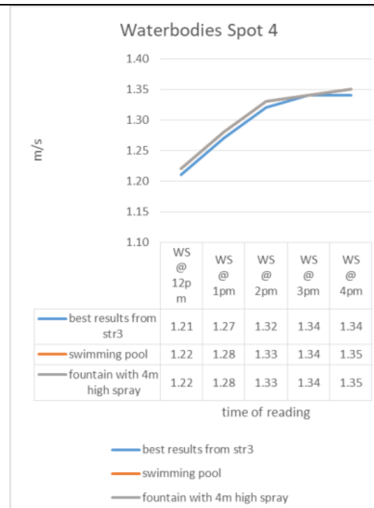
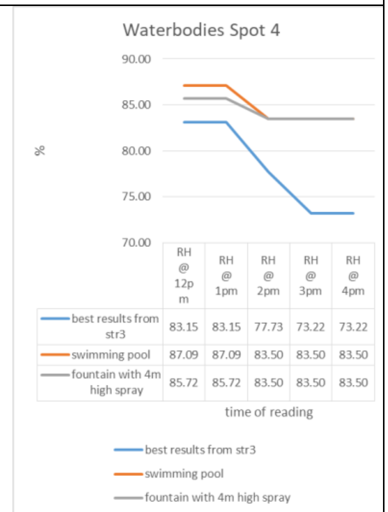
<table>
<tr><td colspan="4">Table 5.16: Waterbodies - Comparison of Simulations 9,10,11 (Measurement Spot 4)</td></tr>
<tr><td>ENVI-met</td><td>Air Temperature</td><td>Wind Speed</td><td>Relative Humidity</td></tr>
<tr><td>Measurement Spot 4</td><td>
</td><td>
</td><td>
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Table 5.16 presents the readings of the measures taken on the five hours at spot 4 in the back side of the yard on the open area. The best readings of air temperature and wind speed lean toward waterbodies option 11. Relative humidity surpass the range of human comfort for greenery option 9 but is acceptable due to large decrease in temperature.

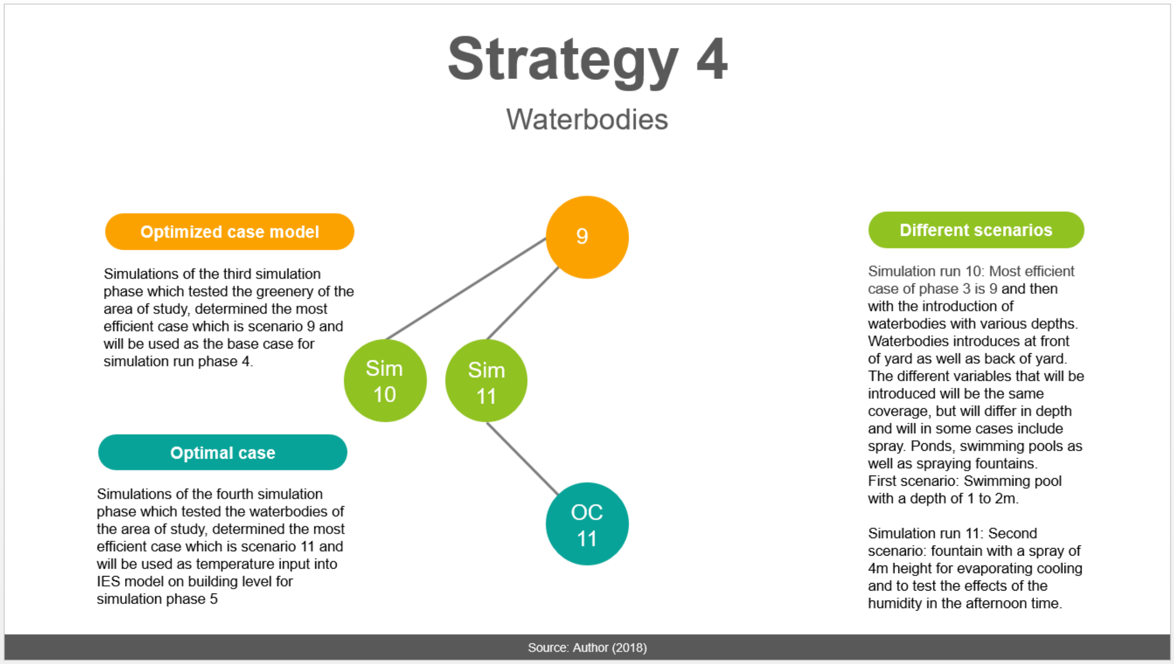


Figure 5.4 - Summary of strategy 4 (Source: Author, 2018)

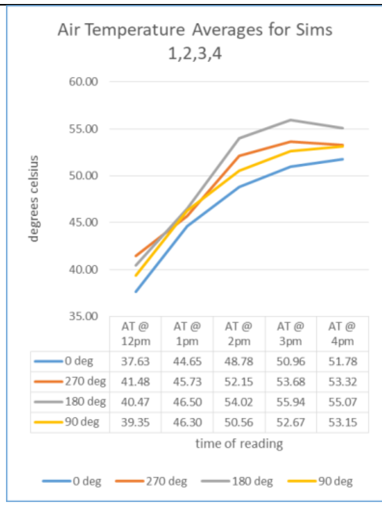
- Waterbodies which is included in simulation 10 and 11 can be used to enhance the outdoor thermal comfort even more by reducing the temperature profile around the villa with an additional 2.2 degrees Celsius. This strategy is also effective with increasing the relative humidity (which cannot be separated with the changes in air temperature) with 6.5 %.
- A total reduction of 16.6 degrees Celsius in air temperature were achieved by introducing these few strategies.

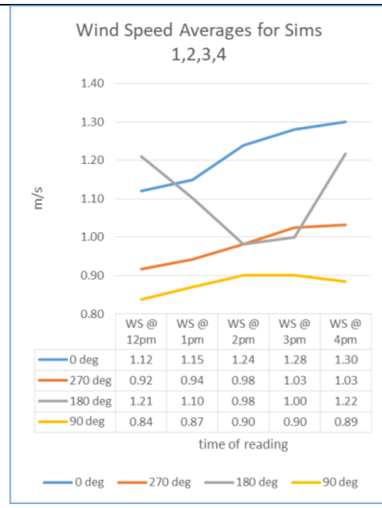
5.5 Summary of ENVI-met simulations results

Table 5.17: Average of five readings for climatic profile around the villa

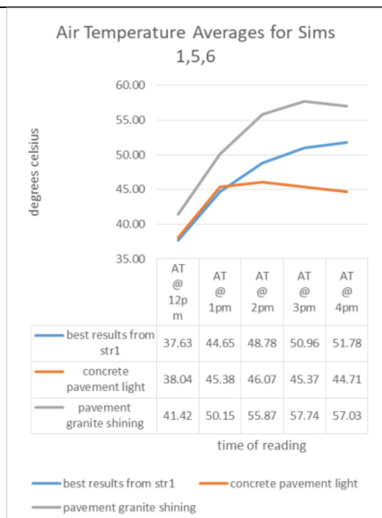
	Average Air Temperature	Average Wind Speed	Average Relative Humidity

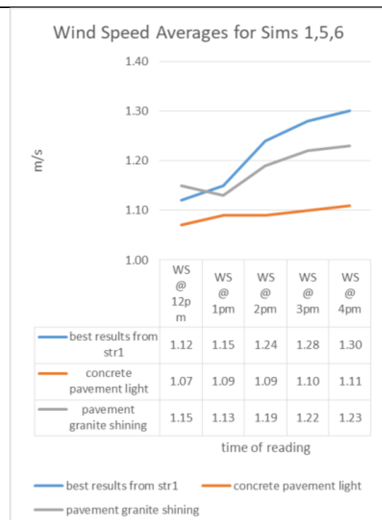
Summary of simulations 1,2,3,4

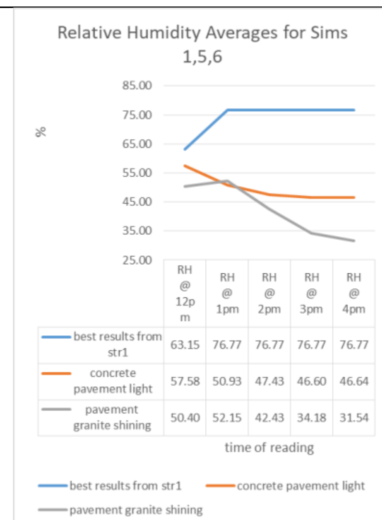




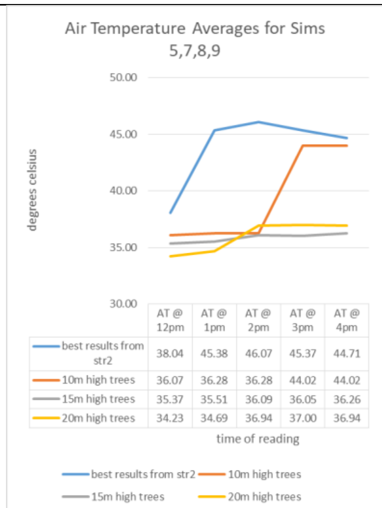
Summary of simulations 1,5,6

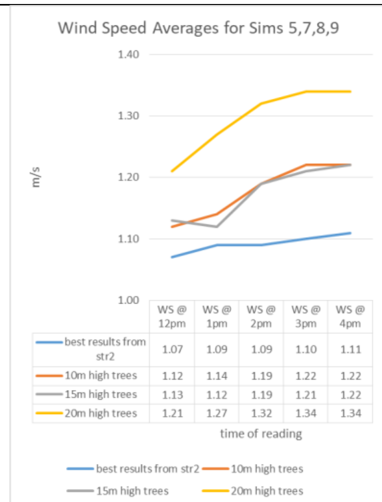


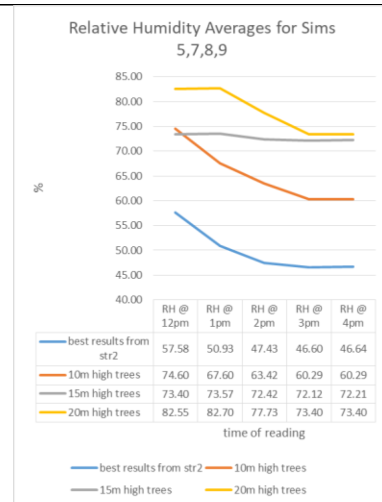




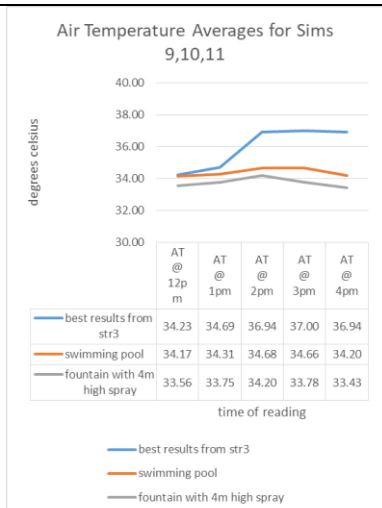
Summary of simulations 5,7,8,9

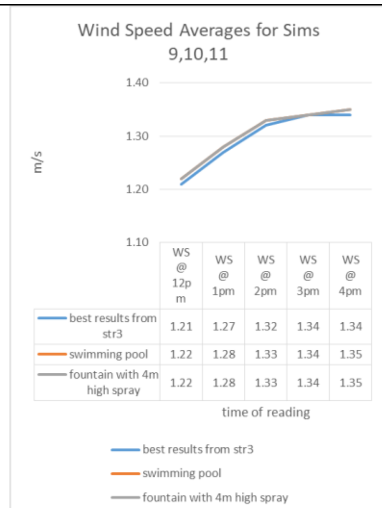


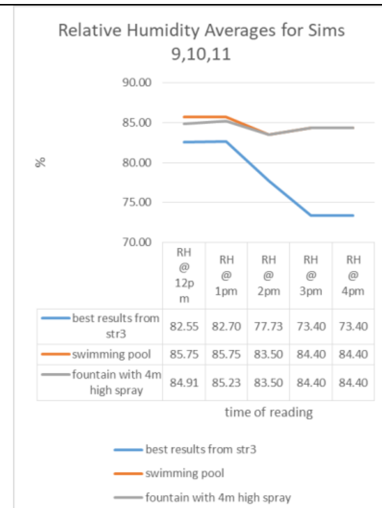




Summary of simulations 9,10,11







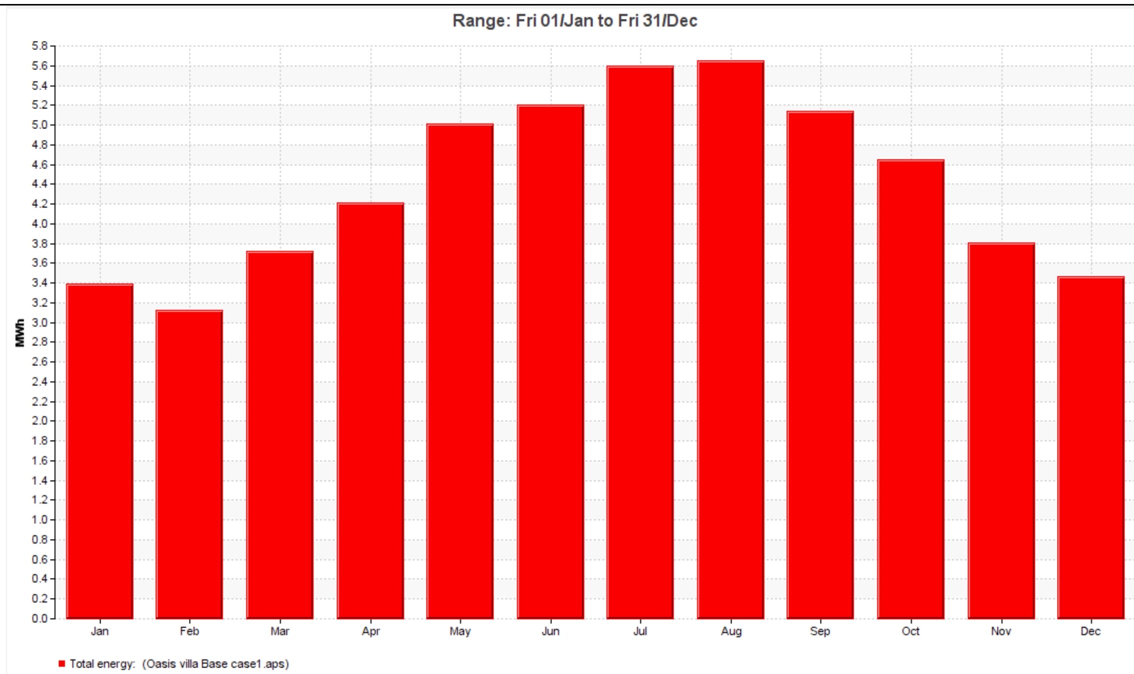
The most sought after readings are the lowest temperature reading, coupled with the highest velocity wind speed within the comfort range, with a relative humidity that preferably falls within the comfort range.

5.6 Energy consumption - IES VE

Simulations of the fourth simulation phase which tested the waterbodies of the area of study, determined the most efficient case which is scenario 11 and will be used as the base case input data for simulation run phase 5 on building level on IES simulation software.

Simulation run 12: Base case on building level done of a single villa. As is.

Simulation run 13: the only variables to be used as inputs into the model are the optimized climatic changes that occurred in the ENVI-met modelling phases and concluded from the results of simulation 11

<table>
<tr><td colspan="2">Table 5.18: Energy Consumption - Comparison of Simulations 12,13 chart</td></tr>
<tr><td>IES
VE</td><td>Energy consumpotion per month chart</td></tr>
<tr><td>Base case energy consumption - Sim 12</td><td>


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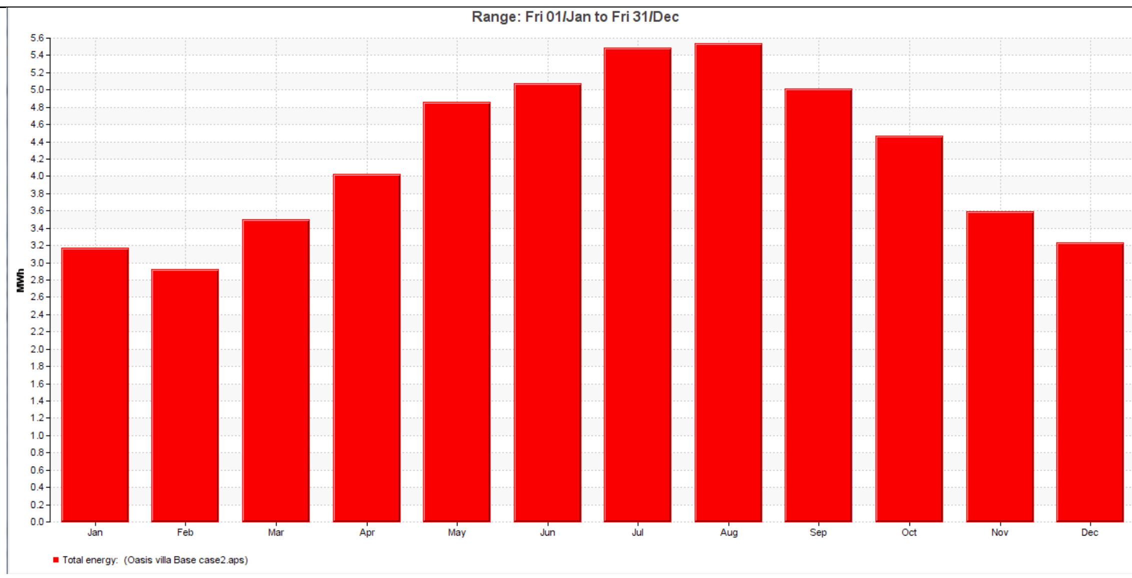
<tr><td>Optimised case energy consumption - Sim</td><td>


</td></tr>
</table>

Table 5.19: Energy Consumption - Comparison of Simulations 12,13

Energy													
Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption Base case MWh	3.3956	3.1257	3.7187	4.2123	5.0091	5.2037	5.6061	5.656	5.1419	4.6464	3.8035	3.4606	52.9796
consumption Optimised case MWh	3.1743	2.9243	3.4967	4.023	4.8552	5.076	5.4843	5.5426	5.0118	4.4724	3.5928	3.2349	50.8883

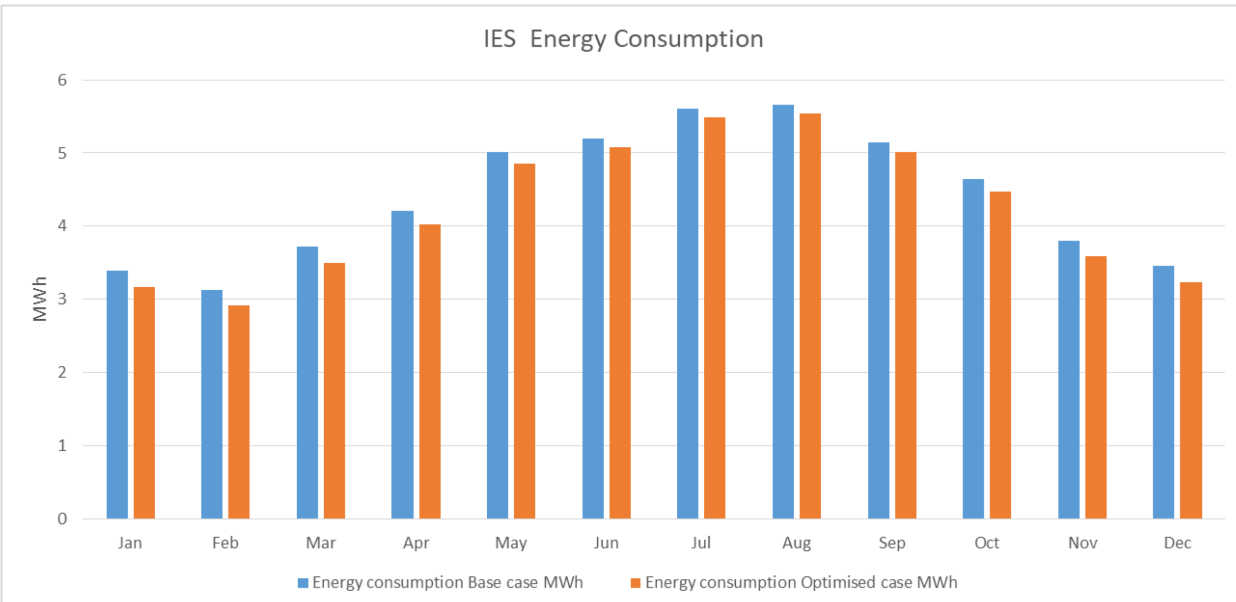


Figure 5.5 - Summary chart of energy consumption (Source: Author, 2018)

Table 5.20: Energy Consumption reduction - Comparison of Simulations 12,13

Energy													
Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption Base case MWh	3.3956	3.1257	3.7187	4.2123	5.0091	5.2037	5.6061	5.656	5.1419	4.6464	3.8035	3.4606	52.9796
consumption Optimised case MWh	3.1743	2.9243	3.4967	4.023	4.8552	5.076	5.4843	5.5426	5.0118	4.4724	3.5928	3.2349	50.8883
savings	0.221	0.201	0.222	0.189	0.154	0.128	0.122	0.113	0.130	0.174	0.211	0.226	2.091

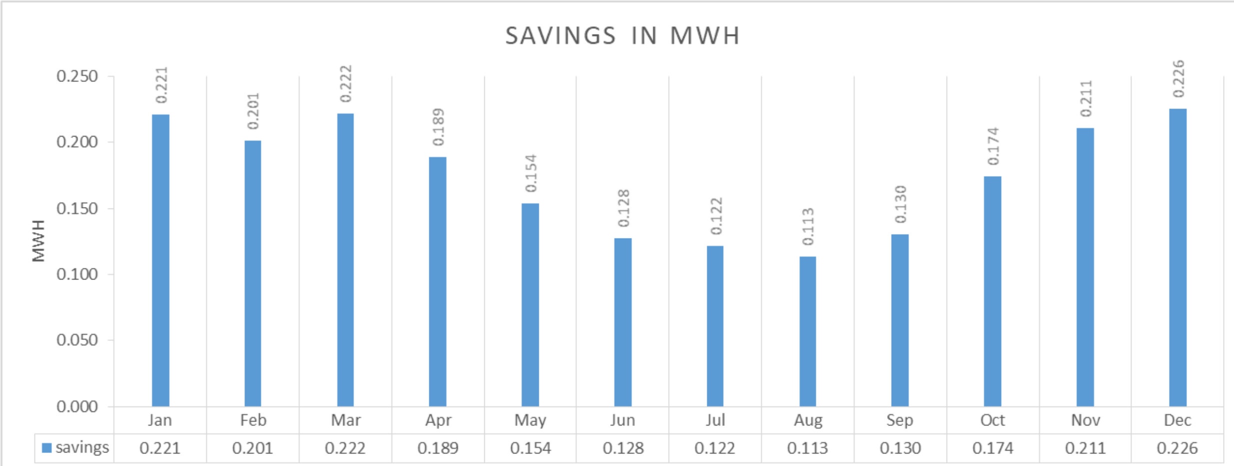


Figure 5.6 - Summary chart of energy consumption savings (Source: Author, 2018)

Table 5.21: Energy Consumption cost savings - Comparison of Simulations 12,13

Energy													
Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption Base case AED	850.88	775.28	939.64	1087.84	1342.88	1405.28	1532.64	1549.92	1385.44	1227.04	965.12	869.08	13931.04
Energy consumption Optimised case AED	789	717.6	879.16	1027.36	1293.6	1364.32	1494.88	1513.76	1343.84	1171.04	906.04	805.8	13306.4
savings	61.9	57.7	60.5	60.5	49.3	41.0	37.8	36.2	41.6	56.0	59.1	63.3	624.6

Total annual savings amount to 2,091MWh = 624,6 AED, thus resulting in a 4,5% saving. In itself, the amount seems insignificant, but considering the development consists of 260 units, savings of 543,660MWh can be saved amounting to a 162,396 AED saving for the development from the residential structures.

To make the correlation between consumption and carbon footprint the units of gCO2eq/kWh are grams of carbon dioxide equivalent per kilowatt-hour or kgCO2eq/kWh kilograms of carbon dioxide equivalent per kilowatt-hour of electricity generated.

Oct 2018 the carbon footprint amounted on 0.441kgCO2eq/kWh = 441kgCO2eq/MWh

And according to US EPA. (2015) the 2091kWh savings for the year amounts to 1.6 metric tons of carbon dioxide emissions when using the calculator.

According to data obtained from DEWA (2016) published statistics the graphs show that 11,922 GWh / 557,121 people = 21,399 KWh per person per year.

According to data obtained from DEWA (2017) published statistics the graphs show that 12,795 GWh / 593,890people = 21,544 KWh per person per year

Consistent information with regards to Dewa statistics from 2017 with estimated consumption of 21,000kWh per person for the year. This is calculated by taking the total energy consumption of the villa for the entire year divided by the amount of people in the villa. Actual readings at 57MWh/2.5(two adults and one child)=22,8MWH=22800kWh which is only 8.6% discrepancy. This number may account for activities for birthday parties, frequent large family gatherings, stay at home mothers, working from home individuals and many more factors. It may also be due to irregular maintenance of the AC and the AC compressor not running on optimal efficiency.

CHAPTER 6

CONCLUSION AND FUTURE RECOMMENDATIONS

6.1 Conclusion

This chapter follows on the section discussing the findings of the simulation. It consists of cross-referencing the findings with the initial (and revised) aim and objectives to determine what was achieved by the dissertation study, what was not covered nor included, and also consists of posing recommendations for future studies to be conducted which may tie in with and contribute to the research in the field.

Based on the 13 simulations that were run in conducting this research, the following conclusions can be extrapolated:

- Orientation, coverage, vegetation and waterbodies play a significant role in engineering the environmental climate conditions of a development.
- Most crucial first decision is the orientation which is included in simulation 1 through 4. If done correctly, this can result in benefits in the average temperature profile around the villa of 3.6 degrees Celsius, wind speed difference of 0.34 m/s.
- Coverage materials which is included in simulation 5 and 6 play a significant role in the outdoor thermal comfort and can result in a difference of 2.9 degrees Celsius just by choosing a lighter shade of pavement.
- Greenery which is included in simulation 7 through 9 play a significant role in the outdoor thermal comfort and can result in a massive difference of 7.9 degrees Celsius just by introducing grass where the sand is and two trees per site at equal spacing to maintain the wind speed conditions. This strategy is very effective in maintaining a good level of relative humidity in residential areas and also affect the wind speed in a positive manner by 0.2 m/s.

- Waterbodies which is included in simulation 10 and 11 can be used to enhance the outdoor thermal comfort even more by reducing the temperature profile around the villa with an additional 2.2 degrees Celsius. This strategy is also effective with increasing the relative humidity (which cannot be separated with the changes in air temperature) with 6.5 %.
- A total reduction of 16.6 degrees Celsius in air temperature were achieved by introducing these few strategies.
- Simulation 12 and 13 which was done in IES VE show firstly the initial environmental condition with the energy consumption of the villa, and then when the optimized climatic profile is fed into the program the calculation of the energy consumption resulted in a total saving of 2,091 MWh per year which is equal to saving 624,6 AED, or seen as a 4,5% saving. Considering the development consists of 260 units, savings of 543,660MWh amount to 162,396 AED saving for the development from the residential structures. The 2091kWh (2,091MWh) savings for the year for one villa amount to 1.6 metric tons of carbon dioxide emissions when using the US EPA calculator.

6.2 Future Recommendations

The following list of issues came up in the research and is recommended for further studies:

- Limitation regarding sustainability pillars: social, economic and environmental. Focus is on environmental pillar due to time constraints and limitation of the duration of the dissertation. Focus of environmental aspect of sustainability of an existing community in the case of UAE. The environmental pillar will have an effect on the other two as you cannot have one without the other. I recommend that a study should be done regarding the social and furthermore on the economic sustainable aspects of communities. This document partially touched on the economic benefits of adopting passive strategies, but a more in-depth study is needed, not only on passive strategies, but to also include the active strategies.

- Limitations regarding weather conditions input are set at most extreme condition of summer time, ideally this study can be repeated to include all summer and winter months to ensure comfort throughout the entire year.
- The focus is on the residential development. This study can be done on commercial, retail and governmental buildings or conducted on the free zones.
- Existing fabric in terms of form, proximity and relation of the adjacent structures have not been modified in this study. This can be a successive study. I recommend that someone come and test the process again with regards to different configuration and proximity of the villa units with each other.

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APPENDICES

Appendix 1 - Strategy 1 - Orientation - 0 degrees

Appendix 2 - Strategy 1 - Orientation - 270 degrees

Appendix 3 - Strategy 1 - Orientation - 180 degrees

Appendix 4 - Strategy 1 - Orientation - 90 degrees

Appendix 5 - Strategy 2 - Coverage - concrete pavement light grey

Appendix 6 - Strategy 2 - Coverage - granite shining

Appendix 7 - Strategy 3 - Greenery - 10m height trees

Appendix 8 - Strategy 3 - Greenery - 15m height trees

Appendix 9 - Strategy 3 - Greenery - 20m height trees

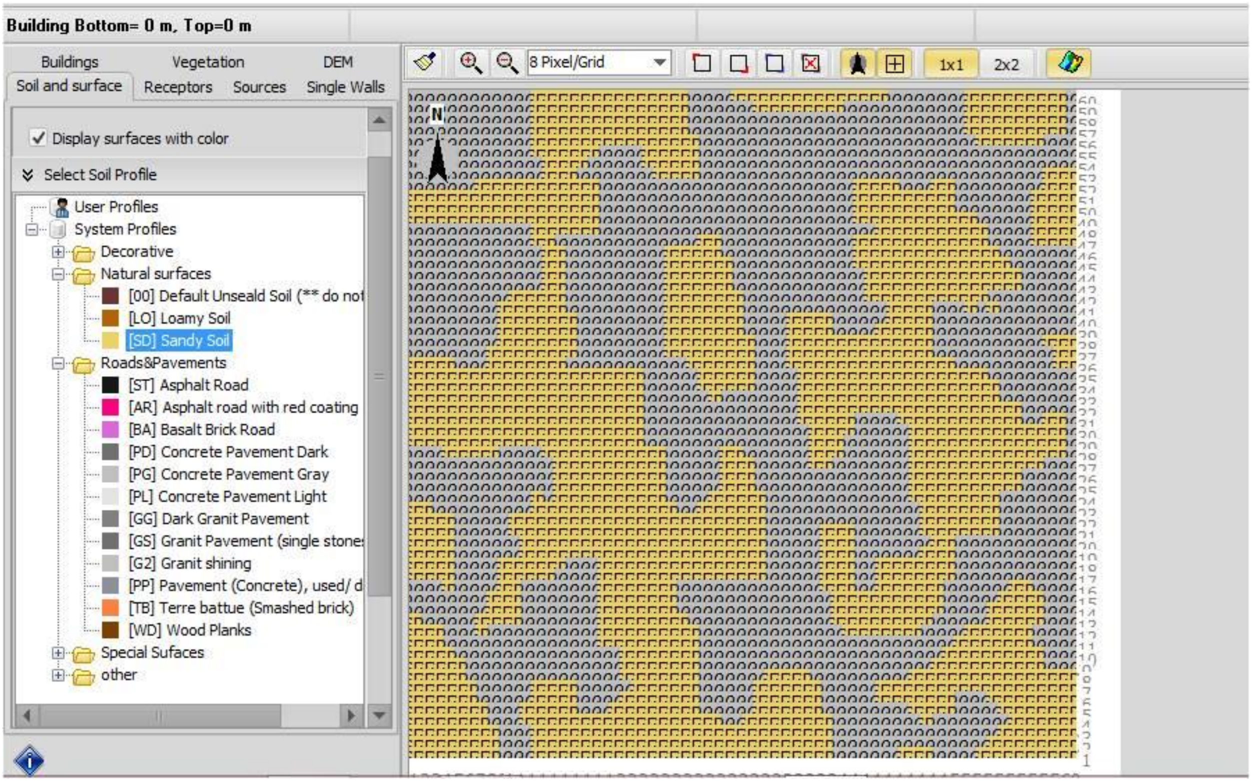
Appendix 10 - Strategy 4 - Waterbodies - swimming pool

Appendix 11 - Strategy 4 - Waterbodies - spraying fountain

Appendix 12 - Strategy 5 - Energy consumption - base case

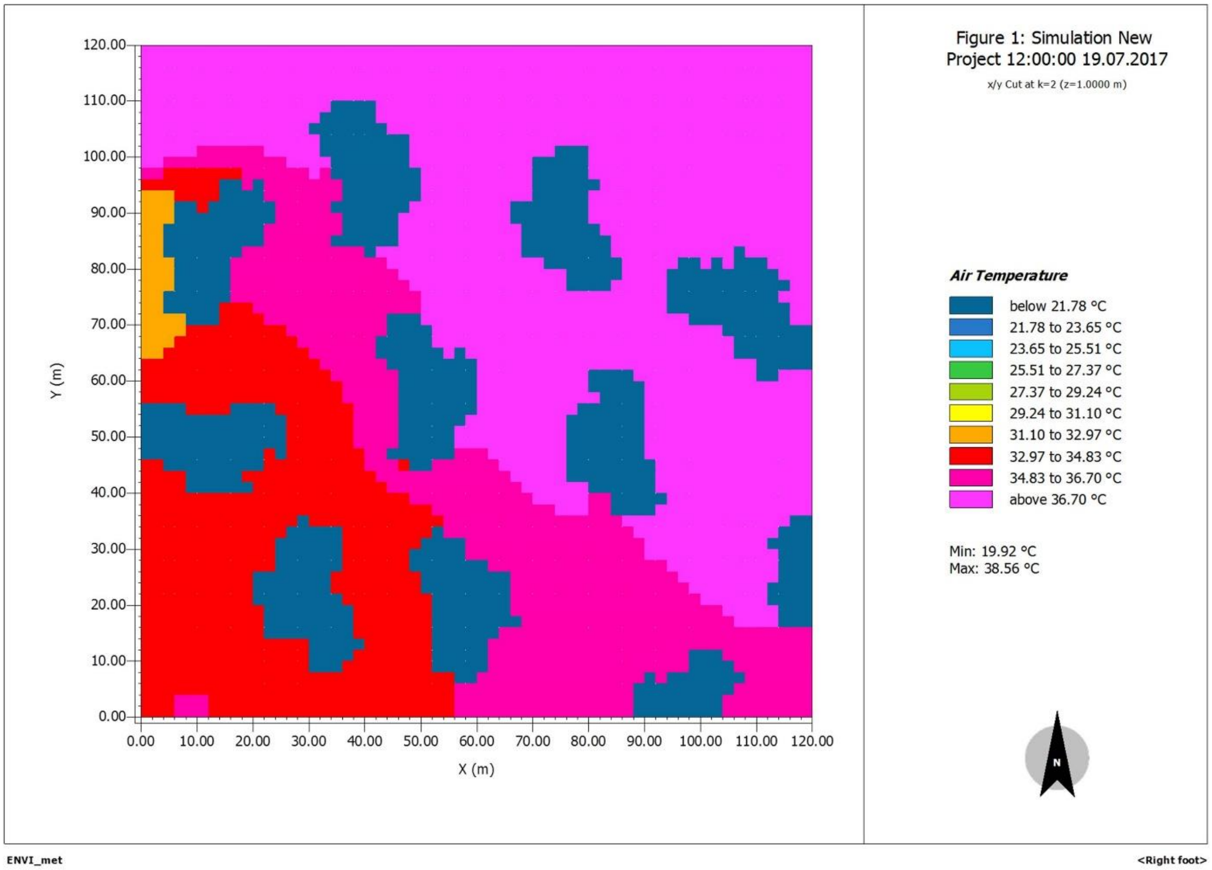
Appendix 13 - Strategy 5 - Energy consumption - optimized case

Appendix 1 - Strategy 1 - Orientation - 0 degrees

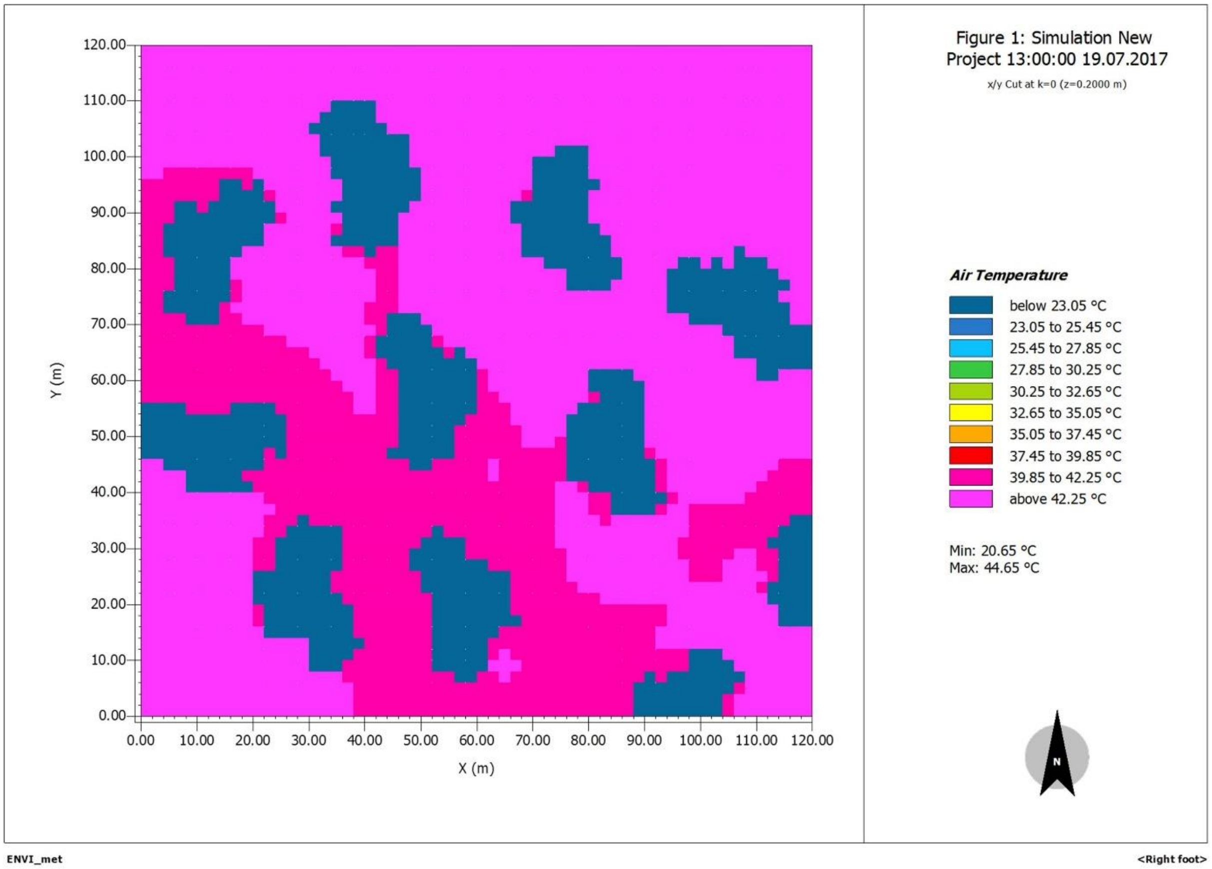


Model building, base case. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

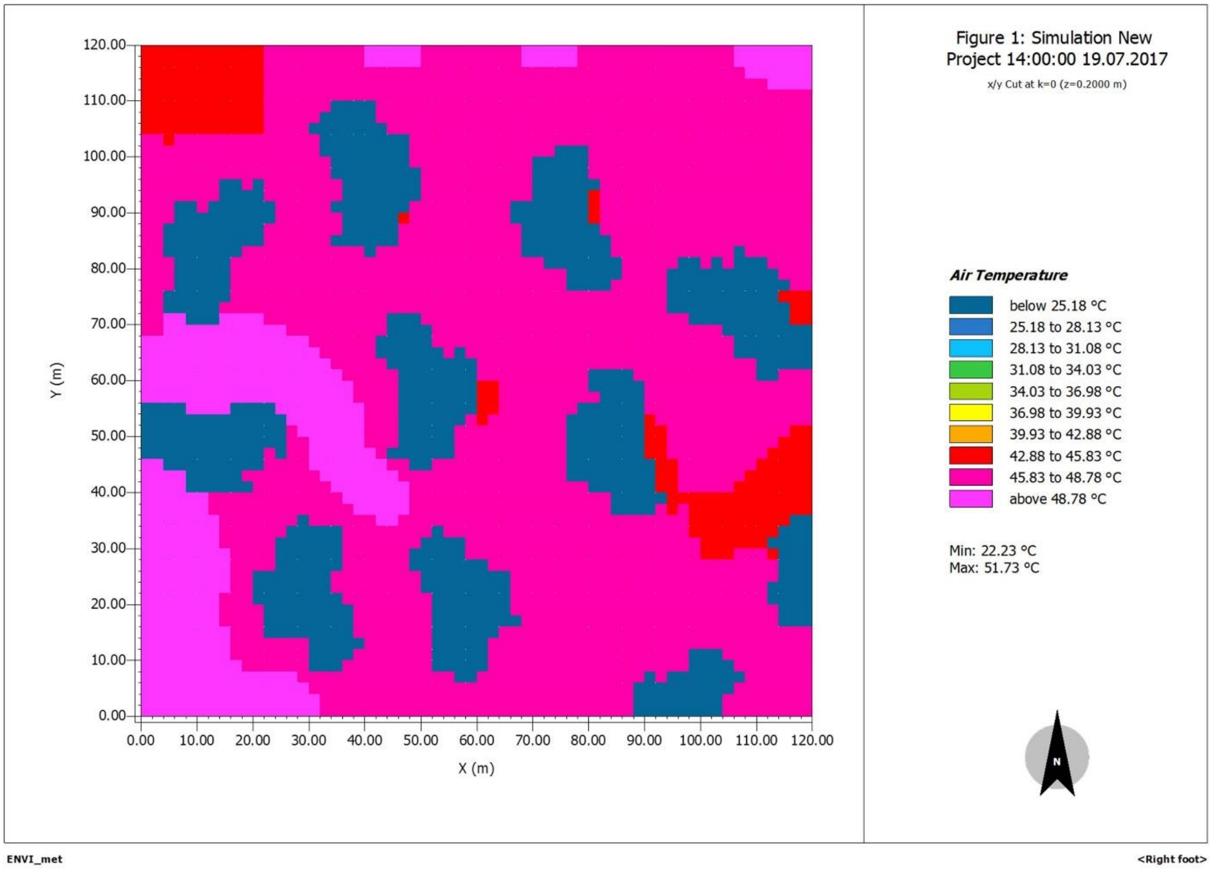
AIR TEMPERATURE



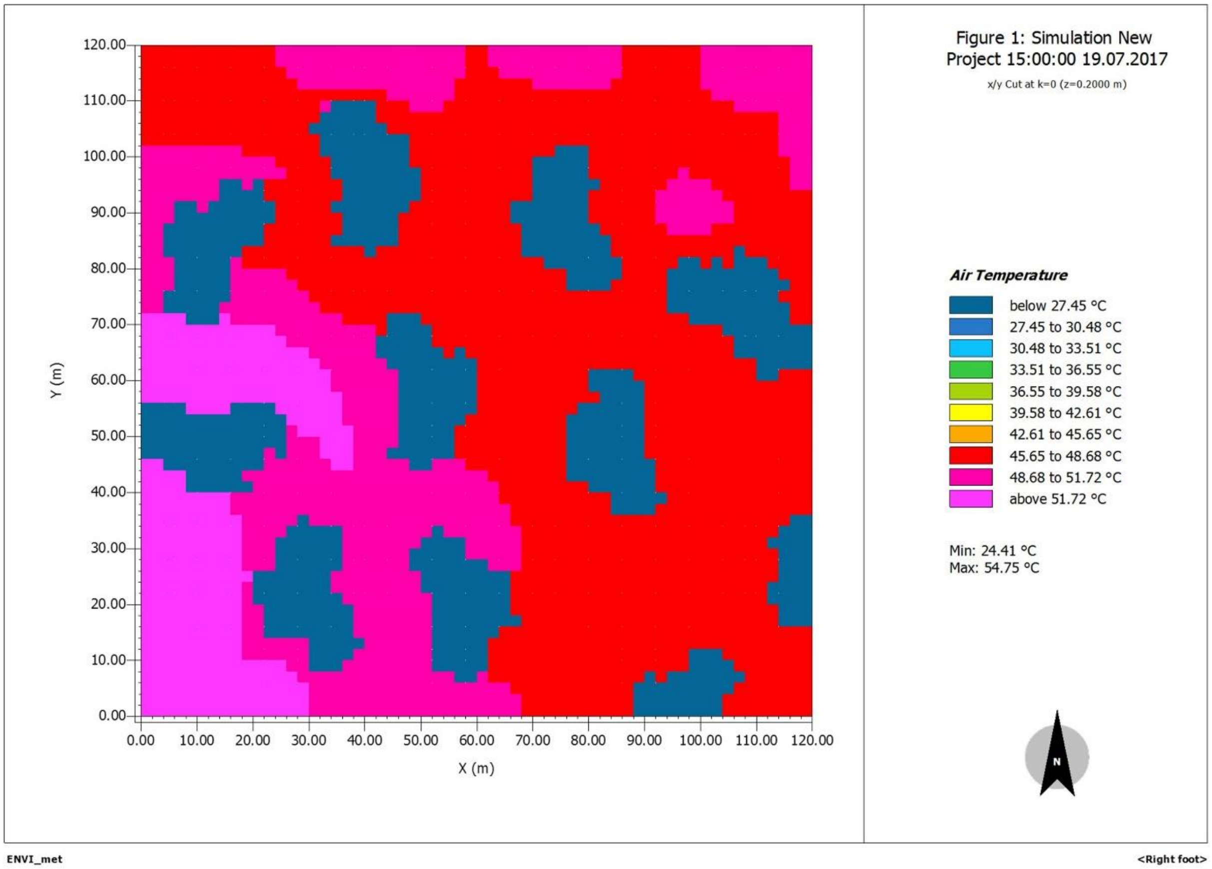
Strategy 1 - Orientation - 0 degrees - Mapping of air temperature at 12pm



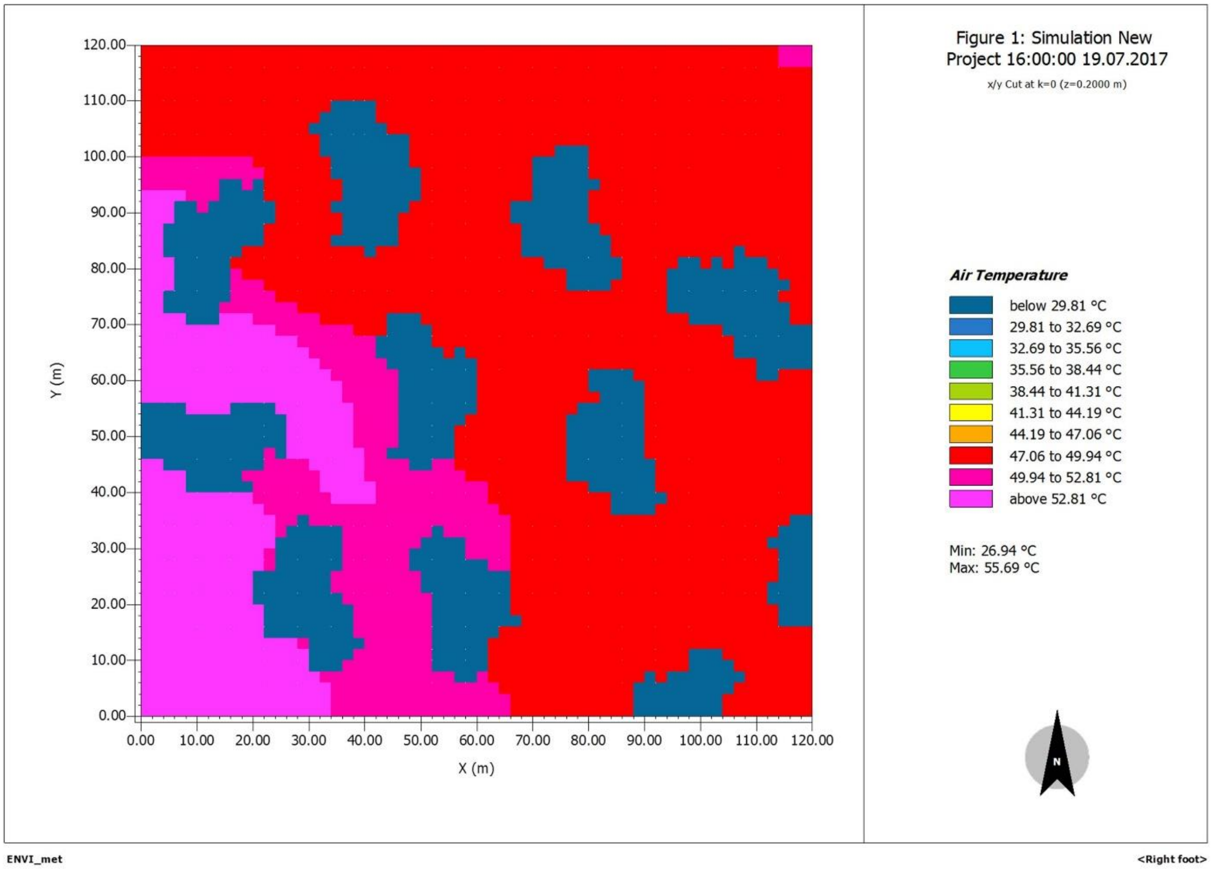
Strategy 1 - Orientation - 0 degrees - Mapping of air temperature at 1pm



Strategy 1 - Orientation - 0 degrees - Mapping of air temperature at 2pm

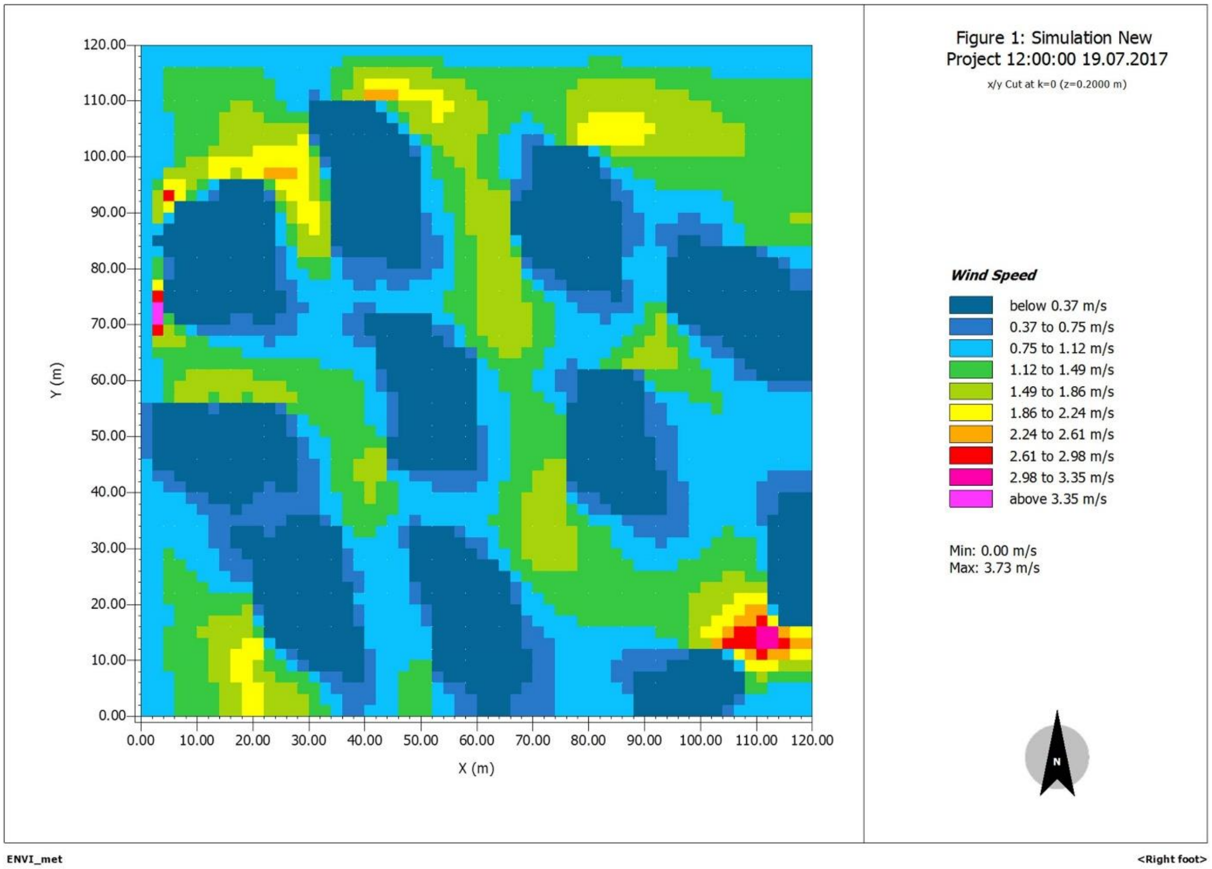


Strategy 1 - Orientation - 0 degrees - Mapping of air temperature at 3pm

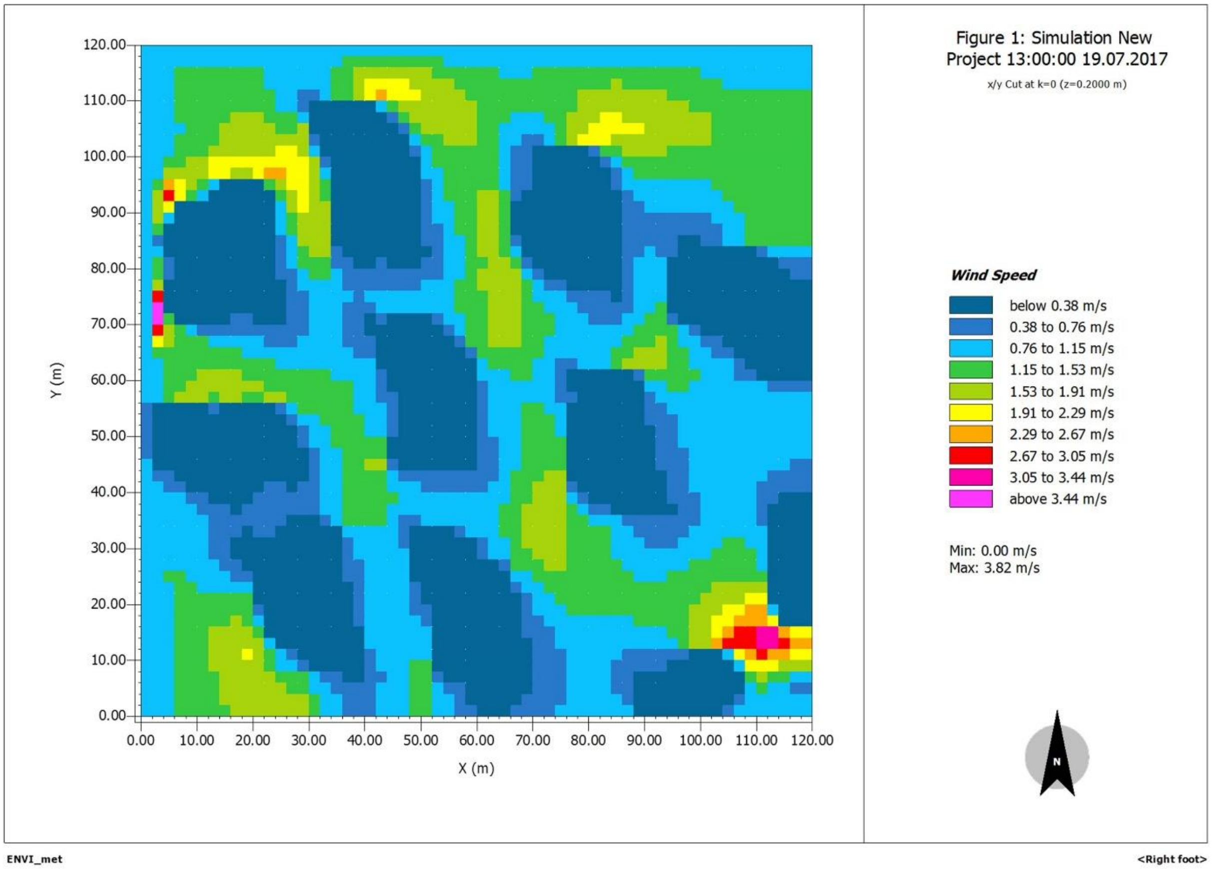


Strategy 1 - Orientation - 0 degrees - Mapping of air temperature at 4pm

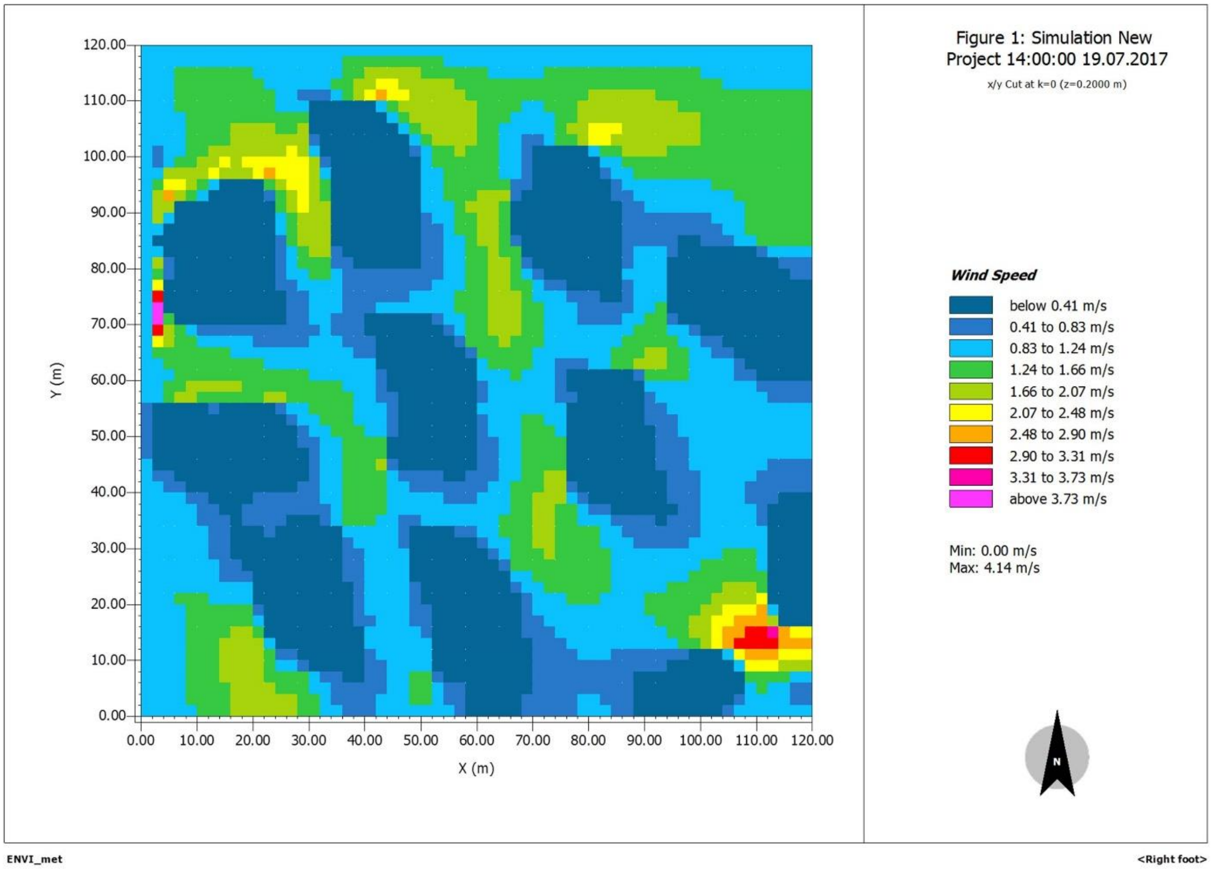
WIND SPEED



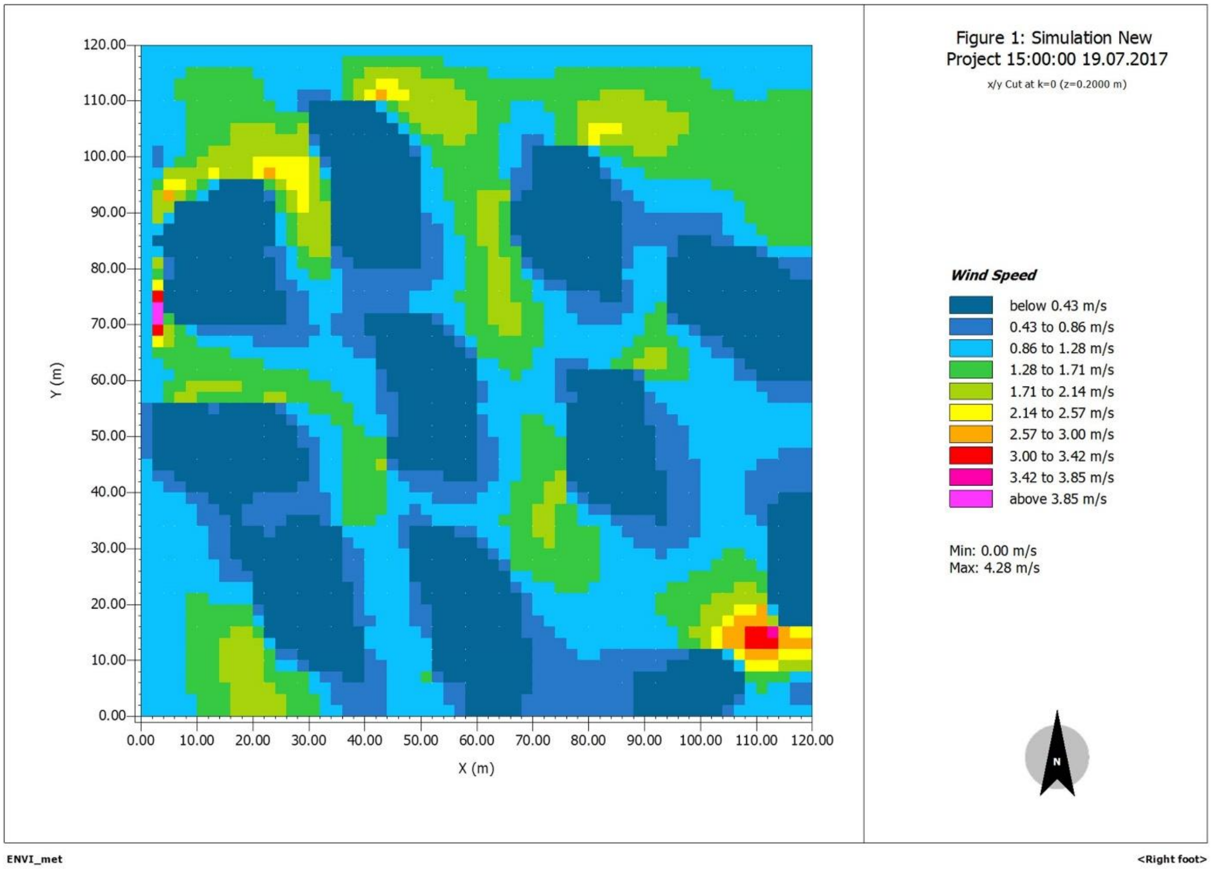
Strategy 1 - Orientation - 0 degrees - Mapping of wind speed at 12pm



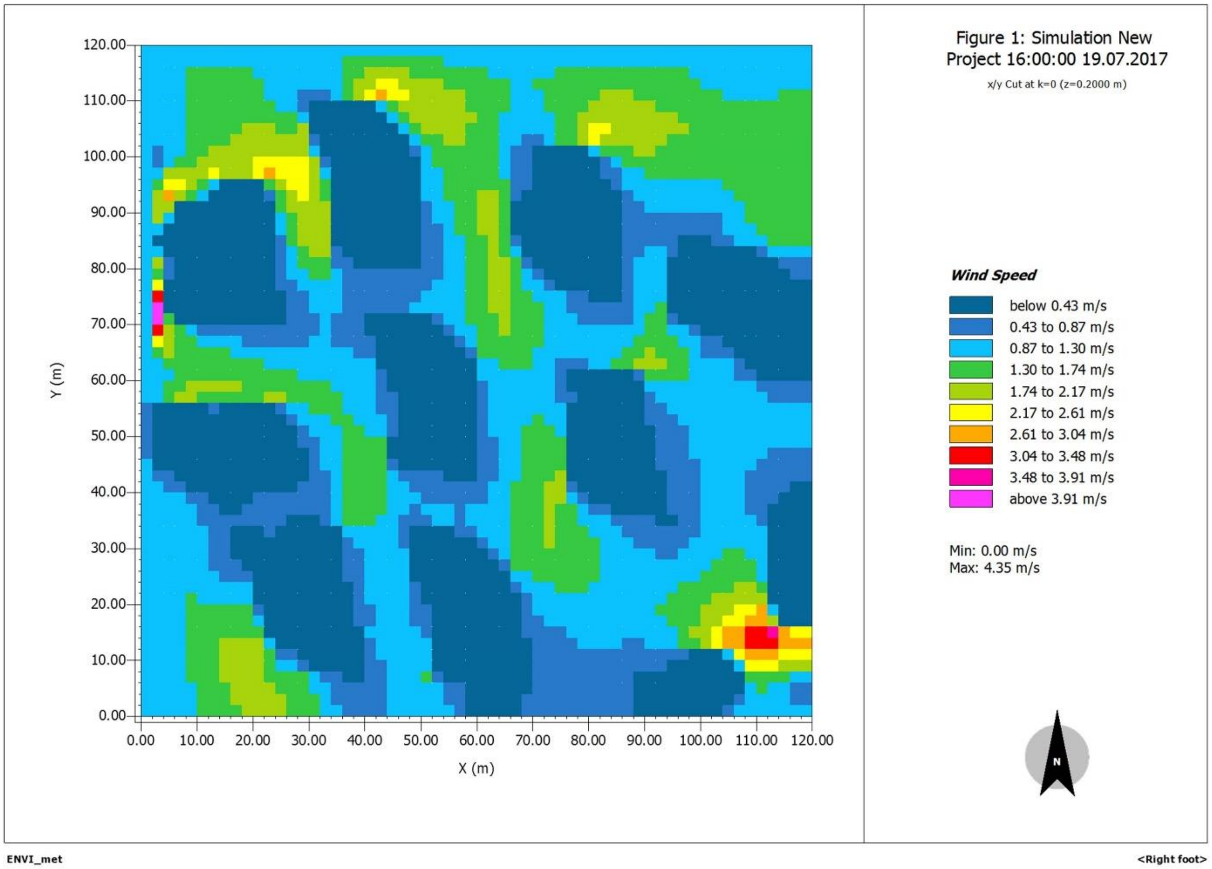
Strategy 1 - Orientation - 0 degrees - Mapping of wind speed at 1pm



Strategy 1 - Orientation - 0 degrees - Mapping of wind speed at 2pm

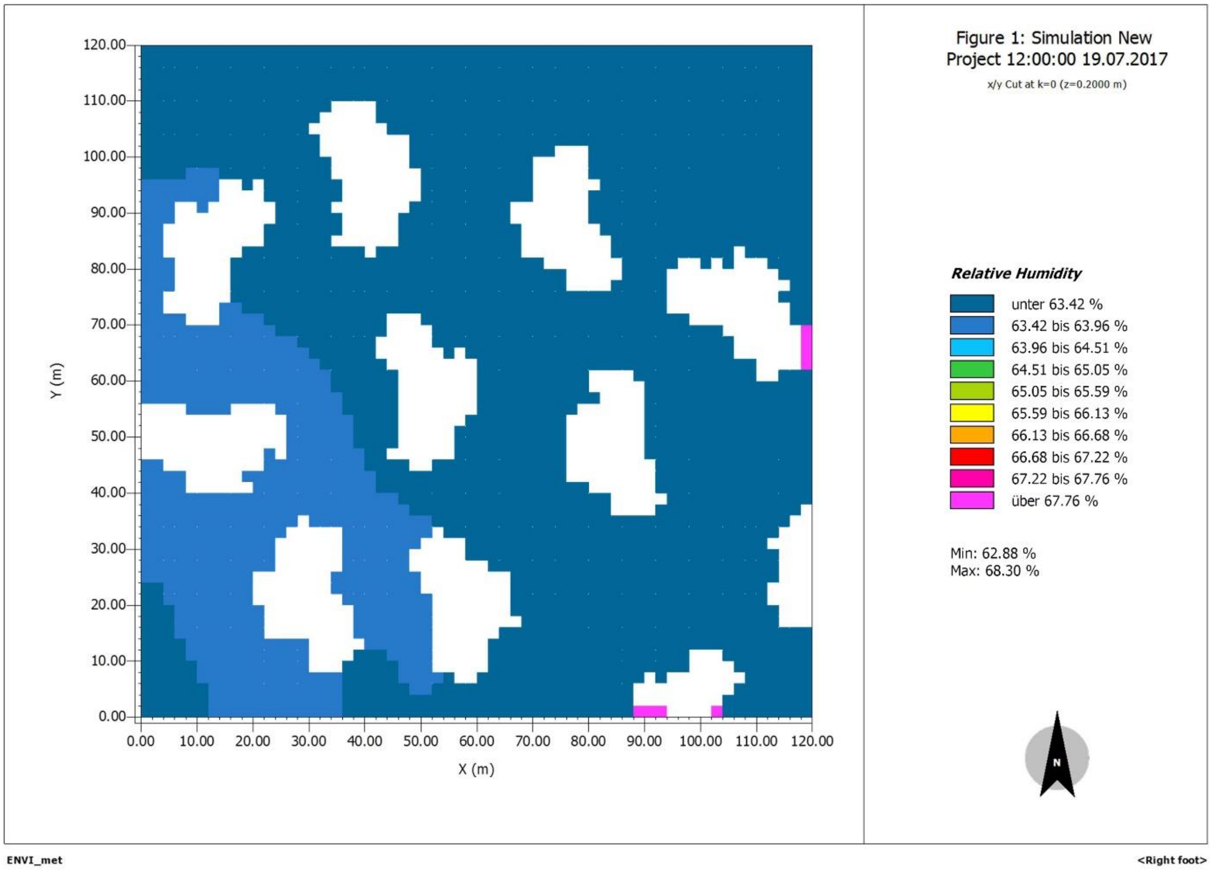


Strategy 1 - Orientation - 0 degrees - Mapping of wind speed at 3pm

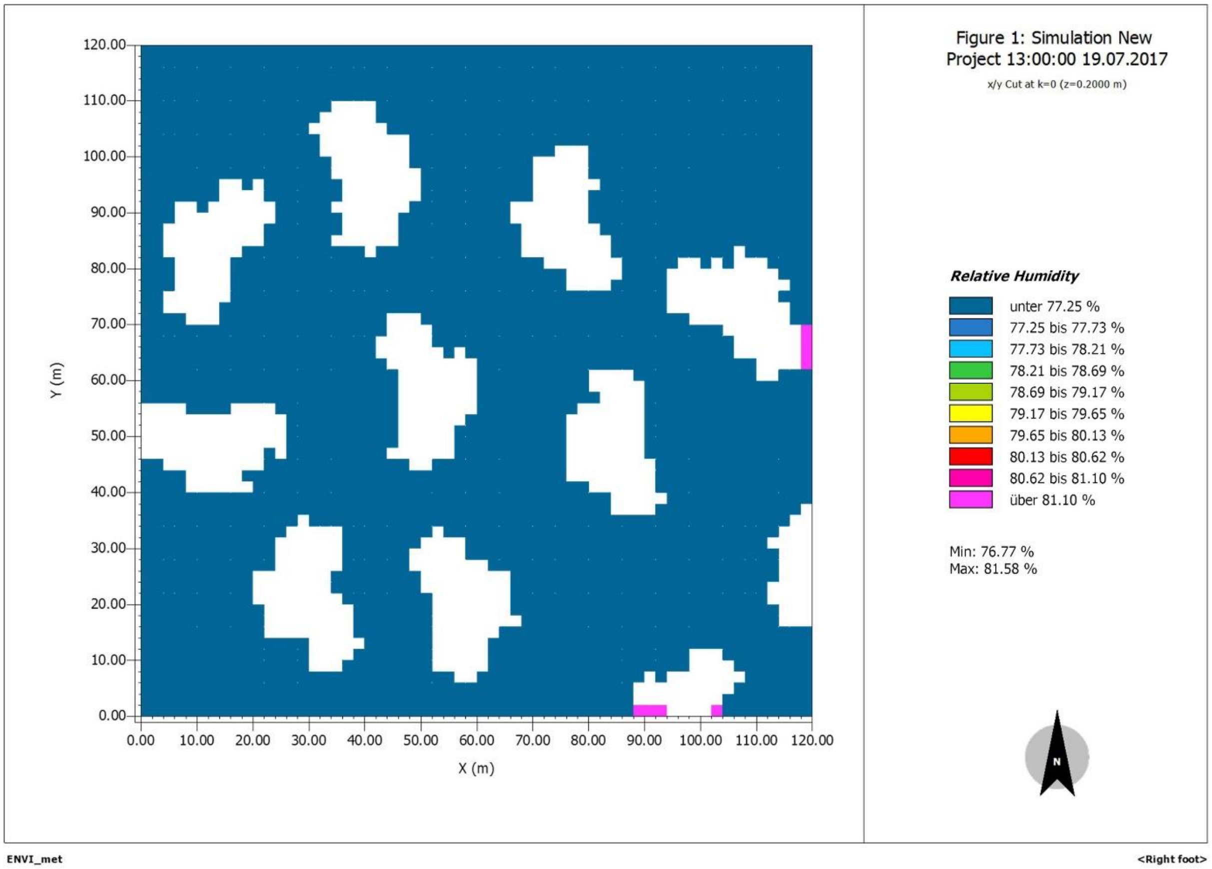


Strategy 1 - Orientation - 0 degrees - Mapping of wind speed at 4pm

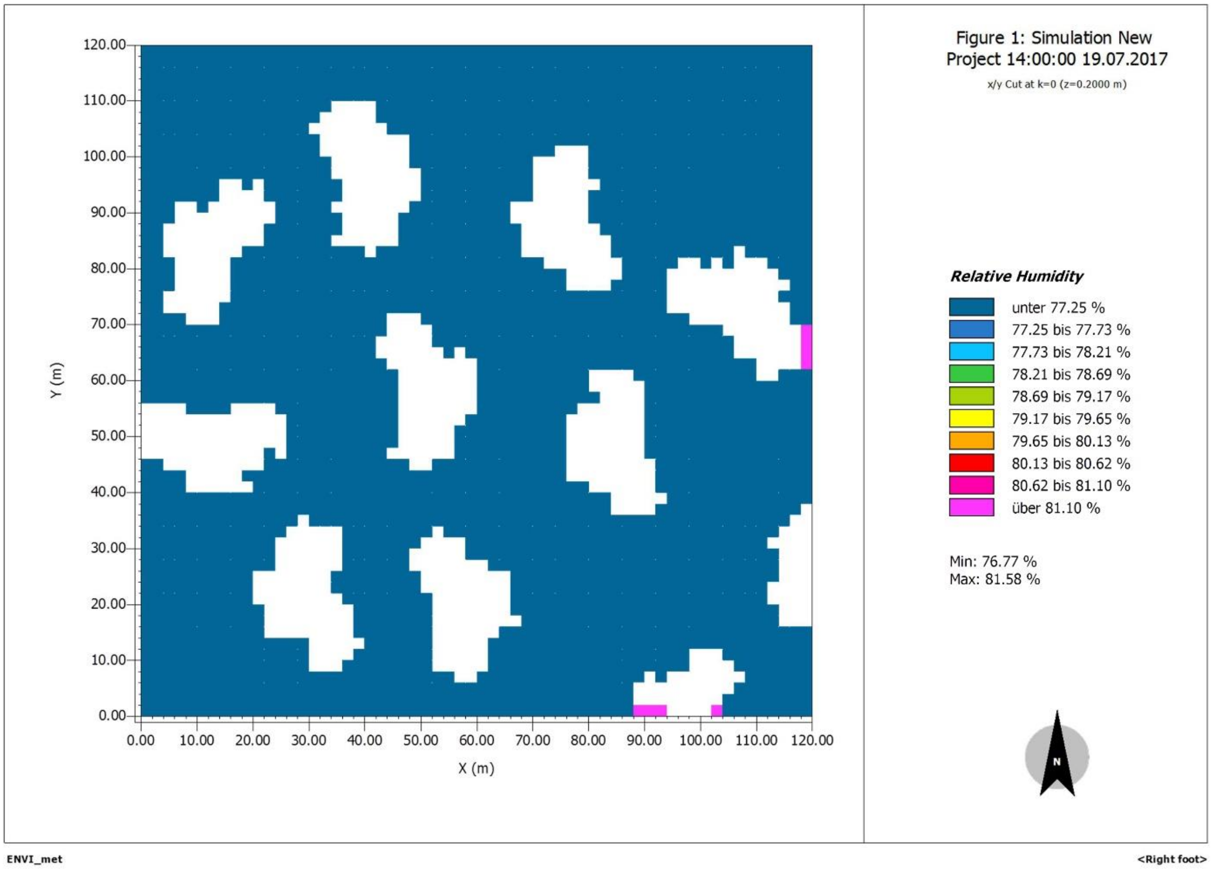
RELATIVE HUMIDITY



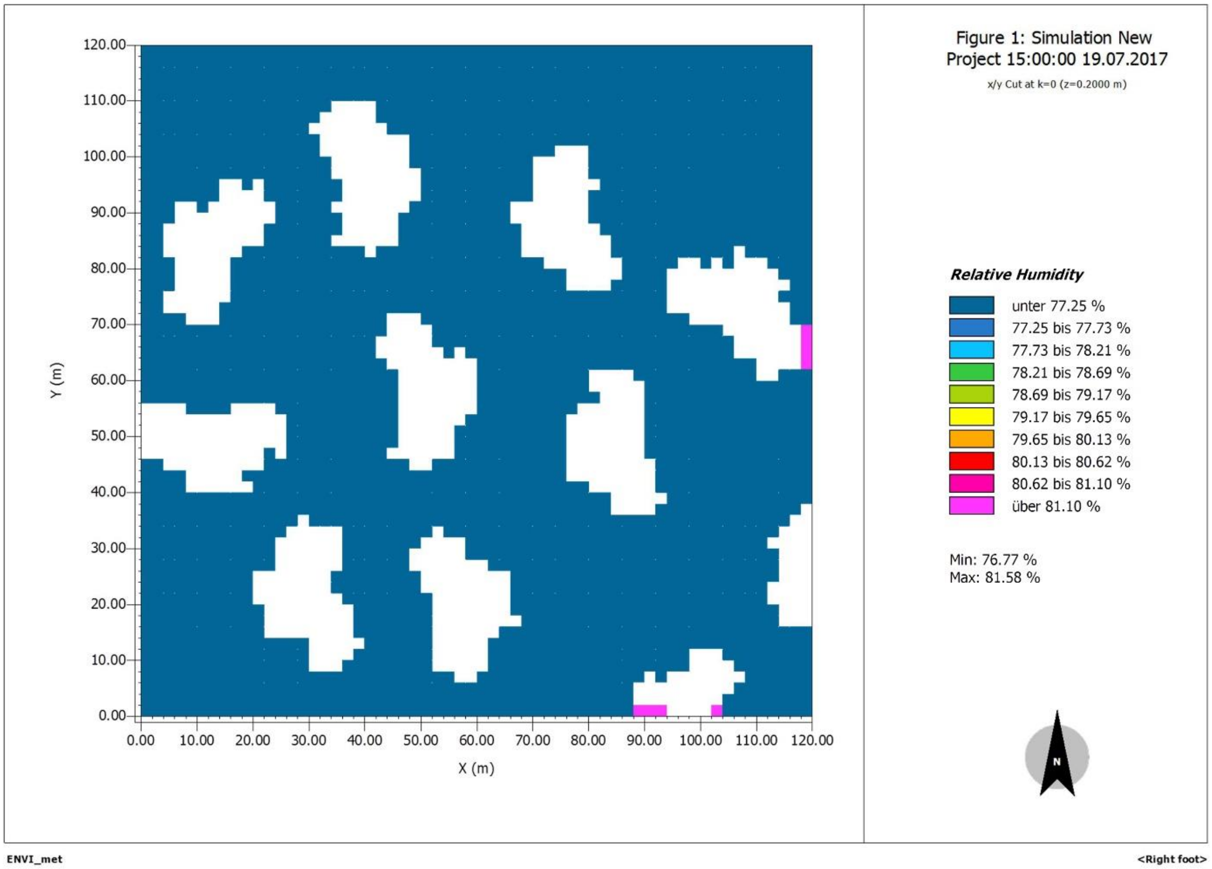
Strategy 1 - Orientation - 0 degrees - Mapping of relative humidity at 12pm



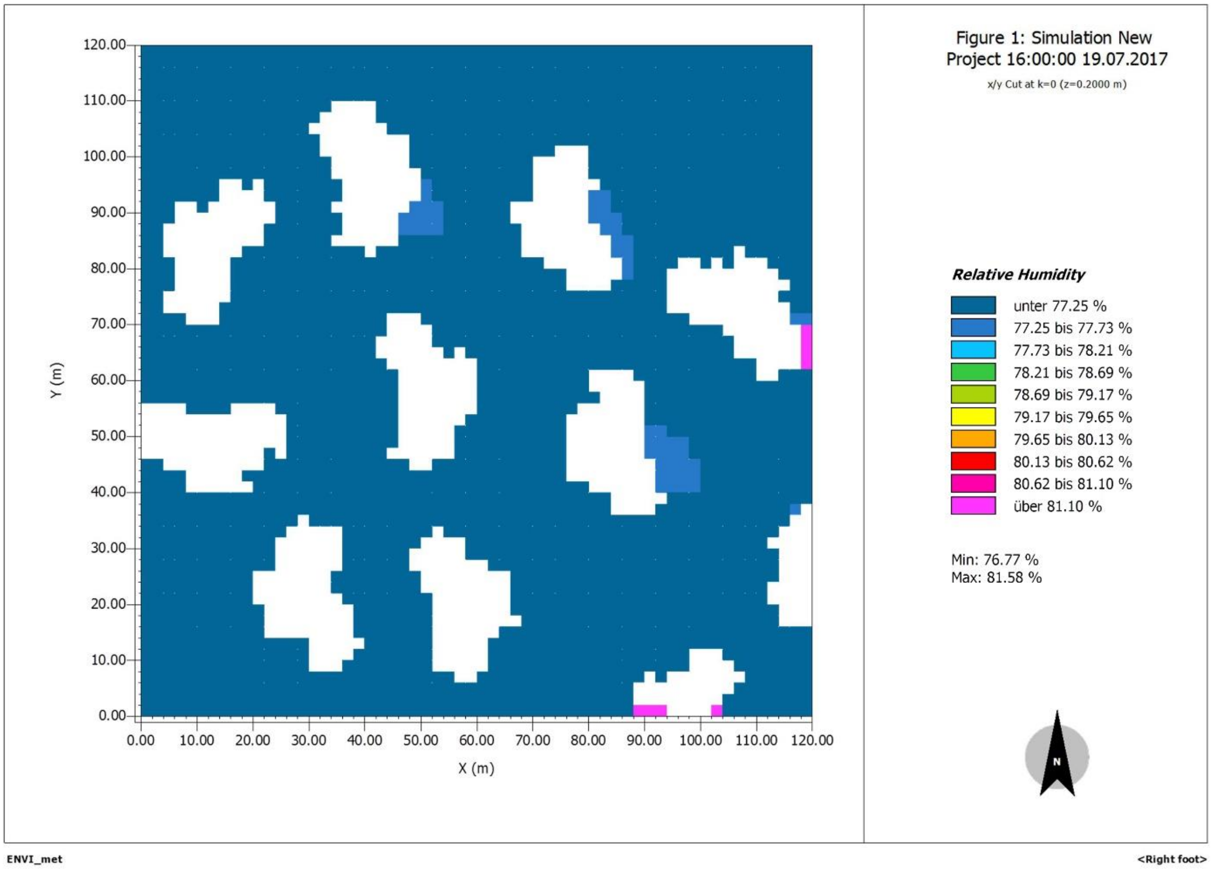
Strategy 1 - Orientation - 0 degrees - Mapping of relative humidity at 1pm



Strategy 1 - Orientation - 0 degrees - Mapping of relative humidity at 2pm

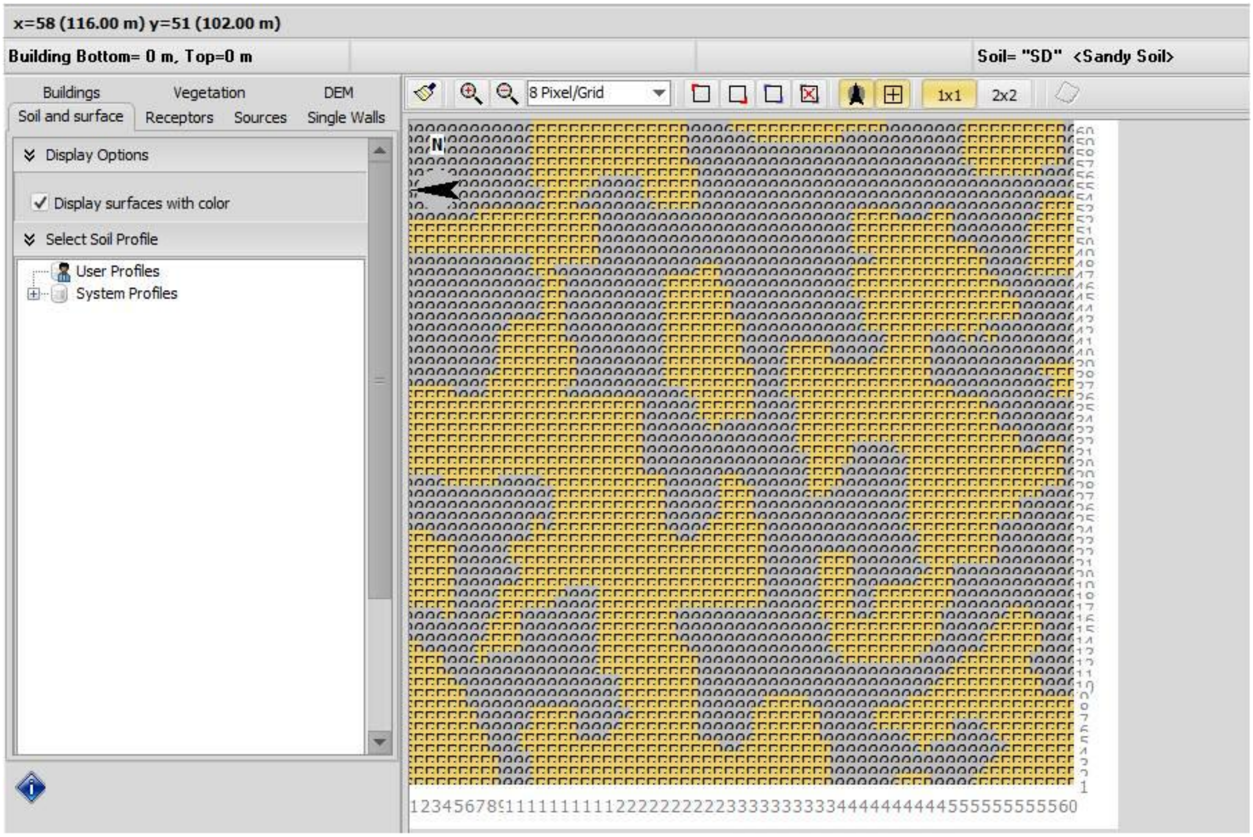


Strategy 1 - Orientation - 0 degrees - Mapping of relative humidity at 3pm



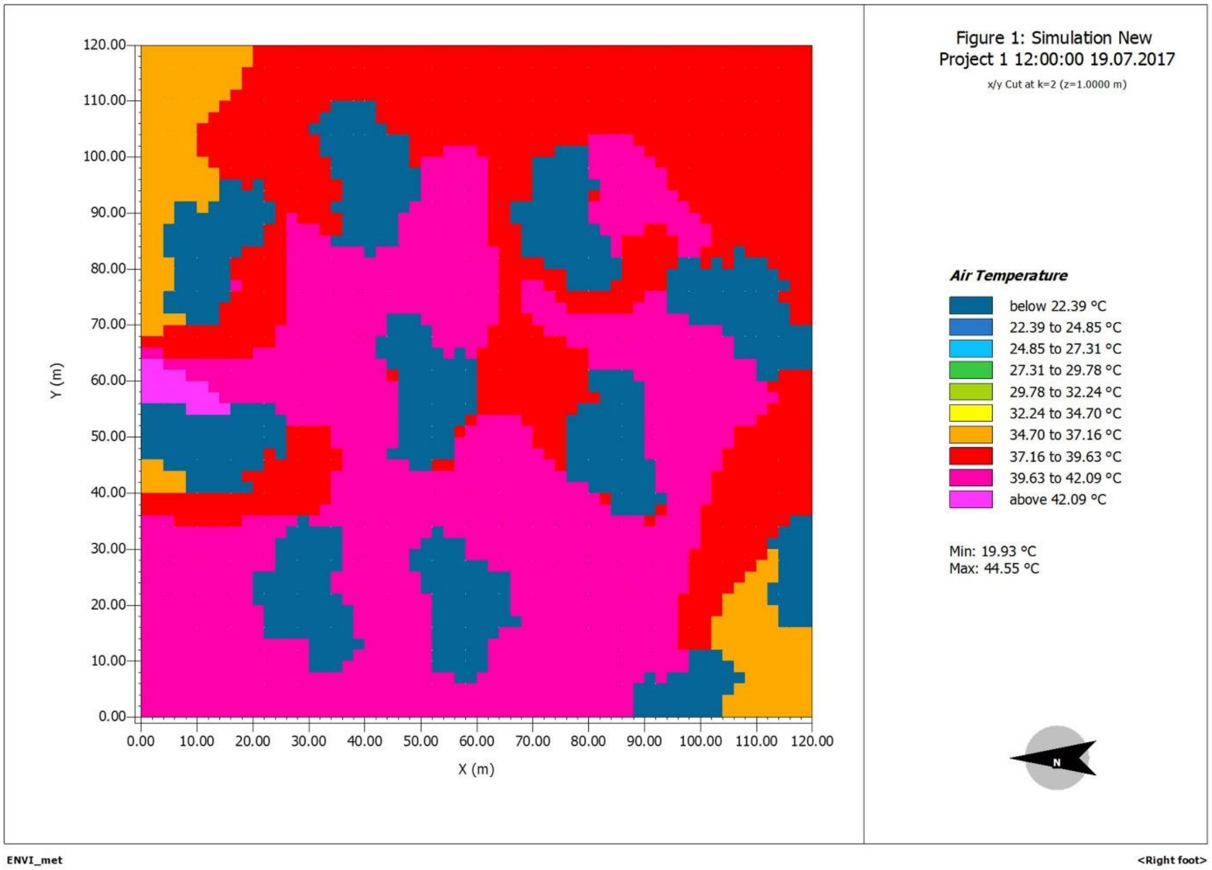
Strategy 1 - Orientation - 0 degrees - Mapping of relative humidity at 4pm

Appendix 2 - Strategy 1 - Orientation - 270 degrees

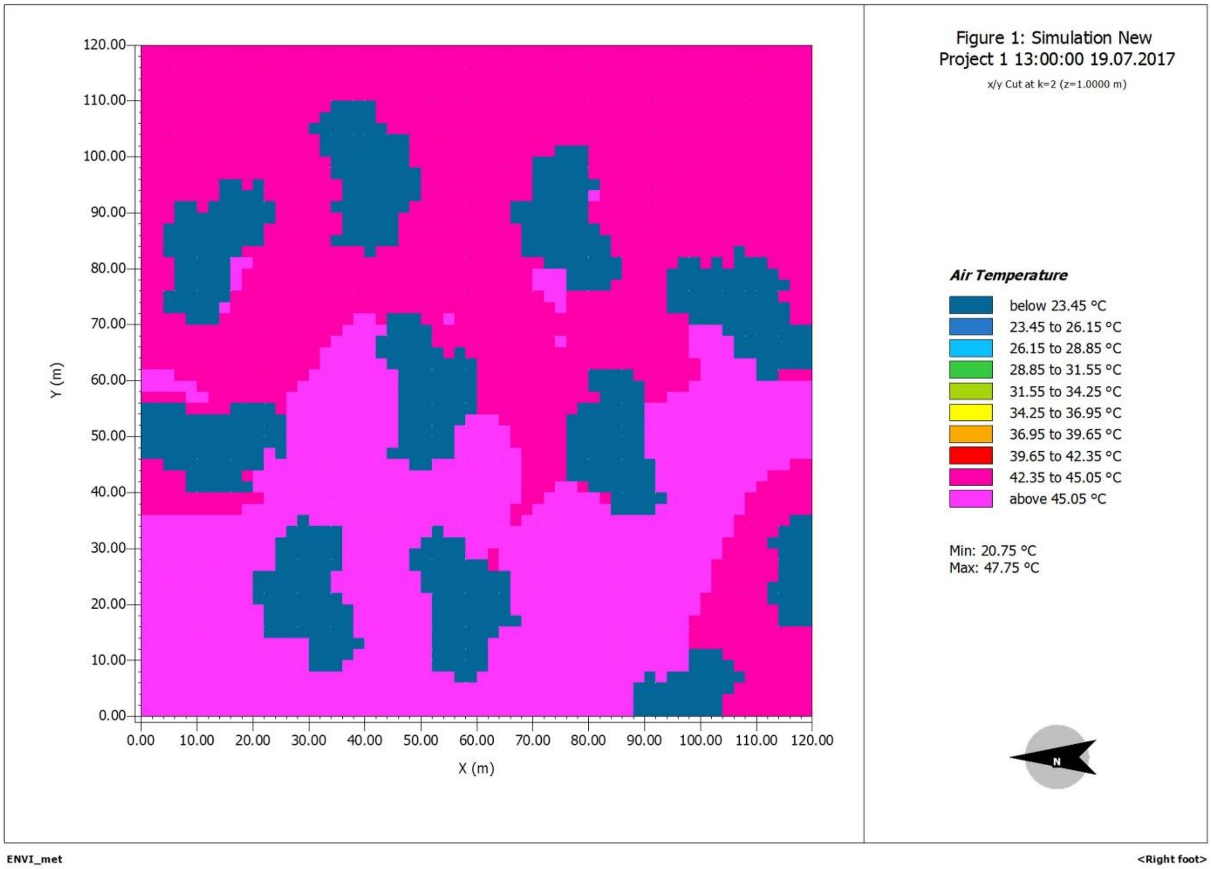


Model building, orientation 270 degrees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

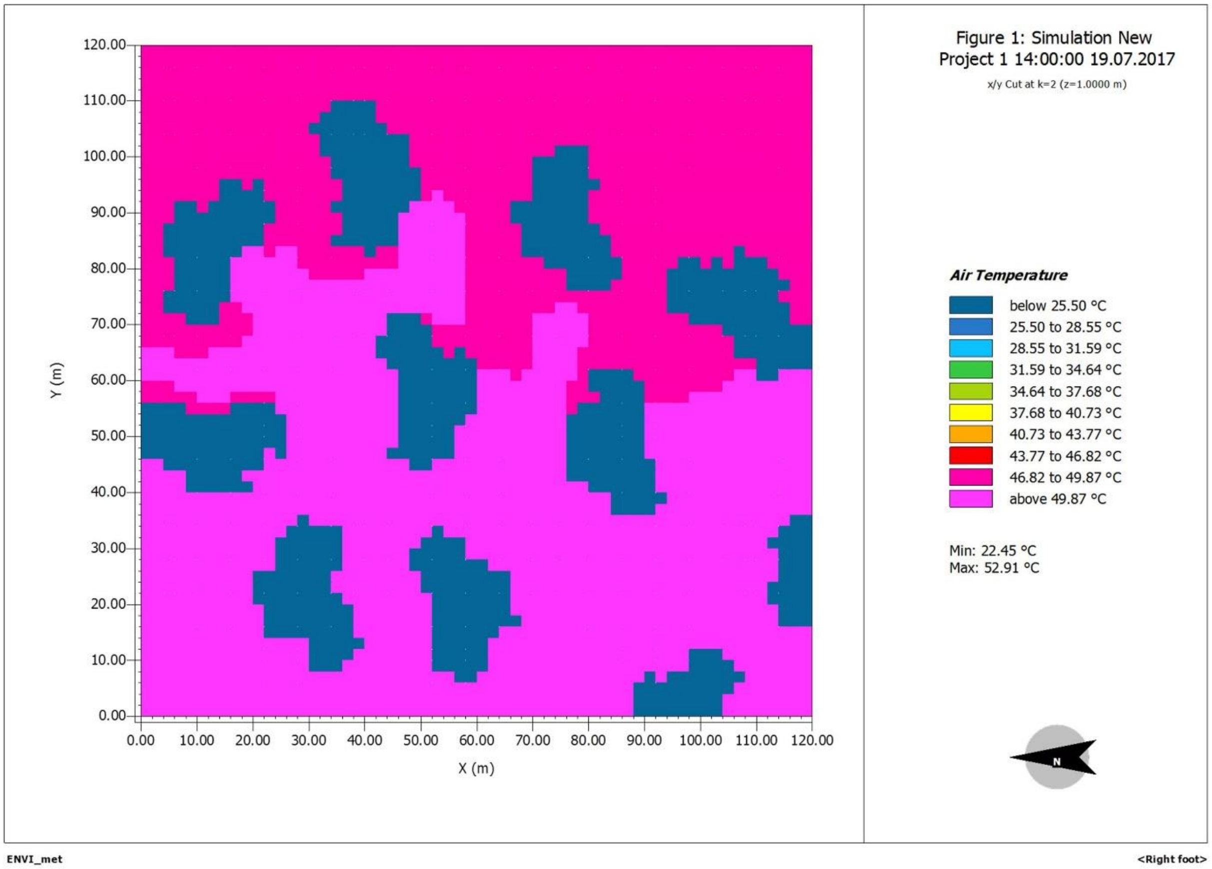
AIR TEMPERATURE



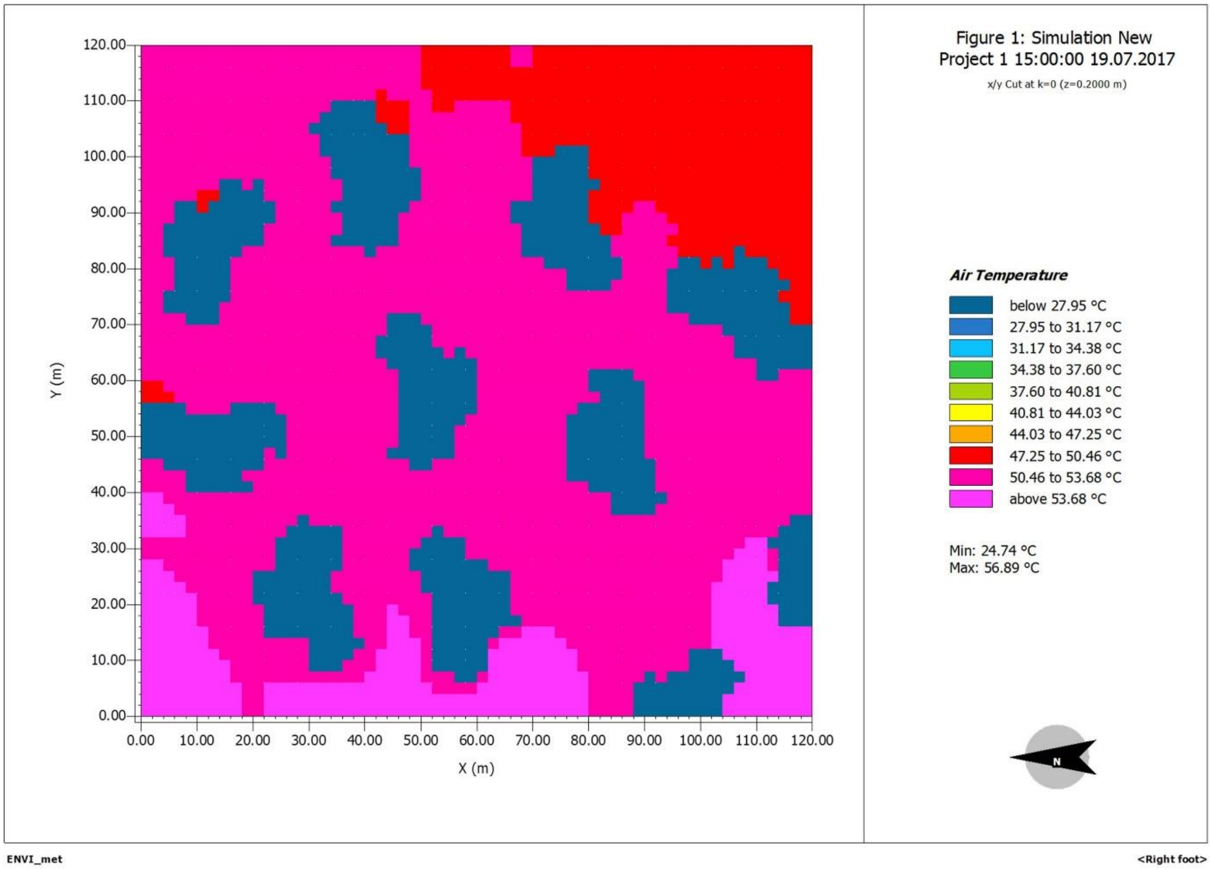
Strategy 1 - Orientation - 270 degrees - Mapping of air temperature at 12pm



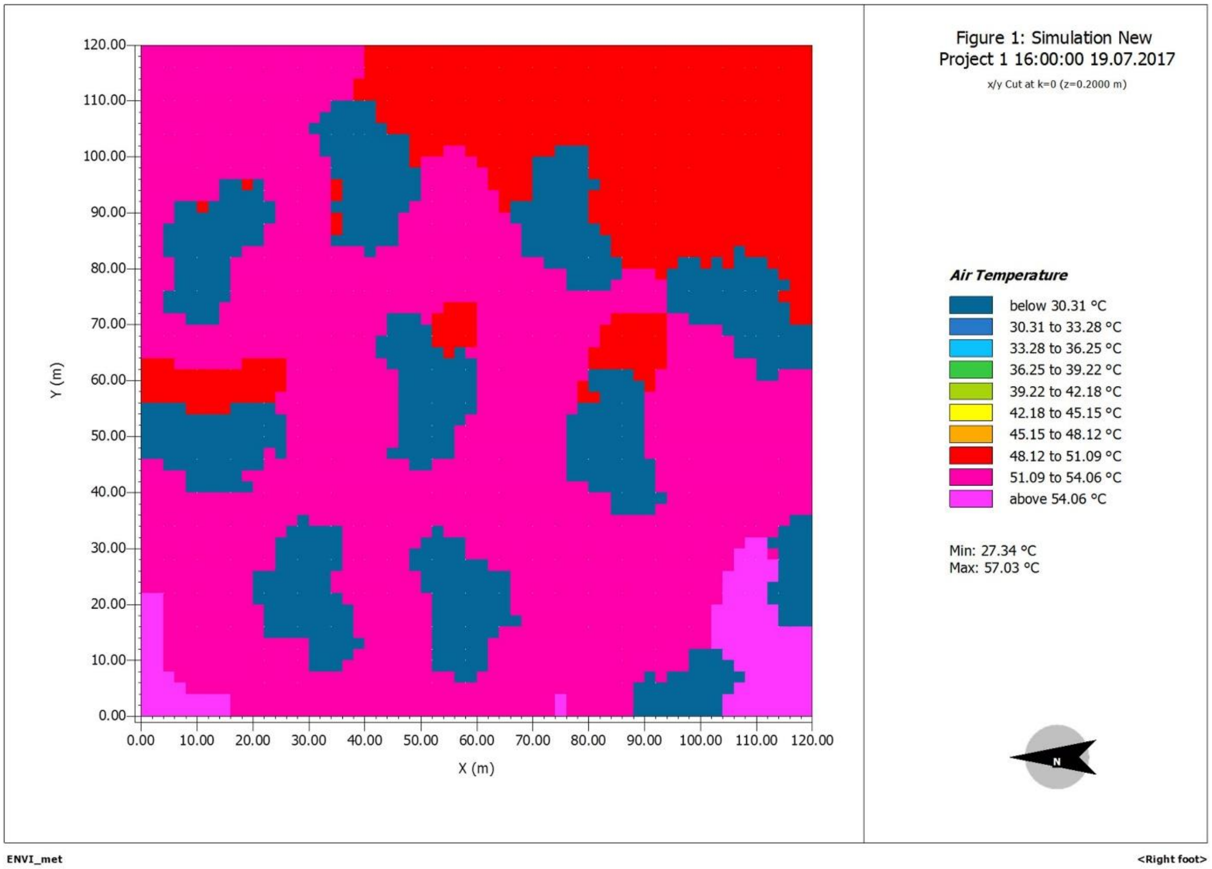
Strategy 1 - Orientation - 270 degrees - Mapping of air temperature at 1pm



Strategy 1 - Orientation - 270 degrees - Mapping of air temperature at 2pm

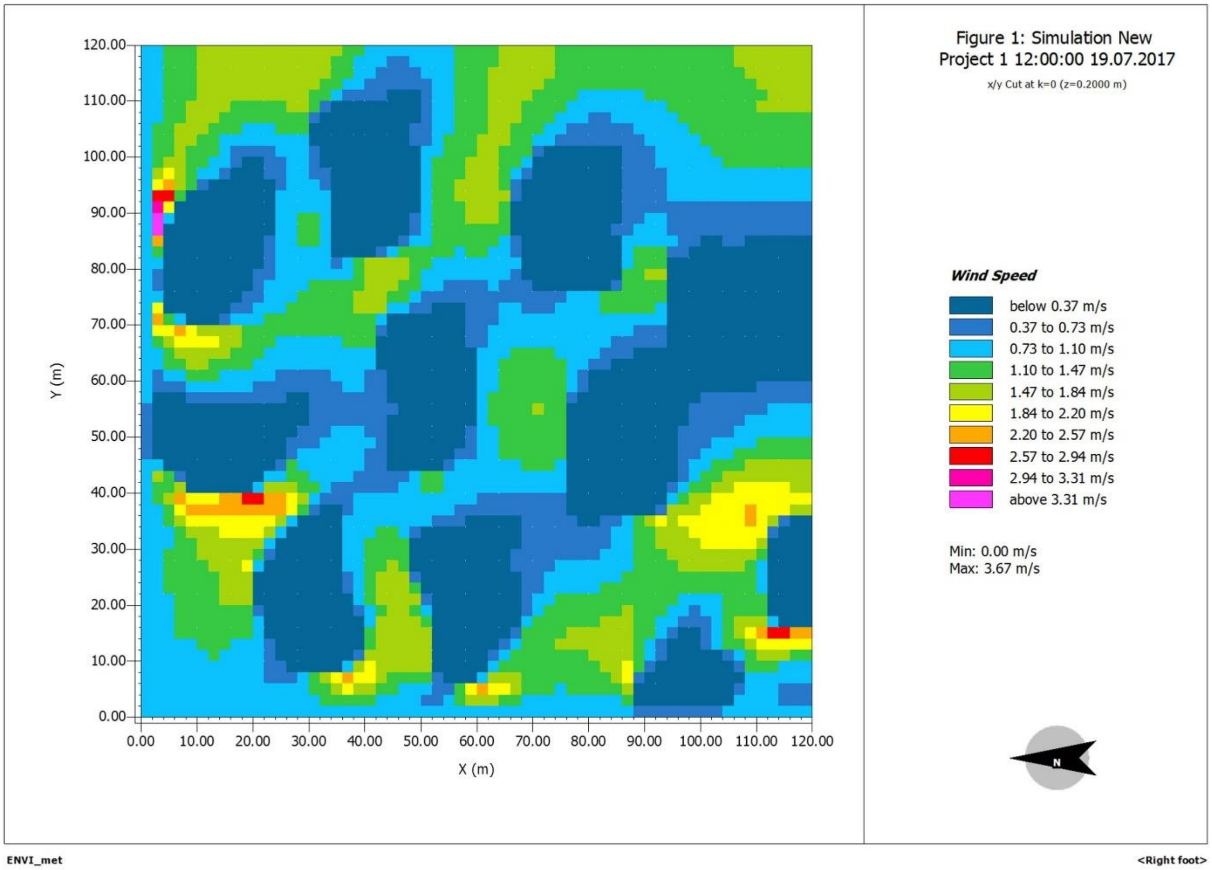


Strategy 1 - Orientation - 270 degrees - Mapping of air temperature at 3pm

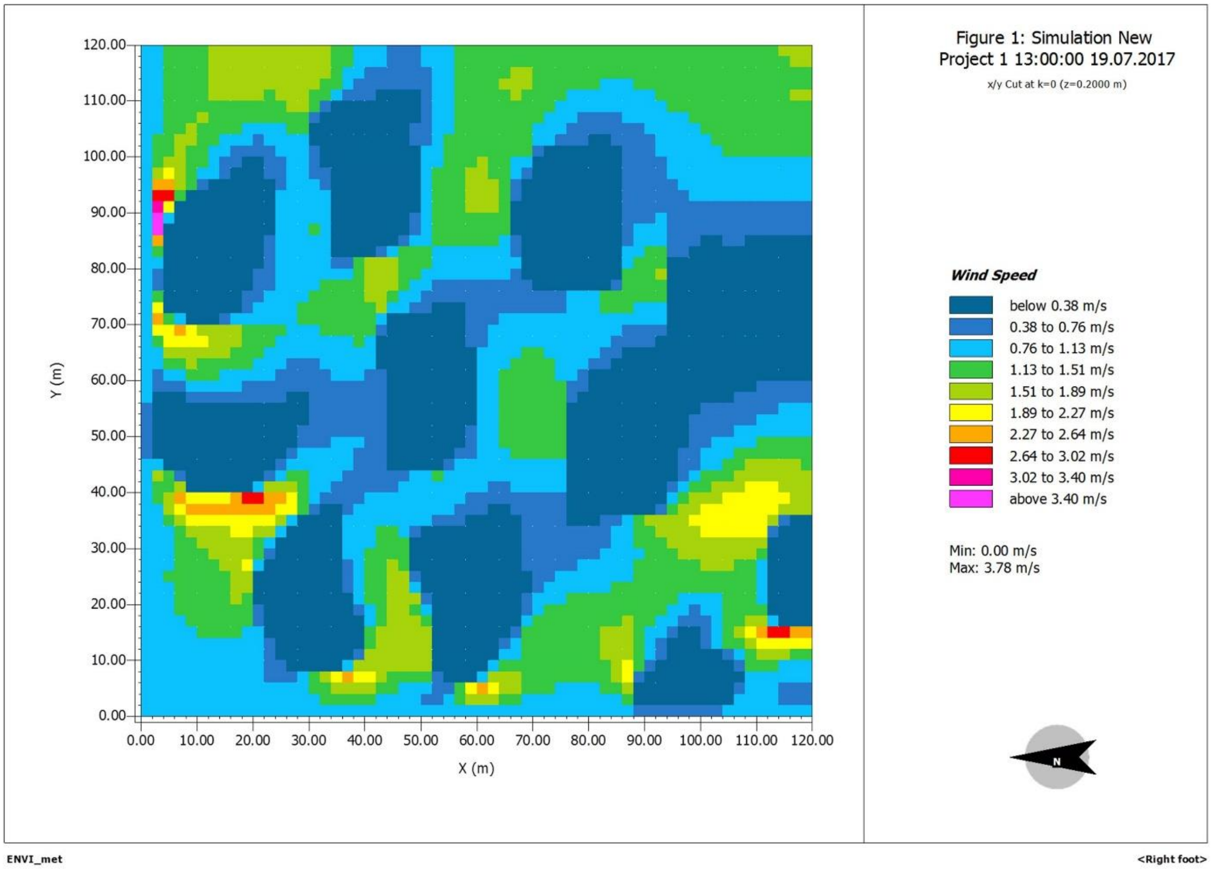


Strategy 1 - Orientation - 270 degrees - Mapping of air temperature at 4pm

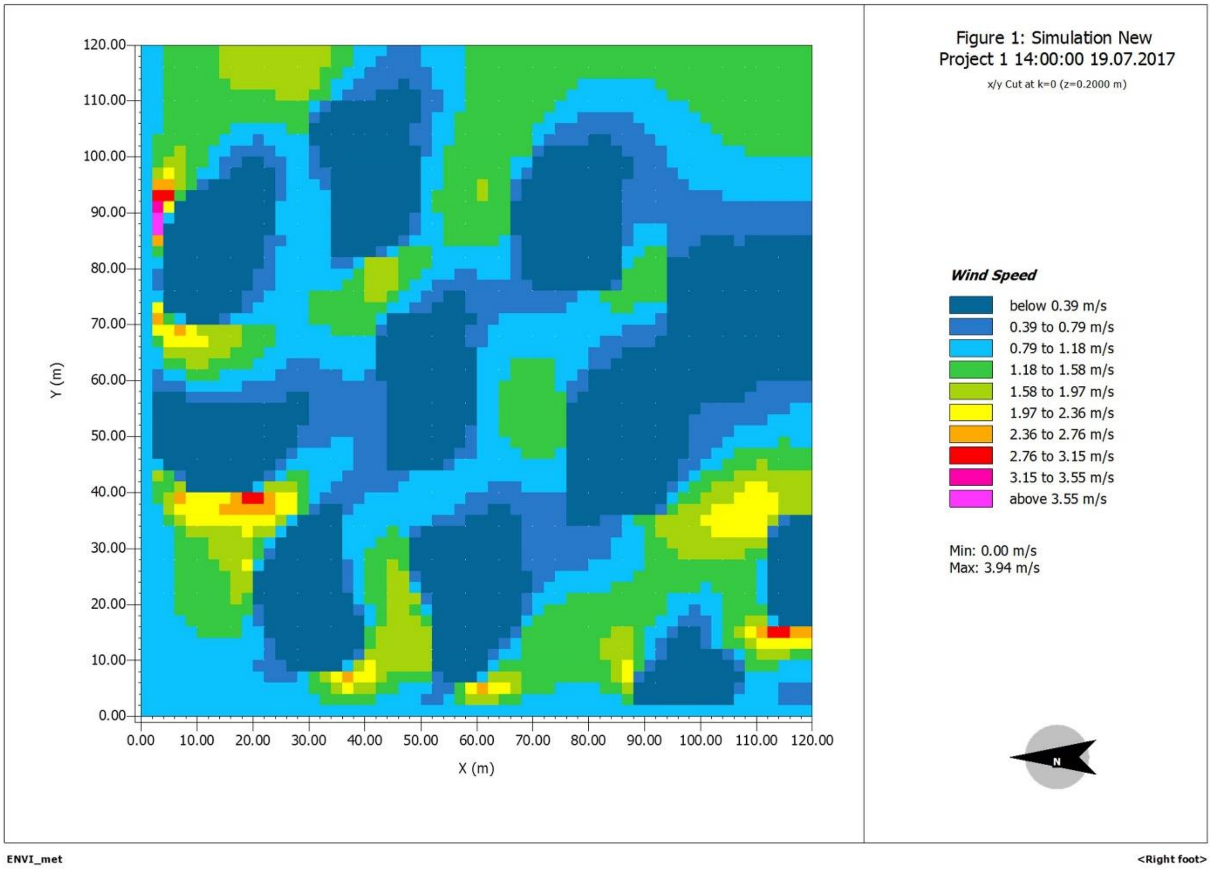
WIND SPEED



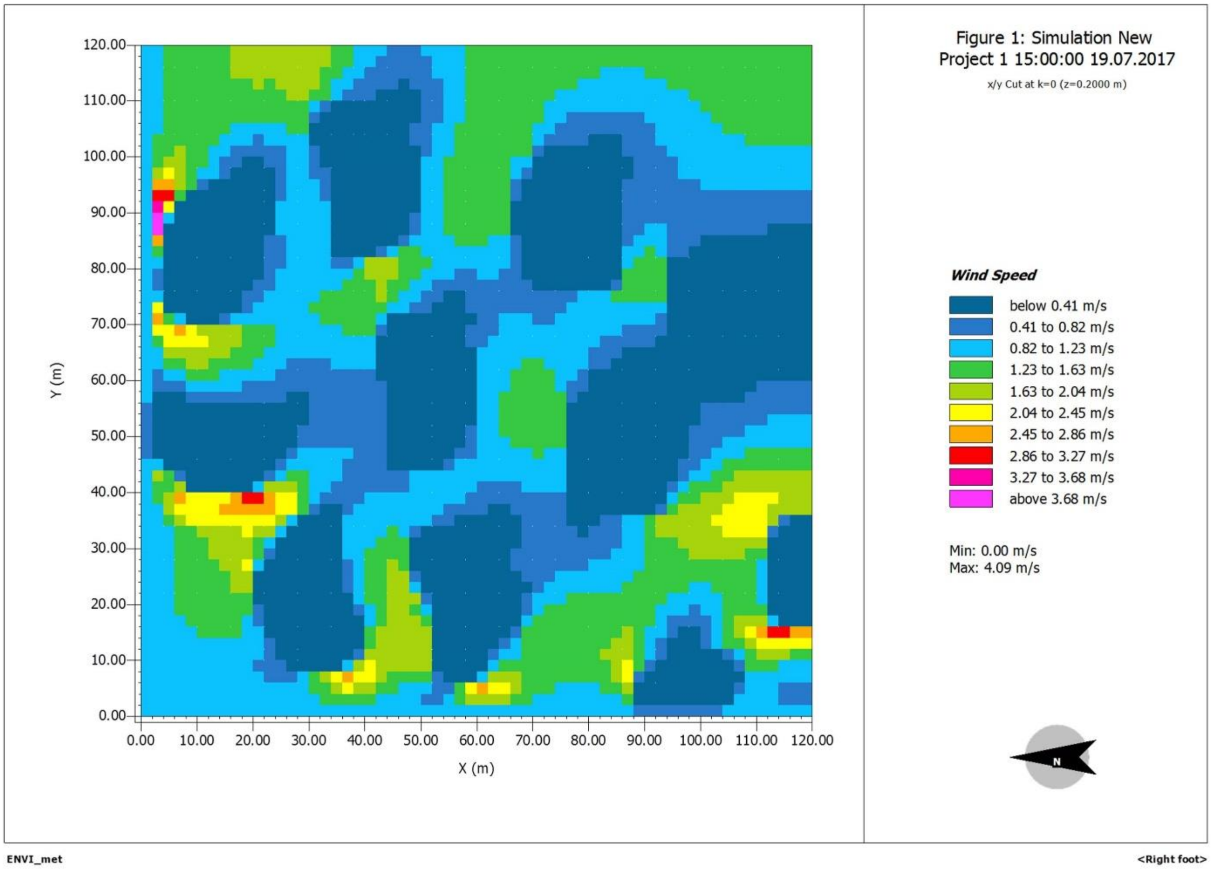
Strategy 1 - Orientation -27 0 degrees - Mapping of wind speed at 12pm



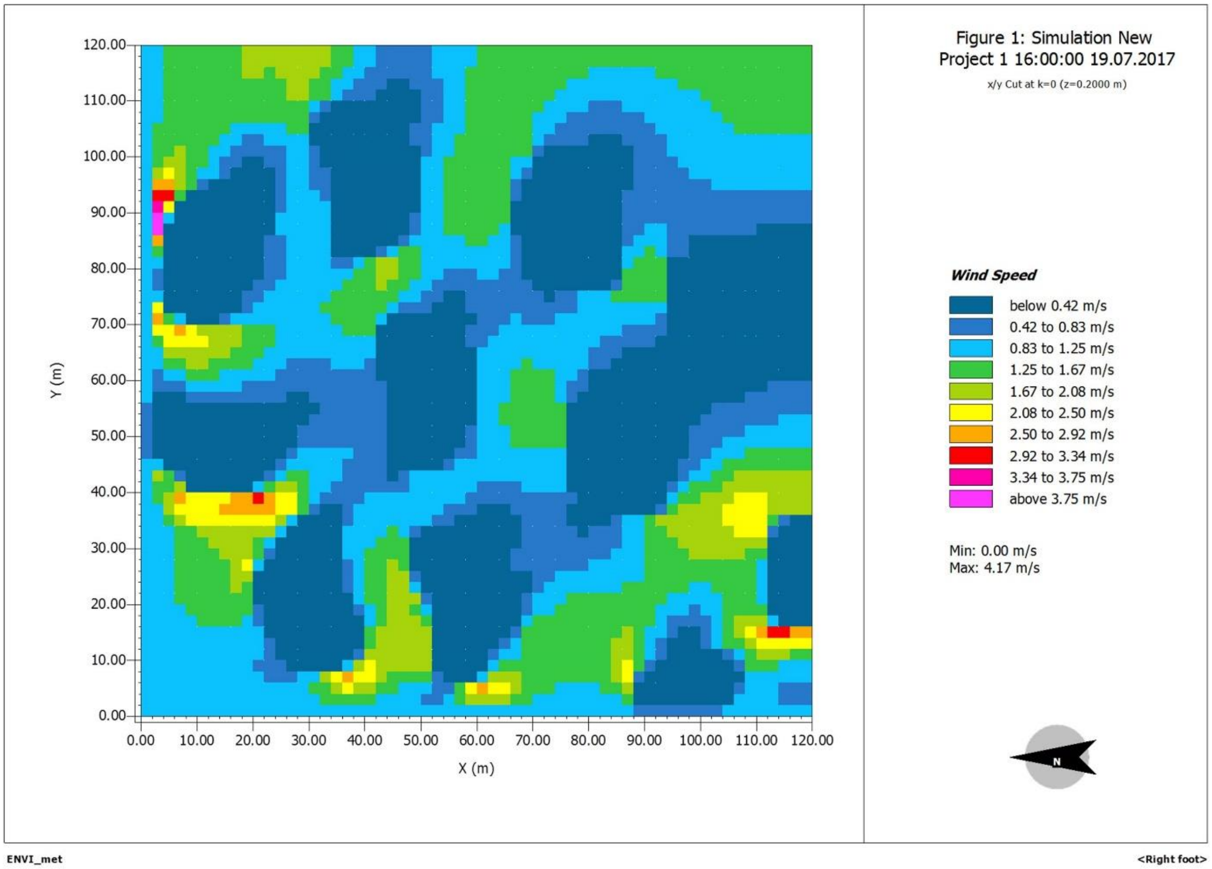
Strategy 1 - Orientation - 270 degrees - Mapping of wind speed at 1pm



Strategy 1 - Orientation - 270 degrees - Mapping of wind speed at 2pm

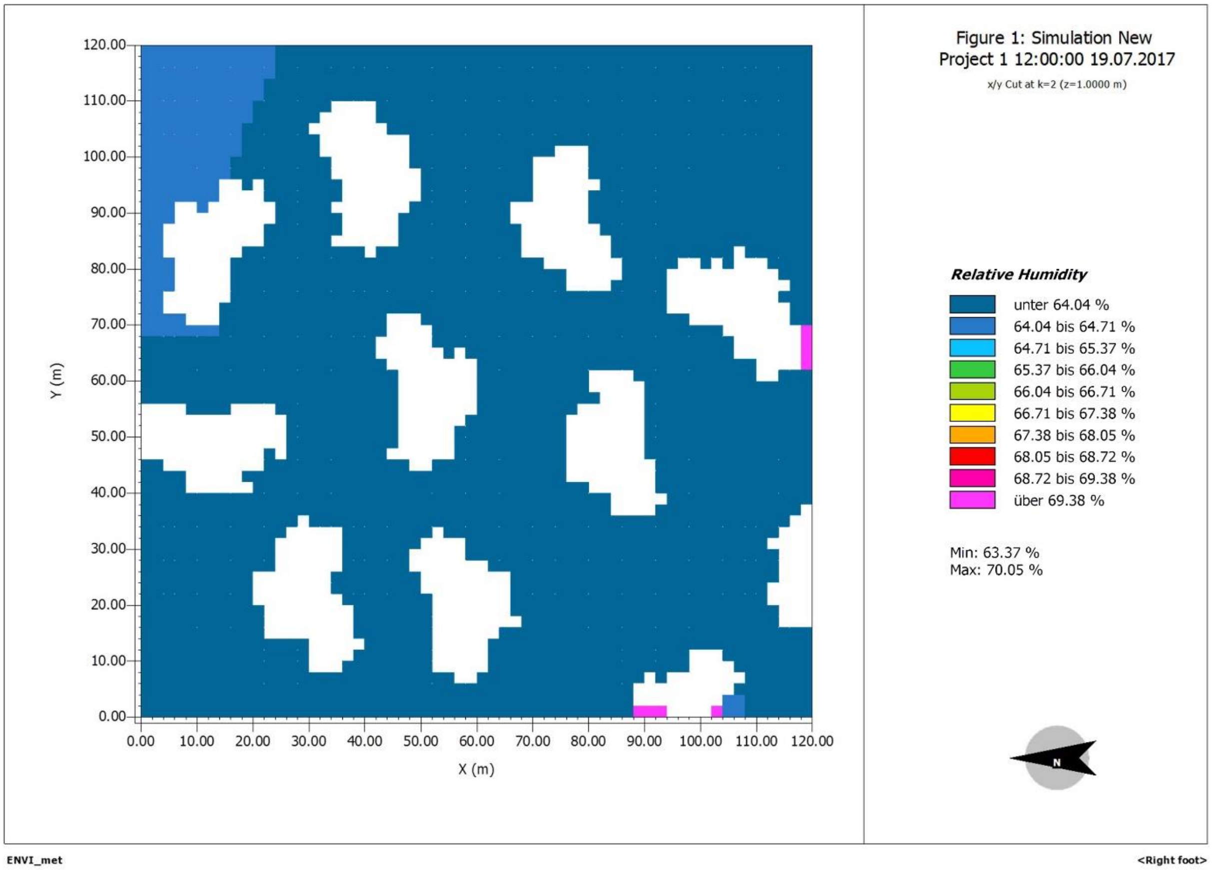


Strategy 1 - Orientation - 270 degrees - Mapping of wind speed at 3pm

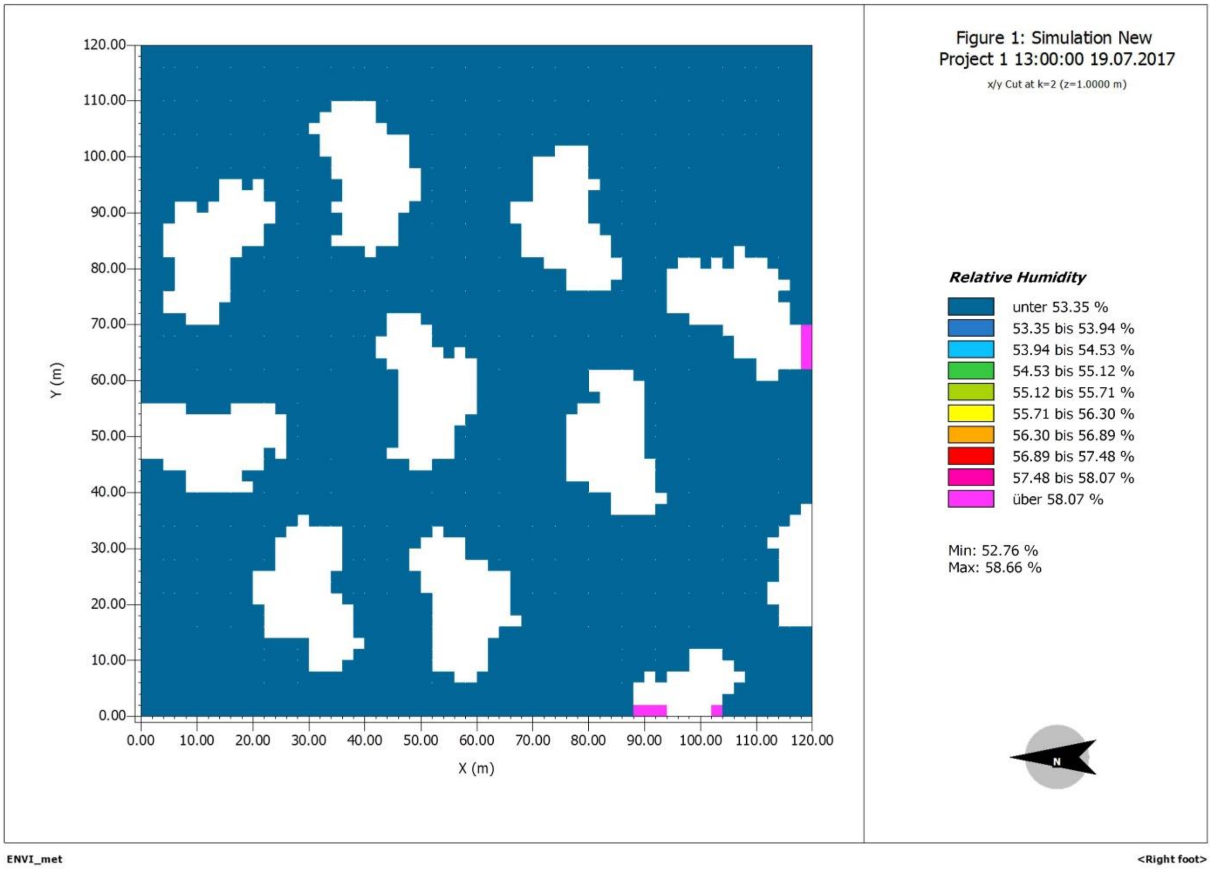


Strategy 1 - Orientation - 270 degrees - Mapping of wind speed at 4pm

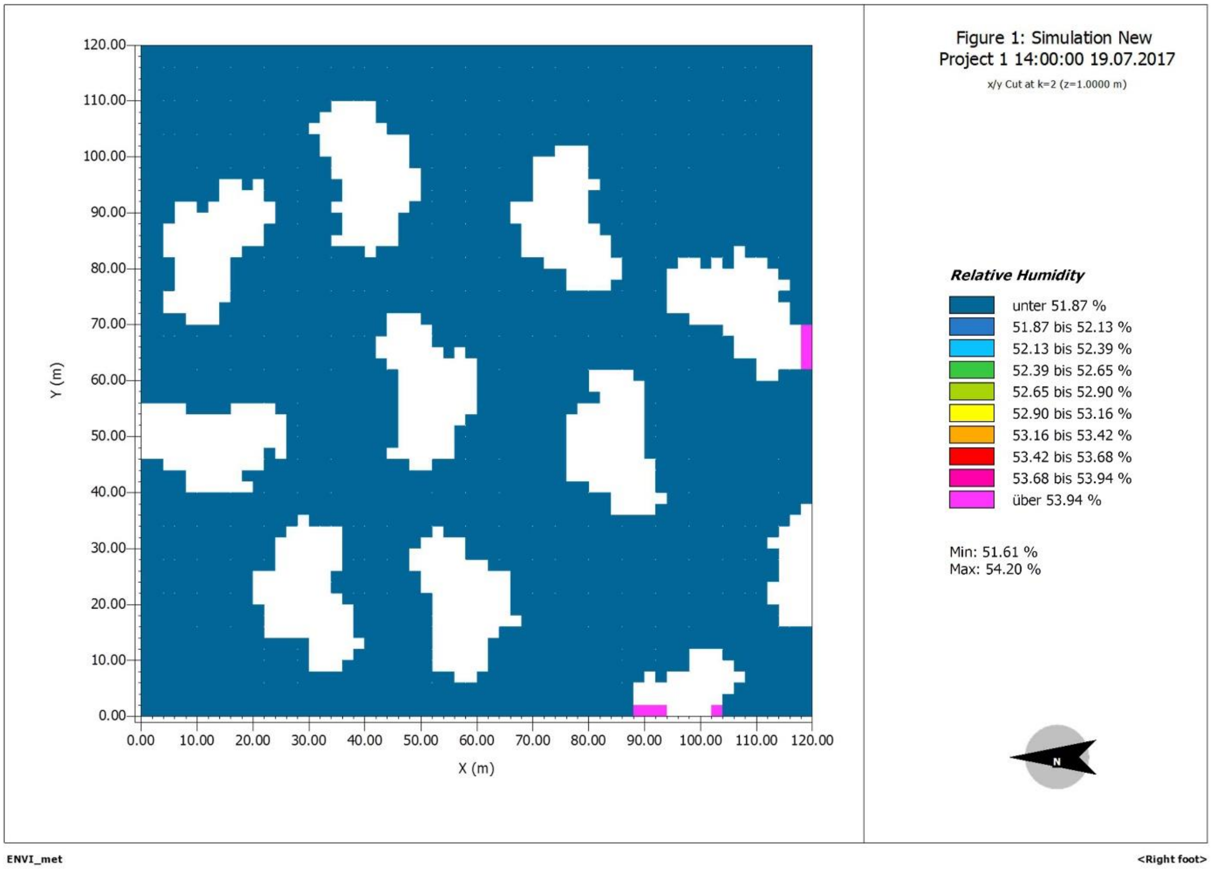
RELATIVE HUMIDITY



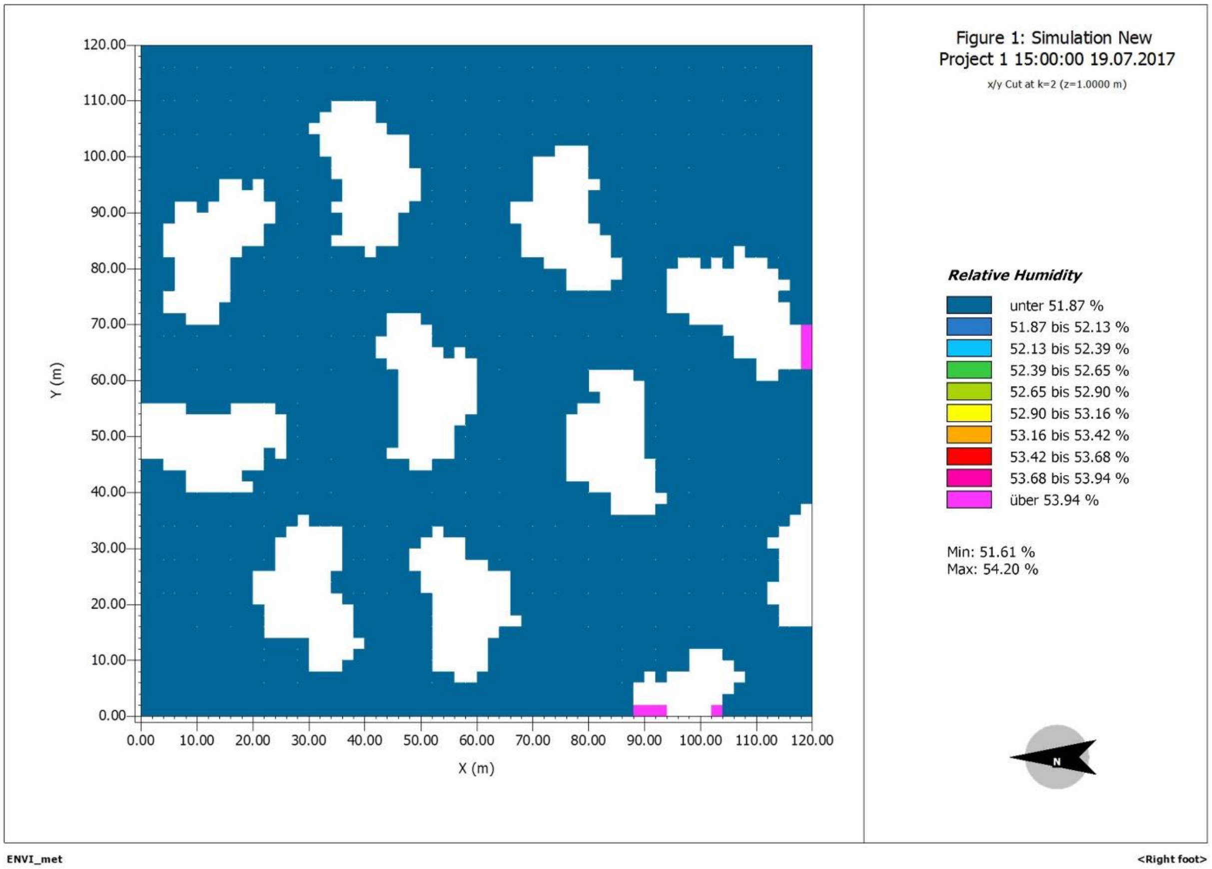
Strategy 1 - Orientation - 270 degrees - Mapping of relative humidity at 12pm



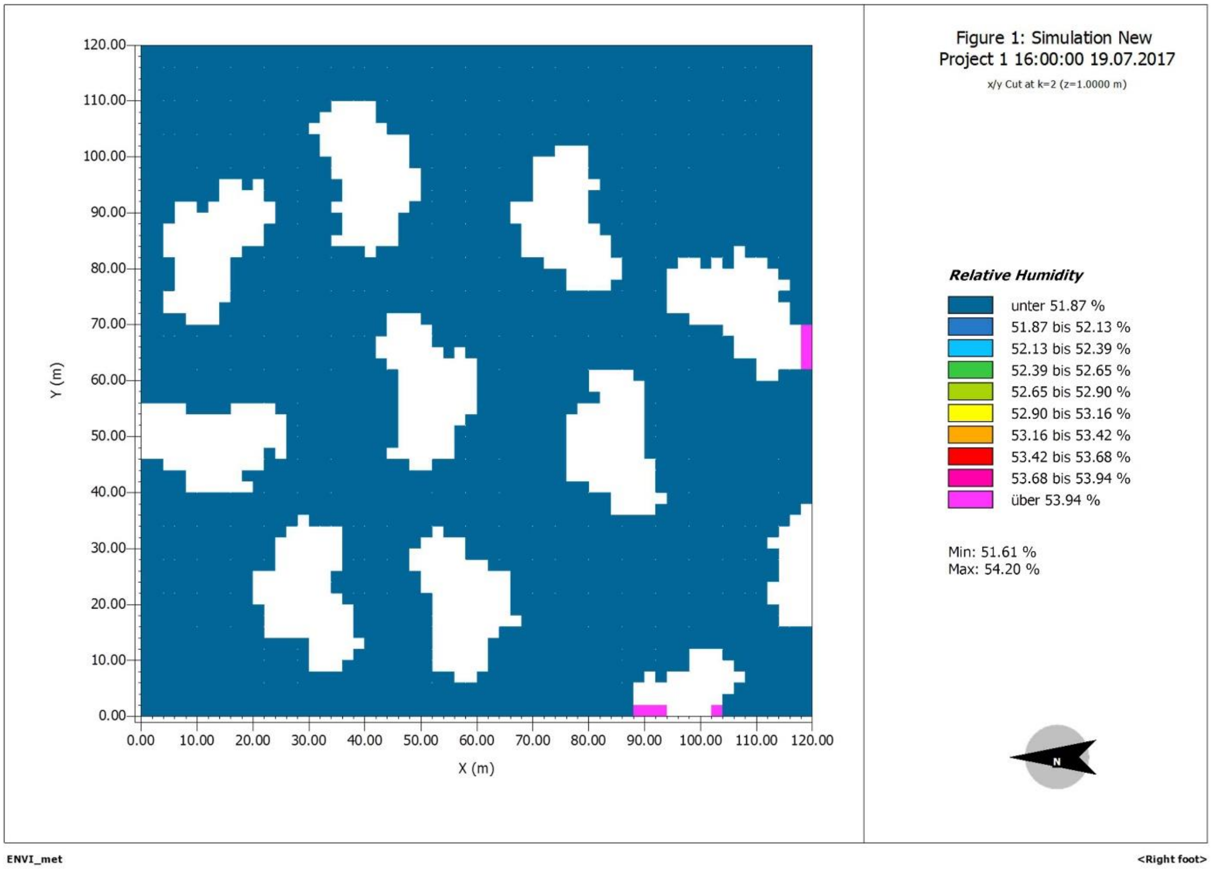
Strategy 1 - Orientation - 270 degrees - Mapping of relative humidity at 1pm



Strategy 1 - Orientation - 270 degrees - Mapping of relative humidity at 2pm



Strategy 1 - Orientation - 270 degrees - Mapping of relative humidity at 3pm

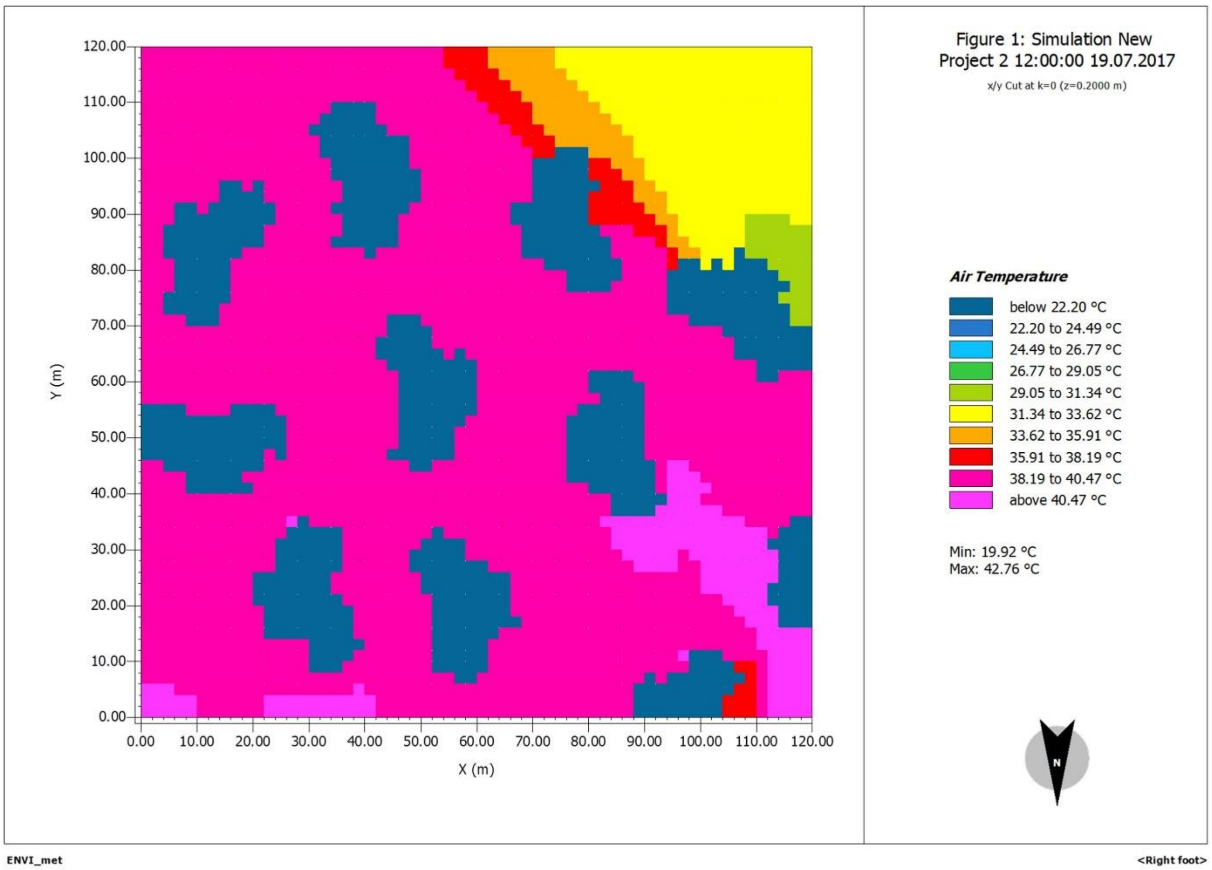


Strategy 1 - Orientation - 270 degrees - Mapping of relative humidity at 4pm

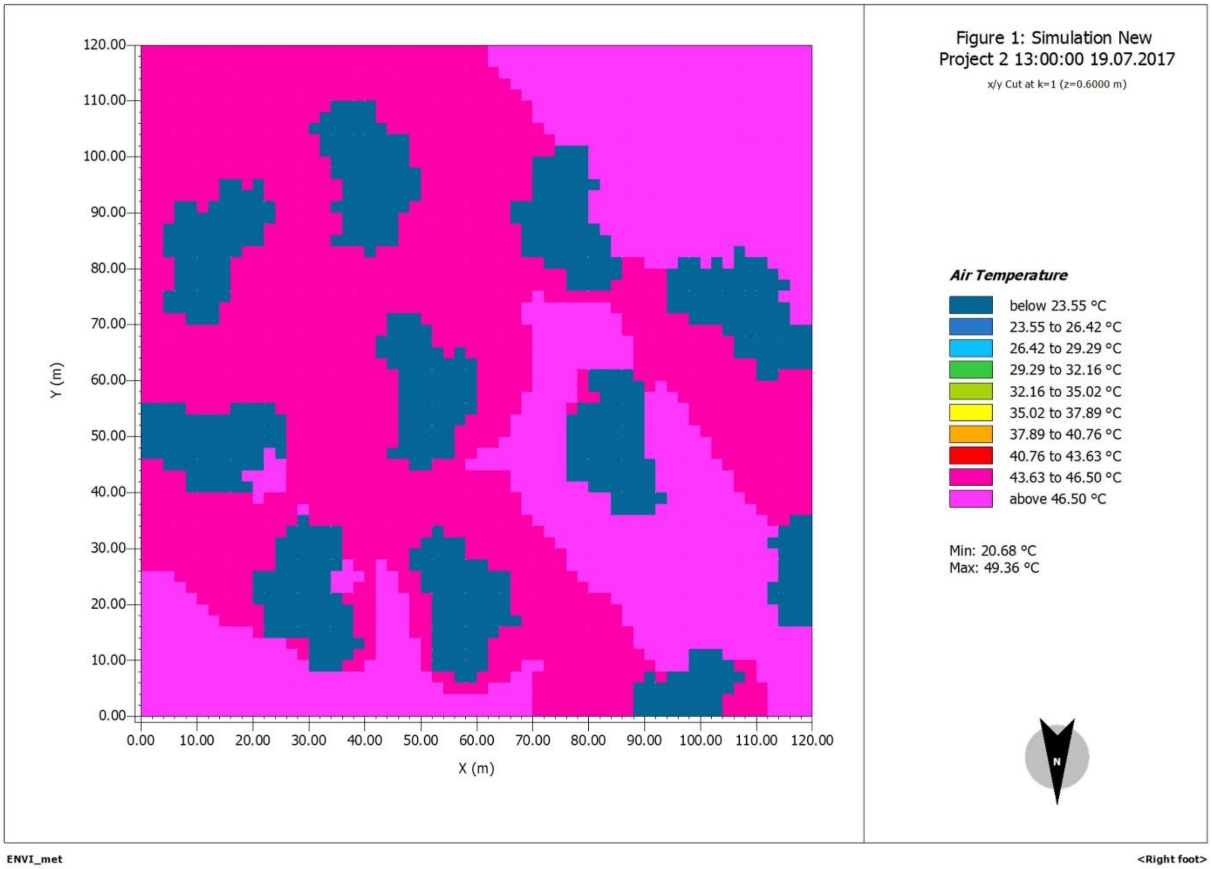
Appendix 3 - Strategy 1 - Orientation - 180 degrees

Model building, orientation 180 degrees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

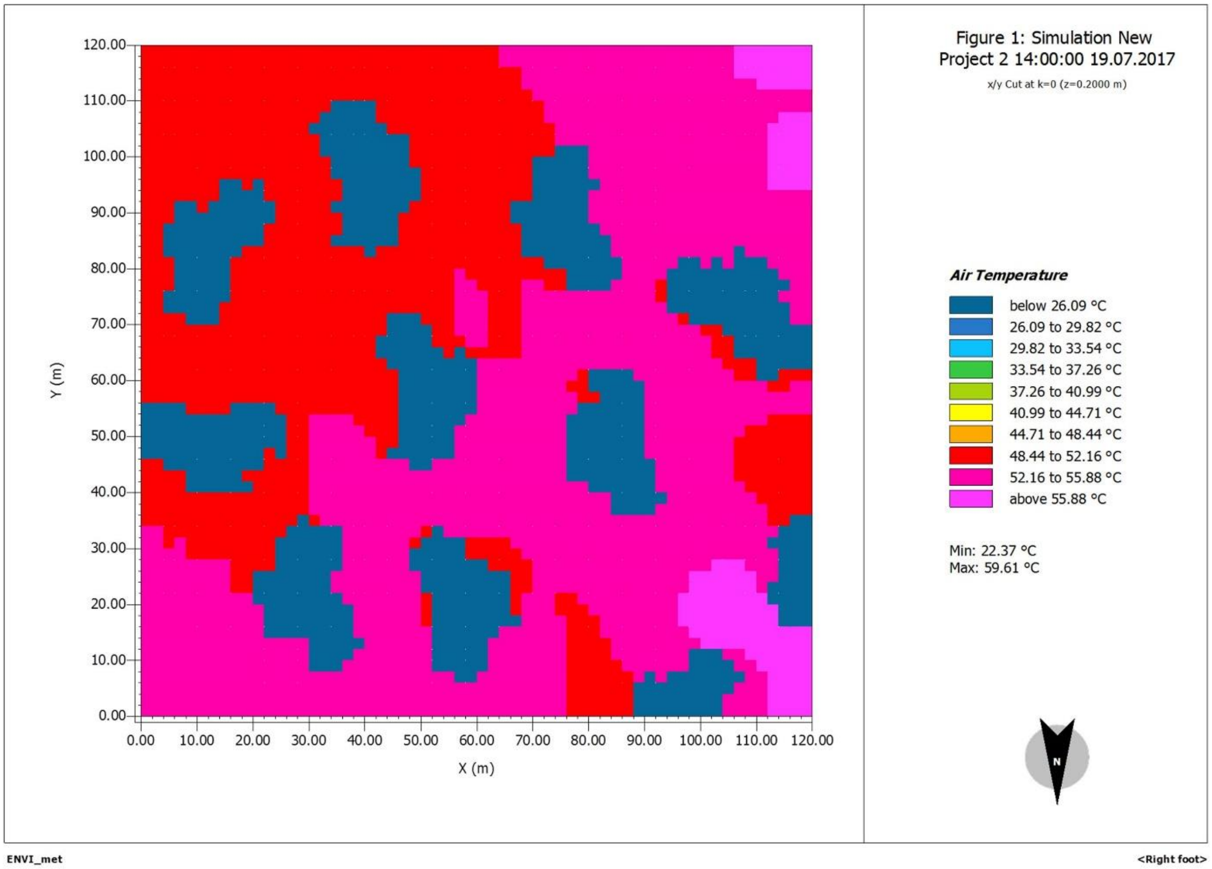
AIR TEMPERATURE



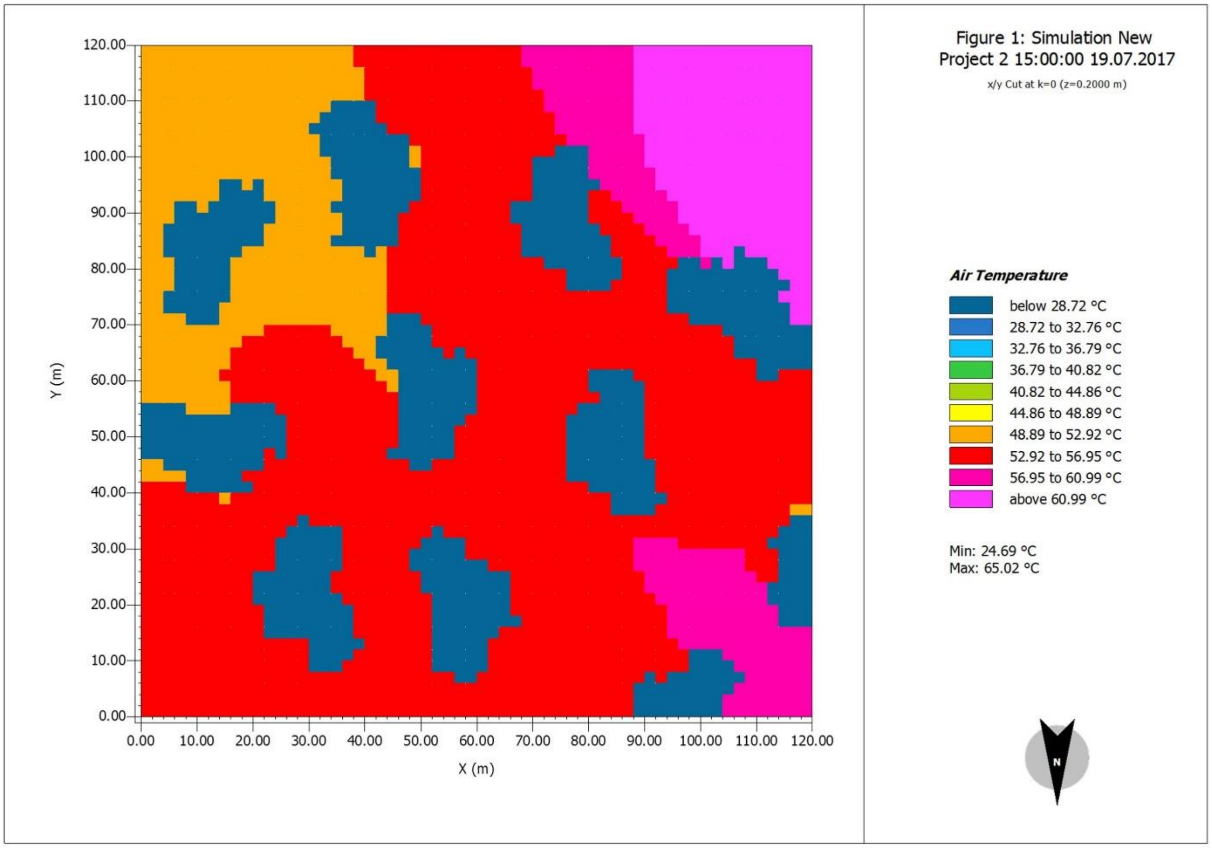
Strategy 1 - Orientation - 180 degrees - Mapping of air temperature at 12pm



Strategy 1 - Orientation - 180 degrees - Mapping of air temperature at 1pm

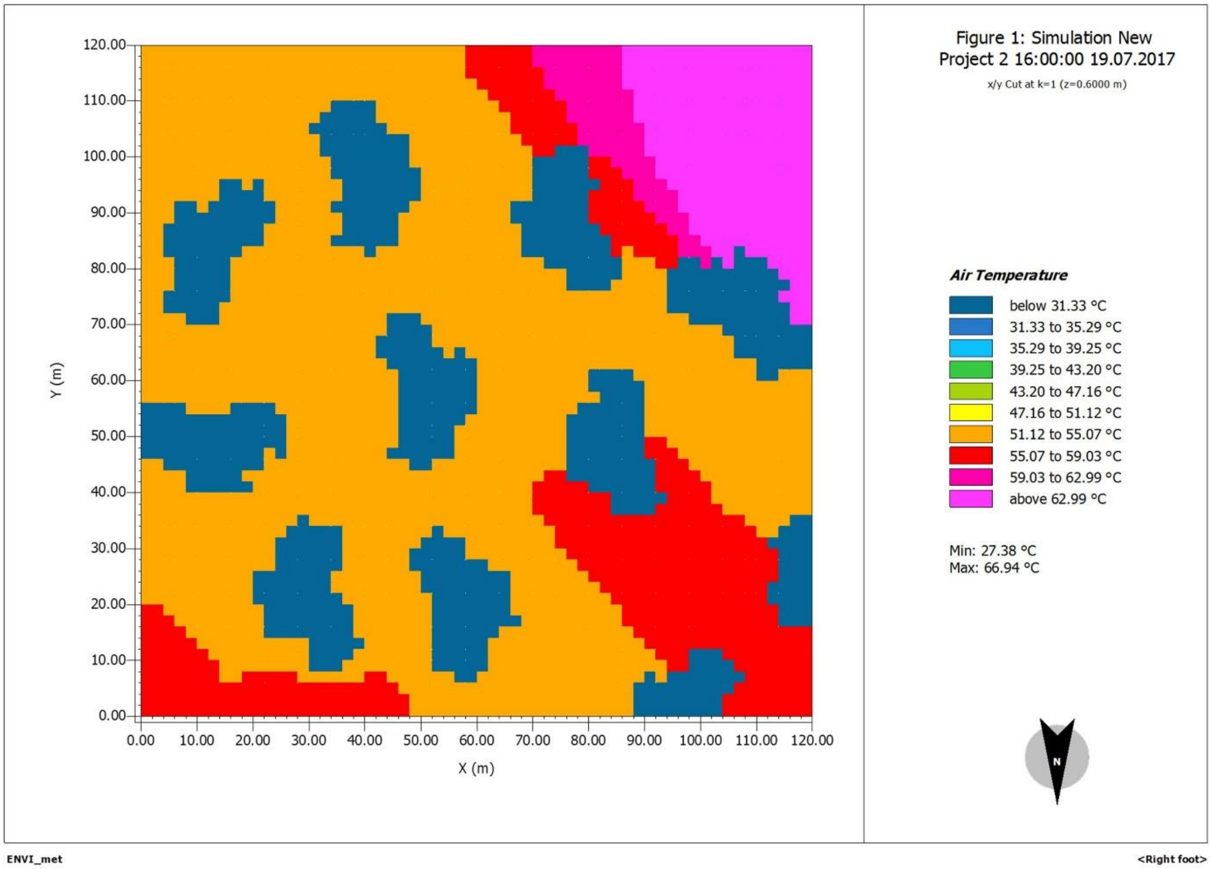


Strategy 1 - Orientation - 180 degrees - Mapping of air temperature at 2pm



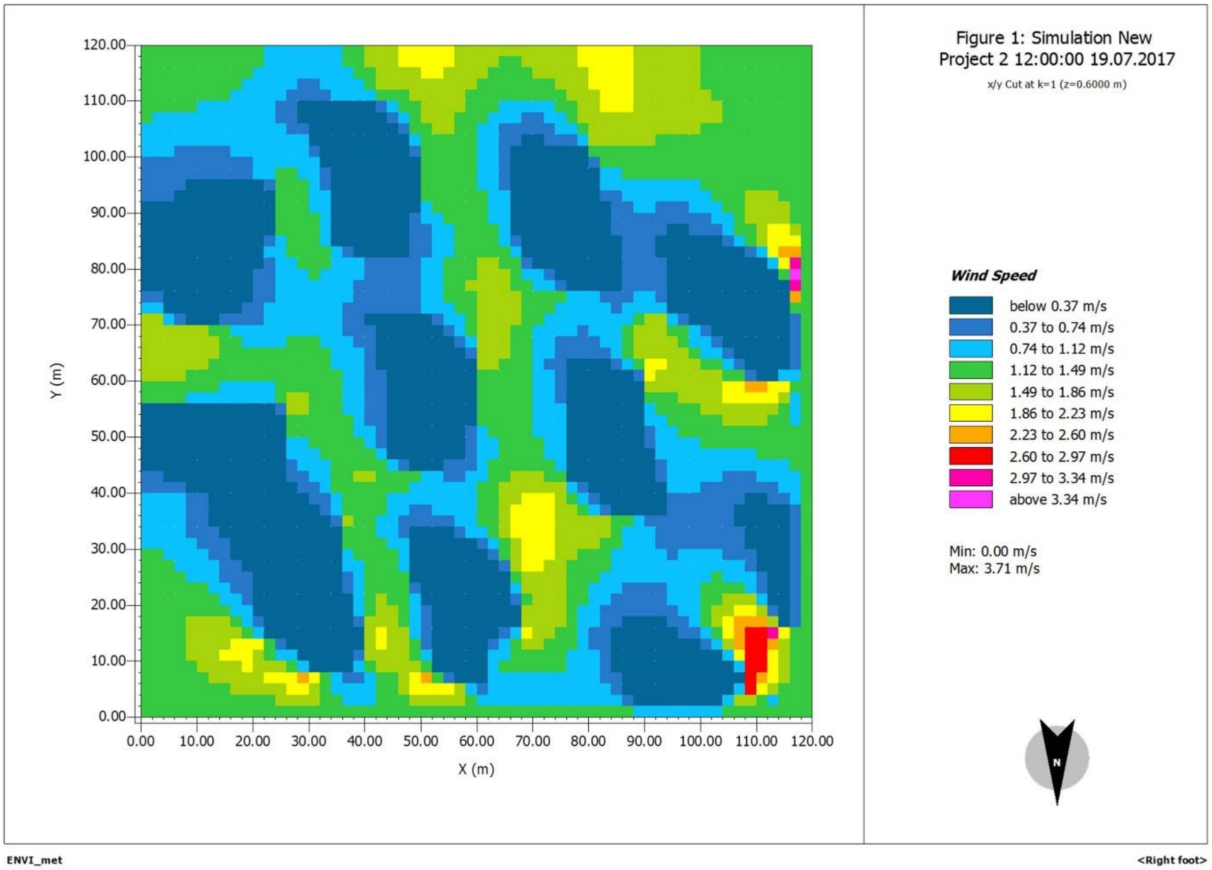
ENVI_met <Right foot>

Strategy 1 - Orientation - 180 degrees - Mapping of air temperature at 3pm

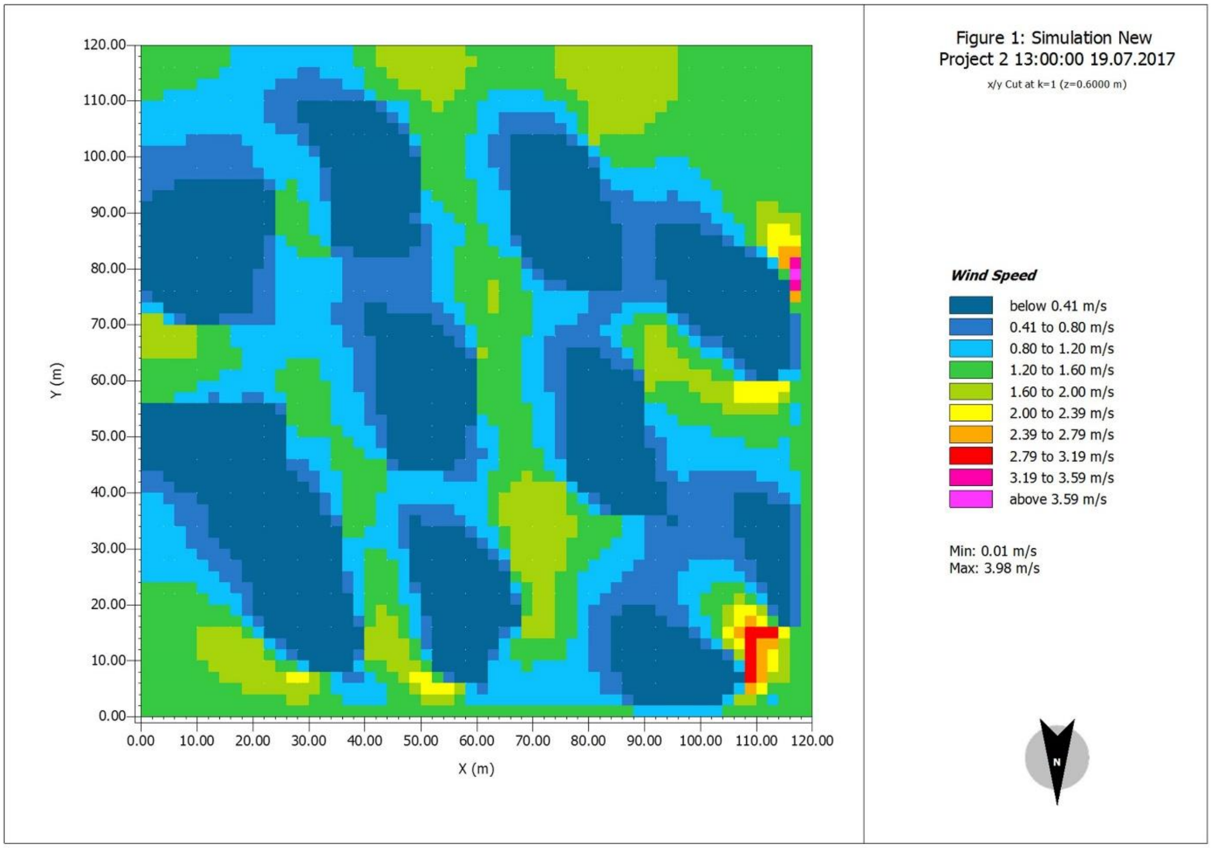


Strategy 1 - Orientation - 180 degrees - Mapping of air temperature at 4pm

WIND SPEED

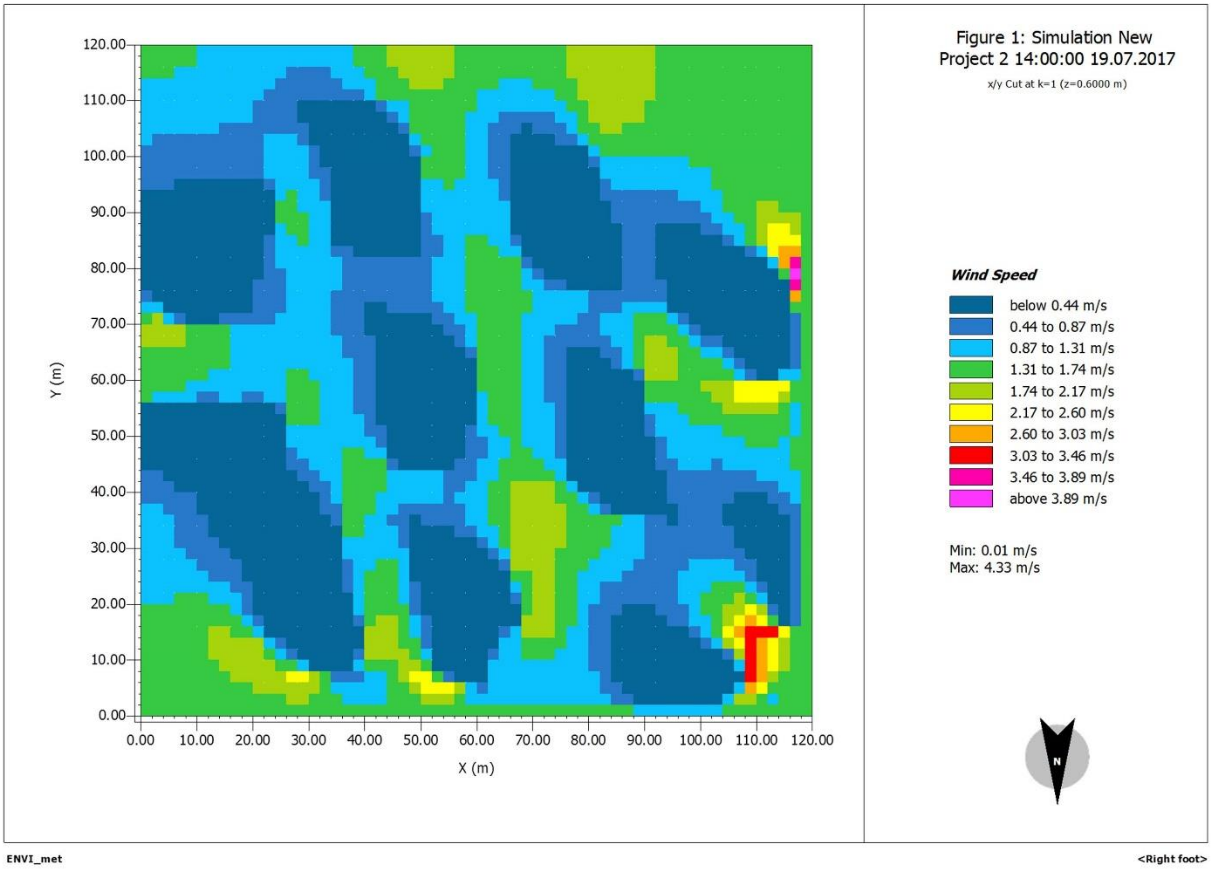


Strategy 1 - Orientation - 180 degrees - Mapping of wind speed at 12pm

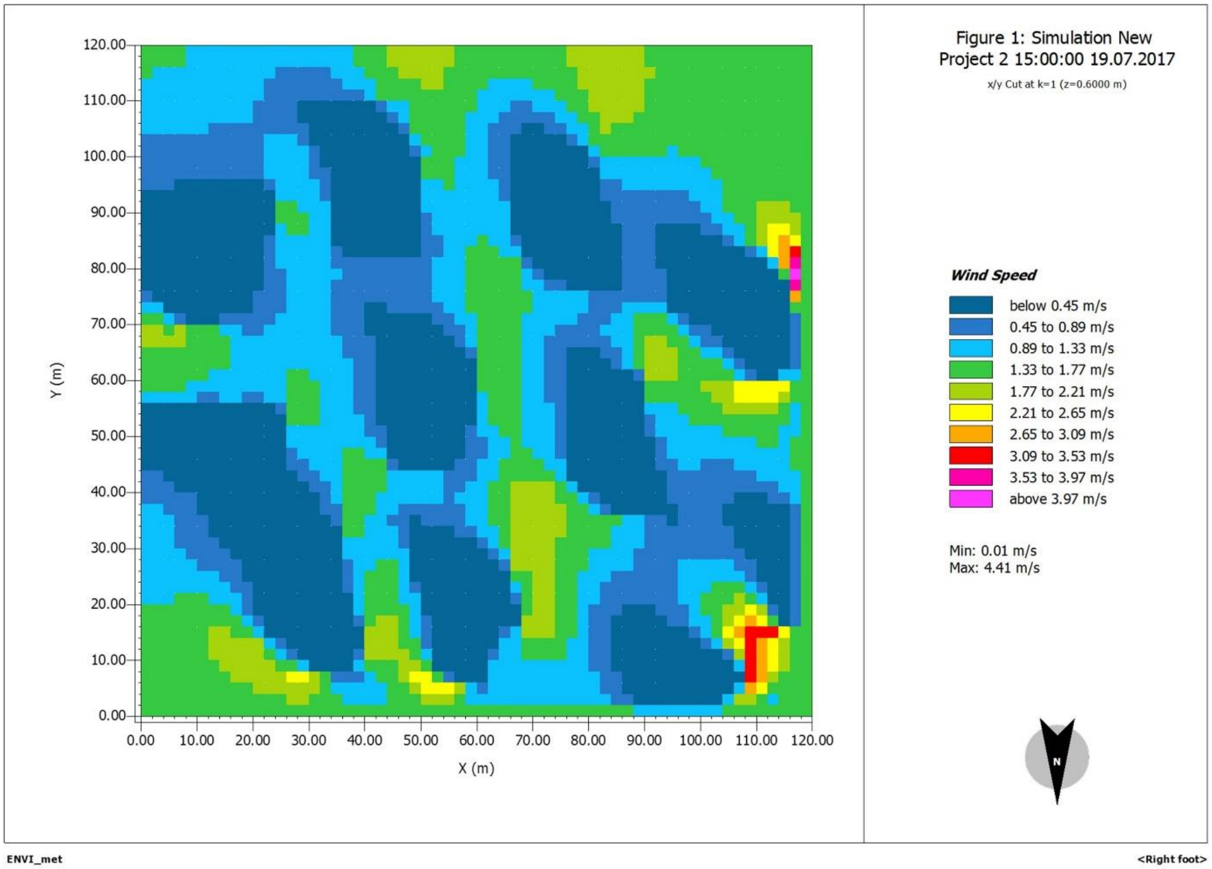


ENVI_met <Right foot>

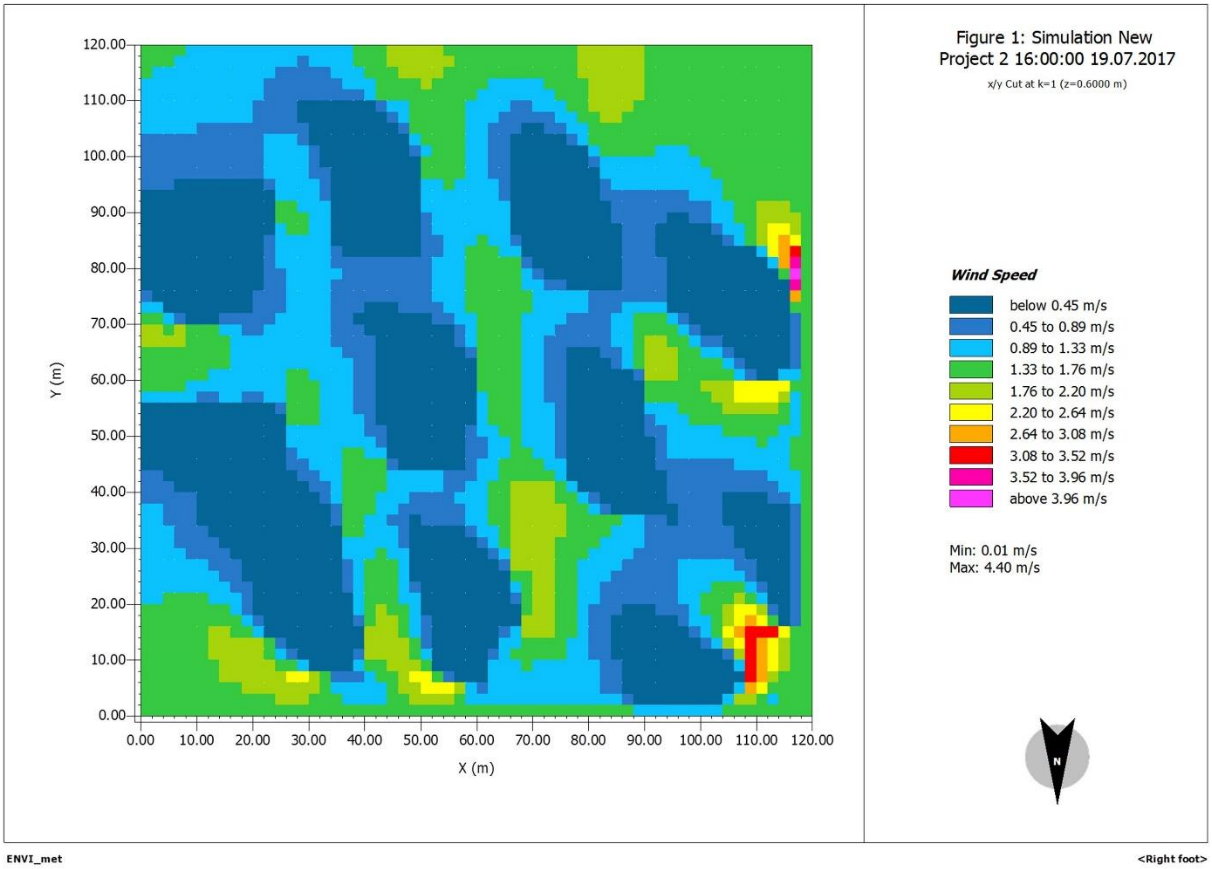
Strategy 1 - Orientation - 180 degrees - Mapping of wind speed at 1pm



Strategy 1 - Orientation - 180 degrees - Mapping of wind speed at 2pm

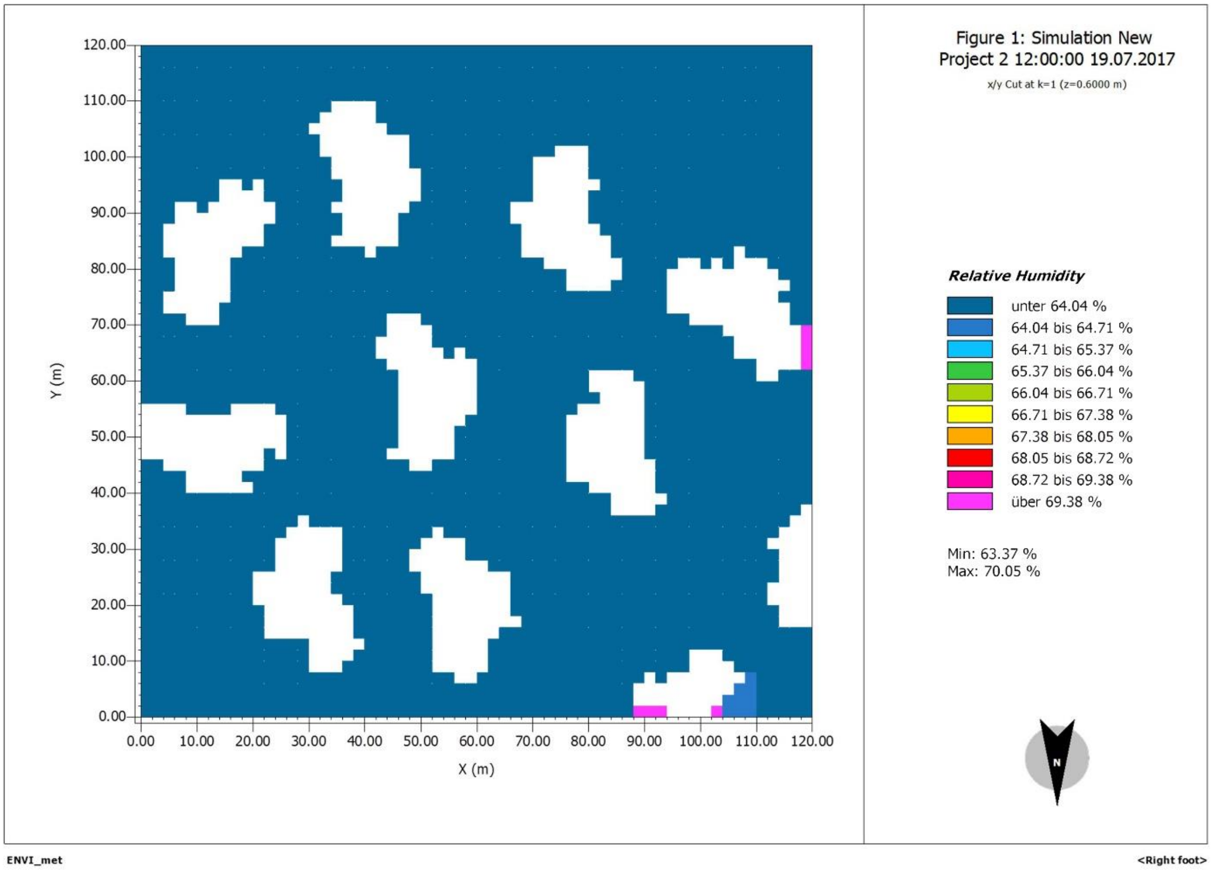


Strategy 1 - Orientation - 180 degrees - Mapping of wind speed at 3pm

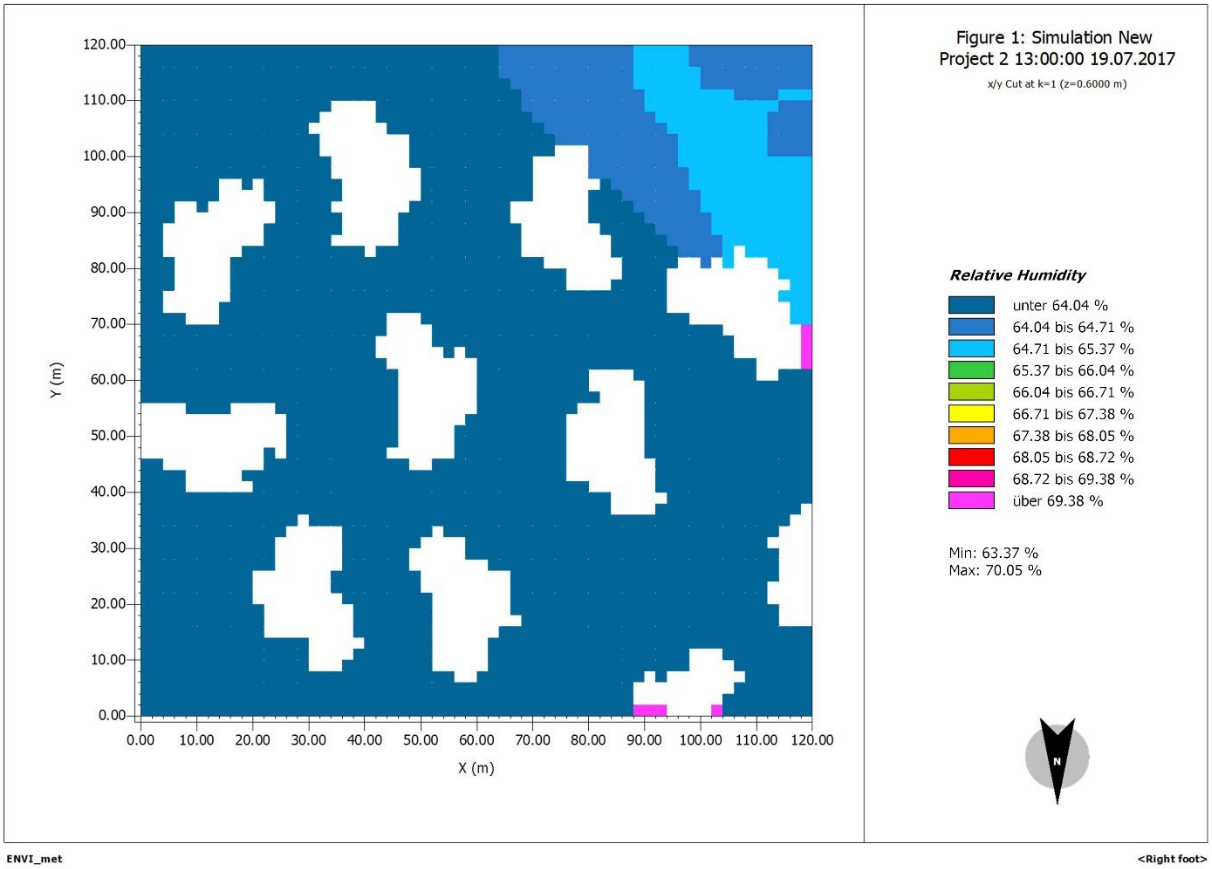


Strategy 1 - Orientation - 180 degrees - Mapping of wind speed at 4pm

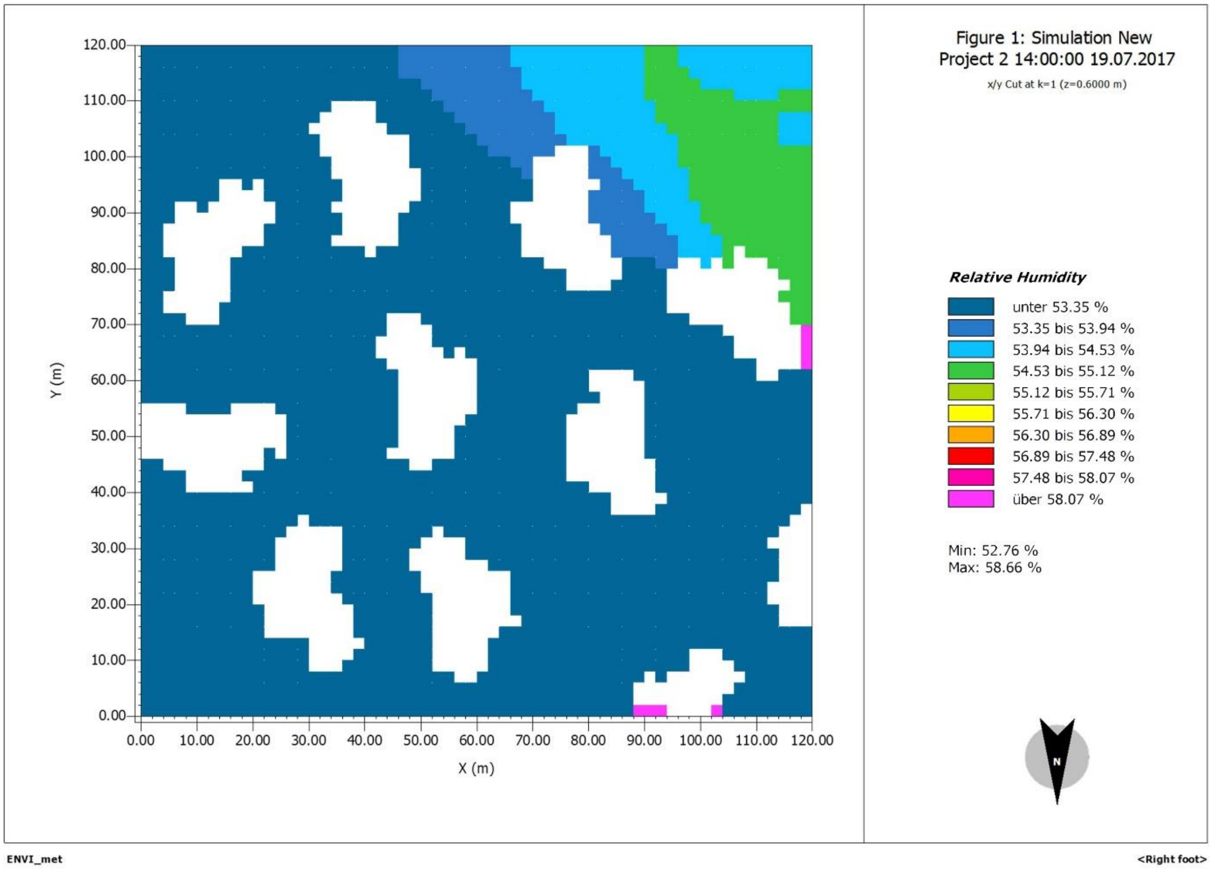
RELATIVE HUMIDITY



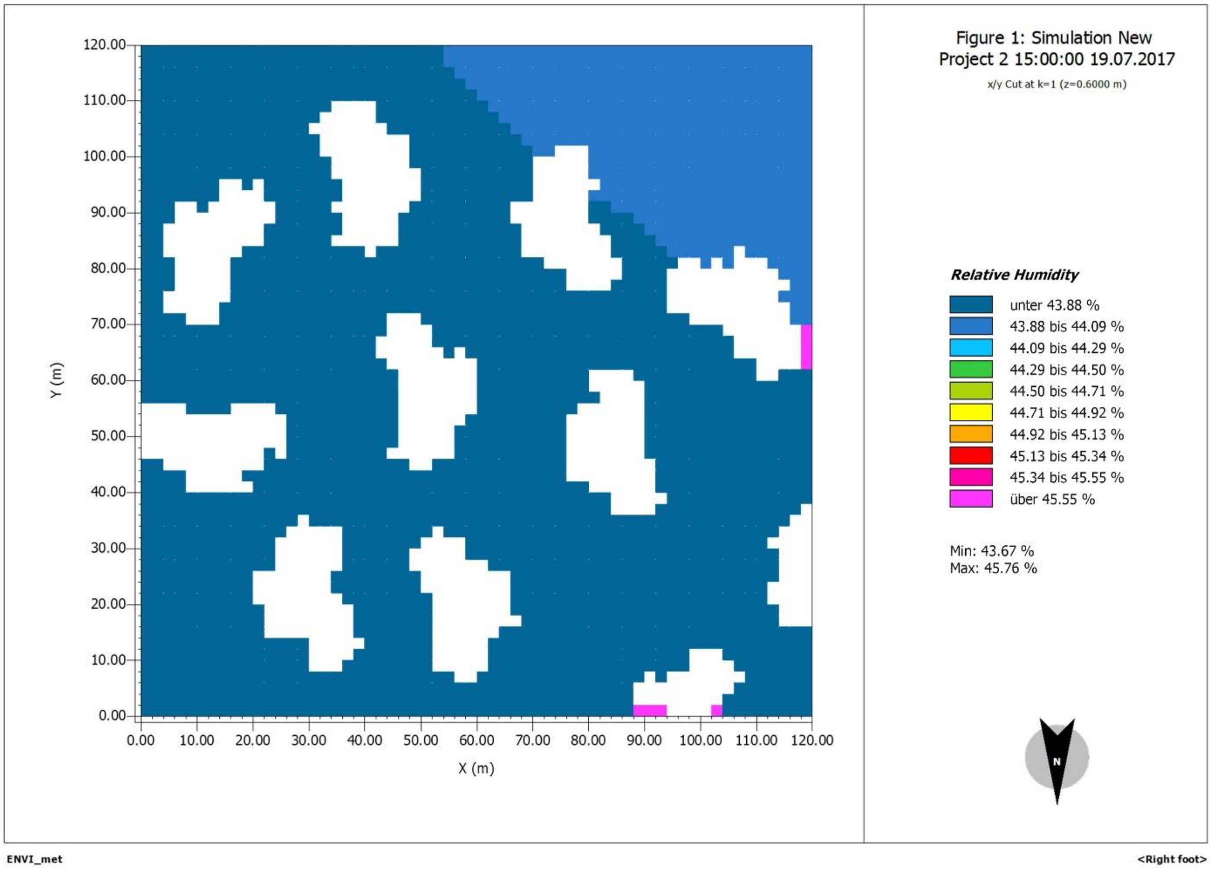
Strategy 1 - Orientation - 180 degrees - Mapping of relative humidity at 12pm



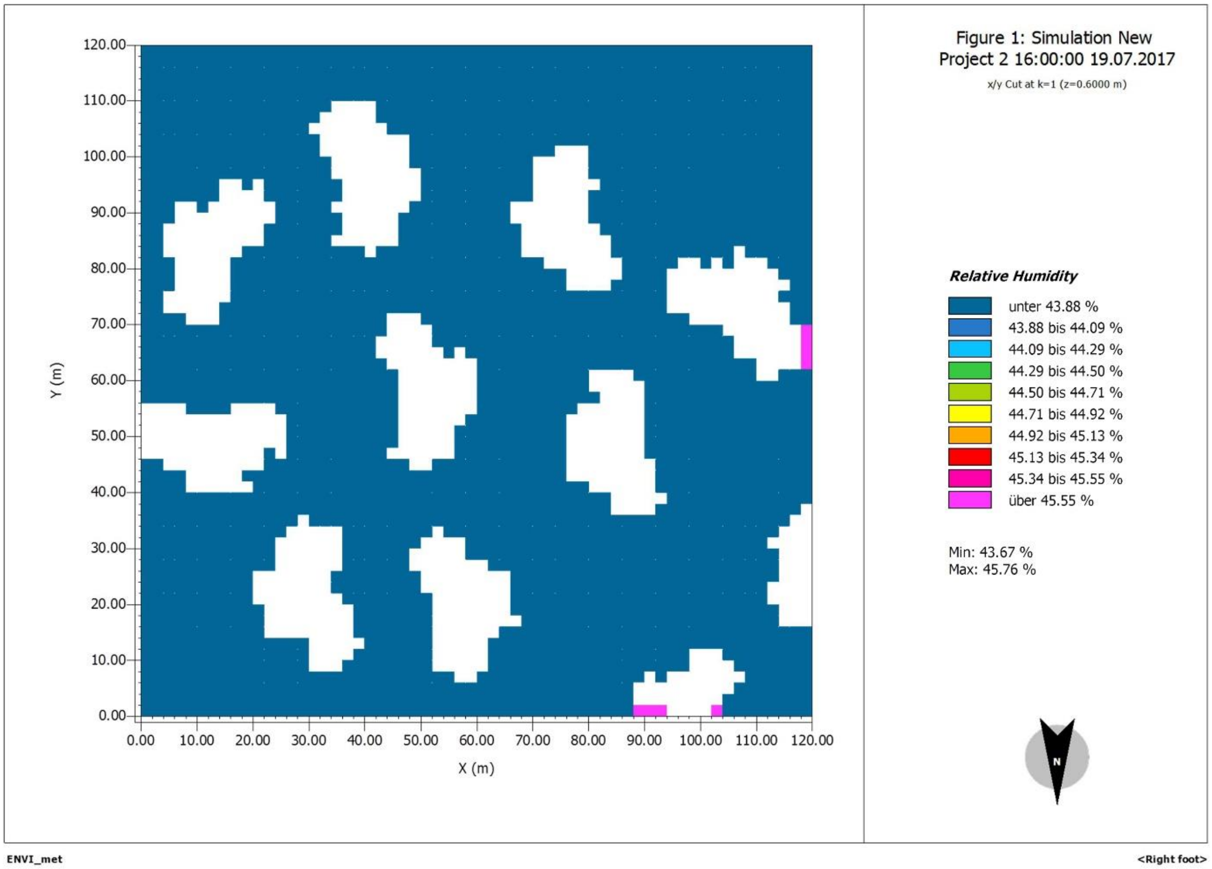
Strategy 1 - Orientation - 180 degrees - Mapping of relative humidity at 1pm



Strategy 1 - Orientation - 180 degrees - Mapping of relative humidity at 2pm



Strategy 1 - Orientation - 180 degrees - Mapping of relative humidity at 3pm

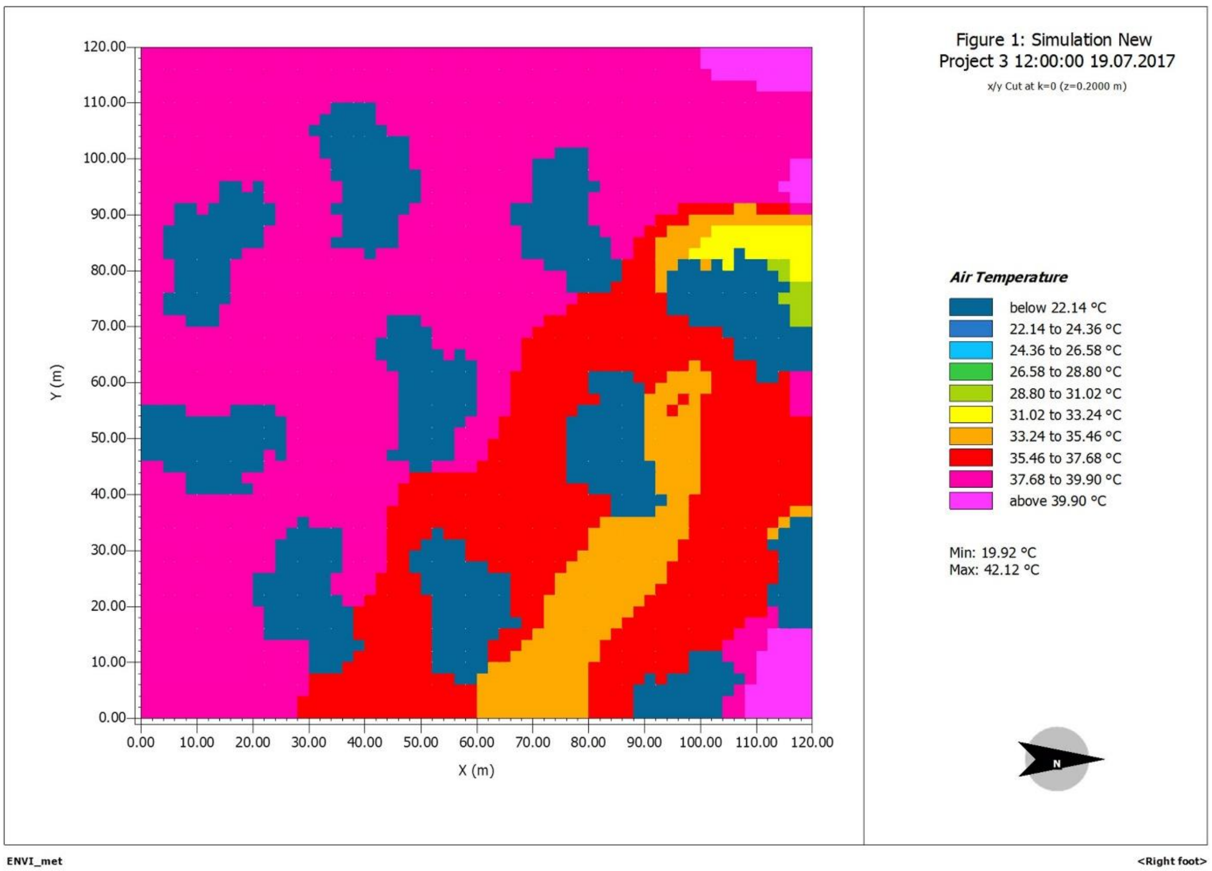


Strategy 1 - Orientation - 180 degrees - Mapping of relative humidity at 4pm

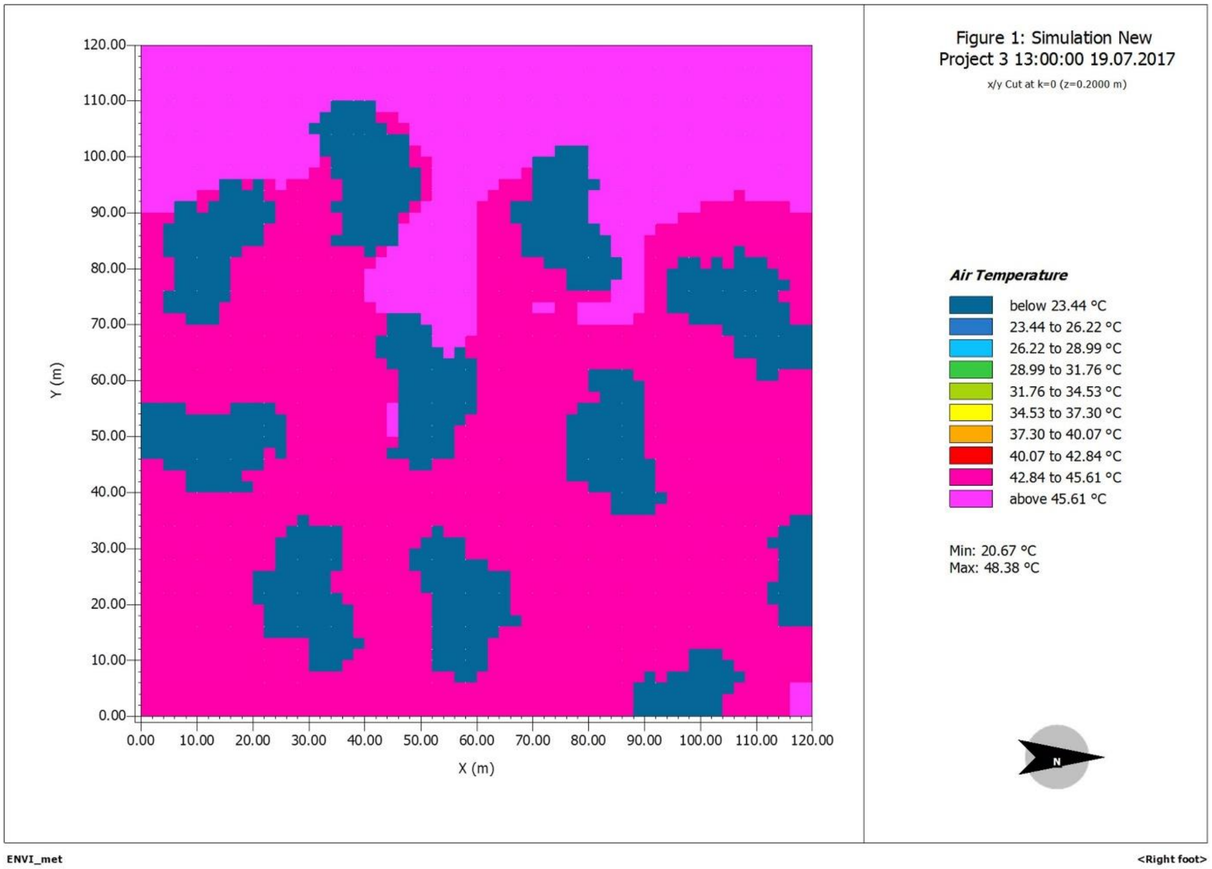
Appendix 4 - Strategy 1 - Orientation - 90 degrees

Model building, orientation 90 degrees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

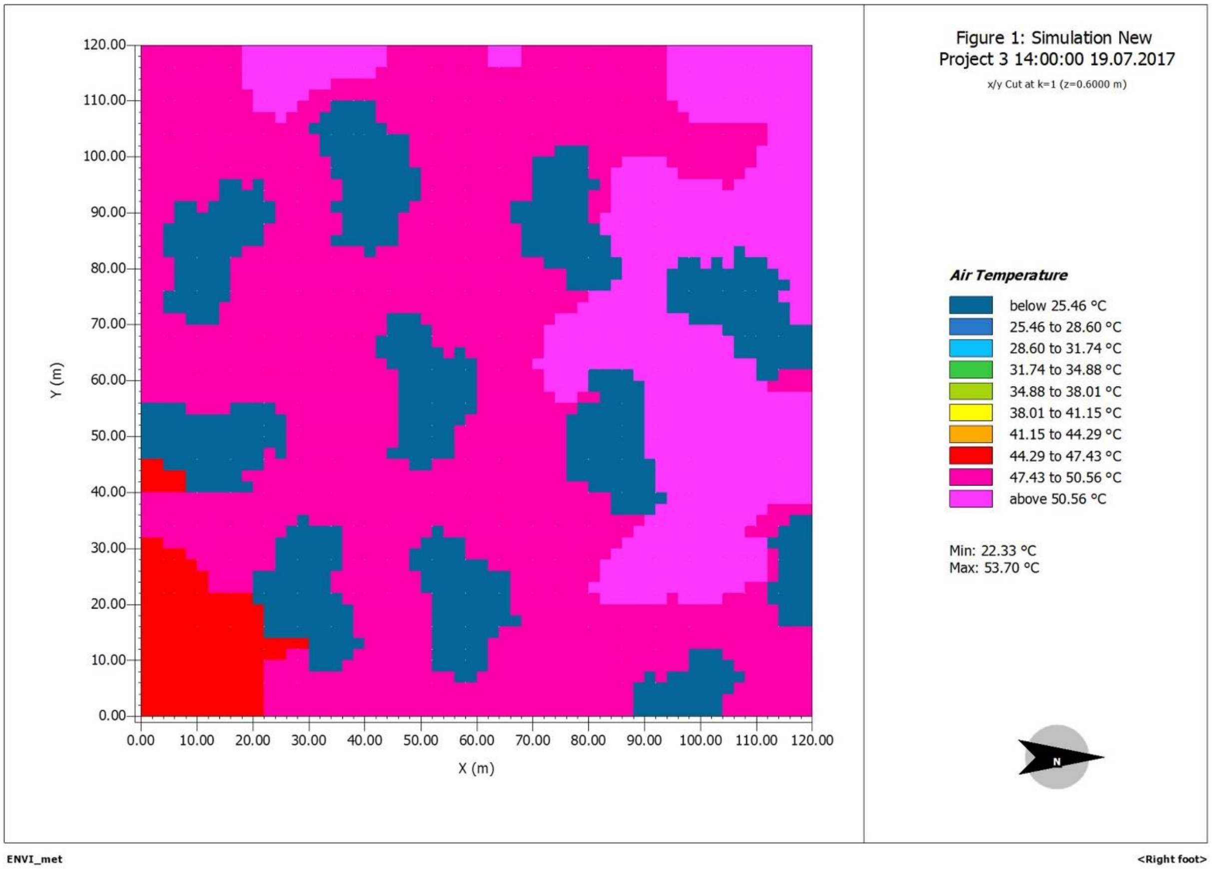
AIR TEMPERATURE



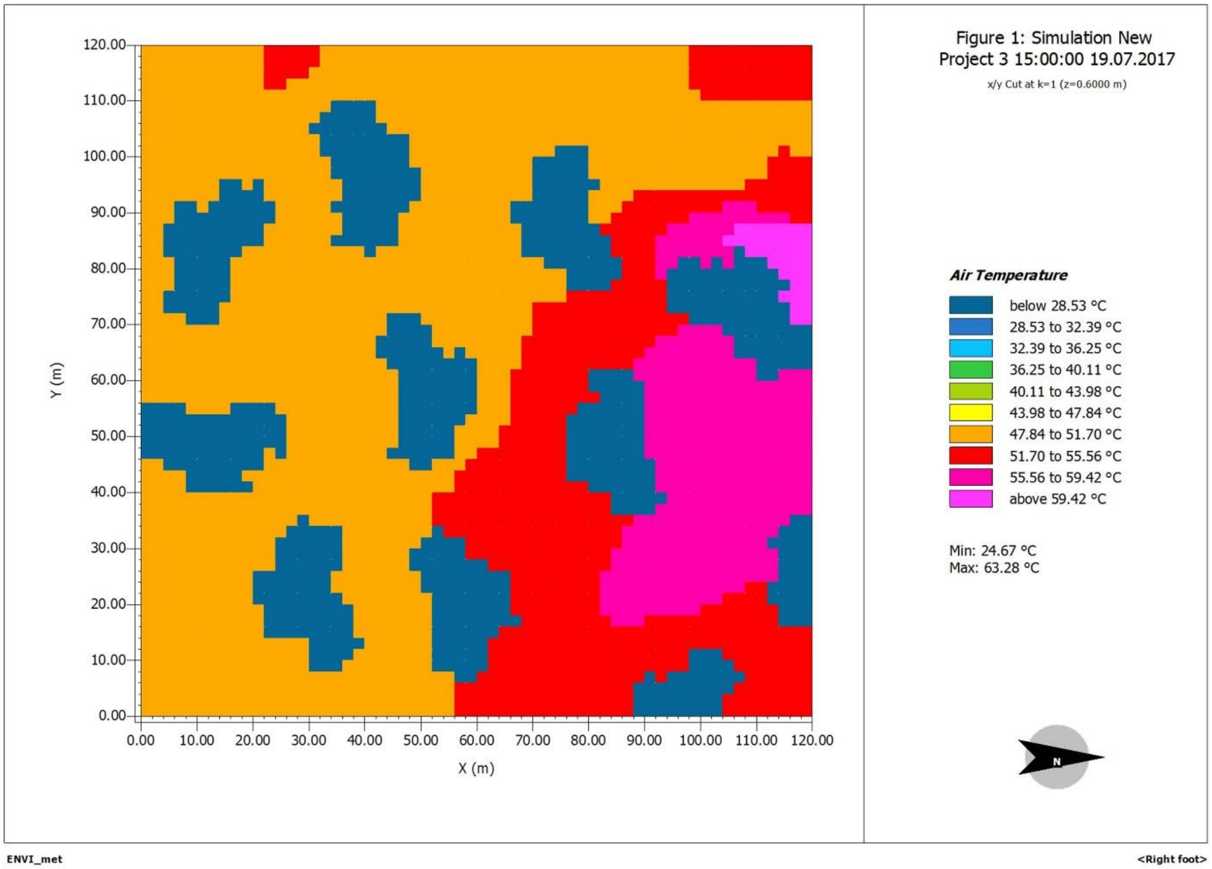
Strategy 1 - Orientation - 90 degrees - Mapping of air temperature at 12pm



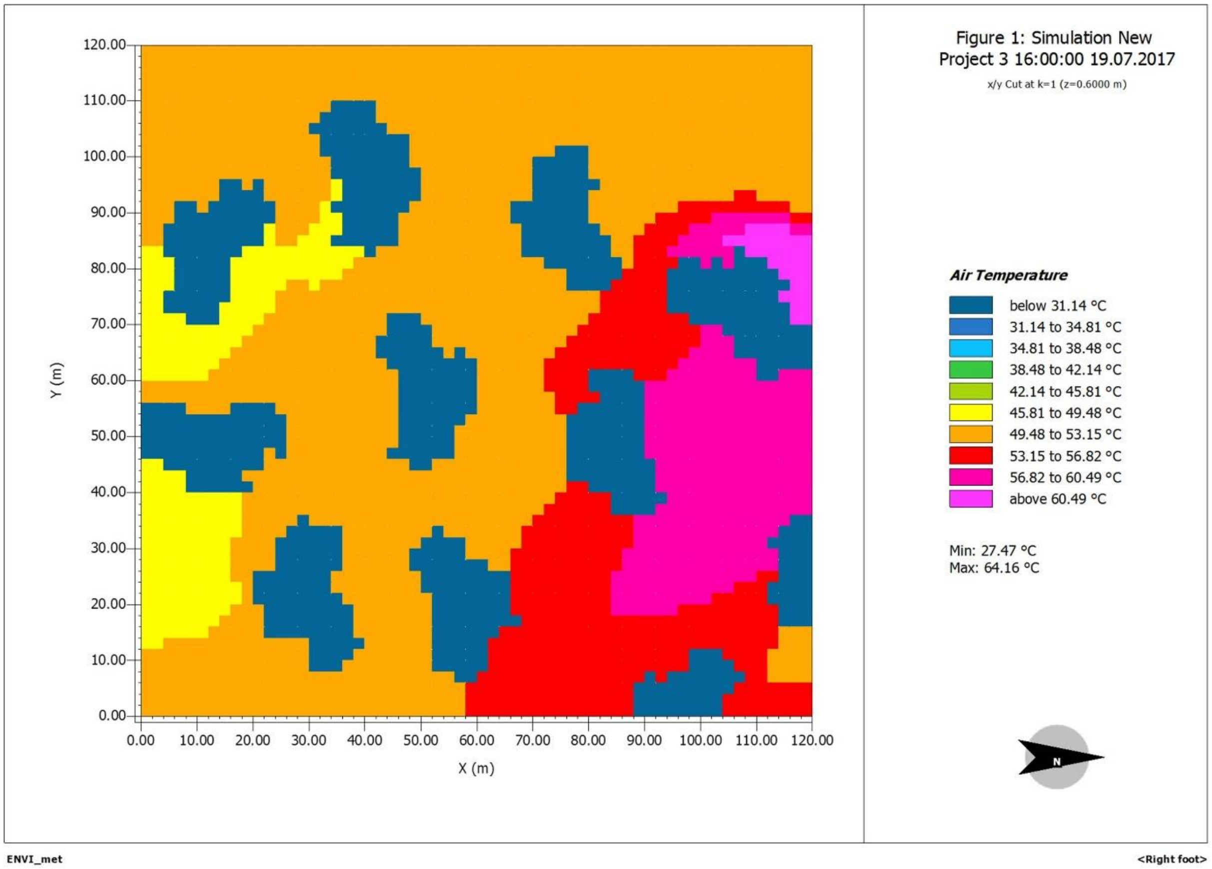
Strategy 1 - Orientation - 90 degrees - Mapping of air temperature at 1pm



Strategy 1 - Orientation - 90 degrees - Mapping of air temperature at 2pm

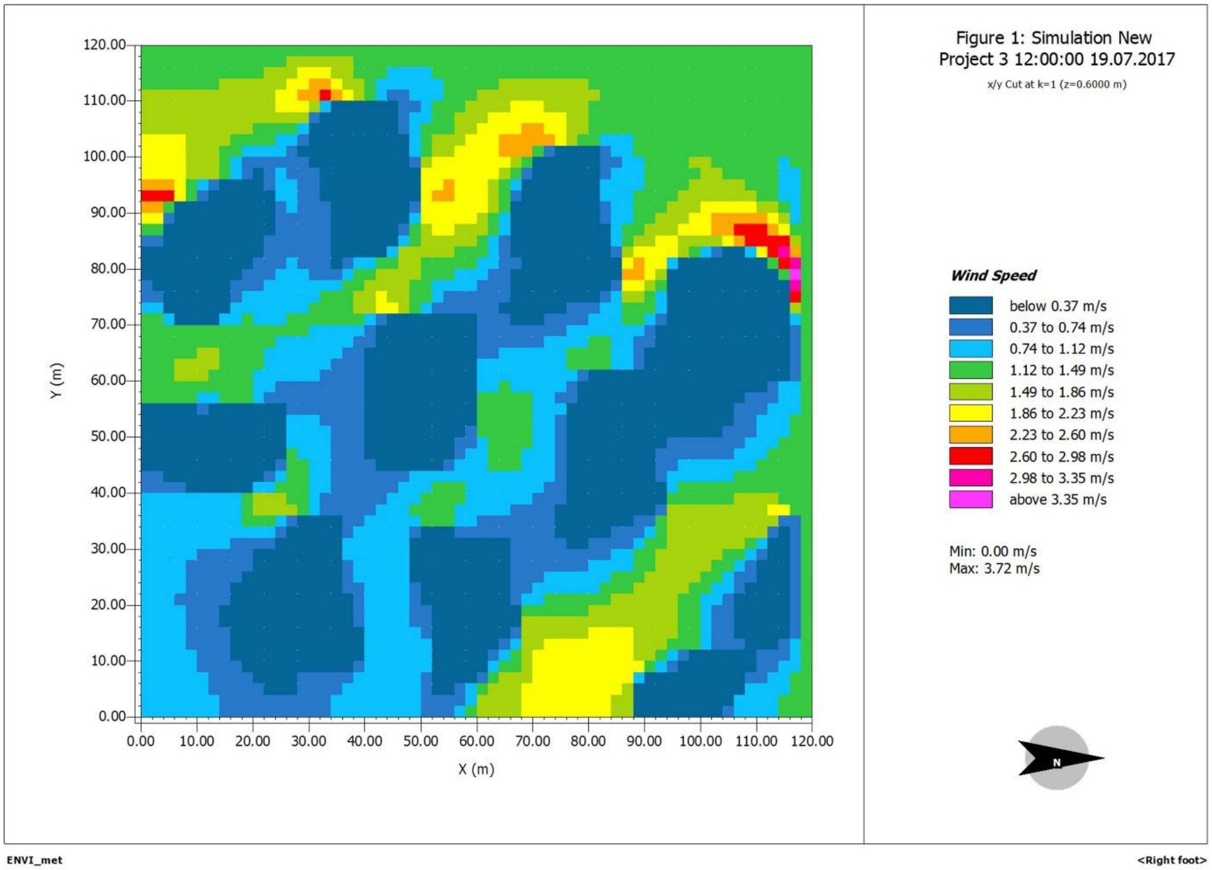


Strategy 1 - Orientation - 90 degrees - Mapping of air temperature at 3pm

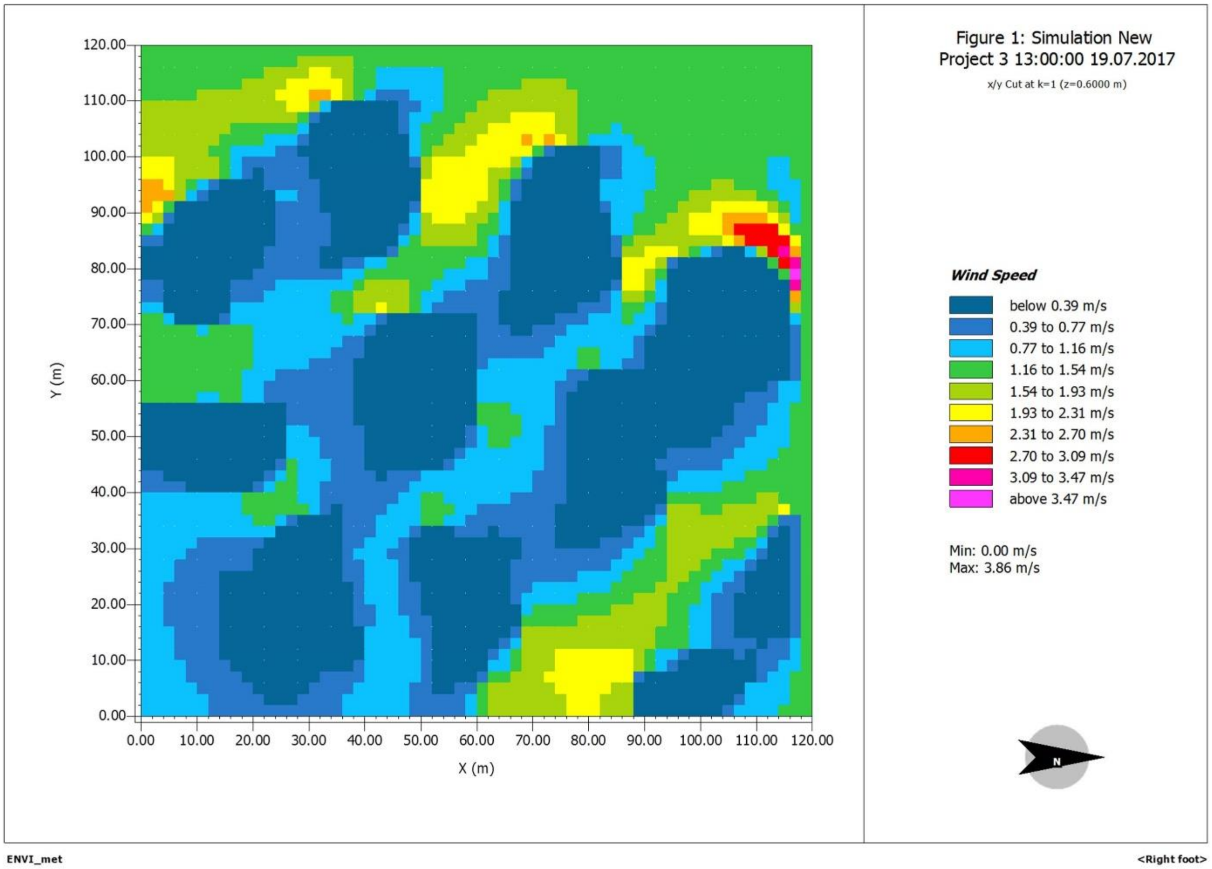


Strategy 1 - Orientation - 90 degrees - Mapping of air temperature at 4pm

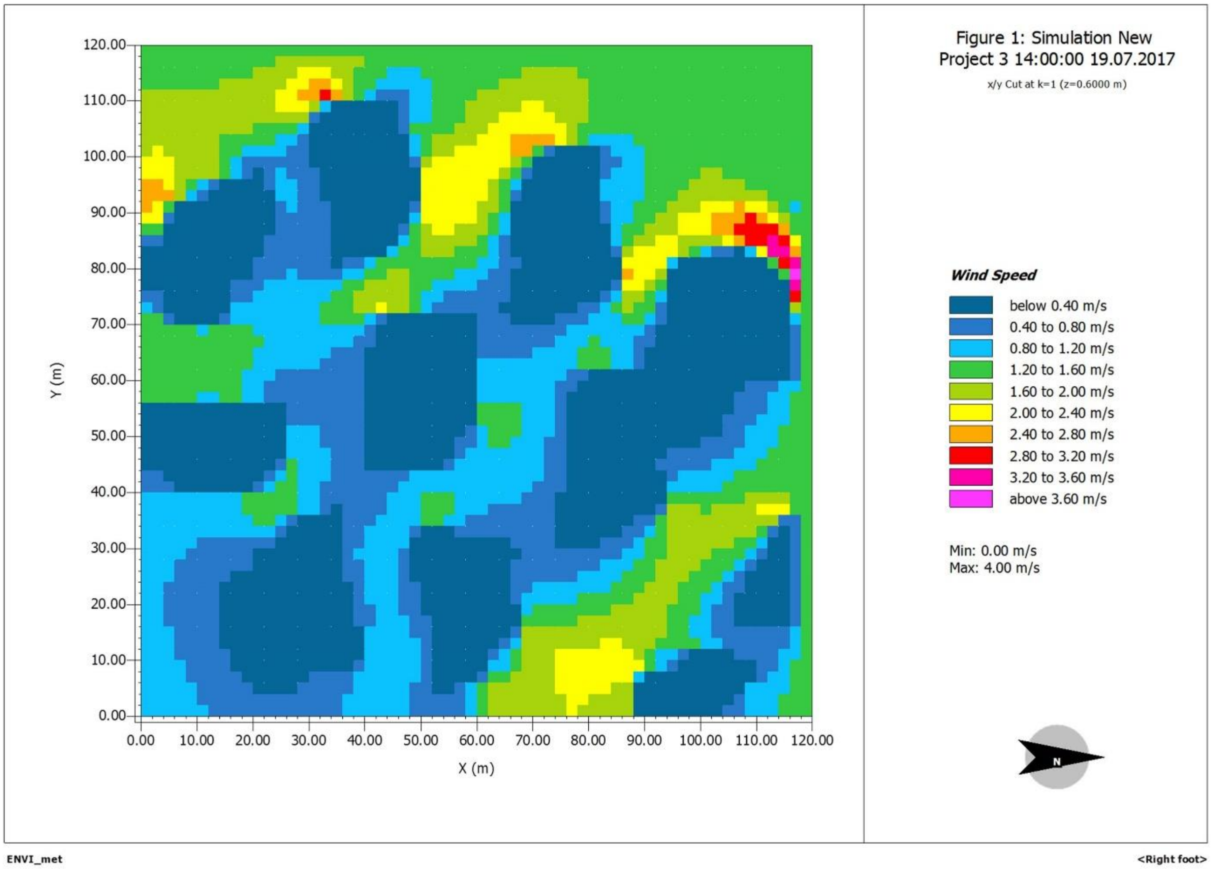
WIND SPEED



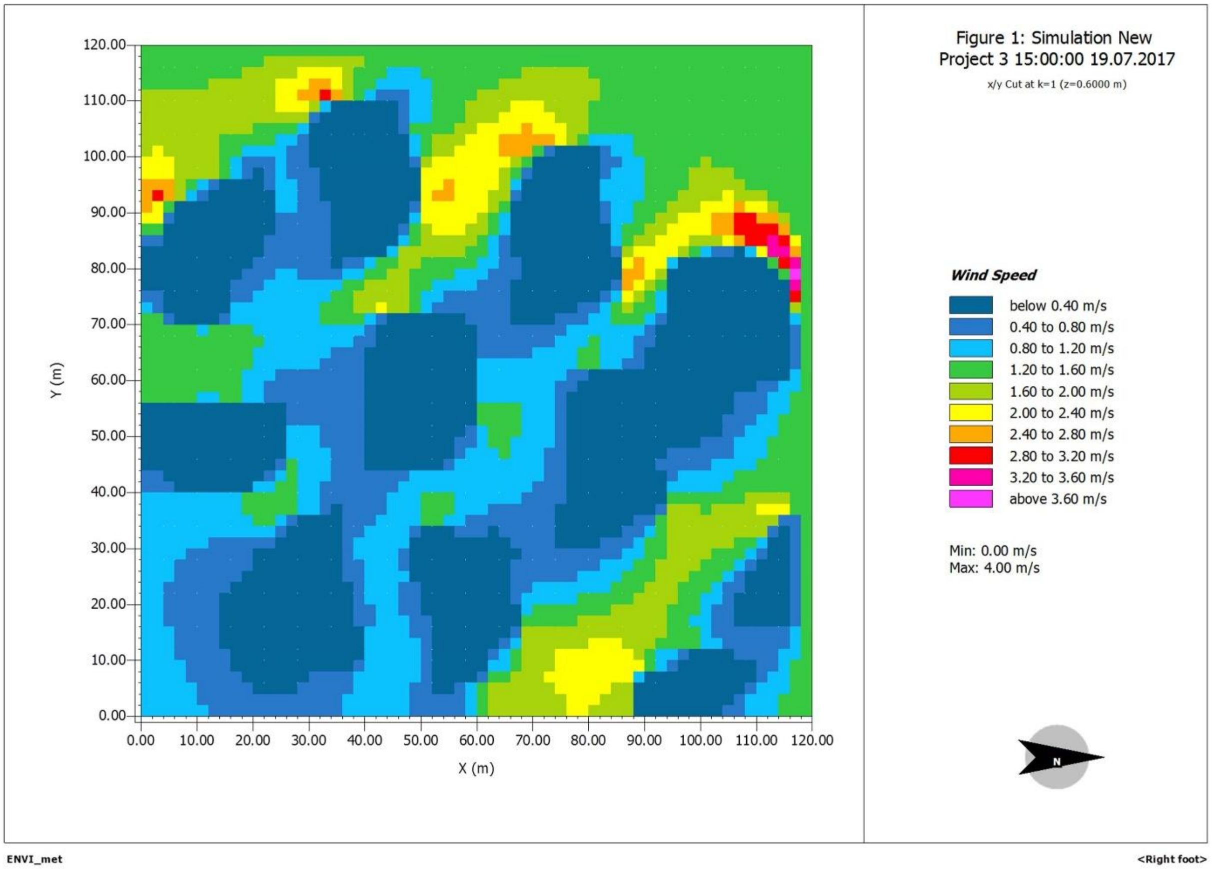
Strategy 1 - Orientation - 90 degrees - Mapping of wind speed at 12pm



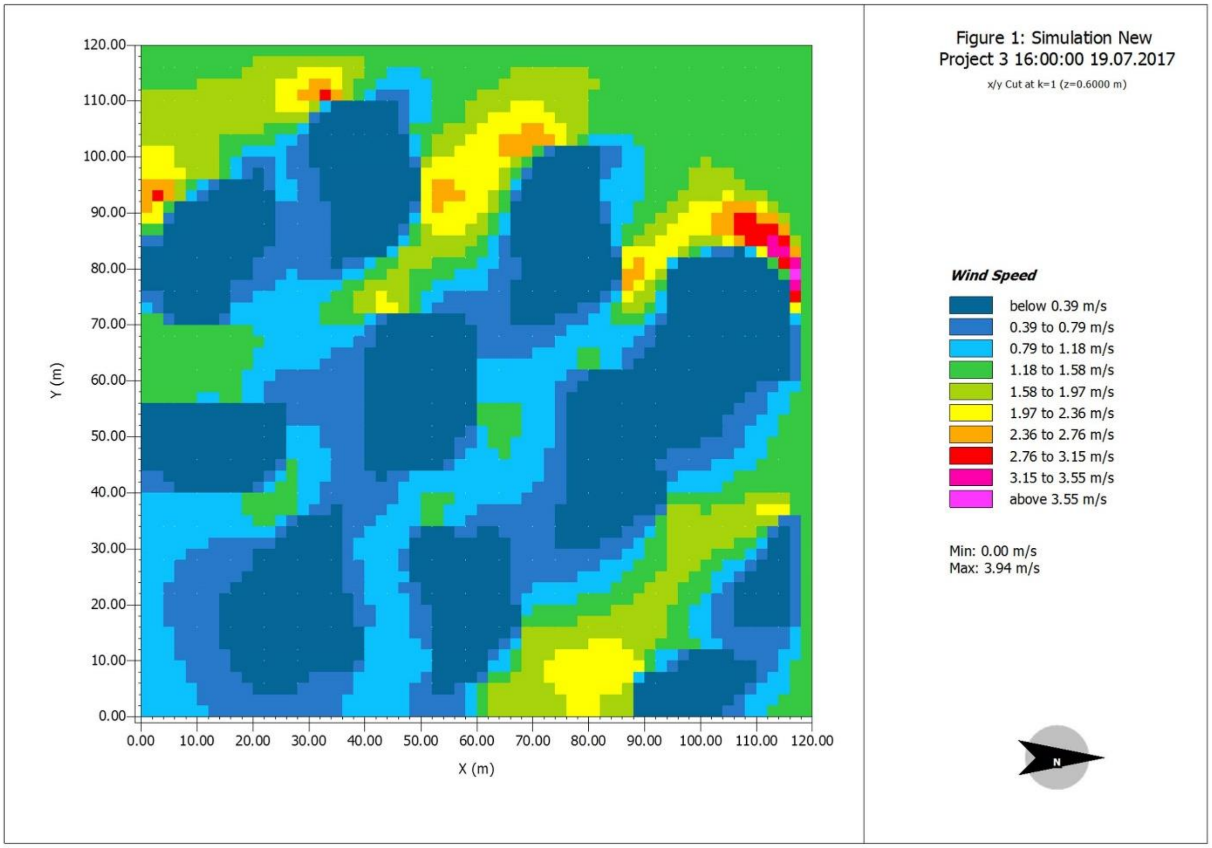
Strategy 1 - Orientation - 90 degrees - Mapping of wind speed at 1pm



Strategy 1 - Orientation - 90 degrees - Mapping of wind speed at 2pm



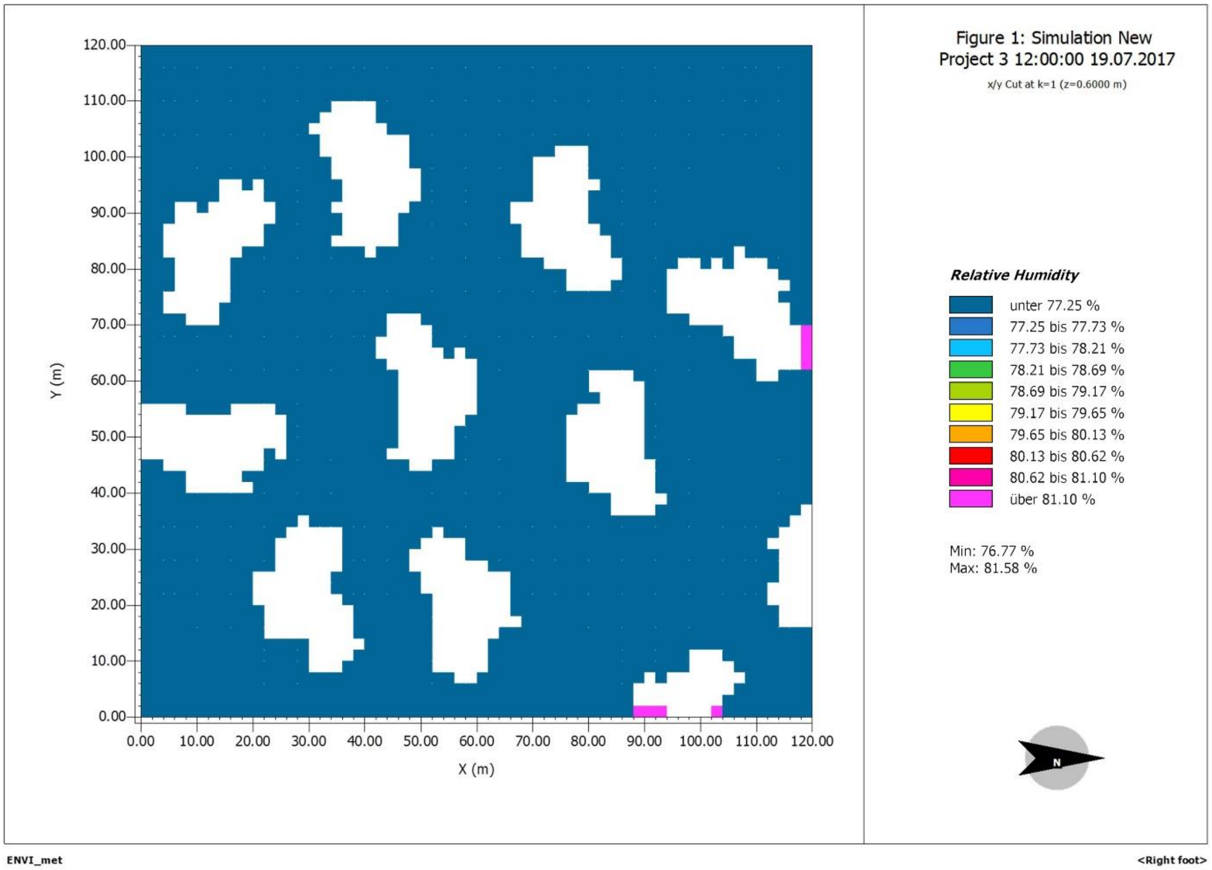
Strategy 1 - Orientation - 90 degrees - Mapping of wind speed at 3pm



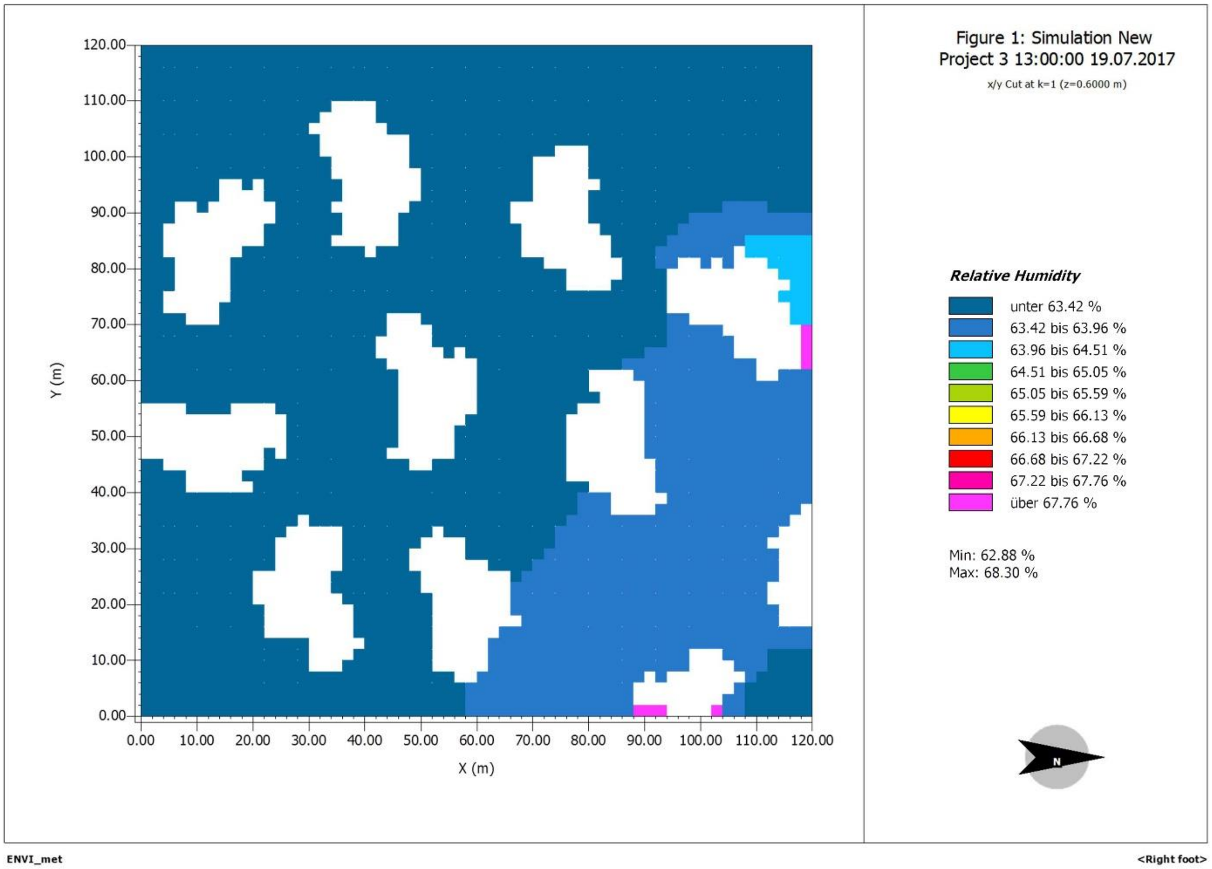
ENVI_met <Right foot>

Strategy 1 - Orientation - 90 degrees - Mapping of wind speed at 4pm

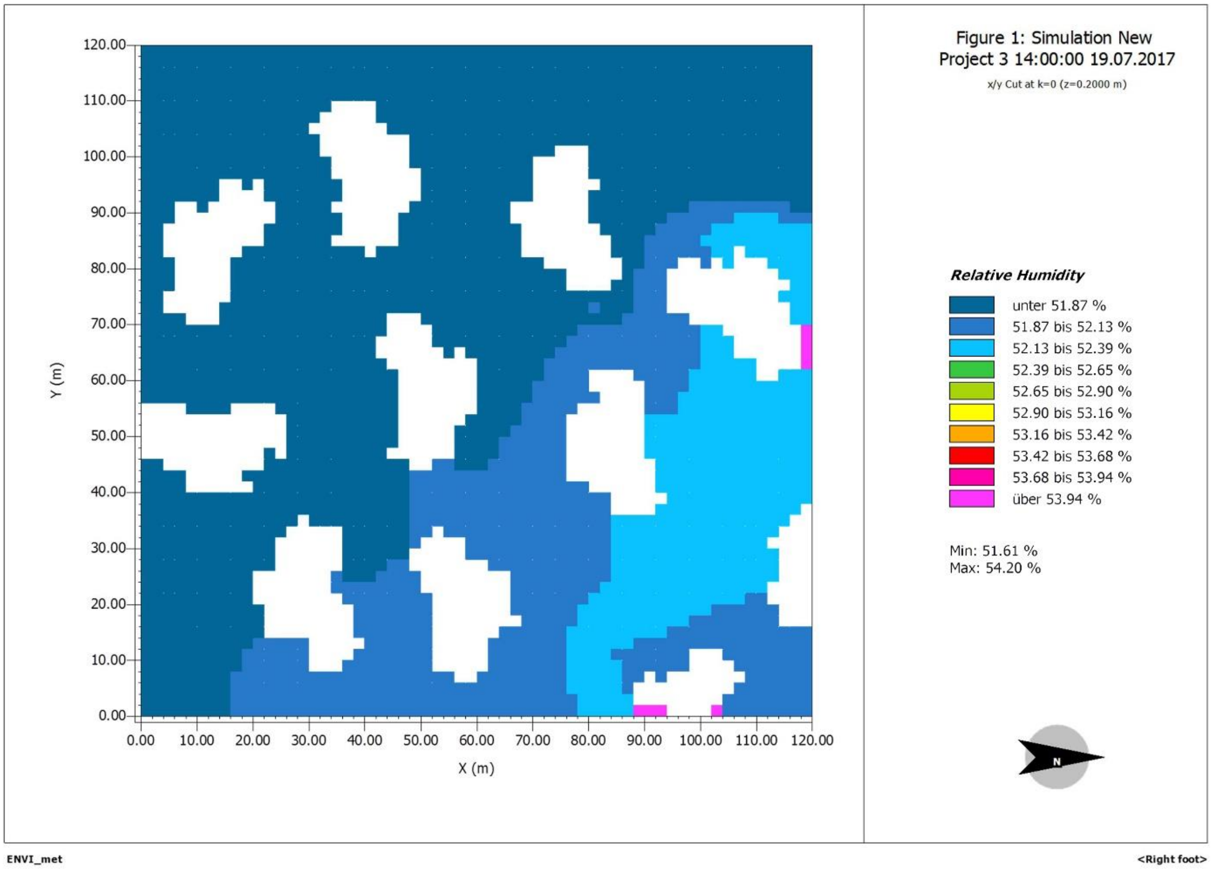
RELATIVE HUMIDITY



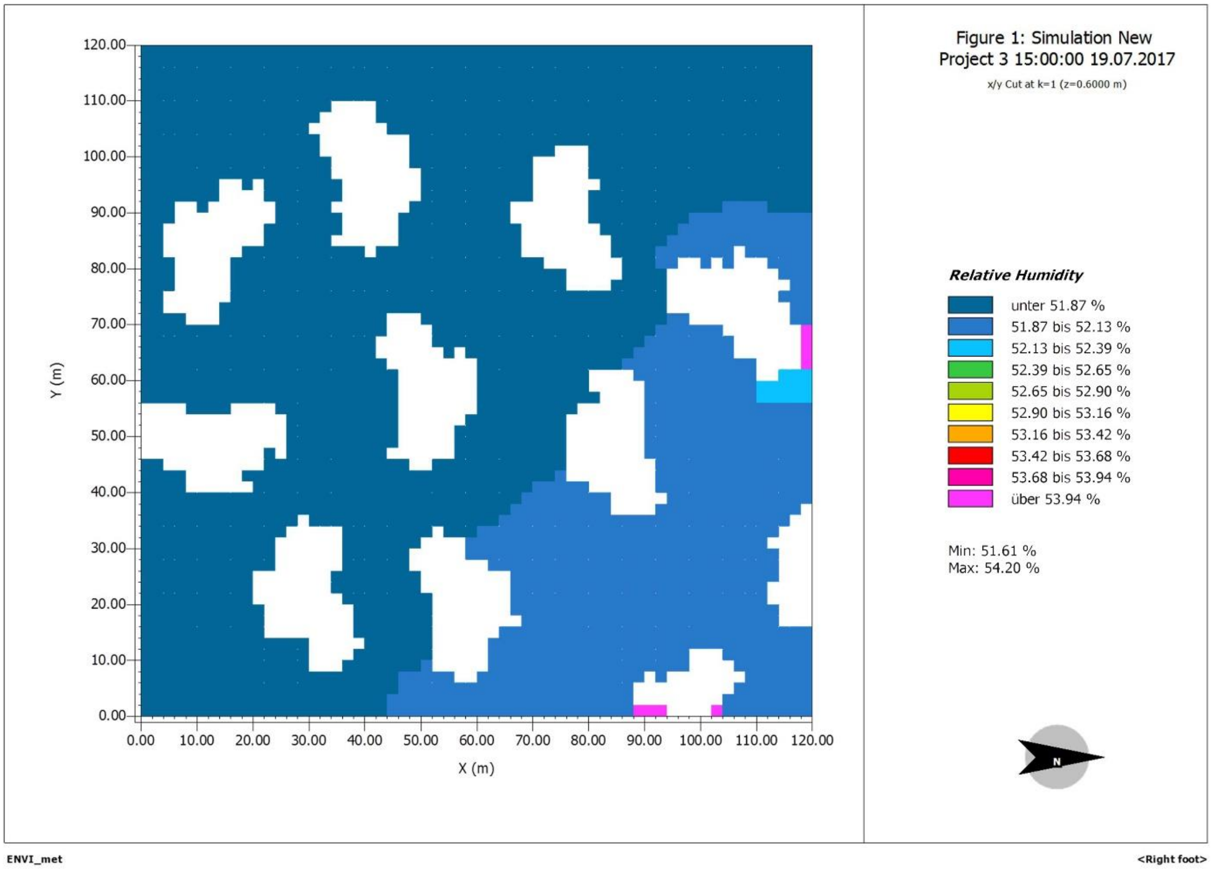
Strategy 1 - Orientation - 90 degrees - Mapping of relative humidity at 12pm



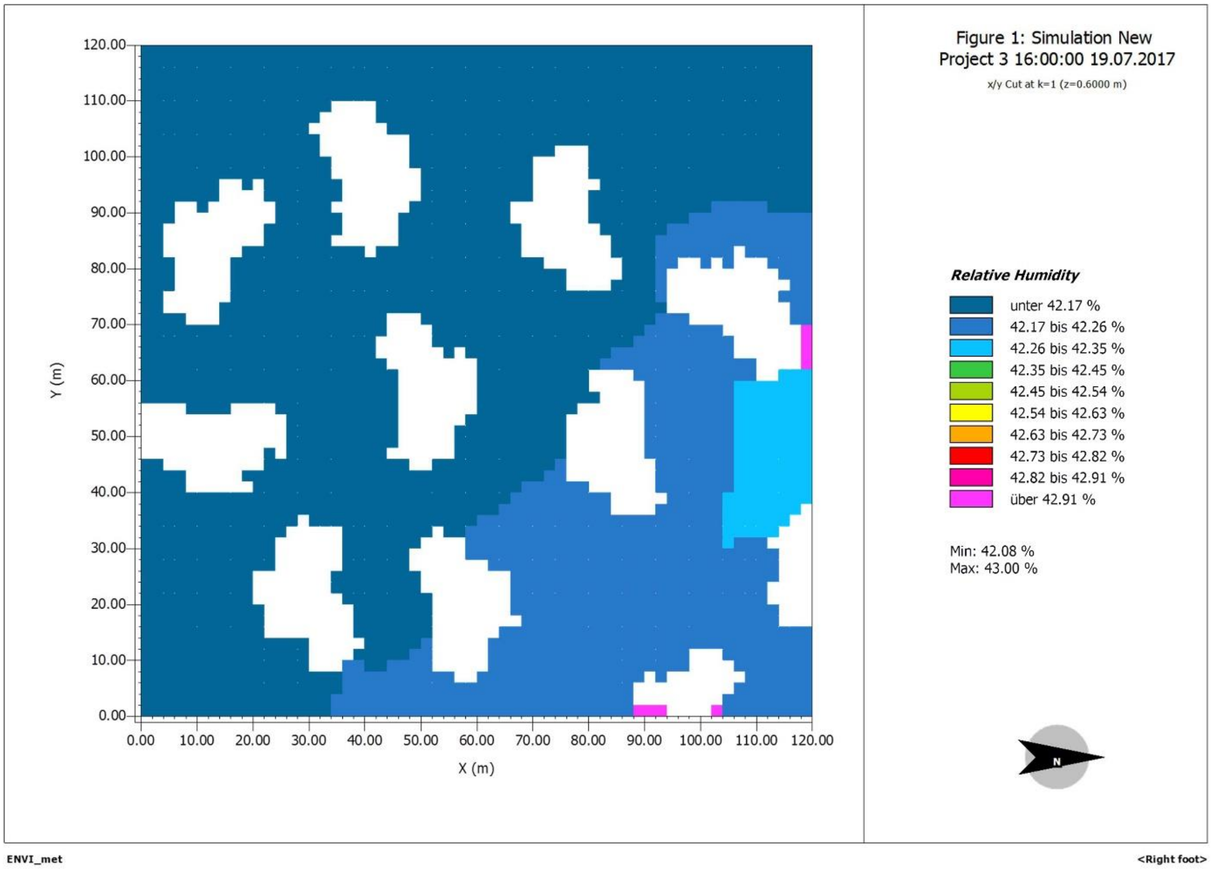
Strategy 1 - Orientation - 90 degrees - Mapping of relative humidity at 1pm



Strategy 1 - Orientation - 90 degrees - Mapping of relative humidity at 2pm



Strategy 1 - Orientation - 90 degrees - Mapping of relative humidity at 3pm



Strategy 1 - Orientation - 90 degrees - Mapping of relative humidity at 4pm

SPOT 1 front yard				
orientation	0 deg	270 deg	180 deg	90 deg
AT @ 12pm	38.56	42.09	40.47	39.90
AT @ 1pm	44.65	45.05	46.50	48.38
AT @ 2pm	48.78	49.87	55.88	50.56
AT @ 3pm	48.68	53.68	56.95	51.70
AT @ 4pm	48.68	51.09	55.07	53.15
	45.87	48.36	50.97	48.74
orientation	0 deg	270 deg	180 deg	90 deg
WS @ 12pm	1.12	0.37	1.12	0.74
WS @ 1pm	1.15	0.38	1.20	0.77
WS @ 2pm	1.24	0.39	0.44	0.80
WS @ 3pm	1.28	0.41	0.45	0.80
WS @ 4pm	1.30	0.42	0.89	0.79
	1.22	0.39	0.82	0.78
orientation	0 deg	270 deg	180 deg	90 deg
RH @ 12pm	62.88	63.37	63.37	76.77
RH @ 1pm	76.77	52.76	63.37	62.88
RH @ 2pm	76.77	51.61	52.76	51.61
RH @ 3pm	76.77	51.61	43.67	51.61
RH @ 4pm	76.77	51.61	43.67	42.08
	73.99	54.19	53.37	56.99

SPOT 2 back yard				
orientation	0 deg	270 deg	180 deg	90 deg
AT @ 12pm	36.70	42.09	40.47	39.90
AT @ 1pm	44.65	47.75	46.50	45.61
AT @ 2pm	48.78	52.91	52.16	50.56
AT @ 3pm	51.72	53.68	52.92	51.70
AT @ 4pm	52.81	54.06	55.07	53.15
	46.93	50.10	49.42	48.18
orientation	0 deg	270 deg	180 deg	90 deg
WS @ 12pm	1.12	1.10	0.74	0.37
WS @ 1pm	1.15	1.13	0.41	0.39
WS @ 2pm	1.24	1.18	0.44	0.40
WS @ 3pm	1.28	1.23	0.45	0.40
WS @ 4pm	1.30	1.25	0.89	0.39
	1.22	1.18	0.59	0.39
orientation	0 deg	270 deg	180 deg	90 deg
RH @ 12pm	62.88	63.37	63.37	76.82
RH @ 1pm	76.77	52.76	63.37	54.12
RH @ 2pm	76.77	51.61	52.76	50.56
RH @ 3pm	76.77	51.61	43.67	36.06
RH @ 4pm	76.77	51.61	43.67	37.36
	73.99	54.19	53.37	50.98

SPOT 3 road surface				
orientation	0 deg	270 deg	180 deg	90 deg
AT @ 12pm	38.56	39.63	40.47	37.68
AT @ 1pm	44.65	45.05	46.50	45.61
AT @ 2pm	45.83	52.91	55.88	50.56
AT @ 3pm	48.68	53.68	56.95	55.56
AT @ 4pm	49.94	54.06	55.07	53.15
	45.53	49.07	50.97	48.51
orientation	0 deg	270 deg	180 deg	90 deg
WS @ 12pm	1.12	1.10	1.49	1.12
WS @ 1pm	1.15	1.13	1.60	1.16
WS @ 2pm	1.24	1.18	1.74	1.20
WS @ 3pm	1.28	1.23	1.77	1.20
WS @ 4pm	1.30	1.23	1.76	1.18
	1.22	1.17	1.67	1.17
orientation	0 deg	270 deg	180 deg	90 deg
RH @ 12pm	62.88	63.37	63.37	76.82
RH @ 1pm	76.77	52.76	63.37	54.12
RH @ 2pm	76.77	51.61	52.76	50.56
RH @ 3pm	76.77	51.61	43.67	36.06
RH @ 4pm	76.77	51.61	43.67	37.36
	73.99	54.19	53.37	50.98

SPOT 4 open space				
orientation	0 deg	270 deg	180 deg	90 deg
AT @ 12pm	36.70	42.09	40.47	39.90
AT @ 1pm	44.65	45.05	46.50	45.61
AT @ 2pm	51.73	52.91	52.16	50.56
AT @ 3pm	54.75	53.68	56.95	51.70
AT @ 4pm	55.69	54.06	55.07	53.15
	48.70	49.56	50.23	48.18
orientation	0 deg	270 deg	180 deg	90 deg
WS @ 12pm	1.12	1.10	1.49	1.12
WS @ 1pm	1.15	1.13	1.20	1.16
WS @ 2pm	1.24	1.18	1.31	1.20
WS @ 3pm	1.28	1.23	1.33	1.20
WS @ 4pm	1.30	1.23	1.33	1.18
	1.22	1.17	1.33	1.17
orientation	0 deg	270 deg	180 deg	90 deg
RH @ 12pm	63.96	63.37	63.37	76.82
RH @ 1pm	76.77	52.76	63.37	54.12
RH @ 2pm	76.77	51.61	52.76	50.56
RH @ 3pm	76.77	51.61	43.67	36.06
RH @ 4pm	76.77	51.61	43.67	37.36
	74.21	54.19	53.37	50.98

averages for simulation 1,2,3,4

orientation	0 deg	270 deg	180 deg	90 deg
AT @ 12pm	37.63	41.48	40.47	39.35
AT @ 1pm	44.65	45.73	46.50	46.30
AT @ 2pm	48.78	52.15	54.02	50.56
AT @ 3pm	50.96	53.68	55.94	52.67
AT @ 4pm	51.78	53.32	55.07	53.15
	46.76	49.27	50.40	48.40

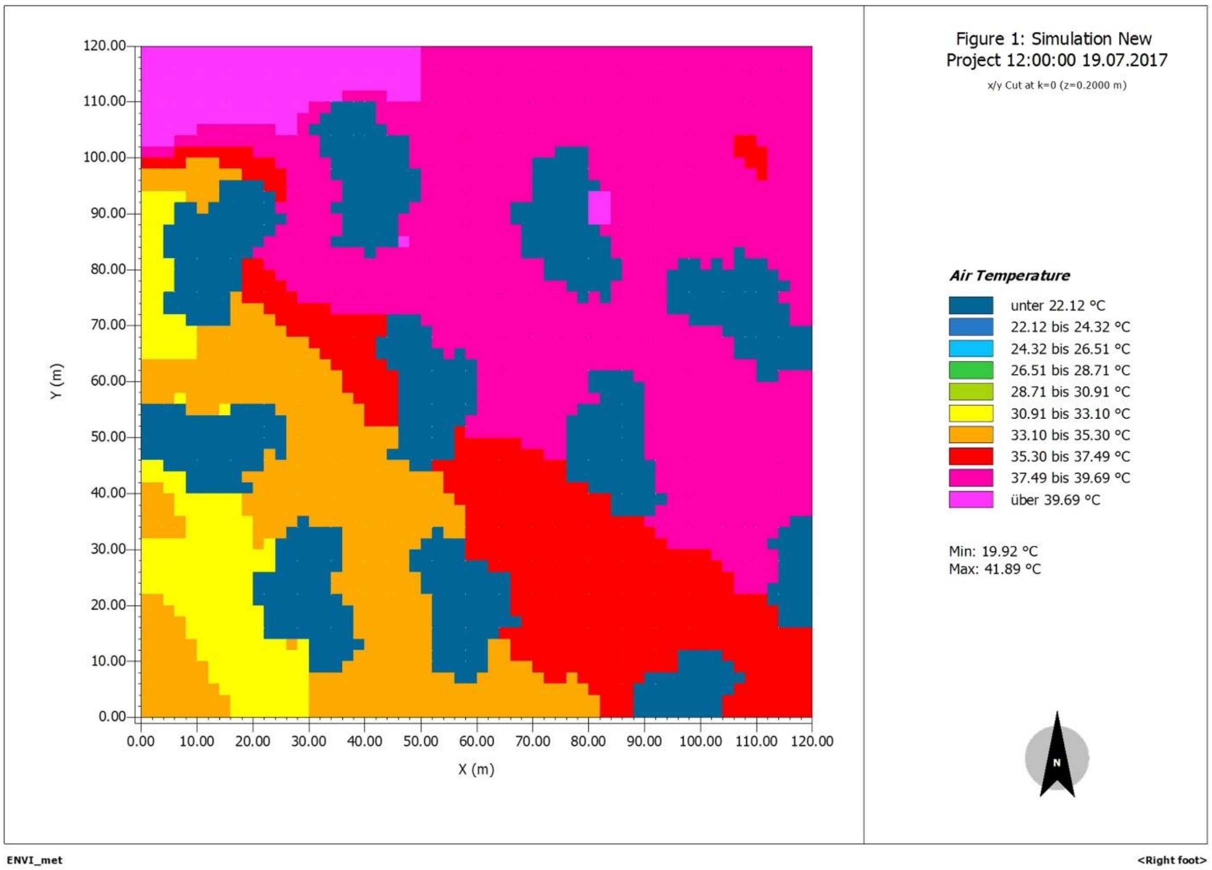
orientation	0 deg	270 deg	180 deg	90 deg
WS @ 12pm	1.12	0.92	1.21	0.84
WS @ 1pm	1.15	0.94	1.10	0.87
WS @ 2pm	1.24	0.98	0.98	0.90
WS @ 3pm	1.28	1.03	1.00	0.90
WS @ 4pm	1.30	1.03	1.22	0.89
	1.22	0.98	1.10	0.88

orientation	0 deg	270 deg	180 deg	90 deg
RH @ 12pm	63.15	63.37	63.37	76.81
RH @ 1pm	76.77	52.76	63.37	56.31
RH @ 2pm	76.77	51.61	52.76	50.82
RH @ 3pm	76.77	51.61	43.67	39.95
RH @ 4pm	76.77	51.61	43.67	38.54
	74.05	54.19	53.37	52.49

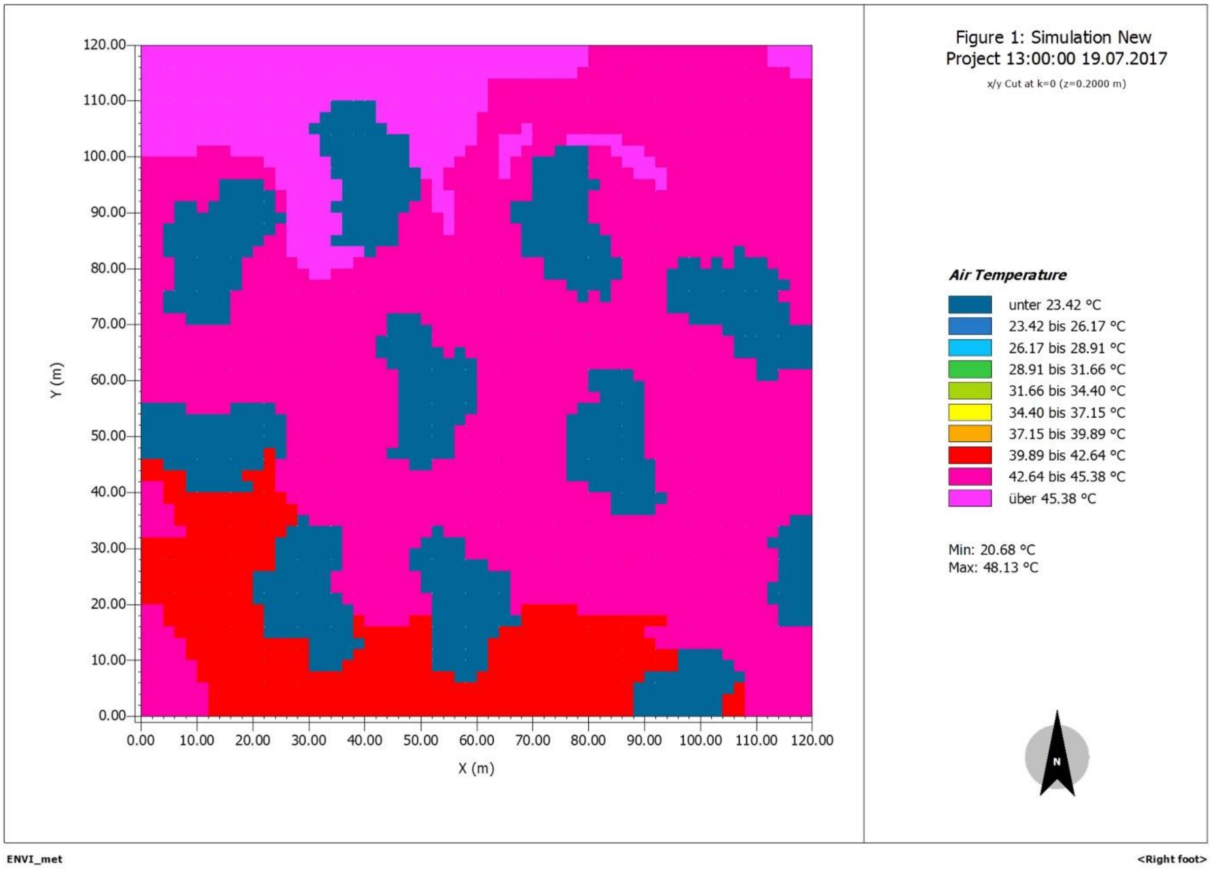
Appendix 5 - Strategy 2 - Coverage - concrete pavement light grey

Model building, Coverage - concrete pavement light grey. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

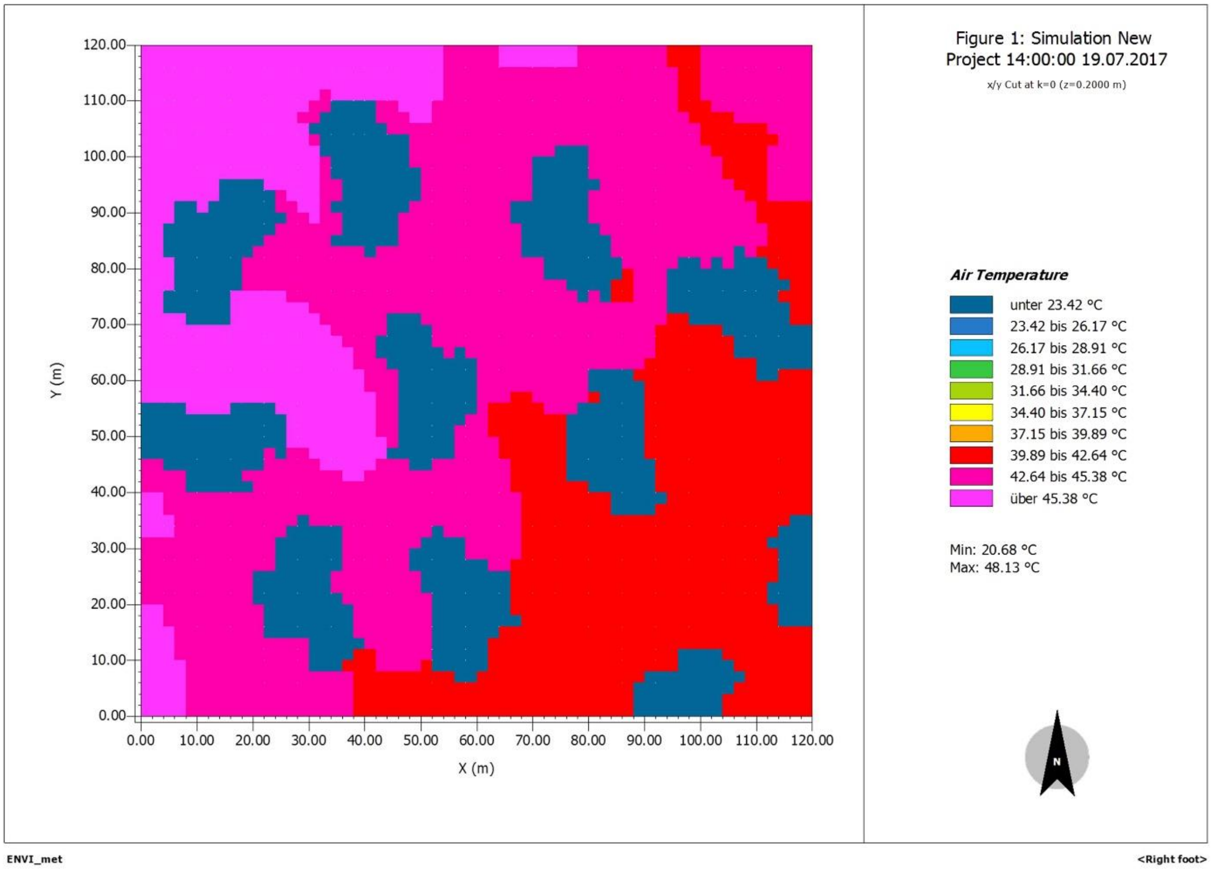
AIR TEMPERATURE



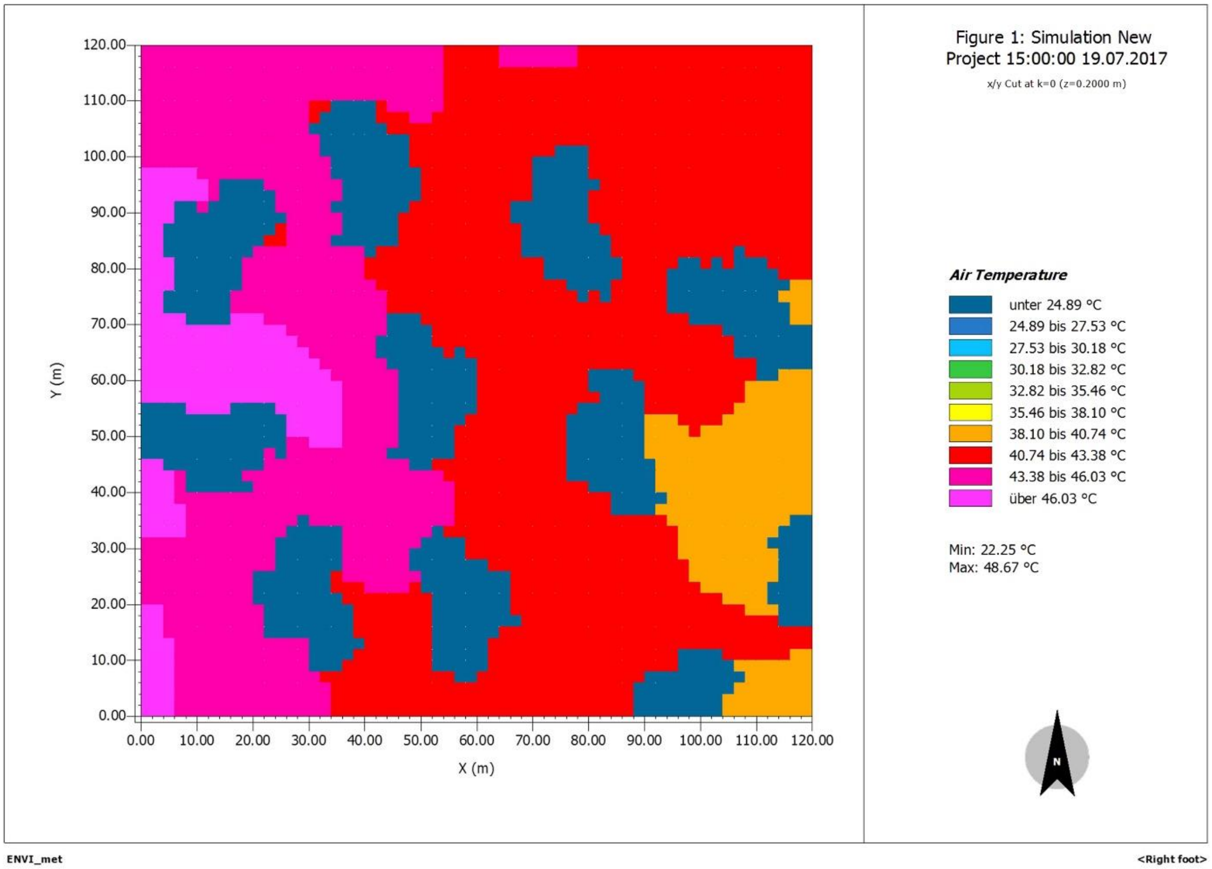
Strategy 2 - Coverage - concrete pavement light grey - Mapping of air temperature at 12pm



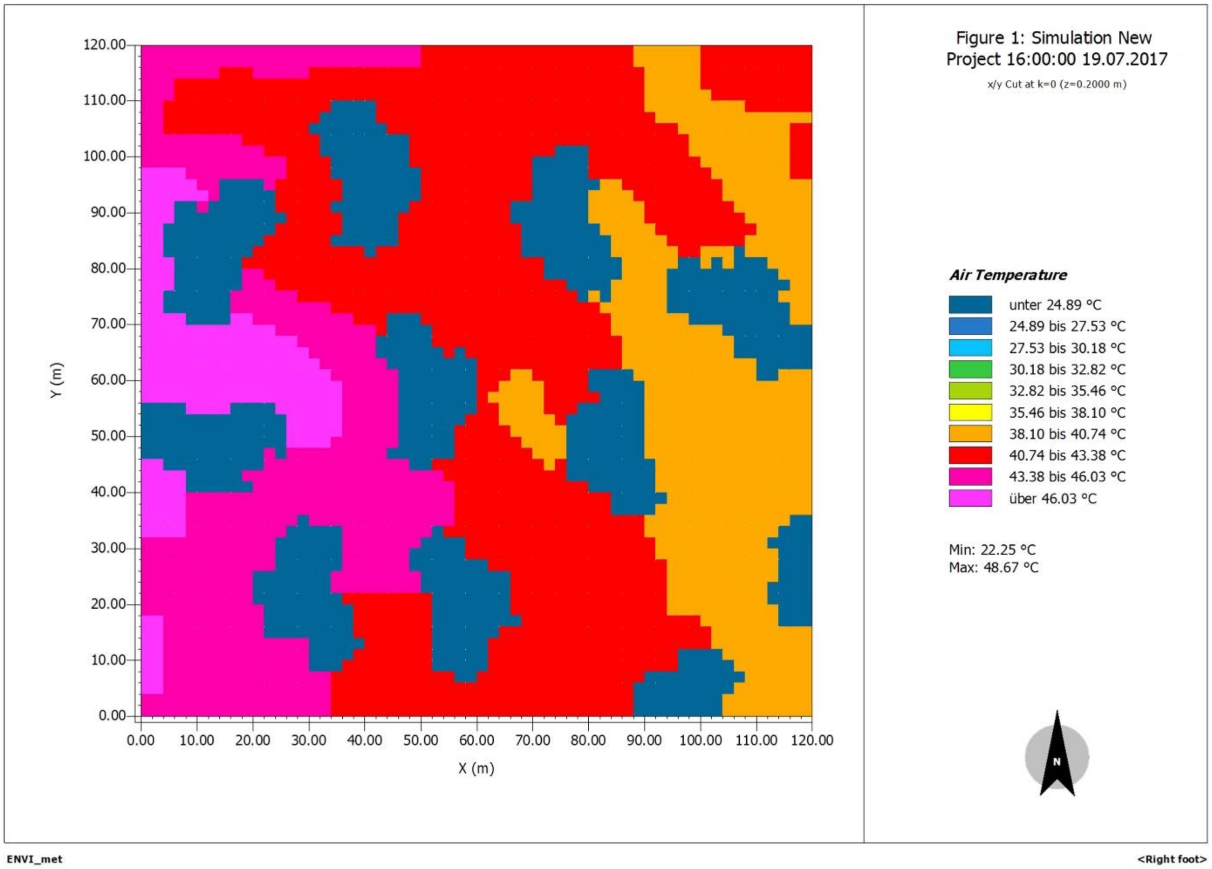
Strategy 2 - Coverage - concrete pavement light grey - Mapping of air temperature at 1pm



Strategy 2 - Coverage - concrete pavement light grey - Mapping of air temperature at 2pm

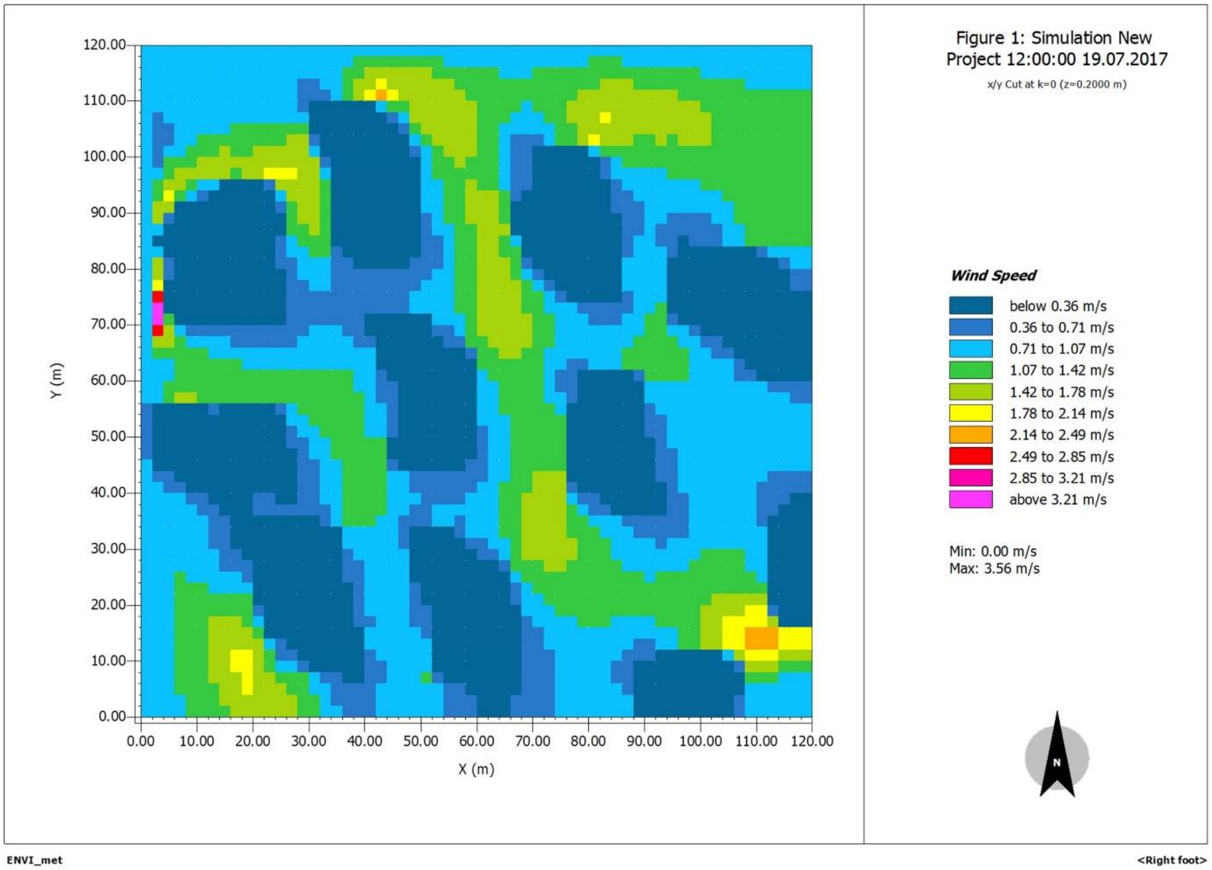


Strategy 2 - Coverage - concrete pavement light grey - Mapping of air temperature at 3pm

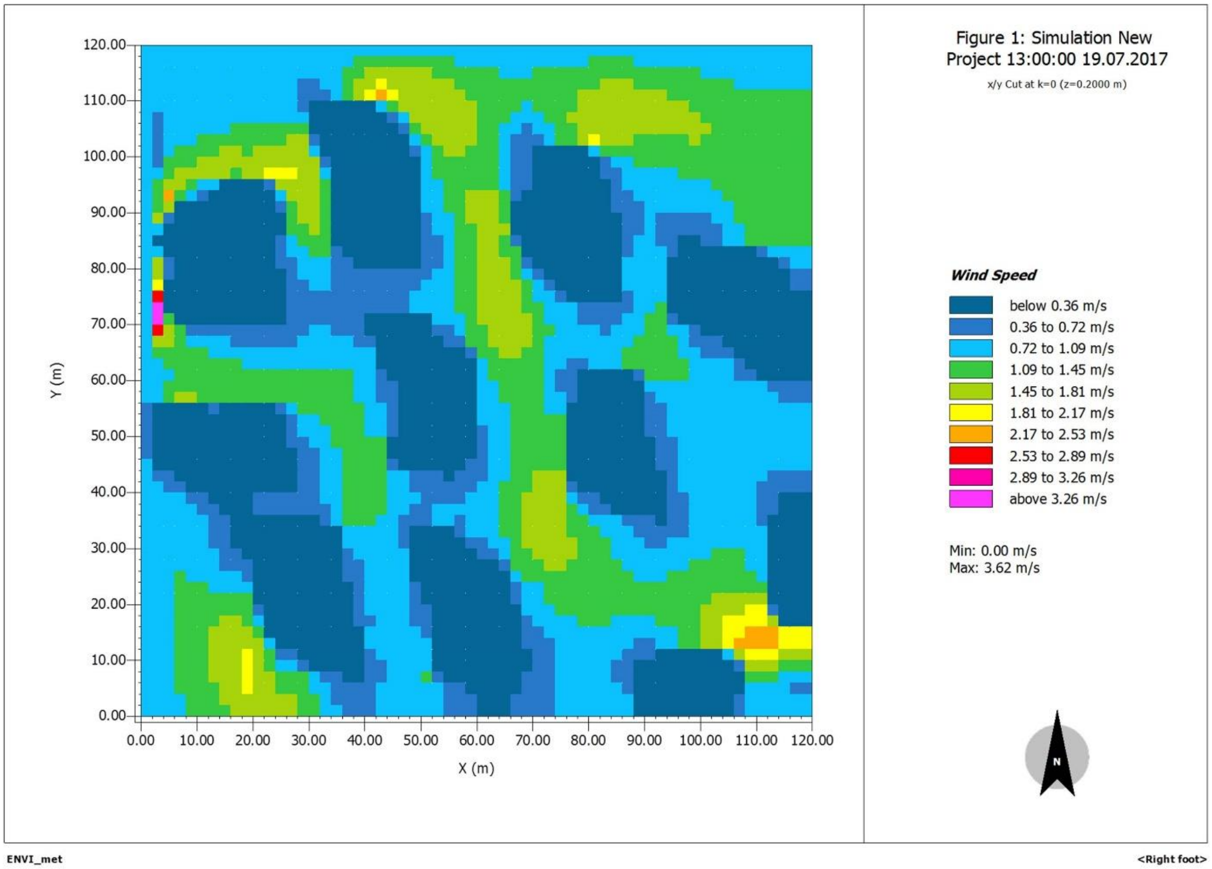


Strategy 2 - Coverage - concrete pavement light grey - Mapping of air temperature at 4pm

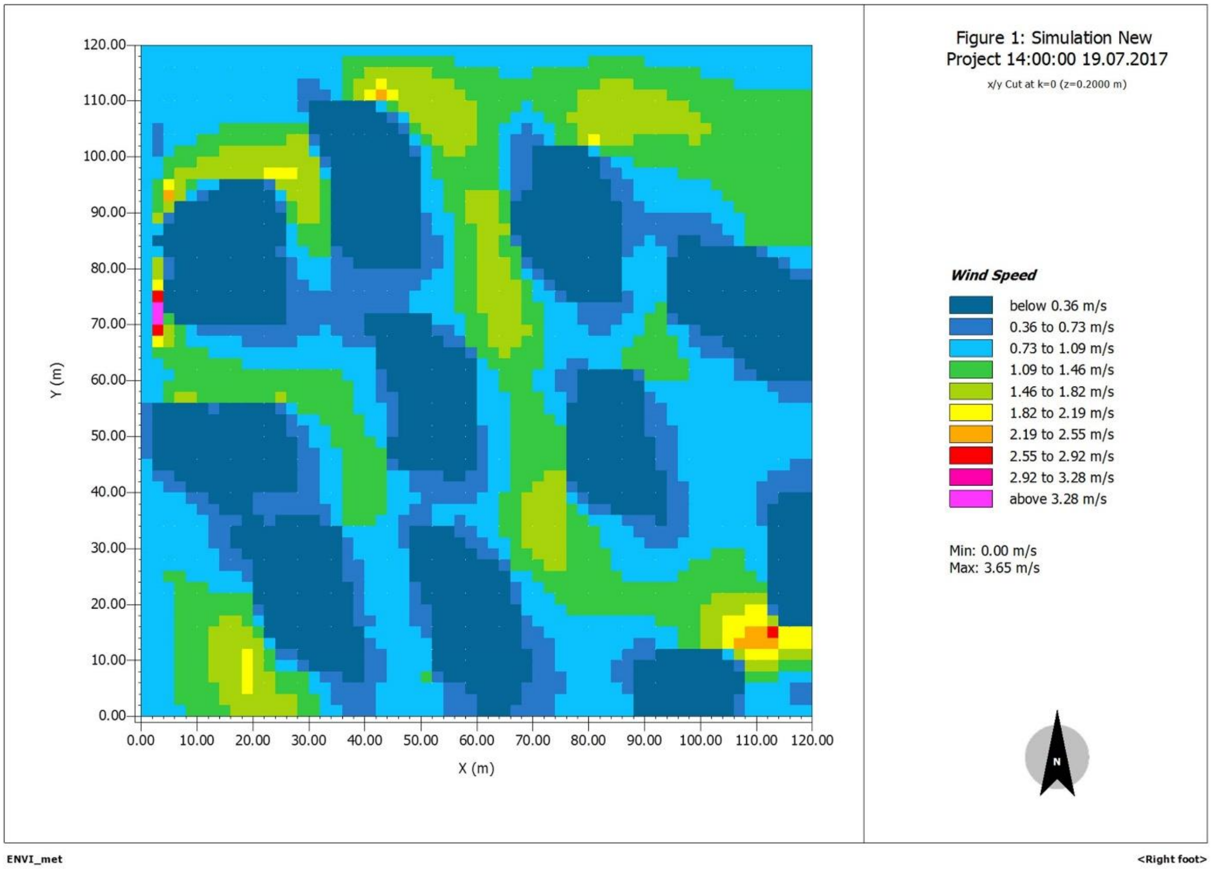
WIND SPEED



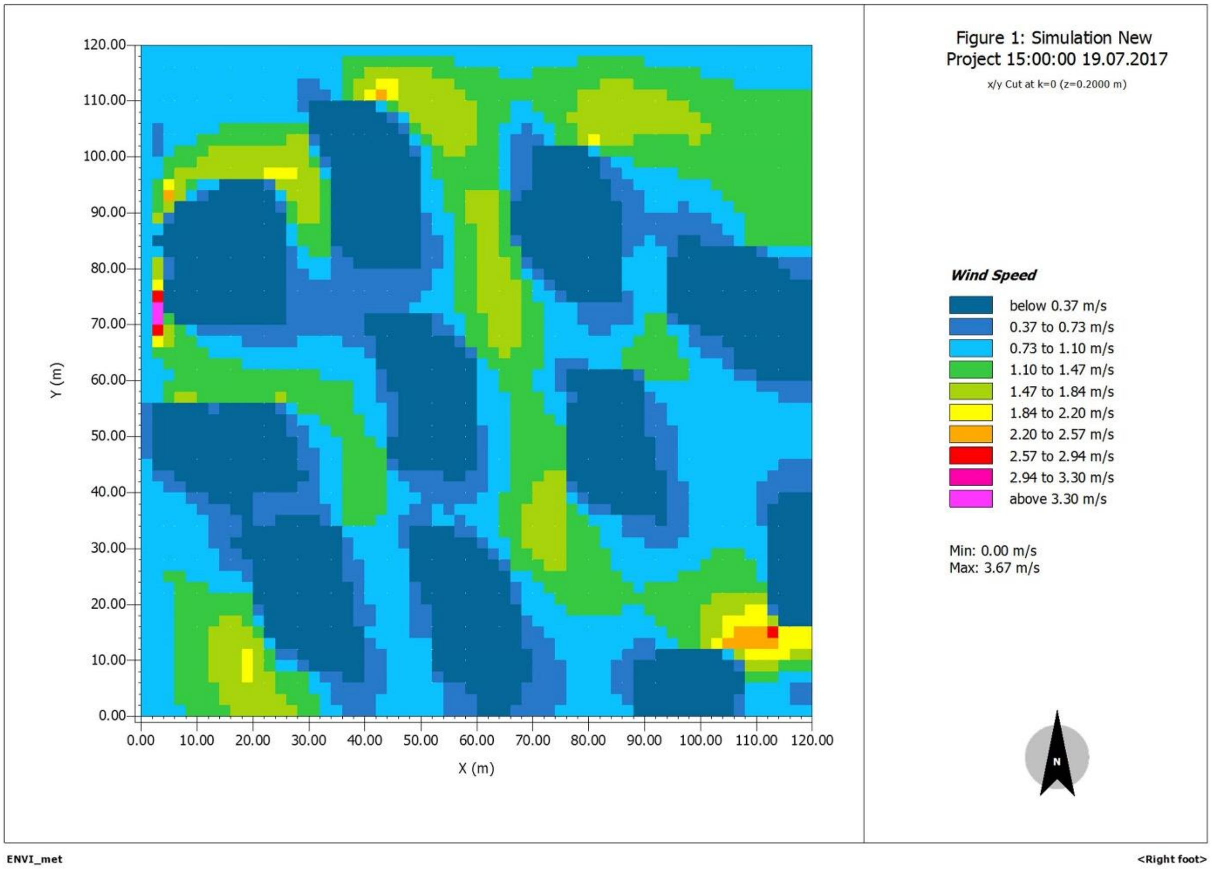
Strategy 2 - Coverage - concrete pavement light grey - Mapping of wind speed at 12pm



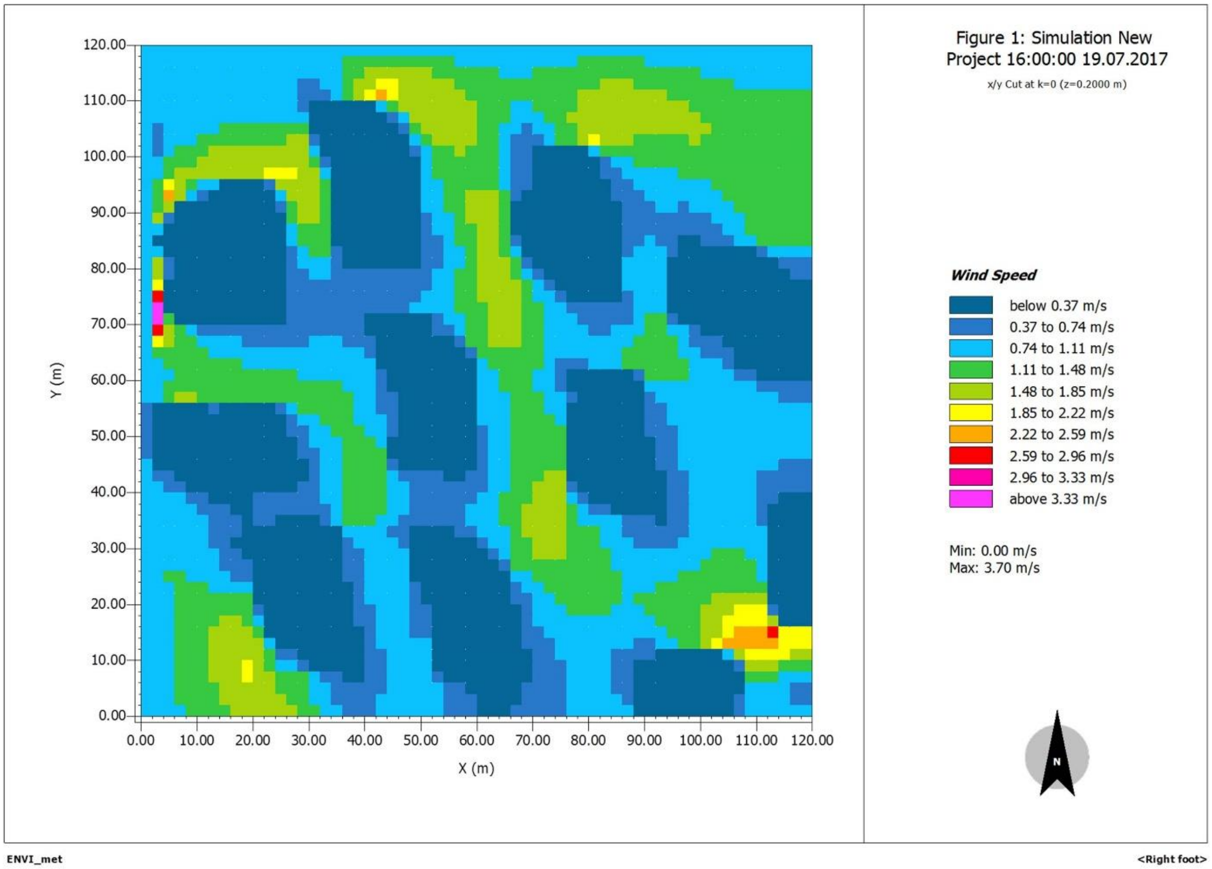
Strategy 2 - Coverage - concrete pavement light grey - Mapping of wind speed at 1pm



Strategy 2 - Coverage - concrete pavement light grey - Mapping of wind speed at 2pm

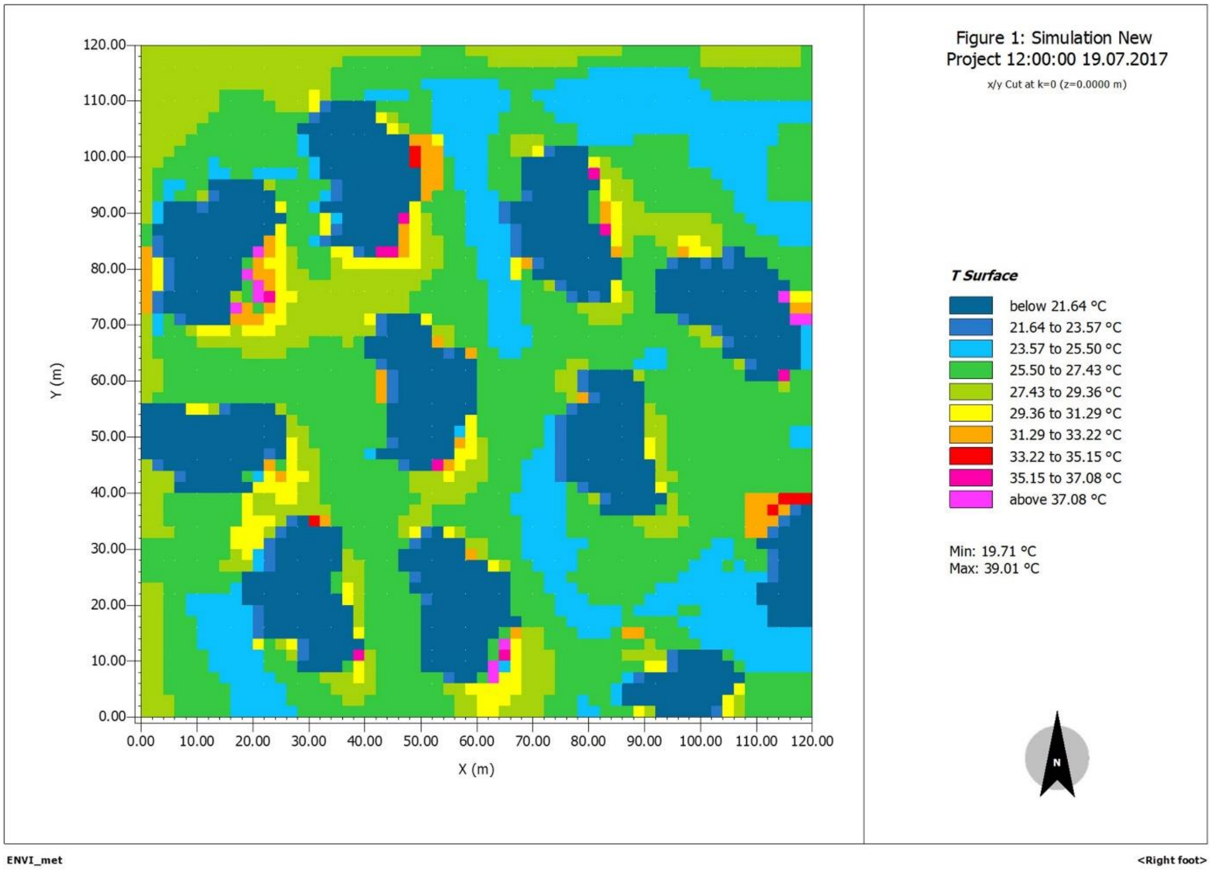


Strategy 2 - Coverage - concrete pavement light grey - Mapping of wind speed at 3pm

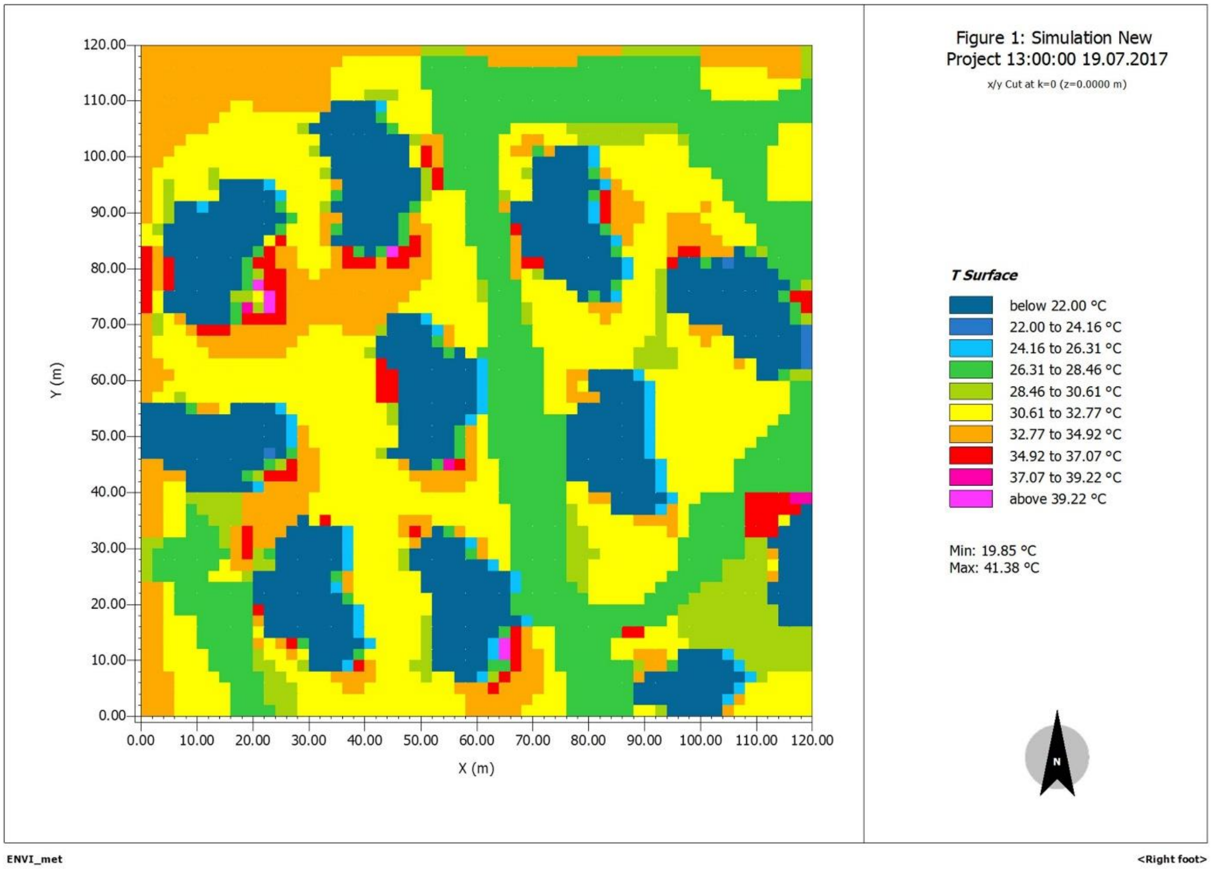


Strategy 2 - Coverage - concrete pavement light grey - Mapping of wind speed at 4pm

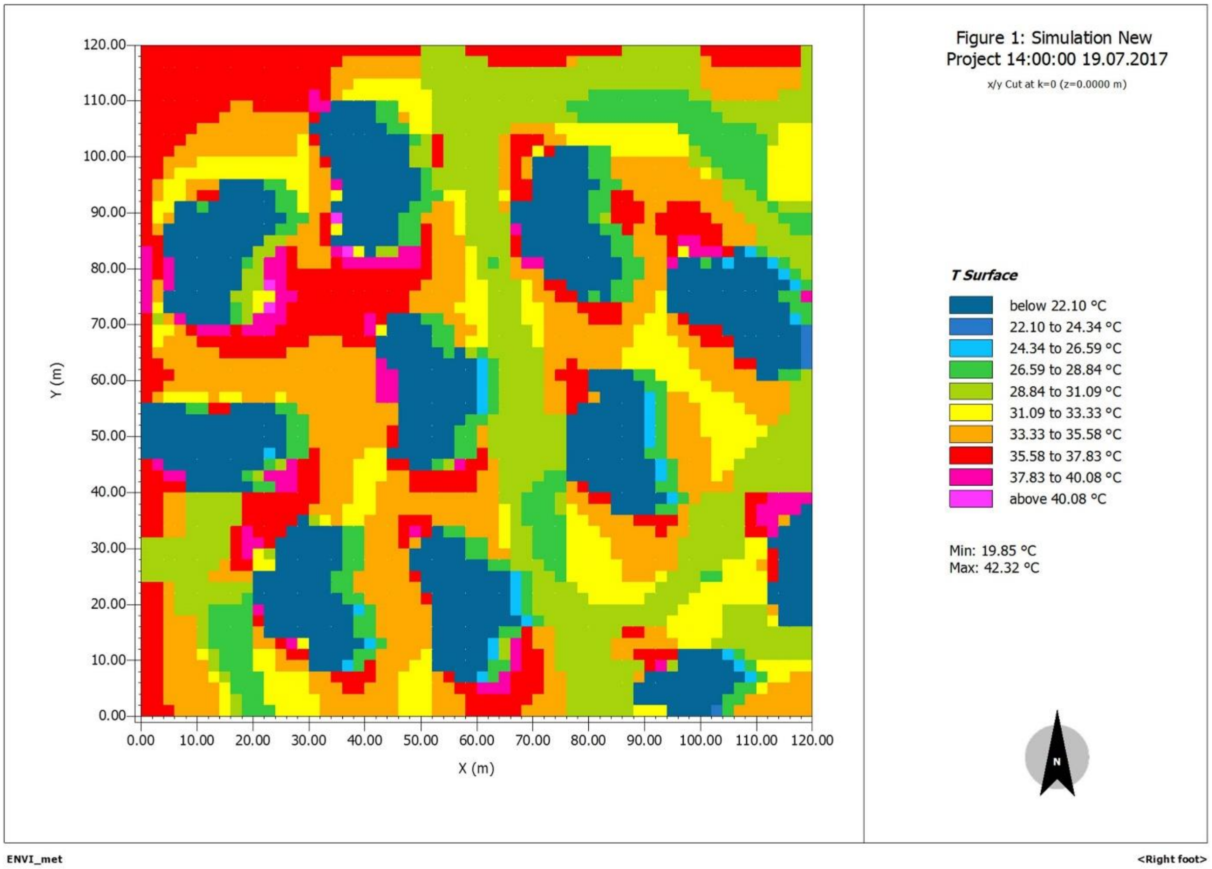
RELATIVE HUMIDITY



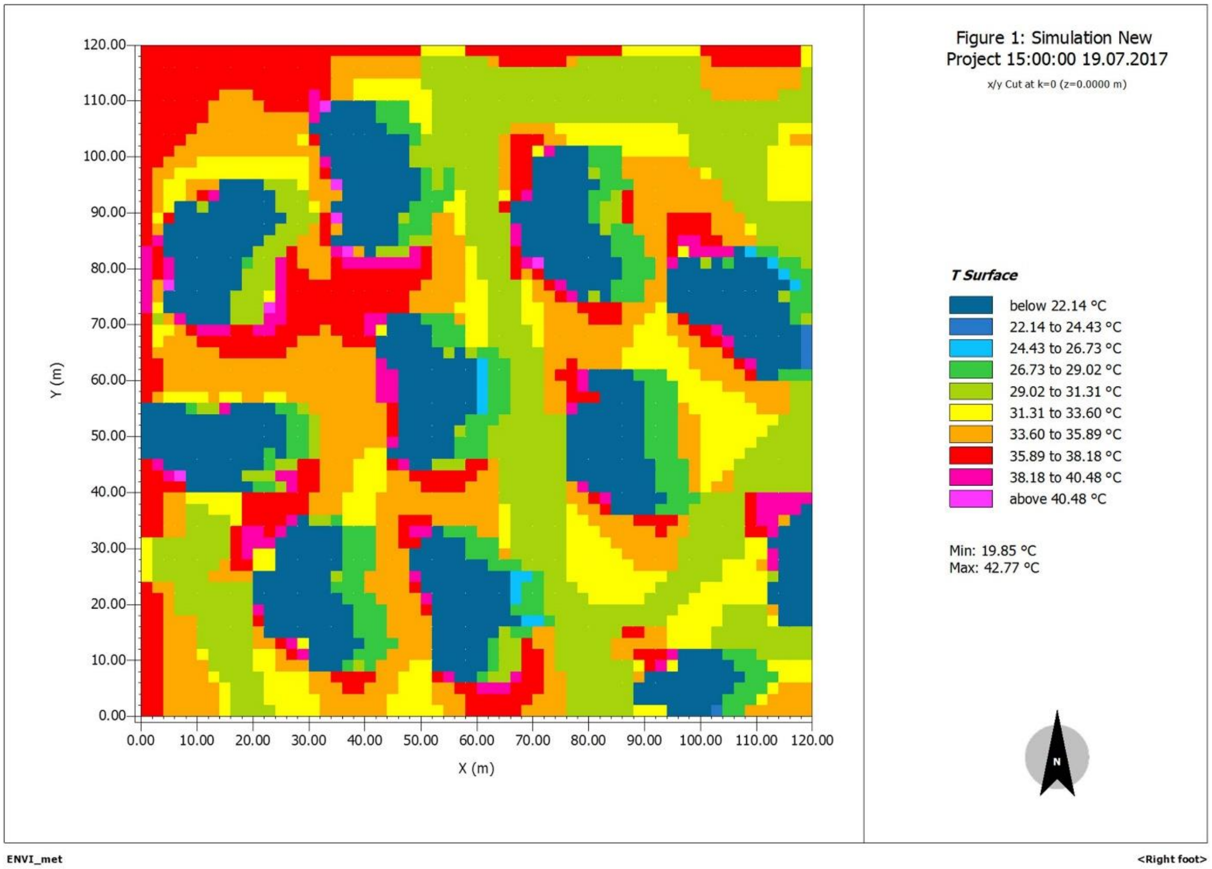
Strategy 2 - Coverage - concrete pavement light grey - Mapping of relative humidity at 12pm



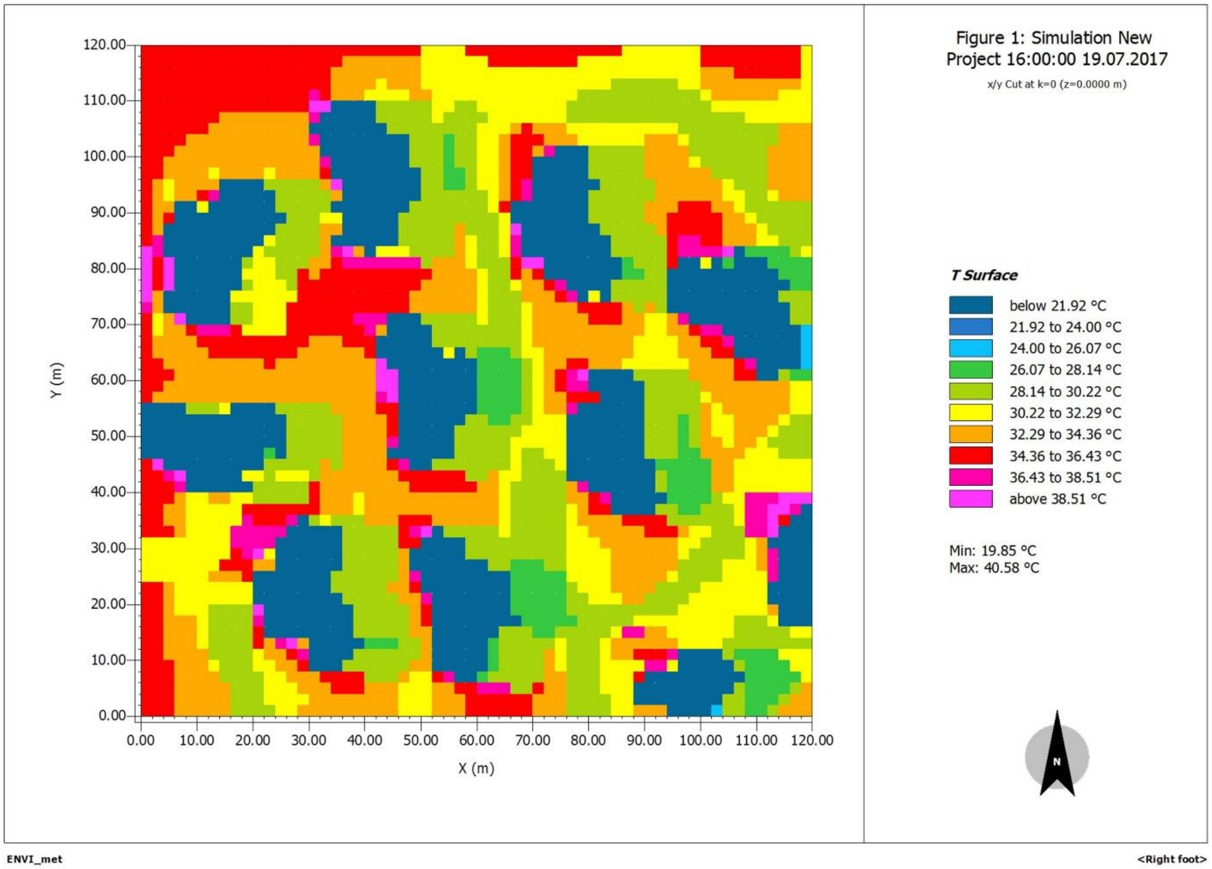
Strategy 2 - Coverage - concrete pavement light grey - Mapping of relative humidity at 1pm



Strategy 2 - Coverage - concrete pavement light grey - Mapping of relative humidity at 2pm



Strategy 2 - Coverage - concrete pavement light grey - Mapping of relative humidity at 3pm

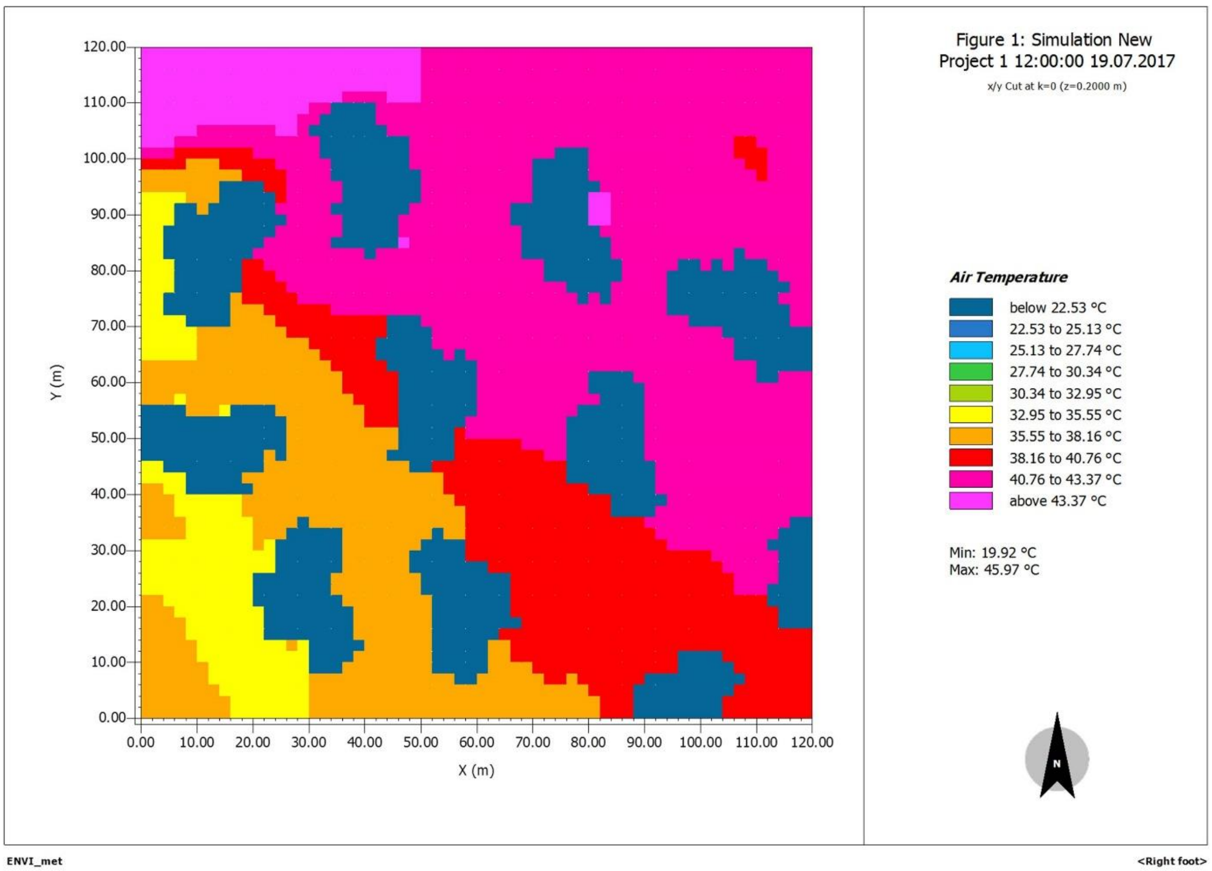


Strategy 2 - Coverage - concrete pavement light grey - Mapping of relative humidity at 4pm

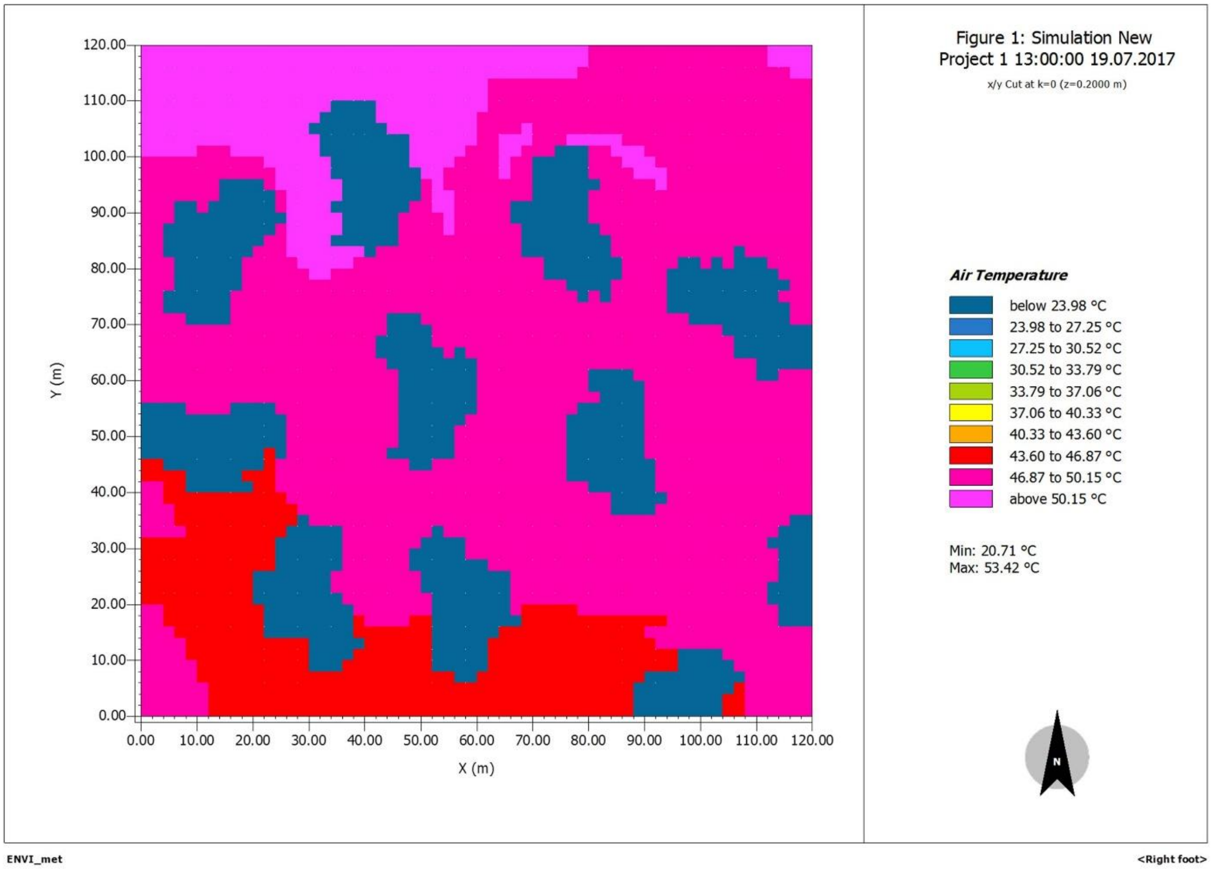
Appendix 6 - Strategy 2 - Coverage - granite shining

Model building, Coverage - granite shining. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

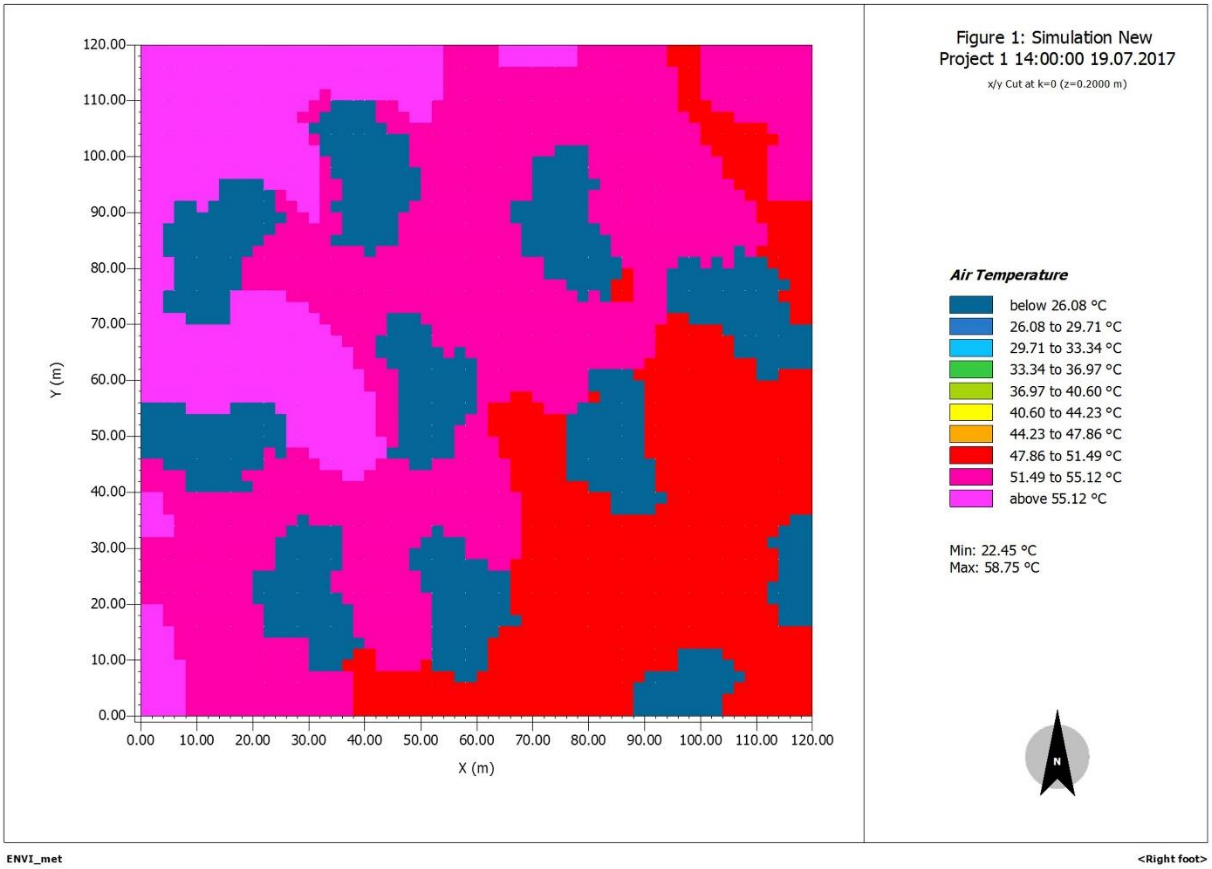
AIR TEMPERATURE



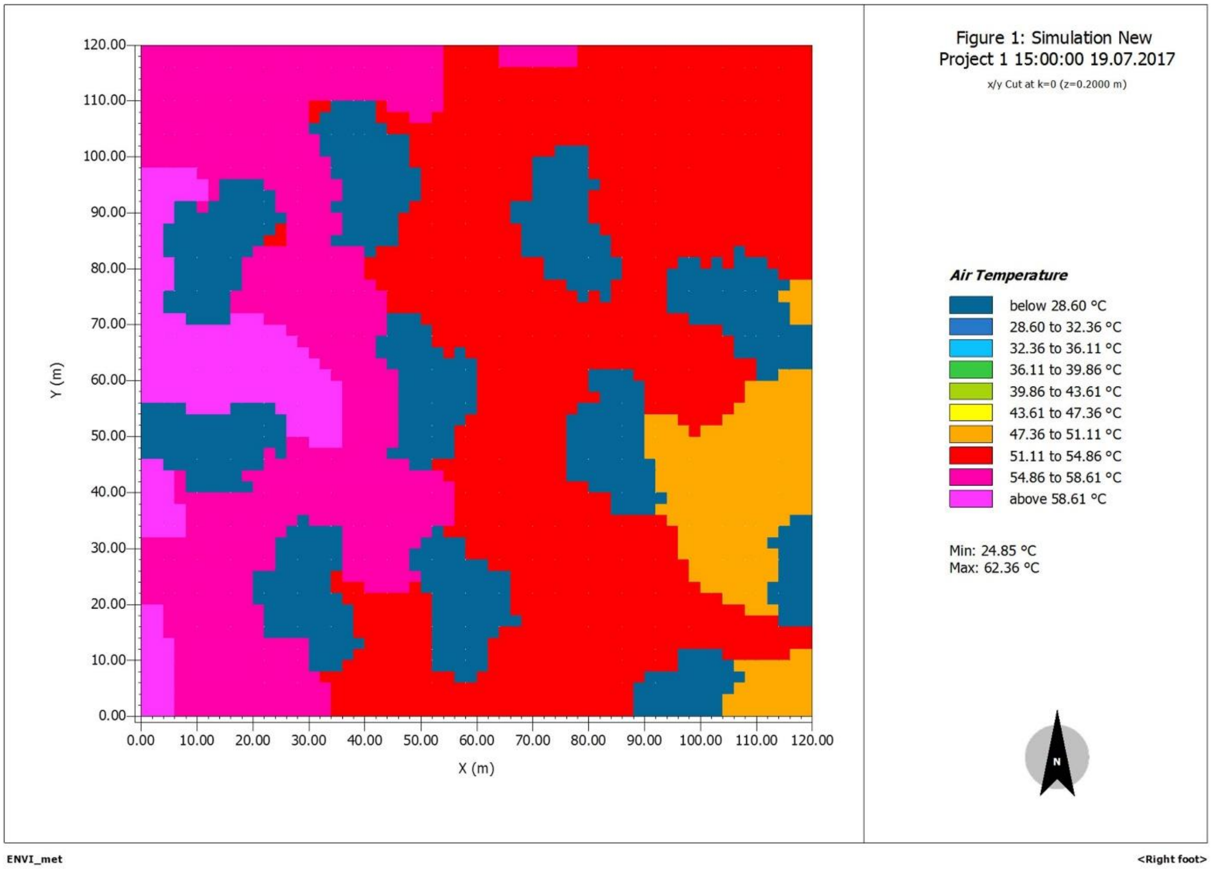
Strategy 2 - Coverage - granite shining - Mapping of air temperature at 12pm



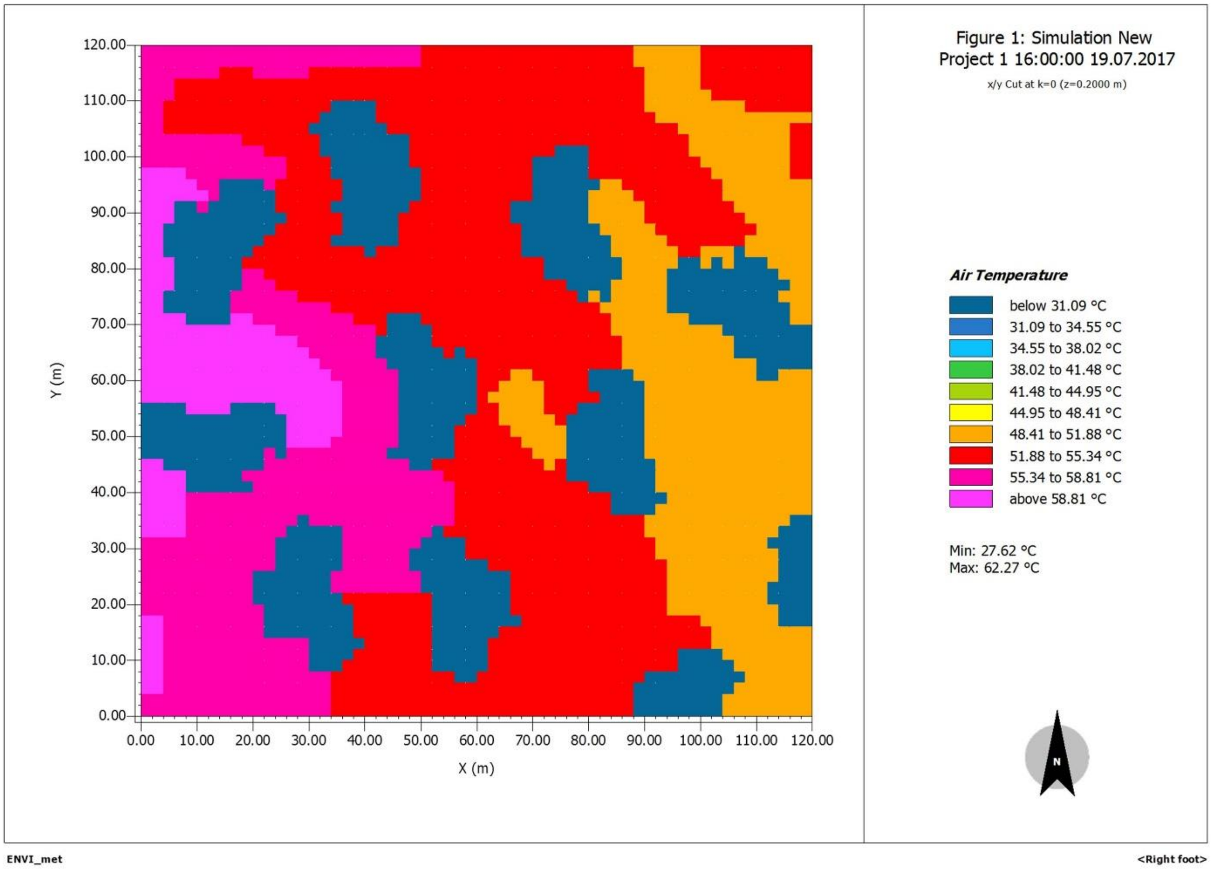
Strategy 2 - Coverage - granite shining - Mapping of air temperature at 1pm



Strategy 2 - Coverage - granite shining - Mapping of air temperature at 2pm

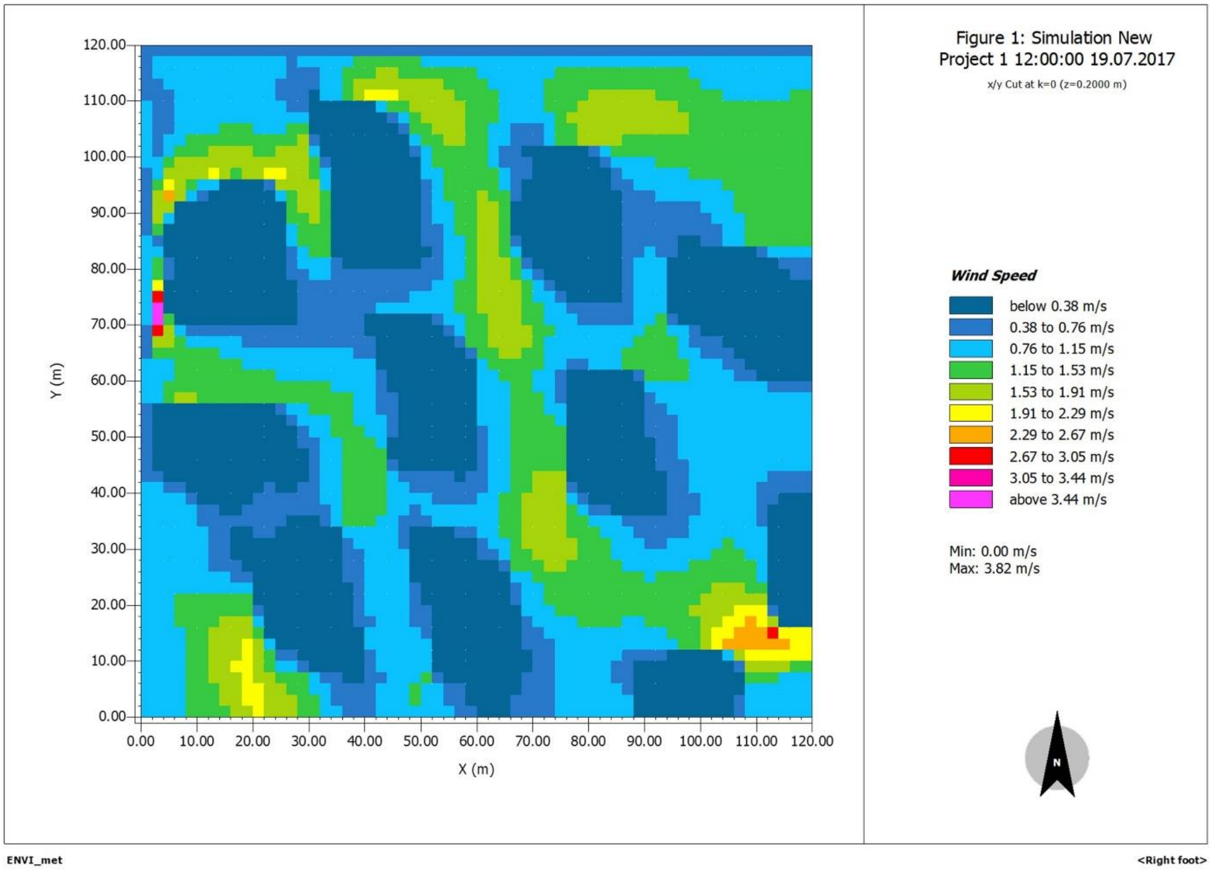


Strategy 2 - Coverage - granite shining - Mapping of air temperature at 3pm

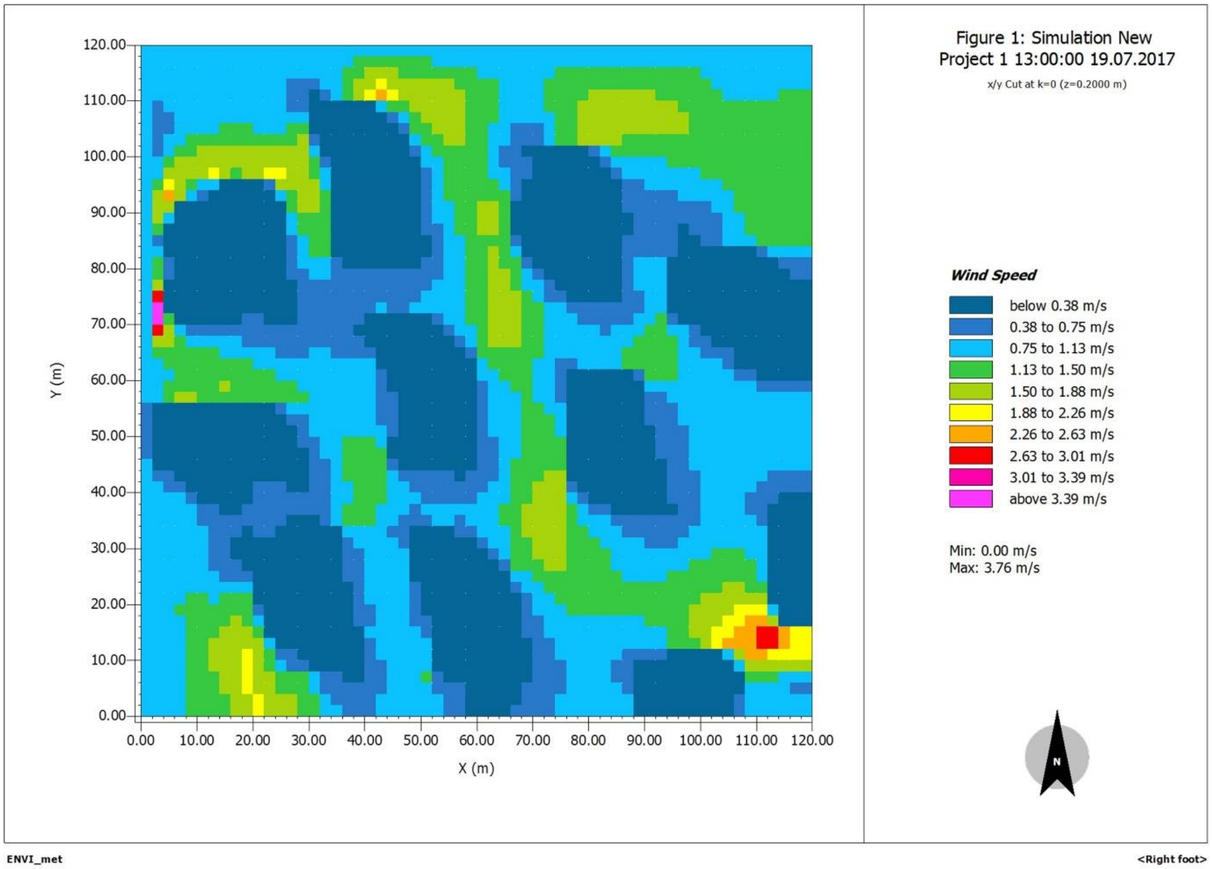


Strategy 2 - Coverage - granite shining - Mapping of air temperature at 4pm

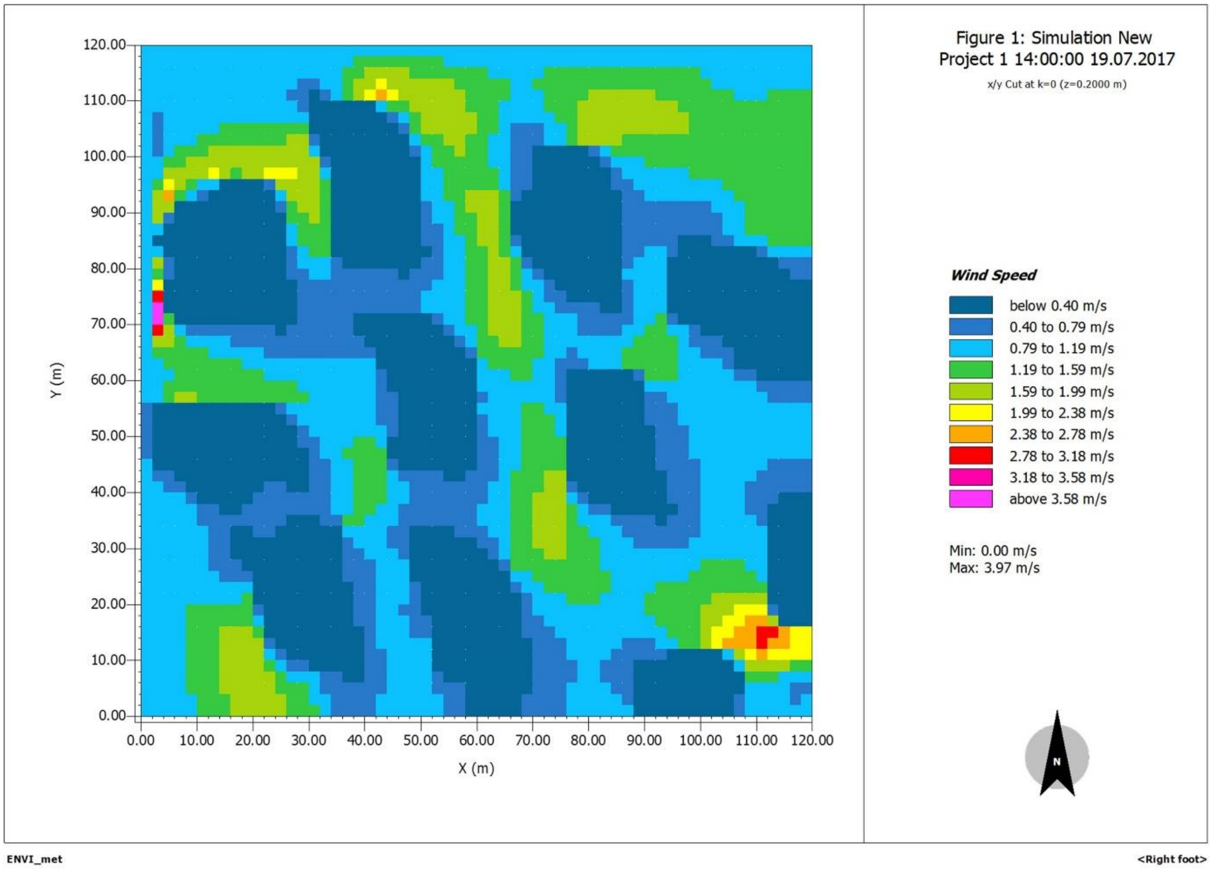
WIND SPEED



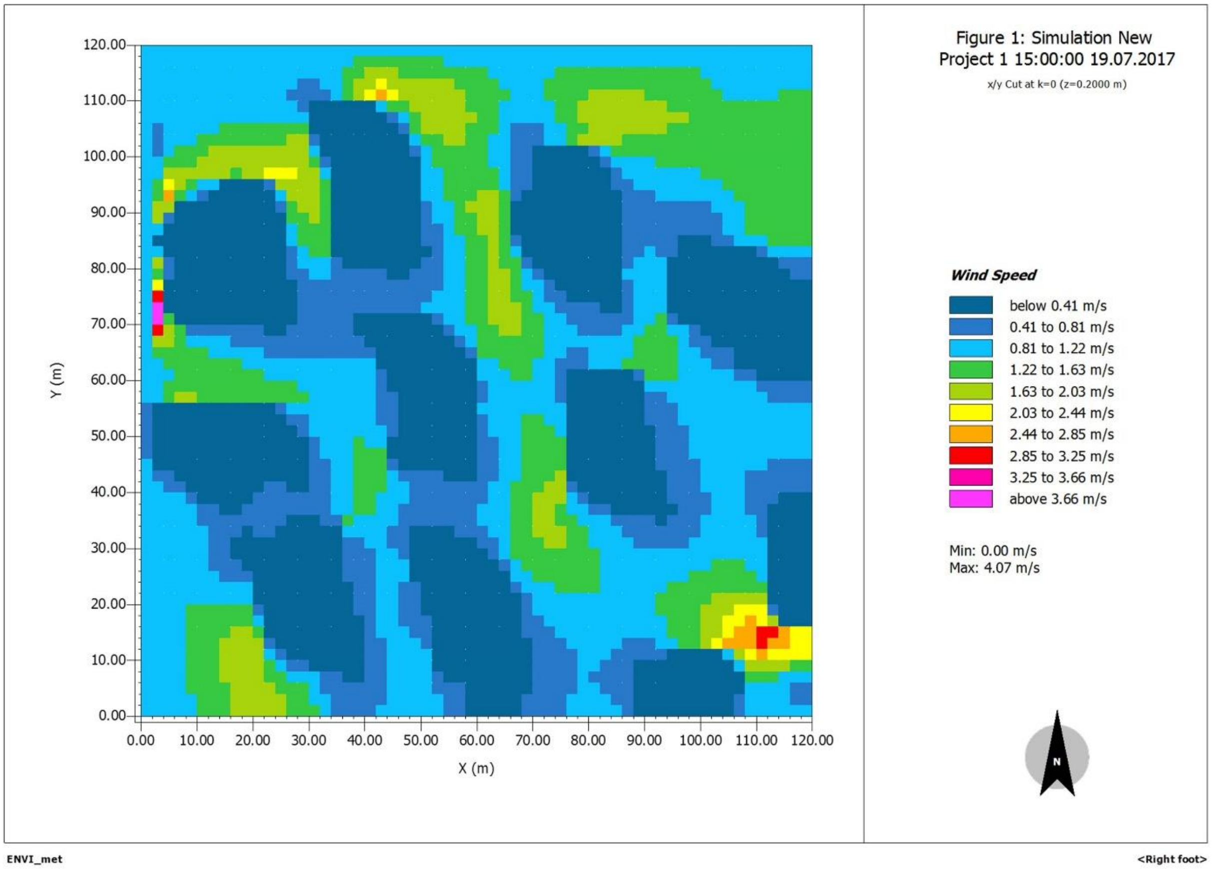
Strategy 2 - Coverage - granite shining - Mapping of wind speed at 12pm



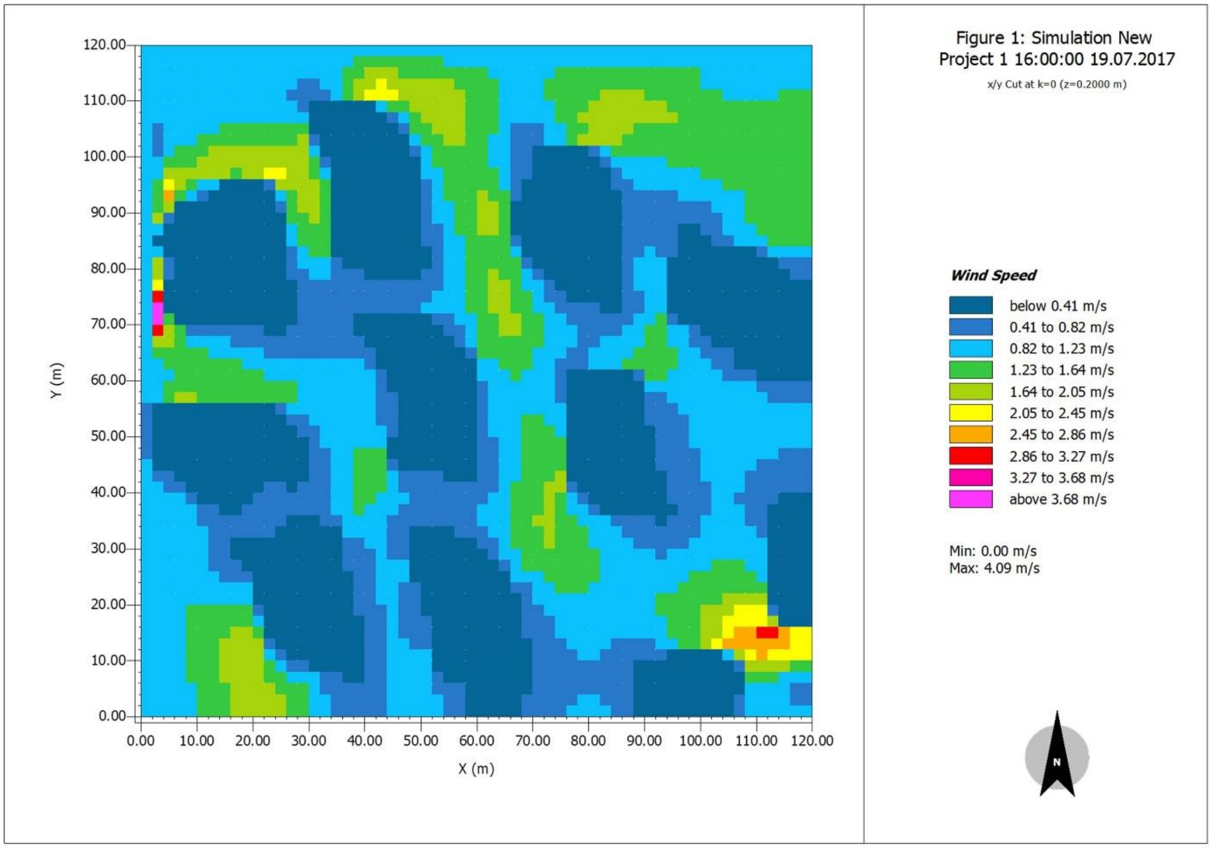
Strategy 2 - Coverage - granite shining - Mapping of wind speed at 1pm



Strategy 2 - Coverage - granite shining - Mapping of wind speed at 2pm



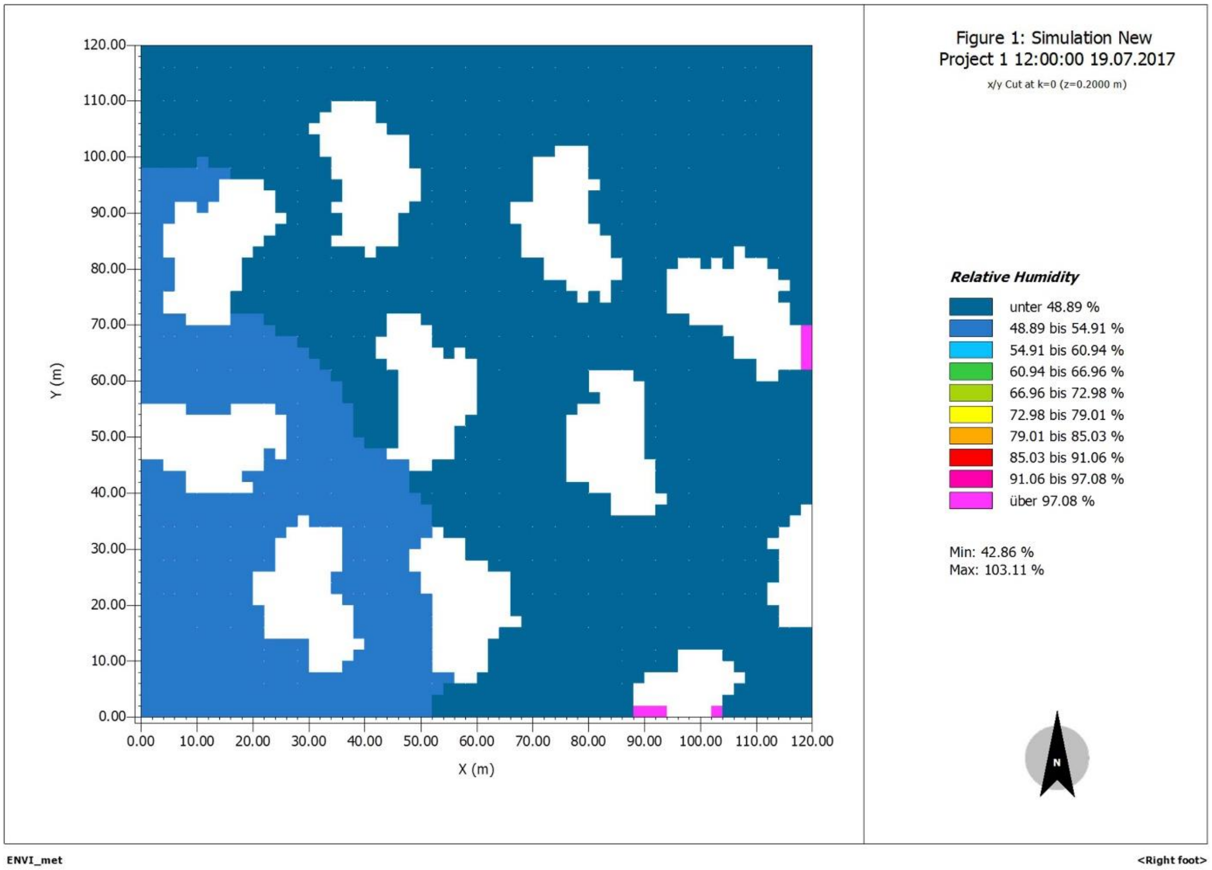
Strategy 2 - Coverage - granite shining - Mapping of wind speed at 3pm



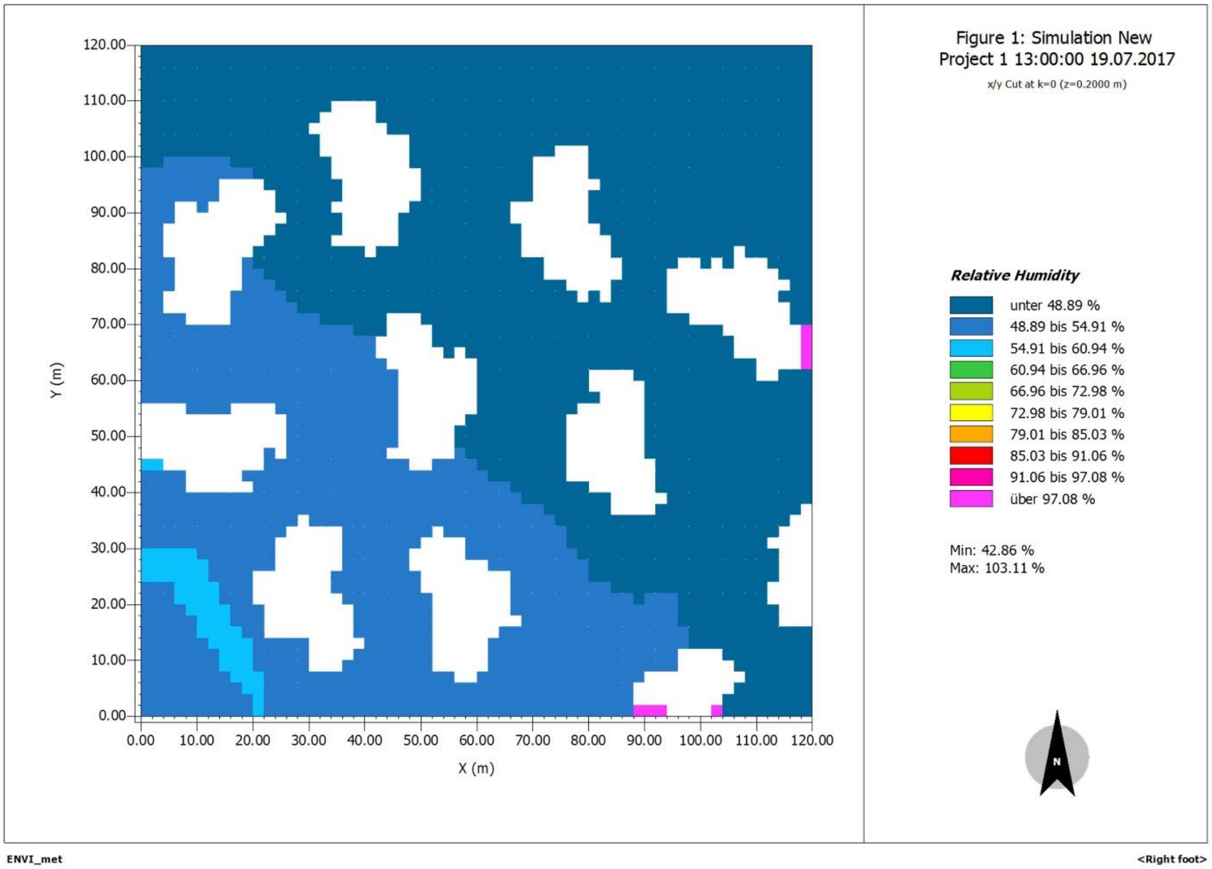
ENVI_met <Right foot>

Strategy 2 - Coverage - granite shining - Mapping of wind speed at 4pm

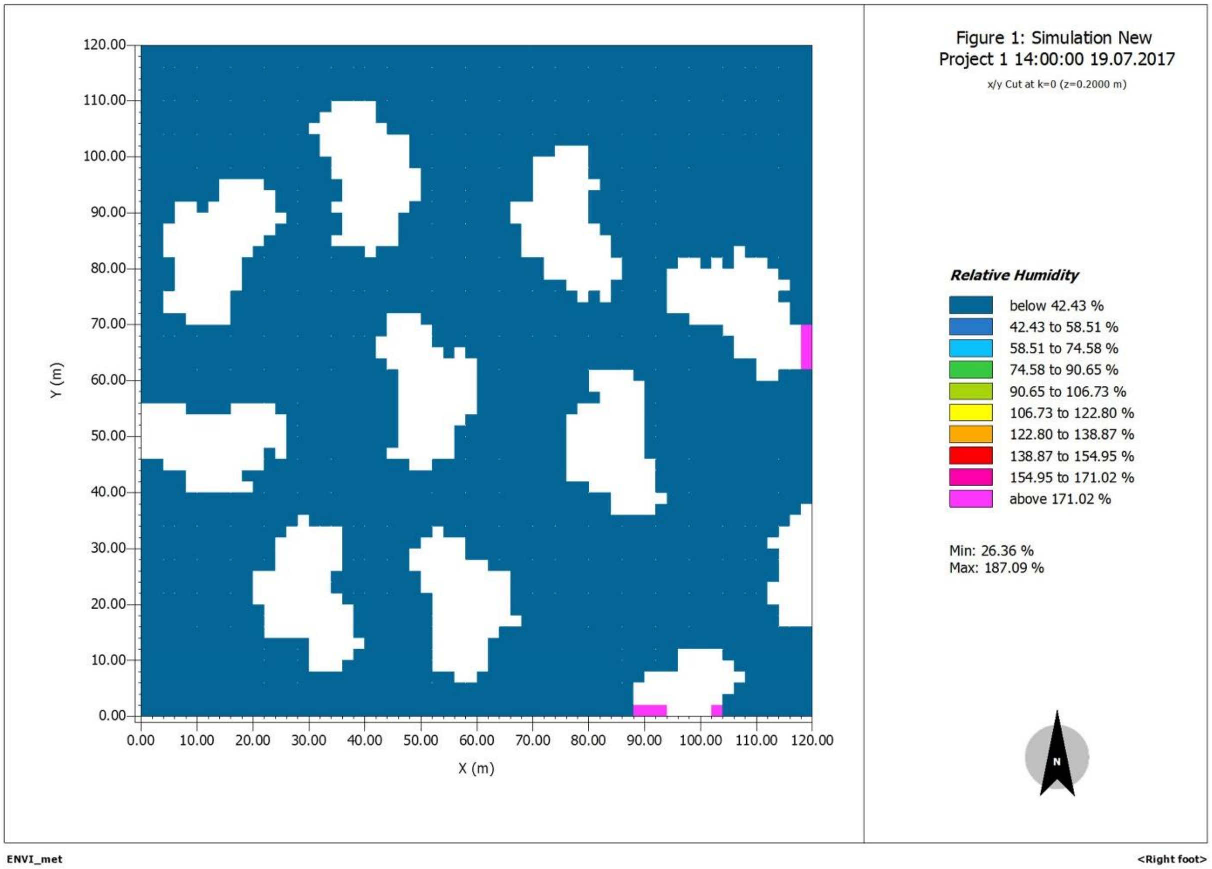
RELATIVE HUMIDITY



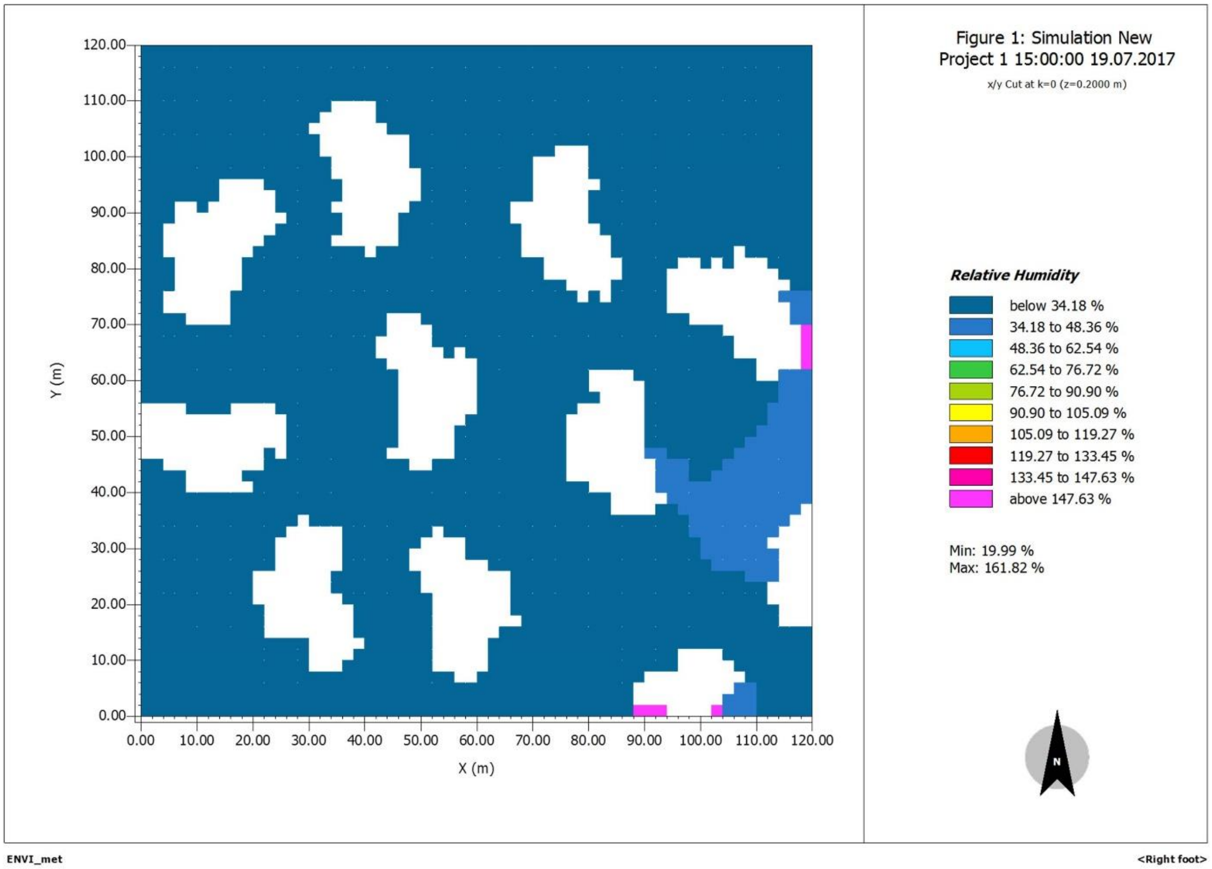
Strategy 2 - Coverage - granite shining - Mapping of relative humidity at 12pm



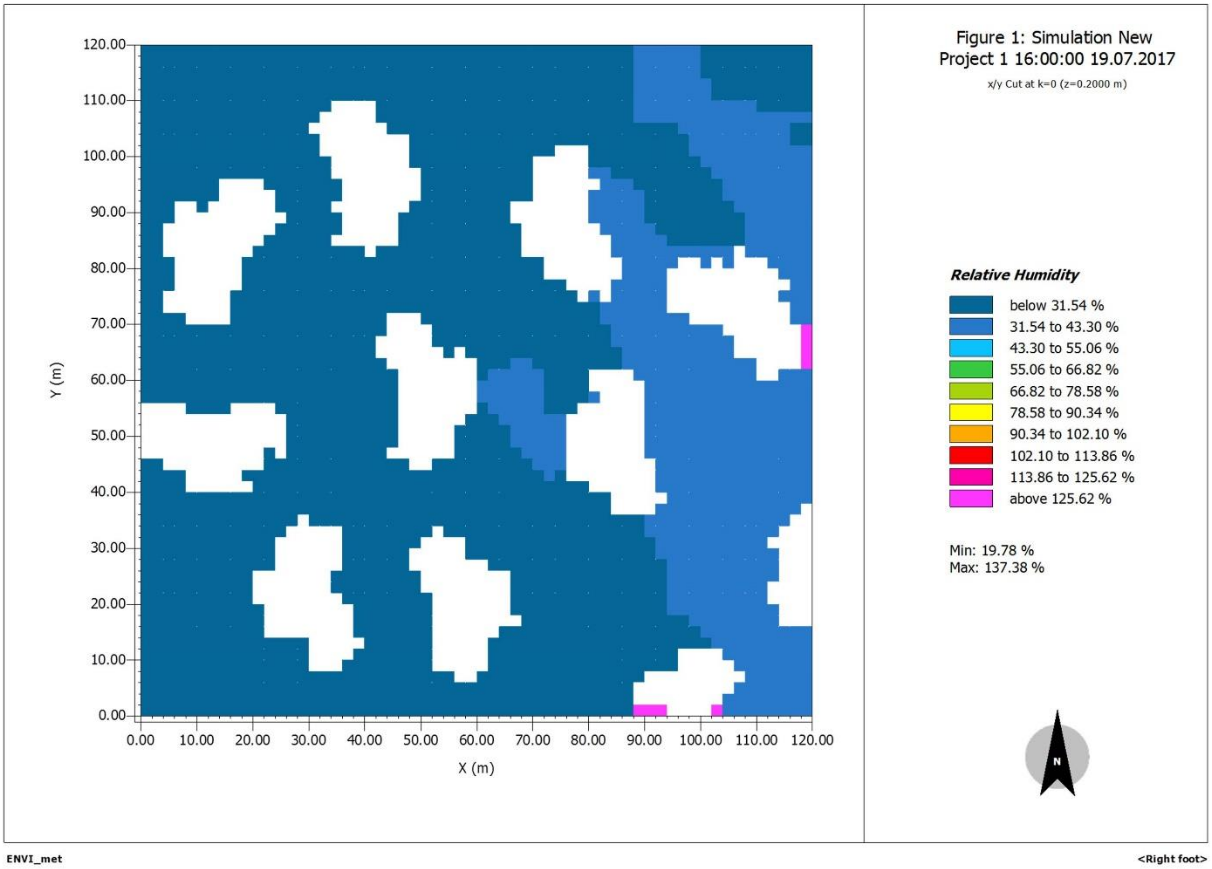
Strategy 2 - Coverage - granite shining - Mapping of relative humidity at 1pm



Strategy 2 - Coverage - granite shining - Mapping of relative humidity at 2pm



Strategy 2 - Coverage - granite shining - Mapping of relative humidity at 3pm



Strategy 2 - Coverage - granite shining - Mapping of relative humidity at 4pm

SPOT 1 front yard			
coverage materials	best results from str1	concrete pavement light	pavement granite shining
AT @ 12pm	38.56	39.69	43.37
AT @ 1pm	44.65	45.38	50.15
AT @ 2pm	48.78	45.38	55.12
AT @ 3pm	48.68	43.38	54.86
AT @ 4pm	48.68	43.38	55.34
	45.87	43.44	51.77
coverage materials	best results from str1	concrete pavement light	pavement granite shining
WS @ 12pm	1.12	1.07	1.15
WS @ 1pm	1.15	1.09	1.13
WS @ 2pm	1.24	1.09	1.19
WS @ 3pm	1.28	1.10	1.22
WS @ 4pm	1.30	1.11	1.23
	1.22	1.09	1.18
coverage materials	best results from str1	concrete pavement light	pavement granite shining
RH @ 12pm	62.88	57.08	48.89
RH @ 1pm	76.77	52.20	48.89
RH @ 2pm	76.77	48.24	42.43
RH @ 3pm	76.77	48.15	34.18
RH @ 4pm	76.77	47.40	31.54
	73.99	50.61	41.19

SPOT 2 back yard			
coverage materials	best results from str1	concrete pavement light	pavement granite shining
AT @ 12pm	36.70	37.49	40.76
AT @ 1pm	44.65	45.38	50.15
AT @ 2pm	48.78	45.38	55.12
AT @ 3pm	51.72	46.03	58.61
AT @ 4pm	52.81	46.03	58.61
	46.93	44.06	52.65
coverage materials	best results from str1	concrete pavement light	pavement granite shining
WS @ 12pm	1.12	1.07	1.15
WS @ 1pm	1.15	1.09	1.13
WS @ 2pm	1.24	1.09	1.19
WS @ 3pm	1.28	1.10	1.22
WS @ 4pm	1.30	1.11	1.23
	1.22	1.09	1.18
coverage materials	best results from str1	concrete pavement light	pavement granite shining
RH @ 12pm	62.88	58.08	48.89
RH @ 1pm	76.77	49.65	55.91
RH @ 2pm	76.77	46.62	42.43
RH @ 3pm	76.77	45.67	34.18
RH @ 4pm	76.77	45.56	31.54
	73.99	49.12	42.59

SPOT 3 road surface			
coverage materials	best results from str1	concrete pavement light	pavement granite shining
AT @ 12pm	38.56	39.69	43.37
AT @ 1pm	44.65	45.38	50.15
AT @ 2pm	45.83	45.38	55.12
AT @ 3pm	48.68	43.38	54.86
AT @ 4pm	49.94	40.74	51.88
	45.53	42.91	51.08
coverage materials	best results from str1	concrete pavement light	pavement granite shining
WS @ 12pm	1.12	1.07	1.15
WS @ 1pm	1.15	1.09	1.13
WS @ 2pm	1.24	1.09	1.19
WS @ 3pm	1.28	1.10	1.22
WS @ 4pm	1.30	1.11	1.23
	1.22	1.09	1.18
coverage materials	best results from str1	concrete pavement light	pavement granite shining
RH @ 12pm	62.88	57.08	48.89
RH @ 1pm	76.77	52.20	48.89
RH @ 2pm	76.77	49.86	42.43
RH @ 3pm	76.77	48.15	34.18
RH @ 4pm	76.77	48.02	31.54
	73.99	51.06	41.19

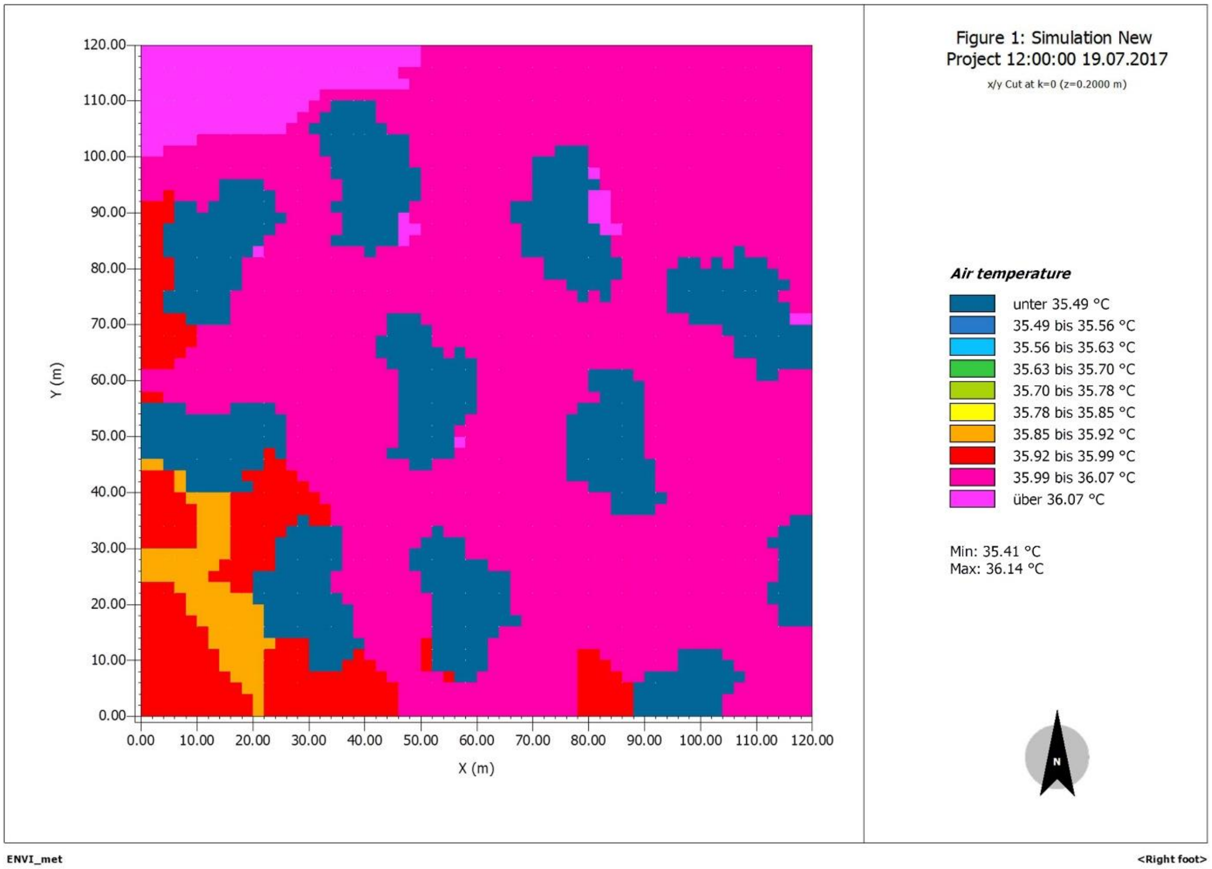
SPOT 4 open space			
coverage materials	best results from str1	concrete pavement light	pavement granite shining
AT @ 12pm	36.70	35.30	38.16
AT @ 1pm	44.65	45.38	50.15
AT @ 2pm	51.73	48.13	58.12
AT @ 3pm	54.75	48.67	62.61
AT @ 4pm	55.69	48.67	62.27
	48.70	45.23	54.26
coverage materials	best results from str1	concrete pavement light	pavement granite shining
WS @ 12pm	1.12	1.07	1.15
WS @ 1pm	1.15	1.09	1.13
WS @ 2pm	1.24	1.09	1.19
WS @ 3pm	1.28	1.10	1.22
WS @ 4pm	1.30	1.11	1.23
	1.22	1.09	1.18
coverage materials	best results from str1	concrete pavement light	pavement granite shining
RH @ 12pm	63.96	58.08	54.91
RH @ 1pm	76.77	49.65	54.91
RH @ 2pm	76.77	44.99	42.43
RH @ 3pm	76.77	44.42	34.18
RH @ 4pm	76.77	45.56	31.54
	74.21	48.54	43.59

averages for simulation 1,5,6			
coverage materials	best results from str1	concrete pavement light	pavement granite shining
AT @ 12pm	37.63	38.04	41.42
AT @ 1pm	44.65	45.38	50.15
AT @ 2pm	48.78	46.07	55.87
AT @ 3pm	50.96	45.37	57.74
AT @ 4pm	51.78	44.71	57.03
	46.76	43.91	52.44
coverage materials	best results from str1	concrete pavement light	pavement granite shining
WS @ 12pm	1.12	1.07	1.15
WS @ 1pm	1.15	1.09	1.13
WS @ 2pm	1.24	1.09	1.19
WS @ 3pm	1.28	1.10	1.22
WS @ 4pm	1.30	1.11	1.23
	1.22	1.09	1.18
coverage materials	best results from str1	concrete pavement light	pavement granite shining
RH @ 12pm	63.15	57.58	50.40
RH @ 1pm	76.77	50.93	52.15
RH @ 2pm	76.77	47.43	42.43
RH @ 3pm	76.77	46.60	34.18
RH @ 4pm	76.77	46.64	31.54
	74.05	49.83	42.14

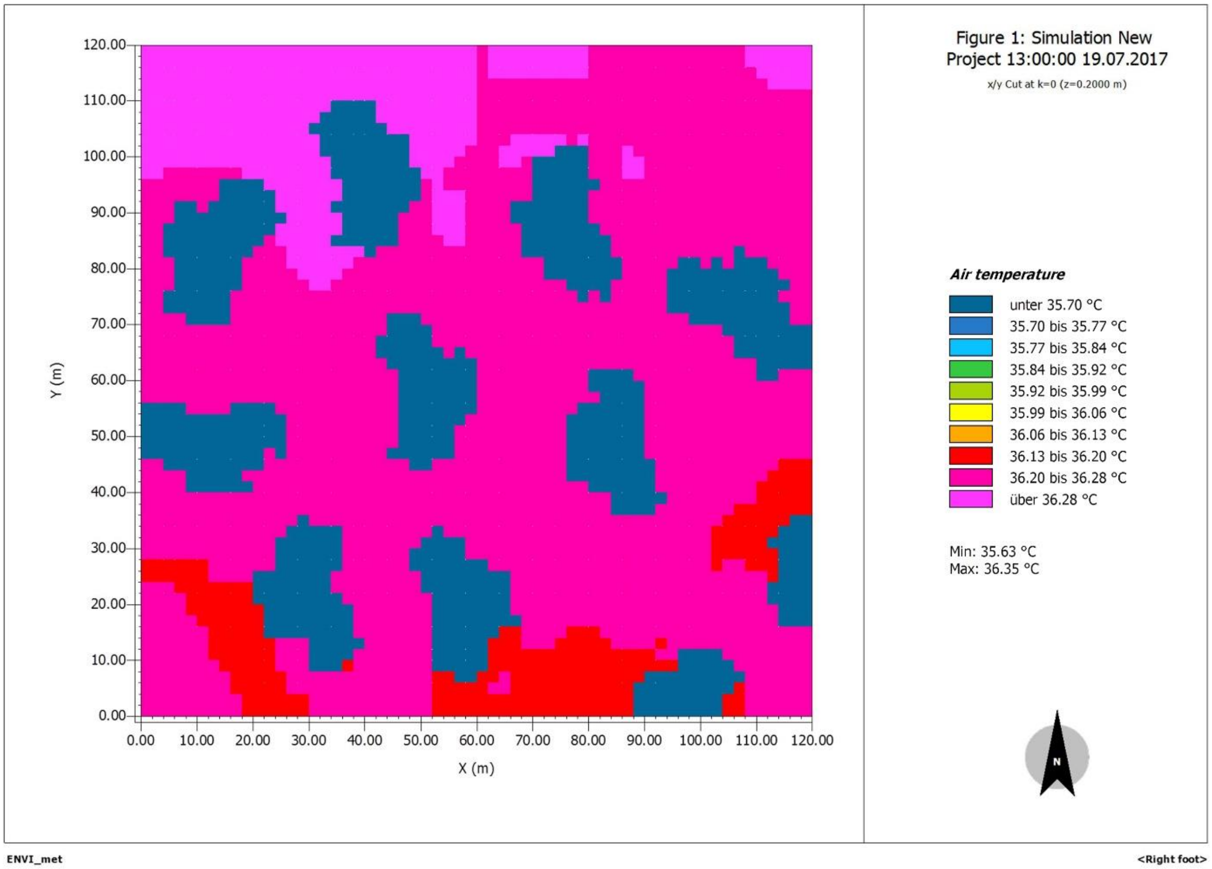
Appendix 7 - Strategy 3 - Greenery - 10m height trees

Model building, Greenery - 10m height trees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

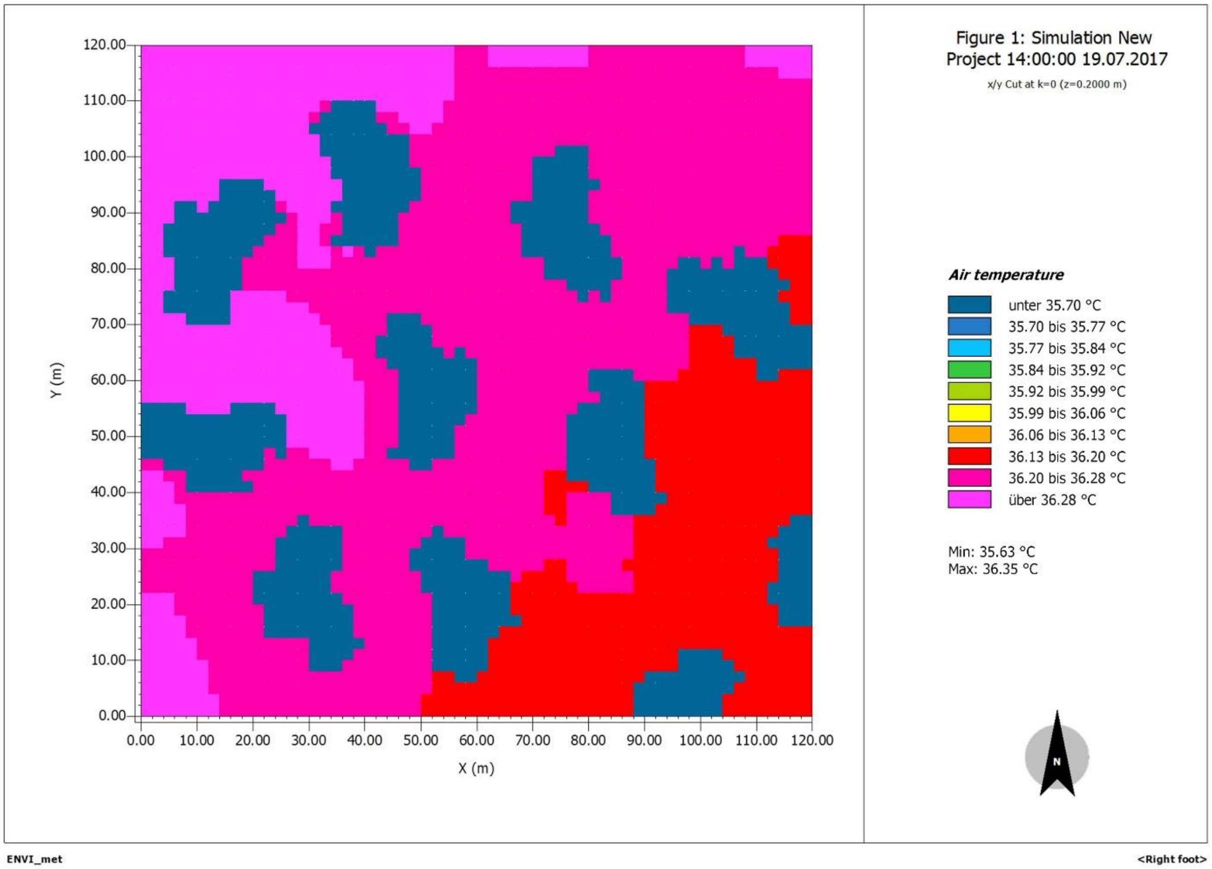
AIR TEMPERATURE



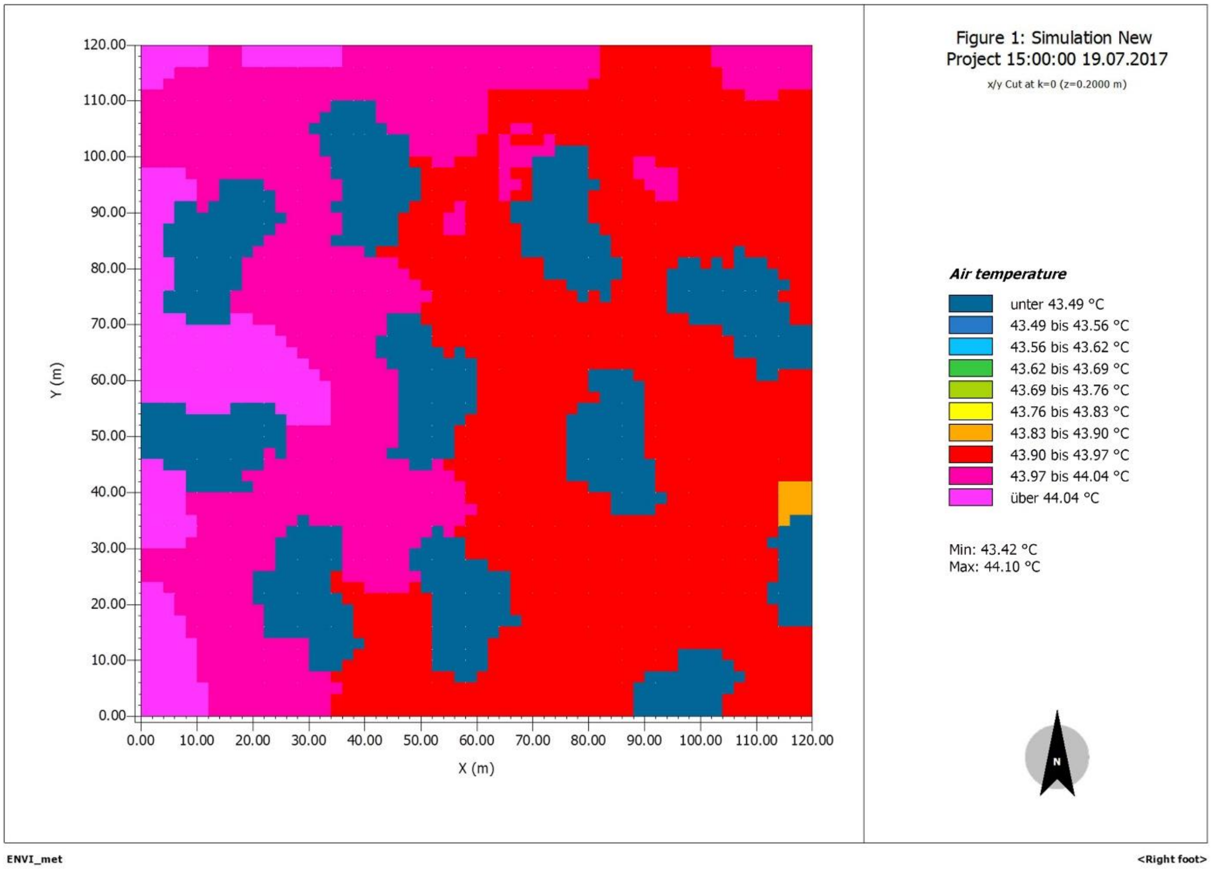
Strategy 3 - Greenery - 10m height trees - Mapping of air temperature at 12pm



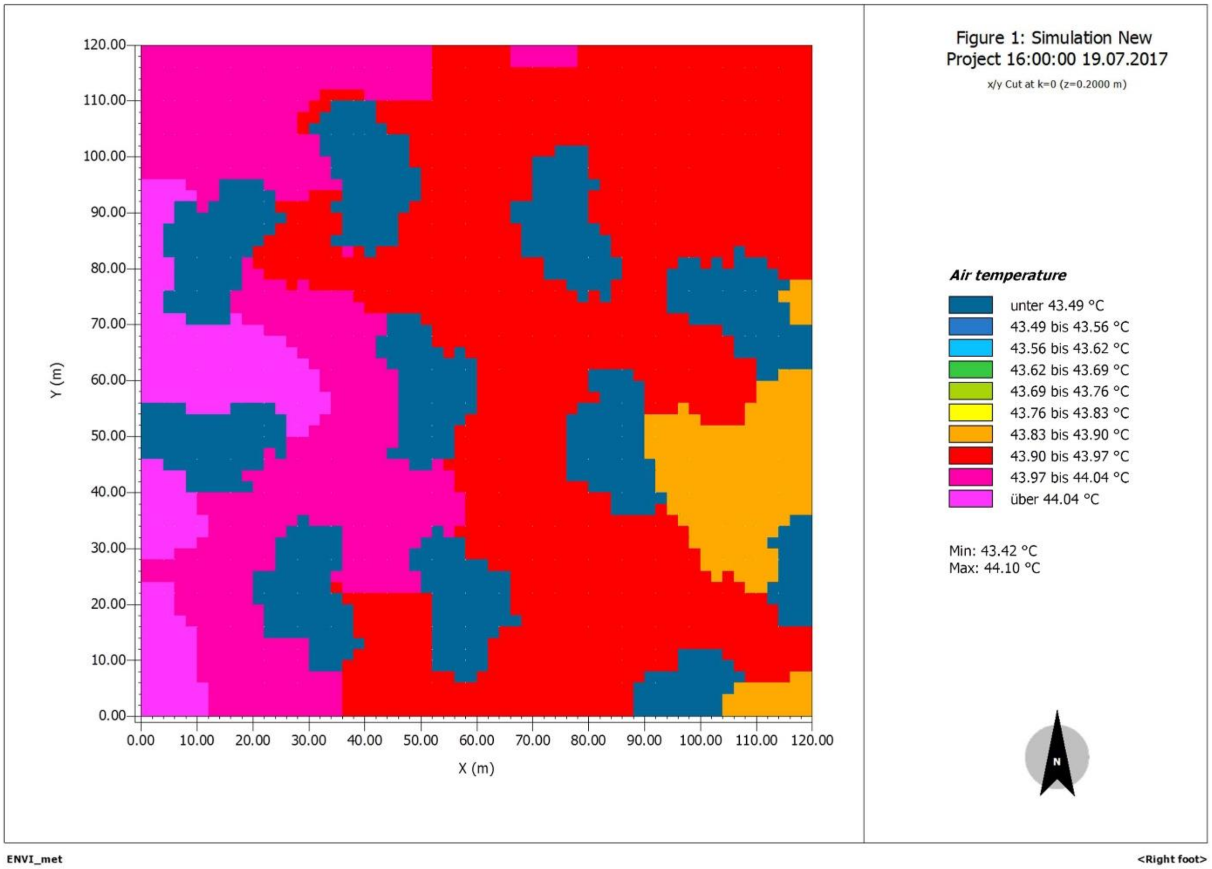
Strategy 3 - Greenery - 10m height trees - Mapping of air temperature at 1pm



Strategy 3 - Greenery - 10m height trees - Mapping of air temperature at 2pm

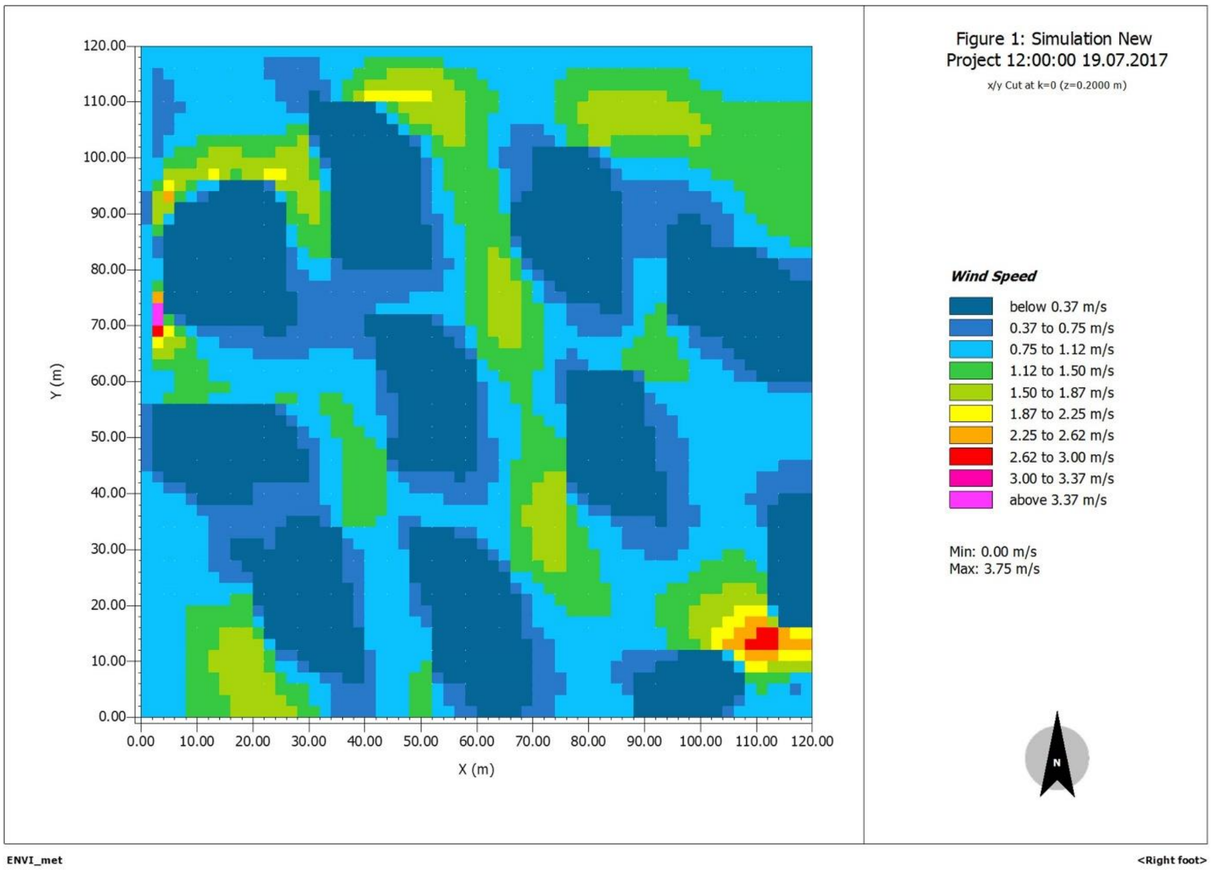


Strategy 3 - Greenery - 10m height trees - Mapping of air temperature at 3pm

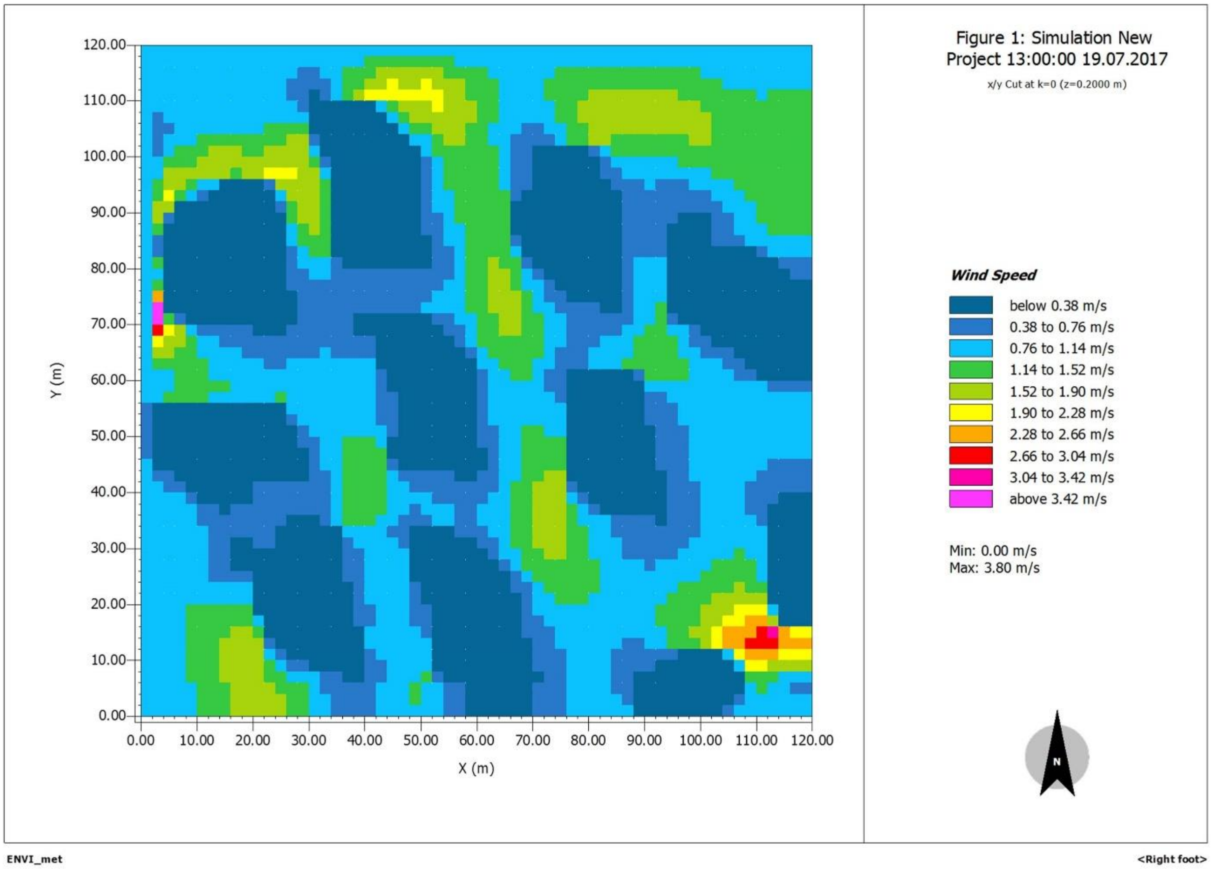


Strategy 3 - Greenery - 10m height trees - Mapping of air temperature at 4pm

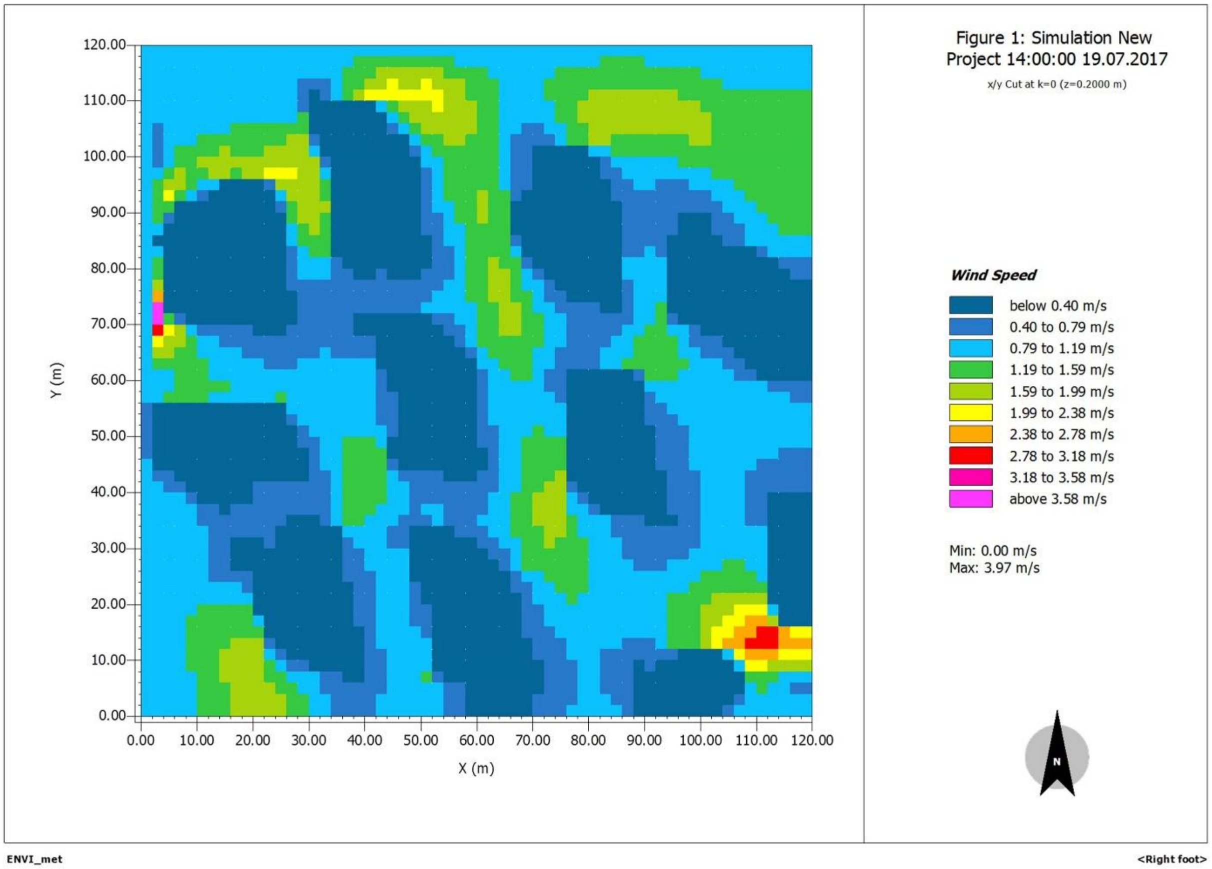
WIND SPEED



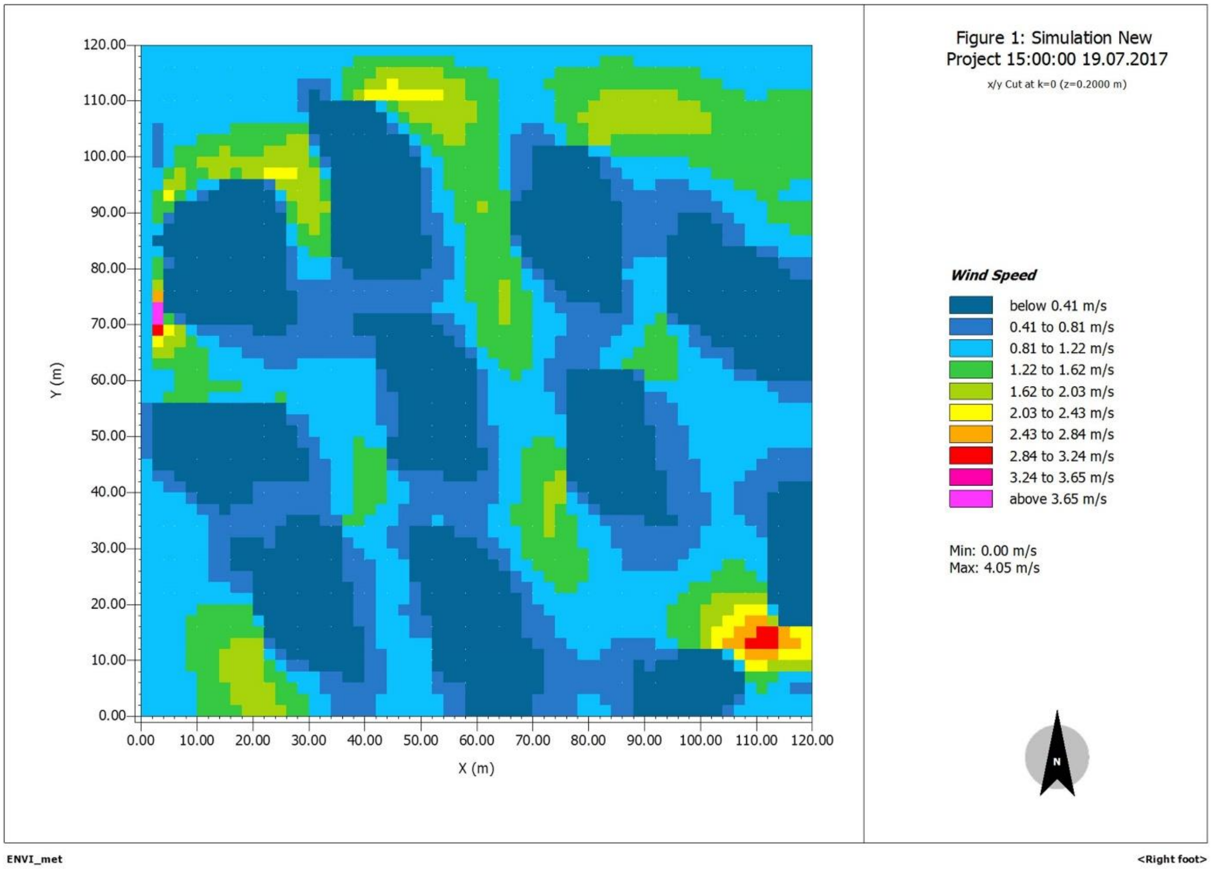
Strategy 3 - Greenery - 10m height trees - Mapping of wind speed at 12pm



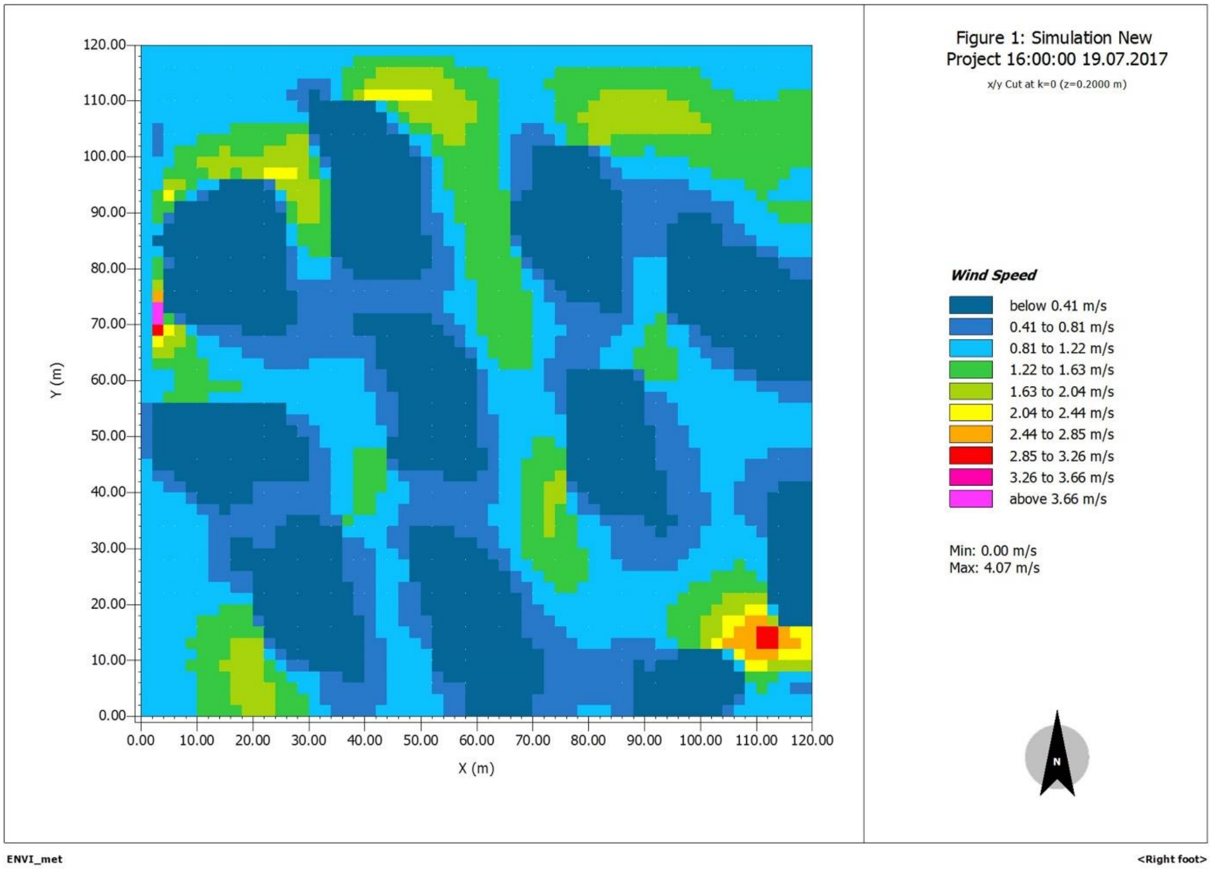
Strategy 3 - Greenery - 10m height trees - Mapping of wind speed at 1pm



Strategy 3 - Greenery - 10m height trees - Mapping of wind speed at 2pm

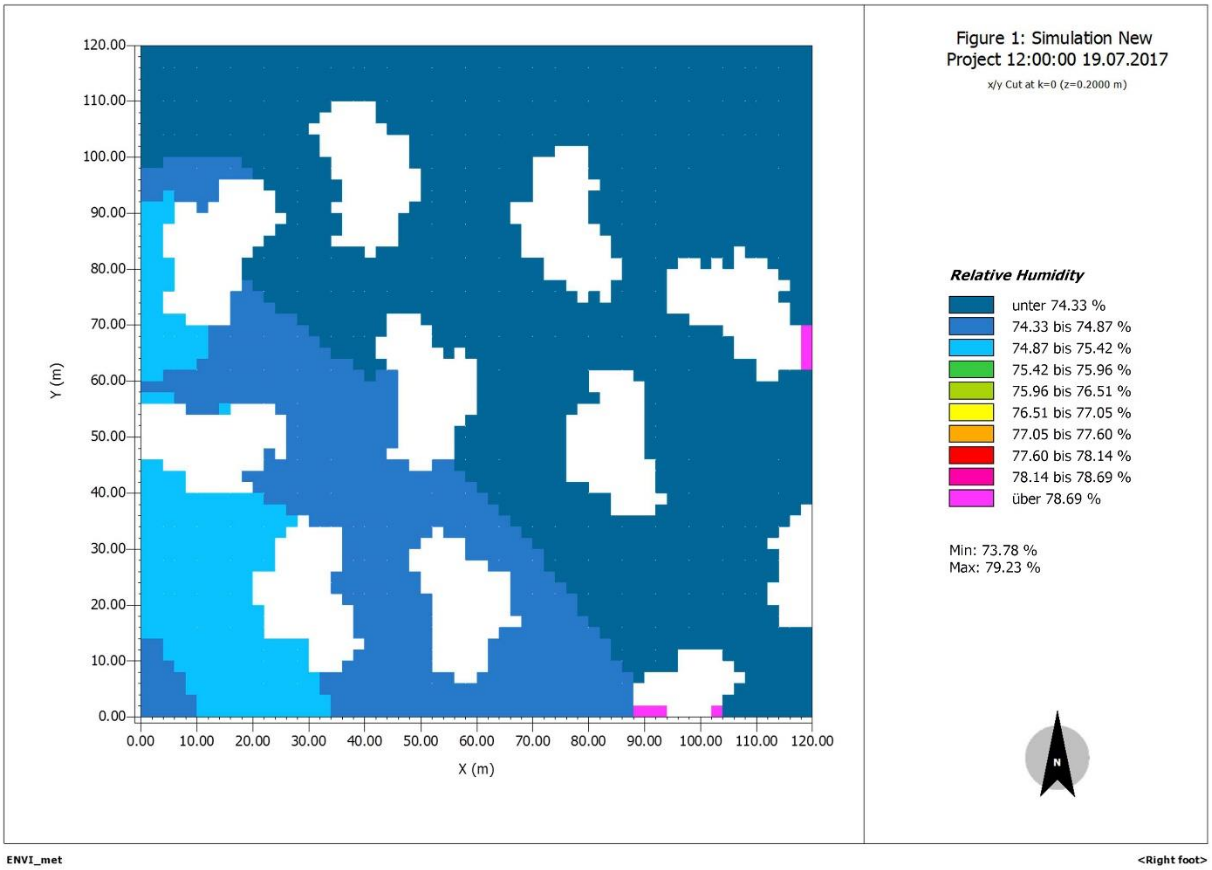


Strategy 3 - Greenery - 10m height trees - Mapping of wind speed at 3pm

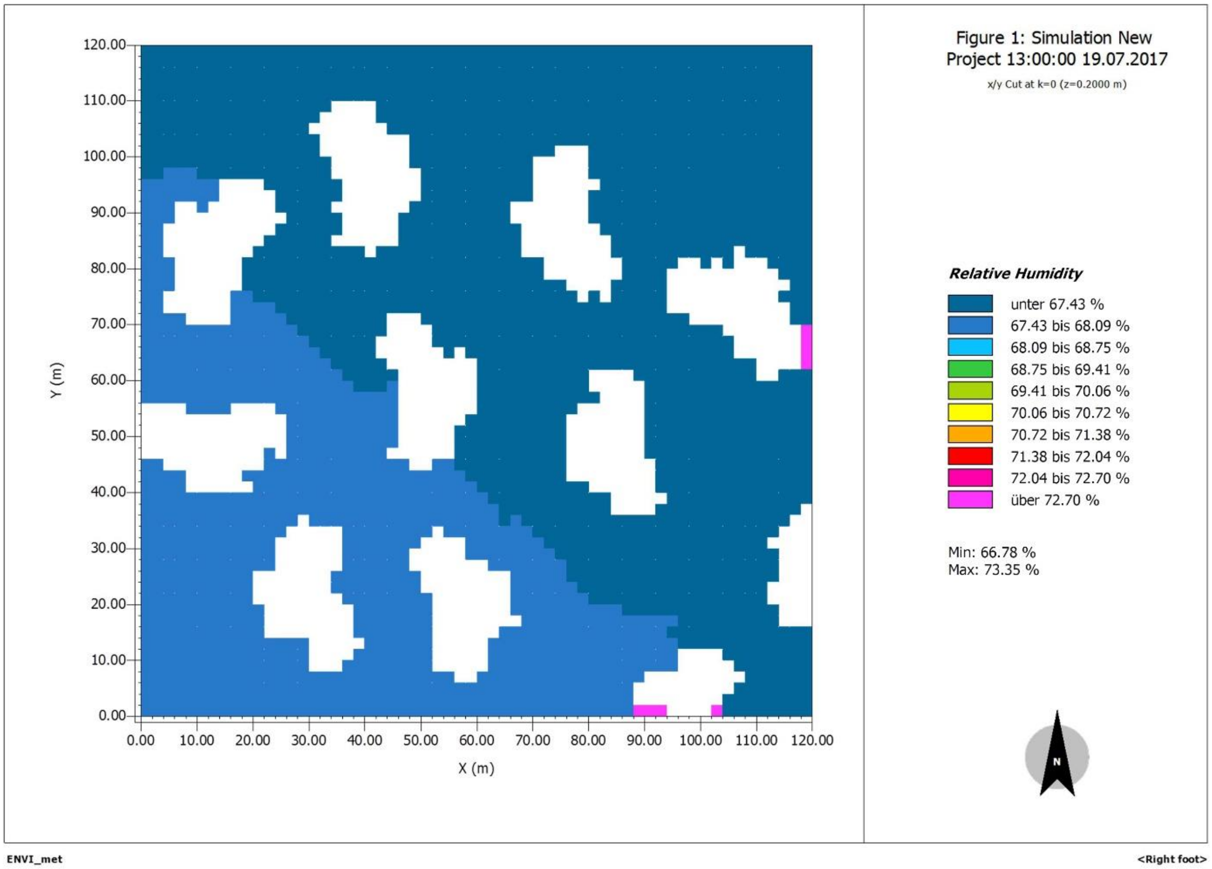


Strategy 3 - Greenery - 10m height trees - Mapping of wind speed at 4pm

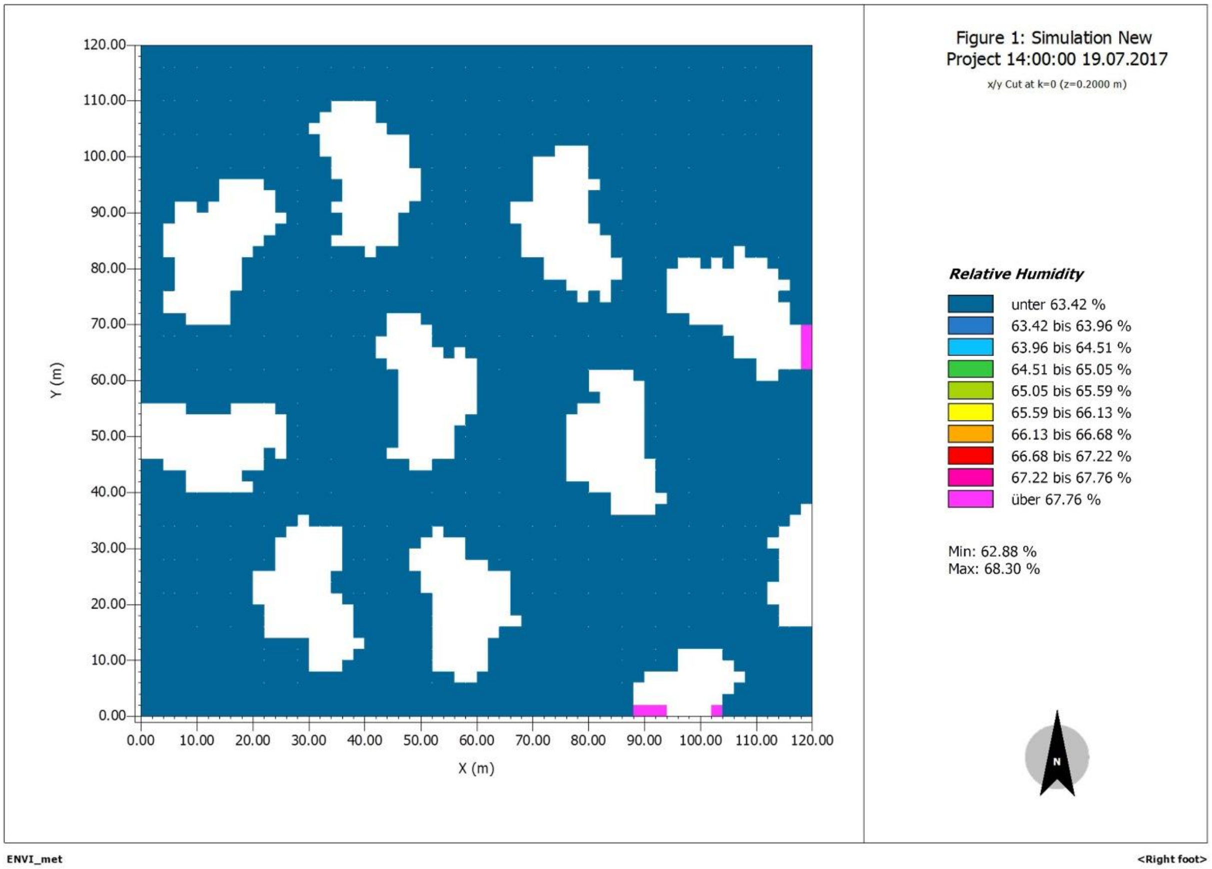
RELATIVE HUMIDITY



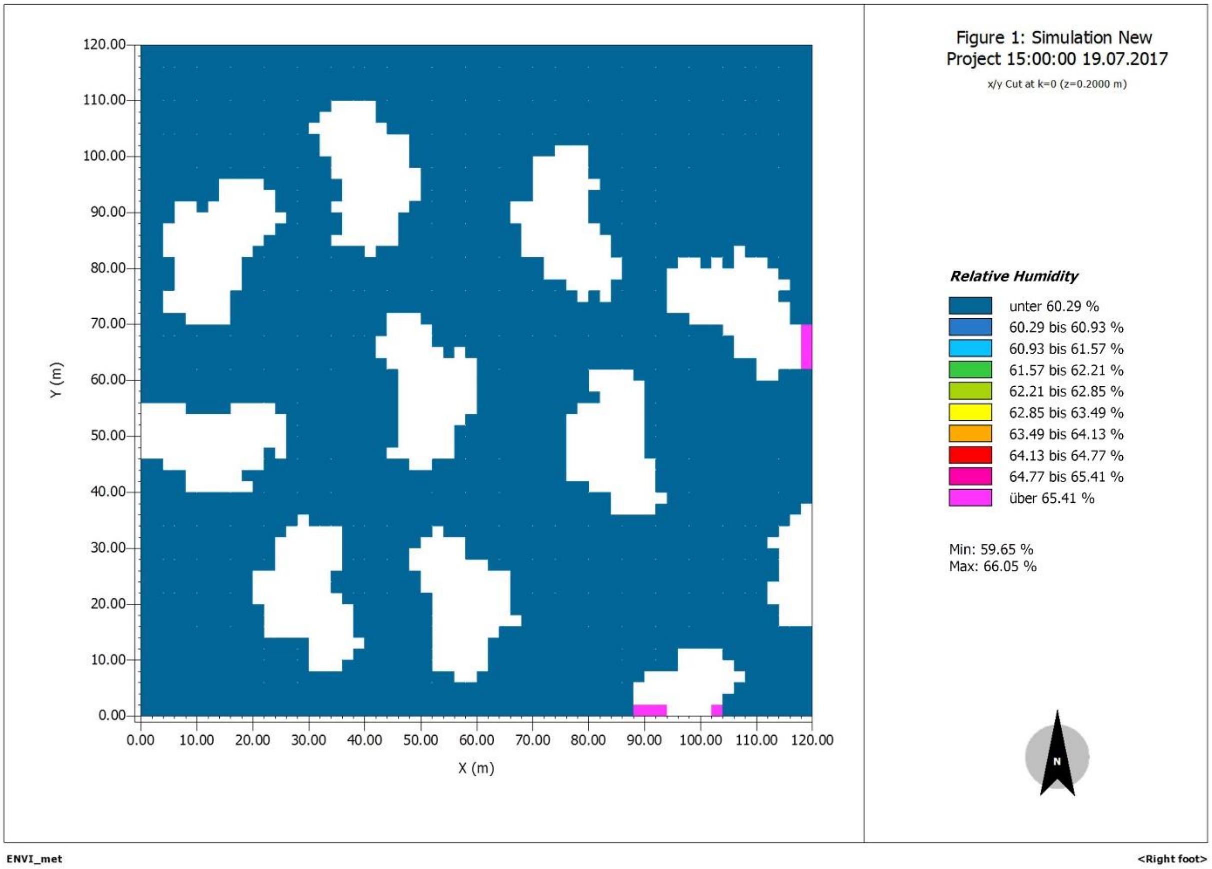
Strategy 3 - Greenery - 10m height trees - Mapping of relative humidity at 12pm



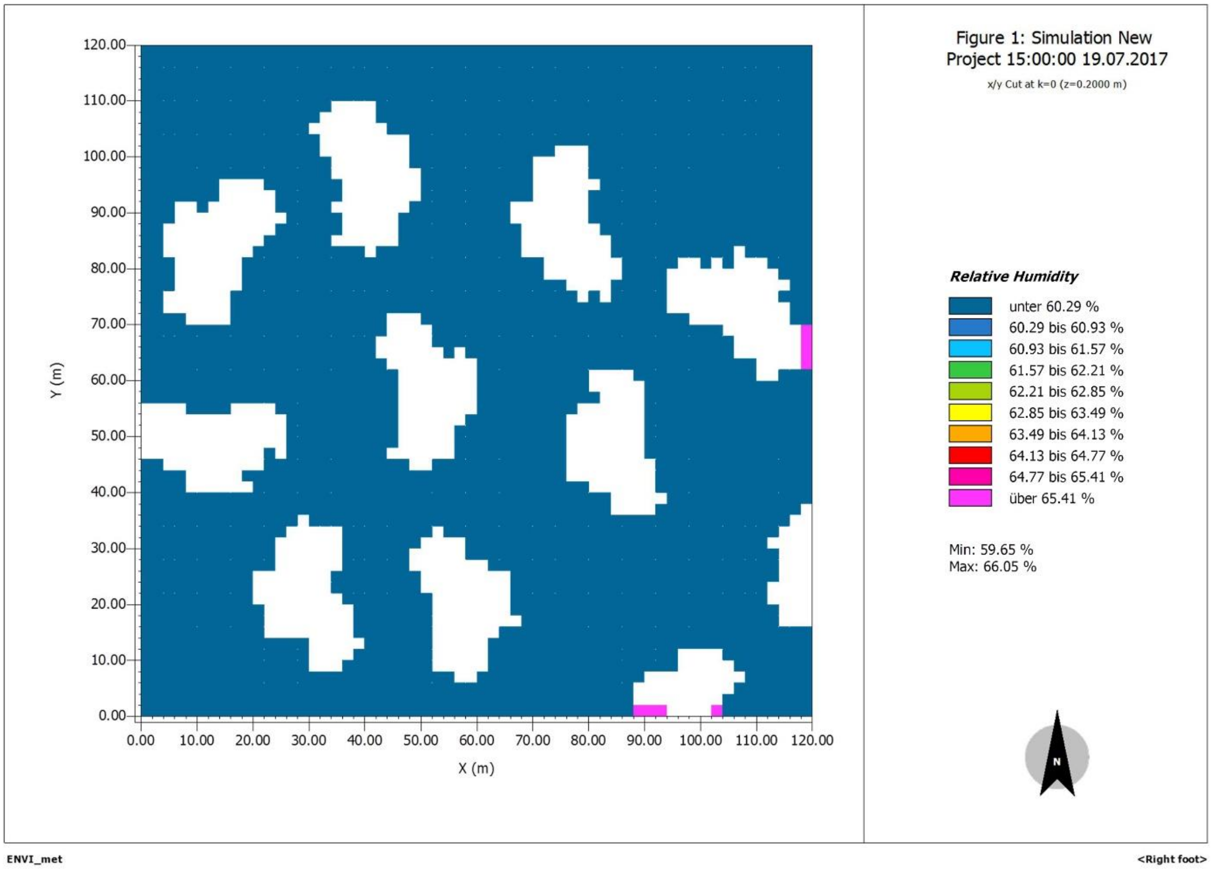
Strategy 3 - Greenery - 10m height trees - Mapping of relative humidity at 1pm



Strategy 3 - Greenery - 10m height trees - Mapping of relative humidity at 2pm



Strategy 3 - Greenery - 10m height trees - Mapping of relative humidity at 3pm

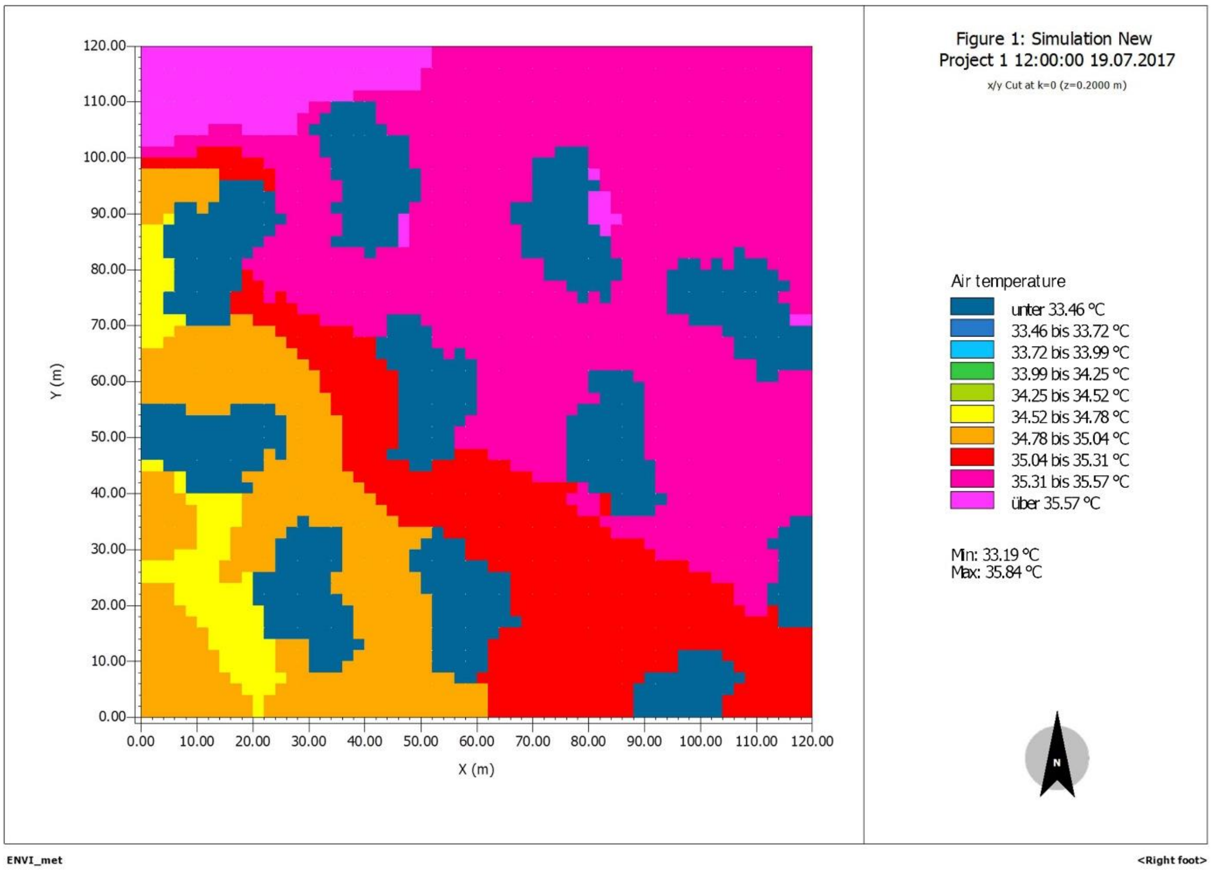


Strategy 3 - Greenery - 10m height trees - Mapping of relative humidity at 4pm

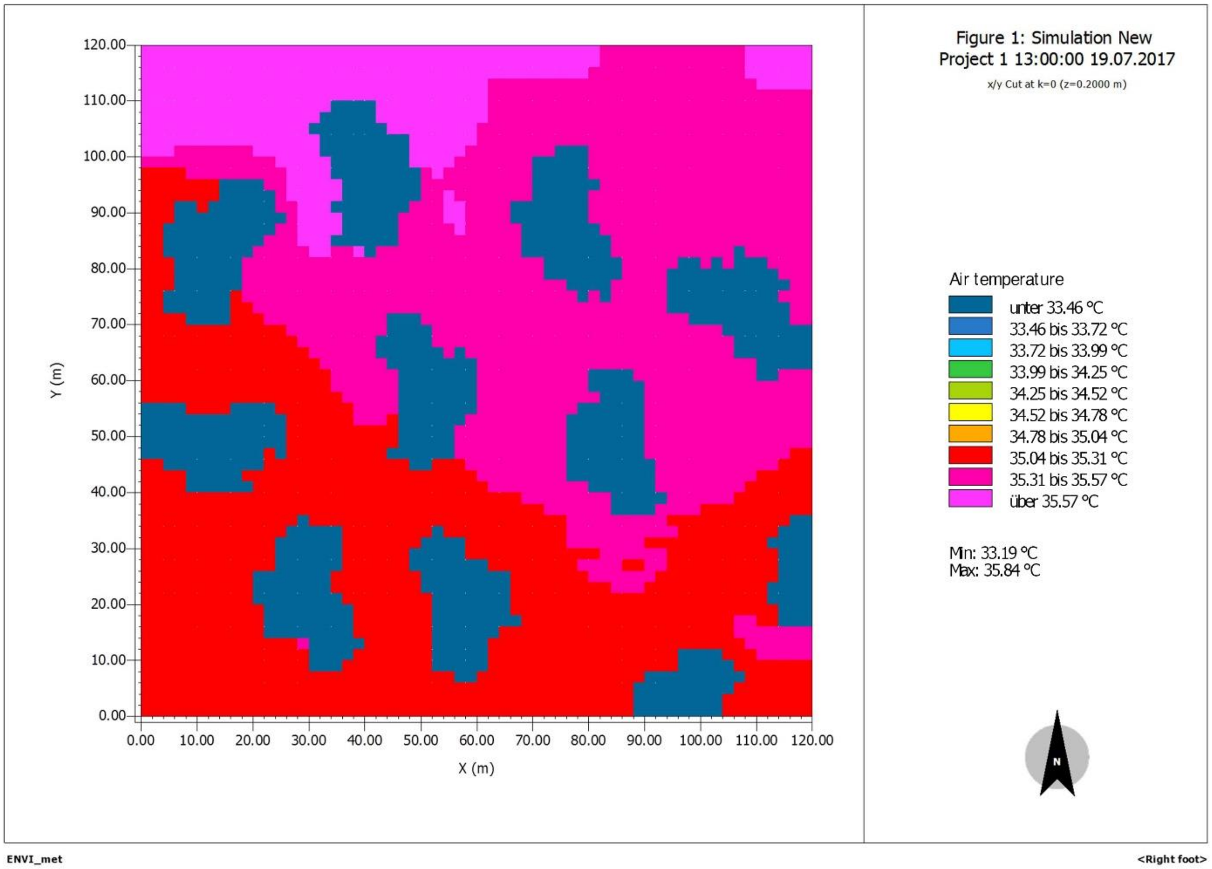
Appendix 8 - Strategy 3 - Greenery - 15m height trees

Model building, Greenery - 15m height trees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

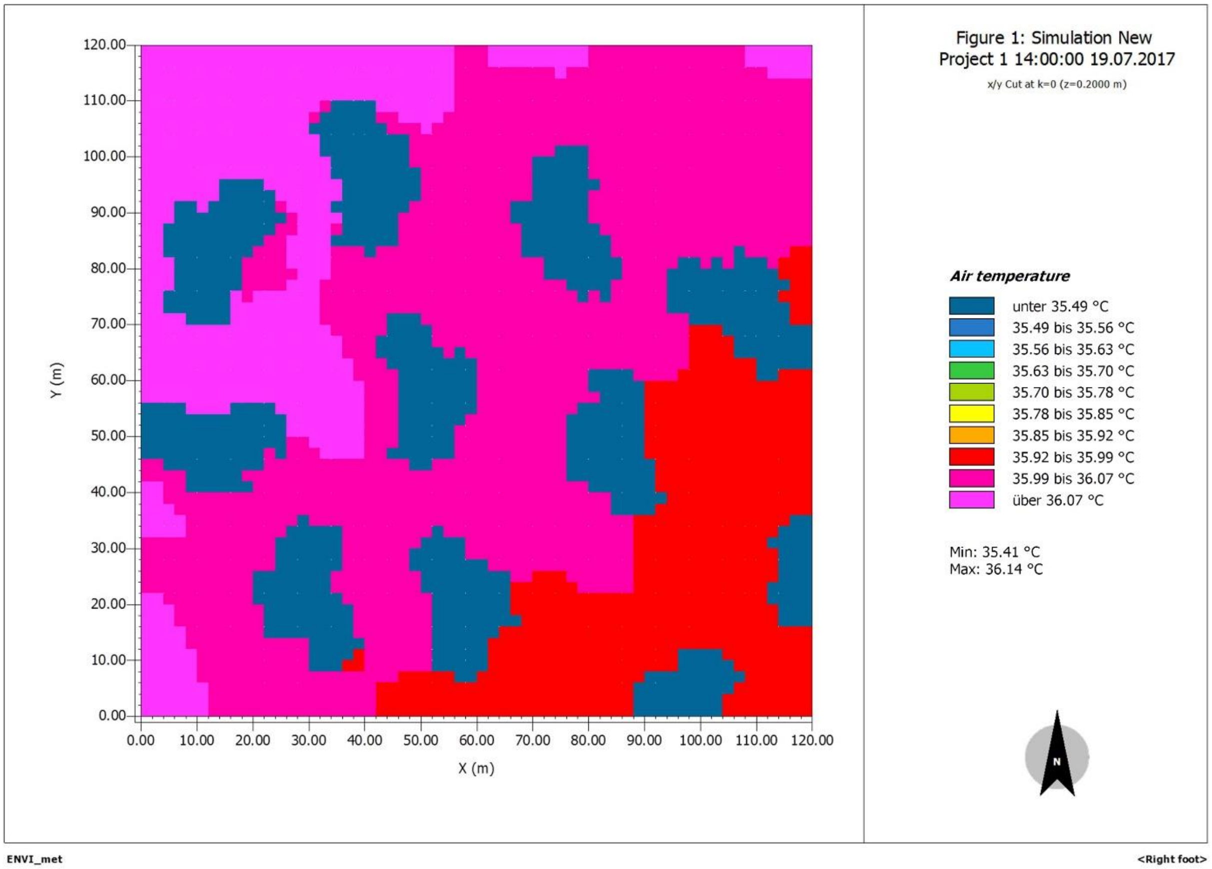
AIR TEMPERATURE



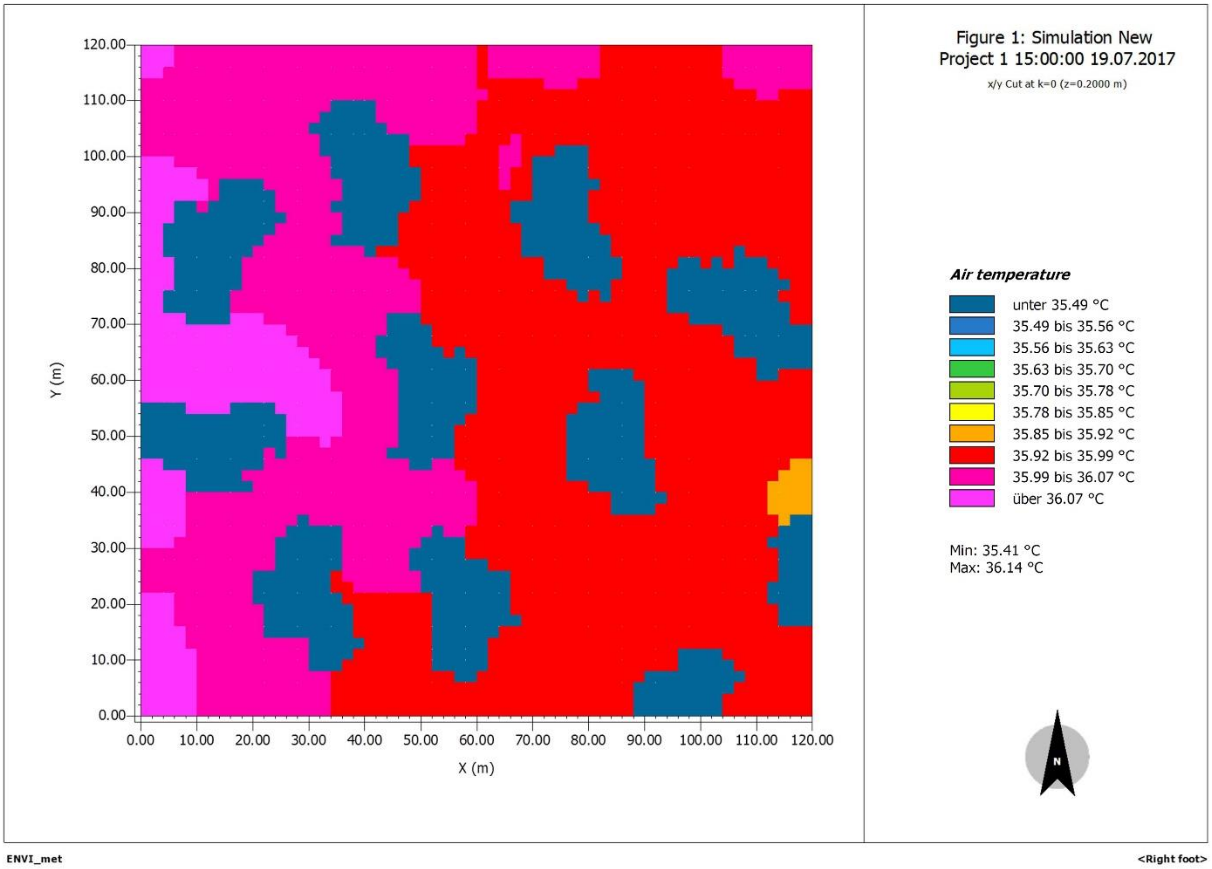
Strategy 3 - Greenery - 15m height trees - Mapping of air temperature at 12pm



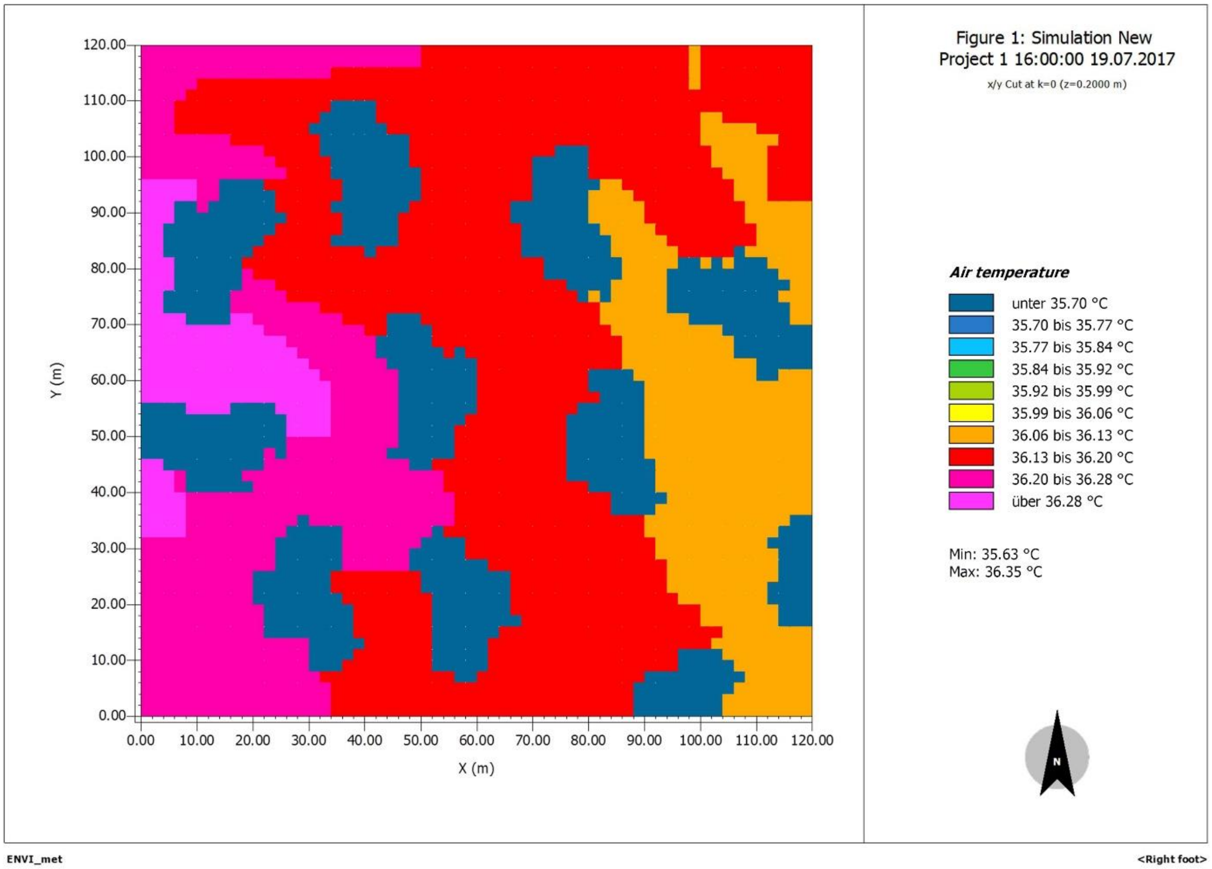
Strategy 3 - Greenery - 15m height trees - Mapping of air temperature at 1pm



Strategy 3 - Greenery - 15m height trees - Mapping of air temperature at 2pm

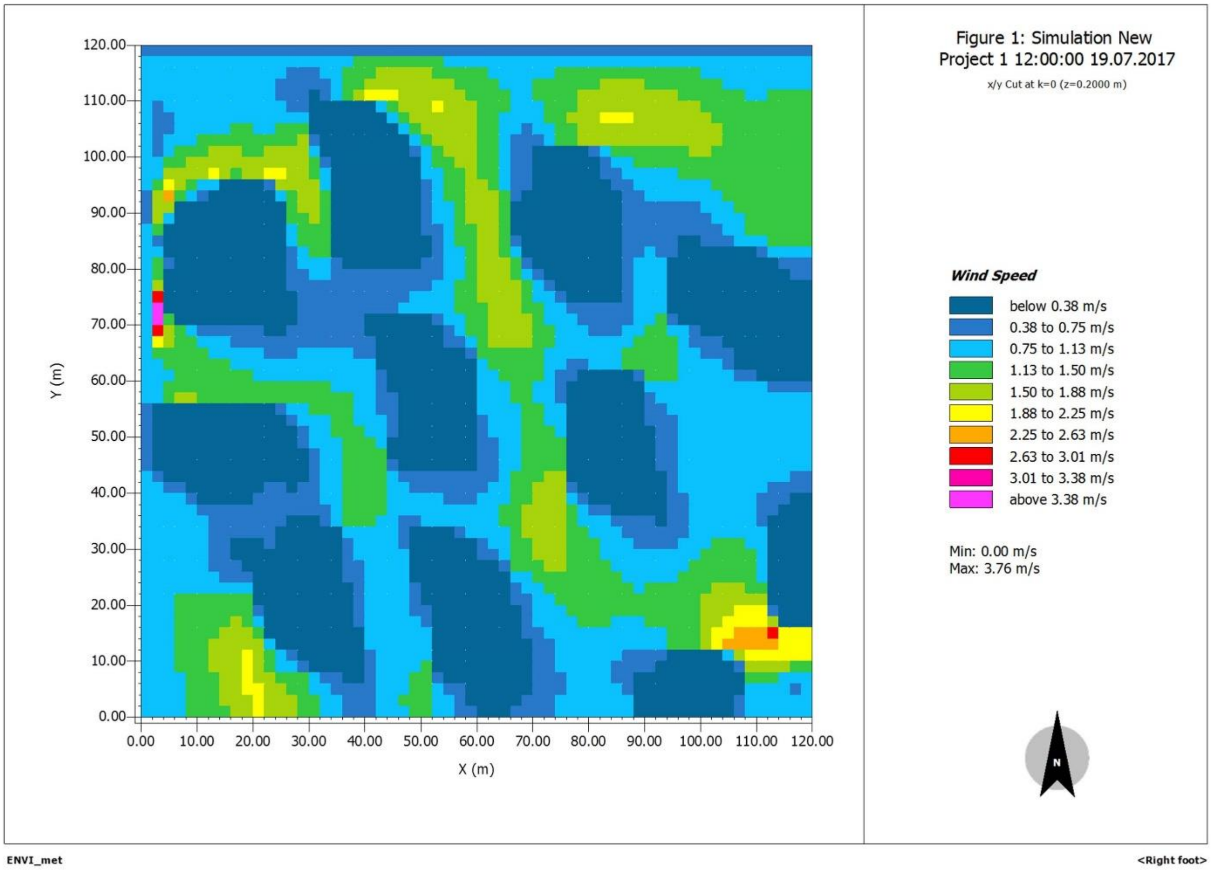


Strategy 3 - Greenery - 15m height trees - Mapping of air temperature at 3pm

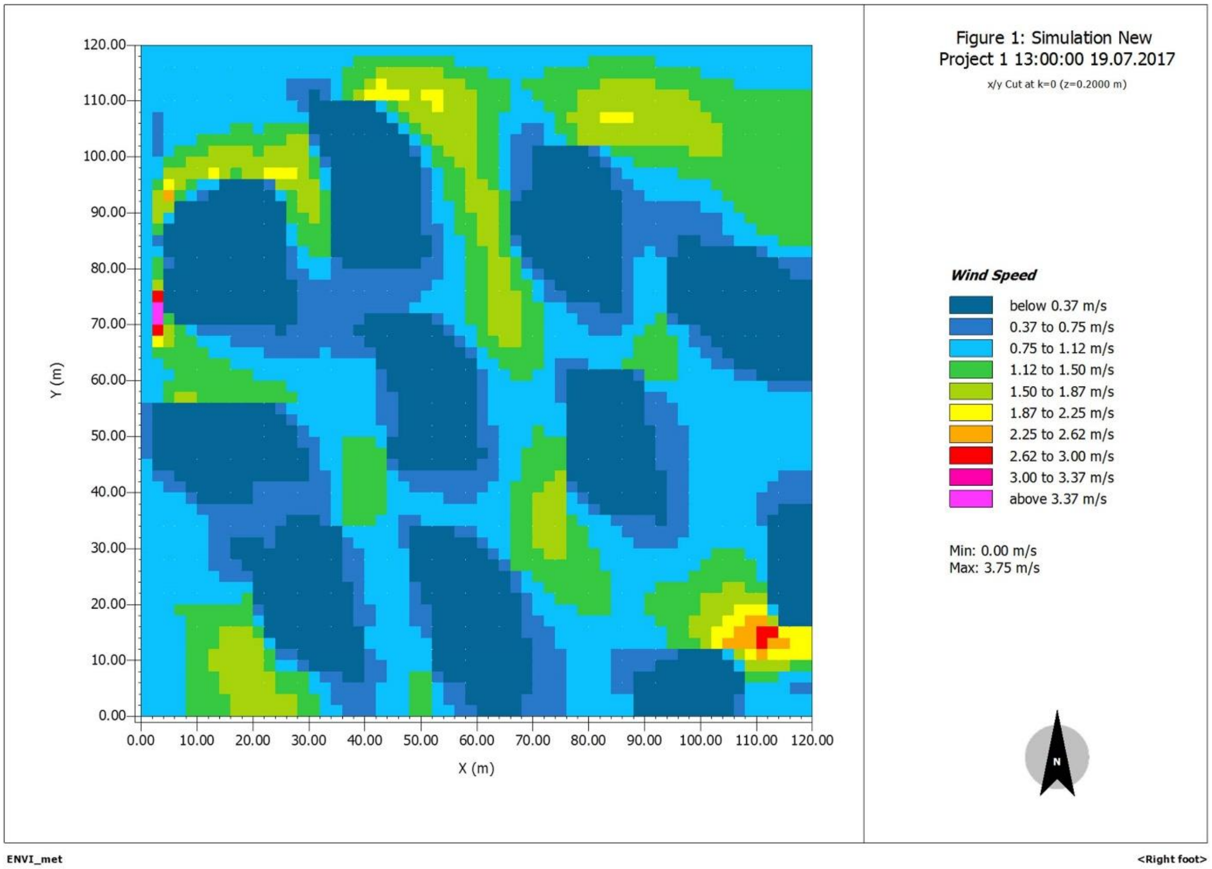


Strategy 3 - Greenery - 15m height trees - Mapping of air temperature at 4pm

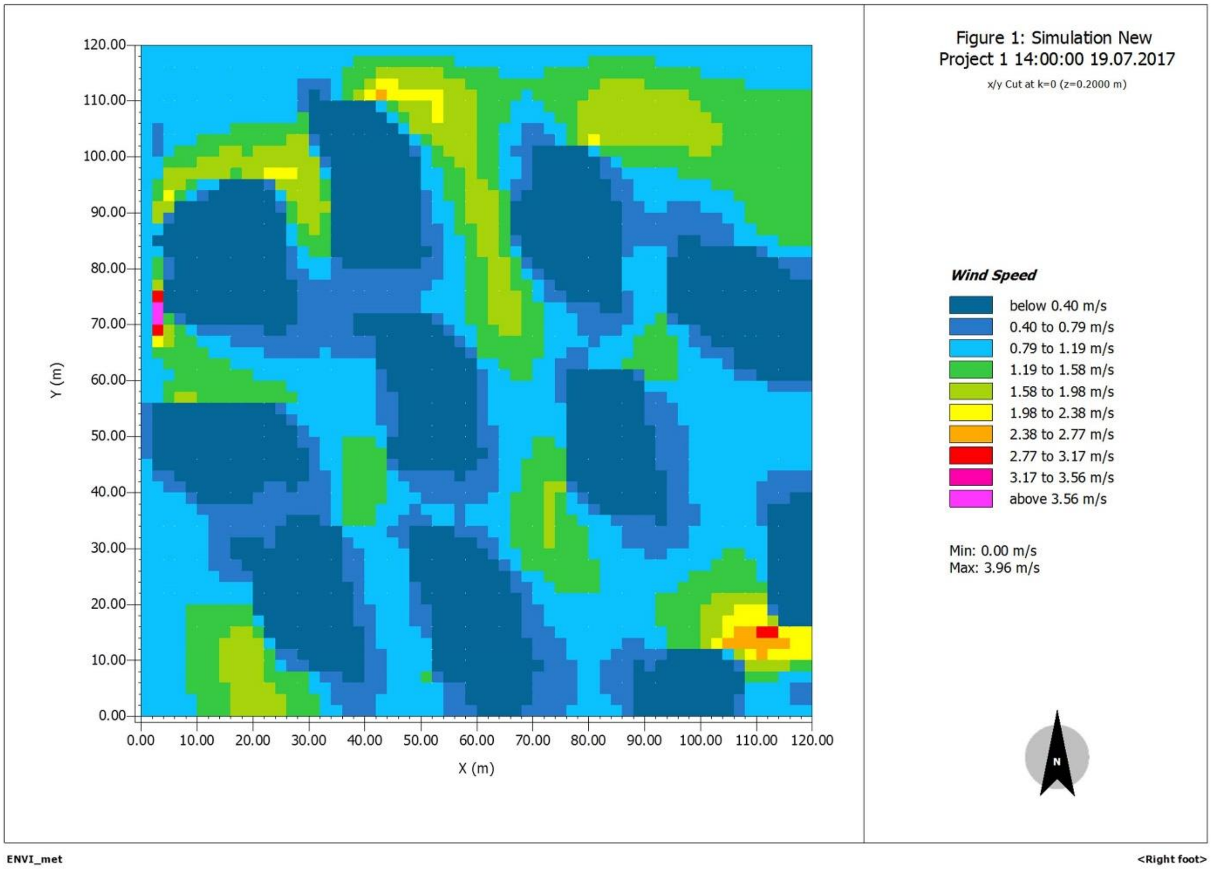
WIND SPEED



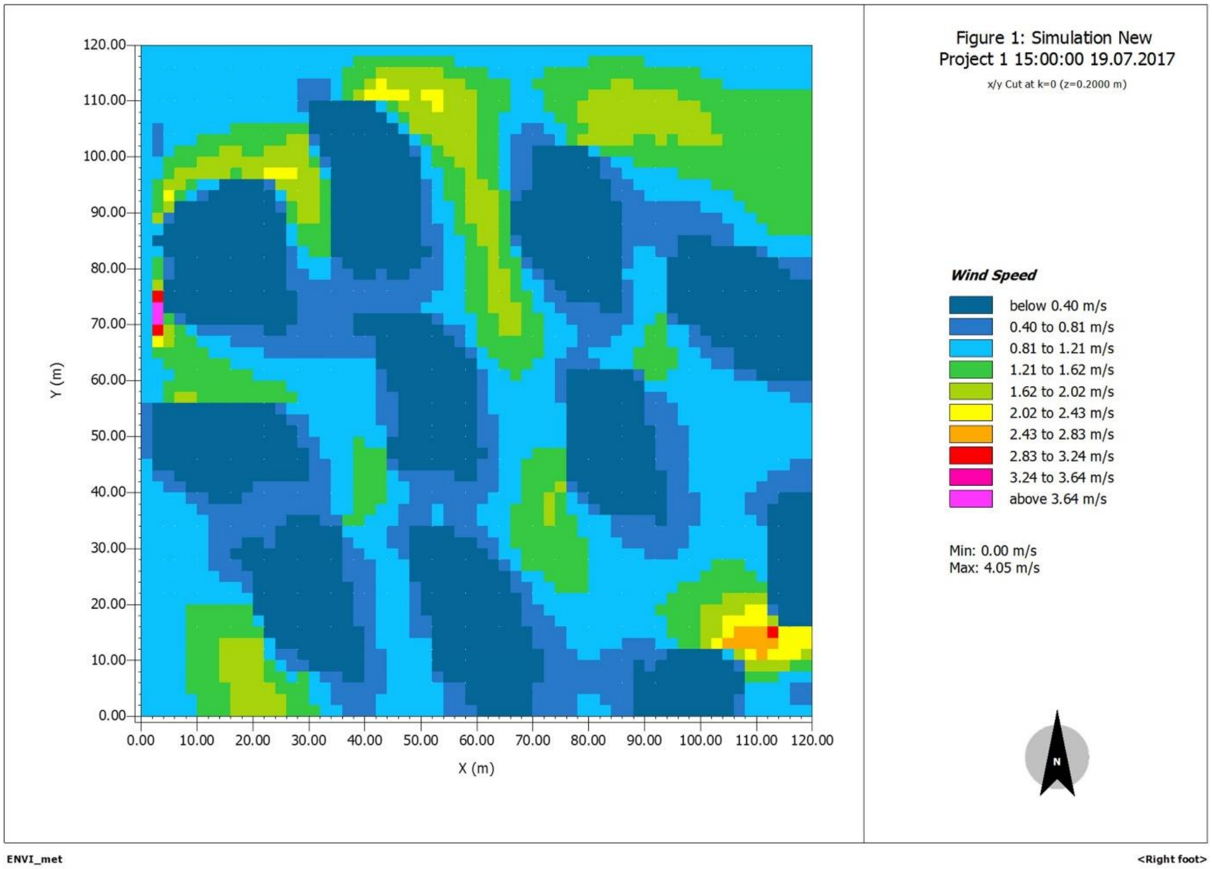
Strategy 3 - Greenery - 15m height trees - Mapping of wind speed at 12pm



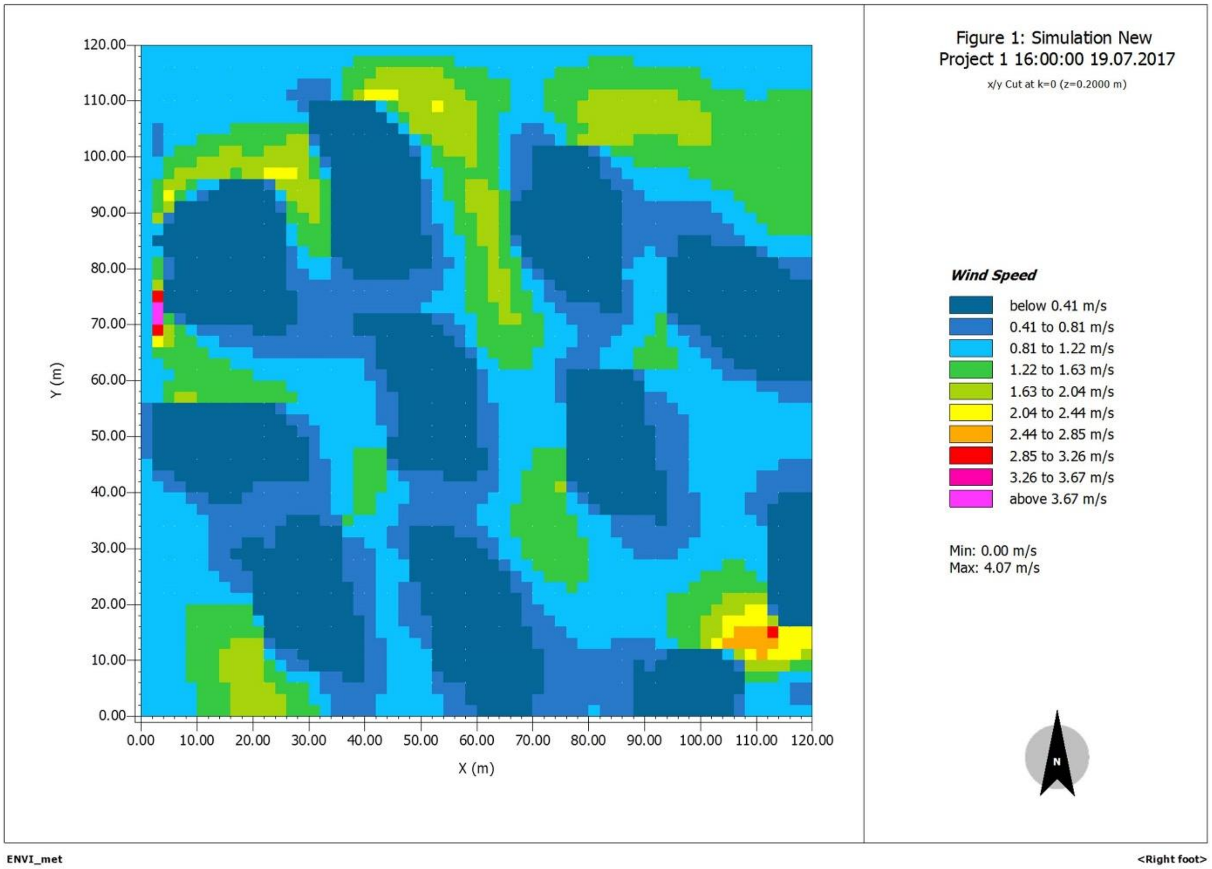
Strategy 3 - Greenery - 15m height trees - Mapping of wind speed at 1pm



Strategy 3 - Greenery - 15m height trees - Mapping of wind speed at 2pm

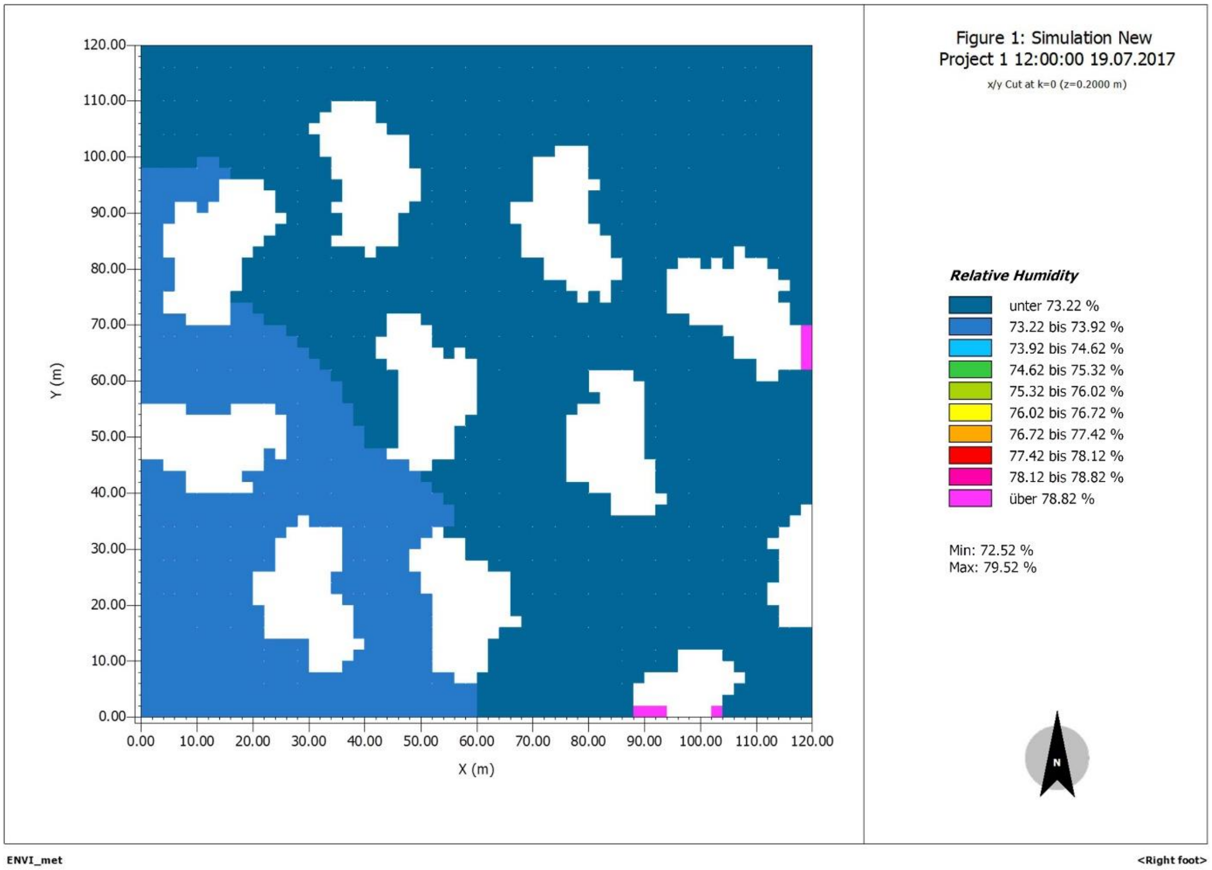


Strategy 3 - Greenery - 15m height trees - Mapping of wind speed at 3pm

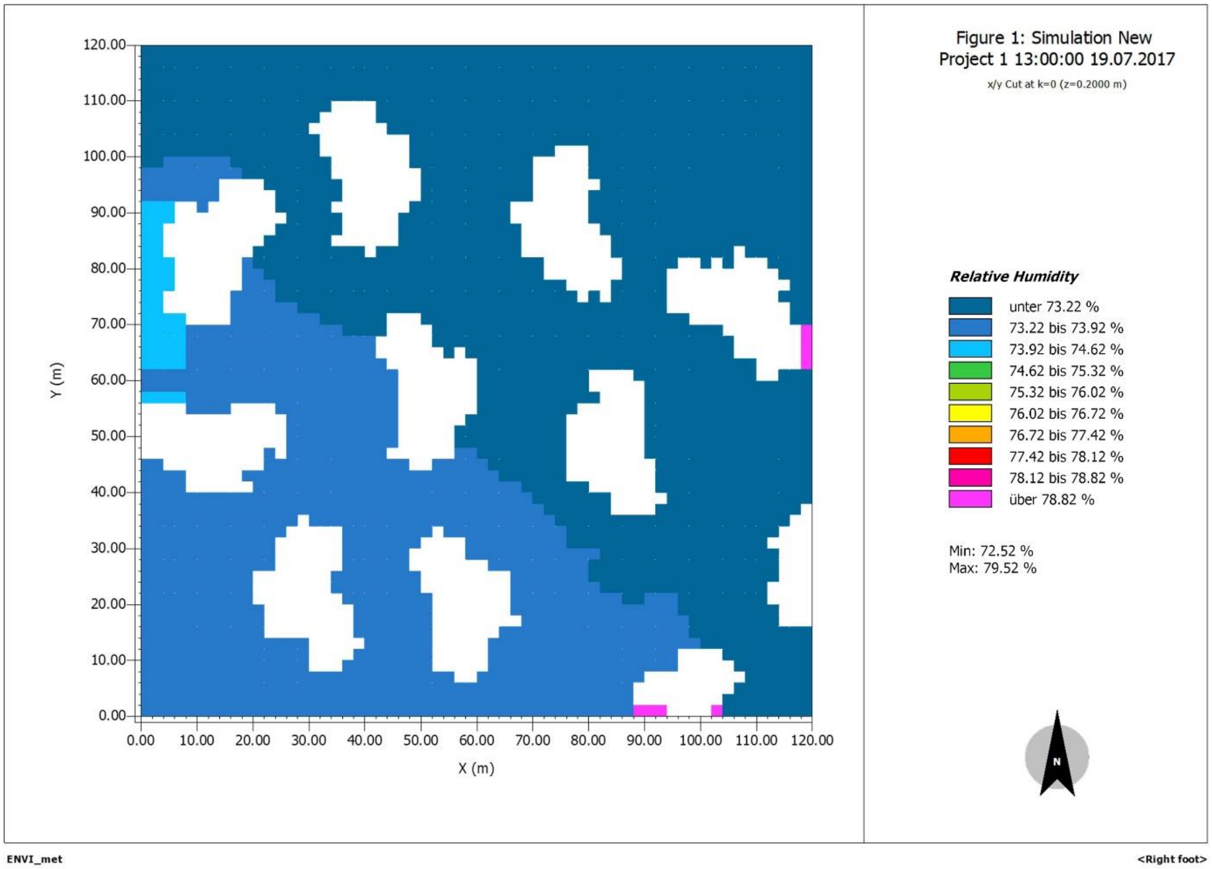


Strategy 3 - Greenery - 15m height trees - Mapping of wind speed at 4pm

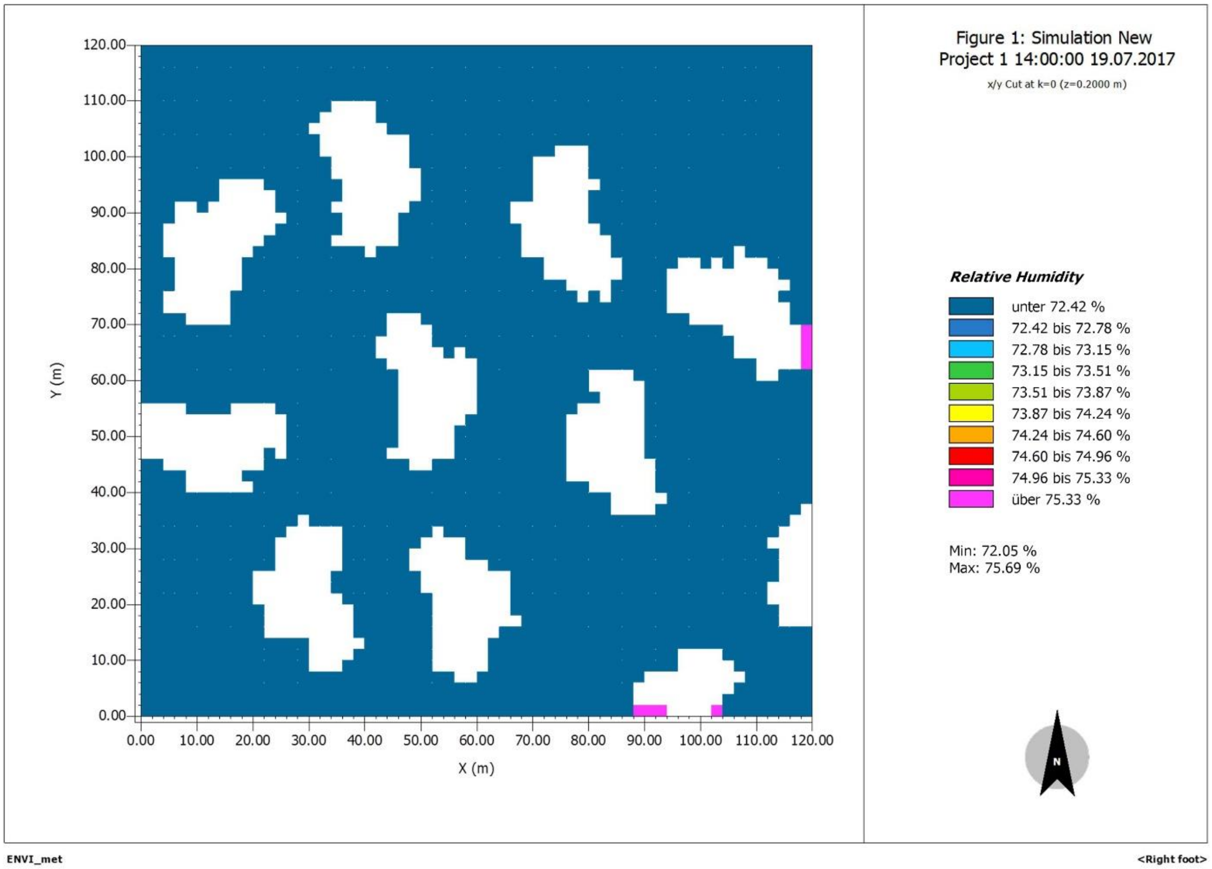
RELATIVE HUMIDITY



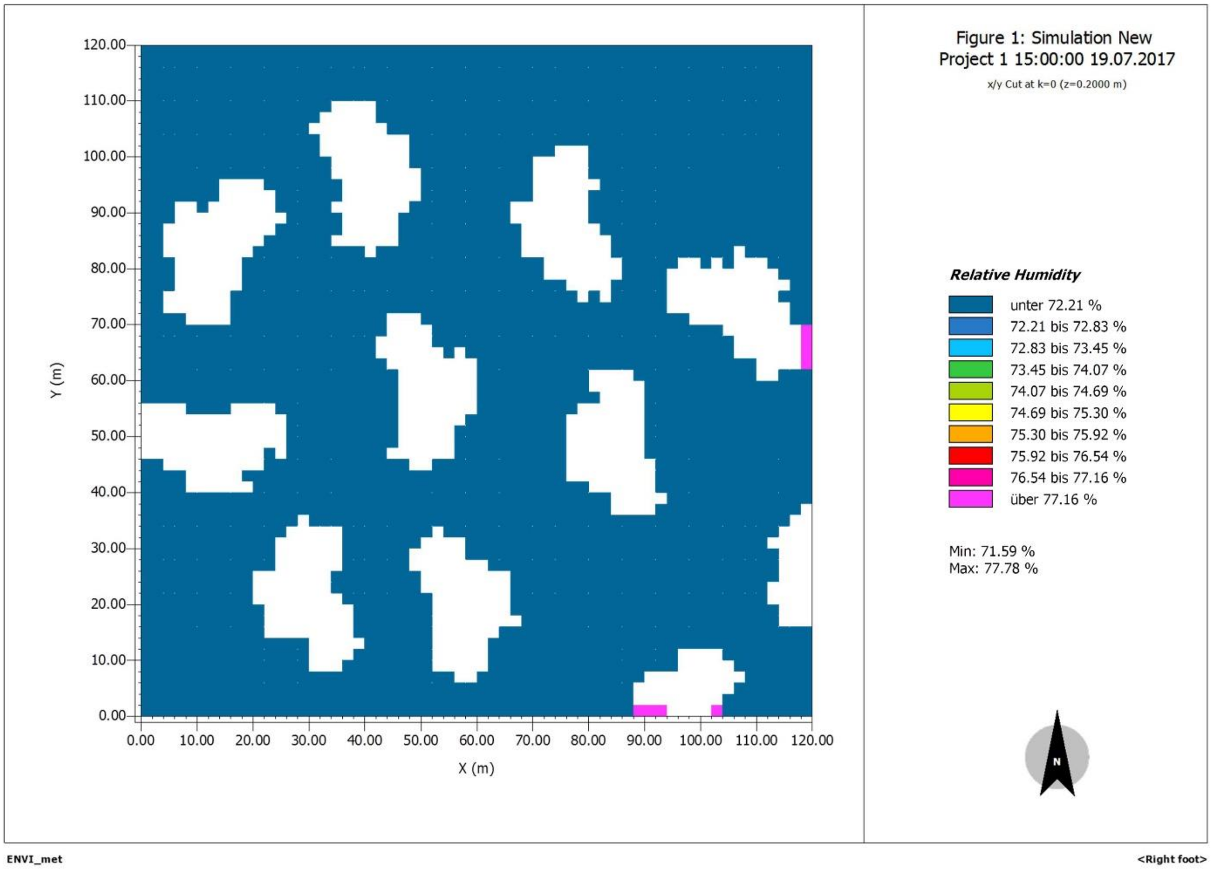
Strategy 3 - Greenery - 15m height trees - Mapping of relative humidity at 12pm



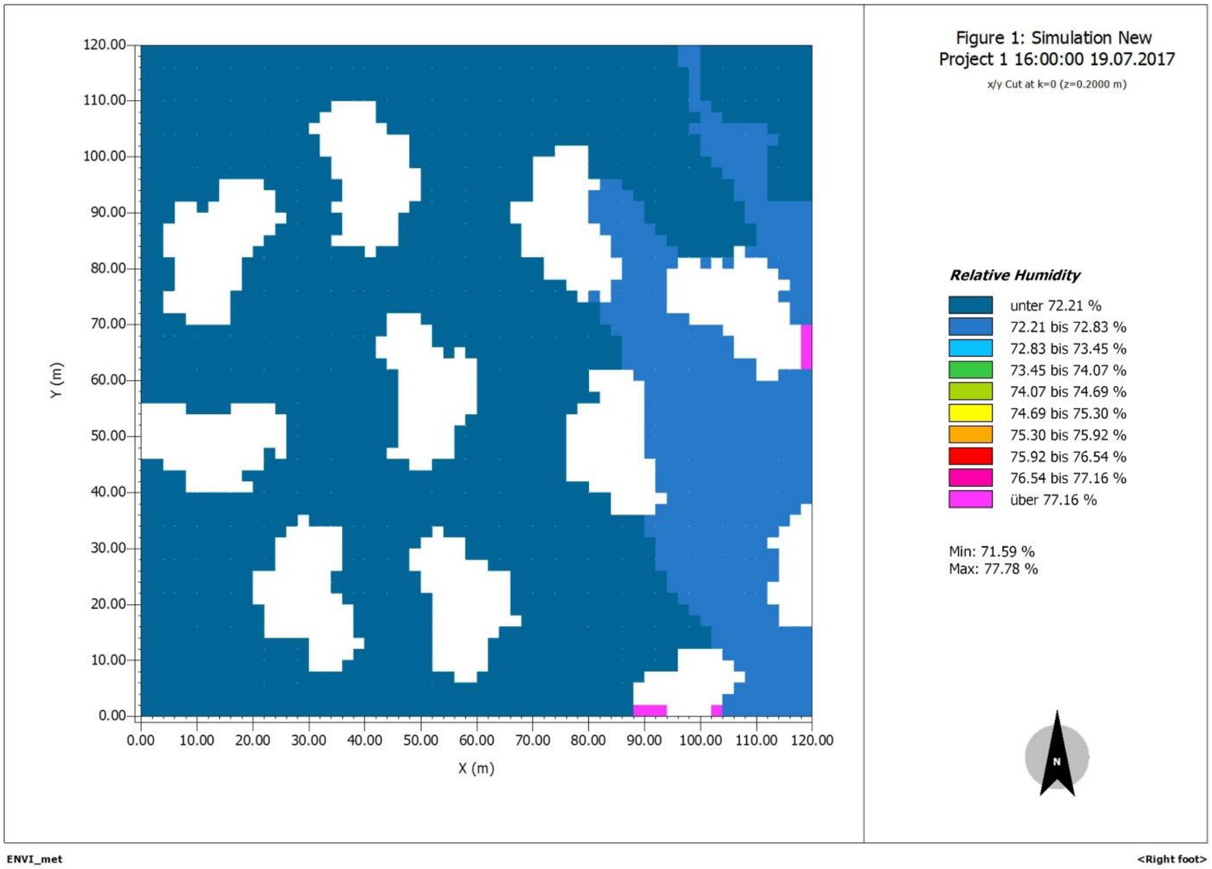
Strategy 3 - Greenery - 15m height trees - Mapping of relative humidity at 1pm



Strategy 3 - Greenery - 15m height trees - Mapping of relative humidity at 2pm



Strategy 3 - Greenery - 15m height trees - Mapping of relative humidity at 3pm

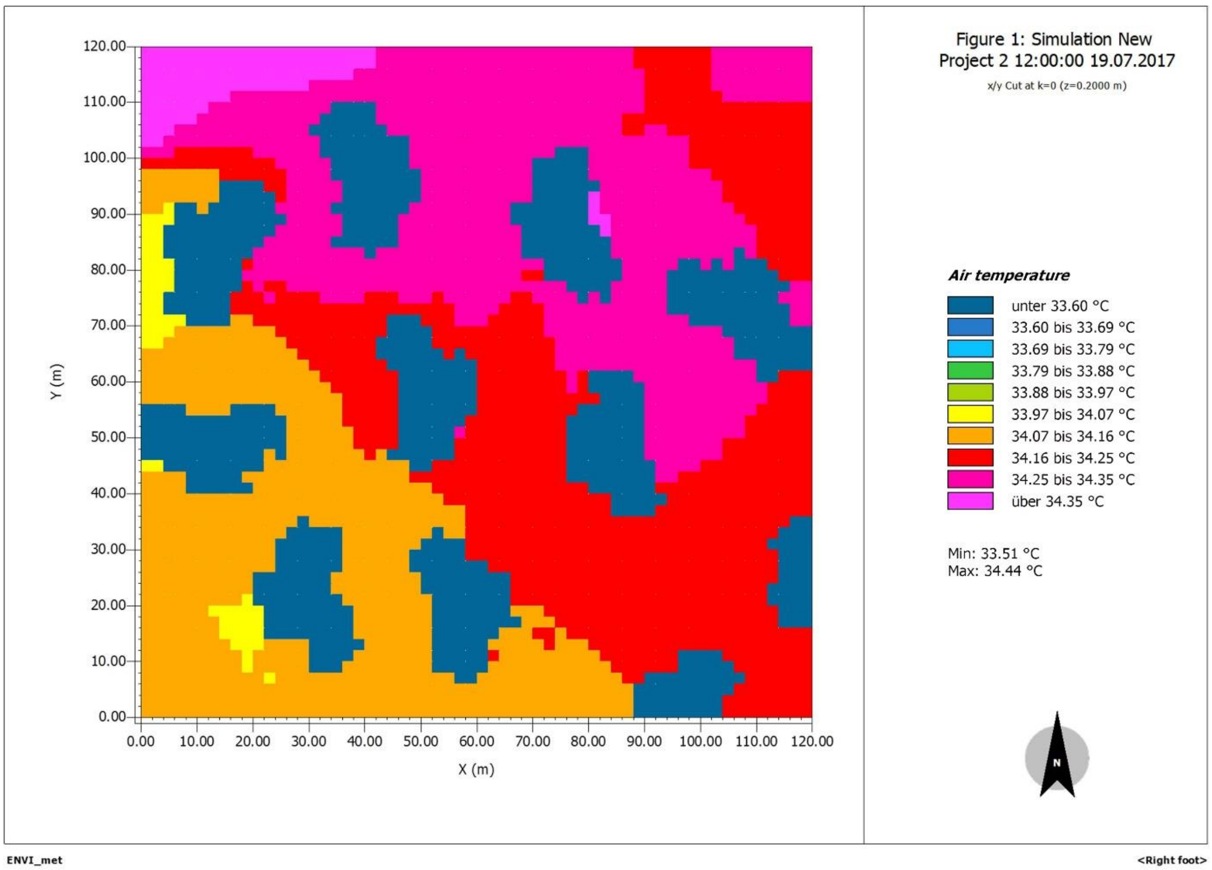


Strategy 3 - Greenery - 15m height trees - Mapping of relative humidity at 4pm

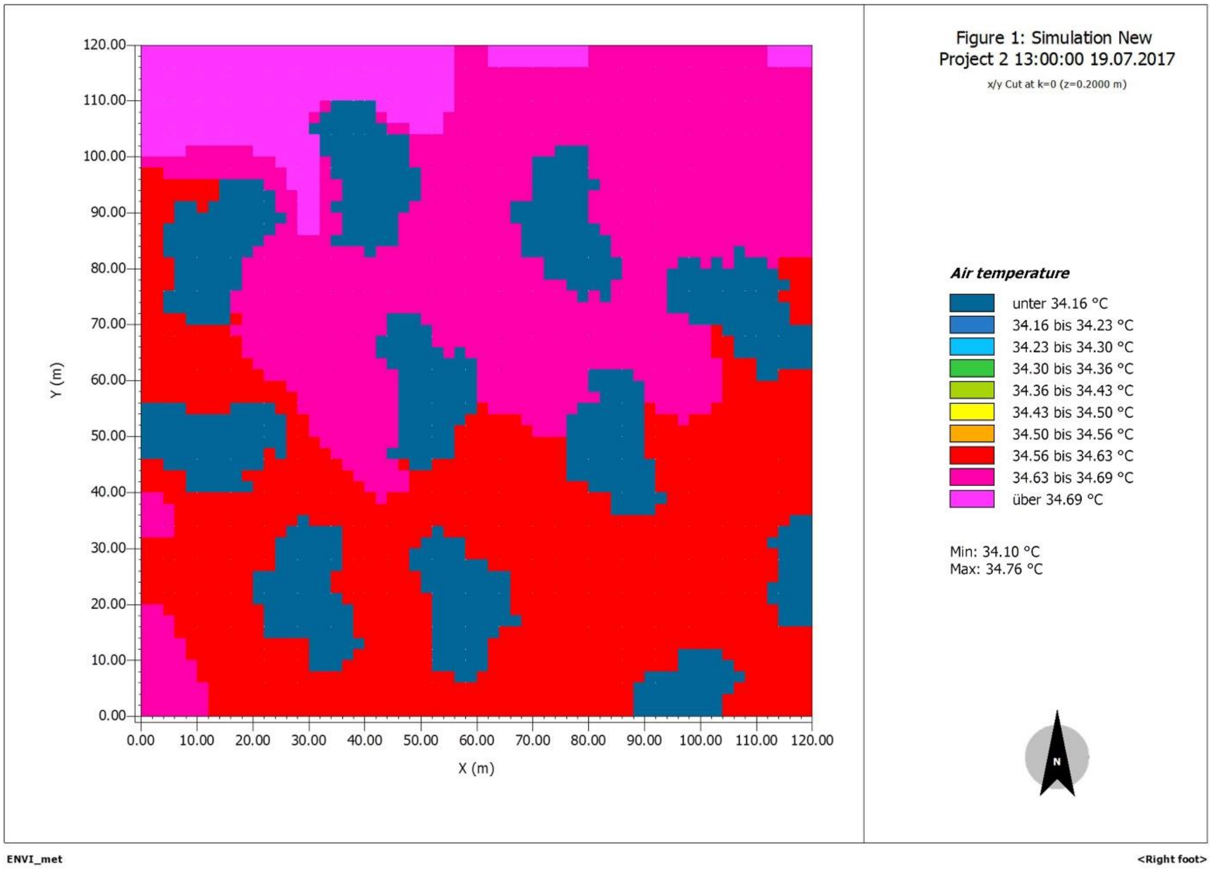
Appendix 9 - Strategy 3 - Greenery - 20m height trees

Model building, Greenery - 20m height trees. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

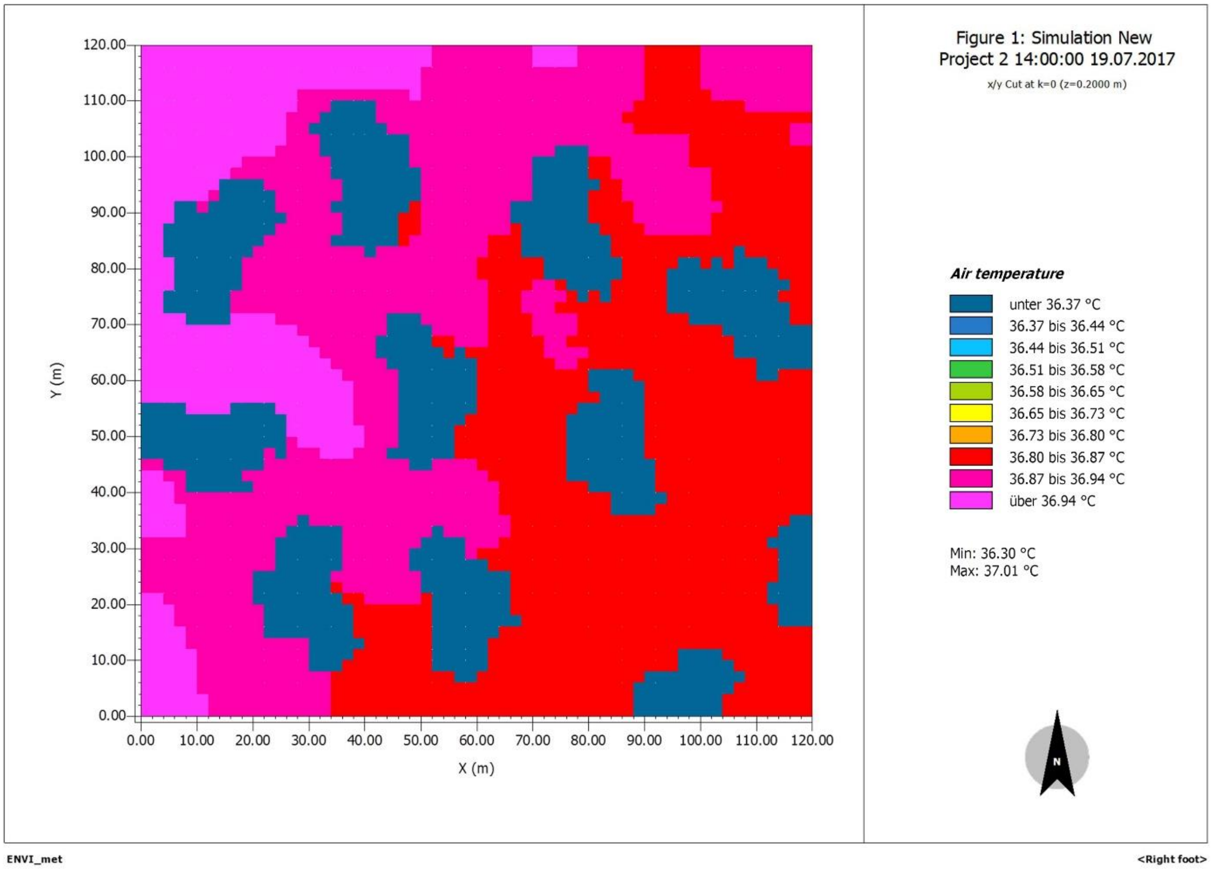
AIR TEMPERATURE



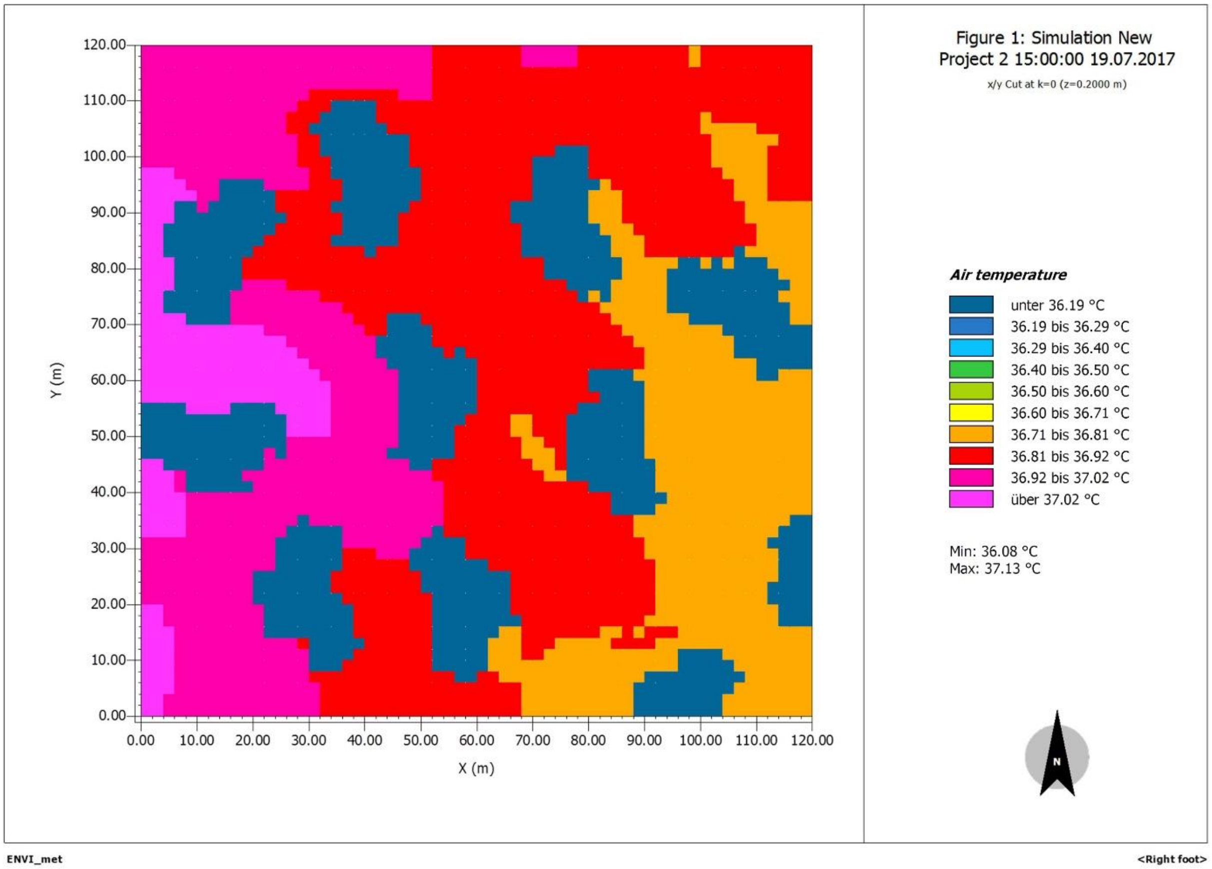
Strategy 3 - Greenery - 20m height trees - Mapping of air temperature at 12pm



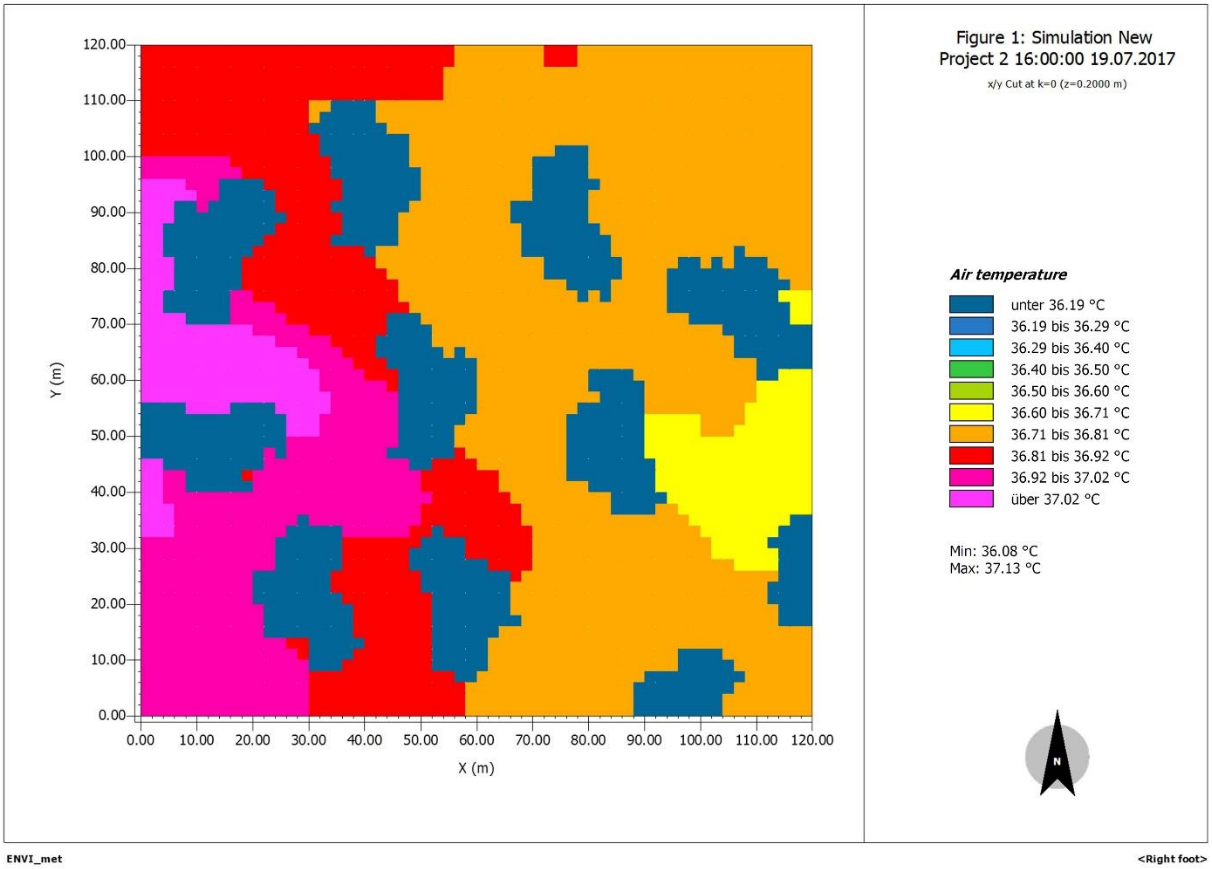
Strategy 3 - Greenery - 20m height trees - Mapping of air temperature at 1pm



Strategy 3 - Greenery - 20m height trees - Mapping of air temperature at 2pm

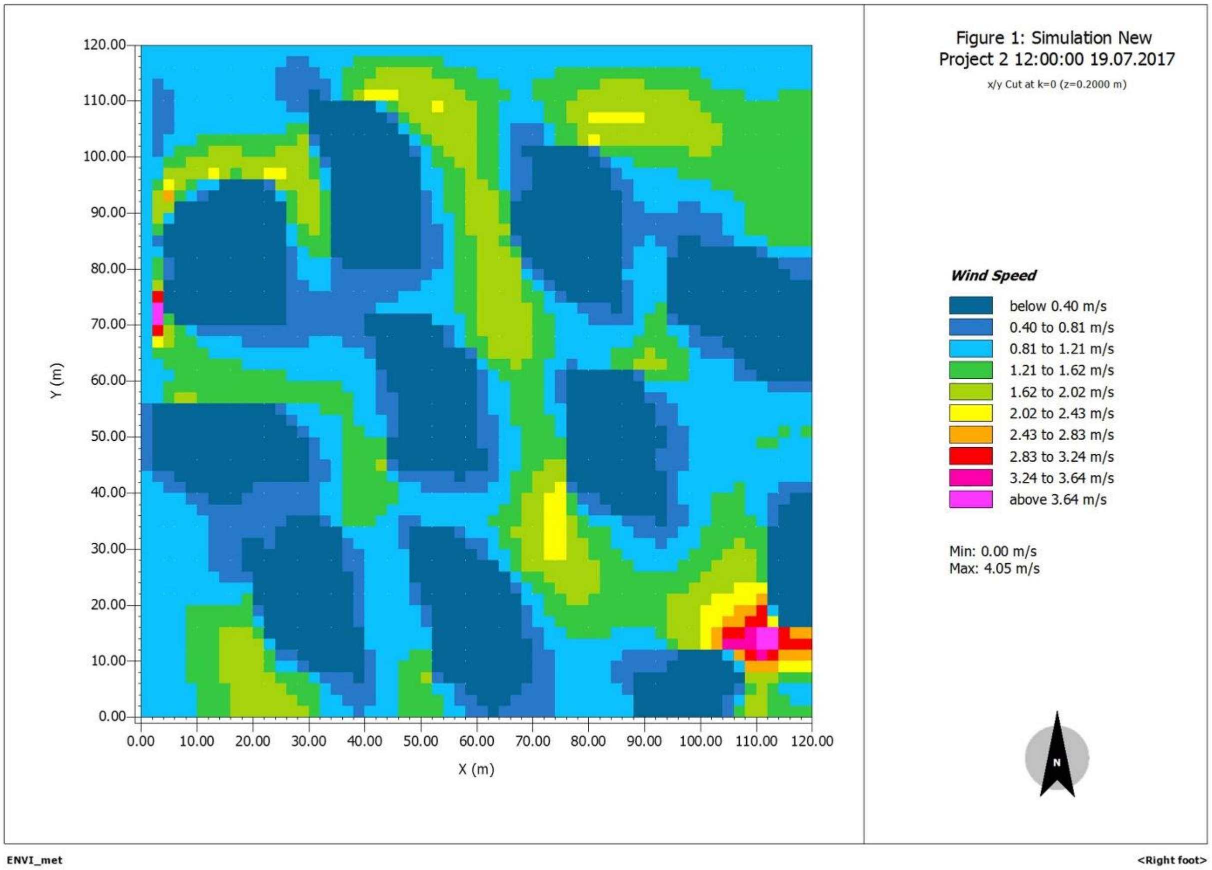


Strategy 3 - Greenery - 20m height trees - Mapping of air temperature at 3pm

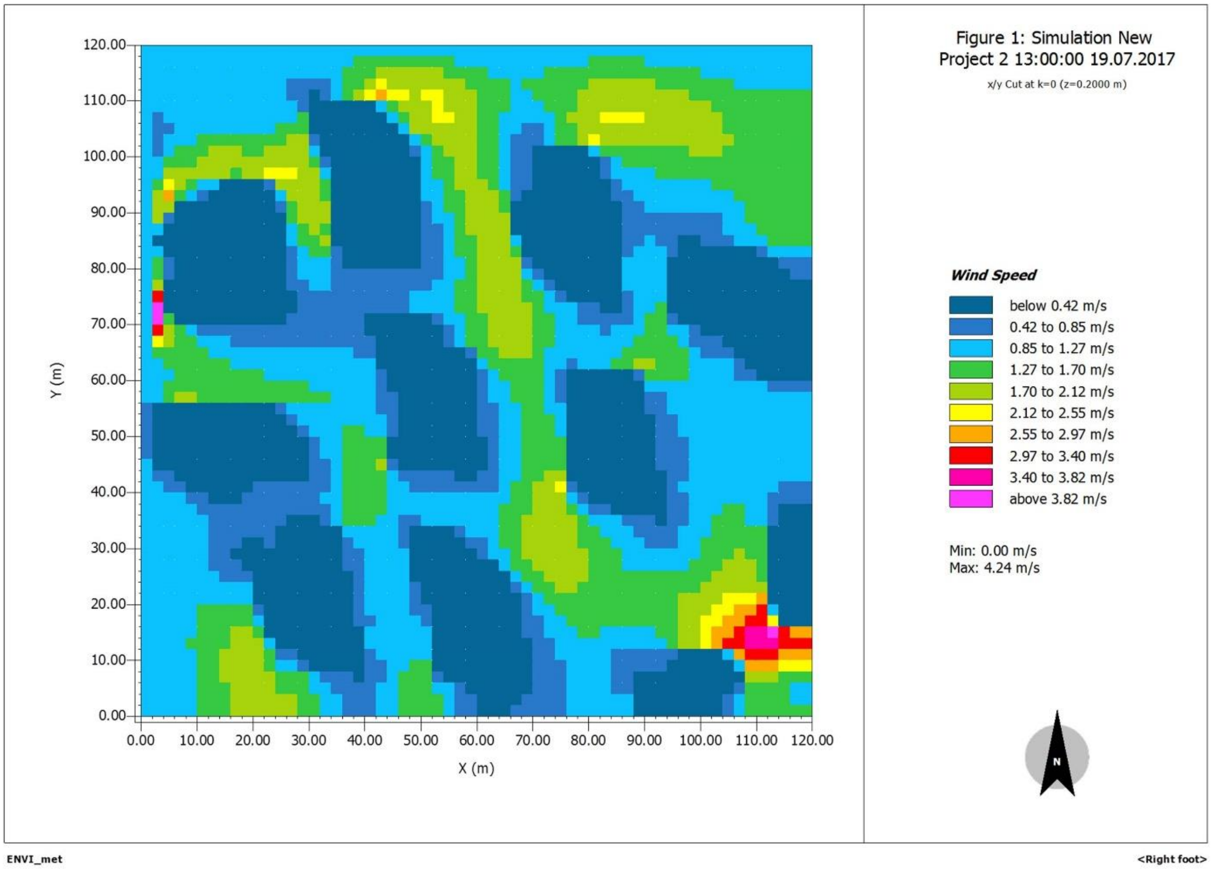


Strategy 3 - Greenery - 20m height trees - Mapping of air temperature at 4pm

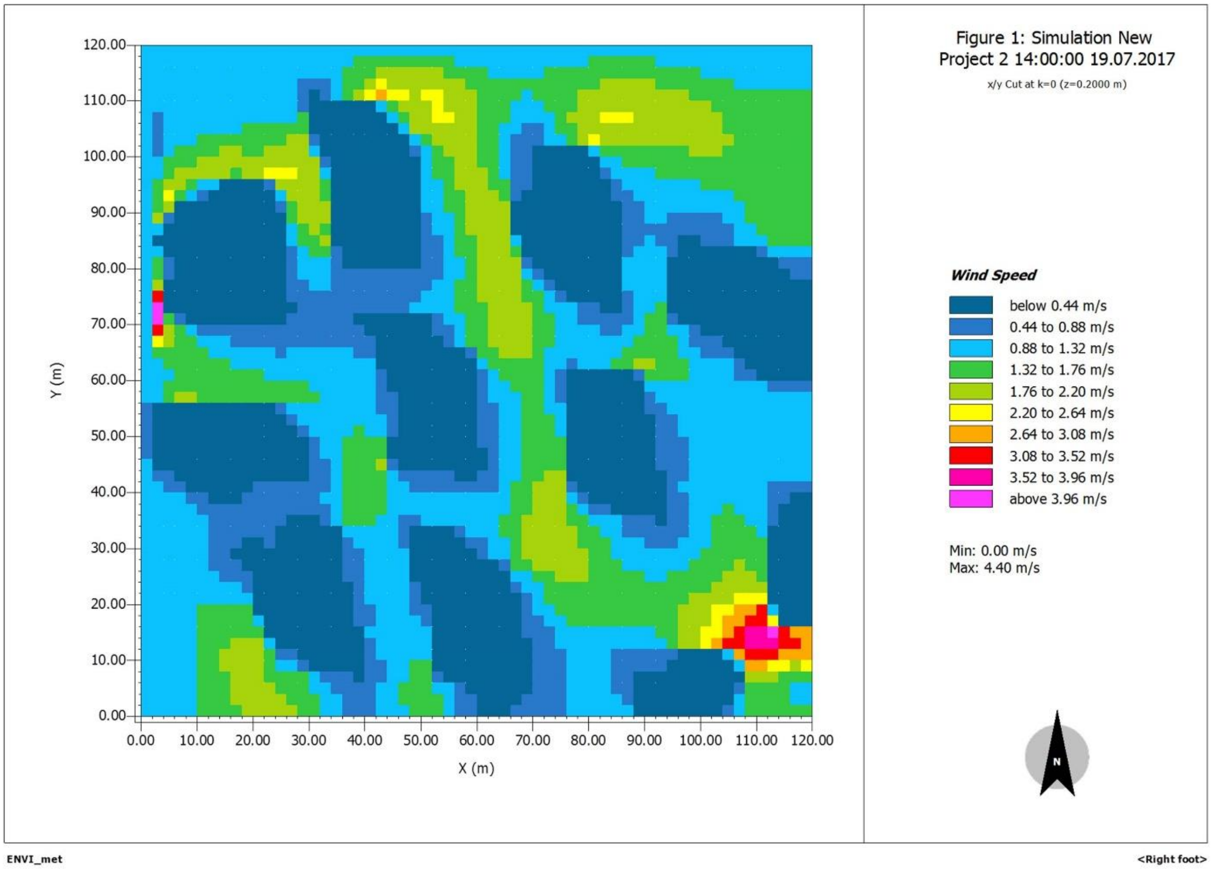
WIND SPEED



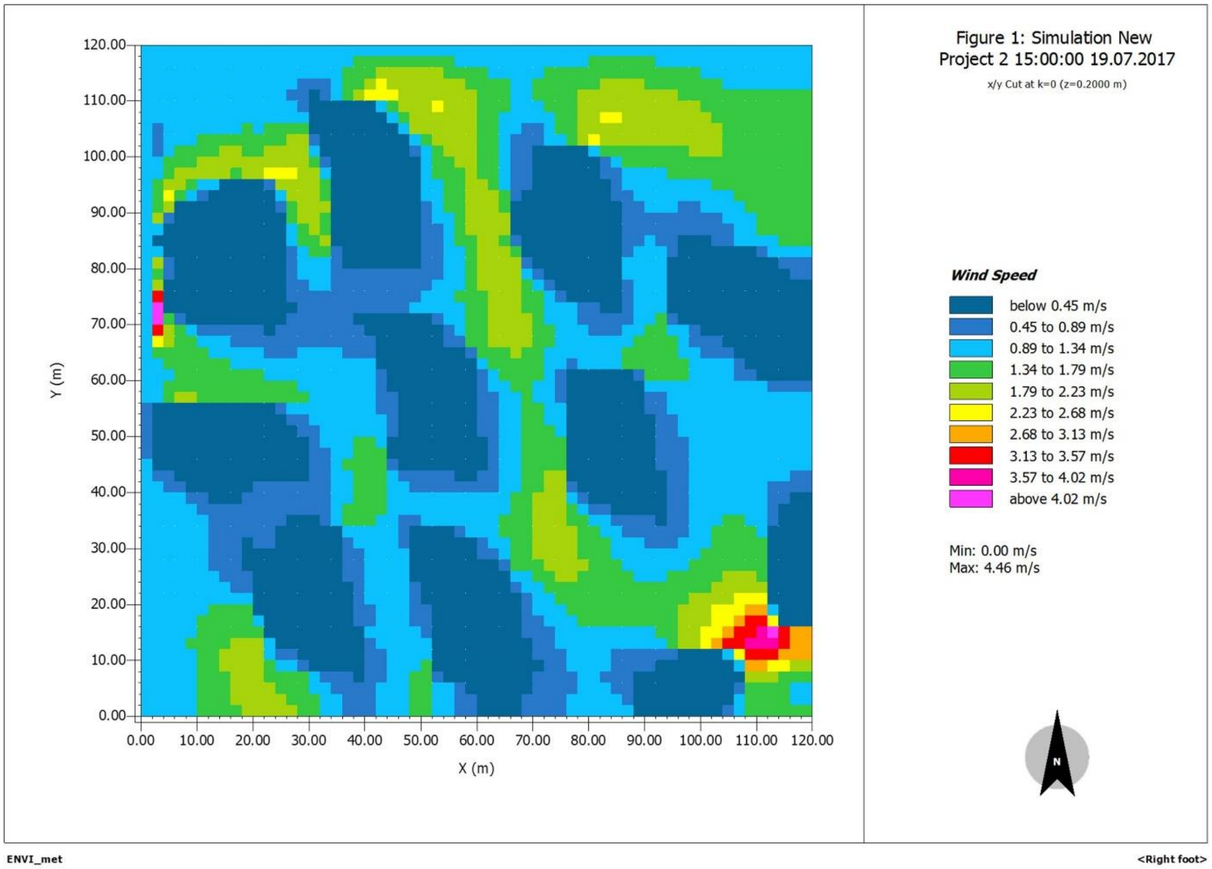
Strategy 3 - Greenery - 20m height trees - Mapping of wind speed at 12pm



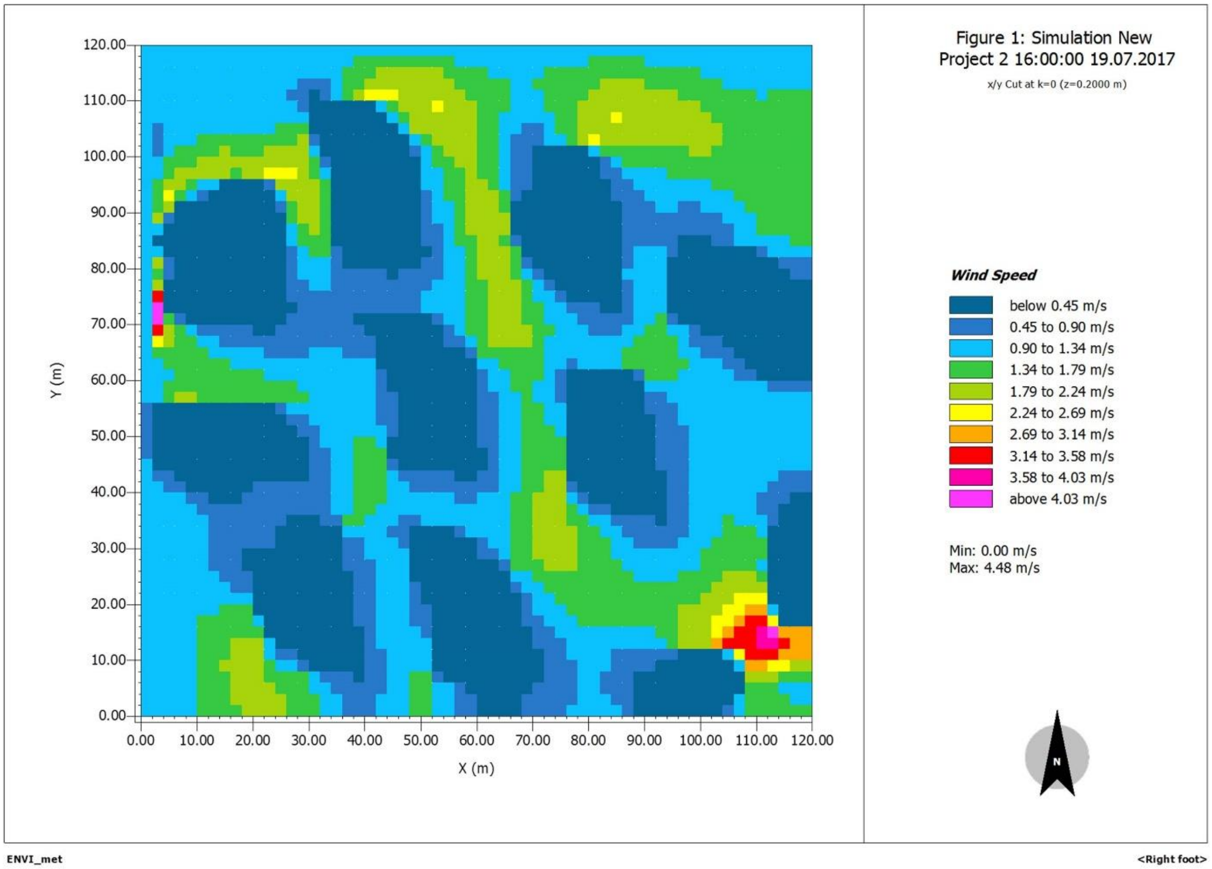
Strategy 3 - Greenery - 20m height trees - Mapping of wind speed at 1pm



Strategy 3 - Greenery - 20m height trees - Mapping of wind speed at 2pm

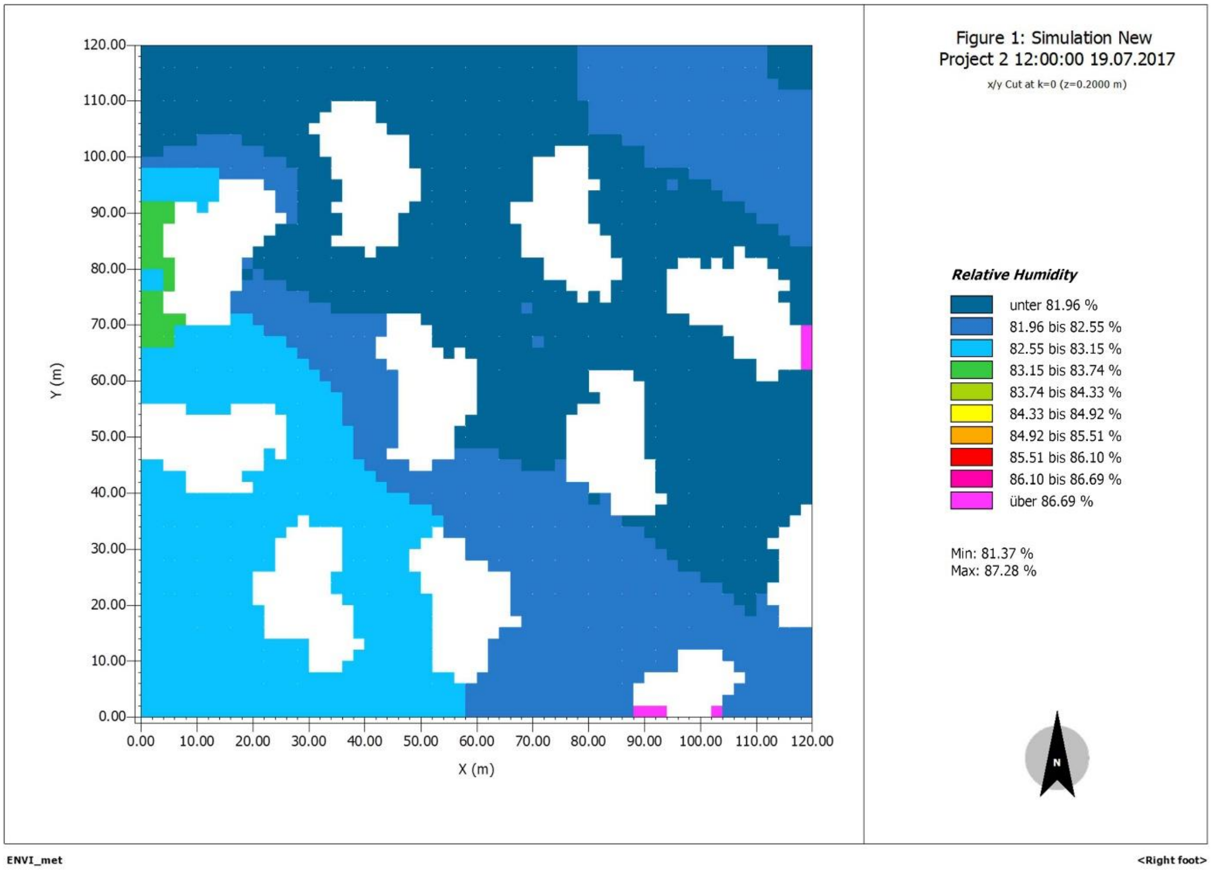


Strategy 3 - Greenery - 20m height trees - Mapping of wind speed at 3pm

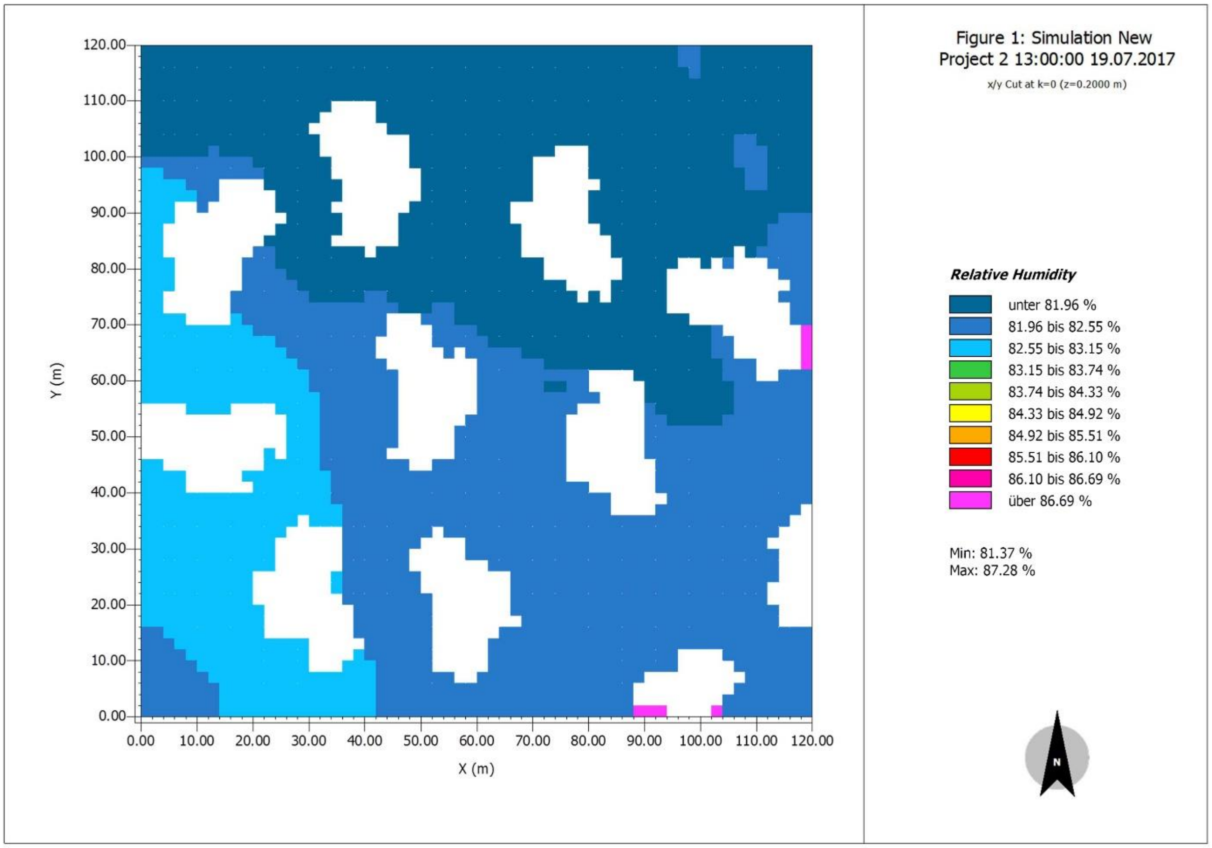


Strategy 3 - Greenery - 20m height trees - Mapping of wind speed at 4pm

RELATIVE HUMIDITY

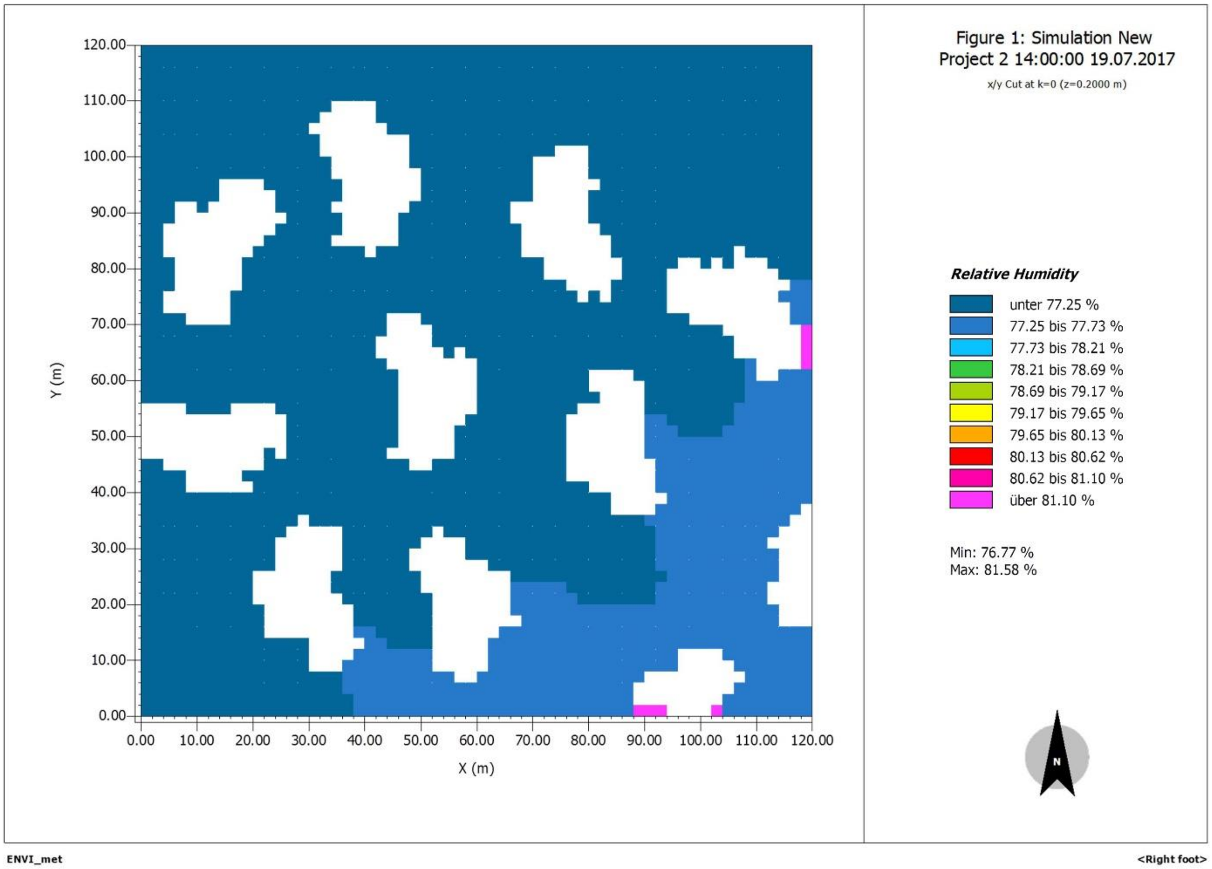


Strategy 3 - Greenery - 20m height trees - Mapping of relative humidity at 12pm

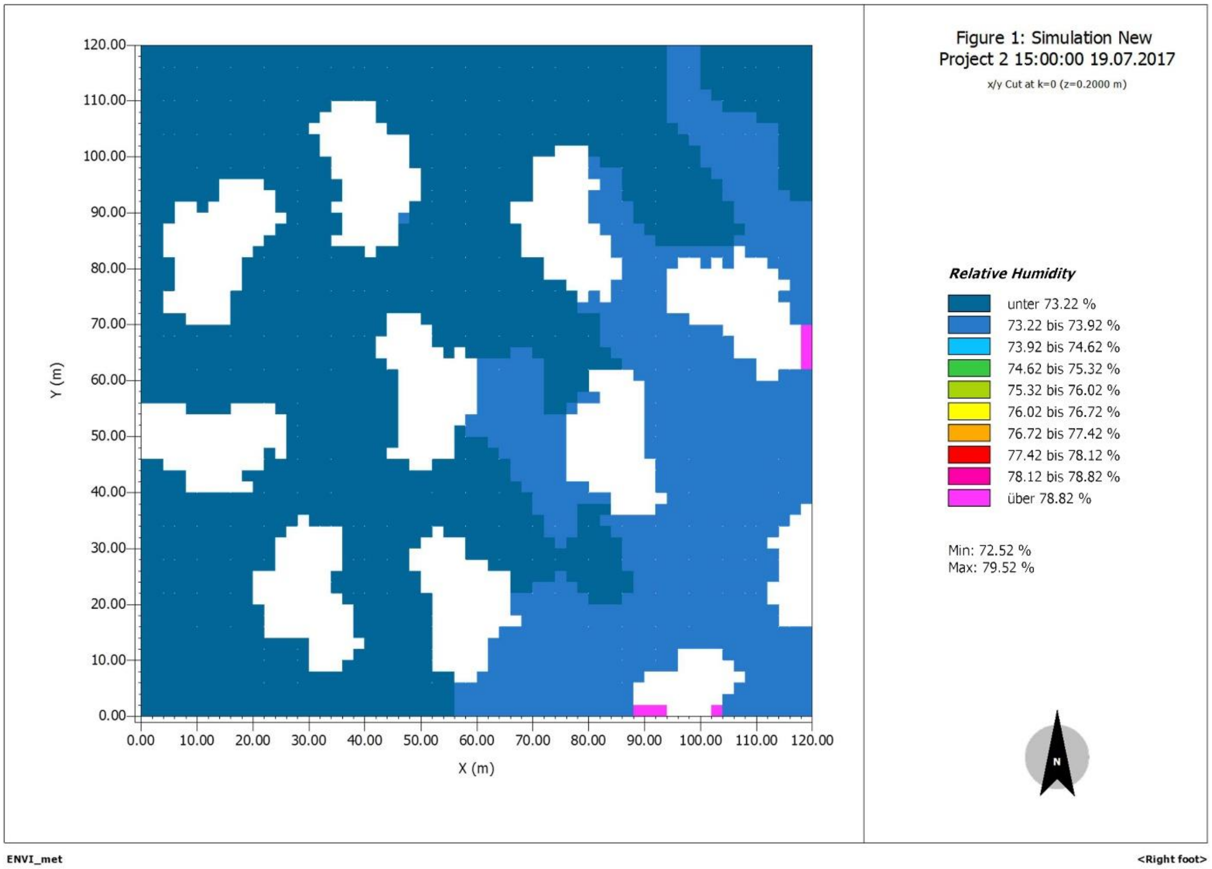


ENVI_met <Right foot>

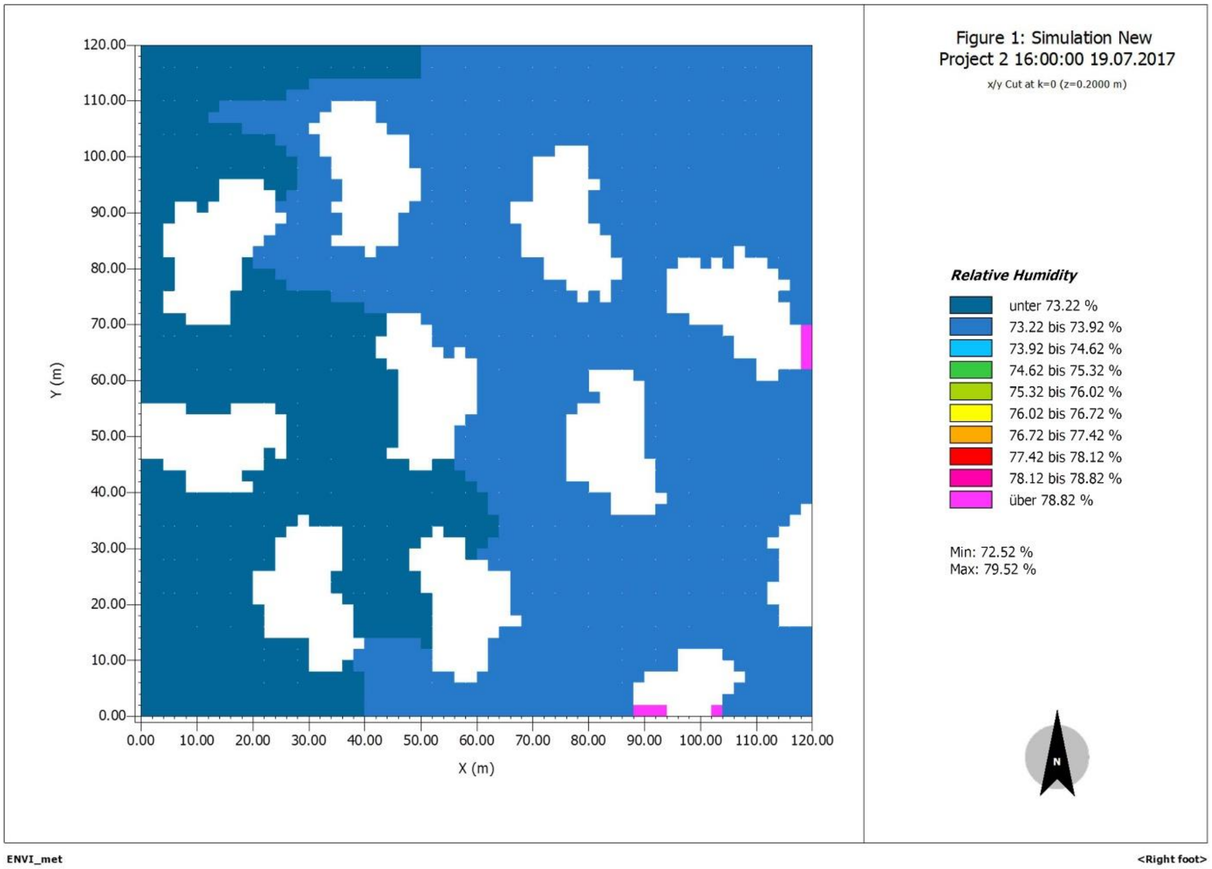
Strategy 3 - Greenery - 20m height trees - Mapping of relative humidity at 1pm



Strategy 3 - Greenery - 20m height trees - Mapping of relative humidity at 2pm



Strategy 3 - Greenery - 20m height trees - Mapping of relative humidity at 3pm



Strategy 3 - Greenery - 20m height trees - Mapping of relative humidity at 4pm

SPOT 1 front yard				
greenery	best results from str2	10m high trees	15m high trees	20m high trees
AT @ 12pm	39.69	36.07	35.57	34.25
AT @ 1pm	45.38	36.28	35.57	34.69
AT @ 2pm	45.38	36.28	36.07	36.94
AT @ 3pm	43.38	43.97	35.99	36.92
AT @ 4pm	43.38	43.97	36.20	36.81
	43.44	39.31	35.88	35.92
greenery	best results from str2	10m high trees	15m high trees	20m high trees
WS @ 12pm	1.07	1.12	1.13	1.21
WS @ 1pm	1.09	1.14	1.12	1.27
WS @ 2pm	1.09	1.19	1.19	1.32
WS @ 3pm	1.10	1.22	1.21	1.34
WS @ 4pm	1.11	1.22	1.22	1.34
	1.09	1.18	1.17	1.30
greenery	best results from str2	10m high trees	15m high trees	20m high trees
RH @ 12pm	57.08	74.33	73.22	81.96
RH @ 1pm	52.20	67.45	73.22	82.55
RH @ 2pm	48.24	63.42	72.42	77.73
RH @ 3pm	48.15	60.29	72.12	73.22
RH @ 4pm	47.40	60.29	72.21	73.92
	50.61	65.16	72.64	77.88

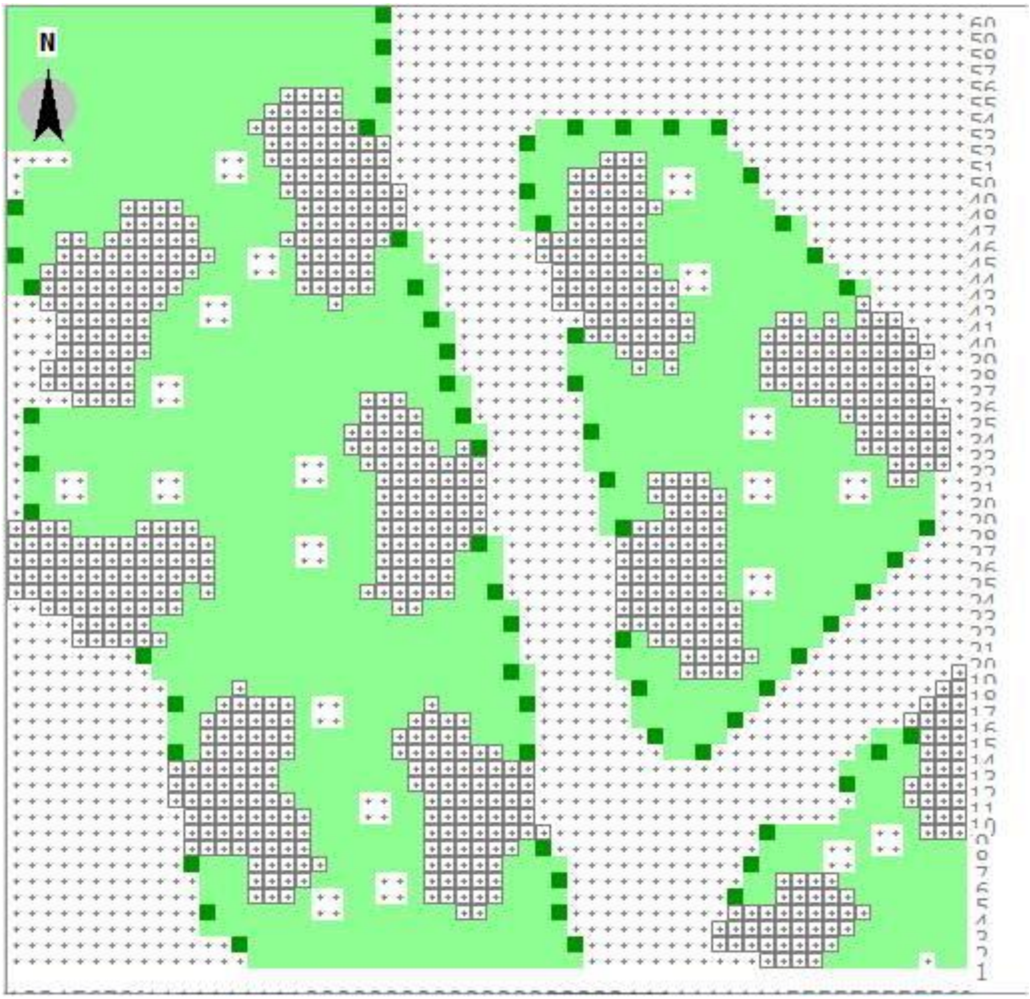
SPOT 2 back yard				
greenery	best results from str2	10m high trees	15m high trees	20m high trees
AT @ 12pm	37.49	36.07	35.31	34.25
AT @ 1pm	45.38	36.28	35.57	34.69
AT @ 2pm	45.38	36.28	36.07	36.94
AT @ 3pm	46.03	44.04	36.07	37.02
AT @ 4pm	46.03	44.04	36.28	37.02
	44.06	39.34	35.86	35.98
greenery	best results from str2	10m high trees	15m high trees	20m high trees
WS @ 12pm	1.07	1.12	1.13	1.21
WS @ 1pm	1.09	1.14	1.12	1.27
WS @ 2pm	1.09	1.19	1.19	1.32
WS @ 3pm	1.10	1.22	1.21	1.34
WS @ 4pm	1.11	1.22	1.22	1.34
	1.09	1.18	1.17	1.30
greenery	best results from str2	10m high trees	15m high trees	20m high trees
RH @ 12pm	58.08	74.87	73.22	82.55
RH @ 1pm	49.65	67.43	73.92	82.55
RH @ 2pm	46.62	63.42	72.42	77.73
RH @ 3pm	45.67	60.29	72.12	73.22
RH @ 4pm	45.56	60.29	72.21	73.22
	49.12	65.26	72.78	77.85

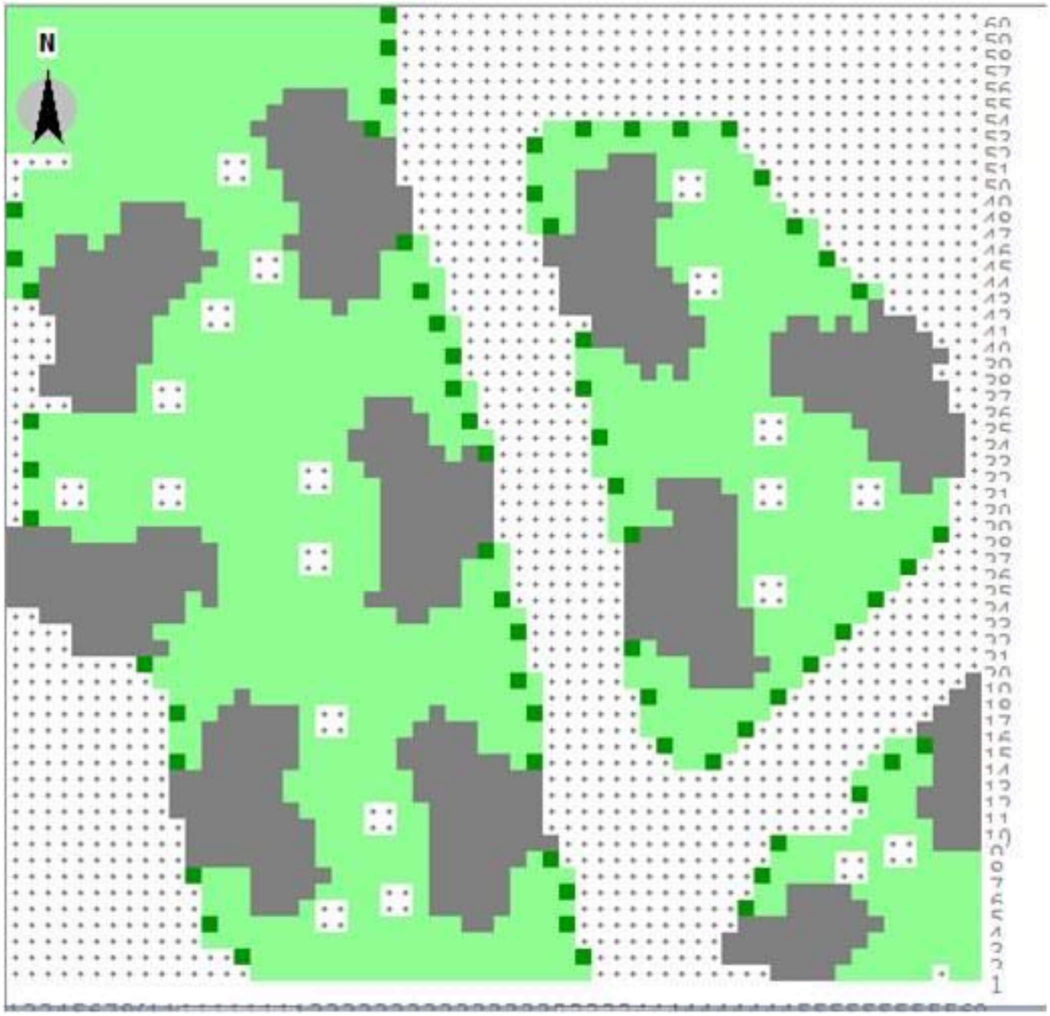
SPOT 3 road surface				
greenery	best results from str2	10m high trees	15m high trees	20m high trees
AT @ 12pm	39.69	36.07	35.57	34.25
AT @ 1pm	45.38	36.28	35.57	34.69
AT @ 2pm	45.38	36.28	36.07	36.87
AT @ 3pm	43.38	43.97	35.99	36.92
AT @ 4pm	40.74	43.97	36.20	36.81
	42.91	39.31	35.88	35.91
greenery	best results from str2	10m high trees	15m high trees	20m high trees
WS @ 12pm	1.07	1.12	1.13	1.21
WS @ 1pm	1.09	1.14	1.12	1.27
WS @ 2pm	1.09	1.19	1.19	1.32
WS @ 3pm	1.10	1.22	1.21	1.34
WS @ 4pm	1.11	1.22	1.22	1.34
	1.09	1.18	1.17	1.30
greenery	best results from str2	10m high trees	15m high trees	20m high trees
RH @ 12pm	57.08	74.33	73.22	82.55
RH @ 1pm	52.20	67.43	73.22	82.55
RH @ 2pm	49.86	63.42	72.42	77.73
RH @ 3pm	48.15	60.29	72.12	73.92
RH @ 4pm	48.02	60.29	72.21	73.22
	51.06	65.15	72.64	77.99

SPOT 4 open space				
greenery	best results from str2	10m high trees	15m high trees	20m high trees
AT @ 12pm	35.30	36.07	35.04	34.16
AT @ 1pm	45.38	36.28	35.31	34.69
AT @ 2pm	48.13	36.28	36.14	37.01
AT @ 3pm	48.67	44.10	36.14	37.13
AT @ 4pm	48.67	44.10	36.35	37.13
	45.23	39.37	35.80	36.02
greenery	best results from str2	10m high trees	15m high trees	20m high trees
WS @ 12pm	1.07	1.12	1.13	1.21
WS @ 1pm	1.09	1.14	1.12	1.27
WS @ 2pm	1.09	1.19	1.19	1.32
WS @ 3pm	1.10	1.22	1.21	1.34
WS @ 4pm	1.11	1.22	1.22	1.34
	1.09	1.18	1.17	1.30
greenery	best results from str2	10m high trees	15m high trees	20m high trees
RH @ 12pm	58.08	74.87	73.92	83.15
RH @ 1pm	49.65	68.09	73.92	83.15
RH @ 2pm	44.99	63.42	72.42	77.73
RH @ 3pm	44.42	60.29	72.12	73.22
RH @ 4pm	45.56	60.29	72.21	73.22
	48.54	65.39	72.92	78.09

averages for simulation 5,7,8,9				
greenery	best results from str2	10m high trees	15m high trees	20m high trees
AT @ 12pm	38.04	36.07	35.37	34.23
AT @ 1pm	45.38	36.28	35.51	34.69
AT @ 2pm	46.07	36.28	36.09	36.94
AT @ 3pm	45.37	44.02	36.05	37.00
AT @ 4pm	44.71	44.02	36.26	36.94
	43.91	39.33	35.85	35.96
greenery	best results from str2	10m high trees	15m high trees	20m high trees
WS @ 12pm	1.07	1.12	1.13	1.21
WS @ 1pm	1.09	1.14	1.12	1.27
WS @ 2pm	1.09	1.19	1.19	1.32
WS @ 3pm	1.10	1.22	1.21	1.34
WS @ 4pm	1.11	1.22	1.22	1.34
	1.09	1.18	1.17	1.30
greenery	best results from str2	10m high trees	15m high trees	20m high trees
RH @ 12pm	57.58	74.60	73.40	82.55
RH @ 1pm	50.93	67.60	73.57	82.70
RH @ 2pm	47.43	63.42	72.42	77.73
RH @ 3pm	46.60	60.29	72.12	73.40
RH @ 4pm	46.64	60.29	72.21	73.40
	49.83	65.24	72.74	77.95

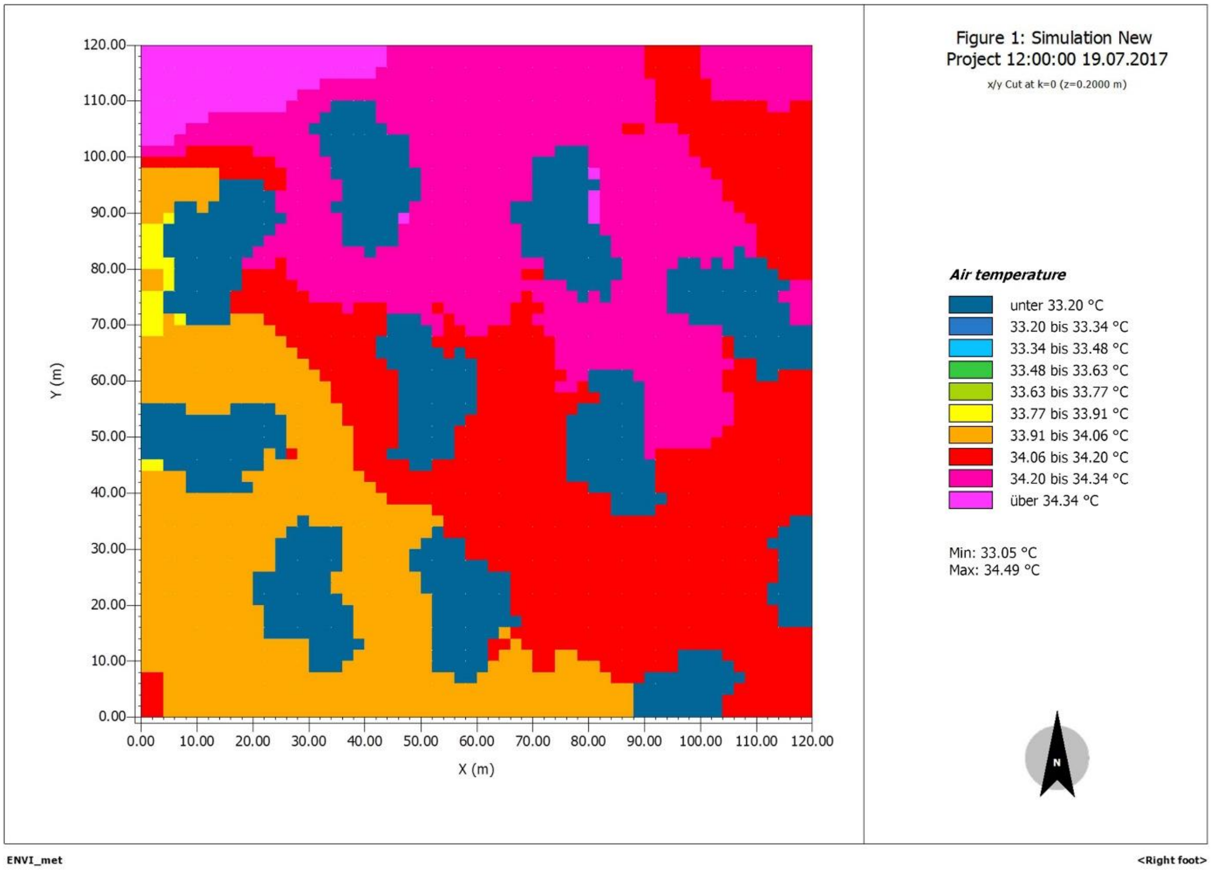
Appendix 10 - Strategy 4 - Waterbodies - swimming pool



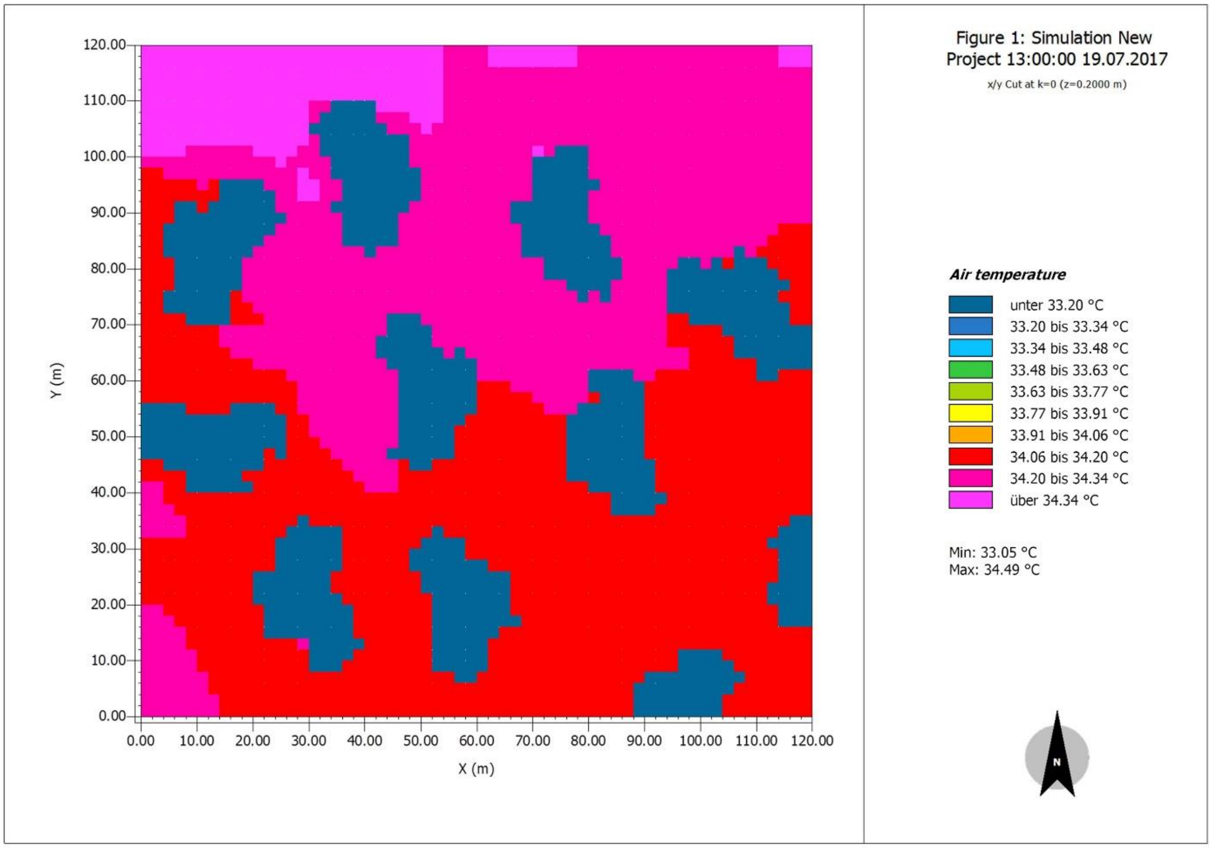


Model building, Waterbodies - swimming pool. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

AIR TEMPERATURE

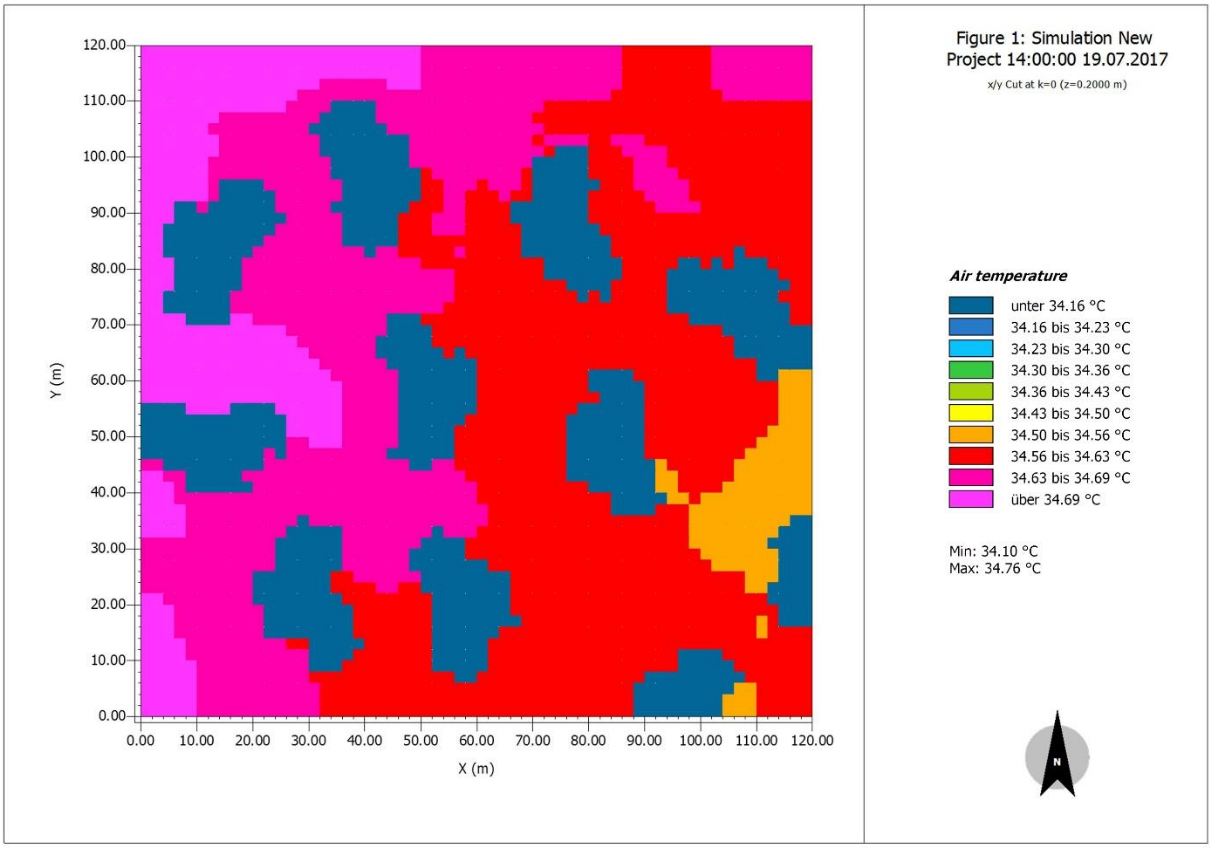


Strategy 4 - Waterbodies - swimming pool - Mapping of air temperature at 12pm

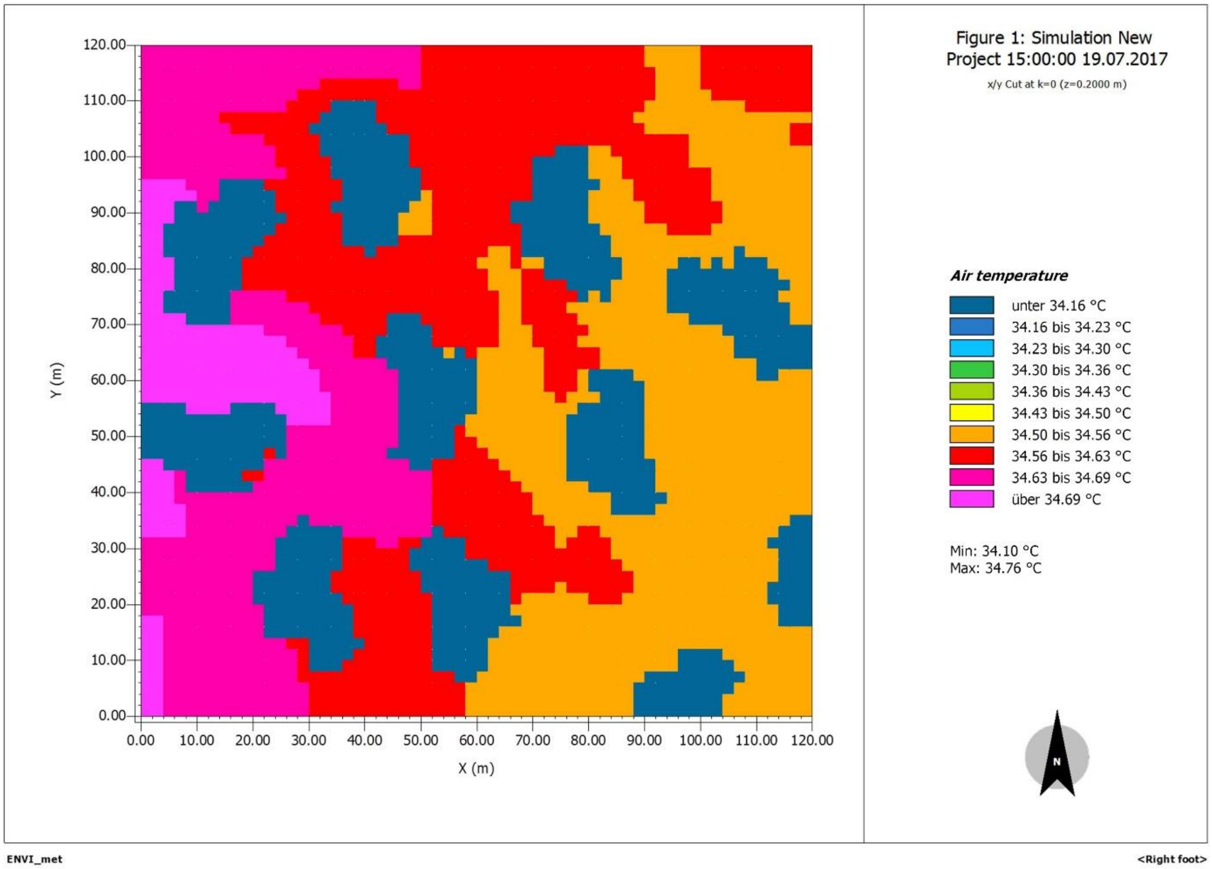


ENVI_met <Right foot>

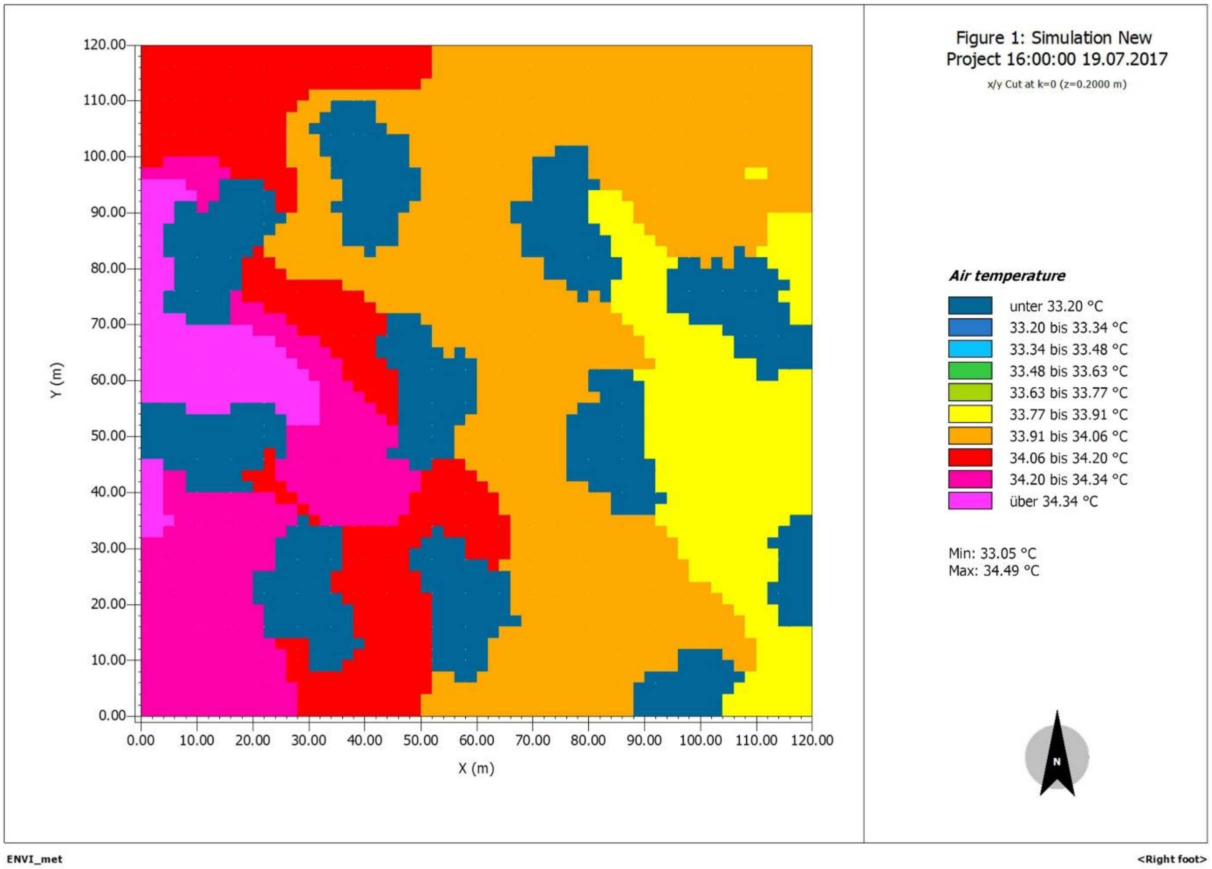
Strategy 4 - Waterbodies - swimming pool - Mapping of air temperature at 1pm



Strategy 4 - Waterbodies - swimming pool - Mapping of air temperature at 2pm

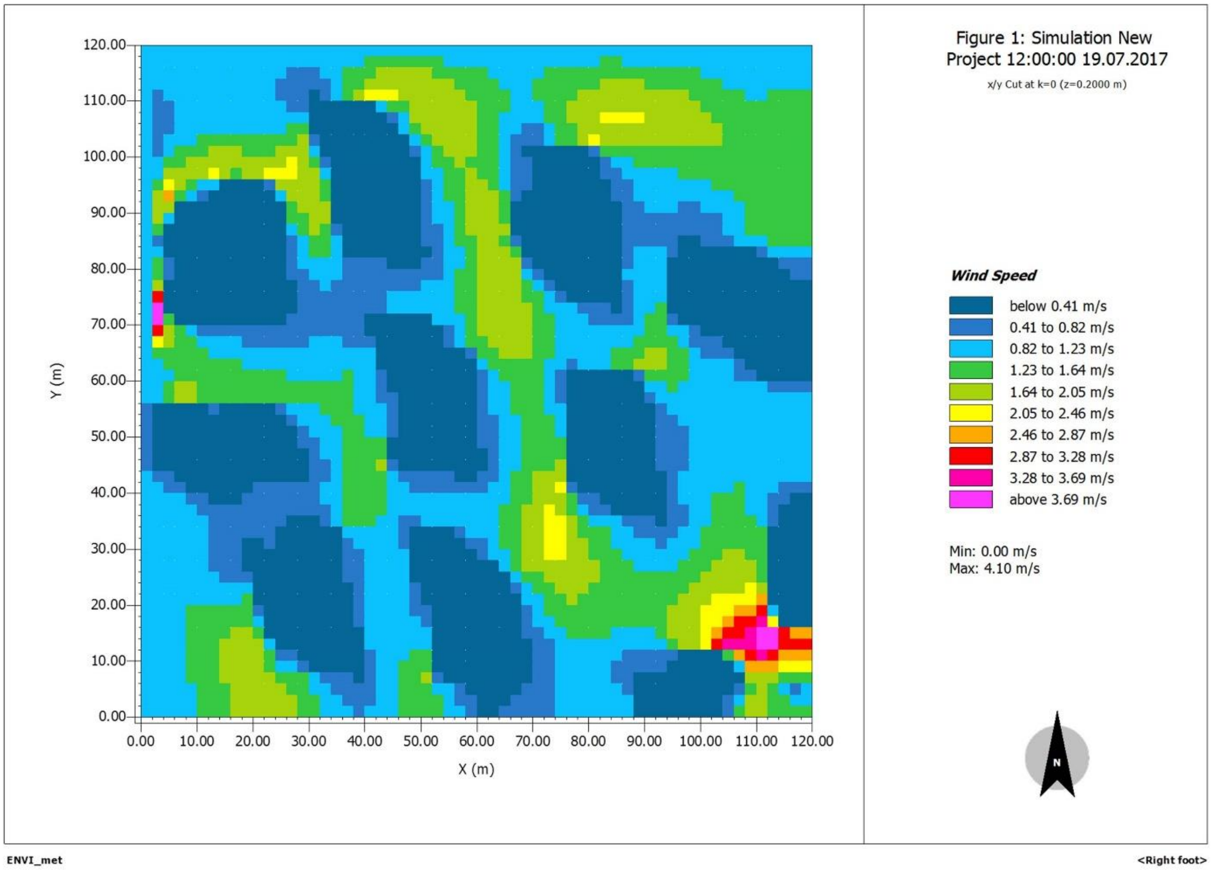


Strategy 4 - Waterbodies - swimming pool - Mapping of air temperature at 3pm

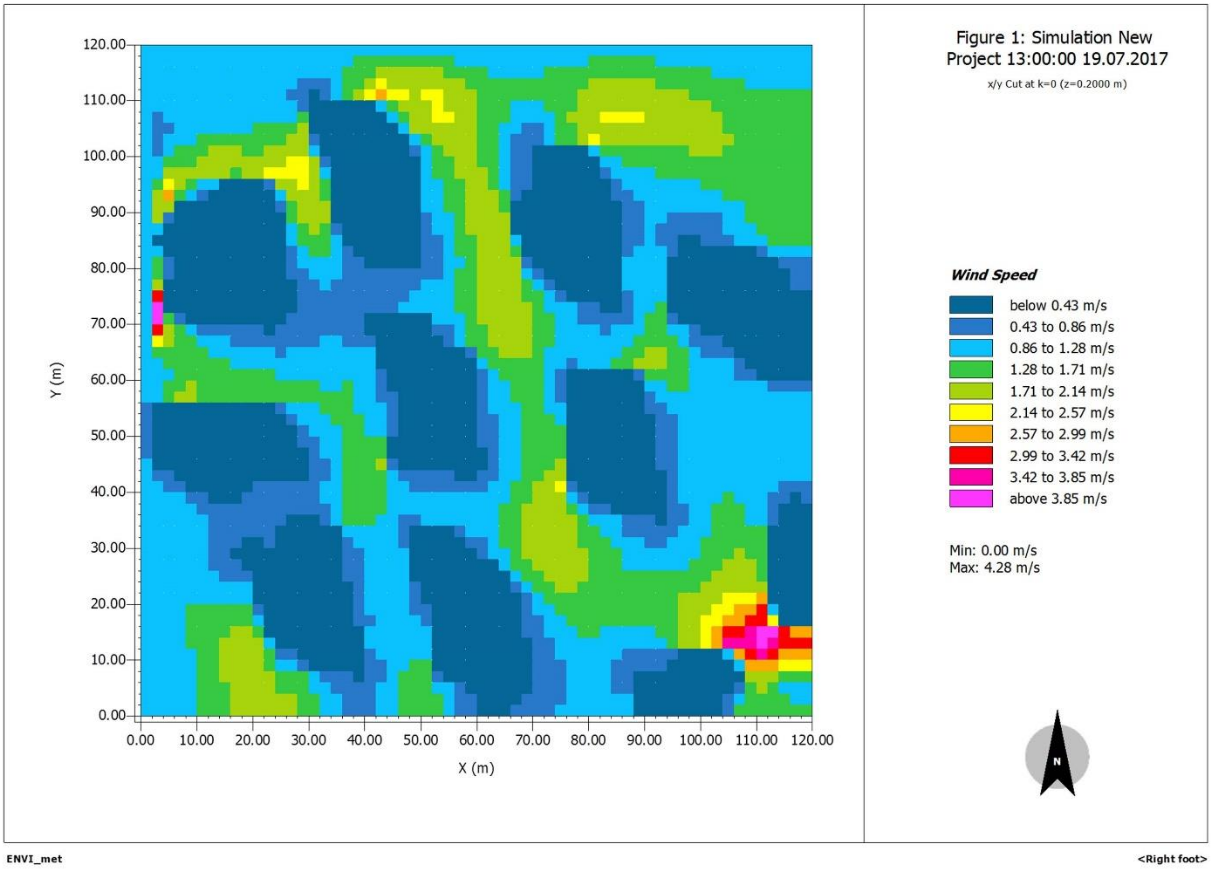


Strategy 4 - Waterbodies - swimming pool - Mapping of air temperature at 4pm

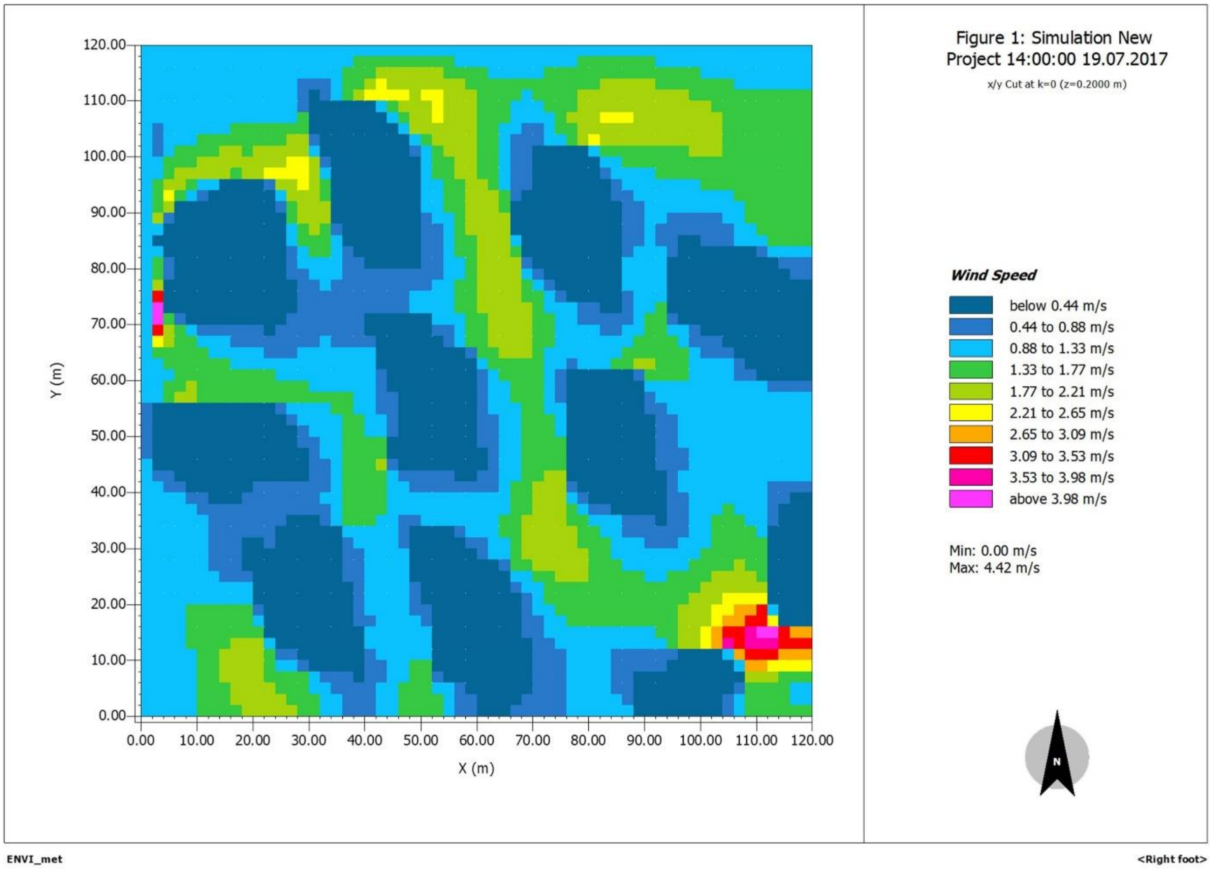
WIND SPEED



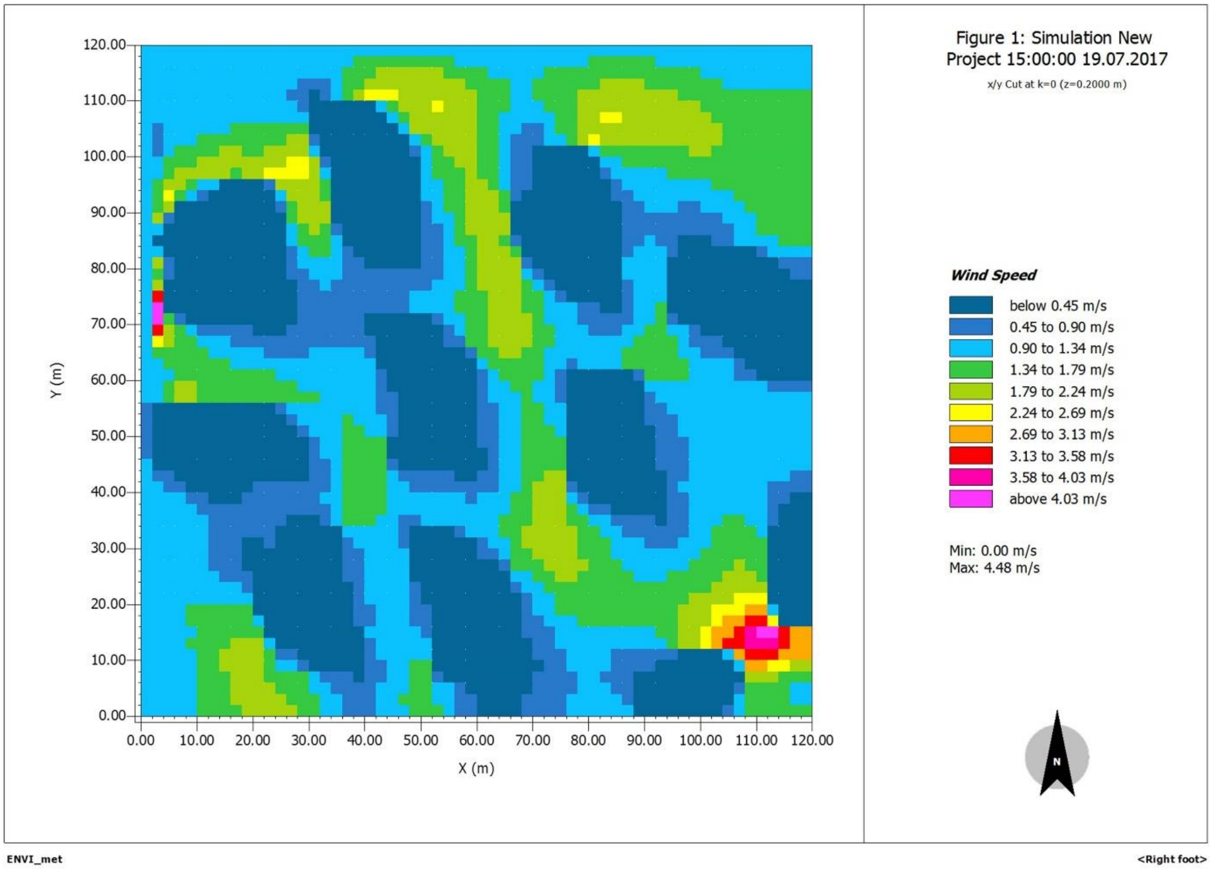
Strategy 4 - Waterbodies - swimming pool - Mapping of wind speed at 12pm



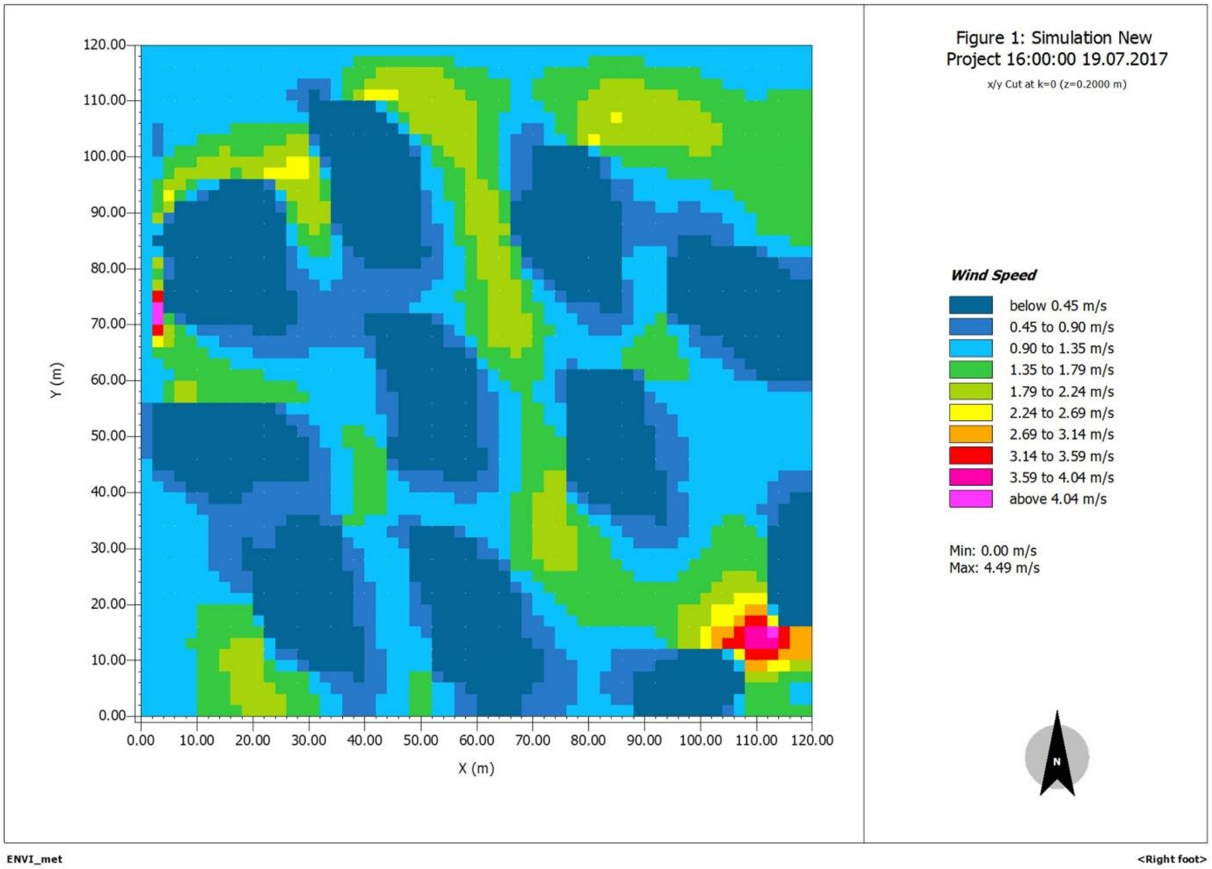
Strategy 4 - Waterbodies - swimming pool - Mapping of wind speed at 1pm



Strategy 4 - Waterbodies - swimming pool - Mapping of wind speed at 2pm

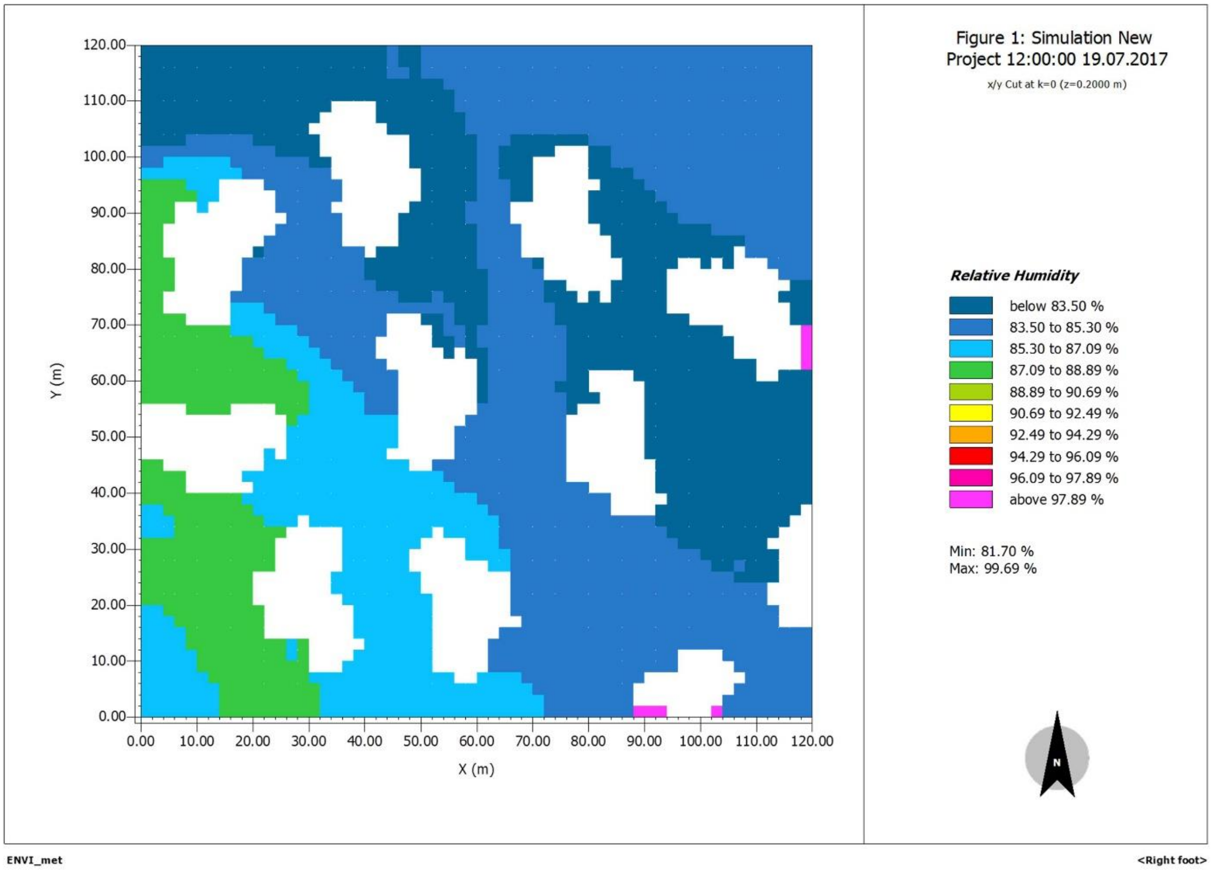


Strategy 4 - Waterbodies - swimming pool - Mapping of wind speed at 3pm

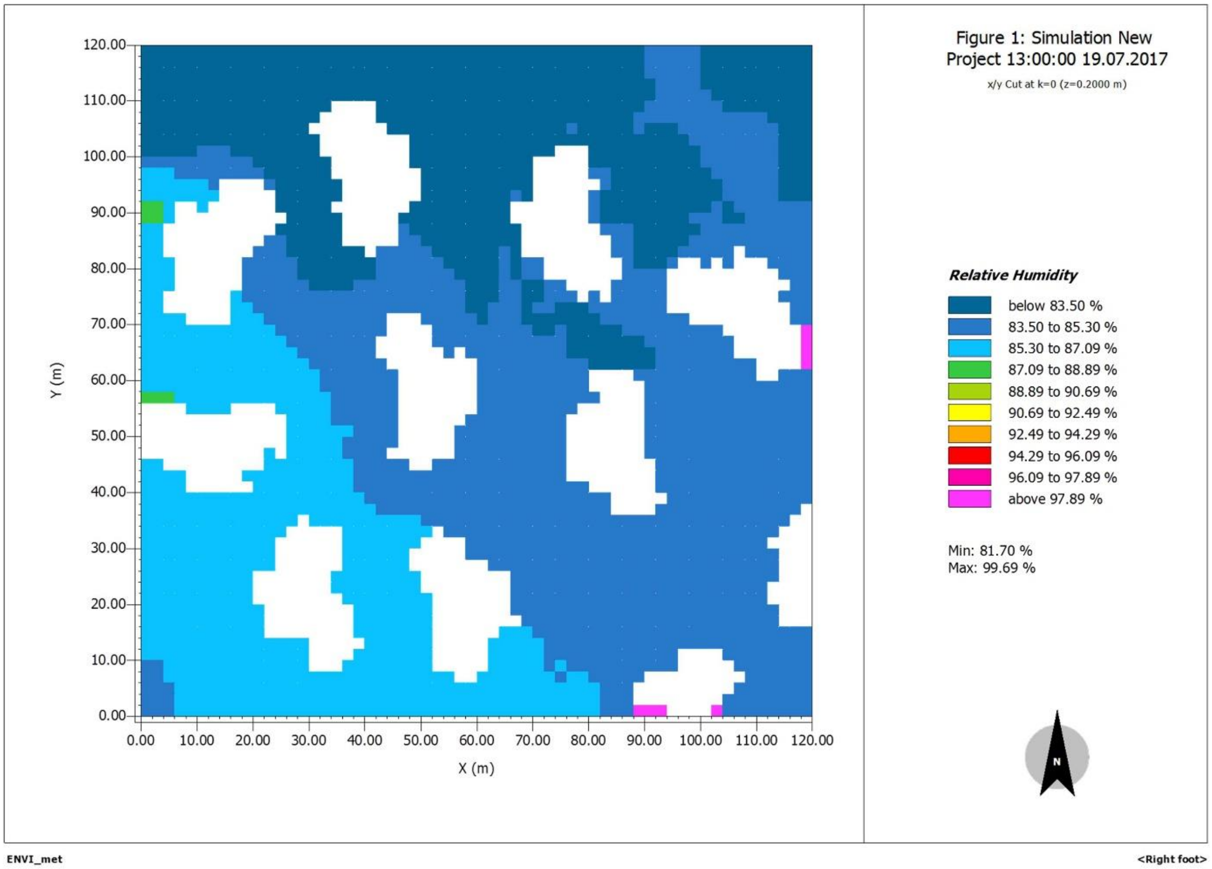


Strategy 4 - Waterbodies - swimming pool - Mapping of wind speed at 4pm

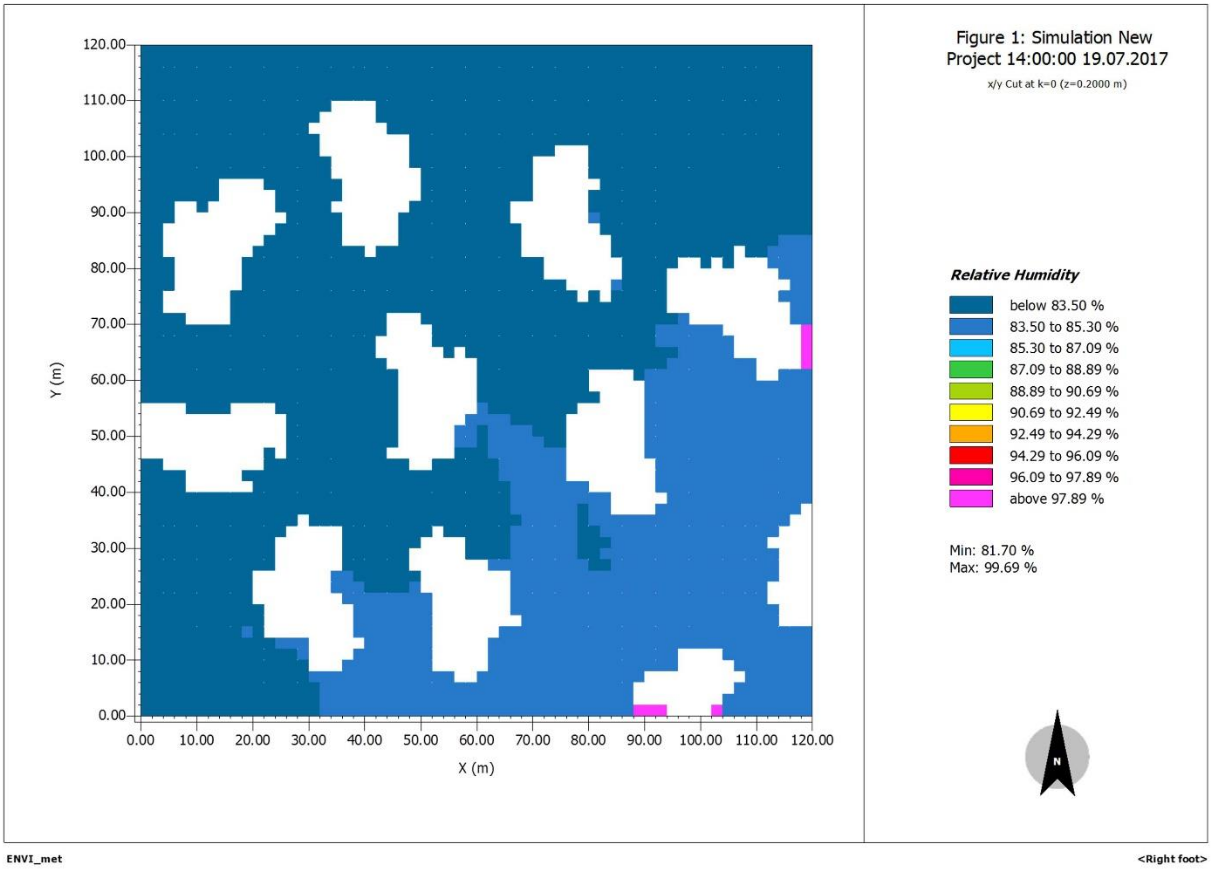
RELATIVE HUMIDITY



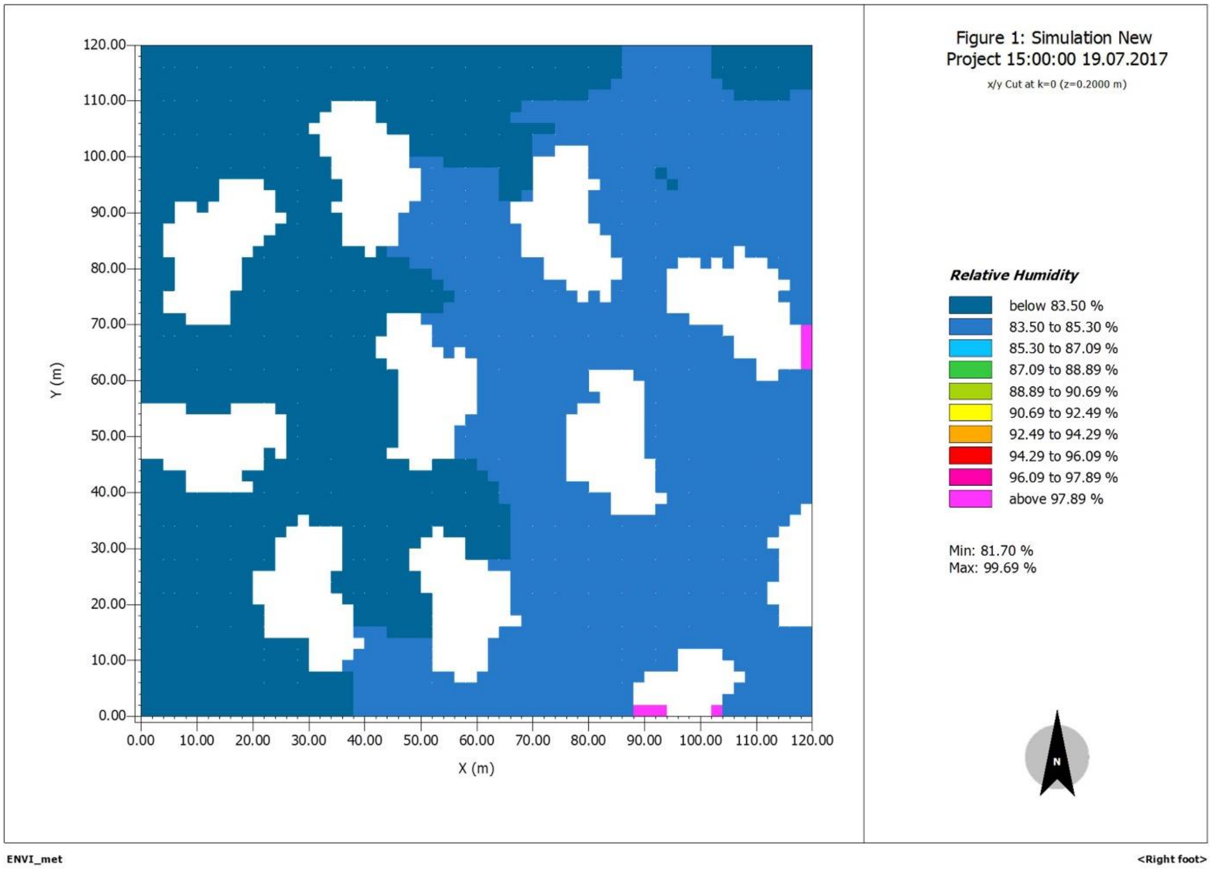
Strategy 4 - Waterbodies - swimming pool - Mapping of relative humidity at 12pm



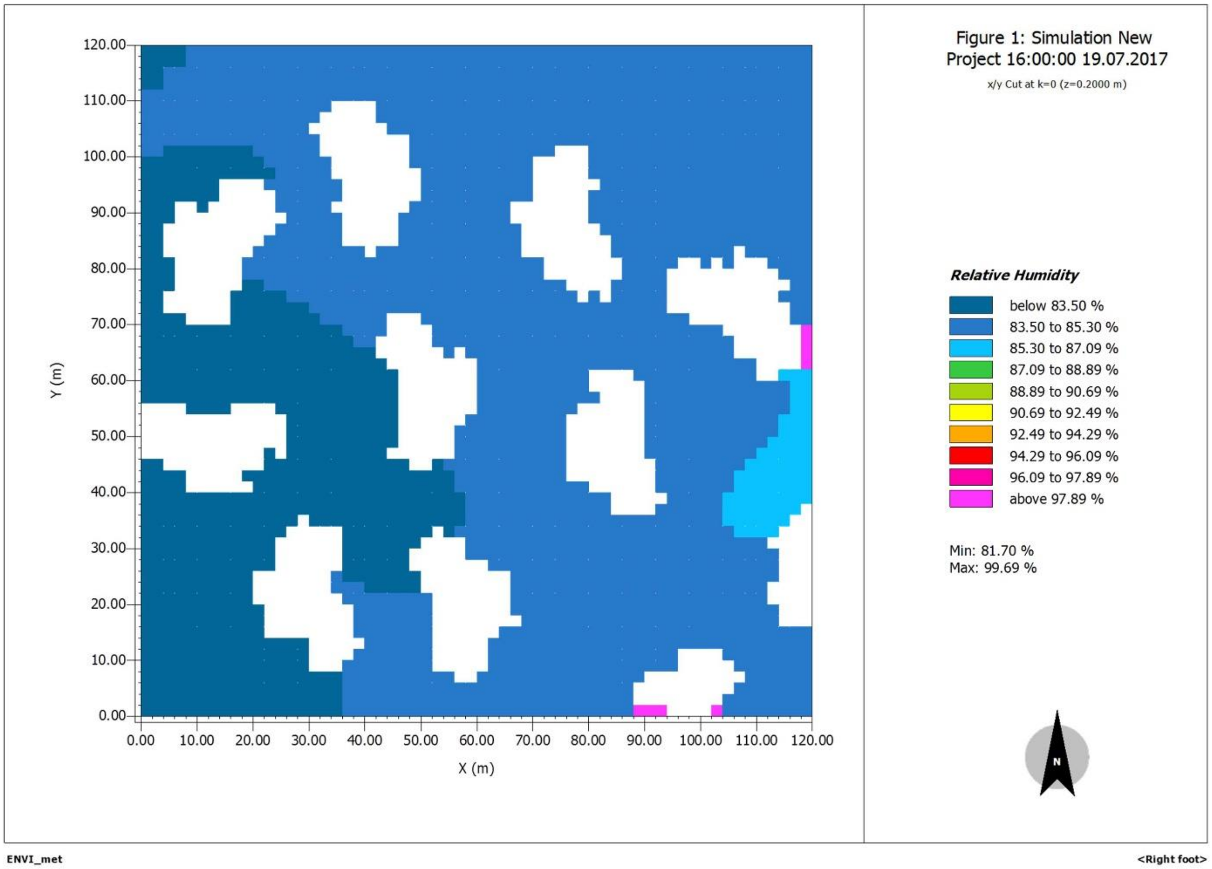
Strategy 4 - Waterbodies - swimming pool - Mapping of relative humidity at 1pm



Strategy 4 - Waterbodies - swimming pool - Mapping of relative humidity at 2pm

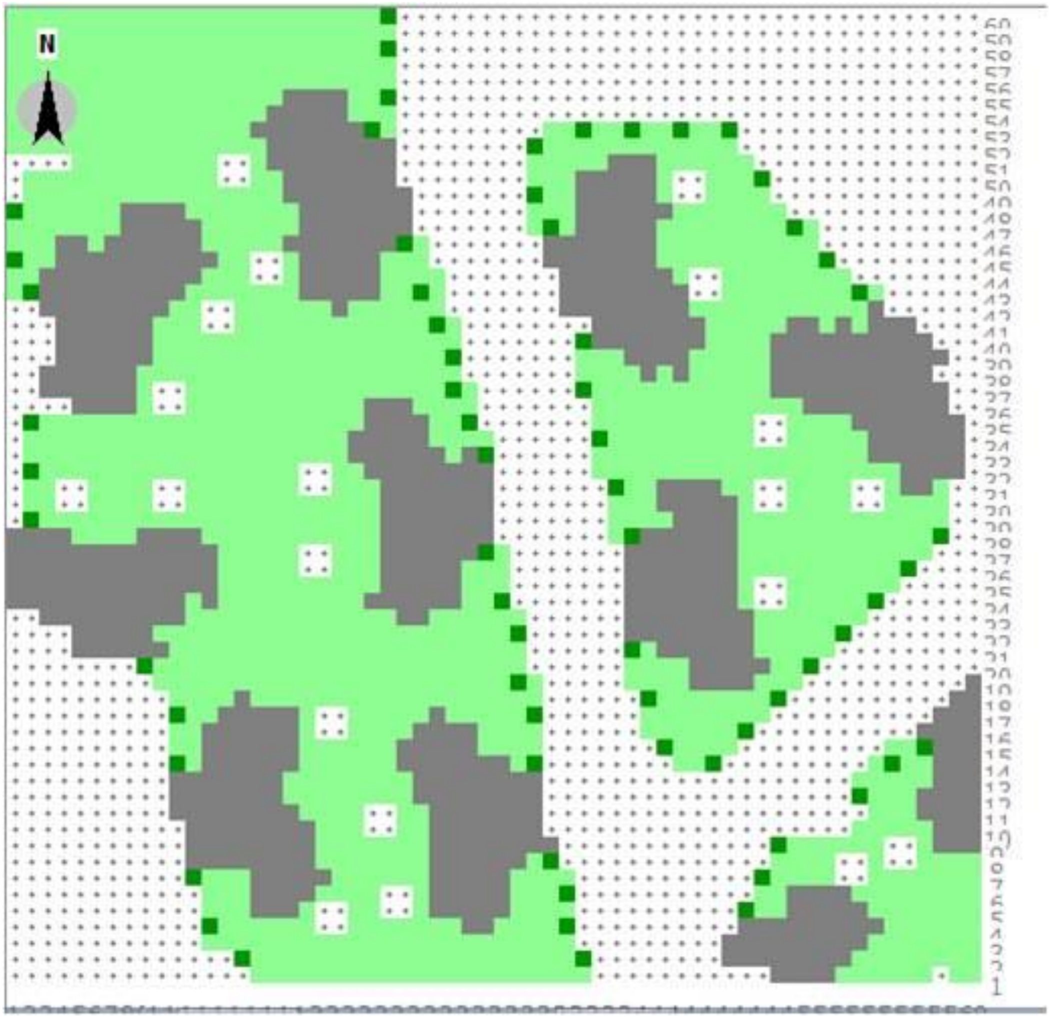


Strategy 4 - Waterbodies - swimming pool - Mapping of relative humidity at 3pm



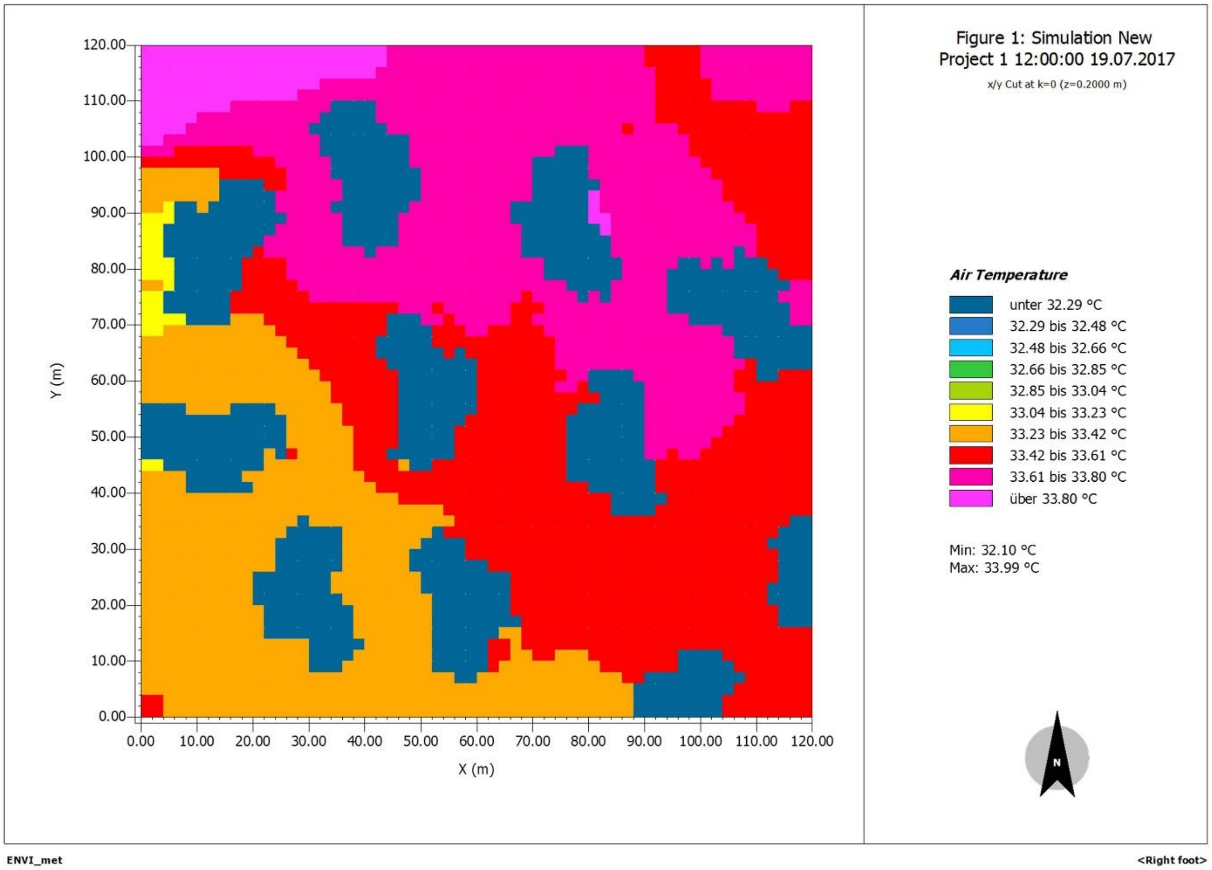
Strategy 4 - Waterbodies - swimming pool - Mapping of relative humidity at 4pm

Appendix 11 - Strategy 4 - Waterbodies - spraying fountain

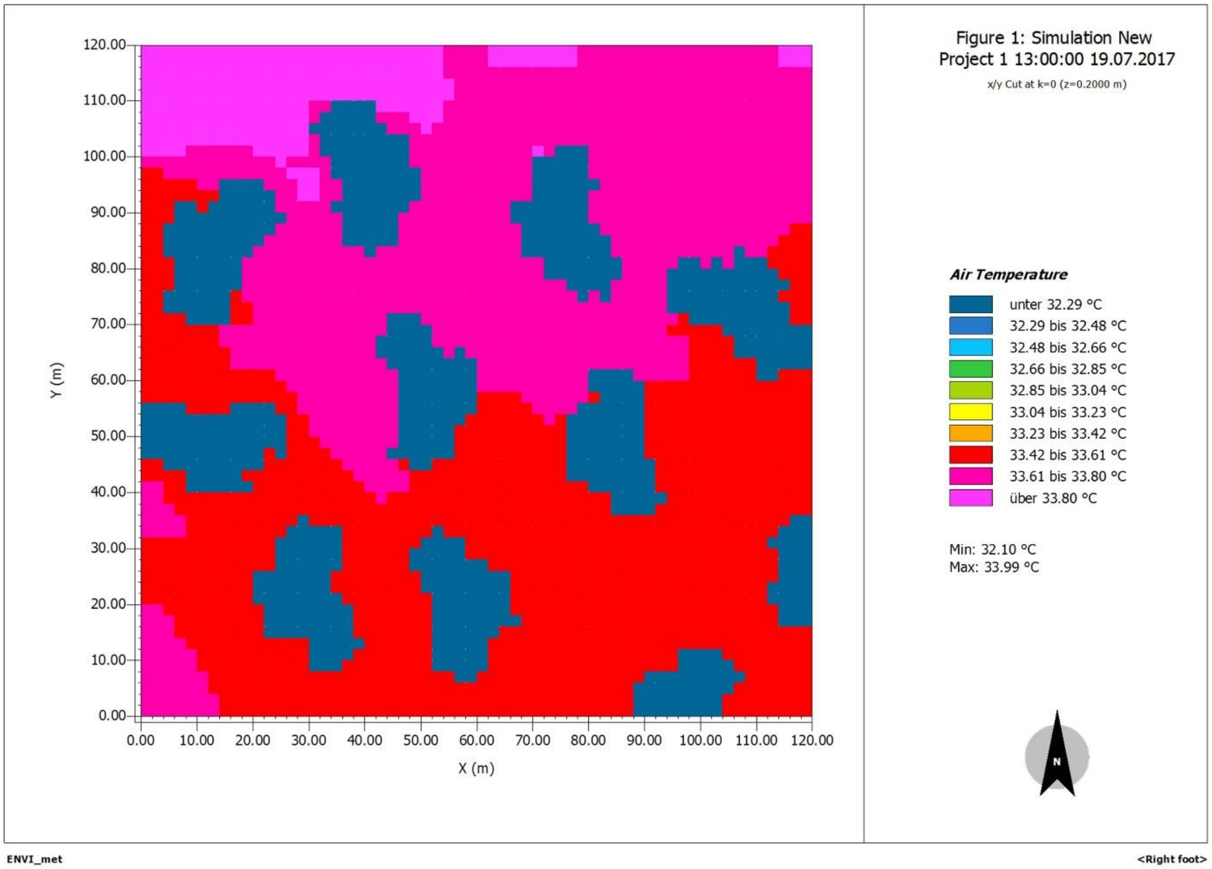


Model building, Waterbodies - spraying fountain. Grey indicates building structures and roads, with brown indicating the natural sandy soil.

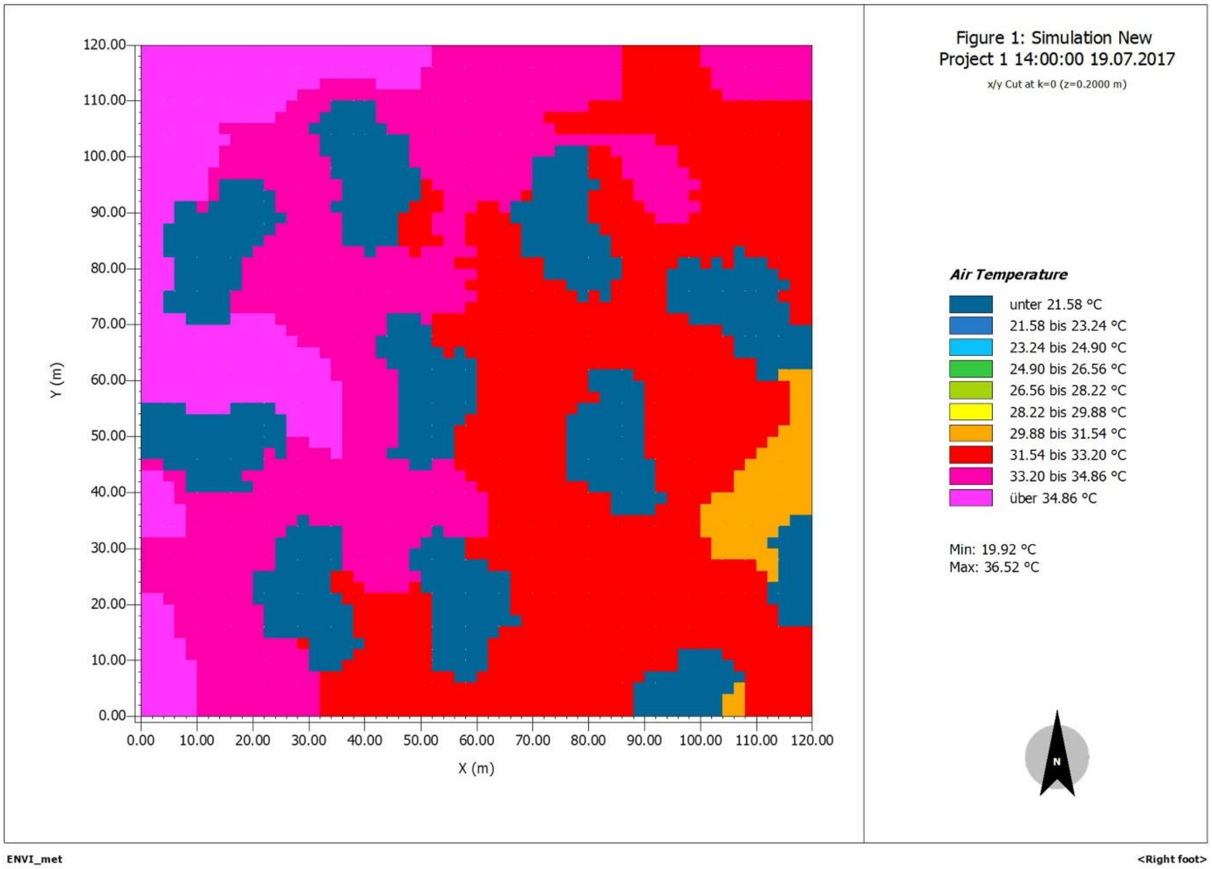
AIR TEMPERATURE



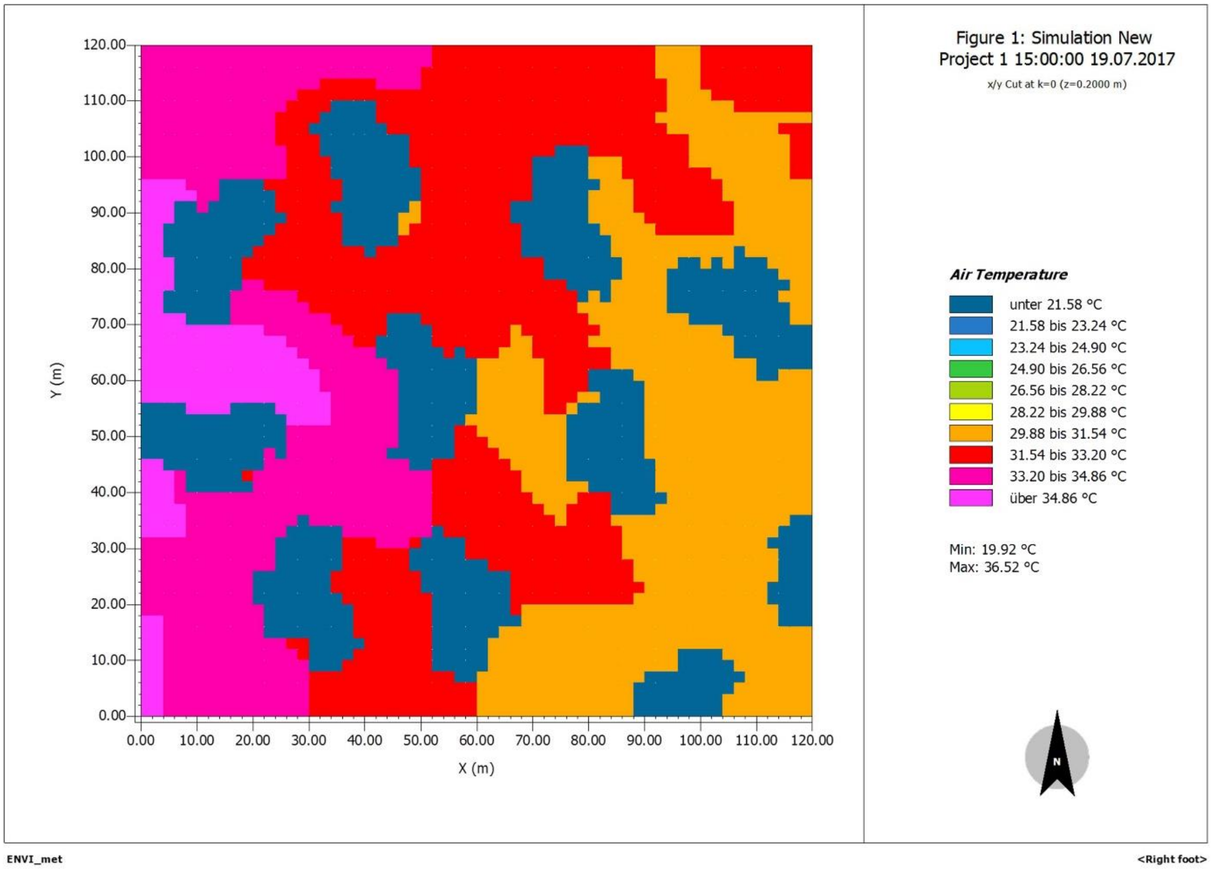
Strategy 4 - Waterbodies - spraying fountain - Mapping of air temperature at 12pm



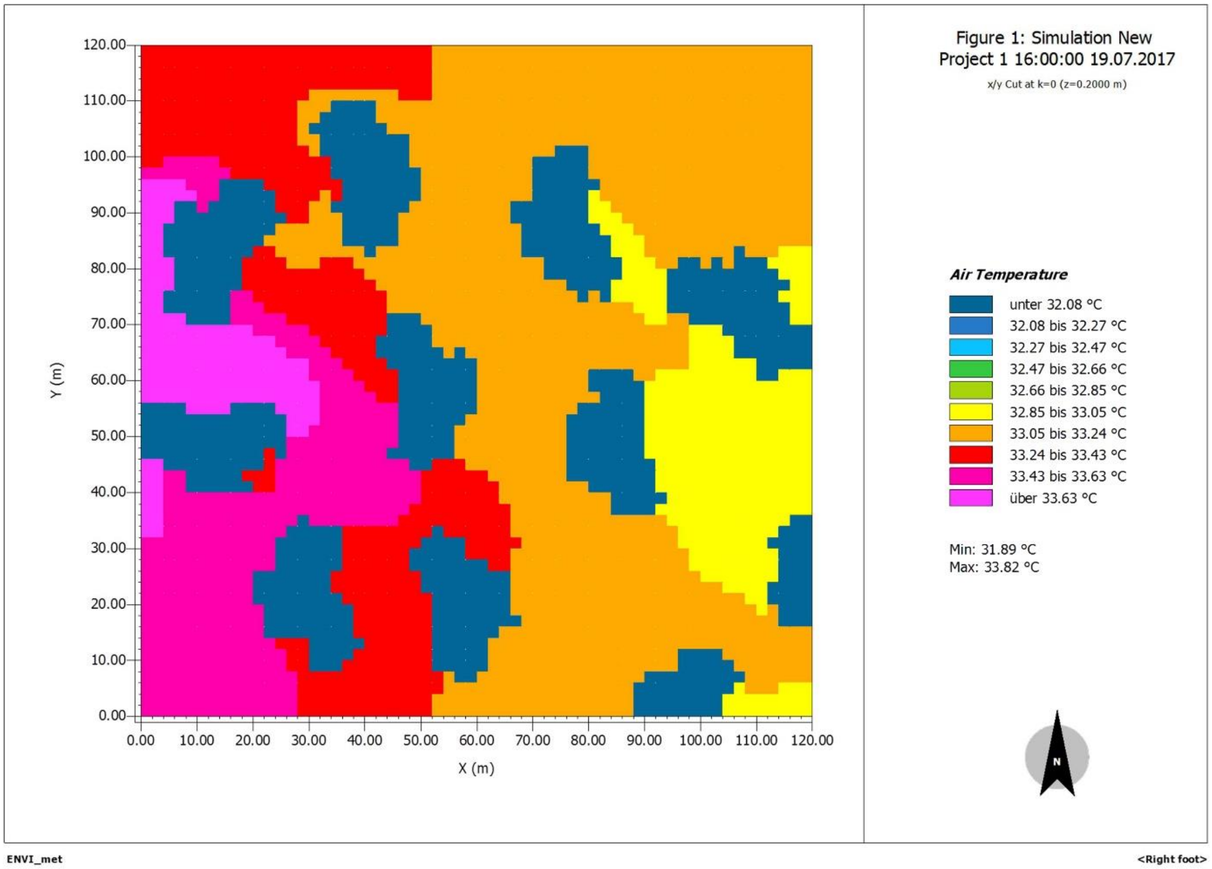
Strategy 4 - Waterbodies - spraying fountain - Mapping of air temperature at 1pm



Strategy 4 - Waterbodies - spraying fountain - Mapping of air temperature at 2pm

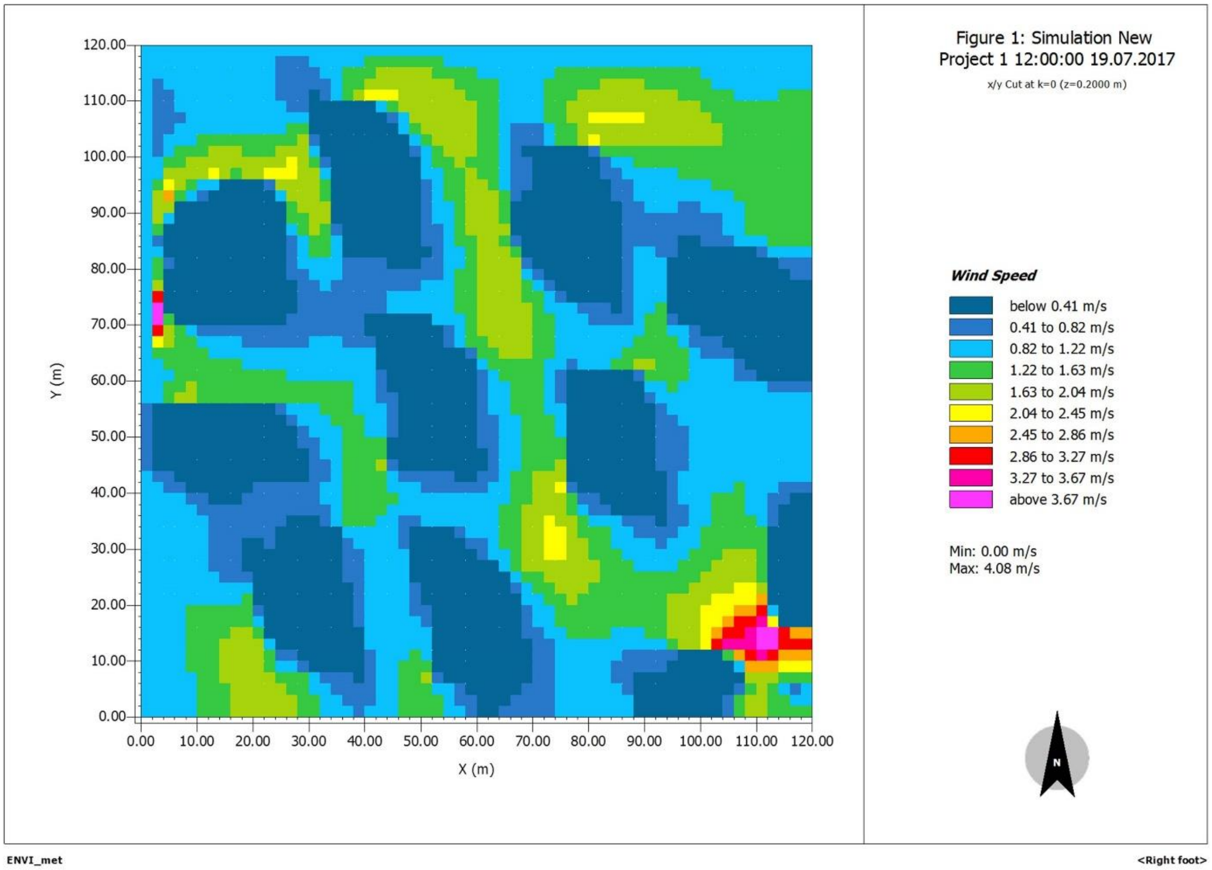


Strategy 4 - Waterbodies - spraying fountain - Mapping of air temperature at 3pm

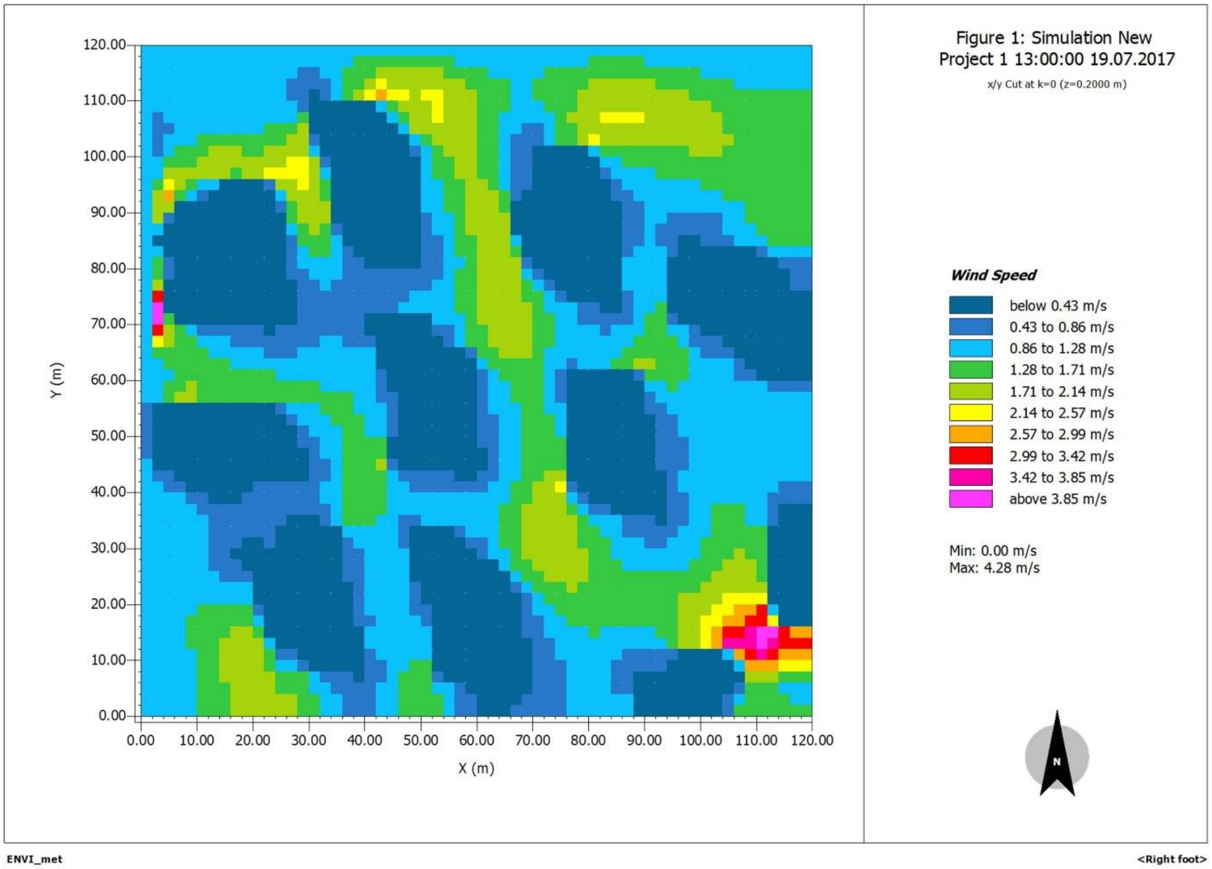


Strategy 4 - Waterbodies - spraying fountain - Mapping of air temperature at 4pm

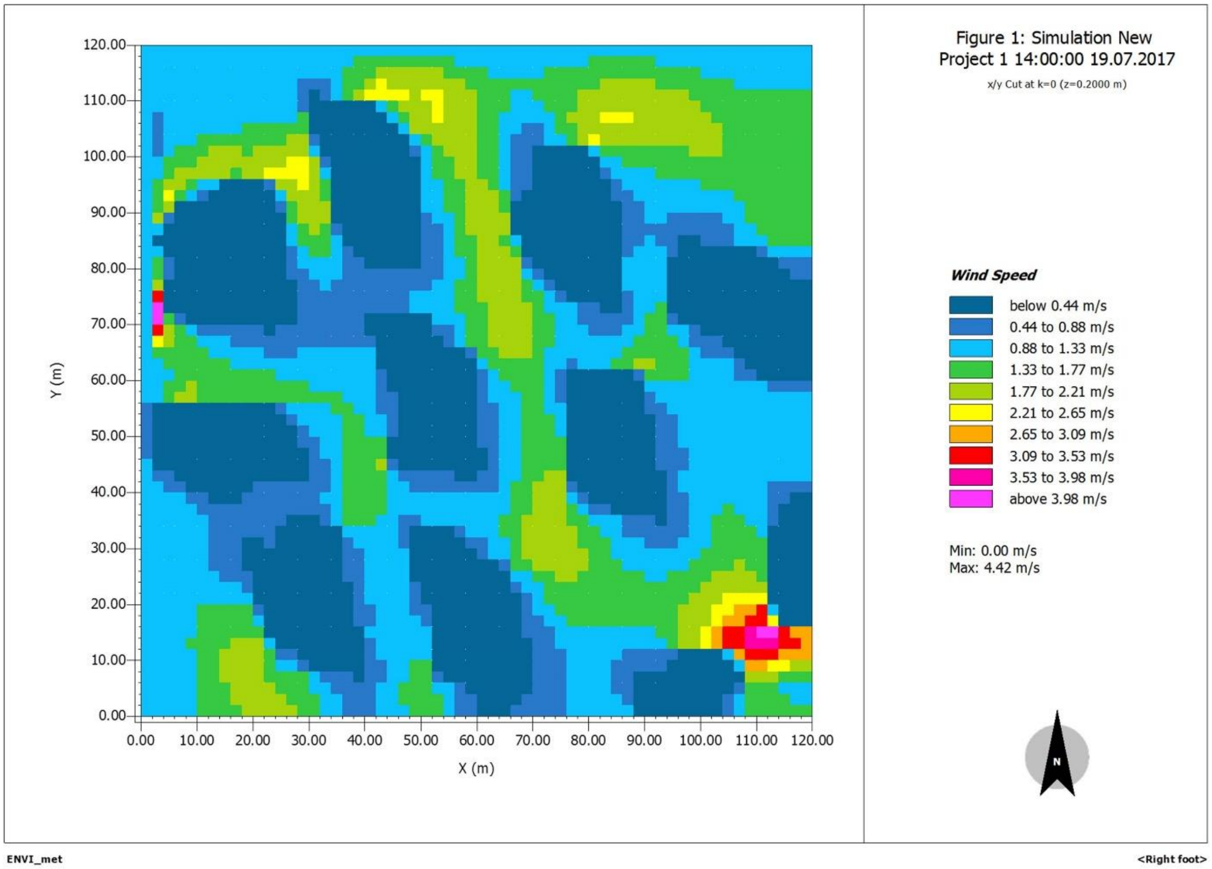
WIND SPEED



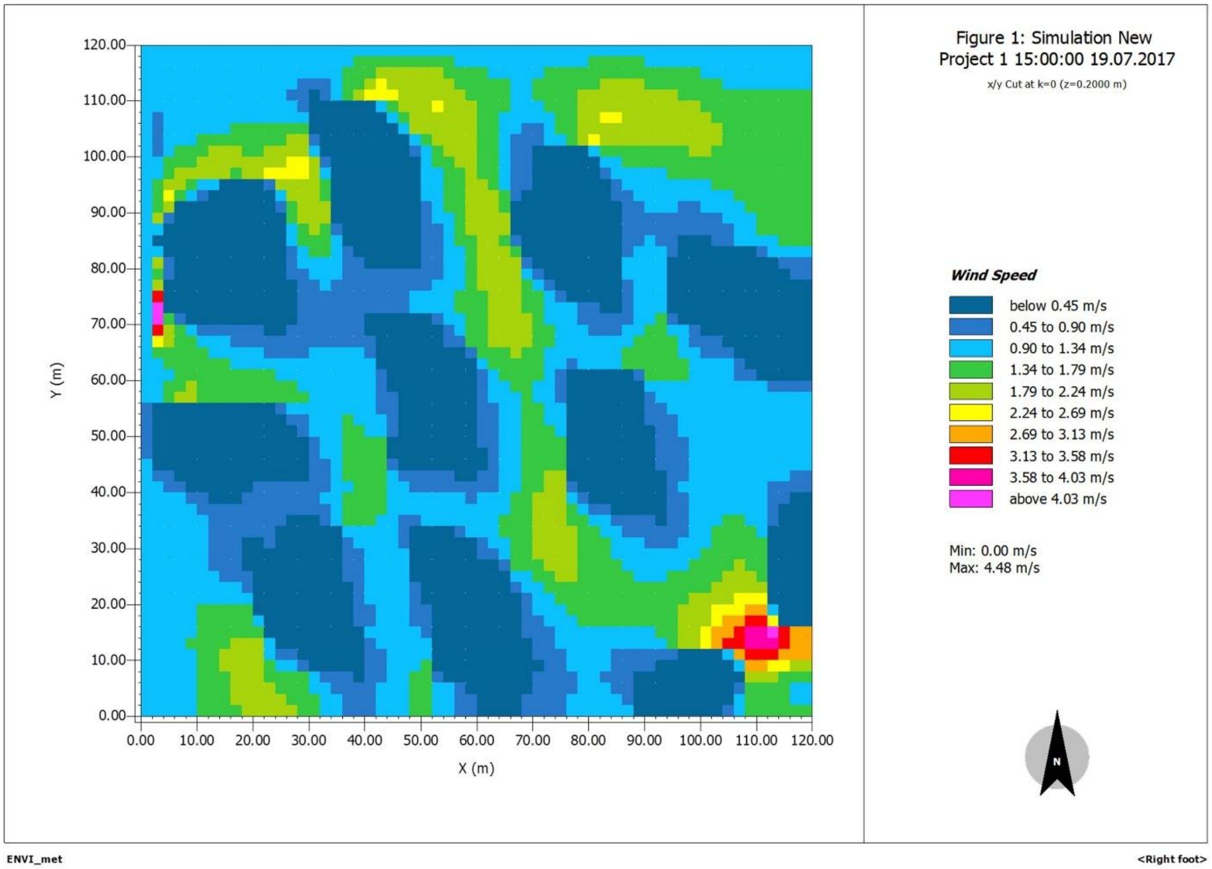
Strategy 4 - Waterbodies - spraying fountain - Mapping of wind speed at 12pm



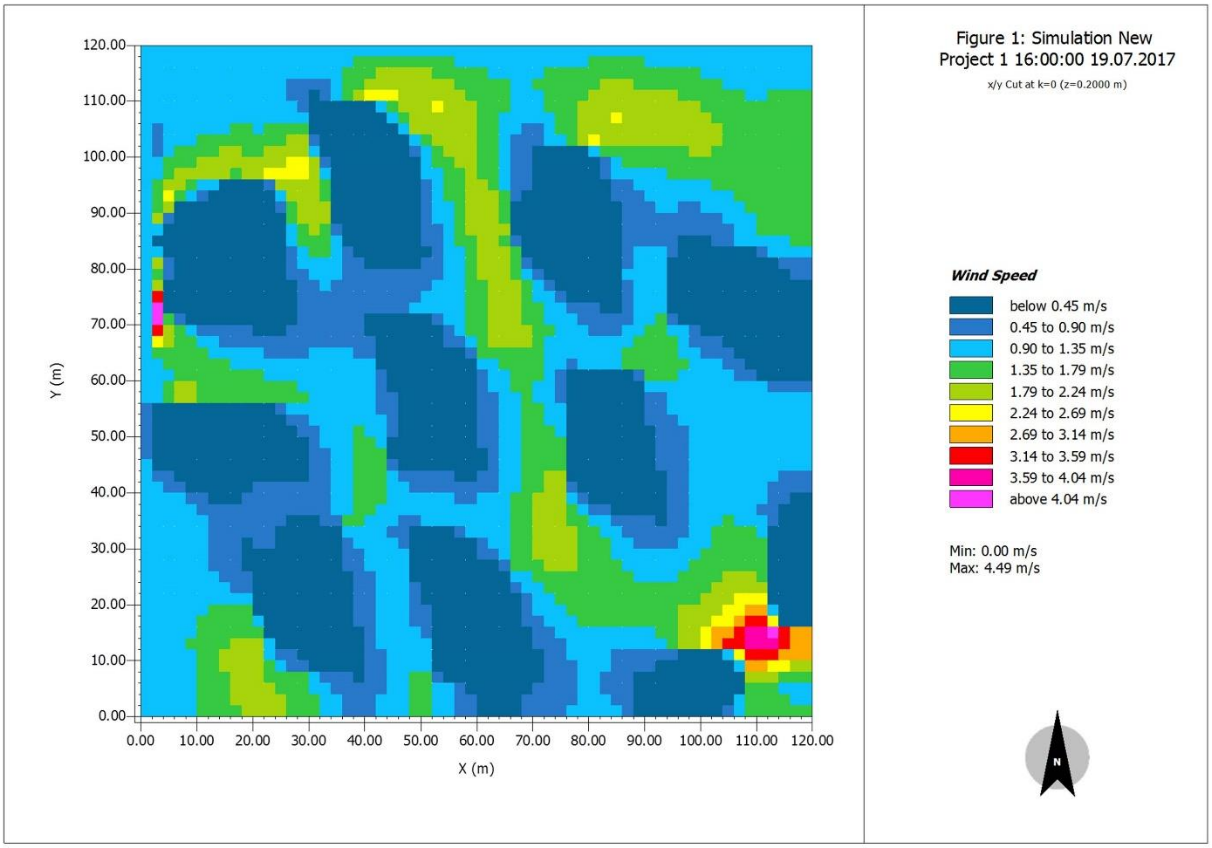
Strategy 4 - Waterbodies - spraying fountain - Mapping of wind speed at 1pm



Strategy 4 - Waterbodies - spraying fountain - Mapping of wind speed at 2pm



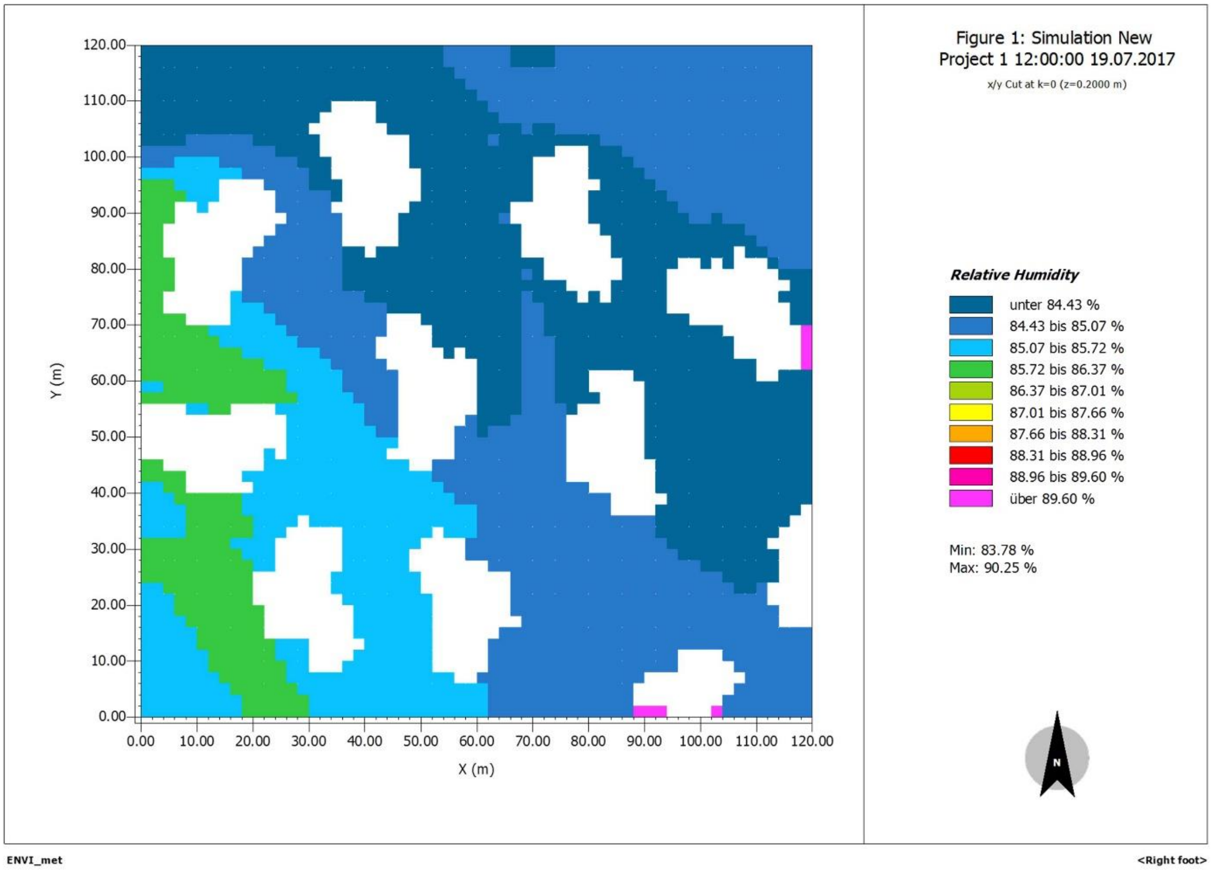
Strategy 4 - Waterbodies - spraying fountain - Mapping of wind speed at 3pm



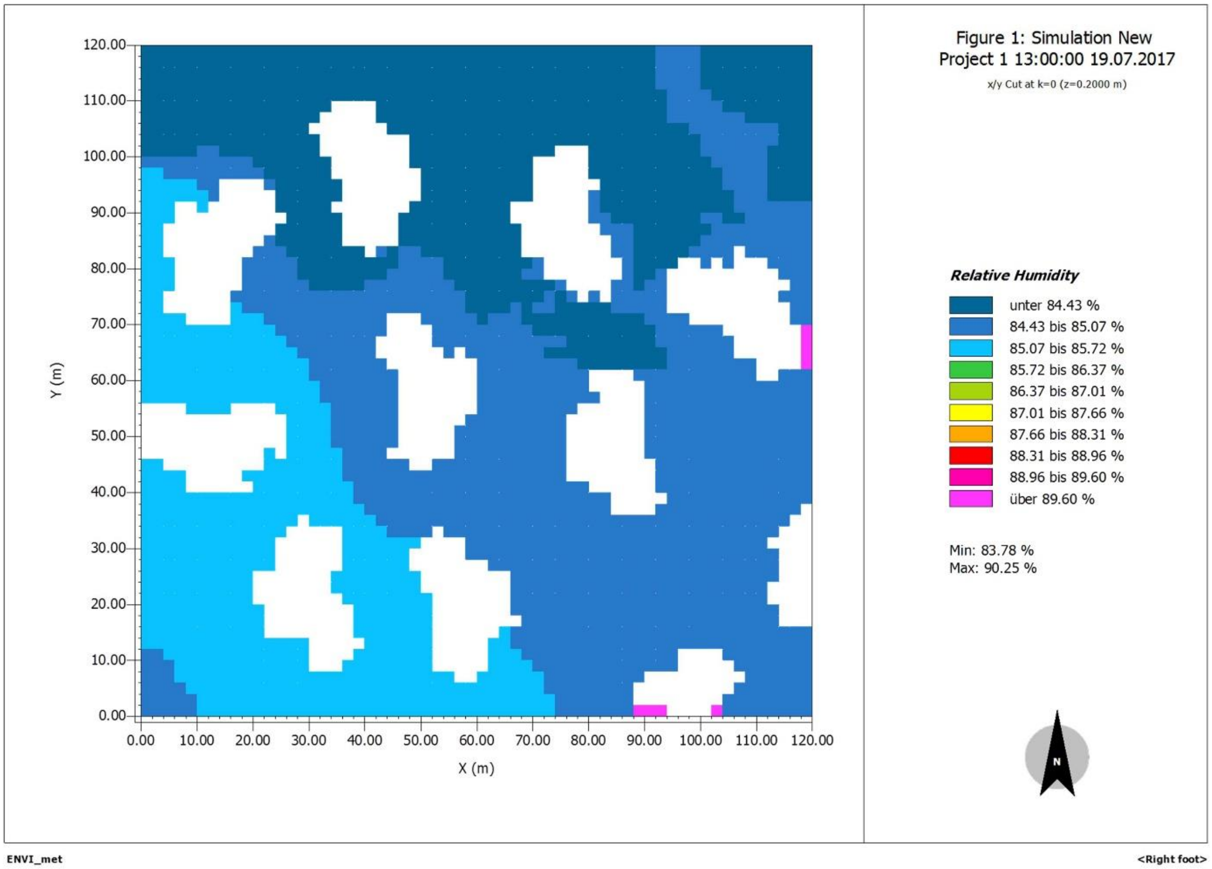
ENVI_met <Right foot>

Strategy 4 - Waterbodies - spraying fountain - Mapping of wind speed at 4pm

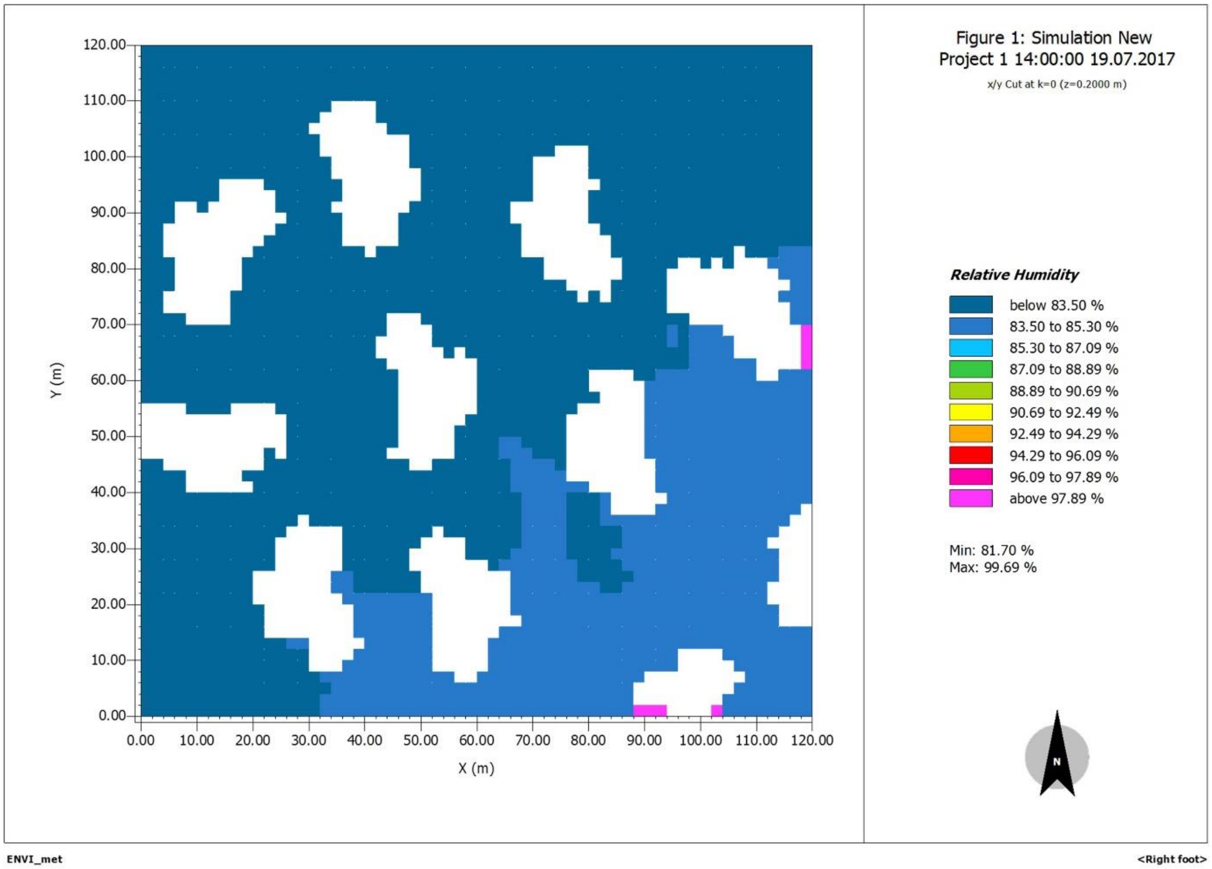
RELATIVE HUMIDITY



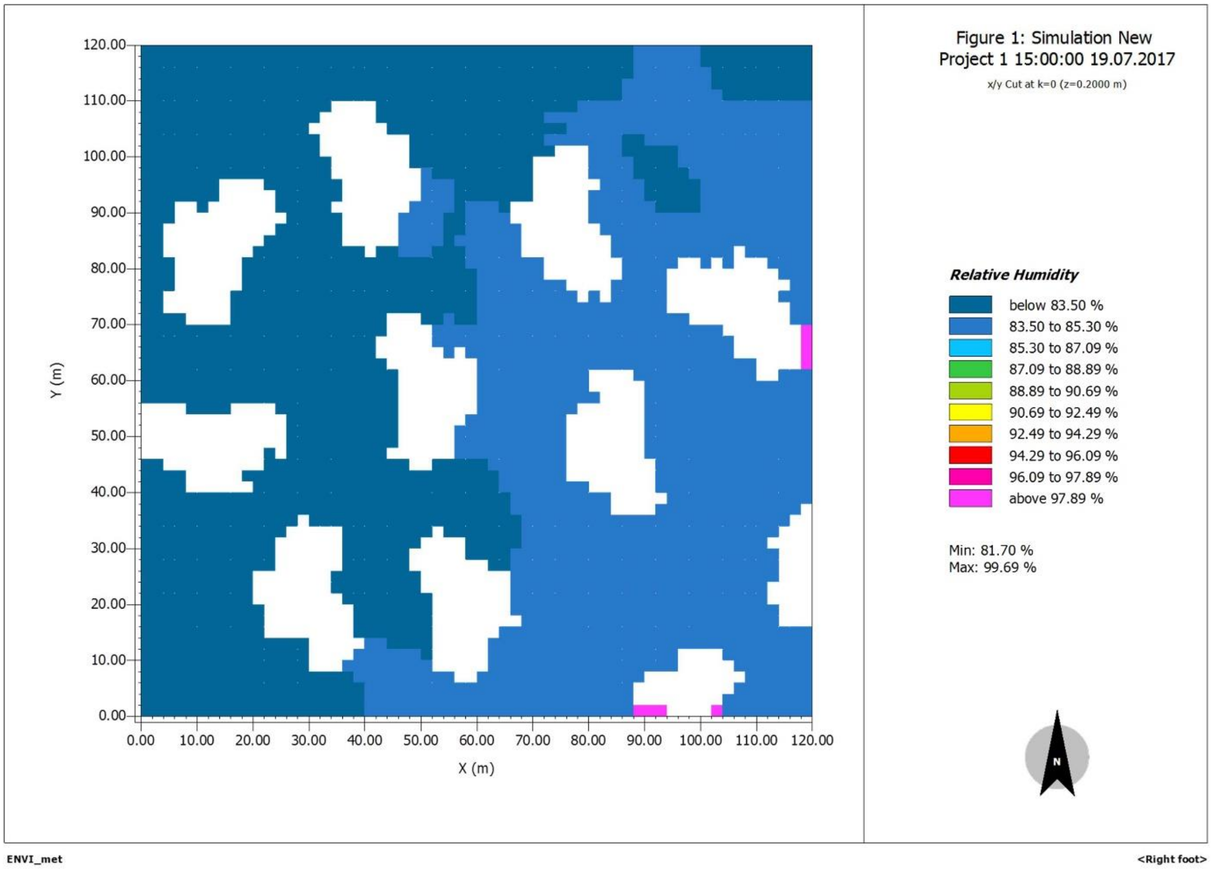
Strategy 4 - Waterbodies - spraying fountain - Mapping of relative humidity at 12pm



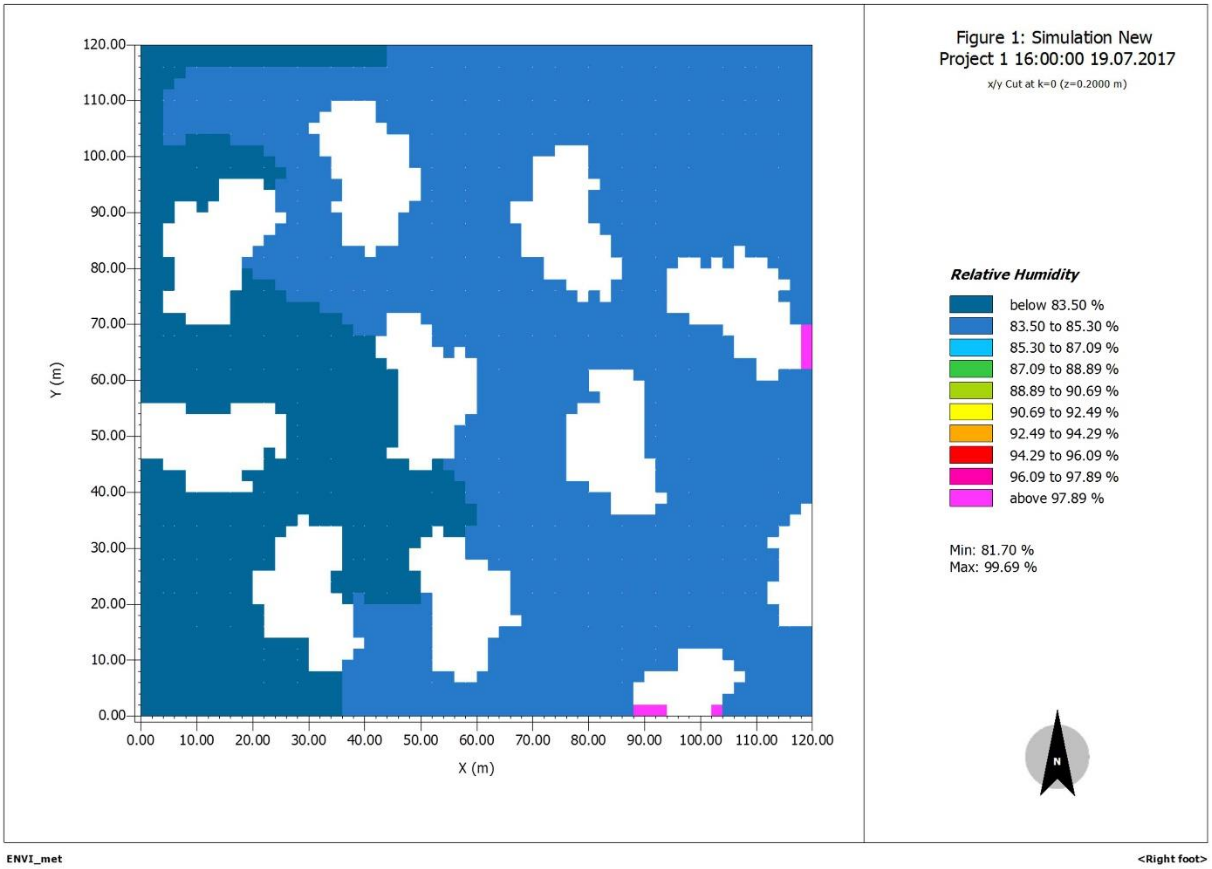
Strategy 4 - Waterbodies - spraying fountain - Mapping of relative humidity at 1pm



Strategy 4 - Waterbodies - spraying fountain - Mapping of relative humidity at 2pm



Strategy 4 - Waterbodies - spraying fountain - Mapping of relative humidity at 3pm



Strategy 4 - Waterbodies - spraying fountain - Mapping of relative humidity at 4pm

SPOT 1 front yard			
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
AT @ 12pm	34.25	34.20	33.61
AT @ 1pm	34.69	34.34	33.80
AT @ 2pm	36.94	34.63	33.20
AT @ 3pm	36.92	34.63	33.20
AT @ 4pm	36.81	34.06	33.24
	35.92	34.37	33.41
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
WS @ 12pm	1.21	1.22	1.22
WS @ 1pm	1.27	1.28	1.28
WS @ 2pm	1.32	1.33	1.33
WS @ 3pm	1.34	1.34	1.34
WS @ 4pm	1.34	1.35	1.35
	1.30	1.30	1.30
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
RH @ 12pm	81.96	85.30	84.43
RH @ 1pm	82.55	85.30	85.07
RH @ 2pm	77.73	83.50	83.50
RH @ 3pm	73.22	85.30	85.30
RH @ 4pm	73.92	85.30	85.30
	77.88	84.94	84.72

SPOT 2 back yard			
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
AT @ 12pm	34.25	34.20	33.61
AT @ 1pm	34.69	34.34	33.80
AT @ 2pm	36.94	34.69	33.86
AT @ 3pm	37.02	34.69	33.86
AT @ 4pm	37.02	34.20	33.43
	35.98	34.42	33.71
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
WS @ 12pm	1.21	1.22	1.22
WS @ 1pm	1.27	1.28	1.28
WS @ 2pm	1.32	1.33	1.33
WS @ 3pm	1.34	1.34	1.34
WS @ 4pm	1.34	1.35	1.35
	1.30	1.30	1.30
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
RH @ 12pm	82.55	85.30	85.07
RH @ 1pm	82.55	85.30	85.07
RH @ 2pm	77.73	83.50	83.50
RH @ 3pm	73.22	83.50	83.50
RH @ 4pm	73.22	83.50	83.50
	77.85	84.22	84.13

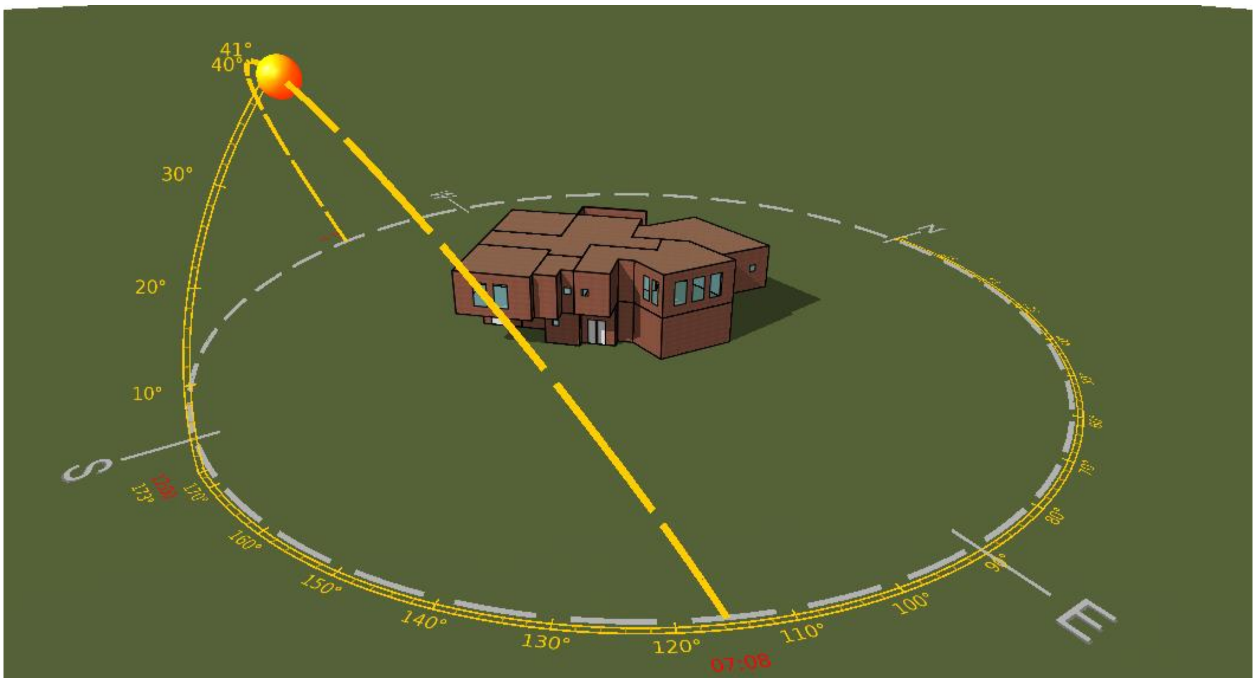
SPOT 3 road surface			
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
AT @ 12pm	34.25	34.20	33.61
AT @ 1pm	34.69	34.20	33.61
AT @ 2pm	36.87	34.63	33.20
AT @ 3pm	36.92	34.56	31.54
AT @ 4pm	36.81	34.06	33.24
	35.91	34.33	33.04
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
WS @ 12pm	1.21	1.22	1.22
WS @ 1pm	1.27	1.28	1.28
WS @ 2pm	1.32	1.33	1.33
WS @ 3pm	1.34	1.34	1.34
WS @ 4pm	1.34	1.35	1.35
	1.30	1.30	1.30
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
RH @ 12pm	82.55	85.30	84.43
RH @ 1pm	82.55	85.30	85.07
RH @ 2pm	77.73	83.50	83.50
RH @ 3pm	73.92	85.30	85.30
RH @ 4pm	73.22	85.30	85.30
	77.99	84.94	84.72

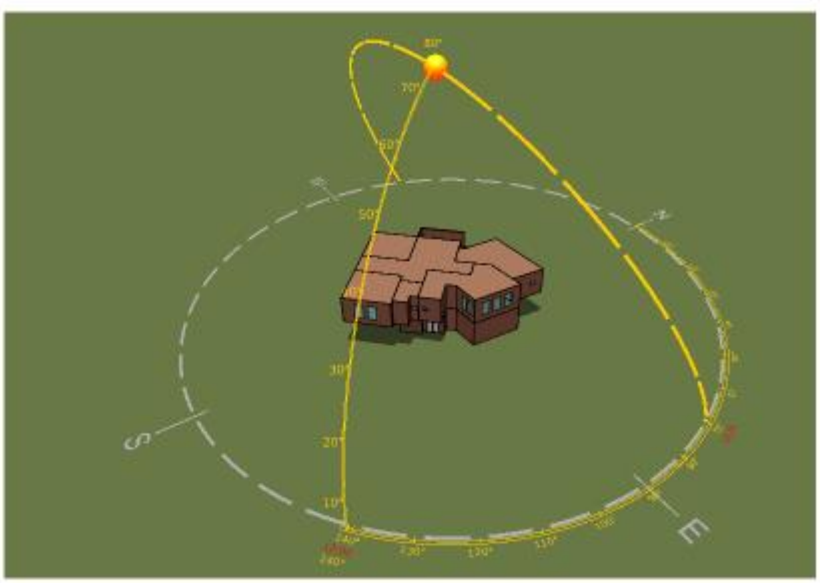
SPOT 4 open space			
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
AT @ 12pm	34.16	34.06	33.42
AT @ 1pm	34.69	34.34	33.80
AT @ 2pm	37.01	34.76	36.52
AT @ 3pm	37.13	34.76	36.52
AT @ 4pm	37.13	34.49	33.82
	36.02	34.48	34.82
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
WS @ 12pm	1.21	1.22	1.22
WS @ 1pm	1.27	1.28	1.28
WS @ 2pm	1.32	1.33	1.33
WS @ 3pm	1.34	1.34	1.34
WS @ 4pm	1.34	1.35	1.35
	1.30	1.30	1.30
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
RH @ 12pm	83.15	87.09	85.72
RH @ 1pm	83.15	87.09	85.72
RH @ 2pm	77.73	83.50	83.50
RH @ 3pm	73.22	83.50	83.50
RH @ 4pm	73.22	83.50	83.50
	78.09	84.94	84.39

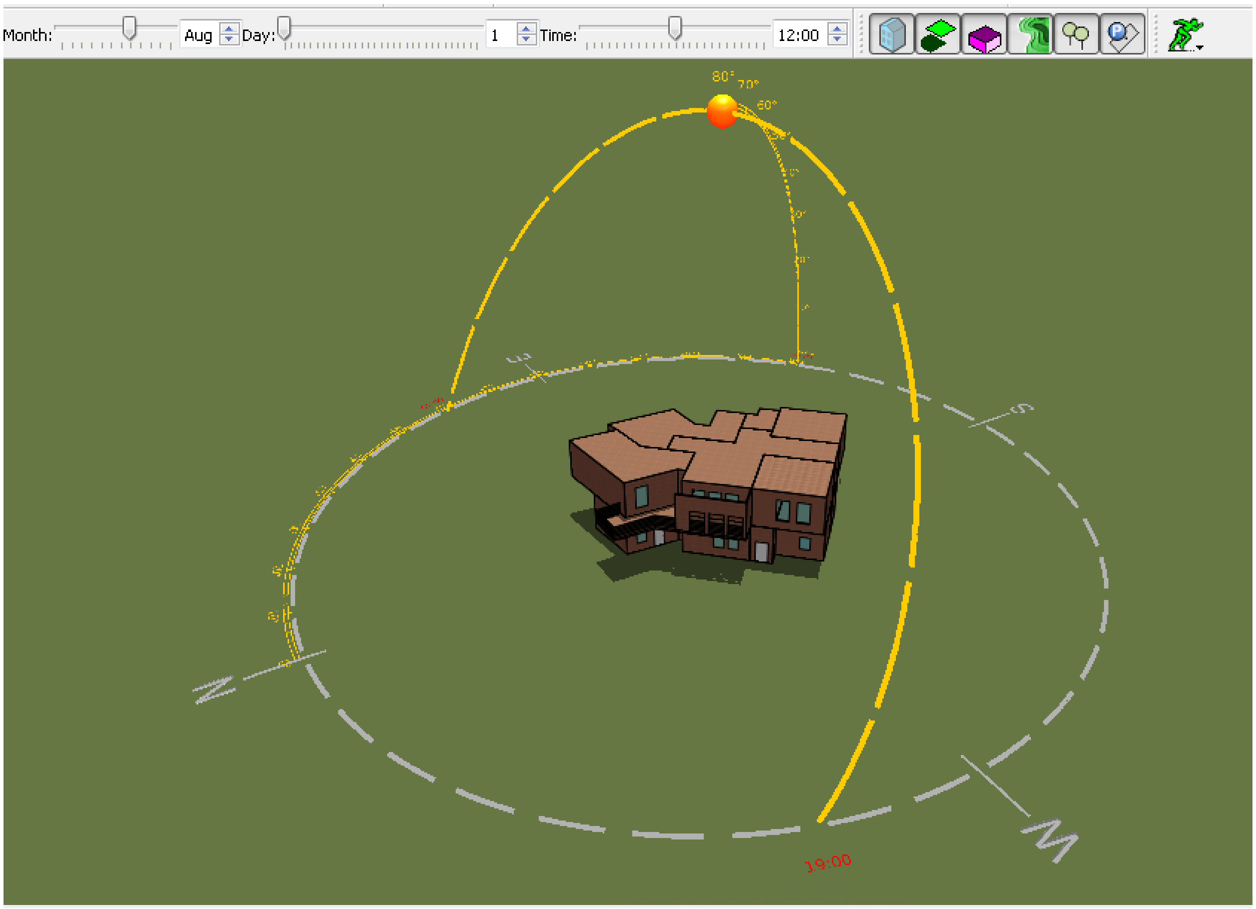
averages for simulation 9.10.11			
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
AT @ 12pm	34.23	34.17	33.56
AT @ 1pm	34.69	34.31	33.75
AT @ 2pm	36.94	34.68	34.20
AT @ 3pm	37.00	34.66	33.78
AT @ 4pm	36.94	34.20	33.43
	35.96	34.40	33.74
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
WS @ 12pm	1.21	1.22	1.22
WS @ 1pm	1.27	1.28	1.28
WS @ 2pm	1.32	1.33	1.33
WS @ 3pm	1.34	1.34	1.34
WS @ 4pm	1.34	1.35	1.35
	1.30	1.30	1.30
waterbodies	best results from str3	swimming pool	fountain with 4m high spray
RH @ 12pm	82.55	85.75	84.91
RH @ 1pm	82.70	85.75	85.23
RH @ 2pm	77.73	83.50	83.50
RH @ 3pm	73.40	84.40	84.40
RH @ 4pm	73.40	84.40	84.40
	77.95	84.76	84.49

Appendix 12 - Strategy 5 - Energy consumption - base case

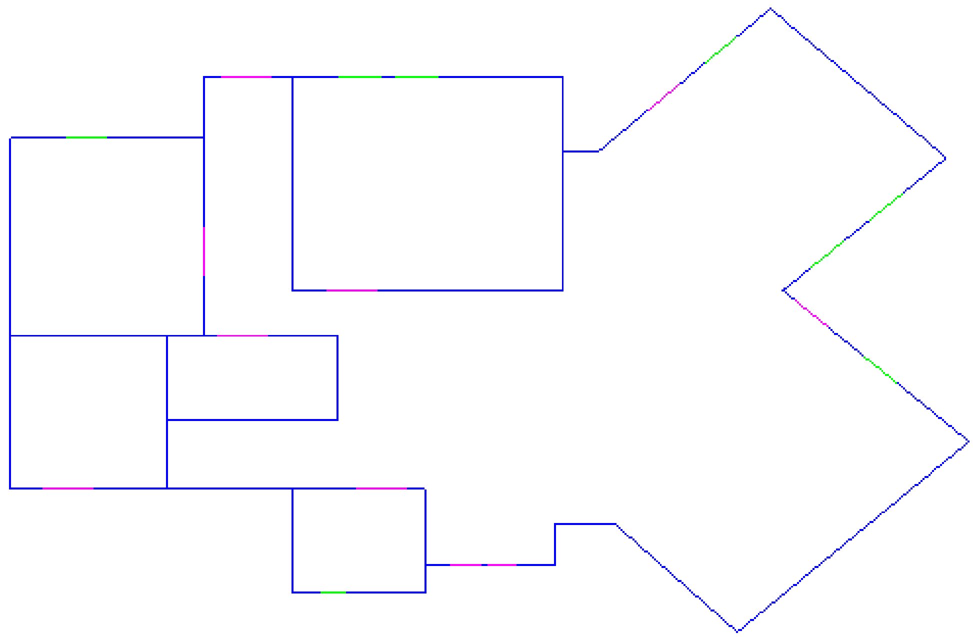
Base Case Model

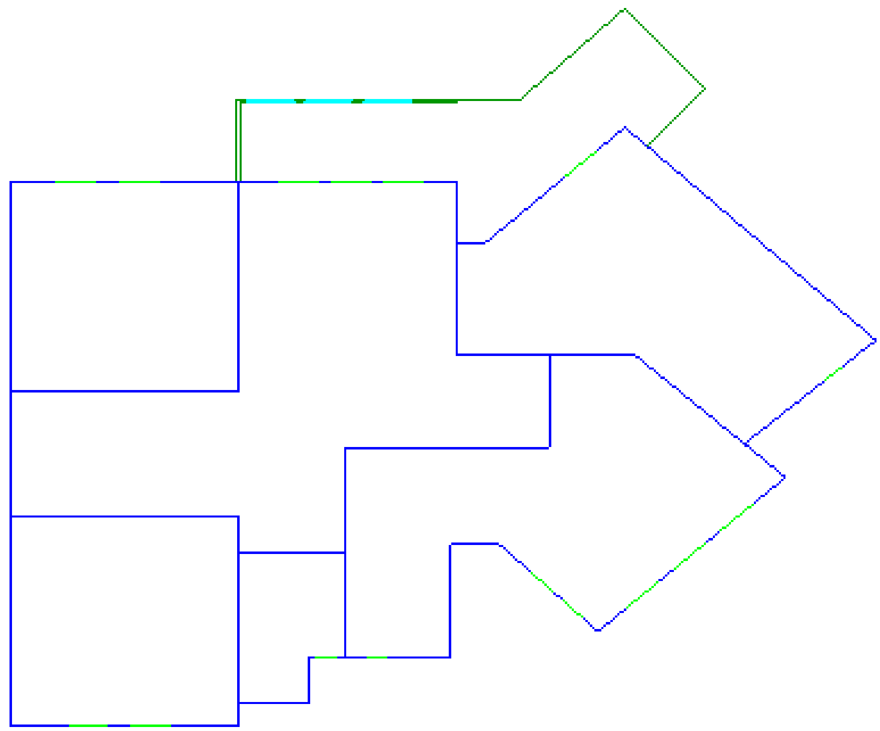




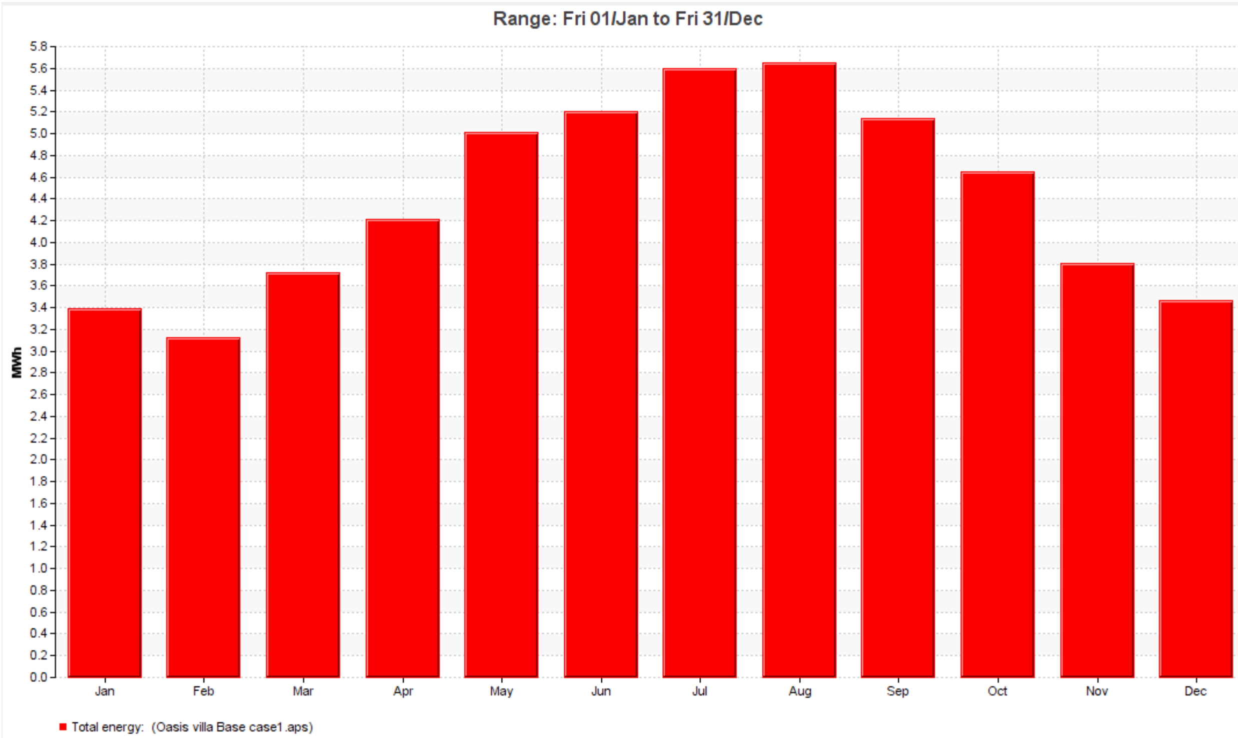


Month:
Aug
Day:
1
Time:
12:00
80°
70°
60°
19:00





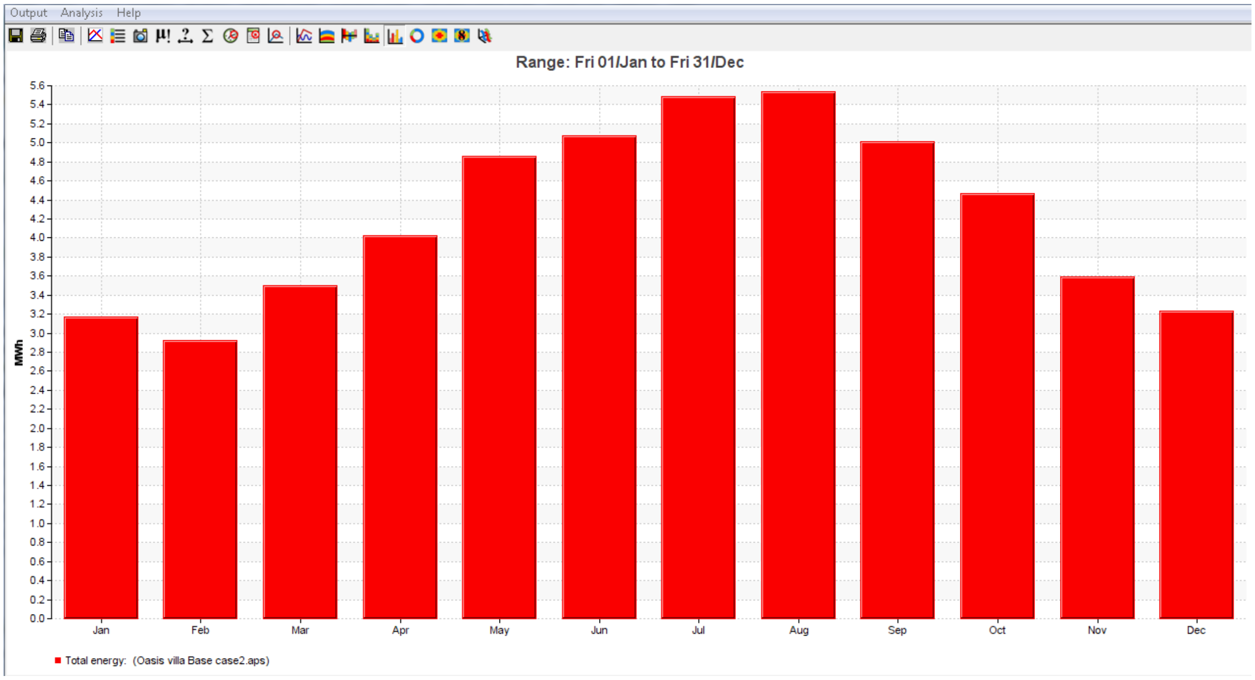
Base Case - Energy Consumption



	Total energy (MWh)
Date	Oasis villa Base case1.aps
Jan 01-31	3.3956
Feb 01-28	3.1257
Mar 01-31	3.7187
Apr 01-30	4.2123
May 01-31	5.0091
Jun 01-30	5.2037
Jul 01-31	5.6016
Aug 01-31	5.6560
Sep 01-30	5.1419
Oct 01-31	4.6464
Nov 01-30	3.8035
Dec 01-31	3.4606
Summed total	52.9751

Appendix 13 - Strategy 5 - Energy consumption - optimized case

Revised Case - Energy Consumption



	Total energy (MWh)
Date	Oasis villa Base case2.aps
Jan 01-31	3.1743
Feb 01-28	2.9243
Mar 01-31	3.4967
Apr 01-30	4.0230
May 01-31	4.8552
Jun 01-30	5.0760
Jul 01-31	5.4843
Aug 01-31	5.5426
Sep 01-30	5.0118
Oct 01-31	4.4724
Nov 01-30	3.5928
Dec 01-31	3.2349
Summed total	50.8883