Future proofing Karachi for Urban Heat Island

لتحوط المستقبلي لمدينة كراتشي من أثار الاحتباس الحراري الحضري

by

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ABSTRACT

Future proofing cities is one of the most researched and pressing topic of this century due to climate change. This research is focused on Urban Heat Island, one of the many issues faced by the mega city of Karachi, due to climate change. Although Karachi has been faced with this concern for years, however, it was emphasized and highlighted during the recent heat waves of 2015 and 2016. The primary methodology used was simulation using ENVI-Met software to access how the temperatures can be reduced in the city. The factors studied were high albedo roofs, cool pavements and roads, vegetation and a combined approach based on LEEDv4 guidelines. The three locations studied in Karachi were mixed-use, commercial and residential areas of Lyari, Saddar and Korangi Five sets of scenarios were tested for each of these areas; Lyari, Saddar and Korangi. First being base case, which is the existing condition, second for high albedo roofs, followed by cool pavements and roads then vegetation and finally a combined simulation. The combined approach was the most effective in all three cases, followed by vegetation. However, in the case of high rise verses low rise, it was observed that in mid to high rise areas, high albedo was more effective than cool pavements and roads. The combined simulation scenario was the efficient case as it reduced the temperatures by 4.5 to 5.23 °C in Lyari, 1.9 °C in Saddar and 2.5°C to 4.5°C in Korangi.

Keywords: Climate change, Urban Heat Island, high albedo roofs, cool pavements and roads, vegetation, Envi-met

ABSTRACT IN ARABIC

يعتبر التحوط المستقبلي للمدن من أكثر الموضوعات إلحاحا وأبحاثا في هذا القرن بسبب تغير المناخ. ويركز هذا البحث على الاحتباس الحراري الحضري الذي يعتبر من أهم عواقب التغير المناخي الذي تتعرض له مدينة كراتشي والتي ظهرت بصورة واضحة خلال الموجات الحارة الأخيرة في عامي 2015 و2016. تم استخدام برنامج ENVI-Met للمحاكات الرقمية في هذه الدراسة. وكانت المناطق الثلاثة التي تمت دراستها في كراتشي مناطق مختلطة الاستخدام والتجارية والسكنية في لياري وسادار وكورانجي على التوالي. وشملت العوامل التي تمت دراستها، منفردة ومجتمعة بناء على مبادئ LEED 4.0: الأسقف ذات العكس الحراري المرتفع، الأرصفة باردة والطرق، وتأثير النباتات. وتم اختبار خمس مجموعات من السيناريوهات لكل من هذه المجالات؛ لياري، سادار وكورانجي. أولا حالة القاعدة التي هي الحالة الحالية، والثانية للأسقف ذات العكس الحراري المرتفع، تليها الأرصفة الباردة والطرق ثم الغطاء النباتي وأخيرا الجمع بين هذه المجموعات. وكان النهج المشترك هو الأكثر فعالية في جميع الحالات الثلاث ومن ثم الغطاء النباتي. في حالة المباني عالية ومتوسطة الارتفاع كانت الأسقف ذات العكس الحراري المرتفع أكثر فاعلية من الأرصفة باردة والطرق. وكان سيناريو النهج المشترك هو الأكثر فعالية حيث تج عنه خفض درجات الحرارة من 4.5 إلى 5.23 درجة مئوية في لياري، 1.9 درجة مئوية في السد و2.5 درجة مئوية إلى 4.5 درجة مئوية في كورانجي.

ACKNOWLEDGMENT

The last couple of months were very challenging and nerve wrecking, where countless hours were spent and endless amount of coffee was consumed, but finally been able to complete my thesis. The knowledge that I have attained during the course of this time will stay with me forever and I will hopefully be able to implement it in my professional career.

I would like to thank my professor Dr. Bassam Abu-Hijleh who has been a great mentor and without his guidance this dissertation would not have been possible. I would like to thank the team at Atkins, especially Mr. Simon Nummy for his support.

This would not have been possible without the constant encouragement by my parents who have always believed in me which has helped me in achieving my goals. My two sisters who were always reassuring and cheering me throughout this time. Last but not the least, my husband, who was always there to listen, advise and feed me with amazing food.

Finally, I would like to dedicate this thesis to my grandmother who is not with us today but she has been a source of inspiration in every step of my life. Thank you for sending your angels and prayers!

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CHAPTER 1

I. INTRODUCTION

Accelerating anthropogenic induced climate change has proven to be contributing to varying precipitation, rising sea levels, heat wave, drought, hurricanes, flood, food scarcity, urban heat island, melting glaciers, rising temperatures and ozone depletion. These are some of the risks countries are facing due to climate change (Macomber, 2016). According to UN report on cities and climate change, 40% to 70% of the GHG emissions are resulting from heavily populated cities (UN Habitat, 2011). Nations, whether developing or developed, are facing the repercussions of rapid urbanization. If cities develop and grow without a sustainable plan and aims, the expected rise in temperature by 2100 is estimated to be 4°C. The United Nation’s Conference on Climate Change held in 2015 also known as COP 21 (Conference of the Parties) was the first international legal agreement between 188 countries for keeping the average global temperature increase below 2°C (Jouan n.d.). The main agenda was targets set by each country to reduce Greenhouse Gas (GHG) emissions under 4 main categories Mitigation, Adaptation, Technology and Finance. This is done in two parts:

- Reducing GHG emissions
- Preparing for adaptation to climate change.

The agreement was an international binding submitted in the form of Intended Nationally Determined Contributions (INDCs) by each country for achieving the goals of reducing emissions and climate change (UNFCC 2015).

Pakistan has been very proactive in the dialogue of climate change ever since its inception, at the historic Rio Earth Summit in 1992. Pakistan has also spearheaded consensus on the elementary founding ideologies of the UNFCCC as well as the four pillars of climate change: Mitigation, Adaptation, Technology and Finance - which have framed the debate ever since (Khan et al. 2011). In December 2015, Pakistan's Intended Nationally Determined Contributions (Pak-INDCs) stated that they will be reducing the emissions and planning to introduce renewable resources in large scale. The Pakistan INDCs were in alignment with the National Climate Change policy of Pakistan to reduce emissions: the power sector will be switching to nuclear, hydro, wind, solar and mass transit systems projects some of which are already in the pipeline. The mitigations costs were still being calculated, but would be looking at support from developed countries to promote and support low-carbon and climate resilient development. Although Pakistan has always been very committed to playing an effective role to adapt to climate change but compared to other countries it looked weak at COP21. Where most countries had targets and goals for each year with percentages of emission reductions and finances for mitigation, Pakistan had no supporting data (UNFCC, n.d.). In this age of climate change, countries should not only be focusing on issues at hand but planning and implementing to reduce the impact of climate change simultaneously.

Based on World Bank 2011 report on climate change, the low-elevation coastal cities are more at risk to climate change (World Bank, 2011). Also mega cities are the main contributors towards climate change hence mitigation and resilience strategies adopted by a city will have a larger impact overall. Therefore, the area of concern selected for this research is the coastal city of Karachi, the largest in Pakistan and the 11th largest megacity in the world. Karachi encompasses an area of 3,527 km^2 and is the capital of the province of Sindh. It lies on the coast of the Arabian Sea and is a hub of business, trade and export (Hasan & Mohib, 2003). The city of Karachi has a varied urban fabric with an infrastructure not suited for the amount of people residing in the city. This influx of people was due to multiple reasons over the years; jobs, better facility in comparison to the surrounding cities and villages, schooling, hospitals, housing and better environment and living conditions for the next generations (Atkins, 2012). Karachi has become the centre for most activities, opportunities, factories and facilities in the province of Sindh. This city has become an amalgamation of multiple cultures, religions and sects. Today 54% of the world's population is living in urban cities and by 2050 it's expected to go up to 66%. This increase in urbanization is only sustainable if the city can accommodate this influx growth on social, economic and infrastructure level. However, in most mega cities this is not the case and Karachi being one of them. Based on the World Urban Prospects report by UN in 2014 reported the expected population of the mega city, Karachi will shoot up to 24 million by 2030. It was the 11^{th} most populated city in the world in 2014 which would go up to 7^{th} position by 2030 if the rural-urban movement is not monitored (UN, 2015). This has caused multiple issues concerning the economic growth, urban sprawl, increased crime rates, shanty towns, loss of biodiversity, loss of vegetation, grey infrastructures and lack of resources like water and food and most importantly it has increased the vulnerability to natural disasters and climatic change due to the dense urban fabric and unplanned settlements (UN, 2015). This increase in population has also contributed to the rise of air pollution and temperatures in the city that are causing multiple health risks and health costs. According to a recent study which was conducted through mobile monitoring, recorded increase in hydrocarbons, O_3, CO and NO_2 between the years from 2007 to 2009 (Marlier et al., 2016). Although, the city of Karachi attracted masses due to the facilities and opportunities in the city but now has deprived many of even the basic amenities due to the lack of planning and infrastructure.

Karachi is facing multiple issues as a mega city: lack for food and water resources, power outage, security, pollution, over population, lack of transportation facilities, traffic, urban sprawl, unemployment, rising temperatures, lack of vegetation, recurring heat waves, raised temperatures in the city centre, crime rates, drought, heat waves, varying precipitation to name a few. The area of concern studied in this research will be urban heat island which was coupled with heat waves in the mega city making the city come to a halt in 2015. The Urban heat island contributes to the extreme and prolonged meteorological events like heat waves. Which increases the vulnerability of all the stake holders of the mega city. Recent episodes of climate change faced by Karachi were in 2015 June and April 2016, where temperatures reached the high fifties, and urban heat island exaggerated the impact on the people and the infrastructure (Lemonsu et al., 2015). There are multiple factors that have contributed to the most recent heat wave in Karachi causing about 1200 fatalities due to dehydration and heat stroke. The growth in the population, urbanization, industrialization, increase in the number of cars, more built environment with reduced or no vegetation, less air movement and lack of ventilation due to high density are some of the contributing factors to the recent heat wave in Karachi (Jamal, 2015). The report by the government on the recent heat wave stated, that it was caused by low-pressure fronts from India but a major issue pointed out was the Urban Heat Island which further enhanced the entrapment of heat. It took into consideration many factors for facing the next heat waves but little was discussed concerning the long-term mitigation actions to be taken at an urban scale, to control the rising temperatures in the mega city (Chaudhry et al. 2015). Based on the Intergovernmental Panel on Climate Change's (IPCC) most recent assessment report the temperatures will be getting worse as shown in figure 01, hence the urgent need for preparedness and adaptation for mega cities like Karachi (IPCC, 2015).

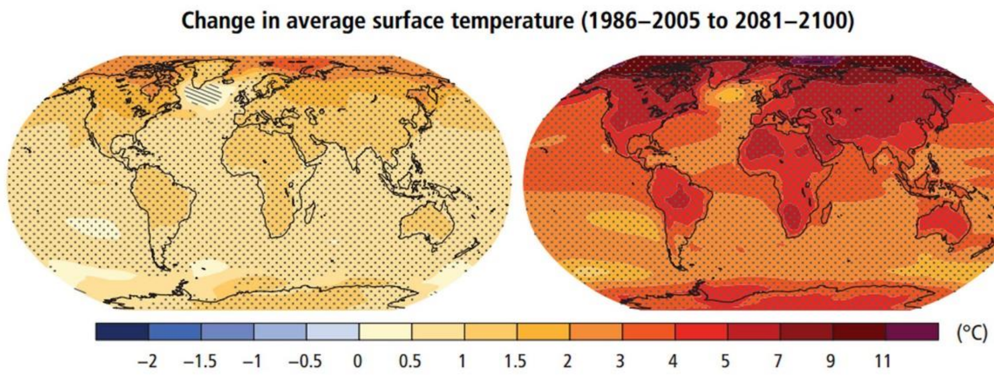


FIGURE 01: IPCC's Atlas representing the predicted rise in temperatures-AR5 (IPCC, 2015)

II. MOTIVATION

Climate change is inevitable, and Pakistan is ranked 16th in the UN most vulnerable cities to climate change. Which is very ironic to its 135th ranking in the emissions of GHG per capita (Khan et al., 2016). Global warming is causing a rise in the average temperature but the Urban Heat Island is contributing to the rise at a city level as well. The change in the micro climate in the city is the cause of the built environment and reduced natural sink (vegetation and trees) of carbon emissions. Which has resulted in loss of biodiversity and led to increasing the energy consumption, deterioration of health due to air pollution and comfort. The coupled impact of the macro (global warming, heat waves and climate change) and micro (Urban Heat Island) change impacts the local ecosystems, economics, peak load and human mortality. US in 1995 and Paris in 2003 also faced similar circumstances due to the coupled effect of UHI and heat waves (Sharma et al., 2016). Karachi is facing a major climatic risk of heat waves and a gap was established concerning the lack of action during the two consecutive episodes in 2015 and 2016. Therefore, the motivation behind the research is to analyse how the urban fabric can contribute towards reducing this impact at a micro and macro level. This will be in alignment with the UN climate change efforts and the Government's Internal Action Plan for climate change.

III. AIM AND OBJECTIVE

The motivation was the gap that was emphasized when the macro and micro climate change was coupled and a devastating impact was seen. Therefore the goal of this research is to assess the potential to reduce the micro climate by reducing the heat island effect in the mega city of Karachi. By aiming to improve the micro climate of the mega city, it can build resilience to heat waves and reduce heat island which in turn might contribute towards decelerate the impact of climate change.

The objectives of the research is to come up with the most efficient and effective approaches suited for Karachi and provide potential keys for retrofitting existing urban fabric and new constructions as well. Another very important factor is to identify which strategy will be the most and least effective. This can support the master planners or key stakeholders in the city of Karachi to understand the implications and effectiveness of implementing a mitigation technique. Additionally, this can act as base work or preparedness to climate change for the key players of the city to be more pro-active and think of future proofing the city instead of being reactive when faced with the issue. This preparedness and mitigation can reduce the vulnerability of the city to climate change.

IV. RESEARCH QUESTIONS

Consequential to the motivation and aim comes the question what needs to be deliberated in this research:

- What is climate change (global concern) and the issue in focus urban heat island (micro climate)?
- What are the possible strategies to combat these issues or at the least reduce their impact?
- Why did the issue arise?
- When was this issue highlighted?
- Where is the area of concern?
- Have other regions faced similar issues and how was the impact of heat island reduced in those regions?
- How these strategies can be integrated in the planning in an effective manner?
- What is the most and least effective strategy to mitigate the local (heat island) and global concern (global warming and heat waves)?

V. RESEARCH PLAN

The importance of a research plan is paramount so that the researcher doesn't deviate from the objective of the research. Simultaneously, the research questions give the researcher a corridor towards achieving the aims and objective. It helps in weaving the research question and the aims together. Below section will provide a schematic of how the aim and objectives will be achieved based on the research questions.

Chapter 01, provided an introduction and a general idea of the scope that will be covered in the research. The main keywords are touched upon are: Climate change, global targets, local issues both macro and micro and the research aims. Chapter 2, will be a thorough review of the key concerns introduced in chapter 01. It will provide an in-depth understanding of climate change, urban heat island and the possible findings from other research papers regarding mitigation and adaptation. Therefore a literature review is imperative for a successful research and is considered as the backbone for the research. This process of reviewing scientific papers in essential to any study as it broadens a researcher's knowledge and findings of research works conducted before on this specific topic. Chapter 3, is dedicated to how similar studies have been conducted previously and what methodologies and software have been used. This will support the researcher in deciding the most appropriate methodology for the research. Chapter 4, will be divided into 3 sections: first part will be the input data and information followed by results from the proposed scenario based on the software and methodology selected. Then analysis of the findings and the pre-established criteria from literature review and recognizing the effectiveness of the proposed scenarios. Lastly, chapter 5, the conclusion will provide a holistic picture of the research and going back to the research questions if they have been answered followed by recommendations for the government and for researchers who want to pursue this topic.

VI. IMPORTANCE OF THE RESEARCH

Even though a lot of mega cities have faced this issue of Urban Heat Island but each city has a unique set of factors that are most effective for them. The strategy that works best for a city 'A' might not be the most effective in city 'B' due to multiple factors like climate, construction, global warming, land-use or nomenclature of the city. In addition to that within a city different landscapes and land-use respond differently to different mitigation strategy. Therefore, based on the literature collected, mitigation strategies will be analyzed and possible scenarios will be discussed most suited to Karachi. The results from the research can identify which strategy will be the most effective and what strategies can be used long-term in Karachi.

CHAPTER 2

I. CLIMATE CHANGE

The global climate has always been in a flux since the beginning but due to the anthropogenic activities the shift has been more rapid. Since the mid-20th century there is a probability of 95% contribution to this shift due to human activity (IPCC, 2014). Technology advancement has been a huge part in identifying the concerns and addressing this issue. Scientist have been collecting and analysing data with the help of satellite images received globally to assess the magnitude of Climate change. John Tyndall in 1860s recognized and highlighted that climate variations were a possibility if there are changes in the atmospheric conditions. He also suggested that the greenhouse effect would be a contributing factor in the change in atmospheric conditions. Later, Svante Arrhenius seconded John's concern and in 1896 in his paper also predicted that the levels of carbon dioxide would substantially rise the surface temperature. Which now is a well recorded and recognized climate change issue of Global Warming (NASA, 2014). In mid-19th century the factors contributing towards rising earth's temperature were already being identified.

At times the terms of climate change and Global warming are used interchangeably, but in principle, global warming is a subset of climate change. Global warming is the heating of the earth's atmosphere whereas Climate change is a broader term which predominantly has occurred due to the entrapment of heat and GHG in the atmosphere. It encompasses rising temperatures, seal-levels, melting glaciers, food scarcity and other climate related changes (Gettelman & Rood 2016).

In the last century the sea level have risen by 8 inches, the average surface temperatures have gone higher by 1.1°C since the late nineteenth century, and these changes are mainly driven by the amount of CO_2 in the atmosphere and other man-made emissions. In the past two to three decades the average global temperature has been the highest in 2016 and the longest spanning summer from January to September (NASA, 2017). Shrinking of ice sheet in Greenland and Antarctic is another example of climate change and global warming. Antarctic between the years of 2002 and 2005 lost 36 cubic miles of ice and Greenland lost about 36 to 60 cubic miles per year. Glaciers are retreating all over the globe as recorded by NASA via satellite images in Africa, Alaska, Himalayas, Rockies, Andes and the Alps. The occurrence of extreme events like heat waves, hurricanes, wild fire, tsunami, extreme rainfall, long dry spans, drought, and extreme low or high temperatures has increased. All the occurrences and events have added up to what we know as climate change and majority has resulted from man-made activities.

a. CAUSE AND EFFECTS OF CLIMATE CHANGE

The planet has an energy budget and climate change is caused by the change in this energy budget, whether naturally or by man. This energy budget is largely governed by the total amount of energy on earth and where it goes. Due to urbanization this change in energy cycle has been disturbed. There is more heat, energy, gases and CO_2 released as compared to the sinks that can absorb this excess energy, like soil, water, natural surfaces or vegetation. This has resulted in a shift and entrapment of this excess energy (Gettelman & Rood 2016).

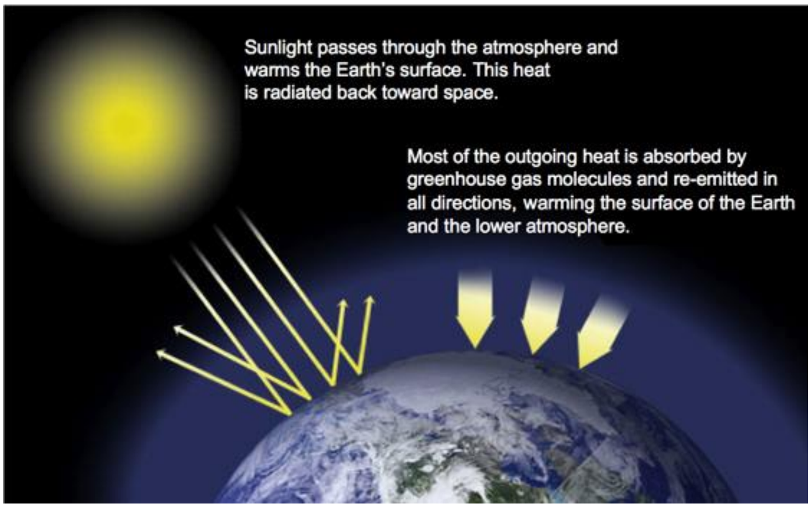


FIGURE 02: Global warming

There is a blanket of greenhouse gases around the earth's surface which primarily comprise of CO_2, NO, methane and water vapour in small amount to maintain the temperature of the earth. However due to the rapid growth by the countries, the balance between the absorption of these gases and release has been disturbed. This has led to the entrapment of heat due to the increase ratio of these gases in the atmosphere. The heat is reradiated and trapped inside the blanket. Most scientist blame the human activities and growth to the current global warming trend (IPCC, 2014). The percentage of water vapour rise in the atmosphere resulting from the earth atmosphere becoming warm has amplified the possibility of precipitation and clouds. Carbon dioxide is released in the atmosphere naturally by respiration and volcanic eruptions but human activities since the industrial revolution has increased the concentration of CO_2 by three times. These include land use changes, deforestation, burning of fossil fuels and waste emissions from the industries. Methane released from landfills, domestic livestock, rice cultivations and agriculture has increase the amount of methane molecules in the atmosphere. Due to the rise in the of usage of fertilizers, fossil fuel and biomass combustion and nitric acid the nitrous oxide percentage has multiplied in the past three decades(IPCC, 2014). These are the natural compounds that were already part of the GHG which have been amplified however there are synthetic elements that are being released into the atmosphere as well which are equally harmful if found in abundance. Elements like carbon monoxide and Chlorofluorocarbons (CFCs) which are also contributing towards depleting the ozone and saturating the GHG. Predicting the exact consequences of changing the natural composition of the atmospheric greenhouse is tough but probability of certain effects seems likely, like the rise in earth's temperature, occurrence of extreme weather conditions in different regions like longer drier spells or heavy precipitation. Rising sea levels are due to melting glaciers and shrinking ice sheets. Rise in pollution in water and atmosphere due to trapped synthetic and natural occurring gases. This shift in the climate has also caused the shift in crop and food patterns resulting in food scarcity in multiple regions (NASA, 2017). The IPCC in their fifth assessment report concluded that the activities that the modern world depends on have raised the CO_2 levels from 280PPM to 400PPM in the last 150 years and 95% is due to the human activities (IPCC, 2014).

In the past three decades, the seasonal mean anomalies have changed drastically as observed in many studies and research. These extreme anomalies is a result of global warming and changing weather patterns combined which has led to a drastic impact on the entire ecosystem including plants, insects and animals (Hansen, Sato & Ruedy, 2012). Some of the effects of climate change are briefly discussed below.

DROUGHT

Based on multiple studies and the calculations of the Palmer Drought Severity Index, there is a drop in moisture globally since 1970's resulting in an increase in drought areas. It is predicted that drought will increase in severity and frequency subsequent to decreased precipitation and increased evaporation due to climate change (Sheffield, Wood & Roderick 2012).

FLOOD RISK

Although the risk and frequency of drought is being predicted and researched extensively however some regions are at a risk of flooding as well. There is limited research conducted for predicting the risk of floods but evidence has shown an increase in the occurrence of floods in some regions. This has been based on the circumstances of glacier melting and expansion of water due to global warming in the low lining areas like the coasts. Extreme weather is also one of the contributors toward the coastal floods such as large cyclonic storms (IPCC, 2012).

GLOBAL WARMING

Global warming is a coupled effect of the atmospheric condition and concertation of CO_2 in the air (Delire, Foley & Thompson 2003). Due to the increase in CO_2 owing to the increase anthropogenic activity, it has amplified a lag in the feedback loop. In the previous centuries the circulation model was at an equilibrium owing to natural land use, excessive vegetation, natural materials, water bodies, lower pollution and population global (IPCC, 2012). Urbanization has disturbed the equilibrium disturbing the carbon cycle and increasing the gas concentration in the atmosphere. This increase in the gasses in the atmosphere has led to the entrapment of the heat from the sun in the atmospheric blanket rising the temperatures globally (Delire, Foley & Thompson 2003).

FOOD INSECURITY

Crop and agricultural productivity is dependent on many factors precipitation, ozone, carbon dioxide, and weather and soil quality. All these factors are in flux due to changing composition of atmospheric condition, rising temperature and extreme weather. Hence there needs to be a shift in the type of crops produced, in order to adapt to the weather and the quantity due to increased population. Warming and climatic trends are reducing the yield productivity by an average of 1.5% per decade and reaching to 4% if the no adaptive measures are taken (Lobell & Gourdji, 2012). Food insecurity in the global market is also dependent on drought and flood in agricultural lands (IPCC, 2012).

EXTREME WEATHER

Extreme weather is a catalyst and an indicator to climate change. An event is established as extreme based on multiple parameters like the impact on the society, vulnerability of the region, economic impact on the city, unexpectedness and fluctuating weather (Katz & Brown, 1992). Moreover, climate change is assisting in frequent occurrences and magnitude of the events like, cyclones, tornadoes, hurricanes, heat waves, wild fire, extreme hot or cold weather (Mirza, 2011). According to the climate extreme index the frequency of these events is increasing (NOAA, 2016).

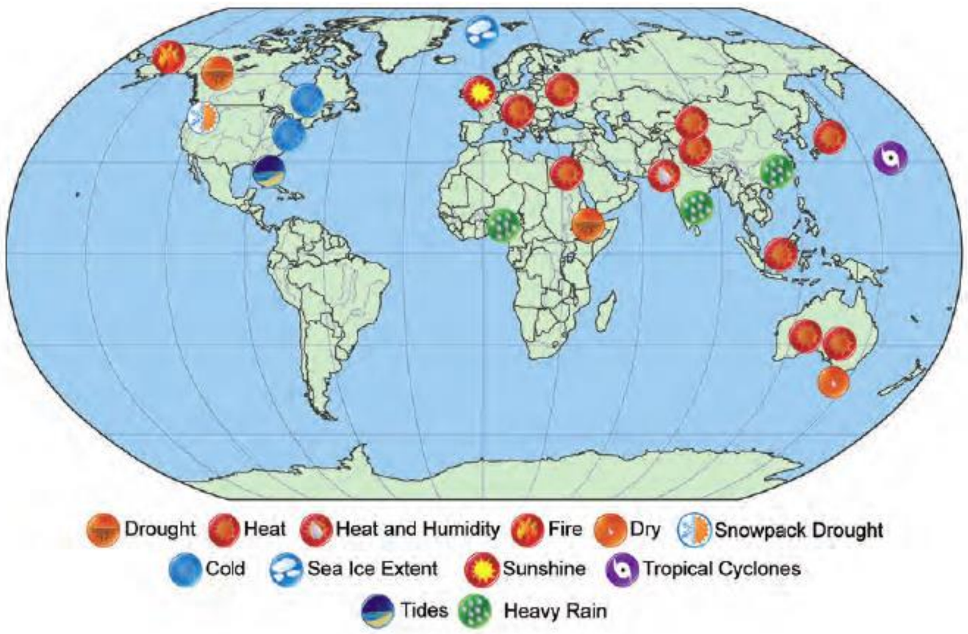
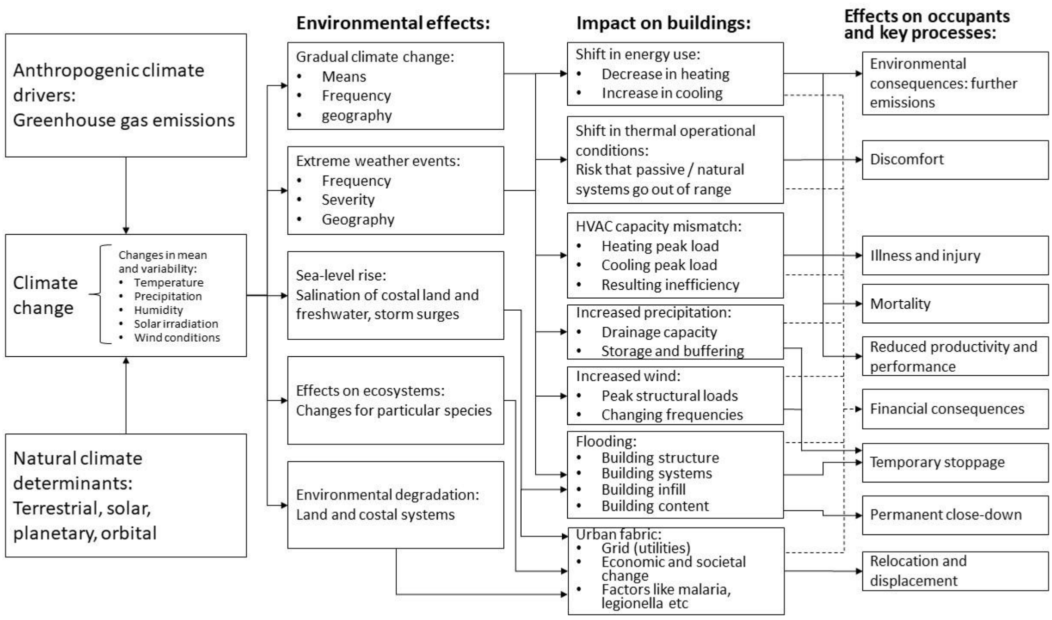


FIGURE 03: World map showing the record extremes in 2015 (NOAA, 2016)

LOSS OF BIODIVERSITY

Predicting the response and effects of climate change on biodiversity by ecologist has become a trend (Dillon, Wang & Huey 2010). Climate change is impacting the biodiversity at different levels, animals are either getting extinct or migrating. Plants on the other hand don't have the luxury of migrating therefore they are getting extinct. Which had impacted the whole ecosystem of different regions. Ecologists are now trying to adapt to the changing climate and discerning solutions for reducing this concern (Bellard et al. 2012).

The chart below summarizes the contributing factors to climate change and their impact on the environment, infrastructure and the citizens.



b. LATEST CLIMATE CHANGE STAISTICS

According to the latest statistics the sea levels are rising at a rate of 3.4mm per year, CO_2 measure in April 2017 was 406.17ppm and the annual global temperature rise in 2016 was 0.99°C (NASA, 2017). Figure 4, 5 and 6 are taken from the NASA website which represent the latest statistics and trend from the past decades. Showing a steep projection to the worsening conditions.

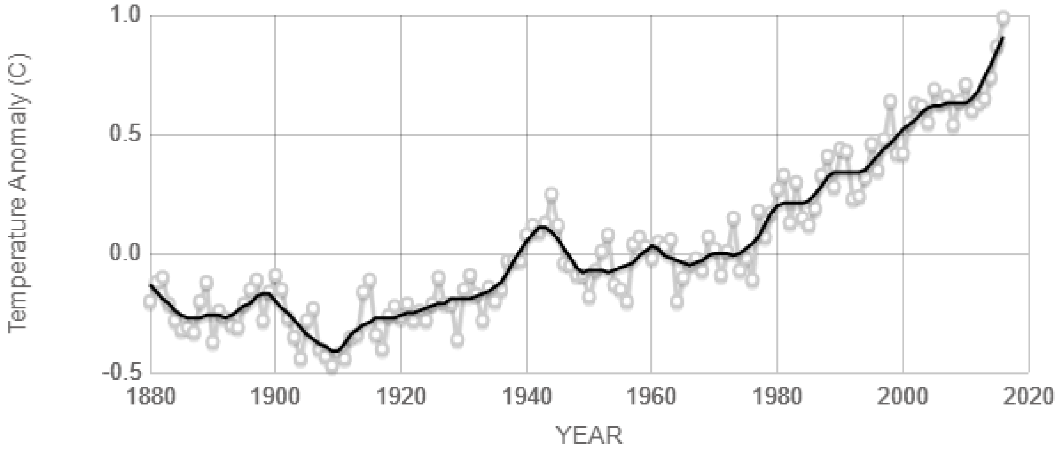


FIGURE 04: Temperature anomaly available by NASA (NASA, 2016)

FIGURE 05: Sea height Variation (NASA, 2016)

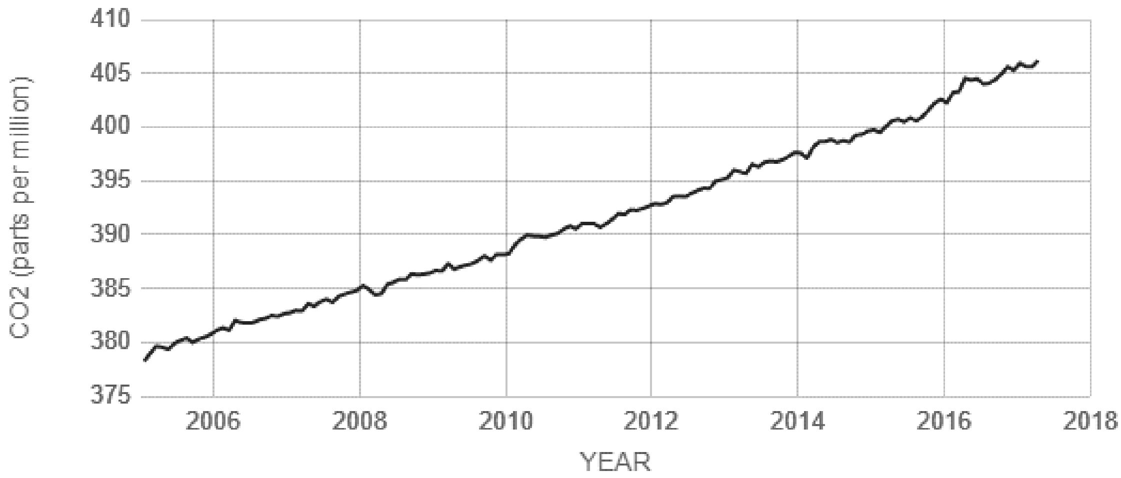


FIGURE 06: Carbon Dioxide rise per year (NASA, 2016)

c. RESPONSE TO CLIMATE CHANGE

Climate is one of the most multifaceted issue facing us today, it encompasses many factors like economics, science, politics, and society and most importantly a moral obligation to future generations. From the previous sections we have established the cause and effects of climate change in brief, in this section we will study how to respond to this change. There are two ways in which this issue needs to be tackled simultaneously: Mitigation and Adaptation. Mitigation is necessary to reduce the impact of climate change and adaptation is essential to meet the need of the hour. The mitigation and adaptation can only be possible if the countries set goals for themselves (NASA, 2017). COP 21 was an effort towards a global response to mitigation. An effort to slow global warming and finding more sustainable solutions for the future.

COP21 is a global response to climate change, the main objective is to decease the rate of climate change by reducing the entrapment of heat in the atmosphere. This can be achieved primarily by reducing the source of the greenhouse gases, natural and synthetic, and secondly, by increasing the natural sinks, which can be done by increasing the vegetation, water, permeable surfaces and using natural materials. This in turn will help in stabilizing the greenhouse gases allowing the ecosystem to acclimatise to the global change and provide sufficient time for sustainable economic development. Since the concern is so huge it needs to address all the factors; economic and science as mentioned above (IPCC, 2014).

Adaptation to climate change has to be addressed in two ways; the need of the hour and planning for the expected change in climate. By adapting we reduce the vulnerability to harmful effects like extreme weather conditions, raising sea levels and food insecurity and simultaneously prepare to adapt to the change in climate. As previously mentioned this is a global issue however the political, moral and social responsibility puts the countries municipalities and other stakeholders on the frontline to adaptation. As they are the key personnel when responding to the issues each city faces from the climate change. They are the ones who have to think of adaptive measures to accommodate local issue faced by the city and meet the global mitigation plan of the country (IPCC, 2014).

Based on the Atkins report on Future proofing for climate change, Pakistan is facing multiple climate change concerns. Karachi is encountering major climate change issues and most recent one being heat waves and other concerns are food and water insecurity, rising temperatures, loss of biodiversity and higher carbon dioxide in the atmosphere (Atkins, 2012).

Other concerns of Karachi which are changing the micro climate are pollution, urban sprawl, shanty towns, higher crime rates, urban heat island, power outage, land use changes, lack of infrastructure, loss of greenery and vegetation and unnatural materials (Atkins, 2012).

Karachi is already on the pathway to adapt to climate change with the support of different local NGOs, USAID and multiple UN support programmes for water, food insecurity, reducing urban sprawl, switching to renewable fuels, sewerage treatment and mass transit. What the city did not anticipate and prepare for was the Heat wave which was amplified due to the Urban Heat Island. Post the heat wave in 2015, the government reported that the cause behind the week long hot weather was due to the low pressure winds from the India however the major issue pointed out was the elevated city temperature which has been a result of primarily change in land use, anthropogenic activities and the built environment. The immediate actions were taken to facility the people but no long term goals were set to adapt and mitigate the issue (Chaudhry et al. 2015). Hence in the next section the research will be narrowed down to micro climate concern of Urban Heat Island in order to assess what actions can the government take to reduce the impact.

II. URBAN HEAT ISLAND

As urban areas develop the nomenclature of the space and land changes. The open space and greenery that are permeable surfaces are replaced by impermeable and artificial materials like concrete buildings, roads, industry and other infrastructures (EPA, 2008). This development leads to one of the most documented phenomenon of climate change in mega cities: the Urban Heat Island (Santamouris, 2014). Many mega cities experience higher temperature in comparison to outlying rural areas: this elevated temperature is what constitutes the phenomenon of urban heat island. In a mega city of one million people the mean annual temperature difference during day time is 1°C to 3°C and on clear night it can be as high as 22°C (EPA, 2008). The atmospheric heat island is often divided into two different types: Canopy layer UHI and Boundary layer UHI. The canopy layer is the air from the ground to the area below the roof tops and trees tops. As for the boundary layer it extends from the tree tops to approximately 1.5 km higher. The figure 07 shows the phenomenon of urban heat island in a mega city. Due to the excessive use of unnatural materials verses open spaces and more permeable surfaces in the rural areas the typical temperature difference can be seen.

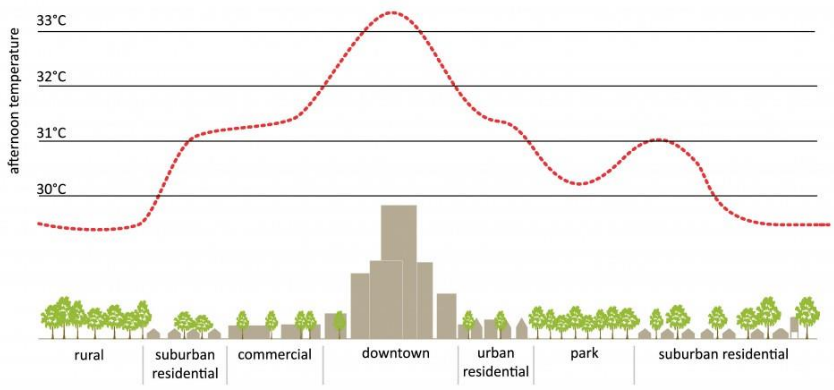


FIGURE 07: Urban Heat Island (EPA, 2008)

Figure 08 shows how densely populated Karachi was in 2012 and the planning division did not foresee the influx of people. This led to unplanned housing, overcrowding, lack of infrastructure and urban sprawl (Cox, 2012).

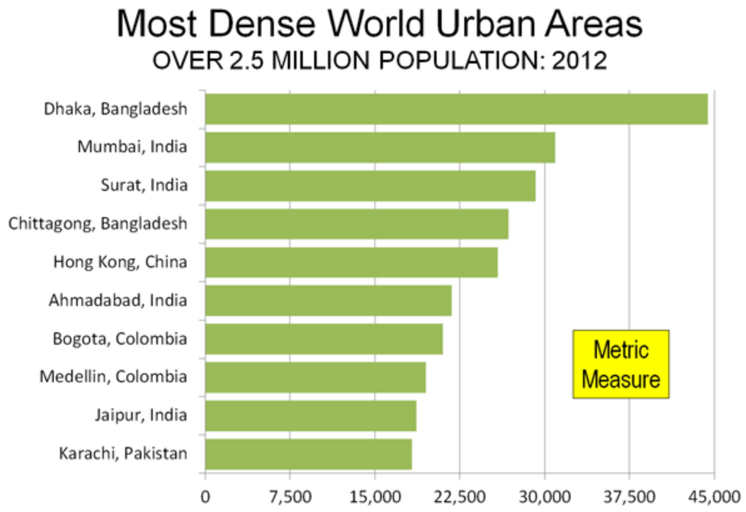


FIGURE 08: Population per kilometre square (Cox, 2012)

Urban Heat Island was first documented by Luke Howard in 1818 during his study of London's climate. Similar findings were found in Paris during the late 19th century. In US heat Island studies were observed during the first half of 20th century (Gartland, 2008). However, the phenomenon of heat islands were not fully appreciated until the mid of 20th century when satellite images were taken and the hotspots around and in the urban areas were seen (Cox, 2012).

Heat Islands are formed in the urban and suburban areas due to high density of construction, population and pollution. There are many factors contributing towards the heat island effect: construction materials that absorb and retain heat, high density and overcrowded areas reducing the wind speed and anthropogenic heat (Santamouris, 2014). Heat islands can be used for our benefit in colder regions but in hotter climates it further increases the city's micro climate increasing the number of heat waves in the mega cities. Heat islands not only adds to the increased temperature in the urban area but also increases the air pollution and use of energy for cooling and maintain the building causing diseases and mortality. The heat island intensity is the largest at night time as the construction materials continue to release heat and reduce the night cooling effect. Also studies have shown that the intensity is more in highly dense areas with little to no vegetation and strongest on clear sunny days and weakest during cloudy and windy days (Gartland, 2008). As per EPA on clear, sunny, summer days the surface temperatures of pavements and roofs can go as high as 27°C to 50°C and at night the urban areas are 8°C to 12°C warmer than rural areas (EPA & CPPD, 2016). The five main causes of heat island are reduced evaporation, increase heat storage, increased net radiation, reduced convection and increased anthropogenic heat. And the characteristics of heat island are primarily hotter air temperatures, hotter surface temperatures, and larger effects during clear, calm weather, and increases over time and thermal inversions (Santamouris, 2014). Heat Storage of construction materials depends on two properties, its conductivity and heat capacity (Gartland, 2008). Hence during our research we will be tweaking with materials of different reflectivity and emissivity to fully comprehend how they can be helpful in the reduction of UHIs. The next section we will be looking at the characteristics and causes of heat islands in more detail to fully comprehend the phenomenon in order to come up with suitable mitigation strategies.

a. CAUSES OF URBAN HEAT ISLAND

In order to reduce the effects of heat island, the cause and reasons behind it need to be understood. Howard, in 1833, proposed a theory which later turned out to be accurate. He proposed that the reason for higher temperatures in the urban areas attributed to lack of evaporation and radiation absorbed and collected by city's surfaces. Further study and research in this avenue determined that this collection of heat was due to two main reasons: urban man-made surfaces with higher thermal storage and water tight materials that don't have the ability to dissipate heat by evaporation. More recent research shows, there are multiple other factors that also contribute towards higher temperatures in the urban areas. The net radiation collected in a city is higher due to higher air pollution, lower solar reflectance and closed urban setting. Due to increase in population in the cities there is increase in the anthropogenic heat generated. The main sources of anthropogenic are air conditioners, industries, cars, building and humans themselves as well (Gartland, 2008). All these dynamics are contributing towards changing the micro-climate of the developed area. Depending on the season and daily weather the intensity of the heat island varies. This is changing the local climate of the city and restricted to that specific area.

However global warming and climate change are a global phenomenon and not restricted to any specific location. They are climatic changes in temperature, humidity, precipitation or wind, recorded over a long periods. This global climate change is also a combination of multiple aspects like Greenhouse emissions, ozone depletion, sun's intensity and changing the composition of the atmosphere due to urbanization, deforestation, burning fossils and exhausting finite resources as discussed in the previous section. When the global climate and local climate are deteriorating at the rate it is currently, proportionately the overall impact of UHI is being observed more with higher intensity especially in mega cities (EPA, 2008).

b. ISSUES CAUSED BY URBAN HEAT ISLAND

INCREASED ENERGY CONSUMPTION

According to multiple studies, higher temperatures raise the peak energy consumption and energy demands. In Athens the coefficient of performance for the mechanical systems drops by 25% and the cooling load is doubled during summers (Hassid et al., 2000). Several studies in the US also showed similar results, with every 1°F rise in temperature there was an increase in the electricity load from 1.5% to 2% (Akbari, Laboratory & United States Department of Energy, 1992). Moreover, an increase in pollution and ozone concentration was also identified (Stathopoulou et al., 2008). In low income dwellings the condition were amplified with outdoor discomfort and thermal indoor conditions leading to health and sanitation issues (Sakka et al., 2012).

AIR POLLUTION

Increase in energy consumption leads to higher GHG emissions and more air pollution. In most regions electricity is produced by combusting fossil fuels, which release CO, NOx, SO_2, GHG and CO_2 into the atmosphere. All these pollutants are harmful for human health and contribute towards trapping the sun's radiation in the boundary layer (EPA, 2008).

HEALTH ISSUES AND DISCOMFORT

Heat islands effect human health by increased outdoor discomfort, heat stroke, respiratory diseases, exhaustion and heat cramps. This increases the risks of heat related deaths and illnesses as the community doesn't have the capacity to cope with the heat (Anwar, 2012).

WATER TEMPERATURES

The water quality due to increased combustion of fossils, poor air quality and hot pavements gets degraded. As the hot polluted water reaches ponds and lakes it impacts the aquatic life as well (EPA, 2008).

The contributing factors for rising temperatures in Karachi are the influx of population, Urban sprawl, improper infrastructure to accommodate the influx of population and adapting to changing temperatures.

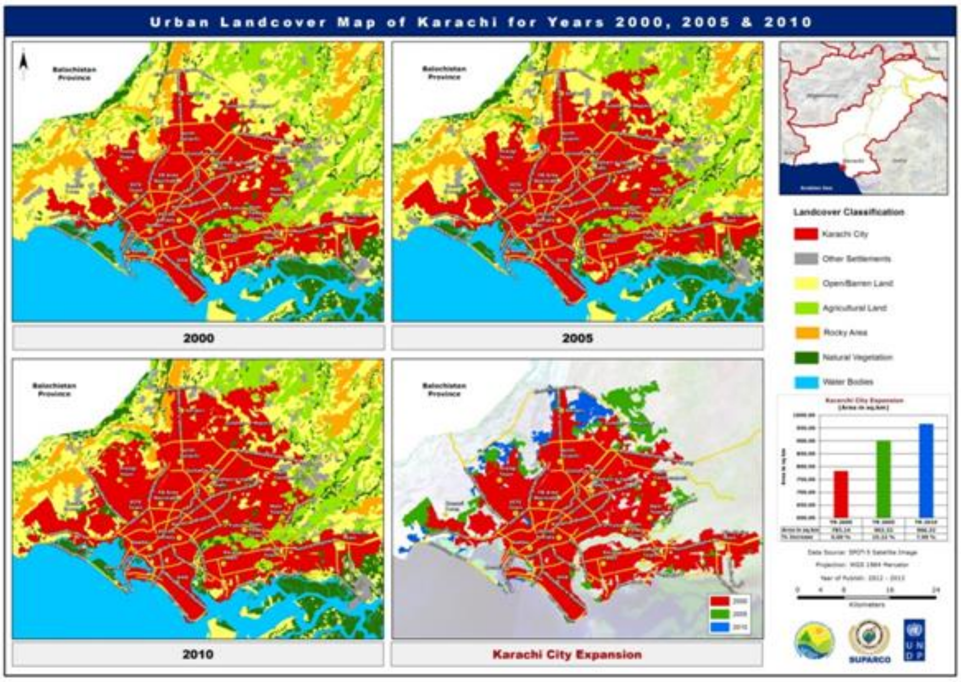


FIGURE 09: Growth of Karachi from 2000 to 2010 (UNDP, 2011)

Private vehicles on the road have increased by 656% between the years of 2002 to 2007 which has led to increase in the use of petroleum products but the worse are the emissions from ill maintained, old cars and diesel busses and cars. Since Karachi is the hub of industry and trade it has seen an increase in industry over the years hence further contributing to the increase in CO_2 emissions and pollution (Anwar, 2012). The challenges faced by Karachi in respect to Heat island effect can be summarised in 7 segments (Anwar, 2012):

- Increase in population density, urban sprawl, unplanned growth and heat islands
- Anthropogenic factors like traffic, built structures, air conditioners.
- Impact on faculties like water, electricity and transport
- Health factors due to rising temperatures, pollution and poor outdoor air quality.
- Shrinking green areas and vegetation
- A more flexible, accessible and comfortable public transport system that can reduce the use of private cars.
- Preparedness towards the emergency response to impacts of climate change like heat waves.

There needs to be a strict measures taken by the government and planning and development authority to promote green and more sustainable solutions to combat the impact of heat island (Anwar, 2012).

A study was carried out in Karachi using a Finite Volume modelling to identify the heat island and the temperature difference between the suburban and city centre. Sajjad Hussain and his team through simulation recorded a temperature difference between 5 to 13°C, and the highest observed temperature were during the night time. The data extracted for simulation was from 3 different sources: Topographic data from GTOPO30, land-use from GLC2000 and Meteorological data from NCEP. They identified the several factors contributing towards the UHI like less vegetation and more artificial materials and surfaces, energy consumption as it is an industrial area, as it is a populous city therefore leading to more anthropogenic activities (more transport, heating and cooling loads etc.)(Sajjad et al., 2015).

Heat waves and UHI have effected Karachi in the sectors of resources, healthcare, basic infrastructure in a huge way. The UHI has increased the consumption of energy and water because of which water shortage has become a priority in the summer seasons. Power-cuts for longer hours when electricity is needs the most. Increase in pollution and power cuts has resulted in a huge load on the health sector, and it was seen in the last 2 episode of heatwave of June 2015 and April 2016 that the hospitals were not equipped to deal with the influx of people. Climate change is not only having an impact on the environment but has had an impact on the infrastructure, healthcare, biodiversity, basic resources and amenities.

Based on the recent surveys and studies carried out by UN habitat under the WASH program, it was established that Karachi was facing a chronic water shortage. The daily demand for water is four billion litres per day. However the major source of fresh water, the HUB dam dried in February 2014. It has had drier spells in the early 20s as well but this has been the longest span for Hub dam being dry. It was the main source of fresh water supply in the city, providing 370 million litres of water per day. This has stripped people of their basic needs and forced them to use water from unsafe sources increasing the likelihood to contracting waterborne disease at high healthcare costs (UN-Habitat, 2014). The most vulnerable groups identified by UN were the homeless, women, children, elderly, people living in shanty towns and individuals suffering from respiratory diseases, diabetes and cardiac conditions (UN-Habitat, 2014).

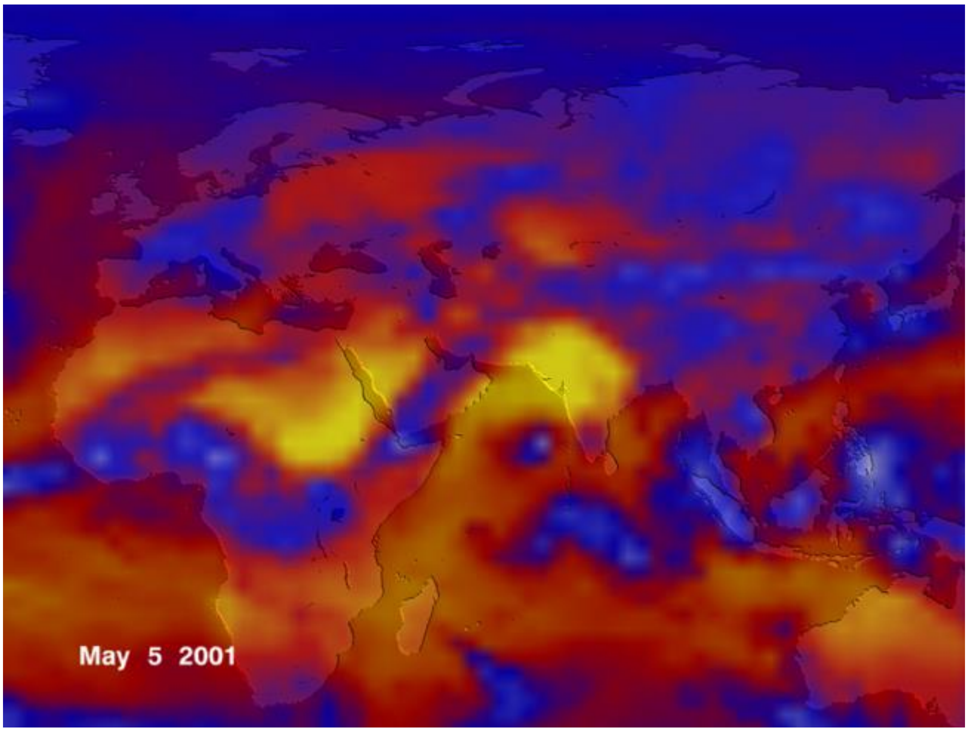


FIGURE 10: Heat wave in Pakistan in 2001 (NASA's Visible Earth, 2009)

c. MITIGATION STRATEGIES

The land use of urban verses the rural is very obvious; the rural areas have open spaces with vegetation and trees for shades, lower structures for ease of breeze and wind movement, and more natural and permeable surfaces in comparison to the urban nomenclature. Urban areas have reduced wind movement due to high built-up area, less permeable surfaces reducing the evapotranspiration, less to no vegetation and barely any open areas. In order to counter balance this change in the nomenclature of the natural environment to the manmade built environment, the focus needs to be towards increasing the evapotranspiration by having more vegetation and permeable surfaces, introducing materials that are more reflective, with lower specific heat capacity so they don't retain the heat from the sun having lighter coloured surfaces and implementing these to the major surfaces like roofs and pavements (EPA, 2008). Research has shown that these strategies towards urban heat Island can led to counterbalancing the impact and accumulation of heat in the cities. There are many techniques like cool roofs, green roofs, increasing natural sinks and high albedo that can be implemented to dissipate the surplus heat (Santamouris, 2014). Therefore, material properties are a very important part of the urban fabric, particularly the solar emittance, heat capacity and solar reflectance. Solar emittance of a material is its ability to emit the infrared (long-wave) readily, the faster it emits the cooler the surface stays. Second property of a material is its heat capacity, the ability to retain heat. The materials and surfaces that have a higher heat capacity tend to store heat for longer periods. The urban materials like steel concrete and stone store the heat from the sun during the day and release the heat at night as appose to rural materials like sand and soil that have lower specific heat capacities. Third and the most important property of materials is its ability to reflect solar energy. Therefore higher solar reflectance or albedo is more suitable for urban surfaces as they can easily reflect the solar energy. Solar reflectance is also correlated to the colour and texture of materials; lighter colour materials reflect more in comparison to darker coloured surfaces. Application of the material properties is discussed in more detail below (EPA, 2015). Multiple studies have shown similar results but in 2016, Flurry, asserted that besides the materials and lack of vegetation other contributing factors are urban sprawl and density. The wind speeds are reduced due to the density, resulting in trapping the short-wave radiation and anthropogenic heat (Flurry, 2016).

ROOFS

Roofs represent a large percent of an urban setting, and the mitigation costs are comparatively less (Mathieu, Freeman & Aryal, 2007). Typical roofing materials reach temperatures of 65 to 90 °C, with a solar reflectance of 5 to 25 percent which means that they absorb 75 to 95 percent of sun's heat. The alternative to typical roofing is cool roofing with a surface temperature staying below 50°C. Cool roofs have two main properties high thermal emittance and high solar reflectance. High thermal emittance helps keep the roof cool as the materials radiate away any collected heat and high solar reflectance will help them reflect solar heat more easily than traditional materials (Gartland, 2008). As per LEED minimum requirements 75% of the roof should have a reflectance of 0.65 (USGBC, 2017).

COOL ROOFING

Traditional roofing not only heats up the roofs from 50 to 90 °C but also creates issues for the indoor environment of the building (Gartland, 2008). It reduces the indoor comfort by increasing the temperature which results in more energy needed for cooling hence higher utility bills and more wear and tear for the cooling units. At an urban or community level traditional roofs increase the demand of electricity especially during peak hours which might lead to blackouts to meet the demand. This also leads to higher emissions increasing smog at an urban scale (Santamouris, 2014). Cool roofing materials need to have high thermal emittance and high solar reflectance. The maximum energy reaching the ground on a clear day at noon is 1200 W/m^2. That includes ultraviolet, infrared and visible. Cool roofs need to have higher albedo (solar reflectance), the recommended are greater values than 70 percent for white roofs and 40 percent for coloured and higher emittance so the material can easily release the heat (Gartland, 2008).

The reflectance of cool roof varies from 30 to 60% depending on the darkness of the colour and the pigment used which is higher in comparison to 5 to 25% of tradition roofs. Titanium dioxide is a pigment used in cool white/grey roofs as it can reflect all the sun's wavelengths whereas other roofing materials can reflect high percentage of infrared but not the visible spectrum. Studies have shown that it can reflect up to 75%. To give colour to the roof other cool materials can be used like chromium oxide with a solar reflectance of 48% and ferrous oxide to give red cool roof with a reflectance of 43 percent which in comparison to tradition roofs is really high. Thermal emittance is equally important for maintaining a cool roof therefore higher the thermal emittance of a material better it is. Most traditional materials have thermal emittance of 80% but metals have a lower emittance varying from 20 to 60% depending on how clean, dirty or rusty they are (Gartland, 2008).

PAVEMENTS & ROADS

Another large surface area in an urban space is the pavement. The most common pavement materials are asphalt and concrete. Concrete stays cooler than asphalt, staying below 50°C whereas asphalt reaches temperatures up to 65°C. The solar reflectance of concrete is 30 - 40% but reduces over time to 25-35%. However the solar reflectance of asphalt increases over time to 10-20% but still being lower than concrete. In contrast cool pavements can reduce the temperatures by 19°C. The main properties of cool pavements are making them lighter in colour to raise the solar reflectance and the other to make them permeable, this way the water can drain through them and evaporate during hot sunny days. The process is like evapotranspiration of the plants the same concept is applied to pavements to keep them cool. Thermal emittance of asphalt and concrete ranges between 85 to 90 percent therefore increasing this characteristic of the material is not that effective. Other cool pavement materials are block pavers and resin-based which can be used for low traffic areas and hiking or biking tracks respectively (Gartland, 2008).

Traditional pavements heat up to 65°C whereas cool pavements heat up to 50°C on a hot clear summer day (Asada et al, 1996; Pomerantz et al, 2000; Grantland, 2001). There are two types of paving materials generally used: asphalt and concrete. To keep the pavements cool two strategies can be used: increasing solar reflectance and/or increasing permeability so they can store and evaporate water. Solar reflectance can be increased by lighter colours which can be done by adding lighter pigments or coatings but glare hazard should be considered. The pavements can be made porous by reducing the amount of small particles from the pavement mix such as sand and smaller aggregates. This leaves voids between larger aggregate allowing water to drain or evaporate. Studies have shown that open graded pavements reach lower temperatures as compared to the traditional ones. Other types of pavers are block pavers which are a bit porous hence reach lower temperatures as compared to asphalt and concrete however they can only be used for lighter traffic. In the case of existing pavements white-topping technique can be used. Two type of white-topping techniques are available, 4 to 8 inches thick and the ultra-thin; 2 to 4 inches thick depending on the requirement. Other higher cement mixtures can be prepared for this technique for heavier traffic and quick drying process. Another technique for making existing pavements cool is using Chip seals. For new construction in a heavy traffic zone interlocking concrete pavers can be used, they are often tinted with pigment therefore have a wide range of reflectance values. Another option is pavement texturing for low traffic where different patterns and colours of asphalt is used. Porous prefabricated lattice blocks for heavy traffic also keep the pavement cool by allowing evaporation and letting water drain through them. Besides keeping the urban area cool, cool pavements have other fringe benefits such as better water run-off management due to porous nature, more durable with less traffic noise. Looking at the complete life cycle of concrete two things need to consider: the high energy use and the carbon dioxide emissions and how to reduce them. There are many ways in which these environmental hazards can be reduced. Using clean or better fuels like natural gas, methane, agricultural wastes that produce less carbon dioxide (Gartland, 2008). As per LEED standards the at least 30% of the non-roof surfaces should be lighter coloured with high albedo and reflectance of minimum 0.3. The recommended material is the cement concrete in light grey of a reflectance of 0.35 to 0.40 and the aged has the reflectance of 0.2 to 0.3. The pavements should have a solar reflectance index of 29 or be an open grid pavement to allow water to seep in. Open pavers, 50% covered with vegetation and 50% SRI of 29 (USGBC, 2017).

VEGETATION

Vegetation and trees have multiple benefits for the urban and suburban environment such as cleaner outdoor air quality, reduced energy use and storm water run-off, conserving the local habitat and biodiversity, improved outdoor comfort and reduced CO_2. The heat island however is reduced in three main ways shading, wind shielding and evapotranspiration. Depending on the type of trees the radiation reaching the ground is reduced by 6 to 10 % in the summers and 10 to 80% in winter months hence reducing the temperature of the surface in the shadows. The evapotranspiration for a large well-watered tree can remove 910 kBTU (960 MJ) of heat during a hot summer day (Huang et al, 1990). Evapotranspiration, as it cools the air around it, it causes the humidity to increase therefore in humid areas the correct balance is the key and is welcomed in dry regions. Many shading strategies can be applied to a building with the help of trees and it has been calculated to reduce the energy consumptions from 7 to 29% (Akbari et al, 1992, 1993). One of the major contributors to greenhouse gases is CO_2 which is contributing towards the global temperature rise and climate change. Trees during the process of photosynthesis take in the CO_2 and release Oxygen. According to American Forestry Association one average sized tree can produce oxygen for up to four people. Also older trees can store up to 1000 times more CO_2 as compared to younger trees. Trees when placed strategically around a building can reduce the hot summer or winter winds depending on the region and requirement of a building. Trees in the process of dry deposition can contribute in reducing the air pollution by collection particulates and absorbing gasses on their leaves. Studies have shown a reduction in Nitrogen oxides, sulphur oxides, ozone and particulate matter from the atmosphere with the help of trees. This indirectly helps as the heat is not trapped in the atmosphere due to air pollution (Gartland, 2008).

Vegetation and trees help during rainstorm as they decrease the storm water run-off as it increases the pervious surfaces in an urban setup. They can act as buffer zones and help in noise reduction. Protection from the direct ultraviolet light in outdoor public places and improved aesthetics if well maintained. Like every other mitigation strategy trees and increased vegetation come with financial implication and maintenance but are compensated by the numerous benefits. Green roofs are also a beneficial way of reducing the heat island effect as the vegetation helps to keep the temperature around and above it lower than a traditional roof. But this can only be implement in new construction or older buildings that can take the load of the green roofs. It also helps improve the indoor temperature therefore resulting in lower energy cost in turn lower greenhouse gas emissions (Gartland, 2008). Study shows that having smaller parks in multiple locations are more effective than having larger but fewer parks, these studies were carried out in London, Chicago and Phoenix (Sharma et al., 2016).

COMMUNITY BENEFITS FROM HEAT ISLAND MITIGATION

The use of mitigation strategies for urban heat island, communities can become more habitable and have a lesser impact on the environment by sustainable means. Based on Lisa Gartland extensive studies it was reported that if these mitigating strategies are applied at a larger scale, they can bring a community's temperature down by 14°C, more energy savings especially during peak hours. Air quality is improved in three interrelated ways; since more energy savings hence less production and less pollution, secondly more vegetation means less smog and cleaner air, thirdly less CO_2 as it is absorbed by more plantation (Gartland, 2008).

The main reason for Karachi facing this problem is the lack of knowledge in identifying the issues and its solutions. In order for suggested solutions to be implemented successfully it is important to have all the stakeholders on board: the government, planning authorities, architects, contractors and suppliers. Motivation and educating these stakeholders and binding partnership with each other will keep them focused and driven. As the strategies come with financial implications it is important to collaborate with organizations, government and NGOs supporting the cause.

BREEAM recommendations for reducing the heat island and increasing the comfort of a community are the introduction of vegetation, use of water (fountains and water features), planning to increase the wind movement and decrease sun exposure , shaded pathways and materials with high reflectance and lower absorption of heat (BREEAM, 2017).

III. CASE STUDIES

Temperature of cities is getting higher due to climate change and heat island observed in high populated areas which has contributed towards energy crisis, pollution, deteriorating comfort and endangering the population. This section will look at studies carried out in different cities and the action taken to mitigate the urban heat island at a city level.

In 2015, a study was carried out to understand the city level impact on urban heat island through 4 different strategies. The model used to study the city level strategies was NEDUM-2D. The four studies were based on 5 different models: “spread out city” which was based on the historical growth and spread of the city to represent the natural trend, “Compact city” which would look at the controlling the urban sprawl and the “green city” in which parks were introduced at different locations by 10%, 30% and 50% by 2100.The results showed that the natural growth trend model showed a 2 to 3°C rise in temperatures and higher during the night. The compacting city model showed conflicting results as the temperatures were higher at night but the buildings provided shadow to each other during the day which increase the indoor comfort. Greening the city seemed to be the best solution as it increased the evapotranspiration and reduced the heat storage at the city level and the temperatures reduced by 3°C to 5°C. However, to what percentage can the greening be applied depends on the water resources and land availability (Lemonsu et al., 2015).

The government of Louisville is taking steps to reduce the impact of Urban Heat Island by mandating commercial building to have cool roofs, home owners to have lighter colours of shingles. They have set a target of increasing their tree canopy from 37% to 45% by encouraging home owners and developers to plant trees for long term benefits. At a city level they are changing and recoating the pavements with lighter paving products (Urban heat island project, 2016) the weather of Louisville is similar to Karachi and so is the relative humidity, however the winters aren’t as chilly as Louisville. Based on the

Government's research a combination of strategies and targets was the best option is reducing the UHI impact.

A study was carried out in Karachi focusing on the energy consumption and the building envelop how the building envelop can contribute towards improving the indoor comfort. The parameters that were studied involved shading, external paint finish, glazing, thermal mass and insulation. The studies showed how these parameters were used to improve the indoor comfort. The use of energy consumption was reduced by 38.5%. Typical construction type is concrete blocks for walls and mud phuska insulation for roofs (Shaheen, Arif and Khan, 2016).

In 2014, Lehmann, in his extensive study of different cities and their coping mechanism for urban heat island, he concluded that each city has its individual character and resources to mitigate the heat island. One solution alone cannot be applicable to all cities. For example in Athens the heat island impacts the temperature up to 8°C. Which means double the cooling load and triple at peak hours. Therefore greening the city and combining with renewable resources for electricity seemed to be the most effective solution. This increased the evapotranspiration and drop in the greenhouse gas emissions. In Sydney, the most effective solution was green roofs for new development as it reduced the storm- water run-off, increased the evapotranspiration and indoor comfort as the green roofs acted as an extra insulation and reducing the cooling loads and bringing the temperatures down by 4°C (Lehmann, 2014). A research supported by national Science Foundation in Chicago in 2015 to 2016 was conducted to understand the efficiency of green and cool roofs. The methodology used was experimental, simulation model and mathematical calculations to validate the results. The data used was for 25%, 50%, 75% and 100% green roofs and 100% cool roofs. The temperature reduction for 25% to 100%

green roofs was recorded to be 1°C to 5°C respectively, for cool roofs it decreased to 6°C - 7°C. Mathematically if both strategies were implemented simultaneously the results were more effective 0.6°C to 8.3°C (Sharma et al., 2016). Another study was carried out under NASA by Griffin and his colleagues after the heat wave in 2002 in New York. They conducted the study on the city level and also selected 5 hotspots which had evidently more temperatures than the whole city as per the LandSat imagery and data. Multiple scenarios were studied from green roofs, reflective surfaces, light coloured roofs and pavements. From the study they estimated that 17% of the area could be planted with trees and greenery but the most effective way to reduce the UHI would be by reducing the impervious dark surfaces like roofs, pavement and roads which sum down to approximately 64%. Up until 2006 Graffin was convinced that the best, cheapest solution for UHI was to have white reflective paint on roof and pavements and lighter colours for roads but after the 2006 heat wave in New York he was persuaded to change his mind. Pennsylvania State University and Graffin's team conducted some experiments to study the most effective and long-time solution for the UHI. Their results reflected that although white reflective surfaces were an affordable and faster mitigation method however it didn't reduce the city level heat since the heat is still trapped and bounced back. The more long-term solution was greenery as it absorbed the heat, acts as sound and heat insulation and reduces the storm water the run-off. The only drawback of green roofing is it couldn't be installed on all roofs due to load and cost (NASA, n.d).

A study for the city of Toronto was carried out using Envi-met. The locations selected were based on three different land-use for doing simulations. Akbari Berardi and Wang, conducted the simulations for different scenarios cool roof, cool pavements, vegetation and cool city. By introducing cool roof and cool pavements similar results were estimated a reduction of 3.9°C, less than 1°C was achieved by adding vegetation. The most effective was a reduction of 3.3°C to 4.6°C caused by the cool city setting (Wang, Berardi & Akbari, 2016).

Cities facing UHI issue with similar climate and higher population like Karachi are Cairo, Athens, New Delhi and Mumbai. In Delhi the study carried out by Mohan and his team showed that the Urban Heat island was the worst at 3pm and 9pm and the most effective strategy was intruding greenery and the least effective was having waterbodies as that increased the humidity (Mohan et al. 2009).

The above case studies look at the steps taken by the government to decelerate climate change and urban heat island. And some statistical study of analysis done by other researchers to reduce urban heat island. These figures will be touched up on once the simulations for the area of study are complete. The next section will determine the methodology and the factors to be considered during the research.

CHAPTER 3

I. METHODOLOGY

From the previous chapter it was established that there are multiple factors contributing to Urban Heat Island. In this chapter a comprehensive analysis will be done concerning what approaches can be implemented to reduce the impact of Urban Heat Island. This will be based on how other researchers have approached this subject. Hence it is essential to review multiple recent articles and multiple different approaches. There is no specific method for the desired objective therefore the need to look at multiple practices is important. Methodologies which will be investigate are as follows: literature review, computer simulation, experimental, case studies, surveys, numerical calculations, mixed methodology and field measurements. Each approach has its advantages, limitations and disadvantages. Previously, the UHI was studied through field measurements as there were no satellites or advance computer programs, followed by remote sensing, later satellite thermal images and now through computer simulations. Once all the research methodologies are investigated the preferred methodology will be identified.

It is also important to understand that there are two primary ways in which research can be conducted, either mixed methodologies: where multiple methodologies are used either in parallel or just as a crutch to the primary methodology. And the other method is approaching the topic in detail using only one methodology supported by historical data. The next chapter will provide assistance towards determining which methodology can be the preferred one.

Initially each methodology used to study urban heat island will be studied and the second half will illustrate what mixed methodology is and how other researchers have used it.

a. LITERATURE REVIEW

Literature review is a back bone of a research paper, it works as a stepping stone for the research one wants to work on. This is a collection of all the recent body of work done by other researchers and scholars. Like in the previous chapter macro climate and micro climate were studied followed by the issue in hand and what are the contributing factors. Literature review makes the research more accurate, reliable and eventually steers you in the direction of your potential result or conclusion. Literature review also reduces the potential of repetition and redundancy of a topic, as it pushes the researcher to take the already conducted research to the next step (Rudasill, n.d.). Santamouris in beginning of 2013 conducted a research for reducing urban heat island. The two factors studied were green roofs and high albedos. The research was done in two stages. First he conducted an in-depth study on green roofs and high albedos separately from other researcher's works, history, experiments and case studies. Later he analysed the combined effect of both parameters and their impact at city level (Santamouris, 2013a). The same year he wrote another research paper in this he researched different types of pavements, their permeability and reflectivity. The literature review was based on how the material specification can to lower the urban heat island (Santamouris, 2013b). In both the research papers multiple recent studies, experiments, history and articles were analysed to reach his conclusions. Similarly, many researchers use literature as the only methodology to reach their desired results for reducing the rising city temperatures. The drawback of using literature review can be that it might not be the most relevant or it may be out dated for the area of concern.

b. EXPERIMENTAL METHOD

Experimental methodology is divided into 2 main categories laboratory and field study. This practice of experimentation can be done on multiple surfaces and can also be used to change the material specifications. In both the scenarios there are 2 type of inputs: dependent and independent. The constant variables are the independent ones which become the base cases and the dependent variable are the ones that are manipulated to get desired results (Blakstad, n.d.). Experimental methodology has been used by planners and scientist to evaluate how a material specification can be manipulated to assist the urban heat island. Multiple articles and papers have used experimental methodology to study different pavements, reflectivity, permeability and albedos of surfaces. A study in China used field and laboratory methods coupled to study the reflectivity of paint on concrete and asphalt. Different reflective paints were applied on concrete and asphalt and readings recorded via thermal imagery camera. These readings were taken in real conditions and then verified in the lab. There were minor differences in results as the lab conditions were not as accurate as the real outdoor environment, painted asphalt showed better results as compared to concrete (Maria et al., 2013). In August 2005, in Japan, Takebayashi and Moriyama carried out experiments on 16 different types of material compositions on pavements. The recordings were done by infrared thermometers. Prior to the field study the instruments were validated for accuracy. The independent variables were asphalt, cement, interlocking block and grass and bare soil were used as base case. Asphalt showed better results due to the water retention and closest to the base case of bare soil (Takebayashi & Moriyama, 2012).

c. FIELD MEASURMENTS

Field measurements can be done in two ways fixed stations and mobile stations. In the fixed stations an advanced thermometer is installed in different areas and hourly/ weekly data is recorded. The advanced environmental sensors/ thermometers have an ability to save hourly and weekly data for temperature, humidity, wind speed, wind direction, air pressure and air quality. Mobile survey, is a way to collect data along a path instead of fixed stations. The mobile surveys are typically done while walking or in a car, this can be done with observational tubes installed in a car or attached to a walking individual. Multiple trips along that road are done during the day to understand the correlation between land use and temperature, air quality, relative humidity, turbulence and air velocity (Gartland, 2008). These traditional ways to study UHI are good, reliable and accurate but they cannot be used for predicting artificial conditions and climate changes. They however can be used to understand correlation between different factors. Another issue with observational data is that it needs to be done over a long period of time to reduce unpredictable errors. It can be very costly, requiring more manpower and time consuming.

d. THERMAL REMOTE SENSING

Thermal remote sensing is used to obtain a thermal image for a study for urban heat island. This was initially done by aircrafts and helicopters equipped with thermal cameras but with the progress in technology, satellites are used to collect this data to provide thermal imagery of a city or area. This is a top view that takes into account the surface and ambient temperature, albedos and emissivity. Many countries use this method to study the hotspots in an urban space to identify which areas are more vulnerable to UHI. Thermal remote sensing like field measurements can be used for validation purposes but not for predicting the effectiveness of a mitigation strategy. This is one of the most expensive method of obtaining data for heat island effect. Another limitation of this the imagery is that the results/image is not clear on a cloudy day, or during high humidity or dusty days. They can be used for evaluating global climatic models, NASA provides the surface temperature imagery at different intervals for multiple locations. Landsat is also an online available source for providing thermal imagery at a larger scale but not city/micro level. The image 11 shows an example of thermal imagery at different times of the day of USA (Scarino et al. 2013).

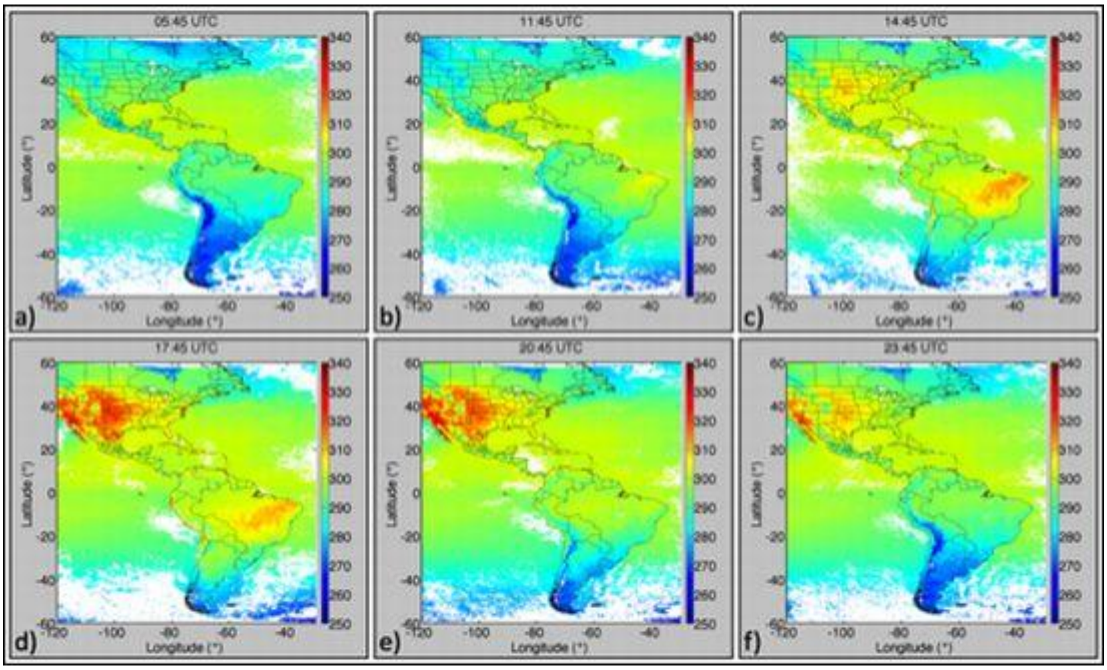


FIGURE 11: Thermal remote sensing of USA (Scarino et al., 2013)

e. NUMERICAL MODEL

Numerical models for urban heat island are also based on dependent and independent factors. However in this case instead of field measurements or lab testing, formulas and empirical data is used to extract outputs for different scenarios. Similar to other methodologies this too can be used in multiple ways to get the desired information. Tromeur with three colleagues investigated the vulnerability and mitigation due to rising temperatures in France. They carried out a study for 10 different cities in France using the daily minimum and maximum temperatures from 1995 to 2005 to predict the median, minimum and maximum temperatures from 2050 to 2100. For predicting the future temperature of a day (F_j) the below formula was used where the symbol 'f j' is hourly evolution temperature change, 'a' and 'b' are the minimum and maximum temperatures of the day respectively and K is the constant derived from the meteorological data (βj and αj) and hourly recorded temperatures.

$$F_j(t) = \frac{\beta_j - \alpha_j}{b_j - a_j} f_j(t) + K_j$$

Second part of the research calculated the heating and cooling loads between 2050 and 2100 due to rise in temperatures. The below formula for heating and cooling load was used: where 18° is considered as the optimum temperature for heat load calculation and 25° as the cooling temperature.

$$\mathrm{UDD18} = \tfrac{1}{\mathrm{NHH}} \sum_{i=0}^{\mathrm{NHH}} (18 - T_{\mathrm{out}_i}), \quad \text{for } T_{\mathrm{out}} \leq 18\,^{\circ}\mathrm{C}$$

$$\mathrm{UDD25} = \tfrac{1}{\mathrm{NHC}} \sum_{i=0}^{\mathrm{NHC}} (T_{\mathrm{out}_i} - 25), \quad \text{for } T_{\mathrm{out}} \geq 25\,^{\circ}\mathrm{C}$$

In the last step vulnerability model was tabulated based on the maximum and minimum temperatures and heating and cooling loads. And a mitigation graph was proposed to reduce the vulnerability models (Tromeur et al. 2012). Silva and Golden in 2012, studied the mitigation strategy of high albedos for the city of Phoenix. Based on Reynold's theory of turbulence, two models are coupled to study high albedos; Mesoscale Model and lumped urban thermal model. A formula, *S*model, is developed which by coupling the mesoscale model and thermal model forming a complex differential equation (Silva &

Golden, 2012). Energy balance equation is also a common method used to evaluate different scenarios. It studies the exchange in energy between the ambient temperature and urban surfaces. The biggest limitation of this method is that it's not a 3 dimensional approach, it only caters to one factor or scenario at a time. If temperature change is being studied for different pavements then it is not accounting for other atmospheric conditions. Some researchers argue that the constant in each equation accounts for the other factors, however it's not the most accurate (Gartland, 2008). Other limitation is the over simplification of the equations which is not the most effective for a multifaceted topic like UHI.

f. COMPUTER SIMULATION

Computer simulation is one of the most common methodology used to assess the success or effectiveness of different mitigation scenarios for Urban Heat Island. This methodology is dependent on the accurate input parameters provided that are analysed through the software. This allows the researcher to investigate the scenarios in a faster and effective way. This method has recently been given preference over the experimental due to the fact that it is less costly, more fast track and can provide predictions based on the scenarios provided. Although this method has become a preferred one but it needs to be validated: the researcher, the ability of the researcher to use the software in an accurately and the software itself. The authentication of the software itself can be done based on the literature and acknowledgment by certified researchers. Many software are available to study mitigation scenarios, however the selection of the software depends on the scale of the model and the objective of the study. They can be divided into Building scale models and micro- scale models. The building scale models are based on the building energy models. The building is treated like an isolated entity and no neighbouring buildings have an influence on them. The atmospheric conditions are external inputs considered into this model like temperature, relative humidity, wind speed, wind direction, moisture and so on. Examples of building energy models are EnergyPlus, IES VE, ESP-r, TRNSYS and in some case REVIT (Mirzaei 2015). The micro- scale models are microclimate models that connect the atmospheric conditions to the building. These computational fluid dynamics (CFDs) are more commonly used for studying the UHI at micro scale as it is equipped to take into account orientation, long-wave, short-wave radiation, temperature, relative humidity, building materials, soil type, vegetation and re-radiation. Commonly used software are ENVI-met, REVIT, RadTherm, FLUID, SOLENE and Cluster Thermal Time Consultant are a fee. IES was used in a study natural ventilation in an urban environment in Malaysia (Rajagopalan, Lim & Jamei, 2014). ENVI-met was used to assess the impact of vegetation on the heat island and was conducted in 3 different areas in Phoenix (Hedquist & Brazel, 2014).To study the outdoor thermal comfort in courtyards, two software were used to generate results. Initially the model was made in ENVI-met and then RayMan was used to convert the data to Physiological Equivalent Temperature. This study was also done for the hottest day in Netherlands in June (Taleghani et al., 2015). Since the aim of the study is to get the potential scenarios of mitigation strategy for reducing urban heat island, a suitable simulation software can be ENVI- met.

g. MIXED METHODOLOGY

Mixed methodology is a way in which a researcher can explore a research question in multiple ways. Since urban heat island is a multifaceted topic it might be an effective way to study the area of concern. The advantage of using multiple methods is to overcome the limitation of exploring an issue by a single procedure. It can act as a framework for supporting the primary method selected to conduct a research. If a quantitative process is used it can address the unexpected results by researching prior studies. It can also help in validating a research, experiment or simulation. Since multiple process will be used either in parallel or supporting each other, therefore the body of work and time impact might be extended to do justice to the methods selected (Creswell and Plano Clark, 2009). Mixed methodology can be further divided into how the researcher is going to present the data. Triangulation: where the process is cross-validated or collaborating the findings. Nested: in which one is the primary method and guides the full research and the secondary is just nested in the process. Finally sequential: this can be done by providing qualitative and quantitative data in parallel, or one followed by the other (Creswell and Plano Clark, 2009). A few ways in which mixed methodology has been used in recent years by researchers is outlined below.

A study was carried out in Toronto, where qualitative and quantitative sequential research was done, one followed by the other. Initially Wang, Berardi and Akbari studied 3 types of land use and their relation between urban heat island and sky view factor followed by the same areas studied for the 4 different mitigation strategies (factors). The mitigation strategies used for simulation were cool pavement, cool roof, vegetation and cool city. And the validation of the software was done with the data from the met station at the city centre (Wang, Berardi & Akbari, 2016).

Song and Park in 2015, carried out an analysis in different location is South Korea. The primary methodology used was simulation triangulated with literature review and field study. The two factors implemented to lower the UHI were green roof and reflective surfaces. It was observed, in the dense areas green roofs were more effective and in the less dense area the reflective surfaces had a slightly better impact. The validation of the software was done by field measurements (Song & Park, 2015).

A research conducted in Tehran was done on similar patterns but with triangulation mixed methodology. Initially all the literature was studied then the primary method, simulations were done followed by cross validation with the literature. The factors studied were a base case, secondly vegetation, then high albedo and finally mix of vegetation and high albedo (Sodoudi et al. 2014).

II. PREFERRED METHODOLOGY

The preferred methodology should be selected based on time, scale, manpower, expertise and cost. The methodologies studied above for urban heat island are all suitable, accurate and reliable. However, taking into account the manpower, time, cost and expertise the preferred methodology for this research is mixed triangulation. Using just one methodology like literature review is a good starting point for a research however since not a lot has been studied in Karachi, it would lack the accuracy of the area of concern due to parameters like land use and local weather. Literature review in the case of Karachi is beneficial to study macro climate, micro climate and Urban Heat Island in depth. In the case of Santamouris he had enough local data and sufficient study on each individual factor (Green roof, high albedo) to carry forward his research. Experimental would require more time, manpower and resources. Consequently, computer simulation is more efficient financially as compared to experimental. Also due to advancement in technology, scientists have developed software to simplify this multifaceted topic where the topic can be studied holistically. Therefore, a mixed methodology would be preferred where simulation is the primary methodology and the results are validated by the literature collected. A prerequisite would be validating the software and the researcher using the software.

The time selected will be the hottest day of 2015 when Karachi was hit by the worst heat wave which is similar to the period selected in the study in Tehran and Toronto. Furthermore, to see the counter impact of this study, simulations will be conducted on the coolest day of 2015 in Karachi. The parameters studied via simulation will be vegetation, high albedo, lighter pigment/colour used for roads and pavements. The selection of the parameters to be studied are based on the study conducted in Tehran and Toronto by Sodoudi (Sodoudi et al. 2014) and his colleagues and Wang, Berardi & Akbari respectively (Wang, Berardi & Akbari, 2016). The software preferred for doing the simulation is ENVI-met-4 as majority of the articles studied for mitigating UHI based on the above parameters, used the same software.

a. SOFTWARE VALIDATION

ENVI-met is a 3D, non-hydrostatic simulation software which was initially designed in 1994 by Prof. M. Bruse, University of Mainz and his team. Since 1994 to date, the software is constantly being developed, vetted and updated. It is based on the fundamental laws of thermodynamics and fluid dynamics. The model includes simulation of a building's physics, flow between and around buildings, bioclimatology, and effect of greenery on micro-climate and pollutant dispersions. There are 5 core applications and 4 helper applications in the software (ENVI-met, 2017).

This software has been validated by government entities, scholars and scientist by endorsing its reliability and the developer's capabilities and certification. This has be revalidated by multiple scholars in their recent articles, reviewed during the research. In 2015, at the International Conference of Information and Communication, Kittas and his colleague presented a paper where they had conducted simulation for six consecutive days and all the data had ‘similar climate conditions in the reference meteorological station’. In the same paper they had conducted a simulation for a pergola with 0% greenery, 50% and then 100% and the simulation data also matched with their experimental data collected. Once plotted on the graph the actual conditions and simulations results were 1:1 showing linear regression (Kittas et al., 2015). Hence validating actual conditions and hypothetical scenarios. Another study carried out at a UNESCO site in Cairo where 5 measuring instruments were installed to measure temperature and relative humidity. The outputs from the simulation were in the maxima and minima of the receptors output (Elnabawi, Hamza & Dudeck, 2013).

For validation of software for the city of Karachi it will be done for the area of Malir. The data collected is from the Pakistan metrological station readings and the YR readings. Yr is a joint venture by the Norwegian Broadcasting Corporation and the Norwegian Meteorological Institute.

Figure 12 is a model space for checking the validity of the researcher if the data collected from the met station and the Yr are in close proximity of the output from ENVI-met. The simulation is done for June 25th, 2016 and the pixels are set at 1 grid equals 2.5m, the north is at an angle of 25°.

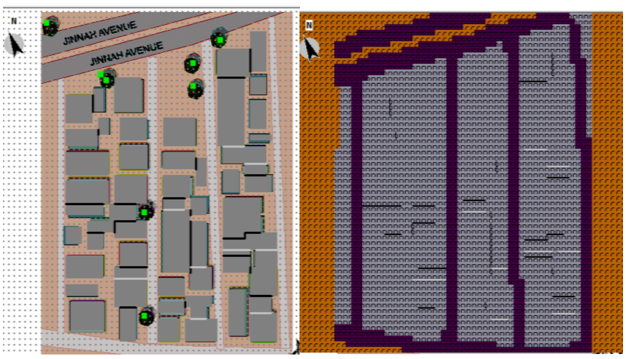


FIGURE 12: Malir Model in ENVI-met

The table below represents the data output from both the Met station and ENVI-met. T_{M}- and W_M are temperature and wind speed at the met station. And $T_{ENVI\text{-}met}$ and $W_{ENVI\text{-}met}$ is data from the Envi- met software. The data is approximately the same and within the range with the Yr data. The Data from the Envi-met is showing the range of minimum and maximum for majority of the pixels.

Time	T_M	$T_{ENVI\text{-}met}$	W_M	$W_{ENVI\text{-}met}$
10:00	31°C	27.5°C - 32°C	3.8m/s (W)	2.8 -4.2 m/s
12:00	32°C	28.9°C – 33.9°C	4.2m/s (W – SW)	3.2 – 5.45m/s
14:00	33°C	29.5°C – 35.6°C	4.2m/s (W – SW)	3.25 – 5.5m/s
16:00	32°C	28.8°C – 34.5°C	4.3m/s (W – SW)	3.08 – 5.4m/s
18:00	30°C	28.2°C – 32.9°C	3.9m/s (W – SW)	3.4 -4.4 m/s
20:00	29°C	27.5°C – 31.2°C	3.8m/s (W – SW)	3.25 -4.1 m/s
22:00	29°C	26.5°C – 29.7°C	3.8m/s (W – SW)	3.2 -4.5 m/s

Limitations of the using ENVI-met are that it can only do micro level simulations and not macro –level due to the “typical resolution of 0.5 to 10 m in space and 10 sec in time” and model space has a grid of 300x300x35 cells. The software also does not take into account the rise in temperature due to transportation and HVAC systems.

APPLICATIONS

The applications the researcher will be using are Photoshop, Google Earth Pro, AutoCAD, headquarters, Spaces, Envi-met (simulation tool), Database manager, Project wizard and Leonardo. Spaces is the application where the area of study is made in 2D and 3D, with the help of the database manger the material specifications will be modified, simulation will be done by the Envi-met tool and finally the results viewed in the Leonardo application. The next section will look at the area of study in detail.

CHAPTER 4

I. KARACHI

Karachi, the home to a population of 23.7 million people, and the seventh largest megacity in the world (World Population Review, 2016). Covering an area 3,527 Km^2 and a population density of 24,000 people per square kilometre. It is the largest and the most populous city in Pakistan, located in the south on the coast of Arabian Sea (Hasan & Mohib, 2003). It is the economic hub of the country, accounting for 95% of the country's foreign trade, 30% of industrial production, close to ninety-five percent of head offices and multinational companies located in the city (Karachi Metropolitan Corporation, 2011). Due to the unplanned growth and constant increase in population the city was divided in 6 districts consisting of 18 towns for ease of governing and administration purpose. They are governed and administered by elected municipal administrations to look after the infrastructure and planning. Figure 13 is the map of Karachi, representing the 6 district boundaries and 18 towns.

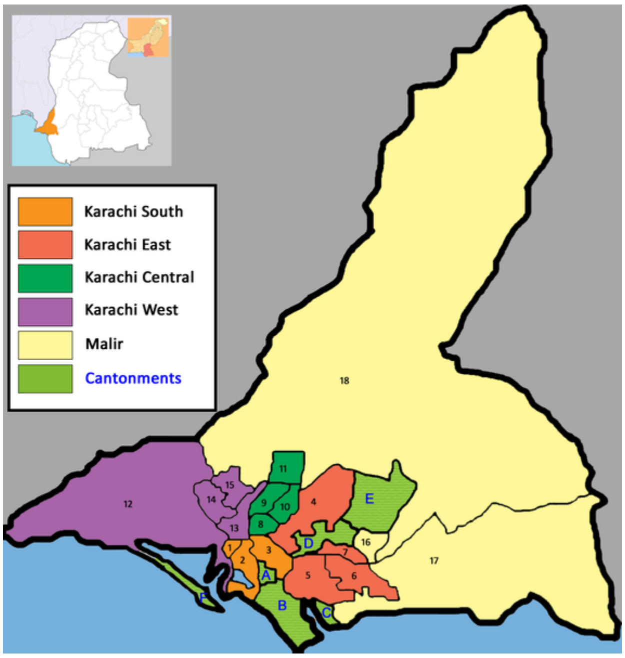


FIGURE 13: Map of Karachi City showing the 18 town boundaries (Karachi Metropolitan Corporation, 2011).

South Karachi is the downtown area of Karachi consisting of the most diverse land-use. From the most posh and modern areas like Defence, Clifton to the historical architectural iconic buildings and finally the unplanned slums of Lyari. It is like a mini-city in itself with residential, commercial and public space, railway station, museums, parks, hospitals, beach, landmarks, hotels and restaurants within the district. Lyari town is the smallest town by area but largest by population (City District Government Karachi, 2010). Lyari sector is unplanned area and flagged as one of the most vulnerable to climate change and during the heatwave episodes of 2015 and 2016 the number of fatalities were higher in this sector.

The east district is home to the industry and white collar offices, it has some museums and parks and universities. It is home to the rich, middle class and the working class depending on the location in the district they live in.

The country side of Karachi with lush green area with farm houses is the Malir district. It is the largest by area and a little less populated in comparison to other districts due to the sizes of the farmhouses.

The west district is home to the largest slum and low-cost housing areas in south Asia: Orangi town. It has huge industrial parks catering mostly to lower middle and working class. (City District Government Karachi, 2010)

The central district is primarily middle class, developed after the partition to accommodate the influx of immigrants from India.

Approximately 13 million people in Karachi are living in unplanned construction or slums, which accounts for 62 percent of the population. Many of these unplanned constructions have high densities of 4500 persons per hector accounting to 6 to 10 people living in one room and about twenty people using one toilet (Hasan, 2015). However there is a major disparity when it comes to high-income society where the density is 200 person per hector.

The climate of Karachi is predominantly temperate with long summers and a few months of comfortable weather. From the chart (Figure 14) it is evident that Karachi is in the comfort zone only for 4 months in a year and the rest of the eight months is summer.

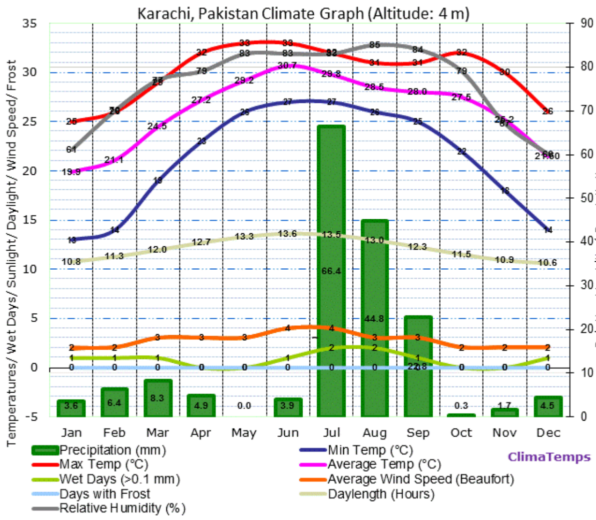


FIGURE 14: Karachi climate graph (altitude: 4m)

The warmest month being May and coolest being January as shown in the graph, Figure 15. The wind speed ranges from 0.9m/s to 4.2m/s (World Weather and climate information, 2017).

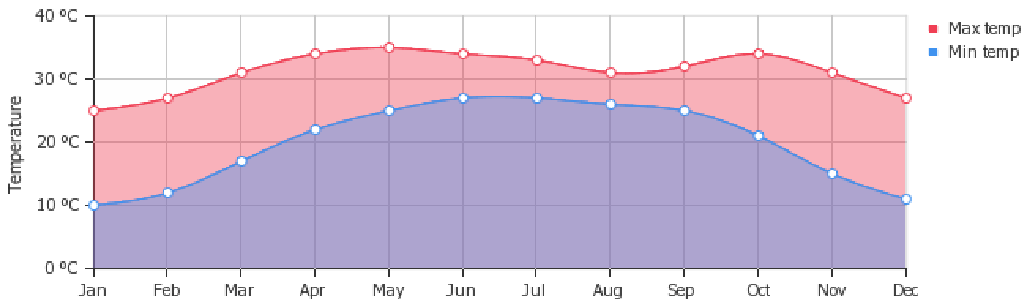


FIGURE 15: Average minimum and maximum temperature in Karachi (World Weather & Climate, 2016)

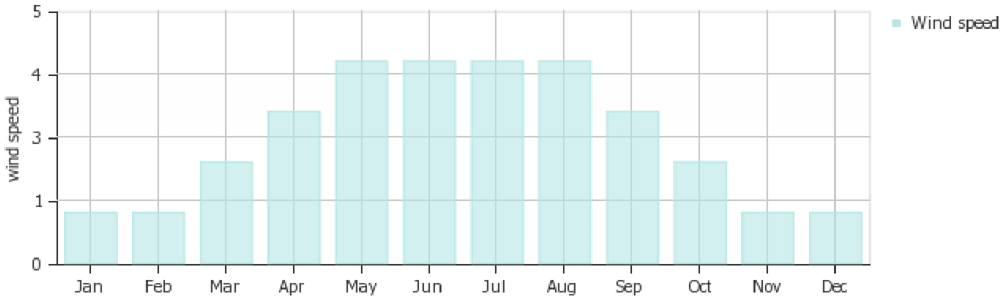


FIGURE 16: Average wind speed in m/s in Karachi (World Weather & Climate, 2016)

Relative humidity is also a very important factor when it comes to feeling hot. Very high humidity or low adds to the discomfort of an individual. The average relative humidity in June is about 80%. During high temperatures the body responds by sweating so the sweat can evaporate leaving the body cooler. However since during the heat wave the humidity was higher the air was already saturated by water and the sweat couldn't evaporate leaving the individuals more uncomfortable.

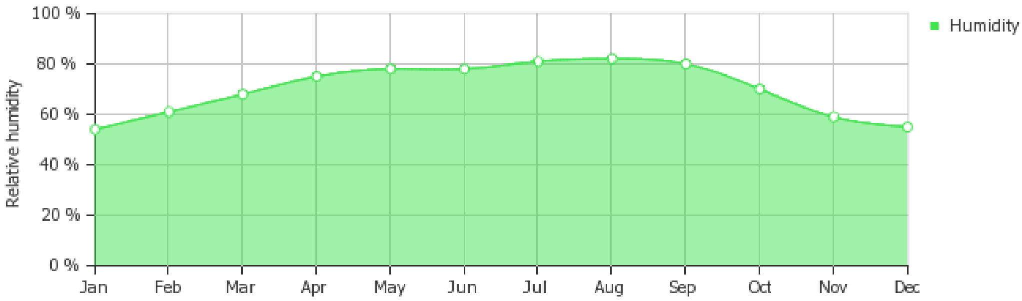


FIGURE 17: Average Relative Humidity in Karachi (World Weather & Climate, 2016)

Although the temperatures were at 45°C, citizens 'felt' hotter due to other factors like high humidity and low winds. More specifically the recorded heat index in Karachi is shown below for the span of June 17th to 24th as observed by Pakistan Metrological department in 2015 (PMD, 2015). Although the maximum temperatures reached during the heat wave was 45 °C but the heat index which is dependent on 2 factors, relative humidity and the temperature, crossed 65°C. As per the government and the meteorological department the Heat wave was a combination of multiple factors: Global

Warming, Urban Heat Island and atmospheric condition. The atmospheric conditions were due to the prolonged low pressure in the southern part of the region. Due to the consistent low pressure, it brought in hot dry air from Rajasthan (India) (PMD, 2015). A notable increase in the heat island has be observed due the growing size and population in the mega city of Karachi. Which has been caused by reduced evapotranspiration due to the reduction of greenery and the use of artificial materials of high thermal storage. Secondly due to the geometry of the mega city and the introduction of high rise structures reducing the wind movement and trapping the heat and pollution. Thirdly due to the increase of pollution and waste caused by Air condition, automobiles, industry and population.

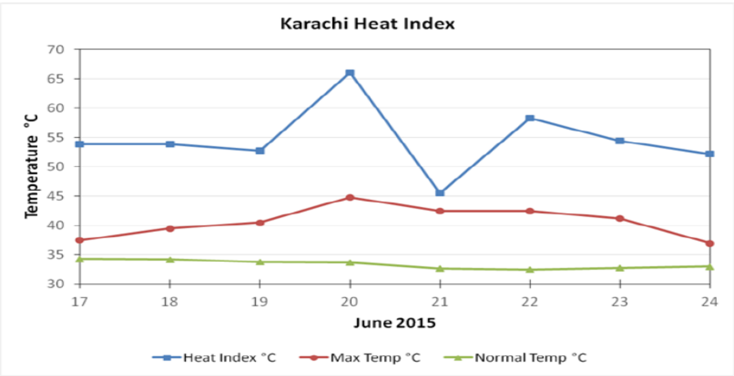


FIGURE 18: Time series of maximum temperatures and heat index observed during the heat wave. June 17th to 24th, 2015. (PMD, 2015)

The relative humidity and temperatures are shown in the graph below between the years of 1961 to 2007. And total increase in heat index during these four and a half decades has been 3°C as shown in the graph, Figure 19 below. These results have been calculated during a study carried out by Zahid and Rasul in 2008 to understand the shift of heat index in each province. This rise in temperature and humidity with a rise in global temperature are contributing towards the increase spans and periods of heat wave experienced by the Sothern part of Pakistan (Zahid & Rasul, 2008).

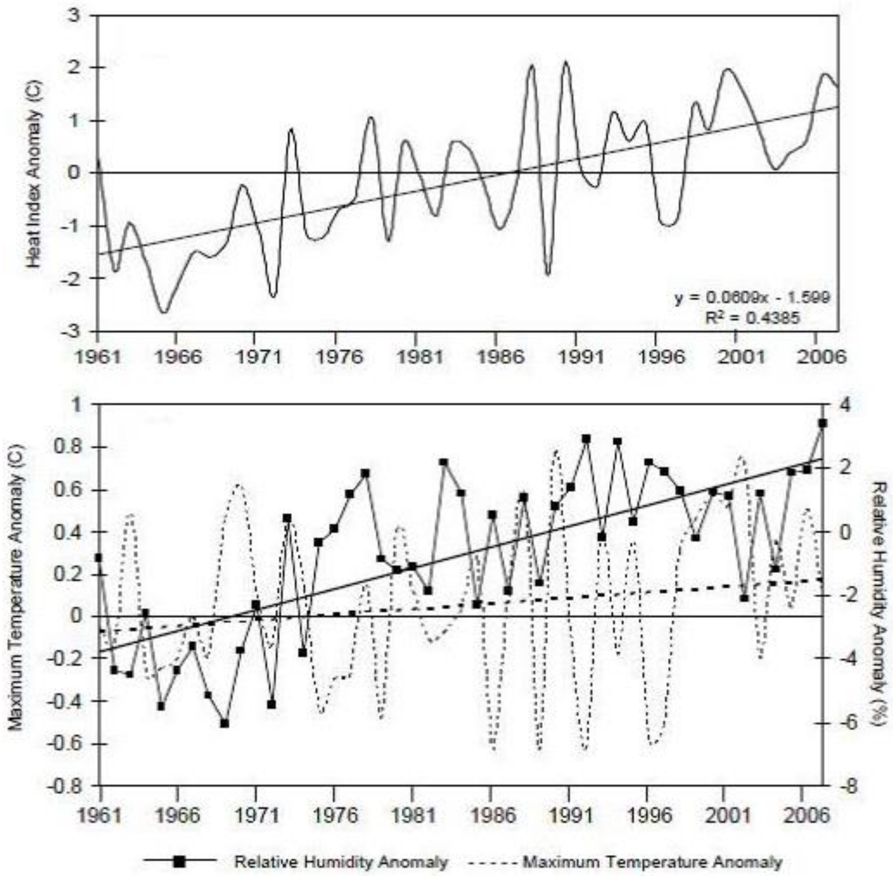


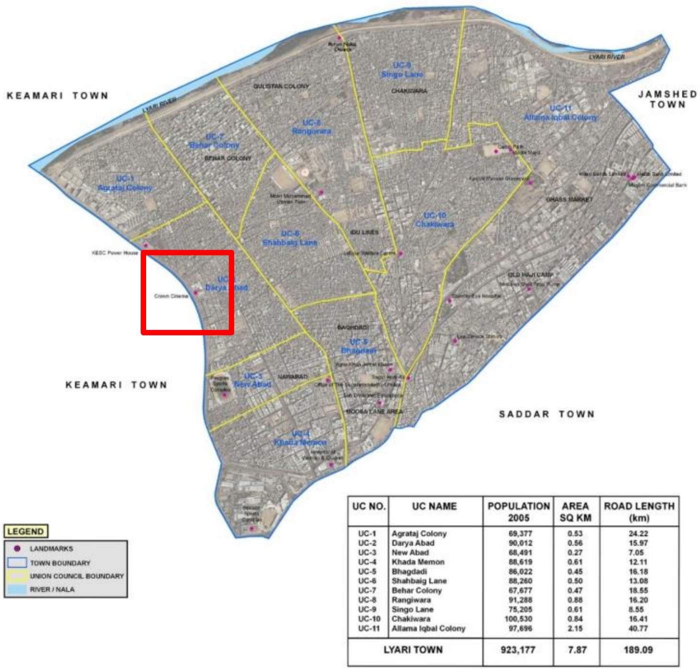
FIGURE 19: The graph above shows the Heat index between the years 1961 to 2006 and the graph is the maximum temperature and Relative Humidity profile for Pakistan (Zahid & Rasul, 2008).

In order to reduce the pollution, in 2007, 2.5 Corynocarpus trees were planned to be planted. As they grow faster compared to other trees, however more research showed that corynocarpus tree cause pulmonary allergies hence the project was suspended. Study carried out by Karachi university department of Botany, recommended that there should be a diversity of trees planted all around the city. The location, climate and use should be considered before plantation. Neem tree (Azadirachta Indica), is a good example of tree that can be planted in a park as it needs proper watering and has deeper roots therefore can’t be planted on a road side. It is an evergreen plant and good for air filtration, and has medicinal benefits and can withstand the climate of Karachi. It is recommended to plant fruiting trees like guava, pomegranate, figs, banyan tree, tamarind and Moringa (Ebrahim, 2015).

A natural disaster causes more damages when it affects an area that is more vulnerable: either in the form of infrastructure or preparedness. Although the temperatures were recorded to by higher in other cities but the deaths were recorded to be higher in Karachi, with majority being in poorly constructed and developed areas like Lyari, Korangi and Malir (Ebrahim, 2016). Therefore, the area of study are selected based on 2 factors vulnerability and land-use: Lyari, Korangi and Saddar. Lyari and Korangi areas saw maximum number of causalities. Lyari is mixed use (residential and commercial), Korangi is residential and Saddar is commercial area.

a. LYARI

Lyari town is the oldest constructed area in Karachi and primarily inhabited by fishermen, Baloch and Muhajirs. It's one of the most neglected areas in terms of infrastructure. As shown in the map below the entire Lyari area is densely populated with no greenery and poorly constructed roads. There is a huge issue to electricity theft and is one of the most notorious areas in Karachi. Due to the low rents in this union council, it has seen a huge influx of people moving in this area from outside Karachi and this has been the case since more than 4 decades now. As mentioned this region was the most effected by heat wave due to lack of facilities like water and electricity. The area of study is a mixed use area with residential, commercial and retail areas primarily for lower and lower middle class. The construction type is mixed but predominantly brick and concrete is used. The age of all the buildings varies from 10 years to 50 years hence the construction is very poor for all the old buildings. The inner roads and streets have illegal encroachments and mostly in really bad conditions. The structure of the houses and buildings is so old that it doesn't have the provision for green roofs. Hence more suitable strategies for this locality might be the implementation of adding greenery, cool roofs and cool pavements.



UC NO.	UC NAME	POPULATION 2005	AREA SQ KM	ROAD LENGTH (km)
UC-1	Agrataj Colony	69,377	0.53	24.22
UC-2	Darya Abad	90,012	0.56	15.97
UC-3	New Abad	68,491	0.27	7.05
UC-4	Khada Memon	88,619	0.61	12.11
UC-5	Bhagdadi	86,022	0.45	16.18
UC-6	Shahbaig Lane	88,260	0.50	13.08
UC-7	Behar Colony	67,677	0.47	18.55
UC-8	Rangiwara	91,288	0.88	16.20
UC-9	Singo Lane	75,205	0.61	8.55
UC-10	Chakiwara	100,530	0.84	16.41
UC-11	Allama Iqbal Colony	97,696	2.15	40.77
LYARI TOWN		923,177	7.87	189.09

FIGURE 20: Lyari showing the area of study (SBCA, 2010)

Figure 21 & 22 show the location and settings for the base case of the Lyari mixed use area with school, restaurant (Dhaba), retail and residential area with one to six storey houses.

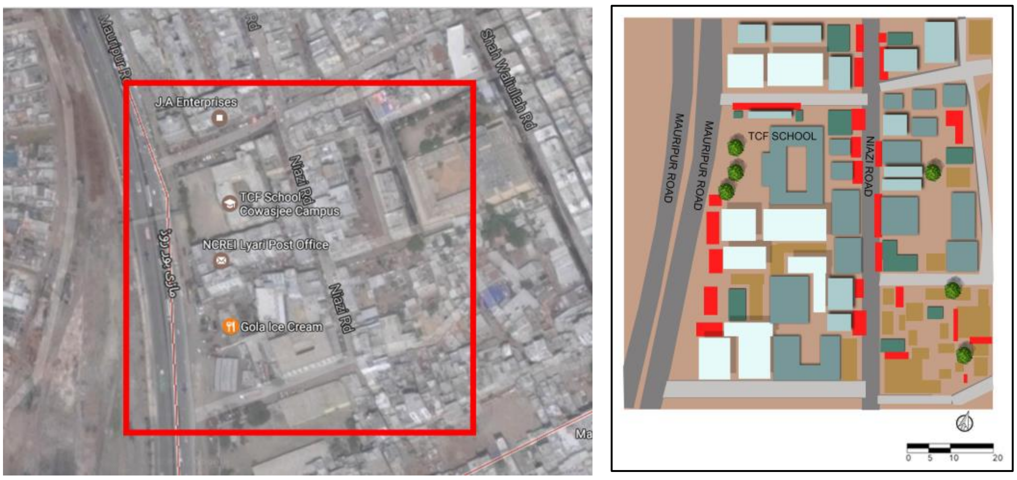


FIGURE 21: Lyari simulation location

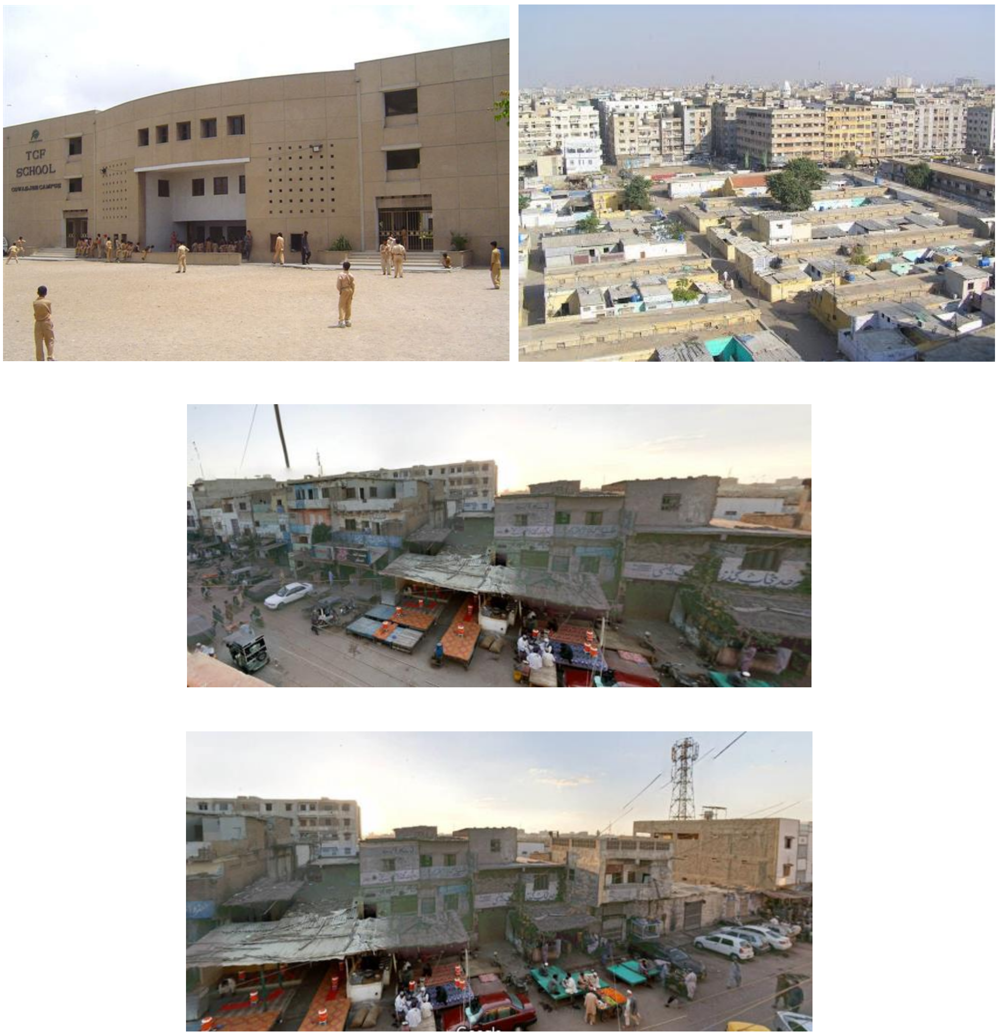


FIGURE 22: Lyari images of the site

The screen shot of the model is shown in Figure 23. The pixels are set at 1 grid equals 2.5m, the north is at an angle of 25° and the exact parameters of longitude and latitude are set (24.862548, 66.987946).

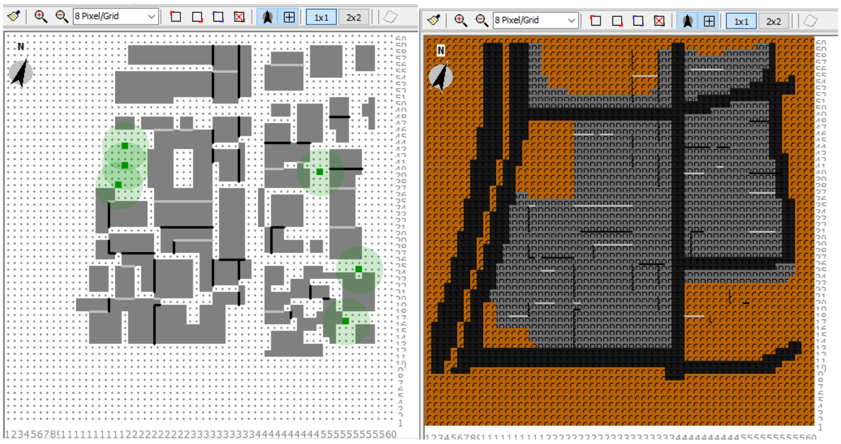
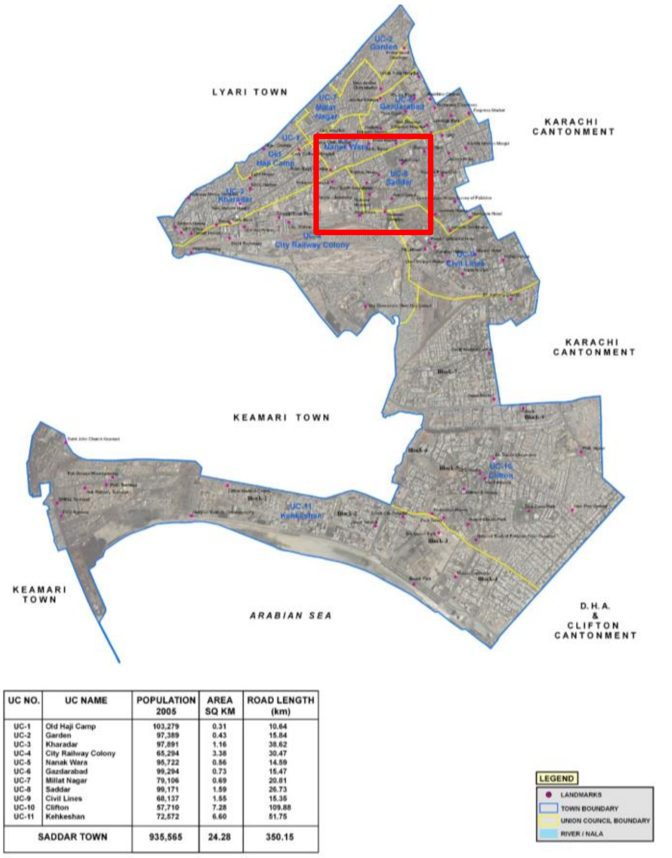


FIGURE 23: Lyari model in Envi-met space

b. SADDAR

Saddar is located in south district, Saddar town is the centre of business in Karachi. It is one of the oldest areas in Karachi and some buildings of the British times can still be found in this area. The area of study selected is a commercial area with one of the most famous streets Zaibunnissa streets and adjustment to the site are the two famous markets, Empress Market and Zainab Market. The construction is mixed as it has structures from British time period, pre-partition and very few buildings constructed in the 70's. The roads, like other sites are poorly maintained.



UC NO.	UC NAME	POPULATION 2005	AREA SQ KM	ROAD LENGTH (km)
UC-1	Old Haji Camp	103,279	0.31	10.64
UC-2	Garden	97,389	0.43	15.84
UC-3	Kharadar	97,891	1.16	38.62
UC-4	City Railway Colony	65,294	3.38	30.47
UC-5	Nanak Wara	95,722	0.56	14.59
UC-6	Gazdarabad	99,294	0.73	15.47
UC-7	Millat Nagar	79,106	0.69	20.81
UC-8	Saddar	99,171	1.59	26.73
UC-9	Civil Lines	68,137	1.55	15.35
UC-10	Clifton	57,710	7.28	109.88
UC-11	Kehkeshan	72,572	6.60	51.75
SADDAR TOWN		935,565	24.28	350.15

FIGURE 24: Saddar (SBCA, 2010)

The figures 25 and 26 show the site pictures, google earth image and the model in space.

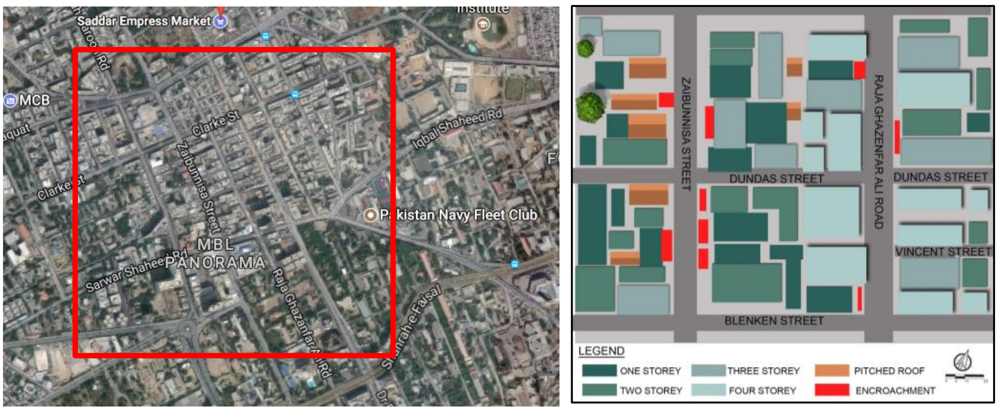


FIGURE 25: Saddar site selection

FIGURE 26: Saddar images of the site

Below screen shots, Figure 27, show the settings for the base case of the commercial and business hub- Saddar. The pixels are set at 1 grid equals 4m, the north is at an angle of 340 and the exact parameters of longitude and latitude are set (24.858164, 67.028743), as shown in the image below.

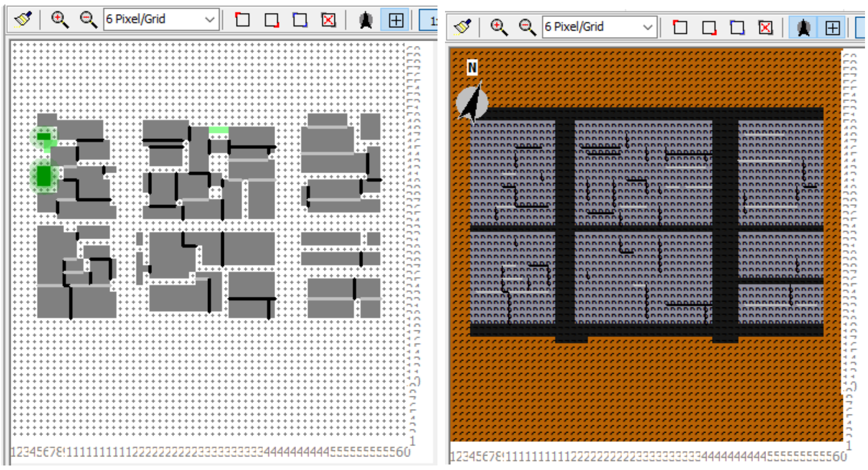
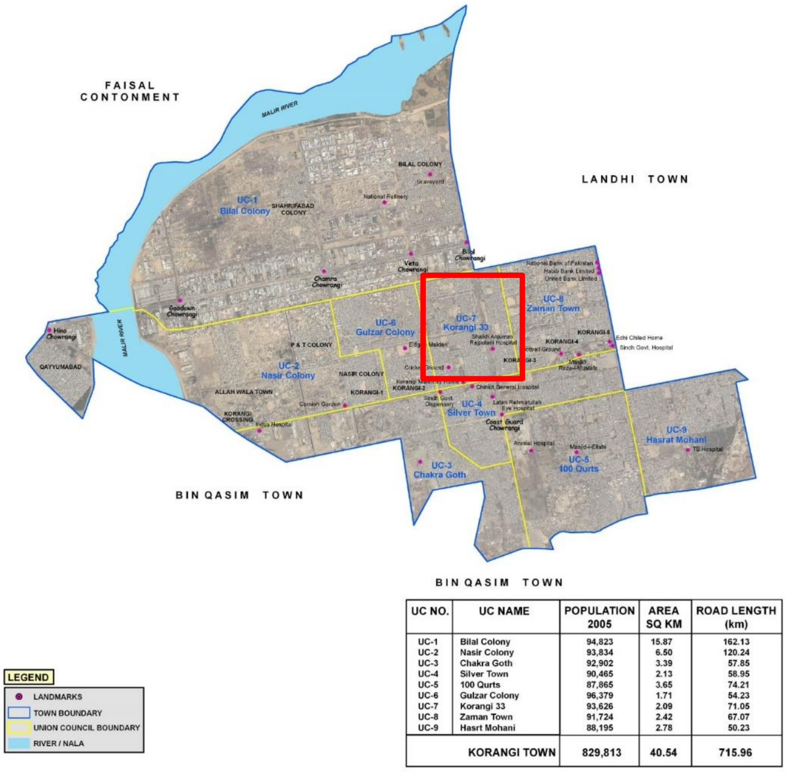


FIGURE 27: Saddar ENVI-met model

c. KORANGI

Korangi district/town is located in the eastern part of Karachi and is divided into 9 union council areas as shown in the figure 28 below. The area of study is in the Union Council 7 called Korangi -33 along the double road connecting Shah Muhammad and Landhi road and is 2km away from the industrial area. Korangi 33 C is mostly residential area consisting of lower and lower middle class. The construction is a primarily column beam structure with hollow block or brick. The number of floors vary from 2 story to 4 storey. The 15 to 20 feet inner streets are poorly constructed and need re-carpeting or construction in most of the locations. The open area around the double road has no vegetation and barely any trees. The area is highly polluted due to the high traffic and the industrial area around it. It had one of the most recorded causalities during the heat wave in June 2015. The industrial area has up to 4500 industries that include textile, pharmaceutical, chemical, flour and steel releasing huge amount of toxins and pollution.



UC NO.	UC NAME	POPULATION 2005	AREA SQ KM	ROAD LENGTH (km)
UC-1	Bilal Colony	94,823	15.87	162.13
UC-2	Nasir Colony	93,834	6.50	120.24
UC-3	Chakra Goth	92,902	3.39	57.85
UC-4	Silver Town	90,465	2.13	58.95
UC-5	100 Qurts	87,865	3.65	74.21
UC-6	Gulzar Colony	96,379	1.71	54.23
UC-7	Korangi 33	93,626	2.09	71.05
UC-8	Zaman Town	91,724	2.42	67.07
UC-9	Hasrt Mohani	88,195	2.78	50.23
	KORANGI TOWN	829,813	40.54	715.96

FIGURE 28: Korangi Map (SBCA, 2010)

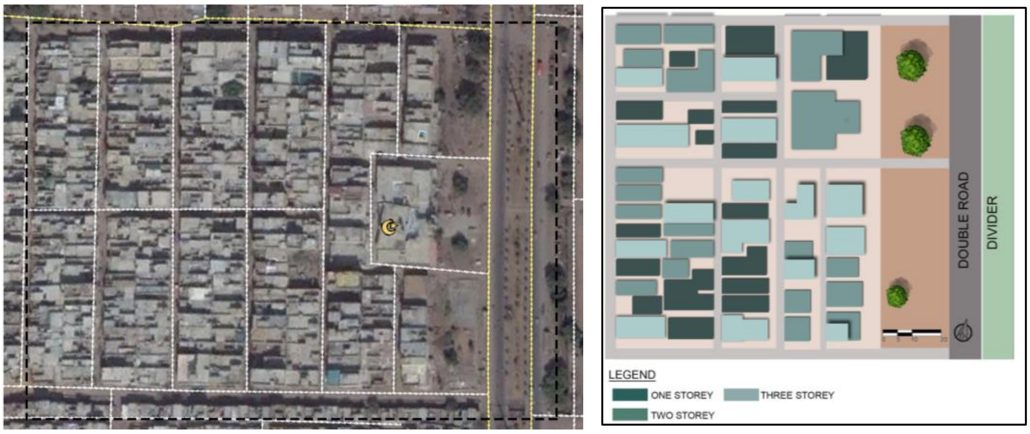


FIGURE 29: Korangi images of the site and location

Figure 30 represents the settings for the base case of the Korangi residential area with one to three storey houses. The pixels are set at 1 grid equals 2.5m, the north is at an angle of 25 and the exact parameters of longitude and latitude are set (24.827220, 67.144980).

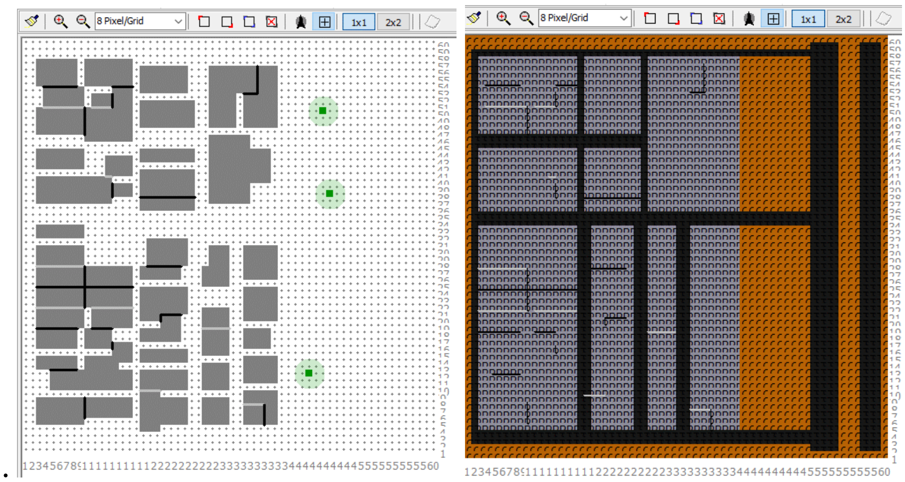


FIGURE 30: Korangi ENVI-met model

II. INPUT PARAMETERS

The first step was to select the area of concern based on the literature collected, by studying the maximum number of casualties and raised temperatures in specific city centres in Karachi as shown above. Lyari, Korangi and the commercial hub Saddar were selected as the area of concern. 2 sets of data were collected and input into the Envi-met software. The first was in the database manger where all the generic material data was inserted for existing conditions and then another for the efficient conditions with higher albedos, lighter coloured pavements, lighter roofs with higher albedo and lighter coloured roads with higher reflectivity based on LEED.

Input parameters were based on the data collected from the met station, YR and material specification based on the literature review. Additional specifications were added to the database of Envi-met based on the base case and the mitigation specs of high-albedo, vegetation and cool pavements and roads.

INPUT DATA

- Start Date: June 20th, 2017
- Start time: 4:00am- as the initial few outputs are typically not accurate
- Total simulation time: 30 hours
- Temperature: 32°C
- Wind speed: 4.1m/s
- Relative humidity: 78%
- Base-Case: As-is conditions of the selected site

FACTORS STUDIED:

- High Albedo
- Cool roads and pavements
- Vegetation
- Efficient case

Efficient case was based on LEED regulations as per below (LEED v4, 2016):

1. Pavements, roads or streets:
    a. 50% of the site should be covered by a combination of these schemes:
        i. Shaded by plants or trees within 10 years
        ii. Install vegetated plants
        iii. Construct shaded structures or paving materials with a three year solar reflectance (SR) of 0.28 or material with initial SR of 0.33.
2. Roofs
    a. 75% of the roof with high Solar Reflective Index (SRI) or 50% of the roof area to be green.
        i. Three year SRI of 64
        ii. Initial SRI of 82
3. Non-roof and roofs properties
    a. A combination of first two are applicable for open area and roofs.
4. Parking
    a. 50 % of the parking should be covered by one of these:
        i. Material of SRI of at least 32 for three years or initial SRI of 39.

Since the sites had a restriction of area and structure not all the specifications mentioned above could be incorporated as per the minimum requirement of LEED. Some items were removed as per below:

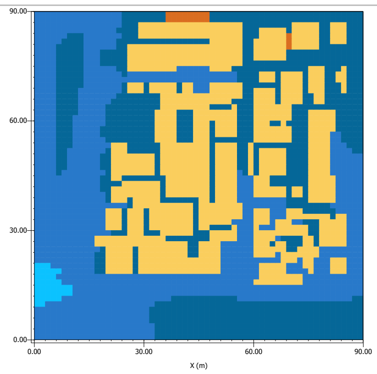
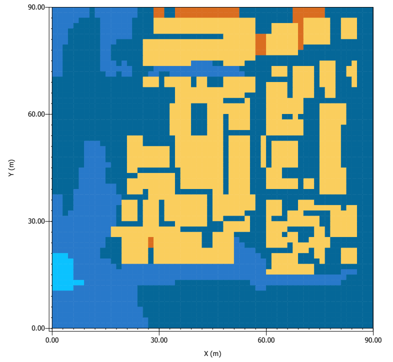
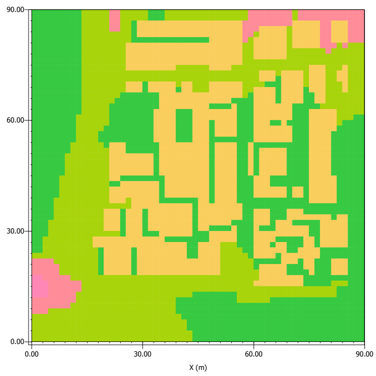
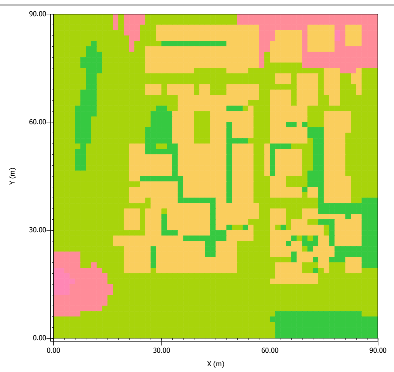
1. Pavements shaded by power generation systems like solar thermal and PVs.
2. Use of open-grid paving system at least for 50% of the area for rainwater run-off and evapotranspiration.
3. Green roofs due to structural integrity of the existing structures.
4. Or a combination of both green roof and high solar reflectance.
5. Vegetated roof for parking areas.

III. RESULTS

LYARI

LYARI BASE CASE – HIGH ALBEDO 20TH, JUNE 2015

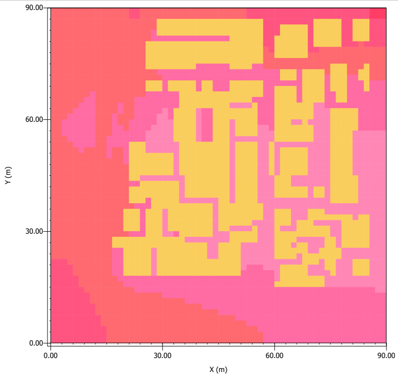
With the introduction of high albedo on the roof from 10:00hrs to 14:00hrs there isn't much difference in temperature on the roofs as seen below in the table. However, around the buildings there is a slight temperature drop of less than 0.9°C but very sporadically. After 14:00, there is an evident temperature drop above the roof. At 16:00 hrs in the base case the temperature above the roof is approximately between 33°C and 34.5°C, whereas in the high albedo roof the temperature is under 31.5°C. The temperature around the buildings in the base case goes as high as 52°C. From 18:00 to 22:00 the temperature of the roofs in the base case keeps increasing from 34.5°C to 39 °C and the temperature around the buildings is at 42°C. Conversely in the high albedo roofs the temperature above the roofs remains between 31.5°C to 33°C or below 31.5°C. The average temperature change for the full day for high albedo roofs remained between 0.21°C to 3.64°C in the case of Lyari which was a mixed land-use are with buildings varying in heights. The temperature difference results are in Appendix A for all the scenarios of Lyari.

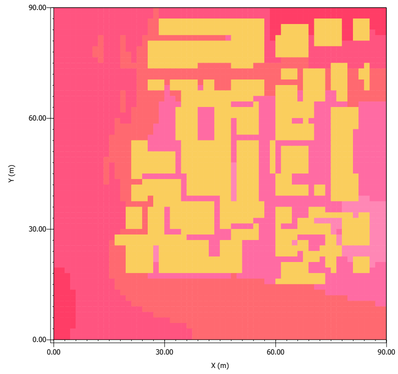
Time	Base case	High Albedo
10:00 ***Air Temperature*** unter 31.50 °C 31.50 bis 33.00 33.00 bis 34.50 34.50 bis 36.00 36.00 bis 37.50 37.50 bis 39.00 39.00 bis 40.50 40.50 bis 42.00 42.00 bis 43.50 43.50 bis 45.00 45.00 bis 46.50 46.50 bis 48.00 48.00 bis 49.50 49.50 bis 51.00 51.00 bis 52.50 52.50 bis 54.00		
12:00 ***Air Temperature*** unter 31.50 °C 31.50 bis 33.00 33.00 bis 34.50 34.50 bis 36.00 36.00 bis 37.50 37.50 bis 39.00 39.00 bis 40.50 40.50 bis 42.00 42.00 bis 43.50 43.50 bis 45.00 45.00 bis 46.50 46.50 bis 48.00 48.00 bis 49.50 49.50 bis 51.00 51.00 bis 52.50 52.50 bis 54.00		

14:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00
- 33.00 bis 34.50
- 34.50 bis 36.00
- 36.00 bis 37.50
- 37.50 bis 39.00
- 39.00 bis 40.50
- 40.50 bis 42.00
- 42.00 bis 43.50
- 43.50 bis 45.00
- 45.00 bis 46.50
- 46.50 bis 48.00
- 48.00 bis 49.50
- 49.50 bis 51.00
- 51.00 bis 52.50
- 52.50 bis 54.00

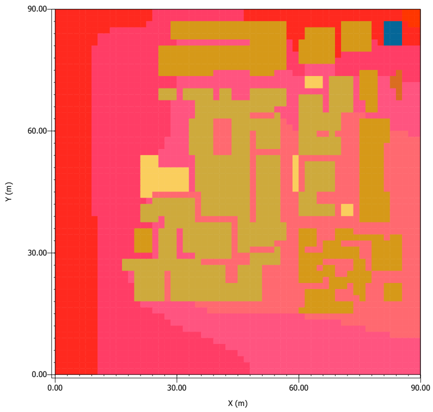


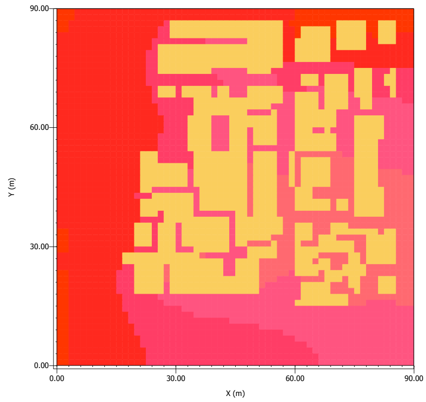


16:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00
- 33.00 bis 34.50
- 34.50 bis 36.00
- 36.00 bis 37.50
- 37.50 bis 39.00
- 39.00 bis 40.50
- 40.50 bis 42.00
- 42.00 bis 43.50
- 43.50 bis 45.00
- 45.00 bis 46.50
- 46.50 bis 48.00
- 48.00 bis 49.50
- 49.50 bis 51.00
- 51.00 bis 52.50
- 52.50 bis 54.00

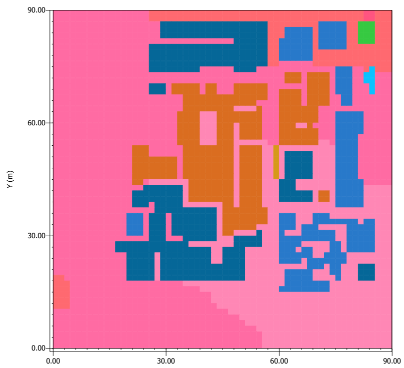


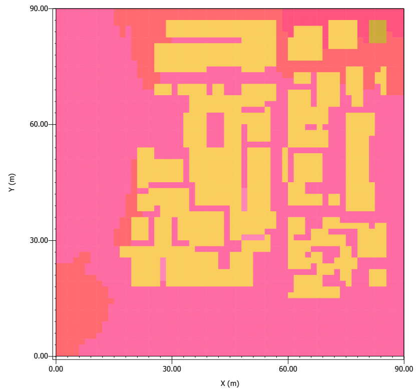


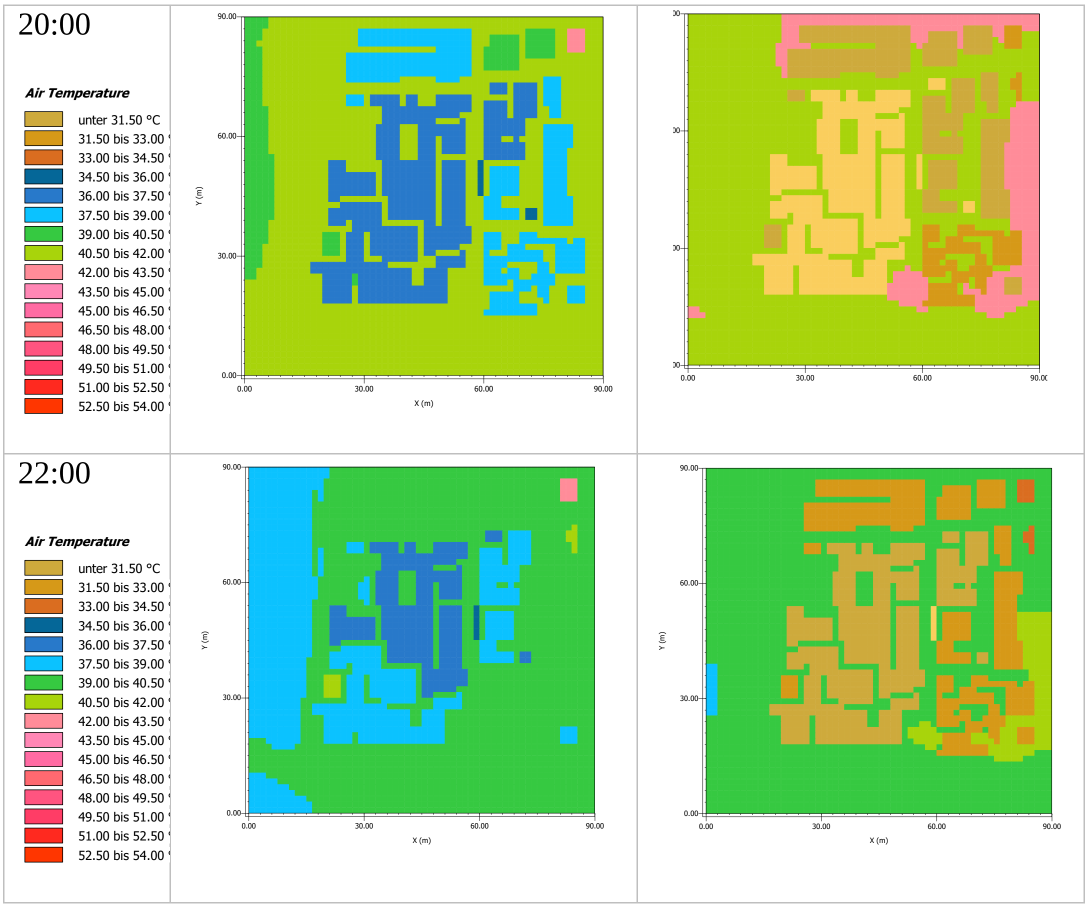
18:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00
- 33.00 bis 34.50
- 34.50 bis 36.00
- 36.00 bis 37.50
- 37.50 bis 39.00
- 39.00 bis 40.50
- 40.50 bis 42.00
- 42.00 bis 43.50
- 43.50 bis 45.00
- 45.00 bis 46.50
- 46.50 bis 48.00
- 48.00 bis 49.50
- 49.50 bis 51.00
- 51.00 bis 52.50
- 52.50 bis 54.00



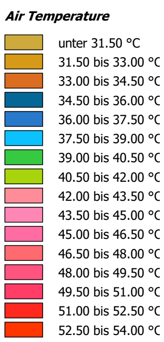
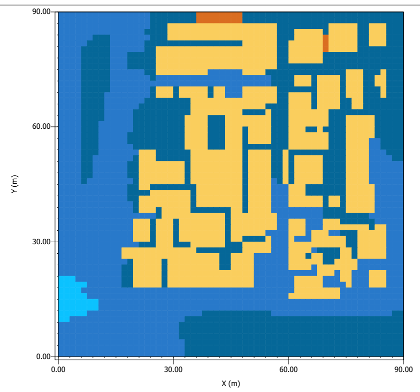
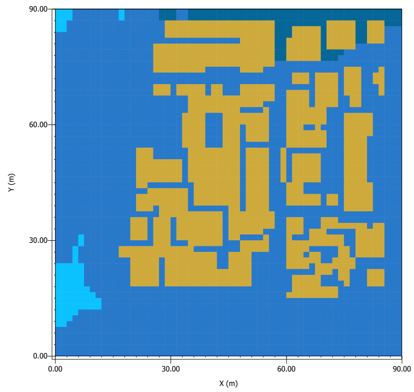
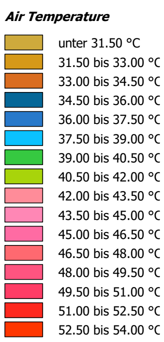
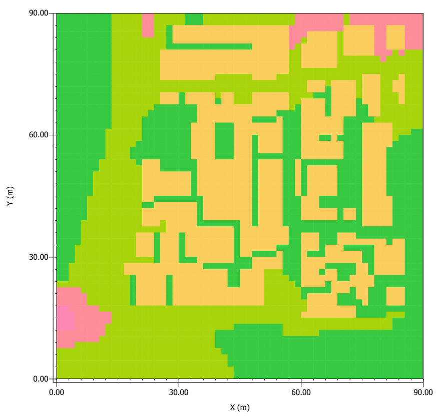
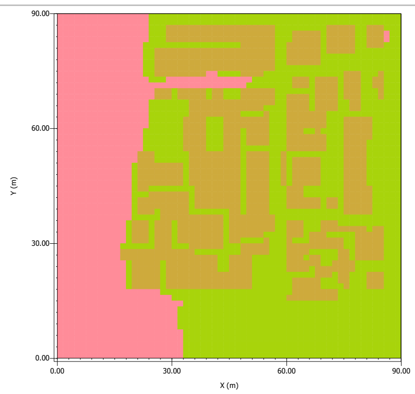


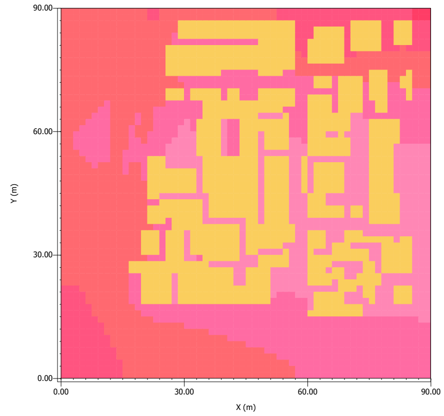
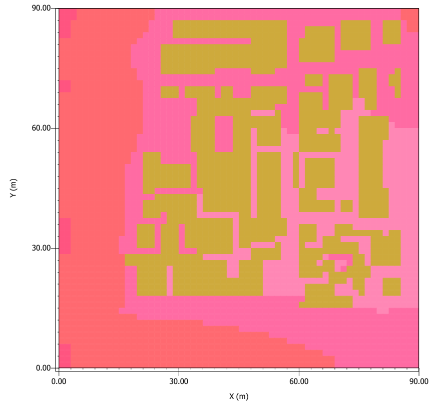
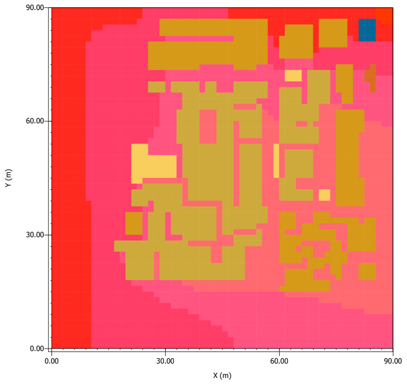
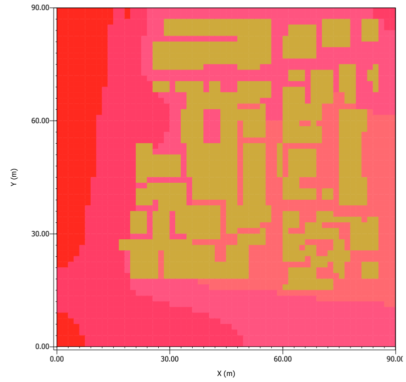
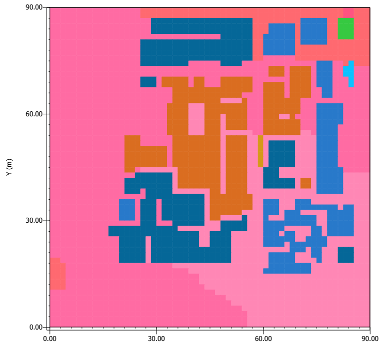
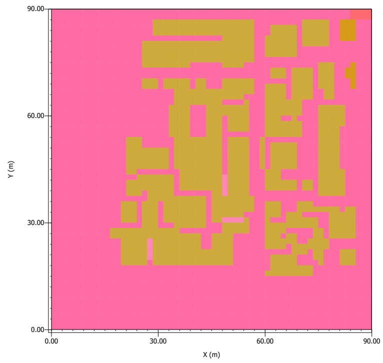


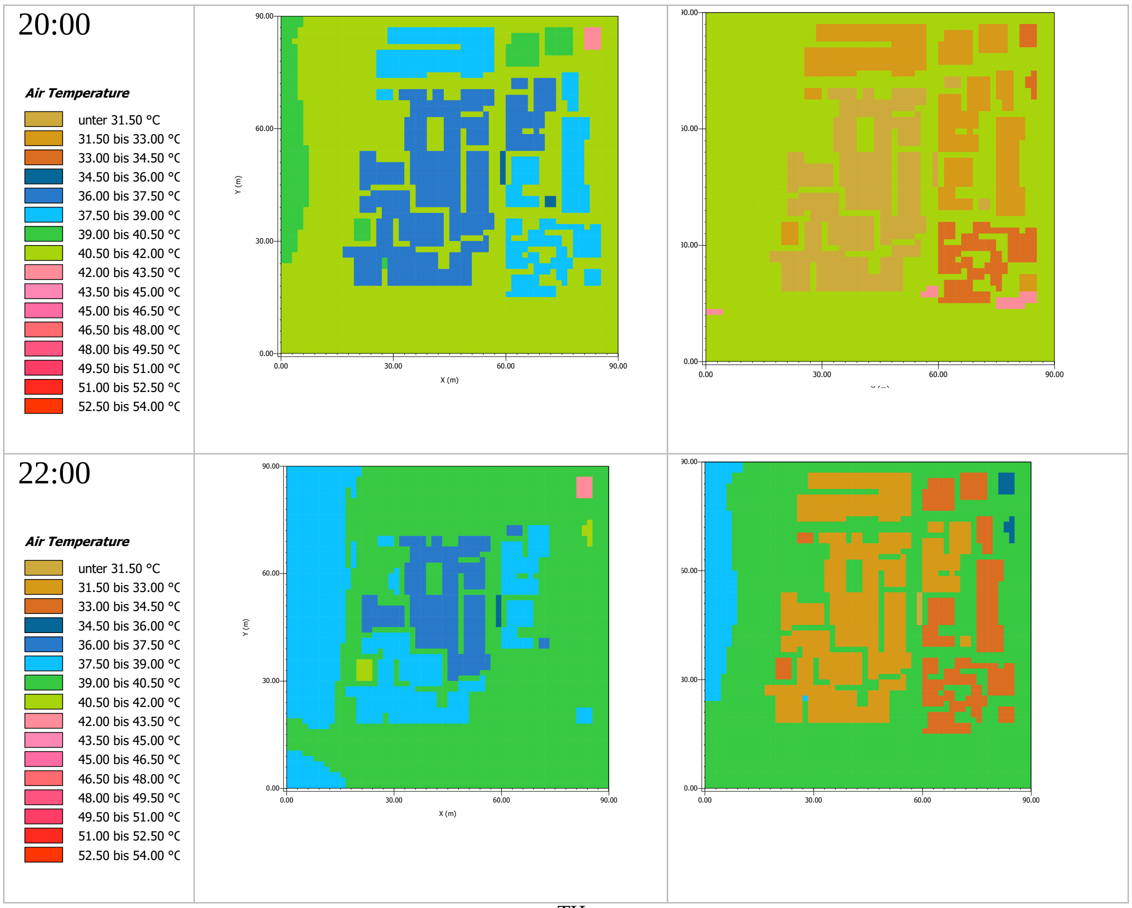
LYARI BASE CASE – PAVEMENTS & ROADS 20[TH], JUNE 2015

From the chart below the temperature in the morning remains 31.5°C to 34.5°C, however between 14:00 hours and 16:00 it reaches it's maximum of 52.5°C. In the case of cool pavement and roads the percentage of area where the temperatures reaching 52°C is less but there is not much significant temperature drop. The surface temperature on the roads and pavements dropped by 0.5°C to 3.12°C, surprisingly the temperature surrounding the buildings dropped further by 4°C. The average temperature difference was from 2.16°C to 4.04°C.

LYARI BASE CASE – PAVEMENTS & ROADS 20TH, JUNE 2015

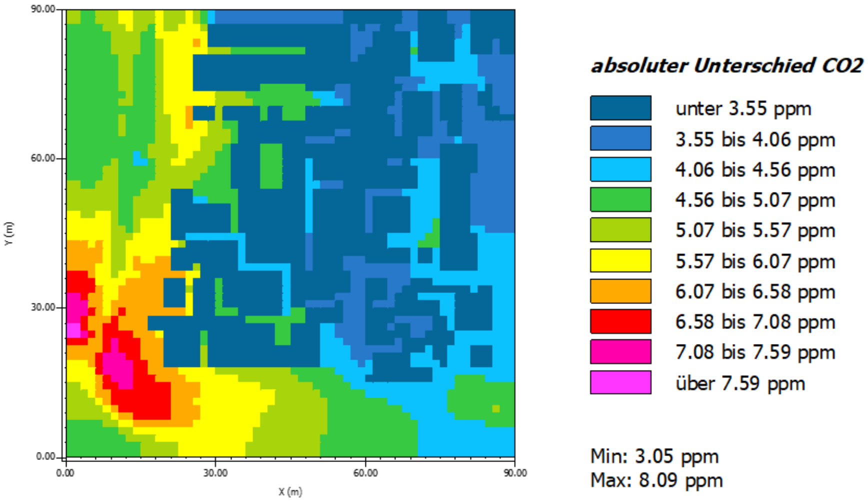
Time	Base case	Pavements & roads
10:00 		
12:00 		

14:00 ***Air Temperature*** unter 31.50 °C 31.50 bis 33.00 °C 33.00 bis 34.50 °C 34.50 bis 36.00 °C 36.00 bis 37.50 °C 37.50 bis 39.00 °C 39.00 bis 40.50 °C 40.50 bis 42.00 °C 42.00 bis 43.50 °C 43.50 bis 45.00 °C 45.00 bis 46.50 °C 46.50 bis 48.00 °C 48.00 bis 49.50 °C 49.50 bis 51.00 °C 51.00 bis 52.50 °C 52.50 bis 54.00 °C		
16:00 ***Air Temperature*** unter 31.50 °C 31.50 bis 33.00 °C 33.00 bis 34.50 °C 34.50 bis 36.00 °C 36.00 bis 37.50 °C 37.50 bis 39.00 °C 39.00 bis 40.50 °C 40.50 bis 42.00 °C 42.00 bis 43.50 °C 43.50 bis 45.00 °C 45.00 bis 46.50 °C 46.50 bis 48.00 °C 48.00 bis 49.50 °C 49.50 bis 51.00 °C 51.00 bis 52.50 °C 52.50 bis 54.00 °C		
18:00 ***Air Temperature*** unter 31.50 °C 31.50 bis 33.00 °C 33.00 bis 34.50 °C 34.50 bis 36.00 °C 36.00 bis 37.50 °C 37.50 bis 39.00 °C 39.00 bis 40.50 °C 40.50 bis 42.00 °C 42.00 bis 43.50 °C 43.50 bis 45.00 °C 45.00 bis 46.50 °C 46.50 bis 48.00 °C 48.00 bis 49.50 °C 49.50 bis 51.00 °C 51.00 bis 52.50 °C 52.50 bis 54.00 °C		

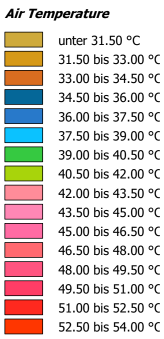
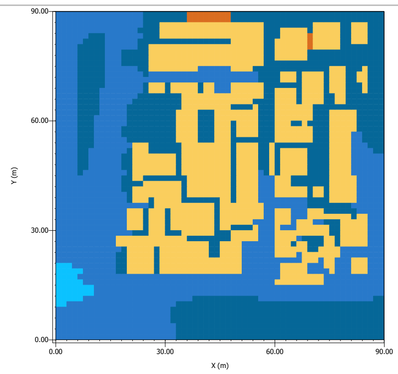
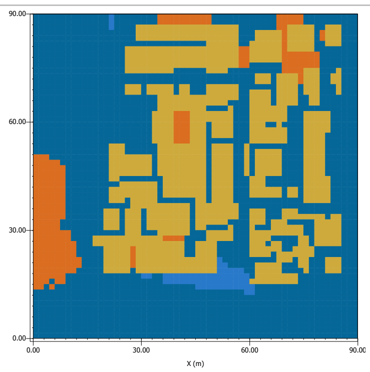
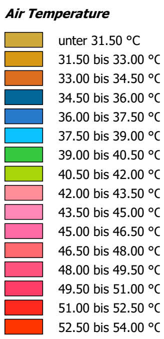
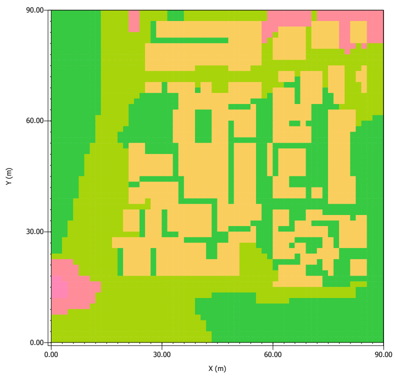
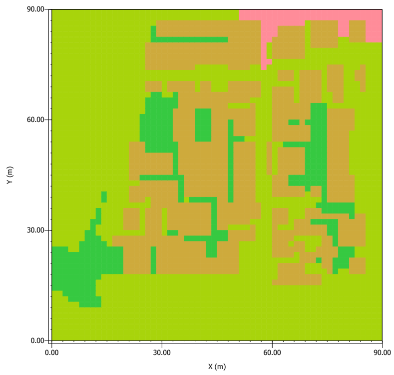


LYARI BASE CASE – VEGETATION 20TH, JUNE 2015

Green belt was added on the main road and trees in the empty area adjacent to the road and inside the school. In the simulation chart below its evident that since morning the temperatures dropped from 0.9°C up to 1.5°C. Between 2pm and 3pm in the school courtyard the temperatures dropped by 2.5°C to 5.7°C. As the evening precedes the temperature difference between the base case and greener solution kept consistent between to 1.5°C to 3°C. Primarily the vegetation increased the evapotranspiration dropping the average temperature of the day by 1.62 °C to 4.21 °C. The carbon dioxide count dropped between 3.05ppm to 8.09ppm as show below.



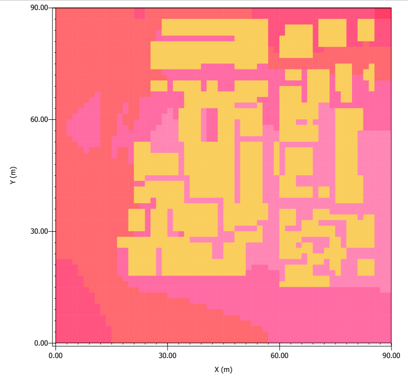
LYARI BASE CASE – VEGETATION 20TH, JUNE 2015

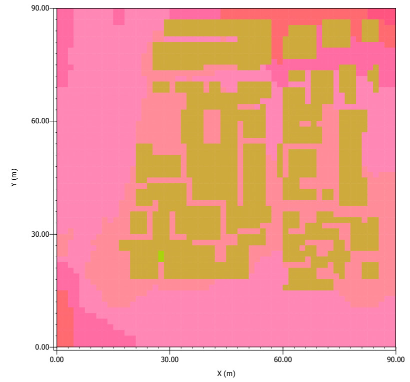
Time	Base case	Vegetation
10:00 		
12:00 		

14:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

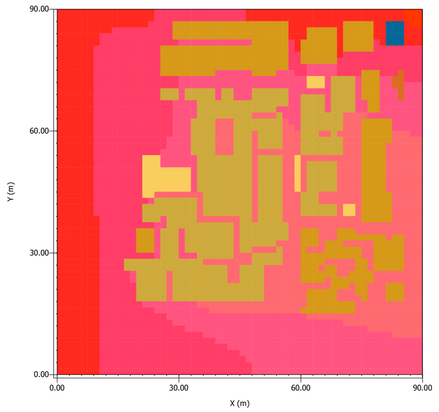


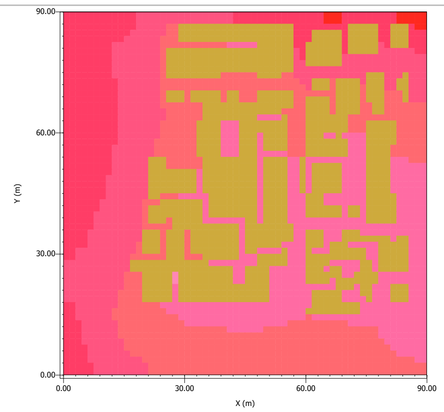


16:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

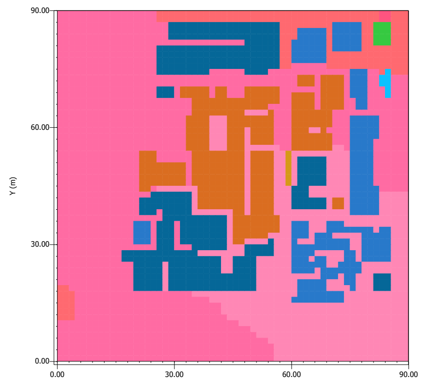


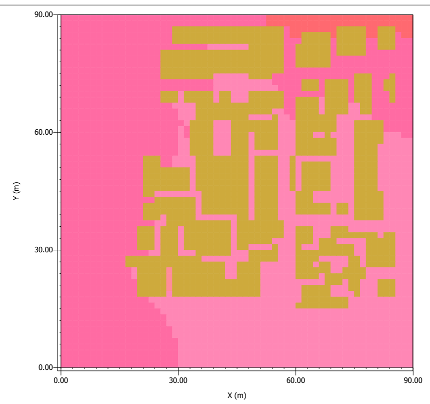


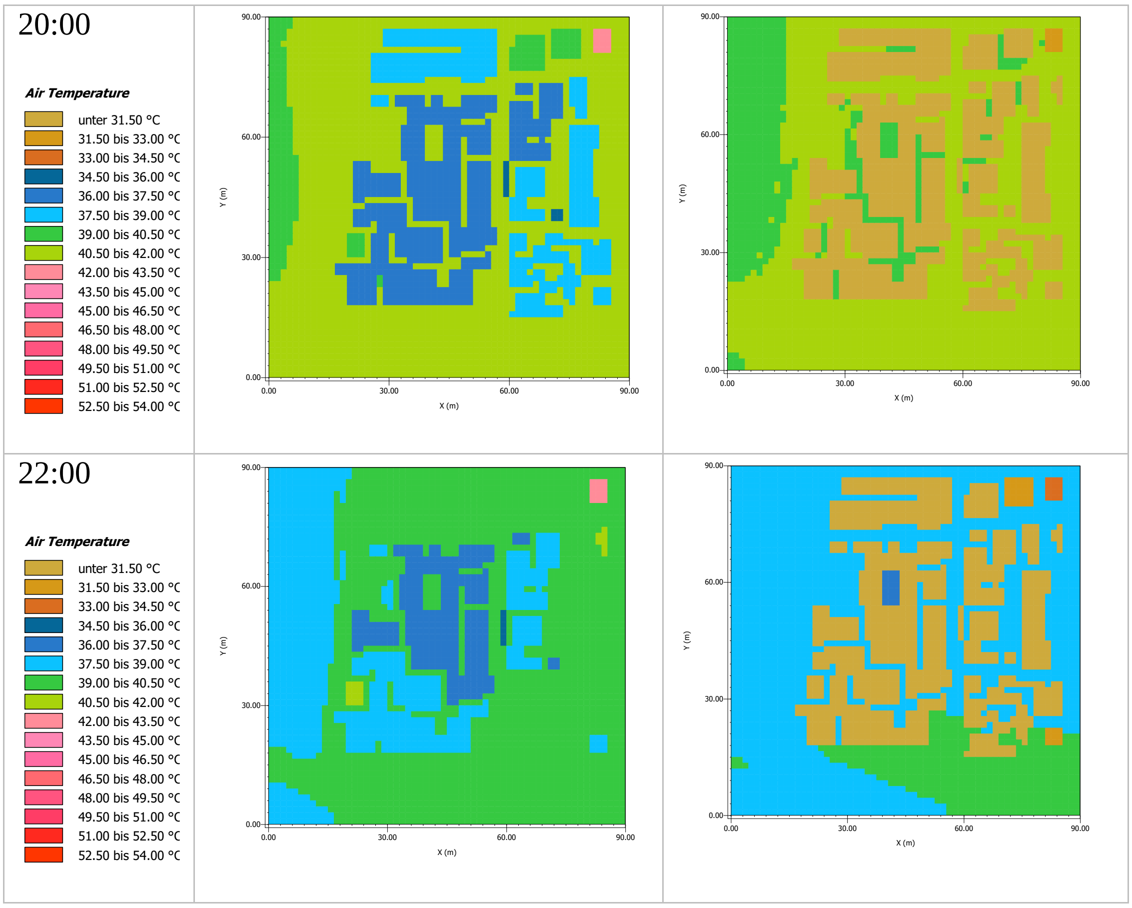
18:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C



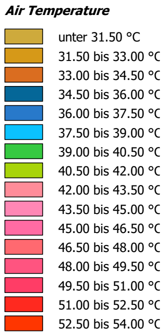
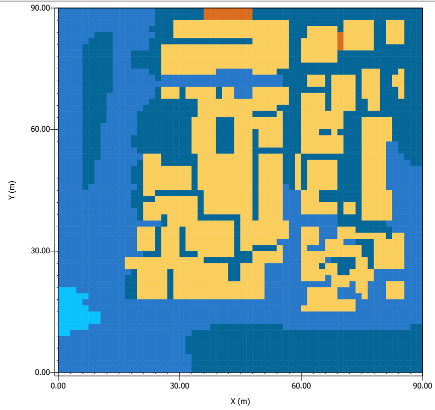
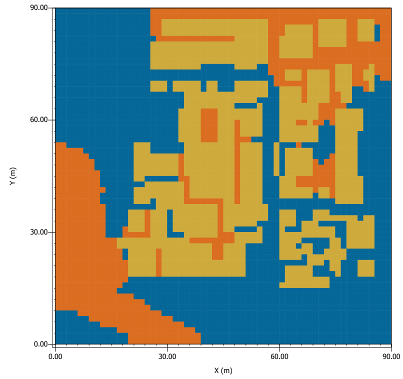




LYARI BASE CASE – EFFICIENT CASE 20TH, JUNE 2015

The efficient case showed more stable results with less fluctuation. Vegetation and green belts were the most effective coupled with high albedo at night and cool pavements and roads during the day. With an average of 4.5°C difference through the day with a maximum temperature difference reaching 5.23°C (See appendix A).

<table>
<tr><th>Time</th><th>Base case</th><th>Efficient case</th></tr>
<tr><td>10:00


</td><td>
</td><td>
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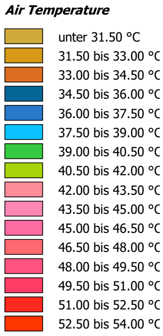
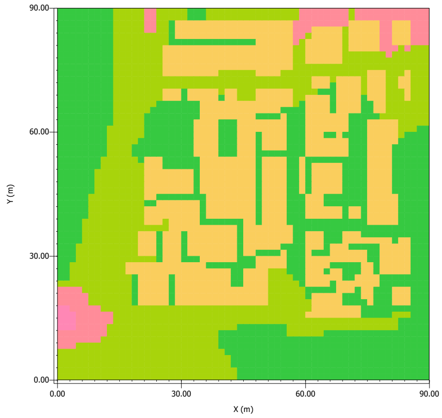
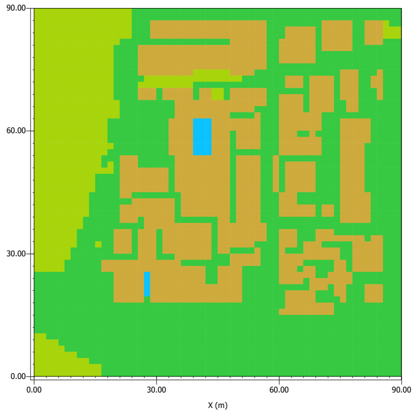
<tr><td>12:00


</td><td>
</td><td>
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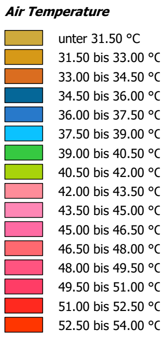
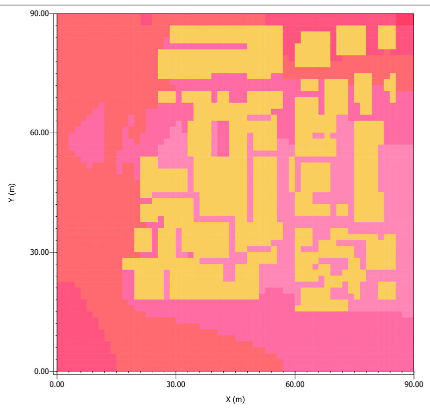
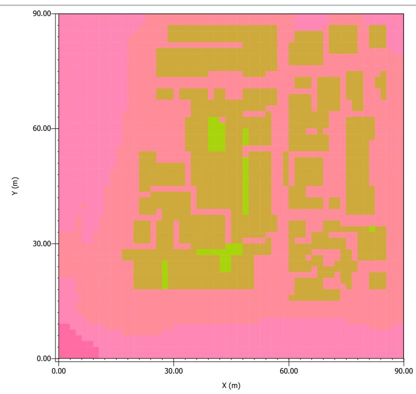
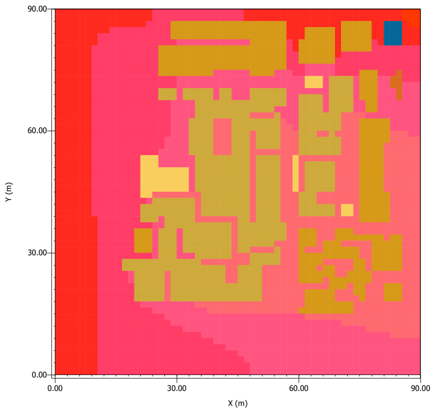
<tr><td>14:00

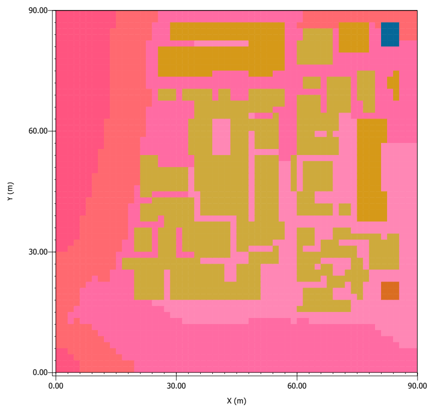

</td><td>
</td><td>
</td></tr>
</table>

16:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





18:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
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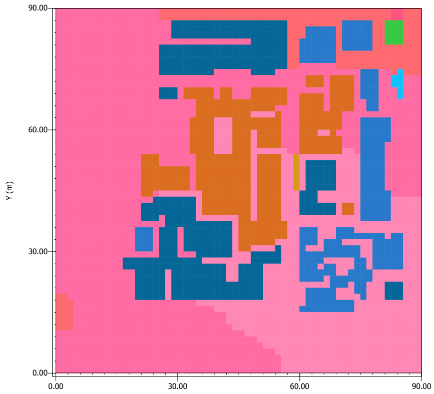
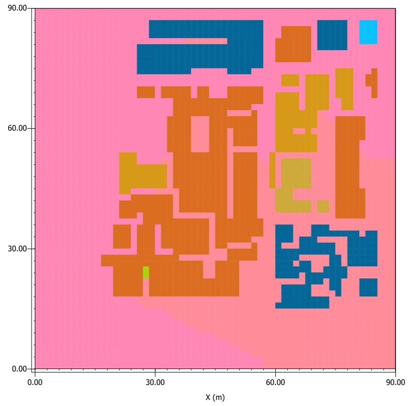
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

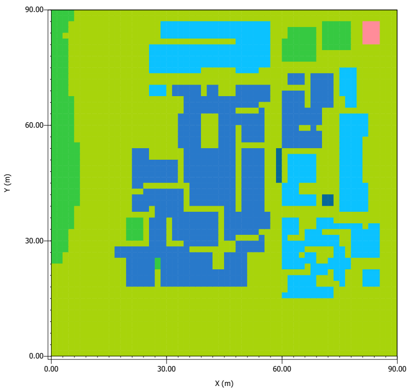


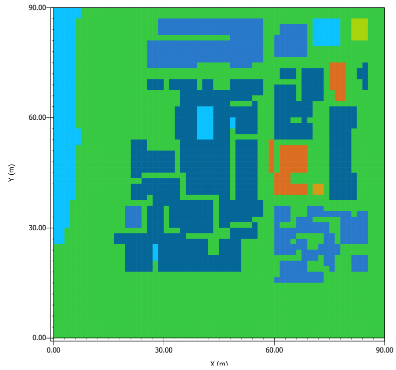


20:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

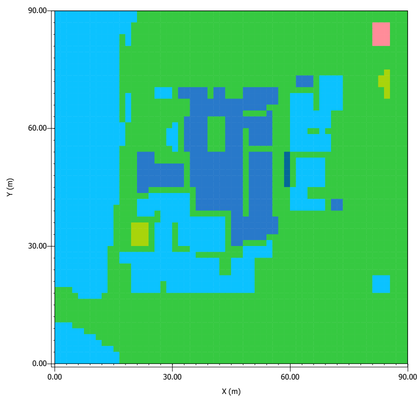


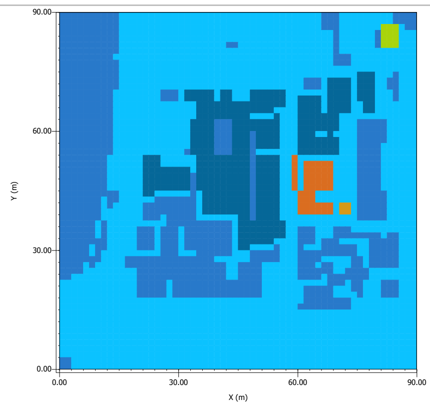


22:00

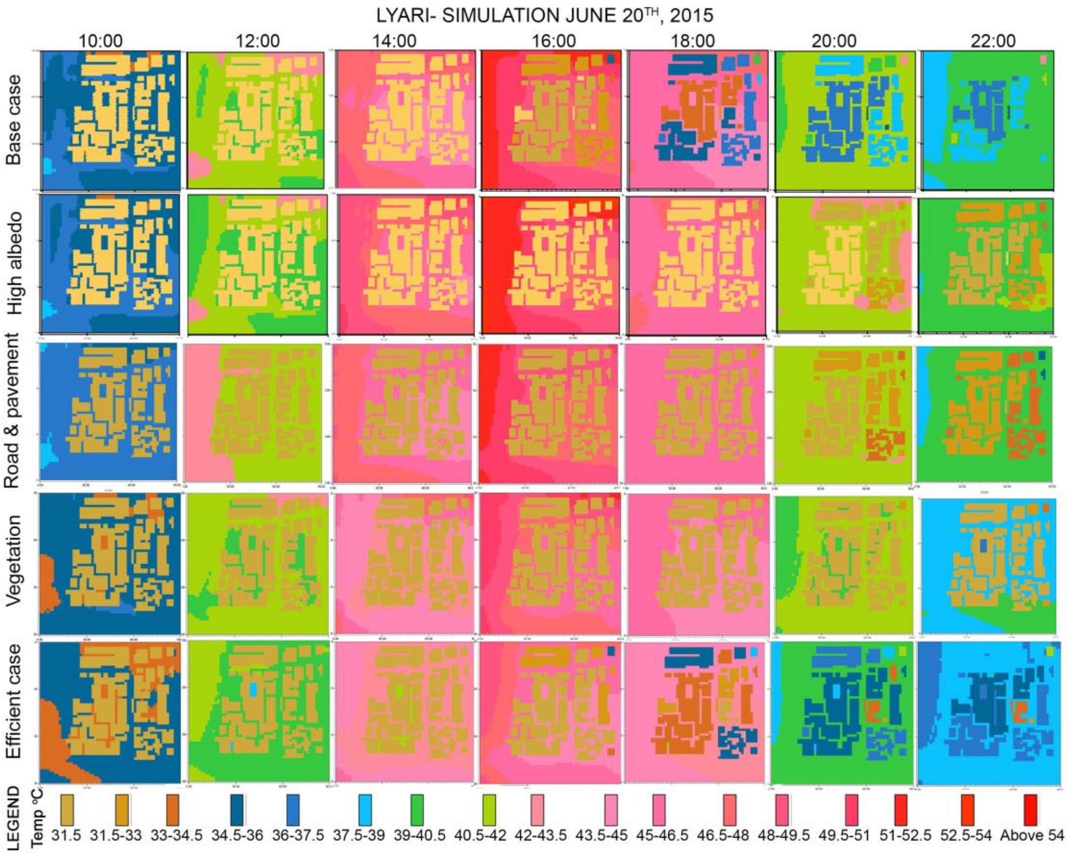
Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

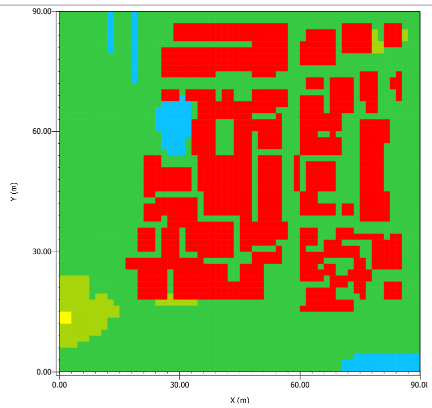
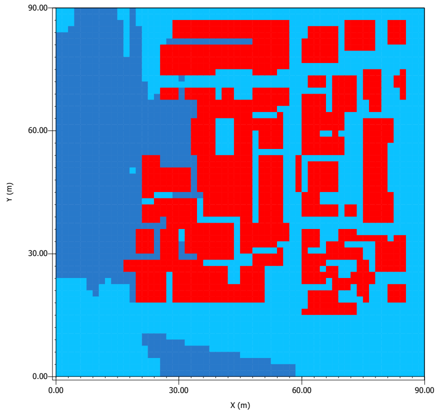
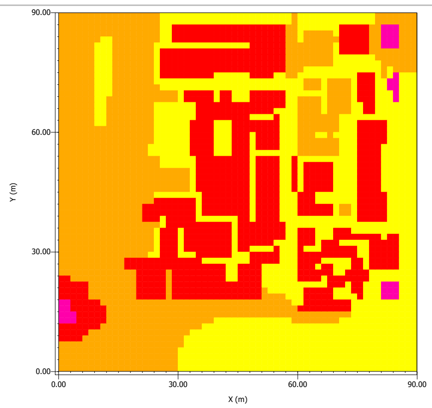
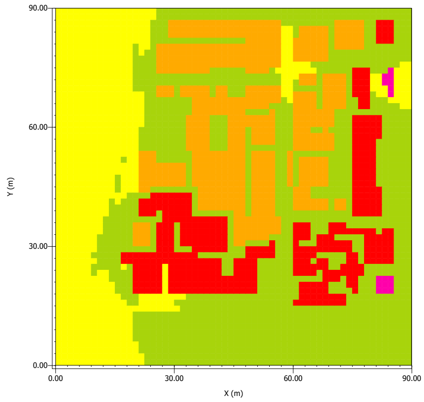
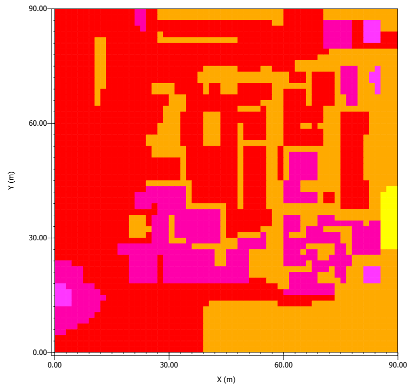
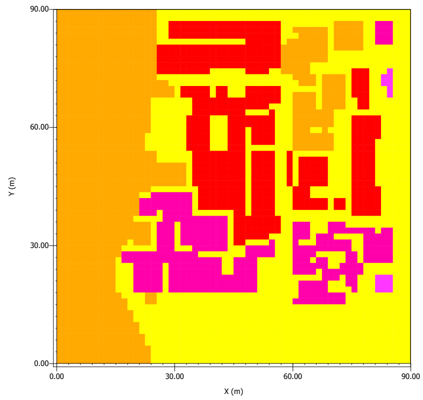




The chart below represents a summary of all strategies combined which represents the gradation of how the temperatures dropped and the uniformity of temperatures reached with the efficient case.



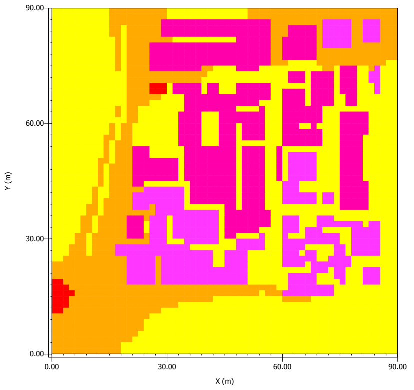
The same strategies were also implemented to test for winter in order to study if there was any negative impact due to the strategies. The results for the winter are given below in the chart. This was conducted for December 26th, 2015. From the chart below it is clear that the average temperature difference in winter is between 1°C to maximum 1.5°C. During the day it remains in the comfort zone and at night and early morning the temperature difference goes up to 1.58°C.

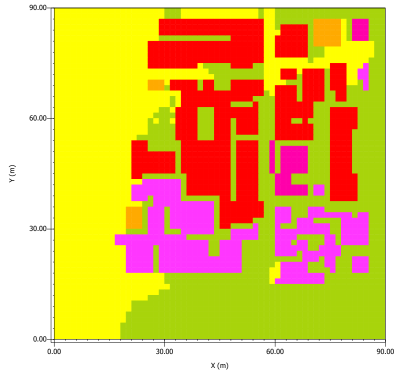
Time	Winter Base case	Winter Efficient case
10:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		
12:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		
14:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		

16:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

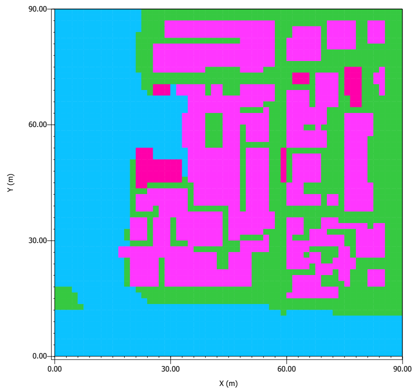


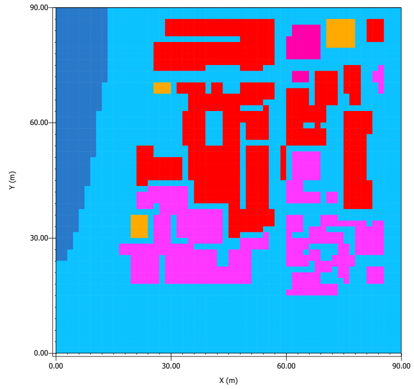


18:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

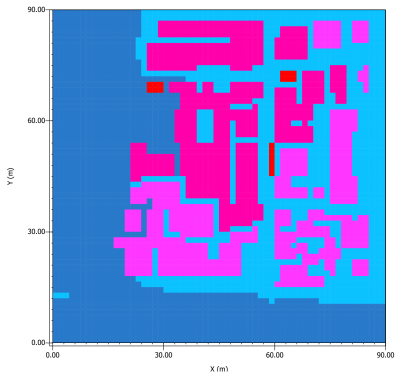


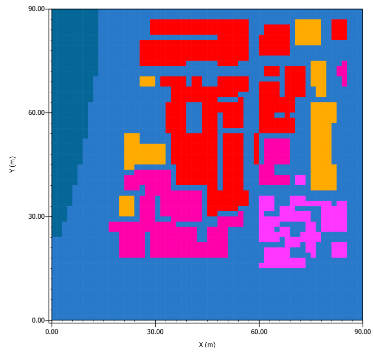


20:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

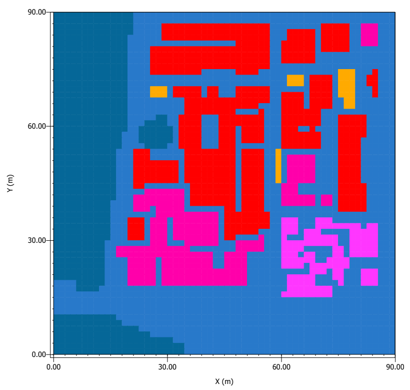


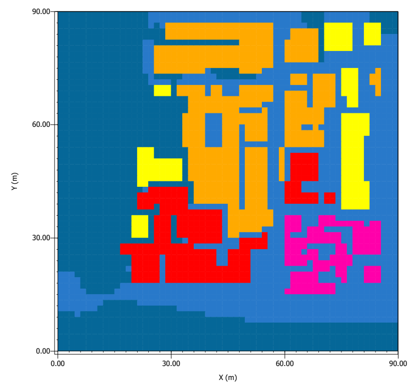


22:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

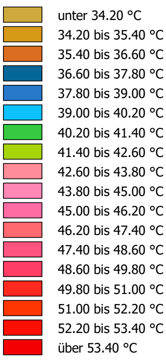
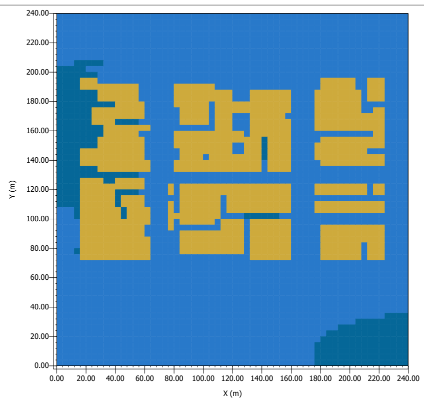
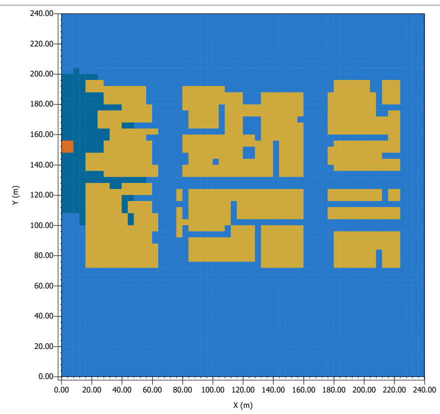
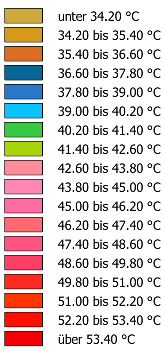
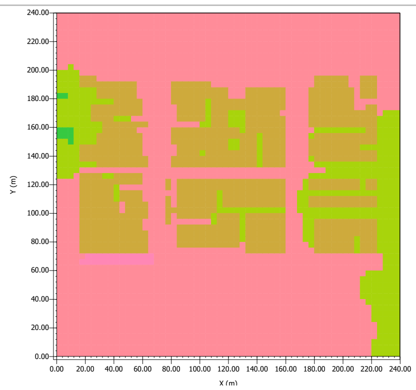
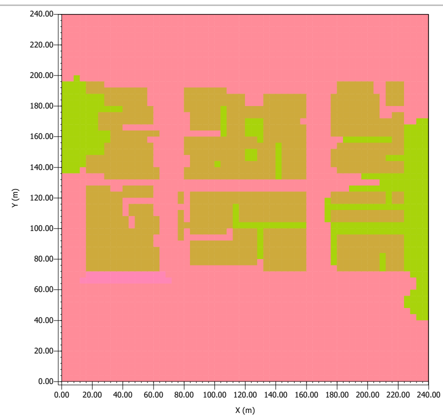




SADDAR

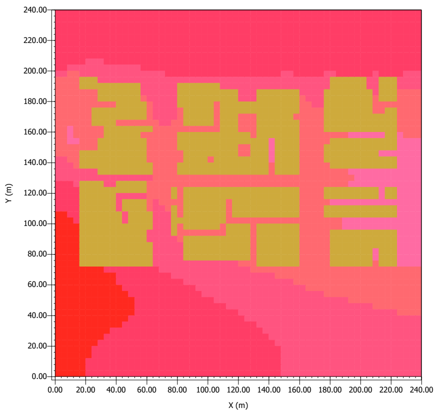
Same strategies were applied to the hub of Karachi- Saddar. Saddar is the business hub and one of the most congested areas in Karachi, as visible from the simulation there wasn't much impact on the surface temperature due to high albedo. Similar to Lyari, high albedo on the roofs only slightly changed the temperatures adjacent to the buildings till 14:00hrs. After 16:00hours we see the temperature of the roofs in the case of high albedo between 34.20°C to 36.60°C whereas in the base case goes up to 45°C. At an average the temperature difference between the base case and high albedo in Saddar is 2.2°C to 4.8°C.

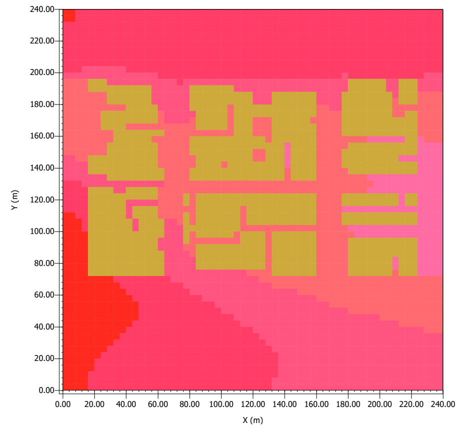
SADDAR BASE CASE – HIGH ALBEDO 20TH, JUNE 2015

Time	Base case	High Albedo
10:00 		
12:00 		

14:00

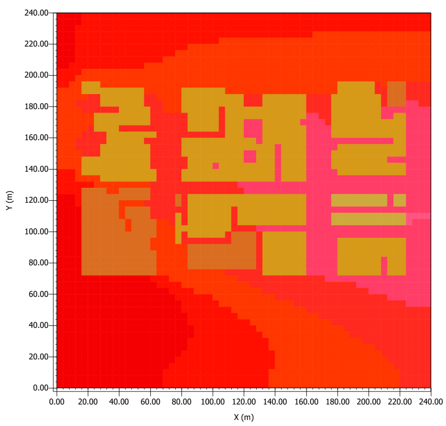
- unter 34.20 °C
- 34.20 bis 35.40 °C
- 35.40 bis 36.60 °C
- 36.60 bis 37.80 °C
- 37.80 bis 39.00 °C
- 39.00 bis 40.20 °C
- 40.20 bis 41.40 °C
- 41.40 bis 42.60 °C
- 42.60 bis 43.80 °C
- 43.80 bis 45.00 °C
- 45.00 bis 46.20 °C
- 46.20 bis 47.40 °C
- 47.40 bis 48.60 °C
- 48.60 bis 49.80 °C
- 49.80 bis 51.00 °C
- 51.00 bis 52.20 °C
- 52.20 bis 53.40 °C
- über 53.40 °C

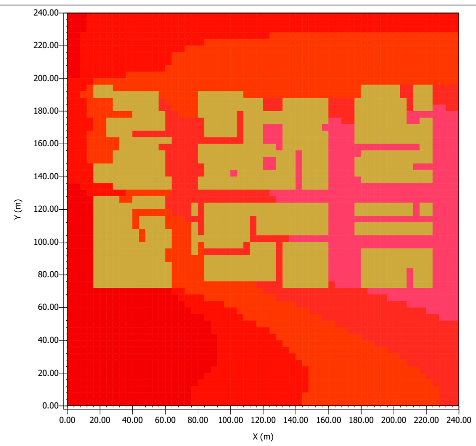




16:00

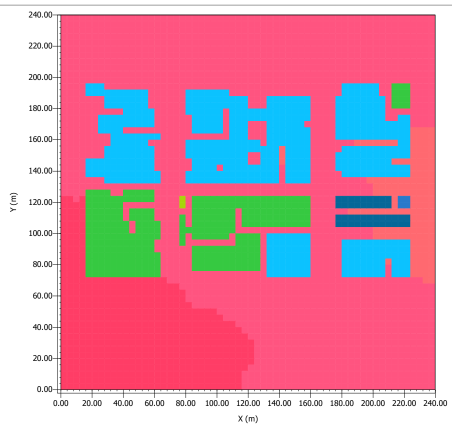
- unter 34.20 °C
- 34.20 bis 35.40 °C
- 35.40 bis 36.60 °C
- 36.60 bis 37.80 °C
- 37.80 bis 39.00 °C
- 39.00 bis 40.20 °C
- 40.20 bis 41.40 °C
- 41.40 bis 42.60 °C
- 42.60 bis 43.80 °C
- 43.80 bis 45.00 °C
- 45.00 bis 46.20 °C
- 46.20 bis 47.40 °C
- 47.40 bis 48.60 °C
- 48.60 bis 49.80 °C
- 49.80 bis 51.00 °C
- 51.00 bis 52.20 °C
- 52.20 bis 53.40 °C
- über 53.40 °C

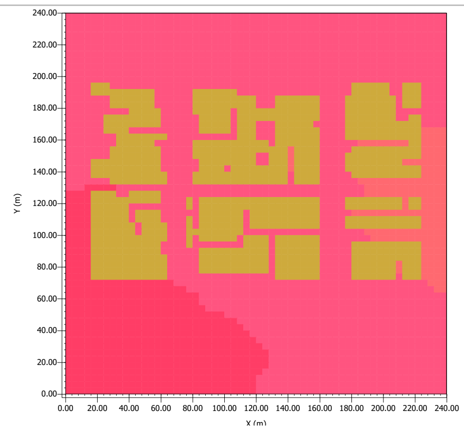


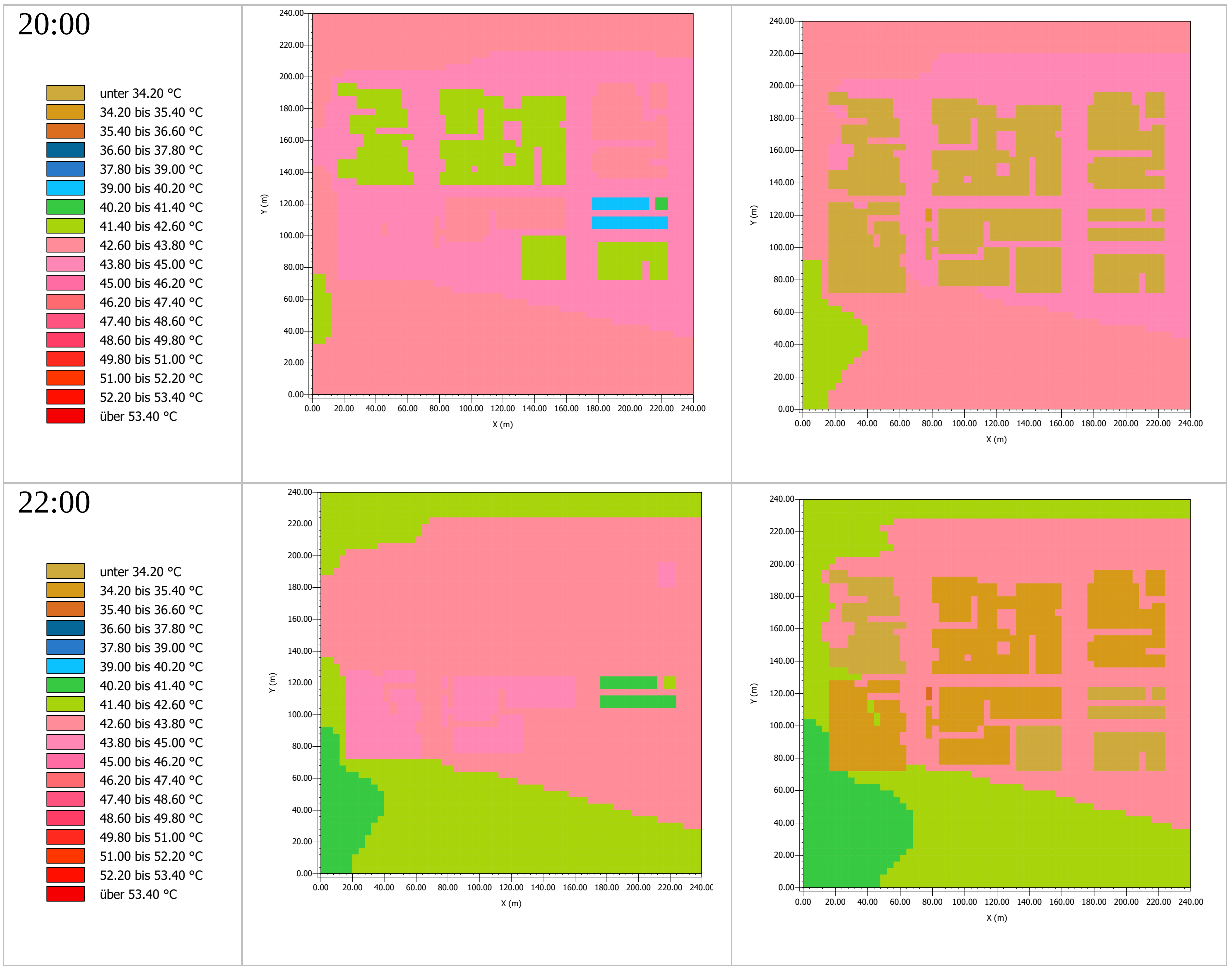


18:00

- unter 34.20 °C
- 34.20 bis 35.40 °C
- 35.40 bis 36.60 °C
- 36.60 bis 37.80 °C
- 37.80 bis 39.00 °C
- 39.00 bis 40.20 °C
- 40.20 bis 41.40 °C
- 41.40 bis 42.60 °C
- 42.60 bis 43.80 °C
- 43.80 bis 45.00 °C
- 45.00 bis 46.20 °C
- 46.20 bis 47.40 °C
- 47.40 bis 48.60 °C
- 48.60 bis 49.80 °C
- 49.80 bis 51.00 °C
- 51.00 bis 52.20 °C
- 52.20 bis 53.40 °C
- über 53.40 °C







SADDAR BASE CASE – COOL ROADS & PAVEMENTS 20TH, JUNE 2015

Cool pavements and cool roads didn't have a drastic temperature difference as evident from the chart below. In the case of Lyari the buildings were 1 to 3 storey, however, in Saddar the buildings are higher. The possible reason of not having a very effective response to the cool roads and pavements could be the entrapment of heat as the area has higher buildings and is very congested. The average temperature difference between the base case and the cools roads and pavements was 0.8°C to 1.2°C.

SADDAR BASE CASE – ROADS & PAVEMENTS 20TH, JUNE 2015

<table>
<tr><th>Time</th><th>Base case</th><th>Roads & Pavements</th></tr>
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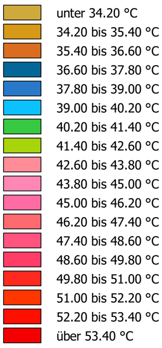
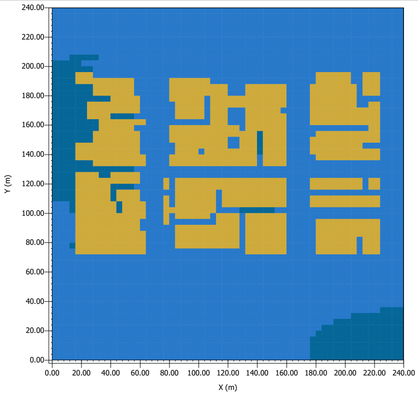
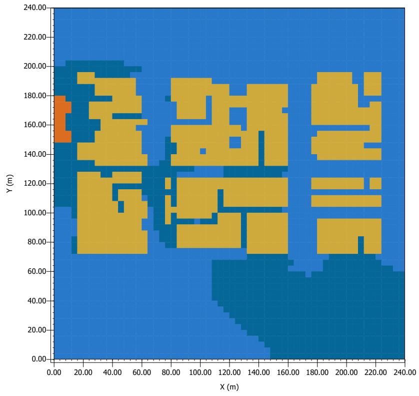
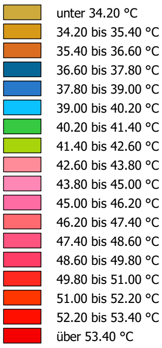
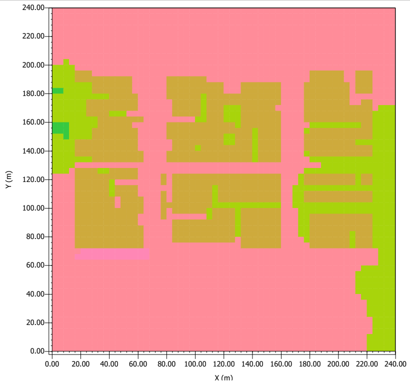
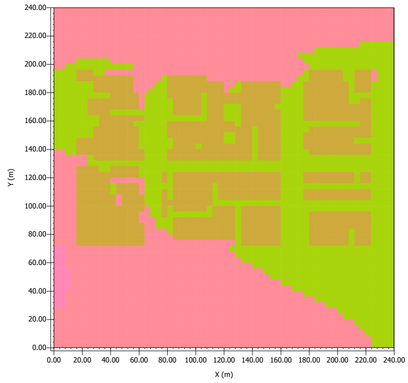
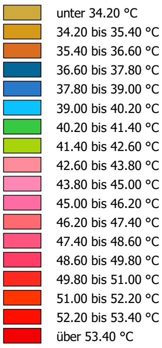
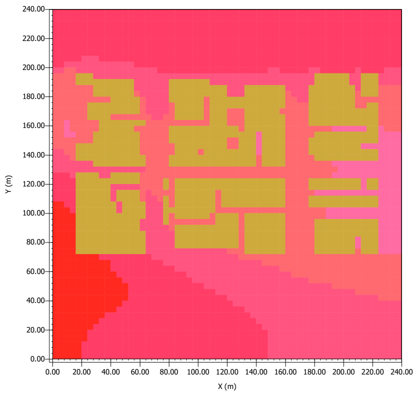
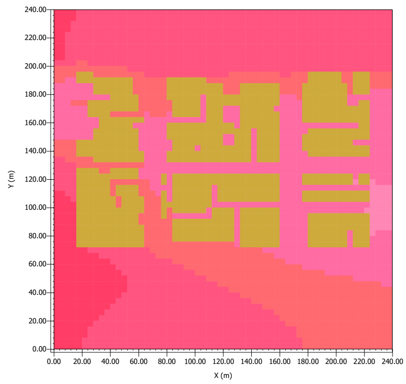
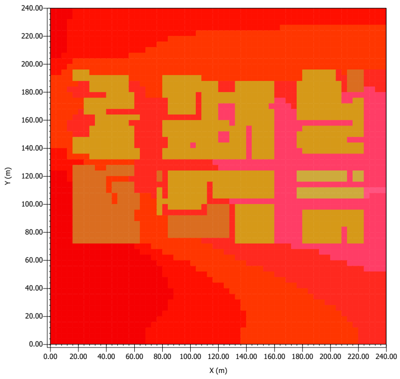
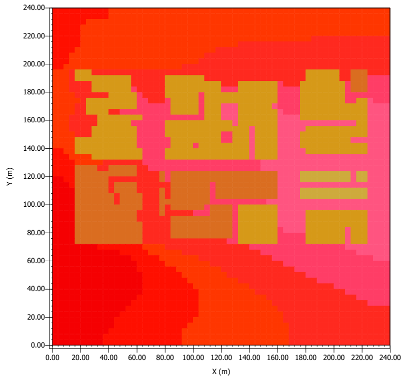

</td><td></td><td></td></tr>
<tr><td>12:00

</td><td></td><td></td></tr>
<tr><td>14:00

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

16:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
37.80 bis 39.00 °C
39.00 bis 40.20 °C
40.20 bis 41.40 °C
41.40 bis 42.60 °C
42.60 bis 43.80 °C
43.80 bis 45.00 °C
45.00 bis 46.20 °C
46.20 bis 47.40 °C
47.40 bis 48.60 °C
48.60 bis 49.80 °C
49.80 bis 51.00 °C
51.00 bis 52.20 °C
52.20 bis 53.40 °C
über 53.40 °C





18:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
37.80 bis 39.00 °C
39.00 bis 40.20 °C
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47.40 bis 48.60 °C
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49.80 bis 51.00 °C
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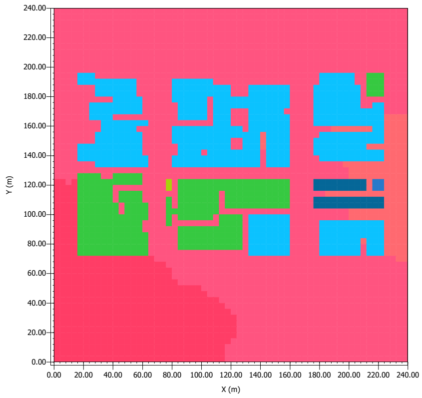
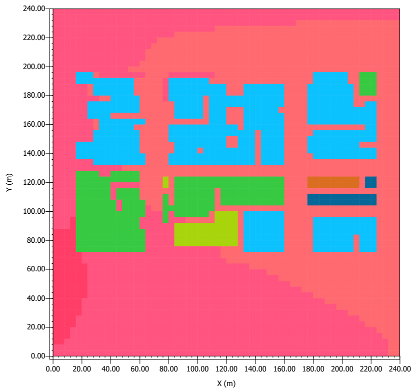
52.20 bis 53.40 °C
über 53.40 °C





20:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
37.80 bis 39.00 °C
39.00 bis 40.20 °C
40.20 bis 41.40 °C
41.40 bis 42.60 °C
42.60 bis 43.80 °C
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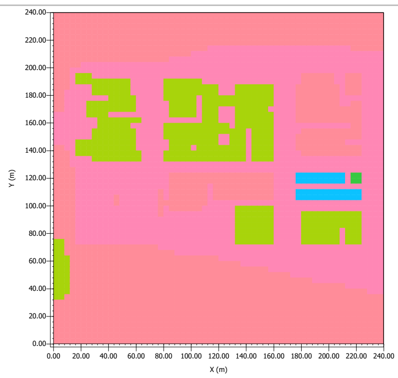
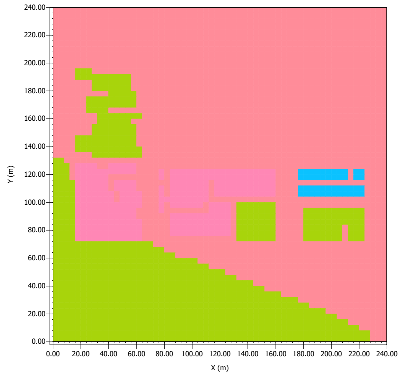
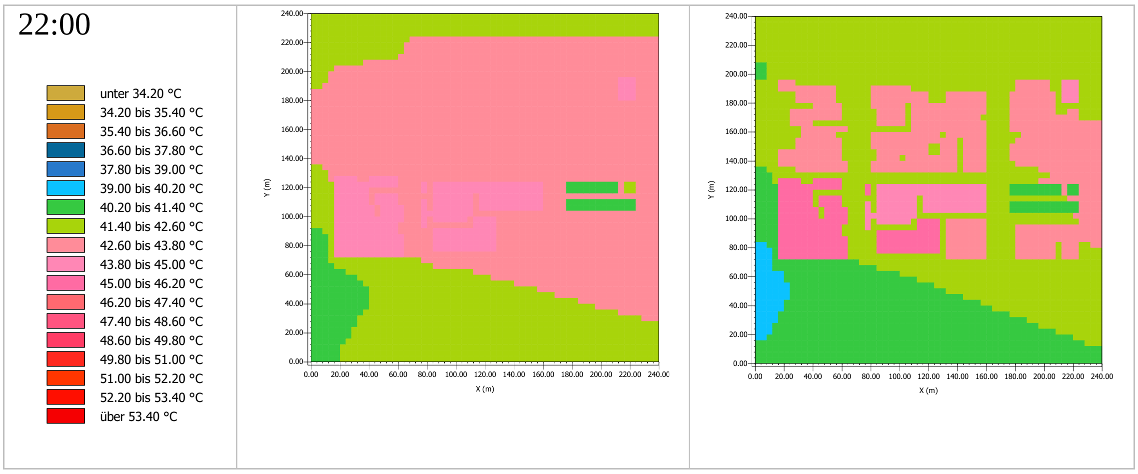
45.00 bis 46.20 °C
46.20 bis 47.40 °C
47.40 bis 48.60 °C
48.60 bis 49.80 °C
49.80 bis 51.00 °C
51.00 bis 52.20 °C
52.20 bis 53.40 °C
über 53.40 °C

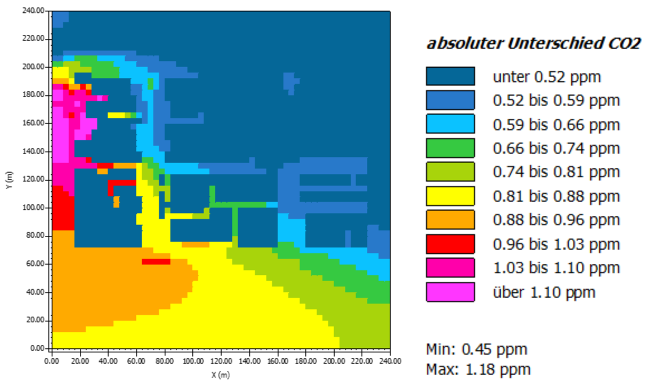






SADDAR BASE CASE – VEGETATION 20TH, JUNE 2015

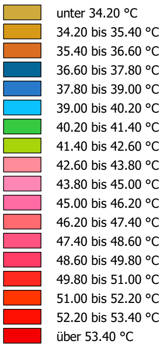
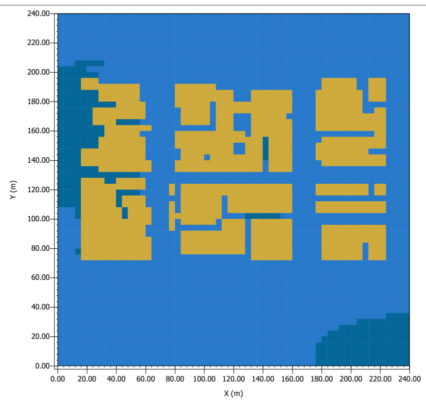
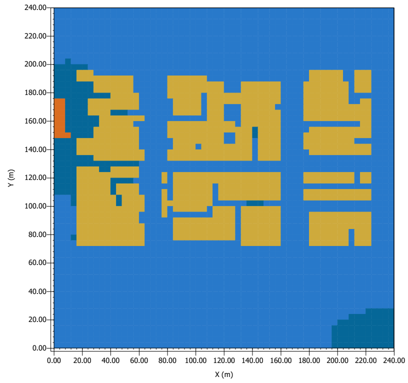
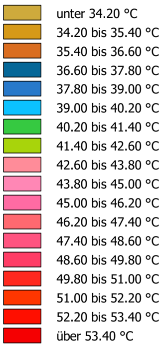
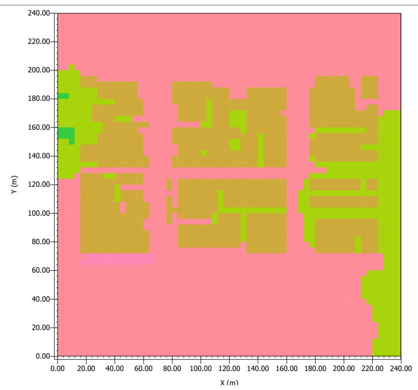
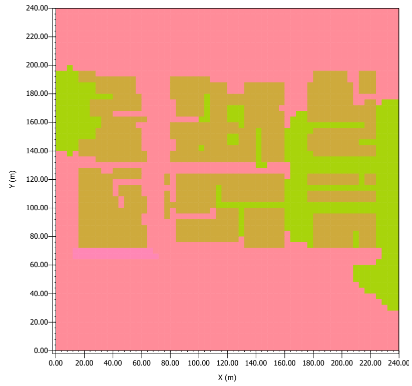
Similar to the results seen in the previous mitigation of roads and pavements, vegetation didn't have a huge impact. The reason being since the area is so congested there were hardly any space for introducing greenery. The only vegetation introduced were the green belts between the main road and trees at intersections. In this case of as-is and vegetation the average temperature difference here is documented to be between 0.6°C to 0.9°C. Even the CO_2 reduction was very low of about 1.18ppm.



Envi-met results for CO_2 reduction in the case of Saddar

The introduction of green roofs could not be a possibility due to the lack of data of structural integrity of the buildings. A hypothetical scenario was however tested which showed more convincing results where green roofs were used. The temperature with the green roofs dropped the temperatures up to 5.2°C.

SADDAR BASE CASE – VEGETATION 20TH, JUNE 2015

<table>
<tr><th>Time</th><th>Base case</th><th>Vegetation</th></tr>
<tr><td>10:00

</td><td>
</td><td>
</td></tr>
<tr><td>12:00

</td><td>
</td><td>
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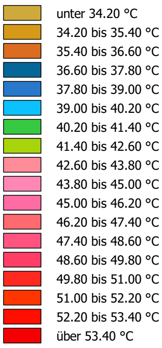
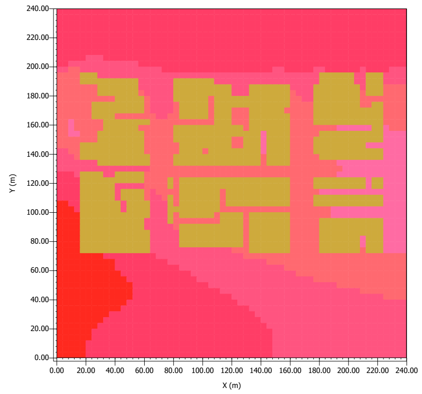
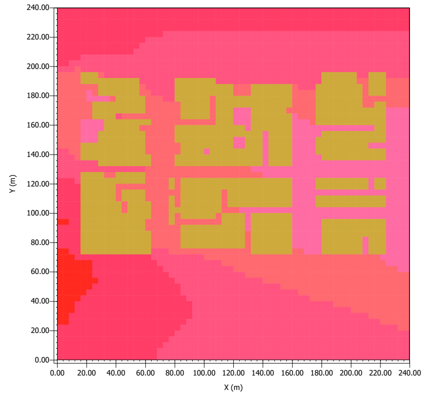

</td><td>
</td><td>
</td></tr>
</table>

16:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
37.80 bis 39.00 °C
39.00 bis 40.20 °C
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48.60 bis 49.80 °C
49.80 bis 51.00 °C
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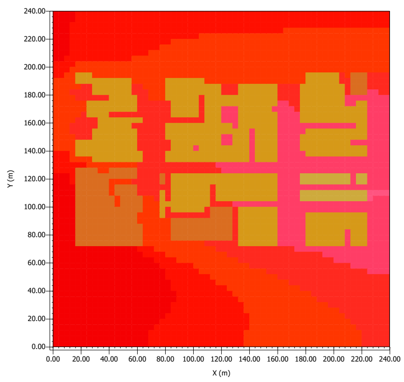
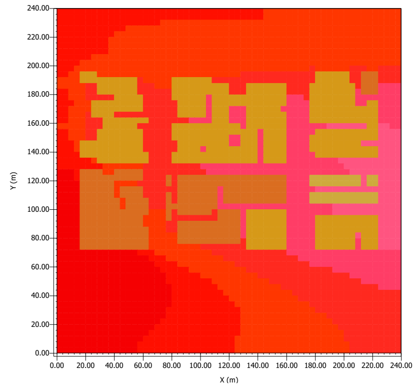
52.20 bis 53.40 °C
über 53.40 °C





18:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
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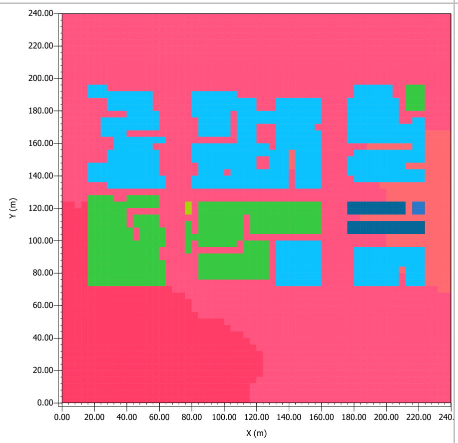
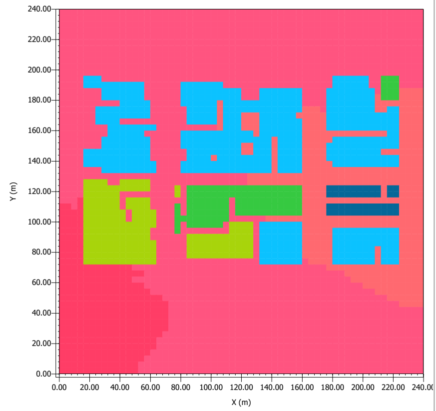
49.80 bis 51.00 °C
51.00 bis 52.20 °C
52.20 bis 53.40 °C
über 53.40 °C





20:00

unter 34.20 °C
34.20 bis 35.40 °C
35.40 bis 36.60 °C
36.60 bis 37.80 °C
37.80 bis 39.00 °C
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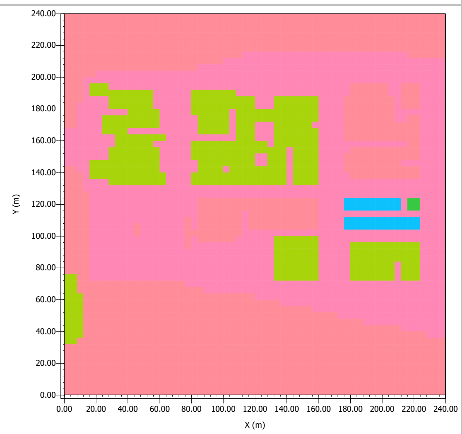
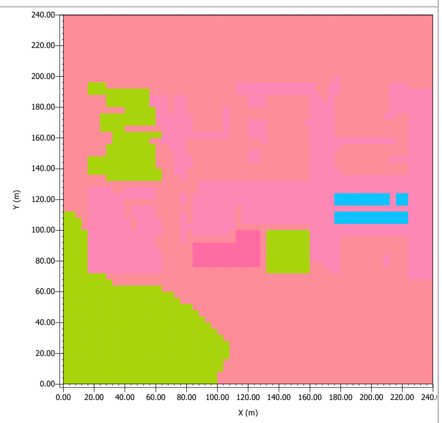
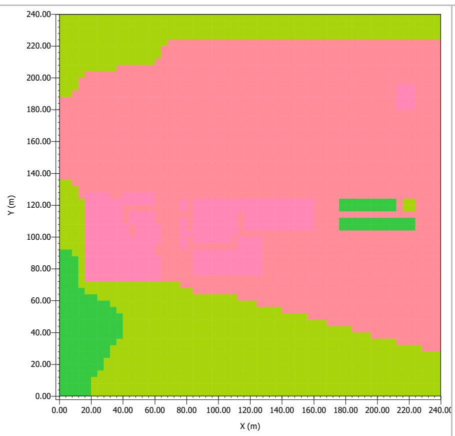
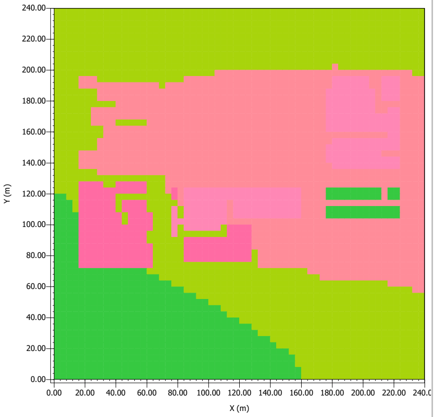
51.00 bis 52.20 °C
52.20 bis 53.40 °C
über 53.40 °C



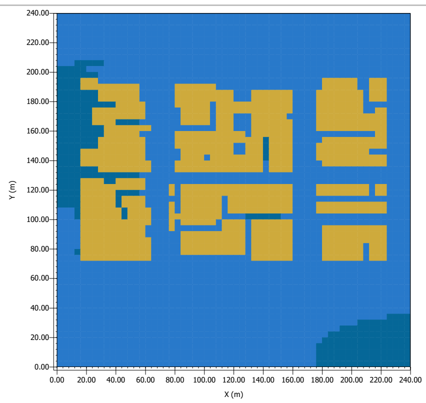
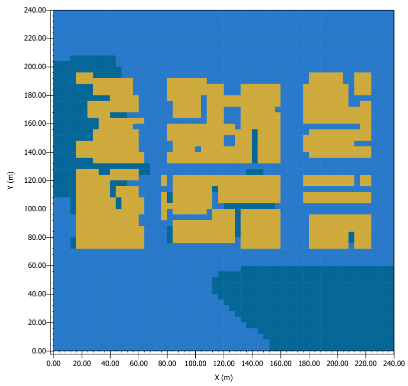


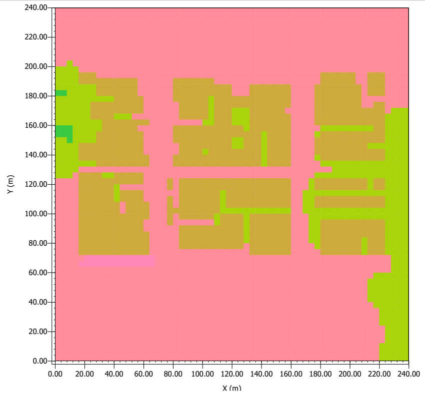
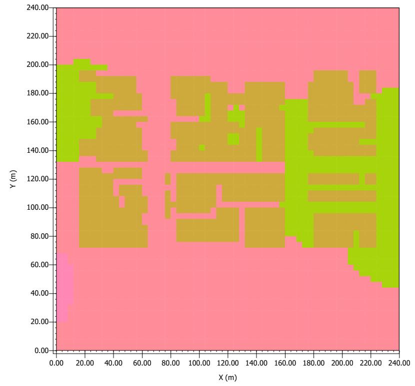
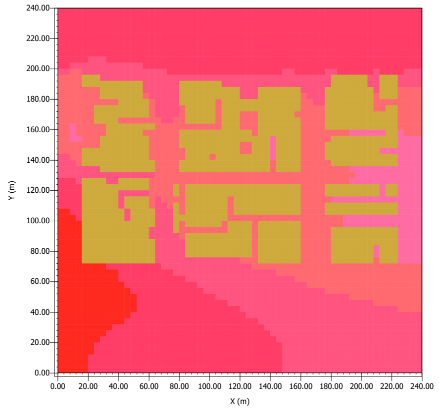
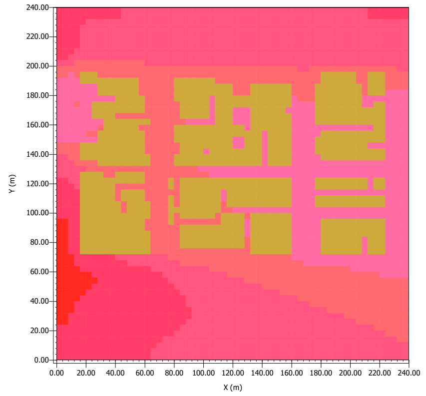
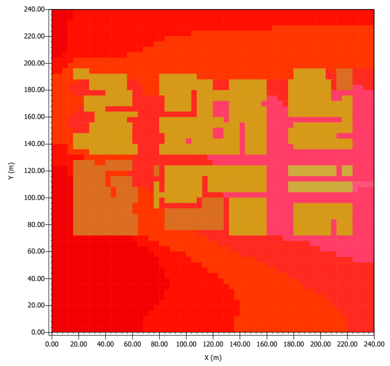
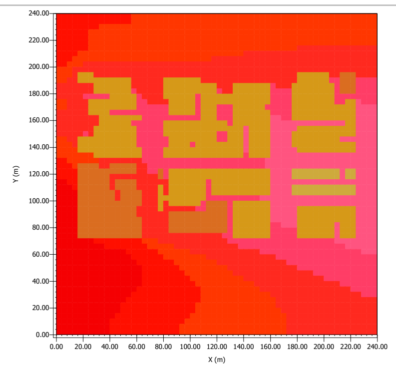
22:00 unter 34.20 °C 34.20 bis 35.40 °C 35.40 bis 36.60 °C 36.60 bis 37.80 °C 37.80 bis 39.00 °C 39.00 bis 40.20 °C 40.20 bis 41.40 °C 41.40 bis 42.60 °C 42.60 bis 43.80 °C 43.80 bis 45.00 °C 45.00 bis 46.20 °C 46.20 bis 47.40 °C 47.40 bis 48.60 °C 48.60 bis 49.80 °C 49.80 bis 51.00 °C 51.00 bis 52.20 °C 52.20 bis 53.40 °C über 53.40 °C		

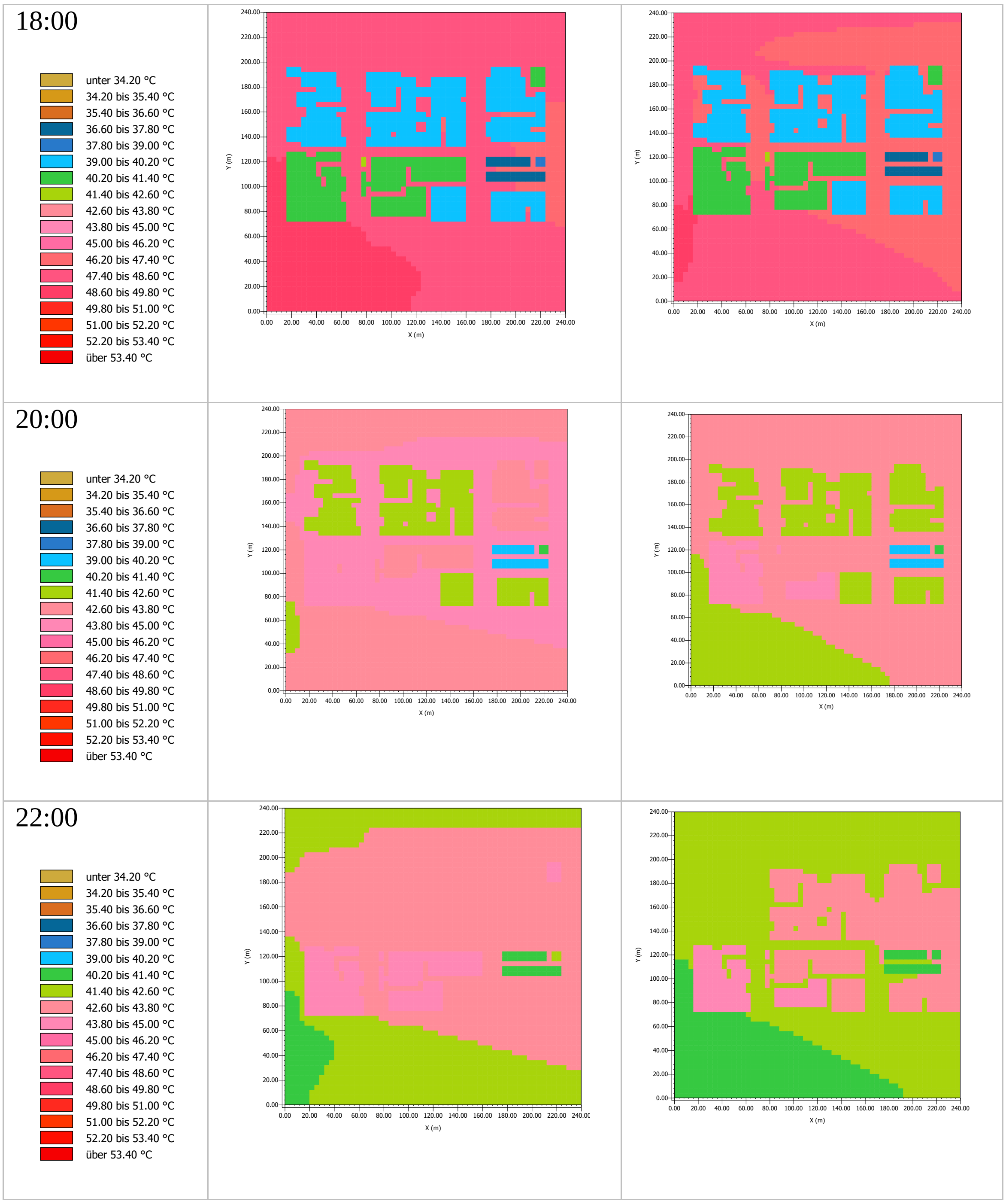
SADDAR BASE CASE – EFFICIENT CASE 20TH, JUNE 2015

From the simulation results it is evident that a densely populated area with mid to high-rise buildings like Saddar the temperature difference between the base case and efficient case could only reach a maximum of 1.9 °C.

SADDAR BASE CASE – EFFICIENT CASE 20TH, JUNE 2015

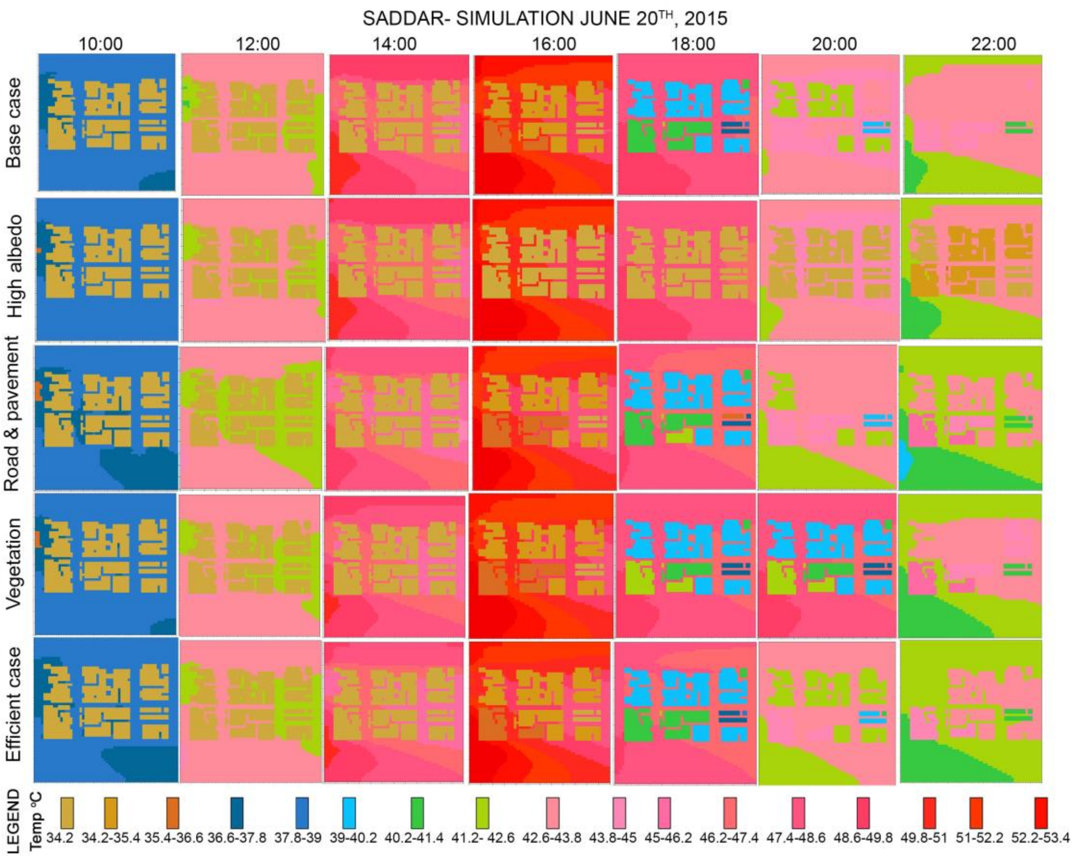
Time	Base case	Efficient
10:00 unter 34.20 °C 34.20 bis 35.40 °C 35.40 bis 36.60 °C 36.60 bis 37.80 °C 37.80 bis 39.00 °C 39.00 bis 40.20 °C 40.20 bis 41.40 °C 41.40 bis 42.60 °C 42.60 bis 43.80 °C 43.80 bis 45.00 °C 45.00 bis 46.20 °C 46.20 bis 47.40 °C 47.40 bis 48.60 °C 48.60 bis 49.80 °C 49.80 bis 51.00 °C 51.00 bis 52.20 °C 52.20 bis 53.40 °C über 53.40 °C		

12:00 unter 34.20 °C 34.20 bis 35.40 °C 35.40 bis 36.60 °C 36.60 bis 37.80 °C 37.80 bis 39.00 °C 39.00 bis 40.20 °C 40.20 bis 41.40 °C 41.40 bis 42.60 °C 42.60 bis 43.80 °C 43.80 bis 45.00 °C 45.00 bis 46.20 °C 46.20 bis 47.40 °C 47.40 bis 48.60 °C 48.60 bis 49.80 °C 49.80 bis 51.00 °C 51.00 bis 52.20 °C 52.20 bis 53.40 °C über 53.40 °C		
14:00 unter 34.20 °C 34.20 bis 35.40 °C 35.40 bis 36.60 °C 36.60 bis 37.80 °C 37.80 bis 39.00 °C 39.00 bis 40.20 °C 40.20 bis 41.40 °C 41.40 bis 42.60 °C 42.60 bis 43.80 °C 43.80 bis 45.00 °C 45.00 bis 46.20 °C 46.20 bis 47.40 °C 47.40 bis 48.60 °C 48.60 bis 49.80 °C 49.80 bis 51.00 °C 51.00 bis 52.20 °C 52.20 bis 53.40 °C über 53.40 °C		
16:00 unter 34.20 °C 34.20 bis 35.40 °C 35.40 bis 36.60 °C 36.60 bis 37.80 °C 37.80 bis 39.00 °C 39.00 bis 40.20 °C 40.20 bis 41.40 °C 41.40 bis 42.60 °C 42.60 bis 43.80 °C 43.80 bis 45.00 °C 45.00 bis 46.20 °C 46.20 bis 47.40 °C 47.40 bis 48.60 °C 48.60 bis 49.80 °C 49.80 bis 51.00 °C 51.00 bis 52.20 °C 52.20 bis 53.40 °C über 53.40 °C		



The image below shows a summary of all the simulations for Saddar in summer.

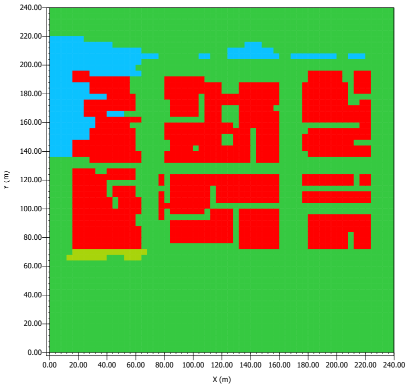
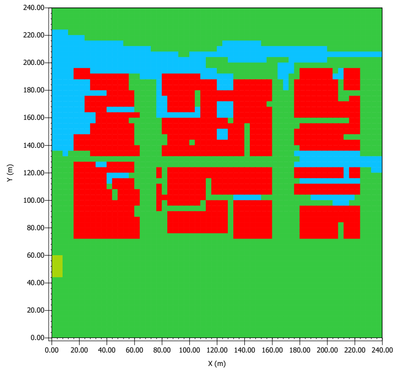
Although the gradient of temperatures dropping is evident from the image below but it wasn’t as effective as in the case of Lyari.

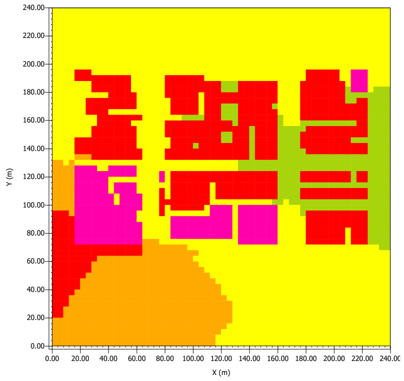
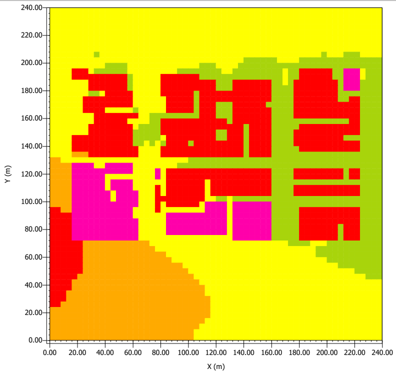


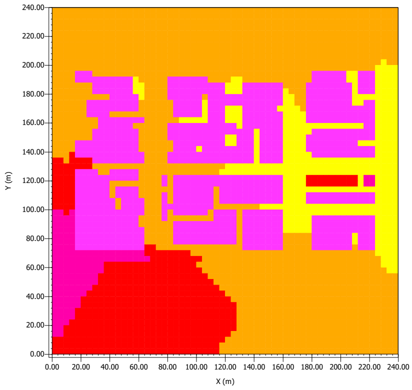
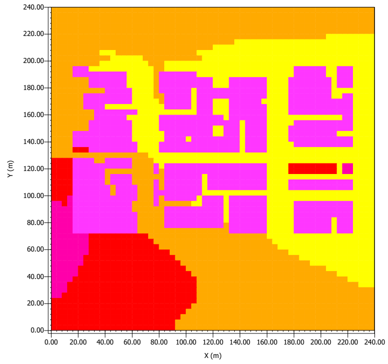
SADDAR BASE CASE AND EFFICENT CASE FOR WINTER- DECEMBER 26TH, 2015.

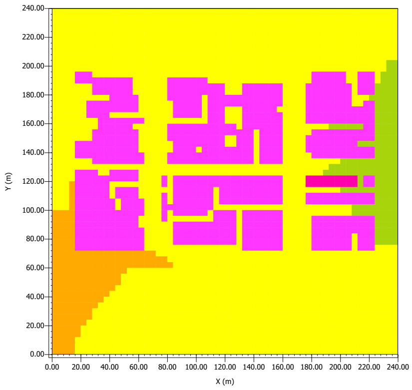
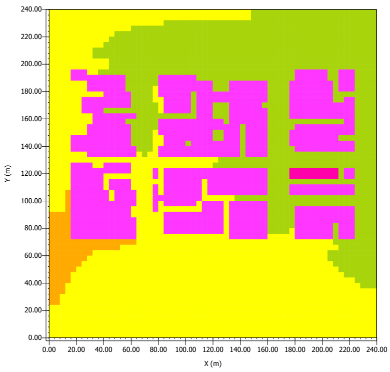
In order to flag if there is any negative impact in winters the below simulation was done between the base case and efficient case. Similar to the study of summer the maximum temperature difference in winter also sways between 0.6°C to 0.8°C, which is very negligible.

<table>
<tr><th>Time</th><th>Saddar Winter Base case</th><th>Saddar Winter Efficient case</th></tr>
<tr><td>10:00

Air Temperature
unter 13.00 °C
13.00 bis 14.00 °C
14.00 bis 15.00 °C
15.00 bis 16.00 °C
16.00 bis 17.00 °C
17.00 bis 18.00 °C
18.00 bis 19.00 °C
19.00 bis 20.00 °C
20.00 bis 21.00 °C
über 21.00 °C</td><td>
</td><td>
</td></tr>
<tr><td>12:00

Air Temperature
unter 13.00 °C
13.00 bis 14.00 °C
14.00 bis 15.00 °C
15.00 bis 16.00 °C
16.00 bis 17.00 °C
17.00 bis 18.00 °C
18.00 bis 19.00 °C
19.00 bis 20.00 °C
20.00 bis 21.00 °C
über 21.00 °C</td><td>
</td><td>
</td></tr>
<tr><td>14:00

Air Temperature
unter 13.00 °C
13.00 bis 14.00 °C
14.00 bis 15.00 °C
15.00 bis 16.00 °C
16.00 bis 17.00 °C
17.00 bis 18.00 °C
18.00 bis 19.00 °C
19.00 bis 20.00 °C
20.00 bis 21.00 °C
über 21.00 °C</td><td>
</td><td>
</td></tr>
<tr><td>16:00

Air Temperature
unter 13.00 °C
13.00 bis 14.00 °C
14.00 bis 15.00 °C
15.00 bis 16.00 °C
16.00 bis 17.00 °C
17.00 bis 18.00 °C
18.00 bis 19.00 °C
19.00 bis 20.00 °C
20.00 bis 21.00 °C
über 21.00 °C</td><td>
</td><td>
</td></tr>
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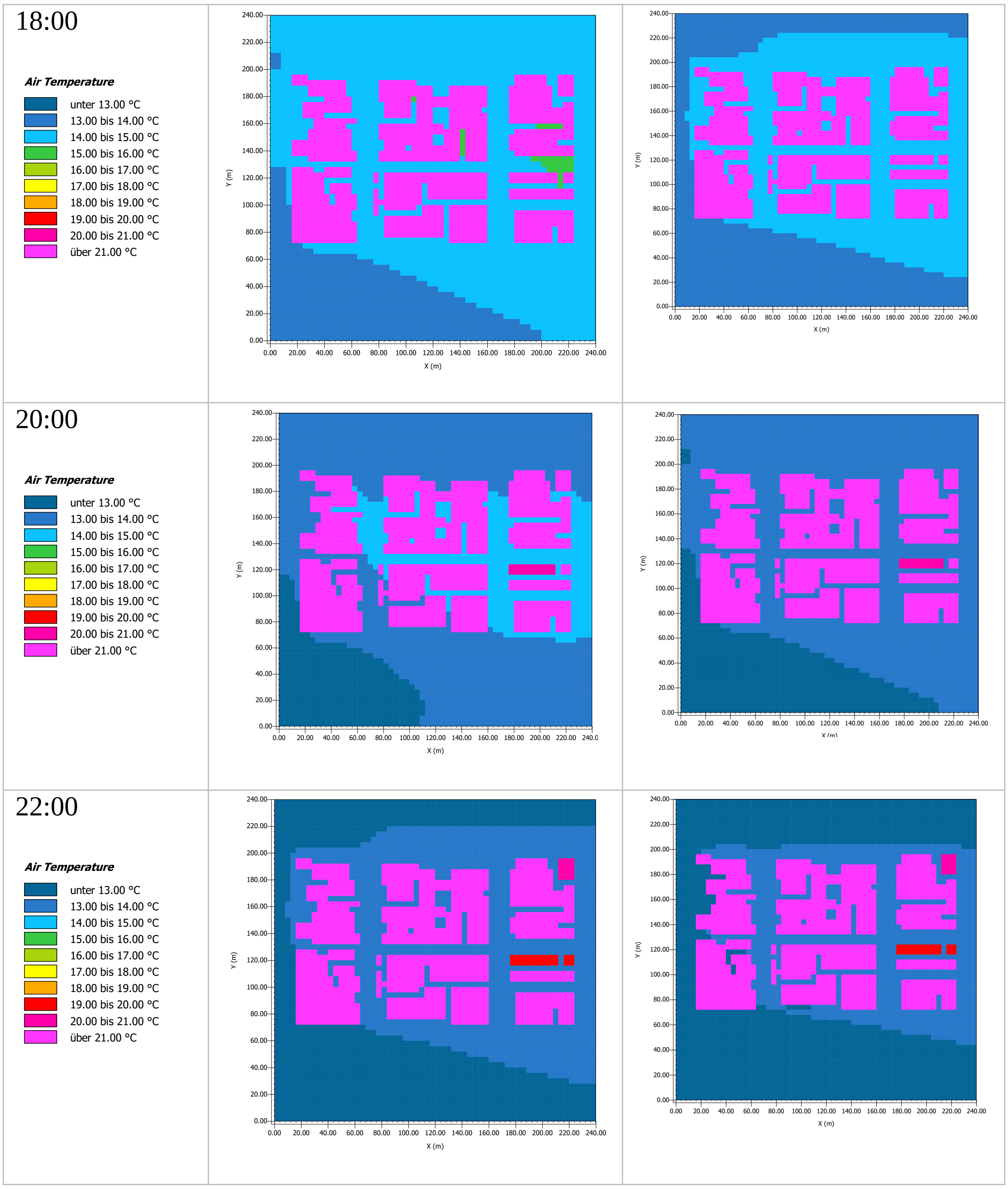
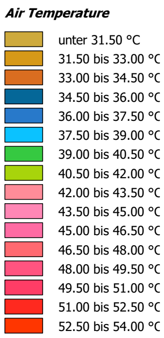
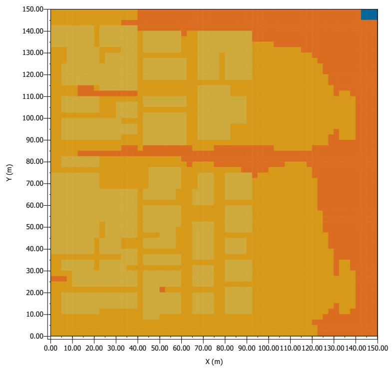
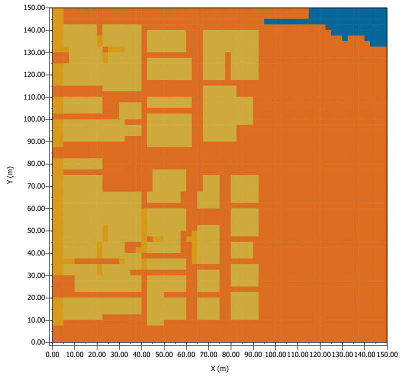
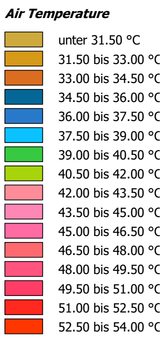
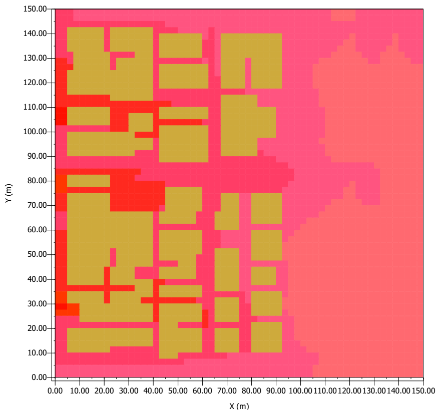
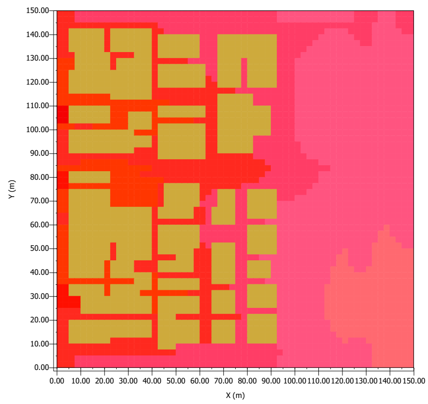


KORANGI

KORANGI BASE CASE – HIGH ALBEDO 20TH, JUNE 2015

The results above show that on 20th, June in Korangi, residential area, the difference between the base case and high albedo roofs varies from 0.75°C to 3°C. During the day the atmosphere around the buildings is cooler than the base case. However at night the temperature of the buildings is up to 1.5°C to 4.5°C cooler than the base case, asserting the fact if high albedo and reflective cool surfaces are used the building retains less heat and is cooler during night time. Further temperature difference variables are attached in Appendix C. For a day at an average the temperature difference between the base case and high albedo roofs was between 1.5°C to 4.5°C.

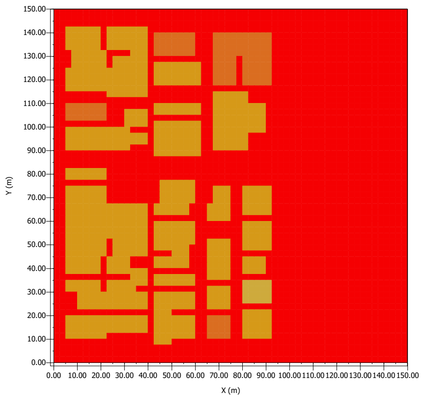
KORANGI BASE CASE – HIGH ALBEDO 20TH, JUNE 2015

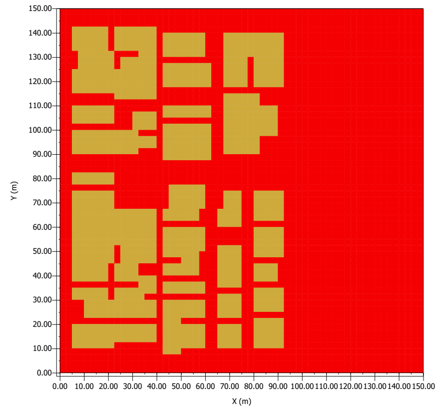
Time	Base case	High Albedo
10:00 		
12:00 		

14:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

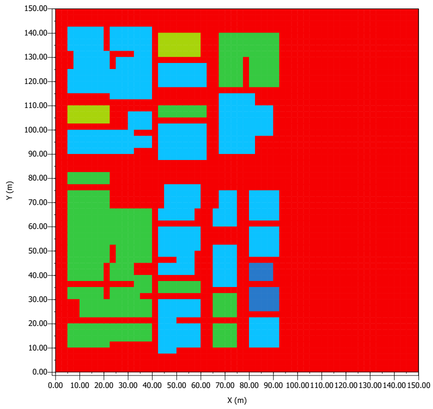


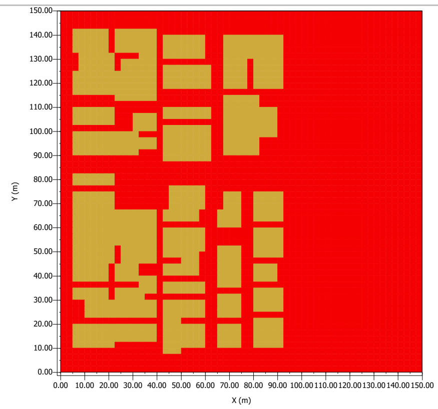


16:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

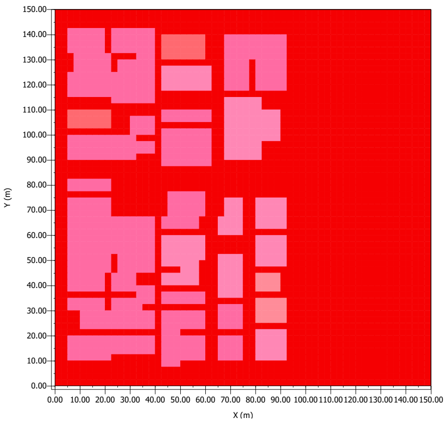


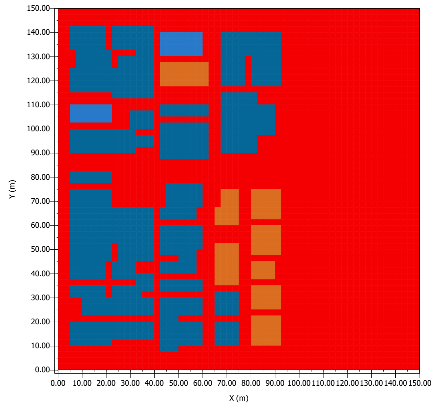


18:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

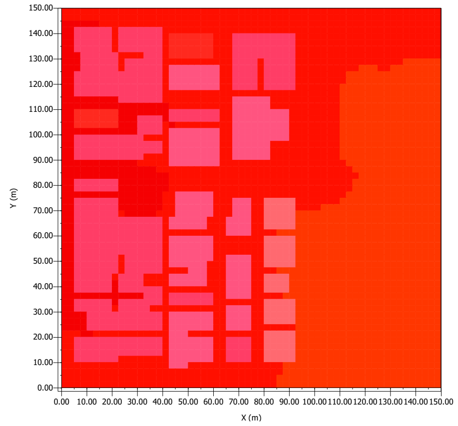


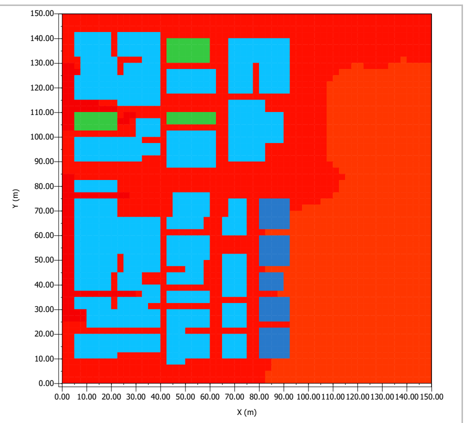


20:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

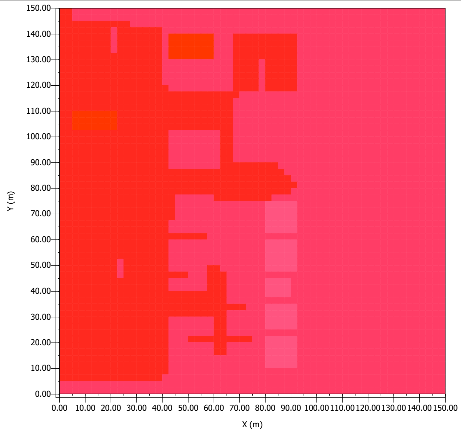


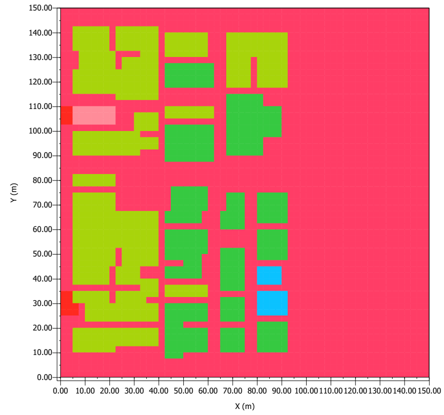


22:00

Air Temperature

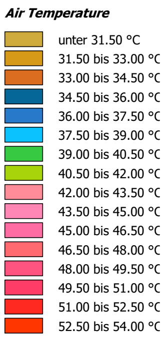
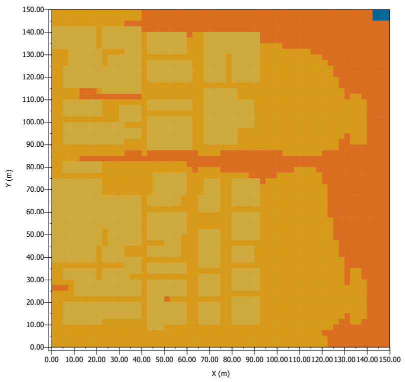
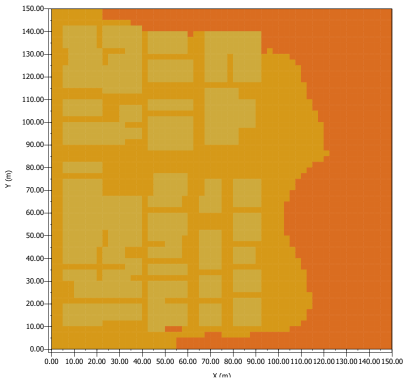
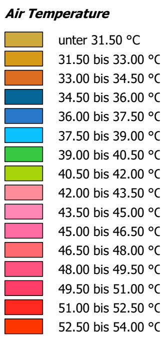
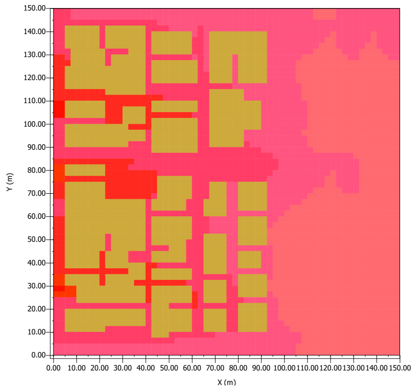
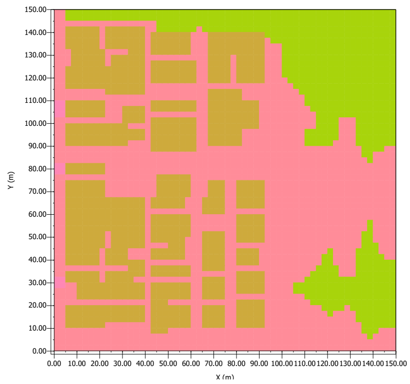
- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

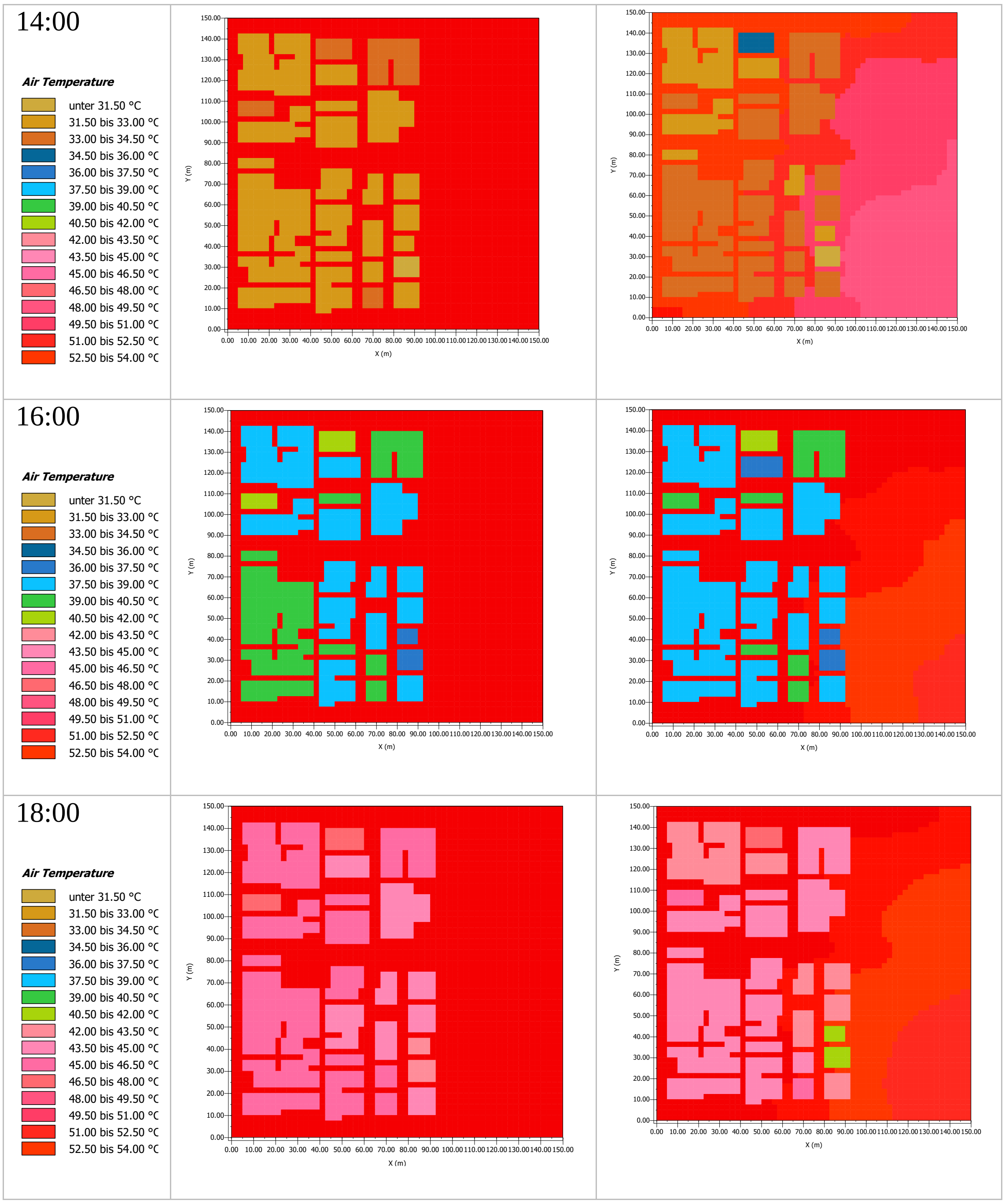




KORANGI BASE CASE – ROADS & PAVEMENTS 20TH, JUNE 2015

During the afternoon time the cool pavements and roads were very effective as the temperature difference with the base case was from 1.5 °C to 3.5 °C. However late evening and at night the difference dropped down 0.5 °C to 2.5 °C. The average temperature change is 1.00°C to 3.0°C as presented below in the chart. This strategy is the most effective for reducing the temperature during day times when there is a lack of space for vegetation.

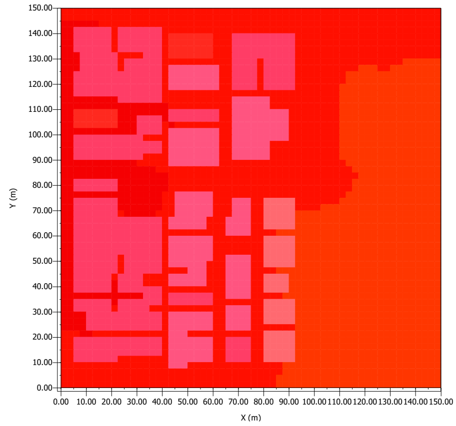
<table>
<tr><th>Time</th><th>Base case</th><th>Roads & Pavements</th></tr>
<tr><td>10:00

</td><td></td><td></td></tr>
<tr><td>12:00

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

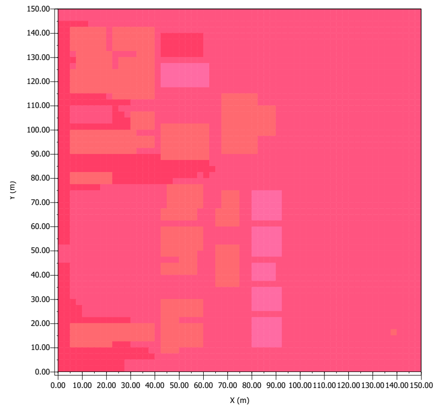

14:00
Air Temperature
unter 31.50 °C
31.50 bis 33.00 °C
33.00 bis 34.50 °C
34.50 bis 36.00 °C
36.00 bis 37.50 °C
37.50 bis 39.00 °C
39.00 bis 40.50 °C
40.50 bis 42.00 °C
42.00 bis 43.50 °C
43.50 bis 45.00 °C
45.00 bis 46.50 °C
46.50 bis 48.00 °C
48.00 bis 49.50 °C
49.50 bis 51.00 °C
51.00 bis 52.50 °C
52.50 bis 54.00 °C
16:00
18:00
X (m)
Y (m)

20:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

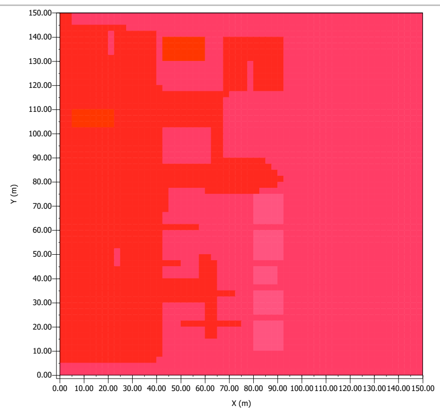


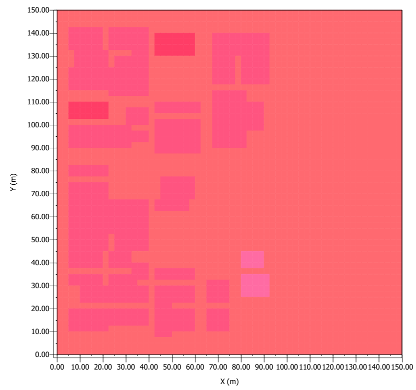


22:00

Air Temperature

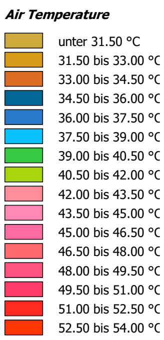
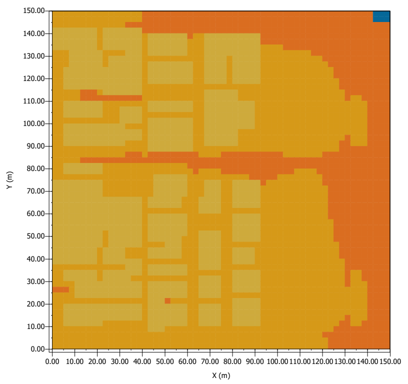
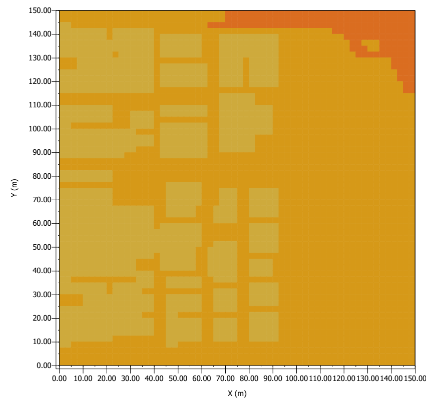
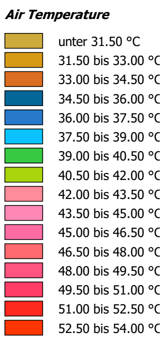
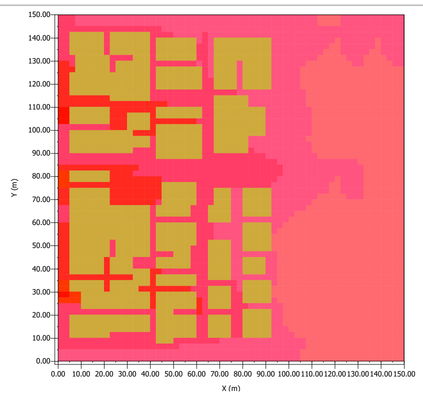
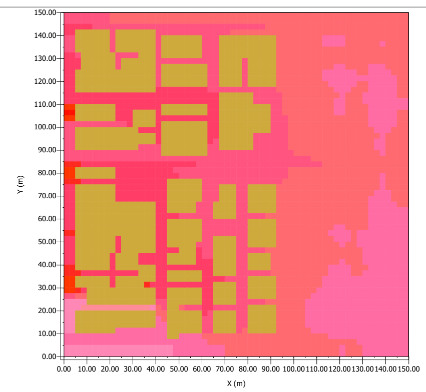
- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





KORANGI BASE CASE – VEGETATION 20TH, JUNE 2015

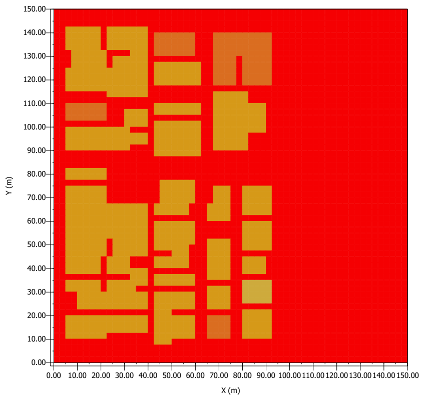
The simulations below shows that adding vegetation was equally effective during the morning time as was cool pavements as the temperature dropped by 3.5 °C. However an average temperature difference was 1.5°C to 3.0°C. Another interesting result was evident in the simulation, the area adjacent to higher building and vegetation were the coolest due to sky view factor. The vegetation had a few limitations: there was restricted space for adding vegetation and the other was the green roofs as per LEED and BREEAM could not be implemented as the building needs to be strong enough to support green roofs and facades. A hypothetical scenario was created where the vegetated case was introduced with green roofs and the temperature dropped further by 0.5°C to 2.5 °C.

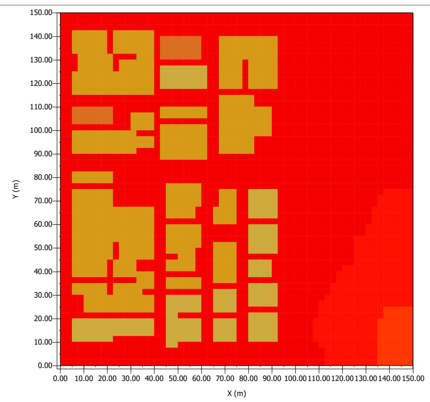
Time	Base case	Vegetation
10:00 		
12:00 		

14:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





16:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
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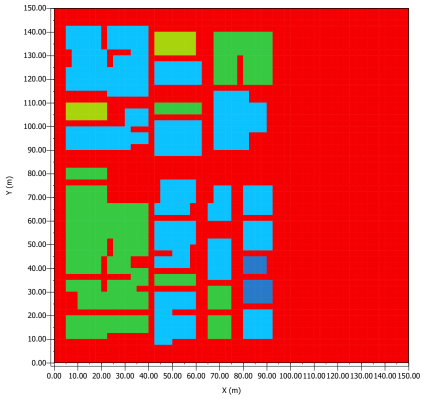
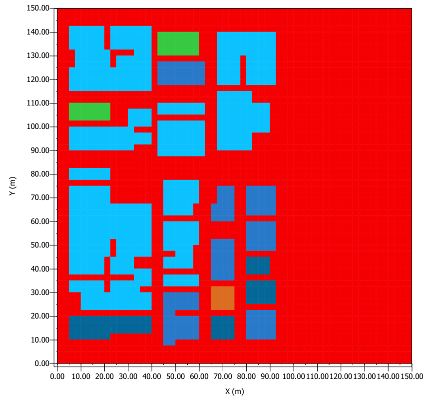
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





18:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
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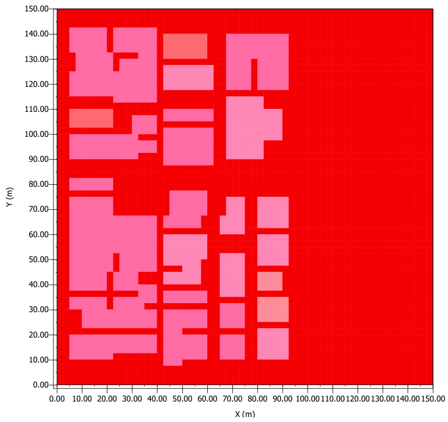
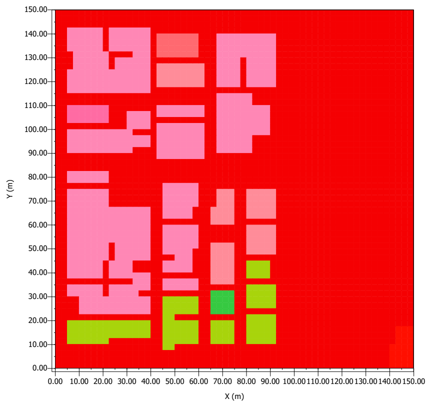
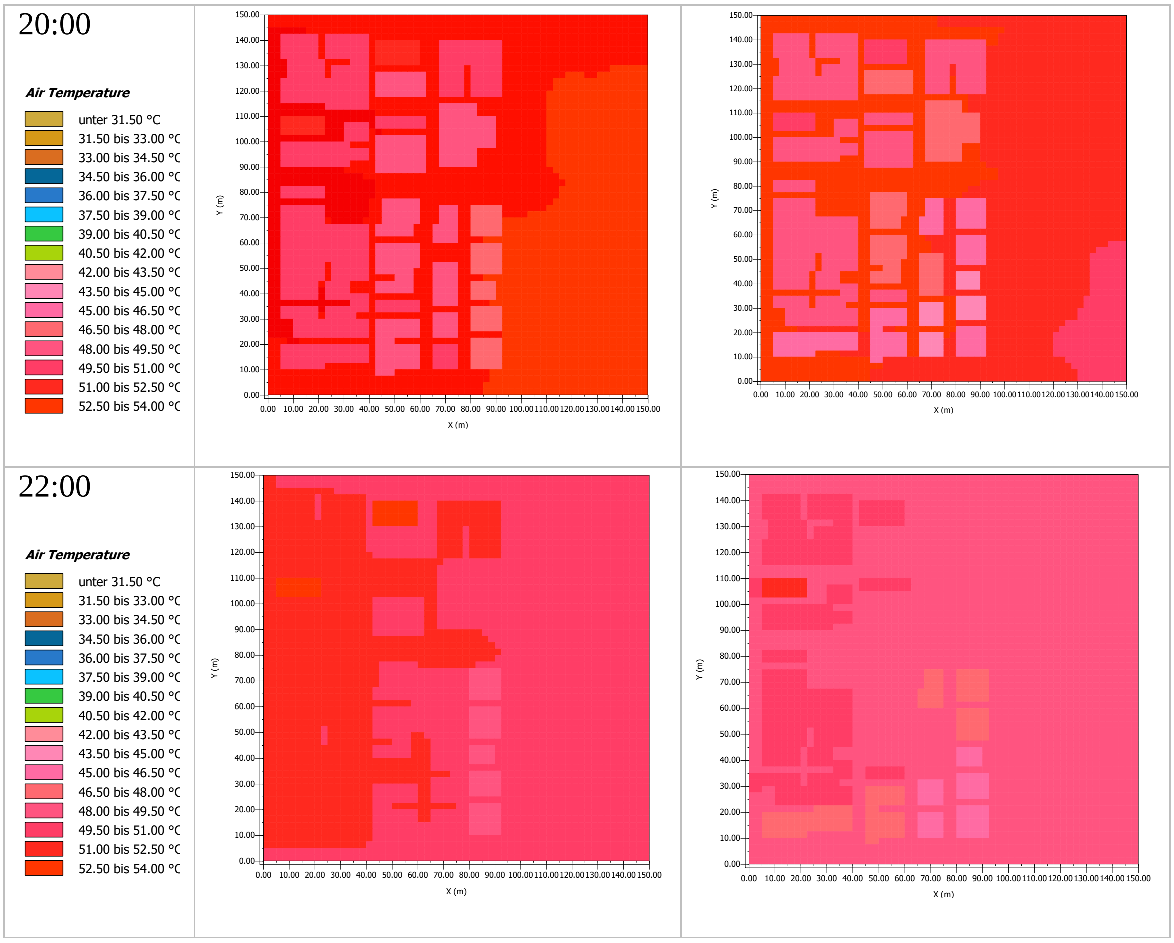
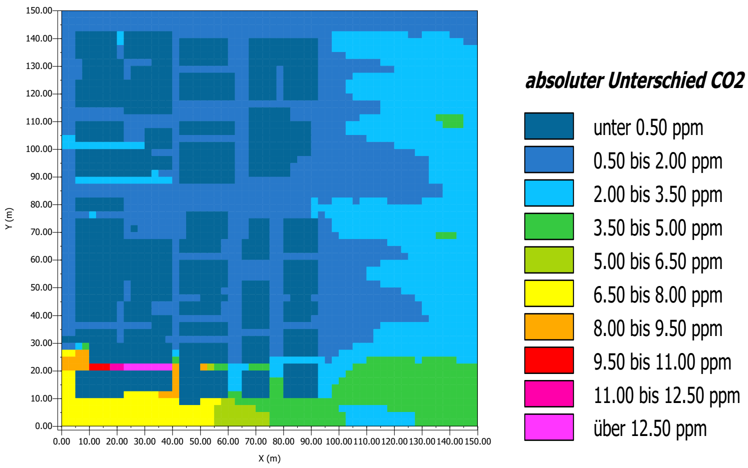
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





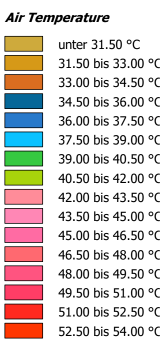
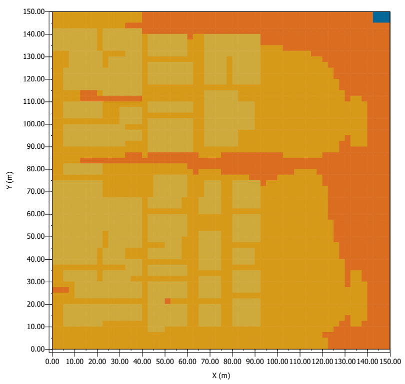
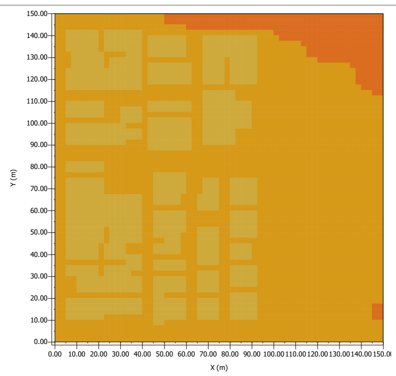


The fringe benefit for adding greenery and trees indicated an increase of wind speed by 1.4m/s on the main road where trees were proposed. Another fringe benefit of adding vegetation was the reduction in CO_2 as shown below. The carbon dioxide count between the base case and vegetation went down to 12.50ppm.



KORANGI BASE CASE – EFFICIENT CASE 20TH, JUNE 2015

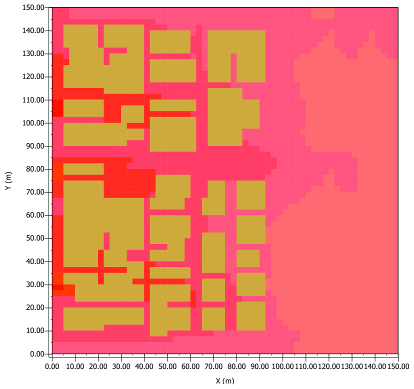
The combined effect of all the strategies has been the most effective as during the day the vegetation and pavements and roads contributed in reducing the surface temperatures by 1.5 °C to 4.5°C and during evening and night the high albedo roofs reduced the temperatures from 4.5°C to 5.5°C . After noon the areas that were introduced with greenery and trees the temperature difference between the base case and efficient case was higher by 1.5°C to 3.5°C because of 3 reasons: the evapotranspiration, permeable surfaces and the shadows caused by the trees. Since the roof albedos were increased, till 11am the difference was only 0.77°C but after noon a drastic difference in temperature of 3.87°C was observed. For the next consecutive 4 hours, the difference between temperatures increased by 1.5 to 2°C and at 16:00 hours it reached the maximum of 4.5°C. Areas around the 3 storey buildings on the west were recorded to have higher temperatures during the evening due to the entrapment of heat and direct exposure to the sun as it was setting. The temperature of the 3 storey buildings on the southwestern side of the area of study recorded higher temperatures till 22:00 hours. At an average the temperatures for the day is estimated to drop by 2.5°C to 4.5°C.

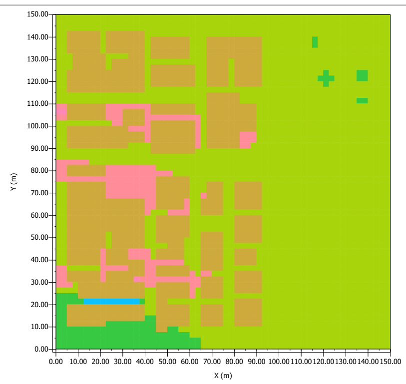
Time	Base case	Efficient
10:00 		

12:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

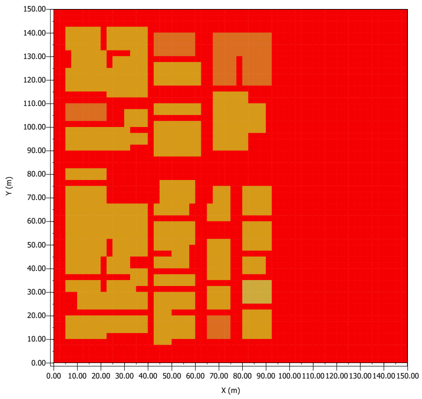


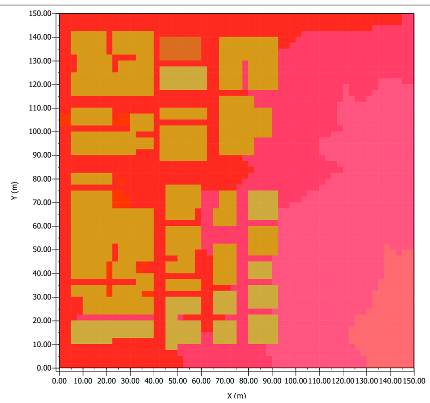


14:00

Air Temperature

- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C

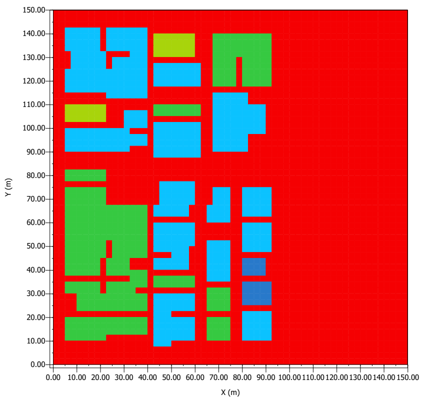


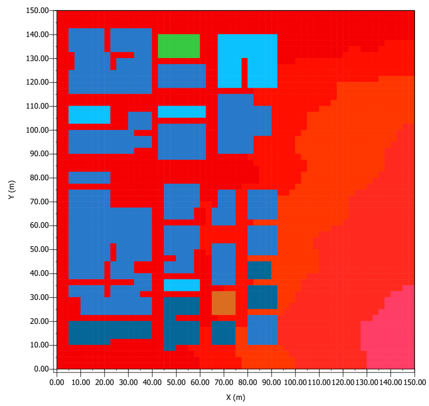


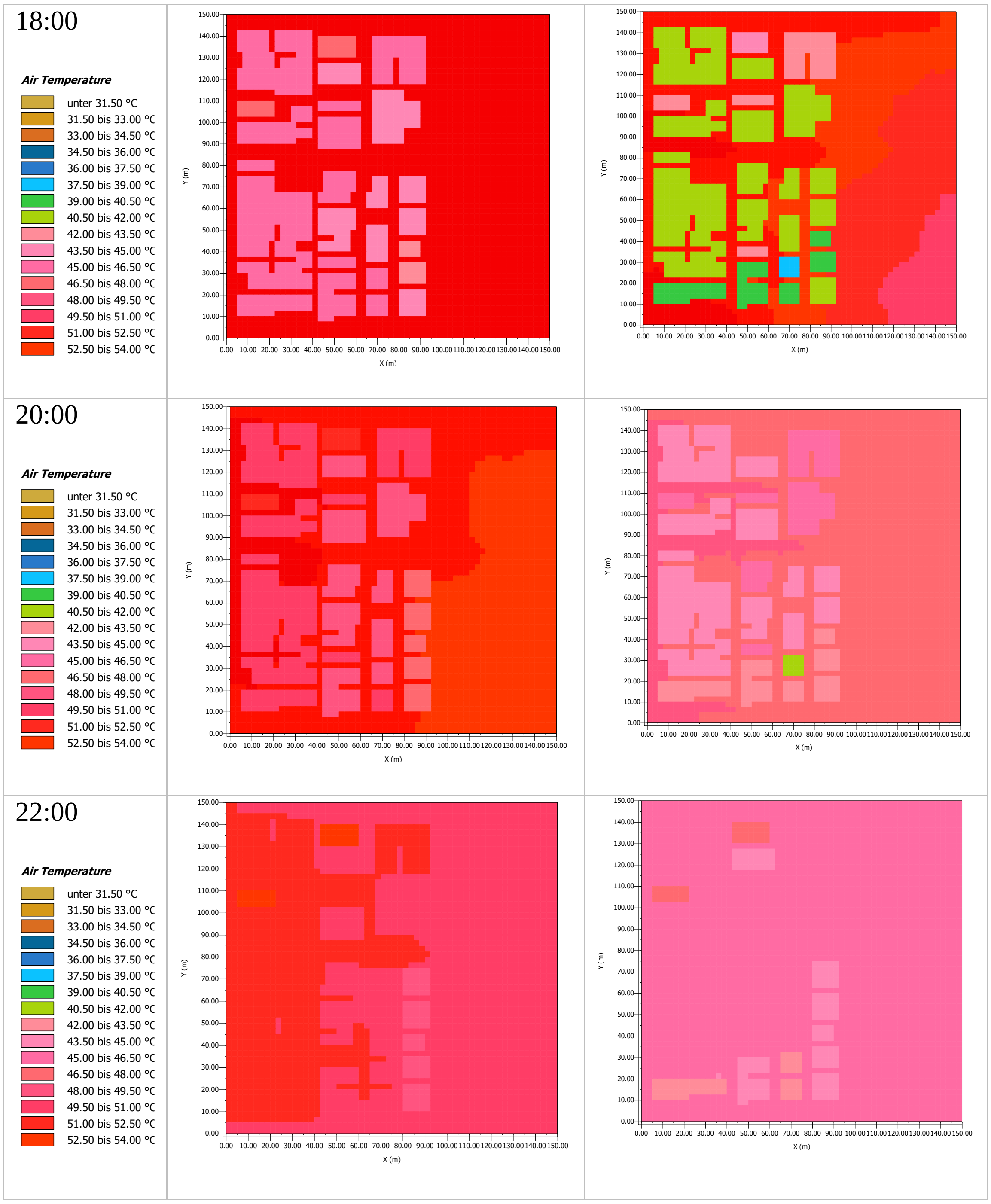
16:00

Air Temperature

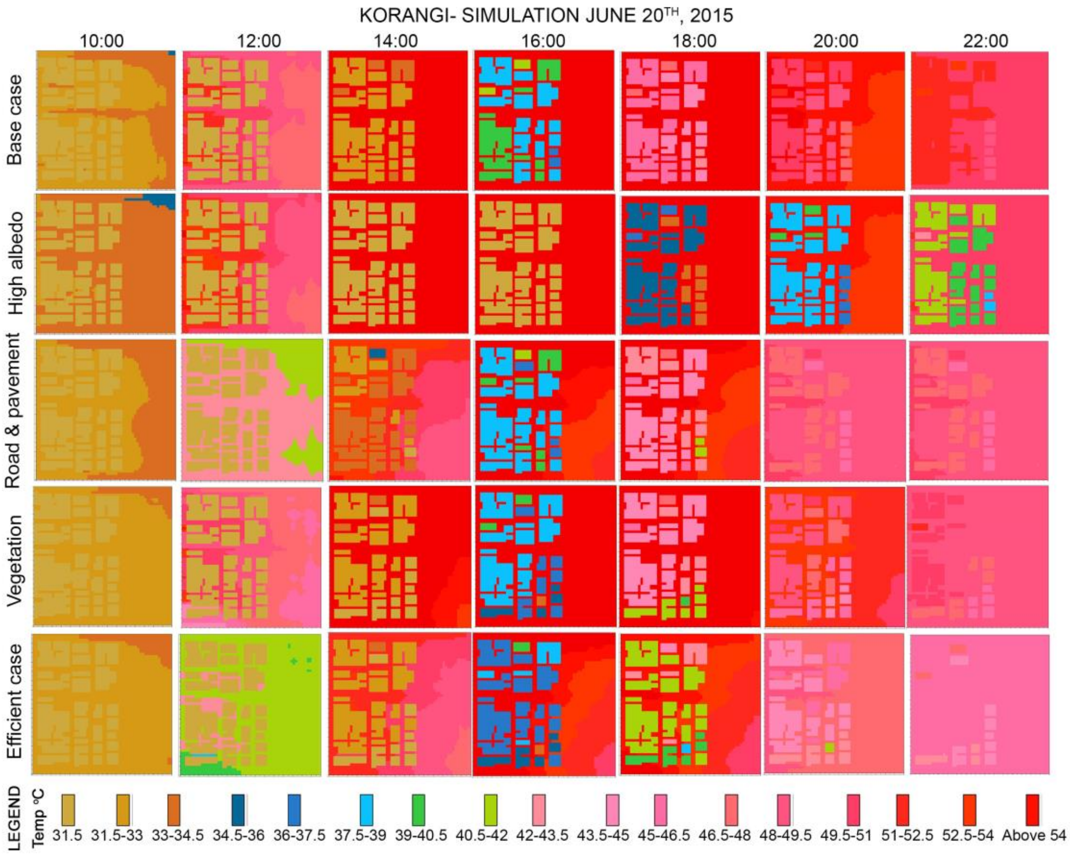
- unter 31.50 °C
- 31.50 bis 33.00 °C
- 33.00 bis 34.50 °C
- 34.50 bis 36.00 °C
- 36.00 bis 37.50 °C
- 37.50 bis 39.00 °C
- 39.00 bis 40.50 °C
- 40.50 bis 42.00 °C
- 42.00 bis 43.50 °C
- 43.50 bis 45.00 °C
- 45.00 bis 46.50 °C
- 46.50 bis 48.00 °C
- 48.00 bis 49.50 °C
- 49.50 bis 51.00 °C
- 51.00 bis 52.50 °C
- 52.50 bis 54.00 °C





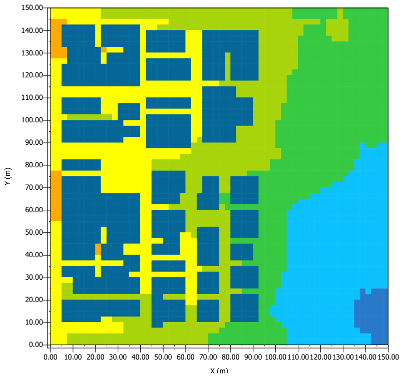
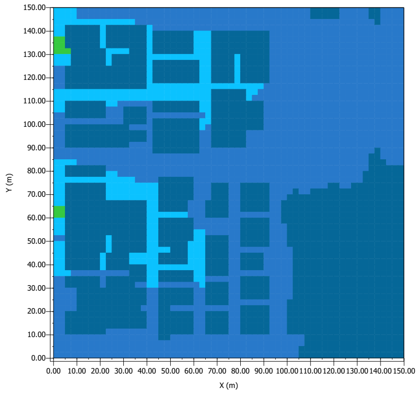
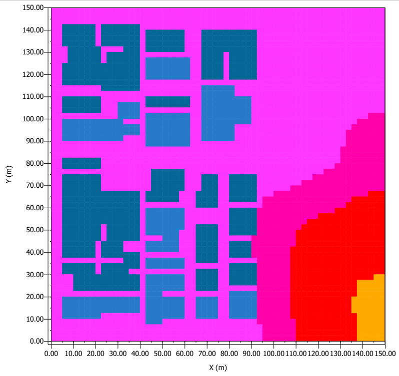
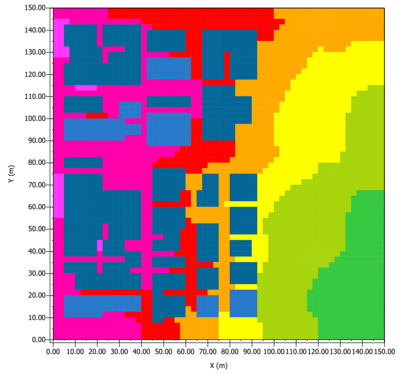
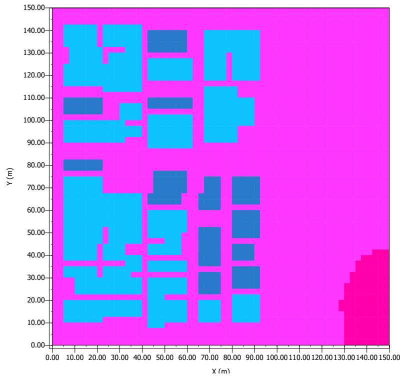
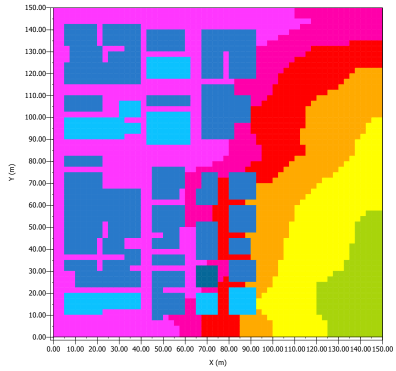


The image below summarizes the simulation results for all the mitigation strategies combined for the residential area of Korangi. It represents the gradual impact of each strategy and its effectiveness. It shows the uniformity of temperatures as it reaches the efficient case.



KORANGI BASE CASE – EFFICIENT CASE, WINTER 25TH DECEMBER, 2015

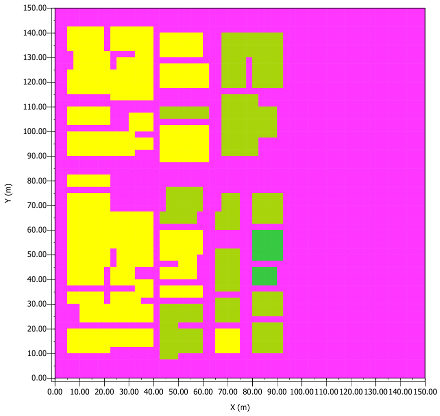
In order to check the counter impact of the simulations in winter another set of simulation was conducted between the efficient case and the base case for December 25th, 2015 which is provided below. The simulation results portray similar results as other winter simulations except for the morning. In the early hours the temperatures drop between 1°C to 3°C. But for the rest of the day it remains consistent between 1°C to a maximum of 1.5°C, remaining between the comfort zone.

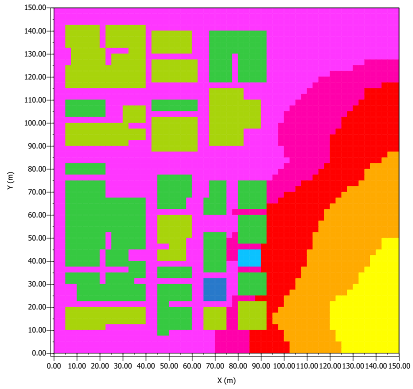
Time	Korangi Winter Base case	Korangi Winter Efficient case
10:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		
12:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		
14:00 ***Air Temperature*** unter 13.00 °C 13.00 bis 14.00 °C 14.00 bis 15.00 °C 15.00 bis 16.00 °C 16.00 bis 17.00 °C 17.00 bis 18.00 °C 18.00 bis 19.00 °C 19.00 bis 20.00 °C 20.00 bis 21.00 °C über 21.00 °C		

16:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

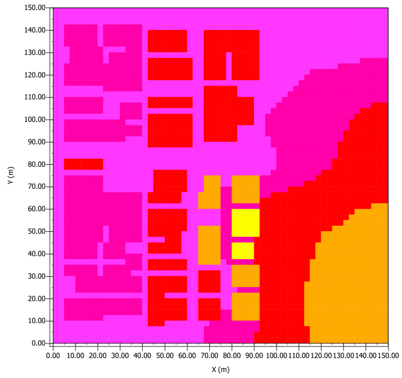


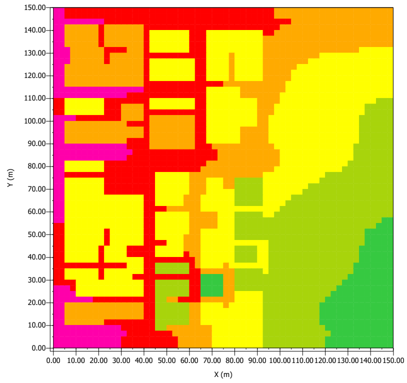


18:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

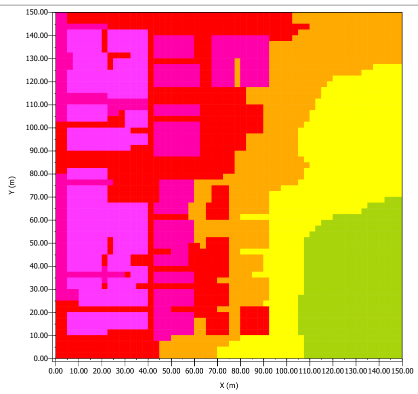


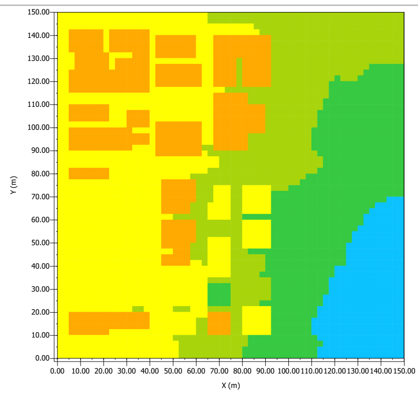


20:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C

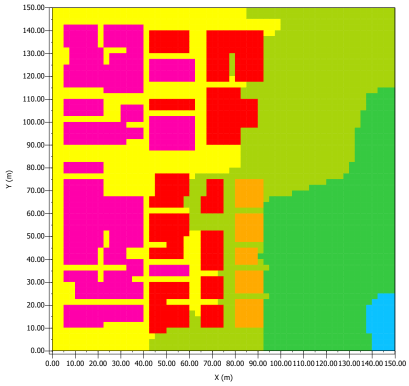


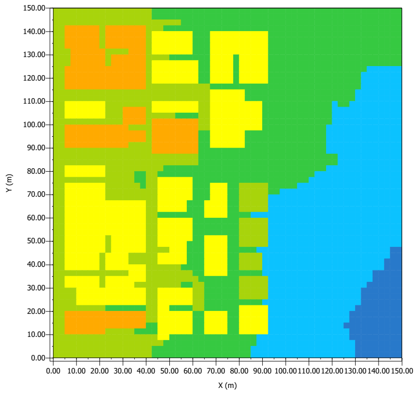


22:00

Air Temperature

- unter 13.00 °C
- 13.00 bis 14.00 °C
- 14.00 bis 15.00 °C
- 15.00 bis 16.00 °C
- 16.00 bis 17.00 °C
- 17.00 bis 18.00 °C
- 18.00 bis 19.00 °C
- 19.00 bis 20.00 °C
- 20.00 bis 21.00 °C
- über 21.00 °C





IV. DISCUSSION

In the below segment, the researcher will assess each simulation strategy individually among the different land-use type and then with results from the research done by other researchers as collected in the literature review.

In the case of high albedo, in all three study areas, it wasn't very effective during the morning however after 16:00 hours we see an evident change of surface temperatures above the roofs. The possible reason for being more effective at night is that high albedo roofs retain less heat during the day. Therefore, at night they are cooler than the existing conditions. The simulation results for cool roofs for the mixed use area of Lyari resulted in a temperature drop of 0.21°C to 3.64°C. Whereas in the case of the commercial hub of Karachi, Saddar, it dropped between 2.2°C to 4.8°C. The residential area showed similar results to Saddar of 1.5°C to 4.5°C however the fluctuation was more in the case of Korangi. The range for all the three locations is approximately between 1.0°C to 4.8°C. Wang, Berardi & Akbari had similar results for the cool roof strategy used for reducing the heat island about 3.9°C (Wang, Berardi & Akbari, 2016). However, Sharma in her study in Chicago reached up to 6°C to 7°C (Sharma et al., 2016). There could be multiple reasons for a drastic drop of 7°C temperature drop: the geometry, land use and the sky view factor as they all play a role when assessing surface temperatures.

The second strategy studied was cool pavements and roads and the best results were for Lyari, mixed use area. The temperatures dropped between 2.16°C to 4.04°C for this strategy, Korangi also saw a drop of 1.00°C to 3.0°C but in the commercial are of Saddar the temperature difference between the base case and cool roof and pavements stayed as low as 0.8°C to 1.2°C. The contributing factors to a low temperature drop in Saddar was due to the mid to high rise buildings and the entrapment of heat within that area. In Toronto, however, the test results by Wang, Berardi & Akbari dropped by 3.9°C, although Toronto also has low to mid-rise buildings. Another underlying factor could be the fact that the wind speed was very low on the day of the heat waves and Karachi was in the low pressure zone as reported by the government.

Vegetation is the most common and widely studies strategy. It showed very diverse results due to two major factors: one green roofs were not used and the other was in Saddar there was no space to plant trees or vegetation therefore only reducing the ambient temperature by 0.6°C to 0.9°C. Whereas, Lyari and Korangi showed more promising results of 1.62 °C to 4.21 °C and 1.5°C to 3.0°C respectively. Lehman in his research of the city of Sydney concluded that increase vegetation could lower the temperatures by 4°C (Lehmann, 2014). Lemonsu and team asserted that vegetation can reduce temperatures from 3°C to 5°C as well (Lemonsu et al., 2015). However in the case for Toronto only 0.5°C to 0.8°C, (Wang, Berardi & Akbari, 2016), was reduced similar to the results of Saddar. In Chicago a combination of cool roofs and green roofs, the temperatures dropped from 6°C to 7°C (Sharma et al., 2016). This would be true in Karachi as well if green roofs could be done for all the new constructions and for buildings that have the structural strength to withstand the weight of the green roofs.

Having multiple factors like cool roof, cool pavements and roads and vegetation to make a cool city can contribute incredibly as seen in the studies carried out by Lisa Gartland, in her studied she proposed a cool city with additional factors like orientation, solar panels and reduction in power due to green roofs and compactness. She estimated the temperature to drop by 14°C (Gartland, 2008). When Akbar and his team implemented high albedo roofs, cool pavements and vegetation combined, they were able to bring the temperatures by 3.3°C to 4.6°C (Wang, Berardi & Akbari, 2016). In the case of Lyari, Saddar and Korangi the temperature drop was 4.5 to 5.23 °C, 1.9 °C and 2.5°C to 4.5°C respectively. Lyari showed very promising results throughout.

Based on Ebrahim's study the most suited fruiting trees for Karachi are guava, pomegranate, figs, banyan tree, tamarind and Moringa (Ebrahim, 2015). They are recommended also due to the fact that Karachi is already facing the issue of resource shortage. This can add to the resources shortage issue highlighted by the UN. These fruiting trees and vegetation can contribute towards reducing the CO_2 as well as tested in the case of Lyari and Korangi.

Lesson learnt from the regulations of the different governments of Louisville, Athens, Canada and US are that implementation, sustenance and maintenance of these regulations is paramount. It's easy to get the regulations in place but it needs to be supported by a maintenance plan as well. Another item that Karachi should look at is reduction in urban sprawl and mass transit system.

All items discussed above assert to the fact that mitigation strategies for even just one aspect of micro climate, UHI, can support the country in meeting local and global climatic goals.

CHAPTER 5

CONCLUSION

It has been established that there is a shift in the climate of Karachi, the occurrence of extreme temperatures, precipitation and drought have escalated. Simultaneously, the city of Karachi saw a huge influx of people from the rural areas for better opportunities and facilities. However, the government and planning authorities did not foresee this huge influx which made it the 11th largest megacity in the world. This oversight made it one of the most vulnerable cities globally to climate change. The city did not have the infrastructure, facilities and resources to accommodate the inflow of people from the rural areas and the ability to cope with the global change in climate.

The issue of Urban Heat Island was amplified when coupled with heat waves and the people who were most affected were the ones who were already victims to on-going issues and living in average to poor conditions. The aim of the research was to understand the gap of why the issue of UHI was not addressed. But through research it was established that Karachi is being hit by climate change at many levels and the government and other agencies are putting in efforts to reduce the impact. The need to prioritize the concerns and addressing each concern of climate change needs to be managed effectively. The government prior to the episode of heat waves was focused on issues which were also very urgent in nature like power outage and food and water scarcity however the heat wave and urban heat island became more pressing issue. They had external help and support provided to them in the on-going climate change matters but another climate change issue of raised surface temperatures and heat wave were overlooked. Which has become a need of the hour.

From the literature it was also established that the mitigation strategies to combat urban heat island can provide sustenance to climate change issues like rising temperatures, extreme climate conditions like heat waves, food scarcity, power outage and reduced carbon sinks. We cannot reduce new construction or existing anthropogenic activities, but we can have checks and balances in place to improve existing conditions and well-planned infrastructure for future growth.

As discussed in chapter 2 the earth has an energy budget but due to urbanization the energy cycle is disrupted. This can be mitigated by multiple strategies like adding plantation and greenery can reduce the GHG. However, this needs to be done specific to the soil and climate of the area. Like in Karachi there is a scarcity of water the plantation has to be selected that doesn't require a lot of watering. Also, another thing that should be taken into consideration is Karachi is facing food scarcity hence fruiting plants can be a better suited solution.

To address an issue first you need to understand the root cause of the problem and the knock-on effect it has on the infrastructure and the impacted society. Specific to Karachi the cause of heat island was broadly because of the unplanned influx of people and dense infrastructure to accommodate the influx, with the addition of global warming, increased GHG, lack of vegetation and unsustainable materials that retained heat. This led to increased energy consumption, air pollution, higher temperatures leading to health issues. Once the issue and the cause were captured the next stage was studying how other cities facing urban heat island issues combated the issue and what methodology and strategy was most effective. To address the issue case studies from other countries were studied. In multiple countries by-laws were enforced like for higher solar reflectance or materials with higher albedo. Cool roofing and vegetation can decrease the energy consumption. For pavements more porous/permeable materials, lighter colors and higher solar reflectance were introduced. As for the GHG, pollution and health a solution of vegetation was seen to be very effective. Therefore, in the case of Karachi the possible strategies discussed and tested were cool high albedo, cool pavements and roads, vegetation and a combination of all three combined approaches as they had shown positive outcomes in multiple locations. Another contributing factor is the land-use is the area is congested with high-rise, low rise, or single housing units. Therefore, the strategies were tested on 3 different land-use: residential, mixed-use and commercial. For future construction the government should take strict steps to incorporate all the strategies tested to be part of the bylaws in the city.

Moving to the city in question and the results from the ENVI-met, the most effective approach tested with the help of ENVI-met for Karachi to improve the as- built conditions was the combined approach. The combined approach included High Albedo, Cool roads and pavements and vegetation. Followed by vegetation and from the case studies we have observed that if the right trees/ vegetation strategies are used then it can tackle the issues of food scarcity, less energy consumption, less pollution and pollutants in the air and hence reducing the GHG emissions as well. Then cool pavements and roads and lastly high albedos on roofs. From the testing results we also learn that between 2pm and 5pm the highest temperatures were reached in all three land- use types.

The other factor that was highlighted was that although each land use the combined strategy might have been the most effective. However, for areas with mid to high rise buildings high albedo on roofs is a more successful strategy over cool roads and pavements. In the case of mid to high-rise the high albedo’s sowed more effective outcome because the heat dissipated from the pavements could have been still trapped between the high-rise clusters.

The estimated temperature reduction with the help of these strategies can go up to 5.2 °C but if green roofs are considered for future constructions the temperature can further drop approximately by 2°C.Through the simulation an estimated temperature drop was 4.5 to 5.23 °C in Lyari, 1.9 °C in Saddar and 2.5°C to 4.5°C in Korangi in the case of the combined strategies. Reducing temperatures, adding vegetation having more permeable surfaces can help achieve the long-term goals the Pakistan Government has set for itself locally and globally for climate change.

RECOMMENDATIONS

The below section looks at the recommendation the researcher has for the above mitigation strategies. Since Pakistan is ranked very high in vulnerability, preparedness and long term planning will be more cost effective and efficient. Just getting the stake holders involved in the application of these strategies is not sufficient a full plan for maintenance and prevention should be in play. The strategies will not be effective if they are not maintained, therefore a maintenance program should be in place when these policies are applied. An inspection authority or Karachi Development Authority should do regular checks for the betterment of the infrastructure and environment of the city. An effective combination of urbanization, sustainability and resilience are critical and require immediate attention for a way forward for mega cities. As it is within a city lies a great opportunity to combat climate change. New land reforms should be made based on the current conditions and the future predictions in order to accommodate climate change but the implementation of the reforms needs to be regulated. The unplanned growth and development has increased the vulnerability and will have huge cost implications if the laws are not implemented. There will be a higher cost impact if we keep rectifying the issues instead of being proactive and making the city more resilient. Foresight, corruption and implementation are some of the major reasons the city of Karachi is facing these issues. A sense of responsibility by the stakeholders like architects, sub-contractors, developers, planners will play a major role if each stakeholder acts more responsibly towards the environment. Educating the community is also a key player of this whole process. There are multiple stakeholders that each need to play their part in order for conditions to improve and then walk together towards a more resilient path of a sustainable city. The municipal authorities and the government have to start a process of keeping a check on all the new and old construction. Making it mandatory to follow new regulations based on sustainability and green architecture and awarding maintenance work to organizations supporting and working towards more sustainable solutions as oppose to low cost bids for architecture and infrastructural projects. Proper infrastructure and mass transit will have a major impact on the environment. If the government improves the public transport and incentives for car pool, the number of cars and motor bikes on the roads can be reduced. Having proper routes and increasing the walkability in the city the pollution can be reduced. Learning from other countries like china and Singapore. Introducing parking fees in congested city centres can push people to use public services. The fringe benefit of encouraging the masses to use public transport is an incentive for the government as they reduce the GHG emissions and pollution. The peripheral benefit of using cool roofs and roof with higher solar reflectance is the reduced heating and cooling loads therefore using lesser energy for cooling and heating indoor spaces. Green roofs are aesthetically appealing, they are beneficial for the ecosystem by creating habitat for animals, insects and birds, reduction in storm water runoff and reduction in the pollution and increasing the natural sink for carbon dioxide.

FURTHER RESEARCH

Other researchers interested in the same topic can look at the below guidelines to take this topic further.

1. Surface temperature mapping needs to be done in order to tackle the issue of urban heat island. With the temperature mapping it will be easy to identify major hotspots and with an immediate and an effect response the UHI can be reduced. The issue can be tackled more effectively, reducing the impact at the major hotspots first and then moving to other areas.
2. For new construction: orientation of building and the urban geometry should be considered as passive means can reduce and support heat island and energy consumption.
3. Green roofs and existing structural and infrastructure can be studied in more detail. As green roofs and vegetation can reduce the energy consumption making the indoor environment cooler, lower temperatures with the help of evapotranspiration.
4. Cost impact of the mitigation strategies can be studied.
5. An analysis of individual mitigation strategy verses the cost impact can support the government in making more effective and efficient solutions.
6. A study on the reduction of CO_2 by increasing the natural sink.

CHAPTER 6

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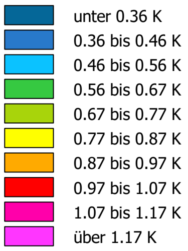
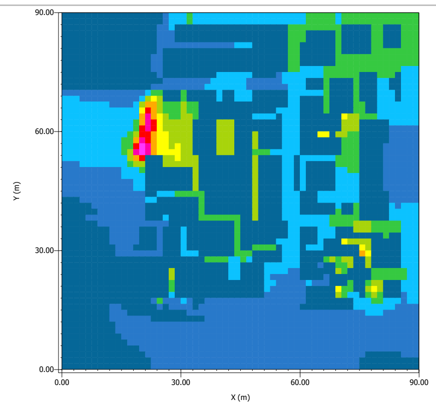
APPENDIX A

LYARI – TEMPERATURE DIFFERENCE BETWEEN BASECASE AND DIFFERENT MITIGATION SCENARIOS

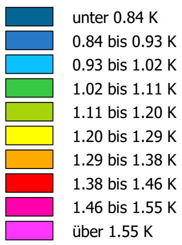
SUMMER BASE CASE VERSUS HIGH ALBEDO

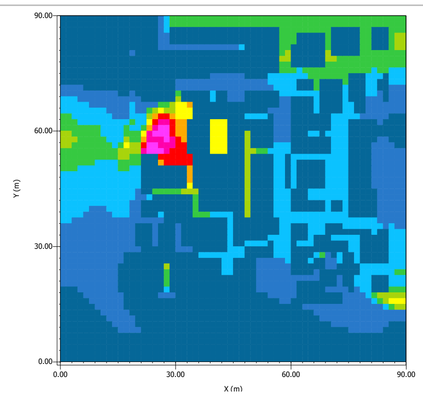
12:00pm



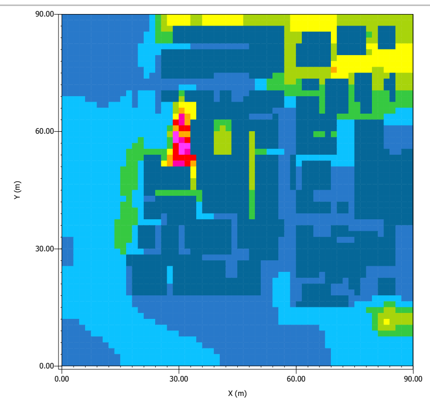


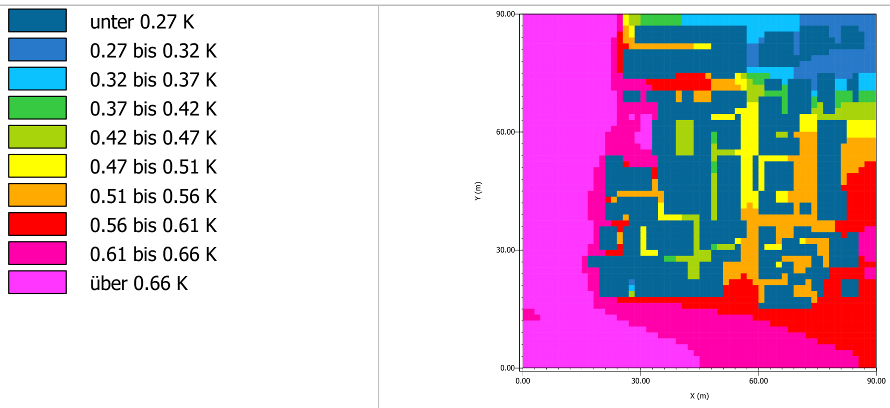
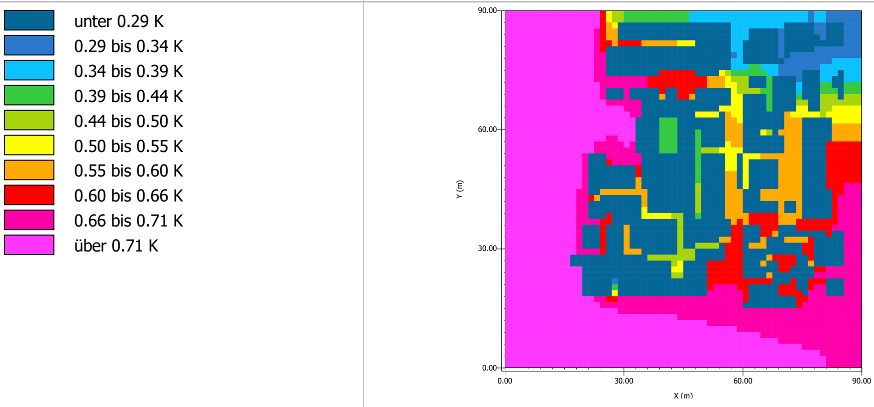
3:00pm





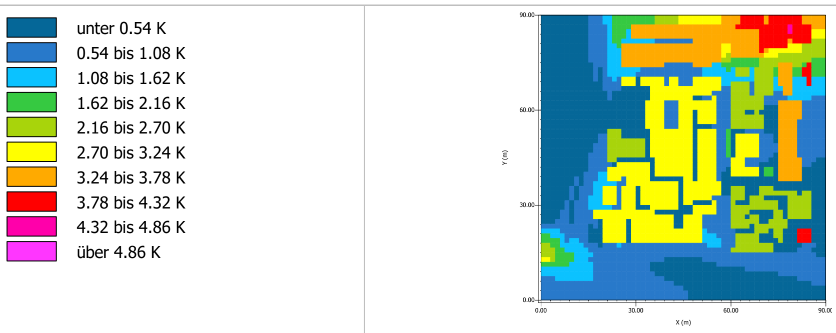
6:00pm

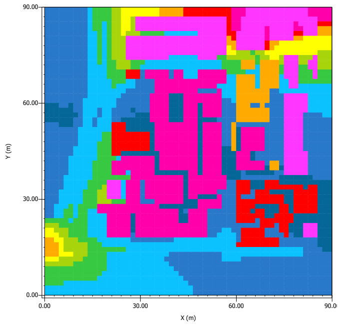
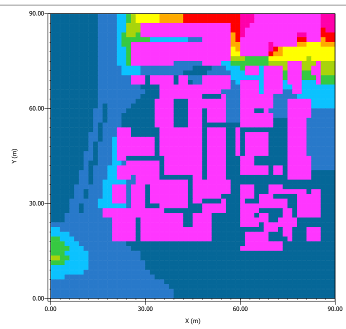
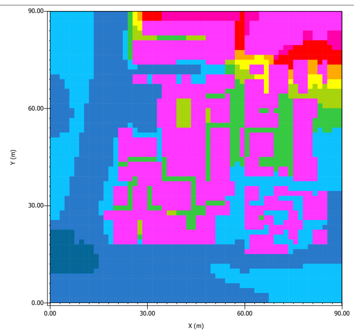
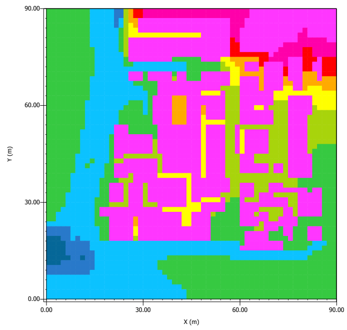


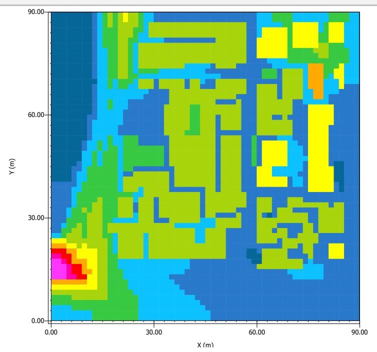
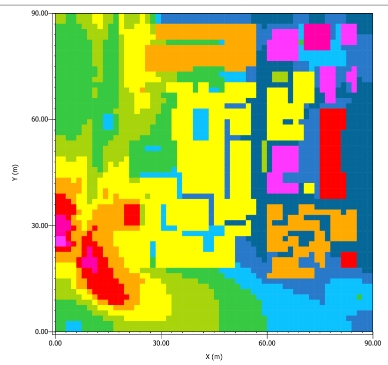
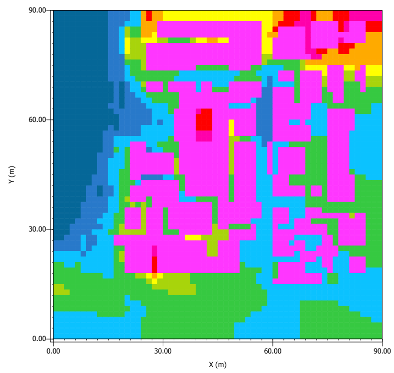
9:00pm	
12:00am	

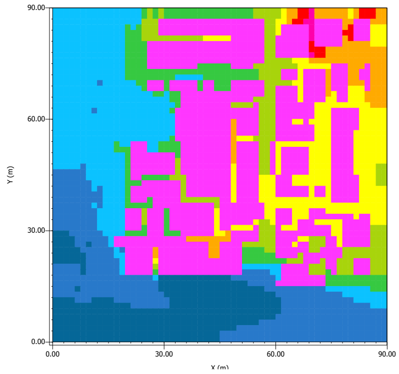
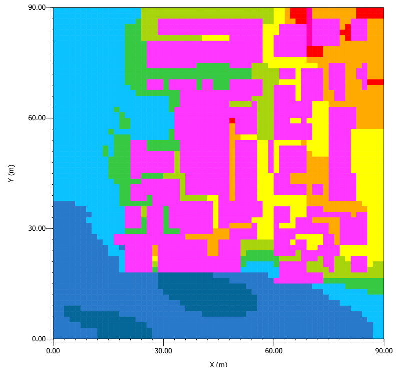
SUMMER BASE CASE VERSUS COOL PAVEMENTS AND ROADS

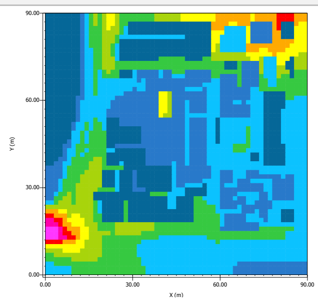
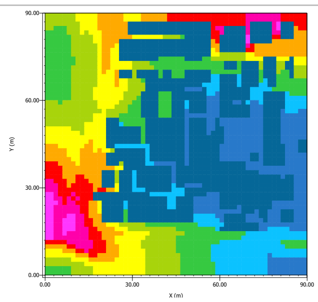
12:00pm

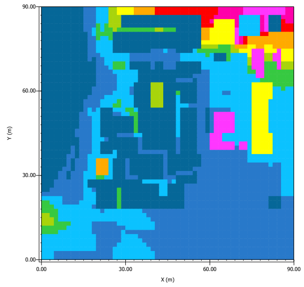
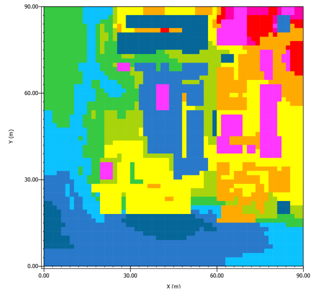
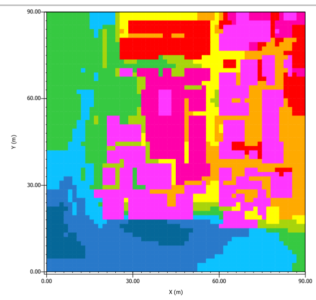


3:00pm	unter 1.28 K 1.28 bis 1.74 K 1.74 bis 2.20 K 2.20 bis 2.66 K 2.66 bis 3.12 K 3.12 bis 3.58 K 3.58 bis 4.04 K 4.04 bis 4.50 K 4.50 bis 4.96 K über 4.96 K	
6:00pm	unter 1.14 K 1.14 bis 1.37 K 1.37 bis 1.60 K 1.60 bis 1.83 K 1.83 bis 2.06 K 2.06 bis 2.29 K 2.29 bis 2.52 K 2.52 bis 2.75 K 2.75 bis 2.98 K über 2.98 K	
9:00pm	unter 0.93 K 0.93 bis 1.04 K 1.04 bis 1.14 K 1.14 bis 1.25 K 1.25 bis 1.35 K 1.35 bis 1.46 K 1.46 bis 1.56 K 1.56 bis 1.67 K 1.67 bis 1.77 K über 1.77 K	
12:00am	unter 0.58 K 0.58 bis 0.68 K 0.68 bis 0.79 K 0.79 bis 0.89 K 0.89 bis 0.99 K 0.99 bis 1.10 K 1.10 bis 1.20 K 1.20 bis 1.31 K 1.31 bis 1.41 K über 1.41 K	

SUMMER BASE CASE VERSUS VEGETATION	
unter 0.59 K 0.59 bis 1.15 K 1.15 bis 1.71 K 1.71 bis 2.26 K 2.26 bis 2.82 K 2.82 bis 3.38 K 3.38 bis 3.93 K 3.93 bis 4.49 K 4.49 bis 5.05 K über 5.05 K 12:00pm	
unter 0.63 K 0.63 bis 1.21 K 1.21 bis 1.80 K 1.80 bis 2.39 K 2.39 bis 2.98 K 2.98 bis 3.56 K 3.56 bis 4.15 K 4.15 bis 4.74 K 4.74 bis 5.33 K über 5.33 K 3:00pm	
unter 1.74 K 1.74 bis 1.87 K 1.87 bis 2.00 K 2.00 bis 2.12 K 2.12 bis 2.25 K 2.25 bis 2.38 K 2.38 bis 2.50 K 2.50 bis 2.63 K 2.63 bis 2.75 K über 2.75 K 6:00pm	

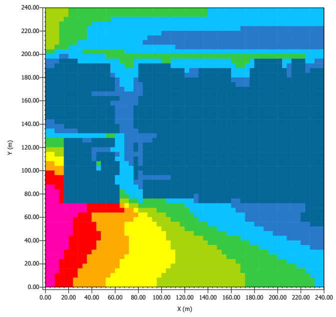
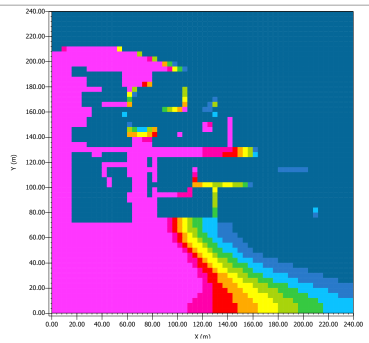
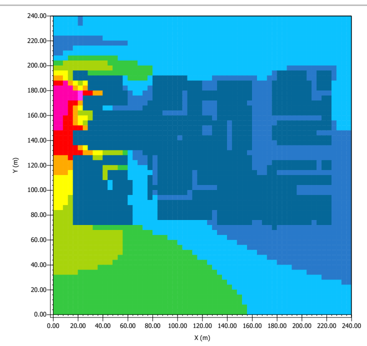
unter 1.83 K 1.83 bis 1.98 K 1.98 bis 2.14 K 2.14 bis 2.29 K 2.29 bis 2.44 K 2.44 bis 2.60 K 2.60 bis 2.75 K 2.75 bis 2.90 K 2.90 bis 3.06 K über 3.06 K 9:00pm	
unter 1.42 K 1.42 bis 1.60 K 1.60 bis 1.78 K 1.78 bis 1.95 K 1.95 bis 2.13 K 2.13 bis 2.30 K 2.30 bis 2.48 K 2.48 bis 2.65 K 2.65 bis 2.83 K über 2.83 K 12:00am	

SUMMER BASE CASE VERSUS EFFICIENT CASE	
unter 0.59 K 0.59 bis 1.15 K 1.15 bis 1.71 K 1.71 bis 2.26 K 2.26 bis 2.82 K 2.82 bis 3.38 K 3.38 bis 3.93 K 3.93 bis 4.49 K 4.49 bis 5.05 K über 5.05 K 12:00pm	
unter 0.63 K 0.63 bis 1.21 K 1.21 bis 1.80 K 1.80 bis 2.39 K 2.39 bis 2.98 K 2.98 bis 3.56 K 3.56 bis 4.15 K 4.15 bis 4.74 K 4.74 bis 5.33 K über 5.33 K 3:00pm	

6:00pm unter 2.88 K 2.88 bis 3.14 K 3.14 bis 3.39 K 3.39 bis 3.65 K 3.65 bis 3.90 K 3.90 bis 4.16 K 4.16 bis 4.41 K 4.41 bis 4.67 K 4.67 bis 4.92 K über 4.92 K	
9:00pm unter 2.80 K 2.80 bis 2.94 K 2.94 bis 3.08 K 3.08 bis 3.22 K 3.22 bis 3.36 K 3.36 bis 3.50 K 3.50 bis 3.64 K 3.64 bis 3.78 K 3.78 bis 3.93 K über 3.93 K	
12:00am unter 1.87 K 1.87 bis 2.02 K 2.02 bis 2.16 K 2.16 bis 2.31 K 2.31 bis 2.45 K 2.45 bis 2.60 K 2.60 bis 2.75 K 2.75 bis 2.89 K 2.89 bis 3.04 K über 3.04 K	

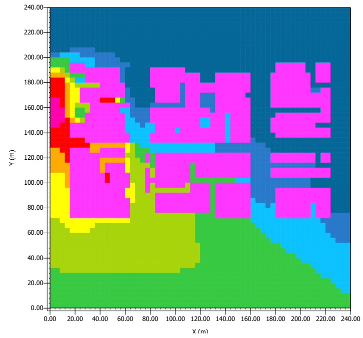
APPENDIX B

SADDAR – TEMPERATURE DIFFERENCE BETWEEN BASECASE AND DIFFERENT MITIGATION SCENARIOS

SUMMER BASE CASE VERSUS COOL ROOFS	
12:00pm unter 0.07 K 0.07 bis 0.14 K 0.14 bis 0.21 K 0.21 bis 0.28 K 0.28 bis 0.35 K 0.35 bis 0.42 K 0.42 bis 0.49 K 0.49 bis 0.56 K 0.56 bis 0.63 K über 0.63 K	
3:00pm unter 0.93 K 0.93 bis 1.04 K 1.04 bis 1.14 K 1.14 bis 1.25 K 1.25 bis 1.35 K 1.35 bis 1.46 K 1.46 bis 1.56 K 1.56 bis 1.67 K 1.67 bis 1.77 K über 1.77 K	
6:00pm unter 0.48 K 0.48 bis 0.55 K 0.55 bis 0.61 K 0.61 bis 0.68 K 0.68 bis 0.75 K 0.75 bis 0.81 K 0.81 bis 0.88 K 0.88 bis 0.95 K 0.95 bis 1.02 K über 1.02 K	

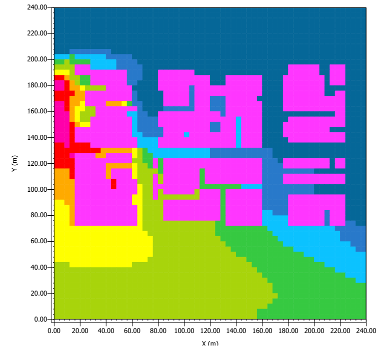
9:00pm

- unter 0.06 K
- 0.06 bis 0.12 K
- 0.12 bis 0.19 K
- 0.19 bis 0.25 K
- 0.25 bis 0.31 K
- 0.31 bis 0.37 K
- 0.37 bis 0.43 K
- 0.43 bis 0.50 K
- 0.50 bis 0.56 K
- über 0.56 K



12:00am

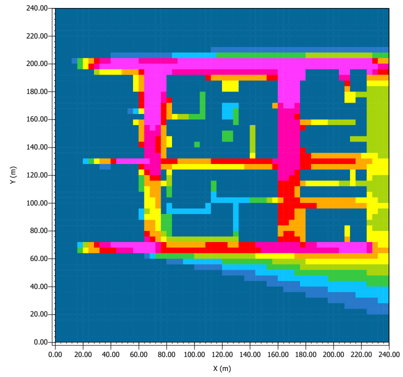
- unter 0.05 K
- 0.05 bis 0.10 K
- 0.10 bis 0.15 K
- 0.15 bis 0.20 K
- 0.20 bis 0.25 K
- 0.25 bis 0.30 K
- 0.30 bis 0.35 K
- 0.35 bis 0.40 K
- 0.40 bis 0.45 K
- über 0.45 K



SUMMER BASE CASE VERSUS COOL PAVEMENTS AND ROADS

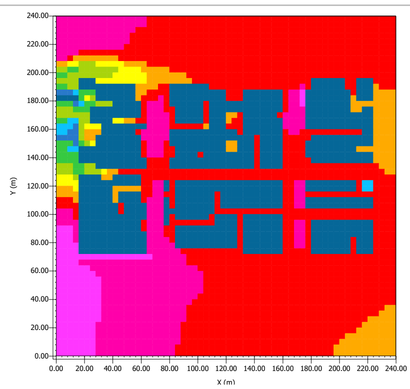
12:00pm

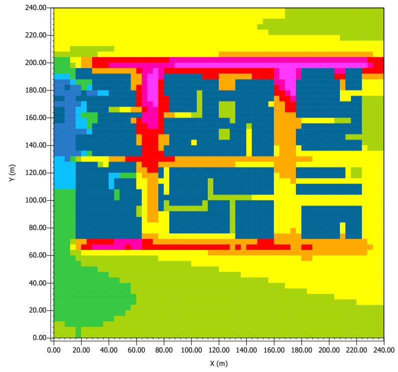
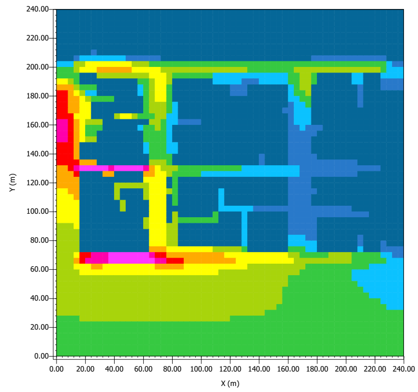
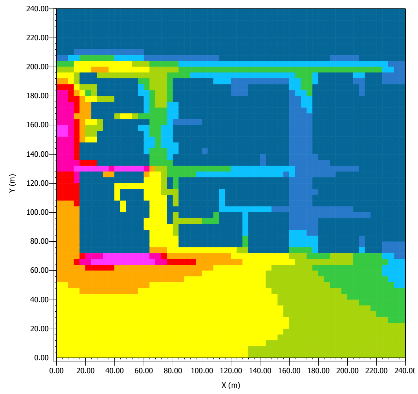
- unter 0.02 K
- 0.02 bis 0.04 K
- 0.04 bis 0.06 K
- 0.06 bis 0.08 K
- 0.08 bis 0.10 K
- 0.10 bis 0.12 K
- 0.12 bis 0.14 K
- 0.14 bis 0.16 K
- 0.16 bis 0.18 K
- über 0.18 K

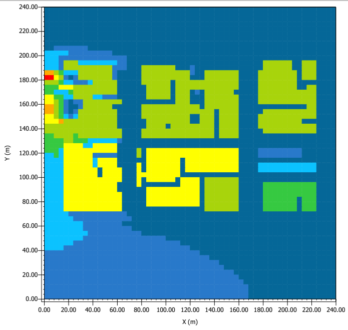
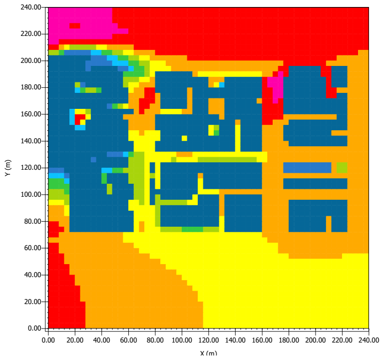
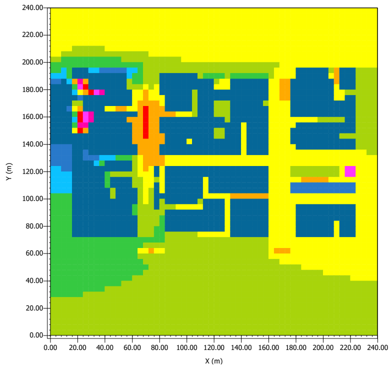
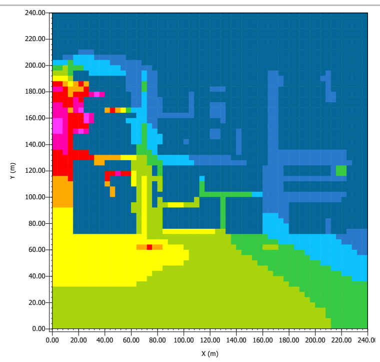


3:00pm

- unter 0.51 K
- 0.51 bis 0.56 K
- 0.56 bis 0.61 K
- 0.61 bis 0.66 K
- 0.66 bis 0.71 K
- 0.71 bis 0.76 K
- 0.76 bis 0.81 K
- 0.81 bis 0.86 K
- 0.86 bis 0.91 K
- über 0.91 K

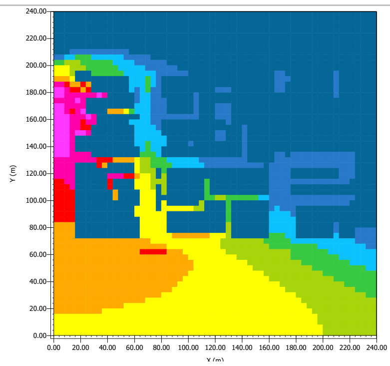


6:00pm unter 0.75 K 0.75 bis 0.79 K 0.79 bis 0.82 K 0.82 bis 0.86 K 0.86 bis 0.89 K 0.89 bis 0.93 K 0.93 bis 0.97 K 0.97 bis 1.00 K 1.00 bis 1.04 K über 1.04 K	
9:00pm unter 0.64 K 0.64 bis 0.68 K 0.68 bis 0.71 K 0.71 bis 0.75 K 0.75 bis 0.79 K 0.79 bis 0.83 K 0.83 bis 0.86 K 0.86 bis 0.90 K 0.90 bis 0.94 K über 0.94 K	
12:00am unter 0.07 K 0.07 bis 0.14 K 0.14 bis 0.21 K 0.21 bis 0.28 K 0.28 bis 0.35 K 0.35 bis 0.42 K 0.42 bis 0.49 K 0.49 bis 0.56 K 0.56 bis 0.63 K über 0.63 K	

SUMMER BASE CASE VERSUS VEGETATION	
12:00pm unter 0.07 K 0.07 bis 0.14 K 0.14 bis 0.21 K 0.21 bis 0.28 K 0.28 bis 0.35 K 0.35 bis 0.42 K 0.42 bis 0.49 K 0.49 bis 0.56 K 0.56 bis 0.63 K über 0.63 K	
3:00pm unter 0.12 K 0.12 bis 0.24 K 0.24 bis 0.37 K 0.37 bis 0.49 K 0.49 bis 0.61 K 0.61 bis 0.73 K 0.73 bis 0.85 K 0.85 bis 0.98 K 0.98 bis 1.10 K über 1.10 K	
6:00pm unter 0.48 K 0.48 bis 0.55 K 0.55 bis 0.61 K 0.61 bis 0.68 K 0.68 bis 0.75 K 0.75 bis 0.81 K 0.81 bis 0.88 K 0.88 bis 0.95 K 0.95 bis 1.02 K über 1.02 K	
9:00pm unter 0.37 K 0.37 bis 0.42 K 0.42 bis 0.48 K 0.48 bis 0.53 K 0.53 bis 0.59 K 0.59 bis 0.64 K 0.64 bis 0.70 K 0.70 bis 0.76 K 0.76 bis 0.81 K über 0.81 K	

12:00am

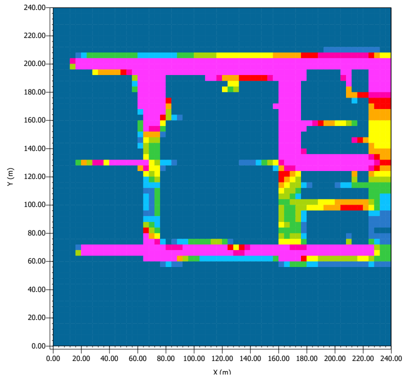
- unter 0.17 K
- 0.17 bis 0.21 K
- 0.21 bis 0.25 K
- 0.25 bis 0.29 K
- 0.29 bis 0.34 K
- 0.34 bis 0.38 K
- 0.38 bis 0.42 K
- 0.42 bis 0.47 K
- 0.47 bis 0.51 K
- über 0.51 K



SUMMER BASE CASE VERSUS EFFICIENT CASE

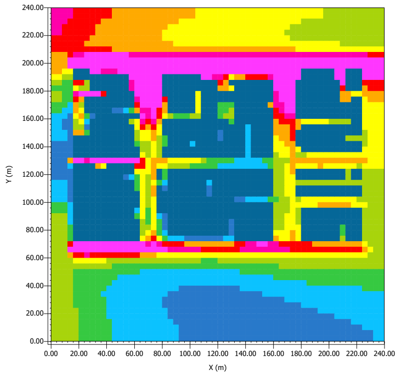
12:00pm

- unter 0.51 K
- 0.51 bis 0.56 K
- 0.56 bis 0.61 K
- 0.61 bis 0.66 K
- 0.66 bis 0.71 K
- 0.71 bis 0.76 K
- 0.76 bis 0.81 K
- 0.81 bis 0.86 K
- 0.86 bis 0.91 K
- über 0.91 K



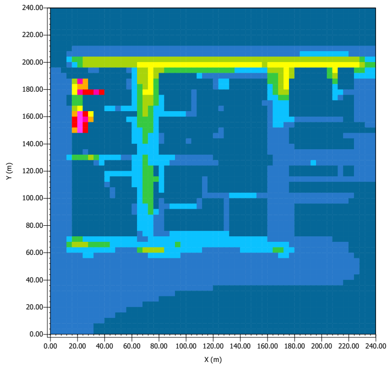
3:00pm

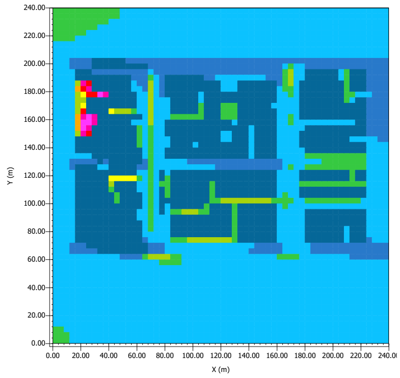
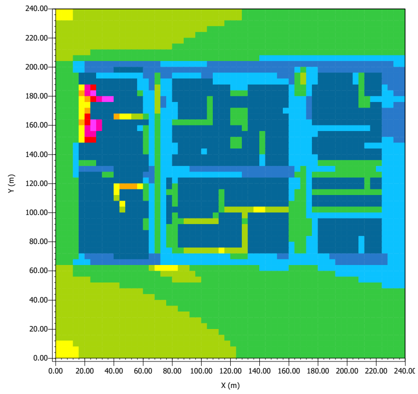
- unter 0.69 K
- 0.69 bis 0.73 K
- 0.73 bis 0.77 K
- 0.77 bis 0.81 K
- 0.81 bis 0.84 K
- 0.84 bis 0.88 K
- 0.88 bis 0.92 K
- 0.92 bis 0.95 K
- 0.95 bis 0.99 K
- über 0.99 K



6:00pm

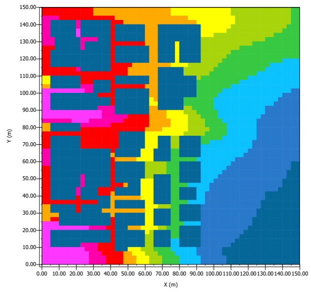
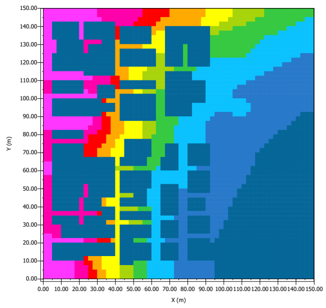
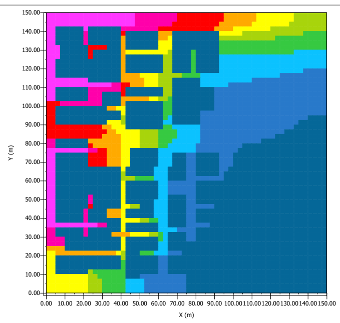
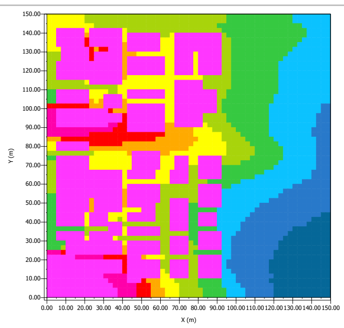
- unter 0.89 K
- 0.89 bis 0.96 K
- 0.96 bis 1.03 K
- 1.03 bis 1.10 K
- 1.10 bis 1.16 K
- 1.16 bis 1.23 K
- 1.23 bis 1.30 K
- 1.30 bis 1.37 K
- 1.37 bis 1.44 K
- über 1.44 K



9:00pm unter 0.17 K 0.17 bis 0.30 K 0.30 bis 0.43 K 0.43 bis 0.57 K 0.57 bis 0.70 K 0.70 bis 0.84 K 0.84 bis 0.97 K 0.97 bis 1.11 K 1.11 bis 1.24 K über 1.24 K	
12:00am unter 0.78 K 0.78 bis 0.83 K 0.83 bis 0.89 K 0.89 bis 0.94 K 0.94 bis 1.00 K 1.00 bis 1.05 K 1.05 bis 1.11 K 1.11 bis 1.16 K 1.16 bis 1.22 K über 1.22 K	

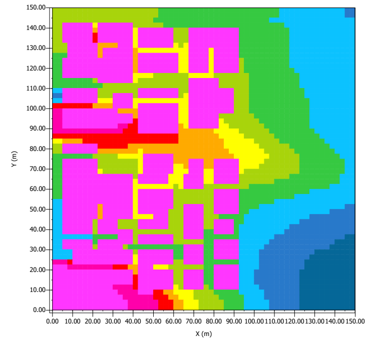
APPENDIX C

KORANGI – TEMPERATURE DIFFERENCE BETWEEN BASECASE AND DIFFERENT MITIGATION SCENARIOS

KORANGI BASE CASE VERSUS HIGH ALBEDO	
12:00pm unter 0.92 K 0.92 bis 1.05 K 1.05 bis 1.18 K 1.18 bis 1.31 K 1.31 bis 1.45 K 1.45 bis 1.58 K 1.58 bis 1.71 K 1.71 bis 1.84 K 1.84 bis 1.97 K über 1.97 K	
3:00pm unter 1.33 K 1.33 bis 1.50 K 1.50 bis 1.67 K 1.67 bis 1.85 K 1.85 bis 2.02 K 2.02 bis 2.20 K 2.20 bis 2.37 K 2.37 bis 2.54 K 2.54 bis 2.72 K über 2.72 K	
unter 0.73 K 0.73 bis 0.79 K 0.79 bis 0.85 K 0.85 bis 0.92 K 0.92 bis 0.98 K 0.98 bis 1.04 K 1.04 bis 1.10 K 1.10 bis 1.16 K 1.16 bis 1.22 K über 1.22 K 6:00pm	
unter 0.72 K 0.72 bis 0.77 K 0.77 bis 0.83 K 0.83 bis 0.88 K 0.88 bis 0.93 K 0.93 bis 0.98 K 0.98 bis 1.04 K 1.04 bis 1.09 K 1.09 bis 1.14 K über 1.14 K 9:00pm	

12:00am

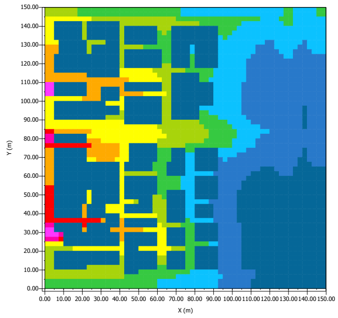
- unter 0.15 K
- 0.15 bis 0.21 K
- 0.21 bis 0.28 K
- 0.28 bis 0.35 K
- 0.35 bis 0.41 K
- 0.41 bis 0.48 K
- 0.48 bis 0.54 K
- 0.54 bis 0.61 K
- 0.61 bis 0.67 K
- über 0.67 K



SUMMER BASE CASE VERSUS COOL PAVEMENTS AND ROADS

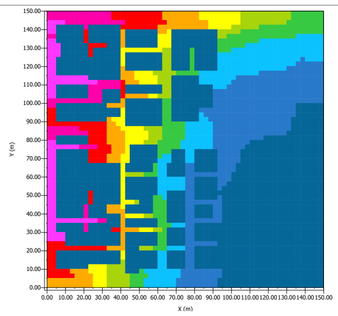
12:00pm

- unter 2.44 K
- 2.44 bis 2.78 K
- 2.78 bis 3.13 K
- 3.13 bis 3.48 K
- 3.48 bis 3.82 K
- 3.82 bis 4.17 K
- 4.17 bis 4.51 K
- 4.51 bis 4.86 K
- 4.86 bis 5.21 K
- über 5.21 K



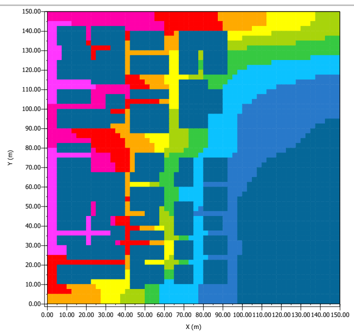
3:00pm

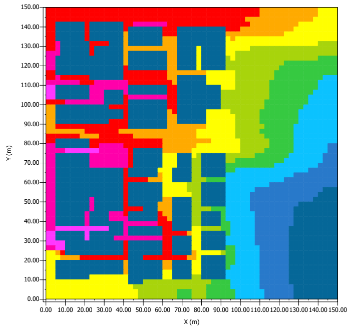
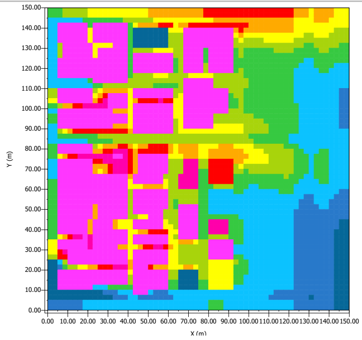
- unter 4.79 K
- 4.79 bis 4.92 K
- 4.92 bis 5.06 K
- 5.06 bis 5.19 K
- 5.19 bis 5.33 K
- 5.33 bis 5.47 K
- 5.47 bis 5.60 K
- 5.60 bis 5.74 K
- 5.74 bis 5.88 K
- über 5.88 K



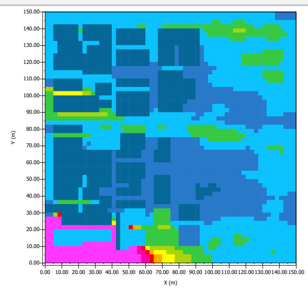
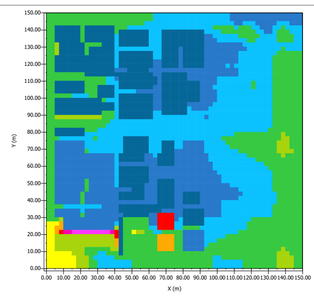
6:00pm

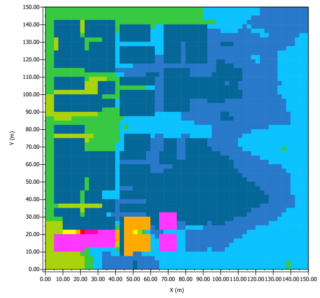
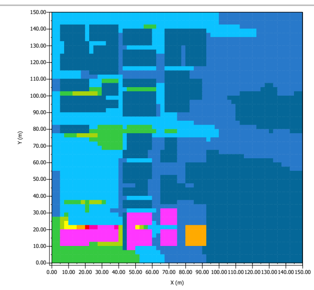
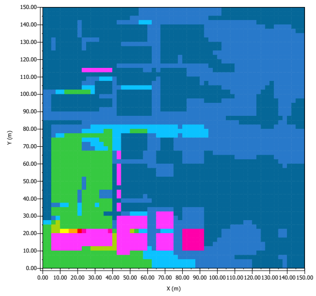
- unter 2.31 K
- 2.31 bis 2.53 K
- 2.53 bis 2.75 K
- 2.75 bis 2.97 K
- 2.97 bis 3.19 K
- 3.19 bis 3.42 K
- 3.42 bis 3.64 K
- 3.64 bis 3.86 K
- 3.86 bis 4.08 K
- über 4.08 K

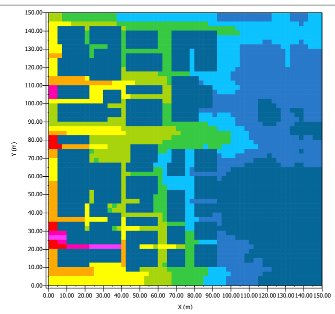


9:00pm unter 2.73 K 2.73 bis 2.77 K 2.77 bis 2.80 K 2.80 bis 2.83 K 2.83 bis 2.87 K 2.87 bis 2.90 K 2.90 bis 2.93 K 2.93 bis 2.97 K 2.97 bis 3.00 K über 3.00 K	
12:00am unter 0.41 K 0.41 bis 0.82 K 0.82 bis 1.23 K 1.23 bis 1.64 K 1.64 bis 2.06 K 2.06 bis 2.47 K 2.47 bis 2.88 K 2.88 bis 3.29 K 3.29 bis 3.70 K über 3.70 K	

SUMMER BASE CASE VERSUS VEGETATION

12:00pm unter 0.50 K 0.50 bis 1.00 K 1.00 bis 1.50 K 1.50 bis 2.00 K 2.00 bis 2.50 K 2.50 bis 3.00 K 3.00 bis 3.50 K 3.50 bis 4.00 K 4.00 bis 4.50 K über 4.50 K	
3:00pm unter 1.17 K 1.17 bis 1.78 K 1.78 bis 2.40 K 2.40 bis 3.02 K 3.02 bis 3.64 K 3.64 bis 4.26 K 4.26 bis 4.87 K 4.87 bis 5.49 K 5.49 bis 6.11 K über 6.11 K	

<table>
<tr><td>unter 2.44 K
2.44 bis 2.78 K
2.78 bis 3.13 K
3.13 bis 3.48 K
3.48 bis 3.82 K
3.82 bis 4.17 K
4.17 bis 4.51 K
4.51 bis 4.86 K
4.86 bis 5.21 K
über 5.21 K
6:00pm</td><td></td></tr>
<tr><td>unter 2.31 K
2.31 bis 2.53 K
2.53 bis 2.75 K
2.75 bis 2.97 K
2.97 bis 3.19 K
3.19 bis 3.42 K
3.42 bis 3.64 K
3.64 bis 3.86 K
3.86 bis 4.08 K
über 4.08 K
9:00pm</td><td></td></tr>
<tr><td>unter 2.37 K
2.37 bis 2.52 K
2.52 bis 2.67 K
2.67 bis 2.81 K
2.81 bis 2.96 K
2.96 bis 3.11 K
3.11 bis 3.26 K
3.26 bis 3.41 K
3.41 bis 3.55 K
über 3.55 K
12:00am</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">SUMMER BASE CASE VERSUS EFFICIENT CASE</td></tr>
<tr><td>unter 2.44 K
2.44 bis 2.78 K
2.78 bis 3.13 K
3.13 bis 3.48 K
3.48 bis 3.82 K
3.82 bis 4.17 K
4.17 bis 4.51 K
4.51 bis 4.86 K
4.86 bis 5.21 K
über 5.21 K
12:00pm</td><td></td></tr>
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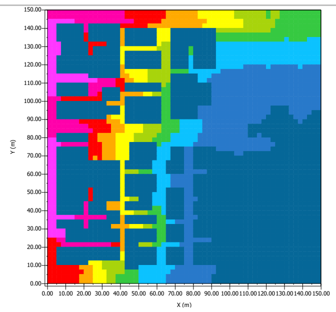
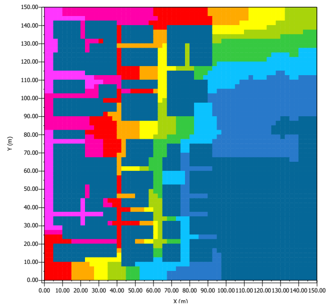
3:00pm

- unter 3.44 K
- 3.44 bis 3.92 K
- 3.92 bis 4.39 K
- 4.39 bis 4.86 K
- 4.86 bis 5.33 K
- 5.33 bis 5.81 K
- 5.81 bis 6.28 K
- 6.28 bis 6.75 K
- 6.75 bis 7.23 K
- über 7.23 K



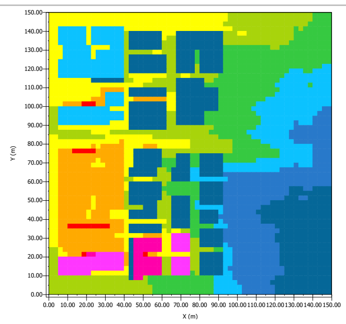
6:00pm

- unter 4.46 K
- 4.46 bis 4.60 K
- 4.60 bis 4.75 K
- 4.75 bis 4.90 K
- 4.90 bis 5.04 K
- 5.04 bis 5.19 K
- 5.19 bis 5.33 K
- 5.33 bis 5.48 K
- 5.48 bis 5.63 K
- über 5.63 K



9:00pm

- unter 2.44 K
- 2.44 bis 2.78 K
- 2.78 bis 3.13 K
- 3.13 bis 3.48 K
- 3.48 bis 3.82 K
- 3.82 bis 4.17 K
- 4.17 bis 4.51 K
- 4.51 bis 4.86 K
- 4.86 bis 5.21 K
- über 5.21 K



12:00am

- unter 0.59 K
- 0.59 bis 1.15 K
- 1.15 bis 1.71 K
- 1.71 bis 2.26 K
- 2.26 bis 2.82 K
- 2.82 bis 3.38 K
- 3.38 bis 3.93 K
- 3.93 bis 4.49 K
- 4.49 bis 5.05 K
- über 5.05 K