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Assessing the Thermal Effectiveness of Implementing Green Roofs in the Urban Neighborhood

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Abstract

The United Arab Emirates demonstrated abundance attention to modern developments, especially when it comes to the ostentatious projects of architecture, thermal comfort, energy efficiency and smart cities. Producing one of the world's most astonishing cities is not the only concern for the government of the United Arab Emirates. The United Arab Emirates paid great attention to implementing various policies and strategies targeting to become among the most sustainable countries in the world. One of these strategies is the implementation of green roofs in residential and commercial spaces.

Researches and studies indicate that green roofs are one of the strategies that result in an ecosystem when it is applied in urban regions. It can reduce the heat island effect that is formed in urban spaces which results in reducing air temperature and pollution in the environment, reducing greenhouse gas emission, energy conservation and many other benefits. This research proved the ability to mitigate heat island and improve thermal conditions when integrating these structures into the new developments and neighborhoods. This is achieved by examining the sequences resulting from integrating green roofs to the rooftops of residential units at Mina Al Arab compound by measuring the thermal parameters and investigating the changes that will occur using ENVI-met simulation program. The simulation compares a green roof system and a conventional roof system at 1:00 pm on a summer day and a winter day.

The results gained from the simulation of Mina Al Arab demonstrated that the green roof system has excellent potential to mitigate heat island effect and improve thermal conditions by decreasing relative humidity, mean radiant temperature, and coefficient of heat exchange.

Keywords: Green roof, Sustainability, Simulation, UAE, Environment;

1. Introduction

The quick expansion in economic and social growth contributed to an obvious increase in the ecological footprint that leads to the heat island phenomenon. Heat island effect is a result of the increase of concrete structures and reduction in open spaces and green surfaces that filters the air and play a magnificent rule in reducing air temperatures around. As a result, a clear increase in pollution and air temperature in urban areas compared to adjacent rural spaces is witnessed.

This increase in air temperatures raises the demand for cooling which requires an abundant amount of energy and power. Studies showed that 70% of the electricity demand is required for cooling in a building in hot dry regions like UAE. Heat island effect increases three times the demand for electrical power, it increases two times the cooling load and decreases the performance of air conditioning machines in a building [1]. An urban heat island profile is presented graphically in figure 1.

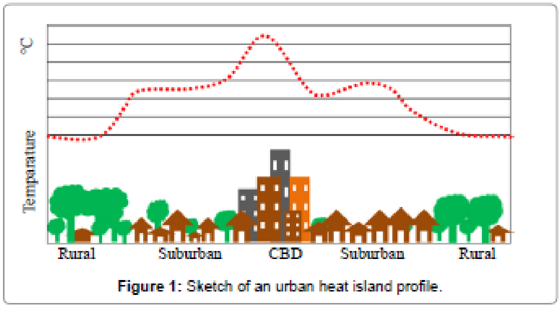

Figure 1. A sketch of an urban heat island profile [2]

Growing plants on the top of buildings roofs is an old idea used by people since the past. People used to grow their herbs and plants for eating and drinking and even for leisure on top of their roofs for centuries. They also planted their roofs in order to protect them from high radiation that caused high temperatures inside their houses [3]. At the beginning of the nineteenth century, before the

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use of green roofs, people used to build water features on the top of roofs in order to cool rooftops and allow the forming of a cool breeze. A few decades later many European countries including Germany and Sweden begin to introduce green roofs into their houses in order to increase vegetation areas that are considered very valuable. Green roofs were used not only for planting, but also as a solution for controlling storm water by absorbing part of it and preventing heat from penetrating to the indoor spaces.

The concept of green roof is reused nowadays to enhance buildings energy performance. In a model research done by Liu and Minor [4], a comparison between a green roof and a normal roof was conducted. Results showed that when a green roof is installed at the top of the building, the energy demand for cooling and heating is up to 3 times less. Green roofs served as a barrier protecting the building's top from solar radiation.

Parizotto and Lamberts [5] examined the thermal effect of a green roof when integrated into a family household in Brazil. The researchers did experiments using different types of roof finishing. These materials are: metal roof, ceramic tiles, and a green roof. By measuring the indoor air temperature, they found out that the lowest indoor temperature was recorded when they used a green roof system, followed by ceramic tiles and metallic system. This is due to the low heat gain property of soil compared to ceramic tiles or metal. Also, the layers of soil and the drainage system work as a buffer zone or as an extra insulation layer that prevents heat transfer to the indoor spaces. Moreover, they found out that the shaded area formed by the higher plants was even less in temperatures. As a result, the demand for cooling is less and the cooling performance is enhanced in the study area.

Alcazar S., Bass B. [6] also investigated the performance of green roofs and its effect on thermal comfort in indoor spaces according to many parameters including soil layer thickness, irrigation and planting density in addition to types of plants used and the area of plants leave. According to his investigation green roofs are one of the greatest methods of insulation or finishing to be used for building roofs in order to reduce heat transfer to buildings. He also recommended using vegetation that has wide leaves area and that grows and expands horizontally in order to maximize the reflection of solar radiation and increase the shaded area.

In a research paper that has been done by Rosheidat and Bryan [7], a simulation study using ENVI-met on a selected area in the city of Phoenix in Arizona was conducted. The aim of their simulation was to calculate the reduction in temperatures in the space. They found out that the temperature is decreased by 5°C in vegetated areas. Moreover, they found out that changing in the surface material and using materials that have high reflectivity also reduced the surface temperature reasonably. Moreover, the difference between materials that have high reflecting abilities and green roofs is compared and found out that green roofs have a higher albedo level and was able to reflect solar radiation more than reflective materials, although these results varied between different types of vegetation types and layer thickness. They also included in their research simulation of water content within layers and indicated that water content leads to a reduction in surface temperatures during the daytime period and that the quantity of temperature reduction is proportional to the quantity of moister content in the green roof layer.

A quantitative case study accomplished by Kumar and Kaushik [8] in India indicated that the thermal performance of a green roof system is influenced by leaf area index and vegetation height by acting as a shading layer that prevents solar radiation. Consequently, heat gain to indoor spaces and indoor air temperatures were reduced.

One of the main challenges that limit the expansion of the green roof system is the lack of policies and regulations that encourages the use of these systems in current and new developments. This can be related to the limited number of researches and studies in this area. Another factor to consider is the lack of experience in the design, implementation and maintenance of the green roof systems. Also, manufacturers of green roof products are located and concentrated only in some countries, thereby increasing the cost of exporting the material to the required place. For instance, the application of green roof system in hot arid regions improves the thermal comfort and reduces the load on the cooling system, while green roof system on the other hand in humid and rainy areas protects construction composition by regulating and handling storm water. It could be a difficult job to alter the present roofing technologies used by developers and contractors, so encouraging new practices can begin through the government for government structures to show their intention to find more viable alternatives and to be a reference for future changes in the building industry [9].

The installation costs are deemed to be one of the factors why green roof systems are unpopular in some areas. However, the availability of a broad range of new products and techniques makes it more feasible and more demanding at reduced market prices. As researchers have proven the advantages of using green roofs, the demand for them has increased by owners of spaces who are prepared to pursue additional sustainable alternatives and by manufacturers and vendors who supply these techniques. As researches and evidence proved the benefits of using green roofs, the demand for it increased by owners of spaces who are willing to go for extra sustainable solutions and by producers and suppliers that are providing these technologies. Consequently, the price of these techniques decreased and became more viable for customers [10].

Abu Dhabi's government has established new policies and guidelines aimed at a sustainable green future and at controlling and reducing city emissions. One of the most important strategies that have been set by the government of Abu Dhabi is Estidama guidelines that aim to a new sustainable future and encourages to adopt new methods, strategies and technologies to face the challenges of the future. Although landscaping and vegetation in Abu Dhabi are challenging due to its hot climate and dusty soil characteristics, in addition to the lack of water resources, however Estidama new guidelines encourage the integration of green roofs and vegetation spaces in order to control and reduce heat island effect in the city.

The theoretical base of this paper is to investigate the potential benefits of green roofs in the urban areas of a hot arid region like the United Arab Emirates that is facing a huge increase in the population size and footprint yearly. This research aims to examine the ability to minimize and control the environmental thermal issues associated with urban developments and to evaluate the positivity of integrating green roofs in the buildings. This will be done by simulating outdoor thermal limitations including surface temperature, relative humidity (RH), mean radiant temperature (MRT) and wind speed. The research findings will certify the contribution and advantages of incorporating green roof systems into urban buildings. One of the objectives of this work is to guide construction architects and designers to enhance their designs to obtain maximum thermal comfort and energy savings in any project according to their requirements.

2. Research study area and methodology

Site examination and computer simulation are the most common methodologies that have been used to study green roofs. The positive point of computer simulation is time and cost-saving by the ability to test different locations, during different seasons of the year using different weather files. Moreover, simulation programs allow for studying and comparing different parameters with the least difficulties and it gives the chance for applying changes on the module and all different parameters. It also saves a lot of time and effort required to measure and observe using sensors and testing machines needed for experimental methodology. Even the module scale, number of floor height, location, and finishing material can be changed and updated. Although simulation methodology is considered very flexible and has many positive aspects, it also has some negative aspects like human errors during input of data or even in the programming of the software that is designed by humans.

In this work, simulation methodology will be used to evaluate the performance of green roof over an urban compound community. The creation of a simulation prototype that integrates a green roof into a building in a social community is a dynamic way to detect its performance and interaction. It gives the chance to observe the impact of weather conditions, the material used in the system, wind and temperature interaction on the prototype. All data obtained from simulation programs will be saved and presented graphically in forms of tables and charts. The software for simulation to be used in this research is ENVI-met. The simulation will provide information to be analyzed so that an ideal solution can be found. The simulation software does not have all local vegetation data of UAE. Therefore, some manual records will be required

The study is conducted in Ras Al-Khaimah which is in the northern area of UAE. Retaining a rich archaeological culture that dates back to 50centuries, Ras Al-Khaimah features a treasure of landscapes and environments, ranging from huge mountains to seaside areas and red sandy desert. Due to its topography Ras al-Khaimah is considered one of the most desirable growing tourist destinations of all the emirates and gulf area, it contains a great range of amenities and resorts that attracts visitors from the surrounding emirates and from all over the world, where many developments, resorts, museums, malls, golf courses and other facilities are available.

The area that will be investigated is a residential area located at Mina Al Arab which is a waterfront luxury development established by RAK properties. Mina Al Arab consists of six districts that have unique characteristics and attractive atmosphere. The urban structure is designed carefully to accommodate different facilities and amenities that please residents and visitors. In addition to being a residential compound, Mina Al Arab contains many luxury resorts and hotels for visitors. The master plan Mina Al Arab is presented in figure 2.

The selected area that will be studied is Bermuda. Bermuda consists of residential villas and townhouses that vary between 2-6 bedrooms with private and shared gardens, open spaces and beach sides as listed in Table 1 and presented in Figure 3.

Figure 2. Mina Al Arab master plan. Source: Rak Properties, 2017.

In this study the simulation of green roof integration will be applied to the 5 different types of units to investigate the effect of the green roof and how does it interact with adjacent buildings and units. All the units are consisted of 2-floor heights and are adjacent to private open gardens, spaces and shared amenities that have different surfaces and Albedo levels. Figures 4, 5 and 6 show perspective, ground and first-floor plan of type D type villa. Each villa has a private roof and a private garden. The building envelope and roof of all types (A, B, C, D and E) are built of concrete.

Table 1. Bermuda villa types and area. Source Rak Properties, 2017

Villa Type & Sizes Sr. No	Model	No. of units	Bedrooms	Build up Area	Approximate Plot Area
1	Type E	48	2	2572.3	2184
2	Type D	61	3	3773.5	3432
3	Type C	23	4	4768.2	6240
4	Type B	20	5	5530.6	6456
5	Type A	5	6	6741.1	7747

Figure 3. Bermuda key plan. Source: Rak Properties, 2017.

Figure 4. Type D villa back view. Source: Rak Properties, 2017.

The Envi-met academic version is used to simulate the required area. The simulation process involves different stages and procedures. The stages include setting up the inputs, modeling the area and assigning materials, setting up a simulation file that contains all settings and visualizing the outputs using Leonardo visualization that is included in the program as shown in figure 7.

Figure 5. Type D ground floor plan. Source: Rak Properties, 2017.

Figure 6. Type D first-floor plan. Source: Rak Properties, 2017.

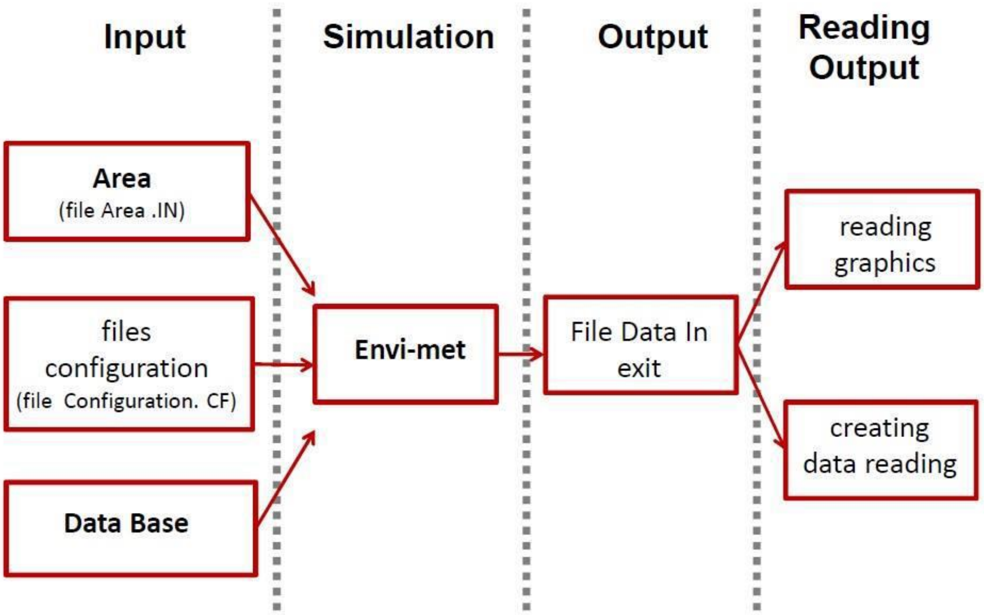


Figure 7. Process of ENVI-met simulation. Source: ENVI-met learning, 2017.

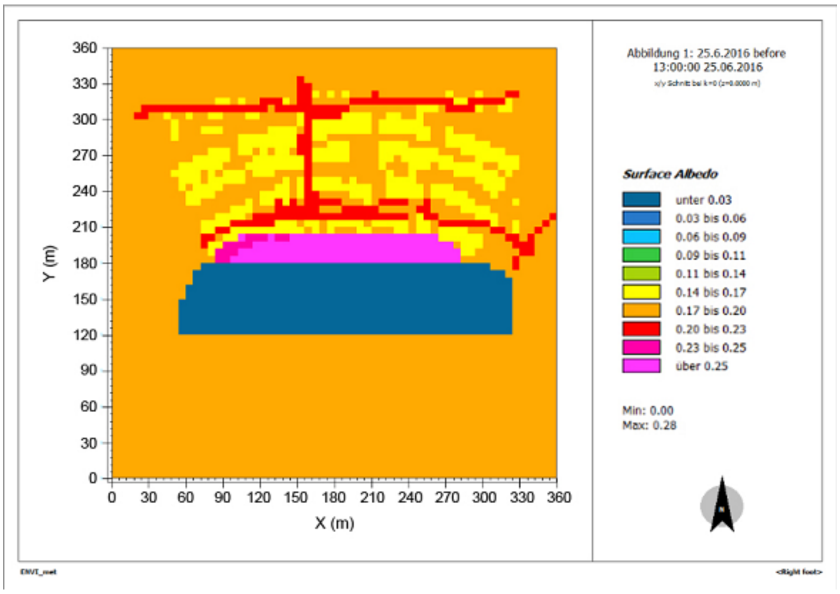
3. RESULTS AND DISCUSSION

The simulation was conducted during summer (25th of June 2016 at 13:00 pm) where sun exposure, radiation and temperatures are at its maximum. The study during winter was conducted on the 25th of January at 13:00 pm. The studies were set in order to investigate and evaluate different parameters. These parameters include surface albedo, heat exchange coefficient, relative humidity, mean radiant temperature and wind speed. Analyzing the results obtained from the tested parameters is performed.

4. Surface albedo

A simulation for the surface albedo was conducted using ENVI-met to evaluate the changes that occur on the albedo level of different surfaces in winter and summer for conventional roof and green roof systems. To conduct the simulation, different inputs were used for the four cases and simulated in order to produce the output files that contain the results of the simulation. The last step is to present the results graphically using Leonardo program

Figure 8 presents the graphical analysis of surface albedo for the four different cases. It is noticed that surface albedo maximum and minimum ranges did not change between summer and winter time, however it did slightly change between the conventional roof and green roof scenarios. According to the simulation done for Mina Al Arab community, the results do not show any potential for green roofs to reduce surface temperatures that are emitted to the surrounding space. Further studies on a larger area with additional information including the type of the installed materials to the green roof system, the area of leaves and the water content may increase the changes of the simulation results.



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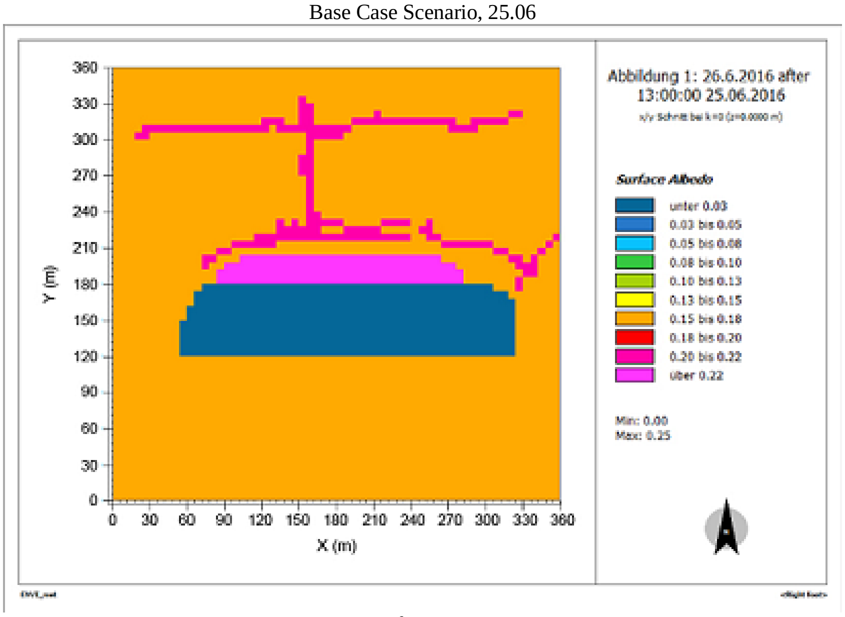

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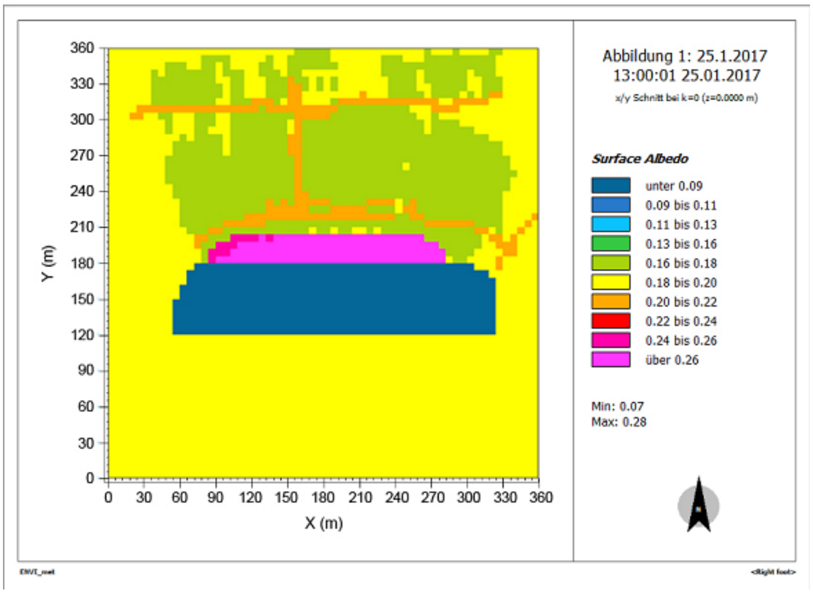

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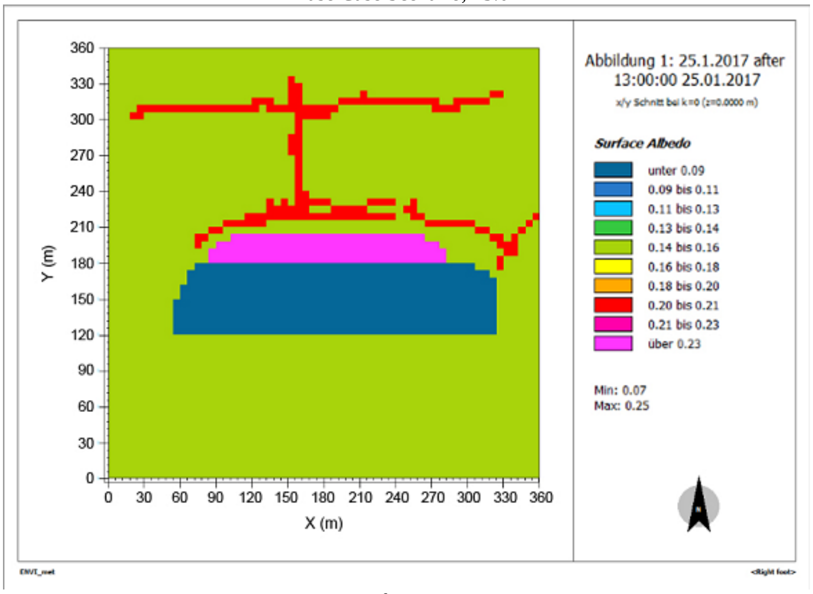

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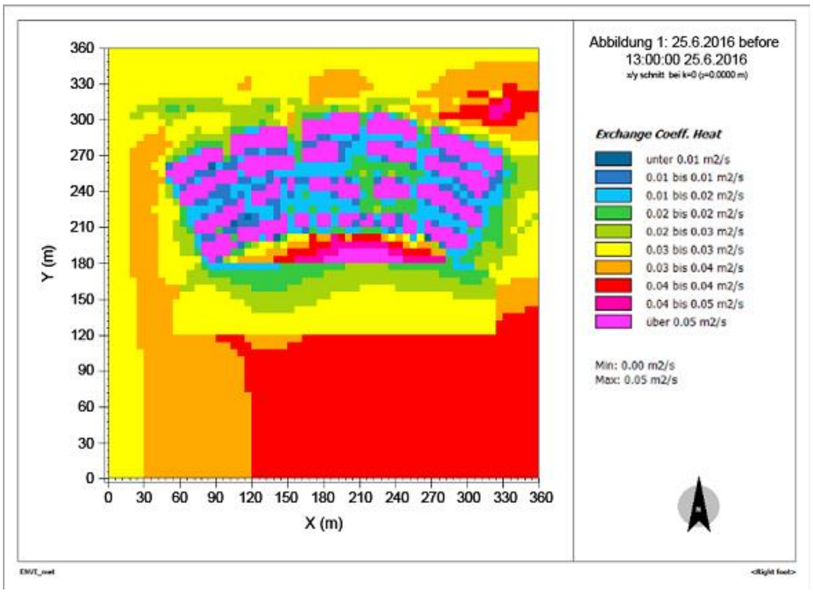
Figure 8. The graphical analysis of surface albedo

5. Heat exchange coefficient

A simulation for the heat exchange coefficient was done to simulate and evaluate the variation of heat exchange levels in the four different cases of roofing systems in the different seasons of the year using the ENVI-met simulation software. As in the previous parameter a simulation was conducted for the different cases producing an output file. The output file is presented using Leonardo rendering software to obtain results and conclusions.

According to the graphical rendering of the heat exchange coefficient simulation results for the different cases shown in Figure 9, the heat exchange coefficient for both the conventional roof and the green roof did not change from summer to winter on the top of the roofs. However, it did change around the building units which means that it affects the surrounding environment and reduces the heat exchange between surfaces and objects. As a result, the potential of using green roofs to reduce the heat exchange coefficient must be considered. It affects the thermal environment of the surrounding area by increasing the comfort zone and it affects the interior spaces or indoor environment.



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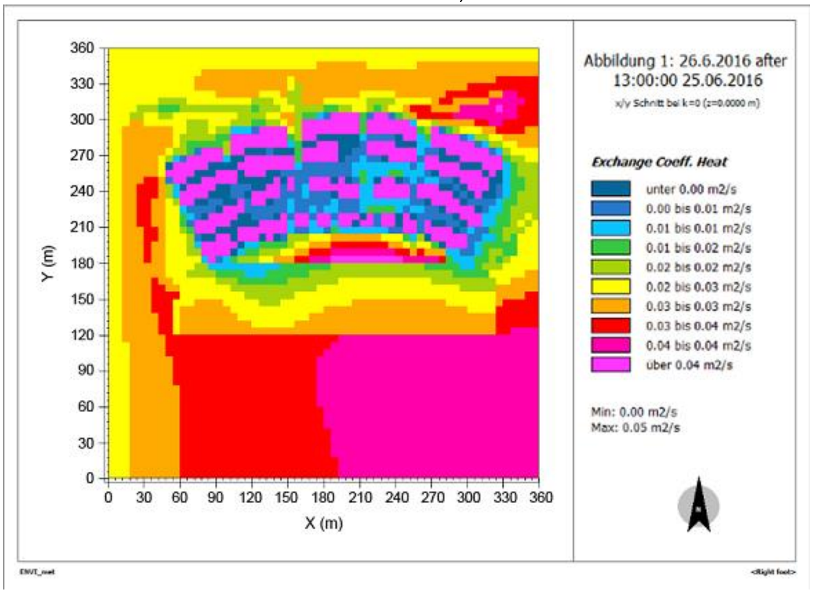

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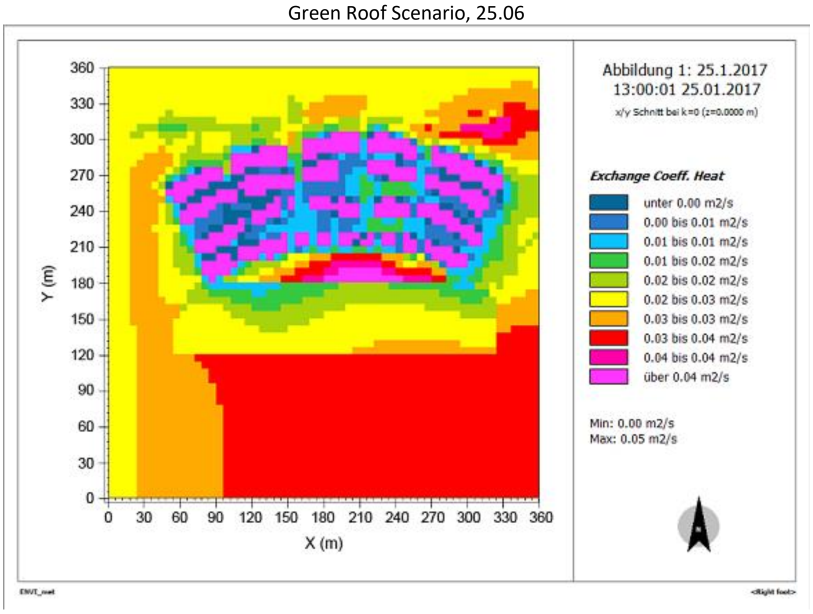

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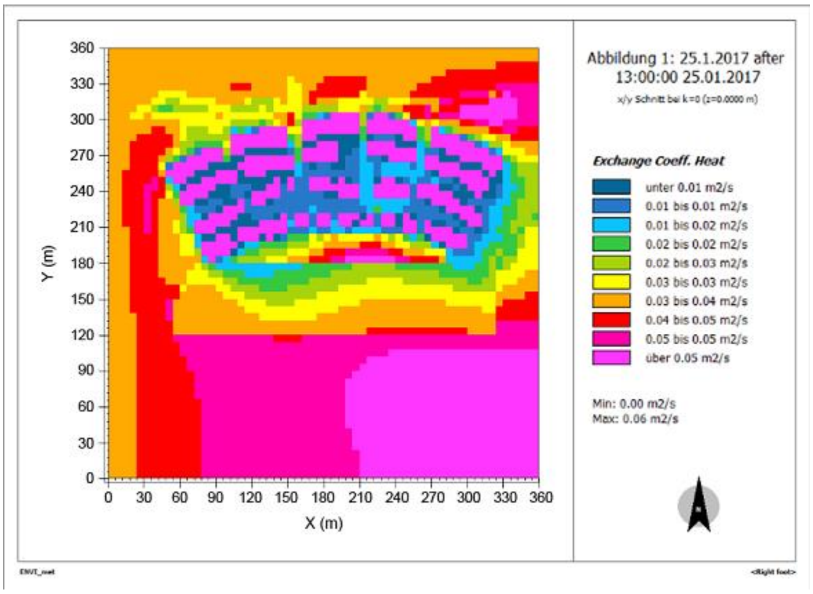

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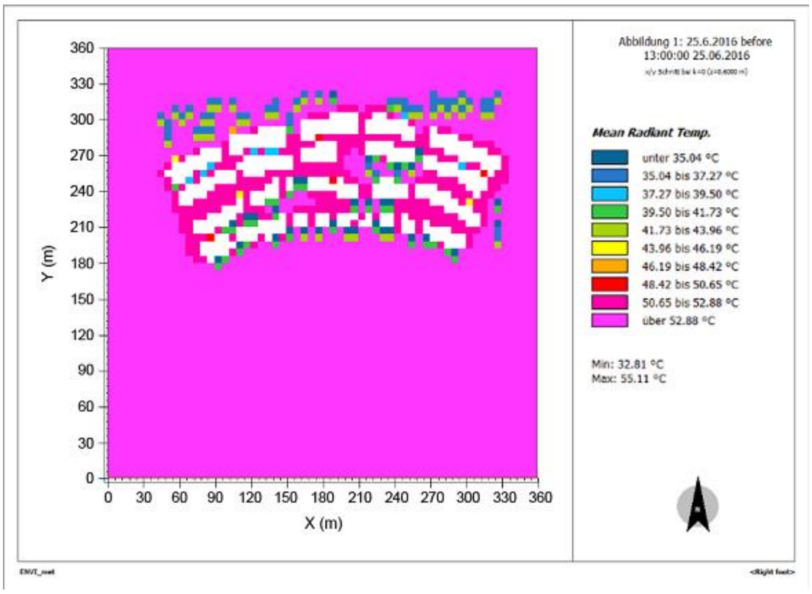
Figure 9. The heat exchange coefficient simulation results

It is essential to consider also that vegetation type and leaf area index can also contribute to the changes in the heat exchange coefficient levels. Vegetation types that are higher in height and have very dense foliage or wide leaves area deliver enough shading on the rooftop that limits or reduces the amount of solar radiation that can reach the rooftop.

6. Mean radiant temperature

Analyzing the mean radiant temperature of the case studies by simulation using ENVI-met software showed the variation in levels between summer and winter, green roof and conventional roof case. To achieve results the simulation was applied to the different cases producing an output file previewed by Leonardo software as shown in figure 10 that illustrates the findings.

The simulation of the 4 cases recorded noticeable changes in the mean radiant temperature levels. The radiant temperature during the summer season ranged from 32 ° C to 55 ° C, but with the integration of the green roof system the radiant temperature ranged from 18 ° C to 43 ° C on the same day, time and weather. For the conventional roof in the winter season mean radiant temperature was ranged between 20°C – 53°C however with the integration of green roof system the percentage of mean radiant temperature dropped to be in the range of 36°C – 52°C. According to the results, the potential of using a green roof system in urban spaces have a great effect on reducing the mean radiant temperature in an urban space. This greatly affects the thermal comfort in the area by reducing the solar waves that are emitting and radiating between surfaces, spaces and the surrounding air. This drop-in means radiant temperature levels, since vegetation surfaces installed on the top of the buildings, emits shorter radiation waves when compared to the compacted hard surfaces and objects like concrete roof used in buildings.



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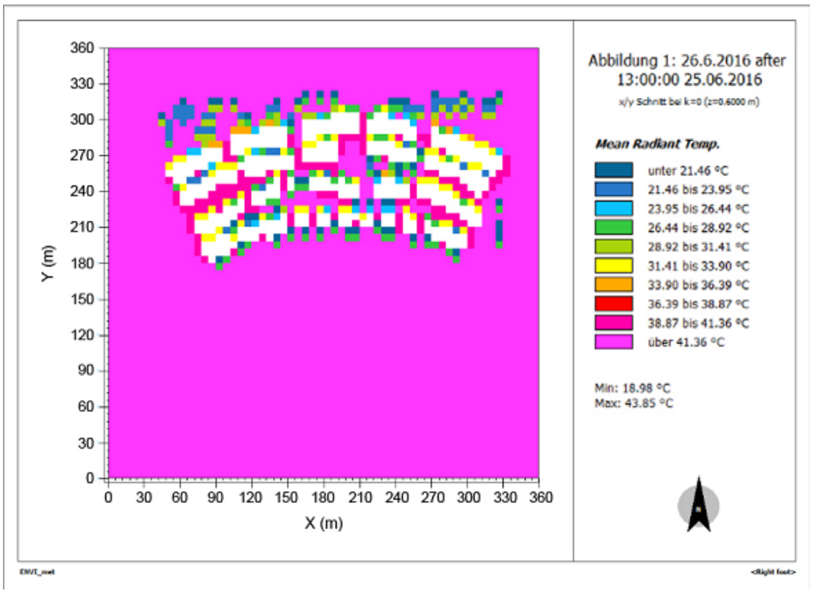

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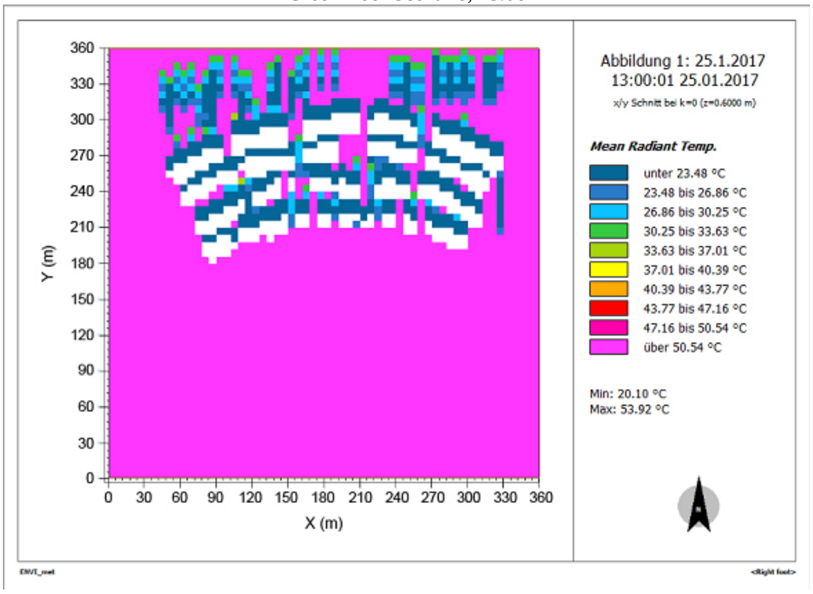

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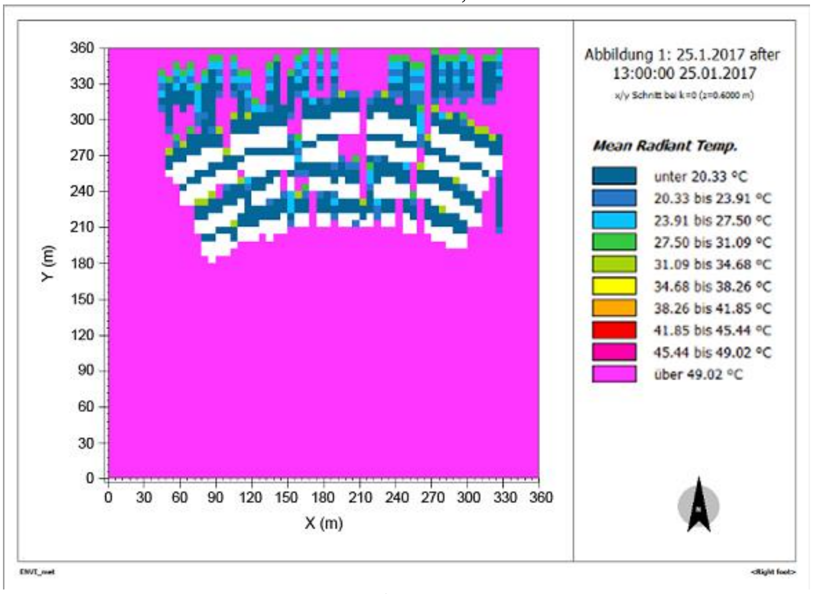

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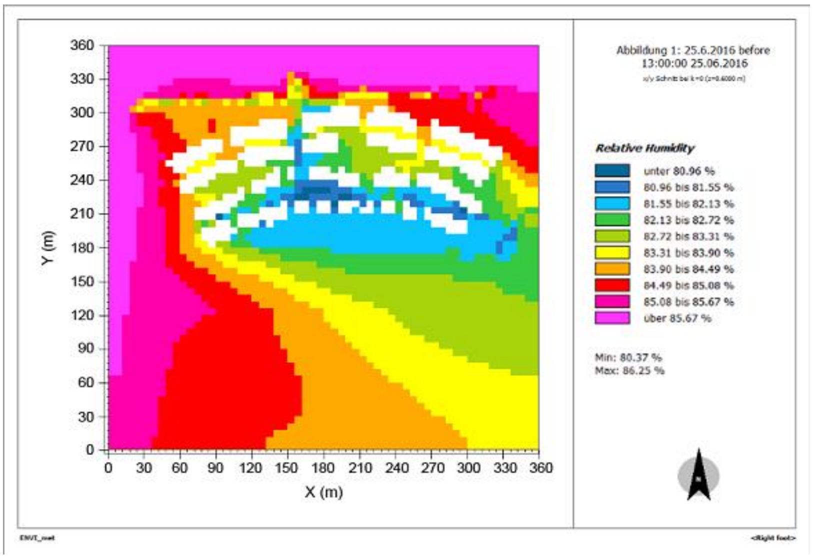
Figure 10. Mean radiant temperature simulation results

7. Relative humidity

According to figure 11 that illustrates the relative humidity levels for the 4 different cases. Relative humidity varied between summer and winter, with conventional roof and with the green roof system.



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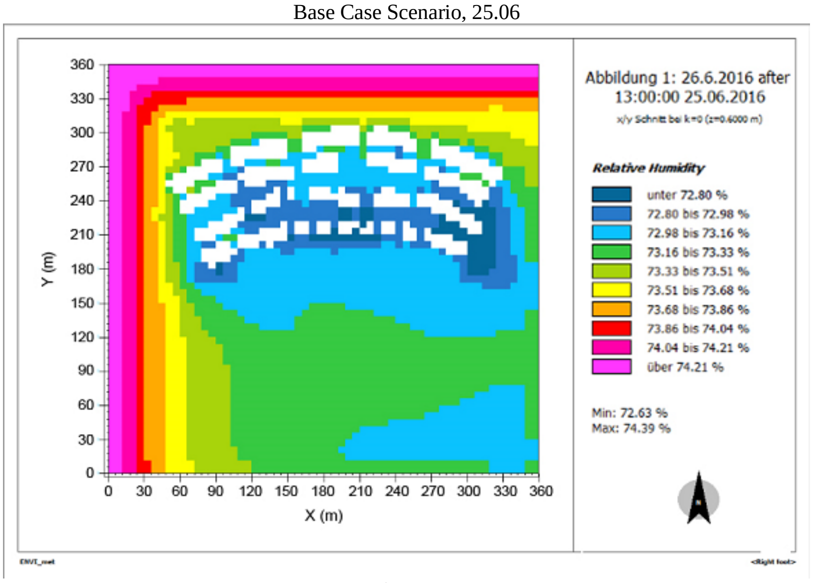

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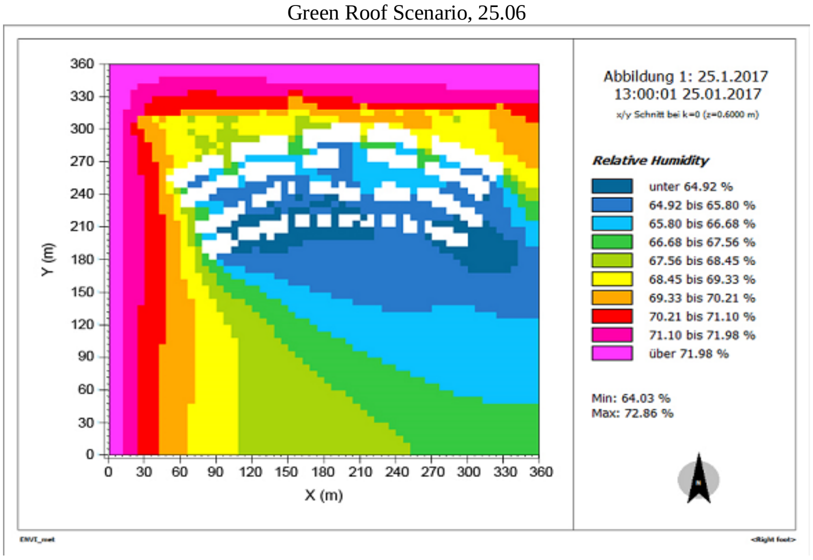

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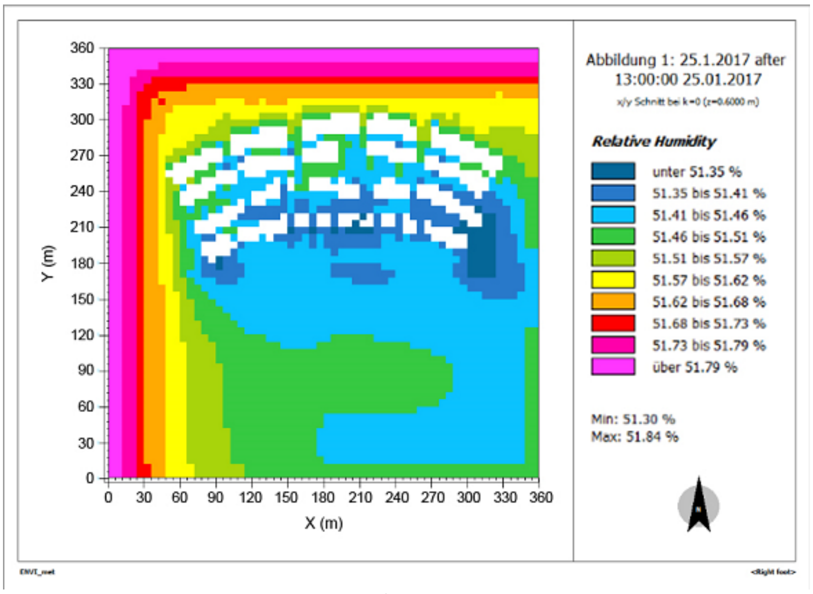

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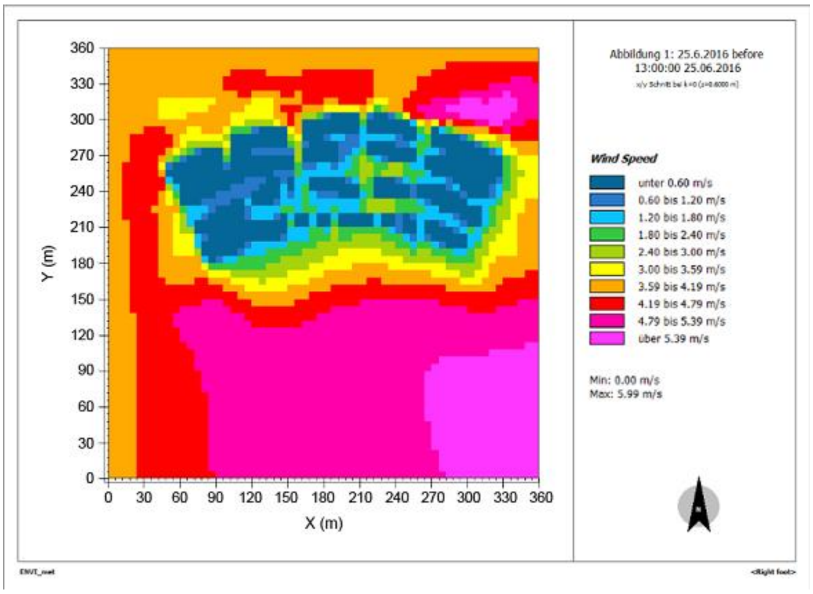
Figure 11. the relative humidity levels simulation results

In the summer season with the conventional roof scenario, the relative humidity ranged between 80 – 86% which records an average of 83%. During the same summer day, time and location but with the integration of green roof system instead of the conventional roof system, relative humidity ranged between 72 – 74% which records an average of 73%. As a result, the relative humidity in summer dropped 10% when the green roof system was integrated. This change in the records increases the potential for using a green roof system to control thermal conditions in an urban area especially during the summer period of the year.

During the winter season, with the conventional roof scenario, relative humidity ranged between 64 – 72% which records an average of 68%. During the same summer day, time and location, with the integration of the green roof system instead of the conventional roof system, relative humidity recorded an average of 51%. According to the results, the relative humidity in winter dropped around 17% when the green roof system is integrated with the urban area selected at 1:00 pm.

8. Wind speed

As shown in the previous simulation of the variable parameters, a simulation for the wind speed parameter using ENVI-met simulation was conducted to show the changes in the levels between summer and winter. The comparison between the different cases presented in figure 12 indicates that wind speed levels didn't change between summer and winter, however it changed slightly when comparing the records between conventional roofing system and green roof system.



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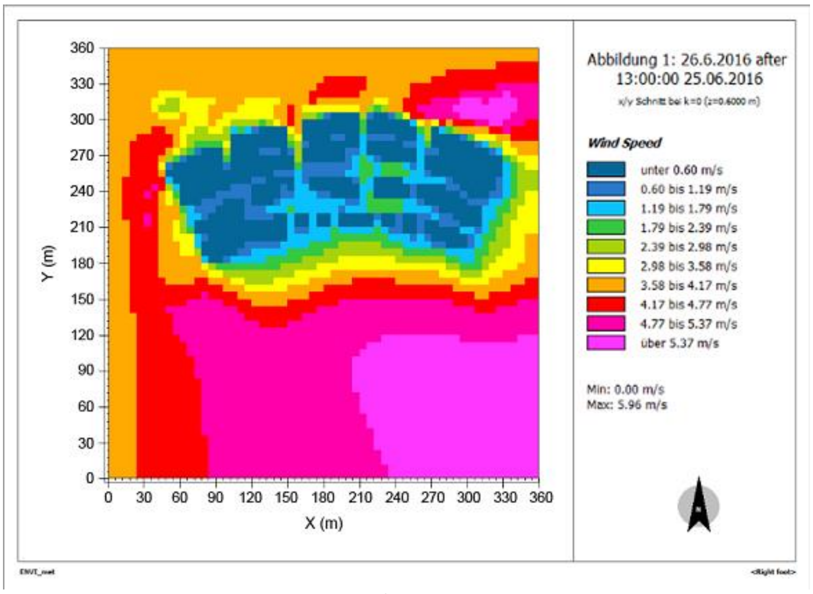

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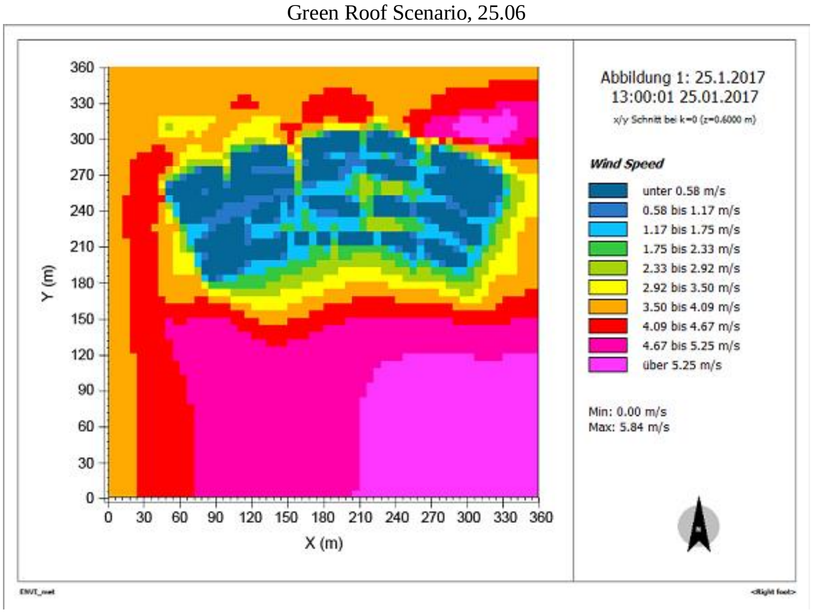

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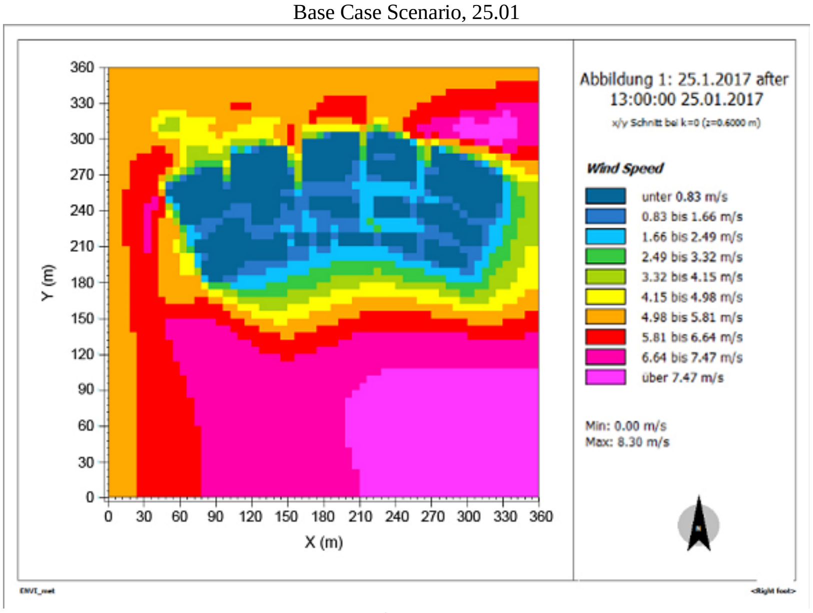

Green Roof Scenario, 25.01

Figure 12. Wind speed simulation results

Wind flow and speed affect the humidity levels which also effects the mean radiant temperature, all these parameters play a marvelous role in controlling thermal comfort in the urban space.

Variation in the floor heights in the urban space also affects the wind speed, flow and pattern. However, this point cannot be considered or determined in this case study where all the units are composed of 2 levels with an average of 6 meters height.

The results of the conceptual model that was conducted for Mina Al Arab urban compound presented evidence and proofs that integration of green roof system highly effects on different parameters that contribute to an enhanced and improved outdoor thermal condition for users.

9. CONCLUSION

This research investigated the integration of vegetation in regions that have hot arid weather like the UAE through ENVI-met simulation software. The simulation using ENVI-met simulation program detected the influence of using green roofs in hot arid climates of Mina Al Arab compound and the potential of integrating this system to the selected area. All the parameters investigated in the research and the outcomes of this research are essential for developers, architects and engineers to promote new innovative methodologies to reduce heat island phenomenon and improve the thermal conditions using green roof systems.

The outcomes that were obtained from the simulation of Bermuda compound area in Mina Al Arab proofed that green roof system has a great potential in mitigating heat island effect and improving thermal conditions by increasing albedo levels of the urban structure surfaces, reducing relative humidity, mean radiant temperature and heat exchange coefficient.

Green roof systems work as an insulation material that can insulate the main roof layer from direct solar radiation as a result reducing longwave radiations and moderate mean radiant temperature through the reduction of exchange heat coefficient. Green roofs when it functions as an insulation system for the rooftop prevent radiation from penetrating the indoor spaces as a result it reduces the demand for cooling and regulates the amount of energy power required for that.

This research showed that when different thermal parameters are evaluated, designers can enhance and improve their designs in order to obtain the maximum levels of thermal comfort and energy saving in any project depending on its requirements and functions.

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