Validation of UWG and ENVI-met models in an Abu Dhabi District, based on site measurements

Citation: Bande, Lindita, et al. "Validation of UWG and ENVI-Met Models in an Abu Dhabi District, Based on Site Measurements." Sustainability 11, 16 (August 2019): 4378. © 2019 The Authors

As Published: http://dx.doi.org/10.3390/su11164378

Publisher: MDPI AG

Persistent URL: https://hdl.handle.net/1721.1/124908

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context sustainability

MDPI

Article

Validation of UWG and ENVI-Met Models in an Abu Dhabi District, Based on Site Measurements

Lindita Bande [1,*], Afshin Afshari [2], Dina Al Masri [3], Mukesh Jha [3], Leslie Norford [4], Alexandros Tsoupos [1], Prashanth Marpu [3], Yosha Pasha [3] and Peter Armstrong [3]

[1] Department of Architectural Engeneering, College of Engineering, UAE University, Al Ain 15551, UAE
[2] Fraunhofer Institute for Building Physics IBP, Fraunhoferstr. 10, 83626 Valley, Germany
[3] Department of Electrical Engineering and Computer Science, College of Engineering, Khalifa University, Masdar Institute Campus, Abu Dhabi 127788, UAE
[4] Massachusetts Institute of Technology, Cambridge, MA 02139, USA
* Correspondence: lindita.bande@uaeu.ac.ae; Tel.: +971-5477-92797

Received: 18 June 2019; Accepted: 1 August 2019; Published: 13 August 2019

Abstract: The city of Abu Dhabi is growing every year in population, urban extent and energy demand. This research focuses on the application of two simulation programs to estimate changes in urban climate associated with continued development in Abu Dhabi: The Urban Weather Generator (UWG) and ENVI-met. Simulation with these two software packages are validated with the site data measured in downtown Abu Dhabi. A comparison analysis (in the different seasons) between the rural data, the simulation output, and the site measurements shows the variations of the UHI in this Middle Eastern city and the potential of the validated tools. The main aims of this study are: (a) to make a seasonal validation of the UWG for the city of Abu Dhabi (referring to urban-rural available data). The tool was previously validated for a year (no seasonal division) for Abu Dhabi, Toulouse, Basel, Singapore, Rome and Barcelona. The simulations are based on the 2016 version of the Urban Weather Generator. The analysis is separated into three main seasons (instead of the full year): winter, spring, summer. (b) To make a seasonal validation and improve the second tool evaluated in this study, ENVI-met 4.0. The software can simulate urban temperature, humidity and wind speed. Guides are proposed for the enhancement of the accuracy of both estimation procedures. Referring to the results, UWG tends to overestimate the canyon temperature during the summer and has a more realistic estimation on the winter season. ENVI-met has better estimations of temperatures during the summer season compared to UWG. Finally, the UWG weather file contributes a more detailed energy model on a mesoscale model. It considers the seasonal effect and shows the impact of the climate on profiling the UHI phenomena. ENVI-met needs improvement in calculating the anthropogenic heat and in calculation of the mean radiant temperature.

Keywords: microclimate; urban weather; UWG software; ENVI-met; site measurements; validation

---

1. Introduction

Abu Dhabi City is developing at high speed and it requires the attention of all the professionals related to urban planning, building construction, project management, local and governmental entities. Abu Dhabi has a hot, arid climate with a fresh winter and a very hot and humid summer. The relative humidity may increase at different times of the day, creating short term urban moisture islands [1]. The thermal properties of the buildings, the streets, the anthropogenic heat (emitted from the traffic and air conditioning waste heat rejection from buildings) are the main contributors to this trapped radiation in the urban canyon. The downtown areas are shifting into car-oriented zones due to the economic changes and the city growth. The need for parking occupies all the internal areas of the majority of the districts. The latest study shows that the release of the anthropogenic heat creates an unstable layer in the lower level of the atmosphere—even during the night—compared to the countryside [2]. Therefore, including the anthropogenic heat, as a parameter in the simulations, is relevant for models prepared for the climate simulations [3,4].

The urban microclimate is strongly connected to the anthropogenic heat released in the canyon. Cities with an efficient public transportation system and a central district cooling plant have a positive impact in improving the urban microclimate [5]. Annual average values show that cities such as Chicago (53 W/m^2), Montreal (99 W/m^2) and Budapest (43 W/m^2) have anthropogenic heat variation from 20 to 40 W/m^2 in summer, and from 70 to 210 W/m^2 in winter. The anthropogenic heat and the traffic schedule follow the same graphic distribution, having one peak in the morning and one peak in the evening [6].

Abu Dhabi has developed rapidly over the past 60 years. During this time the urban settlement has grown from the main island towards the desert. The buildings located on the main island are mostly above 10 floors in height. There are several districts with different building typologies. However, high-rise buildings in the downtown area, contributing to an increase of the UHI (Urban Heat Island) values, are gradually replacing low-rise buildings. The hot, arid, countries have very specific weather conditions with summer air temperatures that can reach 50 °C, therefore, the built environment has a strong impact on increasing the air temperatures within the city [7,8].

The internal part of the majority of the downtown districts has medium rise residential buildings. From the material and the façade architecture, the different building age is easy to recognise. In the older buildings—built round 1990—the windows are smaller and are inserted inside the façade wall. In the buildings built after 2000, the buildings have a fully glazed façade. In the perimeter, two of the older buildings have been demolished and a new office/residential building will be built. The same process is happening as well in other similar districts. In a hot, arid, climate city such as Abu Dhabi, the decisions made in the urban planning scale influence the building scale [9].

The urban data has relevant importance into studies connected to the UHI phenomena, energy saving in buildings, and urban energy [10]. Given the primacy of sensible heat exchanges, the urban air dry-bulb temperature is an important parameter in all building energy simulations. The UHI phenomena have been studied for decades and there have been several attempts to determine air temperature data, which is closer to the urban reality than the rural, Typical Meteorological Year, data, used in standard building energy simulation software. Unzeta et al. developed a software that estimated the urban air temperatures based on a rural weather file [11]. The tool is user-friendly. There are some steps to follow during the installation. The initial information such as the city location, the north orientation etc., is relevant for the outcome of the simulations. The UWG can calculate the air temperature in a neighbourhood by considering the prevailing urban environment. The canyon properties, the building materials, the building schedule etc., define the intensity of UHI [12].

The boundary conditions are crucial for building the model before it goes into the simulation process. A study conducted in Sydney through ENVI-met shows the numerical equations used in creating micro-scale models that show the surface interaction (different surface typology) [13]. UHI can be analyzed with different CFD (Computational Fluid Dynamics) software. The highest intensity of UHI occurs three to four hours after sunset in the commercial areas. This is a result of the temporal variation of the urban canopy level of UHI intensity in the city of Singapore. This study shows that the UHI intensity has a significant seasonal variation [14,15]. Previously, ENVI-met 4.0 was used for a research in Bilbao [16].

Recent studies have shown an improvement in both the modelling part and the post-processing part of the ENVI-met simulations [17]. Energy software, such as Energy Plus, has improved the energy simulation scale of detail. The site data are crucial to define the scale of accuracy of the results [18].

The mitigation strategies efficiency is connected to several factors, including the climate zone of the case study. Vegetation is one of the most efficient mitigation strategies; therefore, there have been a large number of studies done in different climate zones [19]. The air temperature can be decreased by up to 0.5 °C by adding vegetation in urban canyons. Such a result is based on the analysis of six variables (surface albedo, sky view factor, altitude, shrub cover, tree cover and average height to floor area ratio) using a regression model [20]. The city's development with a high density of buildings generates an increasing heat island phenomenon [21]. Different materials used for the streets, pavements, building facades, and rooftops, absorb the heat from the direct solar radiation and release it during the night, causing an increase in the air temperature into the urban canyon. In certain cases this value might reach 2 °C [22]. The Abu Dhabi 2030 is one of these initiatives and an Estidama rating system (a local equivalent rating system of LEED) is applied in the latest development plans of the city with the aim of producing a sustainable city [23].

The main objectives of this research are:

(a) To make a seasonal validation of the UWG for the city of Abu Dhabi. The UWG has been partially validated for the city of Abu Dhabi (no seasonal study), for the city of Singapore and previously for the cities of Toulouse, Basel, Rome and Barcelona [24–26]. The accuracy and the calculation method has been recently improved [24]. It can be used to estimate the UHI effect and building energy consumption at a neighbourhood scale considering the green area, the density of the buildings, etc.

(b) To make a seasonal validation of ENVI-met 4.0 for the city of Abu Dhabi. Previous validation for such a climate has not been conducted. Considering the usage of such a tool by architects and urban planners the results of this study has a relevance to the region. The models are prepared based on realistic data from the material collected and from the site survey. The accuracy of the models, and boundary conditions, bring results close to the site data. The results are compared with the version 3.1 and the site measurements.

(c) To estimate the impact of the anthropogenic heat into the air temperature and correct the results of the ENVI-met accordingly. This correction is also relevant for the calculation of the PET (Physiological Equivalent Temperature), where ENVI-met is massively used (as a post-process of the air temperature calculation, the increase of the anthropogenic heat has an impact on the increase of the UHI [25]).

The validation in point (a) and (b) is done for the three main seasons: winter, spring, summer. Autumn has similar behavior with spring, therefore it was decided not to include this season as part of the analysis This research is an attempt to provide more detail on the differences of the UHI in these three seasons, and to analyze the accuracy of the UWG and ENVI-met.

2. Methodology

The research field concerns the urban planning in new cities and the strategies for the mitigation of the Urban Heat Island Effect. Since the case study is situated in the Middle East, the building typology and characteristics are related to the specific climate zone. The several scenarios considered in the UWG simulations are based on the historical use of trees and shading, in a district area of a typical Middle-Eastern City [25].

Initially, a site survey was conducted to compile the construction characteristics of the buildings, the district urban location, the street pattern, the location of the green areas, the number and type of the trees, the parking lots, and the number of cars at the peak hours, etc. The UWG simulations principle is based on equations that do not require relevant time in calculating the results (hours). The input parameters are similar to the ones of the ENVI-met models (building materials, pavement properties, green areas). ENVI-met, on the other hand, does not include the anthropogenic heat as an input parameter. However, ENVI-met is a CFD (computational fluid dynamic) software and provides a level of modelling accuracy that UWG lacks. Therefore, the results of UWG and ENVI-met have a different scale of precision [26].

Measuring the site data (air temperature, relative humidity, wind speed) from the downtown area of Abu Dhabi proved to be difficult. Foreign citizens, who move very often, mainly inhabit the city center. The installation of the node (multi-level unit of sensors) network was challenging, considering the climate of Abu Dhabi. Nonetheless, the sensors registered reliable data that is used in this validation. Although there were several sensors (air temperature, relative humidity, wind speed) installed on the main island of Abu Dhabi, in the calibration/validation process, only the ones that presented the most stable and reliable measurements were used. However, the results are informative and can be interpreted in different application contexts. Furthermore, the measured data files were displayed as a user-friendly tool in order to make the validation process faster.

This study proceeded as per the following steps (referring to Figure 1):

2.1. The case study,
2.2. The rural data,
2.3. The urban data,
2.4. Urban Weather Generator file creation/simulations,
2.5. ENVI-met model creation/simulations,

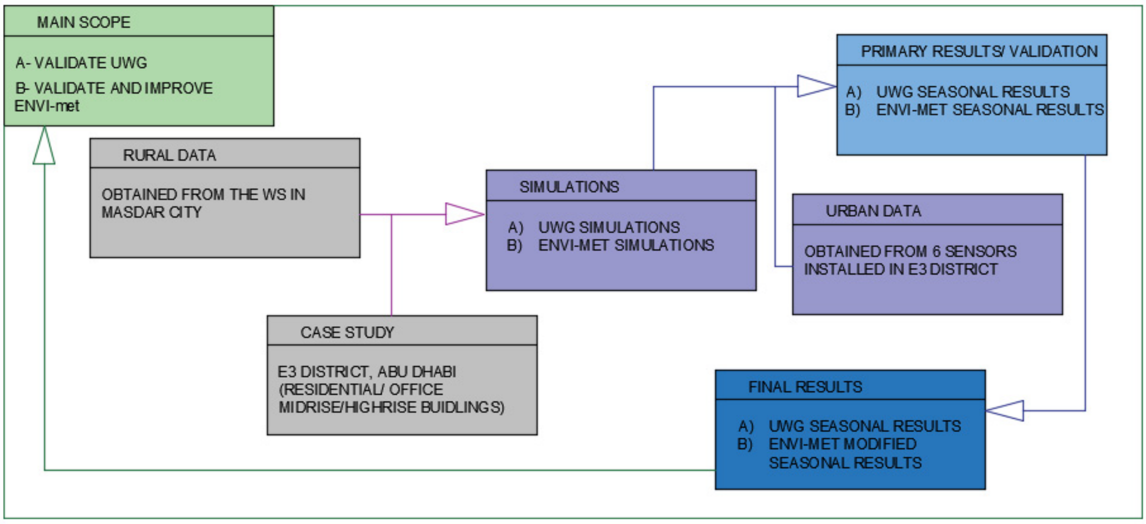

Figure 1. Flow Chart of the methodology followed in this study.

2.1. The Case Study

The case study taken into consideration for this research (due to the available data: air temperature, wind speed and relative humidity, measured in the same district) is located on the main island of Abu Dhabi, surrounded by the streets of Zayed the First Street, Sultan Bin Zayed the First Street, Fatima Bint Mubarak Street and 5th Street. This is a representative district among others with similar properties, characterised by high-rise residential, hotel and office buildings on the borders of the area, and low-rise residential buildings inside the area. The site was visited and measurements were taken. There were meetings with residents to determine the occupants' behaviour. Based on the information taken from the Abu Dhabi Municipality and from the site verifications, Table 1. was produced as a basis for the simulations done in this study.

High residential and office buildings create a barrier to the external conditions surrounding the district. This influenced the temperature values on ENVI-met. This barrier has an important role in the CFD simulations due to the adaptation time of the boundary conditions. Decision-making must analyse many factors and one of them is the Heat Island Effect. In this case, this study aims to prove that by making such interventions on an urban scale there can be a significant impact on a building scale. The city of Abu Dhabi is being transformed every day. Despite the architectural and construction studies—the urban planning analysis is crucial. A detailed urban model at a mesoscale level can improve the building's energy consumption calculations.

Since Abu Dhabi is a developing city, most of the inhabitants work in the construction sector and, more recently, the services sector. This influences the templates in terms of occupancy. Also, based on a previous survey done in the area, the inhabitants of the buildings in this district are mostly non-UAE citizens [27]. The highest range of the cooling load is in the evening time due to the occupancy of the buildings. Furthermore, parts of the building are an elementary school and a mosque. There are open parking plots over all the free areas (occupied by buildings or streets). The biggest buildings are oriented in the southern and northern part of the district. In the southern part, the building line creates shading over the parking lots. The pavement used in the district is a standard pavement, and the asphalt does not have any special characteristics for mitigating the UHI [27,28].

The site survey was crucial in understanding the district changes, building typology, street materials, etc. [29]. Defining the distance between the buildings, their heights and their occupancy schedule is related to the heat released to the canyon from the AC units, which in some cases (older buildings) are on every floor. The older buildings located in the centre have frames around the windows and the balconies come forward compared to the façade wall. The space dedicated to the parking lots and the space dedicated to parks and common areas can also be noted. The surrounding areas help understand the height of the buildings in the case study area and makes a comparative case of the district typology.

Table 1. District characteristics.

Description (Areas in m^2)	District E3
Typology	Medium and High-rise Buildings
Number of buildings	70
Maximum number of floors	20
Minimum number of floors	5
Maximum border dimensions	582 × 331
Total area	193,819.0
Building area	46,651.0
Building area in %	24.7
Asphalt area	93,992.0
Asphalt area in %	48.5
Paved area	53,176.00
Paved area in %	28
Existing number of trees	24

2.2. The Rural Data

The rural file is the base used in the UWG simulation. The data used for this validation is taken from the weather station of the Field Station—an isolated laboratory building near the Abu Dhabi airport, located 28 km from downtown. The area is surrounded by a desert that connects Abu Dhabi to Dubai and Al Ain. This station undergoes regular maintenance to ensure data quality and continuity. Some tests were done with the TMY weather, from the nearby airport weather station, taken as a rural reference. However, since this validation is done for the year 2016 to 2017 (when the downtown sensors were operating), it was decided to use the Field Station's rural measurements exclusively.

The rural station is part of a rural network of weather data stations such as the Beam Down and the Wind Mast. They surround the Masdar City area. The stations have different scopes in taking the site measurements and their sensors are installed at different levels. In this study, the Field Station, which has sensors for air temperature, wind speed, DHI (Diffuse Horizontal Irradiance), GHI (Global Horizontal Irradiance), at two and 10 m from the ground level, is referred to. In the next five years, this area, now considered as rural, will be developed with new buildings, mainly residential. However, for this 2016 to 2017 study, the field station records rural data [30].

2.3. The Urban Data

The measurements used in urban districts in Abu Dhabi are denoted Phase I and Phase II. The six nodes in Phase I were installed in the E3 district in summer 2016. The Phase II nodes (20 units) cover surrounding districts near E3. The site measurements taken in this Phase II, are used mainly to validate the ENVI-met model, comparing it with the UWG Urban Weather Generator, and estimating the contribution of the anthropogenic heat to the air temperature in the E3 district (as a representative district of the downtown area) [31]. The district typology selected in this analysis, E3, features mid-rise and high-rise buildings, and has a structure similar to the majority of the districts in downtown Abu Dhabi. The 3D of the district is shown in Figure 2. The number of the nodes was six. Each node had four levels of sensors. The nodes were placed in the middle of the urban canyon with an equal distance from both sides of the surrounding buildings. Figure 3 shows the rural and urban locations of the sensors.

The main purpose of the downtown sensor network is to measure temperature, relative humidity, DNI and GHI. This real data is used to validate the energy and CFD models developed in the laboratory. Sensors are carefully positioned on different urban sites (normally distributed all over the district). The sensors have direct access to the urban canyon. The sites are inspected every two weeks in order to check the condition of the sensors [32]. Figure 4 shows network of the nodes installed in Abu Dhabi main island, specifying more details about their installation and the distance from the canyon, etc. As is customary in such measurement campaigns, there were some technical problems, for example, one of the sensor's solar panels, previously exposed to the sun, was under the shade of a new building for most of the day. The 3D model in Figure 2 shows the district physiognomy, and the orientation toward the northern position. The main typologies of the districts where the buildings are located are villa district, high-rise district, high-rise/mid-rise district and mid-rise district [33–37].

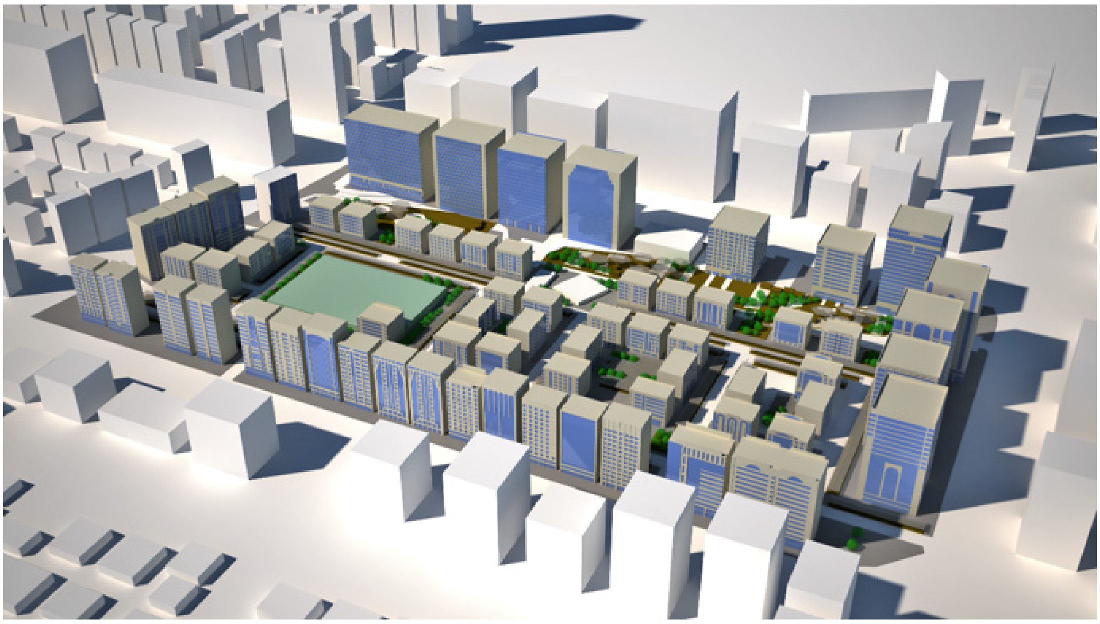

Figure 2. 3D view of the E3 District taken from the east façade.

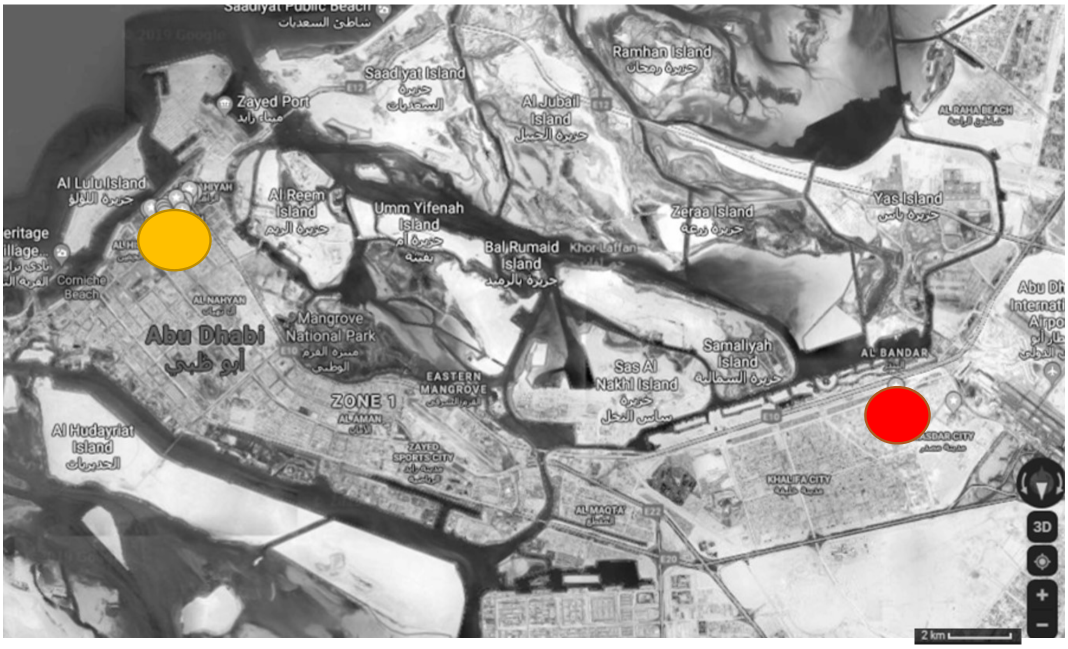

Figure 3. The location of the rural weather station (orange circle) and urban sensors (yellow circles).

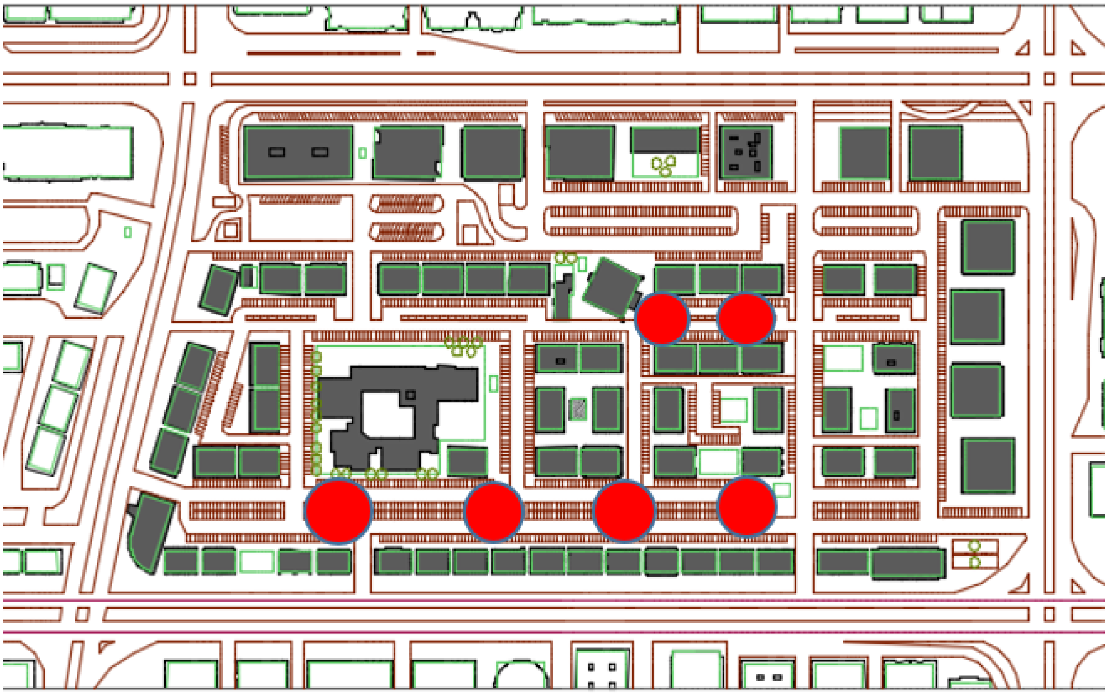

Figure 4. Sensors locations (red circles, scale 1:1000).

2.4. The Urban Weather Generator

The Urban Weather Generator (UWG) is an MIT-developed simulation program that estimates UHI phenomena. In this research, the weather files created with the UWG will be compared with the urban and the rural data for the specific periods of time taken in the study, which is autumn (2016). The UWG considers average characteristics of the urban area such as the building height, the surfaces parameters, the building characteristics, the anthropogenic heat, etc. This brings the results closer to the real conditions in an urban environment, which can be beneficial not only to urban planners and architects, but also to other professionals that need to run the energy simulations of a building located inside the city. The rural weather file is the main input to the rural UWG software [11]. Other inputs are city location, the urban parameters, the district parameters and the building parameters. Building parameters (Table 2) include the wall and roof packages with thermo-physical characteristics such as heat capacity and thermal conductivity. The urban parameters (Table 3) include the urban road characteristics and the anthropogenic heat emitted into the canyon. The values shown in Table 4 are an average for the residential district based on a recent study. Commercial and office districts show higher values of AH. District parameters include the use of the buildings, the average height, the built area ratio, vertical-to-horizontal built ratio, the vegetation density, etc. [38,39].

Other considered parameters are the air conditioning efficiency and the fraction of the waste heat released into the urban canyon by the chillers. UWG has been previously validated for Toulouse, Basel, Singapore, and for Abu Dhabi (however, on a one-year cycle). The sessional validation of the UWG in Abu Dhabi (with its special type of climate) contributes to a complete characterization of the software's applicability. Some UWG inputs were kept at their default values (such as soil properties and albedo of the pavement) but the main characteristics of the walls, windows, roof, and urban planning are specific to this district. An important input value that UWG considers when generating the weather file is the vertical-to-horizontal built ratio (VHu), which was calculated to be 2.2. Figure 5 shows a typical urban canyon with the factors included in the UWG calculation (materials of the buildings, road, vegetation, AH due to traffic). Detailed information about the code is given in the annex section [24,30,40,41].

Table 2. The building parameters [33].

Description	**District E3**	
Typology	**Medium and High-Rise Buildings**	
Building use	Group 01	Group 02
Total Distribution	38%	34%
Glazing ratio	0.5	0.25
Window U-value	2.4 W/m^2	3.88 W/m^2
Cooling set point	22 °C	22 °C
Cooling COP	2.5	
Glazing ratio	0.5	
Cooling setpoint	22	
Building albedo (walls)	0.5	
Building emissivity (roof and walls)	0.91	

Table 3. The urban parameters [2].

Description	**District 3**
Non-Building Sensible Heat (W)	11
Non-Building Latent Heat (W)	0
Urban Road albedo	0.165
Urban Road emissivity	0.95

Table 4. Building typology distribution [29].

	Distribution of the Building Typologies						
	Residential	**Commercial**	**Offices**	**Restaurant**	**Hotel**	**Hospital**	**Common Areas**
Group 01	8.7	2.4	1.8	0.1	1.4	0	1.3
Group 02	54.5	6.5	12.7	0.6	9.7	0.3	9.7

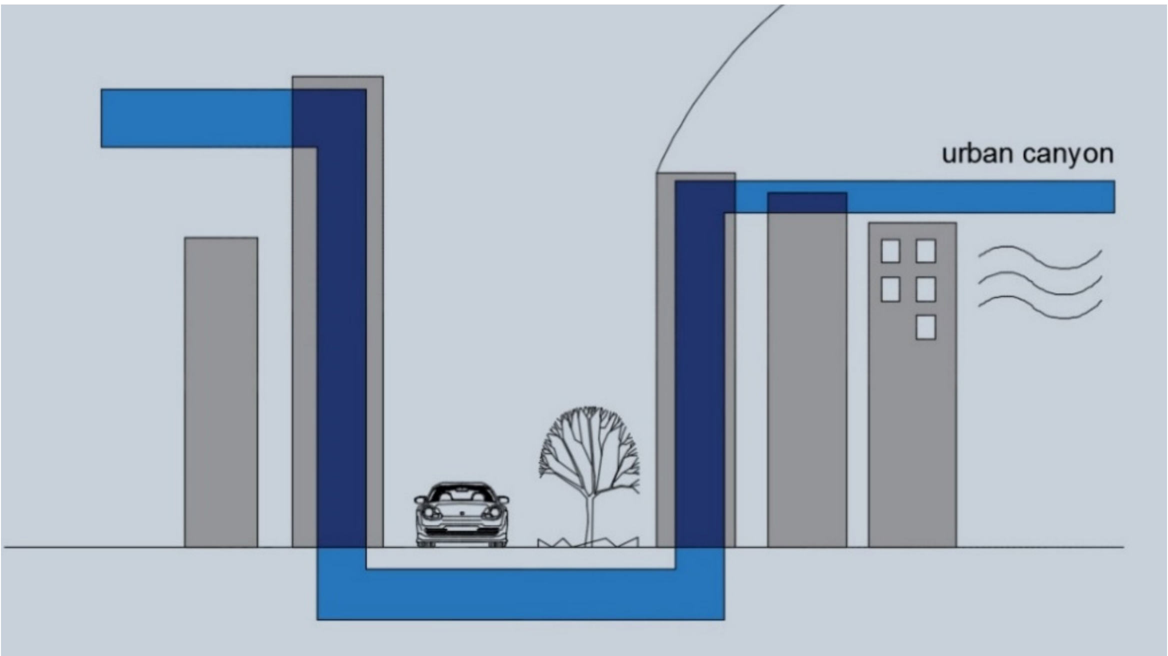

Figure 5. The UWG simulation parameters [11].

The anthropogenic heat calculated in the simulations is based mainly on the literature (Table 3) [2]. The calculations of the anthropogenic heat levels in the city of Abu Dhabi is an ongoing project. There have been attempts using satellite images to calculate the number of cars during a certain hour of the day in different seasons. This methodology indirectly calculates the anthropogenic heat emitted from the cars. The BTEX method uses the volatile organic compounds to define the anthropogenic heat profile in the city of Abu Dhabi. As there are several sensors measuring the air quality in the main island, this method gives reliable results for the city. The top-down method is used to calculate the AH levels and the calibration is done through the bottom-up method based on the satellite images of the area under study [2,40,42].

Figure 6 shows an estimation of the traffic-related anthropogenic heat rate in Abu Dhabi [2]. These values are taken as a base for the UWG simulation with different scenarios in order to understand the impact of the AH on the air temperatures. The peak during the working days is in the morning at 8.00 a.m. and in the evening time at 9.00 p.m.; while at the weekend, people tend to use their cars during the evening [2].

Table 4 shows a distribution of the building typology in two separate groups: Group 01 and Group 02. Each includes a range of building types: residential, commercial, offices, restaurant, hotel, hospital and common areas. Group 01 buildings are mainly medium rise (offices) and use single-glazed windows (Table 2), while Group 02 has double-glazed windows and includes mainly the high-rise buildings built after 2000 [29].

Table 5 shows the six different scenarios that highlight the impact on urban temperatures of AH, vegetation and shading devices. The main scenarios for the three seasons that are considered in this study are: including the Anthropogenic Heat (UWG01); excluding the Anthropogenic Heat (UWG02); including only AH released from the AC (UWG03); including only the AH released from the cars (UWG04); including an increase in the vegetation (UWG05); and including an increase in the shading devices (UWG06). The main seasons compared are summer 2016 (month of June), winter 2016 (month of December), and spring 2017 (month of March). These are the seasons that have a bigger impact on the city life and outdoor thermal comfort. Another reason for selecting these specific seasons is the available urban weather data due to the remote sensing network installed in Abu Dhabi Main Island. The spring of 2017 was not a regular season, with the amount of rain being uncommon for the city. It shows an interesting behavior of the software in this study. Furthermore, the simulation of the ENVI met refers to one day (24 h profile) and the boundary conditions are an average of the same period of time that the UWG was analyzed [34].

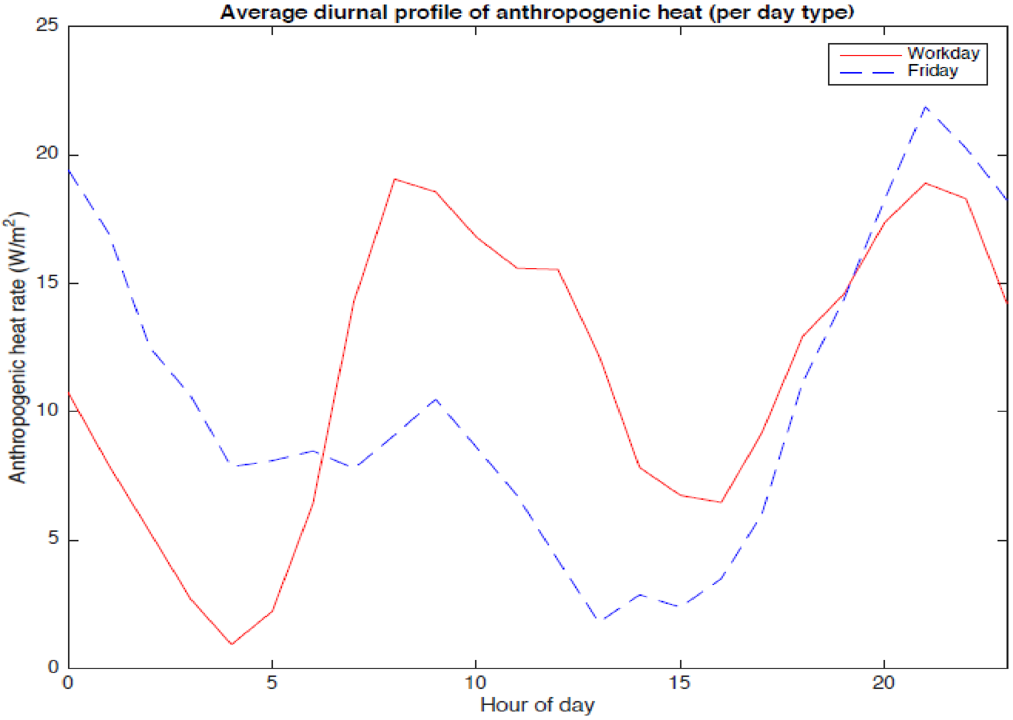

Figure 6. Average daily profiles of traffic related anthropogenic heat rate in Abu Dhabi [2].

Table 5. The different scenarios analyzed in UWG.

Season	Scenario 01	Scenario 02	Scenario 03	Scenario 04	Scenario 05	Scenario 06
Autumn (2016)	Including the Anthropogenic Heat	Excluding the Anthropogenic Heat	Including only AH released from the AC	Including only the AH released from the cars	Including an increase in the vegetation	Including an increase in the shading devices

2.5. ENVI-Met Models

Figures 7 and 8 show the 3D model in ENVI-met of the 15 buildings (a portion of the district). The urban shading devices cover the parking lots and the inner parts of the district. These structures are positioned at two different levels to improve the wind flow. The distance between the buildings can sometimes reach 10 m, and in other cases more than 40 m.

Before starting the work in ENVI-met, there was a pre-processing phase of the district in AutoCAD. In this program, version 4.0, it was possible to rebuild the full district based on a bitmap image taken from an AutoCAD file. The image stays as a base. The scale is adapted according to the pixels of the program. Each pixel represents 4 m in the plan in order for the full district to fit in the model of 180 × 180 [35]. Two files were built: the base file is the one closest to the real conditions, and the second file is the one with the inserted shading devices.

The models were built in the map area, then brought into the simulation settings where various lists of parameters were set. In the map area, the streets, their materials, the pavement and asphalt, and the building typology and height are defined. Here, the model is being built in 3D in parallel with the 2D plan. Since the heights of the buildings varies, there is a scale factor applied to the 3D in order to have a lighter version of the model. The size of this model is 180 × 180 grid cells. The second uses a more detailed scale in the ENVI-met software (the lowest resolution is 100 × 100 and the highest is 250 × 250) [26].

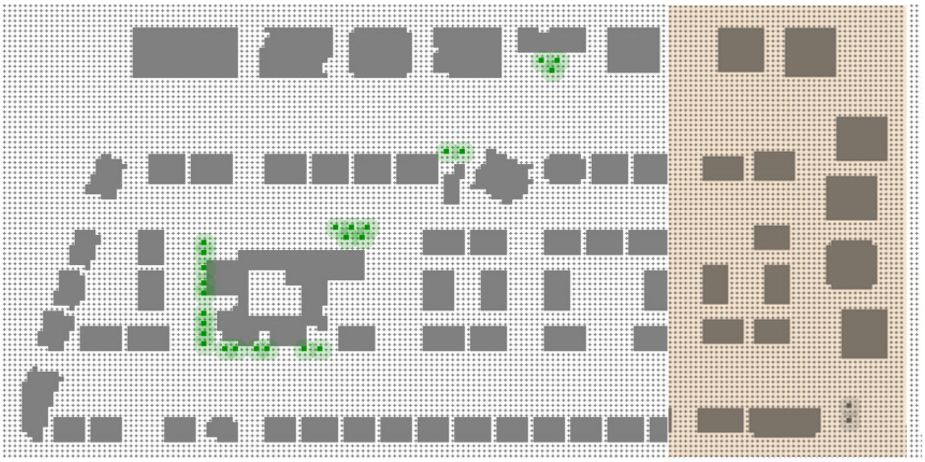

Figure 7. ENVI-met plan view. The grey and the beige area represent the full district. The beige area is the detailed model in ENVI-met.

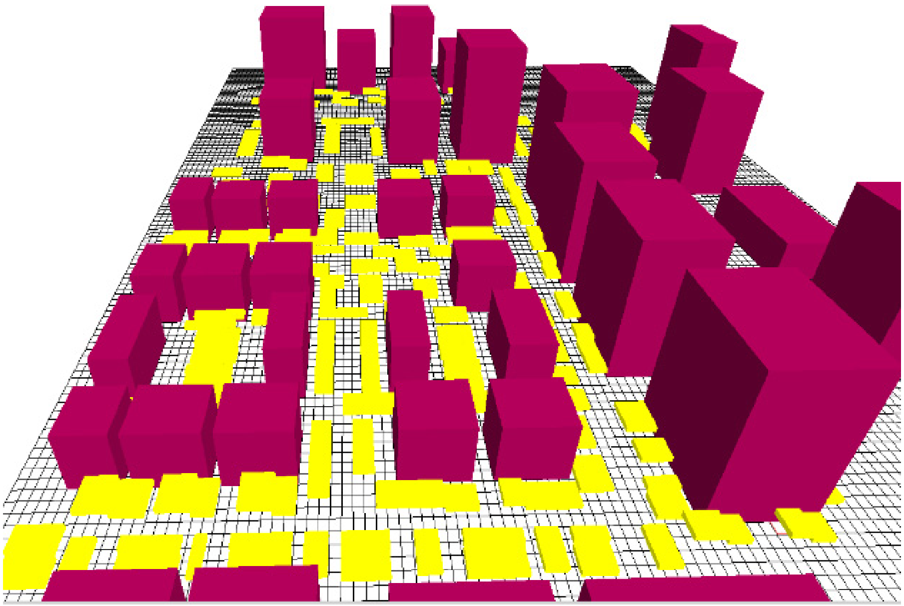

Figure 8. E3 District. ENVI-met detailed 3D model, the urban shading devices are shown in yellow and the buildings in red.

There were some difficulties in applying a wide range of materials to the surfaces. At this point, the program must improve the capacity of modifying the materials (in this case, the soil materials, in order to improve the heat fluxes, are referred to). In the other following step the models were prepared for the simulation process. The boundary conditions were one of the important steps. The files were provided from Masdar for the year 2016. Then, other parameters, such as the location and the specific day of the year to run the simulation, were specified, and then the simulations carried on. The simulation day was calculated based on the equinox, when there is a larger difference in the angle of the sun. The boundary conditions for the three seasons are shown in the Annex section.

It is important to mention that the soil properties used from the software were increasing the mean radiant temperature into the canyon and therefore, after several trials, the soil was re-modelled. The layers composing the soil have different thickness from the standard material given in the ENVI-met materials and are closer to reality. Therefore, a new type of soil was created. The asphalt was recreated, as the one in the template did not consider the heat fluxes in the different layers of the asphalt, such as the gravel and the sand underneath [36]. According to a study done in Singapore, the top layer of the soil has its worse performance during dry conditions. According to a second study done in Melbourne the soil layers are responsible for an over prediction of the ratio of sensible to latent heat flux due to a limitation in the vertical moisture transfer. As a result, the top layer dies too quickly [37].

The walls of the buildings do not have window divisions, however, there is a new wall with average characteristics. The green shading is assumed to be a tree created with the characteristics of local trees, a height of 5 m, and a root system that can take water from the soil. The thickness of the tree is 1 m—while in reality it might reach 0.5 m, assuming the planting of the specified types of plants. The shading devices (urban structure that shade parts of the streets) in this model are not linear, but are interrupted in order to improve the air circulation and bring the model closer to the real conditions [38].

The main changes mentioned in this section are grouped in Table 6. The irrigation profile is set on the boundary template, although the type of irrigated soil is set initially in the modelling part of the study. The post-processing activity in this research is focused on averaged values at the heights of 2 and 10 m.

The main inputs for the simulations are shown in Appendix A. Although the values in Appendix A mention a 24 h profile, the simulations can run for an estimation of 48 h. The time consumed for each ENVI-met simulation (two weeks on average), due to the size of the model 180 × 180, guided this study into the results of the first 24 h.

Table 6. ENVI-met main changes.

Size of the Model	Modified Materials	Boundary Conditions Changes	Post-Processing Activity
180 × 180 cells	Soil profile Pavement Asphalt Buildings wall	Irrigation profile Soil thickness Cloud distribution	Air temperature 2 m Air temperature 9 m

3. Results

Figure 9 shows the results of the winter season. The results of the spring season are shown in Figure 10 and the summer season in Figure 11.

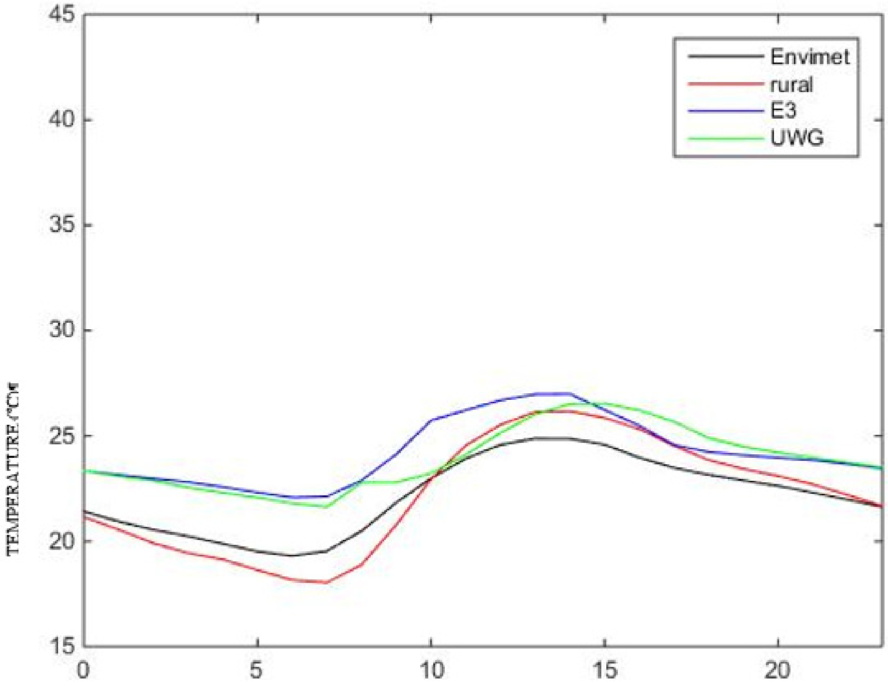

Figure 9. ENVI-met results compared to the urban and rural data for the winter (December) 2016.

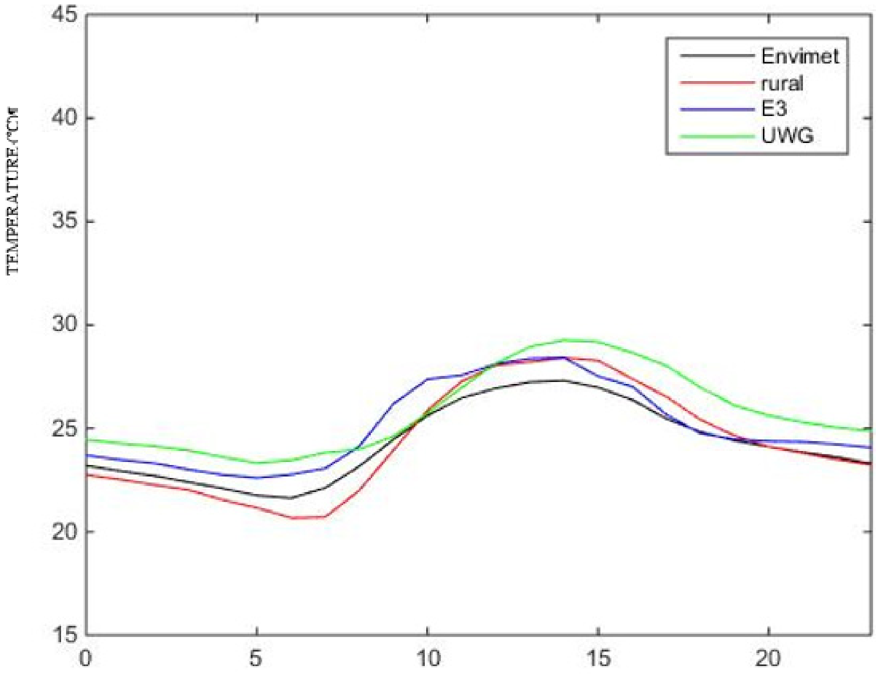

Figure 10. ENVI-met results compared to the urban and rural data for the spring (March) 2017.

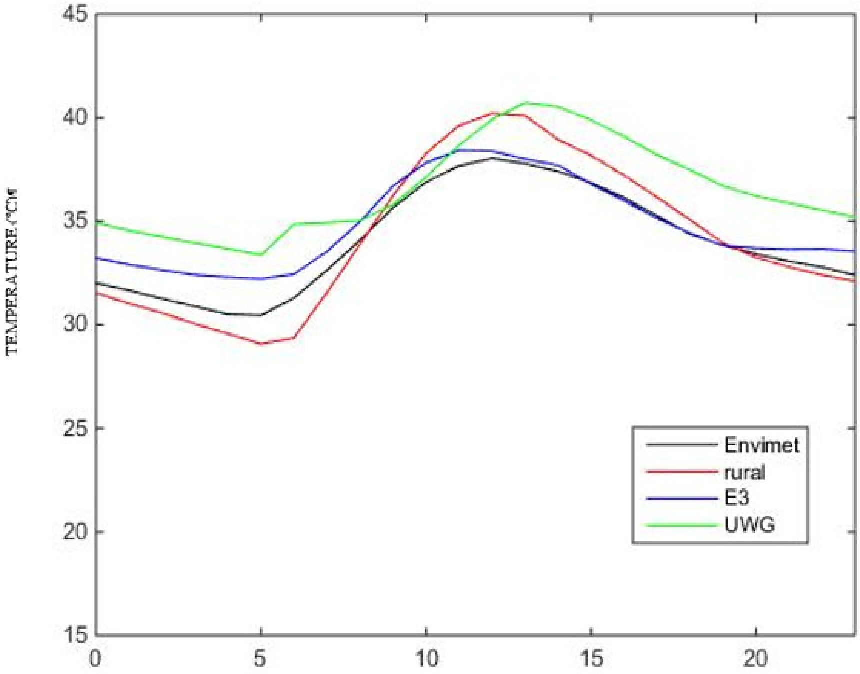

Figure 11. ENVI-met results compared to the urban and rural data for the summer (June) 2017.

The results from UWG and ENVI-met are shown in Tables 7 and 8. They show the average daily air temperature differences from each scenario, compared to the base case average air temperature of the district. The UHI phenomena reaches a value of 2 °C in the winter season, comparing the urban and rural measured data. The values of the six scenarios are shown in Table 7. The impact of the AH reaches 0.1 °C in the summer season. The other scenarios (03 to 04) seem to have a minor effect on the air temperatures (scenarios 03 to 06, as described in Section 2.4, include vegetation, shading etc.). The biggest impact of the scenarios from one another appears to be during the winter season where the weather is more stable. Spring 2017, as mentioned above, was not a common season due to the heavy rains and changes of humidity. This might explain the minor impact of the vegetation shading on the UWG results.

Table 8 shows a comparison between the values of average daily air temperature into the canyon, received from UWG and ENVI-met. They refer to one day of simulation, and they refer to the same day of measurement in the corresponding season. The best behavior of the UWG is during winter 2016, while the best behaviour of ENVI-met is during the summer season, 2017. For the ENVI-met, the results are shown in two scenarios: the direct results coming from Leonardo (the post-processing part of the software,) and the modified results. In the modified results, a value of 0.53 °C is added to the obtained results, referring to a study where this is the estimated impact of the anthropogenic heat, absent in ENVI-met. This average of 0.53 °C is considered the variation of the anthropogenic heat during the day as an average [33]. The spring and summer 2017 show negative impact for the UWG. UWG tends to follow the measured data with a shift of 1 h in the peak hour. ENVI-met follows the same peak, but with few degrees less. UWG has a shift of a few hours in the peak of the site measurements and ENVI-met has a smaller difference compared to the winter season. UWG overestimates the urban canyon temperatures during the peak hour and the afternoon time. ENVI-met has a better behavior during this season. Table 9 shows the calculation of the RMSE (root mean square error measures the average magnitude of the errors in a set of predictions without considering their direction) and MBE (mean bias error is a quadrating scoring rule that measures the average magnitude of error as well).

Table 7. Comparison of results for the UWG (refer to Table 5).

	Winter 2016 (°C)	Spring 2017 (°C)	Summer 2017 (°C)
UWG01	0.29	−0.71	−1.71
UWG02	0.33	−0.73	−1.60
UWG03	0.29	−0.77	−1.65
UWG04	0.33	−0.73	−1.60
UWG05	0.27	−0.79	−1.68
UWG06	0.28	−0.77	−1.65

Table 8. Comparison of results for UWG and ENVI-met, average daily values (°C).

	Winter 2016	Spring 2017	Summer 2017
urban/UWG	0.29	−0.71	−1.71
urban/ENVI-met (no AH)	2.04	0.23	0.79
urban/ENVI-met (AH)	1.51	0.76	0.26
urban-rural	1.99	0.71	0.59

Table 9. RMSE and MBE calculation [33].

	Winter 2016	Spring 2016	Summer 2017
	RMSE (K)		
ENVI-met (no AH)	2.11	0.88	0.97
ENVI-met (AH)	1.63	0.50	0.62
UWG (case01)	0.89	1.19	2.06
	MBE (K)		
ENVI-met (no AH)	2.04	0.76	0.79
ENVI-met (AH)	1.53	0.23	0.26
UWG (case01)	0.29	−0.71	−1.71

It is shown a good behavior of UWG during the winter season and for ENVI-met in the summer season (Table 9). According to a study conducted by Bueno in a mesoscale model in Basel (Switzerland) and Toulouse (France), the RMSE varies between 0.8 and 1.2 (K) in the summer and winter season [12].

4. Conclusions and Future Work

The UWG weather file gives a contribution with a more detailed energy model on a mesoscale model. The weather file, produced from UWG, has a valuable impact in having results of energy models that are closer to reality. It considers the seasonal effect and shows the impact of the climate on profiling the UHI phenomena. However, further studies must be conducted in other climate zones to understand the behavior of UWG in the specific zones. Additionally, this software considers the canyon as one homogenous entity [39,40].

Table 7 that shows the difference between the urban data and the main scenarios that are considered in this study. UWG has reliable results and the minimum margin error is 0.1 °C (averaged 24 h value for the summer). This result is promising and is closer to the site measurements than the ENVI-met maximum difference of 1.5 °C (for winter). Referring to the graphs shown in Figures 8–10, UWG has a better performance during the winter season and ENVI-met has better results in the summer season. The peak hours of UWG have a shift of a maximum 2 h compared to the measured data. ENVI-met seems to follow the same curve of the measured data in the three seasons, but with a larger difference in temperature. However, a seasonal analysis based on site data must be carried out (ongoing work).

The several trials of the ENVI-met models included the impact of vegetation on the microclimate. However, the results taken from the simulations showed minor differences with the base case. Further studies must be conducted in order to fully understand the ENVI-met principles of calculation. The difference with the site measurements of the air temperature can reach 0.83 to 0.94, where 1.00 is the perfect agreement between measured and modelled values. Meanwhile, for the other parameters, such as the wind, this value can be between 0.26 to 0.39, and for mean radiant temperature—0.51 to 0.87. The version 4.0 of ENVI-met shows an improvement, compared to the previous version 3.1, in the relative humidity calculation and especially in the air temperature calculation. However, there is room for improvement in calculating the heat island effect in the peak hours [16].

The evapotranspiration process does not always comply with the plant selected, meaning that the soil irrigation and some plants do not contribute to the process. Additionally, the simulation time on the case study of 180 × 180 cells, is quite long and it might take several days if the model is very detailed and has a considerable number of trees [41,42].

The Abu Dhabi Municipality has a complete database for almost all the districts in Abu Dhabi (from the early stages of the city development [33]). The correct information about the building structure will help with the understanding of whether different retrofit strategies can be applied to current buildings, in addition to external changes, or to internal air changes. A comparison between different district typologies and the efficiency of the above software would be of great value to researchers. Since the energy consumption of the buildings takes 80% of the total energy consumption in UAE, and 70% of this energy use goes to the cooling load, the local authorities have shown an interest in developing such detailed studies [22,27].

Author Contributions: The author contribution is a per the following: conceptualization, L.B. and A.A.; methodology, L.B.; software, D.A.M., M.J., Y.P.; validation, L.B., A.T.; formal analysis, L.B.; investigation, L.B.; resources, P.M.; data curation, P.A., A.T., M.J.; writing—original draft preparation, L.B.; writing—review and editing, L.B.; visualization, L.B.; supervision, A.A., L.N.; project administration, A.A.; funding acquisition, P.M.

Funding: This work was funded under the Cooperative Agreement between the Masdar Institute of Science and Technology (now part of Khalifa University), Abu Dhabi, UAE and the Massachusetts Institute of Technology, Cambridge, MA, USA, Reference Number 02/MI/MIT/CP/11/07633/GEN/G/00.

Acknowledgments: The authors acknowledge the continuous support from the colleagues of Masdar Institute of Science and Technology (now Khalifa University), Abu Dhabi, UAE and the Massachusetts Institute of Technology, Cambridge, MA, USA.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Note: rH stands for relative humidity

A.1 The ENVI-met Boundary Conditions for the Winter 2016.

```
Start Simulation at Day (DD.MM.YYYY): = 21.12.2016
Start Simulation at Time (HH:MM:SS): = 00:00:00
Total Simulation Time in Hours: = 24
Wind Speed in 10 m ab. Ground [m/s] = 2.95
Wind Direction (0:N..90:E..180:S.270:W.) = 311
Roughness Length z0 at Reference Point [m] = 0.01
Initial Temperature Atmosphere [K] = 295.62
Specific Humidity in 2500 m [g Water/kg air] = 7
Relative Humidity in 2 m [%] = 76.18
% End main data .....................................................
[OUTPUTTIMING]________________________________________
Output interval main files (min) = 60.00
Output interval log files (min) = 30.00
Include Nesting Grids in Output (0:n,1:y) = 0
[SOLARADJUST] ________________________________________
Factor of shortwave adjustment (0.5 to 1.5) = 0.90
[CLOUDS] ________________________________________
Fraction of LOW clouds (x/8) = 0.00
Fraction of MIDDLE clouds (x/8) = 0.00
Fraction of HIGH clouds (x/8) = 0.00
[SOILDATA] ________________________________________
Initial Temperature Upper Layer (0–20 cm) [K] = 301.15
Initial Temperature Middle Layer (20–50 cm) [K] = 297.50
Initial Temperature Deep Layer (below 50 cm)[K] = 293.00
Relative Humidity Upper Layer (0–20 cm) = 95.00
Relative Humidity Middle Layer (20–50 cm) = 90.00
Relative Humidity Deep Layer (below 50 cm) = 85.00
[SIMPLEFORCE] ________________________________________
Hour 00h [Temp, rH] = 295.58, 84.10
Hour 01h [Temp, rH] = 295.42, 84.60
Hour 02h [Temp, rH] = 295.25, 85.60
Hour 03h [Temp, rH] = 295.11, 86.20
Hour 04h [Temp, rH] = 294.59, 86.80
Hour 05h [Temp, rH] = 294.50, 88.30
Hour 06h [Temp, rH] = 294.41, 88.70
Hour 07h [Temp, rH] = 294.93, 89.50
Hour 08h [Temp, rH] = 295.88, 86.60
Hour 09h [Temp, rH] = 296.64, 80.80
Hour 10h [Temp, rH] = 297.27, 73.00
Hour 11h [Temp, rH] = 298.84, 65.40
Hour 12h [Temp, rH] = 300.10, 59.80
Hour 13h [Temp, rH] = 300.76, 56.40
Hour 14h [Temp, rH] = 301.01, 55.20
Hour 15h [Temp, rH] = 300.64, 56.90
Hour 16h [Temp, rH] = 299.96, 60.50
Hour 17h [Temp, rH] = 298.69, 66.00
Hour 18h [Temp, rH] = 297.15, 73.50
```

```
Hour 19h [Temp, rH] = 296.55, 76.50
Hour 20h [Temp, rH] = 296.05, 78.50
Hour 21h [Temp, rH] = 295.53, 80.00
Hour 22h [Temp, rH] = 294.97, 81.80
Hour 23h [Temp, rH] = 294.36, 83.60
```

A.1 The ENVI-met Boundary Conditions for the Spring 2017.

```
Start Simulation at Day (DD.MM.YYYY): = 21.03.2017
Start Simulation at Time (HH:MM:SS): = 00:00:00
Total Simulation Time in Hours: = 24
Wind Speed in 10 m ab. Ground [m/s] = 2.95
Wind Direction (0:N..90:E..180:S.270:W.) = 311
Roughness Length z0 at Reference Point [m] = 0.01
Initial Temperature Atmosphere [K] = 297.84
Specific Humidity in 2500 m [g Water/kg air] = 7
Relative Humidity in 2 m [%] =57
% End main data ..................................................
[OUTPUTTIMING]________________________________________
Output interval main files (min) = 60.00
Output interval log files (min) = 30.00
Include Nesting Grids in Output (0:n,1:y) = 0
[SOLARADJUST] ______________________________________
Factor of shortwave adjustment (0.5 to 1.5) = 0.90
[CLOUDS] ______________________________________
Fraction of LOW clouds (x/8) = 0.00
Fraction of MIDDLE clouds (x/8) = 0.00
Fraction of HIGH clouds (x/8) = 0.00
[SOILDATA] ______________________________________
Initial Temperature Upper Layer (0–20 cm) [K] = 301.15
Initial Temperature Middle Layer (20–50 cm) [K] = 297.50
Initial Temperature Deep Layer (below 50 cm) [K] = 293.00
Relative Humidity Upper Layer (0–20 cm) = 95.00
Relative Humidity Middle Layer (20–50 cm) = 90.00
Relative Humidity Deep Layer (below 50 cm) = 85.00
[SIMPLEFORCE] ______________________________________
Hour 00h [Temp, rH] = 295.59, 70.30
Hour 01h [Temp, rH] = 295.25, 71.40
Hour 02h [Temp, rH] = 295.03, 71.00
Hour 03h [Temp, rH] = 294.69, 71.90
Hour 04h [Temp, rH] = 294.19, 74.70
Hour 05h [Temp, rH] = 293.80, 75.80
Hour 06h [Temp, rH] = 293.40, 77.20
Hour 07h [Temp, rH] = 294.27, 74.00
Hour 08h [Temp, rH] = 296.15, 67.00
Hour 09h [Temp, rH] = 298.40, 58.60
Hour 10h [Temp, rH] = 300.38, 51.10
Hour 11h [Temp, rH] = 301.73, 46.40
Hour 12h [Temp, rH] = 302.51, 45.10
Hour 13h [Temp, rH] = 302.84, 44.80
Hour 14h [Temp, rH] = 302.99, 44.00
Hour 15h [Temp, rH] = 302.61, 45.50
```

Hour 16h [Temp, rH] = 301.65, 50.20
Hour 17h [Temp, rH] = 300.25, 55.40
Hour 18h [Temp, rH] = 298.54, 62.40
Hour 19h [Temp, rH] = 297.62, 65.80
Hour 20h [Temp, rH] = 297.06, 67.90
Hour 21h [Temp, rH] = 296.71, 68.70
Hour 22h [Temp, rH] = 296.33, 69.50
Hour 23h [Temp, rH] = 296.14, 69.20

A.1 The ENVI-met Boundary Conditions for the Summer 2017.
Start Simulation at Day (DD.MM.YYYY): = 21.06.2017
Start Simulation at Time (HH:MM:SS): = 00:00:00
Total Simulation Time in Hours: = 24
Wind Speed in 10 m ab. Ground [m/s] = 2.95
Wind Direction (0:N..90:E..180:S.270:W.) = 311
Roughness Length z0 at Reference Point [m] = 0.01
Initial Temperature Atmosphere [K] = 307.78
Specific Humidity in 2500 m [g Water/kg air] = 7
Relative Humidity in 2 m [%] =57
% End main data ....
[OUTPUTTIMING]
Output interval main files (min) = 60.00
Output interval log files (min) = 30.00
Include Nesting Grids in Output (0:n,1:y) = 0
[SOLARADJUST]
Factor of shortwave adjustment (0.5 to 1.5) = 0.90
[CLOUDS]
Fraction of LOW clouds (x/8) = 0.00
Fraction of MIDDLE clouds (x/8) = 0.00
Fraction of HIGH clouds (x/8) = 0.00
[SOILDATA]
Initial Temperature Upper Layer (0–20 cm) [K] = 301.15
Initial Temperature Middle Layer (20–50 cm) [K] = 297.50
Initial Temperature Deep Layer (below 50 cm) [K] = 293.00
Relative Humidity Upper Layer (0–20 cm) = 95.00
Relative Humidity Middle Layer (20–50 cm) = 90.00
Relative Humidity Deep Layer (below 50 cm) = 85.00
[SIMPLEFORCE]
Hour 00h [Temp, rH] = 304.57, 72.40
Hour 01h [Temp, rH] = 303.99, 73.90
Hour 02h [Temp, rH] = 303.51, 74.50
Hour 03h [Temp, rH] = 302.95, 74.90
Hour 04h [Temp, rH] = 302.53, 75.20
Hour 05h [Temp, rH] = 302.09, 75.10
Hour 06h [Temp, rH] = 302.64, 71.70
Hour 07h [Temp, rH] = 305.01, 63.30
Hour 08h [Temp, rH] = 307.34, 55.70
Hour 09h [Temp, rH] = 309.79, 46.00
Hour 10h [Temp, rH] = 312.13, 38.10
Hour 11h [Temp, rH] = 313.58, 33.80
Hour 12h [Temp, rH] = 314.28, 32.60

Hour 13h [Temp, rH] = 314.47, 34.70
Hour 14h [Temp, rH] = 313.62, 39.50
Hour 15h [Temp, rH] = 312.76, 41.80
Hour 16h [Temp, rH] = 311.63, 46.20
Hour 17h [Temp, rH] = 310.29, 51.30
Hour 18h [Temp, rH] = 308.77, 56.80
Hour 19h [Temp, rH] = 307.34, 63.20
Hour 20h [Temp, rH] = 306.54, 67.00
Hour 21h [Temp, rH] = 306.03, 69.00
Hour 22h [Temp, rH] = 305.61, 69.70
Hour 23h [Temp, rH] = 305.18, 70.10

References

1. Böer, B. An introduction to the climate of the United Arab Emirates. *J. Arid Environ.* **1997**, *35*, 3–16. [CrossRef]
2. Afshari, A.; Schuch, F.; Marpu, P. Estimation of the traffic related anthropogenic heat release using BTEX measurements—A case study in Abu Dhabi. *Urban Clim.* **2017**, *24*, 311–325. [CrossRef]
3. Santamouris, M. Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Sol. Energy* **2014**, *103*, 682–703. [CrossRef]
4. Khan, S.M.; Simpson, R.W. Simulation of mixing depths incorporating the urban heat island effect. *Environ. Model. Assess.* **2001**, *6*, 183–193. [CrossRef]
5. Sailor, D.J. A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. *Int. J. Climatol.* **2011**, *31*, 189–199. [CrossRef]
6. Taha, H. Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat. *Energy Build.* **1997**, *25*, 99–103. [CrossRef]
7. Available online: https://www.ncm.ae/en#!/Radar_Merge_Sat/26 (accessed on 12 August 2019).
8. Thomas, A.E.; Elizabeth, A. *Sustainable Landscapes for Residential Neighborhoods in Dubai: An Analysis of the Relationship between Ambient Temperature and Water Requirements of Landscape*; Dubai University: Dubai, UAE, 2013.
9. The Man behind Abu Dhabi's Master Plan | The National. Available online: http://www.thenational.ae/uae/heritage/the-man-behind-abu-dhabis-master-plan (accessed on 13 December 2016).
10. Oke, T.R.; Maxwell, G.B. Urban heat island dynamics in Montreal and Vancouver. *Atmos. Environ.* **1975**, *9*, 191–200. [CrossRef]
11. Unzeta, B.B.; Norford, L.K.; Britter, R. An Urban Weather Generator Coupling Building Simulations with a Physically Based Urban Model. In Proceedings of the 7th International Conference on Urban Climate (ICUC-7), Yokohama, Japan, 29 June–3 July 2009.
12. Bueno, B.; Hidalgo, J.; Pigeon, G.; Norford, L.; Masson, V. Calculation of Air Temperatures above the Urban Canopy Layer from Measurements at a Rural Operational Weather Station. *J. Appl. Meteorol. Climatol.* **2013**, *52*, 472–483. [CrossRef]
13. Oke, T.R. *Boundary Layer Climates*; Routledge: London, UK, 1987.
14. Chow, W.T.L.; Roth, M. Temporal dynamics of the urban heat island of Singapore. *Int. J. Climatol.* **2006**, *26*, 2243–2260. [CrossRef]
15. Huttner, S.; Bruse, M.; Dostal, P. *Full 3D Editor Numeriacl Modelling of the Urban Microclimate—A Preview on ENVI-MET 4.0*; The seventh Internation Conference on Urban Climate: Yokohama, Japan, 2009.
16. Acero, J.A.; Arrizabalaga, J. Evaluating the performance of ENVI-met model in diurnal cycles for different meteorological conditions. *Theor. Appl. Climatol.* **2016**, *131*, 1–15. [CrossRef]
17. Bruse, M. Simulating Microscale Climate Interactions in Complex Terrain with a High-Resolution Numerical Model: A Case Study for the Sydney CBD Area (Model Description). Available online: http://www.envi-met.net/documents/papers/CBDSimu1999.PDF (accessed on 10 February 2019).
18. Oke, T.R. Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *J. Climatol.* **1981**, *1*, 237–254. [CrossRef]

19. Giridharan, R.; Lau, S.S.Y.; Ganesan, S.; Givoni, B. Lowering the outdoor temperature in high-rise high-density residential developments of coastal Hong Kong: The vegetation influence. *Build. Environ.* **2008**, *43*, 1583–1595. [CrossRef]
20. Stewart, I.D. A systematic review and scientific critique of methodology in modern urban heat island literature. *Int. J. Climatol.* **2011**, *31*, 200–217. [CrossRef]
21. Hamdi, R.; Schayes, G. Sensitivity study of the urban heat island intensity to urban characteristics. *Int. J. Climatol.* **2008**, *28*, 973–982. [CrossRef]
22. Abu Dhabi Urban Planning Council—Abu Dhabi Vision 2030. Available online: http://www.upc.gov.ae/abu-dhabi-2030.aspx?lang=en-US (accessed on 1 February 2017).
23. Estidama. Available online: http://estidama.upc.gov.ae/ (accessed on 10 July 2019).
24. Bueno, B.; Roth, M.; Norford, L.; Li, R. Computationally efficient prediction of canopy level urban air temperature at the neighbourhood scale. *Urban Clim.* **2014**, *9*, 35–53. [CrossRef]
25. The Man behind Abu Dhabi's Master Plan | The National. Available online: http://www.thenational.ae/uae/heritage/the-man-behind-abu-dhabis-master-plan#page3 (accessed on 10 June 2018).
26. Bruse, M.; Fleer, H. Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environ. Model. Softw.* **1998**, *13*, 373–384. [CrossRef]
27. Ministry of Environment and Water of UAE. *UAE State of Green Economy 2014*; Ministry of Environment and Water of UAE: Abu Dhabi, UAE, 2014.
28. Paolini, R.; Mainini, A.G.; Poli, T.; Vercesi, L. Assessment of Thermal Stress in a Street Canyon in Pedestrian Area with or without Canopy Shading. *Energy Procedia* **2014**, *48*, 1570–1575. [CrossRef]
29. Mao, J.; Yang, J.H.; Afshari, A.; Norford, L.K. Global sensitivity analysis of an urban microclimate system under uncertainty: Design and case study. *Build. Environ.* **2017**, *124*, 153–170. [CrossRef]
30. Cassano, S.; Francisco, C.; Ganglani, P.M.; Sathish, A.; Pinto, Z. *Atlas Environmentla of Abu Dhabi Emirates*; Environmental Agency: Abu Dhabi, UAE, 2011.
31. Oke, T.R. Initial guidance to obtain representative meteorological observations at urban sites. *World Meteorol. Organ.* **2004**, *81*, 51.
32. Toppi, T.; Zangheri, P.; Paolini, R. *Simplified Method for Modification of Weather Data File for Energy Simulations within Urban Areas*; Politecnico di Milano: Milan, Italy, 2009.
33. Lindita, B. *Heat Island Mitigation Strategies, with Focus on the Urban Shading Devices. The Case Study of Abu Dhabi Main Island, United Arab Emirates*; Politecnico di Milano: Milan, Italy, 2017.
34. Bande, L.; Cabrera, A.G.; Afshari, A.; Martin, M. Evaluation of Smart Shading Structures in Mitigating Urban Heat Island in a District of a Hot Arid Climate City (Abu Dhabi). In Proceedings of the 9th Internation Conference on Urban Climate (ICUC-9), Toulouse, France, 20–24 July 2015.
35. Karakounos, I.; Dimoudi, A.; Zoras, S. The influence of bioclimatic urban redevelopment on outdoor thermal comfort. *Energy Build.* **2018**, *158*, 1266–1274. [CrossRef]
36. Roth, M.; Lim, V.H. Evaluation of canopy-layer air and mean radiant temperature simulations by a microclimate model over a tropical residential neighbourhood. *Build. Environ.* **2017**, *112*, 177–189. [CrossRef]
37. d'Argent, N.M.J. *A Microclimatic and Bioclimatic Modelling Assessment of the Compact City Morphology*; a Case Study of Melbourne@ 5 Million; Monash University: Melbourne, Australia, 2012.
38. Home | Envimet. Available online: http://www.envi-met.com/ (accessed on 10 June 2018).
39. Roth, M.; Jansson, C.; Velasco, E. Multi-year energy balance and carbon dioxide fluxes over a residential neighbourhood in a tropical city. *Int. J. Climatol.* **2016**, *37*, 2679–2698. [CrossRef]
40. Carfan, A.C.; Galvani, E.; Nery, J.T. Study of thermal comfort in the City of São Paulo using ENVI-met model Estudio del confort térmico en la ciudad de São Paulo utilizando el modelo ENVI-MET. *Núm* **2012**, *78*, 188–4611.
41. Yaghoobian, N.; Kleissl, J. Effect of reflective pavements on building energy use. *Urban Clim.* **2012**, *2*, 25–42. [CrossRef]
42. Ozkeresteci, I.; Crewe, K.; Brazel, A.J.; Bruse, M. Use and evaluation of the ENVI-met model for environmental design and planning. An Experiment on Lienar Parks. In Proceedings of the 21st International Cartographic Conference (ICC), Durban, South Africa, 10–16 August 2003; pp. 10–16.