Microclimate Effects and Irrigation Water Requirement of Mesic, Oasis, and Xeric Landscapes

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Abstract

Urban irrigation is an essential process in land-atmosphere interaction. It is one of the uncertain parameters of the urban hydrology because of the presence of various microclimates. This study investigates the microclimate effects and irrigation water requirements of three landscape types in an arid region of Phoenix, AZ. The microclimate effect encompassed surface temperature, air temperature, and wind speed. The three landscapes include mesic, oasis, and xeric. The simulation was conducted using ENVI-met software for the hottest day of the year (23rd June 2011). The simulated model was validated using ground data. Results show that the mesic landscape induced cooling effects, both in the day-time and nighttime, by reducing the surface temperature and air temperature. However, the mesic landscape showed high-water consumption because of high leaf area density. The oasis landscape showed more day-time cooling than the mesic landscape, but the nighttime warming was similar to the xeric landscape. However, the potential irrigation water requirement was lower than the mesic landscape. Moreover, microclimate conditions varied spatially in each neighborhood. The xeric landscape showed lower wind speeds and air temperatures between the buildings. Overall, the oasis landscape proved to be the most efficient of the three landscapes for water consumption and day-time cooling.

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Key Points:

- Microclimate conditions of three landscape types were simulated at 1-meter resolution
- The oasis landscape is relatively efficient for irrigation water and decrease in diurnal air temperature
- The presence of buildings and trees decreases the wind speed within the neighborhood when compared to outskirts

Abstract

Urban irrigation is an essential process in land-atmosphere interaction. It is one of the uncertain parameters of the urban hydrology because of the presence of various microclimates. This study investigates the microclimate effects and irrigation water requirements of three landscape types in an arid region of Phoenix, AZ. The microclimate effect encompassed surface temperature, air temperature, and wind speed. The three landscapes include mesic, oasis, and xeric. The simulation was conducted using ENVI-met software for the hottest day of the year (23rd June 2011). The simulated model was validated using ground data. Results show that the mesic landscape induced cooling effects, both in the day-time and nighttime, by reducing the surface temperature and air temperature. However, the mesic landscape showed high-water consumption because of high leaf area density. The oasis landscape showed more day-time cooling than the mesic landscape, but the nighttime warming was similar to the xeric landscape. However, the potential irrigation water requirement was lower than the mesic landscape. Moreover, microclimate conditions varied spatially in each neighborhood. The xeric landscape showed lower wind speeds and air temperatures between the buildings. Overall, the oasis landscape proved to be the most efficient of the three landscapes for water consumption and day-time cooling.

Keywords: Microclimate effects, urban landscapes, surface temperature, urban evapotranspiration, urban irrigation

Introduction

Over the decades, communities in arid regions have devised policies such as turf grass removal or replacement and the introduction of synthetic turf grass as a heat mitigation strategy (St. Hilaire et al., 2008). These policies have been adopted in the southwest United States as mitigation to drought emergencies. Recent policies include the Southern Nevada Water Authority's Water Smart Landscapes program, in which turf grass lawns were removed for a certain amount of money. In some cases it was replaced by low water consumption plant species. The program reportedly reduced outdoor water consumption by 50% (Southwest, 2006). Another similar policy was adopted by the metropolitan water district of southern California. The program replaced 15.3 million square meters of turf with native species (Pincetl et al., 2019; Sovocool, 2005). While these strategies may seem to have immediate benefits such as reduced per capita water consumption, their long term benefits are questionable (Brelsford & Abbott, 2018).

The replacement of vegetated surfaces with impervious surfaces exacerbates temperatures especially in arid regions because of reduced transpiration rates and higher thermal admittance (Fisher et al., 2011). This results in night time warming, which has been long known as the heat island effect (OKE, 1987). In urban areas, the heat island effect causes air temperature to be warmer than in the rural surroundings (Saher et al., 2019). This discourages outdoor activities for residents, causing detrimental impacts to their mental and physical health (Wood et al., 2017). Therefore, alternative strategies such as water efficient landscapes have recently gained attention in arid regions (Chow & Brazel, 2012; Middel et al., 2015; Mitchell, 2014). Water efficient landscapes include a variety of species ranging from rain fed to low water use (Overview, 2013).

The radiation absorption capacity of the land covers, shade from trees and buildings, and surface roughness change air temperature and wind speed, resulting in evapotranspiration (ET) changes. The tree-turf landscape, also known as mesic landscape, induces high ET. The landscape consists of highly water-intensive landscapes, including turf grass and nonnative species, and is irrigated with sprinkler irrigation with lower efficiency. However, recently mesic landscapes have been under scrutiny due to inherent high water consumption (Kjelgren et al., 2000). Policymakers have been focusing on replacing the landscape with alternatives such as a low-water-use landscape. These landscapes are celled xeriscaping and oasis landscapes. The xeric landscape includes native species. The irrigation source is drip irrigation with 75% efficiency, which can be interpreted as low water wastage compared to the mesic landscape. Consequently, landscapes have low ET rates in the summertime. The oasis landscapes are a combination of low and high-water use plants. The landscape is irrigated by both sprinkler and drip irrigation; therefore, ET is lower than in the mesic landscape.

Simulating vegetated landscapes on a finer scale has been a challenge, as neither remote sensing datasets nor climate stations can interpret the ground conditions (Nouri et al., 2013; Saher et al., 2020). Remote sensing datasets have a coarse resolution, which cannot capture the spatial variability of the plant species (Nouri et al., 2013). In addition, weather stations involve point measurements that do not include spatial variability (Litvak et al., 2017; Litvak et al., 2014; Litvak & Pataki, 2016).

The soil-atmosphere-plant interaction has been studied using urban canopy models. Kusaka and Kumara (2004) coupled a single layer urban canopy model to simulate the air temperature between two buildings. Another study by Chen et al. (2011) modeled a multi-layer urban canopy to understand the emissions and heat trapping between two buildings. Both canopy models are limited to five-meter resolution. Recent studies have coupled the urban canopy models to Noah land surface models (LSM) to improve the spatial resolution (Long et al., 2014; Vahmani & Hogue, 2014). The Noah LSM models vary between 30 m to 100 km in resolution and are more suitable for a local scale. In addition, these tools are computationally heavy and data intensive.

The computational fluid dynamics (CFD) approach has recently gained attention to simulate the microclimate conditions of urban landscapes (Crank et al., 2020; Middel et al., 2014; Vahmani et al., 2016; Vahmani & Hogue, 2014; Wang et al., 2018). The CFD model ENVI-met has been developed to understand the neighborhood scale level effects of soil-atmosphere-plant interactions in terms of surface and atmospheric exchanges. Developed originally for temperate climates zones, ENVI-met has recently been recognized in arid climate zones. A study by Middel et al. (2014) investigated the air temperature for various urban forms of five neighborhoods in Phoenix, AZ. The study reported 95% accuracy between the simulated and observed models. Later, Crank et al. (2020) validated the mean radiant temperature of ENVI-met simulations in five fields of Phoenix, AZ between 2014 and 2017 with five 23-hour simulations. The study reported that the model should not be used under micrometeorological or morphological extremes without ground validation. A recent review paper by Saher et al. (2020) suggested ENVI-met as microclimate evaluator for better estimation of irrigation water requirements.

This study builds on two modeling studies by Middel et al. (2014, 2015) to investigate the microclimate effects and potential irrigation water requirements of high and low water use landscapes in arid Phoenix, Arizona. To simulate the ground conditions, this study employed ENVI-met version 4.4, which allows modeling trees in 3D as opposed to 2D in version 3.5 used by Middel et al.

2. Study Area

The North Desert Village (NDV) was used as a study area. It is located at Arizona State University's Polytechnic campus. It has three experimental sites with mesic, oasis, and xeric landscapes (Figure 1). The experimental sites were established in 2004 and designed to provide the Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER) group a platform to study the plant-soil-water impacts in terms of thermal and anthropogenic effects (Martin et al., 2007).

The mesic landscape site included a mix of non-native, high water-use plants, trees, and turf grass (green pixels, Figure 1). The oasis and xeric landscapes used non-native, desert-adapted species. Both neighborhoods are in proximity to each other and have the same urban form; therefore, their local climate zone is the same. The mesic landscape site is mostly covered with turf grass and trees such as *Acacia stenophylla*, *Malus*, and *Myrtus communis*. The oasis landscape encompassed a patch of turf grass, shrubs, and trees surrounded by single-story residential buildings. Similarly, the xeric landscape was modeled with shrubs, vines, and trees that have a sparse leaf area density. Each landscape had a micrometeorological station to monitor the air temperature at 2 m height, and to monitor the surface temperature, soil heat flux, and volumetric water content at 30 cm depth. The stations were installed in the center of the landscapes (red star, Figure 1). The micrometeorological stations are used for the model validation.

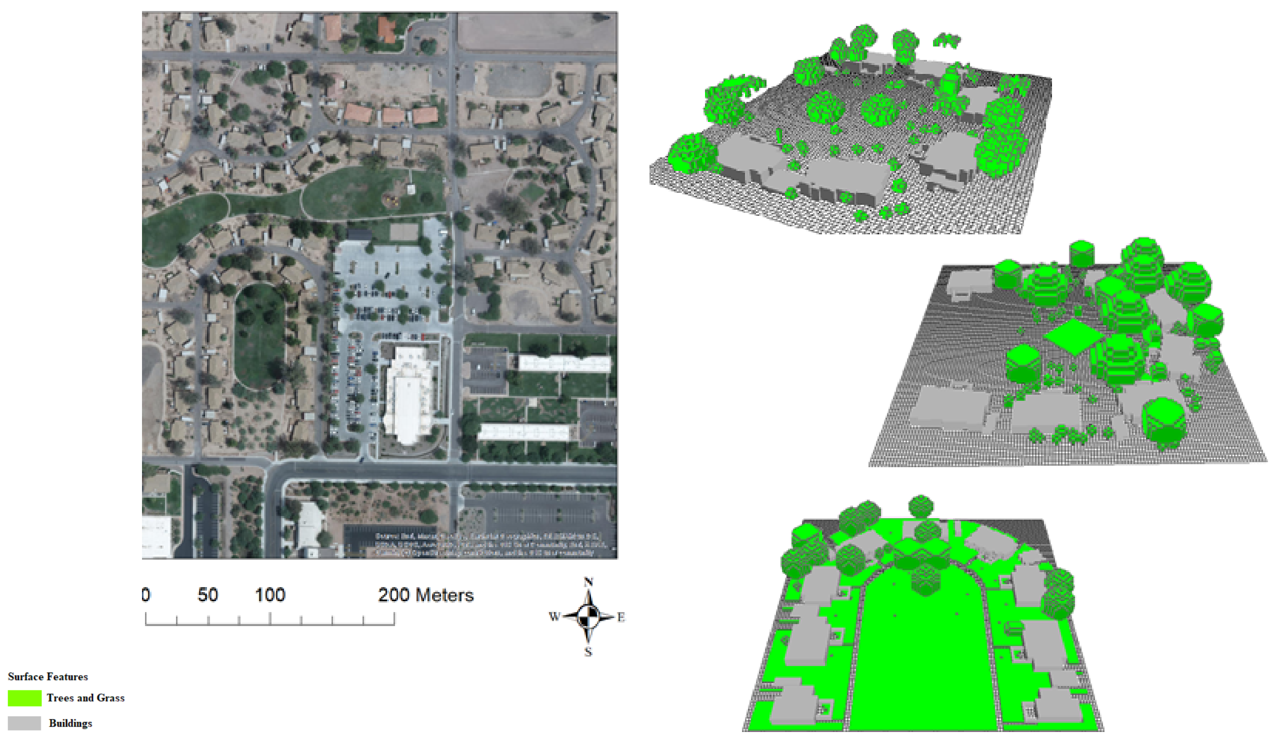


Figure 1. Study area showing the mesic, oasis, and xeric landscape with their surface features; red stars in each landscape indicate the weather station used for the model validation.

Methodology

3.1 ENVI-met Overview

ENVI-met is a three-dimensional CFD model used to simulate the physical processes of surface-plant-air interaction. It can model the ground conditions at spatial resolutions ranging between 0.5 and 10 meter grid cell size. The model simulates the conditions for 24 to 48 hours with a 1- to 5-second time step.

The ENVI-met database provides information on soil types and profiles, plants, walls, and ground surfaces.The plant database includes a variety of tree species, hedges and grass, along with generic palm, deciduous, and coniferous trees of different sizes. The species are classified into high- and low-leaf-area density. ENVI-met allows the user to customize trees in an Albero tool where the user can create a 3D-plant based on its geometry, leaf area density, transmissivity, and biomass. The soil database includes both marbled and natural soils including loamy sand, basalt, cement concrete, and many more. The limitation of the current ENVI-met version is that it only supports uniform building materials. The profile database models the ground layers using a combination of soil types. It models a 200 cm deep ground layer. The profile database includes a range of surfaces, including loamy and sandy soil, as well as different types of roads and pavements.

3.2 Model Setup

The model setup required two major steps. First, the 3D model domain needs to be established through digitizing or importing data from shapefiles or Open Street Maps via Monde. Second, the meteorological forcing data for the day of interest needs to be defined in a simulation file along with other model parameters, such as time step and simulation time.

While ENVI-met input data for buildings and ground surfaces was adopted from the study by Middel et al., 2014, the vegetation layer was replaced with 3D trees in ENVI-met version 4.4. The inventory for the species in each neighborhood is listed in Table 1. Based on the height and species of each tree in the ENVI-met 3.5 domain, a new 3D tree was selected from the ENVI-met database that most closely resembled the shape, type (coniferous vs. deciduous), and leaf-area-density (LAD) of the 2D tree.

Table 1. Trees, shrubs, and vines in the study area modeled using 2D plants in ENVI-met 3.5.

Species Biological Name	Mesic Landscape	Oasis Landscape	Xeric Landscape
Trees			

Species Biological Name	Mesic Landscape	Oasis Landscape	Xeric Landscape
Acacia salinica		•	
Acacia stenophylla	•	•	•
Brachychiton populneus			•
Brahea armata			•
Corymbia papuana		•	
Eucalyptus camaldulensis	•	•	
Eucalyptus microtheca			•
Eucalyptus polyanthemos	•		
Fraxinus uhdei		•	
Fraxinus valutina			•
Malus (apple)	•		
Melaleuca viminalis	•	•	•
Myrtus communis	•	•	
Parkinsonia hybrid			•
Phoenix dactylifera	•	•	•
Pinus eldarica	•	•	
Pinus halepensis			•
Pistacia chinesis	•		
Platanus wrightii	•		
Platycladus orientalis	•	•	•
Prosopis hybrid			•
Prunus cerasifera		•	
Ulmus parvifolia	•	•	
Washingtonia filifera			•
Shrubs and Vines			
Bougainvillea hybrid		•	
Caesalpinia pulcherrima		•	
Caesalpinia gilliesii			•
Calliandra californica			•
Carissa macrocarpa		•	
Chamaerops humilis		•	
Encelia farinosa			•
Hesperaloe parviflora			•
Lantana hybrid		•	
Leucophyllum candidum			•
Leucophyllum frutescens		•	
MacFadyena unguis-cati		•	
Myrtus communis	•	•	
Nerium oleander		•	•
Rosa hybrid	•		
Ruellia brittoniana		•	
Ruellia peninsularis			•
Tacoma capensis	•		

- modeled in the landscape

As soil in the model area, we selected loamy sand from the ENVI-met 4.4 database. Building walls were modelled as stucco with asphalt shingle roofs. In contrast to ENVI-met 3.5, version 4.4 allows hourly forcing of air temperature and humidity. Forcing data were retrieved from the nearby Mesa airport (Table 2).

Table 2. ENVI-met weather input (hourly) for June 23, 2011.

Hour	Air Temperature (°C)	Relative Humidity (%)
1	30.3	16
2	29.1	17.6
3	27.6	21.7
4	26.3	25.1
5	26.3	25.1
6	26.3	23.5
7	26	19.4
8	27.5	15.7
9	30.4	13.6
10	33.7	12.4
11	35.1	12.3
12	37.1	11.2
13	39.4	9.7
14	40.6	8.7
15	41.9	7.8
16	42.8	7.3
17	43.5	7.2
18	43.1	7.1
19	42.3	7
20	40.5	7.9
21	38.7	9.2
22	36.9	10.7
23	35.2	12.8
24	33.4	14.8

3.3 Model Evaluation

The model was evaluated by comparing the simulated hourly air temperature with the observed. The study followed the methodology suggested by Willmott (1981). The deviation between the observed and simulated values was reported using root mean square error (RMSE) and mean absolute error (MAE). The bias in the model was calculated using mean bias error. The index of agreement between the observed and simulated data points was calculated to determine the degree to which the model was error free. It ranged between 0 and 1; a value of d=1 indicated that the simulated and observed values were error free.

The simulated data were extracted at a receptor in the domain (red star, Figure 1). The model was validated by comparing the time series of air temperature at 2 m with the simulated data points (Figure 3). Because of model spin up time, the literature suggested using only the sunshine hours for validation (Battista et al., 2016; Lin & Lin, 2016; Zhang et al., 2017). Therefore, the validation was done for 15 hours.

Determination of Microclimate effects

Spatial maps and time series plots were created for the three landscapes in order to understand the microclimate effects. In this study, the microclimate effects are limited to air temperature, surface temperature, and wind speed patterns in the three landscapes. These effects are investigated in an open sky setting and between the buildings. Ten random nesting grids of shrubs, turf grass, and trees were considered. The sampling was done for the open sky plants and between the buildings. The mean of the ten random samples was considered.

Determination of Potential Irrigation water requirement

The potential irrigation water requirement is the function of evapotranspiration and irrigation efficiency. The evapotranspiration was estimated using the ENVI-met model. The values considered were the average of the cells in the open sky, while the irrigation efficiency was assigned based on the landscape type. The plant stomata in the model was assigned a zero value for the hours of the sunset. The xeric landscapes used drip irrigation and its efficiency ranged between 75% and 90%. Because of the application of reclaimed water and leaching factors, the study considered a conservative approach and assigned 85% as irrigation efficiency. The mesic landscape used sprinkler irrigation for the turf grass, with an irrigation efficiency of 75%. An average of both the irrigation practices (80%) was assigned to the oasis landscape. Because the landscape utilized shrubs and trees, along with a small parcels of turf grass; therefore, it was assigned a drip irrigation system.

The three landscapes were compared with a cool-season grass, namely tall fescue, and Bermuda grass. The evapotranspiration of both grass types is higher than the landscapes. The landscapes were compared to the two types of grass in order to understand the difference because of the mixed species.

1.

Results and Discussion

(a)

Model Evaluation

Overall, the three landscapes conform to the ground conditions, as shown in Figure 2. The xeric landscape showed a high RMSE of 1.92°C. The second highest value was observed for mesic landscape (1.50°C), followed by oasis landscape (0.86°C). The ENVI-met tool reportedly performed poorly in areas with xeric landscape, as it was designed for temperate climates (Chow & Brazel, 2012b; Crank et al., 2020b).

Table 3 Model evaluation using basic statistics between observed and simulated air temperatures at 2 meters.

Model Parameters	Mesic	Oasis	Xeric
RMSE	1.50	0.86	1.92
MBE	0.91	0.21	1.69
MAE	1.33	0.56	1.70
d	0.98	1.00	1.00

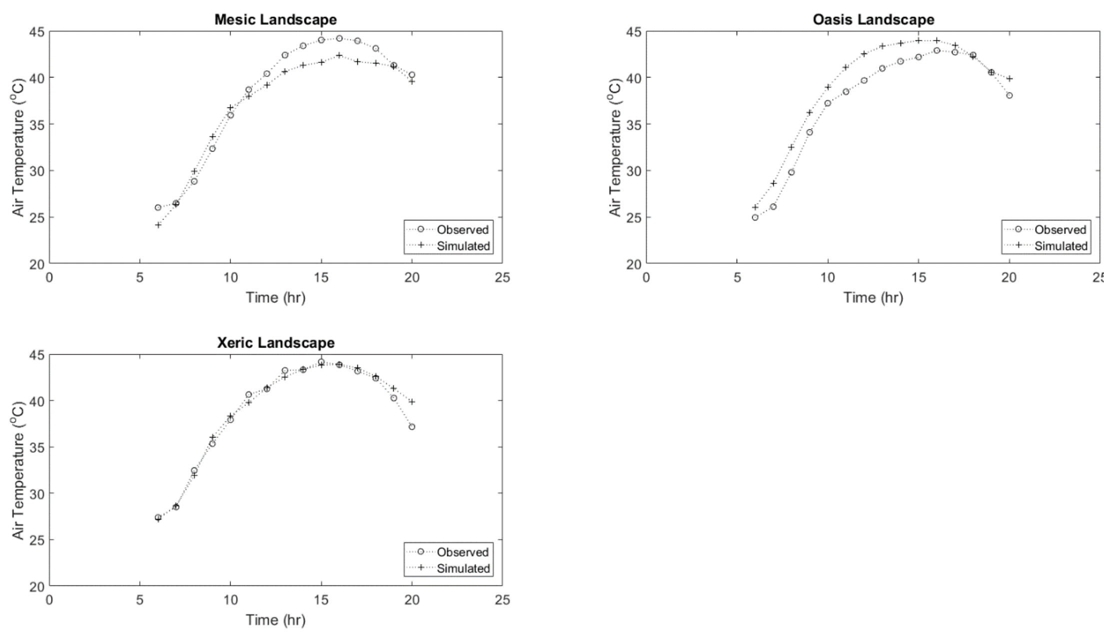


Figure 2 Model evaluations by comparing the observed and simulated air tem-

perature at 2 meters height for mesic (a), oasis (b), and xeric (c) landscapes

Microclimate effects of Landscapes

To explain the microclimate conditions, this section is divided into three subsections. In the first subsection, variations of surface temperature at noon in mesic, oasis, and xeric landscapes are explained through spatial maps. The second subsection explains the spatial variations of wind speeds through 3D spatial maps provided for the mesic, oasis, and xeric landscapes. The third subsection provides the diurnal variation of air temperature and wind speed at two meters height. An open sky vegetated surface, as well as the vegetated surface between the buildings are considered for the diurnal effects. The diurnal variations are explained using a line graph.

Variation in Surface Temperature

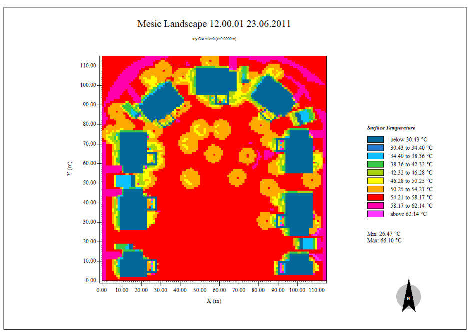
The building height, soil type, and soil profile are the same for the three landscapes. The three landscapes are in the same local climate zone and less than one mile from one another. Therefore, it is safe to assume that the diurnal surface temperature variations are because of the surface energy exchanges. Figure 3 shows the surface temperature variations of the three types of landscapes at noon. The blue color shows lower temperatures, while red and pink show higher temperatures.

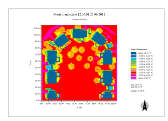
Figure 3 (a) shows the mesic landscape with eleven single story buildings, having a five meter height, surrounded by trees and turf grass. The highest temperature in the landscape was reported as 66°C, visible at the border of the neighborhood (pink spots), while the lowest temperature reported was 26°C, observed for the shaded surfaces between the buildings. A median value of 55.5°C was observed for the landscape. Additionally, the surfaces with tree shade (orange pixels) show 4°C lower surface temperature than the turf grass surfaces (red pixels). The lowest temperature was observed for the surfaces having both engineered shade (buildings and overhang) and tree shade (cyan pixels). An 8°C difference in temperature was observed between the surfaces under tree shade and engineered shade. In addition, a difference of 4°C was observed between the turf grass surfaces with and without tree shade.

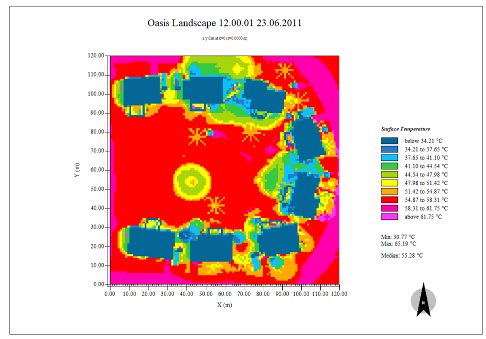
The average surface temperature of oasis landscape is comparable to mesic landscape, as shown in Figure 4 (b). However, the lowest temperature observed in the landscape was 5°C higher (31°C), and the maximum temperature was 1°C lower (65°C) than the mesic landscape. The highest temperature was observed for the hardscapes (pink and red pixels) at the outskirts, while the surfaces between the buildings and under the tree shade showed lower temperatures (yellow and green pixels). In addition, the surfaces between the buildings were 4-9°C cooler than the open sky surfaces, as visible in Figure 3 (b).

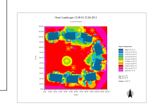
The xeric landscape was 1°C warmer in terms of average surface temperatures than the mesic and oasis landscapes (Figure 3(c)). The maximum surface temperature was observed at the border of the neighborhood being 1°C higher than the mesic landscape and 2°C lower than the oasis landscape. The minimum surface temperature was 7°C higher than the mesic landscape and 3°C higher than the oasis landscape.

Overall, the variations in minimum surface temperature can be inferred into cooling due to landscape. The cooling effects were higher for the mesic landscape because of its tree/turf landscape. The xeric landscape contributed relatively less in cooling the surface.







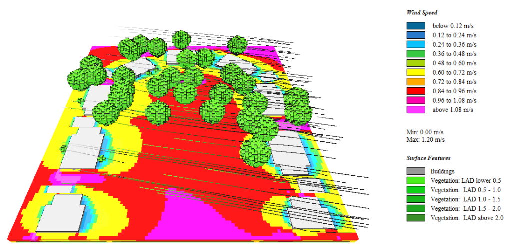


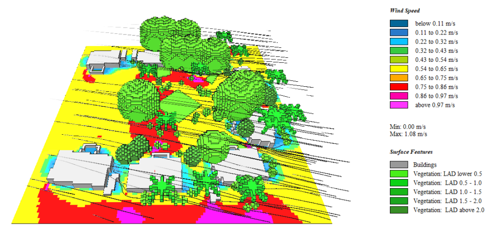
Spatial Variation in Wind Speed

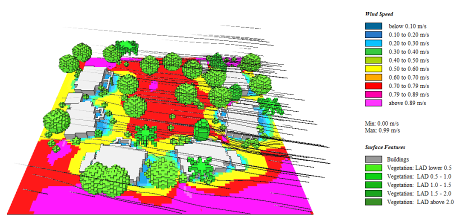
Figure 4 presents a 3D view of the landscapes with surface features and wind speed. The presence of buildings and trees reportedly reduces the wind speed by breaking kinetic energy, causing turbulence (Fisher et al., 2007). In the mesic landscape, the maximum wind speed was reported as 1.20 m/s (pink and red pixels), and the minimum wind speed was 0 m/s (cyan and yellow pixels), as shown in Figure 4 (a). The mesic landscape was modeled with high-leaf-area density shrubs and trees, ranging between 15-25 meters. The increased wind speed was observed at the border of the neighborhood, while the low wind speeds were observed surrounding the buildings and trees.

In the case of the oasis landscape, the wind speed was higher for the surfaces between the buildings and trees, as shown in Figure 4 (b). The landscape was modeled with spherical trees, having a crown of 15 meter and depth of 20 m. The difference was 0.1 m/s between the surfaces obstructed by the buildings and the open sky.

The xeric landscape was modeled with low-leaf-area density and spherical trees and shrubs ranging between 5-15 meters (Figure 4 (c)). Relative to the two landscapes, the xeric landscapes showed lower wind speeds. However, the wind speed within the buildings was 0.3 m/s higher than the oasis landscape and 0.1 m/s more than the mesic landscape.







Diurnal Variation in Air Temperature and Wind Speed

Figure 5 (a) shows the average behavior of the air temperature for mesic, oasis, and xeric landscapes. The turf grass surfaces were considered for the air temperature response. Turf grass within open sky and surrounded by buildings and trees was reported. This was done to understand the thermal effects of the presence of the buildings and trees. Peak air temperature was observed at 15:00 h with 48°C. The lowest air temperature was observed at 6:00 h (25°C). Overall, no major difference was observed for the vegetated surfaces with open sky or between buildings.

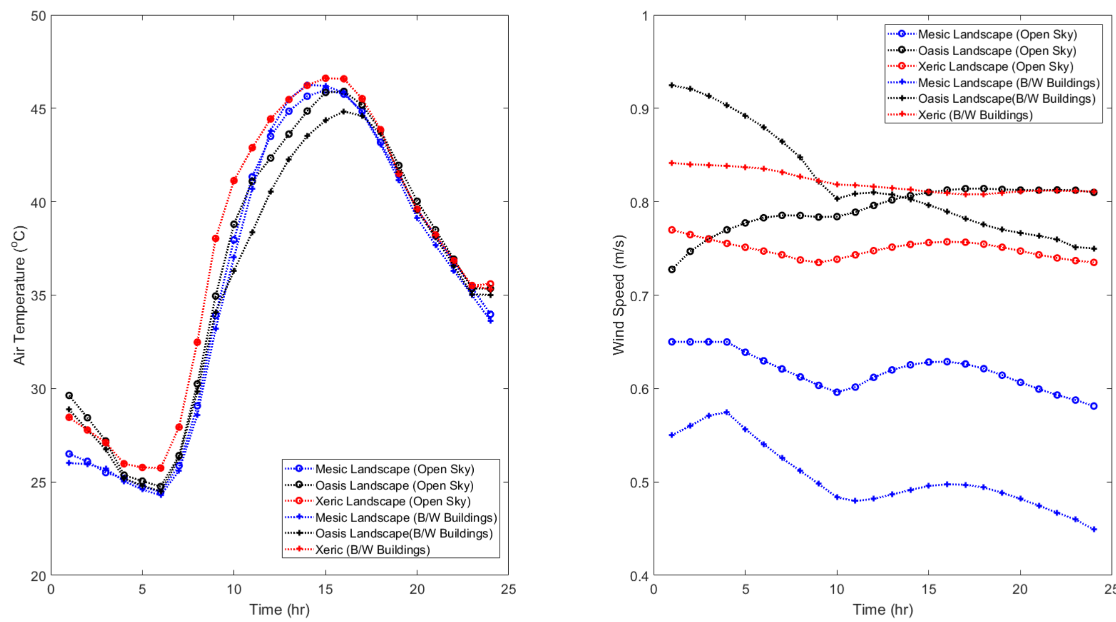


Figure 5. (a) Diurnal variation of air temperatures for the landscapes; (b) diurnal variation of wind speeds for the landscapes

Lower air temperature was observed for the mesic landscape. This behavior was expected. However, the mesic landscape showed a 2°C higher air temperature during peak daytime hours (11:00 h-13:00 h) for the surfaces between buildings. This effect could be induced by the emissions of the wall surfaces, causing heat trapping.

The oasis landscape showed a similar pattern of air temperature variation as the mesic landscape. However, interestingly, the air temperature of an open sky surface between 11:00-13:00 h was 1°C lower than the mesic landscape. Furthermore, a drop in air temperature (2°C) was observed for prolonged periods (10:00-16:00) in the oasis neighborhood between buildings. However, nighttime air temperature was observed to be similar to the xeric landscape.

The xeric landscape showed, on average, 3°C higher temperature than mesic and xeric landscapes. The xeric landscape employed low water consuming plant species with a sparse-leaf-area density. This reduces the transpiration rates, and therefore, increased air temperatures. The air temperature of the xeric landscape in an open sky and between surfaces showed the same behavior.

Figure 5 (b) shows the overall wind speeds of the landscapes. The mesic landscape showed a lower range of wind speed, while the oasis and xeric landscapes showed a similar range for wind speed. The modeled mesic landscape was comprised of 26 spherical trees surrounded by 11 single story houses of five meters height. The presence of trees reduces air temperature and lowers wind speeds (Chatzidimitriou & Yannas, 2016; Litvak et al., 2014; Pataki, McCarthy et al., 2011). Both oasis and xeric landscapes were modeled with 10-15 trees, which explains the low wind speeds in the open sky.

The wind speed for the oasis landscape was higher than the xeric landscape. In the case of open sky surfaces, increased diurnal variation of wind speed was reported in the oasis landscape while the surfaces between buildings showed a decrease in wind speed.

Potential Irrigation Water Requirement of Landscapes

The irrigation water requirements of the landscapes were estimated as a function of evapotranspiration and irrigation efficiency. The values of evapotranspiration are the average over the landscape. Overall, the mesic landscape showed higher values of evapotranspiration, followed by the oasis and xeric landscapes as shown in Figure 6. The evapotranspiration rates were high between 11:00 h and 12:00 h, followed by a steep drop in the afternoon (13:00 h-15:00 h). This diurnal effect was uniform throughout the three landscapes. The oasis landscape showed lower evapotranspiration rates (~0.3 mm/hr.) than the mesic landscape. The xeric landscape showed overall lower evapotranspiration throughout the day, with, on average, a 0.5 mm/hr lower evapotranspiration rate than the mesic landscape, and a 0.3 mm/hr lower than the oasis landscape.

The comparison of evapotranspiration with tall fescue showed a decrease in evapotranspiration (Figure 6(a)). The mesic landscape showed a 50% decrease evapotranspiration while the oasis and xeric landscapes showed 52% and 56% decrease in evapotranspiration. In a similar way, the comparison of landscapes with short Bermuda grass showed a decrease of 43%, 46%, and 53% in mesic, oasis, and xeric landscapes, respectively.

The potential irrigation water depths were determined using the irrigation depths. This was estimated as a function of evapotranspiration and irrigation efficiency. The irrigation depth of the mesic landscape was slightly higher than the oasis landscape (~0.1 mm/hr.) as presented in Figure 6(b). However, the xeric landscape showed 0.5 mm/hr lower irrigation water depth than the xeric and mesic landscapes. The irrigation water depth of landscapes in comparison with tall fescue was lower; having 50%, 55%, and 64% decrease in mesic, oasis, and xeric landscape. In a similar way, the comparison of irrigation water depth between short Bermuda grass and landscapes showed a decrease of 43%, 49%, and 59% for mesic, oasis, and xeric landscapes.

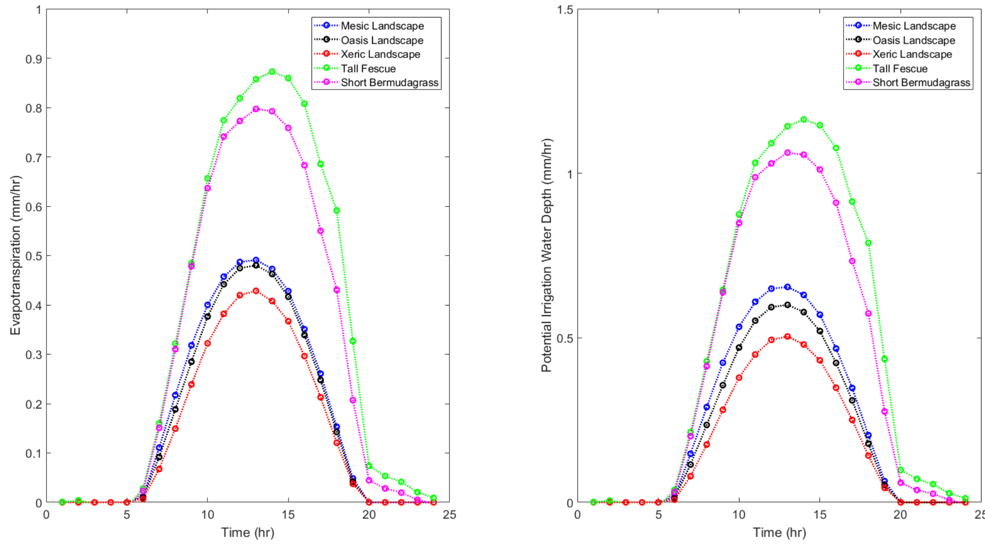


Figure 6 (a) Evapotranspiration rates of the landscapes; (b) potential irrigation water depths of the landscapes.

1. **Discussion**

This study hypothesized that the ET and IWR would be lower for xeric landscape, as it is categorized as low water use landscape. As the decreased ET induces higher daytime air temperature, it was assumed that higher daytime cooling would be reported by the mesic landscape, having higher ET. The results support the hypotheses. A 5-year study by Sovocool, (2005) in Las Vegas, NV, reported similar findings, with 76% water savings in single family houses because of xeric landscape compared to mesic landscape.

Another hypothesis was that the ET of turf grass would be higher than tree transpiration. The ET of Bermuda grass and fescue was 43% higher than mesic landscape; therefore, the results conform to the hypothesis. In addition, the results corroborated well with previous studies with similar hypotheses. For instance, Litvak et al., (2014) reported the summertime ET of turf grass at between 2 and 6 mm/day, while the tree transpiration remained less than 1 mm/day. The study was conducted in the Los Angeles metropolitan area, in California, an arid region, using portable cuboid chamber measurements (in-situ approach). The findings reinforce the approach for water smart landscape (WSL) programs, focused on reducing per capita demand by removing turf grass. However, the long term water benefits of replacing the turf grass with WSL and synthetic turf grass still remains unclear. In another study, Brelsford and Abbott, (2018) analyzed twelve year monthly water consumption records for 300,000 households in Las Vegas, Nevada and estimated the average water saving per square meter of turf removed. The study reported no evidence of water savings per unit area being influenced by the value of the rebate.

A major limitation of this study is the coarse approach towards the irrigation system. The study utilized the irrigation efficiency values from the literature. The irrigation water requirement is attributed to both ET and irrigation efficiency. Although this study employed a high resolution modeling approach to quantify ET, the irrigation efficiency was used from the literature. Hilaire et al. (2008) highlighted that the 66% of water savings due to xeric landscape is attributed to precise irrigation systems. Another limitation is the constant diurnal wind regime (Crank et al., 2020b). The ENVI-met considers average wind speed and uses hourly forcing to prepare diurnal spatial wind profiles. Future studies could focus on assessing the accuracy of modeled and calculated wind speed by installing an anemometer at 2m.

Regardless of the limitations, this study is helpful to water managers in understanding the water requirements of mesic landscapes, compare to xeric and oasis landscapes. In addition, the study highlights the implication of WSL programs. The study is significant to urban climate scientists, as it highlights the importance of changes in surface temperature and air temperature due to presence of mesic, xeric, and oasis landscape. In addition, the study emphasizes the role of buildings and trees in lowering wind speed.

Conclusions

This study simulated three typical landscapes in an arid region to understand the microclimate conditions and irrigation water requirements. The goal was to determine a microclimate and irrigation water efficient landscape. The three landscapes include mesic, oasis, and xeric. The microclimate effects were determined by analyzing the spatial maps and diurnal plots of surface temperature, wind speed, and air temperature. The landscapes were modeled using the North Desert Village plant data with an aid of an ENVI-met tool. The tool utilizes building and atmospheric physics algorithms to determine the plant-soil-atmosphere interaction. The landscapes were simulated for 24 hours for the hottest day of the year, i.e., June 23, 2011, using Phoenix, AZ's climate data.

Findings suggest oasis landscapes are 5°C warmer on average with respect to surface temperature than mesic landscapes. The xeric landscape was 1°C warmer than the mesic and oasis landscapes over the hardscapes. Additionally, the vegetated surfaces for the xeric landscape were 7°C warmer than the mesic and oasis landscapes.

The presence of trees decreased the wind speeds of the landscapes. This was evident from the difference of wind speeds between the three landscapes. The mesic landscape, with tall trees (height-15-25m), showed lower wind speeds, especially between buildings and trees, while the xeric landscape, modeled with shrubs and sparse-leaf-area trees, having heights of 5 m, showed higher wind speeds.

Overall, the mesic landscape induced a cooling effect. However, the surfaces between buildings were 2°C warmer than the surrounding area at noon time indicating heat trapping. On the other hand, the oasis landscape showed 2°C lower air temperature than the mesic landscape at the peak daytime. However, the oasis landscape showed nighttime air temperature similar to the xeric landscape.

The potential evapotranspiration of the mesic landscape was highest, followed by the oasis and xeric landscapes. The oasis landscape showed, on average, a 0.1 m/sec reduction in the depth of irrigation. The xeric landscape reported the lowest depth for irrigation.

The most efficient landscape is the oasis landscape, as it contributes to daytime cooling, with lower irrigation water requirements compared to the mesic landscape. The xeric landscape is the more water efficient landscape; however, it did not promise outdoor thermal comfort, including reduced air temperature or dense shading.

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Open Research

Part of the data used is from Middel et al., 2014: https://doi.org/10.1016/j.landurbplan.2013.11.004. The database for the Mesic, Oasis, and Xeric landscape is available at the given repository: http://doi.org/10.5281/zenodo.5015501. The software used for the analysis was ENVI-met version 4.4.1 and has a restricted access.

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