# Integrating landscape tactics into building energy performance evaluation based on urban morphometry

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*This paper presents a comparative analysis of urban landscape strategies to reduce building energy consumption to urban energy simulations for two climate zones in the US: Hot and dry Phoenix, Arizona and warm and humid, yet heating dominated Des Moines Iowa. Spatial strategies for high, medium and low density urban spatial typologies were tested to improve urban microclimate for buildings and surrounding environments. Other variables were window to wall ratio In the heating dominated climate of Iowa with about 6500 heating degree days, vegetative coverings are only effective for the warm summer months most effective with larger window to wall ratios. In the hot and arid climate of Arizona, the vegetative covering are effective across the whole year.*
*KEYWORDS: Microclimate, Vegetative Covering. Landscape strategies, Urban Energy Modeling*

## 1. INTRODUCTION

This paper presents landscape strategies and spatial design guidelines for medium density urban and spatial typologies to improve urban microclimate for buildings and surrounding environments. The likelihood of extreme heat events is predicted to increase in the Midwest region of the US. This trend is exacerbated by the heat storage capacity of the dense built environment of urban area (urban heat island effect); and the fact, that many residences in low-income neighbourhoods do not have central air-conditioning systems (e.g., up to 50% of low-income homes in the study area). Vegetation can mitigate these effects by reducing reflected radiation, reducing surface heat fluxes, and increasing evapotranspiration. Efforts to integrate these effects in combined building-microclimate energy models have only recently been attempted, for example Kubilay et al., (2019) and Taleghani et al. (2016), [1, 2]. This project will add a design workflow to integrate climatic impact of landscape strategies into building energy modelling.

## 2. BACKGROUND AND RECENT LITERATURE

Current literature into natural ventilation and computational fluid dynamics (CFD) [3] and urban microclimate such as Erell and Pearlmutter (2011) [4] provided the basis for this investigation. The project proposed here is based on a multi-year effort to expand the microclimate and urban heat island modelling capacity of urban energy modelling tools as a collaboration between Architecture, Landscape Architecture, Urban Ecology, Data Science and Computational Fluid Dynamics to develop a workflow for an urban energy model of a mid-size city in the Midwest of the USA integrating impact of trees and vegetation. Furthermore, landscape tactics as highlighted by Margolis and Robinson (2007) [5] provided the basis for this investigation into landscape-based regenerative strategies for urban climate mitigation. Remote-sensed satellite-derived urban surface temperatures for Urban Heat Island (UHI) prediction can be integrated as well as future typical meteorological year data sets (FTMY) to integrate climate change predictions into building energy simulations [6, 7]. The project uses the capacities of DIVA for Rhino [8] and the urban modelling interface (*umi*) developed at MIT [9] to improve heat flux prediction onto the building envelope for energy modelling [10]. This method will integrate qualitative landscape features, tactics and components in the urban landscape such as vertical garden membranes, green roofs, and other built surface considerations with thermal building and near-building environment data (surface temperature, vegetation, evapotranspiration) to construct a probabilistic model that predicts thermal fluxes on the building envelope.

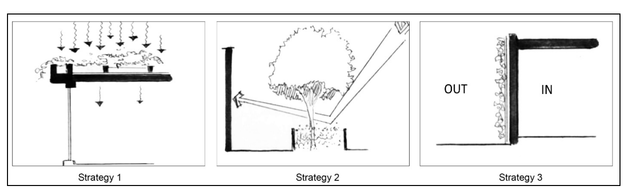

*Figure 1: Landscape strategies. Strategy 1: Groof; Strategy 2: shade trees; Strategy.3: Green surface*

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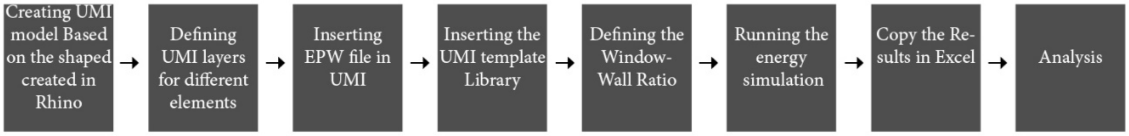


*Figure 2: Workflow overview for simulation scenarios*

## 2. METHODOLOGY

Spatial density as the proportion of the width and height of the street canyon is a known metric for urban climatology called urban morphometry [3, 4], yet the integration of trees and vegetation is not fully developed when considering this metric for building energy performance. This project thus used urban energy modelling techniques to integrate the combined effects of vegetation on building heat fluxes by shading the buildings from solar radiation as shade and by reducing temperature through evapotranspiration (transfer radiation into latent heat) to develop landscape characteristics (Figure 2).

Landscape design guidelines for spatial densities and three different climatic locations were developed based on solar radiation exposure in the urban canyon spaces which enables connection to urban energy modelling enhancing urban design capacities.

First, the vegetative features were investigated in each landscape strategy using drawings and models, including consideration of location and seasonal and temporal scale. Then specific qualitative landscape features and tactics on and around the building (facades, roofs) such as trees, ground cover, vertical gardens, and other surface considerations were noted for each urban typology. While outdoor comfort and microclimate can already be conducted using the tool Envi-MET, this project provides a novel investigation into qualitative and quantitative landscape design strategies for building energy consumption as well as outdoor climate in the age of climate change. This project will contribute to the improvement of design prediction capabilities for integration of vegetation into building and urban energy models. Metrics then predict reduced energy use intensity (EUI) for each proposed strategy per urban classification in three climates (Midwest, Arizona, Florida) (Figure 1 and Figure 3):

1. High height - High density: High rise: Multi story tower blocks in dense urban surroundings.
2. Low Height - High Density: Residential: one or two stories single houses, small shops, warehouse, light industrial, few trees.
3. Medium Height and Density: Residential: two or three story large and closely spaced, semidetached and row houses, less than 5 story; blocks of flats with open surroundings, shops, schools.
4. High height and Low density: Residential: Less than 6 story row and block buildings and major facilities

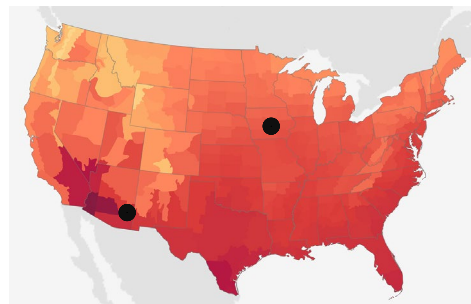

*Figure 3: Map of the US with the two climate location (colors indicate altitudes (darker = lower)*

*Table 1: Overview of the simulation scenarios discussed here*

| Energy Simulation Scenarios | | |
|---|---|---|
| Location: Des Moines, IA | | |
| **Scenario 1** | **Scenario 2** | **Scenario3** |
| High Height, Low Density-Without Trees-40% Window to Wall Ratio | High Height, Low Density-With Trees-40% Window to Wall Ratio | High Height, Low Density-With Green Walls-40% Window to Wall Ratio |
| High Height, Low Density-Without Trees-50% Window to Wall Ratio | High Height, Low Density- With Trees-50% Window to Wall Ratio | High Height, Low Density- With Green Walls-50% Window to Wall Ratio |
| High Height, Low Density-Without Trees-60% Window to Wall Ratio | High Height, Low Density- With Trees-60% Window to Wall Ratio | High Height, Low Density With Green Walls-60% Window to Wall Ratio |
| High Height, Low Density-Without Trees-70% Window to Wall Ratio | High Height, Low Density- With Trees-70% Window to Wall Ratio | High Height, Low Density- With Green Walls-70% Window to Wall Ratio |
| High Height, Low Density-Without Trees-80% Window to Wall Ratio | High Height, Low Density- With Trees-80% Window to Wall Ratio | High Height, Low Density- With Green Walls-80% Window to Wall Ratio |

| Location: Phoenix, AZ | | |
|---|---|---|
| **Scenario 1** | **Scenario 2** | **Scenario3** |
| High Height, Low Density-Without Trees-50% Window to Wall Ratio | High Height, Low Density- With Trees-50% Window to Wall Ratio | High Height, Low Density- With Green Walls-50% Window to Wall Ratio |

**3. SIMULATION SCENARIOS**

For the comparative simulation scenarios for this paper, two climates were selected: Hot and dry Phoenix, Arizona and heating dominated Des Moines, Iowa with warm and humid summer as noted in Table 1. In the first set of simulations, a city block with an area around 78,000 $m^2$ was modelled for the climate of Des Moines, Iowa for high-height, high density (Figure 4). In the second set of simulations, high height – low density was computed for Des Moines using the same parameter as in Set 1. This scenario was selected as it is most receptive to all three selected scenarios (Figure 5).

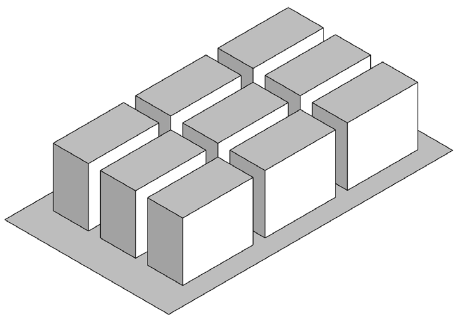

*Figure 4: Modeling scenario for High-Height – High Density*

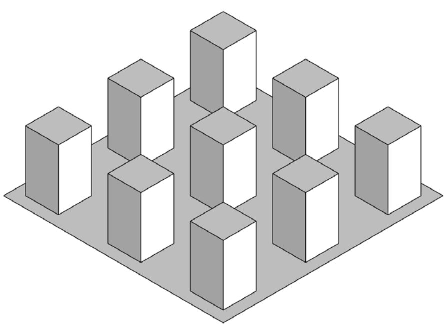

*Figure 5: Modeling scenario for High-Height –Low Density*

The model includes nine buildings and the related street canyons. EnergyPlus weather data for the location was uploaded in the software. The geometric shapes of buildings, trees, and living surfaces were created according to their real dimension such as building height and width, tree trunk and canopy) and then the appropriate software layers for various site elements were chosen. A typical individual tree was created to represent the structures of the species (Amelanchier arborea or Acer palmatum) in the site including the total height, trunk height, canopy width, and canopy height. To evaluate the heat reduction and energy saving effect of both trees and living surfaces, a scenario of "bare ground" was created, which is devoid of any vegetation or natural elements. In addition, a scenario with trees around the buildings, and another one with green surfaces on/above buildings were modeled to determine the cooling effect of these natural features. The rectangular surfaces represented living walls and green roofs. The buildings' façades and the green surfaces are the same size in the model (Green walls are 22×12 $m^2$ and green roofs are 12×12 $m^2$). The green surfaces were attached to the building's facades and roof with a short distance of 60 cm. In order to separate them from the buildings in the energy simulations modeling, SHADING was selected for them as the material. Additionally, in each scenario for Des Moines, Iowa, the window-wall ratio was adjusted from 40% to 80% to include the impact of building opening on its energy performance.

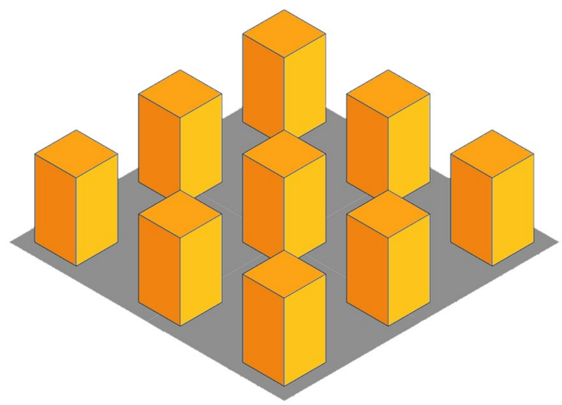

*Figure 6: Scenario 1: High-Rise |Low-Density | No Trees*

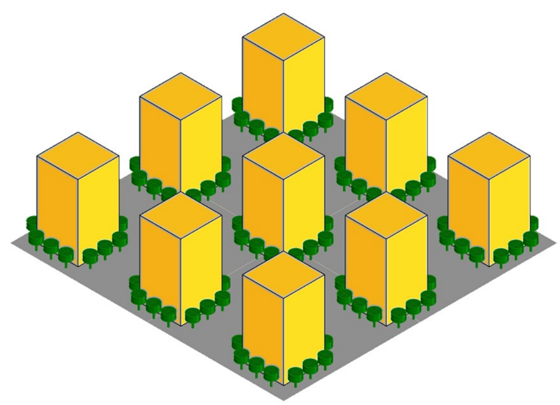

*Figure 7: Scenario 2: High-Rise |Low-Density | With Trees*

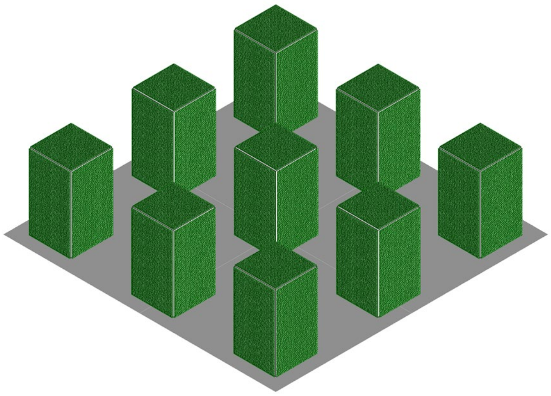

*Figure 8: Scenario 3: High-Rise |Low-Density | Vegetative Surfaces*

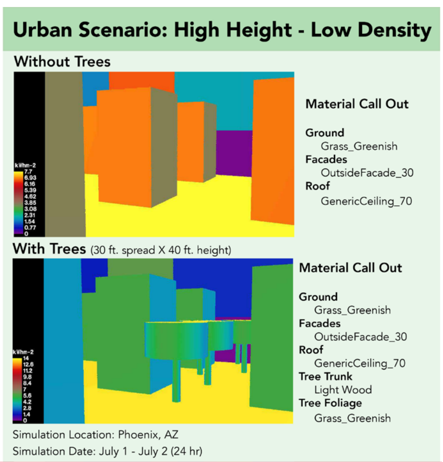


Figure 9: *Exposure to solar radiation high height, low density, Phoenix AZ with and without landscape tactics*

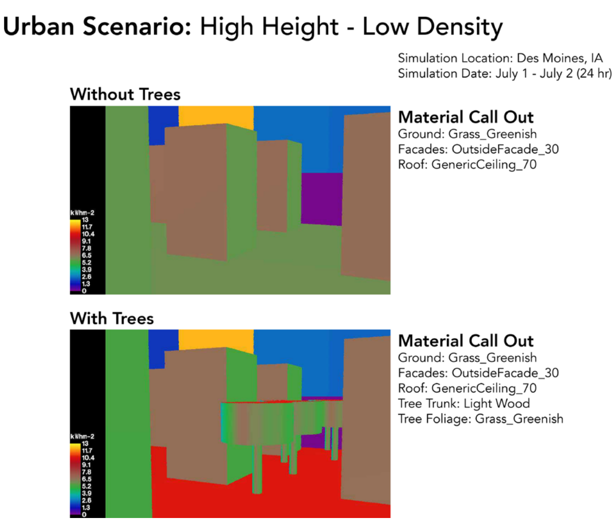


*Figure 10:* Exposure to solar radiation high height, low density Des Moines, IA, with and without landscape tactics

In the third set of simulations high height- low density urban morphometry was simulated for Phoenix, Arizona. For the Phoenix, Arizona scenarios, 50% window to wall ratio was selected. The results of the models illustrate the energy consumption for each building and the overall amount. The colours in the simulation scenarios in Figures 6 to 8 relate to the colours in Figures 11 to 12.

Based on the climatic data for the selected locations, the plant hardiness map was consulted and a design guide for of plant prepared. A selection is presented in Table 2 based on the three planting strategies noted in Figure 1.

*Table 2: Exemplary selection of planting suggestion for the USDA planting zone 4 and the three planting scenarios (Fig. 1)*

| | | |
|---|---|---|
| **Green Roof** | Miscanthus or Maiden Grass | Miscanthus sinensis cultivars |
| | Switchgrass | Panicum virgatum |
| **Shade Trees** | Hedge Maple | Acer campestre |
| | Lacebark Elm | Ulmus parvifolia |
| **Vegetative Walls** | Sweet Autumn Clematis | Clematis paniculata |
| | Baltic English Ivy | Hedera helix 'Baltica' |

## 4.COMPARATIVE RESULTS

Once all simulations for Des Moines Iowa and Arizona were completed, comparative charts were created. Figure 12 on the next page shows the overall results for Des Moines, IA for the warm season June to August differentiated by window to wall ratio. Taken the barren built form as the baseline, the decrease in energy consumption with trees is between 2 to 3 %, but with complete vegetative covering on all five sides, a 41 to 45%, with the highest reduction of 41% related to the highest window to wall ratio (80%) during cooling season. In the heating dominated climate of Iowa with about 6500 heating degree days, vegetative coverings are only effective for the warm summer months, as noted in Figure 12. On the contrary in the hot and arid climate of Arizona, the vegetative covering of all five sides of the building has an effect across the whole year as can be noted in Figures 13 and 14. The simulations also indicate, that vegetative walls and roofs have the most impact with larger window to wall ratios.

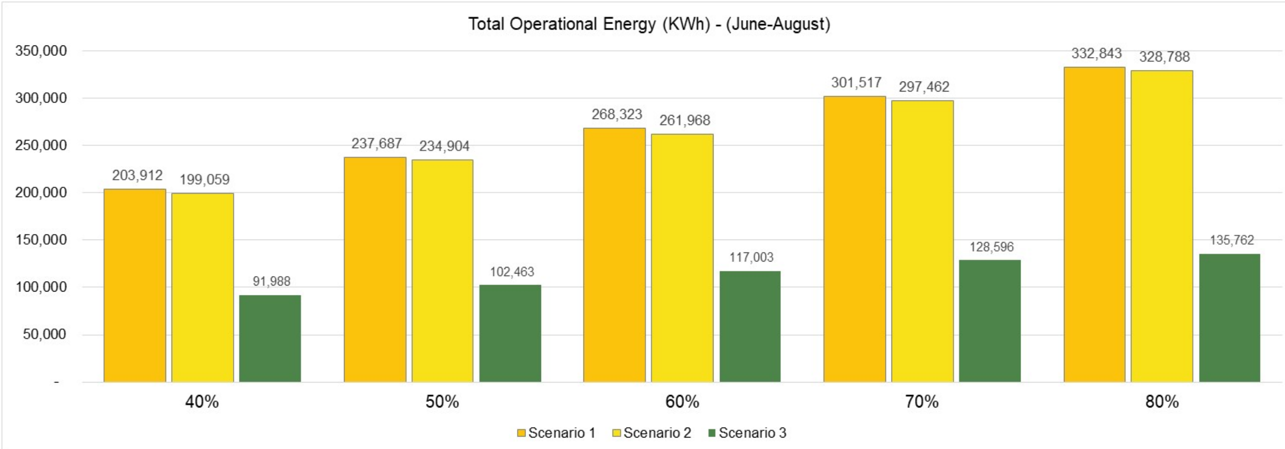


*Figure 11: Simulation results in umi for the warm season (June to August) in Des Moines, Iowa*

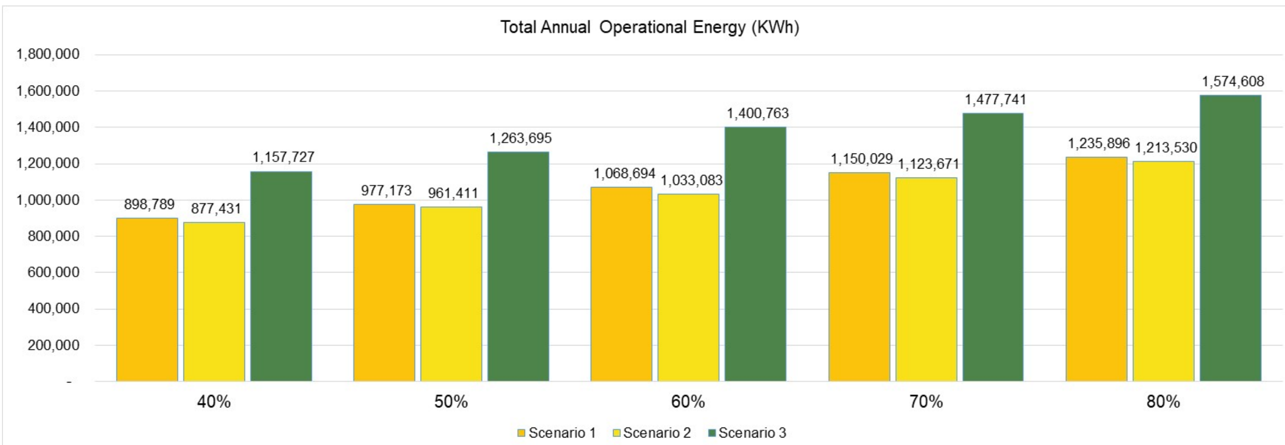


*Figure 12:* Simulation results in umi for the full year in Des Moines, Iowa

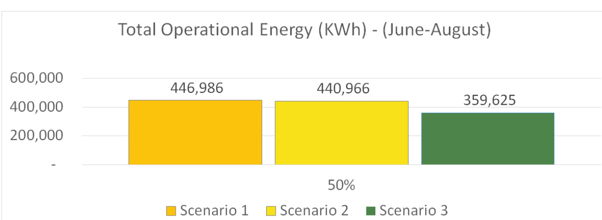


*Figure 13: Simulation results in umi for the warm season June to August in Phoenix, Arizona*

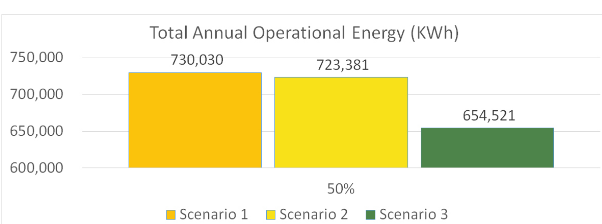


*Figure 14: Simulation results in umi for the full year*

## 5. RECOMMENDATION AND FUTURE WORK

The results derived from the presented simulations indicate an important relationship between urban morphometry, vegetative strategies and climate. It has also been noted, that measured data is not readily available. Therefore the research team will utilize a custom designed versatile Mobile Diagnostic Lab (MDL) designed for a variety of building energy research applications. It is composed of an 8'(W) × 10'(L) × 9'(H) experimental cabin and an attached mechanical room on a 19' long trailer with air suspension (Figures 15, 16). The MDL envelope is airtight, and part of the wall section is exchangeable. It houses a programmable HVAC system, and an expandable data acquisition system (DAS). The DAS can collect data at different frequencies with multiple sensors. Currently, about 250 data measurement points are able to collect data on interior air temperature and humidity, surface temperature and heat flux inside and outside the experiment cabin, power generation, and consumption.

*Figure 15: Experimental set up of the MDL testing climatic impact of vegetative covering*

*Figure 16: Experimental set-up of the MDL testing climatic impact of a green roof.*

The research capacities of the MDL enable study of diverse heat transfer paths through building assemblies, heat transfer between building surfaces and surrounding microclimate, baseline energy consumption for different climates, and CFD models for natural ventilation and passive heating. A heat flux sensor will measure the impact of vegetative coverings on heat flux on the building enclosure first in Iowa, then next summer in Arizona.

## 6. CONCLUSION

The impacts or improvements expected from this research for regenerative and sustainable design are manifold. Considering three distinctly different urban typologies, densities, and climates this project made progress towards linking 'natural infrastructure' to building energy efficiency. This research has moved forward by developing a landscape design matrix that can be applied to four selected urban density scenarios in three climate related cities. By using climate data, assigning materiality and pinpointing nodes within DIVA and *umi* for Rhino, this study related landscape interventions to surface radiation and natural ventilation techniques. This project will contribute to the improvement of design prediction capabilities for integration of vegetation into building and urban energy models. Metrics will predict reduced energy use intensity (EUI) for each proposed strategy per urban morphometry classification.

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