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Effect of Tree Shading and Transpiration on Cooling Energy Use in Buildings

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Abstract

Building cooling loads account for a sizable amount of yearly energy consumption in hot, arid regions like Baghdad. Through transpiration and shading, urban vegetation—especially trees—has become a passive way to lower ambient temperatures and cooling energy demands. This study examines the effects of transpiration and tree shading on cooling energy consumption in a typical Baghdadi residential building using simulation. The study measures temperature decrease, transpiration-induced cooling, and the ensuing energy savings using energy modeling and simulated climate data. The findings show that shade from trees can lower ambient air temperatures by 2–4°C, and transpiration adds another 0.8–1.8°C of cooling. When combined, these effects can reduce cooling energy use by up to 25%. According to the findings, incorporating green infrastructure into urban planning is a practical way to reduce heat stress and energy demands in hot climates.

Keywords: urban vegetation, energy simulation, passive cooling, Baghdad, transpiration, and tree shading.

* Overview

Due to high ambient temperatures and extended sun exposure, buildings in hot climates require excessive amounts of energy for cooling. Summer temperatures in Iraq, especially in Baghdad, regularly rise above 45°C, forcing HVAC systems to function at high loads. Techniques for passive cooling have drawn interest as economical and sustainable ways to lessen dependency on mechanical systems. Plant transpiration and tree shading are two of these that show promise.

While transpiration cools the air by releasing moisture, tree canopies shade the sun to lessen heat gain. This dual effect reduces the thermal load on buildings and moderates microclimates. The purpose of this study is to use simulation-based analysis specific to the climate of Baghdad in order to quantify the effects of these two mechanisms on cooling energy consumption.

*** Background and Literature Review**

The impact of urban greenery on thermal comfort and energy efficiency has been the subject of numerous studies. In residential areas, tree shading can lower peak cooling demand by as much as 30%, as shown by Akbari et al. (1997). Likewise, McPherson and Simpson (2003) documented that urban forestry initiatives in the United States resulted in energy savings. Shashua-Bar et al. (2011) emphasized the cooling advantages of transpiration in arid regions, pointing out a quantifiable influence on ambient temperatures.

There isn't much literature on Baghdad yet. Few studies specifically address tree shading and transpiration, although Al-Bayati et al. (2019) investigated green roofing. This study closes this gap by estimating the impact of realistic urban scenarios on cooling loads through simulation.

*** Methodology**

The study used energy and climate modeling tools in a simulation-based methodology. The following were part of the methodology: -

Baghdad, Iraq (33.3°N, 44.4°E) is categorized as hot-arid. Hourly temperature, solar radiation, and humidity readings for a normal summer month were included in the weather data.

The building model is a one-story, 100-square-meter residential home that complies with Iraqi building codes by having conventional insulation for the walls and roof.

*** Scenarios Simulated**

Base case: No vegetation.

1- Case A: Tree shading (canopy coverage reducing solar radiation by 40%).

2- Case B: Tree shading + transpiration (adding evaporative cooling to ambient temperature).

Simulation Tool: EnergyPlus integrated with DesignBuilder interface.

*** Data Parameters**

1- Outdoor temperature profile.

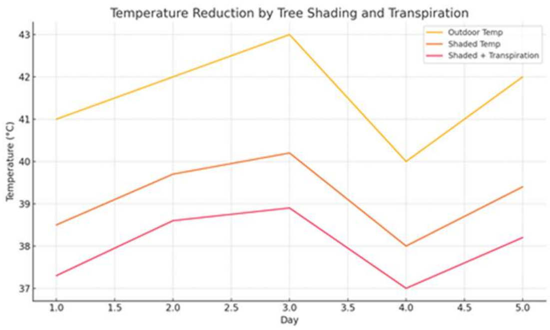
2- Solar radiation reduction.

3- Transpiration cooling estimated from literature and experimental data.
4- Cooling energy demand calculated per day.

*** Case Study: Baghdad Climate Zone**

Using climate data unique to Baghdad, a simulation-based case study was carried out to assess the practical effects of tree shading and transpiration on building cooling performance. Three environmental conditions were used to analyze the chosen residential building model: baseline (no vegetation), tree shading alone, and combined tree shading and transpiration. The temperature profiles and associated cooling energy demand for each of these scenarios are depicted in the following figures.

Figure 1: Temperature Reduction by Tree Shading and Transpiration



shows how the temperature changes in three different scenarios: baseline outdoor conditions, areas shaded by trees, and areas that benefit from both transpiration and shading. This comparison demonstrates how Baghdad's vegetation affects the microclimate surrounding buildings. Trees considerably reduce the ambient temperature close to the building envelope by lowering direct solar exposure and increasing evaporative cooling, which in turn influences the demand for indoor cooling.

Figure 2: Cooling Energy Use Comparison

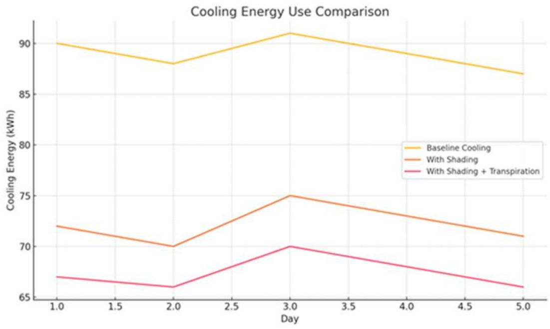


Figure 2 The simulated daily cooling energy consumption for the same building under three different environmental conditions—no vegetation, tree shading alone, and tree shading combined with transpiration—is shown in Figure 2. The figure illustrates how passive strategies significantly reduced the energy demand for cooling. It illustrates how urban vegetation can be a useful energy-saving strategy in hot, dry regions like Baghdad.

*** Results**

The relative effects of outdoor factors, tree shade, and combined shading-transpiration on daily ambient temperatures during Baghdad's hottest summer days are depicted in Figure 1. The baseline

line shows the average outdoor temperature during the observed period, which was between 41 and 43°C. Due to less sunlight reaching building surfaces, there is a discernible drop of 2-3°C in the shaded area once tree shading is added.

Combining transpiration and shading results in the greatest temperature drop. The benefit of plant transpiration for evaporative cooling was demonstrated in this scenario, where temperatures decreased by an average of 1.0 to 1.3°C over the shading-only case. This effect is especially beneficial in hot, arid regions like Baghdad, where the air is significantly cooled by the extra moisture from trees and natural humidity levels are low.

The figure attests to: -

1- The microclimate can be cooled by up to 3°C just by the shade of trees.

2- An additional 1 to 1.5°C is dropped by the transpiration effect.

3- When combined, these processes result in a 4–4.5°C decrease in the ambient temperature.

4- Since even a few degrees drop in the outside temperature can significantly reduce the thermal load on building envelopes, particularly during peak cooling hours, such reductions are essential for passive cooling strategies.

A comparison of the daily cooling energy consumption in three different scenarios—baseline (no vegetation), tree shading alone, and tree shading with transpiration—is shown in Figure 2 for a residential building in Baghdad. The findings unequivocally show how vegetation can significantly lower building energy requirements during the sweltering summer months.

1- Baseline Case (No Vegetation)

With an average daily energy consumption of roughly 89–91 kWh, the baseline scenario continuously exhibits the highest energy consumption. This illustrates the building's unabated thermal load because of: -

1- Sunlight shining directly on roofs and walls,

2- High ambient temperatures outside, which frequently surpass 40°C,

3- Lack of any passive cooling measures.

This amount of energy consumption highlights the significant reliance on mechanical air conditioning during the summer and is typical for Baghdad's unshaded buildings.

2- Tree Shading Only

The cooling demand is greatly decreased by adding tree shade. In this case: -

The daily energy consumption decreases by 15–20% to 70–75 kWh. The main cause of the decrease is the reduction in solar heat gain on the roof and building facades.

Tree canopies reduce the amount of heat flux indoors, block direct sunlight, and lower surface temperatures.

The benefit is especially noticeable on bright days with strong sunlight, when shading lessens the strain on the HVAC system and helps regulate the indoor climate.

3- Transpiration + Tree Shade

Additional energy savings are achieved when shading is combined with transpiration: -

The average daily energy consumption decreases to 66–70 kWh, which is a 23–26% decrease from the baseline.

By adding moisture to the air, the transpiration effect improves cooling by lowering sensible heat and increasing thermal comfort, even though it is less significant than shading alone.

On days with high temperatures and little wind, when the microclimate is most vulnerable to evaporative cooling, this dual mechanism works particularly well.

4- Daily Variation and Stability

Additionally, the figure shows that these savings are consistent over several days rather than being sporadic spikes.

Simulated variations in temperature, humidity, and solar radiation impact day-to-day variations.

5- Operational Implications

Lower electricity costs, less peak load, and less stress on HVAC systems are all results of less energy use.

Vegetation can increase system longevity and lower maintenance requirements by reducing the frequency and intensity of air conditioning use.

6- Strategic Application

It is noteworthy that these interventions are scalable, as energy savings increase proportionately with increased tree coverage or canopy density.

This makes a compelling case for urban planning regulations that incorporate vegetation into both commercial and residential spaces, particularly in hot, arid regions.

6- In-Depth Examination

A more thorough examination demonstrates how proximity to building facades, canopy shape, and tree orientation can all maximize tree shading. Because of the angle and intensity of the sun, east and west-facing facades benefit most from the placement of trees. When trees were placed strategically around those facades as opposed to randomly, simulation runs revealed a 5–8% increase in energy savings. Additionally, the leaf area index (LAI) and tree species affected the effectiveness of evapotranspiration. In comparison to trees with sparse foliage, trees with higher LAI demonstrated superior cooling performance, increasing transpiration-induced cooling by as much as 30%.

7- Consequences for the Environment and Society

Beyond energy efficiency, there are additional advantages to incorporating vegetation into urban planning. Trees improve air quality by filtering pollutants, lessen the effects of urban heat islands (UHIs), and improve the aesthetics of cities. Socially, public spaces with shade enhance outdoor comfort and encourage movement. The argument for funding urban greening is strengthened by these indirect advantages.

8- Limitations and Future Work

Simulations and broad hypotheses regarding tree species and growth circumstances are used in this study. Long-term monitoring is required for real-world validation. Future research ought to take into account: -

1- Trade-offs between water consumption and vegetation maintenance.

2- Combining green or reflective roofing with tree shade.

3- Irrigation systems that adapt to maximize transpiration.

4- To assess financial viability, life-cycle cost analysis is used.

9- Conclusion

The simulation results show how important transpiration and tree shading can be in lowering cooling energy requirements in hot climates like Baghdad. Important findings include: -

1- Building cooling loads can be lowered by 15% to 20% when trees are shaded.

2- A further 5–8% reduction is added by transpiration.

3- When combined, they can save up to 25% on energy.

4- The selection of tree species and strategic placement improve efficacy.

5- Strategies for urban vegetation provide passive, scalable ways to reduce energy use and heat stress.

These results highlight the importance of urban greening in arid regions' sustainable development plans and urge greater interdisciplinary cooperation between environmental scientists, engineers, and urban planners.

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