International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 12906-12913


# Simulating the Carbon foot Print Reduction of an Arid Urban form Applying Canopy Layer Green Coverage under Climate Change Scenarios

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**Abstract**

As an overlap between micro and local climate scales, urban form design has recently attracted insights towards sustaining built environments, and would still in a mess without spot lighting to its measures in a time of changing climate. of those measures, carbon concentration is responsible for a major role in global warming. In this research, the domestic carbon foot print of an urban form in the arid climatic zone of Giza of Egypt has been estimated in present and future before and after applying urban canopy layer green coverage as an adaptive strategy for climate change. The suggested green coverage includes local trees in addition to green roofs and green walls. Both urban and building simulations were performed conjunctionally via a conversion cycle of EPW-CSV-EPW to relate canopy layer green coverage to indoor environment and its HVAC and domestic uses that conclude specific carbon emissions. This cycle is applied to let weather files represent outdoor interactions after applying the greenery elements that literally affect reductions might occur as only indoor simulations do not account for the cooling effects of greenery, for energy consumption and in turn for $CO_2$ reduction. Results show considerable reductions in $CO_2$ after adaptation but with variant values corresponding to the examined future climate scenarios (2020, 2050 and 2080).

**Keywords:** climate change, $CO_2$, canopy layer, green coverage.

## INTRODUCTION

### Climate change and carbon emissions

Climate system is influenced by human anthropogenic emissions of GHGs. Since the middle of the last century, many changes of extreme weather and climate events have been observed, including an elevation in surface air temperature, increase in frequency of extreme events such as droughts, floods and changes to patterns of precipitation. However, the increase of surface air temperature is regarded as the most obvious change in the global climate [1]. Moreover, the likelihood of such irreversible impacts for people and ecosystems could not be reduced unless sustained reductions in GHG emissions, together with mitigation for present and adaptation for future, are to be considered. It's predicted that global mean surface temperature change will likely be 0.3°C to 0.7°C under the four Representative Concentration Pathways (RCPs) for 2016-2035, and 2.6°C to 4.8°C under RCP8.5 for 2081-2100. Likewise, global surface temperature change is projected to exceed 1.5°C for 2081–2100 [2]. Urbanization contributes to climate change with its increased emissions of GHGs, alteration of the properties of atmospheric boundary layer, i.e. turbulence, temperature, and moisture field. Furthermore, the frequency, intensity, and duration of heat waves are more likely to increase in cities with rising surface and near surface air temperatures [3, 4].

Heat waves are expected not only to increase temperatures and become more frequent, but also interact with UHI and cause extreme heat stress events [5]. Moreover, heat waves have a negative impact on heating and cooling loads of buildings that were originally designed for certain thermal conditions with an average of 11% [6, 7]. Thus, the combination of rapid urban growth with its thermal stress, and heat waves induced by future climate change with concluded GHG highlights the need for investigating its concentrations as it contributes to the atmospheric radiative forces and more global warming potential in turn [2, 8].

From these standing points, the passive design strategies both on building and urban scales that can mitigate climate change symptoms in existing climate conditions and adapt for future ones are vital for part of the chain built environment – energy – GHG – climate change. One of these strategies helping $CO_2$ as one of the GHG affecting environments is the urban vegetation as is consumes $CO_2$ to generate O2. In this concern, building performance simulation packages importance had increased in the last decade as it ease dealing with the complexities of modeling and calculating of sustainability measures of built environments. Among such complexities, files of weather data uploaded to simulate examined sites have been developed to represent different conditions both in present and future. "Among the methodologies used to predict future weather data of climate change scenarios, the morphing methodology published by the Chartered Institution of Building Services Engineers (CIBSE) and its tool is the only method that allows the generation of Typical Meteorological Year, TMY2 (which is used to compile the weather file extension EPW) TMY2/EPW files to predict the thermal performance of future for any site in the world and have been used for environmental studies in Egypt" [9-11].

The fact that neither outdoor simulation packages can simulate indoors nor indoor packages can simulate outdoors derived concluding the coupling outdoor-indoor simulation methodology to let weather files represent outdoor interactions after applying any passive design strategy/ies elements that literally make improvements as only indoor simulations do not account for the cooling effects of greenery, for energy consumption and in turn for $CO_2$ reduction, [9]. That is why this work studied how greenery elements can reduce carbon foot print of a whole site using both building and urban simulations to calculate carbon foot print reduction after applying urban canopy layer green coverage.

## URBAN ADAPTIVE STRATEGIES

### Fabric geometry adjustments

Urban areas induce such profound local climatic modifications and are commonly known as the urban canopy layer (UCL). More often than not, it's quite difficult to find a representative urban canyon with regards to all adjusting parameters: aspect ratio, orientation, construction materials, presence of vegetation, etc. [12]. Based on studies conducted by Nunez and Oke [13], and Yoshida et al. [14], it was proven that, besides the canyon geometry, the shading involved by orientation and the presence of canyon-axis air flow, substantially affects the energy budget of an urban canyon [15], the heat gained by fabric that affect domestic energy consumption and GHG in turn [9].

On the other hand, a compact city is meant by a city, in which compactness and density are created by means of geometrical adjustment to avoid all the problems of modern design of cities [16]. Compactness is a strategy that proposes more achievable forms of sustainable built environment.

Furthermore, scales such as compactness degree should be taken into account as it represents the overall degree of compactness of an urban site. While compactness degree scale (CDS) is calculated by multiplying the total floor area ratio of an urban site by the average height of canopy layer in this site, it may control the whole urban morphology and by which wind flow and access may significantly differs [17-19]. In a more recent study, Fahmy and Elwy used the parametric techniques to optimize thermal and visual comfort levels in a hot arid urban site based on its CDS. They concluded that, among simulated cases, urban forms around CDS of 6.0 at 45 and 135 degrees of urban canyon street axis are the optimum cases for outdoor visual and thermal comforts [20].

### Urban canopy green coverage

Vegetation, as widely emphasized, can play a major role in improving the microclimate for its several benefits in acoustics, pollution alleviation, aesthetic values, social issues in addition to the energy savings in the buildings induced by less cooling or heating loads [21, 22], which for instance, could reach up to 5 K lower temperatures and 50% less wind speed [23, 24]. Mainly, vegetation possesses three main characteristics which, to a large extent, affect the climate, namely shading, evapotranspiration and wind blockage [25, 26]. On the one hand, different studies confirmed that, within an urban canyon, the effectiveness of vegetation is a green-to-built-up area ratio dependent as such the size, density, shape, age, species and latitude of the plant [27].

On the other hand, other studies argued that orientation, volume and shape are found to be key factors of tree efficiency rather its density. For instance, in relation to shading, a tree that is supposed to drop shadow over a western façade would be more efficient than these shading eastern [23].

Trees lines, as reported by McPherson [28], should not be underestimated as it leads to about 50% to 65% of energy savings in streets or yards with high energy loads [29]. However, vegetation due to its drag force of plant canopies, negatively affects wind speed especially when gathered in groups [26]. In addition, it was investigated that the cooling effect by shading gradually increases from street edge to the center of the canyon. However, at different measuring points in the same street, air temperature varied according to the non-uniform shading [30]. Norton et al. suggested a hierarchical approach for prioritization of street trees with respect to their width, orientation, and aspect ratio. However, more studies have to be performed for a local context [31]. Moreover, the degree to which shading affects the microclimate was found to be related to the seasonal climatic conditions of the canyon [32].

Numerous studies have investigated the effect of using vegetation in reducing what is called by Urban Heat Island (UHI) [22, 26, 28], on which more light is to be shed later on in this chapter, however, Edward NG et al. [33] argued that the effectiveness of using vegetation in mitigating the microclimate is remarkably dependent on the buildings' heights of the UCL, where the cooling effect is more explicit when building heights are 20 meters or less, than when they are 40-60 meters. Furthermore, they argued that using the tree plantings are more effective than using grass turfs, particularly at green coverage more than 34%. In addition, a framework to prioritize green infrastructure to mitigate high temperatures in urban landscapes, was developed by Norton et al. [31].

Furthermore, trees canopy parameters, leaf area density (LAD) and leaf area index (LAI), were investigated by Jonckheere et al. and Montes et al. [34, 35], and discussed by others, [19, 36], in order to study tree heat exchanges with the surrounding environment and on which some light is shed in chapter 4. In this respect, LAI is defined as *"a dimensionless value of the total upper leaves area of a tree divided by the tree planting ground area";* whilst LAD can be defined as *"the total leaves area in the unit volume of tree horizontal slices along the height of a tree that can give an idea about the vertical leaves distribution".* Abundant studies were made to calculate the LAI and LAD using field measurements [34], or instrumentations along with empirical models [37, 38].

It was found that vegetation can ameliorate the microclimate by both the interception of incident solar long wave and short wave radiations and evapotranspiration. The latter is due to water and vapor cycle from leaves' surfaces to air, designated as the soil-tree-air system, in case of providing the soil with sufficient water supply [26, 29]. In this concern, within a tree environment, the latent heat rises and the sensible heat is minimized which, in turn drives to lowering air temperature Ta [39]. Achieving cooler surrounding air leads to ameliorating outdoor comfort levels and indoors as well, as a result of the modification of the ambient conditions [22]. Urban moisture is mainly comprised by two prevailing sources; advection and evapotranspiration, where vegetative cooling may be effectively determined through measurements of specific humidity, as reported by (Kurn 1994) [39], and followed by many others [19, 26, 36], using the first regression equation by Jensen and Haise [40], to calculate the contribution of evapotranspiration.

A further study was experimented by Shahidan to evaluate different trees according to their LAD, and he confirmed that the evapotranspiration rate is larger with higher density of trees. Further to that, the use of more trees with high density of tree such as Ficus Benjamina can create a solid shading with almost 100% of thermal radiation filtration as it influences the reduction of ground surface temperature and the increase of evapotranspiration rate and hence, resulting in larger moisture content to the urban area [36].

Analogous to the transect approach by Duany [41], which seeks to organize the physical elements of human habitat; building, lot, land use and street, in ways that maintain the integrity of different types of rural to urban environments to find the appropriate relationship between the town and the countryside [42], Fahmy [19] developed a passive urban planning tool that can be defined as a city's regularly distributed parks and gardens urban structure along the rural-to-urban providing a hierarchy of passive vegetative techniques; urban tree shading, evaporation from green surfaces, and nocturnal cooling nodes. Among those green surfaces of valuable and literally recorded beneficial application, are the roofs [43, 44] and green walls [45, 46].

## METHODOLOGY

To study the effects of the proposed urban canopy layer green coverage (trees, green walls and roofs) on the indoor domestic $CO_2$ emissions in response to certain energy consumption, the outdoor and indoor environments have been conjunctionally simulated through two building performance simulation packages; ENVI-met and Design Builder. ENVI-met CFD numerical package is capable of simulating surface-plant-air-soil interactions and generate a detailed set of meteorological output [47]. These output data have been used in a following step by Design Builder [48] to estimate the $CO_2$ emissions before and after the application of urban canopy green coverage elements as neither Design Builder nor any other building indoor simulation tool accounts for outdoor greenery microclimatic effects that hypothetically reduce fabric $CO_2$ emissions. Input data for ENVI-met simulations were the raw weather data files in present, 2020, 2050 and 2080. The Climate Change World Weather Generator was applied to generate future weather files which uses the morphing methodology to have weather data for the aforementioned targeted years, [49] and is used as data input for ENVI-met numerical simulations of base and adapted (greenery) cases in future, BC and AD respectively.

The urban site case study is part of 6th of October city located near Giza, 29° 47' N and 31° 2' E, has three prototypes of residential buildings. As a satellite town and part of the urban area of Greater Cairo, Egypt, it's 17 km far away from the great pyramids of Giza and 32 km from downtown metropolitan Cairo. 6th of October City climate is classified as hot desert or BWh according to Köppen classification. METEONORM tool has been applied to generate the weather data of examined urban site in EPW, [50]. Analyzing the site weather data, the extreme summer week is 21st: 27th of July with a maximum dry bulb temperature of 42.7°C recorded on the 21st of July. The typical summer week is between 29th of July and 4th of August with a daily average dry bulb temperature of 28.3°C. Maximum daily global radiation is in June with 7788Wh/m². The maximum recorded direct solar radiation was 9719 Wh/m² on the 8th of July. The site has housing typologies; A, B and C, (ground + 5 typical floors) but with different urban forms. Typologies A and C have 4 flats per floor whereas B has 5 flats per floor. Type A has a total floor area of 330m2 with a flat area of 72m2; type B has a total floor area of 455m2 with a flat area of 75m2 and type C has a total floor area of 275m2 with a flat area of 55m2, difference between total floor area and the sum of flats' areas is the services area.

Figure (1) shows the location of the case study on the climatic map of Egypt whereas figure (2) shows the layout of case study. Applied green roofs were extensive after Morakinyo et al., [51] whereas the green walls have been modeled after the novel vertical greenery module proposed by Serra et al., [52]. The urban street canyon trees applied to adapt the two sites to climate change were Casia Nodosa, Cassia Leptophylla and the Ficus Nitida which are commonly used in Egypt. Figure (3) shows the site model in ENVI-met modeling user interface. Figure (4) shows the introduced green coverage elements. Figure (5) shows the case study model in Design Builder.

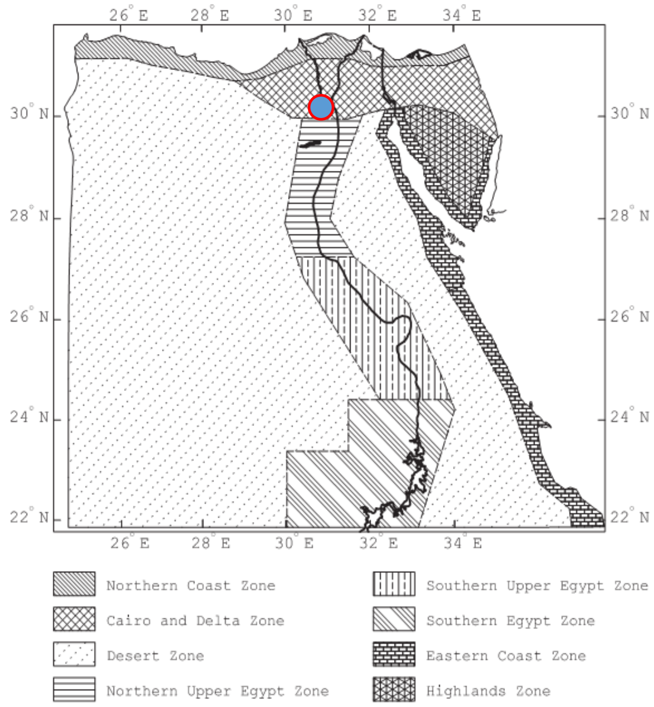


**Figure 1:** Urban site case plotted on the climatic zones map of Egypt according to EREC, [53].

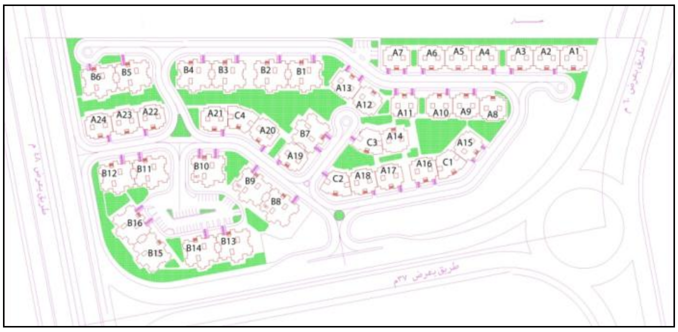

**Figure 2:** Layout of case study.

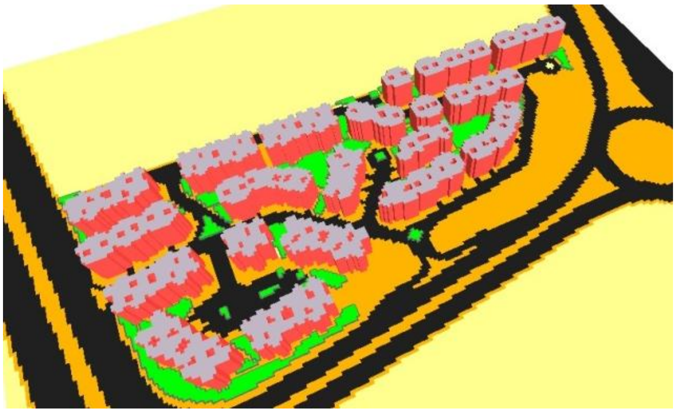

**Figure 3:** Modeling of base case; BC in ENVI-met V4.0.

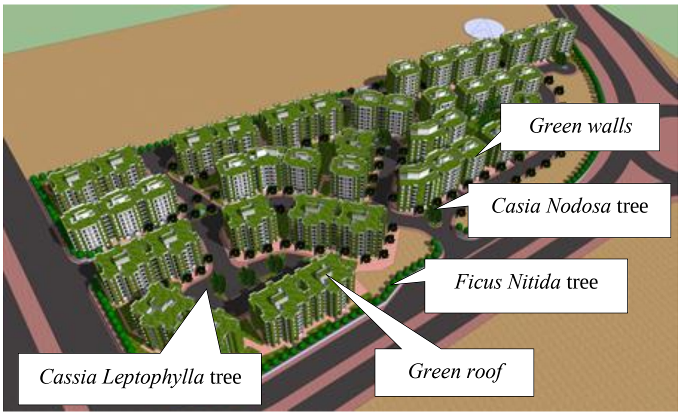


**Figure 4:** The proposed urban canopy layer green coverage elements.

**Figure 5/a:** Modeling of apartment building type A within urban site in Design Builder showing.

**Figure 5/b:** Modeling of apartment building type B within urban site in Design Builder showing.

**Figure 5/c:** Modeling of apartment building type C within urban site in Design Builder showing.

**RESULTS AND DISCUSSIONS**

In all base and adapted cases, simulation results showed reductions from base to adapted as expected owed to the green coverage of urban canopy layer applied to prototypes A, B and C.

The energy consumption and cost of the whole case study site corresponding to the domestic appliances' uses which reveal a specific carbon foot print is presented in figure (6) and (7) which indicate comparisons of energy (electricity from grid) and cost savings calculated using the Egyptian residential feed-in tariff for the simulation month (July). In comparison to their base cases, results show that energy savings after green adaptation for whole urban site achieved 10.0%, 12.3%, 14.6% and 16.9% for 2080, 2050, 2020 and present conditions which is corresponding to 23.8%, 16.1%, 19.8% and 26.0% of cost savings respectively in July. It is noticed that the cost savings is decreasing from present time towards 2080 from 26.0% to 23.8%.

With regard to CO2 emissions, figure (8) shows the total carbon foot print of the urban site prototypes in Kg/Annum for the base cases (present, 2020, 2050 and 2080) in comparison to their adapted cases with greenery in the same climate conditions of present, 2020, 2050 and 2080). Figure (9) shows the carbon foot print comparisons for each housing typology A, B and C.

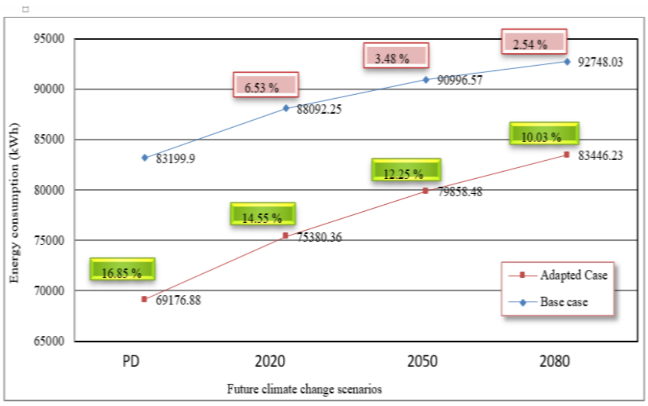


**Figure 6:** Energy consumption of July month at present and future climate change scenarios.

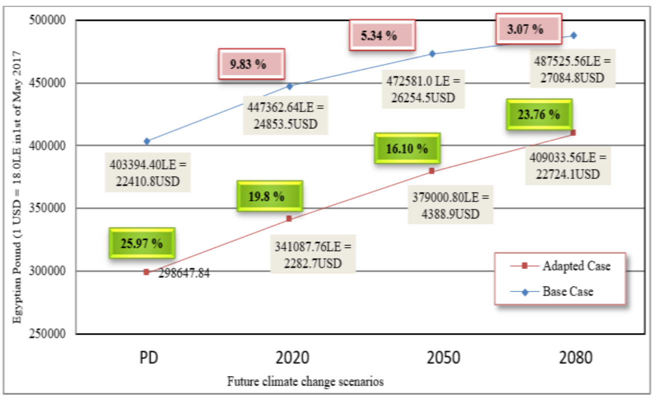


**Figure 7:** Energy cost of July month at present and future climate change scenarios.

All the examined housing prototypes expressed improvements in their carbon foot print. The much concern was to the share of emissions of prototype C which was minimum because of the number prototype C buildings (4buildings) followed by the share of prototype B (16 buildings) and then the prototype A (26 buildings). The total emissions of whole site has been reduced by 1299 kg/annum of CO2 in present, 1061 kg/annum in 2020, 579 kg/annum in 2050 and 857 kg/annum in 2080. The reduced amount of emissions is generally decreasing by the end of century which gives an indication that the applied urban greenery wouldn't be sufficient to adapt the site case study for climate change effects by the increase of air temperature, heat stress, energy consumption and intron the corresponding carbon emissions. This would imply that more than the applied urban greenery as passive design strategies should be considered as well as the area covered by trees canopies but with precautions to the wind blockage and trapped heat might occur at early evening which reveals urban heat island effects.

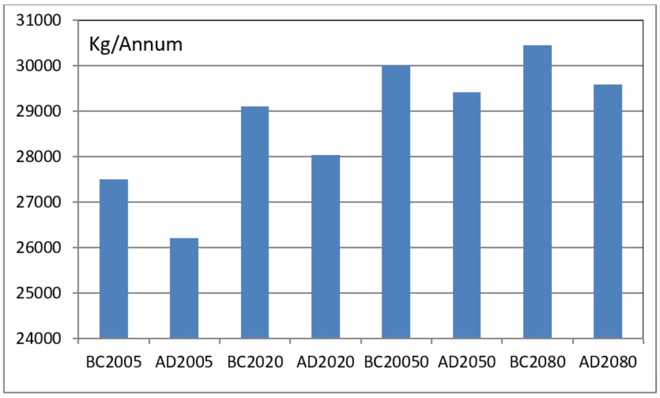


**Figure 8:** Comparison of total CO2 emissions at present and future climate change scenarios for the examined urban site.

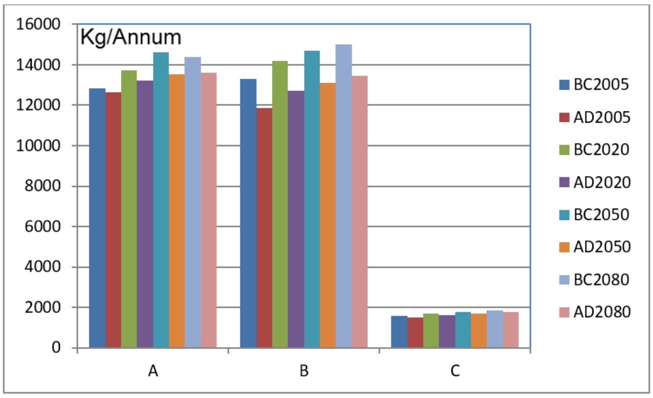


**Figure 9:** Comparison of total CO2 emissions at present and future climate change scenarios for the examined urban site housing typologies.

## CONCLUSION

This paper investigated the effects of urban canopy layer greenery in reducing the carbon foot print of a residential urban site in Giza, Egypt in present and future. The suggested green coverage includes local trees in addition to green roofs and green walls. Both urban and building simulations were performed conjunctionally via a conversion cycle of EPW-CSV-EPW to relate canopy layer green coverage to indoor environment and its HVAC and domestic uses that conclude specific carbon emissions. This cycle was applied to let weather files represent outdoor interactions after applying the greenery elements that literally affect reductions might occur as only indoor simulations do not account for the cooling effects of greenery, for energy consumption and in turn for CO2 reduction.

The coupled ENVImet - DesignBuilder simulation results showed considerable reductions in total emissions of whole site. The reduced amount of emissions is generally decreasing by the end of century which gives an indication that the applied urban greenery wouldn't be sufficient to adapt the site case study for climate change effects by the increase of air temperature, heat stress, energy consumption and intron the corresponding carbon emissions. An important conclusion appeared is that extra passive design strategies should be considered in addition to the applied urban greenery as well as the area covered by trees canopies but with precautions to the wind blockage and trapped heat might occur at early evening by trees.

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