HTWK Leipzig University of Applied Sciences

Evaporative cooling strategies in urban areas:

The potential of vertical greening systems to reduce nocturnal heat stress

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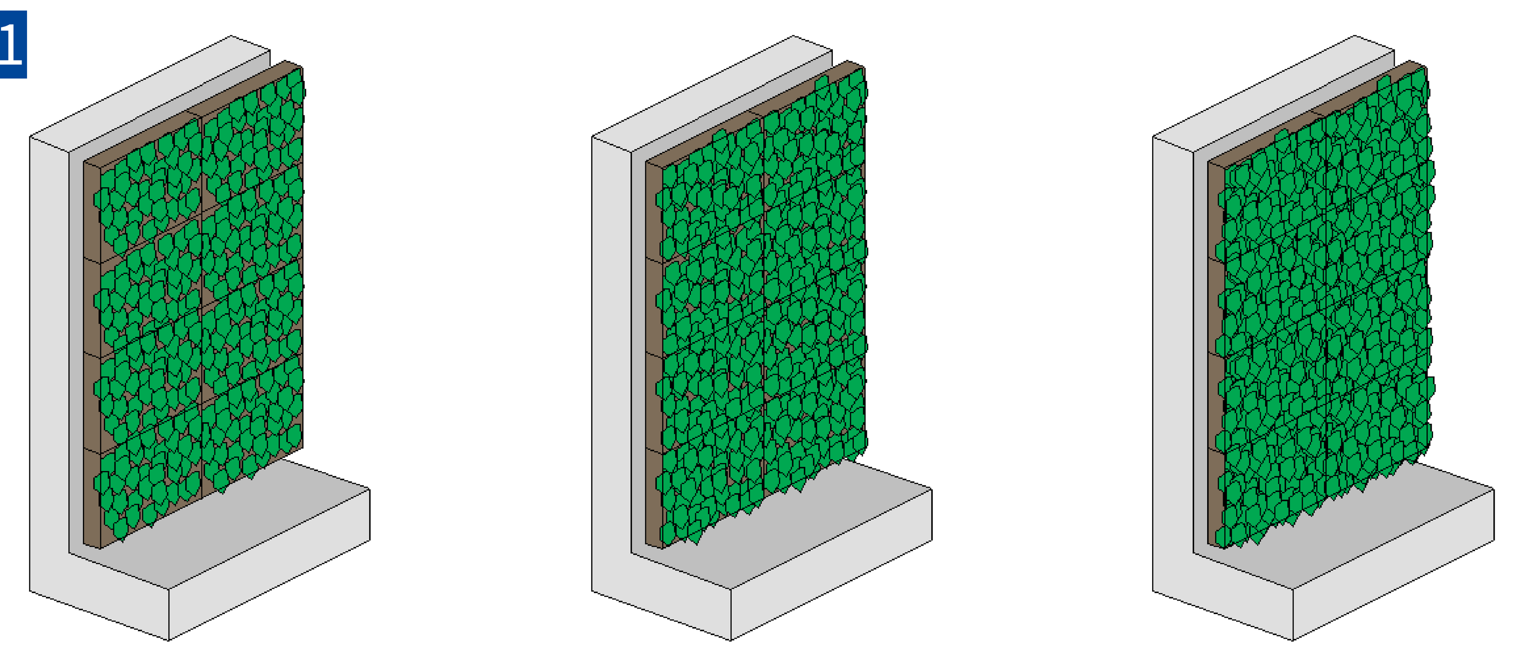
Introduction

The anthropogenic climate change results in a steady increase in hot days ($T_{max} \geq 30°C$), tropical nights ($T_{min} \geq 20°C$) and heavy rainfall affecting the quality of human comfort, especially in urban areas. Sealed surfaces avoid infiltration and evaporation of rainwater, while solar radiation is often being reflected without making use of it. Vertical greening systems, often a first-choice mitigation strategy, are able to store a remarkable amount of water and evaporate it through their leaves, while also functioning as a natural shading system. This study aims to investigate the efficiency of different vertical greening systems, varying in Leaf Area Index (LAI) and orientation, in terms of cooling in different climate zones. The LAI is defined as the one-sided leaf area per unit ground surface (LAI = leaf area/ground area; m^2/m^2) and helps to find out whether a higher density of greening increases efficiency and if potential advantages of a higher LAI prevail the increasing need for irrigation.

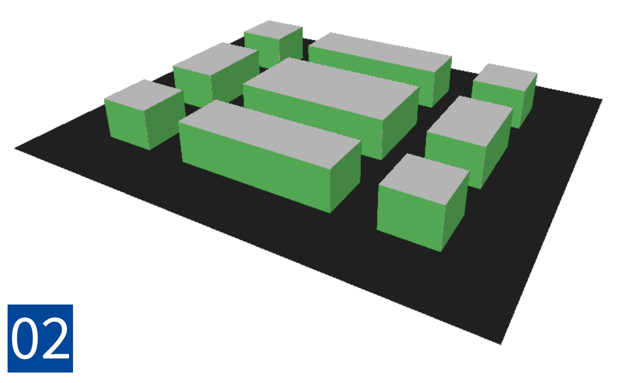
01



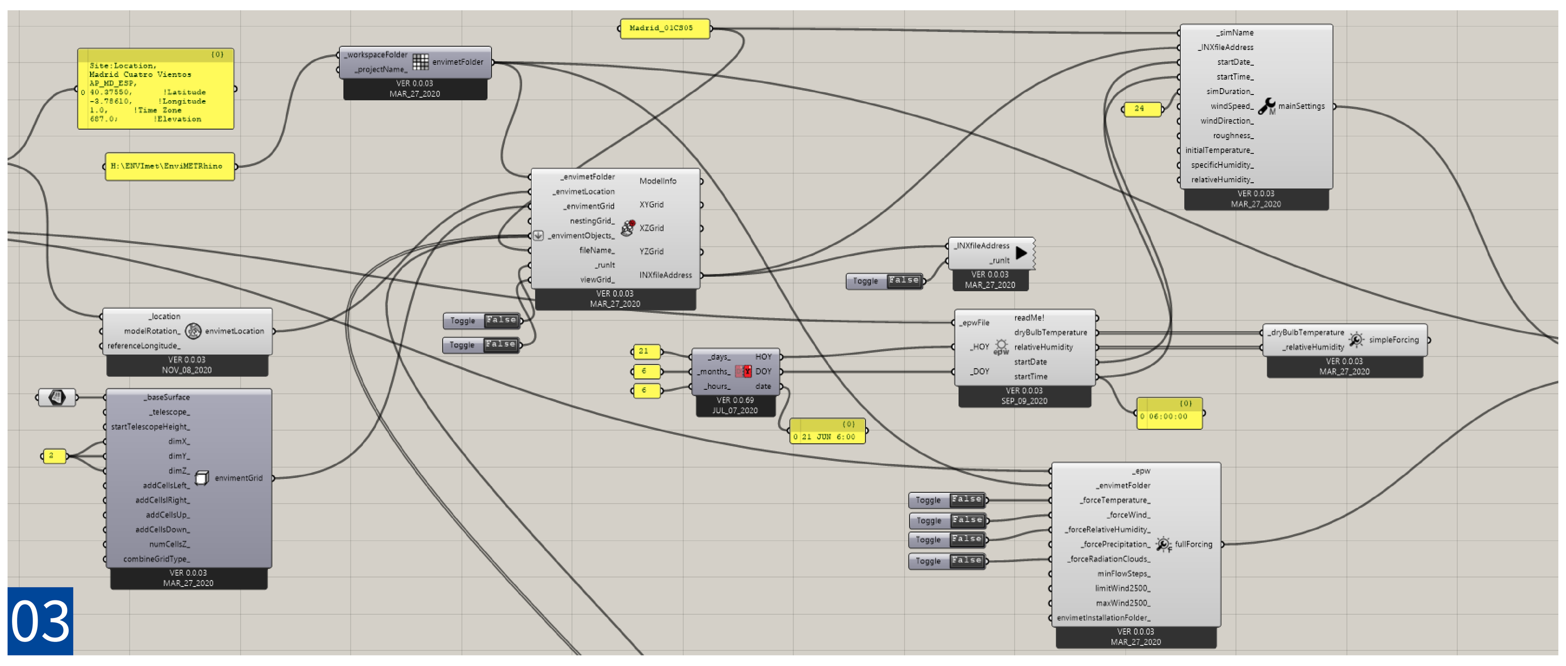
Greening systems with different Leaf Area Indices (LAI=1, LAI=2, LAI=5)

Methodology

Combining the software solutions Rhinoceros 3D, Grasshopper and ENVI-met a common urban neighbourhood was modelled and provided with different types of greening, while including local weather data of the three locations Berlin (moderate climate), Madrid (subtropical climate) and Singapore (tropical climate). Four scenarios were created for each of the locations, containing one reference scenario (no greening) as well as three greening scenarios with different LAI respectively (LAI=1, LAI=2, LAI=5). The 24-hour simulation period started on the 21st of June 6am, ending on the 22nd of June 6am and was selected as a representative summer day.



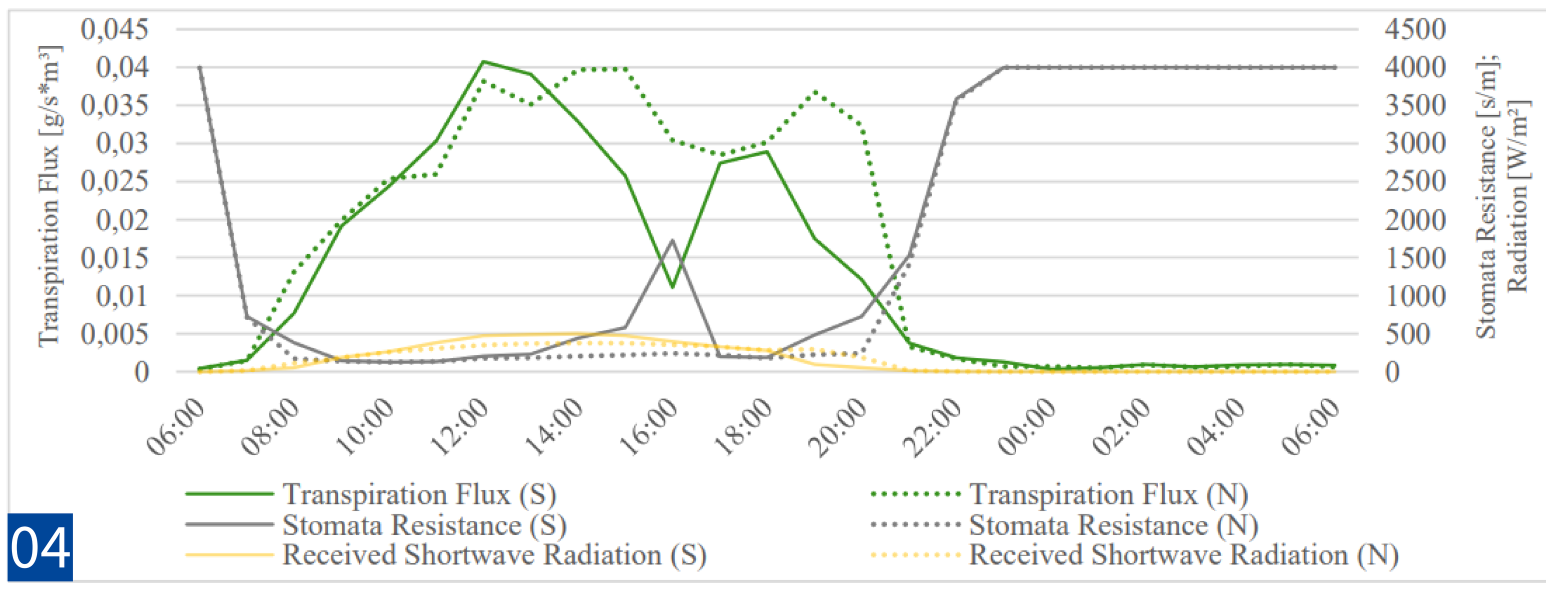
02 Reference neighbourhood (with greening)



03 Workflow Grasshopper – ENVI-met

Results

The rate of evaporation in general depends on different external factors. Transpiration however, is the loss of water from the plant through evaporation via stomata, little pores in the leaves' epidermis and responsible for gas exchange. As Figure 4 examplifies, a high stomata resistance (closure) causes a decrease in transpiration fluxes. One reason for stomatal closure may be a lack of blue- and red-light, i.e. during night-time. Also high leaf temperatures have an effect on the stomata, as they close as a self-preservation mechanism to prevent dehydration. Comparing the transpiration fluxes of a north and a south facade, the differences are significant, as the north-orientated greening, not being exposed to the sun, shows almost no stomata resistance during midday.

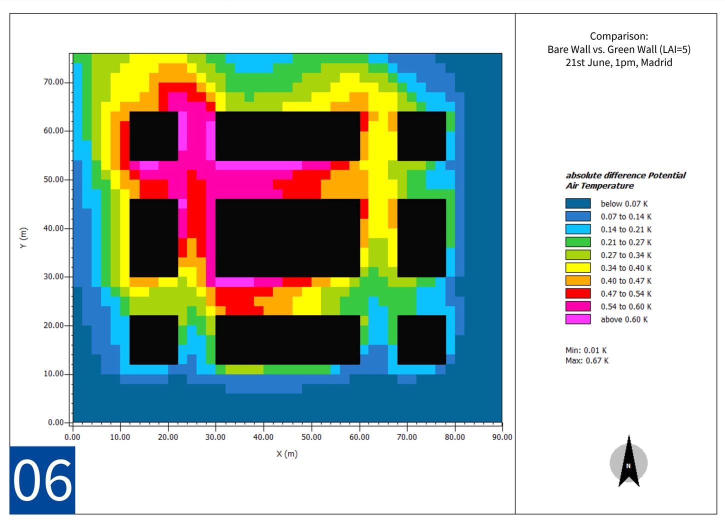


04 Transpiration fluxes and stomata resistance (north and south façade, Madrid)

Comparing the wall surface temperatures of a bare concrete wall to the ones provided with greening, temperature differences of up to 11.00K could be recorded on a south facade in Madrid (Berlin: 18.28K, Singapore: 6.94K). These remarkable decreases also affect the indoor wall surface temperatures during night-time with differences of up to 0.96K (Berlin: 1.45K, Singapore: 0.85K) (see Figure 5).

05 Wall surface temperatures with and without greening (Madrid, LAI=1, 2nd floor, south façade)

To examplify the effects the greening had on the outdoor microclimate, a representative spot (2m x 2m) in between two buildings, was picked. Comparing the different scenarios, the most dense greening (LAI=5) had the biggest effect on the potential air temperature. Figure 6 shows an example of the decreases in potential air temperature for the reference neighbourhood (Madrid, 1pm). The greatest effects over a day were found in Madrid and Berlin with a maximum difference of 0.71K. In Singapore the maximum difference was only 0.3K, due to a higher relative humidity limiting transpiration. During night-time (6pm to 6am) an average decrease of 0.1K could be observed in Madrid (Berlin: 0.08K, Singapore: -0.22K). The effects therefore seemed to be almost non-existent. One of the main reasons for that are, as mentioned above, limited transpiration fluxes during night-time due to a high stomata resistance.



06 Change in potential air temperature (1pm, Madrid)

Conclusion

The results show that vertical greening systems may influence both: the outdoor microclimate and building surface temperatures. In terms of shading, the greening had a significant impact on the outdoor wall surface, lowering temperatures up to 18.28K during midday in Berlin, while also affecting the indoor wall surface temperatures (-1.45K during night-time). As different LAI did not show major differences regarding shading, lower densities (i.e. LAI=1) can be recommended to keep water consumption within limits. The rate of evaporation depends on many external factors like wind, relative humidity and air temperature. However, the transpiration of a plant via stomata also depends on the availability of light and on the leaf temperature. Evaluating the transpiration fluxes, drastic decreases could be observed on the south facades during midday, whereas the greening on the north facade, not being exposed to the sun, showed steady fluxes and no stomata resistance. This proofs that orientation is one of the key factors when installing green walls, as low leaf temperatures may be substantial for transpiration. Regarding outdoor microclimate, the simulations showed a maximum decrease of potential air temperature of only 0.71K on a street canyon, in between two buildings provided with greening. The average night-time difference of potential air temperature for the outside was only 0.1K, as transpiration decreases, due to a lack of light. Vertical greening systems do have many advantages like supporting biodiversity, improving air quality or protecting the building. However, green walls do not fully exploit the potential of evaporative cooling, due to the mentioned restrictions. Innovative evaporative cooling systems, providing higher and adjustable transpiration fluxes, could make a significant difference and help to fight heat stress in urban areas - even during night-time.

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