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Performative Evidence of Smart and Urban Trees - Assessing the thermal and visual impact of large scale urban shading structures via simulation

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Abstract

This contribution presents specific results from a project pertaining to large scale urban shading structures. These structures were named as "smart and urban trees". Thereby, we understand artificial structures that should be implemented in urban agglomerations at places and locations, where no other green-blue infrastructures can be deployed. As such Smart and Urban Trees do not pose a competition for real trees, but a supplement whenever real trees cannot be integrated in the cityscape (e.g., due to underground installations or means of transport). Whereas the project per se did address a large number of aspects of such Smart and Urban Trees (e.g., aesthetics, construction, organizational aspects, end-user acceptance, etc.), this contribution reports on the impact of such Smart and Urban Trees on thermal (physiological equivalent temperature, indoor temperatures in adjacent buildings) and visual surroundings (impact on daylight availability in the surrounding buildings), both in the public space and in the surrounding buildings. Toward this end, a case study district / neighborhood was chosen as virtual test bed for different Smart and Urban Tree designs. It could be proven that the envisioned structures can significantly contribute to mitigation of overheating phenomena, also in comparison to real, living trees.

Introduction

Cities worldwide increasingly experience the so-called Urban Heat Island effect. This phenomenon, which is interlinked with the Climate Change, has been matter to observation and scientific research for already a long time (e.g. Landsberg 1981), and is widely, prominently and intensively published since about 20 years (amongst others: Crutzen 2004, Alcoforado and Andrade 2008, Roth 2013). Roth (2013, P143) defines it as "*a phenomenon whereby urban regions experience warmer temperatures than their rural, undeveloped surroundings. The UHI is the most obvious atmospheric modification attributable to urbanization,8 the most studied of climate effects of cities and an iconic phenomenon of urban climate*". In the City of Vienna, Austria, the issue of Summer Overheating has been considered a serious issue for some years now. In 2018 the Vienna Environmental Protection Department published an Urban Heat Island Strategy Plan for the City of Vienna (MA22 2018), which suggests several strategic actions for climate-sensitive urban planning, such as protecting urban air flow and open space networks, adaptation of the urban structure and development, increasing surface permeability and adapting building styles, protecting and expansion of green and open spaces, and conservation and expansion of the stock of (street) trees. In other words, this strategy plan identifies green-blue infrastructure as key element into cooling the city in summer times. In 2019, the Urban Heat Vulnerability Map of Vienna, Austria was published (Hitzekarte 2019), which identified the densely populated central districts allocated from Northwest to Southwest around the Vienna Ringstraße as well as the city center as being most vulnerable regarding summer overheating. These districts are characterized by a comparably old building stock, very little public greenery, and little possibility to add regular green-blue infrastructure. In the street canyons of these regions there is a high degree of competition for public space usage, and we find a dense net of subsoil-installations, pipes, and even metro stations and metro lines. Therefore, trees are often not really an option in such situations. Fig. 1 shows the requirement of substrate space for differently sized trees as well as a section through a typical street in densely populated areas. Needless to say, wherever possible trees are by far the first choice in climate change and Urban Heat Island Mitigation, given their functions such as cooling in summertime by providing shadow and evaporative cooling, dust binding, CO2-binding, noise dampening, O2-generation, positive impacting onto the human psyche, and many more. Moreover, most trees are perfectly adapted to the seasonal needs of people in the city: During summertime there is a lot of shading and cooling effect, in Wintertime there is only very little obstacle to the desired sunlight due to the seasonal drop of leaves. The well renowned climatologist Hans-Joachim Schellnhuber just recently suggested that planting and growing of 100 billion trees might allow to mitigate the climate change and help in restauration of the climatic balance (DerStandard 2023) However, there might be parts in the historic urban city centers and core districts where the planting of (reasonably sized trees) cannot be realized in a feasible way.

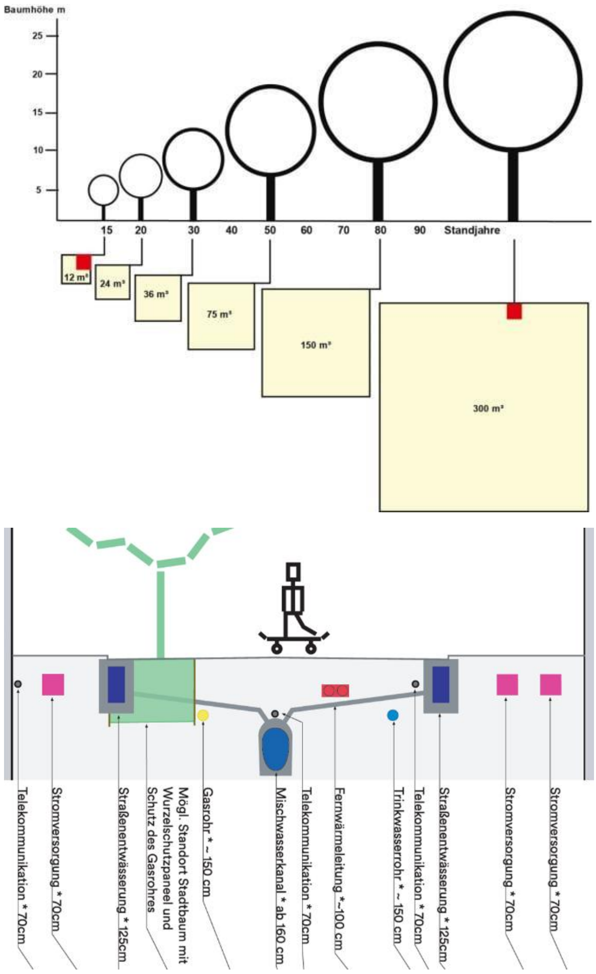


Fig 1: Typical substrate space needs of trees dependent on their height and lifeage (Top; Futurezone 2021); Typical pipes and lines below the street surface (Bottom; kommraus 2019)

Toward this end, the present contribution illustrates approach, effort, and results of a recently conducted R&D-project named Smart and Urban Tree. In this project, artificial structures have been envisioned, designed, and multiperspectivally evaluated as an alternative for urban situations not suitable for classical blue-green infrastructures.

Case Study Site & Trees versus Smart and Urban Trees?

As already reckoned, we **do not** understand our suggestion of Smart and Urban Trees as a general alternative to other means of green-blue infrastructure, but rather as a supplementary alternative for difficult or impossible urban situations. While trees require certain substrate volume, as well as water bodies require tight surfaces, the Smart and Urban Tree idea is to bridge the lack of availability of either by technical means, e.g. in form of an situation-adapted foundation of the artificial structure foreseen for shading. To fundamentally proof the concept, a street canyon of the 7th district in Vienna has been chosen. This case study location is in the most vulnerable parts for heat stress in the city. Furthermore, a surface reconstruction has to be planned and executed soon, as a new metro line is currently constructed and major parts of tunnels and station outlines will be positioned below the case study location (Kirchengasse, 7th district of Vienna). Fig. 2 illustrates the case study situation prior to the metro building site. Fig. 3 shows a map of the demonstration site. In a very first attempt to compare – in detail for the demonstration site – the performance of natural trees, artificial structures, and no measures at all, we generated a comparison based on subjective experiences, illustrating advantages (+), disadvantages (-) and potential ambiguous impacts and aspects (+/-), see Fig. 4. While the “no intervention at all” variant does not really feature a lot of positive effects, it can be clearly seen that trees have advantages as well as Smart and Urban Trees have, however, in different aspects. Vice versa, there are negative aspects in both intervention concepts that are required to be considered prior to any planning and intervention.

Fig.2: View of Kirchengasse, 1070 Vienna, prior to the metro construction works (im7ten 2022)

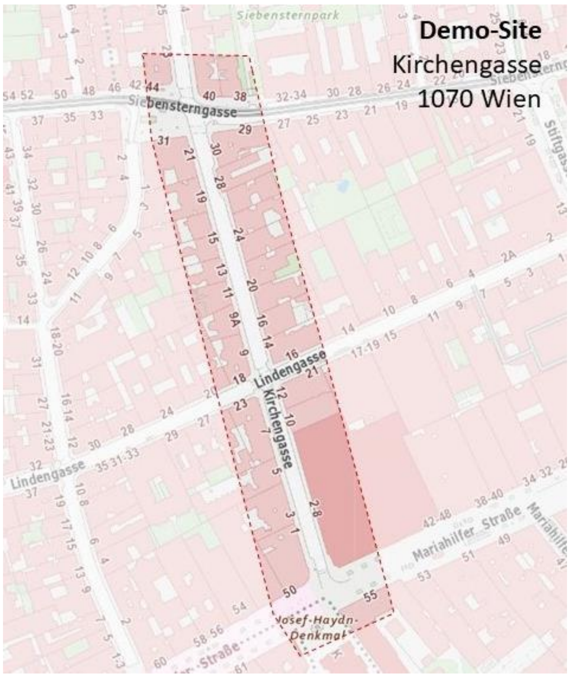


Fig 3: Map of the Case study site (ViennaGIS 2022, adapted by the authors)

Comparable structures and efforts

There is a number of comparable projects that address artificial shading or tree structures for cities. The famous *Metropol Parasol* in Sevilla, Spain (Fig. 5a) acts as an urban identifier on a large public space and provides some urban shading. The Supertree Grove (Fig. 5b) in Singapore does provide some small-scale urban shading, but also acts as landmark and touristic highlight. The University of Natural Resources and Life Sciences in Vienna proposed mobile "Climate Islands" that should increase the urban microclimate in selected squares of the city (Fig. 5c). In some German cities, urban furniture was equipped with moss plants and other greenery to provide some dust-binding and air cleaning as well as some microclimatic effects for people passing by or waiting for the public transport (Fig. 5d). In a previous attempt to provide some improvement for the microclimatic situation in courtyards, the authors conducted a design studio with graduate students adressing green artificial structures (Fig. 6a), which can be compared to the shared garden tower in the second district of Vienna (Zirkusgasse 40/42, Fig. 6b)

Fig. 5.5aMetropol Parasol (top left, Mayer 2024), 5b. Supertree Grove (top right, Supertree 2024), 5c. Climate islands (bottom left, Climate Islands 2023), 5d. moss filter furniture (bottom right, Baunetzwissen n.d.)

Aspect	Natural Tree	Smart & Urban Tree	No inter-vention
Greenary (Integration of greenery)	+	+/-	-
Shadow casting	+	+	-
Seasonal shading	+	+/-	-
cooling effect by shading and evaporation/mist	+	+	-
(Day)Light / (Day)Light control	+/-	+	-
Inhibition of free air movement	-	-	+
„Rain protection" / roofing effect	+/-	+/-	-
Additional functions can be integrated (light, spray, E-charge, ...)	-	+	-
Active electricity/Energy production (PV)	-	+	-
(Neigbor/Occupant)Acceptance	+	?	
Improvement of the street space	+	+	-
Seasonal use/usages of the street space	+/-	+	+
Implementation is simple and proven	+	-	n.a.
Can be implemented quickly and immediate	-	+	n.a.
Root space / foundation freely configurable	-	+	n.a.
Water not required for "maintenance"	-	+/-	n.a.
Costs (construction and maintenance)	+/-	-	n.a.
Care / maintenance	+/-	+/-	n.a.
Pollution of the soil	+/-	+/-	n.a.
Pollution of the construction (e.g. birds)	+	-	n.a.
Not-affected / affected building regulations	+	-	n.a.
Fire brigade access	+/-	+/-	+
Parking lot displacement	+/-	+/-	+
Unsealing	+	+	-
CO_2 binding with a metal construction SUT	+	-	-
CO_2 binding with a wooden construction SUT	+	+/-	-
O2 generation	+	-	-
Noise cancellaton	+	+	-
Dust binding	+	+	-
"Residue-free" / simple dismantling	+	+/-	
Impact on cultural heritage	+	+/-	+

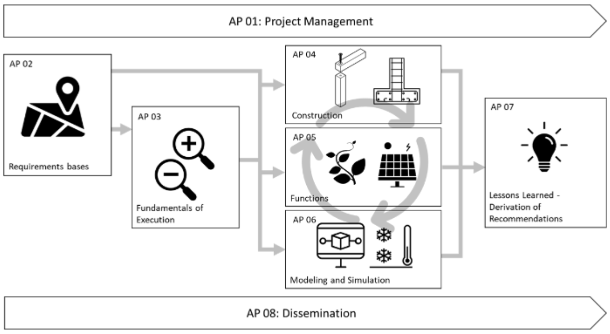
Fig. 4: Comparison of Aspects/Interventions: trees, Smart & Urban Trees and no intervention at all (authors)

Fig. 6.6a Design Studio result for a courtyard tower garden (left, Fig. by the authors); 6b. existing courtyard tower garden in 2nd district of Vienna (right 2pos 2024

Many recent and past studies address the impact of urban shades for exterior spaces and adjacent buildings: Tola et al. (2023) assessed the impact of natural and artificial shades along Mediterranean coast promenades and found that without shading these spaces can be considered as “dead” during day. Razzaghmanesh et al. (2021) proofed that urban tree canopies provide significant temperature drops in densely populated urban areas. El-Sokaily (2022) could proof that large-scale shading design is an effective mean for reducing unhealthy values in the most commonly used thermal indices such as mean radiant temperature MRT, Universal Temperature Climate Index UTCI and Physiological Equivalent Temperature PET. Needless to say, there are many other publications in-depthly describing aspects of material and dimensions of shading devices, as well as impact of green-blue infrastructure, but a literature review is neither goal nor possible in this presentation. Rather, our own approach and case study is shown.

Design & Evaluation Methodology

We deployed a multi-perspective working mode to be able to fundamentally assess all aspects of the envisioned Smart and Urban Trees. Fig. 7 illustrates the principal project workflow. While the work packages addressing requirement basis (what is expected by such Smart and Urban Tree structures) and fundamentals of execution (how to generally construct/design such structures) can be considered as empirical work, the work packages pertaining to construction, functions, and modelling and simulation have been considered as “proof work” of concepts that iteratively interact and optimize outcomes. During the project it became clear that – given the exploratory structure of the project – many workflows would have to be conducted parallelly. Thus, Fig. 8 illustrates the reality of the project by far better than the original workplan.



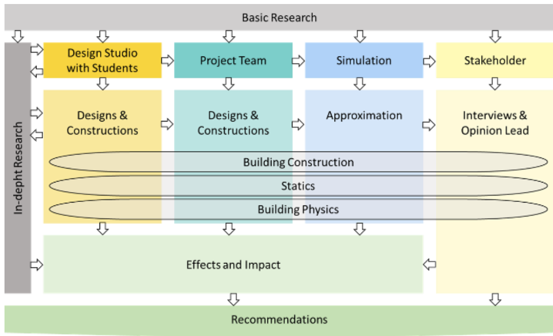


Figure 7 (top). Envisioned Workflow of the Project Smart and Urban Tree (Figure by the authors); Figure 8. Real workflow matrix as designed during the project (Figure by the authors)

While the fundamental research can be considered to have acted as basis for all other working steps, we in parallel deepened and widened the fundamental research throughout the whole project duration. That had to do with the fact that for each component, e.g. the envisioned functionalities of the smart and urban tree (power generation via PV, power fuel station for E-Bikes, social hub, artificial light carrying structure, water misting devices, …) as well as for constructions, and organizational aspects (e.g. involved governmental bodies for a realization in the public street areas) a whole rat tail of standards, laws, application guidelines, etc. had to be studied and adapted for purposes of the envisioned structure. Based on the basic research, we conducted a graduate students design studio for designing and testing Smart and Urban (SUT) tree variants, we ourselves designed some SUT-variants, we discussed simulation domains that later should be utilized for evaluation of the finalized designs, and we started to conduct qualitative interviews with interested and/or involved stakeholders. These stakeholders included the Viennese building authorities, the different magistrate bodies dealing with city illumination, public transport, street surfaces, parking lot distribution, fire safety, and heritage protection, dwellers of surrounding buildings, owners of adjacent shops, scientists from different departments such as sociology, traffic planning, urban space use and utilization, law, and public finance/economics, as well as the local ICOMOS officials. For these interviews a guideline was designed in the early stages of the project. Regarding the simulation efforts, we primarily decided to look at the impact on the street level in view of thermal impact, and the effect our artificial structures would have onto adjacent buildings in view of temperature drops and impact on natural lighting inside of the buildings (not discussed in this paper). Given the extensive structure of the demo site and the multitude of impacting factors, it was clear that simulation efforts in these domains had to be started by strongly simplified models to reach any results. This, however, can be considered as a weak spot of the study, but given the multi-perspective approach, we were happy to reach some general statements about the performance of the proposed Smart and Urban Tree structures. In this contribution we will focus on the thermal performance domain. Toward this end, the operative (indoor) temperatures of different variants have been derived via Designbuilder (Designbuilder 2022), while the PET (physiological equivalent temperature) was chosen as indicator for the outdoor / street level evaluations. Thereby, the tool envimet (Envimet 2022) was deployed. For the Designbuilder simulations, we chose a timestep of 15 minutes. Shading elements were modeled based on single-surface library elements, utilizing standard surface qualities regarding reflectance and transmission. The building envelope properties were assumed to correspond to the most common building typology (which were 19th century Gründerzeit-buildings, featuring casement windows (U_{Win} = 2.7 $W.m^{-2},K^{-1}$, Total solar transmission / SHGC = 0.74, direct solar transmission = 0.67, light transmission = 0,801) and plastered brick-walls (U = 1.05 $W.m^{-2}.K^{-1}$)

Results

Overview about designed SUTs

During the design studio 10 different designs for smart and urban trees had been generated. While all these designs feature certain strengths and weaknesses, two categories could be clearly distinguished: (i) Solitary & hybrid constructions consist of individual, self-bearing structures that would allow positioning in different suitable spots in streets. They might be combined with each other but work also as solitaire structures. Fig. 9 showcases some of these designs. (ii) Composite structures react on the linearity of the demonstration site street and work with fewer supporting columns, as they have a “body” that is situated above the streetlevel which is supported by a small number of supporting structures. Such structures require an in-depth planning process and need to consider different aspects, such as the possibility for fire brigades to use ladders onto adjacent building facades. Fi. 10 illustrates some of the composite structure designs derived from the design studio.

Setup and results of simulation-based impact assessment

As already indicated, we did simplify the SUT designs for the purposes of performance simulation. To assess the indoor conditions in adjacent buildings we used a generic floor plan that closely resembles typical *Gründerzeit* Floor Plans and put this floor plan once on a 1st floor height (about 4 m above the ground) and a 4th floor height (about 15 m above ground) in different positions in the road. Fig. 11 illustrates this set-up exemplarily. Additionally, the shading effect by the smart and urban trees was also approximated. Instead of a detailed model of each of the architectural designs, the effective shading area was calculated and added to the model to ensure reasonable calculation times. Variants of the calculation included different settings for HVAC in the building (unconditioned/passive vs. conditioned), different climate data sets (2022, 2050 – RCP 8.5), shading element material (void/no material, wooden elements, PV-elements), the seasonality (all year versus cooling period) and the height of the applied shading above ground (8m above ground, 18 m above ground). Fig. 12 highlights the setup of the simulation model for an 18m high model including sunposition and shades of 15th April, 03:00 pm.

Figure 9. Examples for solitary and hybrid structures (Figure by the authors)

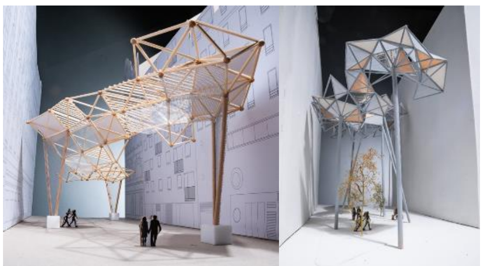


Figure 10. Examples for composite structures (Figure by the authors)

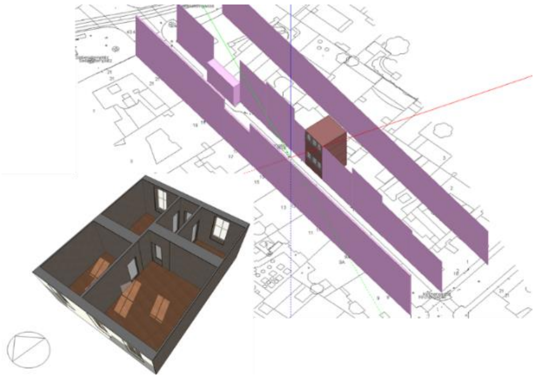


Figure 11. Exemplary setup for indoor temperature assessment via simulation (generic floorplan) (Illustration: The Authors)

Fig. 12. Simulation model for indoor thermal conditions (18m high shading elements, 15th April 03:00 pm; Illustration: The Authors)

To provide an insight into the derived results for indoor thermal conditions, we compare the operative temperature for one of the rooms of the floor plan (living room) in the 1st floor and in the 4th floor, with a limited set of variables (Fig. 13). What can be seen is that SUTs obviously in the analysed case only make sense in 18m height, as the impact of the lower variant (8m) is neglectable (1st floor) or unfavourable (4th floor due to reflection effects). Fig. 14 does show resulting temperature differences for the living room and a children's room for different orientation of the main façade (west/east – resembling the north-south orientation of the street) for the 18m application for both climate data sets. For the street temperatures, different scenarios for different positions within a large grid (about 900.000 grid points, 2x2 m grid) were evaluated. The scenarios included no intervention, classical (few) trees setups and small-scale greenery, 8m or 18m high wooden elements, and 8m or 18m high PV elements (Fig. 15.). Exemplarily, the results for the PET for an assumed hot summer day (10.07.) should be shown for position D in the Case study road (Figure 16). Assumptions/Settings include that PET is derived on 1.8m above ground, 2m/s wind from southeast is blowing, and that the summer day is free of clouds. What can be seen is that the no intervention scenario performs worst, while the cooling effect is larger at 18 m element height (PV slightly better than wooden elements). During the day the classical tree setup, due to the adjacency to the next tree, performs best. However, what should not be forgotten is that the tree model includes evaporative cooling, while the SUTs just shade.

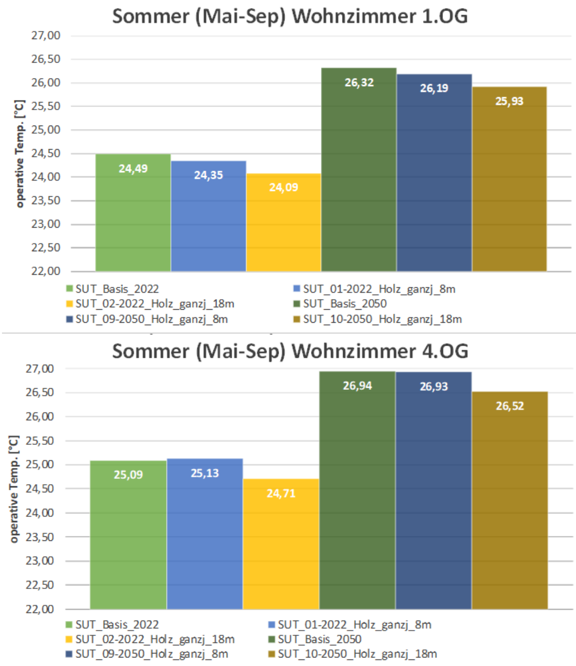


Fig. 13. Results for the application case as illustrated in Fig. 11 and 12; Top: 1st Floor, bottom: 4th floor; SUT_BASIS_2022/2050 – operative temperature (ot) without shading, climate data of 2022/50; SUT_xx_2022/205_Holz_ganzj_8m/18m – ot with wooden shading on 8/18 for climate data of 2022/2050 (illustration by the authors).

Stakeholder interviews

The interview partners in general had a benevolent attitude toward the idea and in part called it “a good idea”. Moreover, the feasibility from perspective of technological realization was confirmed. However, especially the district governing politicians were not convinced about the suggested case study location and instead suggested roads with tram lines that literally make any tree plantation impossible but would allow for technically advanced SUTs. Some of the stakeholders emphasized that a participatory process and holistic planning in case of realization is of crucial importance. Especially the shop owners identified the importance of an unique, iconic appearance of SUT structures for purposes of branding/identification with a location, but in general considered the idea as very good as customers want shaded, cool spaces in front of their shops during summertime. Generally speaking, most stakeholders were convinced that legal adaptations to building regulations (e.g. to utilize adjacent facades for mounting / structural purposes) might not be allowed yet, but are just a matter of adaptation and “suffering pressure” in view of increased climate change impact.

Temperaturdifferenz Sommer (1.Mai- 15.Sep)					
Ausrichtung	**Klimadaten**	**Geschoß**	**Zimmer**	**Mittelwert**	**Maximum**
West	2022	1.Obergeschoß	Wohnzimmer	0,41	1,48
			Kinderzimmer	0,4	1,23
		4.Obergeschoß	Wohnzimmer	0,36	1,13
			Kinderzimmer	0,51	1,67
	2050	1.Obergeschoß	Wohnzimmer	0,41	1,46
			Kinderzimmer	0,4	1,06
		4.Obergeschoß	Wohnzimmer	0,42	1,73
			Kinderzimmer	0,6	2,01
Ost	2022	1.Obergeschoß	Wohnzimmer	0,3	0,94
			Kinderzimmer	0,44	1,29
		4.Obergeschoß	Wohnzimmer	0,53	1,62
			Kinderzimmer	0,57	1,7
	2050	1.Obergeschoß	Wohnzimmer	0,29	0,91
			Kinderzimmer	0,46	1,33
		4.Obergeschoß	Wohnzimmer	0,57	1,91
			Kinderzimmer	0,62	1,87

Figure 14. Temperature differences achievable for east and west oriented rooms in different climate sets on different floors with an 18m SUT shading applied. (Illustration by the authors)

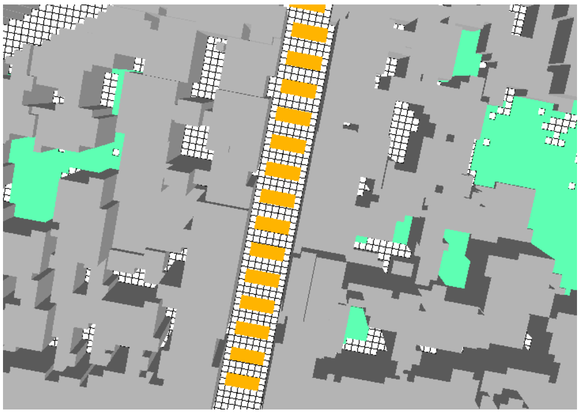


Figure 15. Envi-Met Modell of the case study area with applied shading elements, 34%/784m² roof coverage (illustration by the authors)

Conclusion

The present contribution highlighted the R&D efforts pertaining to the generation of artificial structures for urban summer shading and cooling. Thereby, we once again want to emphasize that the study does not suggest replacing natural greenery by our SUTs, but rather consider SUTs as an alternative for locations where there is no possibility for other green-blue infrastructure. In such locations, a SUT could even house (small-scale) plants to at least try to mimicry some of the tree effects. However, the study in general showed that SUTs can have a positive impact on the urban microclimate on street levels and in adjacent buildings. Needless to say, this was just an exploratory study with several shortcomings and large potentials for more in-depth studies. Politicians we talked to, all agreed that full-scale mock-ups based on the designs developed by students and project team would facilitate the assessment of the impact, not only on the urban climate, but also pertaining to acceptance of adjacent dwellers and shop owners. As such, we believe that the next step is to set up a project to realize such a Smart and Urban Tree at a critical spot in the city (not necessarily in the demonstration area that was used in this study, but rather at large scale places, or complex situations, e.g. street with tram lines). Moreover, as SUTs currently were examined on their shading impact, but not on additional technical implementation of water vaporization as mean of cooling, this should be integrated as topic in future studies.

Acknowledgement

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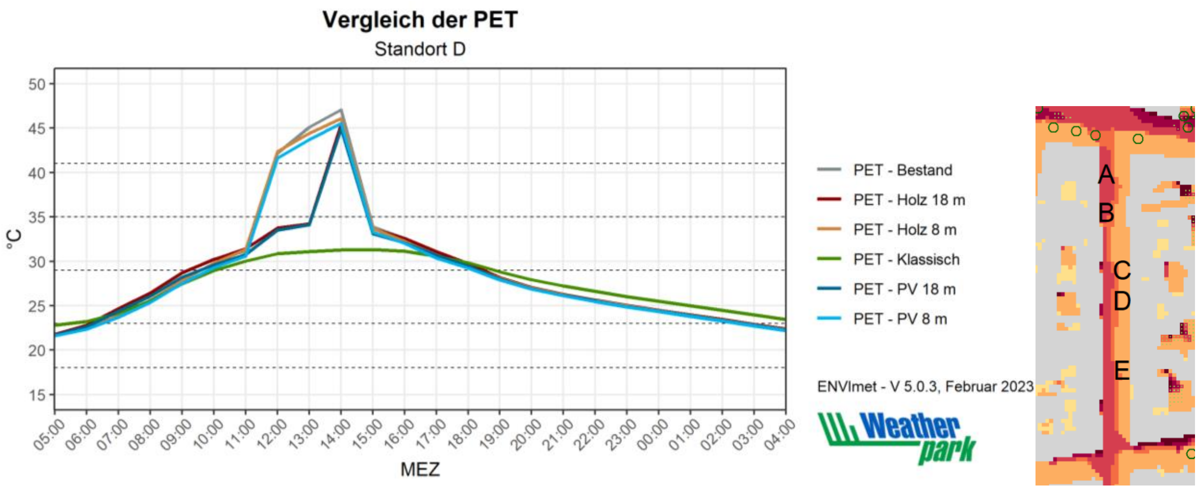

Figure 16. PET-Performance time row on standpoint D (hot summer day) (illustration by the authors)

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