An optimized model for a thermally comfortable Dutch urban square

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ABSTRACT: Is there a model for a thermally comfortable mid-sized urban square in the Dutch climate context which offers sufficient wind protection and a good distribution of sun- and shade places? To answer this question, a 'research by design' process was followed. This process included the design of different alternatives of spatial configurations that were expected to generate thermal comfort in different seasons. These configurations were then tested with Envi-met® simulations on their effects for different seasons and different squares. The 'research by design' process showed that for the Dutch context of mid- sized urban squares the most optimal model that could be developed and tested, were sequences of 'urban shelterbelts'. These consist of 25 m high deciduous trees and have transparent wind screens in the trunk space. The 'urban shelterbelts', when placed perpendicular to the dominant Southwesterly winds both protect the squares from these winds and also offer sufficient shaded situations. This optimized model can be used to address thermal comfort in urban square design, but it needs to be adjusted to each place and embedded in the integral design of a square.

Keywords: urban squares, outdoor comfort, 'research by design'

1. INTRODUCTION AND OVERVIEW

Microclimate- ignorant design of public squares is problematic. This is, amongst other reasons, caused by the lack of knowledge about microclimate responsive design amongst urban designers [1, 2]. A way to make climate knowledge more accessible, is the generation of easy to use design guidelines.

In order to create such design guidelines, it is often helpful to use a 'research by design' process. 'Research by design' is understood "as the development of knowledge by designing, studying the effects of this design, changing the design itself or its context, and studying the effects of the transformations. The 'TOTE model' from systems analysis may be recognized in this: Test→ Operate→ Test→ Exit." [3] . Therefore- similar to the methods used in engineering or in R&D, design alternatives are developed and then tested through simulations of the future situation. The alternatives that score most optimal can be considered as design guidelines [4].

This paper describes the path of generating such spatial patterns for climate- responsive design and testing of these patterns on their effects. Firstly, I specify the underlying typical Dutch climate situations for outdoor sojourn. These form a framework for the climate design proposals as well as a basis for the microclimate simulations. Secondly, I outline the relevant scientific microclimate knowledge for generating patterns that are expected to improve microclimate on Dutch squares. Eventually, I describe the design process which was done for two different case- squares, the Spuiplein in The Hague and the Grote Markt in Groningen, both located in the Netherlands. From this, I draw conclusions on optimized models for microclimate responsive design of Dutch squares.

2. RELEVANT DUTCH CLIMATE SITUATIONS

The main climate situations that have to be addressed in outdoor space design are described in this section. This includes design for different seasons and respecting people's perception of microclimate. Earlier research has shown that microclimate perception relates to the more salient or extreme situations [5] . This mainly concerned wind problems because these situations come about more often in the Dutch situation. Apart from that we can expect that more heat waves will occur in the future and that also these will affect people's long-term microclimate perceptions. Deduced from that, I assume that hot situations will become salient in the future as well. Hence, the two situations 'windy' and 'hot' form the starting point for the analysis of situations relevant for thermal comfort in outdoor spaces.

These two quite contrary situations and their impact on the two squares in Den Haag and Groningen were simulated in the microclimate simulation software ENVI-met® for the existing situation of the square's spatial settings.

The climate data used were based on the average data from the Royal Dutch Climate Institute KNMI for the weather stations close to the respective cities (see windroses and temperatures in [6]). The first input dataset described a 'windy' day is a typical day at the beginning or end of the outdoor seasons, when stronger winds occur and the sun altitude is lower. In this case the 15th of November was chosen because around that time longer shadows occur than at the beginning of the outdoor season. For the wind situation a typical (and in the Netherlands predominant) cyclonic climate situation is chosen with the prevailing wind direction Southwest. These

Southwest winds are generally stronger than from other directions [7]. The entire set of simulation input data for the windy situation can be seen in “input data windy” and the simulations of the existing situation on maps “existsit-sims” on the website [8].

The second input dataset represented a day within a heat wave in summer where the impact of the direct sun radiation and heat emission from the environment can be problematic. The day chosen was 21st of June because it is the longest day of the year and it is also the day with the shortest shadow patterns. For the wind situation a typical anticyclonic weather situation was chosen with the rather soft Easterly winds that are typical for these situations. The entire set of simulation input data for this situation can be seen in “input data hot” and the simulations of the existing situation on maps “existsit-sims” on the website [8].

3. SCIENTIFIC KNOWLEDGE BASIS FOR MICROCLIMATE COMFORT PATTERNS

To generate preliminary patterns for thermal comfort in Dutch squares, the microclimate literature was consulted. The factors that can actually be influenced by smaller scale urban design are wind and mean radiant temperature [9].

In a coastal country like The Netherlands wind speeds are generally higher and in the Dutch climate, wind protection can help significantly to achieve better thermal comfort in outdoor places. This wind protection is most effective when it buffers the strong and predominant South Westerlies. In order to generate simple patterns for wind protection elements, basic quantitative knowledge was used to specify the cavity and wake areas around wind shelter elements. The most common general guideline is based on Nägeli [10]. Although also other rules of thumb were developed later that are partly conflicting with Nägeli’s, this rule is most often cited in the literature. Because of that, I used Nägeli’s rule. It describes the general effects of wind screening objects with different densities on the size of the sheltered area at the leeside, depending on the height of the screening objects. This rule of thumb concerns obstacles that are at least 12 times as long as their height (see fig. 1).

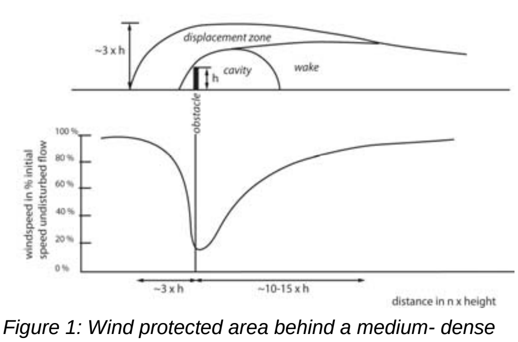

Figure 1: Wind protected area behind a medium- dense obstacle according to Nägeli, adapted from Oke 1987

The most important parameter for the influence of mean radiant temperature is sun and shadow [11,12]. The patterns of sun and shadow can nowadays easily be simulated in 3D- design software and therefore SketchUp shadow simulations were used as a tool in this research by design to conduct first studies on sun and shadow patterns.

4. PRELIMINARY SPATIAL PATTERNS FOR MICROCLIMATE COMFORT

I translated the requirements for optimized sun- and shadow situations and wind adaptation into spatial patterns by making desk-estimations based on the rules of thumb on wind shelter discussed above and through SketchUp shadow simulations. Here, certain options that would not be viable in public square design practice, like too dense covering by pergolas, roofs, trees or other objects were avoided. Microclimate adaptation elements also must not subdivide the place too much on eye- level because that can negatively influence the feeling of safety. The patterns I considered most appropriate are described in the following.

4.1 Generation of preliminary patterns for wind protection

For the ‘windy’ day simulated for the two squares it became apparent that the wind speeds in the central areas of the squares can easily reach 4m/s and higher in the existing situation. In order to create a comfortable situation for sojourn, the wind speed has to be reduced at least 50%. Therefore, wind buffering screens were selected that, when distributed in a proper sequence, are expected to bring wind speed reductions of 50% over the whole area. All of these screens should be directed perpendicular [13] to the South-West in order to block the prevailing (and also strongest) winds in the most efficient way. Since vegetative materials or other permeable elements are more efficient in creating longer wakes [10], I decided to use such permeable elements. The preliminary pattern I considered useful was a 15m tall row of trees with transparent ‘medium dense’ windscreens in the trunk areas. This transparent screen is chosen because it does not hamper the possibility to oversee the square which is important for the public’s feeling of safety. I call this an ‘urban shelterbelt’ (fig. 2).

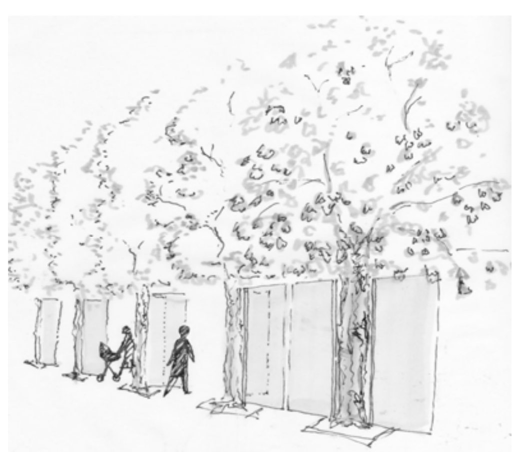

Figure 2: principle of the ‘urban shelterbelt’

4.2 Generation of preliminary pattern for sun- and shadow comfort

People prefer a small- scaled distribution of sunny and shaded areas on the square. This way it is easy to make a choice between sunny or shady places without having to move over long distances. I generated series of shadow simulation patterns for common shading devices that can be placed in many squares without hampering the functions. The elements that were most viable on the squares were mid-sized trees (15 m high and 15 m crown diameter, see fig. 3). This was considered the most suitable preliminary pattern because it suggests to offer benefits throughout the whole outdoor season.

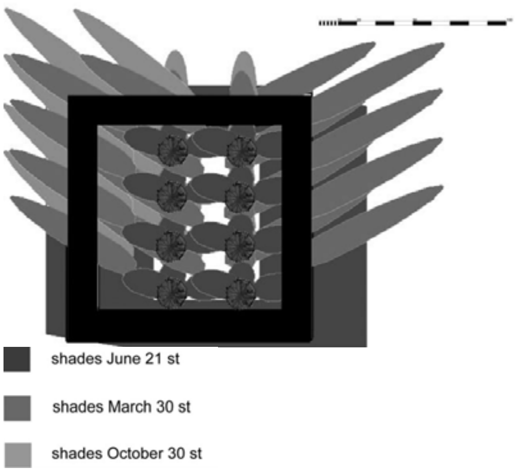

Figure 3 tree- shadow pattern for all outdoor seasons projected in non- shaded areas of a square of 100 x 100 m

These preliminary patterns for wind and shade were combined in the next step and then tested further in ENVI-met® microclimate simulations.

5. TESTING ALTERNATIVES ON THE CASE- SQUARES

5.1 General method

In this section I document the process of generating and testing climate responsive patterns for Dutch squares of medium to large size. The preliminary patterns described in the preceding subchapter were combined and projected on the squares Spuiplein, Den Haag and the Grote Markt in Groningen.

Since the simulation software did not offer possibilities to model the 'urban shelterbelt' with its different structures of trees and artificial windscreens, this was substituted with a structure completely consisting of vegetation in the simulation input.

The alternatives for new patterns were simulated on their microclimatological effects with the same input data that were used to simulate the existing situation in the squares described earlier. The simulation results of the existing situation and the alternatives were compared for five points in time per day: 9,11,13,15 and 17 hrs. In order to evaluate effects of the new alternatives, simulations of the different alternatives were compared to the simulations of the existing situation. This is described separately for the alternatives on the website [8].

All the alternatives were assumed to improve thermal comfort. In this testing phase the Predicted Mean Vote (PMV) value became the most important indicator for thermal comfort improvement. This index combines all the important microclimate factors and thus also shows how, for instance, shadow- casting elements have effects on the wind field and how wind- buffering elements also cast shadow.

5.2 Developing and testing alternative 1

The first alternative was derived from the preliminary patterns: a combination of a a medium dense urban shelterbelt of 15 m height and a 40 x 40 m grid of 15 m high shadow trees with open trunk space and a dense crown (fig. 4).

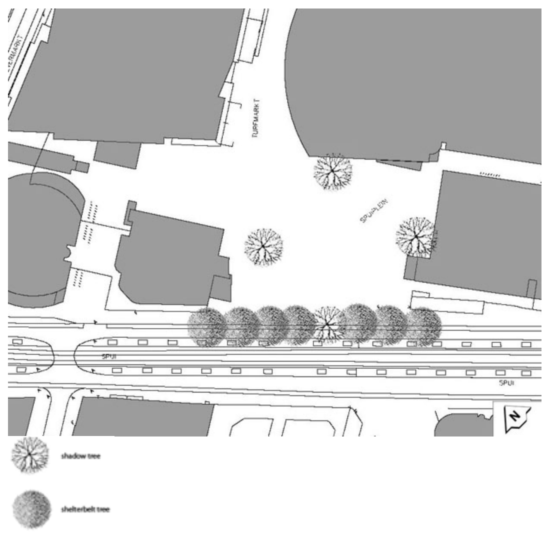

Figure 4 Alternative 1: urban shelterbelt 15 m high and 40 x 40 m grid 15 m high shadow trees projected on Spuiplein, Den Haag

The first patterns were then simulated for their effects on microclimate over whole days in the 'windy' and 'hot' situation for the two locations in Den Haag and Groningen. The differences in PMV on pedestrian level (1.60 m) can be seen in graphical form and a textual specified discussion on the website [8], posters on "altern1-sims" and table 1).

From the simulations of this alternative projected on both squares, some conclusions could be drawn which had impact on the development of the second alternative. Concerning the shadow patterns of the trees, the shades in the autumn situation showed unexpectedly low PMV values. This seemed somewhat unrealistic because trees have lost foliage in autumn and thus cast less shadow. Therefore I decided to simulate the trees in a foliated and defoliated state in following alternatives.

The wakes of the urban shelterbelt were considerably smaller than expected. This had consequences for the settings in later alternatives.

In alternative 1, in both squares the PMV values improved slightly for the entire square and surroundings, when compared to the existing situation. In the hot situation the PMV values changed up to one PMV unit towards comfortably cooler and in the windy, cooler situation the PMV values changed up to one PMV unit towards comfortably warmer in large areas of the two squares. From the simulations it was not possible to conclude why this general improvement occurs. It seems that this effect is based on the higher roughness in the wind field, as well as the general climate buffering effect of vegetation on air temperature. Since I wanted to find out if this effect of vegetation is important, I developed alternative 2 with more vegetation.

5.3 Developing and testing alternative 2

Due to the simulations for alternative 1 showing that the wind shelter effects of the urban shelterbelt of 15m height were not reaching far enough, in alternative 2 the shelterbelt was heightened to 25m. Also, the shelterbelt was entirely closed as opposed to the first alternative where a shade tree with an uncovered trunk area was inserted (which showed a too strong funneling effect). The shadow effect of trees in alternative 1 during the autumn days was too strong, so more attention was given to the species of trees selected as shadow trees. The selection of species for the shadow trees was now based on the times when foliation starts. Tree species that develop foliage late and cast it early are suitable. In summer the foliage should be as dense as possible for efficient shading and in all other seasons the shade should be as minimal as possible. Tree sorts that have these foliation properties are Acer rubrum, Fraxinus pennsylvatica, Juglans nigra, Liriodendron tulipifera and Tilia cordata [14].

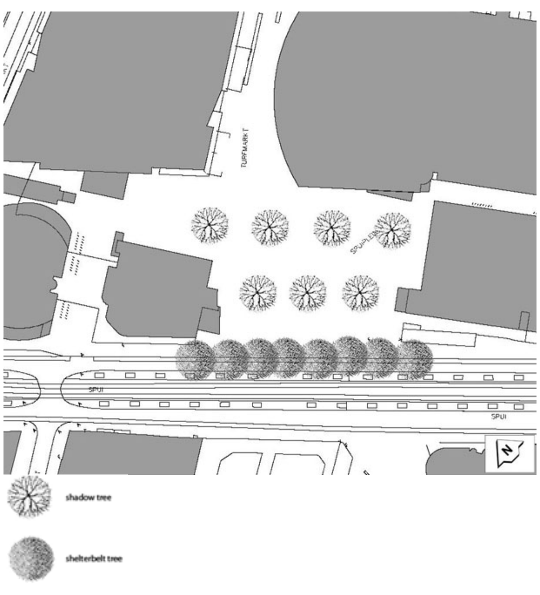

Figure 5 Alternative 2: urban shelterbelt 25 m high and 25 x 25 m grid 15 m high shadow trees projected on Spuiplein, Den Haag

In order to represent the seasonal foliage properties appropriately, the simulation- input data for the autumn situation were adjusted. The shadow trees were given a lower leaf area density (LAD) value of LAD 0.2 and the urban shelterbelt was simulated with slightly more foliage of LAD 0.5, representing a species such as Fagus sylvatica that keeps some foliage over winter and is thus assumed to bring about better wind protection than an entirely bare tree. Since I assumed that the trees have an overall positive effect on PMV I also decided to densify the shadow tree pattern to 25 x 25 m.

The effects of the second alternative (25 m high medium dense shelterbelt and 25 x 25 m grid of 15 m high dense trees, fig. 5) were then simulated for microclimate effects over whole days in the ‘windy’ and ‘hot’ situation for the two locations in Den Haag and Groningen. The resulting differences in PMV on pedestrian level can be seen on the website [8], posters on “altern2-sims” and table 2.

The results of the simulations for alternative 2 indicated that there was- again- a slight improvement on PMV for the whole square and surroundings, but this was not significantly more than in alternative 1. In the hot situation the PMV values changed up to one PMV unit towards comfortably cooler and in the windy, cooler situation the PMV values changed up to one PMV unit towards comfortably warmer. So the assumption that more trees bring a significant effect for PMV could not be confirmed.

Furthermore, the results showed that the effect of shade overruling wind buffering effects of trees was still prominent, even though seasonal differences in leaf densities were now taken into account in the simulations.

Also with respect to the wind situation, the weak buffering effects in alternative 1 occurred again in this alternative, showing much shorter wakes than expected. A medium dense shelterbelt of 25 m height still seems not sufficient to keep the wind speeds considerably lower for the entire squares.

5.4 Developing and testing alternative 3

In the preceding simulations one important effect occurred between the influence of shade and wind shelter: the shadows of the trees seemed to have such a strong local effect on PMV that they can balance out their own wind buffering effects or the wind buffering effects of other trees. This effect was very evident in the ‘windy autumn day’ situations and especially in the second alternative where significantly more shadow trees were used than in the first alternative. In the cooler seasons, the shadow trees, albeit the fact that they have little foliation, seem to have a strong negative effect on PMV. Therefore, in the third alternative I abolished trees that only serve to cast shadow. For trees that also buffer wind, the situation is different. Their shadows also cause cooler areas in spring and autumn, even though their wind shelter effect might be minimized by the shadow. On the other hand, they also generate wind protected areas that are largely situated in the sun and are therefore much more comfortable in spring and autumn.

The earlier simulations showed that the wind buffering effects of the vegetation seemed to have a smaller spatial extension than was expected based on the scientific literature. For example, increasing the height of the urban shelterbelt in the second alternative had rather limited effects, whereas according to the literature a shelterbelt of this height should have been more than sufficient to create a 50% wind reduction for the entire squares. This might have to do with the fact that the shelterbelt had shorter length extensions than 12x h.

Therefore, I decided to use several urban shelterbelts in sequence for improvement of the wind situation. The chosen distance between shelterbelts was based on the lower foliage density values during spring and autumn when the wind situation is most problematic. I assumed that a distance of 50 m between the urban shelterbelts, which is only 2 x h of the shelterbelt itself, should offer ample wind protection.

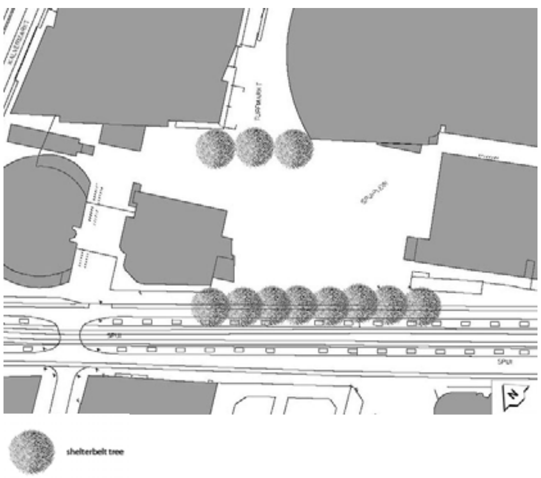

Figure 6 Alternative 3: urban shelterbelts 25 m high with 50 m distance projected on Spuiplein, Den Haag

The impacts of the third alternative (25 m high medium dense urban shelterbelt in sequence of 50 m) were then simulated for microclimate effects over whole days in the ‘windy’ and ‘hot’ situation for the two locations in Den Haag and Groningen. The resulting differences in PMV on pedestrian level can be seen on the website [8], posters on “altern3-sims” and table 3.

Alternative 3, in comparison to the other two alternatives shows the best effects, but it still could be more optimal. The simulated wind buffering effect was not as strong as expected, but this also might be attributable to the way how the urban shelterbelt was simulated. As mentioned earlier, due to the limitations of the simulation software it had to be substituted with a vegetation element, whereas the actual urban shelterbelt should consist of trees and an artificial transparent wind screen in the trunk space. Considering all the literature consulted (albeit some conflicting assertions), in an area of 2 x h behind a wind screen, the wind protection should be more efficient than the simulations suggest.

I could have continued to study and research more fine-tuned options through ‘research by design’. But due to the limitations of the simulation software as well as the inexplicable results of some simulations (see ‘general remarks’ in overview of simulation results, website [8], tables 1-3) I doubt if the simulation tools were sufficiently developed to conduct a more refined research by design. The uncertainties about causes and effects made it increasingly difficult to generate fine-tuned design hypotheses and it was uncertain if the simulations will truthfully predict the effects and verify or falsify the design hypotheses. Therefore, I decided to terminate the process after generating this alternative because it clearly shows better results than the first alternatives and is a very evident improvement compared to the existing situation.

Due to these significant improvements it can be called an optimized model for a climate- responsive design of a Dutch square. This pattern with its focus on wind protection is also expected to appeal to people’s spatial microclimate expectations in a positive way. As mentioned earlier, Dutch people’s microclimate perception is mainly focused on wind effects. Hence, in urban design responding to microclimate perception, strong images should be offered that suggest wind protection. This optimized model is expected to offer such cues for wind-protection due to the smaller scaled rhythm of spatial enclosure and clear visual suggestion of wind protection by the urban shelterbelts.

6. AN OPTIMIZED MODEL FROM ‘RESEARCH BY DESIGN’

The optimized model pattern (alternative 3) can be easily used as a design ‘layer’ for microclimate response in the beginning of the design process. In general, this pattern can be used in all parts of North Western European cities that have similar climate to the Netherlands. It is vital that the model pattern is introduced at the beginning of the design process of a square refurbishment or design of a new square. When this pattern is not included early it will be very difficult to introduce the required structural changes in a later design phase. The model can be compromised with other design requirements (e.g. functions, aesthetics) and offers some flexibility. For example, the urban shelterbelts can be placed on a slightly larger distance from each other or their orientation can be changed with some degrees without losing too much of their effects. When circulation requires this, also some smaller areas can be opened in the shelterbelts. Also, making the transparent wind screens under the trees movable will enable the passage of vehicles (e.g. when a market has to be installed) and slow traffic flows. As long as this urban shelterbelt pattern is not getting entirely disrupted in the integrated practical design process, this pattern will always help to improve the local microclimate. Since this model will get adjusted by ‘carving’ or ‘twisting’, clustering etc. to a site in the further integrated design process, the results will always be site-specific solutions and no square that was designed according to this model will be like the other.

Although the generation of such models by ‘research by design’, as shown in this example, generally seems a clear and straightforward process, this is often not the case. In this ‘research by design’, for example, the generation of a model with the help of scientific literature was problematic due to conflicting assertions in the scientific literature. For the designer who has not developed this fundamental knowledge it is not possible to make sense of these contradictions. Similarly, ambiguous simulation results make it difficult to generate clear design hypotheses on cause- and effect relations of design interventions. Although simulations can be a very useful tool to predict climate, they are only as precise as their underlying mathematical models and the way how these are integrated in the simulations. Fortunately, simulation tools are in constant development and are calibrated to make better predictions. In the future they will be increasingly useful to be integrated into ‘research by design’ processes.

I have shown that a ‘research by design’ process can help to generate optimized design patterns. The optimized climate responsive design model I developed can be helpful for many Dutch square design or refurbishment projects. However, there are also public space design projects where it will not be possible to apply this rather generic pattern or where it has to be compromised to such an extent that it loses its effect. In those cases, small scaled design solutions that are precisely fitted to the place can be useful.

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