5 Climate adaptation strategies: Achieving insight in microclimate effects of redevelopment options[10]

The previous chapter is an almost theoretical approach to study thermal comfort effects. The increasing complexity from an open field to a single building and finally a combination of various vegetation types gives insight in the relative effects of changes in the urban environment on thermal comfort. This chapter aims to answer a part of the research question: What is the indication of general and/or location specific effects of heat mitigation measures on thermal comfort in The Netherlands? Here location specific effects of climate adaptation measures on the microclimate are studied for a specific urban type common for the Netherlands that can be characterised as *low-rise open urban blocks of houses* (Berghauser Pont & Haupt 2009). Sub-research questions answered are: What are the effects on air temperature and human comfort for the temperate climate condition of the Netherlands? And: Is there a difference in effect in relation to scale (urban block, neighbourhood, city)? The results provide adaptation solutions for this specific neighbourhood and input for the generic design guidelines for the Netherlands at the end of part III.

§ 5.1 Introduction

Urban development projects usually do not respond to existing microclimatic variations, nor do they attempt to make beneficial changes to the urban thermal environment. As a result, many design decisions create undesirable effects in the spaces around buildings or at the scale of the urban thermal environment (Evans & Schiller, 1996).

Especially urban heating will increase due to a combination of climate change and expansion and densification developments (Watkins et al., 2007), in chapter 2 this is

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[10] This chapter presents the Journal article 'Climate adaptation strategies: Achieving insight in microclimate effects of redevelopment options' (Kleerekoper 2015). Section 5.1 and 5.2 have been adjusted to better connect to the other thesis chapters.

described in detail. Microclimate changes in cities can be influenced by the design of buildings and the surrounding public and private areas (Oke, 1988, Katzschner, 2010), in chapter 3 the design measures are described in detail. Urban orientation and structure can also have an effect on the microclimate. Although research has been done into cooling effects of design measures to improve the urban microclimate, little is known about the actual impact on Dutch neighbourhoods (Mees & Driessen, 2011). The urban typology is diverse in The Netherlands and cooling effects can vary significantly in urban type.

This article reports on a first study of the effects of design decisions made on the microclimate of a specific urban type common for The Netherlands. The urban type can be characterised as *low-rise open urban blocks of houses* (Berghauser Pont & Haupt, 2009). In chapter 8 the common urban types are further elaborated. The selected area, the *Couperusbuurt* (Figure 5.1), was built in 1960 under the urban master plan *Algemeen Uitbreidings Plan* by Van Eesteren (1934) to the West of Amsterdam, known as Amsterdam Nieuw-West (Feddes, 2011).

FIGURE 5.1 Urban structure of the Couperusbuurt, Amsterdam (Bosatlas, 1999 & Middel, 2002).

§ 5.1.1 Climate adaptation for a redevelopment project

Until the 19th century, urban areas in The Netherlands were built to provide shelter from rain, wind and cold. In 1901 national building regulations were introduced in the building sector to improve human comfort and health. In the following decades, the concept of 'dwelling' developed under the modernist movement. The open urban blocks that dominate the urban area of Amsterdam Nieuw-West were designed according to the basic ideas of this architectural style: light, air and space. Figure 5.2 shows one of the green open blocks of the *Couperusbuurt*.

FIGURE 5.2 Impression of the Couperusbuurt in Amsterdam, The Netherlands.

Since the completion of this area in the 60's, people's needs for dwelling size and facilities have changed. However, people's comfort needs have not changed significantly therefore the focus for this case study lies on preserving the actual climate conditions. The existing green and openness can be preserved, while redevelopment takes place to improve dwelling conditions. The redevelopment plan requires a mix of dwelling types and sizes, additional dwellings and parking facilities. The local council wishes to attract a wider range of people by proposing to integrate extra parking space inside the housing blocks and to add one to two levels to the buildings. These proposals will be analysed on their impact relating to heat accumulation. The adjustments are first simulated separately, followed by sets of measures that potentially affect and intensify each other. It is essential for planners and policy makers to know what combinations are effective and those that are not. No figures or general conclusions are currently available to describe the effects of the combinations of adaptation measures.

§ 5.2 Methodology

§ 5.2.1 Research method

This study concerns the effects found in a single urban type. Effects on the microclimate can be measured in actual temperature or in differences of comfort level. Both are considered in this study. The results will point to solutions for this specific neighbourhood and provide input, together with outcomes of other research projects, for generic design guidelines for The Netherlands.

In this study we focus on a number of specific measures: street trees, grass fields, pavement materials roof and façade colours, and building height. Vegetation and pavement materials are analysed within three alternatives for a parking solution inside an urban block. Figure 5.3 shows the existing situation and the three parking variants. The effect of the measures is evaluated at two different scale levels. First, the effects on the temperature distribution at the urban-block level and secondly, the effects at the neighbourhood scale. The climate adaptation measures were analysed on their relative effect on increasing or decreasing temperature or comfort level.

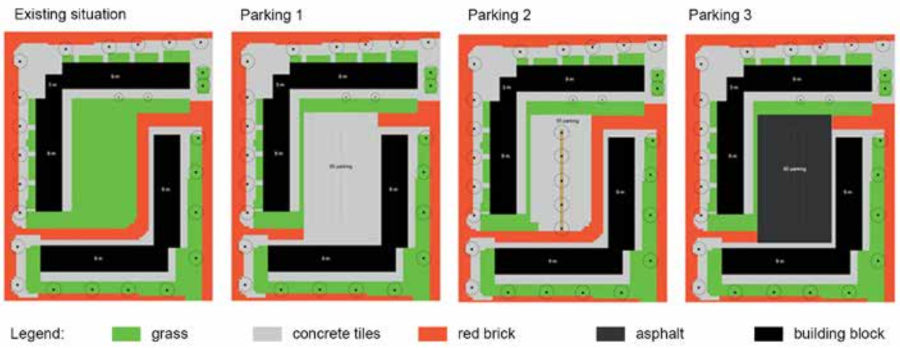

FIGURE 5.3 The existing situation and the three parking variants that were modelled in ENVI-met

§ 5.2.2 Simulation methodology

To evaluate design measures applied in the *Couperusbuurt* the neighbourhood was analysed with the ENVI-met micro climate model (Bruse & Fleer, 1998). In section 4.2.3 the model is introduced in more detail.

The climate condition for the simulations in this study is based on an average heat-wave situation in The Netherlands (summarized in Table 5.1) occurring from 1950 through 2011 (KNMI, 2011). The predominant wind direction during heat and cold waves is North-East to East. It is notable that wind from the South is rare during a heat wave (Figure 3.11 in chapter 3). The yearly average wind direction is South-West to West, also the strongest winds come from the South West, which is exactly opposite to the wind direction during heat and cold waves. If air-flow is desired during warm periods it is important to take notice of the effect of stimulating flows during cold and stormy weather. In The Netherlands both the orientation of the average wind direction and prevailing wind during heat waves, result in an undesired colder situation in autumn, winter and spring.

Daily average wind speed	2.2 m/s
Prevailing wind direction	N-E
Daily average temperature	296 K (23°C)
Daily average humidity	65 %

TABLE 5.1 Climate conditions on an average day in a heat wave in the period 1950 through 2011 in The Netherlands, The Bilt.

§ 5.2.3 Comparison of the measures on the human comfort indicator PET

This study opted for the PET comfort indicator that was also used in the previous simulation chapter. The PET indicator is introduced in chapter 2.2. To calculate the PET values in this study a 'measurement point' is chosen at a height of 1.5 metre in the middle of the urban block. The RayMan program (Matzarakis et al., 2007) was used to convert the output data from ENVI-met into PET.

§ 5.3 Case-studies presentation

The first step in this study is to model and calculate the reference situation, which is based on the actual configuration and land use. Then, for various situations, the development of the air temperature is calculated and evaluated. In the variants 1 to 12, only one of the parameters changes, compared to the reference situation or the previous variant. Variant 13 combines parameter values that resulted in higher temperatures, while variant 14 combines parameter values that resulted in lower temperatures. The focus of the analyses is at the urban block and neighbourhood level.

§ 5.3.1 Simulation variants at urban block level

Table 5.2 gives the parameters per variant at block level. For the façade and roof albedo realistic values are used; these are given in Table 5.3 (Taha et al., 1988, Prado and Ferreira, 2005, Oke et al., 1989, Peutz, 2009). Variant 0 represents the existing situation where most variants will be compared. Variants 1-4 have a different land cover in the inner court yard with additional trees in variant 2. Variants 5-12 and 25-30 have only one changed parameter compared to the existing situation. The varying parameters are building height, roof albedo and facade albedo. In variants 13-24 the parameter changes in the variants mentioned above are combined in different ways.

VARIANT	PARKING SITUATION	ALBEDO FACADES	ALBEDO ROOFS	BUILDING HEIGHT (M)	ROOF TYPE
0 existing	Only grass	0.2	0.3	9	Slanted
1 no green	Only pavement	0.2	0.3	9	Slanted
2 parking 1	Parking 1	0.2	0.3	9	Slanted
3 parking 2	Parking 2	0.2	0.3	9	Slanted
4 parking 3	Parking 3	0.2	0.3	9	Slanted
5 height 12 m, slanted roof	Only grass	0.2	0.3	12	Slanted
6 height 12 m, flat roof	Only grass	0.2	0.3	12	Flat
7 height 15 m, flat roof	Only grass	0.2	0.3	15	Flat
8 albedo facades 0.40	Only grass	0.4	0.3	9	Slanted
9 albedo facades 0.60	Only grass	0.6	0.3	9	Slanted
10 albedo facades 0.10	Only grass	0.1	0.3	9	Slanted
11 albedo roofs 0.05	Only grass	0.2	0.05	9	Slanted
12 albedo roofs 0.85	Only grass	0.2	0.85	9	Slanted
13 mix 1	Parking 1	0.4	0.05	9	Slanted
14 mix 2	Parking 2	0.2	0.85	9	Slanted
15 mix 3	Parking 2	0.6	0.85	15	Flat
16 mix 4	Parking 2	0.1	0.85	15	Flat
17 mix 5	Parking 3	0.4	0.05	9	Slanted
18 mix 6	Only grass	0.4	0.05	9	Slanted
19 mix 7	Only pavement	0.4	0.05	15	Flat
20 mix 8	Parking 2	0.4	0.85	15	Flat
21 mix 9	Parking 2	0.2	0.85	15	Flat
22 mix 10	Parking 2	0.1	0.05	15	Flat
23 mix 11	Parking 2	0.4	0.05	15	Flat
24 mix 12	Parking 2	0.3	0.05	15	Flat
25 albedo facades 0.30	Only grass	0.3	0.3	9	Slanted
26 albedo facades 0.50	Only grass	0.5	0.3	9	Slanted
27 albedo facades 0.70	Only grass	0.7	0.3	9	Slanted
28 albedo facades 0.80	Only grass	0.8	0.3	9	Slanted
29 albedo roofs 0.50	Only grass	0.2	0.5	9	Slanted
30 albedo roofs 0.70	Only grass	0.2	0.7	9	Slanted

TABLE 5.2 The variants at urban block level with their parameter values.

MATERIAL	TYPE/COLOUR	ALBEDO
Concrete pavement		0.40
Asphalt		0.20
Sandy soil		0.30
Bitumen	Black	0.05
Roofing	White Ecoseal	0.85
Ceramic tiles	Red	0.30
Aluminium/Stainless steel	Blank	0.60
Brick	White/light colour	0.40
Brick	Red	0.20
Brick	Dark	0.10

TABLE 5.3 The albedo of the façade, roof and pavement materials used in the variants.

§ 5.3.2 Simulation variants at neighbourhood level

Table 5.4 gives the parameters per variant at neighbourhood level. In the neighbourhood variants all roofs are flat due to the limitations with modelling roof shapes. The corresponding variant simulated at the urban block scale is also given. Not all urban block variants are simulated at the neighbourhood scale due to limitations in computing time.

VARIANT	PARKING SITUATION	ALBEDO FACADES	ALBEDO ROOFS	BUILDING HEIGHT (M)	ROOF TYPE
0 existing corresponding block variant 0	Only grass	0.2	0.3	9	Flat
1 no green corresponding block variant 1	Only pavement	0.2	0.3	9	Flat
2 parking 1 corresponding block variant 2	Parking 1	0.2	0.3	9	Flat
3 parking 2 corresponding block variant 3	Parking 2	0.2	0.3	9	Flat
4 parking 3 corresponding block variant 4	Parking 3	0.2	0.3	9	Flat
5 height 15 m corresponding block variant 7	Only grass	0.2	0.3	15	Flat
6 albedo facades 0.4 corresponding block variant 8	Only grass	0.4	0.3	9	Flat
7 albedo facades 0.6 corresponding block variant 9	Only grass	0.6	0.3	9	Flat
8 albedo facades 0.1 corresponding block variant 10	Only grass	0.1	0.3	9	Flat
9 albedo roofs 0.05 corresponding block variant 11	Only grass	0.2	0.05	9	Flat
10 albedo roofs 0.85 corresponding block variant 12	Only grass	0.2	0.85	9	Flat
11 mix 1 corresponding block variant 13	Parking 1	0.4	0.05	9	Flat
12 mix 2 -	Parking 2	0.2	0.85	9	Flat
13 mix 4 -	Parking 2	0.6	0.85	9	Flat
14 mix 3 corresponding block variant 15	Parking 2	0.6	0.85	15	Flat

TABLE 5.4 The variants at neighbourhood level with their parameter values.

Note that the simulations are performed without actual cars on the parking lot. This is representative for the use of these parking lots, which are mostly empty during daytime and occupied in the evenings. During the day the pavement receives a lot of radiation, which is stored as heat then released after sun-set. The expectation is that cars do not influence the release of heat. In a case where the parking lot is occupied during the day, the expectation is that the daytime thermal comfort decreases due to additional reflection, while night time temperatures will remain lower. However, they will still be higher compared to the existing situation with only grass. It is expected that heat released from the cars themselves is temporary and negligible.

§ 5.4 Results and discussion

This results and discussion section starts with the results from the case studies presented in the previous section. A third sub-section discusses the simulation results based on thermal comfort instead of air temperature differences.

The temperature effects of the variants in the first two sub-sections are analysed on two aspects. One aspect concerns the temperature extremes that occur in an area due to its urban configuration. Because of these extremes, the maximum and minimum temperatures at 01:00 PM in the variants are compared to the maximum and minimum temperatures in the reference situation at the same time. The other aspect is the size of the area where temperatures, compared to the reference situation, are higher or lower. The calculated average temperature for the reference situation is 27°C (300 K). The light-green colour in Figure 5.4 indicates 27-27.5°C. In order to compare the variants with each other as well as with the reference situation, grid cells that are higher or lower than the reference situation are counted and the difference from the reference situation is then given as a percentage.

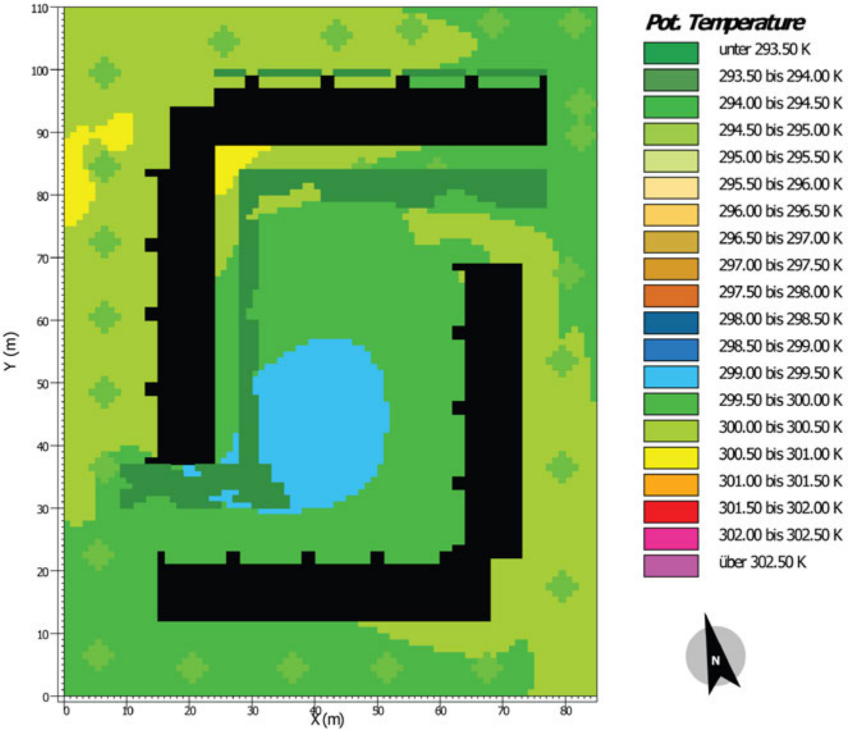

FIGURE 5.4 ENVI-met simulation output for the reference situation at 01:00 PM at urban block level.

§ 5.4.1 Comparison of the measures by temperature effect at urban-block level

The simulation results at the urban block level are presented in this section. First an overview of all measures is given. Thereafter, separate themes are discussed in the following order: vegetation and land cover scenarios, building heights, roof albedos, façade albedos and a mix of different adaptation measures.

The temperature extremes that occur at 01:00 PM in the simulation at block level at two meters height are given in Figure 5.5. In the minimum temperatures, the largest difference between the reference situation and the simulation variants occurs when there is no green (variant 1 and 19). None of the variants result in lower minimum temperatures than the reference situation. Adjusting building height and albedo properties (variants 5-12) does not show a large effect for these minimum temperatures, but it does show urban cooling and heating effects for the maximum temperatures. Increasing the building height to 15 metres (variant 7) and a highly reflective roof (variant 12) result in the largest temperature decrease of the maximum temperatures. This implies that increasing the amount of shadow with higher buildings and reflecting solar radiation at roof level have the highest impact on temperature extremes in the area.

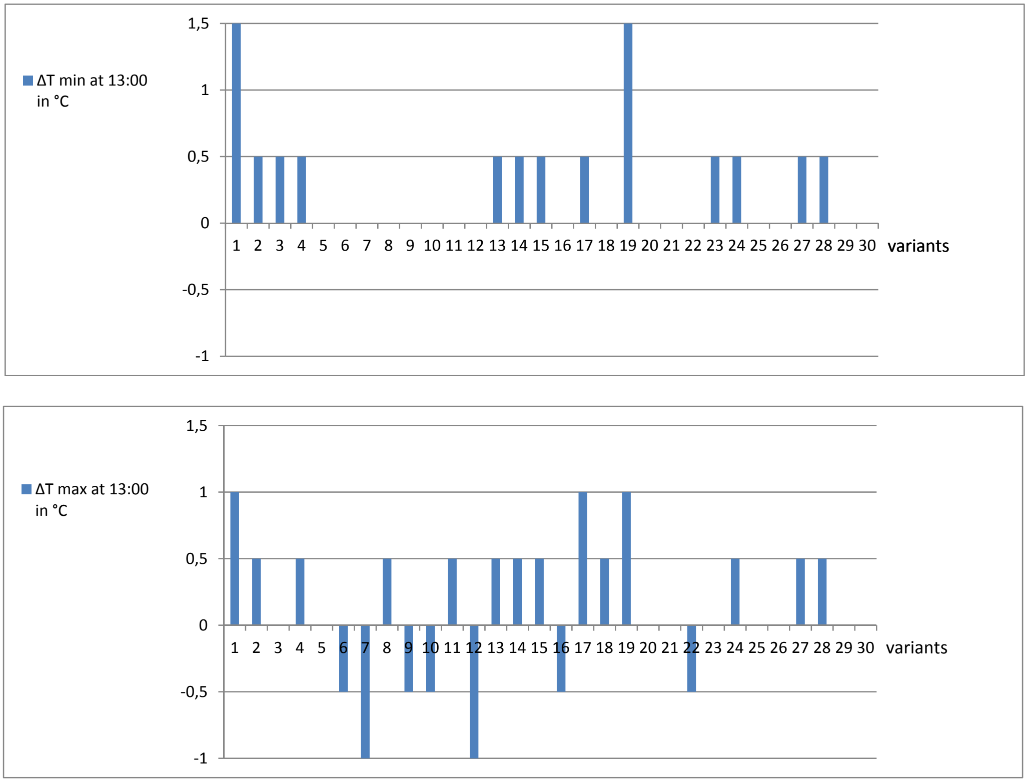

FIGURE 5.5 The minimum and maximum air temperature difference between the reference situation and the variants for 01:00 PM at urban block level. Above: minimum temperatures (ΔTmin block x - ΔTmin block ref), below: maximum temperatures (ΔTmax block x - ΔTmax block ref).

Apart from the variant without green, there are two other variants that result in a temperature increase of 1°C. The combination without green, with a dark roof, a medium-dark façade and 15 metre tall buildings (variant 19) has a higher temperature increase, mainly because of the lack of green and the dark roofs. This variant also has the highest minimum temperatures. The combination of an asphalt parking space and dark roofs (variant 17) also leads to a 1°C temperature increase of the maximum temperature, even though this simulation includes trees and hedges, in contrast to variant 19. Important to mention here is that the area that is prone to temperature increases is very small (Figure 5.6). It is also interesting to compare variant 17 with

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variant 13, where variant 17 has trees on the concrete parking space and variant 13 is the same except for the trees. The simulation results show that the trees on a parking space may lead to higher temperatures. This could be explained by the blocking of airflow or the obstruction of reflection from facades to the sky. The differences in minimum and maximum temperature between the variants give a limited indication of temperature effects. It does not indicate the size of the area with the highest or lowest temperatures.

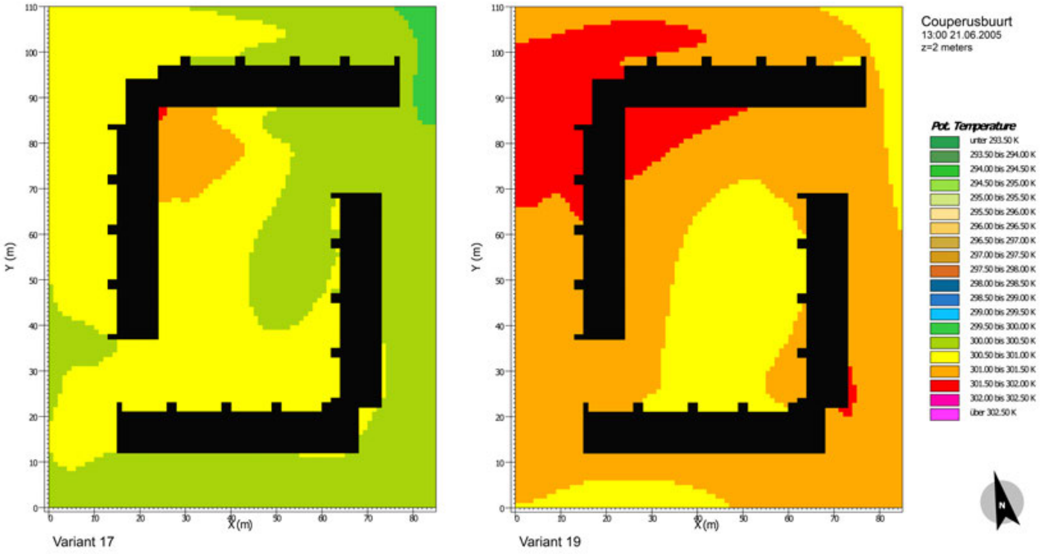

FIGURE 5.6 ENVI-met simulation output for mix 5 (v17) on the left and mix 7 (v19) on the right at 01:00 PM at urban block level.

For a better insight into the temperature distribution per variant, the following sections discuss the area percentage that reaches 27°C or more.

Many studies have endorsed the cooling effect of vegetation (Kleerekoper et al., 2012). However, a clear general effect of trees, for example, is not so easy to formulate. A tree performs differently with variations in size, form, species, water availability and its direct environment. Trees next to water perform differently than when they are surrounded by pavement or when they stand next to a tall building. Figure 5.7 shows that existing vegetation has a large cooling effect in the case of the *Couperusbuurt*. Without green the whole area would be 1 to 2°C warmer (variant 1).

Generally the effect of different pavement materials is measured by looking at the surface temperatures. A study of land covers indicates that the average monthly and average daily maximum temperatures increases from grass, bare soil, concrete pavement to asphalt (Herb et al., 2008). In Figure 5.7 the difference in paving material shows a heating effect on the air temperature of around 10% of the area when asphalt is used instead of concrete tiles. Variant 3, which has concrete pavement with trees, results in the coolest parking variant. Nevertheless, 20% of the area still has higher temperatures compared with the existing situation. In the following paragraphs other parameter changes are analysed for their effect on the air temperature. In the last section combinations are analysed in order to counteract the 20% heating of the area by a new parking situation.

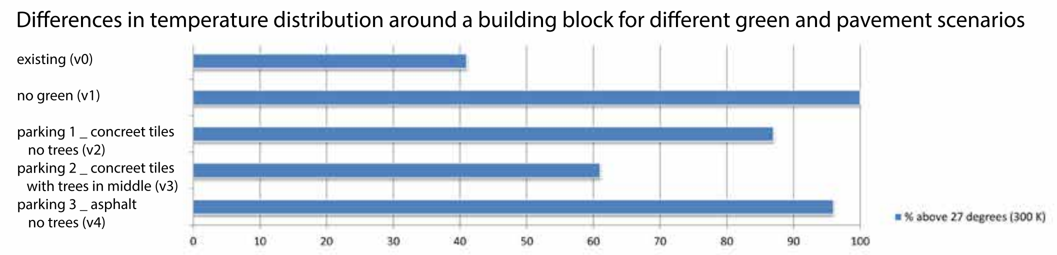

FIGURE 5.7 The percentage of the area where the calculated temperature at 2 meter height is 27°C or more for different green and pavement scenarios.

Increasing building height results in a cooler environment due to more shadow (Figure 5.8). The flat roofs (variant 6) have the same height as the top of the slanted roofs (variant 5), which also results in more shadow, and thus a cooler direct surrounding. With a roof height of 15 meters the whole area remains cooler than the threshold of 27°C. This is also due to the chosen time of 13:00hrs when shadows of buildings still have a delaying effect on temperature increase. At 21:00 the high buildings cause a heating (compared to the reference situation) of 0.5-1.0°C in about 30% of the area.

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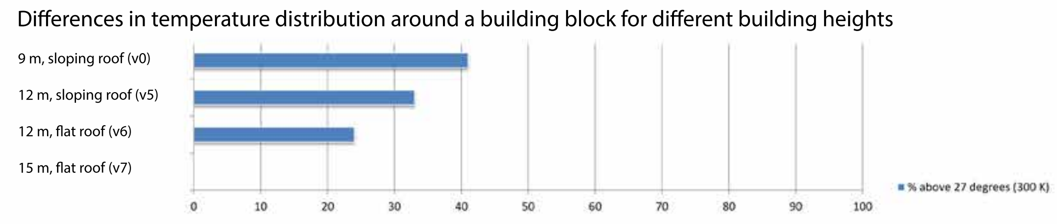

FIGURE 5.8 The percentage of the area where the calculated temperature at 2 meter height is 27°C or more for different building heights.

The albedo of roofs at 9 metres height shows a clear relation with the air temperature at 2 metres height around the urban block (Figure 5.9). The higher the roof albedo, the more radiation is reflected, the cooler the surrounding area becomes. With a lower roof albedo from 0.3 to 0.05 (darker) as with variant 11, the air temperature at 2 metres height is increased by 0.5 to 1°C, a temperature increase show in 7% of the area. Even though this is a relatively small area, the warmer air is in close proximity of the building and can have a large effect on indoor comfort as well. The variants with a higher roof albedo show a similar cooling effect in 6 to 10% to even more than 40% in variant 12. In this last variant the albedo is increased from 0.3 to 0.85, which decreases the air temperature at 2 metres height up to 0.5°C.

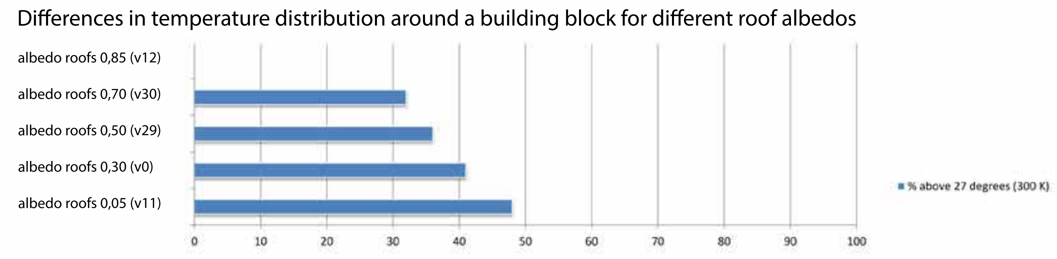

FIGURE 5.9 The percentage of the area where the calculated temperature at 2 meter height is 27°C or more for different roof albedos

This result strengthens the findings of other studies where a higher roof albedo is suggested as a cooling measure. Roof albedo is a measure that has influence at the building, neighbourhood and city scale. A study for the hot climate of California, USA, concludes that a higher roof albedo is the most effective and economic way to lower temperatures city-wide (Bretz et al., 1998). The results from the simulations in this study suggest that a higher roof albedo is also effective for the temperate climate of The Netherlands. A study on the effect of albedo on the indoor comfort shows that the amount of overheating hours is influenced by increasing the value of the albedo. An increase of the albedo value from 0.3 to 0.8 causes a decrease in the amount of overheating hours with 20-50% (Haak, 2012).

It is remarkable that facades with a higher albedo do not always show a decrease in temperature. The simulations in Figure 5.10 result in an increased temperature due to a change in façade albedo from 0.2 in variant 0 to 0.3, 0.5, 0.7 and 0.8 in respectively variant 25, 26, 27 and 28. This difference can be a result of the effect of high albedos on the overall heat balance. In this case the heat is reflected from the façade to the street or the opposite façade where it is changed into latent heat. This is different from the cooling effect that trees have on the heat balance where radiant heat is converted to energy to grow and evaporate water.

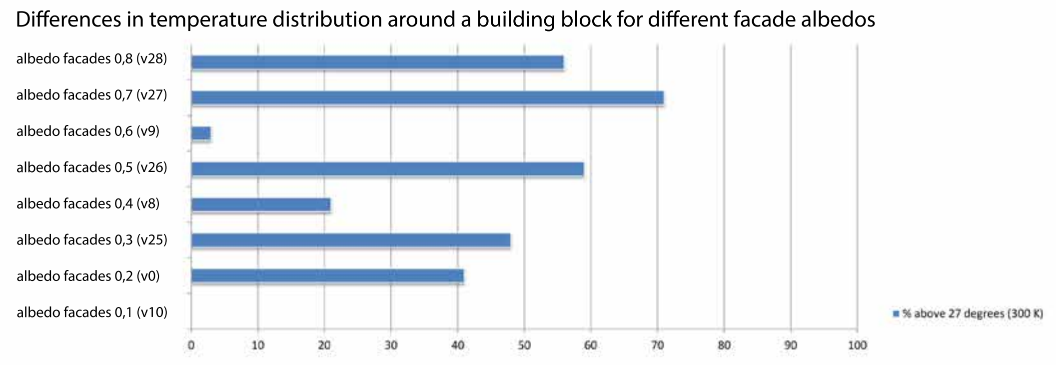

FIGURE 5.10 The percentage of the area where the calculated temperature at 2 meter height is 27 °C or more for different facade albedos.

A peculiar result is the temperature decrease when the albedo is increased to 0.4 and 0.6 (variant 8 and 9) and when it is lowered to 0.1 (variant 10). The simulated air temperature at two metres height does not show a linear relation with the façade albedo. The varying temperature results could be explained by the local difference in heating. Here, only the temperature at two metres height is considered, while the heat could be accumulating elsewhere. The question is what is causing the decrease in temperature with a very low albedo? A probability is that, heat that is not reflected is absorbed by the façade material and when temperatures drop at night this energy will be released. More research is required to confirm this idea.

When climate adaptation measures are combined they can amplify or counteract their heating or cooling effects. The largest cooling effect of the combined measures is 28% of the area in variant 16 (Figure 5.11). This variant combines the coolest option for all parameters including parking situation with trees; very low façade albedo; very high roof albedo; and high building height. In variant 22 only the roof albedo is changed to a relatively low albedo, compared to variant 16. There is a slight heating of the area, but the other cooling parameters counteract the effect of the pavement enough to result in a cooler situation than the existing situation with the grass field. Variant 21 has a slightly higher façade albedo (0.1 to 0.2), compared to variant 16. The slight change in façade albedo has in this case more influence on the area than the large change in roof albedo. Variant 14 is the same as variant 21, except for the building height. The change in building height from a 15 metre flat roof to a 9 metre high slanted roof (in combination with a façade albedo of 0.2, a very high roof albedo and trees in the middle of the parking lot) results in cooling of 7% of the area, compared to the existing situation. All combinations discussed here can counteract the heating effect of the extra pavement that is needed for parking spaces. The largest cooling effect is reached with an increased building height of 15 metres.

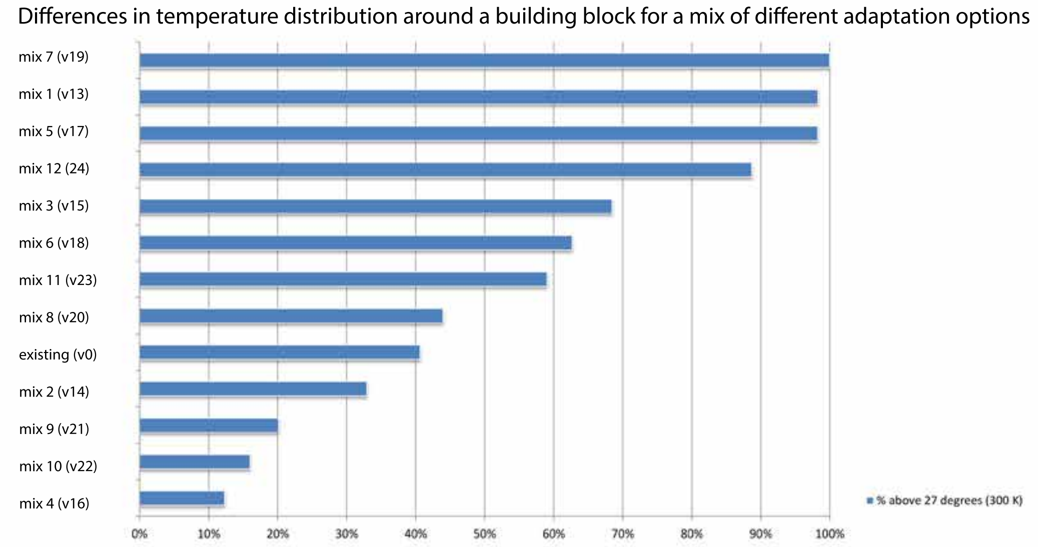

FIGURE 5.11 The percentage of the area where the calculated temperature at 2 metres height is 27°C or more for different combinations of parameters.

On the other hand a combination of adaptation measures that individually decrease temperatures do not always result in an expected overall cooling effect. A combination that should be avoided is the combination of increased façade albedo when there are trees close to the building. The parking variant with trees in the middle and a very high roof albedo is simulated for different façade albedo's in variant 14 and 15. In variant 14 the façade albedo is the same as the reference situation (0.2). The heating effect of the extra pavement for the parking lot is counteracted by the high roof albedo and trees on the parking lot. In fact, these two elements result in an even cooler area than the existing situation. The higher façade albedo of 0.6 in variant 15 results in heating in 35% of the area. An explanation for this result could be the extra reflection from the facades that is not returned to the sky because the trees obstruct the reflection and trap the heat beneath their leaves.

Another remarkable result is the relatively large difference in heating between variant 23 and 24, while they only have a small difference in façade albedo; 0.4 for variant 23 and 0.3 for variant 24. In this case, the 0.1 decrease in façade albedo leads to heating in 30% of the area. This implies that façade albedo has a large effect on the air temperature. Based on the simulations in this research it is difficult to draw any conclusion about the coolest façade albedo because there is not a linear relation with increasing albedos and air temperature. The specific context that is modelled and the height and distance from the facade have a significant influence on the effect of the façade albedo.

When parameters are combined that individually lead to heating, they all lead to temperature increase. In variant 13 and 17 the combination of adaptation measures that solely lead to higher temperatures cause a temperature increase of 1 to 2°C in a large part of the area. The combination of effects leads to more heating than the hottest parking variant (variant 4) alone. In both variants there are no trees on the parking lot and the buildings have a low roof albedo. From these results, we can conclude that the combination of a dark roof with extra pavement should be avoided because this will lead to extra heating.

If the whole area is paved, as is the case in variant 1, and this is combined with a low roof albedo the result is a temperature increase of 2°C (variant 19). The higher building height that leads to a decrease of air temperature in a significant part of the area, as simulated in variant 7, does not counteract the effect of the extra pavement. In variant 23 all parameters are equal to variant 19 except for the amount of vegetation and thus pavement; the extra vegetation in variant 23 leads to cooling in 40% of the area, compared with variant 19. From this we can conclude that the amount of pavement versus vegetation is more dominant for the air temperature than building height. If extra pavement is added and the amount of vegetation is decreased, a higher building height does not counteract the heating effect.

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The results presented so far imply that urban cooling measures can result in better performance once applied in combination, but that this is not always the case and that they might even counteract one another's cooling effect.

§ 5.4.2 Comparison of the measures by temperature effect at neighbourhood scale

In this section we present the simulation results at the neighbourhood level. The differences between the minimum and maximum temperatures are given, followed by the differences in percentage of the area where temperatures are higher or lower compared to the reference situation. The calculated average temperature for the reference situation is 25°C (298 K). The dark blue colour in Figure 5.13 indicates 25-25.5°C. To compare the variants with each other and with the reference situation the grid cells that are higher or lower than this reference situation are counted and the difference from the reference situation is given in percentages in Figure 5.14.

The first clear difference for the existing situation between block (Fig. 5.4) and neighbourhood (Fig. 5.12) level is a difference in the prevailing temperature. Calculations on neighbourhood level result around two degrees cooler than block level. The temperature magnitude is 2°C at the scale of the urban block. As expected, the temperature magnitude is larger at neighbourhood scale, where ΔT = 3°C.

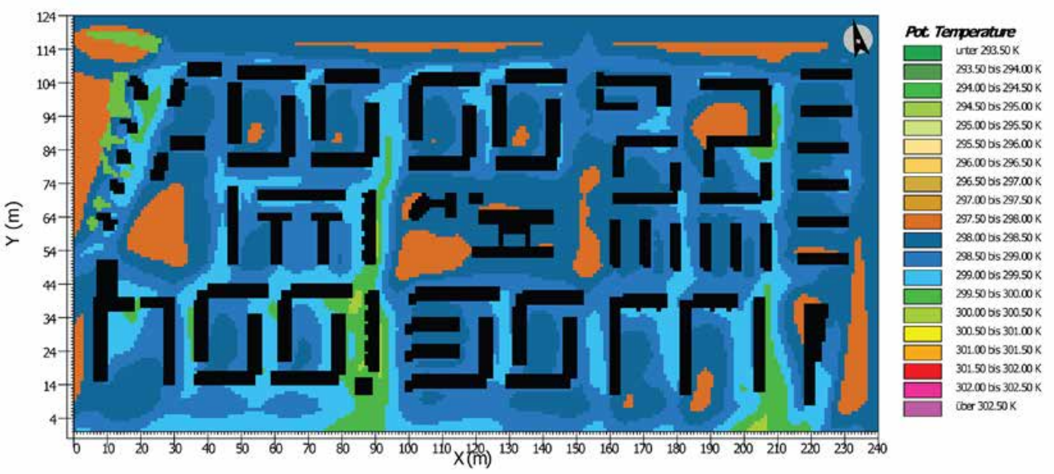

FIGURE 5.12 ENVI-met simulation output for the reference situation at 01:00 PM at the neighbourhood level.

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As with the urban block results, the simulation results at the neighbourhood (Figure 5.13) do not show large differences in the minimum and maximum temperatures between variants, at least not larger than 0.5°C. There is no clear relationship between the increase or decrease of minimum temperatures at urban block and neighbourhood level. The minimum and maximum temperatures of an entire neighbourhood do not represent the potential heat stress that might be experienced locally. If only one area is heating up significantly because it is an open square without shadow elements, the same square will not show a much higher temperature if the pavement material inside the building block is changed to asphalt. For a more detailed analyses we look also here at the difference in the size of the area that is affected.

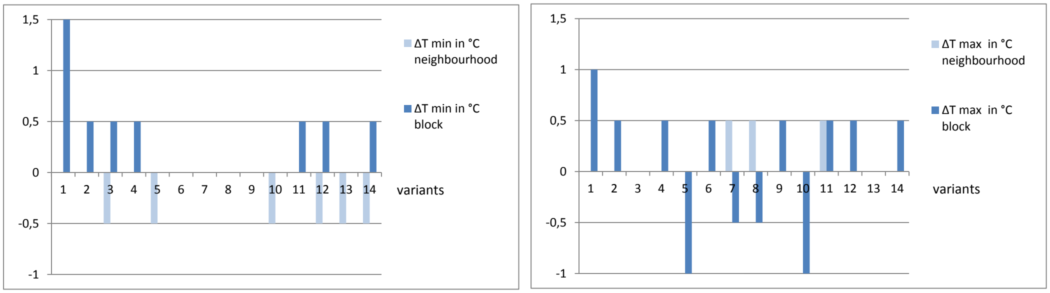

FIGURE 5.13 The minimum and maximum temperature difference between the reference situation and the variants for 01:00 pm at neighbourhood level with the corresponding urban block variant. Left: minimum temperatures (ΔTmin neighb. x - ΔTmin neighb. ref), right: maximum temperatures (ΔTmax neighb.x - ΔTmax neighb.ref)

When comparing the area that is influenced by a variant compared to the reference situation, all the neighbourhood variants, have a smaller magnitude than the corresponding variant at block level. In Figure 5.14 the percentage of the area that is cooler or warmer is given for both block and neighbourhood level. We expect that most of the variants have the same direction in effect: if the variant is cooler at urban block scale, it is also cooler at the neighbourhood scale. However, differences can occur when the heat is reflected outside of the boundaries of the urban block, but stay within the boundaries of the neighbourhood. This is the case for the maximum temperatures in variants 7 and 8 as explained in the following paragraphs.

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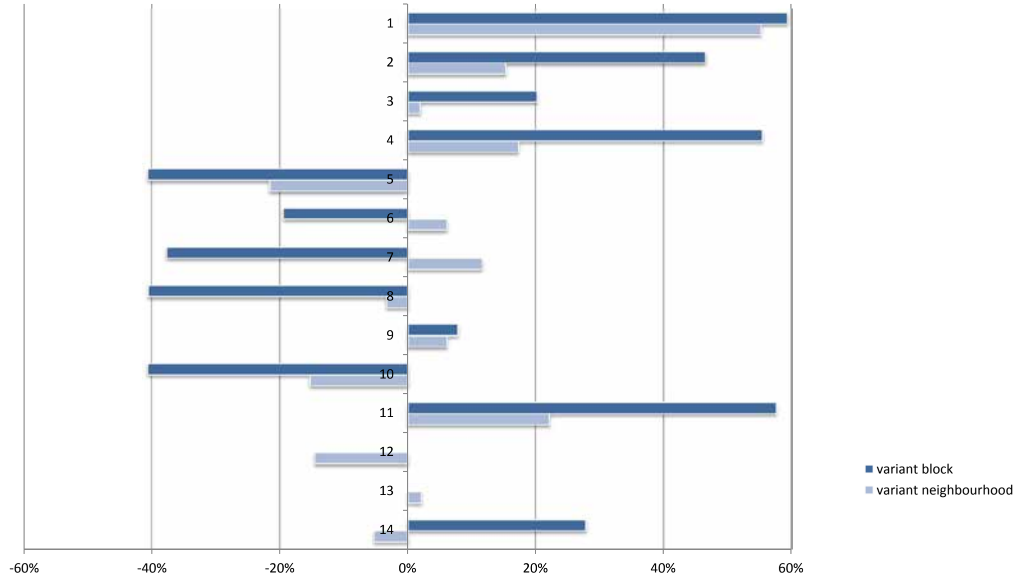

FIGURE 5.14 The percentage of the area where the calculated temperature at 2 metres height has increased or decreased compared to the reference situation at block and neighbourhood level

Areas without green heat up the most at both urban block and neighbourhood level (variant 1). At neighbourhood level this variant has by far the largest impact. The other variants all follow the line of the effects at block level. Replacing the existing grass field with concrete pavement (variant 2) leads to higher temperatures, as is the case for asphalt (variant 4). Trees have a significant cooling effect at the neighbourhood level, also the trees above pavement as in variant 3. The higher buildings in variant 5 lead to a large area with cooler temperatures. Note that the effect of building height can be different in the late afternoon.

For roof albedo we also find a clear relation between the neighbourhood and the building block level. A lower roof albedo (variant 9) shows an increase in temperature and a higher roof albedo (variant 10) a significant decrease in temperature.

The simulation results show contrasting effects for the variants with a different façade albedo. The variants 8, 0, 6 and 7 have an albedo of respectively 0.1; 0.2; 0.4; 0.6. When the albedo increases, the temperature at neighbourhood level increases. Such a linear effect is not visible at the urban block scale. An explanation for this difference is that reflection from the façade causes an extra heat load at street level within a certain distance from the façade but at a different distance it results at less heat load. At neighbourhood level a higher albedo does not result in more heat loss to the sky or boundary layer. Instead it increases the overall temperature.

§ 5.4.3 Comparing measures based on thermal comfort

The calculated PET values in Figure 5.15 show large differences between the variants: the differences between variants in PET are larger than in air temperature alone. Because the comfort indicator is strongly influenced by radiant heat, large differences occur when the measurement point is in or out of the shade. In variant three the area is obviously perceived as the coolest, this is caused by the shade on the measurement point of the trees in the middle of the urban block.

An unexpected difference was found between variant 1 (without vegetation) and variant 2 (parking variant with concrete pavement instead of the green meadow) where the air temperature and the PET give a contradictory result. The variant without green results in a cooler PET value than the parking variant, even though the parking variant is surrounded by hedges. The variant without green does result in a higher air temperature and mean radiant temperature. An explanation for this difference in PET is possibly the lower airflow from 1.15 m/s for variant 1 to 0.93 m/s for variant 2, and the higher relative humidity respectively 54% and 57%. The surrounding vegetation blocks the wind and increases the relative humidity and therewith counteracts the higher air temperature and radiation resulting in a cooler thermal perception.

Another contrasting effect between the PET and the air temperature shows with variant 2 (parking variant with concrete pavement) and variant 4 (parking variant with asphalt). This difference can be explained by looking at the height of the measurement point at 1.5 metres. At this point the heat of the asphalt has less influence on the air temperature. For the comfort indicator the reflected radiance from the light concrete pavement predominates. A similar effect is perceived on a snow plain where the reflected light can cause sunburn and allows skiing without jackets and sleeves, despite of the low air temperature. The cooler experience at 1.5 metres height on asphalt instead of concrete pavement does not say anything about how it feels to walk here on bare feet. The asphalt material itself will heat up more than the concrete tiles, which will result in warmer feet.

The former section showed a clear correlation between a higher roof albedo and a lower air temperature. The PET does not show the same trend in the simulations performed, nor can we conclude from these simulations on the effect of façade albedo on thermal comfort.

Finally, the combination of variants only shows a decrease in temperature for variants 14, 15 and 16. These all have parking with trees in the middle and a high reflective roof. But the same parameters do not lead to the same cooling intensity for variants 20 and 21. They have differences in façade albedo which might cause extreme differences in the perceived temperature.

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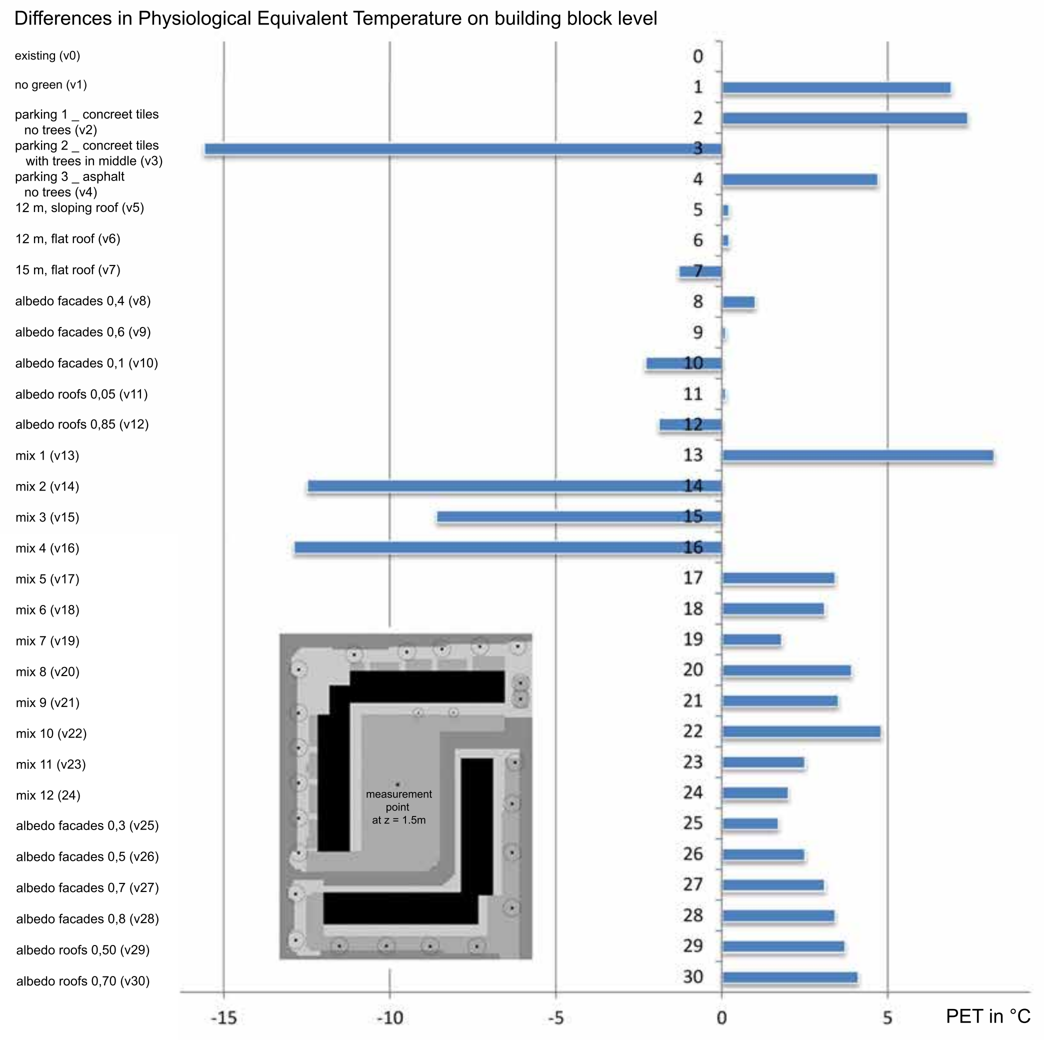

FIGURE 5.15 The effect of different variants on the Physiological Equivalent Temperature (PET) compared to the existing situation.

§ 5.5 Conclusions

The simulations discussed in this chapter indicate the effects of single adaptation measures at the urban block and neighbourhood level. Measures that lead to cooling in the studied area are: adding vegetation, increasing the building height and a higher roof albedo. Measures that lead to heating are adding pavement and a lower roof albedo. At building block level the effect of the façade albedo does not result in a clear linear relation with higher or lower temperatures. However, at neighbourhood level there is a clear relation and this study demonstrates that a higher façade albedo leads to heating.

Results concluded that increasing the amount of shadow by heightening buildings and increasing the reflection of solar radiation at roof level have the highest impact on the maximum temperatures in the studied neighbourhood. For larger height to width ratios additional building layers could also lead to temperature increase. Note that creating shadow on South facing walls by vegetation could even have a higher impact, but was not tested for this neighbourhood. The study does reconfirm the significant cooling effect of vegetation, which has by far the largest potential to diminish heating compared to the other studied adaptation measures.

The three simulated parking variants give an insight into the consequences of changing a grass field in the middle of an urban block into a paved parking lot. All the parking variants result in extra heating of the area, even when trees are added in the middle of a parking lot, the results still do not compare favourably to the comfort levels of grass. In addition to the positive effect of the grass field on thermal comfort, it also offers additional benefits such as recreational space, air filtering, a habitat for flora and fauna, mental benefits, etc. All these aspects should be considered before making the decision to create parking spaces inside the open building blocks.

In this study, various combinations of individual cooling adaptation measures do not always result in better performances overall. Even so, trees might not always lead to cooling, and their effect depends on the context in which they are placed. They might obstruct reflection of heat to the sky and block cooling airflow. On the other hand, the combination of variants that individually lead to a hotter environment all resulted in extra heating. More variants need to be tested to get conclusive information about the best combination of adaptation measures in their context.

The simulations performed at both the urban block and neighbourhood level correspond well. The effects at the urban block level have a greater magnitude than at neighbourhood level. This could simply be caused by larger volumes being less influenced by the changes in the variants. The urban block and neighbourhood level only show a different outcome for the façade albedo as described in the first paragraph of this section.

Finally, the coolest paved scenario (variant 3 and 16) calculated for the redevelopment of the *Couperusbuurt* was a parking lot paved with concrete tiles and planted with trees in the middle. In addition, highly reflective roofs and increased building height lowers the temperatures even more.

Temperature effects were measured in air temperature and the thermal comfort indicator PET. However, due to model limitations, this solely provides an indication of the direction of the effect and an indication of the relative difference in temperature effect between the variants. It does not provide an exact temperature prediction. The air temperature and PET result in different outcomes for the same variants. The variants may even contrast, as with a cooling variant measured in air temperature and a heating variant when measured in PET. This study considered a fixed measurement point for the PET value, this contributed to the understanding of thermal perception and the parameters in the built environment that can influence it. A direct comparison between air temperature and PET failed to offer definite conclusions. A reason for this dissimilarity is the domination of the direct local environment of the measurement point on the PET value.. The PET can vary enormously from shadow to sun or from sheltered from wind to fully exposed, while the air temperature varies only a little. To make an analysis of an area based on the PET, a set of measurement points spread over that area is required.

General conclusions from this case study include the following: Vegetation can be the most effective measure to prevent heat accumulation, depending on the reflectiveness and distance from facades. A higher reflectivity of roofs seems to lead to a cooler environment at street level, while a higher reflectivity of facades can cause extra heating. Future research is needed to indicate the tipping points of albedo and height to width ratios in relation to urban heating. With taller buildings the amount of shadow increases, as a consequence less heating occurs. Such overshadowing being a positive scenario in summer, but not in winter. This study focussed on one specific typology, in addition, other typologies should be studied to realize more climate proof neighbourhoods.

After the location specific measures that were analysed in this chapter, the following chapter aims to indicate effects without context dependencies.

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§ 5.6 References

Ahmad, S. (1992), "Some effects of urban parks on air temperature variations in Kuala Lumpur, Malaysia". Cutest '92 Conference on Thermal Environment, Special in Tohwa: The second Tohwa University International Symposium, Fukuoka, Japan, 7-10 September 1992.

Albers, R., Bosch, P., Blocken, B., Dobbelsteen, A.A.J.F. v.d., Hove, L. v., Spit, T., Ven, F. v.d., Hooff, T. v. and Rovers, V. (2015), "Overview of challenges and achievements in the Climate Adaptation of Cities and in the Climate Proof Cities program". Building and Environment, Vol. 83, pp.1-10.

Ali-Toudert, F. and Mayer, H. (2006), "Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate". Building and Environment, Vol. 41, No. 2, pp. 94-108.

Berghauser Pont, M.Y. and Haupt, P.A. (2009), Spacematrix. Space, Density and Urban Form, Delft University of Technology.

Bosatlas (1999), De Grote Bosatlas, Wolters-Noordhoff, Groningen.

Bretz, S., Akbari, H. and Rosenfeld, A. (1998), "Practical issues for using solar-reflective materials to mitigate urban heat islands". Atmospheric Environment, Vol. 32, No. 1, pp. 95-101.Bruse, M. and Fleer, H. (1998), "Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model". Environmental Modelling and Software, Vol. 13, No. 3-4, pp. 373-384.

Ca, V., Asaeda, T. and Abu, E. (1998), "Reductions in air conditioning energy caused by a nearby park". Energy and Buildings, Vol. 29, No. 1, pp. 83-92.

Defraeye T, Blocken B., Carmeliet J. (2012) "CFD simulation of heat transfer at surfaces of bluff bodies in turbulent boundary layers: Evaluation of a forced-convective temperature wall function for mixed convection". J Wind Eng Ind Aerod; 104-106 p. 439-446.

Esch, M.M.E. v., Bruin-Hordijk, T. d. and Duijvestein, K. 2007. The influence of building geometry on the physical urban climate: a revival of 'light, air and space'. PLEA2007—- The 24th Conference on Passive and Low Energy Architecture. TU Delft.

Evans, J.M. and Schiller, S.D. (1996), "Application of microclimate studies in town planning: a new capital city, an existing urban district and urban river front development". Atmospheric Environment, Vol. 30, No. 3, pp. 361-364.

Fahmy, M. and Sharples, S. (2011), "Urban form, thermal comfort and building CO2 emissions – a numerical analysis in Cairo". Building Services Engineering Research and Technology, Vol. 32, pp. 73-84.

Feddes, Y. (2011), De groene kracht. De transformatie van de Westelijke Tuinsteden Amsterdam., SUN, Amsterdam.

Fiala, D., Havenith, G., Bröde, P., Kampmann, B. and Jendritzky, G. (2012), "UTCI-Fiala multi-node model of human heat transfer and temperature regulation". International Journal of Biometeorology, Vol. 56, No. 3, pp. 429-441.

Fröhlich, D. and Matzarakis, A. (2014) "Human-biometeorological estimation of adaptation- and mitigation potential of urban green in Southwest Germany". Third International Conference on Countermeasures to Urban Heat Island, Venice, Italy.

Futcher, J.A. (2008) "658-ICE TEA CITY". 25th Conference on Passive and Low Energy Architecture. Dublin.

Haak, A.J.C. (2012), "Climate change and heat stress in residential buildings. Evaluation of adaptation measures.", TU Eindhoven.

Herb, W.R., Janke, B., Mohseni, O. and Stefan, H.G. (2008), "Ground surface temperature simulation for different land covers". Journal of Hydrology, Vol. 356, No. 3-4, pp. 327-343.

Höppe, P. (1999), "The physiological equivalent temperature - A universal index for the biometeorological assessment of the thermal environment". International Journal of Biometeorology, Vol. 43, No. 2, pp. 71-75.

IPCC (2007), "An Assesment of the Intergovernmental Panel on Climate Change, Summary for Policymakers".

Jauregui, E. (1991), "Influence of a large urban park on temperature and convective precipitation in a tropical city". Energy and Buildings, Vol. 15, No. 3-4, pp. 457-463.

Jendritzky, G., Maarouf, A. and Henning, S. (2001) Looking for a Universal Thermal Climate Index UTCI for Outdoor Applications. Windsor Conference on Thermal Standards. Windsor, UK: Network for Comfort and Energy Use in Buildings.

Katzschner L, Thorsson S. (2009) Microclimate Investigations as Tool for Urban Design. In The seventh International Conference of Urban Climate, Yokohama, Japan.

TOC

Katzschner, L. (2010), "Outdoor Thermal Comfort under Consideration of Global Climate Change and Urban Development Strategies". Adapting to Change: New Thinking on Comfort, Windsor, UK, 9-11 April 2010 2010, Network for comfort and energy use in buildings, London, pp.

Kleerekoper, L., Esch, M.M.E. v., and Salcedo, T.B. (2012), "How to make a city climate-proof, addressing the urban heat island effect". Resources, Conservation and Recycling, Vol. 64, No. 0, pp. 30-38.

Kleerekoper, L., Dobbelsteen, A.A.J.F. v.d., Hordijk, T., Dorst, M.J. v. and Martin, C. (2015), "Climate adaptation strategies: achieving insight in microclimate effects of redevelopment options". Smart and Sustainable Built Environment, Vol. 4, No. 1.

Klein Tank, A.M.G. and Lenderink, G. (2009), "Klimaatverandering in Nederland; Aanvullingen op de KNMI'06 scenario's", KNMI, De Bilt.

Klok, L. (2010), "Hittebeperkende klimaatmaatregelen voor Rotterdam onderzocht met Envi-met microschaal klimaatsimulaties", 034.21618, TNO, Kennis voor Klimaat.

KNMI (2011), "Lijsten en extremen". Available at: http://www.knmi.nl/klimatologie/lijsten/ [Accessed August 2014].

Lahme, E. and Bruse, M. (2003), "Microclimatic effects of a small urban park in a densly build up area: measurements and model simulations". Fifth International Conference on Urban Climate, Lodz, Poland, 2003, Department of Meteorology and Climatology Faculty of Geographical Sciences University of Łódź, pp. 273.

Lewis, J., Nicholas, F., Seales, S. and Woollum, C. (1971), "Some effects of urban morphology on street level temperature at Washington DC". Journal of Washington Academic Science, Vol. 61, pp. 258-265.

Lindberg F, Holmer B, Thorsson S. (2008) "SOLWEIG 1.0 – Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings". Int J Biometeorol; 52.

Matzarakis, A., Rutz, F. and Mayer, H. (2007) "Modelling radiation fluxes in simple and complex environments—application of the RayMan model". International Journal of Biometeorology, Vol. 51, No. 4, pp. 323-334.

Matzarakis, A. and Amelung, B. (2008) "Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans". Seasonal Forecasts, Climatic Change and Human Health. Springer.

Mayer, H. and Höppe, P. (1984), "Die Bedeutung des Waldes für die Erholung aus der Sicht der Humanbioklimatologie". Forstwissenschaftliches Centralblatt, Vol. 103, No. 1, pp. 125-131.

Mees, H.L.P. and Driessen, P.P.J. (2011), "Adaptation to climate change in urban areas: Climate-greening London, Rotterdam, and Toronto". Climate law, Vol. 2, No. 2, pp. 251-280.

Middel, G. (2002) "TOP 10 data set P1661". Topografische-Dienst, Data Archiving and Networked Services.

Nishimura, N., Nomura, T., Iyota, H. and Kimoto, S. (1998), "Novel water facilities for creation of comfortable urban micrometeorology". Solar Energy, Vol. 64, No. 4, pp. 197-207.

Oke, T.R. (1988), "Street design and urban canopy layer climate". Energy and Buildings, Vol. 11, No. 1-3, pp. 103-113.

Oke, T.R., Crowther, J.M., McNaughton, K.G., Monteith, J.L. and Gardiner, B. (1989), "The Micrometeorology of the Urban Forest [and Discussion]". Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, Vol. 324, No. 1223, pp. 335-349.

Peutz (2009), "Energetische aspecten bij toepassing Ecoseal EP White dakbedekking", E 376-1, E 376-2.

Prado, R.T.A. and Ferreira, F.L. (2005), "Measurement of albedo and analysis of its influence the surface temperature of building roof materials". Energy and Buildings, Vol. 37, No. 4, pp. 295-300.

Rafailidis, S. (1997), "Influence of building areal density and roof shape on the wind characteristics above a town". Boundary-Layer Meteorology, Vol. 85, No. 2, pp. 255-271.

Robitu, M., Inard, C., Groleau, D. and Musy, M. (2004), "Energy balance study of water ponds and its influence on building energy consumption". Building Services Engineering Research and Technology, Vol. 25, No. 3, pp. 171-182.

Shashua-Bar, L. and Hoffman, M. (2000), "Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees". Energy and Buildings, Vol. 31, No. 3, pp. 221-235.

Shashua-Bar L, Pearlmutter D, Erell E. (2011) "The influence of trees and grass on outdoor thermal comfort in a hot-arid environment". Int J Climatol, 31(10), p. 1498-1506.

Spronken-Smith, R.A. and Oke, T.R. (1998), "The thermal regime of urban parks in two cities with different summer climates". International Journal of Remote Sensing, Vol. 19, No. 11, pp. 2085-2104.

Taha, H., Akbari, H., Rosenfeld, A. and Huang, J. (1988), "Residential cooling loads and the urban heat island--the effects of albedo". Building and Environment, Vol. 23, No. 4, pp. 271-283.

Topografische-Dienst (2002), TOP 10, Data Archiving and Networked Services.

Watkins, R., Palmer, J. and Kolokotroni, M. (2007), "Increased temperature and intensification of the urban heat island: implications for human comfort and urban design". Built Environment, Vol. 33, No. 1, pp. 85-96.

Wong, N.H., Lee, S.E. and Li, S. (2007), "Thermal Performance of Facade Materials and the Impacts on Indoor and Outdoor Environment", Singapore.

Yang, X., Zhao, L., Bruse, M. and Meng, Q. (2013) "Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces". Building and Environment, Vol. 60, pp. 93-104.

Yu, C. and Hien, W.N. (2006), "Thermal benefits of city parks". Energy and Buildings, Vol. 38, No. 2, pp. 105-120.

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