

Reducing Heat and Improving Thermal Comfort through Urban Design – A Case Study in Ho Chi Minh City

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Abstract—Ho Chi Minh City (HCMC), in the south of Vietnam, is undergoing rapid urbanization and is one of the world's cities most affected by climate change. A comparative analysis among different scenarios for a case study located in a re-development area in HCMC revealed how urban design can contribute to reduce heat and improve thermal comfort in urban areas. Isoline mappings made with the climate modelling software ENVI-met have provided evidence that enhanced street greenery has the most remarkable impact on urban thermal comfort.

Index Terms—Climate change, Ho Chi Minh City, urban heat island effects, urban design.

I. INTRODUCTION

The impacts of Urban Heat Islands (UHI) are significant in big cities. Reducing UHI effects will decrease energy consumption, improve urban thermal comfort and mitigate the impacts of climate change related to heat. There are five main factors that cause UHI: absorption of solar radiation, anthropogenic heat generation, thermal storage, decreased evaporation and reduced ventilation [1]. Among these factors, climate responsive urban design can reduce solar radiation absorption and thermal storage through the use of appropriate materials. Moreover, it can enhance evaporation and ventilation through strategies such as increasing vegetation and adjusting the building orientation. Therefore, urban design plays an important role in mitigating UHI effects. Through comparing different modelled urban design scenarios, this paper demonstrates how urban design can mitigate the impacts of UHI.

The case study is chosen in HCMC. This city is severely affected by climate change and UHI effects [2], [3]. The city's annual mean temperature has been increased by 0.5 °C in 2007 compared to the period of 1991-2000 [4]. There is a need to analyse appropriate urban design measures in order to mitigate UHI effects in the city's developments. The case study is a quarter of a large-scale re-development project, located near to the central business district of HCMC (Fig. 1).



Fig. 1. Location of the case study area in Ho Chi Minh City

II. METHODOLOGY

Different scenarios have been modelled and simulated by the three-dimensional and non-hydrostatic climate model ENVI-met [5]. Scenarios consider different urban forms, wind directions, vegetation and building materials. ENVI-met results are shown in temperature isoline maps. Within this study, it is important to note that ENVI-met is used mainly to compare the differences among scenarios, not to give absolute information on specific temperatures. The model input information is shown in Table I.

TABLE I: MODEL'S INPUT INFORMATION

Location	HCMC, Vietnam, 10°46'N, 106°43'E
Simulation time	36 hours, from 10:00am 01.02.2013
Wind speed	2 m/s
Wind direction	30° to the North (parallel to the canal)
Initial Temperature	301°K (28°C)
Relative Humidity	70%
Specific Humidity	17 g/kg
Solar radiation	0.5

The simulation date is chosen for 01 February 2013 during the dry season of HCMC, when the UHI effects can be observed more significantly. Simulations last thirty-six hours, and the outcome data is shown at 2pm on the second simulation day when the air temperature is at peak and the calculation has accumulated the storage effect from the first day exposition.



Fig. 2. The Baseline scenario

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The research follows a comparative methodology. The comparisons are based on a reference to a typical urban pattern, the so-called Baseline Scenario (Fig. 2). In this scenario, the adopted paving and building materials, building forms and greenery that are commonly used in HCMC provide a reference. The comparative scenarios consist of different urban design measures that allow the study of UHI factors in the case study: building orientation, greenery and materials. These are compared both separately and in a combined format (Table II). The comparative study has analysed various distributions in air temperature, surface temperature, ventilation and physical equivalent temperature among these scenarios.

TABLE II: SCENARIOS

Baseline Scenario	Alternative scenario	Description	
Typical urban design in HCMC	A. Building Orientation	Improve ventilation by building orientations	
	B. Material	1) Cool Paving	Use light colour and permeable paving materials
		2) Light/Dark Roof	Use light colour and reflexive roofs
	C. Greenery	1) Roof greenery	Green roofs
	2) Street greenery	Maximise street and public greenery	
	D. Combined	Combine the above scenarios	

III. RESULTS

A. The Influence of Building Orientation

In this alternative scenario, most of the buildings are re-orientated parallel to the main wind direction. Meanwhile, the other buildings, which are not parallel to the wind direction, are elevated with empty ground floors and are shown by dash lines in the maps. Building heights are also adjusted; the nearer to the canal, the lower the building heights. Although the building forms are changed, the total gross floor area of this alternative scenario is kept similar to the Baseline Scenario.

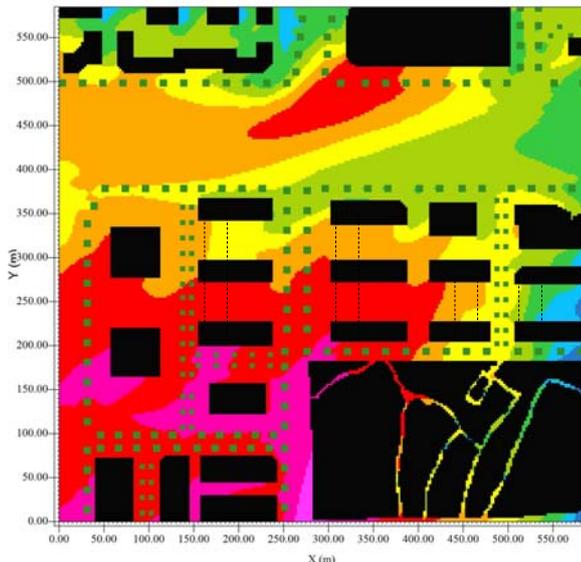


Fig. 4. Air temperature of the Building Orientation Scenario. Horizontal cut at z = 1.65m

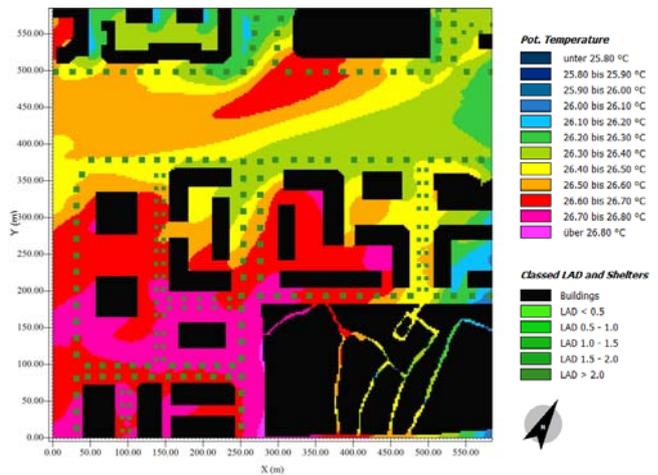


Fig. 3. Air temperature of the Baseline Scenario. Horizontal cut at z = 1.65m

As shown in Fig. 3 and Fig. 4, there is a reduction of 0.1-0.2 °C in air temperature at the waterfront, where winds are free to flow through the buildings. Here, it is proven that wind ventilation improves the urban cooling. However, air temperature at the southern corner is almost the same in both scenarios. This is a limitation of this alternative: orientating buildings parallel to the main wind direction will improve urban cooling at areas near to the canal; nonetheless, these new building forms and the increased heights of some buildings will create new wind blockages, thereby decreasing the wind penetration for areas off of the canal. Therefore, air-cooling will not be improved equally for the whole quarter, only for a part of it.

B. The Influence of Paving and Roof Materials

1) B1-Cool Paving

The Baseline Scenario is simulated with common surface materials in HCMC, which are concrete for the sidewalk and public space pavement and basalt asphalt for the roadway. The Cool Paving Scenario, on the other hand, is simulated with light coloured bricks for the pavement, porous gravel asphalt for the internal streets and basalt asphalt for the main roadways. The basalt asphalt is comprised of nine vertical grid boxes of basalt asphalt and loam down to the fourteenth grid box of the soil model. The porous gravel asphalt is

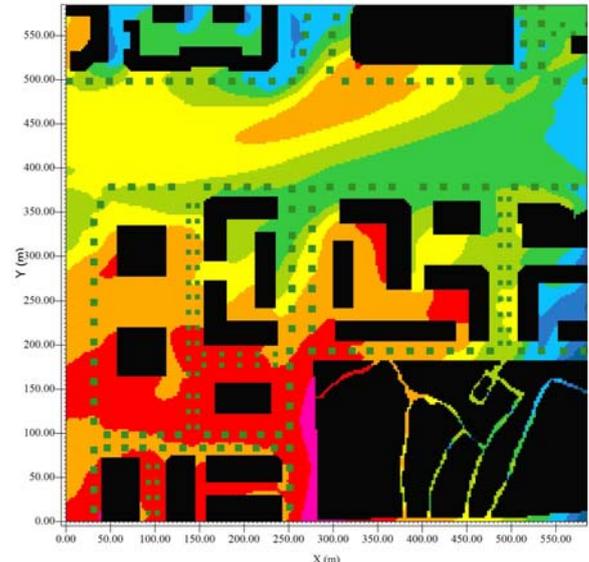


Fig. 5. Air temperature of the Cool Paving Scenario. Horizontal cut at z = 1.65m

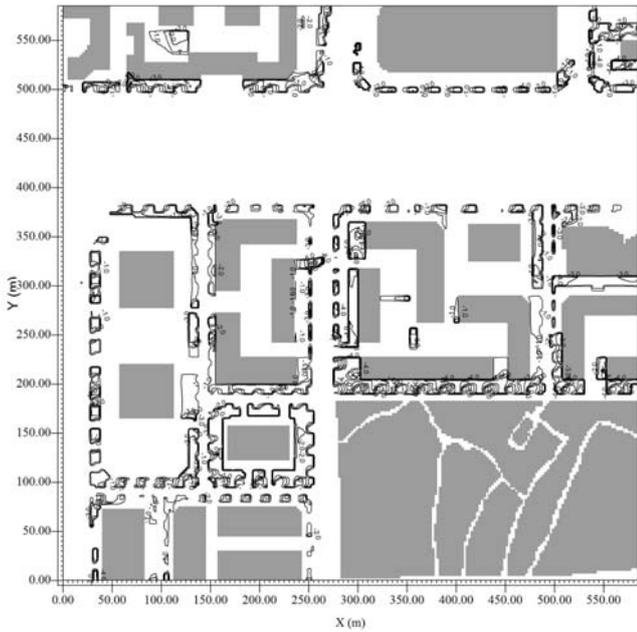


Fig. 6. Comparison of surface temperature between the *Cool Paving Scenario* and the *Baseline Scenario*. Isoline interval 1°C

generated with four grid boxes of gravel asphalt, then three grid boxes of basalt, and then loam down to the fourteenth grid box. The porous gravel asphalt has a hydraulic conductivity at saturation of $0.7 \cdot 10^6 \text{ ms}^{-1}$.

The result shows that the air temperature at the pedestrian level of the Cool Paving Scenario is reduced by 0.1 to 0.2°C for the whole area (Fig. 3 & Fig. 5). However, when analysing the surface temperature of the two scenarios, these variations are even larger. Most of the areas are reduced by 1°C to 2°C; in some areas up to 4°C are reduced (Fig. 6).

2) *B2-Light Roof and Dark Roof*

The Baseline Scenario is simulated with grey coloured concrete roofs. In practice, black and water-proof concrete roofs are also often used in HCMC. Therefore, in order to reveal the effects of roof colours on air temperature, the study compares a Dark Roof Scenario with a Light Roof Scenario. The Dark Roof Scenario uses dark coloured concrete with only 5% of reflection, while the Light Roof Scenario uses light coloured concrete with up to 75% of reflection.

The results show that, with a lighter roof colour, the air temperature at the roof levels is reduced only by 0.07°C (Fig. 7); and, the air temperature at the pedestrian level remains almost unchanged. This variation is not significant. One probable reason is that not only roof colour, but also roof material, determines roof temperature.

C. *The Influence of Green Roofs and Street Greenery*

1) *C1-Green Roof*

Similar to the light roof and dark roof comparison, the study also compares green roofs with conventional roofs. The Green Roof Scenario is simulated with exactly the same materials as the Baseline Scenario; additionally, both 50cm high grass and 150cm high bushes are added along the perimeter.

According to Fig. 8, at the roof levels of the green roof buildings, air temperature can be reduced by 0.2°C. The amount of temperature reductions in this scenario is more significant than in the Light Roof Scenario. This is because the green grass and bushes on the roof-tops dissipate heat as with an air-cooling system. By reducing significantly roof temperature, this alternative will reduce building energy consumption for mechanical air cooling. Similar to the Light Roof Scenario, the air temperature at the pedestrian level in this Green Roof Scenario remains mostly unchanged.

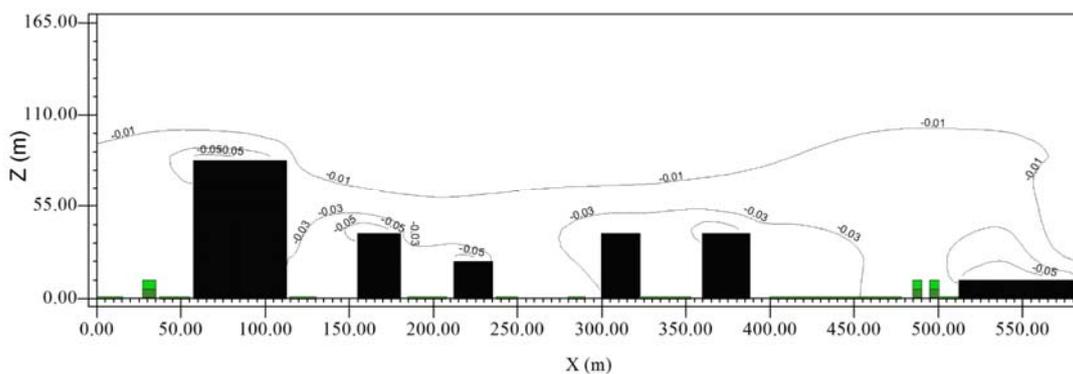


Fig. 7. Comparison of air temperature between the *Dark Roof Scenario* and the *Light Roof Scenario*; Vertical cut at $y=311\text{m}$. Isoline interval 0.02°C

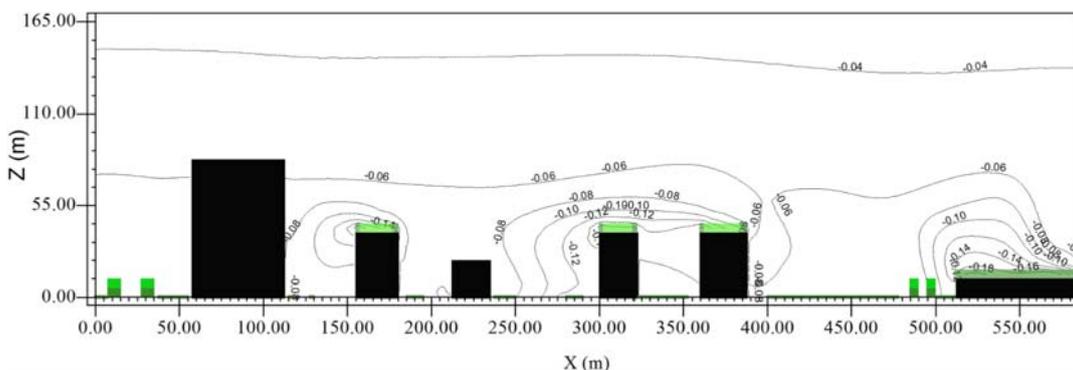


Fig. 8. Comparison of air temperature between the *Street Greenery Scenario* and the *Baseline Scenario*; Vertical cut at $y=311\text{m}$. Isoline interval 0.02°C

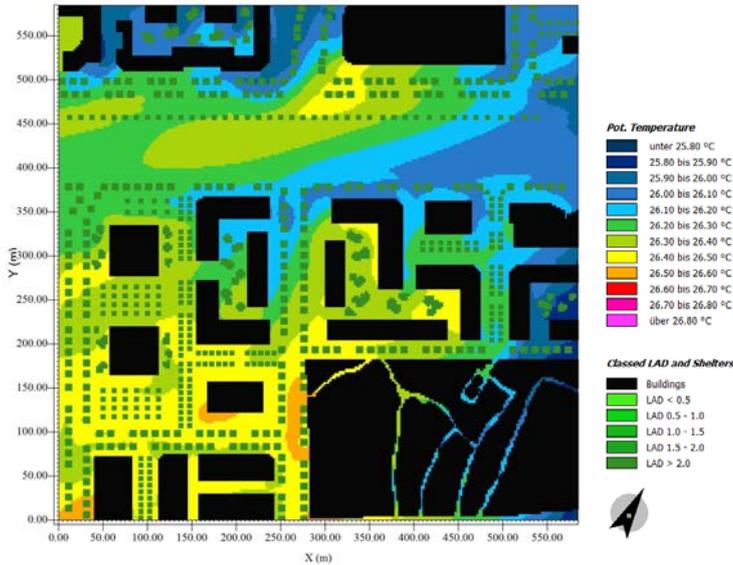


Fig. 9. Air temperature of the *Street Greenery Scenario*. Horizontal cut at $z=1.65\text{m}$

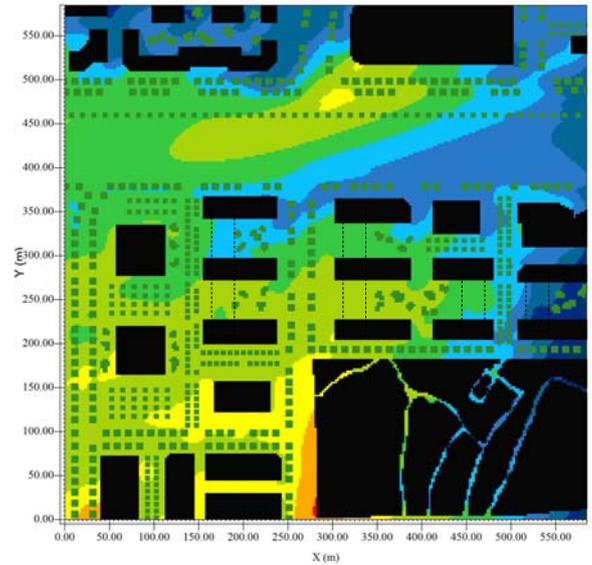


Fig. 11. Air temperature of the *Combined Scenario*. Horizontal cut at $z=1.65\text{m}$

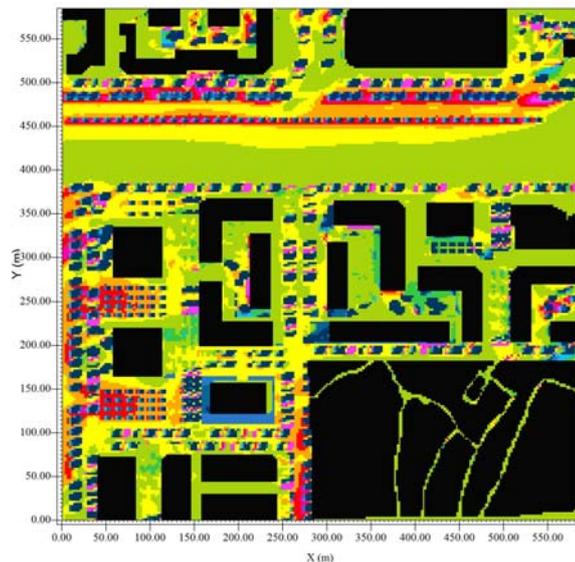


Fig. 10. Comparison of the PET between the *Baseline Scenario* and the *Street Greenery Scenario*. Horizontal cut at $z=1.65\text{m}$.

2) C2-Street Greenery

The alternative scenario is simulated by maximising tree plantation along streets and in courtyards. The street tree model used in this scenario is the 'T3 tree model' in ENVI-met with 10m height, dense crown and leafless base. When comparing this alternative scenario with the Baseline Scenario, it has been shown that the temperature is reduced over the whole quarter, up to 0.5°C (Fig. 1 and Fig. 9).

In addition to the air temperature comparison, the Physical Equivalent Temperature (PET) is also used to compare. PET is used to analyse thermal comfort conditions based on a heat-balance model between thermal conditions of the human body and its outdoor conditions [6], [7]. The outdoor conditions are taking not only air temperature, but also humidity, wind velocity and mean radiant temperature, into account.

According to Fig. 10, the PET variations between the Street Greenery Scenario and the Baseline Scenario are more significant than the air temperature. In most of the areas, PETs are reduced notably, ranging from 6°C in shaded areas, to 1°C in the streets and the courtyards. Nonetheless, the reductions do not occur everywhere in the whole quarter. For

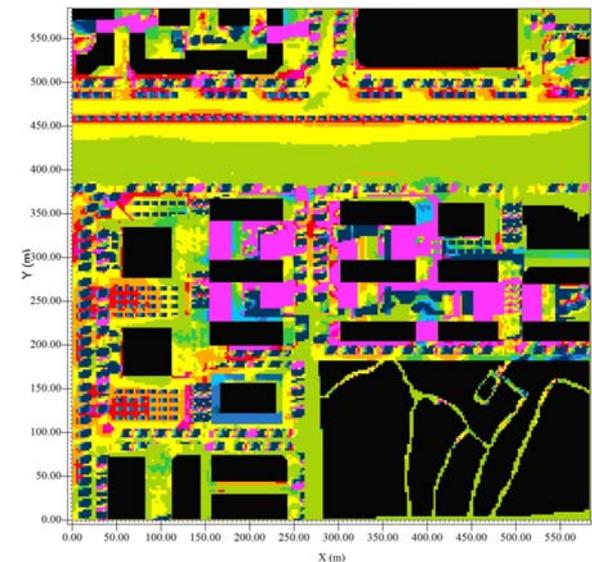


Fig. 12. Comparison of the PET between the *Baseline Scenario* and the *Combined Scenario*. Horizontal cut at $z=1.65\text{m}$.

example, in the un-shaded areas of the two parks at the southern corner, thermal stress is increased. This can be explained by the reduction of ventilation caused by the densely-planted trees.

D. The Influence when Combining Building Orientation, Street Greenery and Cool Pavement

To analyse the effects of combining different urban design measures into one scenario, the so-called Combined Scenario is created. In this scenario, all the factors of building orientation, cool paving materials and optimal street greenery are implemented. Green roofing and cool roofing are not combined, since this simulation attempts to analyse the thermal improvement at the pedestrian level only.

The result shows that the air temperature at the 1.65m level can be reduced up to 0.6°C (Fig. 11). The reductions are most significant at the waterfront and the southern corner. However, this improvement is just slightly higher than the improvement in the Street Greenery Scenario.

When analysing the PET of the Combined Scenario and Baseline Scenario, the result shows that there is a similar improvement of thermal comfort in the streets and open

spaces, as with the Street Greenery Scenario (Fig. 12). Nonetheless, at the locations where buildings have been re-orientated, there is an increase in thermal stress due to changes of the building forms.

IV. CONCLUSION

Simulation data on PET and air temperature at the pedestrian level are synthesised as shown in Fig. 13 and Fig.14. Here, the two scenarios of light roofs and green roofs are not shown, since their influences at the pedestrian level are insignificant. Combined with the spatial maps and findings above, the study concludes as follows:

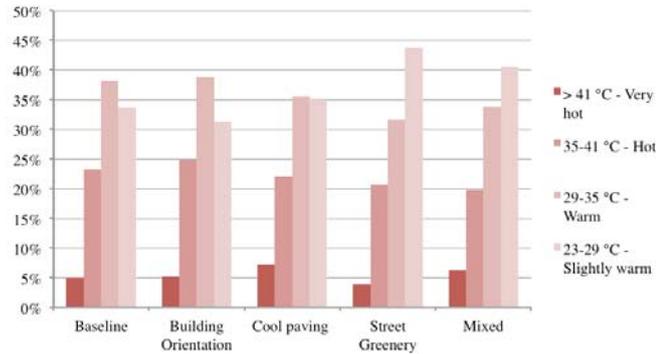


Fig. 13. Physical Equivalent Temperature (PET), by scenario, at the pedestrian level z=1.65m.

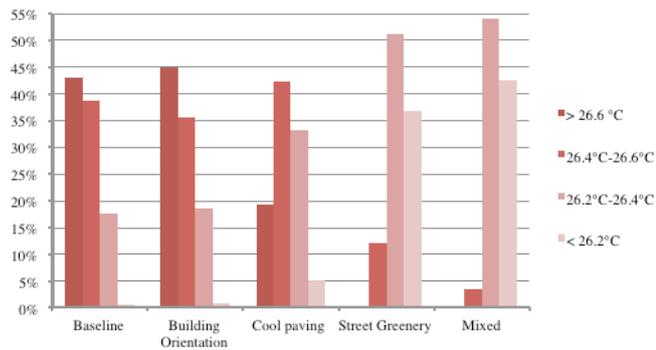


Fig. 14. Air Temperature, by scenario, at the pedestrian level z=1.65m.

- 1) Street greenery has the most remarkable impact on enhancing urban thermal comfort and reducing air temperature. This finding is further supported by additional research regarding urban thermal comfort [8], [9], [10].
- 2) Orienting buildings according to the main wind direction will reduce the air temperature along the re-oriented blocks. However, the cooling impacts are not equal for the whole quarter since the new building forms create new wind blockages and alter the micro-ventilation.
- 3) Cool paving materials reduce the air temperature remarkably at the surface level and, by proximity, at the pedestrian level. However, in terms of thermal comfort, cool paving materials do not contribute to an increase.
- 4) Although green roofing does not have a significant impact on the air temperature at the pedestrian level, it can reduce significantly the roof temperature and hence, will help to reduce energy consumption in cooling

buildings.

- 5) Changing roof colours to lighter colours also reduces the roof temperature. However, the reduction is slight and is not as remarkable as green roofs.
- 6) By combining building orientation, street greenery and cool paving into one urban design scenario, the overall air temperature at the pedestrian level will be reduced notably. Nonetheless, these improvements in thermal comfort are not as significant as in the Street Greenery Scenario.

V. FURTHER RESEARCH

This paper is focused on comparing the impact of different urban design components on the UHI effects. Further research is needed to analyse the impact of each urban design component in detail such as the use of different kinds of building and paving materials, or the use of different vegetation types. Costs and benefits of the alternatives will also have to be quantified in order to weigh measures and propose feasible recommendations.

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