A WIND-SUN EXPOSURE ANALYSIS METHOD TO PREDICT PEDESTRIAN URBAN COMFORT AT EARLY DESIGN STAGE: REGNBÅGENSALLÉN AT LULEÅ UNIVERSITY CAMPUS, SWEDEN

/ MARIE-CLAUDE DUBOIS, ÖRN ERLENDSSON, SAEED EBRAHIMABADI, ANNA EKLUND AND NIELS DE BRUIN
White arkitekter & Luleå University

marie-claude.dubois@white.se; marie-claude.dubois@ebd.lth.se; orn.erlendsson@white.se; saeed.ebrahima-badi@ltu.se; anna.eklund@white.se; niels.debruin@white.se

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ABSTRACT

A simulation methodology was developed as part of the landscape project *Luleå Campus Regnbågensallén* ("Rainbow Alley") at Luleå University, Northern Sweden, an area exposed to cold winds in an extreme Nordic environment. This methodology aimed to integrate wind and solar exposure data in order to improve exterior thermal comfort and guide design decisions at an early design stage. The method uses a combination of advanced CFD (computational fluid dynamics) simulations and solar access analysis combined into a highly communicative and intuitive microclimate map highlighting areas with optimal comfort conditions. This article presents the results obtained with the simulation methodology as well as some discussion about the validity and usefulness of the method. By improving pedestrian comfort conditions, the landscape design is promoting outdoor activities like walking and cycling, which are key to support the future development of a truly sustainable Nordic city.

INTRODUCTION

The urban context offers a rich and varied environment influencing the way we are using urban spaces through movement and activities.[1] Furthermore, buildings, obstacles, trees and shrubs that define urban spaces affect our perception of the environment by providing constantly changing thermal, acoustic, visual and olfactory stimuli enriching the senses. Of all the influences which impact on town form, especially in harsh conditions, the most compelling is likely to be climate.[2] In the urban context, favorable microclimates are an essential condition for the conviviality of cities in fostering environmental, social and economic exchanges.[3] Research confirms that microclimatic parameters are of prime importance to support activities which take place on site, and up to a certain point, determine how this site can be exploited.[4] Climatically responsive urban design is fundamental to sustainability: when the design of spaces between buildings is informed by the opportunities and constraints of the local climate, pedestrian comfort is enhanced – encouraging city dwellers to conduct more activities outdoors, and in turn to moderate their dependence on air-conditioned buildings and private vehicles.[5]

However, climate issues often have a low impact on the urban planning process in practice. Much recent architectural discourse has concentrated on aspects of construction or aesthetics, while the analysis and review of environmental strategy has received considerably less attention.[6] Thermal qualities – warm, cold, humid, airy, radiant, cozy – are an important part of our experience of a space; they not only influence what we choose to do there but also how we feel about the space.[7]

In order to develop a landscape concept going beyond the aesthetic paradigm, a simulation methodology was developed as part of a real landscape project called *Regnbågensallén* at the Campus of Luleå University in Northern Sweden. This method combines wind and solar access data into microclimate maps at specific times of the year in order to predict and improve exterior thermal comfort and guide design decisions at an early design stage.

BACKGROUND: THERMAL COMFORT THEORY AND MODELS

A design method accessible to architects and urban planners was devised by Brown & DeKay[8] based on two climate parameters: wind velocity and solar access, which offers a simpler means for assessing outdoor microclimate, applicable in all seasons and at an early design stage.Ebrahimanadi et al[9] showed that this method correlates with the more precise calculation of the spatial distribution of the outdoor standard effective temperature (OUT_SET*) used in more advanced climate analyses. The simpler microclimate maps method proposed by Brown & DeKay[8] and further developed by Ebrahimanadi et al[9] and Potvin et al[3] uses different combinations of solar access and wind conditions in accordance with climate context and season. For example in cold climates, spaces that are sunny and sheltered from wind are favorable in all seasons whereas in a tropical humid climate, a combination of shadow and wind is favorable.[9] This suggests that in cold climates, designers should aim to create spaces that are sheltered from wind and have maximum solar access to maximize comfort.

METHOD

CONTEXT: LULEÅ UNIVERSITY

Regnbågsallén is a landscape project at Luleå Technical University (LTU) (latitude: 65.33°N; longitude: 22.08°E) commissioned to White Architects in 2015. LTU is Sweden's most Northern university and the only one with secure snow cover, a quality which is central to the project's development. One of the main areas of the project is the so-called *Regnbågsallén* ("Rainbow Alley"), which is a central, pedestrian street oriented along an East-West axis and linking the main university pavilions. (Figure 1) The Rainbow Alley is designed so that the focus is on three dimensional forms and three dimensional surfaces rather than a nice urban "floor" since this one will be covered with snow most of the year.

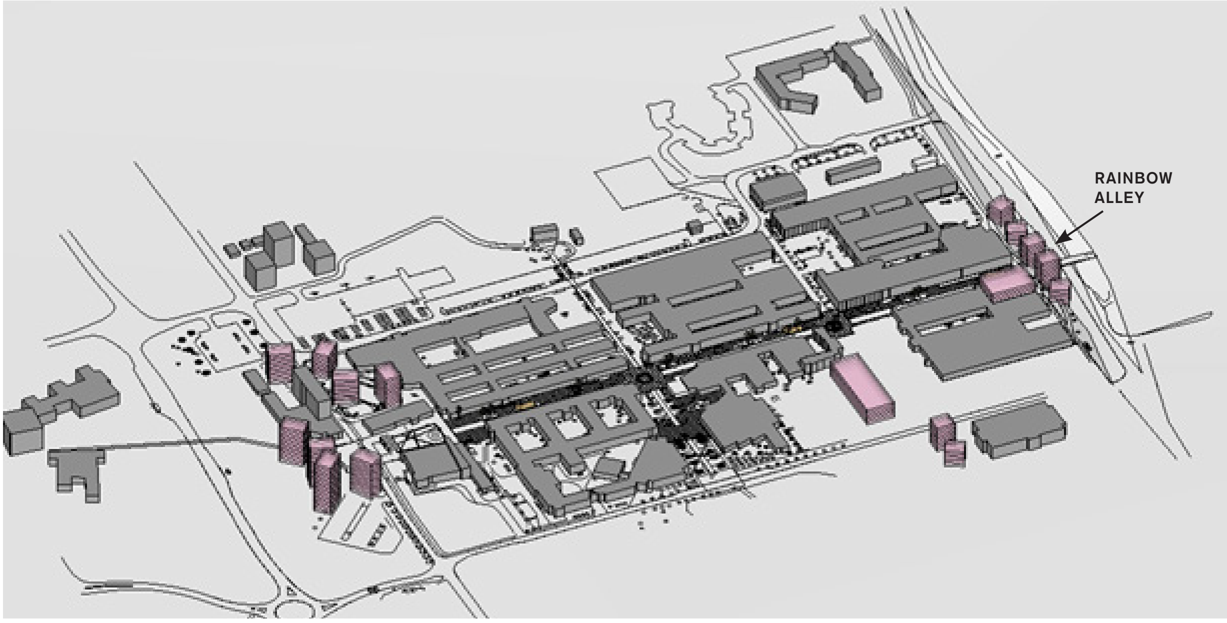

FIGURE 1. Drawing showing Luleå University Campus in an early design phase (by Egil Blom, architect, White arkitekter).

WIND DATA

Wind statistics from Luleå Airport show that on average, wind speeds are not really extreme, ranging from 3.0 to 3.7 m/s as shown in Table 1 and 2. As the wind roses indicate, the most frequent wind directions are from South and North, respectively. (Figure 2) Three cases were therefore considered in this study:

1. South,
2. North,
3. Extreme wind from South.

Nr	Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Yearly
16286	Luleå	(m/s)	3.2	3.2	3.4	3.1	3.3	3.4	3.3	3.2	3.3	3.3	3.2	3.2	3.2

TABLE 1. Average wind speed in m/s for the period 1991 – 2004, source SMHI.

Nr	Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Yearly
16286	Luleå	(m/s)	3.0	3.0	3.2	3.5	3.3	3.7	3.6	3.5	3.6	3.7	3.5	3.3	3.4

TABLE 2. Average wind speed in m/s for the period 1961 – 1990, source SMHI.

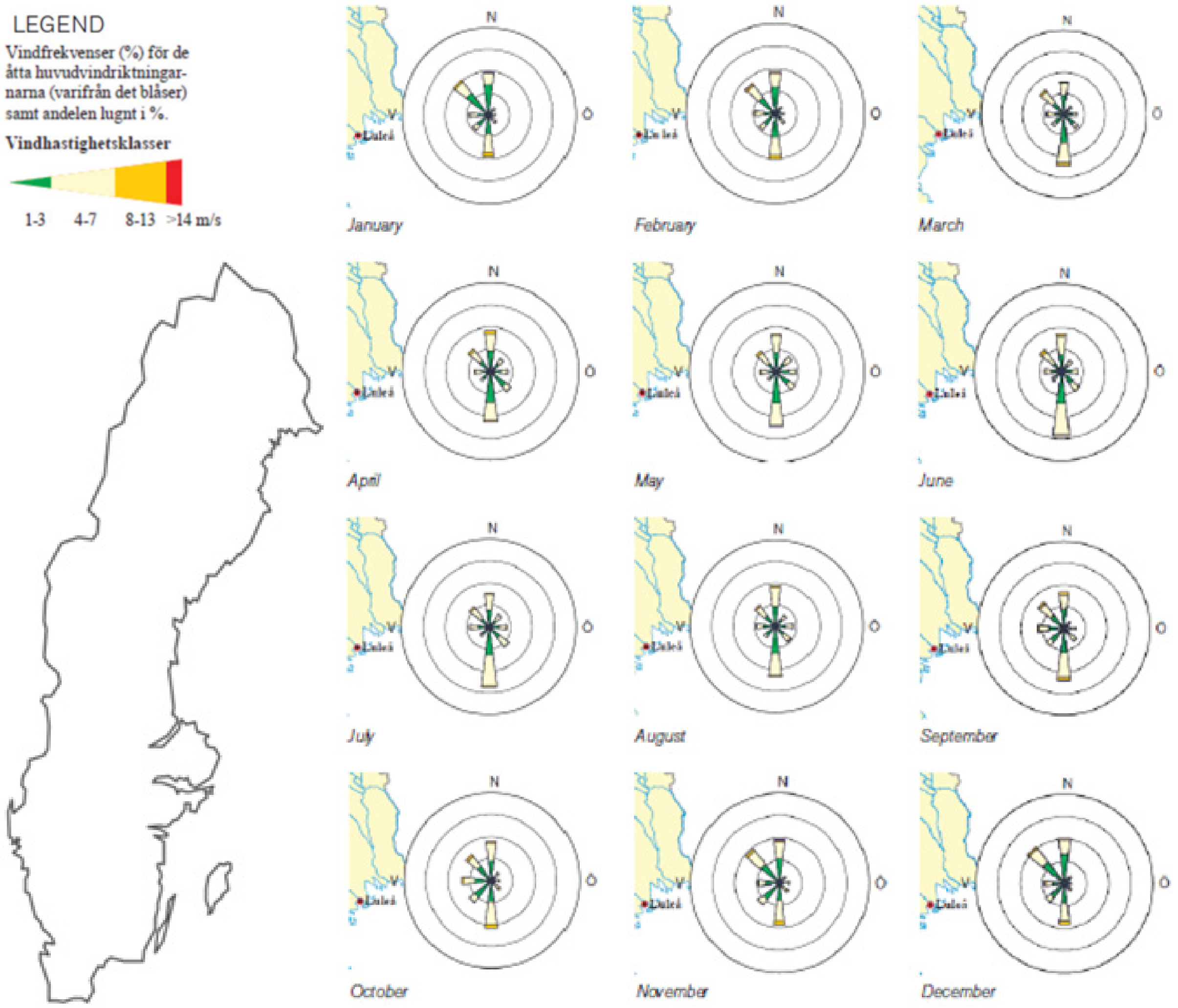

FIGURE 2. Map of Sweden indicating the geographical position of Luleå, wind roses for Luleå showing monthly average directionality of wind frequency (in %), source SMHI (Sveriges meteorologiska och hydrologiska institut).

COMPUTER PROGRAMS

The method uses a combination of advanced CFD (computational fluid dynamics) simulations with the program Autodesk CFD[10] and solar shading analysis using the program SketchUp Shadow tool (Version Pro 2015)[11]. The output of these two programs are then combined using the program Adobe Photoshop, which is a raster graphics editor, in order to produce micro-climatic maps combining wind and solar access information. Thermodynamic aspects such as thermal inertia, long-wave heat radiation and reflectivity of materials are not taken into consideration in this process.

RESULTS

RESULTS FROM THE WIND SIMULATIONS

Results for two of the three simulated cases are presented in this article.

South wind analysis: Figure 3 shows the results for the larger area with a wind simulation from a South direction. For this case, an average wind speed of 3.43 m/s was used as it corresponds to the average wind speed for the months of March, June and September. Figure 3 shows the wind distribution for the entire analysis area, while Figure 4 and 5 present an enlarged view of a cluster of towers planned in the South-West area. Figure 3-4 show that wind speeds are very calm in the East-West passage between the buildings (dashed line in Figure 4, which is in fact the “Rainbow Alley”) while several regions (marked with a red square) can be problematic due to sharp building corners, higher building masses and narrow gaps between buildings (Figure 4 and 5). In general, the campus area appears to be quite well sheltered from Southern winds although the North-South paths do create accelerations as shown by the dashed lines on Figure 4. Coniferous trees can be planted to break up the turbulent winds that appear in these regions.

North wind analysis: Figure 6 shows the wind distribution for a North wind of 3.43 m/s for the entire analysis area, while Figure 7 and 8 show some enlarged views of key areas. Figure 6-7 show that wind speeds are rather calm in the East-West passage (Rainbow Alley) between the buildings while one region in particular (marked with a red square) can be problematic due to higher building masses, sharp building corners and narrow gaps between buildings. The wind paths that were previously marked in Figure 3-4 for the South wind case appear to be less problematic for the North wind case since the existing buildings on the site create a good wind protection along these paths. Instead there are now problematic areas between buildings in the North-West corner as shown in Figure 7-8.

Simplified wind map: In order to better define areas of lee and high wind, the results from the wind simulations were simplified into a three tone wind diagram as shown in Figure 9. Note that these three-tone maps represent wind speed categories of 0-1.67, 1.67-3.33, >3.33 m/s, which roughly correspond to the categories of calm to gentle breeze identified by Boutet[12]. The maximum wind speed in these maps was set to 5 m/s since in general, wind speeds above this threshold can cause wind perceived as uncomfortable. Figure 9 clearly shows that there are some corner effects (light grey) created by a new planned tower on the South-West area and that the North-South passages have a higher wind speed than the East-West street (Rainbow Alley). This observation has consequences for the planning of the site: the tower is moved and the East-West passages are provided with vegetation for higher wind protection.

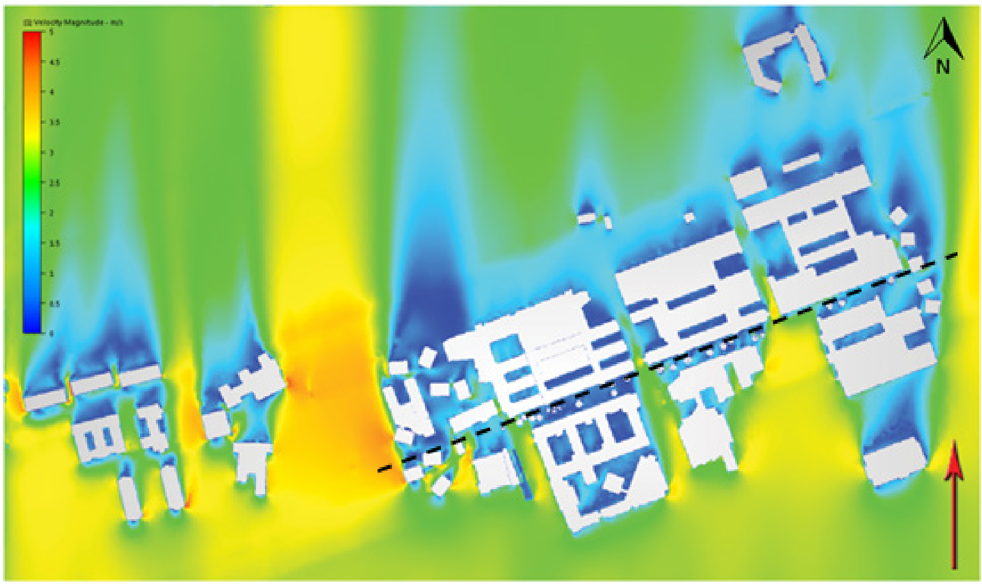

FIGURE 3. Overview for the analysis area with wind blowing from South at 3.43 m/s. Wind speeds are shown on a scale from 0 to 5 m/s. A red arrow shows the direction of the wind.

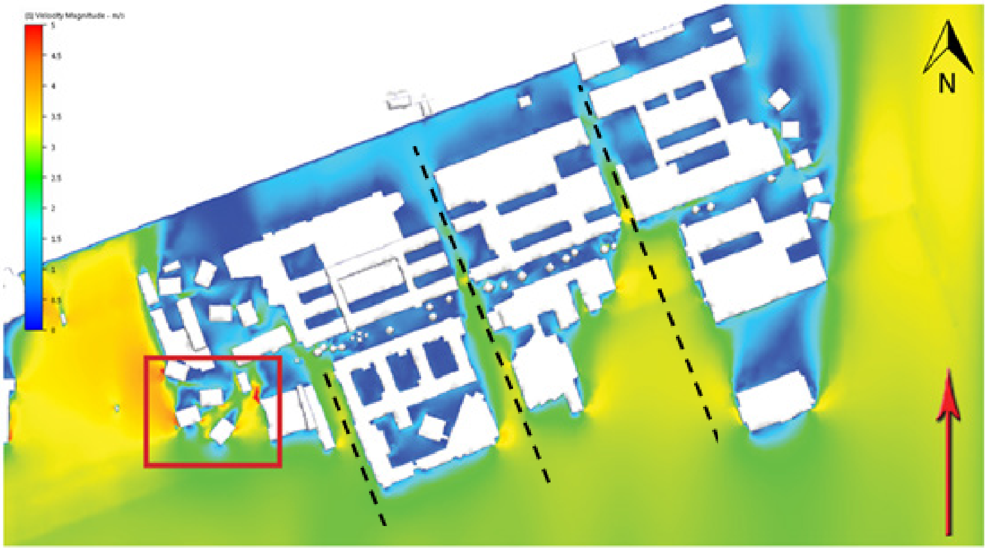

FIGURE 4. Wind speeds 1.5 m above the ground level. A problematic area, marked with a red square, is enlarged in the next figure. The white area in the upper left corner is due to a change in the topography.

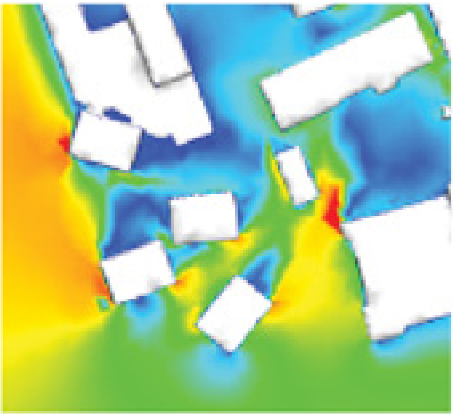

FIGURE 5. Enlarged view of wind effects around the planned towers with turbulent winds around corners and in narrow passages

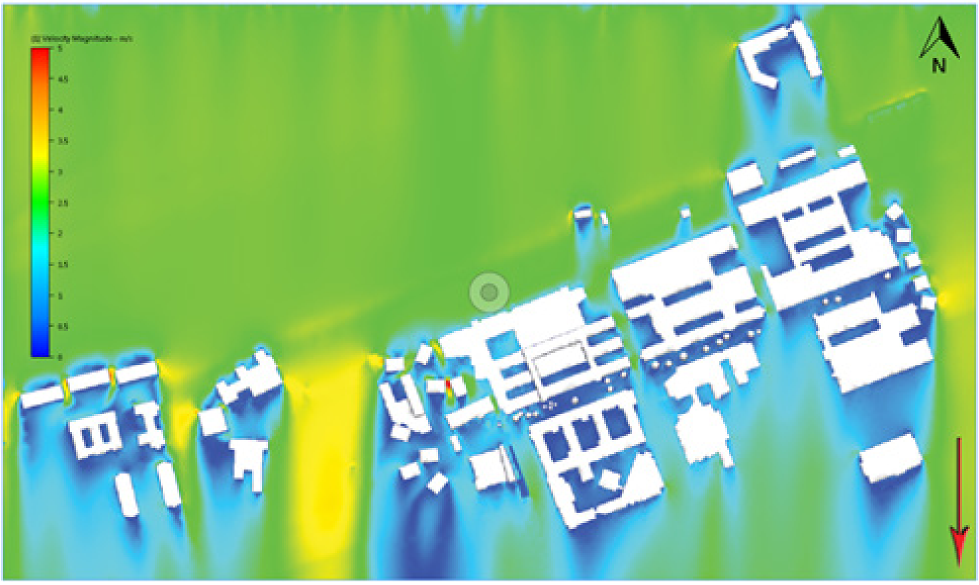

FIGURE 6: Overview for the analysis area with wind blowing from North at 3.43 m/s. Wind speeds are shown on a scale from 0 to 5 m/s. A red arrow shows the direction of the wind.

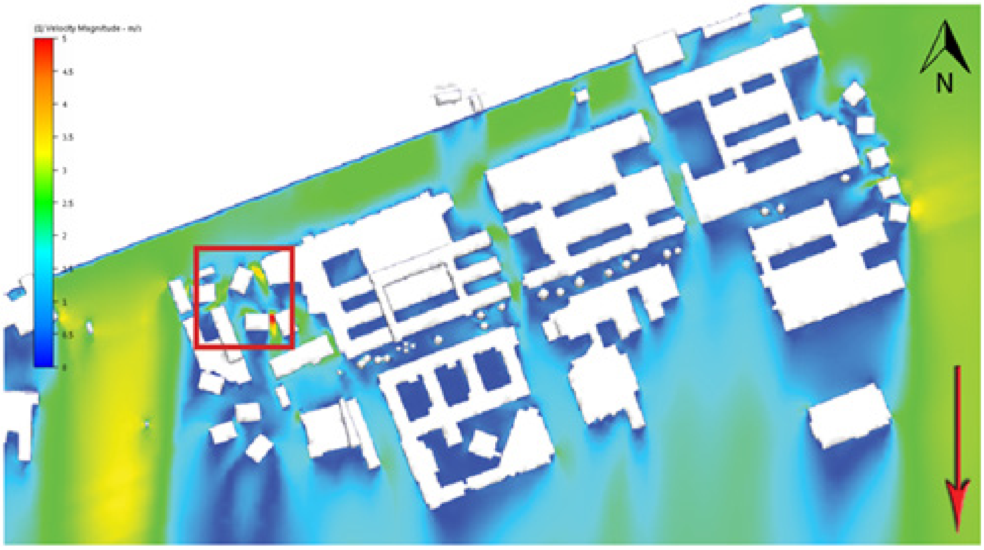

FIGURE 7: Wind speeds 1.5 m above ground. The red square shows a problematic region with high wind speed.

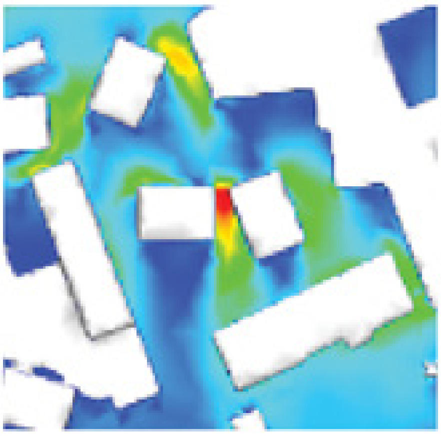

FIGURE 8: Enlarged view of wind effects around the planned towers with turbulent winds around corners and in narrow passages.

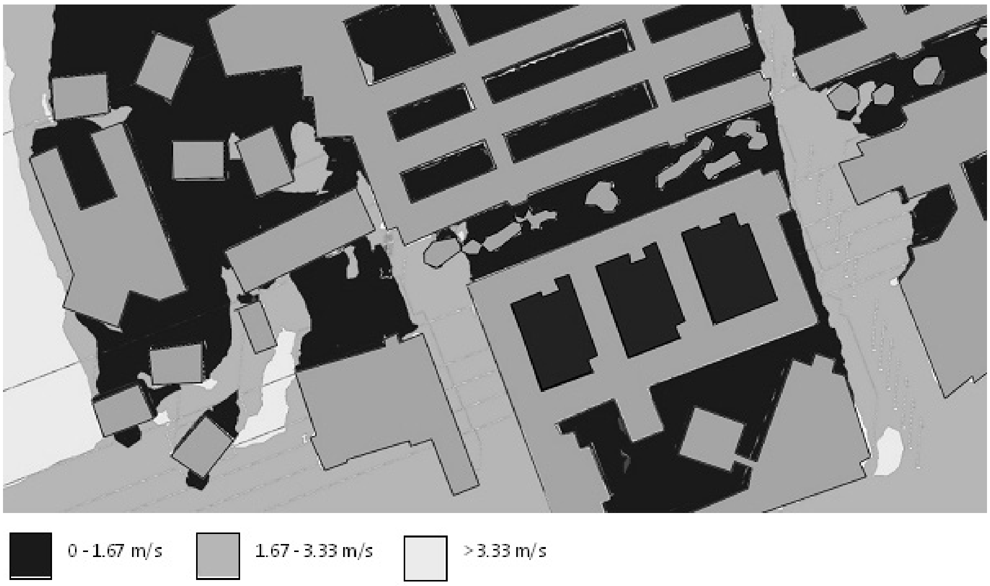

FIGURE 9: Three-tone map wind analysis.

SOLAR ACCESS MAPS

The solar access for the spring and fall equinoxes was studied in particular. The summer solstice was not studied since there are virtually no students on the campus at that time while during the winter solstice, the sun hardly rises above horizon at this high latitude and shadows are extremely long. Figure 10 shows how the campus buildings create shade on the ground at 9:00, 12:00 and 15:00 hours respectively. Note that Figure 10 also shows that the north side of the Rainbow Alley is in the sun at 12:00 and 15:00 hours at the equinoxes, a fact which was exploited by the design team by placing the outdoor walking path in this area.

These images were combined into a single image shown in Figure 11. Figure 11 shows the areas which are 1) exposed to sun, 2) once in shadow, 3) twice in shadow and 4) three times or more in shadow. Note that the white areas 'exposed to sun' are only for the simulated hours i.e. at 09:00, 12:00 and 15:00 hours.

MICROCLIMATIC MAPS

By superposing the simplified wind (Figure 9) and solar access maps (Figure 11), simulation results can be combined into a microclimatic map as shown in Figure 12. In this map, the regions that are exposed to sun and with low wind speed (black in Figure 12) are colored orange. Here wind and sun are weighted equally for simplification although this may not be experienced in this way in reality. On the other extreme, areas that are three times in shadow (black, Figure 11) and wind exposed (light grey, Figure 11) are colored blue in the microclimatic map (Figure 12). All other combinations of conditions are given intermediate color codes.

This colour code simply allows emphasizing the areas where exterior thermal comfort is likely to be extremely good or extremely poor and the ranges in between. In this case, it is possible, for instance to decide that all areas of the microclimatic map that are colored light or dark blue should not contain any key exterior functions or that some measures should be developed to improve thermal comfort in these areas. Figure 12 shows the areas that are most in shadow and generally more windy (#2 blue) while emphasizing the areas that are most suitable for outdoor activities i.e. most in the sun and lee (#6 orange). In general, in this case, this microclimatic map emphasized that a planned tower on the South-West side would create shadow in an area which would have been suitable for outdoor activities (inside the circle). It also showed that some intersection would be suitable for micro plazas (circle on the right side). Finally, it emphasized that the North-South passages between the buildings needed accrued wind protection while the Rainbow Alley itself did provide more acceptable (protected) wind conditions although the shadow produced by existing buildings could not be modified.

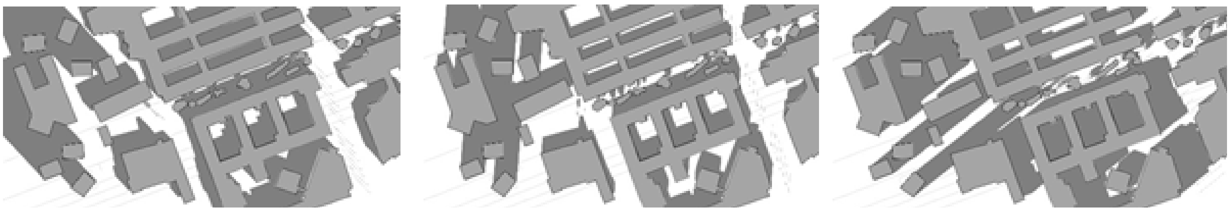

FIGURE 10. a) March 20th, 9:00 hours b) March 20th, 12:00 and c) March 20th, 15:00

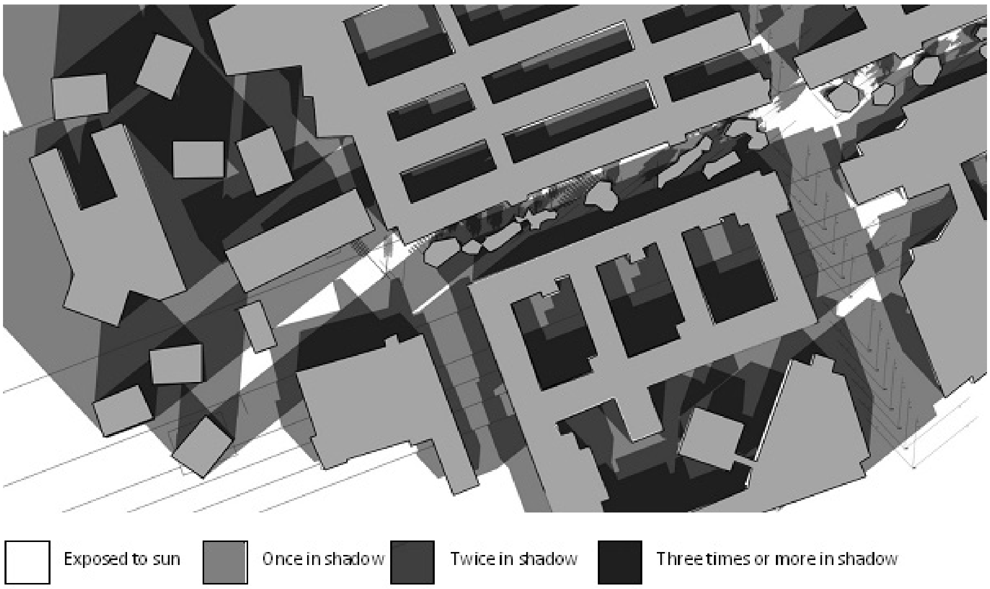

FIGURE 11. Solar access map for March 20th.

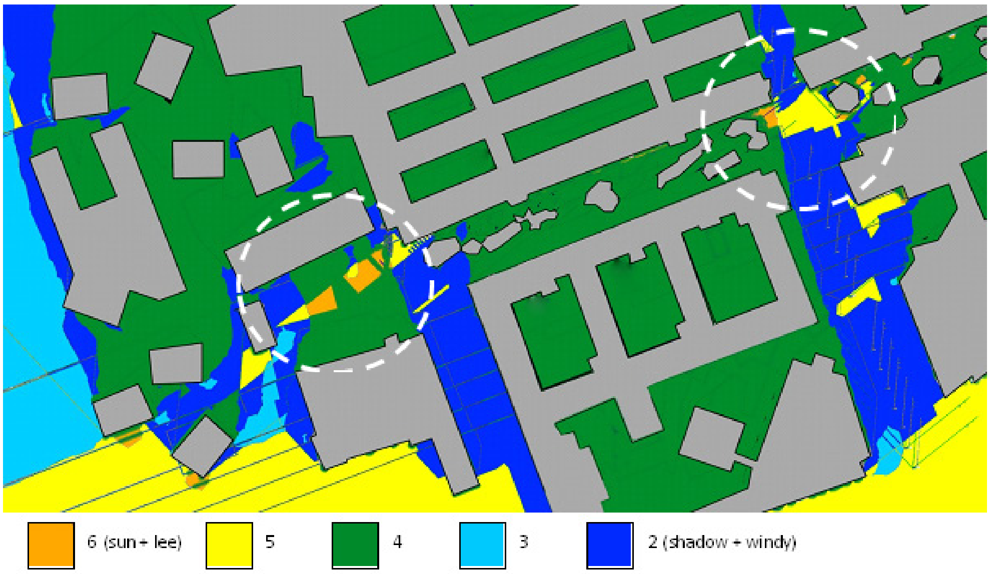

FIGURE 12. Combined micro-climatic map showing areas of sun and lee to areas of shadow and wind.

DISCUSSION AND CONCLUSIONS

This paper shows that the microclimatic maps are useful at the early design stage in order to initiate a discussion on climatic parameters within the urban and landscape design team and draw attention to specific microclimatic phenomena. The simulations also allowed confirming wind effects that architects and planners had anticipated intuitively, as e.g. the protection provided by buildings along the Rainbow Alley or other similar effects.

However, it was found during the process that the wind simulations are too time-consuming to be realistically included in a normal time frame of building practice. In this case, about 45 hours were needed to prepare (parametrize) the model for simulations, run the simulations, analyze and present the results. Wind simulations also require involving a simulation expert in the team due to the complexity of the reliable simulation programs. In addition to the scarcity of available simulation experts in private practice and absence of agreed simulation budget by clients, the time frame for wind simulations is a real barrier in the workflow of urban and landscape design offices, where a fast input to the design is required, normally about 2-3 weeks. On the other hand, the study showed that the solar access analysis is rather straightforward and can be achieved within a few hours, which is a reasonable time frame at the early design stage.

One conclusion of this study is thus that the key for future development in this field and in the area of urban microclimate analysis should emphasize on making the wind simulation tools more readily available and simpler to the users so that results may be obtained more quickly and to a lower cost. Another improvement could be that the solar access tools are directly embedded within the wind tool in order to avoid the last iteration.

Despite the limitations of each computer tool used in this research, the method fails to convey impression of the flow of thermal and experiential sensations that will be experienced in reality. As outlined by Pallasmaa[13], computer imaging tends to flatten our magnificent, multi-sensory, simultaneous and synchronic capacities of imagination by turning the design process into a passive visual manipulation, a retinal journey.An architectural work is not experienced as a series of isolated retinal pictures, but in its fully integrated material, embodied and spiritual essence. Note also that a study of comfort in itself is limiting since climatic diversity is a fundamental criterion alongside comfort.[6]

On a more technical note, it should be emphasized that the combination of solar access and wind effects can only provide a proxy of the thermal comfort experienced on site. As outlined by various comfort models, thermal comfort is also influenced by other parameters such as clothing, activity, but most importantly humidity, air temperature and velocity, solar radiation intensity (not only access), and the temperature of surrounding surfaces, their thermal inertia, etc. A full analysis of a large urban context would entail knowledge of these parameters, which would require information, not to mention expertise and computer power, which are not normally available at the early design stage.

Aside from desirable development in the speed and accuracy of wind simulations, the planned future development of the method within the practice of White Architects include the integration of solar radiation intensity on facades and surfaces, and integration of thermal data (temperature of surfaces) in the simulation process.

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ENDNOTES

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