Microclimatic Performance of Urban Developments
A simplified analysis and representation technique

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ABSTRACT: This paper presents the methodology developed to assess the microclimatic impacts of new high density developments within existing urban fabrics in a Nordic climate. Site microclimates were determined by analyzing the combined availability of sun and wind as proposed by Brown and DeKay. Wind data simulation represented a challenge for this study because of the sheer size of the area under study, the number of development options, and a close deadline. For those reasons, CFD modeling was not an option and the team reverted to a sand particles erosion technique using an hydraulic flume and scale models. This erosion technique is based on the threshold erosion speed of fine sand particles. Individual seasonal results of the sun and wind simulations where transposed into spreadsheet matrices and then added according to a microclimate desirability scale. Those numerical results can be used to compare the relative microclimatic performance of any street or public space according to a particular urban development in the studied areas. Moreover, results were translated into a comprehensive color matrix showing at a glance the global microclimatic performance of the existing and proposed city developments.

Keywords: microclimate, wind, sun, comfort, urban design

INTRODUCTION

Favorable microclimates are an essential condition for the conviviality of the city fostering environmental, social and economic transactions. Recent researches confirm that the microclimatic parameters are of premium importance in relation to outdoor activities that take place on a site, and up to a certain degree, they determine how a particular site can be exploited [1]. Under the severe Canadian climate, a 'sun and lee' combination represents the best microclimate in terms of comfort whereas the 'shade and wind' combination represents the worst microclimate for all seasons except for summer whereas 'shade and wind' may only become desirable for a short period. Urban environments, depending on their density, porosity and rugosity, offer a multitude of thermal transitions that can either be perceived as subliminal or difficult by users of the public realm [2]. When planning for new developments or modifying the geometry of the urban fabric under severe climates, stakeholders should try to improve the existing microclimate or, at least, minimize the negative impacts of the new development. Potvin [3, 4] speculated on the perceived equivalent temperature differentials when moving from a set of thermal conditions to another using Penwarden's equation for outdoor thermal comfort [5]. Table 1 illustrates such transitions from A to B according to sets of sun and wind conditions (0, 1 or 2 values). Moving from A, a wind protected and sunny area (02) to B, a wind exposed and shaded area could therefore lead to a -13^{0}C equivalent thermal differential sensation.

Table 1 : Equivalent temperature differentials when moving from A to B as a function of sun and wind sets of conditions.

		B								
		(00)	(01)	(02)	(10)	(11)	(12)	(20)	(21)	(22)
	(00)	*0,0*	*2,5*	*7,5*	*-4,5*	*-3,5*	*-1,5*	*-5,5*	*-5,0*	*-3,0*
	(01)			*5,0*	*-7,0*	*-6,0*	*-4,0*	*-8,0*	*-7,5*	*-5,5*
	(02)				*-12,0*	*-11,0*	*-9,0*	*-13,0*	*-12,5*	*-10,5*
A	(10)					*1,0*	*3,0*	*-1,0*	*-0,5*	*1,5*
	(11)						*2,0*	*-2,0*	*-1,5*	*0,5*
	(12)							*-4,0*	*-3,5*	*-1,5*
	(20)								*0,5*	*2,5*
	(21)									*-3,0*
	(22)									*0,0*

Low density and uniform urban fabrics tend to minimize abrupt thermal differentials whereas high density and non-uniform fabrics tend to increase thermal differentials by the greater occurrence of high wind speed, turbulence and reduced sun exposure. This paper present the methodology developed to analyze the microclimatic impact of new urban development proposals in the rapidly developing west front of Quebec City. Figure 1 shows the extent of the 72000m^2 urban block where a series of dispersed two to three story high commercial buildings are to be replaced by ten to twenty-one story high administrative and high-density residential pavilion types of buildings within the next five years (fig. 2). Although this quarter has been developed according to the North-American car dependent culture, the City would prefer to reverse that trend and encourage pedestrian, cycle and public transport strategies on all four major streets. Public transport hubs and landscaped sidewalks are planned on the Laurier Boulevard and Route de l'Église bordering respectively the South-East and the South-West sides of the development area.

Figure 1: Urban Development Area.

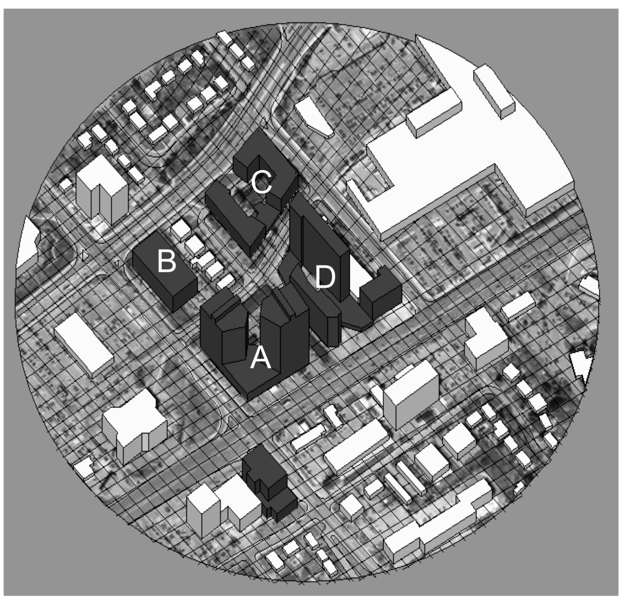
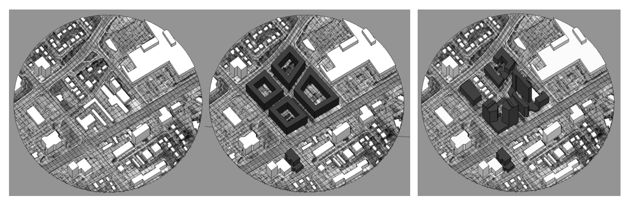


Figure 2: Proposed Development (A-17+23 stories, B-8 stories, C-10 stories, D-13-20 stories)

From literature review and previous wind simulation studies conducted by the authors [6, 7], the following hypothesis can be suggested:

- Blocks B and C should not pose any serious microclimate anomalies since their height is relatively low; the courtyard configuration of Block C should even create a positive wind reduction within the block;
- The twin towers of Block A are likely to generate a major Venturi (funnelling) effect in their gap under both dominant winds from WSW and ENE; and
- The thin and elongated shape of Block D in the SE-NW axis is perpendicular to the dominant WSW and ENE winds. Under a WSW wind, the lower building on the SW side of the tower should generate an important Wise (downwash) effect.

The comparative results are generated from the analysis of three different configurations: the Existing proposal (a), the Courtyard type (b) of development and the Proposed (c) development from a private developer (fig. 3). The Courtyard configuration was added by the research team for its potential in optimizing urban comfort on the site. It represents the maximum possible built density respecting the actual ten story high municipal regulation. Such zero alignment configurations should also promote controlled microclimates within the urban blocks and provide optimal passive strategies such as daylighting, passive heating and passive cooling. The renting floor surface of the courtyard configuration was calculated to be some 28% higher than the proposed highly variable proposals in terms of heights and footprints.



a) Existing b) Courtyard c) Proposed

Figure 3: The three comparative configurations.

METHODOLOGY

Site microclimates most favorable for outdoor comfort were determined by analyzing the combined availability of sun and wind as proposed by Brown and DeKay [8]. Table 2 shows the values of the different combinations of microclimatic conditions according to their desirability by season. Sun and Lee conditions are to be optimized whereas Shade and Wind are seldom required even in the summer.

Table 2: Values of microclimatic conditions for outdoor spaces under a cold climate (Brown & DeKay, 2001, p. 23)

	Winter	Equinoxes	Summer
Sun + Wind	4	4	4
Sun + Lee	5	5	5
Shade + Wind	1	1	1
Shade + Lee	2	2	2

The shadow patterns for the three configurations shown in figure 3 are generated for solstices and equinoxes at three standard time periods of outdoor use: 8:30, 12:00 and 15:30, with the Sketch-up software. Figure 4 presents the shading patterns of the Proposed configuration (fig. 3c) showing important shading of the public spaces at the winter solstice and the equinoxes.

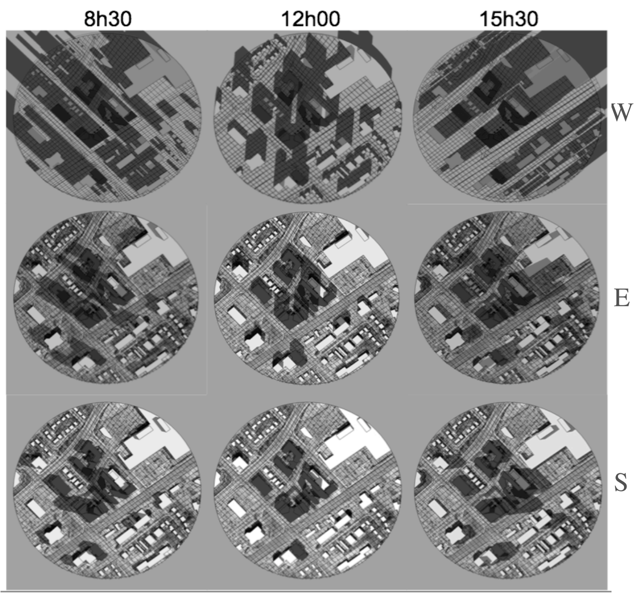


Figure 4: Seasonal solar shading simulations for the Proposed urban development.

Wind data simulation represented a particular challenge for this research because of the sheer size of the area under study, the number of development options and the urge for results. For those reasons, time consuming CFD modeling was ruled out and the team reverted to a sand particles erosion technique using an hydraulic flume and scale models. This erosion technique developed by Potvin [9] is based on the threshold erosion speed of fine sand particles in a water flow. Even today, with the current limitation of CFDs in modeling, the complex wake effect behind obstacles, this experimental technique shows several advantages such as ease of observation of the aerodynamic phenomenon since the flow speed is reduced by a factor 5 compared to real wind speeds and the graphical results of erosion patterns that can be digitally analyzed. This experiment used a fine silica particle that has a 5 m/s (18 km/h) erosion threshold speed corresponding to the Quebec City area annual mean wind speed. The erosion of the particles therefore signals wind speed superior to 18 km/h whereas the accumulation of particles signals wind speed inferior to the site mean wind speed. Figure 5 illustrates the experimental setting in plan and section. An acrylic scale model at 1:1500 is mounted on a rotating disk allowing the simulation of different wind directions. The studied area of the model cannot exceed one third of the section width and half of the water height in order to avoid the turbulence effect of the working section sidewalls and the agitated water surface. A small scale-model also represents more clearly the wind conditions at human scale. Flow speed is regulated using the tailgate *(déversoir)* and the water debit. The vertical wind gradients are calibrated upstream to represent a suburban wind regime $U/U_g=(Z/Z_g)^{0,238}$ [9] and the average mean wind speed of the two prevailing seasonal wind directions WSW and ENE (fig. 5).

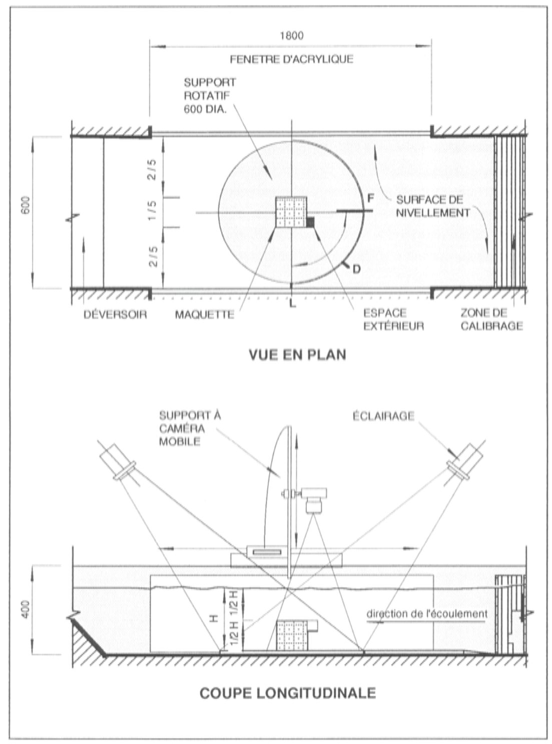


Figure 5: Plan and cross view of the experimental section of the hydraulic water flume.

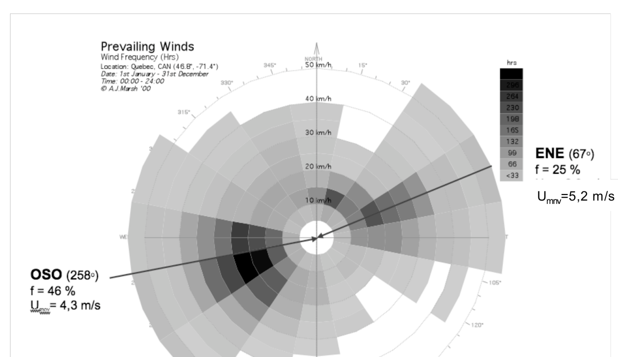
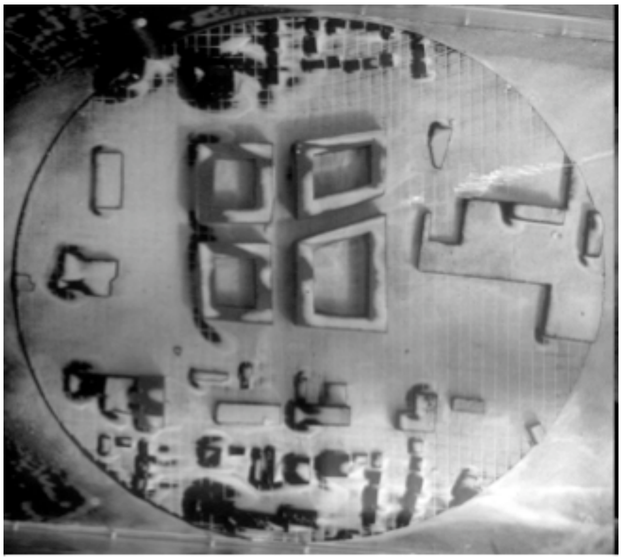


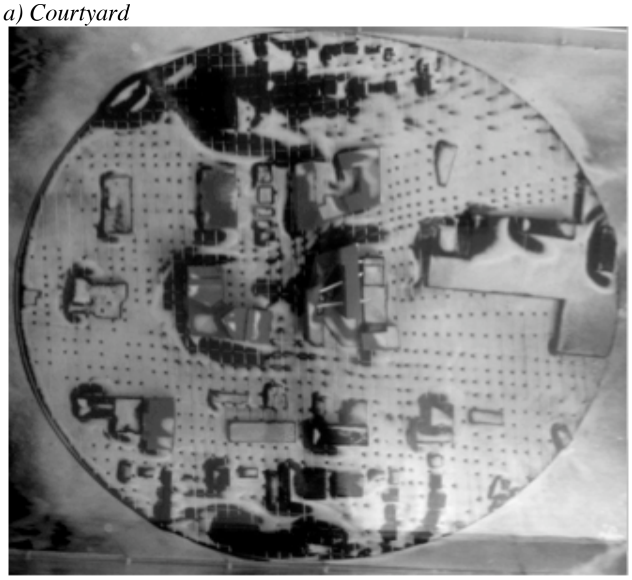
Figure 6: Annual wind directions and frequencies for Quebec City (from CWEC climate files on ECOtectv5.2).

Figure 7 presents the erosion patterns around the Courtyard and Proposed configurations under a WSW wind. Major erosion patterns produced by strong funneling and downwash effects can be seen in an around

Blocks A and D of the Proposed configuration (fig. 7b) compared with relatively little erosion around Blocks B and C. The advantageous wind reduction of the courtyard is fully demonstrated both in a) Courtyard and b) Proposed configurations erosion patterns.



a) Courtyard



b) Proposed

Figure 7: Wind Erosion Patterns under WSW wind for the Courtyard and Proposed configurations.

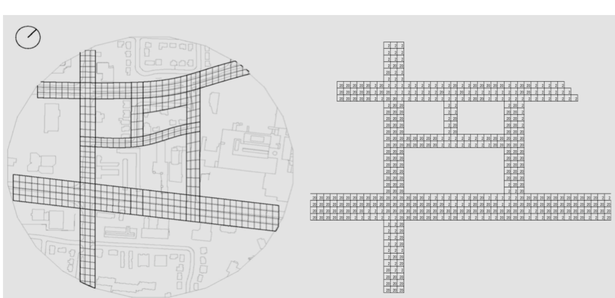


Figure 8: Actual street layout converted into an EXCEL matrix.

A grid cell system was devised for the numerical analysis of the resulting shadow and wind patterns. Figure 8 illustrates the actual street layout grid of public outdoor spaces and the converted orthogonal grid cell into an EXCEL matrix. The sponsor of the study required that only public spaces (streets and sidewalks) be considered in the report. Streets where therefore divided into 3 cells wide patterns representing a sidewalk-centre-sidewalk layout apart from the Boulevard Laurier, which was divided into a 4 cells wide pattern to represent its importance as a major thoroughfare. Seasonal daily shadows and wind patterns were transposed into separate grid cell matrices in numerical numbers and rendered in two-tone grey scale whereas black is a negative force and light grey is a positive force (fig. 9). The addition of these matrices produces sums that are then translated in values of microclimatic conditions identified in Table 2. By applying four grey scales values from white (best combination) to black (worst combination) the resulting grid cell becomes a powerful and expressive image of the seasonal microclimatic performance of a given space.

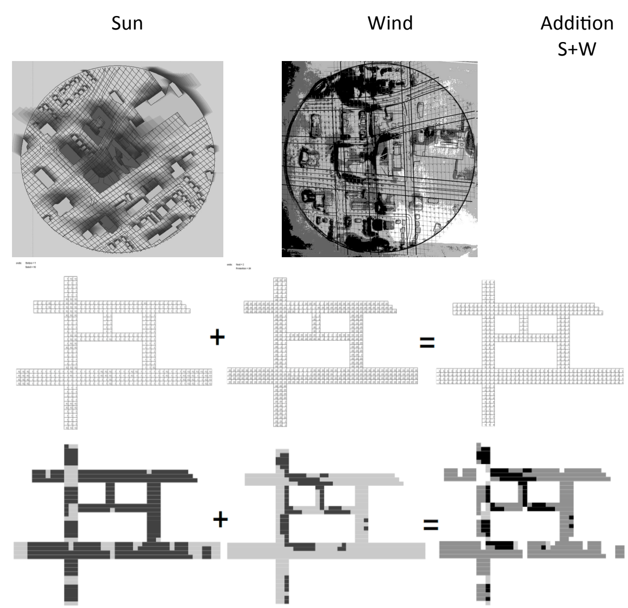
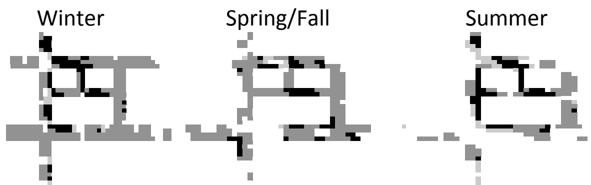
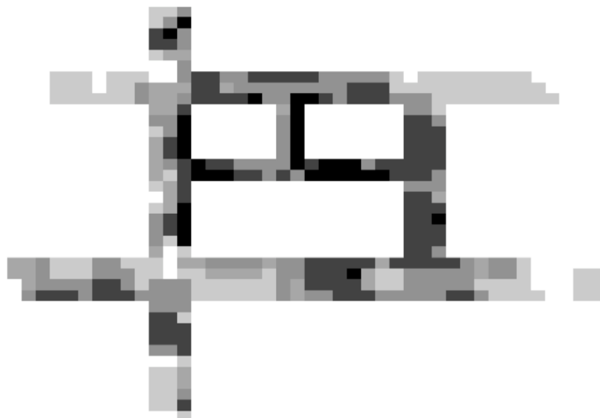


Figure 9: Seasonal combination of sun and wind patterns into numerical and gray scale seasonal matrix (Winter matrix shown for the Proposed configuration).

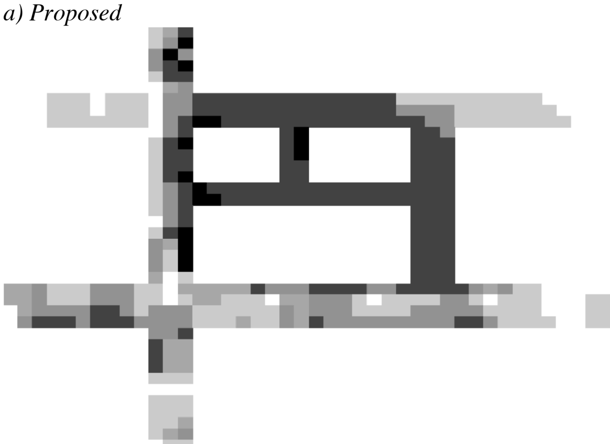
RESULTS

The seasonal combination values are added to generate the graphical annual microclimate rating. In this particular case, seasonal values were given the same importance but the results could be pondered to express a particular seasonal use of the outdoor space. Figure 10 shows the 6-tone grey scale rendering of the annual microclimatic performance of the three configurations under study. A 14 dynamic color scale rendering has also been developed for a more refined interpretation of urban comfort.

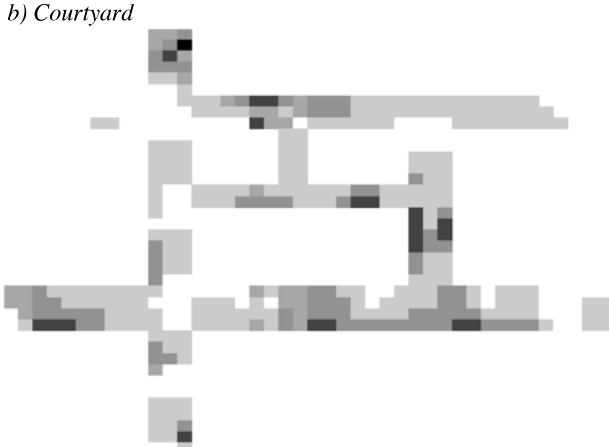




a) Proposed



b) Courtyard



c) Existing

Figure 10: Annual Microclimate Matrices showing the most favourable (White-Sun+Lee) to the most unfavorable (Black-Shade+Wind) zones of the public areas around the Proposed configuration.

Table 3 and figure 11 present the microclimatic performance of the three urban forms by street and mean values. The average score for the Existing form is 80% comfortable compared to 47% for the Courtyard and 48% for the Proposed development. The almost identical 40% reductions of comfortable microclimates in the Courtyard and Proposed forms were not expected but figure 10 may help explain these results by showing the distribution of the microclimatic conditions in space. The Courtyard appears to have a relatively well-distributed combination of mostly wind and shaded areas (dark-grey cells) on Hochelaga, Germains-des-Prés, Soulanges et Bois-Gomin whereas the Proposed configuration appears to suffer from punctual highly uncomfortable wind exposed and shaded areas (black cells) on almost every streets. The negative results on the NE, NW, and central streets for the Courtyard configuration are mainly due to their important and continuous shading masks from the 10 story high blocks. These results suggest that sun and wind could have been pondered, giving more importance to wind, to represent at best the importance of wind protection under a severe cold climate. A street by street analysis shows that microclimates improved with a Courtyard configuration on Bois-Gomin, de l'Église and Boulevard Laurier, the most important circulation routes whereas they deteriorated on Hochelaga, Soulanges and Germains-des-Prés. It is also particulary important to note the relative uniformity and presence of several white cells on Boulevard Laurier for the Courtyard configuration. Such results suggest a high potential for sedentary activities such as cafés or outdoor bus stations.

The limited difference of performance between the Courtyard and the Proposed configurations is mainly due to the restriction in the studied areas. As stated earlier, the aim of this sponsored research was to study the microclimates of the public spaces around a Proposed development. The private areas within each of the blocks were left blank and unanalyzed. A look back at figure 7 suggests that results could have been much more differentiated in favor of the Courtyard type since this configuration clearly generates good microclimates inside the central courtyards by wind protection and improve sun penetration right to the ground floor.

Table 3: Percentage of microclimatic performance by street for the Existing, Courtyard and Proposed urban form.

	Urban Configuration		
Street	**Existing**	**Courtyard**	**Proposed**
	%	%	%
Hochelaga	78,2	43,4	51,5
Soulanges	85,0	35,5	41,5
Bois-Gomin	74,5	37,8	34,5
de l'Église	87,1	58,2	56,0
Germain-des-Prés	75,7	38,6	44,0
Boul. Laurier	76,3	67,8	61,5
Mean	79,5	46,9	48,2

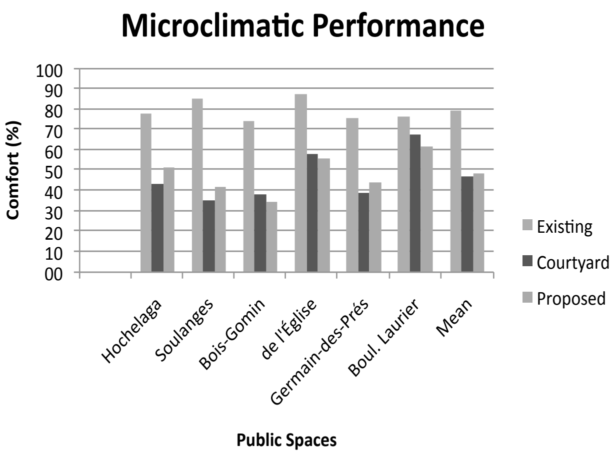


Figure 11: Microclimatic performance by street for the three urban configurations.

CONCLUSION

The objective of this paper was to present a simplified analysis and representation technique for the assessment of the microclimatic performance of urban built environments. The technique is based upon the microclimate analysis method devised by Brown and DeKay [8] where sun and wind patterns are gradually added to generate microclimatic grid cells that are then analyzed according to microclimate values defined by sun and wind desirability. This paper proposed a numerical translation of the Brown and DeKay method using simple EXCEL matrices and an improvement of the wind pattern analysis by using an original sand erosion technique. This erosion technique provides a much more detailed and rapid analysis of the wind phenomenon at the scale of an entire city block. The representation of the resulting microclimates in grey scale and dynamic false color rendering offers a powerful yet simple medium for communication between the different stakeholders of a complex urban development.

The technique was demonstrated through a case study of a proposed urban development in Quebec City. A comparative microclimatic study of the Existing environment, a Courtyard hypothetical configuration and the Proposed development configuration showed the ability of the technique to represent complex microclimatic phenomena according to urban morphology. The uniform ten story high Courtyard configuration has been found to produce the most comfortable microclimates on heavily used streets but not on the overall public space. The consideration of the private courtyards microclimate within each block in the final analysis would have undoubtedly favored the Courtyard configuration over the Proposed projects. The limited difference of performance between the studied configurations also suggests that sun and wind desirability could have been pondered with more accuracy at the onset of the research to highlight the importance of the windchill factor and dynamic comfort on the provision of outdoor comfort in Nordic urban environments.

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REFERENCES

1. Nikolopoulou, M. (2004). Outdoor Comfort, in Environmental Diversity in Architecture. Spon Press, Great Britain: p. 101-119.
2. Ouameur, F., Potvin, A. (2007). Urban Microclimates and Thermal Comfort in Outdoor Pedestrian Spaces. In Proceedings of ASES Solar 2007. Cleveland, 7-13 July 2007.
3. Potvin, A. (1997). Movement in the Architecture of the City - A Study in Environmental Diversity. PhD Thesis. Cambridge University, Cambridge, 178 p.
4. Potvin, A. (2000). Assessing the Microclimate of Urban Transitional Spaces. In Proceedings of PLEA2000 (Passive Low Energy Architecture). Cambridge, July 2000.
5. Penwarden, A.D. (1973). Acceptable Wind Speeds in Towns, in Building Sciences, Vol. 8: p. 259-267.
6. Potvin, A (2001). Études climatiques–CME-Sainte-Foy. For Bélanger, Beauchemin architectes, June 2001, 74 p.
7. Potvin, A (1998). Optimisation microclimatique de la banlieue nordique en fonction du vent, SCHL (Société canadienne d'hypothèque et de logement). Centre canadien de documentation sur l'habitation, 174 p.
8. Brown, G.Z., Dekay, M. (2001). Sun, Wind and Light : Architectural Design Strategies. John Wiley and Sons Inc, New York.
9. Sanni, R.A., Surry, D., Davenport, A.G. (1992). Wind Loading on Intermediate Height Buildings in the Revue canadienne de genie civil. NRC-CNRC, Vol.19, no.1, February 1992: p.148-163.
10. Potvin, A. (1995). 'Wind in Architecture: An Erosion Technique to Assess Wind Behaviour About Buildings'. In Proceedings of the International Conference for Teachers of Architecture. Florence, Italy, 28-30 sept. 1995.