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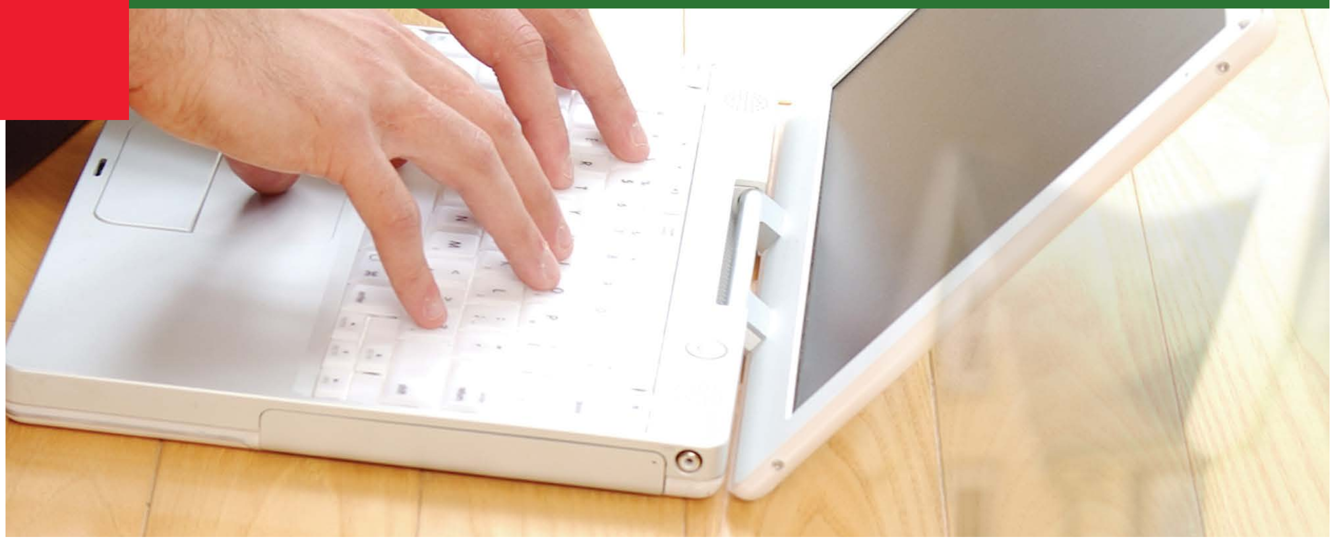

Design Guide for Urban Heat Island Mitigation Measures

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Design Guide for Urban Heat Island Mitigation Measures
(Summary Report)

ERP Contract No.: 6585-B208

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December 2011

This project was funded by Canada Mortgage and Housing Corporation (CMHC) under the terms of the External Research Program, but the views expressed are the personal views of the authors and do not represent the official views of CMHC.

Table of Contents

List of Tables

List of Figures

Executive summary

This guide, which is intended for municipal stakeholders, sets out the broad parameters and identifies the major steps needed to reduce the impact of heat islands.

The phenomenon of heat islands has been common knowledge for quite some time, and its impact on health no longer needs to be demonstrated. A heat island is defined as an urbanized area where summer temperatures can be 5 to 10°C warmer than the immediate environment. People most affected are often in financial need, socially isolated and elderly. This phenomenon is felt more acutely when combined with increased pollution, thus favoring the appearance of periods of smog. That is why Montréal and Toronto are studying this problem that is only getting worse in our major cities.

All of the urban planning instruments for Montréal and Toronto were reviewed to identify normative elements (layout diagrams, land-use plans, regulations, programs, incentives, etc.) that could relate either closely or remotely to measures to reduce heat islands on their respective territories. The elements were classified into three major planning categories: indicative, incentive and normative.

For Montréal, the metropolitan planning documents revealed that no one element is directly linked to heat islands across the island, but several are indirectly. This generally involves policies and programs focused on sustainable development, environmental development or simply more intensive greening of all types. There is mention of heat islands in the City of Montréal's land-use plan, and some courses of action are proposed. Looking at Montréal as a whole, bylaws differ from one borough to the next, and some standards repeat themselves, but some pertain specifically to boroughs such as in the case of the greening of parking spaces for industrial use or specific requirements for roofs. However, greening is often chosen for esthetic rather than ecological reasons.

Interventions are more targeted in Toronto. The City of Toronto land-use plan mentions the reduction of heat islands in two places. First, this is included in the section on avenue development (redevelopment of major arteries). Second, in the section on the natural environment, the plan states that the City supports and encourages innovative ways of producing energy, green industries and green design. Toronto is the first city in North America to have

implemented green roof bylaws for new developments, whether residential, commercial, institutional or industrial.

The Toronto Green Standard (TGS) is a strategy proposed by the *Climate Change – Change Is in the Air* action plan that supersedes, to some extent, LEED across Toronto. This action plan proposes performance measurements and directions concerning sustainable construction and sites. Various programs such as the Live Green Toronto Program, Eco-Roofs Program, Trees Across Toronto Program and the Greening City Operation are also in place.

This guide also provides various mitigation measures that are divided into six sections:

1. **The reduction of parking spaces**, which is still essential, given the area they take up and their impact on neighbouring residential areas (the Halo Effect).
2. C**hanges to roofs and facades** representing an affordable solution that is gradually being adopted city-wide.
3. **Architectural considerations and urban geometry** that have a major impact on the microclimate and are aimed more at new projects.
4. **Increased permeability, catchment of surface waters and water bodies** as a solution that must be brought in gradually for both rehabilitative and new projects.
5. Increased green spaces as an option that is all too often set aside when projects come up for which the economic impact is deemed to be a priority.
6. Use of certain materials with better physical properties.

The information gathered shows that technology and know-how exist, but some development practices are applied quite often without the entire impact having been measured. The financial issue, we believe, is not a major impediment; very often, the cost would be the same if mitigating measures were built in from the start of the projects. One positive development is that more and more municipal stakeholders are aware of the issues, and development practices are gradually changing.

1. Introduction

Under CMHC's External Research Program, it was decided to produce two versions of the *Design Guide for Urban Heat Island Mitigation Measures*.

- **Version 1**: The shorter version entitled the *Summary Report* is intended for municipal stakeholders and discusses the causes of heat islands and certain solutions. It summarizes some urban planning instruments that are aimed at reducing the presence of heat islands.
- **Version 2**: This one entitled *Complete Report* (≈400 pages) examines in detail the fundamental parameters associated with heat island, abundantly illustrated heat portraits from Montréal and Toronto and provides a description and analysis of their urban planning instruments. Mitigation and development measures are proposed, and several references are also provided.

2. What is a heat island?

The literature describes three main types of heat islands, namely:

1- Boundary layer urban heat islands (atmospheric layer);

2- canopy layer urban heat island at the top of trees and/or buildings. This is where people live, i.e., between the surface and the treetops/building tops.

3- surface urban heat islands **which we will be looking at in this guide**.

What is a heat island?

Heat islands are defined as urbanized areas which, in the summer, reach temperatures 5 to 10°C warmer than the immediate environment, according to the authors (figure 1).

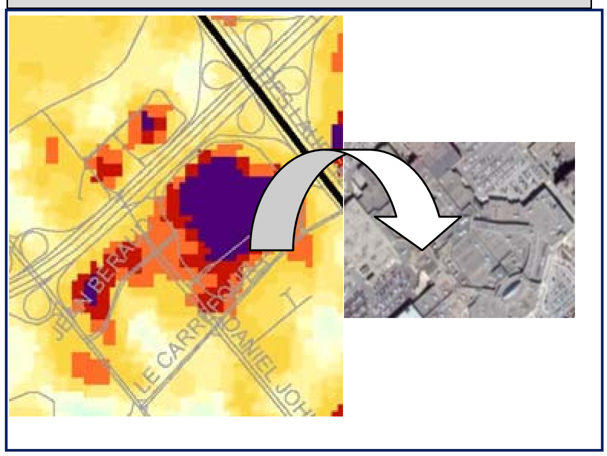

Figure 1: Example of a heat island (purple) located in the Carrefour Laval shopping centre in Laval.

Some fundamental notions and parameters associated with heat islands are described in table 1: albedo, emissivity, SRI (solar reflectance index), urban canyons, SVF (sky view factor) and permeability.

3. The causes of heat islands

Heat islands are a long-standing and known phenomenon, as they are closely related to urban development. With the advent of industrialization in the late 18th century and particularly in the 19th century, the territory was radically transformed by development practices.

The main causes:

- *More built spaces*
- *Reduced green spaces*
- *Environmental densification*
- *More impermeable surface areas*
- *Inappropriate use of some materials (albedo, emissivity, SRI)*
- *Wear and poor maintenance of materials (especially roofs)*
- *Reduced air circulation*
- *Changes to the height/width ratio of buildings*
- *Building orientation*
- *Use of some motors (automobiles, air conditioners, etc.)*
- *Choice of inappropriate sites (basins-topography-, lack of waterways and, of course, the surrounding climate.*

When there is **mineralization**, that is, when a natural environment is transformed, it is noted that the temperature rises.

When **vegetation** is present, that is, when the biomass increases, the temperature drops.

Moreover, technological advances have resulted in the creation of new materials. For example, it has been shown that synthetic turf increases the presence of heat islands (figure 2). Though they appear harmless, these materials cause thermal degradation of more than 5°C. Unfortunately, municipal stakeholders and representatives of institutions underestimate the thermal impact of these synthetic surfaces.

Figure 2: One example of a synthetic turf field being installed at the foot of Mount-Royal (Vincent d'Indy water reservoir; September 19, 2011).

Table 1: Summary of the various parameters and fundamental notions associated with heat islands.

Parameter	Definition	Examples
Albedo	Albedo is the relationship between reflected solar energy based on incident solar energy. Its value varies from 0 (black) to 1 (white). It is affected by several factors such as texture, humidity and age (level of material wear)	Water = 0 New asphalt = 0.04 <u>Tar paper</u> = 0.05 Asphalt (5 years) = 0.12 <u>Elastomer</u> = 0.8 Snow = 1
Emissivity	Emissivity quantifies the capacity of a body to absorb and re-emit the heat releasing it. Its value varies between 0 (low capacity) and 1 (high capacity) or it can be expressed as a percentage.	Unpainted aluminum = 0.04 <u>Elastomer</u> = 0.4 <u>Tar paper</u> = 0.93 New Portland cement = 0.9
Solar reflectance index (SRI)	SRI is derived from the combination of emissivity and albedo. It is being increasingly used by the construction industry (materials) Its value theoretically varies from 0 (low) to 100 (high) It was developed to guide choices. ASTM standard E-1980-01[1] shows how it is calculated.	<u>Tar paper</u> = 2.2% <u>Elastomer</u> = 83.1% Note that even though tar paper scores well on emissivity, its low albedo directly affects its SRI.
Urban canyon	Urban canyons are based on urban geometry and microclimates where, on a reduced scale, the density of the built space is taken into consideration along with the height and width of buildings	See the sky view factor.
Sky view factor (SVF)	The sky view factor, also called the angle of opening to the sky, represents the level of obstruction of a site. Various methods of calculation are used, but essentially the height (H) of buildings and their width (W) are taken into account. Its value is positive and varies from 0 (very open) to more than twice the H and W ratio (presence of a canyon)	When the height/width ratio is <0.25, it will be considered open. An H/W ratio = 0.5 or H/W = 1 will be dihedral, less open; and a ratio of H>2W will be considered a canyon, not very open[2].
Permeability	Permeability is the soil's capacity to allow a liquid to penetrate it. High permeability will be conducive to vegetation and will lower the incidence of surface runoff.	Residential area (low density) ≈ 70% Densely constructed area = 20%

Conversely, some cities that are have plentiful green spaces and irrigated lands and located in dry areas can sometimes have negative heat islands, that is, "cool islands", when compared with nearby territories. In the same vein, some authors point out that the development practices in several cities in the United Kingdom aimed at altering energy management in urban settings to bring about climate change there, must be carefully evaluated, if it is meant to influence health effects. Though bringing down urban temperatures in the summer stands a good chance of reducing the mortality rate due to extreme heat, one must bear in mind that in some countries, particularly the United Kingdom, the mortality rate attributable to extreme cold is far higher than that caused by intense summer heat. As a result, any major intervention relating to the built area of a city must be given careful consideration.

Dense urban areas are naturally inclined to generate major changes in temperature, infra-urban ventilation, humidity, energy balance, precipitation, etc. The focus of studies is on the urban canopy, in particular, when urban heat islands are analyzed, which often limits the understanding of more complex dynamics of ventilation and movement of hot or cold air masses in the gaps of urban forms (ventilation corridors between large buildings, urban canyons, etc.).

Several fluid dynamics studies have been conducted to gain a good understanding of the thermal effects of the built stock and the combined effects of circulating air masses at street level (pedestrian comfort), which sometimes makes it possible to determine the optimal dispositions of buildings with respect to the others. The variable geometry of urban morphology, materials used in facades and the location of condensers used by air conditioning systems have been the subject of several simulations. (CFD: *Computational Fluid Dynamics*). Some have shown that temperature in the middle of a narrow canyon of buildings with facades possessing a low albedo could increase by 2.5^{o}C.

As well, strategically locating some buildings in a space increases air velocity and movements, generating slight temperature declines (35-per-cent increase in velocity and a decline of 0.7^{o}C).

Heat islands are no stranger to major regions such as Montréal and Toronto.

Considering the increased mineralization of their urbanized areas, devegetation and development practices, what we end up with are territories that have been thermally degraded, and their suburbs are also affected. What is more, some studies in Toronto tend to show that there is a relationship between air pollution, heat wave periods and mortality.

It is important that we quickly take a different approach because it costs far less to take preventive measures than to react to the errors that have been committed. Materials with higher albedo and emissivity, the preservation of and increases in the number of green spaces (roofs and facades), which contribute to evaporation, more permeable surfaces, adapted morphology and architecture and bona fide regulations to this effect would help reduce the risk associated with heat waves in an urban environment.

4. Urban functions and the presence of heat islands

A strong correlation between urban functions and surface temperatures ($r \approx 0.68$) has been extensively demonstrated in the literature. Depending on the materials and how they are combined, major temperature variations have been noted.

If we look at average surface temperatures in areas where 16 urban functions are performed (figure 3), we can see that highly mineralized areas show the highest temperatures.

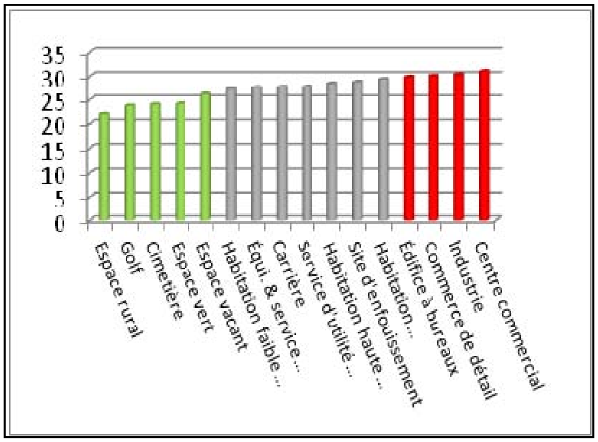

Figure 3: Average surface temperatures (^{o}C) of 16 urban functions in Montréal on July 14, 2011 (Source: Image Landsat 5, original data, A. Berthé).

Highly mineralized functions such as shopping centres and industries (the right side of the histogram, figure 3) show temperatures that are at least 8^{o}C warmer than functions such as *rural spaces*, *golf and green space* (the left side of the histogram).

Moreover, the effect of heat islands is not limited to the physical frontiers of the function (figure 4). A heat island can affect a neighbourhood more than 100 m away. For example, the average temperature of a residential space will not only have its own temperature, but also those of its industrial and commercial neighbours. Consideration must not be given to functions that cover the widest surface area, but also to those that boost the temperature of the area in question.

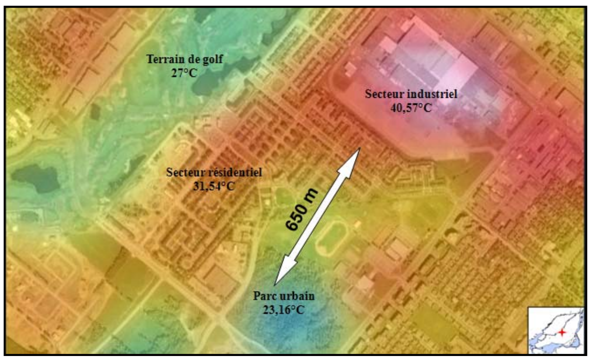

Figure 4: Surface temperature of various urban functions on June 27, 2005 in Montréal. The halo effect is felt more than 100 metres away (Source: Image Landsat 5, P. Martin).

5. Heat maps of Montréal and Toronto

Urban heat islands are detected and located in various ways, that is, by satellite imaging, airborne imaging, thermal camera or by digital thermometer.

In this project, we have opted for satellite imaging by Landsat 5, band 6 (120 metre resolution resampled at 30 metres) for financial and convenience reasons.

Airborne coverage (hyperspectral thermal and visible) at 5 metres would have been quite relevant in finely assessing the thermal impact of some surface materials such as white and green roofs, small green spaces, etc. and heat losses, but this would have required much more processing time. Moreover, it would have cost about $130,000 (in 2012) to acquire this imaging merely to cover the Montréal Island.

In any event, the pictures produced by Landsat 5 are relevant, as they show Montréal and Toronto according to various administrative divisions: census metropolitan areas (CMAs), municipalities/census subdivisions, boroughs/districts. The Montréal and the Toronto images are dated July 14, 2011, and July 7, 2010, respectively. These dates address both technical and climatic considerations.

Three families of maps were produced to produce a picture of heat islands in Toronto and Montréal.

1. Heat map;
2. Normalized Difference Vegetation Index (NDVI) map;
3. Normalized Difference Build-up Index (NDBI) map.

5.1 Picture of Montréal

Table 2 summarizes the thermal image, the vegetation index (NDVI) and the build-up index for the Island and the Montréal CMA (excluding the island) in 2011.

Heat islands in Montréal

Of the 480 km^2 area of the Montréal Island, 70 km^2 are considered heat islands, or 15 per cent (>30.94^{o}C) (figure 5). They are mainly found in the centre/south, north and east (figure 6). The tolerable range (>25.94^{o}C and <30.94^{o}C) represents the majority (64 per cent) of the Island (≈300 km^2), and the coolest portion which is below average and located mainly on the west part of the island, accounts for ≈20 per cent (≈100 km^2). As for the CMA,only 5 per cent or 80 km^2 are affected by heat islands, as we could have expected (excluding the Montréal Island, the agricultural area and waterways). Given the increasing urbanization, **the country picture of suburbs will continue to worsen from a thermal standpoint** if development practices are not changed, as was the case in some suburbs located in the west part of Montréal Island (for example, the Valois district in Pointe-Claire).

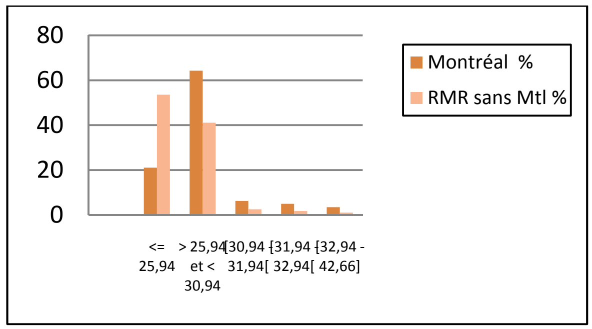

Figure 5: Distribution (%) of temperatures (^{o}C) in five classes for Montréal Island and the Montréal CMA (without Montréal Island) on July 14, 2011; compiled using Landsat 5 (band 6).

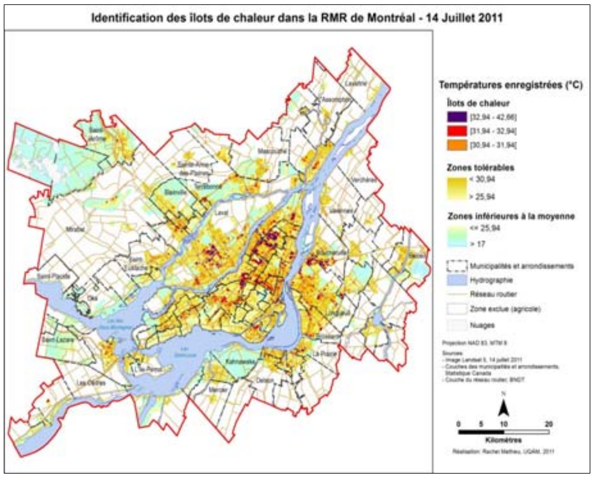

Figure 6: Heat map of the Montréal CMA on July 14, 2011 (Source: Landsat 5, band 6).

In 2011, the Plateau Mont-Royal, Saint-Léonard, Villeray–Saint-Michel–Parc-Extension, Anjou and Montréal-Nord boroughs had the largest surface area covered by heat islands. Hampstead, Dorval Island, Montréal West and Senneville were at the other end of the scale.

If a finer scale is used, it is noted that the spatial distribution of heat behaviour varies significantly within a few hundred metres. This scale also provides an opportunity to appreciate the thermal diversity of boroughs/municipalities and the beneficial effects of vegetalized spaces (Maisonneuve Park, Lafontaine Park, low-density residential space, etc.); and also those associated with thermal degradation caused by highly mineralized commercial and industrial spaces.

The vegetation index in Montréal

The vegetation index (NDVI) quantifies the biomass to some extent and is largely used in forest cover inventories, even though it tends to saturate the extreme values[1]; it varies from -1 (absence of vegetation) to +1 (very dense vegetal cover).

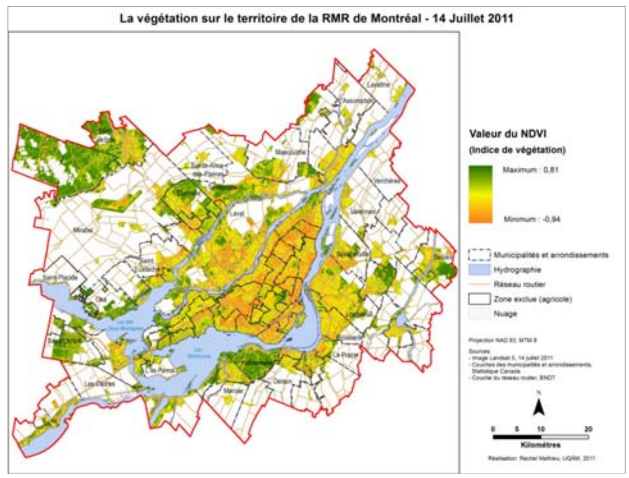

Figure 7: Picture of the biomass of the Montréal CMA (Source: Landsat 5, bands 3 and 4).

[1] When the highest value of the vegetation index (NDVI) is achieved, that is, +1, this implies a very dense biomass and indicates that the threshold has been reached, in which case it cannot discriminate a higher value, which is saturation in other words. Therefore, very vegetalized spaces are undervalued to some extent, as the NDVI exceeds 1+, which is a mathematical impossibility given the method used to calculate this index.

Table 2: Synopsis of the urban space of the Montréal Island and the Montréal Metropolitan Area based on three themes: thermal (temperatures °C), vegetation index (expressed vegetative biomass, NDVI) and the build-up index (mineralized space; NDBI).

		Montréal km²	**Montréal CMA (without the Montréal Island) km²**	**Montréal %**	**Montréal CMA (without the Montréal Island) %**
Temperatures (°C)					
Under average	<= 25.94	100.92	780.66	21.04	53.56
Tolerable	> 25.94 & < 30.94	308.24	599.13	64.27	41.11
Island	[30.94 - 31.94]	29.93	36.77	6.24	2.52
Island	[31.94 - 32.94]	23.84	25.47	4.97	1.75
Island	[32.94 - 42.66]	16.65	15.48	3.47	1.06
Total		**479.59**	**1457.51**	**100.00**	**100.00**
NDVI (Vegetation index)					
Very low	[-0.94 - 0.08]	109.72	115.05	22.88	7.89
Low	[0.08 - 0.26]	122.67	185.37	25.58	12.72
Average	[0.26 - 0.41]	110.75	323.00	23.09	22.16
High	[0.41 - 0.59]	87.82	318.79	18.31	21.87
Very high	[0.59 - 0.82]	48.62	515.30	10.14	35.35
Total		**479.59**	**1457.51**	**100.00**	**100.00**
NDBI (build-up index)					
Very low	[-0.82 - -0.16]	35.02	438.38	7.30	30.08
Low	[-0.16 - -0.07]	57.67	257.74	12.03	17.68
Average	[-0.07 - -0.03]	122.89	366.03	25.62	25.11
High	[0.03 - 0.14]	142.20	259.97	29.65	17.84
Very high	[0.14 - 0.98]	121.80	135.39	25.40	9.29
Total		**479.59**	**1457.51**	**100.00**	**100.00**

CMA 9 (which still excludes Montréal Island) has 8 per cent (≈115 km^2) of its space in very low biomass space mainly in Laval and Longueuil (figure 7). The most vegetalized class ([0.59 – 0.82]) is 35 per cent (≈515 km^2).

Meanwhile, ≈50 per cent of Montréal Island territory (≈223 km^2) is included in very low and low biomass classes ([-0.94 - 0.08] and [0.08 - 0.26]). The highly vegetalized class represents 10 per cent of its surface area and is mainly located on the west part of the Island and in some parks in the centre (Mount Royal).

Superimposing the heat map of the Montréal CMA (figure 6) on the biomass map (figure 7) clearly illustrates the "vegetalized space and low temperature" relationship, which is also corroborated by the map of the built space (figure 8) "mineralized space and high temperature".

The build-up index in Montréal

The build-up index (NDBI) shows the mineralization rate, which ranges from -1 (no mineralization) to +1 (high presence of mineralization). This index is the corollary of the vegetation index. Since the satellite bands used by the NDBI (bands 4 & 5 rather than 3 & 4) are different, it is more sensitive to the elements in the built space.

The highly mineralized class accounts for 9 per cent (≈135 km^2) of the CMA (figure 8), which largely consists of Laval and Longueuil. On the other hand, 30 per cent of the CMA is considered to have very low mineralization (≈440 km^2), which corresponds to the highly vegetalized class of the NDVI we have just discussed (35 per cent; ≈515 km^2).

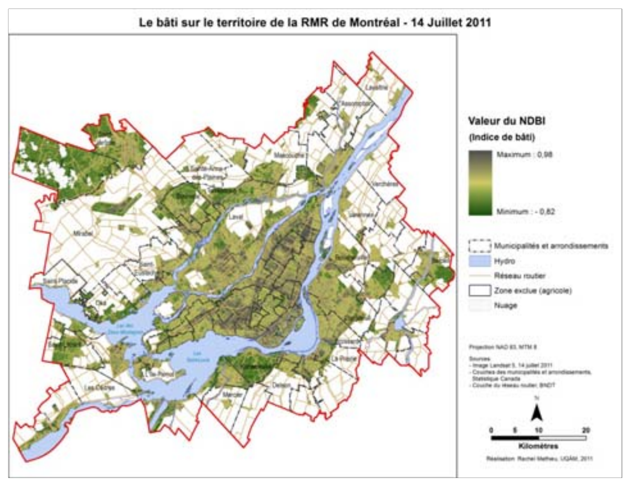

Figure 8: Picture of the built space in the Montréal CMA (Source: Landsat 5, bands 4 and 5).

As a result, 25 per cent of Montréal Island (≈120 km^2) is very highly mineralized ([0.14 – 0.98]) and 30 per cent (≈142 km^2) highly mineralized [0.03 – 0.14]. Both classes account for more than 50 per cent of the Island, underscoring the importance of turning interest also to mitigating elements for already built spaces, not just for new projects. The central south and east sectors are included, but so too are the sectors in the west such as Dorval, Saint-Laurent, Lachine and the areas along the highway in Pointe-Claire.

5.2 Picture of Toronto

Clarification: *It is important to point out that Toronto's geographical situation (its proximity to Lake Ontario among other things) has a major effect on its thermal picture. This is why comparing Toronto with Montréal on the same level is difficult. All of the build-up along the shore is significantly affected by this phenomenon. Furthermore, the presence of cirrus and cirrocumulus clouds on the picture also affected the picture, even though we did apply masks to reduce the effects.*

Table 3 summarizes Toronto's picture on the three parameters discussed: thermal behaviour, the vegetation index and the build-up index for the city of Toronto and the CMA.

Heat islands in Toronto

More than 70 per cent of the area in the city of Toronto (figure 9) is in the tolerable range (>26.22 and < 31.22), with 20 per cent below average (26.22°C). Only 37 km^2 or 6 per cent of its area are covered by heat islands, mainly in the northeast or the northwest and none in the south. This appears to be a minimum given (we believe) the impact of Lake Ontario, the shading effect, the cirrus and cirrocumulus clouds and its urban morphology.

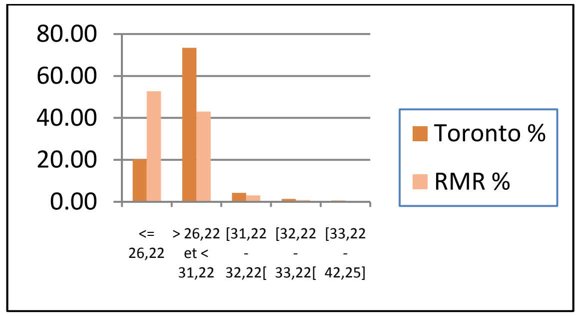

Figure 9: Distribution (%) of temperatures in five classes (°C) for Toronto and the Toronto CMA on July 7, 2010, compiled with the help of Landsat 5 (band 6).

More than 50 per cent (≈1,400 km^2) of the Toronto CMA is below the average temperature. Heat islands account for close to 5 per cent (≈115 km^2) of its territory.

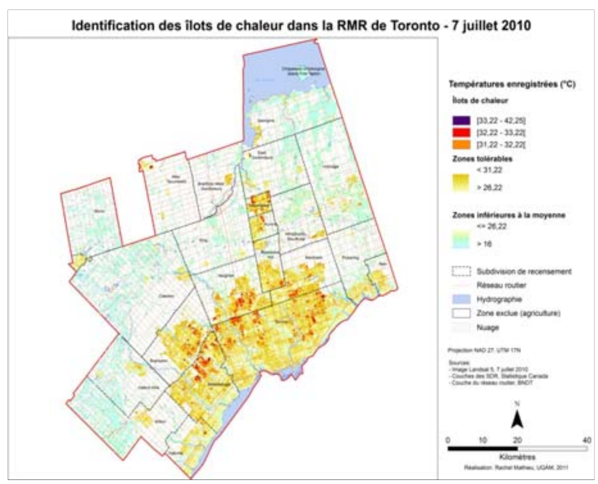

Figure 10: Thermal picture of the Toronto CMA (Source: Landsat 5, band 6).

It is noted that the heat islands are mainly centred (figure 10) in the northeast part of Mississauga, southeast of Brampton, in

East Vaughan, Markham Centre, and

Newmarket and Aurora.

Table 3: Summary of the urban space of Toronto and the Toronto Metropolitan Area based on three themes: thermal (temperatures °C), vegetation index (expressed vegetative biomass, NDVI) and the build-up index (mineralized space; NDBI).

		Toronto km²	**Toronto CMA km²**	**Toronto %**	**Toronto CMA %**
Temperatures (°C)					
Below average	<= 26.22	119.90	1431.08	20.35	52.69
Tolerable	> 26.22 and <31.22	432.50	1167.99	73.41	43.01
Island	[31.22 - 32.22]	25.28	82.47	4.29	3.04
Island	[32.22 - 33.22]	8.05	22.75	1.37	0.84
Island	[33.22 - 42.25]	3.46	11.57	0.59	0.43
Total		589.19	2715.85	100.00	100.00
NDVI					
Very low	[-0.97-0.095]	117.39	309.29	19.92	11.39
Low	[0.095-0.25]	151.32	425.47	25.68	15.67
Average	[0.25-0.41]	189.69	516.34	32.20	19.01
High	[0.41-0.57]	87.15	448.17	14.79	16.50
Very high	[0.57-0.83]	43.63	1016.59	7.41	37.43
Total		589.19	2715.85	100.00	100.00
NDBI					
Very low	[-0.667 - -0.18]	46.93	857.85	7.97	31.59
Low	[-0.18 - -0.07]	101.02	567.76	17.15	20.91
Average	[-0.07 - 0.04]	204.12	583.49	34.64	21.48
High	[0.04 - 0.16]	143.66	428.95	24.38	15.79
Very high	[0.16 - 1]	93.45	277.80	15.86	10.23
Total		589.19	2715.85	100.00	100.00

<u>**The vegetation index in Toronto**</u>

With respect to the vegetation index (NDVI), vegetative coverage is considered quite low over more than ≈10 per cent of the area (≈300 km^2) of the Toronto CMA (figure 11) and low over another 15 per cent (≈425 km^2).

In other words, more than one quarter of the Toronto CMA has little vegetation. On the other hand, more than 35 per cent has very high vegetative coverage. As expected, figure 11 shows a low NDVI for the southern section.

The city of Toronto has close to 20 per cent of the very low vegetation class (≈115 km) and 25 per cent (≈150 km) of low vegetation, which means that close to 45 per cent of the city has little vegetation.

It is interesting to note that this proportion is very much like that of the Montréal Island (48 per cent: low and very low NDVI). Given the reservations expressed about the low values on the city of Toronto heat map and the weather conditions that prevailed when that picture was taken, it was noted that the shoreline sectors of Toronto, its downtown area and Etobicoke have a very low NDVI and thermal behaviour in the higher tolerable zone. This led us to hypothesize that the effect of Lake Ontario is declining.

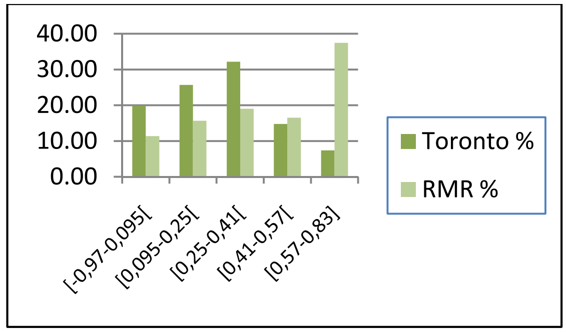

Figure 11: Distribution (%) of the biomass (NDVI) in five classes for Toronto and the Toronto CMA on July 7, 2010, compiled using Landsat 5 (band 6).

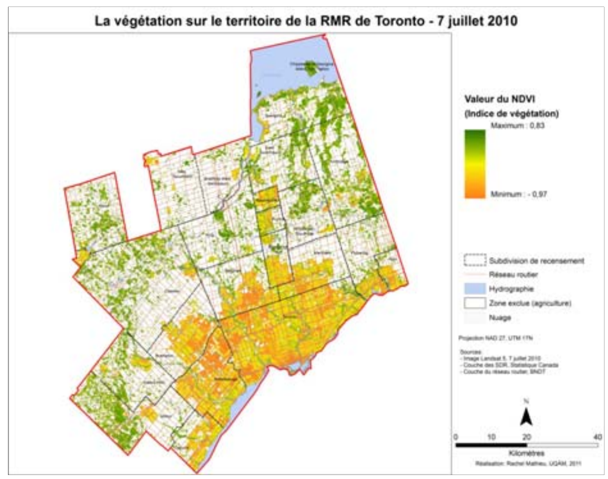

Figure 12: Picture of the biomass in the Toronto CMA (Source: Landsat 5, bands 3 and 4).

<u>**The build-up index in Toronto**</u>

It has been noted that the Toronto CMA has about 700 km^2 (25 per cent) in the high and very high classes of the NDBI (figure 13). The distribution of the NDBI coincides with the NDVI map and the temperature map with the exception of the city of Toronto. The percentage is comparable to that of the Montréal CMA (≈27 per cent).

Some 40 per cent of the city of Toronto is in the high and very high category, as is the Montréal Island that also posted 40 per cent. Figure 14 shows that the areas with a high build-up index overlap quite nicely with those with a low biomass (the previous NDVI map in figure 12). Again, the downtown area is dark (a high NDBI) but has temperatures in the upper section of the tolerable zone class.

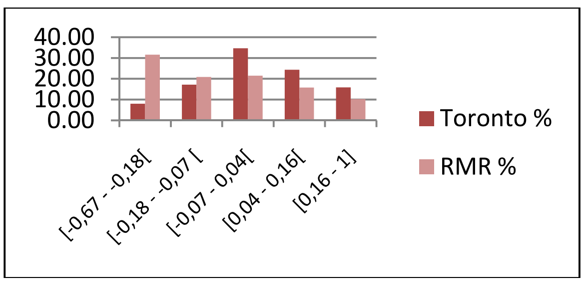

Figure 13: Distribution (%) of the build-up index (NDBI) in five classes for Toronto and the Toronto CMA on July 7, 2010, compiled using Landsat 5 (band 6).

When we look at the 24 census subdivisions (municipalities) of the Toronto CMA, eight clearly stand out with rising temperatures: Newmarket, Vaughan, Markham, Mississauga, Brampton, Aurora, Richmond Hill and Toronto. They have more than 5 per cent of the heat islands, while Vaughan and Newmarket have 13 per cent and 17 per cent, respectively.

The proportion of biomass (NDVI) presented and that of the build-up space very clearly show the high correlation between all of these parameters. It is noted that a large proportion of the Mississauga is built up with a concentration of heat islands in the northeast area.

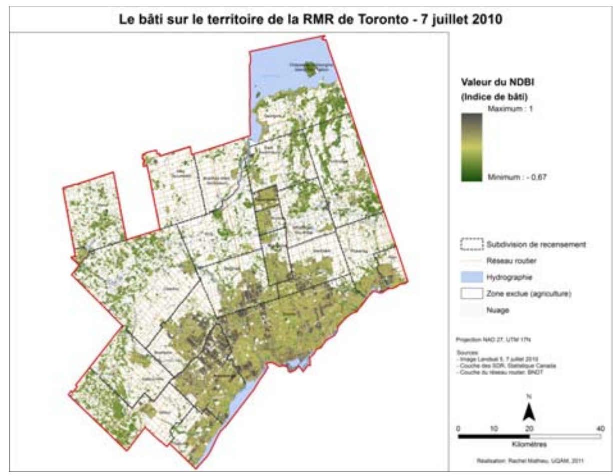

Figure 14: Picture of the build-up space in the Toronto CMA (Source: Landsat 5, bands 4 and 5).

6. Mitigation measures to counter the proliferation of heat islands.

The battle against heat islands demands that we change our development practices. In this section, we will discuss six items we consider fundamental in order to address this issue.

In the field, what is clearly needed is a combination of various measures relating to thermal degradation. In some instances, the measures would prove more beneficial when new projects are built, while other measures could be taken when rehabilitative work is undertaken to correct the errors of the past.

Some benefits:

- Lower surface temperatures and felt temperatures.
- Lower mortality
- Better quality of life
- Less smog
- Smaller temperature variances
- Energy savings
- Higher property values
- Less flooding
- Water reuse
- Increased life of roofs.

6.1 Fewer parking spaces

Given the importance of the automobile and the associated paved space (between 30 and 45 per cent), this item is paramount in the fight against heat islands. As mentioned, the surface area and the impact of parking spaces in commercial and industrial functions are such, that various courses of action are needed:

- parking garages with a green roof;
- underground parking;
- more shading due to the planting of vegetation (for example, 50 per cent shading achieved after 15 years in Sacramento);
- introduction of green belts and more permeable surface areas to promote evapotranspiration; and
- more surface areas set aside for bicycles (use of permeable surfaces).

Figure 15: Parking garage at the Université de Montréal at the foot of Mount Royal

6.2 Changes to roofs and facades

The surfaces of buildings in a city represent an important element, as do façades. Depending on the materials used, they can store a great deal of heat.

- Introduce cool roofs and cool façades by using materials with a high solar reflectance index (SRI) greater than 64 (high albedo and high emissivity). The useful life of roofs would be extended, because there would be less fluctuation (retraction/expansion) during the day and at night; the use of white roofs, for example the Rosemont–La Petite-Patrie borough; refer to the excellent publication by the U.S. Department of Energy [(3)].
- Maintain and clean roofs on a regular basis.
- Lean toward green roofs on public institutions.
- Plant roof gardens.

Figure 16: Use of vegetation on the High Line in New York, December 2011.

- Use self-supporting vines as vegetation on facades (pointing south and west) on residential, commercial, industrial and public buildings. It is a very affordable solution.
- Plant trees with deciduous leaves along the perimeter of residential buildings (pointing south and west).
- Use photovoltaic awnings (but check the cost before choosing this option).

Figure 17: Green roofs can be encouraged by public authorities for municipal buildings and museums as they are in Chicago. Peggy Notebaert Nature Museum (Museum of the Chicago Academy of Sciences) June 2011.

6.3 Consideration of architecture and urban morphology

This approach involves physical phenomena, the modelling of which is complex. Nonetheless, various measures should be retained:

- Avoid constructing surrounded buildings.
- Avoid dense construction in topographic depressions.

- Vary the height of buildings to promote air movement.
- Maintain the height/width ratio at less than 1 (sky view factor, or SVF).
- Allow for strong ventilation along highways and between more densely populated wards.
- Consider orientation in both the construction of buildings and the planting of vegetation.

6.4 Increased permeability, surface water catchment and waterways

It has been shown in several cities that the presence of waterways reduces ambient temperatures:

- Incorporate water bodies into new public, housing and recreational projects.
- Arrange for the surface water catchment to water and grow vegetation (for example: LEED-certified buildings in Chicago).
- Reduce the width of roadways (this can be accomplished while also ensuring the safety of citizens). Depending on rehabilitation needs, such portions of the roadway could be gradually turned over to the adjoining properties and would pay for themselves through increased tax revenues.
- Promote geothermal technologies(example: in Toronto).

Figure 18: A building with LEED platinum certification in Chicago: the Chicago Center for Green Technology (CCGT), June 2011.

6.5 Increased green spaces and vegetalized surfaces

It is clear that increasing green spaces is one of the preferred options both in terms of their preservation and for new projects:

- Increase vegetalized surfaces (properties with at least 40 per cent of vegetalized space have been shown not to have heat islands). Tree shading reduces the surface temperature by at least 5°C (CMHC, A Guide to Innovation in the Design and Construction of High-Rise Residential Buildings, p. 97).
- Reduce and stop the use of artificially vegetalized surfaces (synthetic turf increases surface temperature by at least 5°C).
- Plant vegetation suited to local conditions (climate harshness, de-icing salts, illnesses, etc. in private and public spaces. It is advised that

at least one tree be planted per property.

Figure 19: Heavy use of vegetation for public and semi-public spaces that have been highly mineralized in Toronto, June 2011.

- Plant trees with deciduous leaves along road arteries.
- Conserve and increase the number of public parks and plant trees.
- Preserve and increase public shoreline spaces, which allows for freer air circulation.
- Develop regulations that actually conserve existing green spaces, which is something that is often bypassed.

6.6 Thoughtful use of covering materials

We have also noted that increased number of materials manufacturers indicate the physical properties of materials on the labels such as the SRI (*solar reflectance index*). This should be considered:

- Introduce the use of cool pavements by using materials with a high albedo and high SRI and which are porous to allow for evaporation.
- Review covering surfaces on roads.
- Reconsider highly mineralized tourist areas.
- Avoid using synthetic materials to the detriment of natural materials.

Figure 20: Use of porous paving stones that have been staggered to facilitate runoff and rain absorption. Chicago, June 2011.

7. Regulatory aspects and urban planning instruments

All of the urban planning instruments for Montréal and Toronto were reviewed to uncover normative elements (layout diagrams, land-use plans, regulations, programs, incentives, etc) that could relate either closely or remotely to measures to reduce heat islands on their respective territories.

This work was not limited to the regulatory framework of the municipal government in each city and instead involved all of the various levels and agencies responsible for development and urban planning in both cities. The elements were classified into three major planning categories: indicative, incentive and normative.

1. **Indicative planning**: This involves providing recommendations, advice, etc. without any obligation to abide by the landscaping terms. As the descriptor suggests, elements are proposed simply as indicators with no constraints, and conversely, they do not include any form of accommodation.

2. **Incentive planning**: This involves offering subsidies, various forms of relief, accommodations or other such things to encourage the actors concerned to comply with the recommendations and criteria proposed.

3. **Normative planning**: This consists of a series of regulations, directives and other things that must be honoured. It is imposed in accordance with variable terms and makes it possible to achieve some objectives more quickly.

7.1 Montréal

As far as Montréal is concerned, the metropolitan planning documents across the island revealed that no one element is directly linked to heat islands, but several are indirectly. This generally involves policies and programs focused on sustainable development, environmental development or simply more intensive greening of all types. The concept development project deals with the following, among other things:

- reduced use of the automobile;
- greater modal share for public transit;
- less greenhouse gases;
- development of green space in the urban space;
- protection of, and increase in, natural spaces;
- networking of green spaces;
- incentive to municipalities to come up with an urban forestry policy;
- creation of the metropolitan secretariat to develop blue and green spaces, which makes an annual financial contribution to park and natural space development projects; and
- planning of arteries by incorporating landscape plantings.

Note that the very recent MMC (Montréal Metropolitan Community) metropolitan development plan has adopted a sizeable number of these elements but has insisted more on maintaining protected areas and protecting the forest cover.

The Montréal Land-Use Plan mentions the term heat island and proposes some courses of action. These elements were covered.

- Reduce mineralized surfaces to reduce the impact of heat islands;
- Limit impermeable surfaces, among others, by reducing the number of parking lots;
- Propose measures to counter heat islands:

    - Plant trees on a priority basis in residential sectors where there is a shortage, in accordance with the tree-related policy.
    - Reduce the size of off-street parking while applying landscaping and green island planting measures.
    - Encourage the greening of roofs on commercial, industrial, institutional and municipal buildings.
    - Develop partnerships between the city and school boards to facilitate the greening of school yards and new school parks.
    - During rehabilitation or completion work on roads, reduce the width of roadways that are too wide and provide landscaping and tree plantings.
    - In large areas to be built, produce road grids and position buildings in a way that allows maximum sunshine and protection from prevailing winds to optimize energy efficiency.
    - Develop and implement incentives to incorporate energy efficiency standards and apply innovative techniques such as green roof fit-ups for new construction and the renovation of existing buildings.
    - Provide retention basins.
    - Use construction materials or roadway coverings that have a high solar reflection factor to reduce the amount of heat captured.

- Limit tree cutting.
- Develop partnerships between the City and Montréal school boards to promote greener school yards and develop new school parks.
- Develop and implement a tree policy.
- Develop a parking policy.
- Support initiatives to develop and promote the greening of lanes.
- Protect eco-territories.
- Revegetate shores.

In its policy to protect and develop natural environments, the City of Montréal identified 10 eco-territories, perimeters with a concentration of protected natural species (parks, natural reserves, etc.) and sites intended for development. These areas are the subject of planning that incorporates these natural settings into the built-up areas by including the conservation costs in the budgets of real estate projects. Furthermore, elements contained in the complementary document in the master plan must be included in the bylaws.

The advantage of including provisions at this level is that municipalities can proceed via a harmonization resolution to incorporate the standards into their bylaws and that a referendum process cannot be undertaken to halt the process. Here are some of the items that were discussed in the document.

- Integrate specific standards when the parking lot is out front, for example, covering materials.
- For medium- or large-sized businesses, allow for green strips for parking lots. For example, green islands must be included in areas of more than 1,000 square metres.
- Limit the number of parking places in the Ville-Marie borough.
- Reduce the number of parking places required for a building located less than 500 m from a subway station.
- Require planning for bicycle parking.
- Promote ecological architectural production for the central area.
- Plant trees.
- Preserve trees.
- Protect trees when work is being done.
- Ensure greening of roofs.
- Put vegetation in front yards.
- Protect Mount Royal.

Local sectoral/specific policies

Tree-related policy

Boroughs in the city of Montréal do not have any obligation as far as this indicative document is concerned. However, it did raise some interesting points:

- Each Montréal borough shall develop its tree plan in collaboration with the Sports, Parks and Green Spaces Division. This could lead to:
    - a planting program (new plantings and replacement);
    - a maintenance program (pruning, fertilization and phytosanitary treatment); and
    - a communication program (awareness and education).
- The City of Montréal shall pursue and develop its applied research program on important elements for the protection and improvement of Montréal's tree heritage.

Strategic sustainable development plan

As is the case with the tree policy, actions are not binding in nature. Here are the main steps to be taken to reduce the incidence of heat islands:

- Reduce the presence of urban heat islands (UHIs):
    - development of a greening strategy;
    - realization of at least one greening project in the downtown area.
    - development of a greening strategy related to heat islands; and

- o reduction of the heat emitted by one or several municipal buildings during replacement work or renovations.
- Reduce the number of parking spaces.
- Increase infrastructures to encourage the use of bicycles.
- Encourage the development of car sharing.
- Increase the area of protected natural environments to move toward protecting 8 per cent of Montréal's territory.
- Implement measures to protect and renaturalize shores.

<u>Boroughs – Land-use plan (borough chapter)</u>

The borough chapter shows more detailed planning at the local level. Here are the main elements selected.

- Encourage the production of ecological architecture in industrial sectors where the presence of trees is often limited.
- Improve the development of the public domain through greening measures.
- Protect and develop parks and green spaces that have been identified.
- Increase the number of parks.
- Develop linear parks.
- Develop an urban forest management master plan.
- Arrange a competition aimed at greening and beautifying streets and lanes in the boroughs, while at the same time devising a strategy with the area to encourage tree planting and revegetation where the plant cover appears insufficient.
- Develop partnerships with the school boards, in particular, to have greener school yards or develop school parks.

Bylaws differ from one borough to the next in Montréal, but some standards are repeated. In some cases, boroughs do stand out from the rest. In Ville St. Laurent, the standards pertaining to the greening of parking lots for industrial use are far more stringent. The Rosemont/Petite-Patrie borough resorts to several actions and eco-responsible measures that truly set them apart. The policies in the land-use plan do not bind the boroughs. Some, though, have included elements that could affect heat islands, particularly the tree policy.
Even though heat islands are not mentioned *per se* in the bylaws, the contacted municipal officials recognize the extent of the problem. More allowance should be made for this issue when the land-use plan is revised. The obligation by boroughs to integrate elements in the complementary document into their bylaws can be clearly seen (for example, bicycle parking,

reduction in the number of parking places near subway stations, tree protection). Items in the complementary document such as tree planting and protection, bicycle parking areas, parking lot landscaping and a reduction in the number of parking spaces near subway stations have found their way into various bylaws. A well structured and sufficiently comprehensive complementary document could have a major bearing on the effectiveness of some measures. Vegetation is often motivated for esthetic rather than ecological regions. Some policies have not yet achieved their objectives. For example, the parking policy in the land-use plan should focus on reducing the effects of urban heat islands, among other things. Some boroughs seem to be proposing innovative measures:

- planting policy in the St. Laurent borough;
- maps of heat islands are available on the Saint-Laurent website;
- greening of lanes in Verdun; and
- cool islands in Verdun.

7.2 Toronto

The City of Toronto land-use plan mentioned the reduction of heat islands in two places – firstly in the section of avenue development. It encourages the incorporation of a sustainable design that (1) reduces the flow of rainwater; (2) reduces water use; (3) cuts waste and promotes recycling; (4) uses energy renewal systems and effective energy technologies; and (5) creates innovative green spaces such as green roofs and a design to reduce urban heat islands.

Secondly, the section of the document dealing with the natural environment claims to support and encourage innovative ways of producing energy, green industries and green design which (a) use methods that reduce the amount of storm water; (b) conserve water and promotes effective measures; (c) include a design that facilitates a reduction of waste and recycling; (d) establish and extend heating and air conditioning district-wide; (e) use effective energy technologies; and (f) develop innovative green spaces such as green roofs and a design to reduce the effects of urban heat islands.

No other elements are directly related to heat islands, but several are indirectly. Some of the elements discussed in the land-use plan deals include the following:

- naturalization and improvement of landscaping;
- planting of trees and preservation of mature trees;
- protection of the natural

environment and existing green spaces from the harmful effects of development;

- use of sustainable technologies to conserve storm water;
- development of green spaces in the urban space: development of new green spaces (and parks) and maintenance of existing green spaces;
- planning of arteries, including landscaping;
- creation of a network of green spaces that connect existing parks and green spaces;
- limitation and removal of parking on the street during the day;
- limitation of parking in the downtown area and inclusion of a maximum of parking spaces for new office development projects;
- expansion of an underground pedestrian network;
- limitation of parking areas directly between the facade of a building and the street or sidewalk; and
- integration of underground parking into building design.

Figure 21: Toronto: Use of climbing plants on the facades of old industrial buildings converted to condominiums; June 2011.

Toronto Green Standard (2009)

The Toronto Green Standard (TGS) is a strategy proposed by the *Climate Change – Change is in the air* action plan that supersedes to some extent the Toronto-wide LEED designation. This action plan proposes performance measures and directions regarding sustainable construction and sites.

There are three versions of the TGS, each one of which deals with a different building type: small non-residential buildings, small residential buildings and medium-sized residential and non-residential buildings. Each version includes recommendations that specifically address heat islands.

All Tier 1 measures are mandatory in order for applications for new developments to be approved, for example, amendments to the zoning bylaws, master plan requests and subdivision plans.

Master plans that are in accordance with both Tiers 1 and 2 of the TGS are eligible for a reimbursement of 20 per cent of the development charges paid to the City.

Change Is in the Air

Change Is in the Air is a monitoring tool the public can use to keep abreast of climate change. It also serves an action plan to determine how the municipality plans on achieving its objectives to reduce greenhouse gases and air pollution. It proposes ideas and strategies, policies, programs and projects needed to meet the municipality's objectives and identifies 27 potential actions that the Toronto municipal government, companies and industries can proceed with to attack climate change and improve air quality.

Change is in the Air Action Plan*:*

(a) Implement the *Live Green Toronto Program*: A support program for individuals, groups of residents, companies and other agencies or organizations in the ward.

(b) Implement the Eco-Roofs Program: a program aimed at making at least 10 per cent of all roofs of industries, businesses and institutions more environmental for 2020, incorporating the Green Roof Incentive program. This would help industries establish more sustainable programs.

(c) Implement the Trees Across Toronto Program, the aim of which is to plant more trees in Toronto and double the tree canopy for 2050.

(d) Greening City Operation: This program is intended to improve the sustainability of City Hall, the largest public green roof in Toronto, and the Nathan Philips Square (LEED Certified Gold).

Figure 22: Toronto; Use of indigenous plants in semi-public spaces in residential areas; June 2011.

Design Guidelines for Greening Surface Parking Lots

This guide touches on some policies in the land-use plan (concerning the build-up environment and the natural environment) and the TGS and also devotes a lot of attention to heat islands. Owners of existing parking lots are not required but are encouraged to follow these directives. It is also used as a guide of parking lots operated by the City of Toronto and City of Toronto agencies. It is divided into five sections dealing with:

1. location and layout (including specifications on grading);
2. vehicle access and circulation;
3. pedestrian access and circulation;
4. landscaping (including requirements on streetscapes and perimeter landscaping, internal landscaping and surfaces); and
5. stormwater management.

Green Roof Bylaws

Toronto is the first city in North America to have passed bylaws on the construction of green roofs on new development. The City of Toronto did so in May 2009 pursuant to section 108 of the *City of Toronto Act*. These bylaws apply to new applications for permits for residential, commercial and institutional development after January 31, 2010 and shall apply to new industrial developments effective on January 31, 2011.

Eco-Roof Incentive Program (2009)

The Eco-Roof Incentive Program promotes using green and cold roofs on commercial, industrial and institutional buildings in Toronto; and helps businesses in Toronto act to combat climate change. This paper clearly indicates that green roofs and cold roofs help in the fight against heat islands. It complements the City of Toronto bylaws on green roofs and is a key component of the City of Toronto's environmental offensive that promises to reduce greenhouse gas emissions by 80 per cent before 2050.

In 2009, the Municipality of Toronto accepted 49 funding applications for this project, covering more than 66,000 sq. m of Eco-roofs.

Figure 23: Landscaping in highly mineralized areas in downtown Toronto, June 2011.

Green Toronto Award

Each year, the City of Toronto, in partnership with Green Living Enterprises, some media and sponsors, recognizes the environmental leadership of various organizations in nine categories:

- Community project
- Energy conservation
- Environmental awareness
- Green design
- Green roof
- Leadership
- Local food

- Water efficiency
- Young people's commitment

On the whole, the policies and measures to mitigate heat islands in Toronto are more the result of indicative and normative planning.

Several ad hoc programs on the management of parking spaces, green roofs and greening are slightly more developed than Montréal's, even though boroughs such as Ville Saint-Laurent and Rosemont–La Petite-Patrie have been increasingly innovating in this area.

8. Conclusion

This project has illustrated to us that our urban environments are thermally deteriorating, but that various positive approaches are nonetheless being taken. Toronto has passed comprehensive bylaws to fight heat islands, while several local initiatives are under way in Montréal.

Mineralization is the main culprit in the degradation, but if careful choices are made before projects are undertaken, one can better prevent heat islands and their effects on health. Conserving existing green spaces, using more carefully selected materials, landscaping that addresses both the issues and their impact, reducing impermeable surfaces and a better public transit policy should reduce the presence of heat islands in urban environments.

In closing, this project provided us with an opportunity to consult numerous documents and see for ourselves that an impressive number of innovative initiatives have been developed in several large American and European cities. The initiatives do exist, and positive findings have been achieved. Now the time has come to take the necessary policy and regulatory measures.

References

N.B. Complete references are found in version 2 (the complete report)

(1) ASTM (American Standard Test Methods), year unknown, *Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surface*, E 1980-01, 3 p., consulted on March 10, 2011, http://www.astm.org/Standards/E1980.htm

(2) Ouarda, M., 2008, *L'influence de la réflectivité des matériaux (albédo sur la modification du microclimat et le confort thermique extérieur*, Université Mentouri, Constantine, 228 pages.

(3) U.S. Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program, *Guidelines for Selecting Cool Roofs,* July 2010, V. 1.2) http://www1.eere.energy.gov/femp/pdfs/coolroofguide.pdf