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An effective public health program to reduce urban heat islands in Québec, Canada

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ABSTRACT *In 2005, the Government of the Province of Québec, Canada, adopted the Climate Change Action Plan for 2006 – 2012. The Institut national de santé publique du Québec (National Institute of Public Health of Québec), charged with implementing the health adaptation component of the Plan, worked to mitigate urban heat islands (UHI) by funding and evaluating 40 pilot projects. These projects explored different methods of fighting UHIs by greening cities in a participative and mobilizing approach led mainly by non-governmental organizations and municipalities. An assessment of temperatures before and after implementing various methods demonstrated that some actions enabled significant gains of coolness and more efficiently mitigated heat (reduction of concrete/asphalt surfaces, increasing vegetation, etc.). An assessment of quality of life showed that projects were positively received by users, especially by those living in vulnerable situations. A lifecycle analysis showed that from the environmental perspective, UHI mitigation measures that do not require fertilization or maintenance are preferable. Finally, communication efforts that raise awareness of UHI and mitigation are of significant importance to program success.*

Keywords Climate change; green areas; urban health; environment and public health; hot temperature; heat wave; Canada.

For over a decade, studies have shown urban green spaces to be beneficial to human health (1, 2). Green spaces have been associated with improved air quality (oxygen production, dust/ozone reduction, etc.), increased physical activity, and decreased stress, leading to better physical and mental health among residents (3 – 7). In Japan, the availability of green space has been shown to promote walking among the elderly, with beneficial impacts on both their health and longevity (1). Some other studies have also reported that the beneficial effects on mortality seem even greater for disadvantaged populations (8).

Urban heat reduction is also one of the proven advantages of green spaces. In a typical city in North America, close to 80% of the surface area is built or paved, which contributes to the creation of intra-urban heat islands (9). The term “urban heat islands” (UHI) refers to the observed temperature difference between urban environments and the surrounding rural areas at the macro scale; “intra-urban heat islands” refer to similar differences within a city. Observations have shown that the temperatures of urban centers can be up to 12°C higher than surrounding urban areas (10). This situation can produce significant adverse effects on human health during heat waves, when significant excess mortality has been noted in hotter zones (11). Urban green spaces, however, can reduce air temperature by 4°C – 8°C. This cooling effect can even extend several hundred meters to

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neighboring areas and reduce the perception of thermal discomfort during heat waves (12, 13).

For 10 – 15 years now, many organizations and researchers have proposed enhanced greening of cities. Some have recommended that city land use and development plans focus more keenly on maintaining and increasing green spaces (1). For instance, in New York City, recommendations for UHI mitigation measures are being implemented, tailored to the circumstances of each of the different boroughs and at levels expected to produce a real beneficial effect (14).

Recent studies have also measured the effects of greening on temperatures in urban areas. In northwest England, a modelling exercise demonstrated that even in suburban areas in temperate cities, a 5% increase in mature deciduous trees can reduce mean hourly surface temperatures by 1°C over the course of a summer's day (15). In Melbourne, Australia, a simulation suggested that average seasonal summer temperatures can be reduced by about 0.5°C – 2°C if the city were replaced by vegetated suburbs and parklands, respectively (16). A study conducted in several American cities used separate health impact functions for projected, average warm season and heat wave conditions in 2050, and found that combinations of vegetation and albedo enhancement could offset projected increases in heat-related mortality by 40% – 99% across metropolitan areas (17). Albedo is known as the fraction of incident solar energy reflected by a surface (18). A high albedo means that the surface reflects a large amount of solar radiation, and less energy is, thus, absorbed by the surface materials.

Since climate change will bring a supplementary burden of heat exposure to cities everywhere, it is important to assess, as precisely as possible, which measures truly reduce urban heat island effects, with minimal negative impact. The present study details how the province of Québec, Canada, implemented such measures in a humid temperate climate over 7 years using a science-based public health approach. The process included four major blocks, namely: a review of existing science; several pilot projects; several evaluations (on effectiveness, impact on quality of life, and a preliminary life cycle analysis of negative environmental impacts); and a major effort to disseminate information and results.

URBAN HEAT EFFECTS AND MITIGATION MEASURES

Under the health component of Québec's 2006 – 2012 Climate Change Action Plan, the *Institut national de santé publique du Québec* (National Public Health Institute of Quebec; INSPQ) received a mandate from its Ministry of Health and Social Services to support projects that decrease the impact of climate change on the health of vulnerable populations. One of the major issues addressed by the INSPQ was the question of fighting UHIs as a climate change adaptation measure.

First, a systematic literature review was prepared on the impacts of UHI (not presented here) and effectiveness of UHI mitigation measures, namely greening measures, urban infrastructure-related measures (architecture and land use planning), storm water management and soil permeability measures, and anthropogenic heat reduction measures (19). The literature review indicated that a range of options is available for heat reduction and cooling in urban areas, as shown in Table 1.

In addition, the review clearly demonstrated the benefits of applying several mitigation measures at the same time. In fact, when these measures are used concurrently, an additive effect is observed in terms of cooling both buildings and cities, which helps protect the population from the negative health impacts of UHIs. This review constituted the basis of further INSPQ actions on the topic.

Although the review did not claim to replace the recommendations of experts in the field, various suggestions for the southern sub-area of Québec province were derived from it. These suggestions guided program implementation and addressed specific questions regarding greening of the cities. One of the main orientations was, as a public health principle, to give priority to applying UHI mitigation strategies in the areas where populations most vulnerable to the heat live. It was also proposed to encourage small- and large-scale greening initiatives, as well as the protection of wooded areas, in order to optimize plant growth and extend plant life.

URBAN HEAT MITIGATION PROJECTS

The literature review constituted a reference document for implementation of local pilot projects on UHI mitigation.

TABLE 1. Options for urban heat island mitigation strategies, Montreal, Canada, 2009

Vegetation and cooling • Urban greening strategy • Selective planting of trees and vegetation • Greening of parking lots • Vegetation around buildings • Green walls • Green roofs	**Sustainable urban infrastructure** • Buildings (reflective materials, building isolation and air-tightness, thermal inertia, windows, shading devices) • Road infrastructure (high-albedo pavement) • Characteristics of the built environment (access to cooling centers, water installations, aquatic facilities, ultraviolet protection in public areas)
Sustainable storm water management • Trees and green roofs • Permeable surfaces • Rain gardens • Retention ponds • Infiltration trenches (or soaking trenches) • Dry wells • Reservoir pavement structures • Watering impermeable pavements with recycled water	**Reducing anthropogenic heat** • Controlling heat production in buildings (artificial lighting and natural light, office equipment, household appliances) • Reducing the number of vehicles in urban areas (densify centers and reduce urban sprawl, mixed-use development, restricting motor vehicle access, public transportation, active transport) • Passive buildings: controlling air conditioning demand (ventilation, solar cooling systems, geothermal heat exchangers, radiant cooling systems)

Source: Prepared by the authors based on results presented by Giguère (19).

Three calls for proposals were made. In this context, more than 40 projects were funded and realized in different geographic areas of the province of Québec. The projects were required to specifically target the implementation of a measure or group of measures favoring the creation of cooling in urban spaces. These measures generally included densification of the vegetation and the improvement/creation of pedestrian streets, parking lots, playgrounds, schools yards, public child care centers, and public places and buildings frequented by vulnerable populations (e.g., housing cooperatives, senior centers). The proposals were submitted to independent review by external experts, with decisions made on the basis of predetermined criteria included in the call for proposals.

Every project had to be finalized by December 2012. Based on project implementation and the required reports submitted by each project leader, the following UHI mitigation efforts were completed: 17 school yards were greened (Figure 1); seven green alleys were created; two white roofs were installed; eight cool places were created; 10 parking lots were greened; four green roofs (Figure 2) covering over 600 m^2 were planted; and 11 projects involving urban agriculture were realized (Figure 3). In all, over 3 000 trees and 26 000 bushes, vines, annuals, and perennials were planted. More than 40 000 m^2 of asphalt pavement was removed and nearly 65 000 m^2 of white roofing was installed. Funding totaled about C$ 15 million (in 2010, US$ 1 = C$ 1), and matching was required to qualify, either in-kind or financially; the total value of projects including matching was estimated at C$ 45 million.

FIGURE 1. Example of a schoolyard after planting vegetation and decreasing pavement, Montreal, Québec, Canada, 2011

Source: National Institute of Public Health of Québec, Canada.

FIGURE 2. Example of a green roof garden in a densely populated area in Montreal, Canada, 2012

Source: AIR IMEX Ltée (aerial photography company), Montreal, Quebec, Canada.

EVALATION OF MITIGATION PROJECTS

Temperature assessment

After some of the pilot projects were completed in Montreal, Environment Canada (the ministry of the environment; Ottawa, Ontario) conducted a study to validate the performance of the various UHI reduction measures (20). Environment Canada used several techniques, including high-resolution modeling, satellite thermal imaging, and an on-site meteorological measurement campaign to assess the environmental benefits of any cooling gains

The characterization of the UHIs has confirmed that daytime temperatures, whether in rural or urban areas, are relatively similar, while night temperatures vary depending on the environment, with urban areas being less susceptible to cooling than rural ones. Data from satellite and on-site measurements showed that in sunny conditions, the UHI effect is always present, even if slight, in places with little vegetation, where the ground coating is waterproof, or for surfaces with low albedo (asphalt, for instance).

The performance study of UHI pilot projects in the Montreal area showed that some of the selected projects enabled significant gains of coolness. It also appeared that the measures taken and descriptions of surfaces and materials before and after work completion are important elements for evaluating thermal response to UHI pilot projects. Also, the choice of materials and colors can have an impact on the effect of the UHI modifications in some places. In addition, changes during the course of the project can result in changes to the anticipated reduction in UHI effect.

The report compared three methods for assessing UHI project impact in terms of temperature reduction. These results can help select best practices and promote the methodologies that produced the clearest evidence. For Environment Canada, numerical modeling provided the best comparison of sites before and after redevelopment, particularly because of its high resolution and the lack of physical constraints when compared to measuring instruments. An assessment of improved coolness could also be made by comparing before and after satellite images, using normalization to allow robust comparisons (Figure 4).

The study results showed the efficiency of several interventions to reduce

UHI effect (reduction of concrete/asphalt surfaces, increased vegetation, etc.), but not all interventions. The most effective and efficient measures will thus be prioritized in the future to achieve the greatest coolness gains possible. Lastly, this study led to the conclusion that the scope and size of the project must be large enough to achieve significant impacts that are measurable with the existing tools.

Quality of life assessment

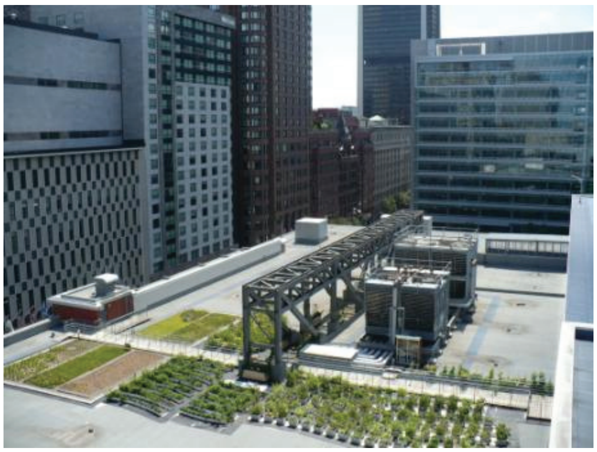
Of the total, 12 pilot projects were also used to assess effects on the quality of life and the well-being of residents and users of the area (21). The evaluation examined dimensions of quality of life identified in a literature review and through consultation with leaders of the participating projects. The evaluation adopted a participatory approach: the interested parties were invited to take part in the development process, implementation, and interpretation of the results. Data sources included brief on-site interviews, online and paper questionnaires completed by users of landscaped areas, and individual or group interviews with representatives of partner organizations. Only one site was measured before any development. For other sites, measures were taken during project development or at completion.

In general, the evaluation indicated that the projects were positively appreciated by the users and other stakeholders, as detailed in Table 2. For users and potential users of the spaces, the projects produced some of the expected effects, getting high marks for attractiveness and quality of the experience, particularly with respect to the dimensions of beauty and comfort. In terms of space security for oneself and for others, positive change perceptions were also recorded. The satisfaction rate was high, indicating overall success and beneficial effect on complex and significant environmental health.

Regarding the projects' effects on extreme heat, results were more mixed. Although users of the spaces were relatively unaware of the projects' intent to reduce heat, and by extension, even less aware of the expected impact on morbidity and mortality, they attached a high level of importance to measures taken against the heat. It appears that these projects can be part of a context for community mobilization against health threats posed by UHIs; however, there is much work to be done to counter the lack of knowledge on heat's affects on human health and its connection to urban development.

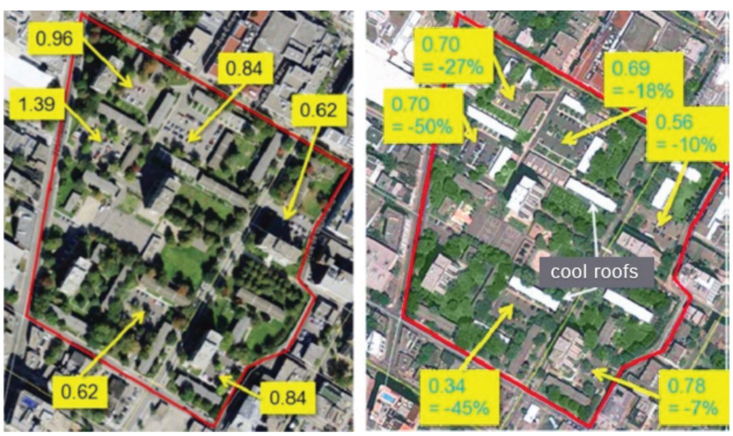
The conclusion of this assessment was positive regarding the relevance and

FIGURE 3. Example of urban agriculture on the roof of a convention center in downtown Montreal, Canada, 2011



Source: National Institute of Public Health of Québec, Canada.

FIGURE 4. Aerial pictures of *Habitations Jeanne-Mance* (public housing), in Montreal, Québec, Canada, 2008 (left) and after several Urban Heat Island (UHI) interventions, 2013 (right)



Note: Numbers in blue show a value decrease of normalized temperature implying a reduction of the UHI effect.
Source: Environment Canada, Ottawa, Ontario, Canada.

TABLE 2. Quality of life evaluation results for some pilot projects on mitigation of urban heat islands after work completion, Montreal area, Québec, Canada, 2013

	Vieux-Beloeil parking lot[a]	Jeanne-Mance parking lot[a]	Aumont Park, Brossard[a]	Calixa-Lavallée schoolyard[a]	St. Clement schoolyard (before work started)[b]	St. Clement schoolyard (during work)[b]
Beauty	1.2	1.7	1.6	1.3	3.7	1.8
Comfort	1.9	2.5	2.1	1.3	3.7	1.8
Coolness	2.6	2.1	2.4	1.3	3.7	1.8
Security	2.0	2.9	2.1	1.7	2.8	2.0

Source: Prepared by the authors based on results presented by Kishchuk (21).
[a] Average on a 5-point scale, where 1 = much more beautiful/comfortable/cool/secure and 5 = less beautiful/comfortable/cool/secure.
[b] Average on a 5-point scale, where 1 = very beautiful/comfortable/cool/secure and 5 = very ugly/uncomfortable/hot/dangerous.

feasibility of UHI mitigation from the perspective of vulnerable people using the spaces. The site development encourages the use of the space and seems to promote positive experiences among the users; however, these factors were not directly or closely linked to the creation of coolness.

Lifecycle analysis

Finally, a lifecycle analysis (LCA) was conducted on 10 UHI mitigation measures applicable to the residential sector to evaluate the potential environmental impacts resulting from implementation and maintenance, as well as dismantling at the end of the project life cycle (22). The measures evaluated were green roof, reflective roof, green wall, planting arrangement, tree, reflective coating, permeable paving, rain garden, infiltration trench, and dry well. It is important to mention that the potential temperature reduction was not taken into consideration in this assessment of environmental impacts. This study was carried out in the framework of urban-greening pilot projects aiming to reduce UHI in the Montreal metropolitan area.

The potential environmental impacts of different UHI mitigation measures were evaluated and each measure was individually compared to a baseline situation equivalent to the *status quo*. Measures were then prioritized according to their potential overall environmental performance. The indicators evaluated were human health, ecosystem quality, climate change, resources, aquatic acidification, and aquatic eutrophication. Table 3 summarizes the results of this assessment.

TABLE 3. Summary of the environmental gains and negative impacts of urban heat island (UHI) mitigation measures compared to a baseline scenario, Montreal, Québec, Canada, 2011

UHI mitigation measures		Indicators[a]					
		HH	EQ	CC	R	AA	AE
Extensive green roof	45 years, chemical fertilization as needed	Slight negative	Average gain	Slight gain	Average gain	Slight gain	Average gain
	No chemical fertilization	Average gain	Average gain	Slight gain	Average gain	Slight gain	Average gain
	25 years, chemical fertilization as needed	Slight negative	Average gain	Slight negative	Slight gain	Slight gain	Average gain
Reflective roof	Elastomeric membrane, 25 years, coated every 5 years	Large negative	Slight negative	Large negative	Large negative	Large negative	Slight negative
	Elastomeric membrane, 25 years, no maintenance	Slight negative	Slight gain	Slight gain	Slight gain	Slight gain	Slight gain
	EPDM membrane, 40 years, annual washing	Slight gain	Slight gain	Slight gain	Average gain	Average gain	Slight gain
	EPDM membrane, 40 years, annual washing	Slight gain	Slight gain	Slight gain	Slight gain	Slight gain	Slight gain
Green wall	With initial chemical fertilization	Slight gain	Average negative	Slight negative	Slight negative	Slight gain	Slight gain
	No chemical fertilization	Slight gain	Slight gain	Slight negative	Slight negative	Slight gain	Slight gain
Planting arrangement	With initial chemical fertilization	Average negative	Average negative	Average negative	Average negative	Average negative	Average gain
	No chemical fertilization	Slight negative	Slight gain	Average negative	Average negative	Average negative	Average gain
	With annual chemical fertilization	Large negative	Large negative	Average negative	Average negative	Average negative	Slight gain
Tree	With initial chemical fertilization	Slight negative	Slight negative	Slight negative	Slight negative	Slight negative	Average gain
	No chemical fertilization	Slight negative	Slight gain	Average negative	Average negative	Average negative	Average gain
Reflective surface	—	Slight gain	Slight gain	Average negative	Average gain	Average gain	Slight gain
Permeable surface	—	Average gain	Average gain	Slight gain	Average gain	Average gain	Average gain
Rain garden	Capture of roof water and initial chemical fertilization	Slight gain	Slight gain	Slight gain	Slight negative	Slight gain	Average gain
	Capture of roof & parking area water and initial chemical fertilization	Average gain	Slight gain	Slight gain	Slight negative	Slight gain	Large gain
	Capture of roof water and annual chemical fertilization	Large negative	Large negative	Slight gain	Slight negative	Slight gain	Average gain
	Capture of roof & parking area water and annual chemical fertilization	Large negative	Large negative	Slight gain	Slight negative	Slight gain	Average gain
Infiltration trench	Capture of roof water	Slight gain	Average gain	Slight negative	Slight negative	Slight gain	Average gain
	Capture of roof & parking area water	Slight gain	Average gain	Slight negative	Average negative	Slight negative	Average gain
Dry well	Capture of roof water	Slight gain	Average gain	Slight negative	Slight negative	Slight gain	Average gain
	Capture of roof & parking area water	Slight gain	Large gain	Slight negative	Slight negative	Slight gain	Large gain

Legend

Slight gain based on indicator (0 > 50%)	Slight negative impact based on indicator (0 > -50%)
Average gain based on indicator (50 > 100%)	Average negative impact based on indicator (-50 > -100%)
Large gain based on indicator (100% >…)	Large negative impact based on indicator (-100% >…)

[a] Human health.
[b] Ecosystem quality.
[c] Climate change.
[d] Resources.
[e] Aquatic acidification.
[f] Aquatic eutrophication.
Source: Prepared by the authors based on the results presented by Martineau (22).

The study did not intend to compare UHI mitigation measures. Many factors, other than the indicators retained for the study—beautification, improved air quality, creation of wildlife habitat—must also be taken into consideration and cannot be quantified on the same basis. However, an LCA can be part of the decisionmaking process leading to implementation of UHI mitigation measures. It offers an additional tool that explores the potential environmental impact of a measure "from cradle to grave." An LCA enables a more informed choice to be made from among various scenarios proposed for the same measure.

Overall, it was found that actions to maintain UHI mitigation measures, especially those that involved fertilization or the addition of a layer of reflective coating to white roofs, can have significant negative impacts. Clearly, planting vegetation always makes an environmental impact in terms of resource consumption, but all measures must be evaluated according to their main function, namely that of reducing ambient temperature during heat waves, as well as their secondary functions. The LCA of secondary functions is important for getting further clarity on prioritizing future UHI mitigation interventions. In this case, the LCA report stated that UHI mitigation measures that do not require fertilization or maintenance (i.e., roof recoating) should be preferred.

DISSEMINATING RESULTS

An important effort was made to disseminate results and promote mitigation of UHIs. A website called *Mon climat, ma santé* (My climate, my health) was developed and has been routinely updated since 2011, engaging 150 000 unique visitors annually (23). The site has two sections, one directed at the general public and one for experts. Over 40 conferences on UHIs have been hosted by the INSPQ climate change team; scores of articles have been published in local newspapers following the announcement or completion of the UHI mitigation projects; and several interviews on radio and television, both by the INSPQ climate change team and project managers, have helped boost awareness of UHI mitigation nationwide.

During the course of the pilot projects, each project leader was required to put into place a communication plan and an education program that addressed the UHI issue and educated the population on its health effects. A successful outcome, for example, was the groups of people living in low-income housing who got together to evaluate the best opportunities for reducing UHI for their buildings. In all, this program rolled out more than 1 000 communication activities in 2010 – 2014.

WHAT NOW?

Based on the results of these pilot projects and the analyses and assessments that followed, initiatives arose for the health adaptation component of the 2013 – 2020 Climate Change Action Plan. For example, a project was launched on 15 October 2015 to densify vegetation in a large portion of Montréal that is crossed by highways and heavily industrialized (24). This area is also densely inhabited by vulnerable and deprived populations. The project is multifaceted and aims to green vacant fields, walls, and roofs; install white roof tops; develop ecological parking; and restore and increase landscaping favorable to biodiversity using the ecosystem-based approach of the United Nations Environment Program (25). This roster of interventions will also promote accessibility by active (e.g., bike riding, walking) and collective transportation, and brings together community stakeholders, as well as representatives from the education, municipal, and health fields, and the private sector as well. Collaboration with academic experts in urban forestry, biodiversity, and water management has also been organized by the initiative. It is hoped that the project will generate interest in similar projects that cool and green our cities, elsewhere in the province and beyond in the very near future.

This program conducted in the province of Québec demonstrates the benefits of urban heat island mitigation measures, not only in terms of heat reduction, but also in terms of social benefits. No doubt this experience can be transposed to numerous other cities, thereby contributing to the public health for the whole Region of the Americas.

Disclaimer: Authors hold sole responsibility for the views expressed in the manuscript, which may not necessarily reflect the opinion or policy of the *RPSP/PAJPH* and/or PAHO.

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RESUMEN

Programa eficaz de salud pública para reducir las islas de calor urbano en Québec, Canada

En el 2005, el Gobierno de la provincia de Québec, Canadá, adoptó un plan de acción sobre el cambio climático para el período del 2006 al 2012. El Instituto Nacional de Salud Pública de Québec (Institut national de santé publique du Québec), encargado de la adaptación del plan para proteger la salud humana, dio un paso para mitigar las islas de calor urbanas (ICU) mediante el financiamiento y la evaluación de 40 proyectos piloto. En estos proyectos se exploraron diferentes métodos para combatir las ICU a base de aumentar las áreas verdes con arreglo a un enfoque participativo y movilizador impulsado principalmente por las organizaciones no gubernamentales y los municipios. Cuando se examinaron las temperaturas antes y después de aplicar distintos métodos, se observó que algunos habían llevado a un enfriamiento ambiental apreciable y que eran más eficientes para aliviar el calor (reducir las superficies de concreto y asfalto, plantar vegetación, y demás). Una evaluación enfocada en la calidad de vida indicó que los proyectos tuvieron buena acogida entre los usuarios, sobre todo los que vivían en situaciones de vulnerabilidad. Un análisis basado en el ciclo vital demostró que, desde el punto de vista ambiental, las medidas para la mitigación de las ICU que no requieren abono ni mantenimiento son las más aconsejables. Por último, las iniciativas de comunicación orientadas a sensibilizar al público en torno a las ICU y su mitigación son muy importantes para lograr que los programas rindan buenos resultados.

Palabras clave Cambio climático; áreas verdes; salud urbana; medio ambiente y salud pública; calor; ola de calor; Canadá.