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# ENERGY AND HEALTH IMPACTS OF GLOBAL WARMING AND HEAT ISLAND EFFECTS IN MONTREAL: A CASE STUDY INTRODUCING A METHODOLOGY BASED ON STATISTICAL MATCHING OF RECORDED WEATHER DATA

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## ABSTRACT

General circulation models (GCMs) suggest that Québec, as in many locations, is likely to experience warmer conditions in the near future due to global warming. GCMs generally predict monthly temperature increases of 1°C to 2°C over the historic monthly averages (e.g. past 40 years) for the southern part of the province. In addition, urban heat island (UHI) phenomena have a compounding effect on global warming trends, further increasing anticipated temperatures in cities, e.g. in downtown Montreal. In northern climates such as Québec, it is increasingly recognized that global warming, compounded by UHI effects, would decrease on-site heating requirements and increase air-conditioning use - but to what extent? Building energy simulation is useful in investigating the energy impacts of global and regional climate change, as long as new weather files can be appropriately generated from forecasted monthly changes (e.g. monthly increases in temperature or precipitation). Such an effort is not straightforward, as the uncertainty in current GCM and UHI forecasts is quite significant in predicting anything than monthly shifts in temperature. This raises questions on the detailed effects of general warming trends, e.g. frequencies in heat waves, peak night/day temperatures? This paper proposes a methodology of generating suitable hourly weather data for future climate scenarios by statistically matching archival data to anticipated monthly shifts in temperature, similar to the *Sandia Method*. A similar methodology is proposed to take into account UHI effects. A case study illustrates the effects of global warming trends and UHI, in broad terms, on residential energy use and on thermal stress in the Montreal region.

## INTRODUCTION

Several general circulation models (GCMs) have been introduced in the last 15 years to predict climate mitigation, for instance global warming as a result of increased greenhouse gases (GHGs) in the atmosphere, changes in land use and increased industrialization.

A compounding phenomenon to global warming is the urban heat island (UHI), which designates a regional warming phenomenon largely attributable to the lack of radiative cooling of (warm) external building surfaces to the (cold) night sky, lack of cooling through evapotranspiration (i.e. lack of vegetation), the prevalence of solar-absorbing surface materials (e.g. sidewalks and streets) and increased heat output from transportation and industrial activities. The well-documented phenomenon can produce outdoor thermal conditions in cities several degrees higher than those of surrounding rural areas. In northern climates such as Québec, global warming, compounded with UHI effects, is expected to decrease heating requirements and increase air-conditioning use - but to what extent? For instance, two out of three single family houses are passively cooled in Québec: will rising temperatures turn free-running buildings - in what would likely still be considered a northern climate - a thing of the past? Strictly from an energy standpoint, will warming trends mean less or more energy use overall?

## CONTEXT AND SCOPE

During the summer of 2007, *l'Agence de l'efficacité énergétique du Québec* (AEE) mandated a task group of academics and consultants to investigate the potential energy impacts of global warming on the future building stock, based on predictions from GCM simulations for the period 2010-2039 in Montreal. The mandate also included energy impact assessments taking into account UHI effects in addition to global warming effects. Finally, the group was mandated to evaluate the impact of warming trends on thermal discomfort/stress within future (free-running) residential buildings, again for Montreal for the period 2010-2039. All assessments were to be based on annual energy simulations using example building models provided by the AEE. Hourly weather data had to be generated to take into account global warming, as predicted by GCM simulations, and UHI phenomena. Predicted median monthly temperature increases estimated by the Ouranos Consortium (Sotille 2006) were provided as targets to account for global warming. No specific indicators were provided as means of considering UHI effects. This paper proposes a methodology of generating future hourly weather data, considering global warming and UHI effects, as input for energy simulation. Similar to the *Sandia Method* (Hall et *al*. 1978), the proposed solution concatenates statistically-representative monthly weather data to anticipated conditions in the future, producing operational weather time series data as energy simulation inputs.

## GCM PREDICTIONS AND ENERGY USE

Several studies have been carried out to assess the energy use implications of global warming for various locations in the world as discussed in Wilbanks *et al.* (2007) and Crawley (2007b), usually based on predictions from general circulation models (GCM). GCMs are computer-driven models for weather forecasting, understanding climate and projecting climate change. According to Intergovernmental Panel on Climate Change (IPCC 2001), GCMs are the most advanced tools currently available to develop climate change scenarios. Provided with various scenarios of greenhouse gas emissions, GCMs can estimate a range of potential climate impacts.

GCM simulation results, such as projected monthly temperatures, have usually low spatial and temporal resolutions and contain biases that can make them unsuitable for e.g. short term local studies. As a means of better circumscribing the extent of uncertainty associated to GCM estimations, it is common to average results from several GCM simulations for a given set of inputs. Results are commonly compiled to provide monthly *mean* or *median*, *optimistic (low)* and *pessimistic (high)* scenarios of e.g. monthly temperature increases in the future. Published energy assessments of climate change have usually focused on median scenarios. A comparison of median predicted temperatures in the future against statistically representative climate data from the recent past (e.g. Canadian Climate Normals 1961-1990) provides a basis for determining weather data differentials (e.g. temperature differentials or delta Ts), which can be subsequently used to predict differences in energy use. Wilbanks *et al.* (2007) review a number of published studies on predicted changes in energy use patterns in the US and elsewhere for various time scales and GCM-predicted delta Ts, based either on econometric or more explicit building energy simulation methods.

One such study is a published report from the Ouranos Consortium in Québec (Chaumont 2005), in which climate projections for 2015-2045 and 2035-2065 were generated based on multiple GMC simulations. Median monthly temperature increases for southern Québec were found to be more important in winter than in summer, and a comparison of past versus future heating degree days (HDD) and cooling degree days (CDD) lead to the preliminary conclusion that global warming would imply net energy savings in the building stock. Recently, Zmeureanu and Renaud (2008) have proposed a method of estimating the potential impacts of climate change on heating energy use of existing houses, based on energy signatures derived from historical energy use data. Case study results for Montreal show a clear reduction of domestic heating energy due to future climate change (2040-2069), based on published Climate Normals (1961-1990).

The general rule that seems to emerge from the Wilbanks *et al.* review is that for locations with more than 4000 heating degree days (18°C based) - i.e. US states bordering Canada and colder regions - global warming would represent net energy savings considering building heating and cooling use, more so for residential than non-residential sectors. Stated otherwise, projected increases in air-conditioning stemming from warmer summer conditions would not outweigh projected savings in heating as a result of warmer winters. This finding is also supported by recent work from Crawley (2007b). The literature provides little information on the energy impact of global warming on both residential heating and cooling, and on thermal discomfort and stress in free-running houses, in northern climates.

## CONSIDERING URBAN HEAT ISLANDS

Streutker (2002) and Crawley (2007a, 2007b) have reviewed several studies on urban heat islands (UHIs), often based on extensive field measurements and providing differences in diurnal and seasonal patterns between urban and rural weather conditions. Runnells and Oke (2000), using Vancouver as an example, illustrate the general pattern: the UHI peaks at night and is at its least perceptible at mid-afternoon, mainly as a result of urban thermal inertia.

Many studies have focused on the thermal interaction between buildings and their surrounding environment. However, as mentioned by Oxizidis *et al*. (2007) and Crawley (2007a), most focus on the thermal impact of buildings on the urban microclimate, rather than on the impact of urban microclimate on building energy use. Kolokotroni et *al*. (2007) clearly show that building heating and cooling energy depends on the degree of urbanization in a particular location (i.e. radial distance from a city centre). Santamouris (2007) discusses the impact of UHI on night ventilation strategies. As pointed out by Ghiaus *et al*. (2006), urban environments, with lower wind speed, higher temperatures (due to the effect of UHI), greater noise and pollution, present disadvantages for the application of natural ventilation. Finally, Taha (1997) observed that the elevation of urban temperature generates a net energy penalty because of increased cooling requirements in several American cities.

Crawley (2007a) proposes a methodology for the generation of typical weather data for energy simulation that considers both global warming (based on selected GCMs, emission scenarios, and period) as well as UHI effects. A program was developed to modify typical year hourly dry and wet bulb temperatures, and direct normal and diffuse horizontal irradiances) using GCM-forecasted changes in cloud cover, temperature, diurnal temperature ranges, precipitation, and vapour pressure. Crawley suggests that UHI effects could be summarized as changes to the diurnal temperature patterns, which were implemented in the same program to change dry bulb and wet bulb temperature profiles.

A widespread hypothesis regarding global warming is that not only should temperatures increase on average but that summer heat waves would potentially be more frequent and more intense. One common technique of modifying typical weather files using GCM-predicted climate parameters is to simply add monthly delta Ts onto hourly temperature time series for a given month, such as suggested in Sotille (2006). Such an approach, while likely suitable for predicting annual energy use, appears obviously inadequate to model extended heat waves, and would also be unsuitable to model the effects of UHI, as the latter clearly is not well represented by a constant upward shift in temperature, but rather by significant changes in diurnal temperature patterns (i.e. warmer nights).

## PROPOSED METHODOLOGY

The proposed solution is based on the general recognition that, while it is necessary to generate hourly (e.g. high frequency) weather times series from archival data sets, there remains considerable uncertainty in predicting short term weather patterns (e.g. increased summer heat waves) from GCM calculations. The main assumption in the methodology - at least for taking into account global warming - is that forecasted climate changes against some reference period - e.g. monthly delta Ts - would allow one to redefine the target criteria to select statistically representative months for 'future' weather files based on archival sets: much like the Sandia Method used to generate statistically representative months for 'current' weather files, based on averages for a given period in the past. In a similar way, UHI could be well represented by comparing differences in temperature ranges and diurnal patterns using one or more sets of archival data for urban weather stations.

*Taking into account global warming*

Table 1 shows the GCM-predicted delta Ts (i.e. monthly mean temperature increases) provided by the Ouranos Group to the AEE for the Montreal region for the period 2015-2045 (median scenario). Months from the period of 1956-2006 that presented the closest mean monthly temperature compared to the forecasted delta Ts (using CWEC data as a reference) are listed. Archival data for the Pierre-Trudeau International Airport, i.e. the weather station selected for CWEC files, was used. Relative differences between the projected monthly increase in temperature and the mean monthly temperatures of the selected months are also listed.

**Table 1: Forecasted increase in mean monthly temperatures for Montreal (2015-2045, median scenario) provided by the Ouranos Group**

| | Increase ($^oC$) | Selected year | Difference (%) |
|---|---|---|---|
| January | 2.23 | 1969 | 0.0 |
| February | 2.38 | 2001 | 0.8 |
| March | 1.79 | 1985 | 1.3 |
| April | 1.71 | 1990 | 5.2 |
| May | 1.83 | 1989 | 5.4 |
| June | 1.63 | 1995 | 0.4 |
| July | 1.49 | 1989 | 2.6 |
| August | 1.80 | 1995 | 5.4 |
| September | 1.47 | 2001 | 6.7 |
| October | 1.56 | 1975 | 0.6 |
| November | 1.53 | 1991 | 1.6 |
| December | 1.88 | 1959 | 5.9 |

Similar to the Sandia method, these individual months are concatenated to form a complete year. Finally, because adjacent months may be selected from different years, discontinuities at the month interfaces are smoothed out for 6 hours at the start and end of each monthly set using curve fitting techniques. Apart from solar data, all other weather variables (e.g. wet bulb temperature, wind speed and orientation) were those of the selected files. Solar data was not changed, as the GCM predictions did not suggest significant changes in cloud cover (less than 10 W/m² difference). This produced the annual weather set labeled 'Ouranos'.

*Taking into account UHI*

The second step was to integrate UHI effect to the newly created 'Ouranos' file. To do so, temperatures over the last 12 years were obtained from urban (e.g. McTavish Station) and rural sites (e.g. Varennes) around Montreal. Then, patterns of UHI intensity were derived from differences between hourly temperatures from both data sets (rural versus urban). This provided UHI patterns and monthly mean delta Ts, which were then used to identify, again in a similar manner to the Sandia Method, monthly archival data from the McTavish (urban) station. Again, discontinuities between months were smoothed out. This generated the annual weather file labeled 'Ouranos-UHI'.

**Table 2: Urban and rural sites used to derive UHI intensity in the Montreal region**

| | McTavish (urban) | Varennes (rural) |
|---|---|---|
| ID | WMO 71612 | WMO 71184 |
| Latitude | 45° 30' 0" N | 45° 43' 0" N |
| Longitude | 73° 35' 0" W | 73° 23' 0" W |
| Elevation | 63 m (206 ft) | 192 m (629 ft) |

As noted by Wilby (2003), it is obviously acknowledged that urban-rural comparisons involving just two stations provide little indication of spatial variations in UHI characteristics within urban settings. Further work would be needed to generate alternate data sets for various urban microclimate settings. Nonetheless, the assumption is that the generated UHI scenario remains one - out of possibly many - likely UHI scenarios.

## COMPARISON OF GENERATED DATA

The two generated weather scenarios using the described methodology, 'Ouranos' (global warming) and 'Ouranos-UHI' (global warming + UHI), are compared to the CWEC file for Montreal, i.e. the historical reference.

Table 3 compares monthly mean and maximum temperatures for all three scenarios. Differences between monthly mean temperatures for CWEC and Ouranos show that, on average, global warming is more strongly felt in winter than in summer. Another noteworthy observation is that the differences in monthly maximum temperatures between CEWC and Ouranos scenarios are usually superior to the differences between monthly mean temperatures for the two scenarios. The observation seems to preliminarily substantiate the usefulness of the methodology. In opposition, and as supported in the literature, monthly maximum temperatures for the Ouranos-UHI scenario are often less than (or approximately equal to) the global warming scenario. In other words, despite a general increase in monthly mean temperatures (from 0.5°C to less than 2°C), one should not expect any substantial increases in monthly maximum temperatures due to UHI.

Figures 1 illustrates the mean hourly differences in temperatures between CWEC and Ouranos-UHI for August. The profile clearly shows that UHI affects more substantially nighttime rather than daytime temperatures.

**Table 3: Comparison of monthly mean (maximum) temperatures (°C) of CWEC (historical), Ouranos (global warming) and Ouranos-UHI (global warming + UHI) scenarios for Montreal**

| | CWEC | Ouranos | Ouranos-UHI |
|---|---|---|---|
| January | -10.5 (10.0) | -8.3 (5.0) | -6.9 (3.3) |
| February | -9.4 (4.4) | -7.1 (7.8) | -5.3 (5.7) |
| March | -3.4 (9.4) | -1.7 (16.2) | -0.2 (10.7) |
| April | 5.2 (23.3) | 6.9 (27.8) | 7.8 (21.4) |
| May | 12.9 (27.2) | 14.8 (30.8) | 15.4 (30.6) |
| June | 18.6 (30.0) | 20.2 (33.3) | 20.8 (32.9) |
| July | 20.7 (31.7) | 22.1 (33.2) | 23.7 (35.0) |
| August | 19.6 (28.9) | 21.5 (35.1) | 23.0 (34.8) |
| September | 14.6 (27.2) | 16.0 (31.3) | 17.4 (31.7) |
| October | 7.8 (22.8) | 9.3 (21.7) | 10.4 (25.0) |
| November | 1.2 (17.2) | 2.6 (18.2) | 3.8 (13.9) |
| December | -6.8 (5.6) | -4.8 (6.1) | -3.8 (7.1) |

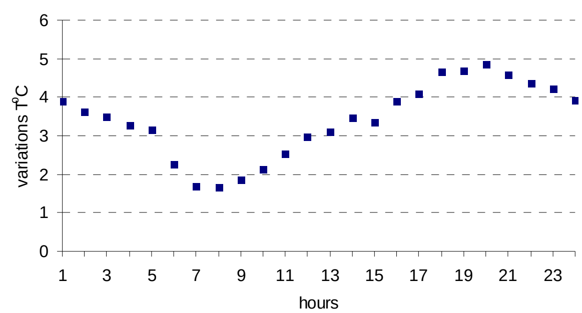


**Figure 1: Mean hourly differences in temperatures between Ouranos-UHI and CWEC data for August**

Table 4 compares heating degree days ($HDD_{18°C}$) and minimum temperatures on file for all three scenarios. As expected, the analysis supports the general understanding that HDD and minimum peak temperatures would decrease noticeably when taking into account global warming and UHI.

Typically, heat waves are described as periods comprising at least three consecutive days with maximum temperatures exceeding some chosen threshold. Tables 5 and 6 show differences in predicted heat waves using either 30°C or 32°C as a threshold. The first line in Tables 5 and 6 indicates the number of distinct heat waves for each scenario, while the second line indicates the number of days that comprise heat waves. Finally, the third line provides an indication of the total number of days when the chosen temperature threshold is exceeded, regardless of whether such days are part or not of identifiable heat waves. Despite noticeable increases in mean and peak summer temperatures (as shown in Table 3), results in Tables 5 and 6 indicate that Montreal's recent climatic history does not suggest any significant increase in the number or extent of heat waves, when considering global warming scenarios. The total number of 'hot' days does increase substantially however. On the other hand, Montreal's recent urban climate history (i.e. which could represent combined global warming and UHI scenario), while not predicting any rise in maximum summer temperatures, does suggest a substantial increase in the number and extent of urban heat waves.

**Table 4: Comparison of heating degree days ($HDD_{18°C}$) and minimum temperatures of CWEC (historical), Ouranos (global warming) and Ouranos-UHI (global warming + UHI) scenarios for Montreal**

| | CWEC | Ouranos | Ouranos-UHI |
|---|---|---|---|
| $HDD_{18°C}$ | 4690 | 4200 (-10%) | 3868 (-18%) |
| min. (°C) | -28.9 | -21.7 | -20.9 |

**Table 5: Comparison of predicted heat waves using 30°C as a threshold criteria for CWEC (historical), Ouranos (global warming) and Ouranos-UHI (global warming + UHI) scenarios for Montreal**

| | CWEC | Ouranos | Ouranos-UHI |
|---|---|---|---|
| heat waves | 1 | 2 | 5 |
| heat wave days | 5 | 7 | 20 |
| days > 30°C | 7 | 21 | 35 |

**Table 6: Comparison of predicted heat waves using 32°C as a threshold criteria for CWEC (historical), Ouranos (global warming) and Ouranos-UHI (global warming + UHI) scenarios for Montreal**

| | CWEC | Ouranos | Ouranos-UHI |
|---|---|---|---|
| heat waves | 0 | 0 | 3 |
| heat wave days | 0 | 0 | 9 |
| days > 32°C | 0 | 5 | 17 |

## CASE EXAMPLE

To gather more insight on the energy and thermal comfort implications of both scenarios within buildings, a residential case study is carried out. The case house was provided by the AEE as an example of future market trends. It is a two storey single family detached house with a heated basement and garage, and a total floor area of 274 m² (or 2950 ft²).

Detailed representations of the house were modeled in both ESP-r (Figure 2) and DOE-2.1E. The ESP-r model provided coupled airflow and thermal simulation (e.g. to study the effects of free-running night cooling strategies), while the DOE-2.1E model allowed a quick yet sufficiently accurate estimation of energy use. Using two distinct models also provided the group with a means of quality control (which indeed became useful). A series of seasonal simulations were carried out to ensure that both models predict approximately the same thermal behavior, which required specific adjustments to the way air exchanges were simulated in DOE-2.1E, requiring the integration of a custom free-cooling function.

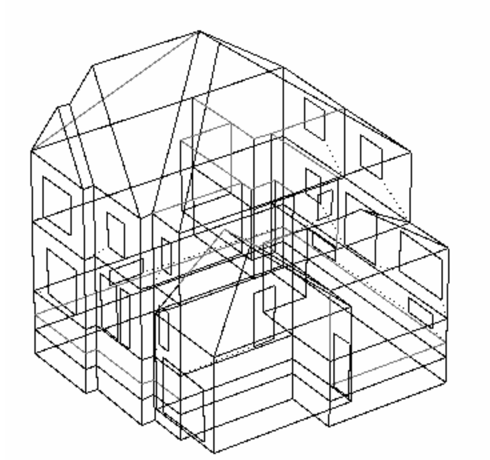

**Figure 2 - ESP-r model of the housing case study**

Building construction is assumed to follow current timber-framed practice standards, compliant to current code specifications. It is mechanically ventilated following code requirements, with heat recovery. The house is equipped with electric baseboard heaters (set point 21.5°C, no night set back), and is modeled with and without central air-conditioning (set point 24.0°C). Under free-running summer scenarios, heating and air-conditioning is assumed to be deactivated, and occupants are assumed to operate window blinds and operable windows under the following (ideal) behavior: Window blinds are retracted in winter and deployed in summer. In free-running modes (summer months), windows are opened when cooler outdoor conditions prevail, and in evenings for night cooling purposes. The front of the house, which faces NNE, has brick cladding while the other facades are vinyl-clad. All windows have insulated glass units (U = 3.2 W/m².K, SHGC = 52%).

Figures 3, 4 and 5 illustrate the energy use distribution for the (air-conditioned) case house, based on the CWEC, Ouranos (global warming) and Ouranos-UHI (global warming + UHI), respectively. All three cases show that Montreal, despite projections of warming trends, should continue to be considered as having a northern climate: heating represents more than 50% of energy use in all cases.

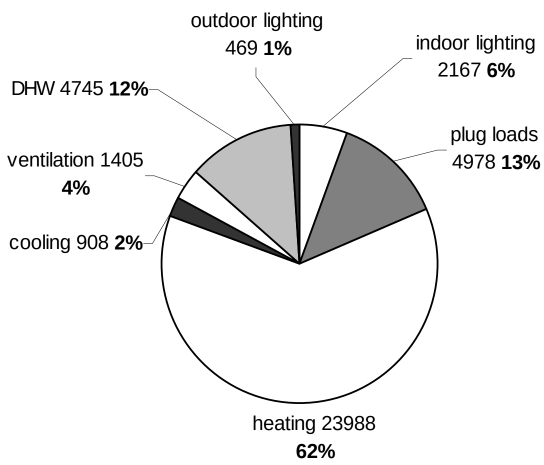


**Figure 3: Case house energy use distribution (CWEC). Values are in kWh/year.**

Warming trends (from CWEC, to Ouranos, to Ouranos-UHI) do increase air-conditioning use substantially, as expected. Air-conditioning operation costs for such a house in the future and set in a Montreal urban setting would cost twice as much as it would for the same house today in the southern Québec countryside. However, the projected costs of air-conditioning would remain fairly low in all cases: at 0.07$/kWh, central air-conditioning would cost this home owner 64$, 111$ and 135$ annually under CWEC, Ouranos, and Ouranos-UHI climate scenarios, respectively, i.e. within the same range of operating costs for swimming pools.

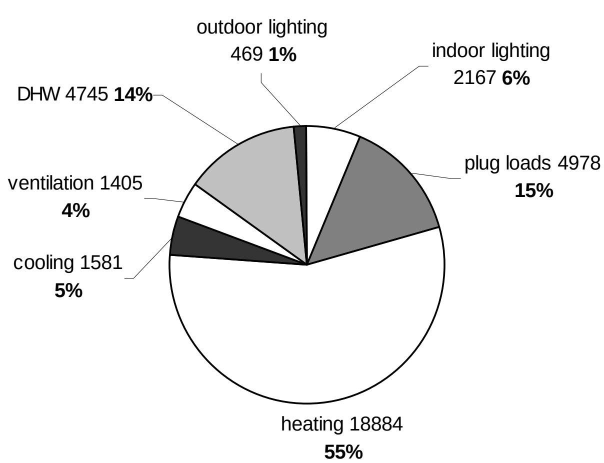


**Figure 4: Case house energy use distribution (Ouranos). Values are in kWh/year.**

By the same token, and as expected, warming trends reduce energy used for heating substantially. Overall, as illustrated in Figure 6, projected savings in heating for the case house, stemming from warming trends, significantly outweigh the projected increase in air-conditioning use. The Ouranos and Ouranos-UHI scenarios represent overall savings against the reference CWEC scenario of 11% and 13%, respectively.

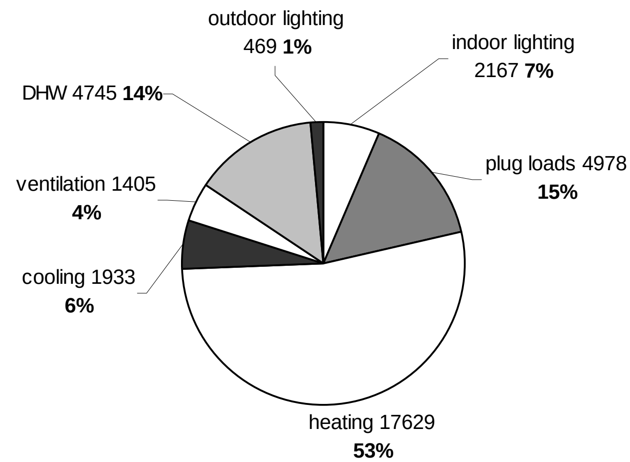


**Figure 5: Case house energy use distribution (Ouranos + UHI). Values are in kWh/year.**

Despite shifts in energy use patterns, global warming and UHI effects do not seem to represent alarming situations in the Montreal context, as long as mechanical cooling is provided. In the absence of mechanical air-conditioning, the situation is more critical. Table 7 provides indoor overheating metrics derived from simulation results, for reference (CWEC), global warming (Ouranos) and combined global warming and UHI (Ouranos-UHI) scenarios, based on the ISO 7933 (2004) standard for hot environments, rather than 7730 (2005) for normal occupancy. ISO 7933 is commonly used to predict sweat rates and internal core temperatures that the human body will develop in response to a given set of (hot) environmental conditions, which could lead to excessive core temperature increase or water loss. Table 7 shows results for a reference case when all windows are open (significant night cooling potential), and when window area is adjusted to provide approximately 50% of the natural air change rate of the reference case (evocative of urban canyon settings, or poorly ventilated units). ISO 7933 metrics were calculated only when the ISO 7730 predicted mean vote (PMV) exceeded +0.5 at a given time step (the annual number of hours indicated in Table 7). Estimated exposure times with which the physiological strain is deemed acceptable (less than 5% water loss through sweating) or *maximum allowable exposure times* (MAET) in hours are also provided. The assumptions are that occupants (in the house continuously) drink regularly, are dressed lightly, have a metabolic rate of 0.8 MET, and, more importantly, that local air speeds are in the order of 0.8m/s (quite optimistic for natural ventilation in urban settings, suggesting the use of local fans).

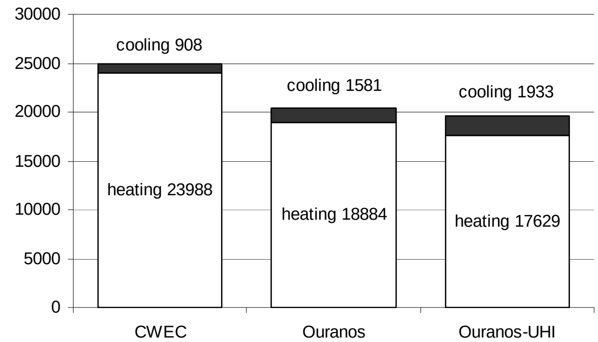


**Figure 6: Comparison of case house energy use (CWEC, Ouranos and Ouranos-UHI). Values are in kWh/year.**

**Table 7: Comparison of predicted thermal stress (ISO 7933) for CWEC (historical), Ouranos (global warming) and Ouranos-UHI (global warming + UHI) scenarios**

| | **CWEC** | **Ouranos** | **Ouranos-UHI** |
|---|---|---|---|
| h > PMV +0.5 | 17 | 53 | 137 |
| MAET (h) | 25 | 22 | 19 |
| **-50% vent.** | | | |
| h > PMV +0.5 | 47 | 97 | 243 |
| MAET (h) | 22 | 19 | 17 |

For the reference case, the ISO 7933 standard calculations do indicate for either climate scenarios that the MAET hours were exceeded, although the Ouranos-UHI case did generate approximately 20 hours with indoor temperatures exceeding 32°C (likely enough to increase mortality rates among the elderly). When natural ventilation rates are approximately cut in half, the MAET hours are systematically shorter. The Ouranos-UHI scenario, in this case, generated 59 consecutive hours of thermal stress (when the calculated limit is 17). This is indeed a source of concern for poorly ventilated housing units; a preliminary conclusion that has been brought to the attention of government and municipal health authorities.

## SUMMARY AND DISCUSSION

This paper proposes a methodology for generating weather data for building energy simulation, based on GCM-forecasted climate/microclimate change due to global warming and urban heat island (UHI) effects. The proposed methodology is based on statistically matching archival data to anticipated monthly shifts in temperature, similar to the *Sandia Method*. A similar methodology is proposed to take into account UHI effects. Improvements to the methodology are anticipated, such as allowing some spatial urban variations (depending on the data availability of urban weather stations), but it should be underlined that its initial purpose is for predicting trends in energy use and thermal comfort in very broad terms, not for the purpose of assessing the energy/comfort implications of a new building design in a specific urban location. The solution has not yet been validated, but it does hold some intrinsic degree of veracity as it does rest on the reuse of measured archival data, i.e. there is indeed, on record, monthly weather data that is statistically similar to forecasted warming trends.

A case study illustrates the effects of global warming (Ouranos scenario) and combined global warming/urban heat island (Ouranos-UHI scenario) trends on residential energy use in the Montreal region. Despite a projected sharp increase in relative air-conditioning use, substantial savings in heating contribute in lowering energy consumption overall. A gross projection of the impact of massively adopting air-conditioning in the Québec residential sector (100% rather than ~30%) under the Ouranos-UHI climate scenario (and the assumption that the investigated house would be statistically representative of the future building stock) suggests a net increase of ~4% in overall energy use. Considering that the Ouranos-UHI scenario represents ~13% savings overall for the investigated house, there remains a net savings in energy use despite massively adopting air-conditioning. One frequent published concern regarding changes in air-conditioning use due to climate mitigation is a very likely increased stress in electrical grids. This is likely to be true for most locations in the world, given the current mix of central electricity generation and the likelihood that peak grid stress occurs in summer. For many reasons (e.g. geographical and climatic), peak electricity use in Québec has historically been much greater in winter than in summer. Despite massively adopting air-conditioning in Québec's new residential stock under the Ouranos-UHI scenario, gross projections indicate that summer electricity peaks would remain under 50% of winter electricity peaks.

Simulation-based assessments of health risks due to summer overheating in the investigated house (free-running variant) suggests that there is room for concern, especially when considering the most vulnerable age groups (elderly and children) in poorly ventilated units. Attempts to reduce overheating risks (or air-conditioning use) through *permanent* design choices (e.g. greater solar reflectivity of envelope materials) have meant, in the investigated case, a net increase in annual energy use. Trying to offset summer health risks while lowering overall energy in such a context strongly supports the integration of seasonal - rather than permanent - design and operational strategies, such as increased urban (deciduous) vegetation, providing both seasonal shading and cooling (through evapotranspiration).

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