Toronto2030 platform and data driven statistical models: UBEM in face of Climate Changes

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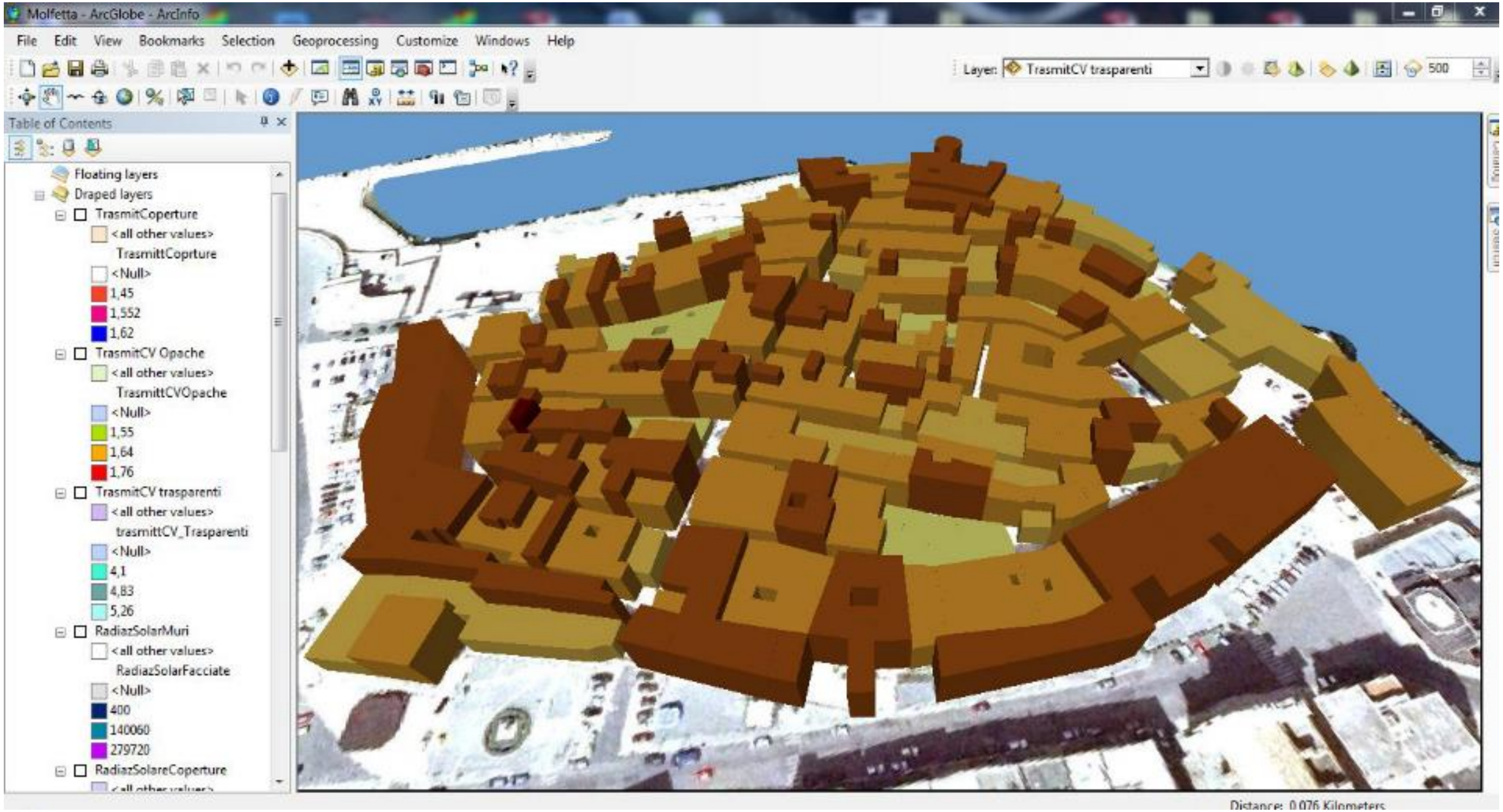
The Climate Reality Project®

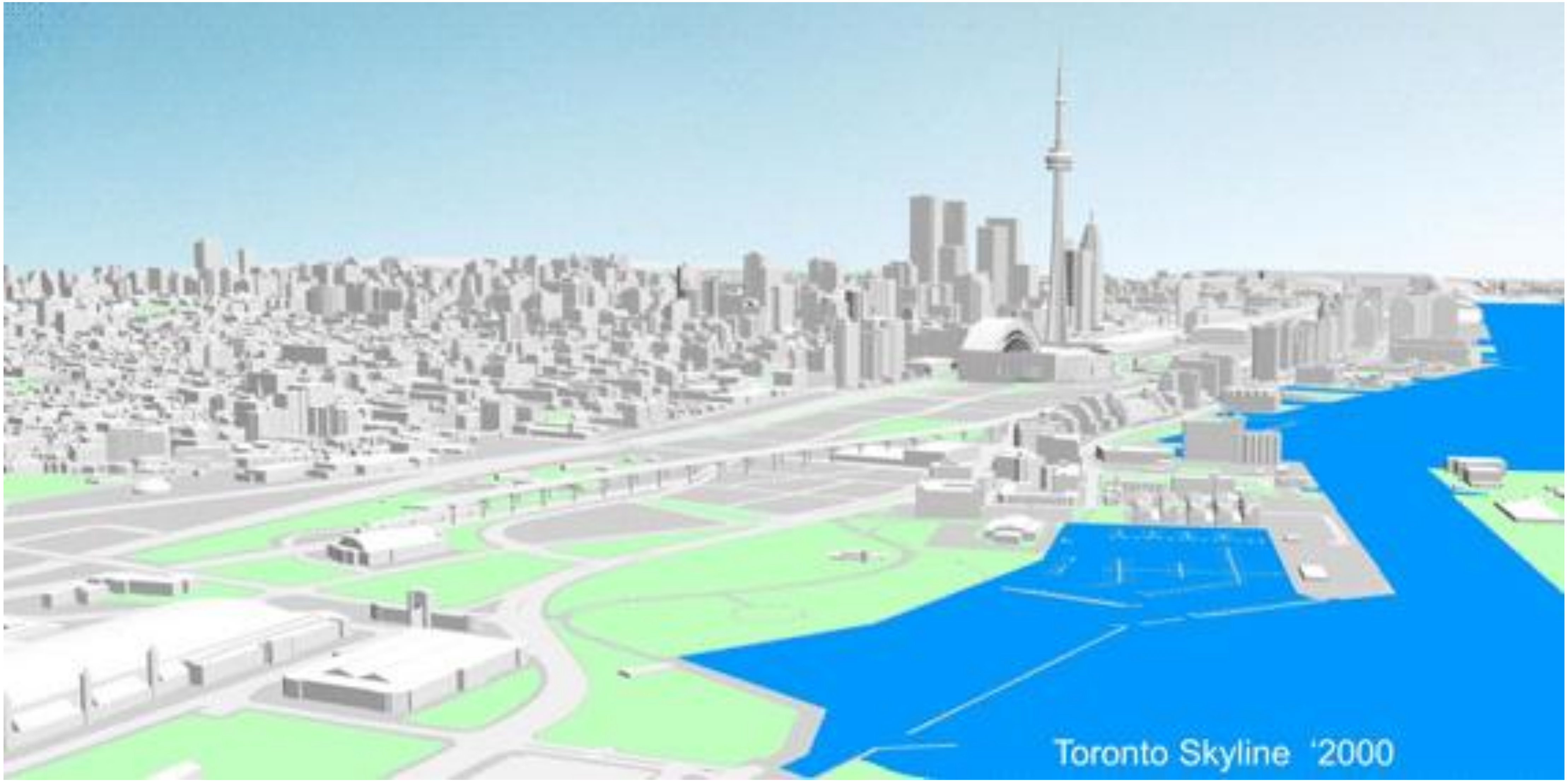
Toronto Metropolitan University

Ph.D. thesis 10 years ago



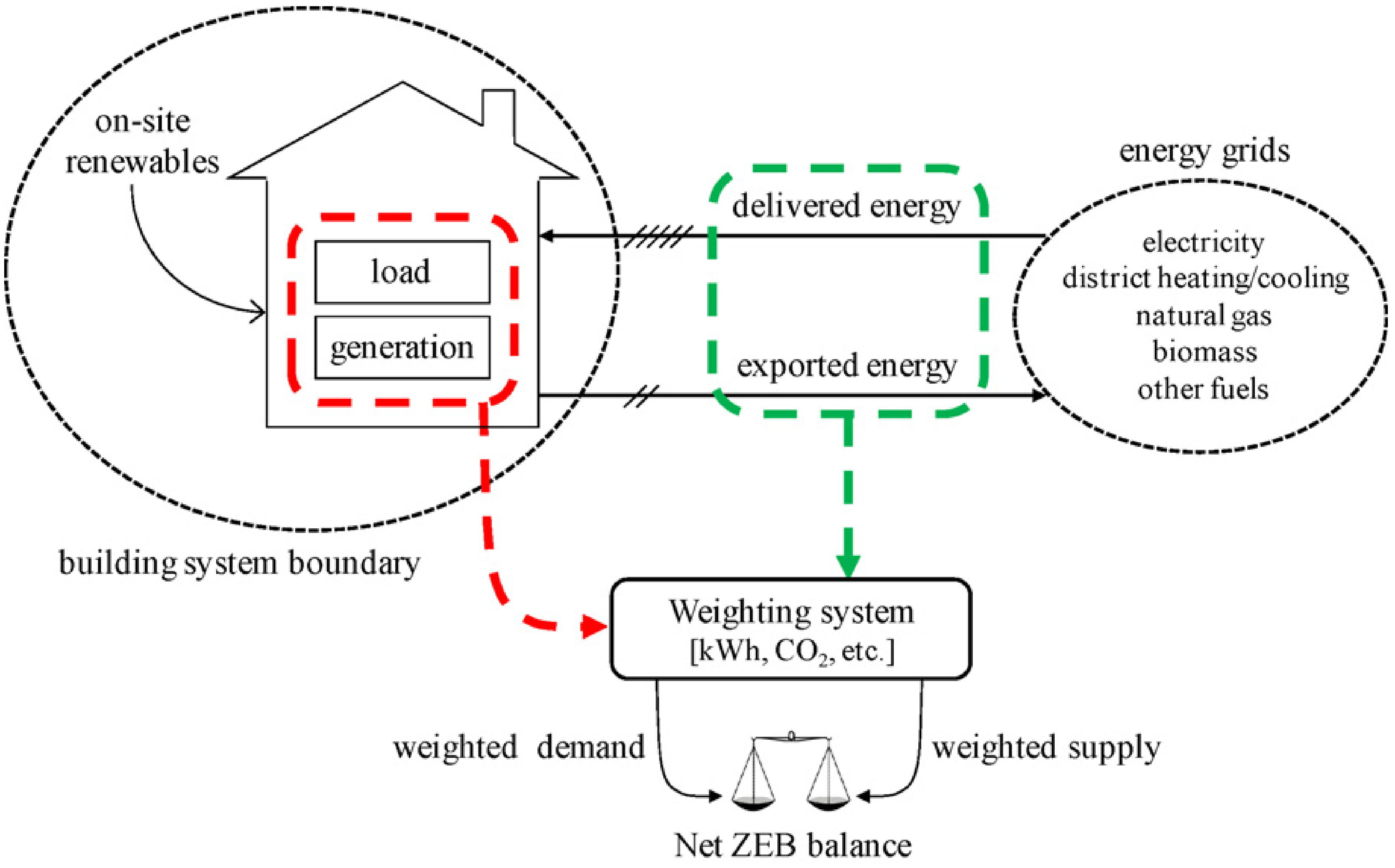
BeTOP - Building efficiency: Testing, Operation and Performance

BeTOP: Zero Building-Urban Energy Group



Buildings and SDG

Many different Zero Energy Building(s)



Berardi, 2020

We work on Models, knowing their limits

Modeled Performance Isn't Actual Performance

BY JAMES V. DIRKES II, P.E., BEMP, MEMBER ASHRAE; BRAD WEAVER, P.E., BEAP, MEMBER ASHRAE

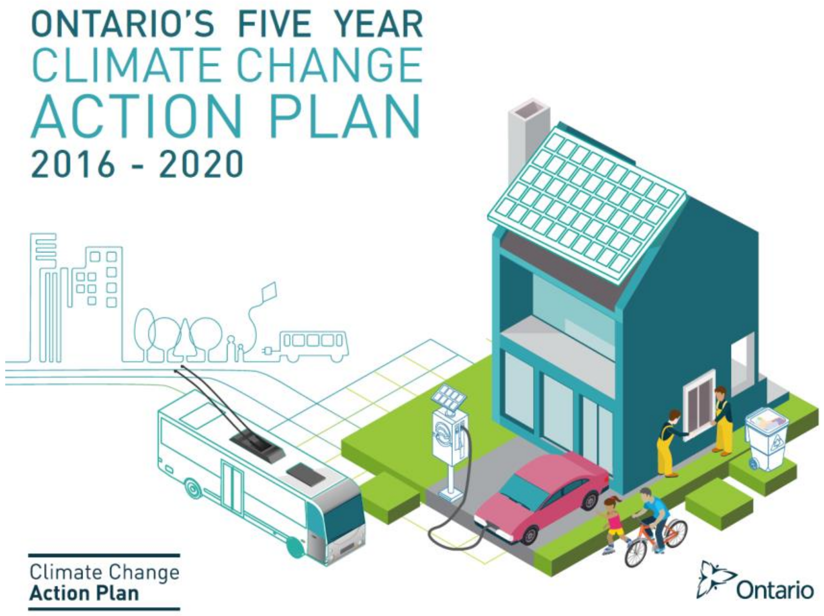
"All (energy) models are wrong, but some are useful." For as long as predictive models of any sort have been prepared, there has been a (sometimes raging) discussion about how accurate they are. Essentially, they're all wrong if you consider accuracy as "matching reality exactly." They can be very useful, however. The challenge is to recognize where and why models diverge from reality and when it matters for the purpose at hand. In other words, how can we maximize "usefulness?"

56 ASHRAE JOURNAL ashrae.org MAY 2016

Why do we need Urban (Energy) Models?

- How green is my city?
- What is the cost of new code compliant?
- What code changes will get us there in the most cost effective manner?
- What technologies will get us to NZEB and how to promote incentive for their adoption?
- We are trying to improve our ability to complete cities scale analyses for assessing energy saving opportunities while minimizing the number of data sources involved..

TransformTO



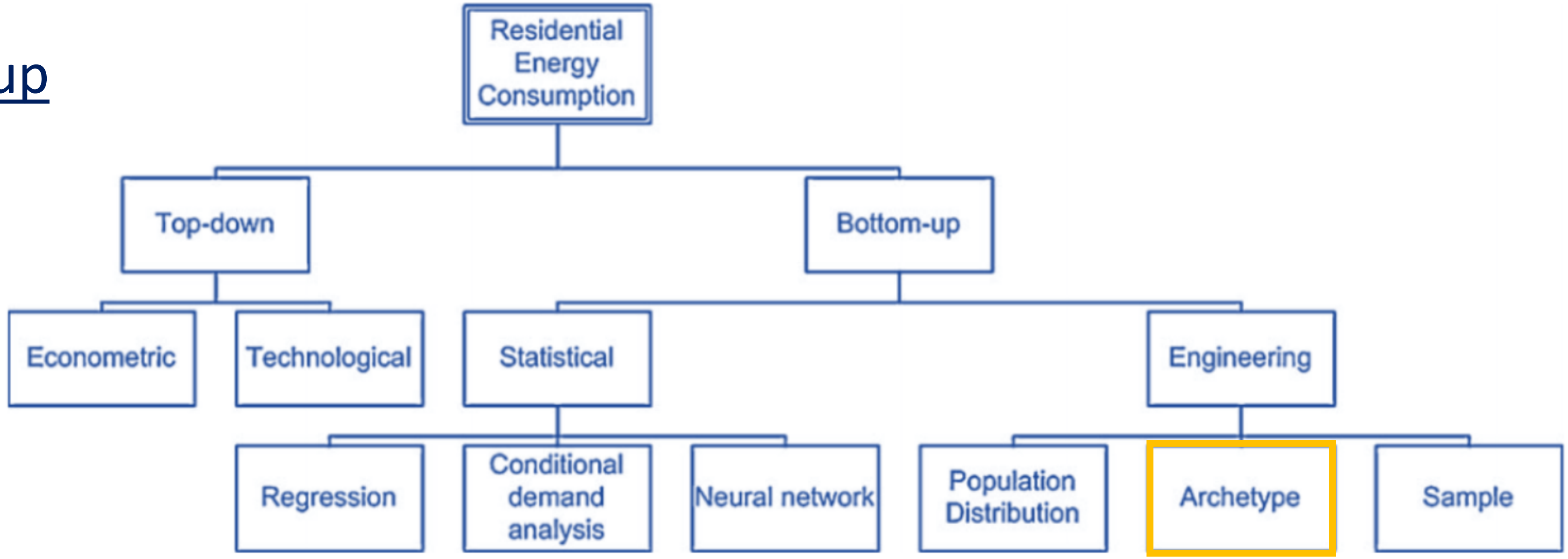
Toronto has leading our agenda

- In response to global challenges, **city governments** world-wide have developed ambitious long-term GHG emission reduction targets such as 40% and 60% by 2025 (San Francisco and London) or 80% by 2050 (New York City and Boston).
- In order to notably reduce those emissions, we need to understand better which sectors and buildings currently cause those emissions and what effects retrofitting programs and supply infrastructure changes may help.
- The importance to understand city-life goes beyond energy modelling and involves parameters such as **GHG emissions**, **urban microclimate**, **walkability**, **daylight distribution** (and **solar access**), and so on..

Possible approaches to UBEM

General approaches to urban (energy) modelling:

- Top-down
- Bottom-up



Bottom-up Models

At the meta-scale (from several dozens to thousands of buildings) "**bottom-up**" urban building energy models (**UBEM**) are a **key planning tool** for utilities, municipalities, urban planners and architects.

"Bottom up" models are based on individual building data processed statistically, analytically or both.

Bottom-up models guarantee:

- Higher detail of the analysis
- Estimate energy consumption of end uses or for individual dwellings
- Results scaled to estimate regional or national energy consumption

Bottom-up Models

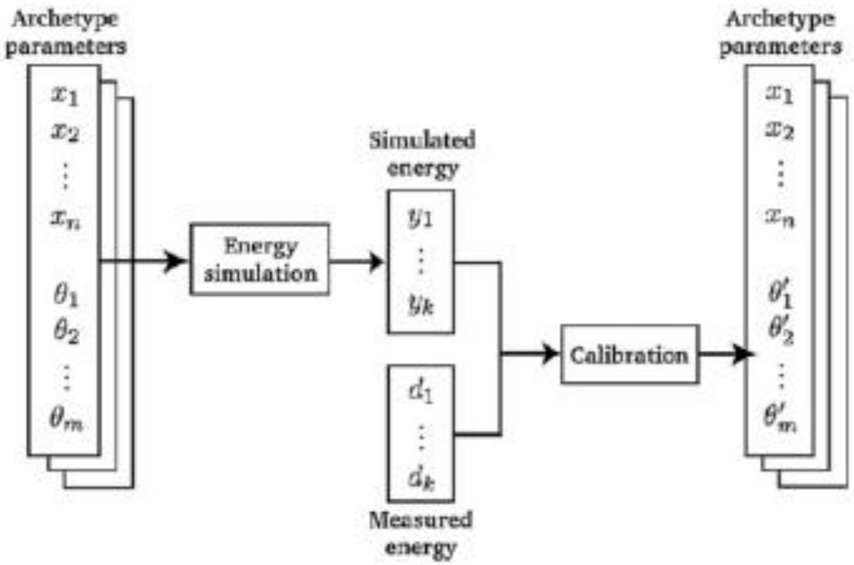
1. Statistical models

- Regressions and historical data for end-uses and energy consumption
- Neural networks
- Conditional demand analysis

2. Engineering models

- Appliance power ratings/usage
- Heat transfer and thermodynamics
- *Example*: Building Performance Simulation tools

Example



x: deterministic parameter
θ: probabilistic parameter

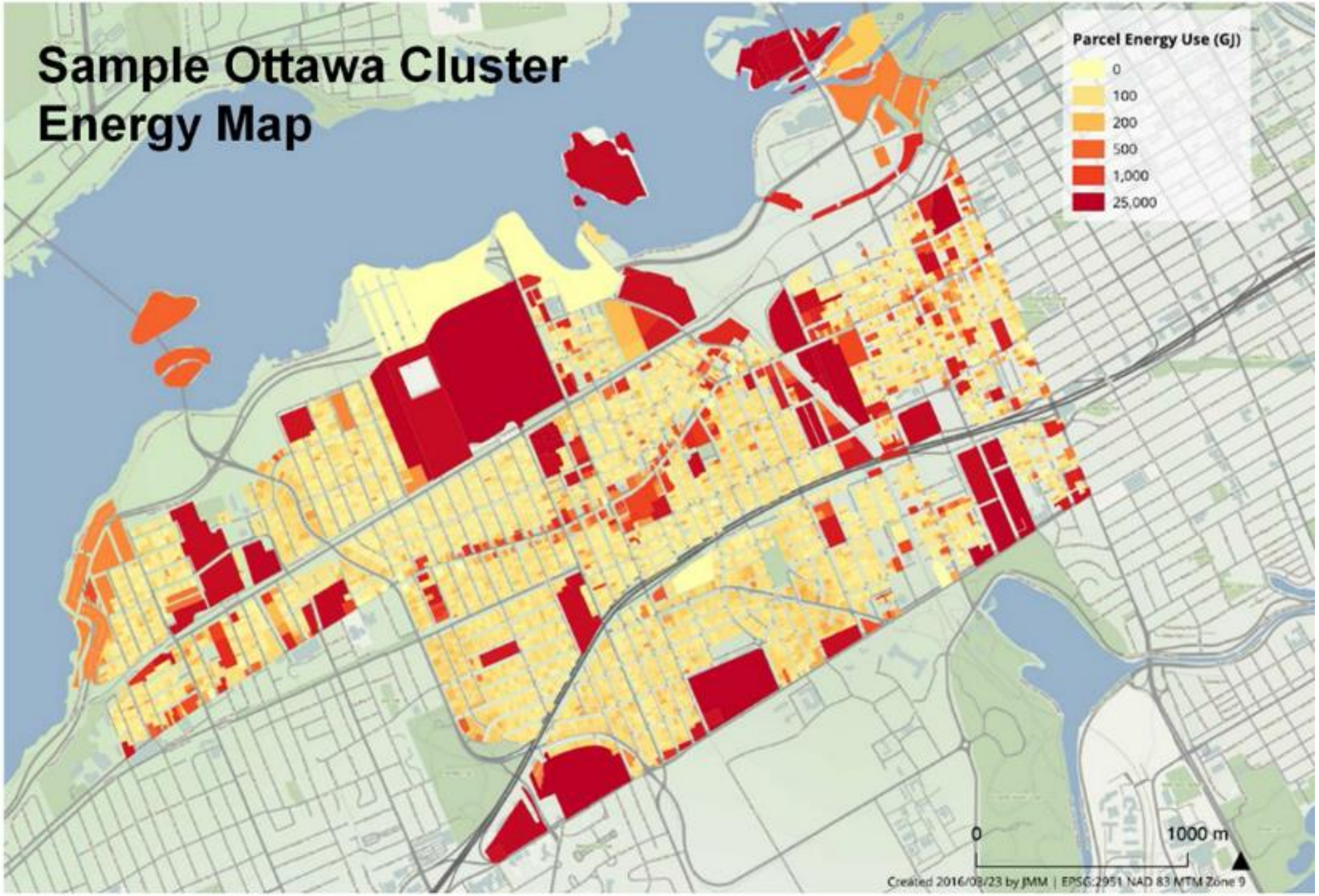
Training set in black box, simulated buildings in purple

Sokol, J., Cerezo Davila, C., & Reinhart, C. F. (2017). Validation of a Bayesian-based method for defining residential archetypes in urban building energy models, *Energy and Buildings*, 134, 11–24.

Data input in UBEM

An UBEM requires the combination of several data sets, including:

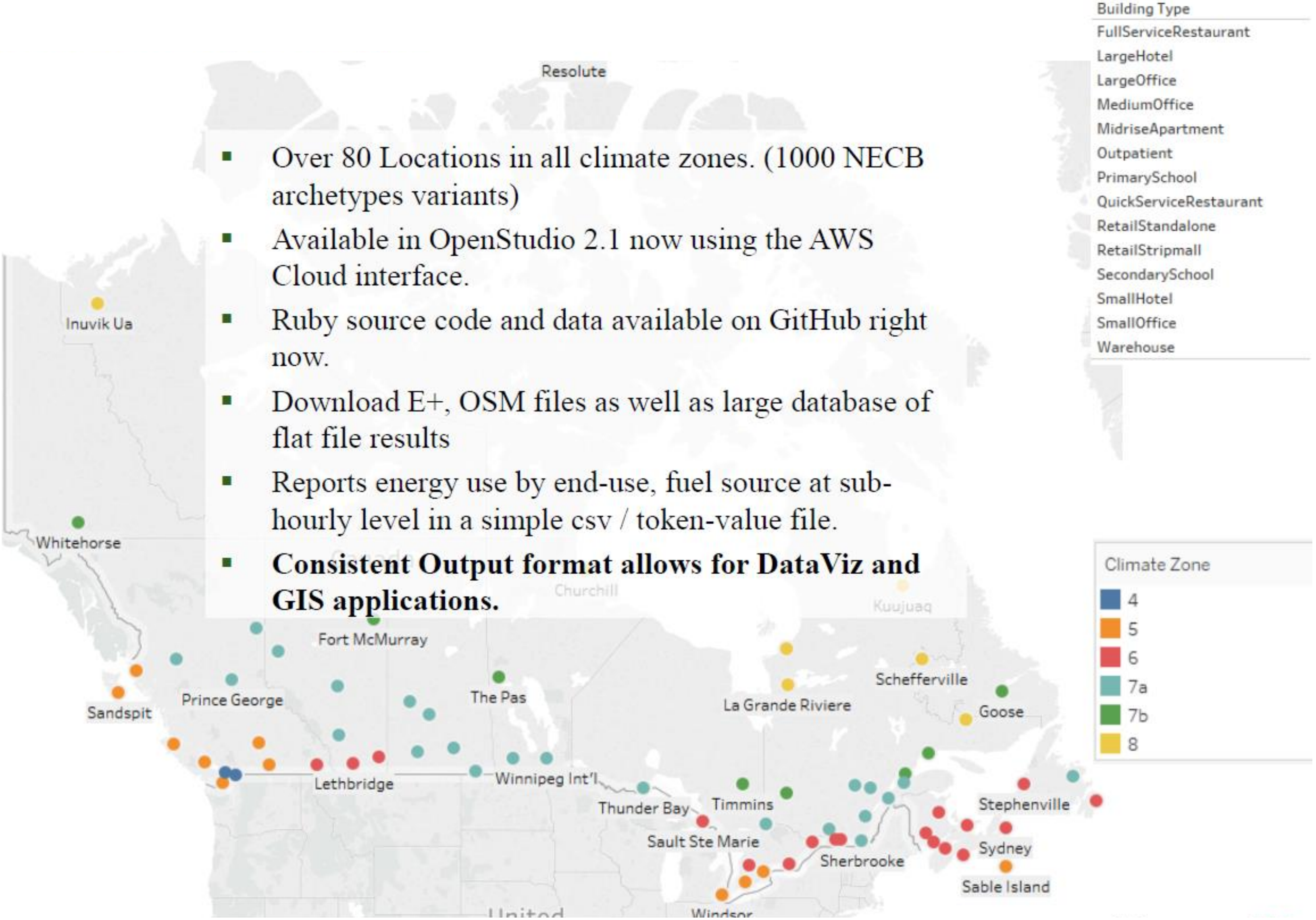
1. climate data: TMY or XMY, UMY, DSY, HSY, etc.
2. building geometry: input data required by an UBEM consists of building envelope shapes and window opening ratios as well as terrain data. City-wide **GIS** databases are increasingly accessible to the public
3. construction standard: non-geometric building properties have to be defined as well, including construction assemblies and HVAC systems. It is therefore necessary for an UBEM to abstract a building stock into “building archetypes”.
4. usage schedules: .. *finally*, some modelling of the variation in the occupant behaviors (at the urban scale) is necessary



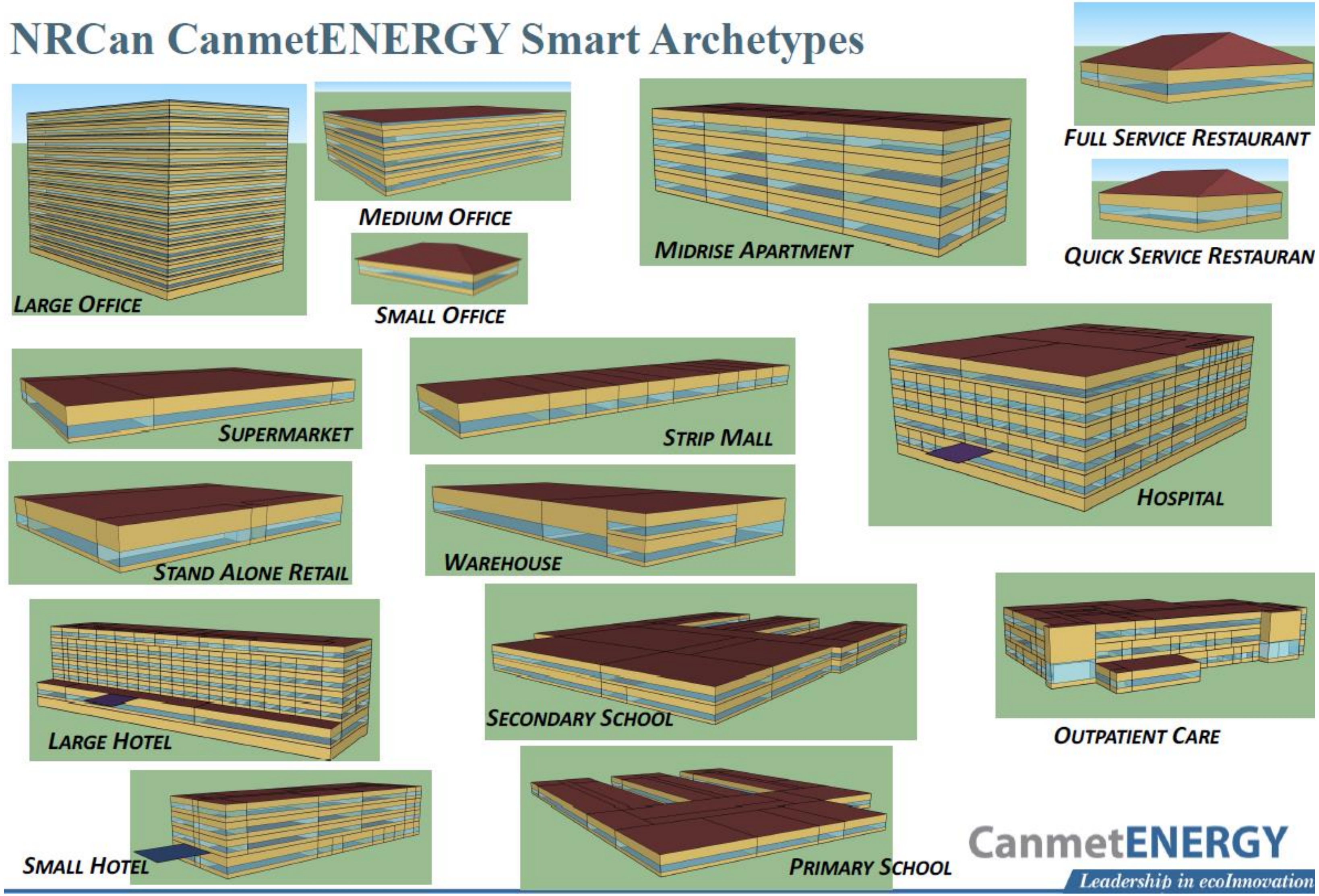
This is an example of an heating energy map for an area of Ottawa that was completed by NRCan to generate building energy estimates – this would be a typical map developed by a municipality as part of a CEP. The colors indicate estimated annual heating energy assigned at the parcel scale.

Current Building Archetypes for Canada

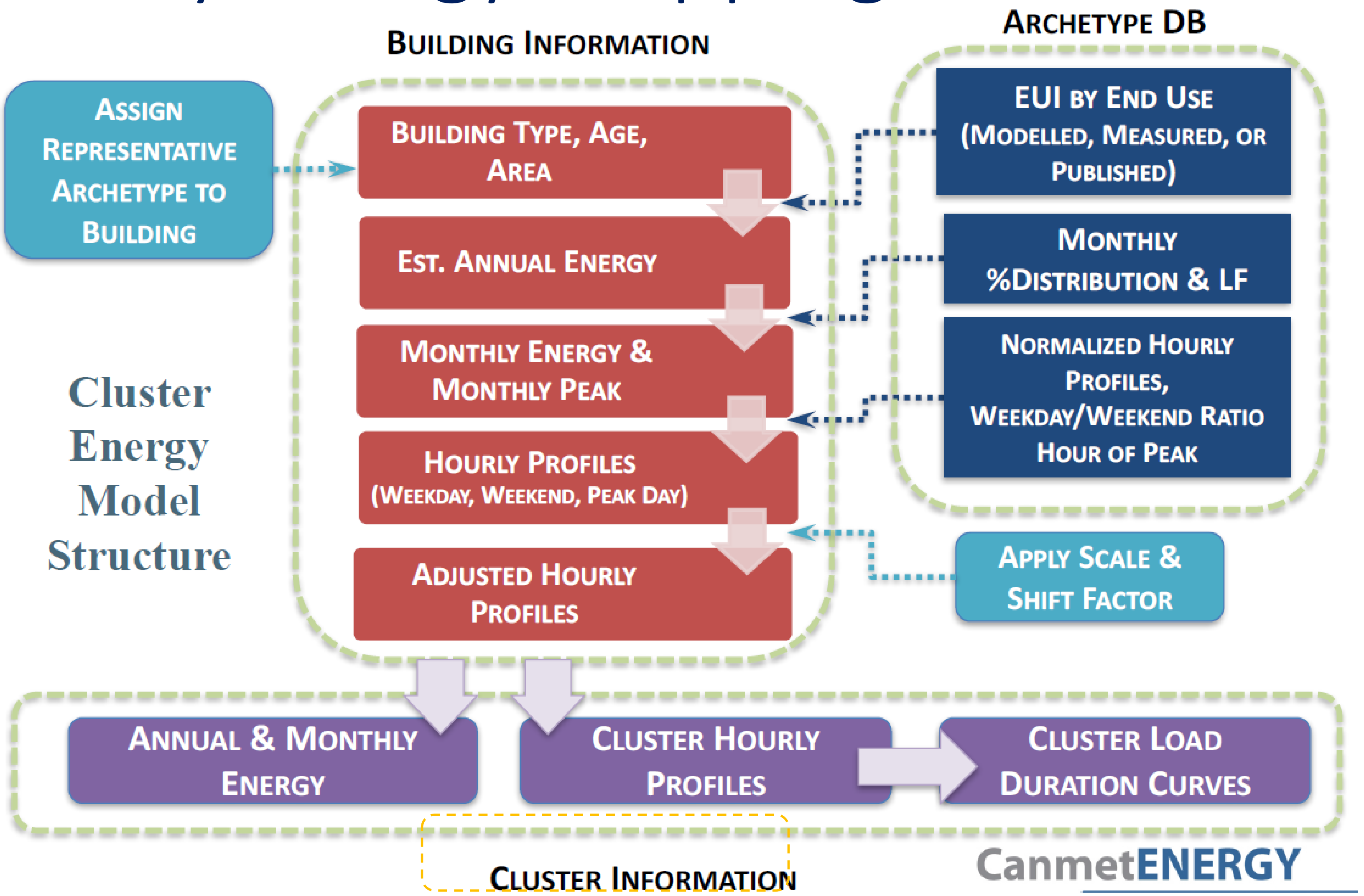
- Over 80 Locations in all climate zones. (1000 NECB archetypes variants)
- Available in OpenStudio 2.1 now using the AWS Cloud interface.
- Ruby source code and data available on GitHub right now.
- Download E+, OSM files as well as large database of flat file results
- Reports energy use by end-use, fuel source at sub-hourly level in a simple csv / token-value file.
- **Consistent Output format allows for DataViz and GIS applications.**



Current Building Archetypes



Community Energy Mapping



Archetypes approach

Table 1
Summary of building archetype definitions.

Scale of application	# of buildings[a]	Segmentation parameters	# of archetypes	Characterize method	B/A ratio	Reference
Urban (Osaka)	1128	Shape/Area	20	Virtual	56	[43]
Urban (Houston)	[b]	Shape/Age/Use/System	30	Virtual	[b]	[35]
Urban (London)	267,000	Shape/Age	144	Virtual	1854	[21]
Urban (Carugate)	1320	Age	7	Sample	189	[29]
Urban (Milan)	[b]	Shape/Age/Use	56	Virtual	[b]	[44]
Urban (Rotterdam)	300,000	Shape/Age	26	Virtual	11,538	[36]
Urban (several US locations)	200	Shape/Age/Use/System	12	Virtual	17	[37]
	33,000		37		892	
	200,000		17		11,765	
	15,000		25		600	
Urban (Basel)	20,802	Shape/Age/Use	20	Virtual	1040	[39]
National (UK)	115,751	Shape/Age	47	Virtual	2463	[28]
National (Italy)	11,226,595	Shape/Age/Climate	96	Sample	116,943	[30]
National (Greece)	2,514,161	Shape/Age/Climate	24	Sample	104,716	[31]
National (Greece)	2,514,161	Shape/Age/Use/System	5	Virtual	502,832	[45]
National (Italy)	877,144	Shape/Age/Climate/System	3168	Virtual	277	[33]
National (Ireland)	40,000	Constructions/Thermal	13	Virtual	3078	[40]
Regional (Sicily)	171,000	Shape/Age/Climate	84	Virtual	2036	[32]
National (France, Spain, Germany, UK)	14,916,600	Shape/Age/Climate/System	92	Sample & Virtual	162,137	[46]
	9,804,090		120		81,700	
	18,040,000		122		147,869	
	20,496000		252		81,333	
National (Finland)	36,000	Age/Use	12	Sample	3000	[34]

[a] Number of buildings to be represented by archetypes.
[b] Number of buildings not available in the study.

Reinhart & Cerezo Davila (2016). Urban building energy modeling – A review of a nascent field. *Building and Environment*, *97*, 196–202.

Toronto 2030

2030 DISTRICTS

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San Antonio
San Francisco
Seattle
Stamford

Emerging Districts

TORONTO

27 MILLION
SQUARE FEET COMMITTED

TORONTO 2030 DISTRICT

The Toronto 2030 District is a cross-sector public-private collaborative working to create a groundbreaking high-performance building district in downtown Toronto, the economic heart of Canada's largest city. The Toronto 2030 District is the first in Canada and the first outside the continental US.

OUR GOALS:

- To cut district-wide emissions in half, including zero-emissions from new buildings by 2030.
- Support a better understanding of where and why energy use, water use, and GHG emissions occur across the District.
- Work in partnership with building owners, service providers and conservation groups to accelerate the adoption of best practices for building design and management.
- Facilitate broad stakeholder dialogues to uncover and overcome systemic barriers to long term reductions in energy use, water use and GHG emissions.

TORONTO 2030 DISTRICT®

http://www.2030districts.org/toronto

Main data sources for Toronto

NEIGHBOURHOOD

Source: Census Profile (Toronto Geoportal, 2016)

Main data:
- population
- socio-economic variables
- level of building maintenance

BLOCK for 2030 District

Source: Toronto Platform (CUI, 2017)

Main data:
- age and function mix
- energy consumption (electricity, natural gas, steam, DLC)
- GHG emissions (from buildings and transports)

BUILDING

Source: Building 3D massing (City of Toronto, 2017; OSM, 2020)

Main data:
- height
- useful heated surface
- heated volume
- SV ratio
- function (available for 50.4% records)

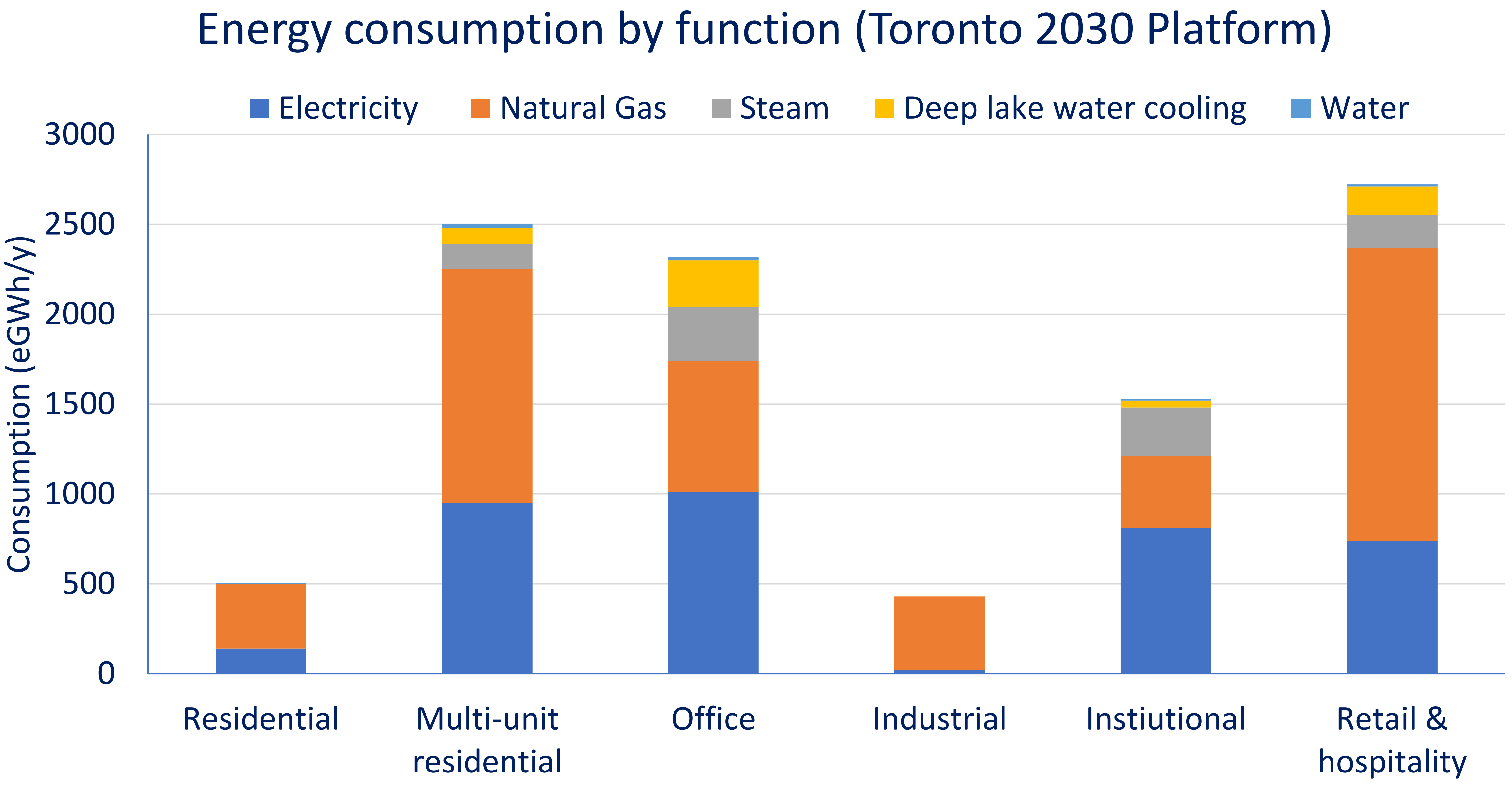
PROVINCE (Ontario)

Source: SHEU (NRCan, 2015); Comprehensive Energy Database (2017)

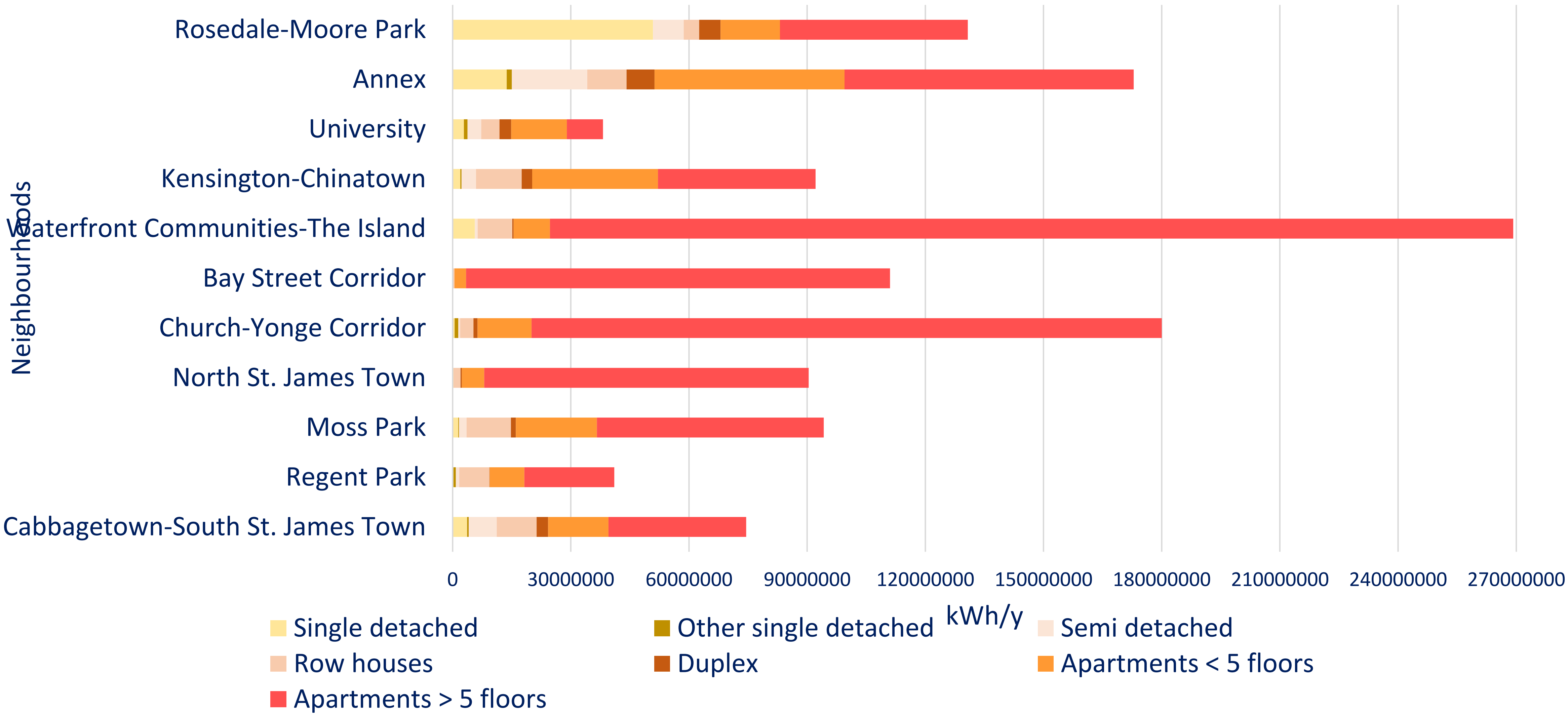
Main data:
- energy consumption by sources and uses
- energy consumption by type of dwelling

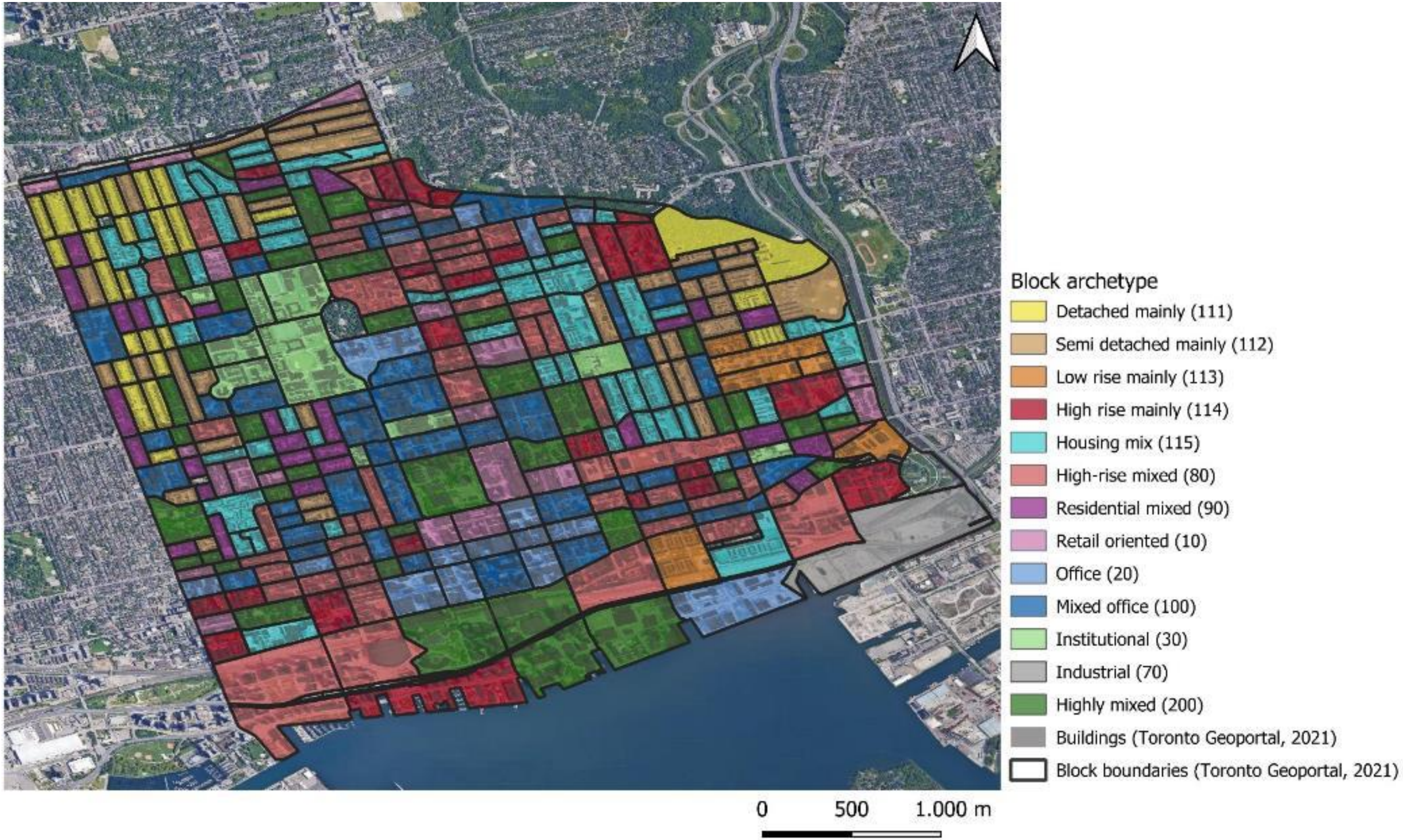
GIS tool

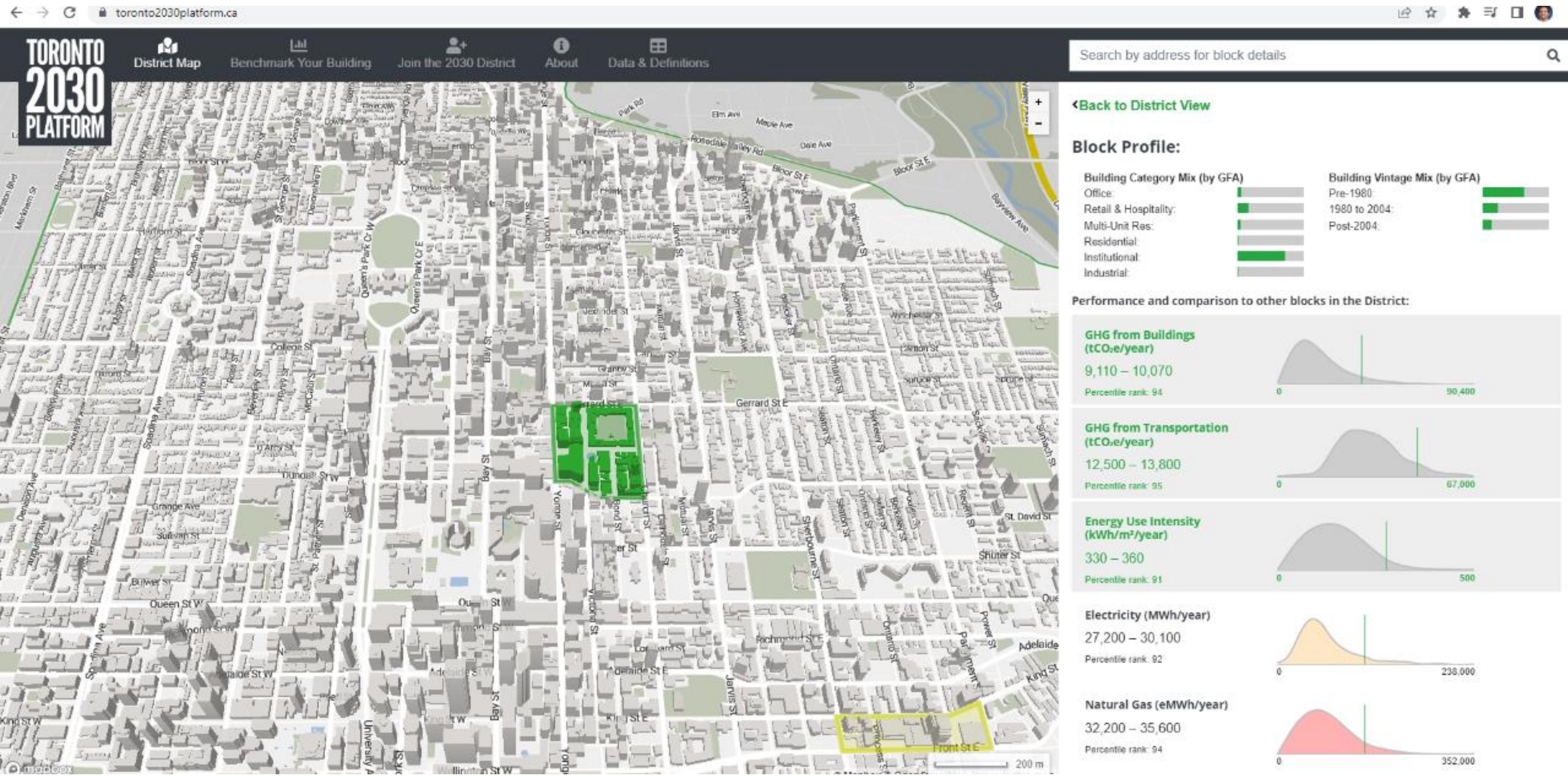
Comparison & validation


Energy consumption by function (Toronto 2030 Platform)
Electricity
Natural Gas
Steam
Deep lake water cooling
Water
Consumption (eGWh/y)
3000
2500
2000
1500
1000
500
0
Residential
Multi-unit residential
Office
Industrial
Instiutional
Retail & hospitality

Total natural gas consumption by household types




Block archetype
Detached mainly (111)
Semi detached mainly (112)
Low rise mainly (113)
High rise mainly (114)
Housing mix (115)
High-rise mixed (80)
Residential mixed (90)
Retail oriented (10)
Office (20)
Mixed office (100)
Institutional (30)
Industrial (70)
Highly mixed (200)
Buildings (Toronto Geoportal, 2021)
Block boundaries (Toronto Geoportal, 2021)
0
500
1.000 m


toronto2030platform.ca
TORONTO 2030 PLATFORM
District Map
Benchmark Your Building
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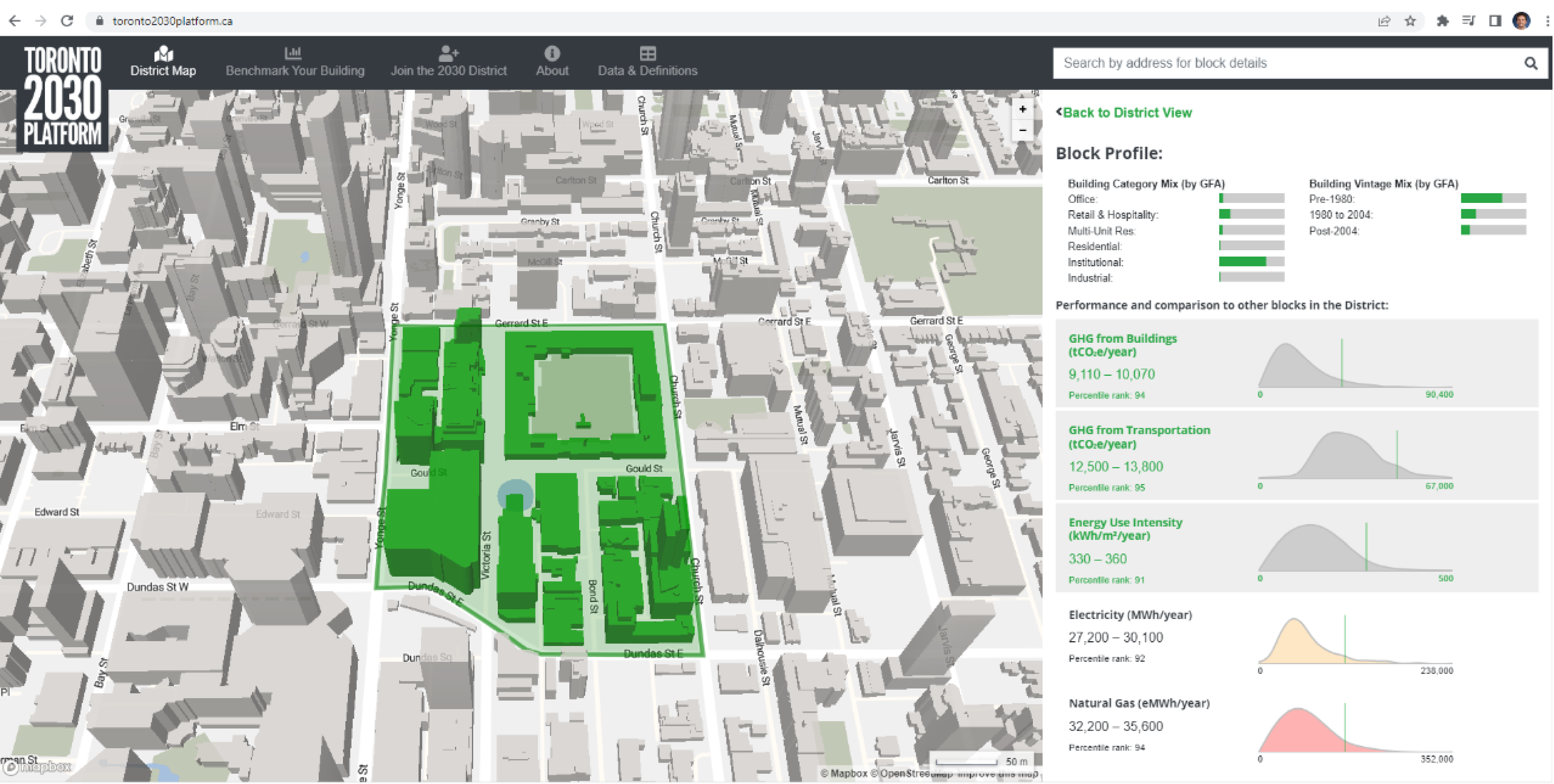
About
Data & Definitions
Search by address for block details
‹Back to District View
Block Profile:
Building Category Mix (by GFA)
Office:
Retail & Hospitality:
Multi-Unit Res:
Residential:
Institutional:
Industrial:
Building Vintage Mix (by GFA)
Pre-1980:
1980 to 2004:
Post-2004:
Performance and comparison to other blocks in the District:
GHG from Buildings (tCO₂e/year)
9,110 – 10,070
Percentile rank: 94
0
90,400
GHG from Transportation (tCO₂e/year)
12,500 – 13,800
Percentile rank: 95
0
67,000
Energy Use Intensity (kWh/m²/year)
330 – 360
Percentile rank: 91
0
500
Electricity (MWh/year)
27,200 – 30,100
Percentile rank: 92
0
238,000
Natural Gas (eMWh/year)
32,200 – 35,600
Percentile rank: 94
0
352,000
200 m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9,110 – 10,070
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90,400
GHG from Transportation (tCO₂e/year)
12,500 – 13,800
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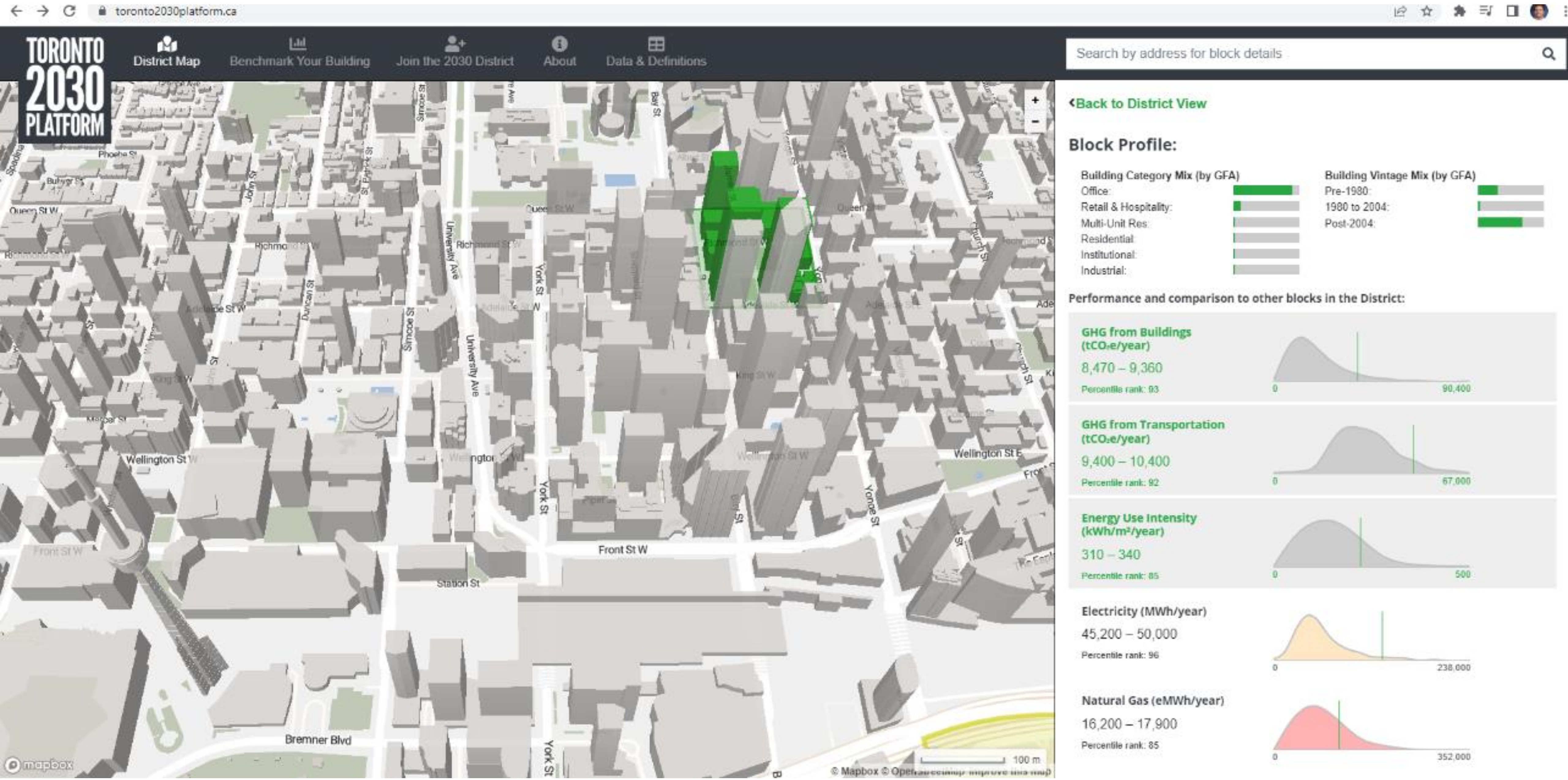
0
67,000
Energy Use Intensity (kWh/m²/year)
330 – 360
Percentile rank: 91
0
500
Electricity (MWh/year)
27,200 – 30,100
Percentile rank: 92
0
238,000
Natural Gas (eMWh/year)
32,200 – 35,600
Percentile rank: 94
0
352,000
Yonge St
Church St
Gerrard St E
Gould St
Victoria St
Bond St
Dundas St E
Dundas St W
Elm St
Edward St
Carlton St
Granby St
McGill St
Mutual St
Jarvis St
George St
Dalhousie St
Bay St
50 m
© Mapbox © OpenStreetMap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Multi-Unit Res:
Residential:
Institutional:
Industrial:
Building Vintage Mix (by GFA)
Pre-1980:
1980 to 2004:
Post-2004:
Performance and comparison to other blocks in the District:
GHG from Buildings (tCO₂e/year)
8,470 – 9,360
Percentile rank: 93
0
90,400
GHG from Transportation (tCO₂e/year)
9,400 – 10,400
Percentile rank: 92
0
67,000
Energy Use Intensity (kWh/m²/year)
310 – 340
Percentile rank: 85
0
500
Electricity (MWh/year)
45,200 – 50,000
Percentile rank: 96
0
238,000
Natural Gas (eMWh/year)
16,200 – 17,900
Percentile rank: 85
0
352,000
Wellington St W
Front St W
Station St
Bremner Blvd
York St
University Ave
Wellington St E
100 m
mapbox

Challenges

UBEM results have to be reported back to the user in spatial and/or temporal form or otherwise.

As interest in UBEM models is likely going to expand over time to include non-experts and the general public, presenting model results via web visualization techniques is challenging.

The challenge of communicating massive amounts of energy data to stakeholders as actionable information falls under the exponentially growing field of **big data visualization**..

UBEM challenges

1. Privacy concerns oftentimes preclude utilities or public agencies to release data and in doing so to calibrate model

2. Building occupants should be treated as individual agents rather than identical robots that repeatedly follow the same activities at the same time. **Stochastic user behavior** models are needed.

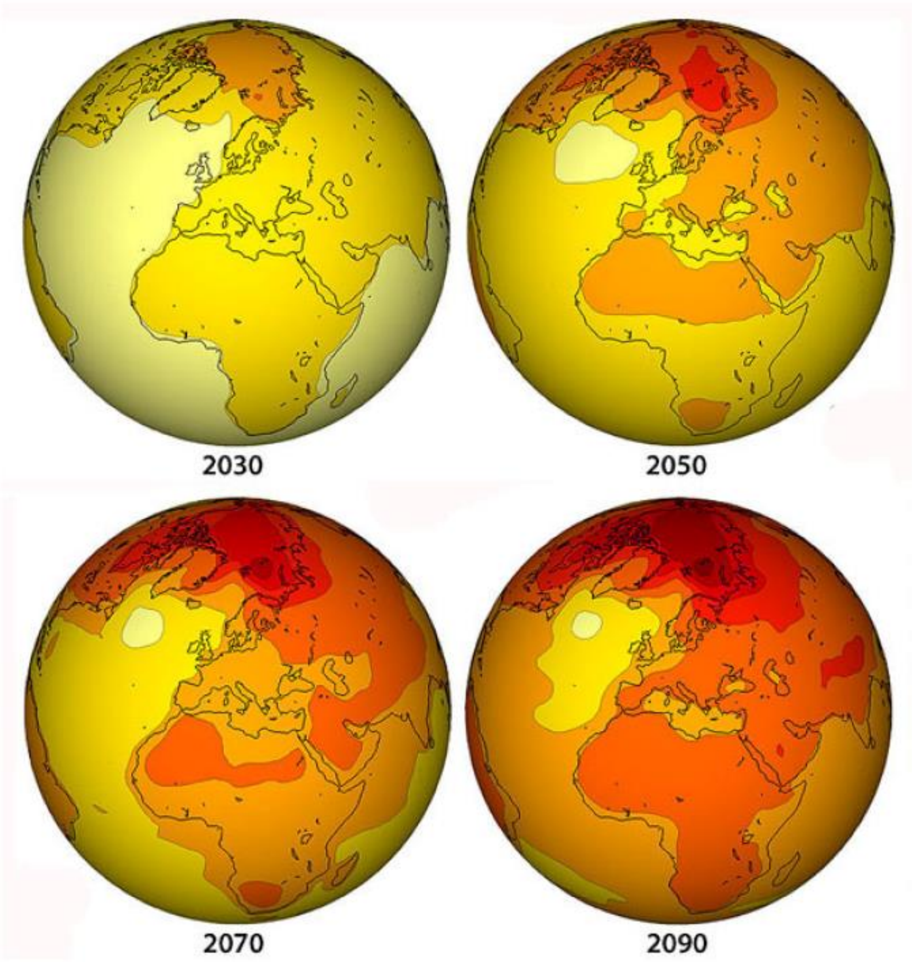
3. Stronger intellectual engagement between planners, policymakers, utility representatives and the building modeling community is necessary.

4. This requires training a new generation of professionals with adequate domain knowledge in all of these areas.

Potential future for Urban Energy Plans

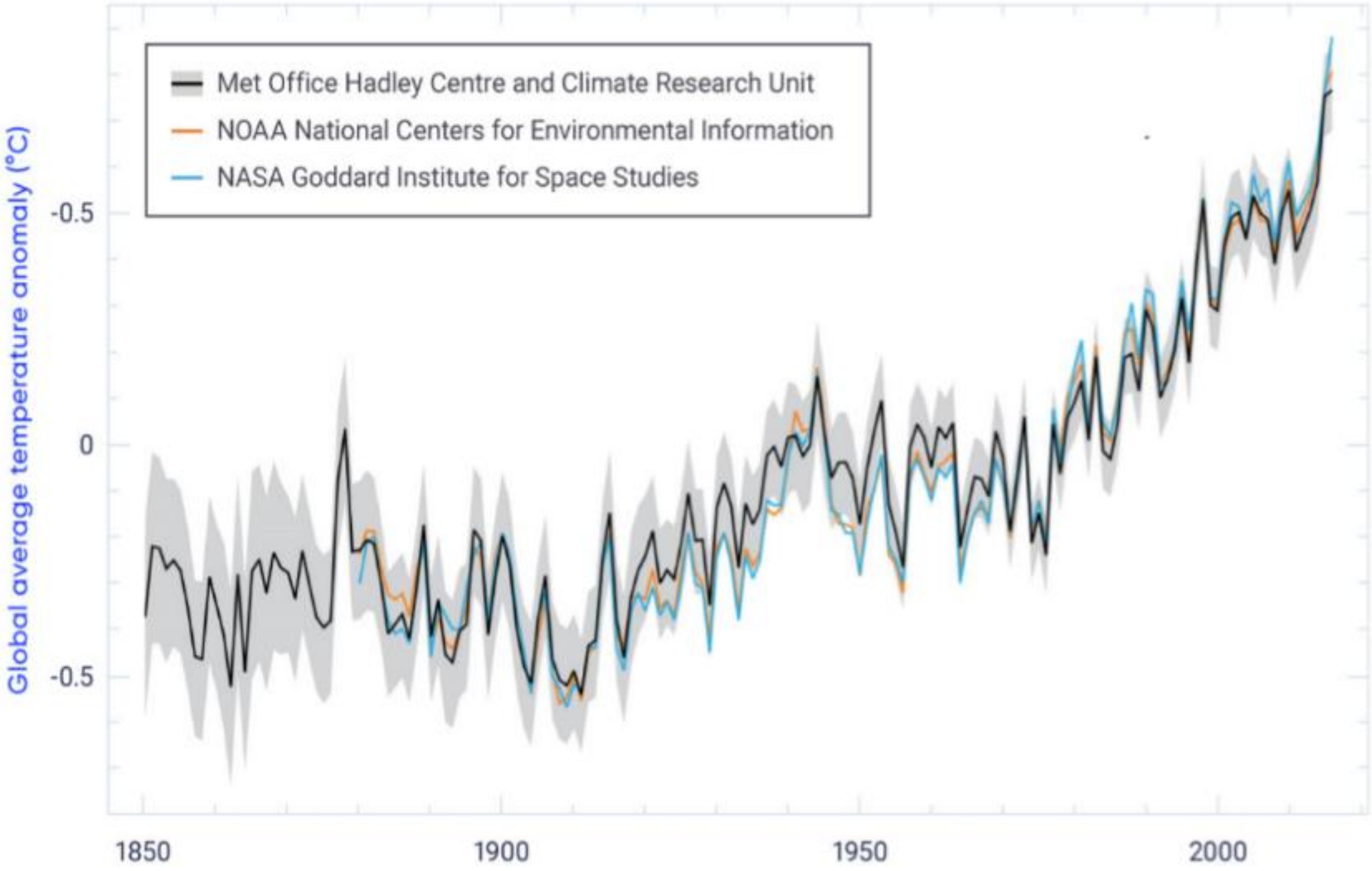
1. Real-time evaluation for balancing energy networks
2. Synergies (and energy exchanges) between different subsystems
3. Integration of technical aspects with user behaviors
4. Integration of historical data but also of externality and uncertainties
5. Availability of large computer clusters for launching massive parallel simulations
6. ..finally, ability to visualize, share and manage future energy consumption

Observed Changes: mitigation & adaptation



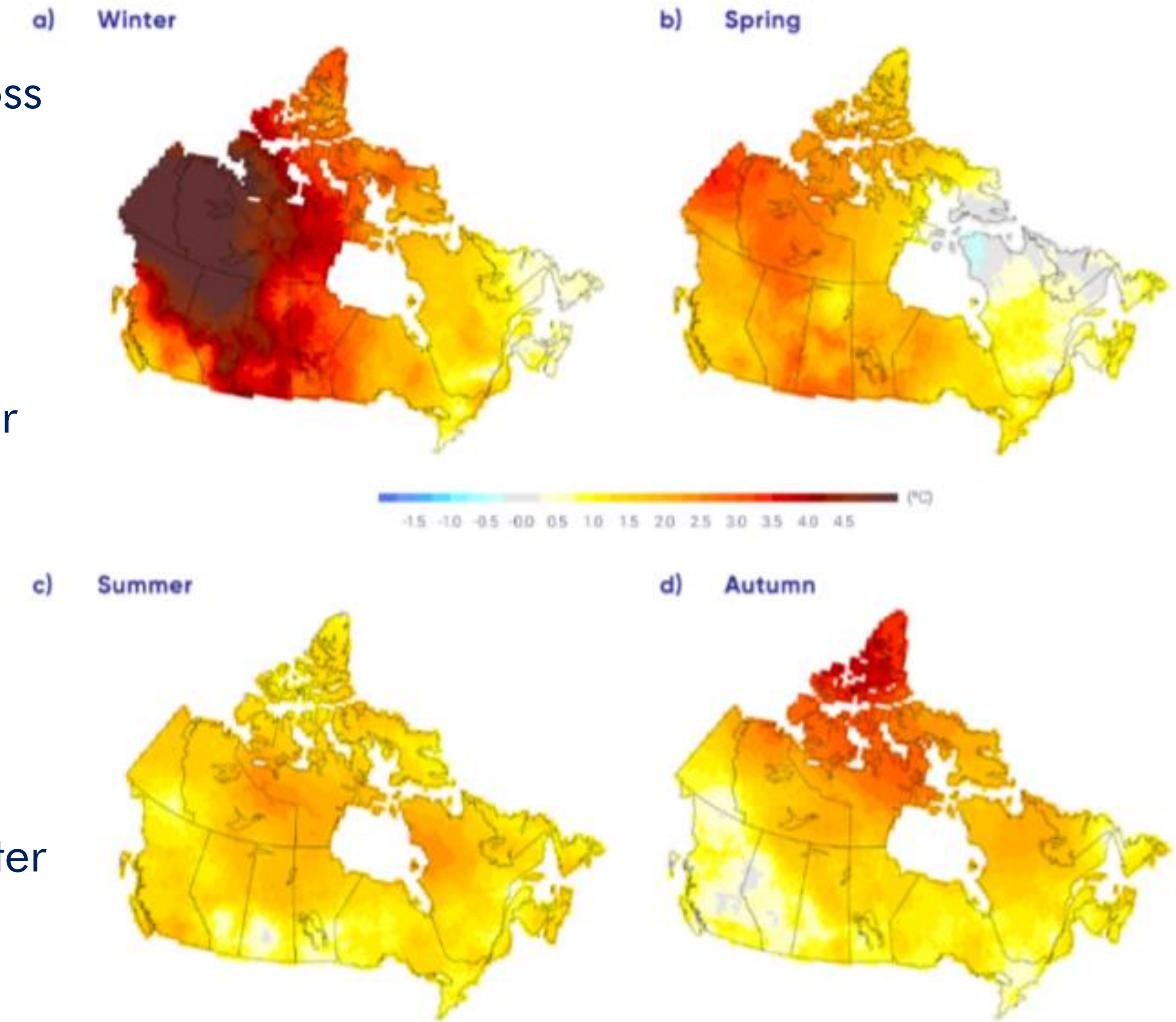
Indicators of Warming

The last four decades (1980–2020) have been the warmest on record. Global temperatures in the last three years are the three warmest years on record for the globe at more than 1°C above pre-industrial level.



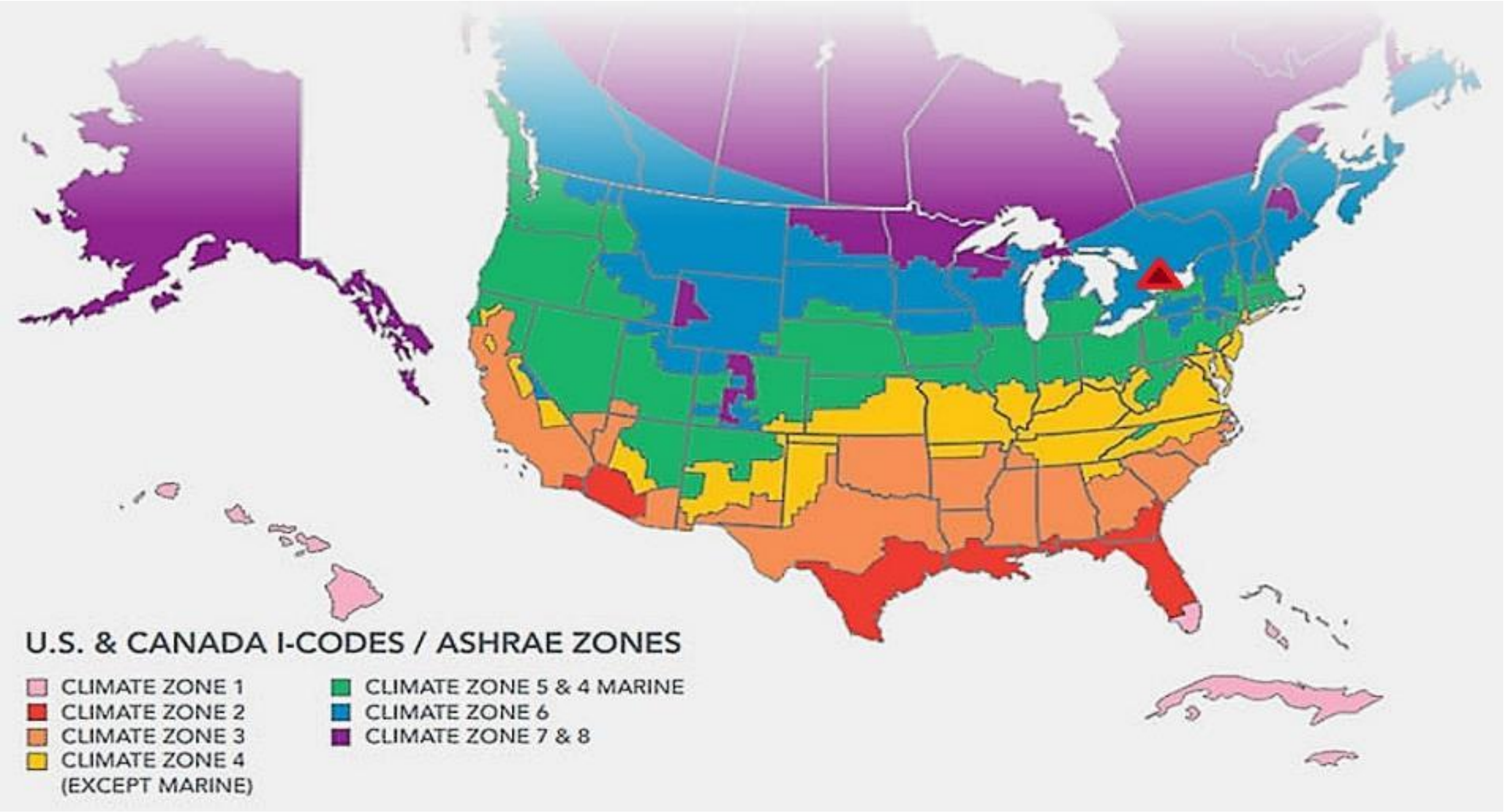
Observed Changes in Canada

- Annual and seasonal mean temperatures across Canada have increased, with the greatest warming occurring in winter
- Between 1948 and 2016, the best estimate of mean annual temperature increase is 1.7°C for Canada as a whole, and 2.3°C for northern Canada
- Fewer heating degree days and more cooling degree days
- Extreme warm temperatures have become hotter while some extreme cold temperatures have become *less cold*..

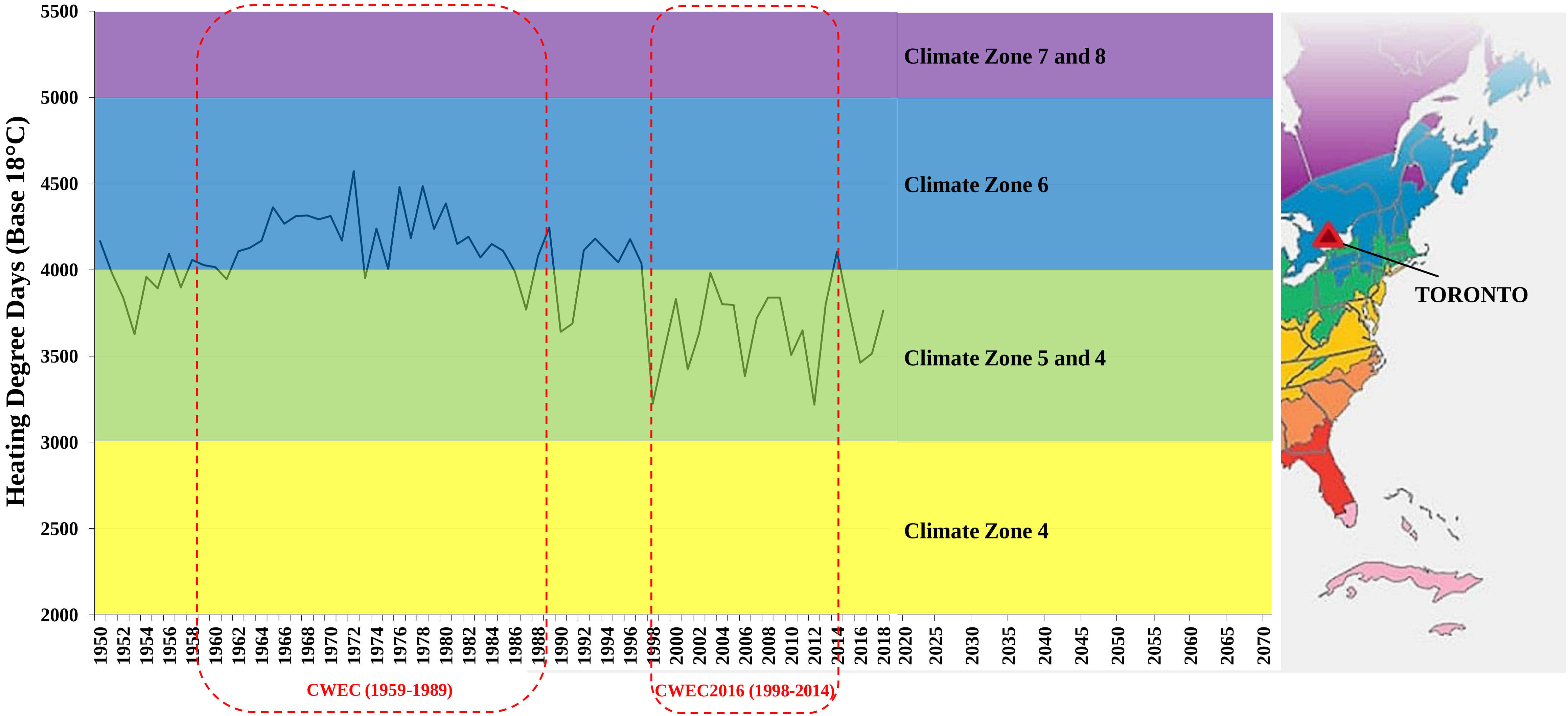


Changing climate & building energy demand

ASHRAE Climate Zone Classification

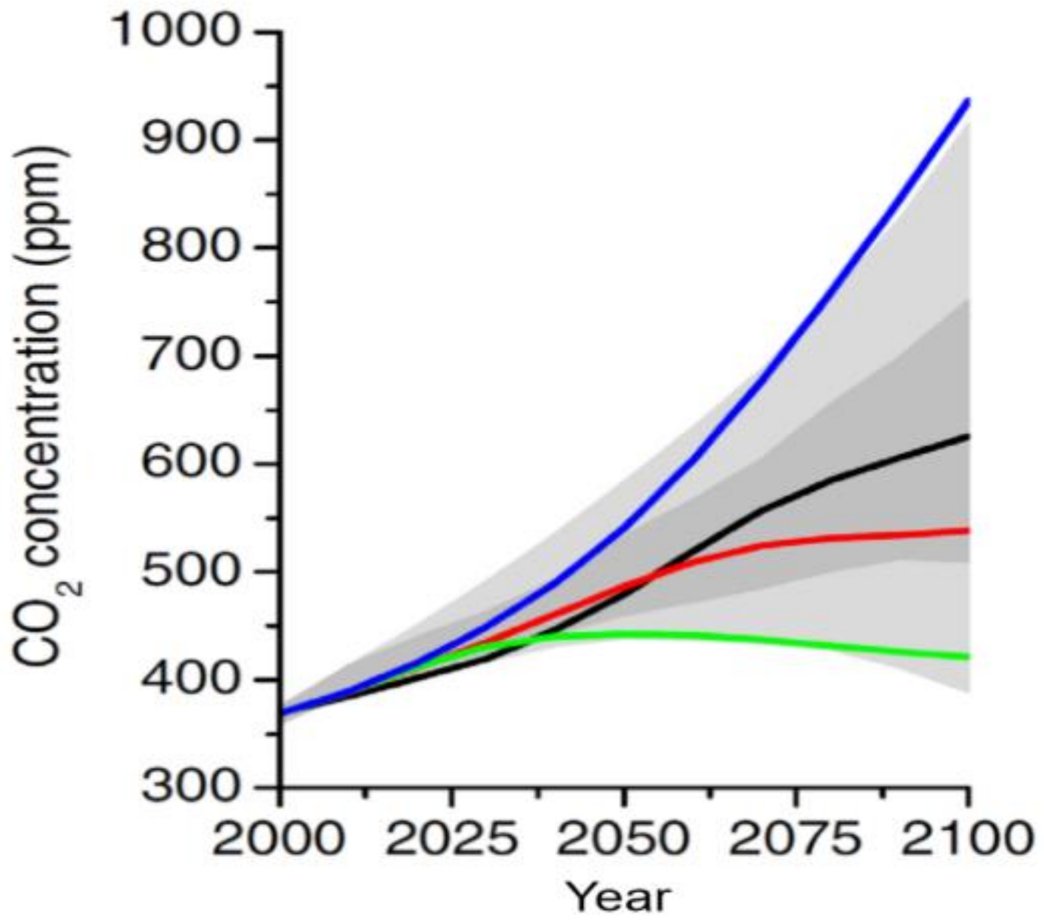


Weather files for building energy simulation describe the typical climate conditions from the time period of 1959-1989 or 1998-2014 (**historical climate observation**)



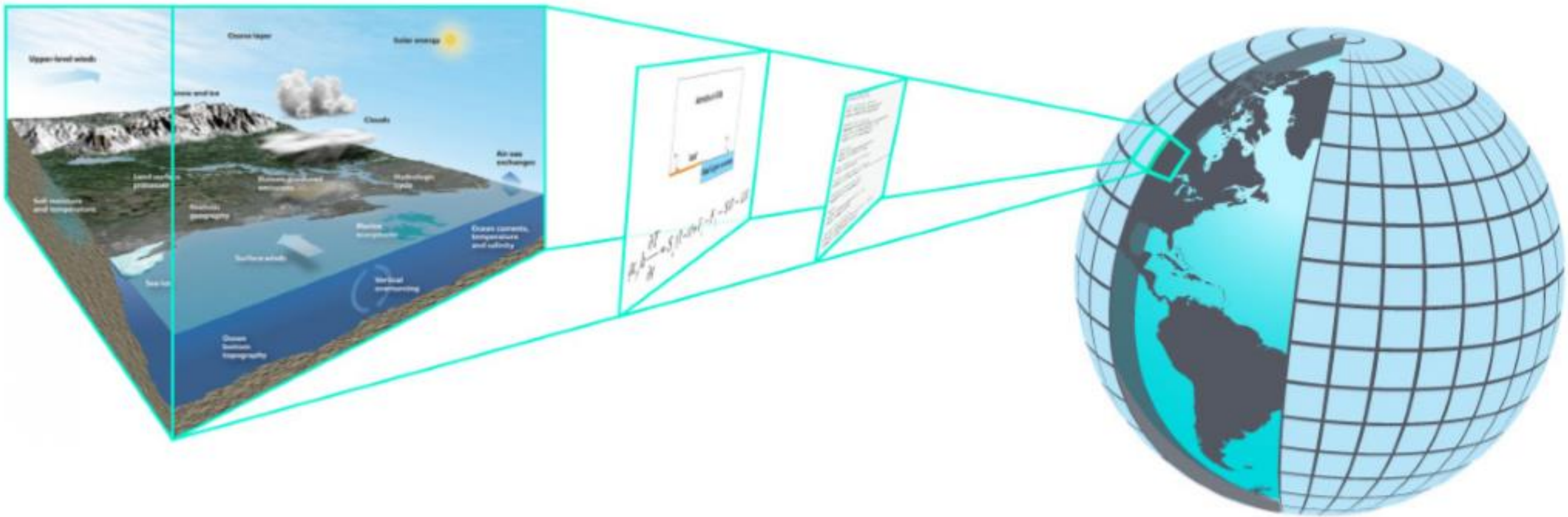
Projecting Future Climate Change

- Making projections about future climate requires projections of future greenhouse gas concentrations or emissions
- Four different scenarios have been used that span a range from low to high emissions: A low emission pathway (**Representative Concentration Pathway -** RCP2.6), intermediate emission pathways (RCP4.5 and **RCP6**), and business-as-usual high emission scenario (RCP8.5)
- These emission scenarios are used as input to **global climate models**



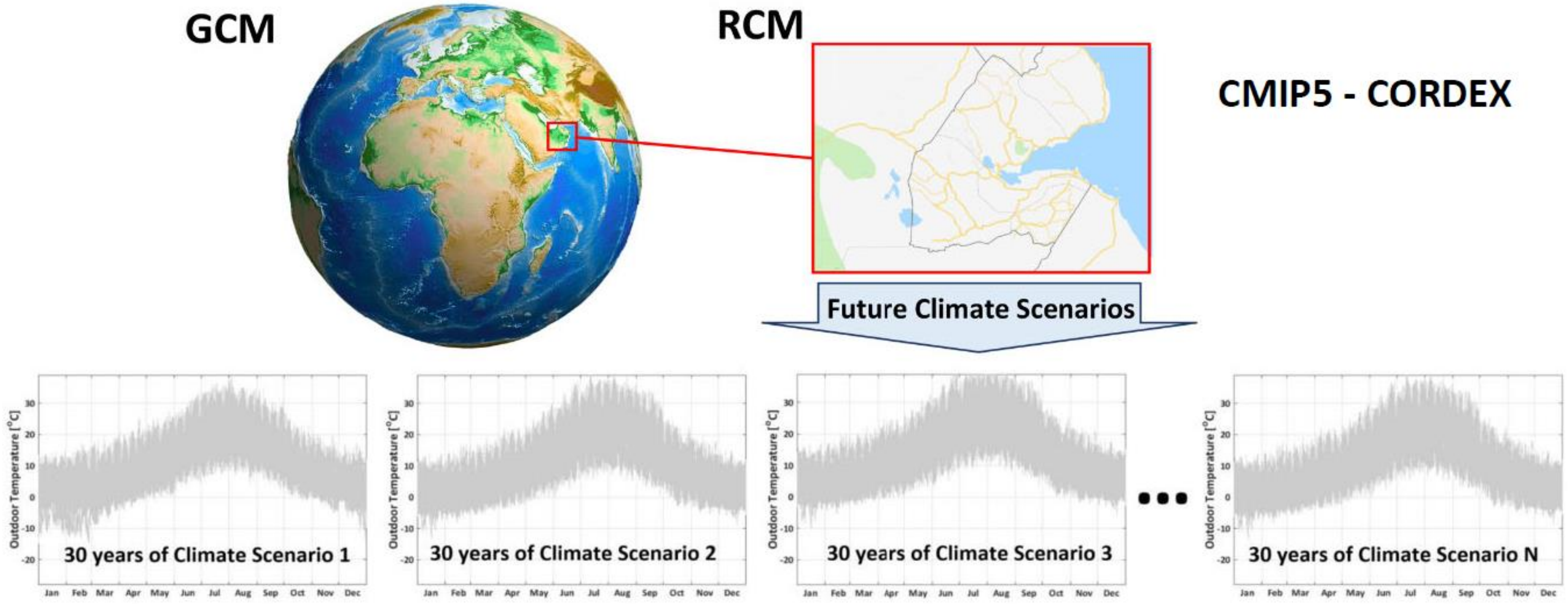
Creating Future Weather Files

- Complex computer models are used to reconstruct atmosphere, ocean, and land interactions
- Mathematical equations describing physical processes are solved on three-dimensional grid

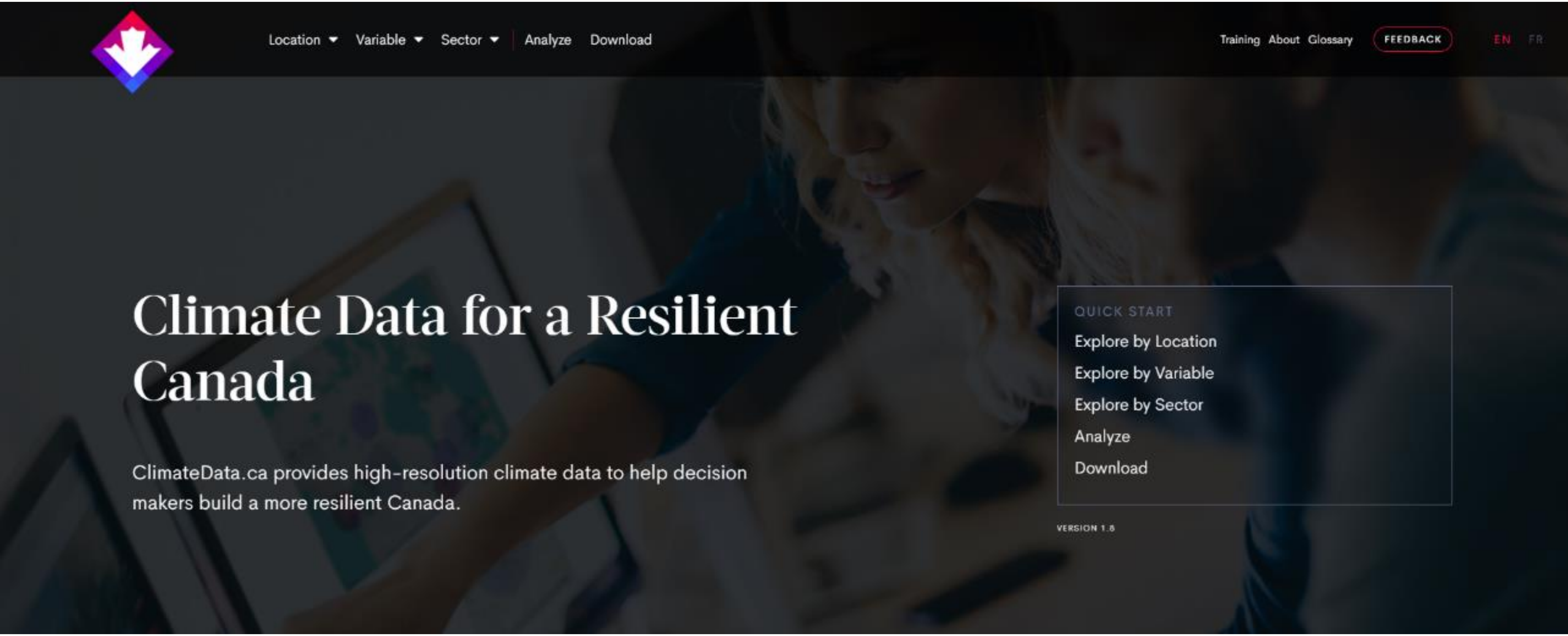


Developed methods for:

- Impact Assessment
- Statistical and Uncertainty Analyses
- Representative Future Weather Scenarios
- Energy System Optimization (stochastic-robust optimization)
- Urban Climate Simulation



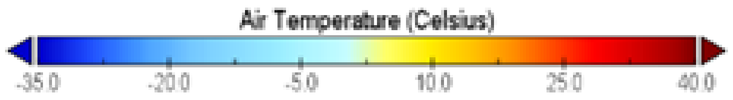
https://climatedata.ca/

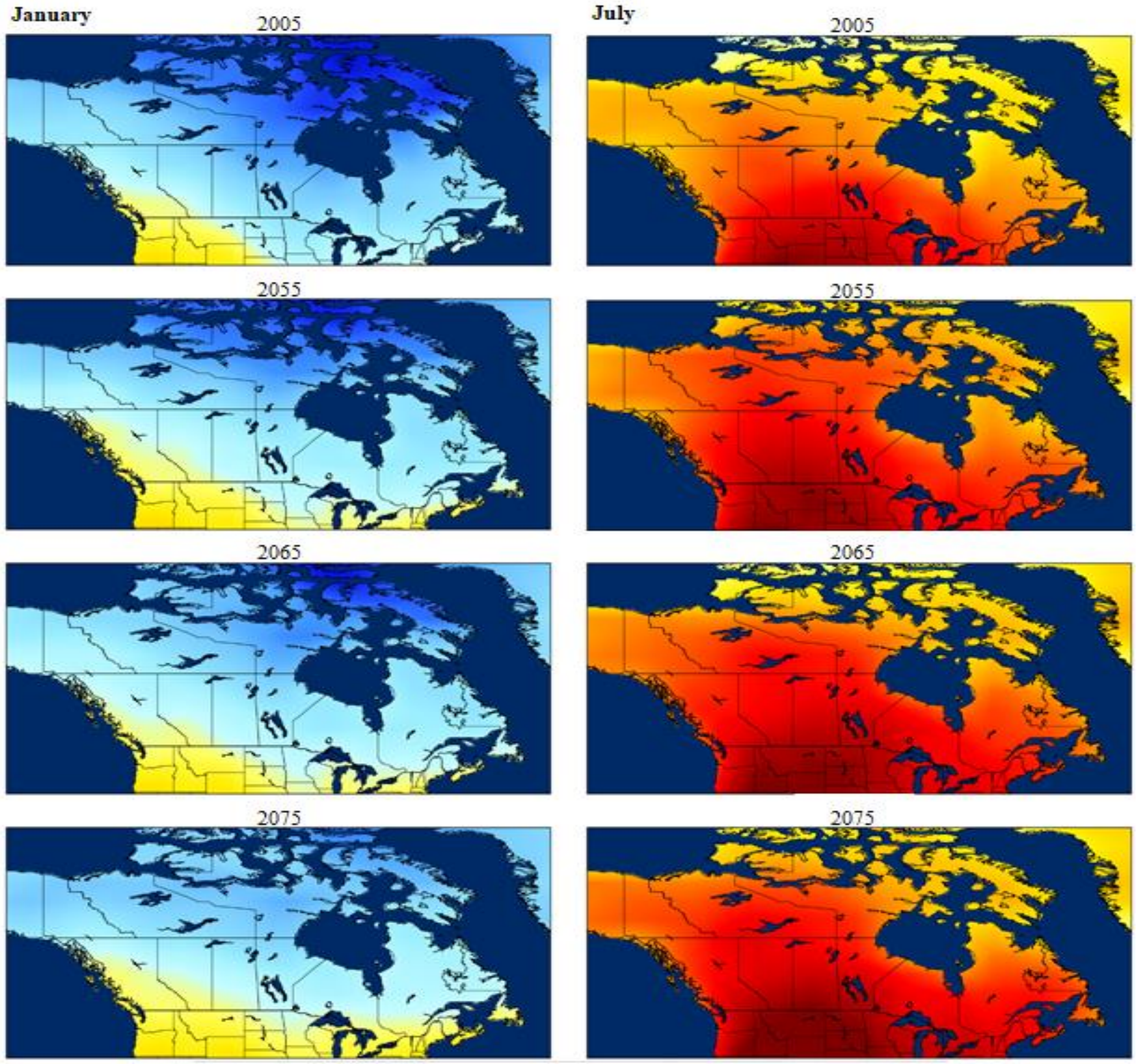


Canada

IPCC - RCP 8.5:

Temperatures in Canada under CanESM2 (Global Climate Model [GCM]) projections for 2055, 2065, and 2075 compared to 2005 temperatures



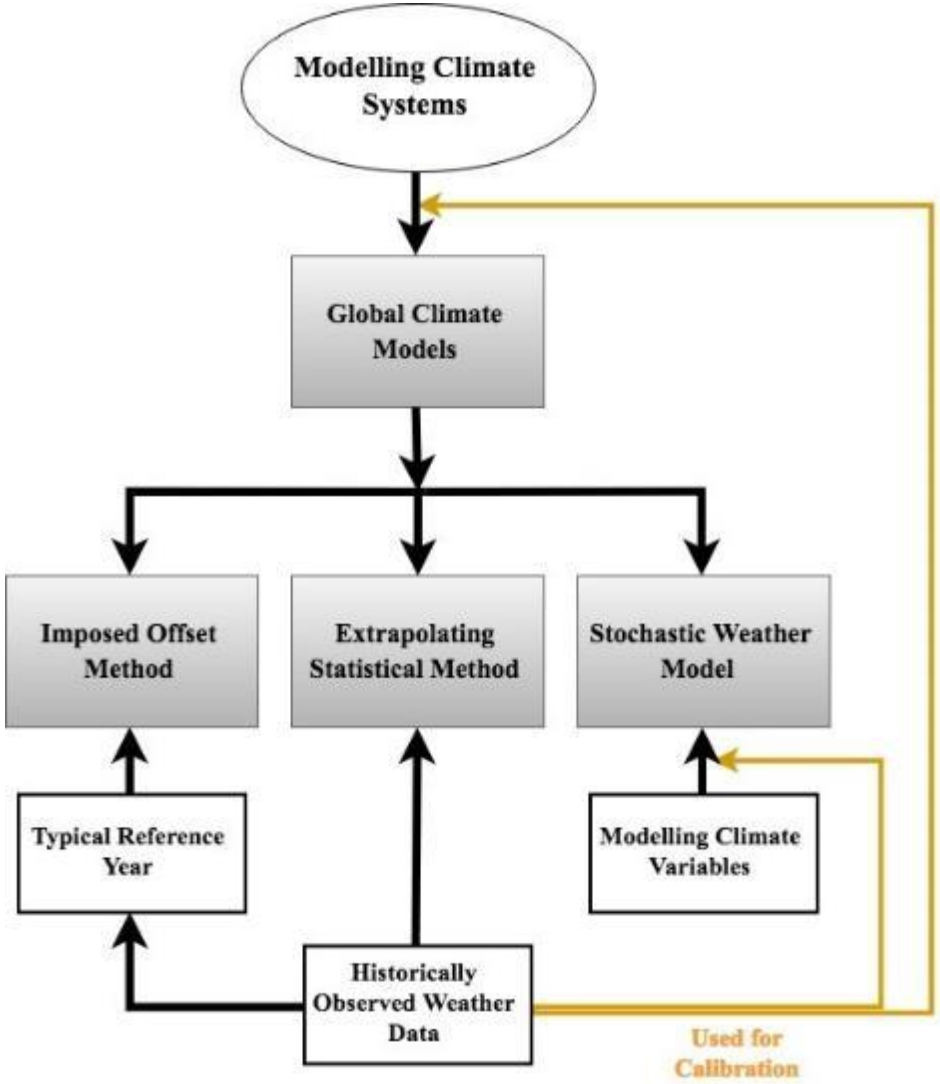


Climate change into a weather file

- **Imposed Offset Method:** predicts future climate information from complex climate models in addition to the recorded typical weather data sets. *This method has been the most widely used*

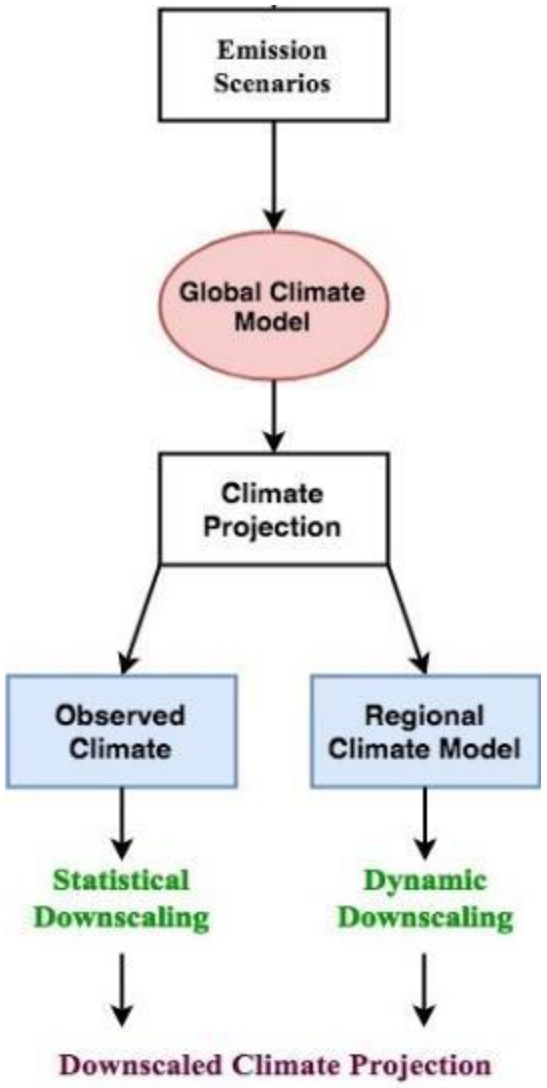
- **Extrapolating Statistical Method:** predicts building energy consumption based on the degree-day method

- **Stochastic Weather Model:** generate future weather data, based on generating an artificial meteorological database



Climate Data for Building Simulation

- **Global Climate Model (GCM)**
  - Only valid and reliable at the global scale and over monthly periods of time
  - Low level of spatial and temporal resolution necessary for local building energy simulation
- **Downscaling**
  - Statistical downscaling
  - Dynamical downscaling



Generating Future Weather File with GCM

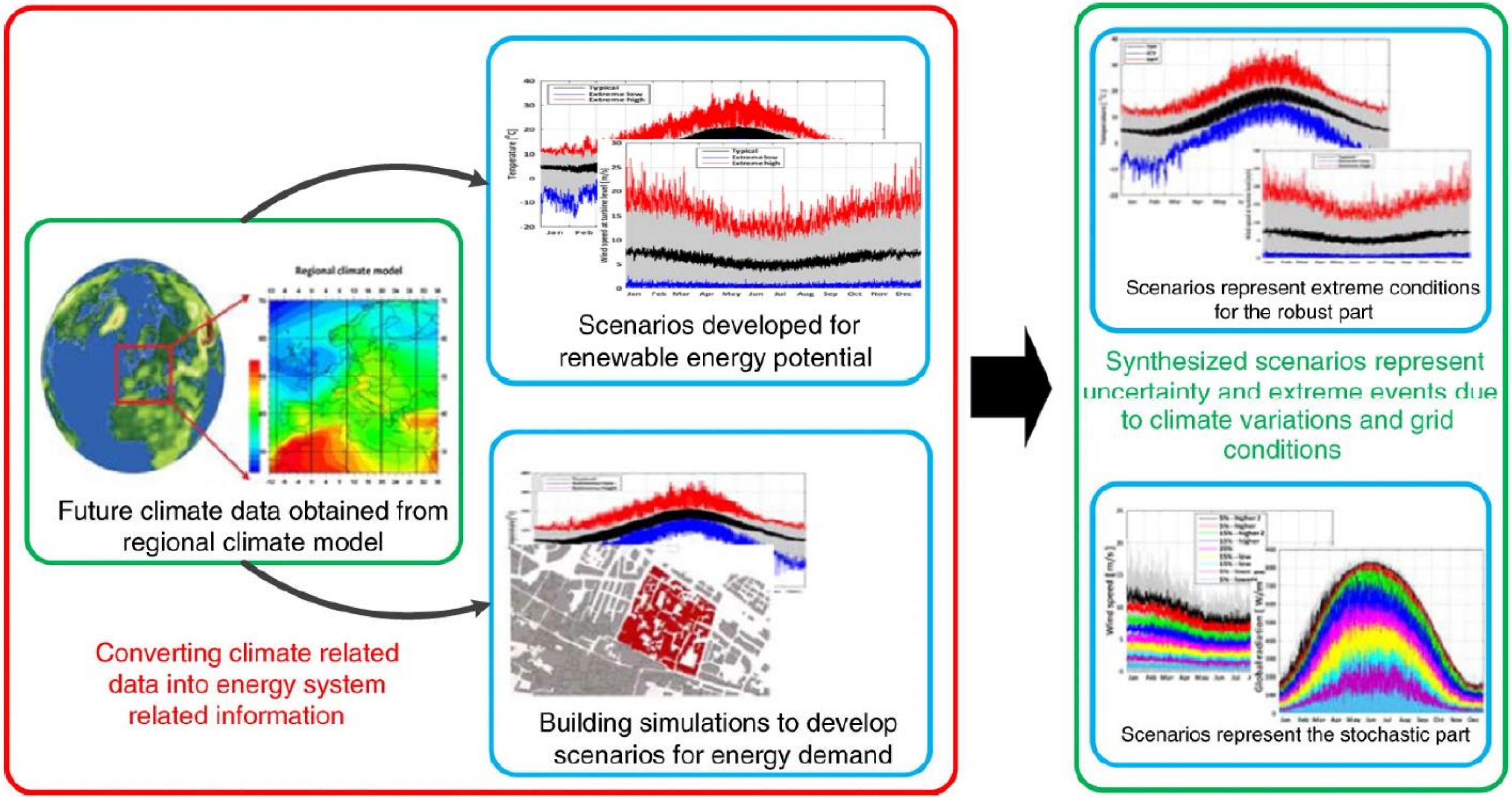
➢ CCWorldWeatherGen tool

A. Hadley Global Climate model 3 (HadCM3)
B. IPCC Emission Scenario: A2
C. Downscaling method: Morphing technique

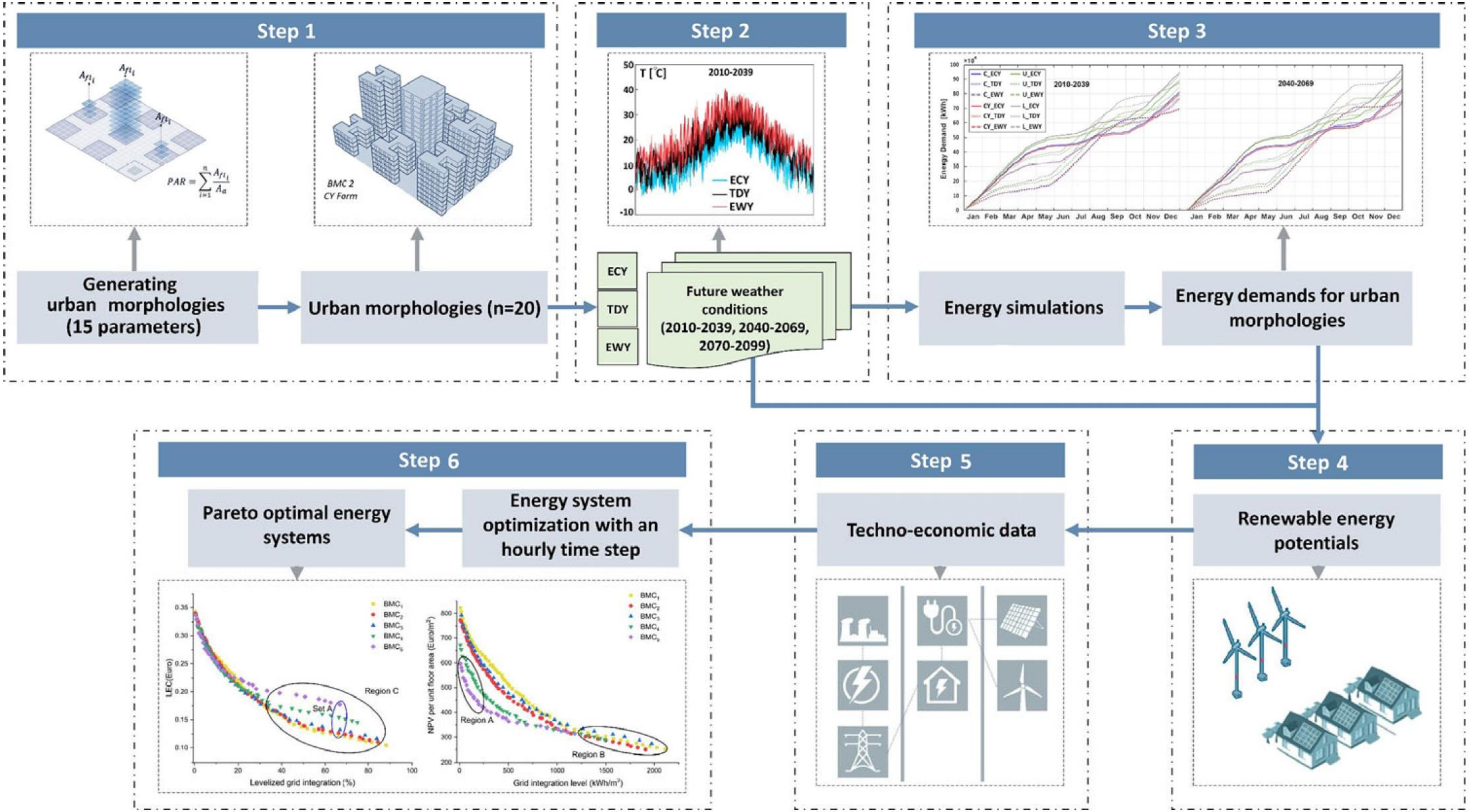
➢ WeatherShift tool

A. Combination of 14 GCMs
B. IPCC Emission Scenario: RCP 8.5
C. Downscaling method: Morphing technique

The interlinks between climate models and energy models are not straightforward. We need to develop a workflow to synthesize a pool of scenarios and link climate models with energy system models.



Interconnected infrastructures in urban areas – Urban climate and extreme weather events



Study 1

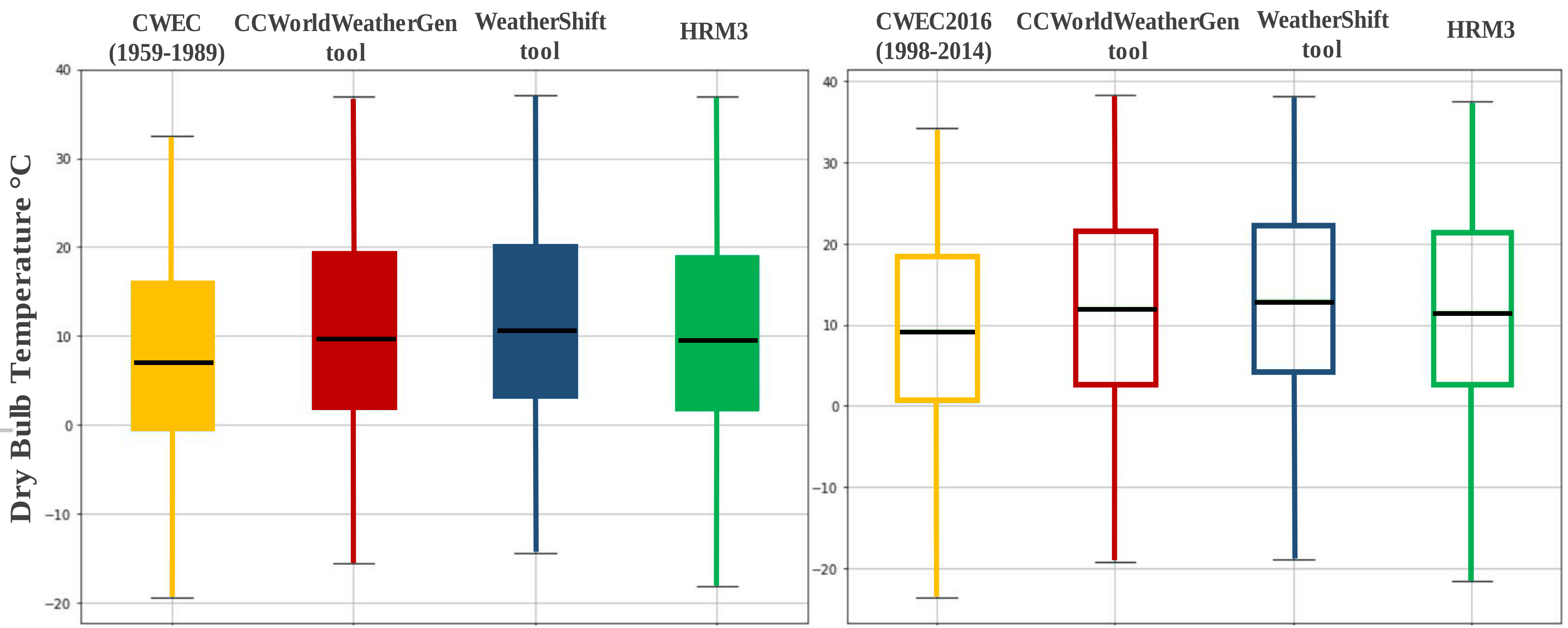
IMPACTS OF CLIMATE CHANGE ON BUILDING HEATING AND COOLING ENERGY DEMAND IN TORONTO

Investigate the effects of climate changes on the heating and cooling energy demand of buildings in the most populated urban region in Canada, i.e. the City of Toronto using various climate models.

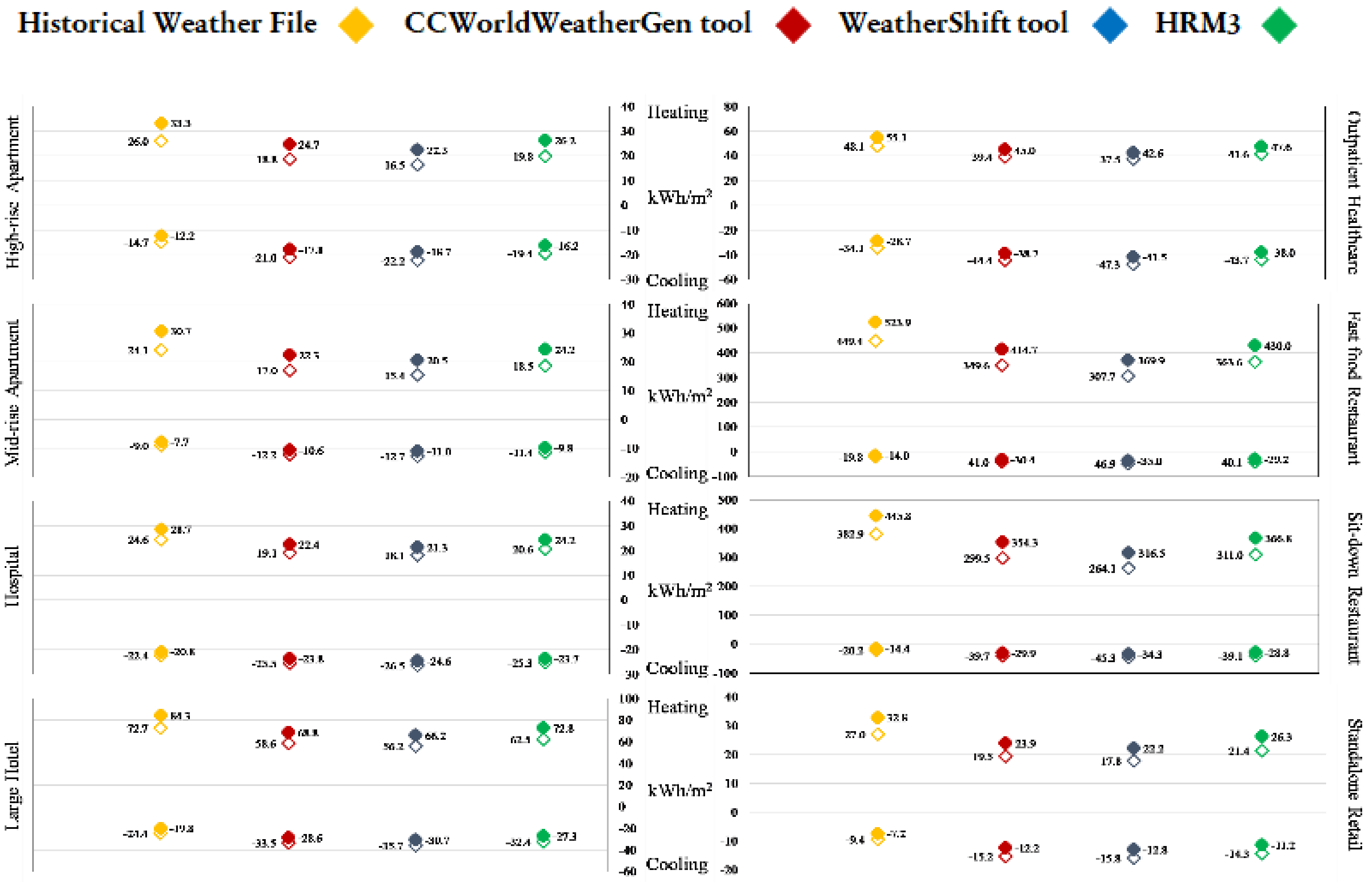
Future weather files for Toronto

- The future weather files forecast a mean temperature increase of 3.7–4.5 C for Toronto. This increase is 2.0 C greater than the IPCC forecast of global mean surface temperature

Weather Files	HDD
CWEC (1959-1989)	4,179
CCWorldWeatherGen tool	3,427
WeatherShift tool	3,157
HRM3	3,509
CWEC2016 (1998-2014)	3,695
CCWorldWeatherGen tool	3,033
WeatherShift tool	2,769
HRM3	3,122



Results: Building Energy Simulation



Heating and Cooling Energy Use Intensity (EUI)

Results: building energy simulation

Heating load of large buildings is not as sensitive to changes in climate conditions as small buildings due to envelope heat loss/gain making up a larger portion of small buildings heating and cooling load than that of large buildings

Buildings with higher insulation level, larger zone ratio, smaller window-to-wall ratio, and lower outdoor air supply are less affected by the outdoor conditions and thus climate change.

Building Type	Baseline Climate			
	CWEC (1959-1989)		CWEC2016 (1998-2014)	
	Heating	Cooling	Heating	Cooling
High-rise Apartment	-29%	42%	-27%	44%
Mid-rise Apartment	-30%	34%	-27%	36%
Hospital	-22%	15%	-21%	16%
Large Hotel	-19%	39%	-18%	46%
Small Hotel	-25%	34%	-24%	35%
Large Office	-24%	36%	-23%	44%
Medium Office	-26%	52%	-24%	64%
Small Office	-33%	39%	-33%	41%
Outpatient HealthCare	-18%	32%	-18%	37%
Fast Food Restaurant	-24%	115%	-23%	126%
Sit-down Restaurant	-24%	105%	-22%	116%
Standalone Retail	-28%	61%	-26%	68%
Strip Mall Retail	-24%	78%	-22%	87%
Primary School	-21%	44%	-21%	48%
Secondary School	-21%	41%	-20%	44%
Warehouse	-23%	109%	-22%	110%

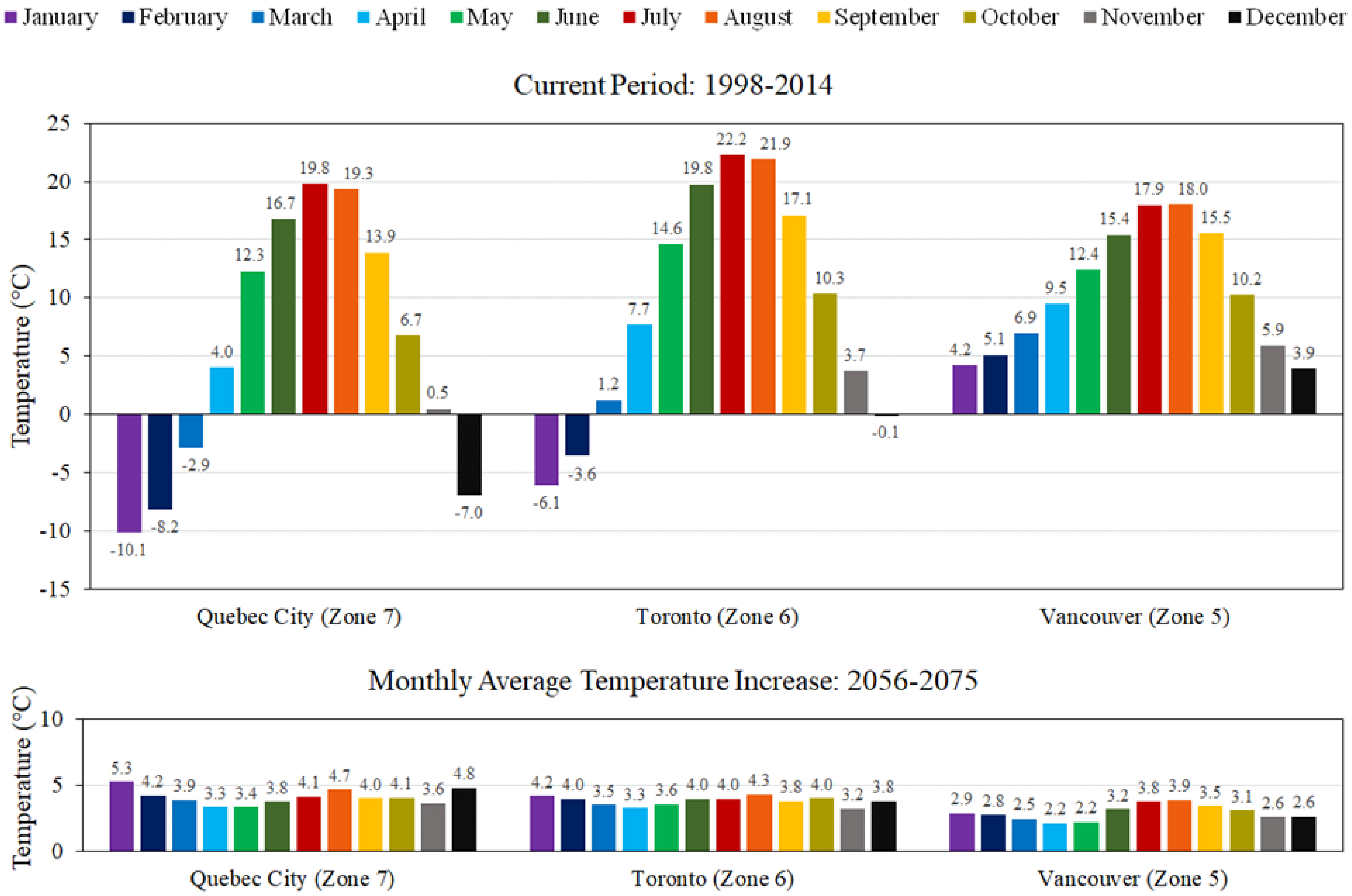
Study 2

INFLUENCE OF SETPOINT TEMPERATURE ON THE ENERGY DEMAND

Quantify the energy demand for various thermal comfort target of a office building in three climate zones across Canada: Vancouver (cool-humid), Toronto (cold-humid), and Quebec City (very cold).

Results: future weather files

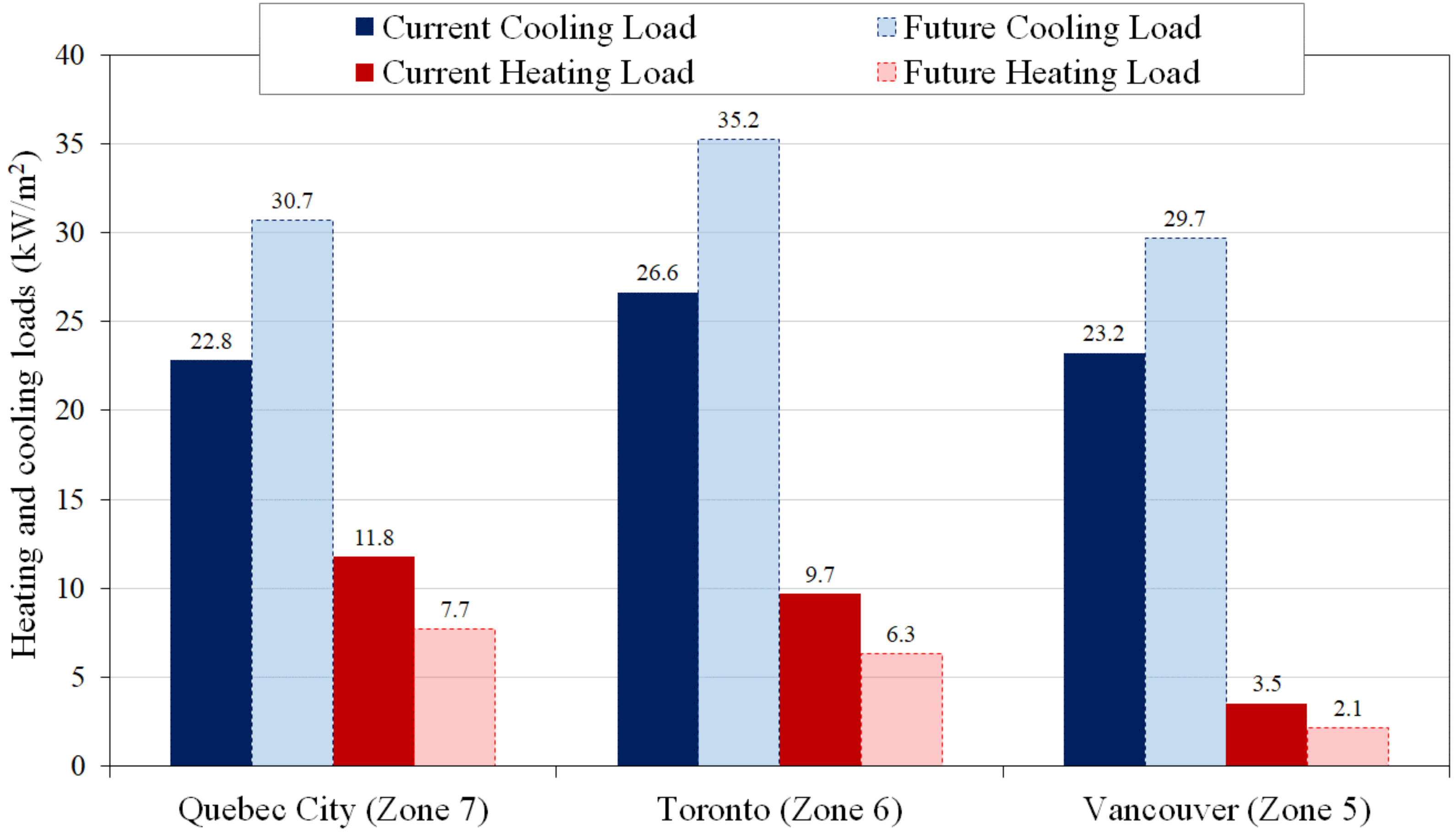
The future weather files illustrate an increase in the range of 3.3 °C to 5.3 °C for Quebec City, 3.2 °C to 4.3 °C for Toronto, and 2.2 °C to 3.9 °C for Vancouver.



Results: cooling and heating loads

There is an increasing trend in cooling load across all cities for the future.

The projected increase in cooling load varies between cities, corresponding to the magnitude of temperature increases in summer.

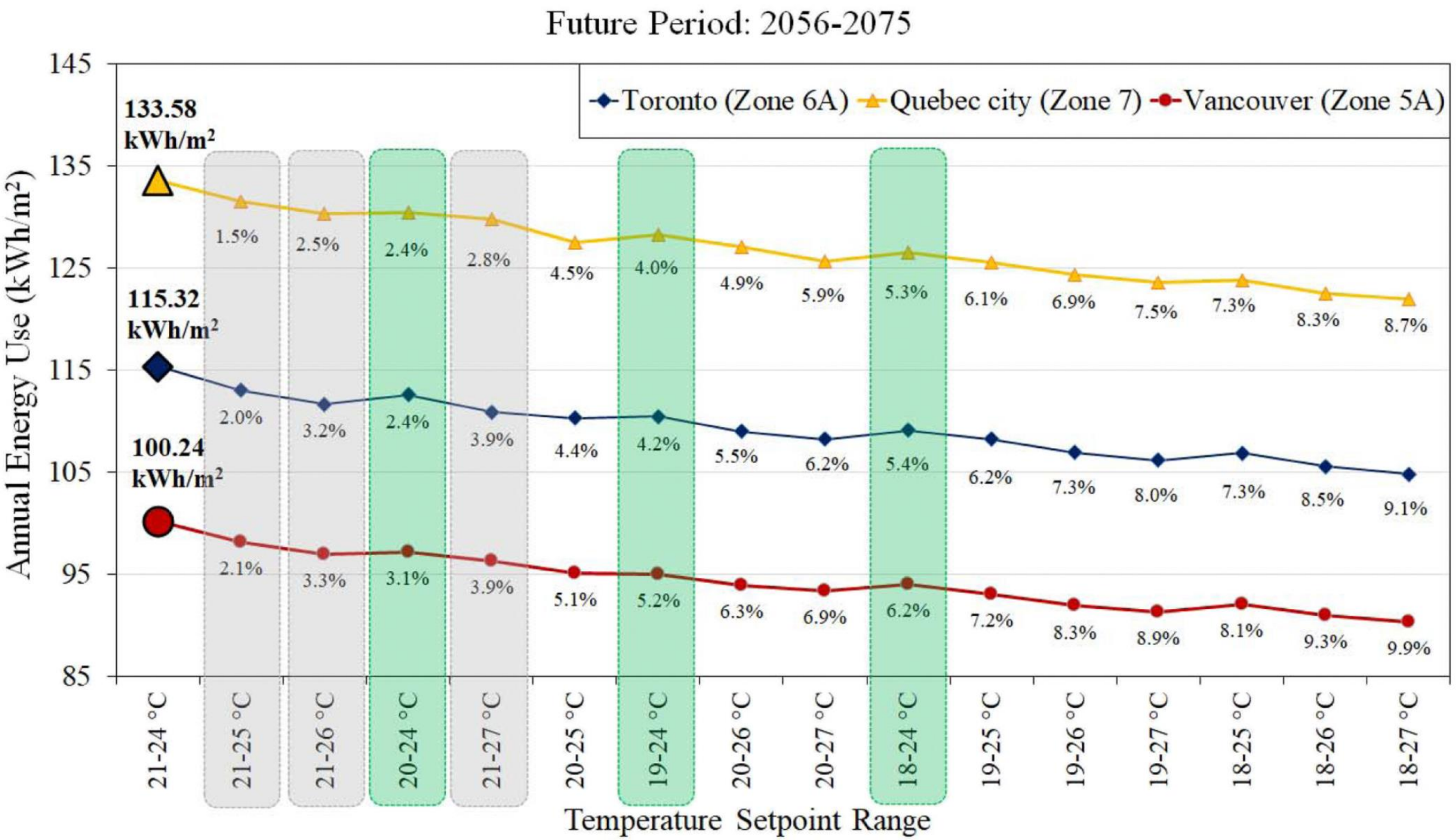


Results: cooling and heating loads

Quebec City: Decreasing heating setpoint by 1°C reduced energy use by an average of 3.8%, while increasing cooling setpoint by 1°C resulted in an average saving of 2.4%.

Toronto: 1°C reduction in heating setpoint lowered energy use by an average of 2.0% and a rise of 1°C in cooling setpoint saved an average of 0.9%.

Vancouver: Decreasing heating and increasing cooling setpoints resulted in an average saving of 2.3% and 0.8% for every 1°C.

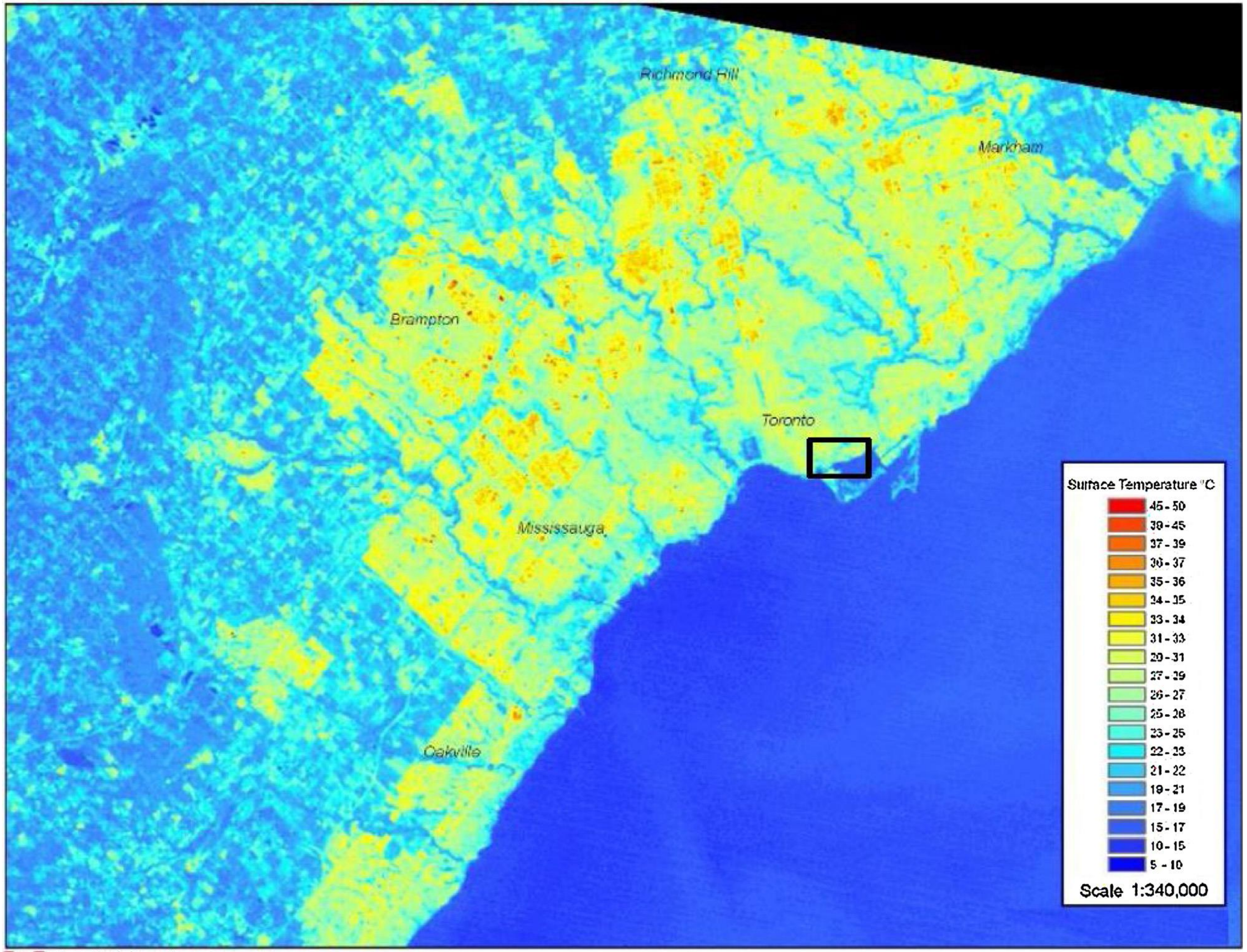


Study 3

URBAN HEAT ISLAND (UHI) and (MICRO-)CLIMATE

UHI

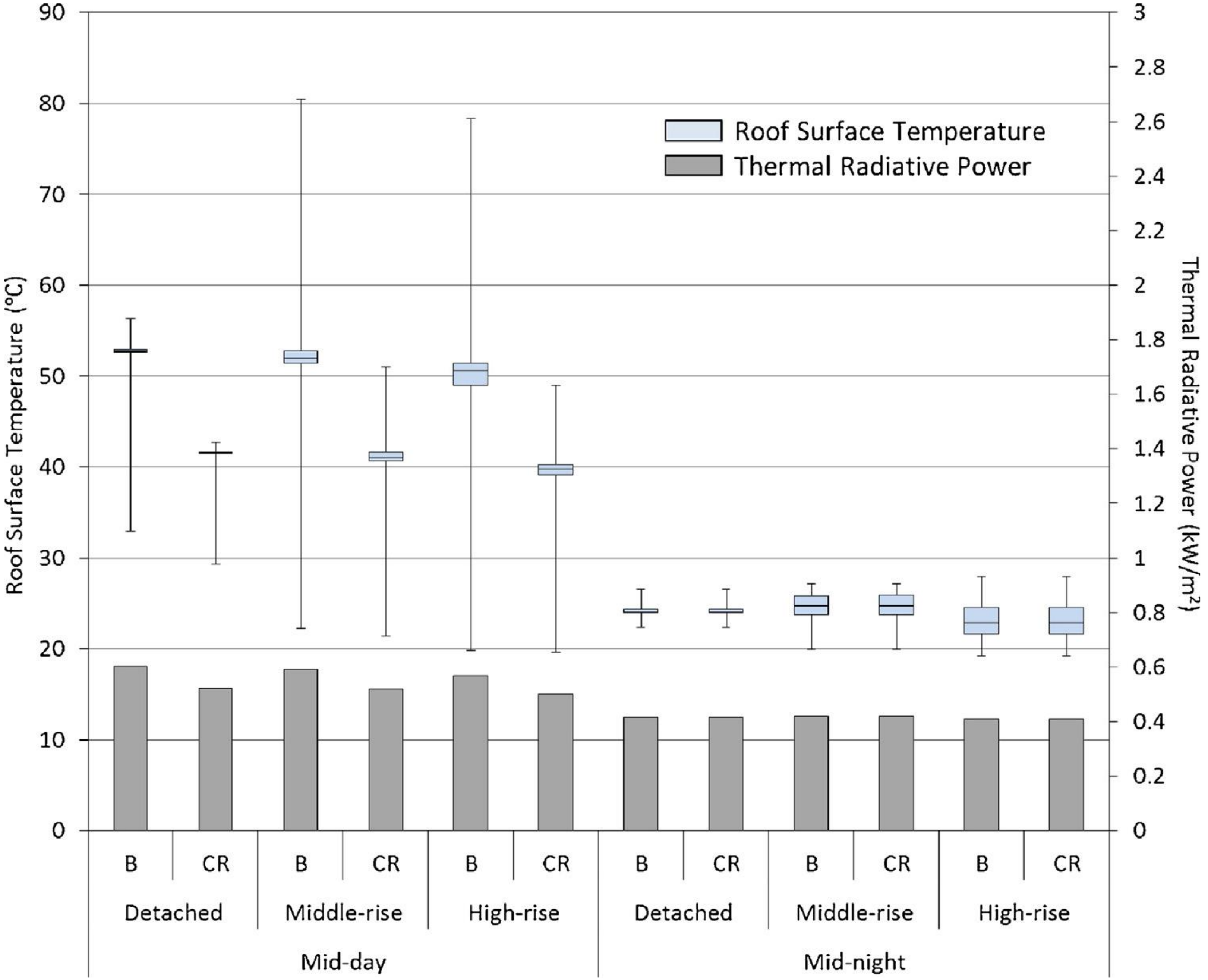
Land Surface Temperatures - Greater Toronto Area - September 3, 2008



Natural Resources Canada / Ressources naturelles Canada
Earth Sciences Sector / Secteur des sciences de la Terre

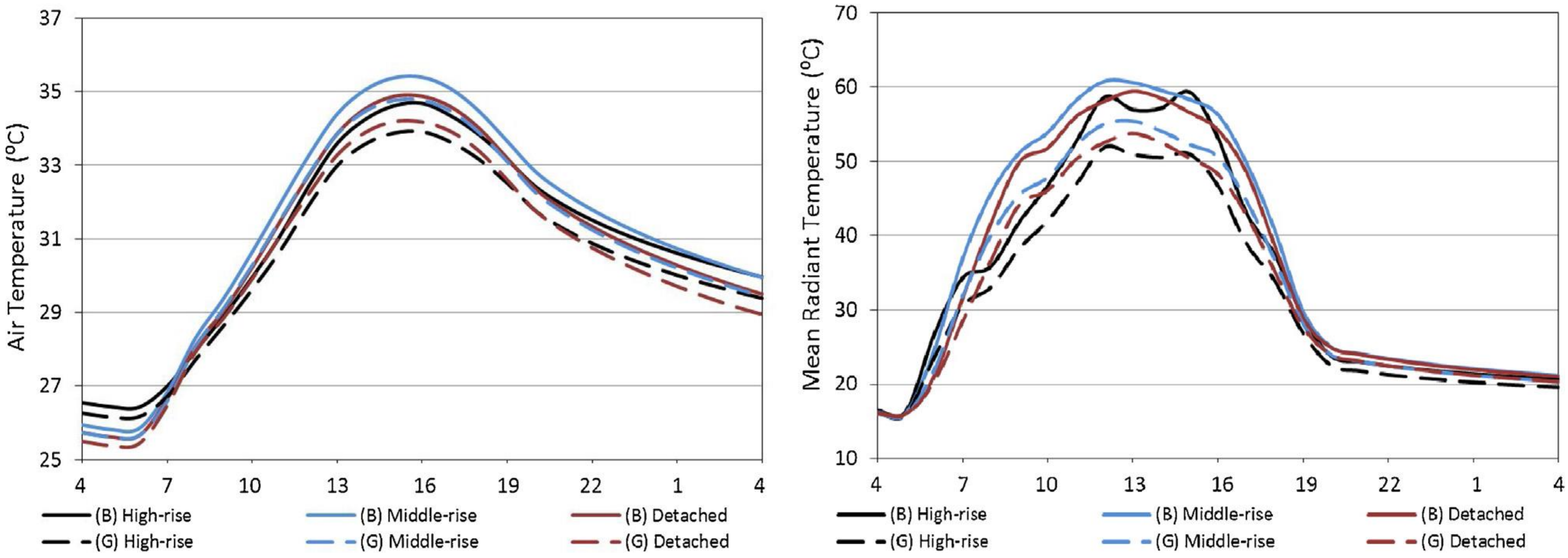
Surface temperatures derived from Landsat TM imagery
Contact: Matthew Maloley, Natural Resources Canada

UHI



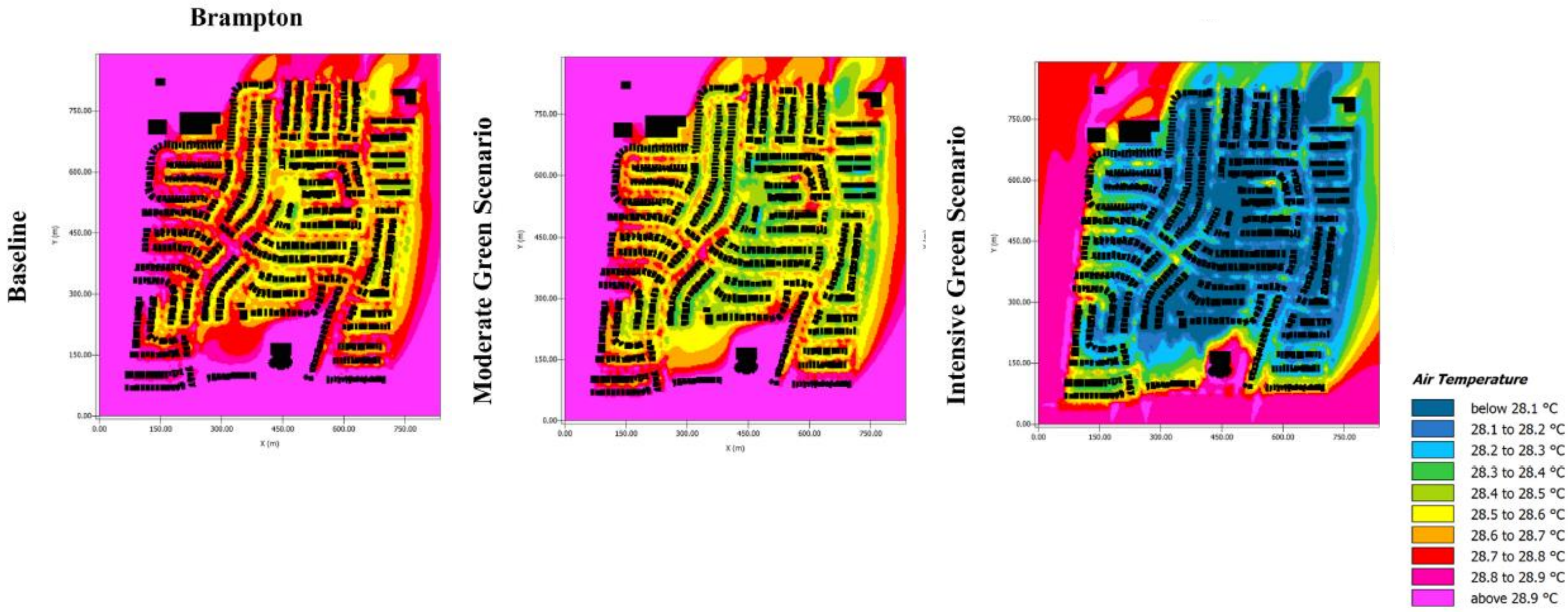
Roof Surface Temperature
Thermal Radiative Power
Roof Surface Temperature (°C)
Thermal Radiative Power (kW/m²)
90
80
70
60
50
40
30
20
10
0
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
B
CR
Detached
Middle-rise
High-rise
Mid-day
Mid-night

UHI



37
35
33
31
29
27
25
Air Temperature (ºC)
4
7
10
13
16
19
22
1
4
(B) High-rise
(B) Middle-rise
(B) Detached
(G) High-rise
(G) Middle-rise
(G) Detached
70
60
50
40
30
20
10
Mean Radiant Temperature (ºC)
4
7
10
13
16
19
22
1
4
(B) High-rise
(B) Middle-rise
(B) Detached
(G) High-rise
(G) Middle-rise
(G) Detached

Mesoscale (WRF) and microscale (Envi-met) modeling



Conclusions

- **Climate change** is a global phenomenon and the warming over the 20th century is unquestionable while the rise in **atmospheric GHG levels**, predominantly carbon dioxide, has been the main driver of **climate warming**
- Global and regional climate models allowed for the projection of future climate conditions, providing information on the impact of climate change on building energy demand.
- Simulation results showed that climate change results in a substantial increase in building cooling loads while reducing heating loads in Canada.
- The magnitude of change in cooling and heating loads are highly dependent on building climate zones, baseline climate and the climate model used for projecting climate change.
- Buildings with higher insulation levels, higher zone ratios, lower window-to-wall ratios, and smaller outdoor air supply are less affected by climate change.

Acknowledgements

https://sites.google.com/site/umbertoberardihomepage/home/research-group

https://www.facebook.com/BeTOPLab/

Toronto2030 platform and data driven statistical models: UBEM in face of Climate Changes

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Toronto Metropolitan University

The Climate Reality Project®

Toronto Metropolitan University