Impacts of Climate Change and Urbanization on Future Building Performance

Drury B. Crawley, Ph.D.
FASHRAE, BEMP, FIBPSA, AIA
Bentley Systems, Inc.

27 February 2017

ASHRAE London Chapter

This ASHRAE Distinguished Lecturer is brought to you by the Society Chapter Technology Transfer Committee

Complete the Distinguished Lecturer Event Summary Critique

- **CTTC needs your feedback to continue to improve the DL Program**
  - ✓ Distribute the DL Evaluation Form to all attendees
  - ✓ Collect at the end of the meeting
  - ✓ Compile the attendee rating on the Event Summary Critique
  - ✓ Send the completed Event Summary Critique to your CTTC RVC and ASHRAE Headquarters

Forms are available at:
www.ashrae.org/distinguishedlecturers

VOLUNTEER!

www.ashrae.org/volunteer

BECOME A FUTURE LEADER IN ASHRAE –
WRITE THE NEXT CHAPTER IN YOUR CAREER

ASHRAE Members who are active at their chapter and society become leaders and bring information and technology back to their job.

YOU ARE NEEDED FOR:

- Society Technical Committees
- Society Standard Committees
- Chapter Membership Promotion
- Chapter Research Promotion
- Chapter Student Activities
- Chapter Technology Transfer

Find your Place in ASHRAE and volunteer

ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request. This course is approved for 2 LU/HSW by AIA; course number is CRAWLEY05.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

EDUCATION PARTNER

Impacts of Climate Change and Urbanization on Future Building Performance

By Drury B. Crawley

GBCI cannot guarantee that course sessions will be delivered to you as submitted to GBCI. However, any course found to be in violation of the standards of the program, or otherwise contrary to the mission of GBCI, shall be removed. Your course evaluations will help us uphold these standards.

Course ID: 0920010369

Approved for:

X General CE hours

X LEED-specific hours

- LEED Green Associate
- LEED AP BD+C
- LEED AP Homes
- LEED AP ID+C
- LEED AP ND
- LEED AP O+M

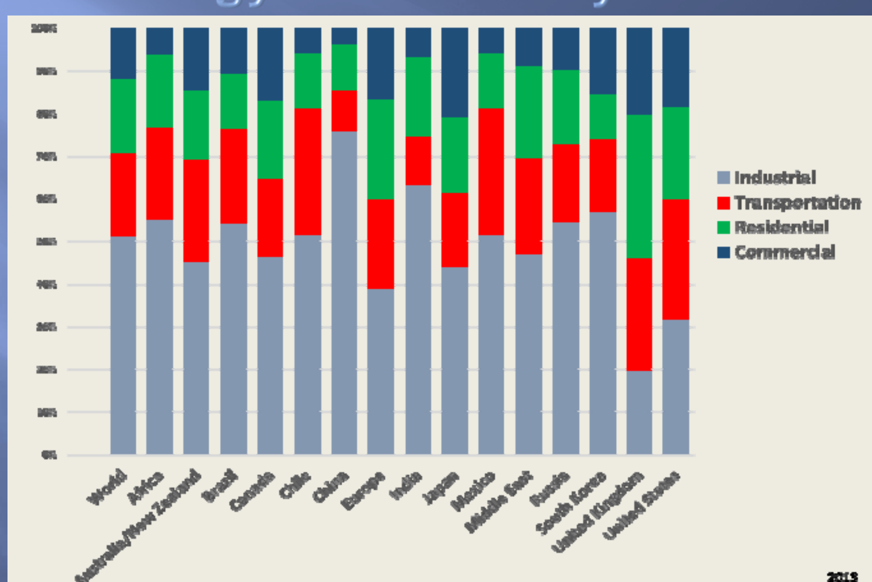
Learning Objectives

- Explain difference between weather and climate
- Recognize climate change scenarios
- Explain impacts of urban heat islands on diurnal temperature
- Explain impact of climate change on energy performance in different climate zones

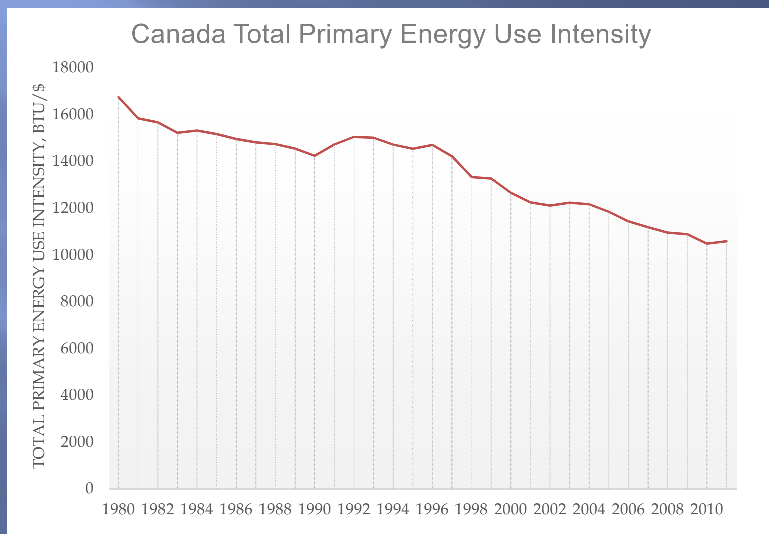
Course Description

With the increasing interest in climate change driven by human activity, recent research has focused on the impact of climate change or urban heat island on building operation and performance across the world. But this work usually aggregates the energy and peak demand impacts across a broad sector. In a recent study, impacts on the operating performance of an office building were estimated based on climate change and heat island scenarios in 25 locations (20 climate regions). This presentation presents the variation and differences among the 20 regions when climate change is introduced. The focus is on changes in comfort conditions, building equipment operation as well as daily patterns of energy performance using prototypical buildings that represent typical, good, and low-energy practices around the world. Other issues such as fuel swapping as heating and cooling ratios change, impacts on environmental emissions, and how low-energy building design incorporating renewables can significantly mitigate any potential climate variation are also presented.

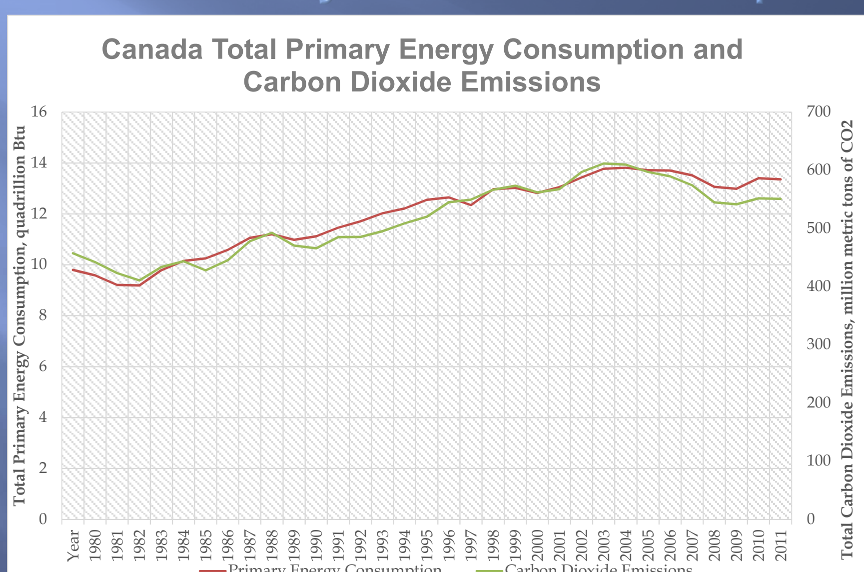
Energy End Uses by Sector



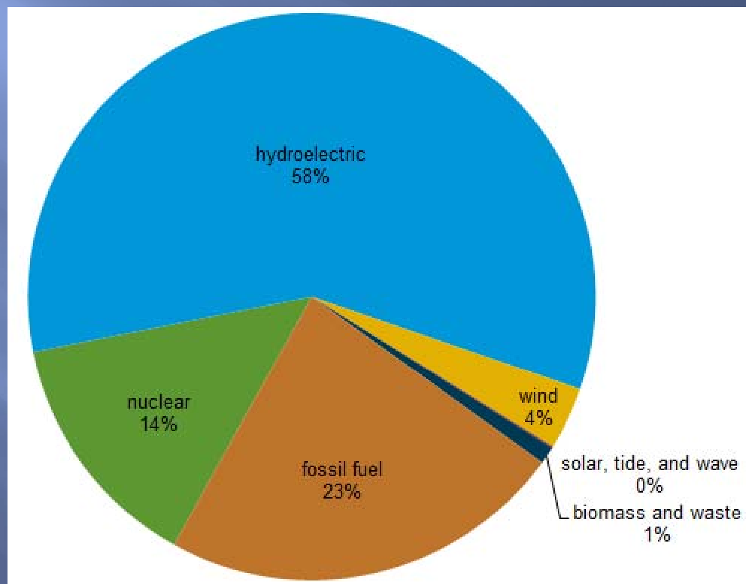
Canadian Energy Use Intensity Continues to Fall



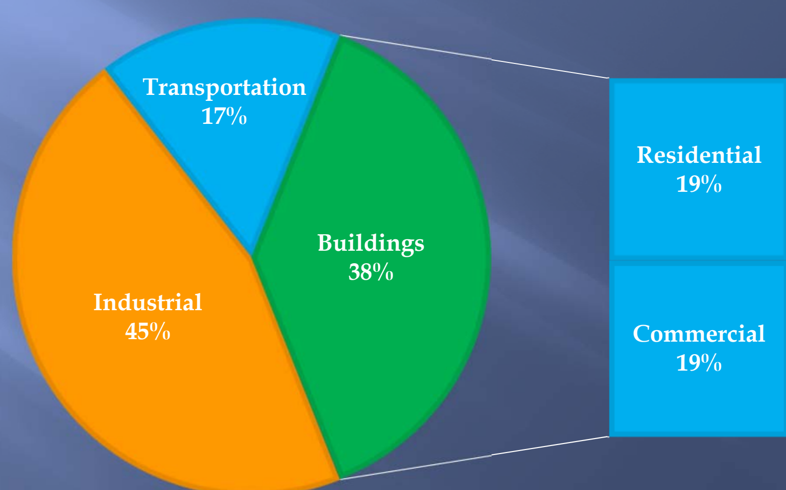
Primary Energy Has Flattened and Carbon Intensity Continues to drop



Canada Electricity Generation

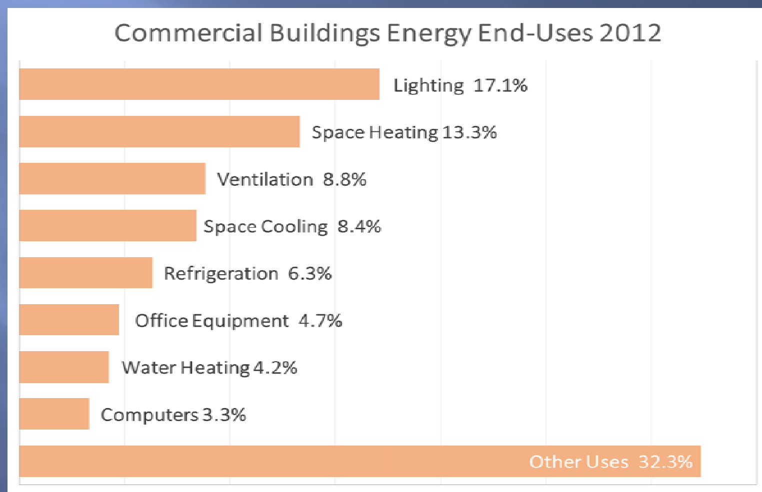


Canadian Buildings' Energy Use



http://www.eia.gov/forecasts/ieo/pdf/ieorefendusetab_4.pdf

U.S. Buildings' Energy Use



Energy Information Administration. 2013. *Annual Energy Outlook 2013, EIA-0383 2013). Washington, D.C.*

Weather ≠ Climate

Weather:

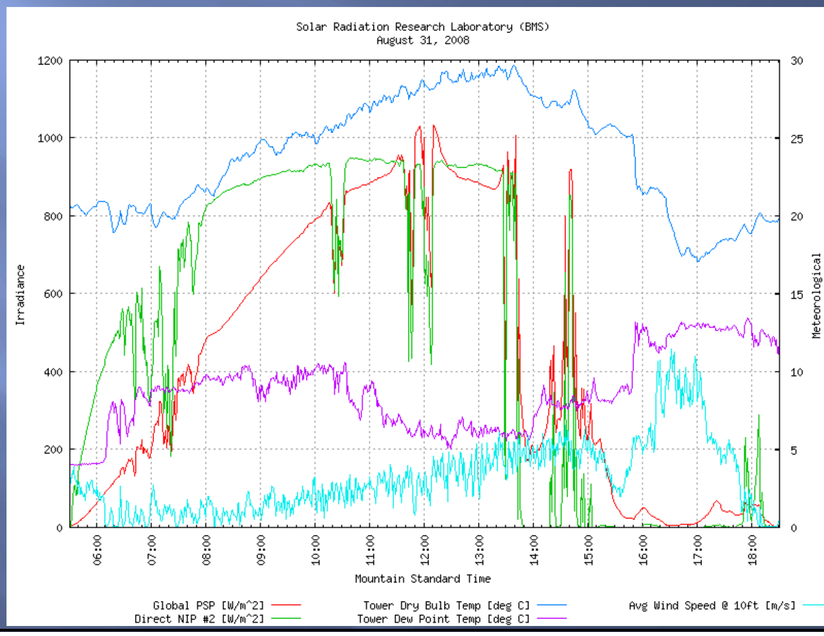
the state of the atmosphere with respect to wind, temperature, cloudiness, moisture, pressure, etc.

Climate:

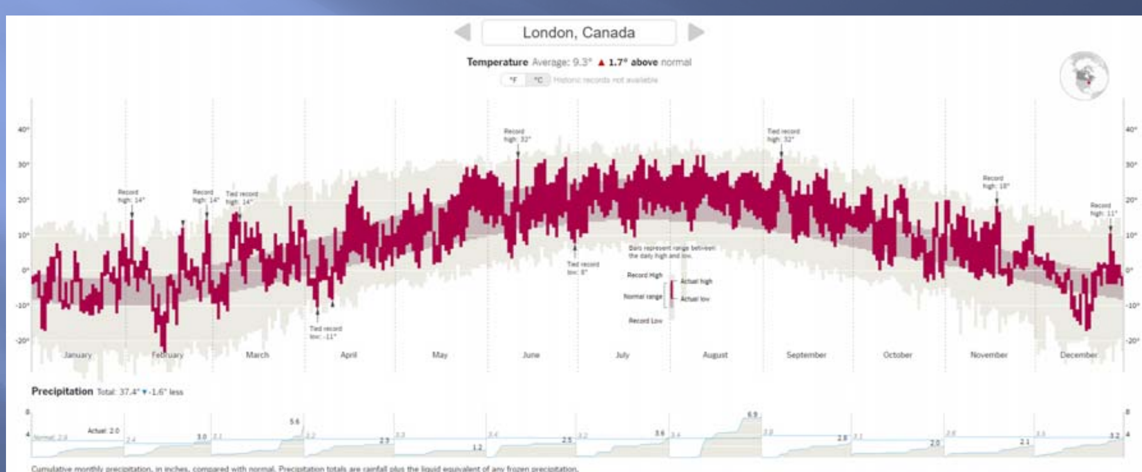
the composite or generally prevailing weather conditions of a region, as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds, throughout the year, averaged over a series of years.

www.dictionary.com

Weather is Variable!

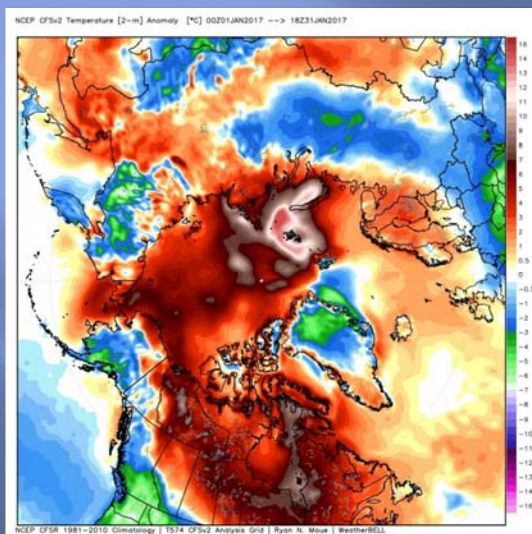


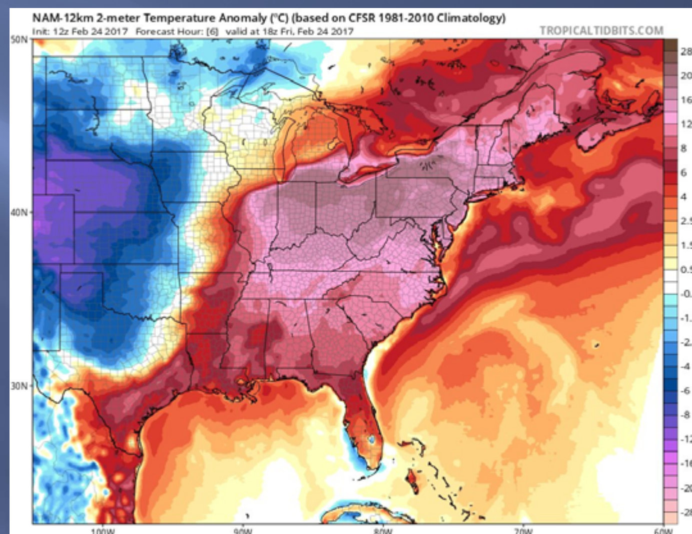
How Much Warmer was 2016 in London?



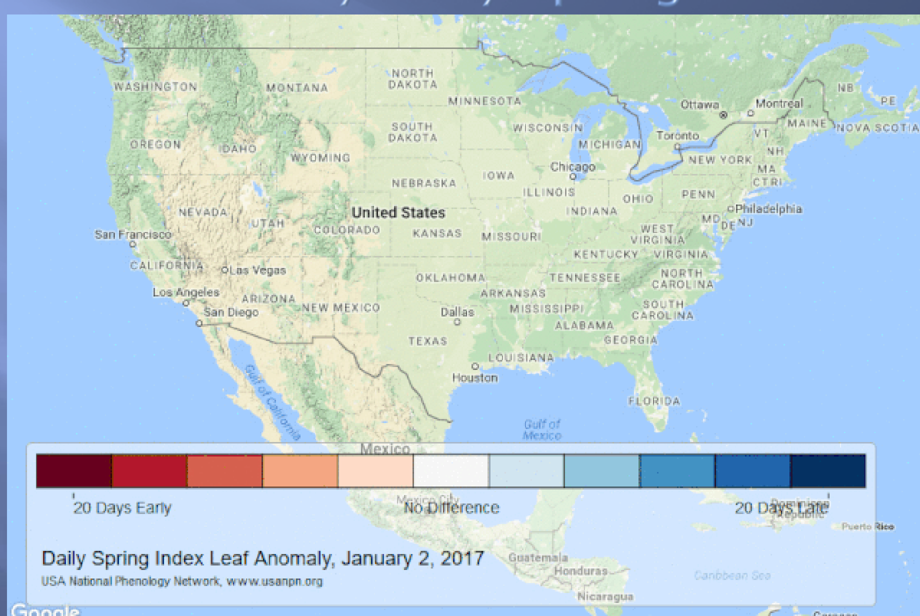
https://www.nytimes.com/interactive/2017/01/18/world/how-much-warmer-was-your-city-in-2016.html

Temperature Anomalies This Year





Very Early Spring



Building Uses for Climatic Data

Building design and performance modeling require weather data to represent climatic conditions of the building location, including:

- Peak heating and cooling design conditions for load calculations (temperature, humidity, solar, and wind conditions for design calculations)
- Building Performance Simulation
  - Typical hourly weather data
  - Actual hourly weather data for calibration to utility bills
  - Future hourly weather data

Simulation Applications and Climatic Data Requirements

Simulation Application	Type of weather data required
Energy design and compliance analysis of fully-conditioned buildings	Typical (full year) hourly data
Performance of un- or semi- conditioned buildings	Typical data not adequate –require application specific data (e.g., warm summer, multi-year data)
Equipment sizing	Design-day or short period calculations using near-extreme conditions
Model calibration, building trouble shooting, control optimization, and actual savings estimation	Weather data observed during the study period at or near the building site
Engineering studies (e.g., hours when economizer is feasible)	Simple weather information (e.g., bin temperature data)
Natural ventilation design	Local wind conditions highly variable – airport data often unreliable for other sites. Locally measured wind data.
Daylighting studies	Hourly illuminance data usually sufficient for sensor-control lighting systems but sub-hourly data often required for visual comfort or control dynamics.
Renewable energy systems	Solar-electric systems require short-term data and spectral variation of incident solar radiation. Wind turbine systems require sub-hourly wind velocity data. (Standard hourly data may produce unreliable results for systems with non-linear characteristics.)

Weather Data Elements for Building Simulation

Element	Model use(s)	Availability and issues
Dry-bulb air temperature	• Exterior surface convection • Infiltration/ventilation sensible heat transfer • Equipment (e.g. air-cooled condenser)	• Universally observed • Significant local effects (e.g. heat island)
Humidity (relative humidity, wet-bulb temperature, or dew-point temperature)	• Infiltration/ventilation latent heat transfer • Equipment (e.g. cooling tower)	• Commonly observed
Solar irradiance (direct and diffuse)	• Fenestration heat gain • Exterior surface heat balance • Solar thermal and photovoltaic systems	• Sparsely measured • If observed, often global only • Model sources widely used • Remote sensing opportunities
Solar illuminance (direct and diffuse)	• Daylight modeling	• Rarely measured (modeled from irradiance)
Sky temperature	• Exterior surface heat balance	• Rarely measured (modeled from temperature, humidity, and cloud cover)
Cloud cover / sky condition	• Sky models (e.g. for daylighting)	• Generally observed • Multiple data representation conventions • Evolution of automated instrumentation introduces uncertainties
Wind (velocity and direction)	• Exterior surface convection • Infiltration • Natural ventilation	• Generally observed • Local effects very significant for both velocity and direction • Low velocity observations unreliable
Ground temperature	• Below-grade heat transfer	• Measured for agricultural purposes, limited exploitation of observed values for building simulation
Ground surface albedo	• Reflected irradiance / illuminance	• Inferable from presence of snow
Weather conditions (e.g. rain)	• Exterior surface wetting	• Generally measured; inconsistent reporting formats

Climatic Data Availability

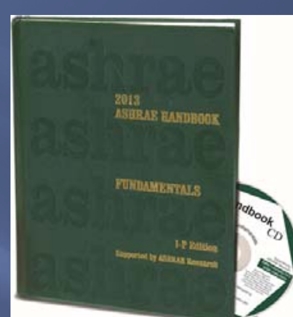
- In the past, usually only available from ground observing stations
  - Rarely includes solar data
  - Temperature/humidity data generally robust.
  - Wind data is problematic – extremely variable due to terrain and site obstructions.
  - Other data can be limited or incomplete.
- Now, more sources incorporate remote sensing (satellite) data. Accuracy is quite good. Advantage – comprehensive global data, relatively decent grid. Not dependant on ground stations.
- In general master data sets such as those from NOAA/NCEI are near-real-time. Data is posted within a few days to weeks.
- But design conditions and data for simulation often require summary and further calculations before it can be used
  - Design conditions based on historical period of record
  - Ground observing stations (near real-time data) do not record solar radiation.

Design Conditions

- Used for design sizing of heating, ventilating, air-conditioning, and dehumidification equipment, as well as or other energy-related processes in residential, agricultural, commercial, and industrial applications.
- Includes as a minimum dry-bulb, wet-bulb, and dew-point temperature, and wind speed with direction at various frequencies of occurrence.
- Typical annual percentiles* used:
  99.6% heating dry-bulb temperature and
  1% cooling dry-bulb temperature with coincident wet-bulb.
- Depending on the application, use other percentiles (99, 0.4, 2, 5) or variables (wind speed, dewpoint, wetbulb, etc.). Monthly cooling percentiles also available (0.4, 2, 5, 10).

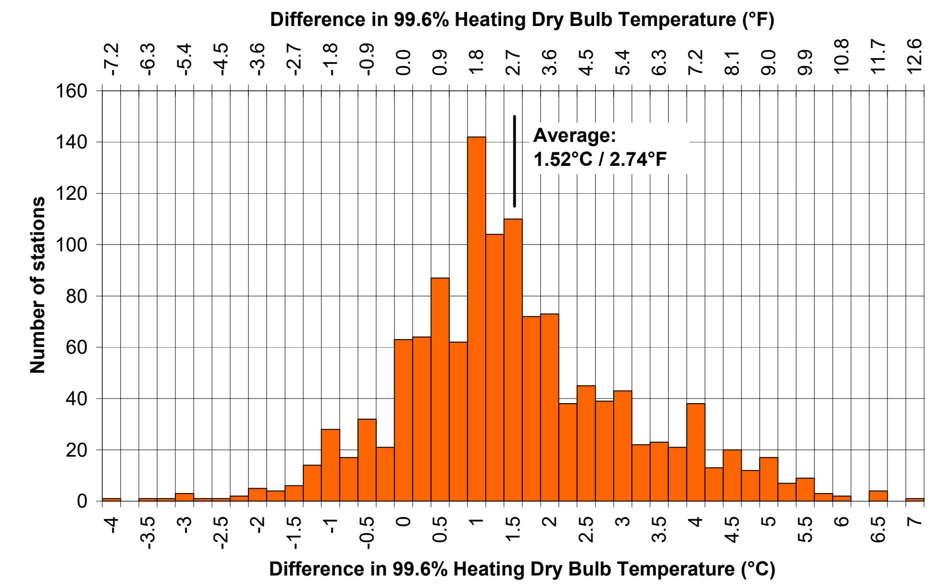
*Percentiles represent number of hours that the design condition can be expected to be exceeded in a typical year, based on15-30 years of data. 99.6% ≈ 35 annual hours (8760 – (99.6% * 8760)). 1% ≈ 88 annual hours (8760 – (1% * 8760)).

Design Conditions (cont'd)



- Best source for design conditions:
  Chapter 14 Climatic Design Information, ASHRAE Handbook-Fundamentals:
  - 6,443 locations through the world
  - Integrated Surface Dataset (ISD) data for stations from around the world provided by NCDC for the period 1982 to 2010
  - Updated every four years
- Climate changing!
  Comparing design conditions for 1274 locations between 1977-1986 and 1997-2006:
  - 99.6% annual dry-bulb temperature increased 1.52°C
  - 0.4% annual dry-bulb increased 0.79°C
  - annual dew point increased by 0.55°C
  - HDD base 18.3°C) decreased 237°C-days,
  - CDD base 10°C increased 136°C-days.

$$\Delta DB^{99.6} = DB^{99.6}_{1997-2006} - DB^{99.6}_{1977-1986}$$

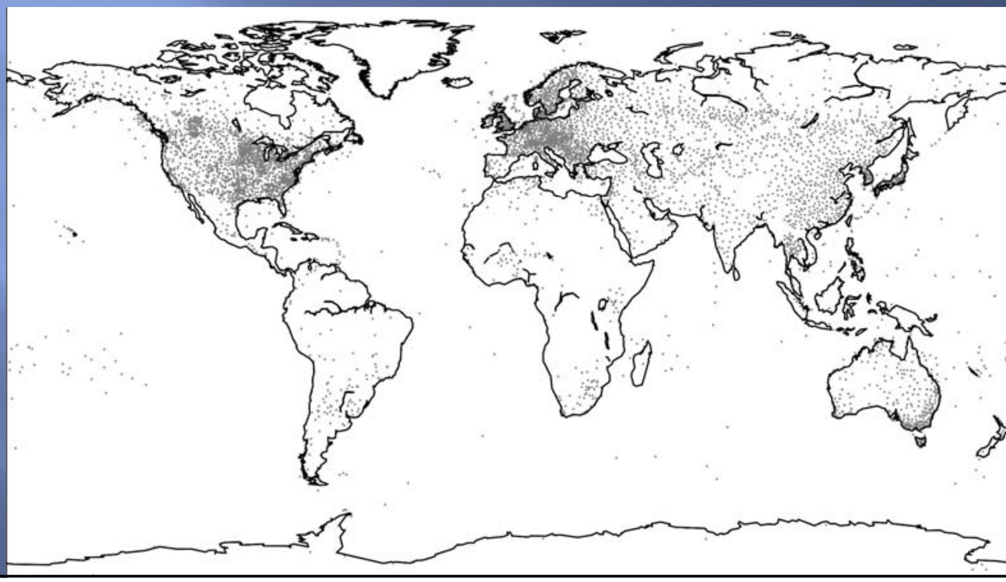


Average Decadal Changes Last '30 Years'

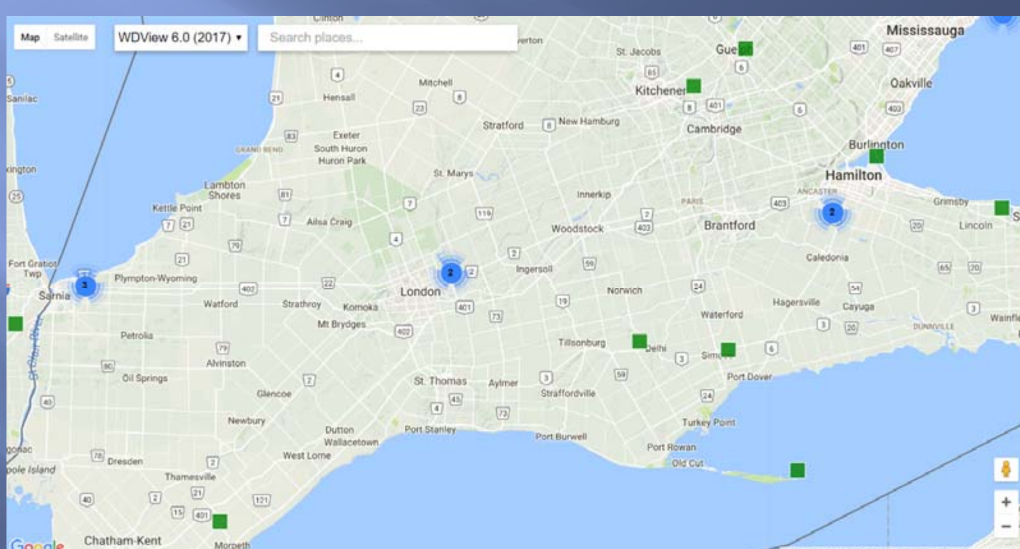
99.6% heating dry bulb temperature	+ 0.76 °C	+ 1.37 °F
0.4% cooling dry bulb temperature	+ 0.38 °C	+ 0.68 °F
0.4% dehum. dew point temperature	+ 0.28 °C	+ 0.50 °F
Dry bulb temperature range	~ 0 °C	~ 0 °F
Average temperature	+ 0.41 °C	+ 0.73 °F
Heating degree-days base 18.3°C / 65°F	- 118 °C-day	- 212 °F-day
Cooling degree-days base 10°C / 50°F	+ 68 °C-day	+ 122 °F-day

28

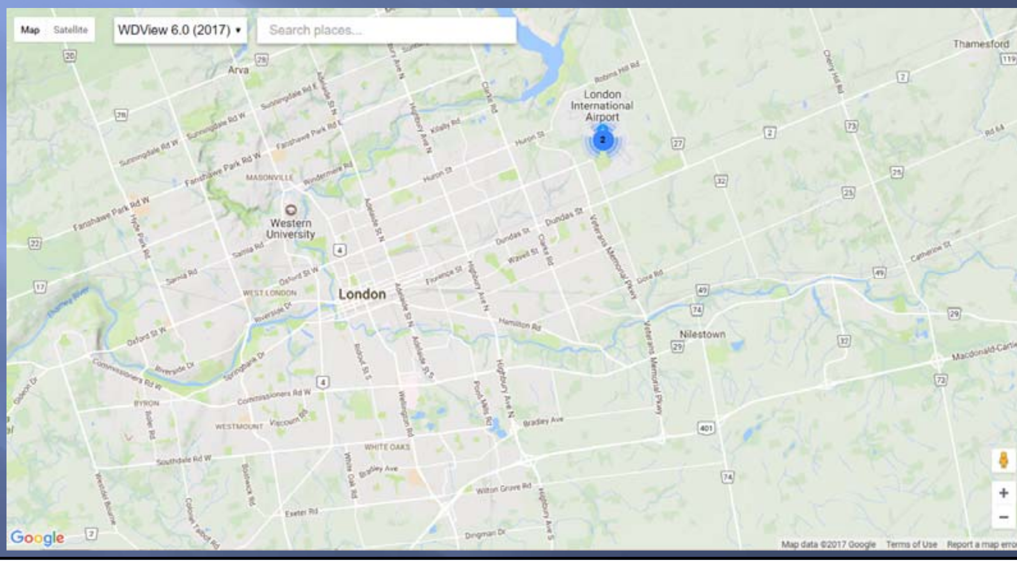
ASHRAE 2017 Handbook Fundamentals Weather Locations



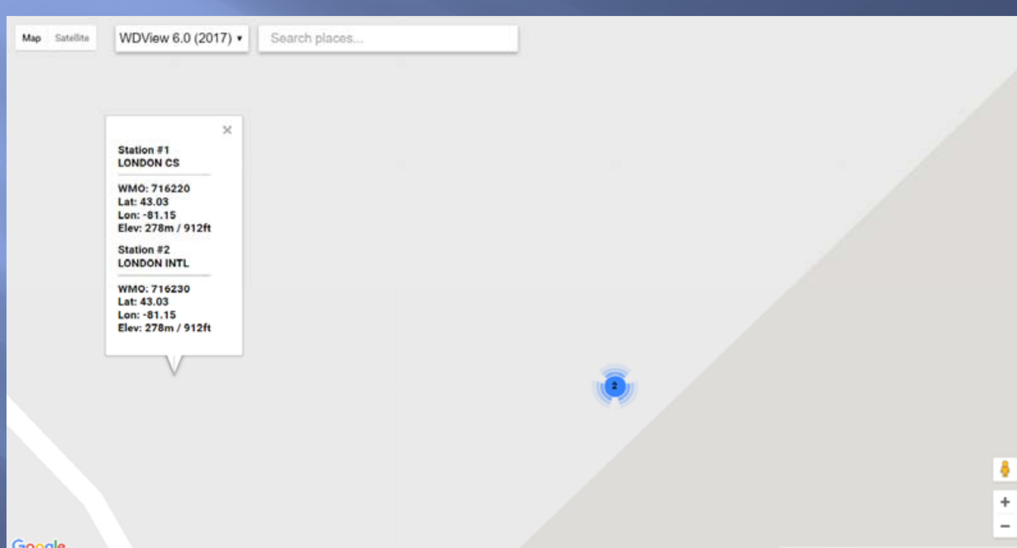
2017 ASHRAE Station Finder



London, Ontario



Local Stations



2017 Fundamentals Design Conditions

2017 ASHRAE Handbook - Fundamentals (SI)

LONDON INTL, ON, Canada WMO#: **716230**

Lat: **43.030N** Long: **81.150W** Elev: **278** StdP: **98.03** Time Zone: **-5.00 (NAE)** Period: **90-14** WBAN: **99999**

Annual Heating and Humidification Design Conditions

	Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
				99.6%			99%			0.4%		1%				
		99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	
(1)	1	-18.2	-15.6	-22.9	0.5	-17.9	-19.7	0.7	-15.1	12.9	-5.0	11.6	-4.1	3.3	250	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

	Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
			0.4%		1%		2%		0.4%		1%		2%				
			DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(2)	7	10.2	30.2	22.4	28.6	21.7	27.2	20.7	23.7	28.2	22.8	27.1	21.8	25.7	4.7	200	(2)

	Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Extreme Max WB	
	0.4%			1%			2%			0.4%		1%		2%			
	DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(3)	22.3	17.6	26.3	21.3	16.5	25.2	20.5	15.7	24.4	72.4	28.4	68.6	27.1	65.1	25.6	29.1	(3)

Extreme Annual Design Conditions

	Extreme Annual WS				Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature								
					Mean		Standard Deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(n)	(o)	(p)		(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	
(4)	10.7	9.4	8.4	DB	-21.9	32.8	3.2	2.0	-24.3	34.3	-26.2	35.5	-28.0	36.6	-30.3	38.1	(4)
(5)				WB	-22.3	25.9	3.2	1.2	-24.6	26.7	-26.5	27.4	-28.3	28.1	-30.6	28.9	(5)

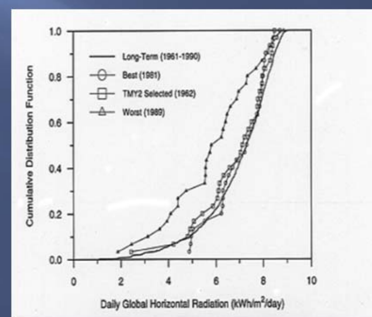
2017 Fundamentals Design Conditions

Monthly Climatic Design Conditions

			Annual (d)	Jan (e)	Feb (f)	Mar (g)	Apr (h)	May (i)	Jun (j)	Jul (k)	Aug (l)	Sep (m)	Oct (n)	Nov (o)	Dec (p)	
(6)	Temperatures, Degree-Days and Degree-Hours	DBAvg	8.2	-5.2	-4.7	0.1	7.1	13.3	18.8	20.8	19.9	16.0	9.8	3.6	-2.1	(6)
(7)		DBStd	10.38	6.17	5.42	6.08	4.95	4.58	3.83	3.07	2.89	3.98	4.44	4.65	5.02	(7)
(8)		HDD10.0	1961	471	411	312	115	18	1	0	0	3	60	197	374	(8)
(9)		HDD18.3	3943	729	644	564	339	167	41	11	16	92	268	441	632	(9)
(10)		CDD10.0	1298	0	0	6	27	121	263	333	307	182	52	6	1	(10)
(11)		CDD18.3	239	0	0	0	1	12	53	86	65	21	2	0	0	(11)
(12)		CDH23.3	1856	0	0	2	12	116	424	670	464	156	12	0	0	(12)
(13)		CDH26.7	419	0	0	0	1	20	104	168	96	29	2	0	0	(13)
(14)	Wind	WSAvg	3.9	4.8	4.5	4.4	4.5	3.9	3.3	3.0	2.8	3.2	3.8	4.3	4.5	(14)
(15)	Precipitation	PrecAvg	953	69	60	75	79	74	82	77	90	86	76	92	93	(15)
(16)		PrecMax	1115	133	96	160	121	109	145	179	227	188	147	147	138	(16)
(17)		PrecMin	577	31	11	14	38	27	36	17	20	12	5	29	34	(17)
(18)		PrecStd	147	30	26	34	22	24	29	40	50	41	36	34	28	(18)
(19)	Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB	11.9	10.4	21.1	25.2	28.9	31.3	32.3	31.6	29.7	24.8	17.1	12.2	(19)
(20)			MCWB	10.9	8.3	16.1	17.8	20.0	22.4	24.3	23.0	21.7	18.7	13.3	10.9	(20)
(21)		2%	DB	8.4	6.8	16.0	21.2	26.6	29.5	30.3	29.1	26.9	21.7	14.8	9.4	(21)
(22)			MCWB	7.7	4.9	11.9	14.6	19.4	21.9	22.8	22.4	20.0	17.0	12.3	8.2	(22)
(23)		5%	DB	4.9	4.2	12.3	18.4	24.1	27.6	28.5	27.4	25.0	19.4	13.2	6.5	(23)
(24)			MCWB	3.8	2.5	9.4	12.8	17.6	20.8	21.8	21.2	19.3	15.5	11.0	5.2	(24)
(25)		10%	DB	2.6	2.4	8.9	15.6	21.7	25.8	26.9	25.9	23.1	17.0	11.0	4.2	(25)
(26)			MCWB	1.5	1.1	6.2	10.8	15.7	19.5	20.9	20.4	18.3	14.0	8.9	3.0	(26)
(27)	Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB	10.9	8.4	16.6	18.4	22.0	24.0	25.7	24.7	23.2	20.1	14.6	11.2	(27)
(28)			MCDB	11.6	9.8	20.9	23.6	27.1	29.5	31.0	28.3	27.8	23.1	16.1	12.0	(28)
(29)		2%	WB	7.9	5.0	12.4	15.8	20.2	22.8	24.0	23.3	21.5	17.6	12.9	8.4	(29)
(30)			MCDB	8.3	6.3	15.0	19.9	25.1	28.1	28.3	27.4	24.8	20.8	14.6	9.2	(30)
(31)		5%	WB	4.0	2.7	9.4	13.8	18.7	21.7	23.0	22.3	20.3	16.0	11.1	5.3	(31)
(32)			MCDB	4.7	4.0	12.0	17.7	22.8	26.2	27.1	26.0	23.3	18.6	12.9	6.3	(32)
(33)		10%	WB	1.6	1.2	6.3	11.5	16.8	20.6	21.9	21.3	19.1	14.5	9.1	3.2	(33)
(34)			MCDB	2.5	2.3	8.6	14.7	20.6	24.6	25.5	24.8	22.1	16.8	10.8	4.1	(34)
(35)			MDBR	6.8	7.4	8.3	10.0	10.7	10.2	10.2	10.3	10.6	9.0	7.0	6.1	(35)

Climatic Data in Building Performance Simulation

- Climatic data needed for simulating representative performance from a single year analysis.
- TMY (Typical Meteorological Year) approach is most widely used– a composite of months (not all from same year), each representative for the period of record.
- Months selected using statistical indices (daily min, mean, max) dry-bulb temperature, dew-point temperature, wind speed, and total global and direct solar radiation. Each method varies weightings of the indices based their importance.



Typical Meteorological Year Hourly Data Sets

- Best for:
  - Comparison of alternatives during design
  - Compliance with building standards/codes and green building rating system points
- Limitations:
  - No explicit effort to represent extreme conditions
  - Files not intended to represent design conditions (can be mild)

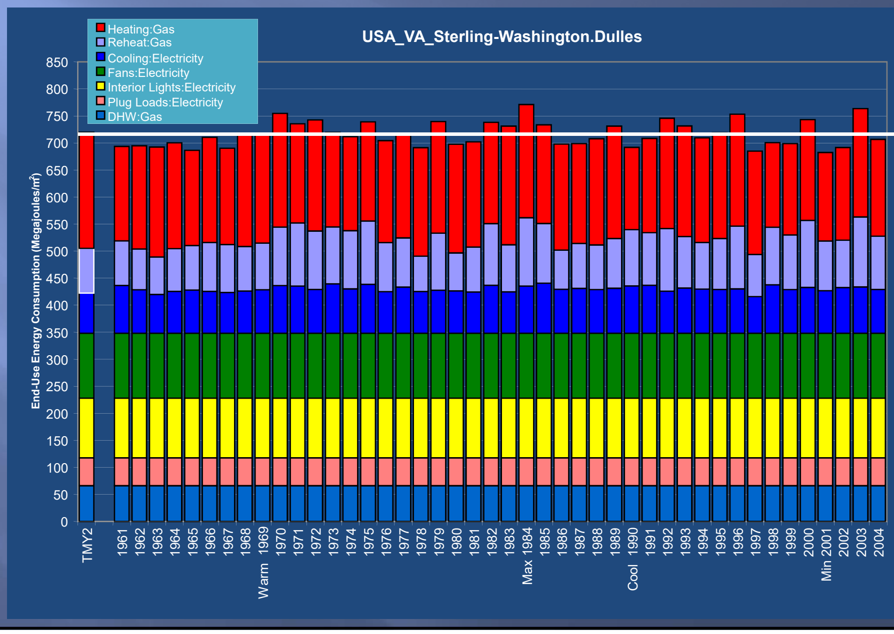
Typical Meteorological Year Weather Data Sets Available

Weather Data Sets		Number of Locations	Geographic Coverage
Acronym	Name		
CTZ2	California Climate Zones 2	16	California
CWEC	Canadian Weather for Energy Calculations	80	Canada
CIBSE	Chartered Institute of Building Services Engineers Test Reference Years and Design Summer Years	14	United Kingdom
CSWD	Chinese Standard Weather Data	270	China
CTYW	Chinese Typical Year Weather	57	China
IGDG	Italian Climate data collection 'Gianni de Giorgio'	66	Italy
IMGW	Instytutu Meteorologii i Gospodarki Wodnej Weather Data Set	61	Poland
IMS	Israel Meteorological Service Weather Data for Israel	4	Israel
ISHRAE	Indian Society of Heating, Refrigerating and Air-Conditioning Engineers	58	India
ITMY	Iranian Typical Meteorological Year	6	Iran
IWEC2	International Weather for Energy Calculations v2	3012	Worldwide (except USA and Canada)
NIWA	National Institute of Water & Atmospheric Research	16	New Zealand
RMY	Representative Meteorological Year	80	Australia
SWEC	Spanish Weather for Energy Calculations	52	Spain
SWERA	Solar and Wind Energy Resource Assessment	156	Belize, Brazil, China, Cuba, El Salvador, Ethiopia, Ghana, Guatemala, Honduras, Kenya, Maldives, Nicaragua, and Sri Lanka
TMY3	Typical Meteorological Year 3	1020	USA, Guam, Puerto Rico, US Virgin Islands

Actual Weather Data

- Actual hourly weather data required to calibrate to utility bills in existing buildings and subsequent evaluation of retrofit alternatives.
- Many sources – some providing near-real time data and/or prediction:
  - NOAA/NCEI/WMO Data Center
  - EnergyPlus Real-Time Weather Data
  - Weather Bank
  - Weather Source
- Biggest issue – how complete are the data – does it include temperature, humidity, wind, solar radiation?

Typical vs. Actual



Future Climatic Data Sets

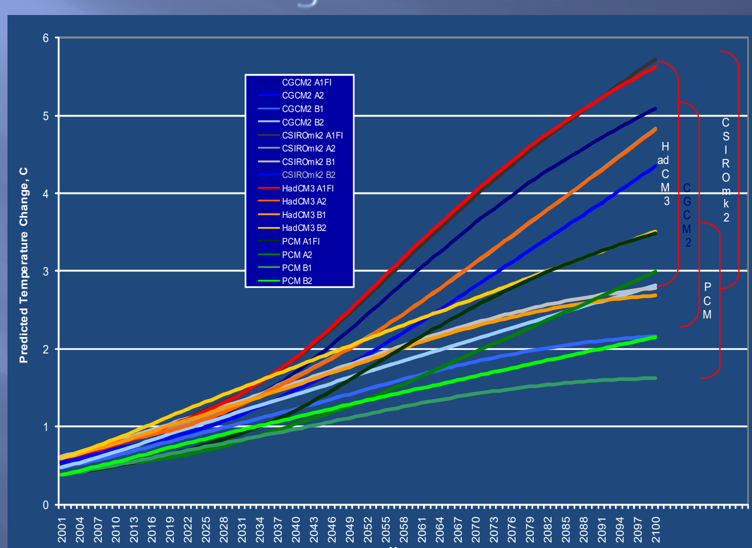
- CIBSE
  - UK only, 14 locations
  - Derived from reanalysis (downscale of lat/long grid) from IPCC (UKCP09)
  - 2020, 2050, 2080
  - Low, medium, high cases
  - See CIBSE TM48
- CCWorldWeatherGen
  - Utility converts an EPW into a IPCC A1FI scenario morphed file.

IPCC Climate Change Scenarios

- Four major storylines developed to represent different demographic, social, economic, technological, and environmental developments.
- Four emissions scenarios from the storylines – A1FI, A2, B1, B2 – represent the range of potential climate impact
- Four major Global Climate Models (GCMs): HadCM3, CSIRO2, CGCM2, PCM)

Result: 16 scenario and climate prediction combinations

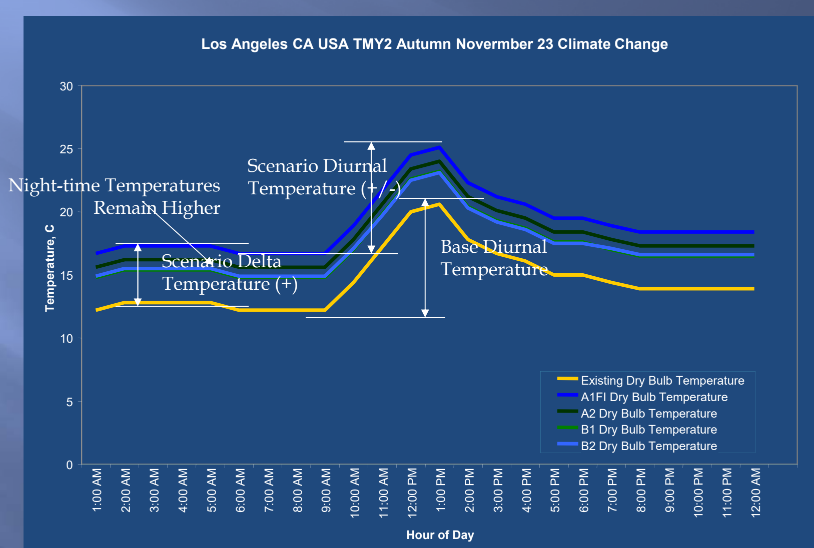
Range of Annual Average Temperature Change Predicted



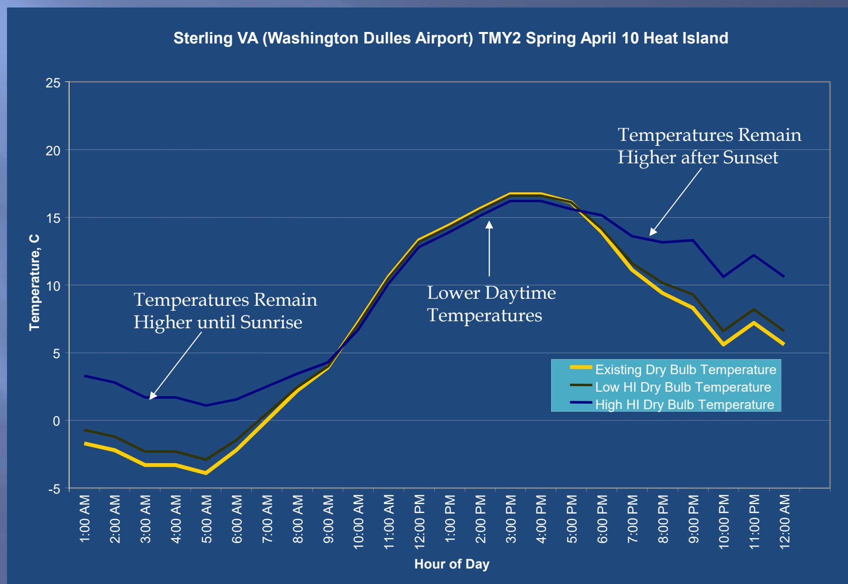
Creating Future Climatic Data

- Methods
  - Dynamic downscaling
    - Physics-based model used to downscale global climate model results
  - Analogue scenarios
    - Find existing locations with comparable data to the predicted climate change scenario results
  - Time series adjustment (morphing)
    - Shift and stretch the existing data to match the predicted monthly change
  - Statistical models
    - Stochastic model trained on observed data adjusts data based on altered frequency distributions of weather variables

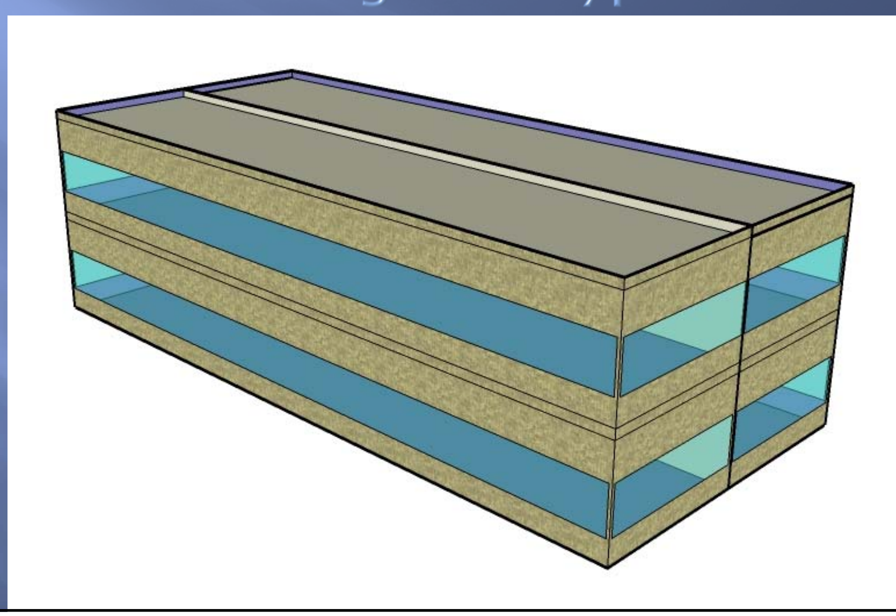
TMY2 Data Morphed with Climate Change Scenarios



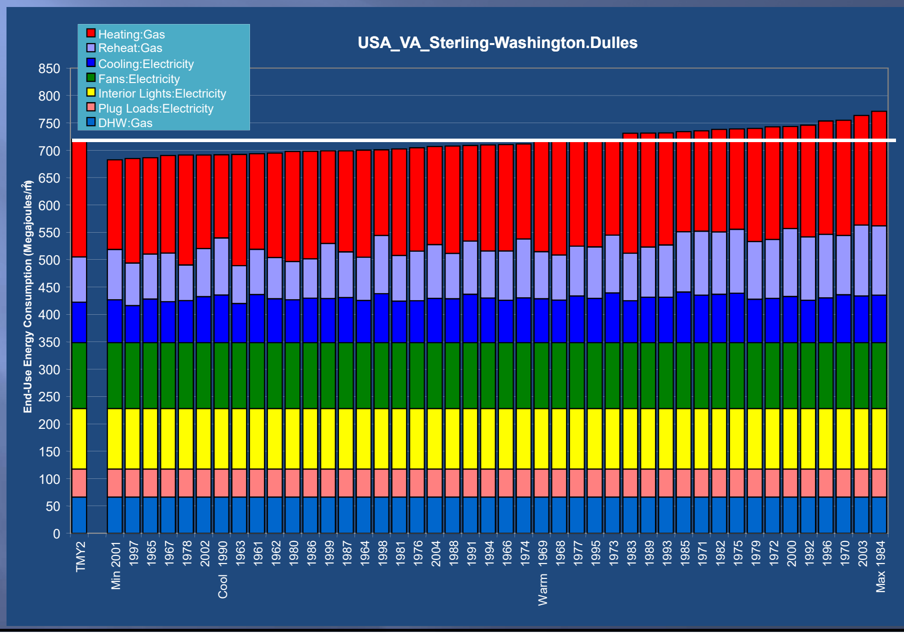
Heat Island



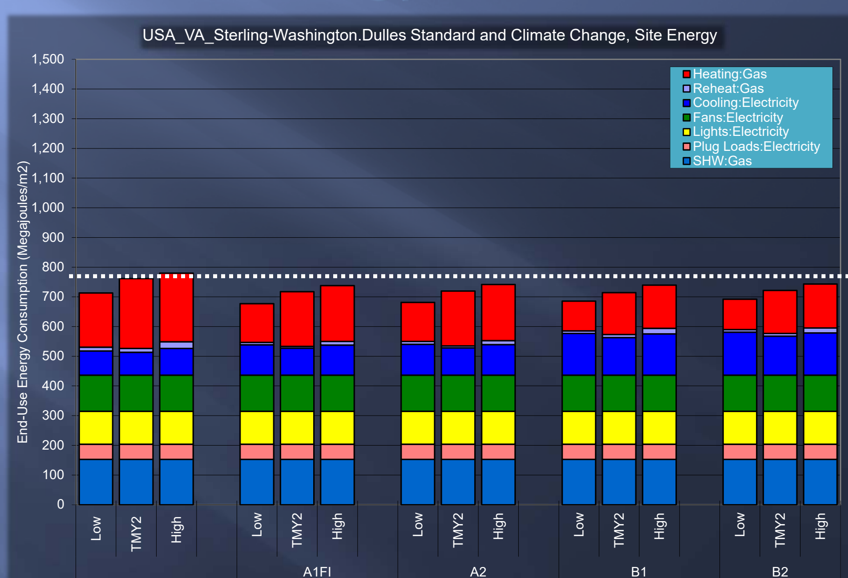
Building Prototype



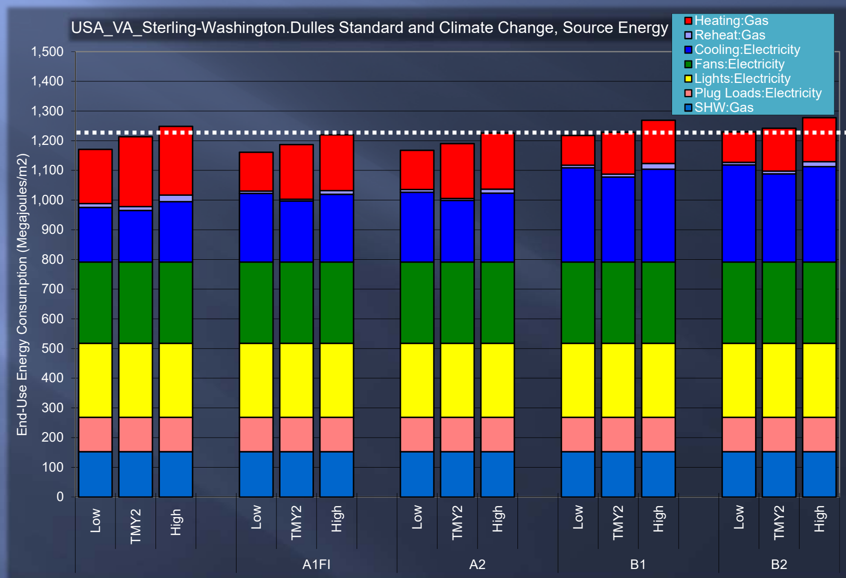
Typical vs. Sorted Actual Years



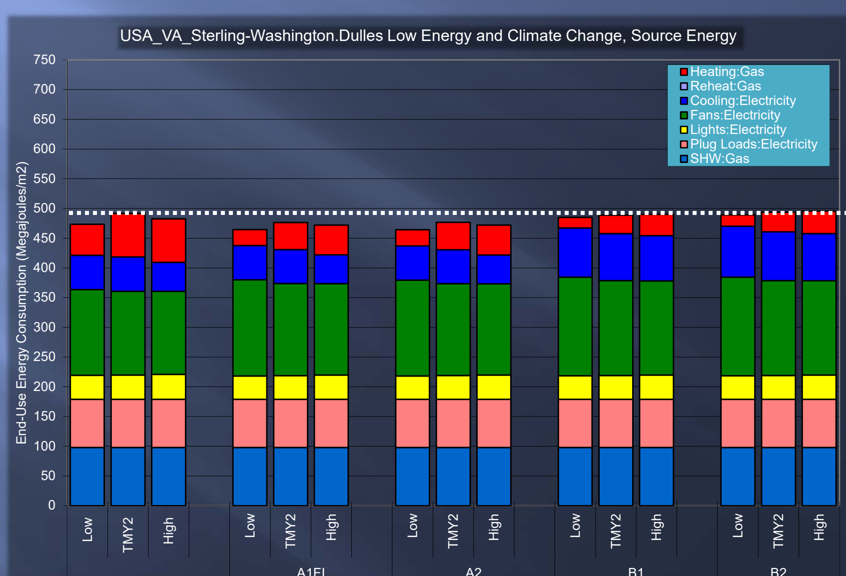
A Snapshot of Results: Site Energy Decreases



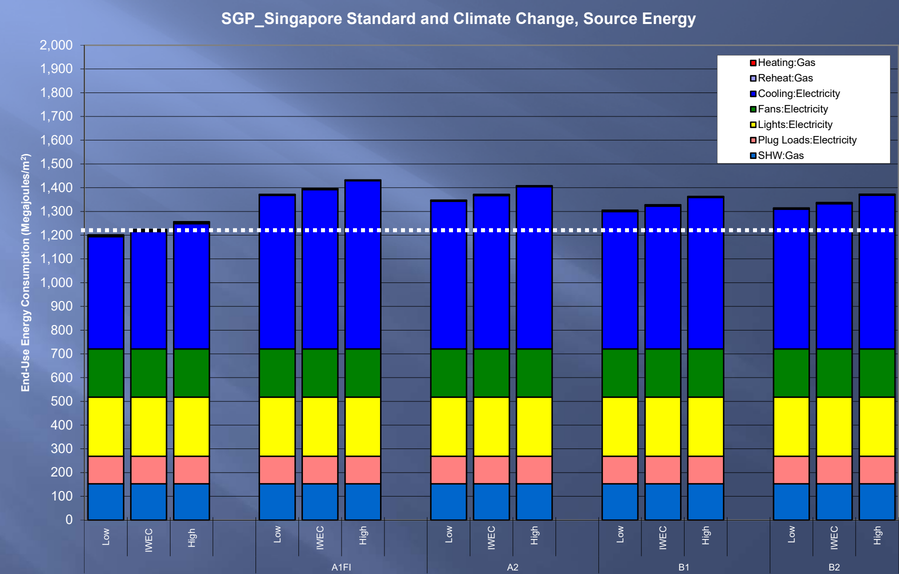
But Source Energy Increases Due to Climate Changes = Increased Emissions



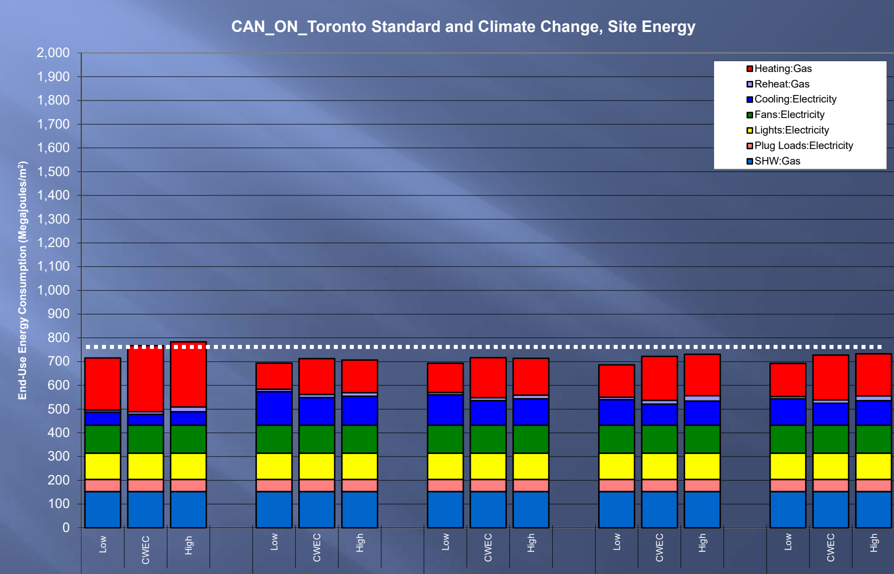
Low-Energy Buildings Can Mitigate Impacts of Climate Variation



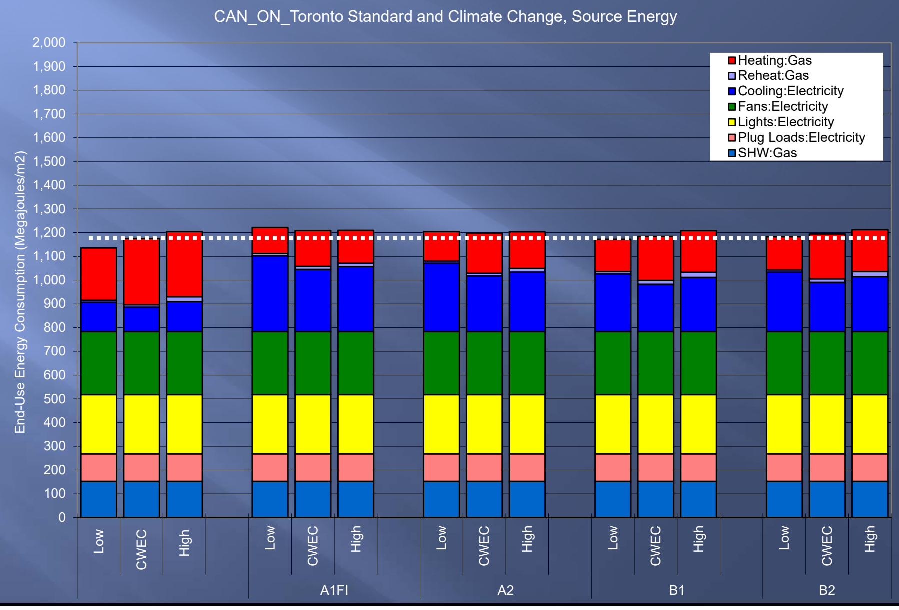
Source Energy Impacts Even Higher in Hotter Climates



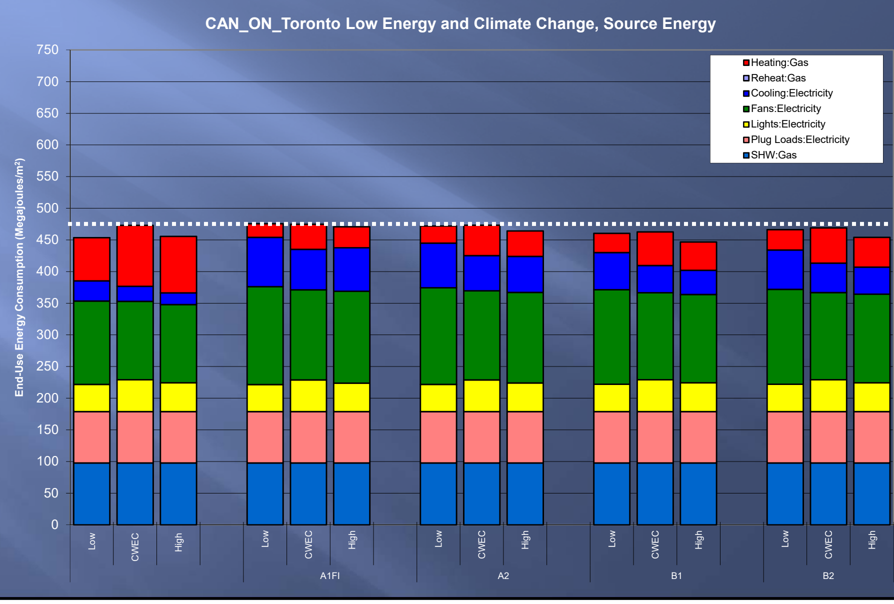
Toronto: Site Energy Slightly Lower



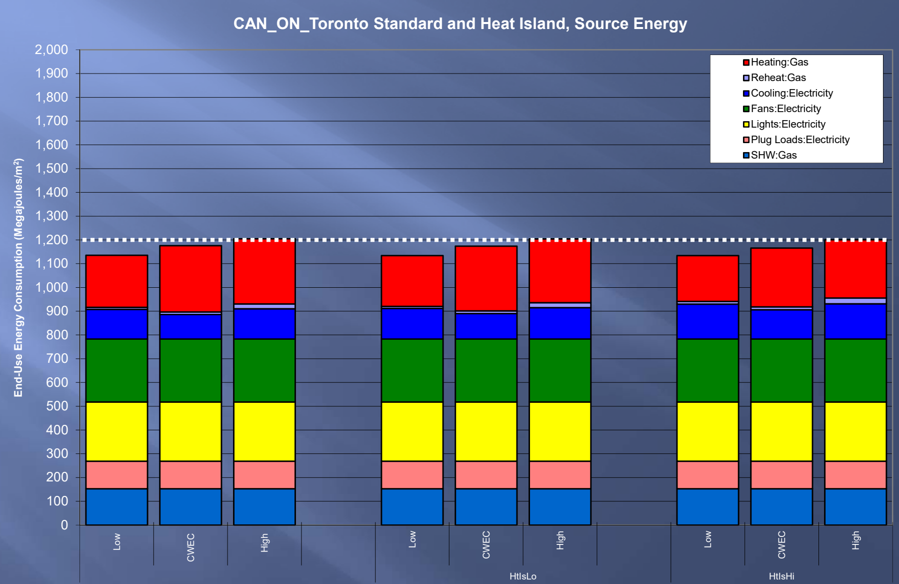
Source Energy Impacts Mild in Climates Such as Toronto



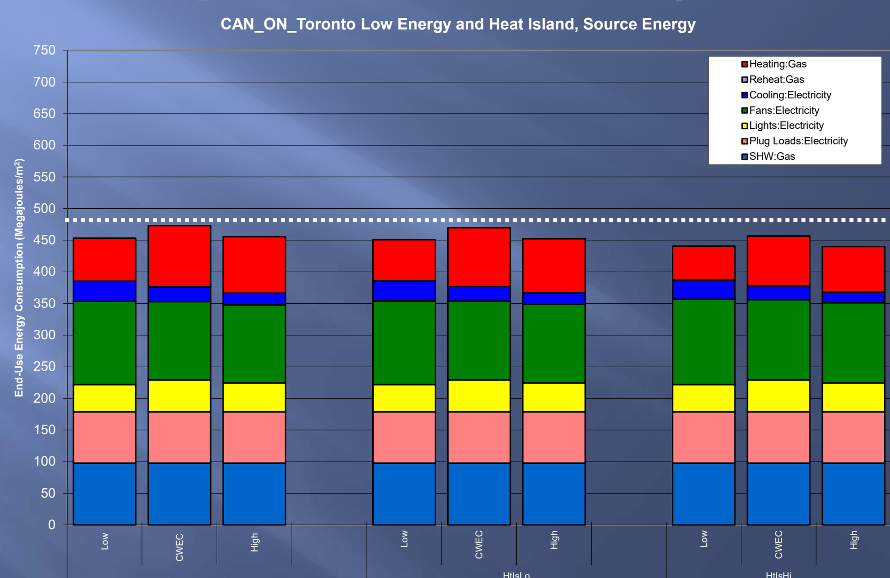
Low-Energy Buildings Mitigate Impacts in Canadian Locations



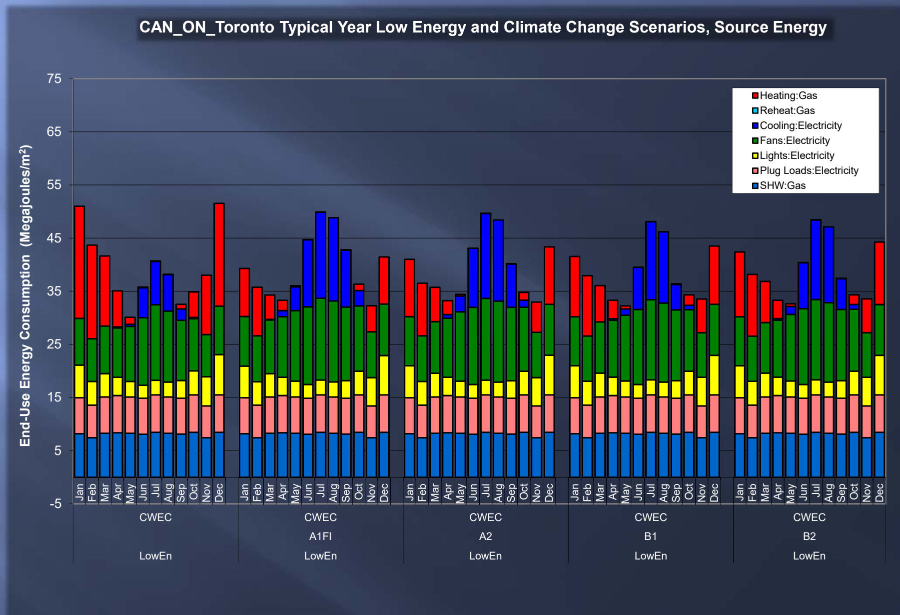
Heat Island Impacts Similar



Low-Energy Buildings Also Mitigate Heat Island Impacts

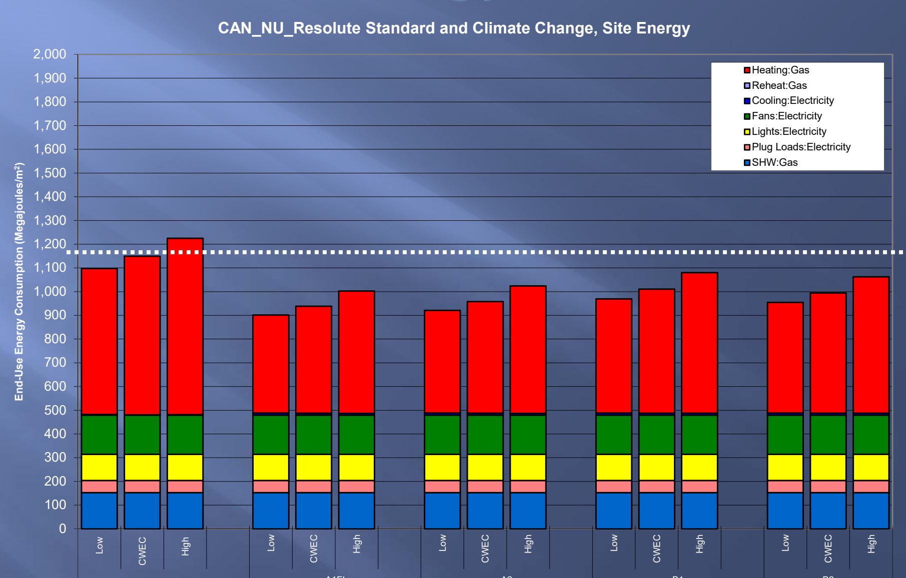


Monthly Predicted Change

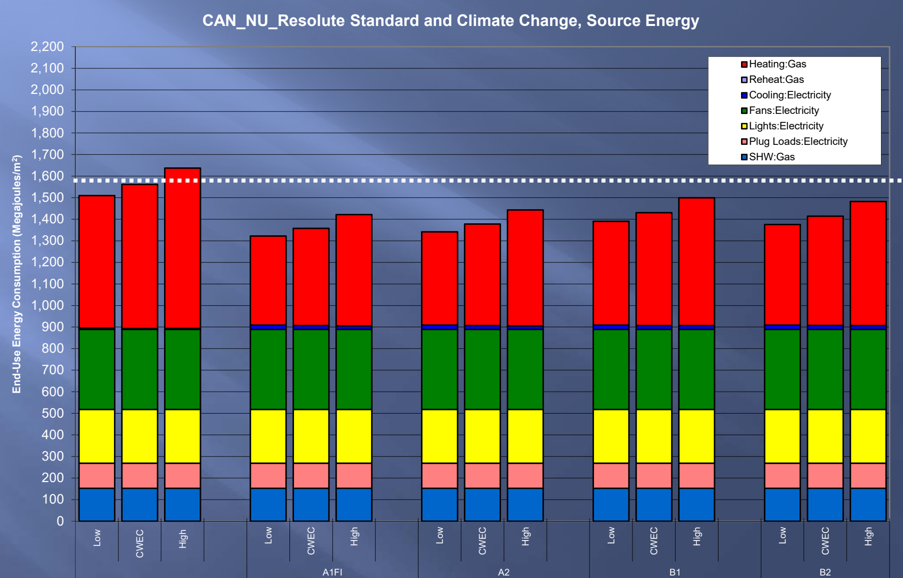


Predicted Monthly Primary Energy End-Use Consumption, in MJ/m2, in Toronto, ON, CAN for Baseline and Four Climate Change Scenarios

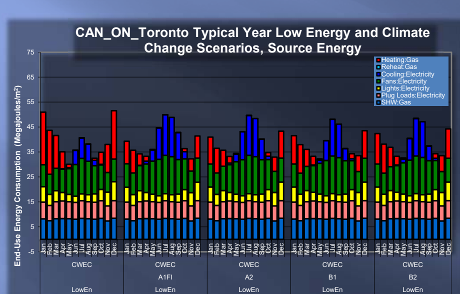
Northern Canada: Site Energy *Lower*

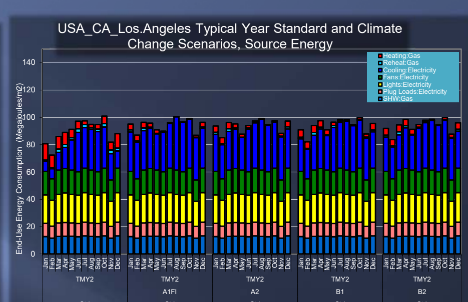


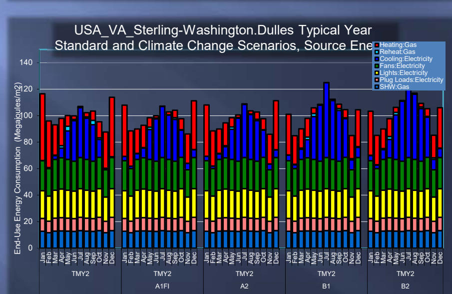
Source Energy in Northern Canada – Even Lower

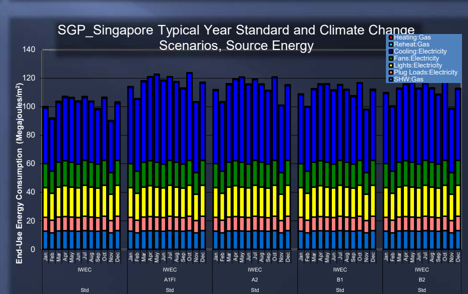


Largest Changes: Monthly End Uses









Summary

- Climatic design data is critical for building design (equipment and systems sizing)
- For building performance simulation, typical (TMY), actual, and future weather can all support building evaluation
  - Some question of whether single TMY is enough (research on XMYs underway)
  - Rich resources of data now available – both ground observing stations and satellite data.
- Climate change scenarios can be represented today by modifying existing hourly weather files
  - Buildings in higher latitude climates (north and south) will likely see decreases (heating decreases more than cooling increases)
  - Buildings in tropical and semi-tropical locations will see increases – but lower than changes in higher latitudes – primarily due to increased cooling
  - Energy-efficient buildings mitigate most impacts of both climate change and heat islands.

Thank you!

Dru Crawley

Dru.Crawley@Bentley.com

@DruCrawley

DruCrawley

Resources/URLs

- Building Performance Simulation for Design and Operation www.routledge.com/books/details/9780415474146/
- ASHRAE Handbook—Fundamentals 2013 www.ashrae.org
- NOAA/NCEI Integrated Surface Data
  Documentation: ftp://ftp.ncdc.noaa.gov/pub/data/techrpts/tr200101/tr2001-01.pdf
  Data: ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00532-TAP-A0001
- Typical Meteorological Year Data Sets (Climate.OneBuilding free weather data in EPW, ESP-r and Radiance formats) climate.onebuilding.org/
- Drury B. Crawley. 1998. "Which Weather Data Should You Use for Energy Simulations of Commercial Buildings?" in *ASHRAE Transactions*, pp. 498-515, Vol. 104, Pt. 2. Atlanta: ASHRAE. climate.onebuilding.org/papers/1998_06_Crawley_Which_Weather_Data_Should_You_Use_for_Energy_Simulations_of_Commercial_Buildings.pdf
- Crawley, Drury B. 2008. "Estimating the Impacts of Climate Change and Urbanization on Building Performance," Building Performance Simulation, pp. 91-115, Vol. 1, No. 2 (June). climate.onebuilding.org/papers/2008_06_Crawley_Estimating_the_impacts_of_climate_change_and_urbanization_on_building_performance.pdf
- Meteonorm www.meteonorm.com
- Weather Underground www.weatherunderground.com
- National Centers for Environmental Information lwf.ncdc.noaa.gov/oa/climate/climatedata.html
- CIBSE Technical Manual 48 (TM48), Use of climate change scenarios for building simulation: the CIBSE future weather years www.cibse.org/index.cfm?go=publications.view&item=449
- Climate Change World Weather Generator (CCWorldWeatherGen) www.energy.soton.ac.uk/ccworldweathergen/
- Dview (tool for displaying and comparing weather data (and CSV data) beopt.nrel.gov/downloadDView

Typical Meteorological Year Weather Data Sets Available

Weather Data Sets		Number of Locations	Geographic Coverage
Acronym	Name		
CTZ2	California Climate Zones 2	16	California
CWEC	Canadian Weather for Energy Calculations	80	Canada
CIBSE	Chartered Institute of Building Services Engineers Test Reference Years and Design Summer Years	14	United Kingdom
CSWD	Chinese Standard Weather Data	270	China
CTYW	Chinese Typical Year Weather	57	China
IGDG	Italian Climate data collection 'Gianni de Giorgio'	66	Italy
IMGW	Instytutu Meteorologii i Gospodarki Wodnej Weather Data Set	61	Poland
IMS	Israel Meteorological Service Weather Data for Israel	4	Israel
ISHRAE	Indian Society of Heating, Refrigerating and Air-Conditioning Engineers	58	India
ITMY	Iranian Typical Meteorological Year	6	Iran
IWEC2	International Weather for Energy Calculations v2	3012	Worldwide (except USA and Canada)
NIWA	National Institute of Water & Atmospheric Research	16	New Zealand
RMY	Representative Meteorological Year	80	Australia
SWEC	Spanish Weather for Energy Calculations	52	Spain
SWERA	Solar and Wind Energy Resource Assessment	156	Belize, Brazil, China, Cuba, El Salvador, Ethiopia, Ghana, Guatemala, Honduras, Kenya, Maldives, Nicaragua, and Sri Lanka
TMY3	Typical Meteorological Year 3	1020	USA, Guam, Puerto Rico, US Virgin Islands

Other Notable Sources for Typical Meteorological Year Data

- Meteonorm
  - Allows users to create a TMY-type file for any location in the world.
  - Interpolates from observing stations and statistics.
  - Does include TRY (European TMY-type files) for a number of locations
  - Useful where no other data exists
- Other sources!
  - IWEC2 with 3012 locations worldwide (outside US/Canada) available from ASHRAE since early 2012.
  - EU Energy Performance Directive requiring simulation, new data sets for Estonia, Finland, Ireland, Slovenia
  - California Climate Zones update…
  - Australia RMY update…
  - ISHRAE update…
  - Others.
- BOTTOM LINE: Know what you're using – the provenance, source, representativeness – before depending on it. Better to test against another file you've used with similar climatic conditions.