Impacts of Climate Change and Urbanization on Future Building Performance

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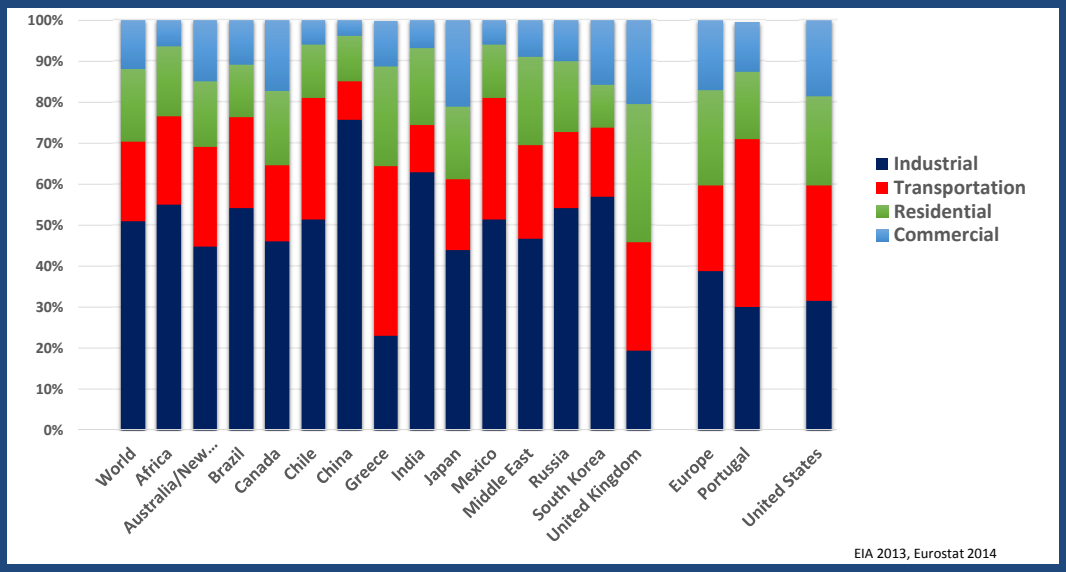
ASHRAE Portugal Chapter

ORDEM DOS ENGENHEIROS

Energy End Uses by Sector



EIA 2013, Eurostat 2014

Weather ≠ Climate

Weather:

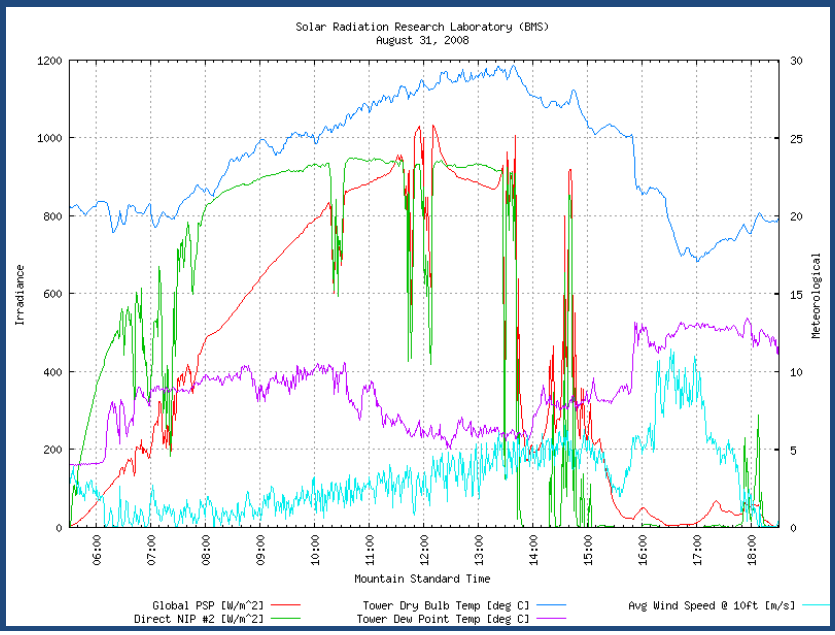
the state of the atmosphere with respect to wind, temperature, cloudiness, moisture, pressure, etc.

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!



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

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 US NCEI are near-real-time. Data posted within a few days.
- 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

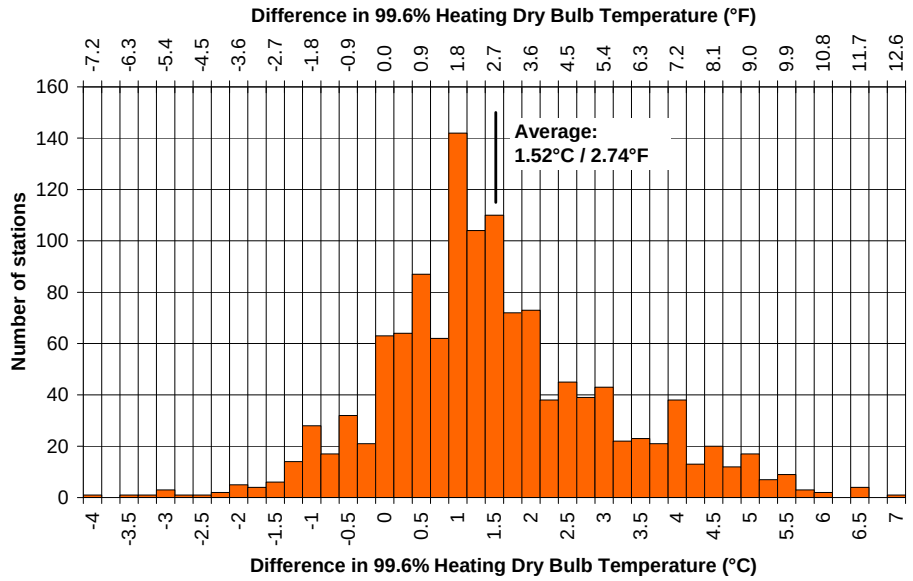
- Used for design sizing of heating, ventilating, air-conditioning, and dehumidification equipment, as well as or other energy-related processes in residential, agricultural, commercial, and industrial applications.
- Includes as a minimum dry-bulb, wet-bulb, and dew-point temperature, and wind speed 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

Example Design Conditions

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ATLANTA MUNICIPAL, GA, USA WMO#: **722190**

Lat: **33.64N** Long: **84.43W** Elev: **313** StdP: **97.62** Time Zone: **-5.00 (NAE)** Period: **86-10** WBAN: **13874**

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	-5.8	-3.1	-15.5	1.0	-1.9	-12.7	1.3	0.1	11.1	4.4	10.5	4.4	5.3	320	(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	9.4	34.4	23.4	33.1	23.3	32.1	23.0	25.2	31.4	24.7	30.4	24.1	29.4	3.9	300	(2)

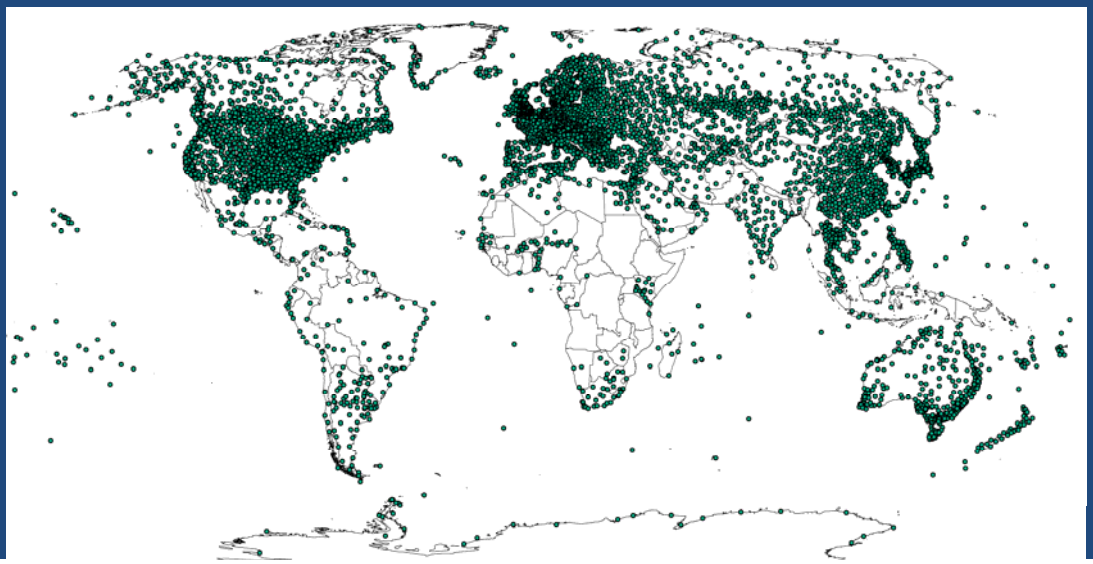
Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours	
0.4%			1%			2%			0.4%		1%		2%		8 to 4 &	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	12.8/20.6	
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
23.5	19.0	27.4	23.0	18.4	26.8	22.6	17.9	26.5	78.3	31.4	76.0	30.4	74.0	29.8	800	(3)

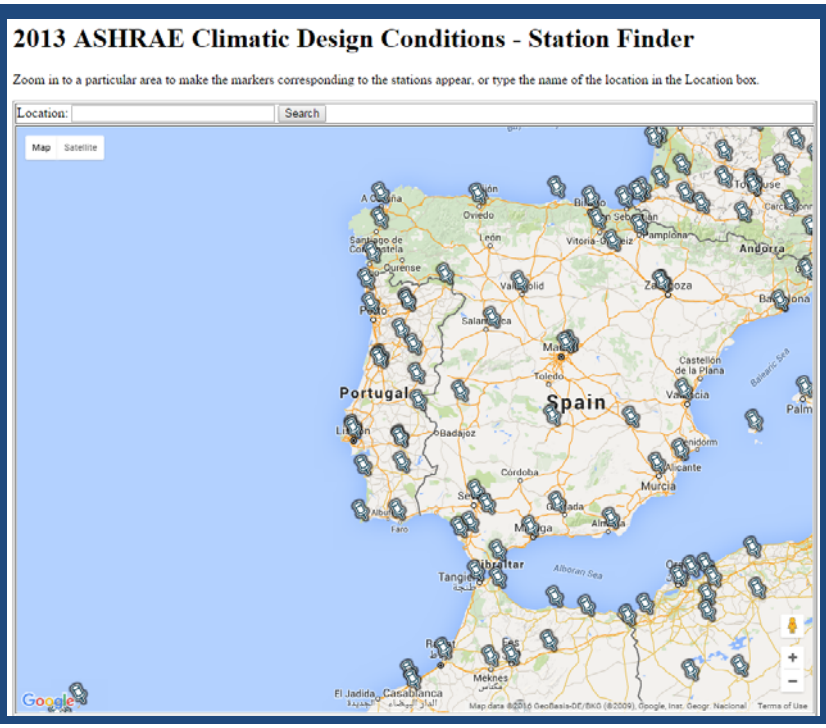
Extreme Annual Design Conditions

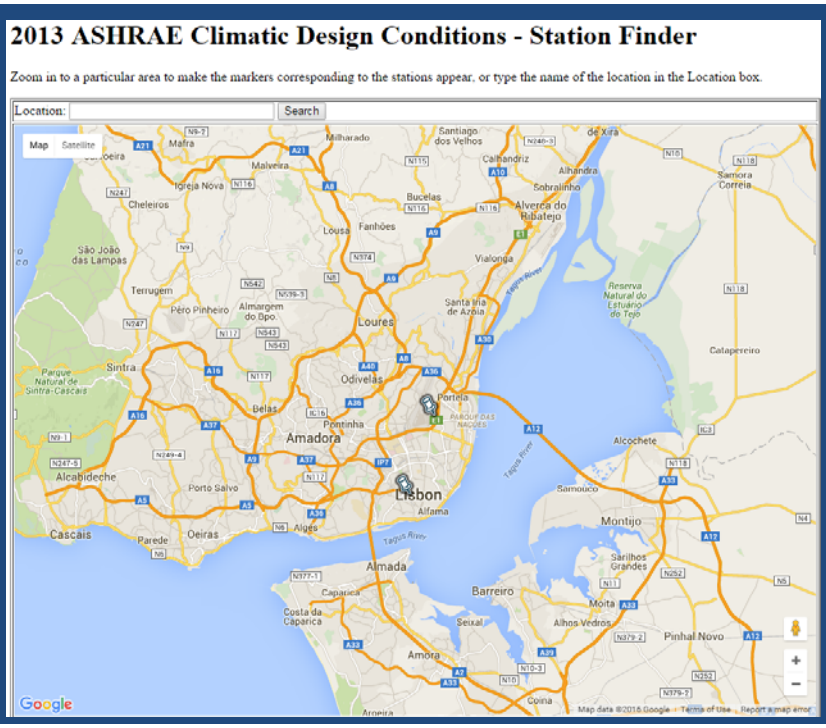
	Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB								
					Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(4)	9.6	8.5	7.7	28.0	-10.0	35.9	2.5	1.8	-11.7	37.3	-13.2	38.3	-14.5	39.4	-16.3	40.7	(4)

Monthly Climatic Design Conditions

ASHRAE 2013 Handbook Fundamentals Weather Locations



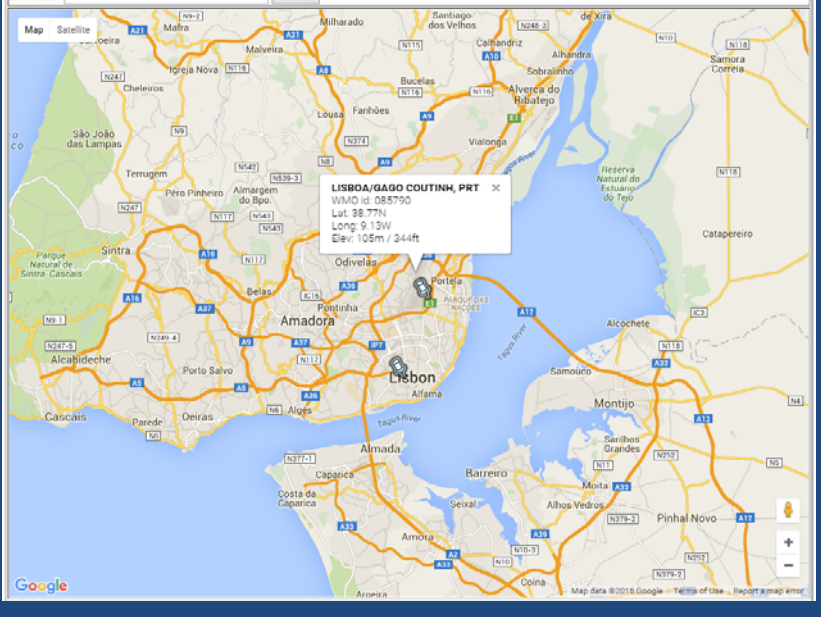

2013 ASHRAE Climatic Design Conditions - Station Finder
Zoom in to a particular area to make the markers corresponding to the stations appear, or type the name of the location in the Location box.
Location:
Search
Map
Satellite
Portugal
Spain
Andorra
Gibraltar
Google


2013 ASHRAE Climatic Design Conditions - Station Finder
Zoom in to a particular area to make the markers corresponding to the stations appear, or type the name of the location in the Location box.
Location:
Search
Map
Satellite
Lisbon
Amadora
Sintra
Cascais
Almada
Barreiro
Montijo
Alcochete
Google

2013 ASHRAE Climatic Design Conditions - Station Finder

Zoom in to a particular area to make the markers corresponding to the stations appear, or type the name of the location in the Location box.

Location: Search



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LISBOA/GAGO COUTINH, Portugal WMO#: **085790**

Lat: **38.77N** Long: **9.13W** Elev: **105** StdP: **100.07** Time Zone: **0.00 (GMT)** Period: **86-10** 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	4.6	5.8	-3.0	3.0	8.3	-0.9	3.6	9.3	10.8	13.6	9.3	13.1	2.7	40	(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)	8	9.7	33.6	20.4	31.5	19.8	29.6	19.3	21.5	30.5	20.8	28.5	20.2	26.9	3.1	330	(2)

	Dehumidification DP/MCDB and HR									Enthalpy/MCDB							Hours 8 to 4 & 12.8/20.6	
	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)	19.2	14.2	22.5	18.6	13.6	22.3	18.0	13.1	22.1	62.8	30.8	60.3	28.7	58.2	27.0	1557	(3)	

Extreme Annual Design Conditions

	Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB									
					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		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)		
(4)	8.8	7.7	6.9	24.7	2.2	37.3	1.5	2.0	1.1	38.8	0.2	40.0	-0.6	41.1	-1.7	42.6	(4)	

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)	
(5)	Temperatures, Degree-Days and Degree-Hours	Tavg	17.0	11.0	12.0	14.3	15.1	17.8	20.8	23.0	23.3	21.7	18.3	14.3	11.8	(5)
(6)		Sd		2.36	2.11	2.51	2.80	2.90	2.87	2.91	2.64	2.52	2.42	2.42	2.43	(6)
(7)		HDD10.0	38	17	7	2	1	0	0	0	0	0	0	1	11	(7)
(8)		HDD18.3	1045	228	177	126	104	45	6	0	0	2	31	123	203	(8)
(9)		CDD10.0	2583	47	63	136	154	241	324	402	413	351	256	130	66	(9)
(10)		CDD18.3	549	0	0	2	8	28	80	144	155	103	28	1	0	(10)
(11)		CDH23.3	3511	0	0	12	46	188	514	1078	1059	531	84	0	0	(11)
(12)		CDH26.7	1238	0	0	1	6	56	176	426	399	163	12	0	0	(12)

(13)	Precipitation		PrecAvg	713	104	104	67	59	37	23	4	3	23	74	110	105	(13)
(14)			PrecMax	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(14)
(15)			PrecMin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(15)
(16)			PrecSD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(16)
(17)	Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB	17.5	19.3	24.9	27.3	31.5	33.6	36.4	36.2	33.8	28.1	22.1	17.9	(17)
(18)			MCWB	13.8	13.9	14.6	17.3	19.3	20.4	21.2	20.9	20.1	17.6	16.4	15.9	(18)
(19)		2%	DB	16.2	17.7	22.5	24.5	28.0	30.9	33.5	33.5	30.7	25.6	20.1	17.1	(19)
(20)			MCWB	13.9	12.9	14.4	15.7	17.3	19.5	20.4	20.5	19.1	17.6	16.5	15.5	(20)
(21)		5%	DB	15.4	16.4	20.6	22.0	25.2	28.6	31.2	31.0	28.4	23.7	19.0	16.5	(21)
(22)			MCWB	13.4	12.8	13.9	14.9	16.8	19.0	20.1	19.8	18.7	17.2	15.9	14.9	(22)
(23)		10%	DB	14.7	15.4	18.6	19.7	22.7	26.3	28.7	28.6	26.2	22.0	17.9	15.6	(23)
(24)			MCWB	12.8	12.5	13.2	14.1	16.2	18.3	19.4	19.2	18.2	16.9	15.2	13.9	(24)
(25)	Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB	15.6	15.4	16.4	18.5	20.5	21.6	22.4	22.5	21.4	20.4	18.8	16.7	(25)
(26)			MCDB	16.3	16.9	21.7	25.3	28.2	31.0	33.1	32.3	29.1	23.4	20.4	17.3	(26)
(27)		2%	WB	14.7	14.7	15.3	16.6	18.5	20.6	21.5	21.5	20.5	19.5	17.7	16.1	(27)
(28)			MCDB	15.7	16.3	19.3	22.2	25.6	28.8	31.2	29.9	26.6	22.5	19.1	16.9	(28)
(29)		5%	WB	14.0	13.8	14.7	15.6	17.5	19.7	20.6	20.7	19.9	18.8	16.8	15.2	(29)
(30)			MCDB	15.0	15.6	18.4	20.1	23.4	26.8	29.2	27.9	25.0	21.6	18.3	16.2	(30)
(31)		10%	WB	13.1	13.1	14.0	14.7	16.6	18.7	19.9	20.1	19.3	18.1	15.7	14.2	(31)
(32)			MCDB	14.4	14.8	17.6	18.5	21.6	25.0	27.3	26.5	23.9	20.7	17.3	15.3	(32)
(33)	Mean Daily Temperature Range		MDBR	5.6	6.2	7.3	7.3	7.9	8.9	9.9	9.7	8.5	6.7	5.7	5.1	(33)
(34)		5% DB	MCDBR	5.7	7.5	10.6	11.0	12.3	12.8	13.4	13.4	12.2	9.5	6.7	5.0	(34)
(35)			MCWBR	4.0	4.4	5.2	5.4	5.7	5.5	5.2	5.1	4.7	4.2	3.9	3.8	(35)
(36)		5% WB	MCDBR	4.5	6.0	8.6	9.3	10.1	11.5	12.1	11.1	9.1	6.9	5.2	4.1	(36)
(37)			MCWBR	3.9	4.1	4.6	4.9	5.3	5.4	5.1	4.7	4.1	3.7	3.8	3.8	(37)
(38)	Clear Sky Solar Irradiance		taub	0.348	0.371	0.360	0.362	0.354	0.357	0.343	0.356	0.364	0.365	0.364	0.367	(38)
(39)			taud	2.588	2.485	2.494	2.409	2.417	2.389	2.441	2.434	2.471	2.544	2.575	2.561	(39)
(40)			Ebn,noon	830	851	900	915	924	918	928	909	883	847	802	777	(40)
(41)			Edh,noon	73	92	99	114	116	119	112	110	100	85	74	72	(41)

Nomenclature: See separate page

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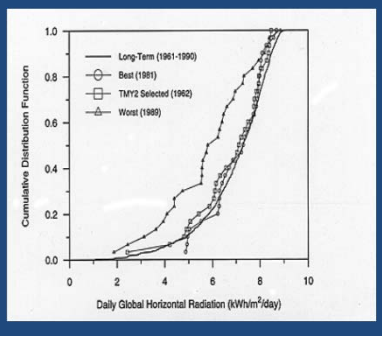
Climatic Data in Building Performance Simulation

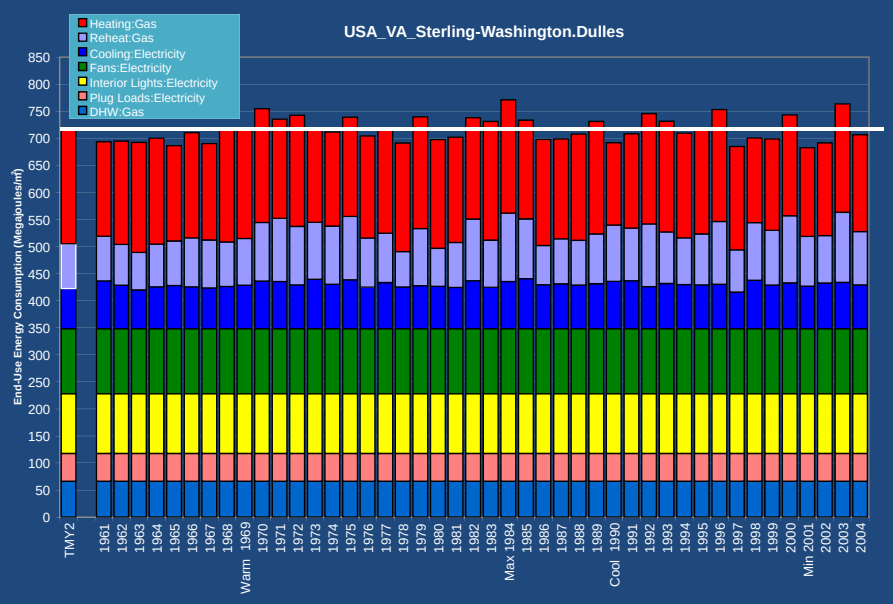
- Climatic data needed for simulating representative performance from a single year analysis.
- TMY (Typical Meteorological Year) approach is most widely used– a composite of months (not all from same year), each representative for the period of record.
- Months selected using statistical indices (daily 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.



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:
  - US NCEI WMO Data Center
  - Weather Underground
  - Weather.com
  - Weather Source
- Biggest issue – how complete are the data – does it include temperature, humidity, wind, solar radiation?

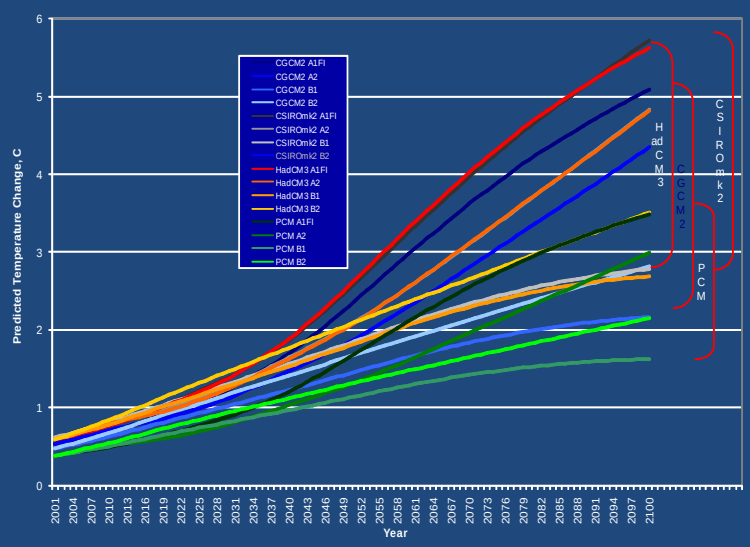
Typical vs. Actual



Future Climatic Data Sets

- CIBSE
  - UK only, 14 locations
  - Derived from reanalysis (downscale of gridded latitude/longitude) 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.

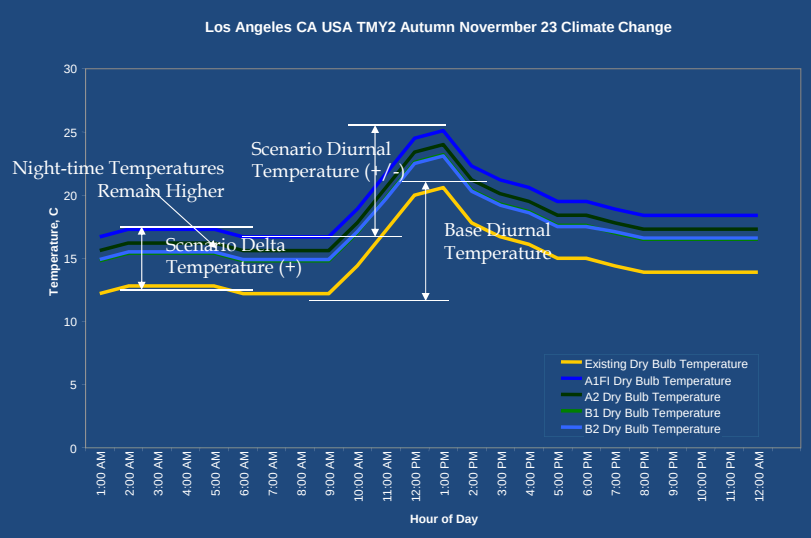
IPCC Climate Change Scenarios: Range of Annual Average Temperature Change Predicted



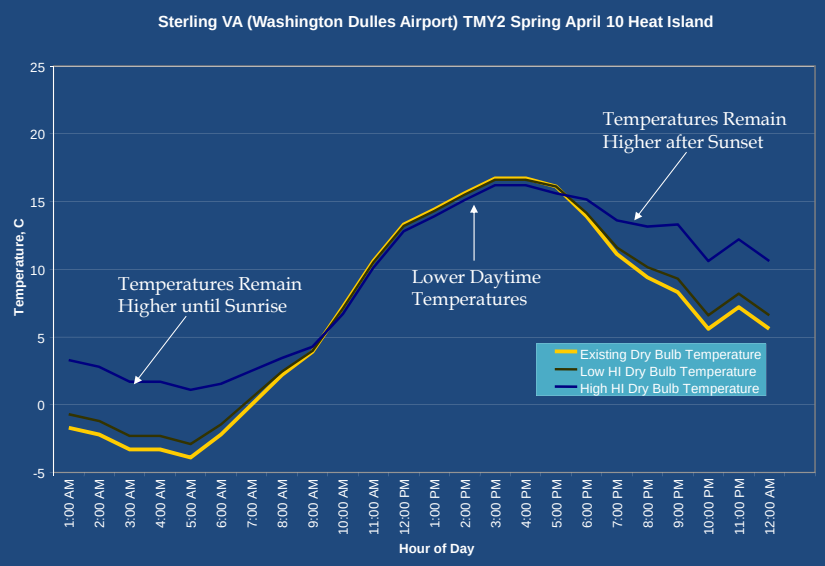
Creating Future Climatic Data

- 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

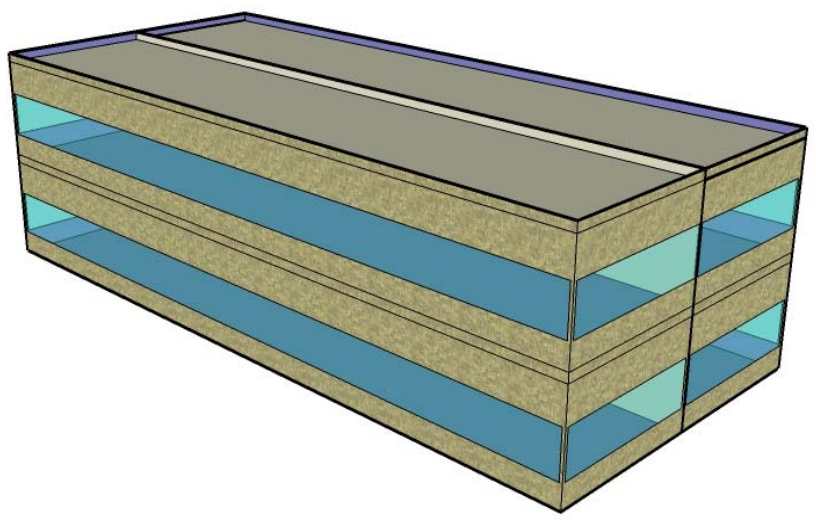
TMY2 Data Morphed with Climate Change Scenarios



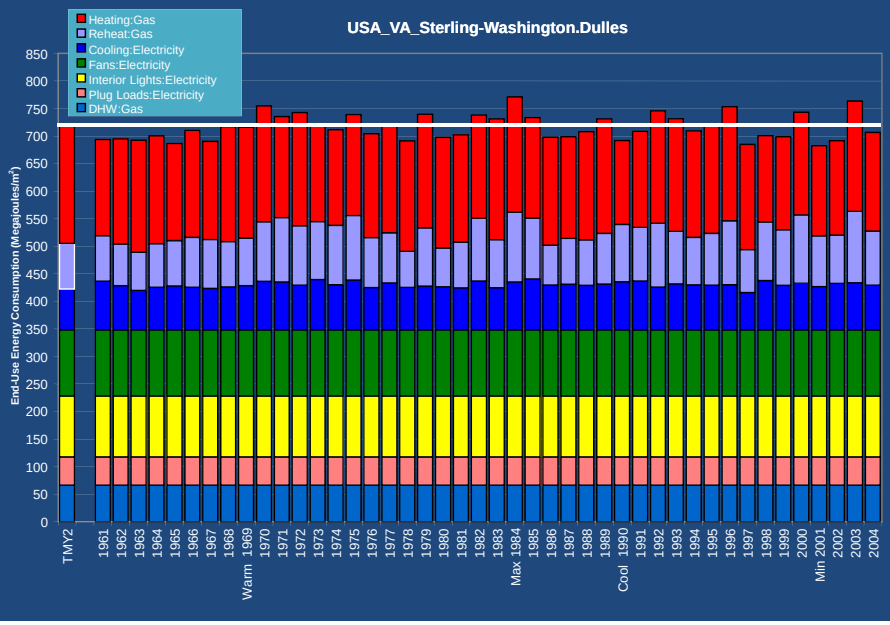
Heat Island



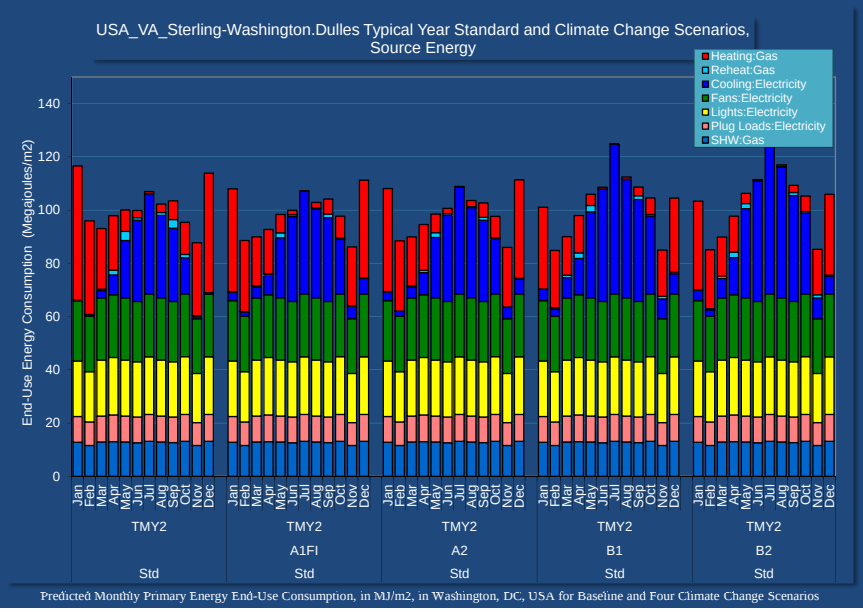
Building Prototype



Typical vs. Actual

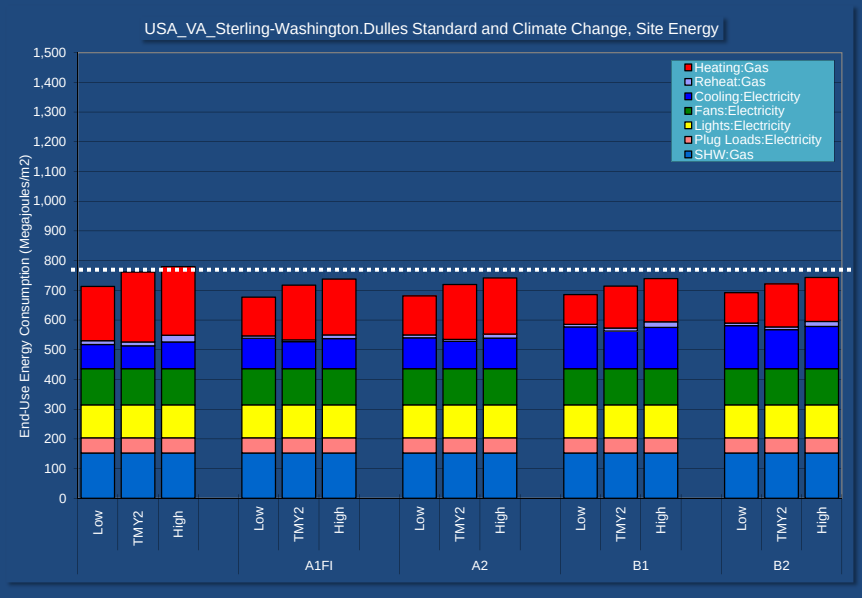


Example Predicted Change

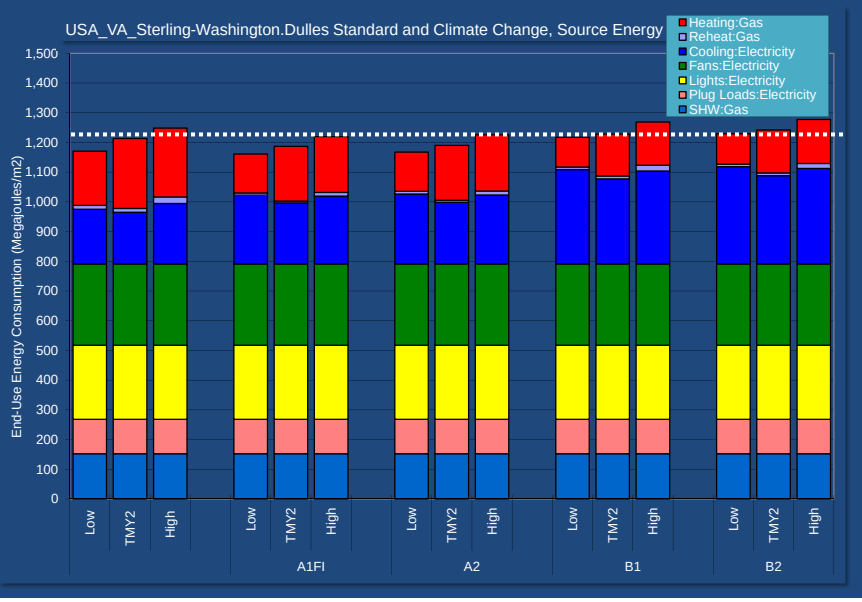


Predicted Monthly Primary Energy End-Use Consumption, in MJ/m2, in Washington, DC, USA for Baseline and Four Climate Change Scenarios

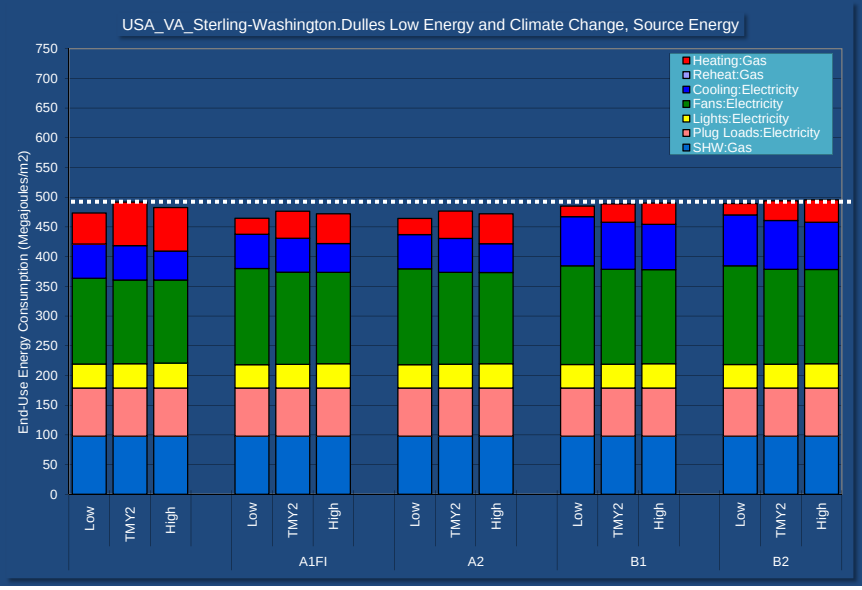
A Snapshot of Results: Site Energy Decreases



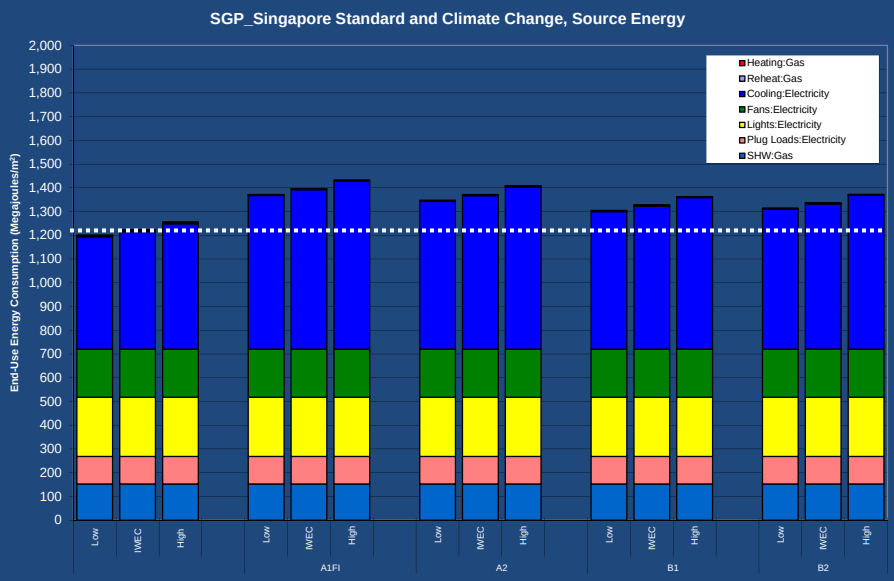
But Source Energy Increases Due to Climate Changes = Increased Emissions



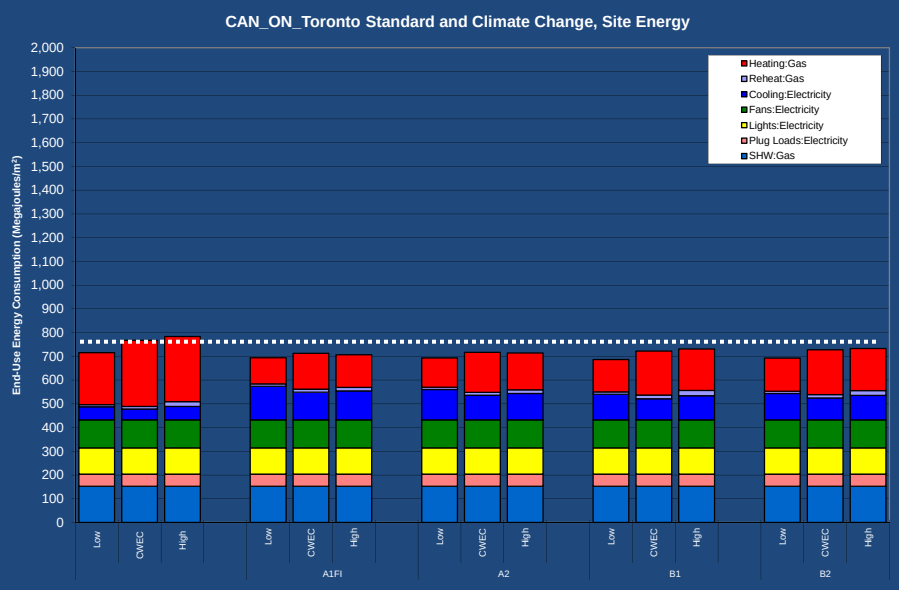
Low-Energy Buildings Can Mitigate Impacts of Climate Variation



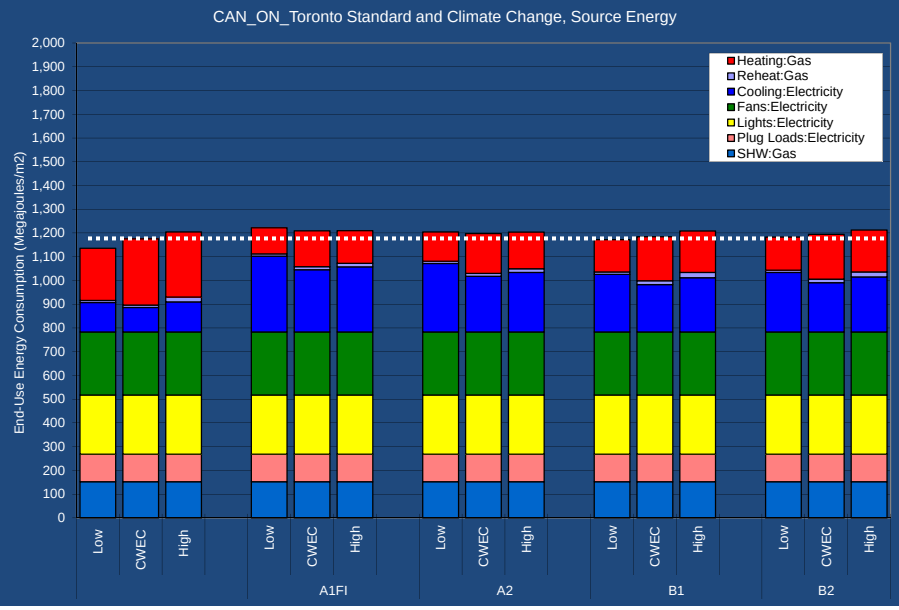
Source Energy Impacts Even Higher in Hotter Climates



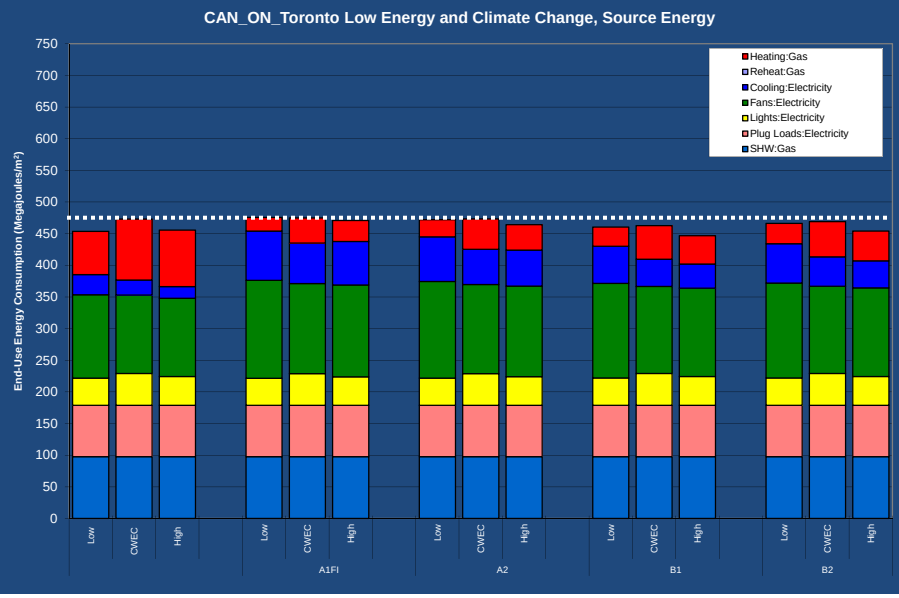
Toronto: Site Energy Slightly Lower



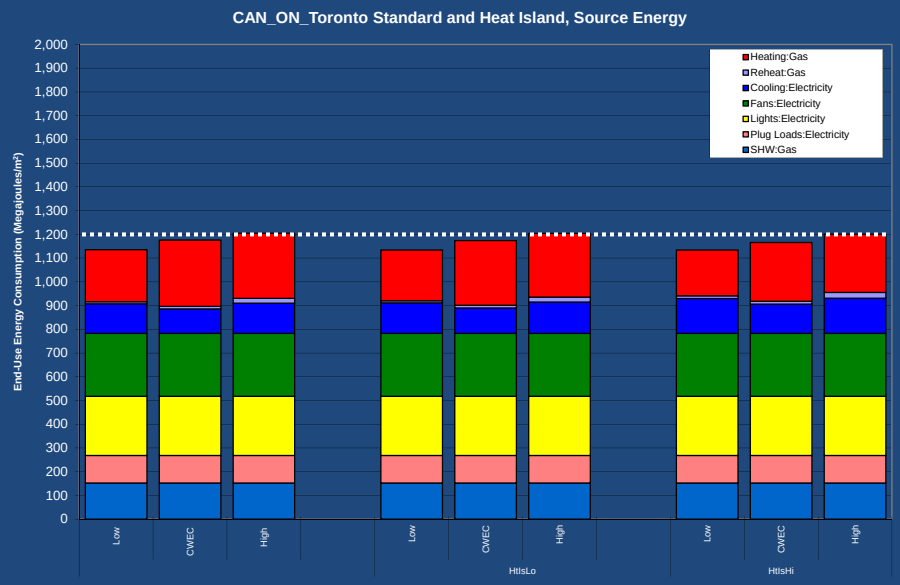
Source Energy Impacts Minor in Climates Such as Toronto



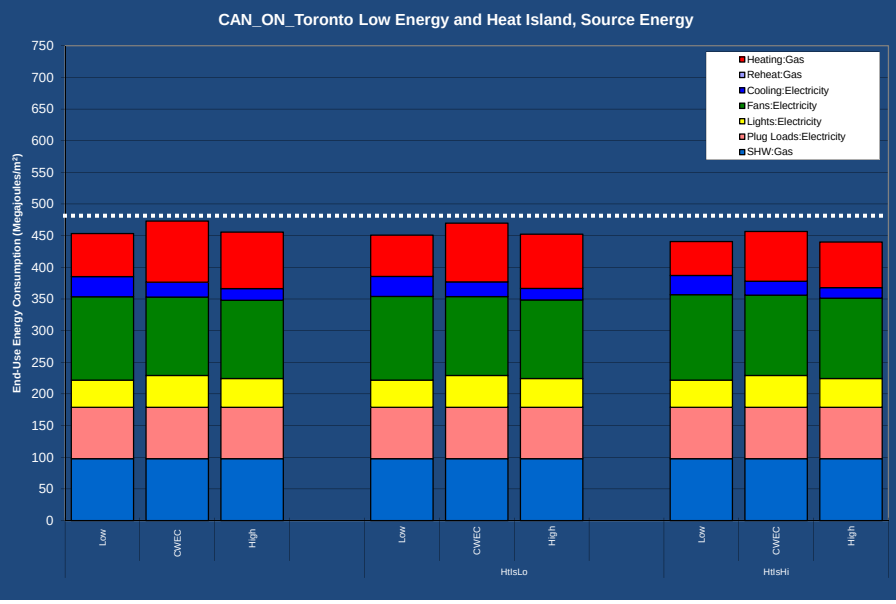
Low-Energy Buildings Mitigate Impacts in Canadian Locations



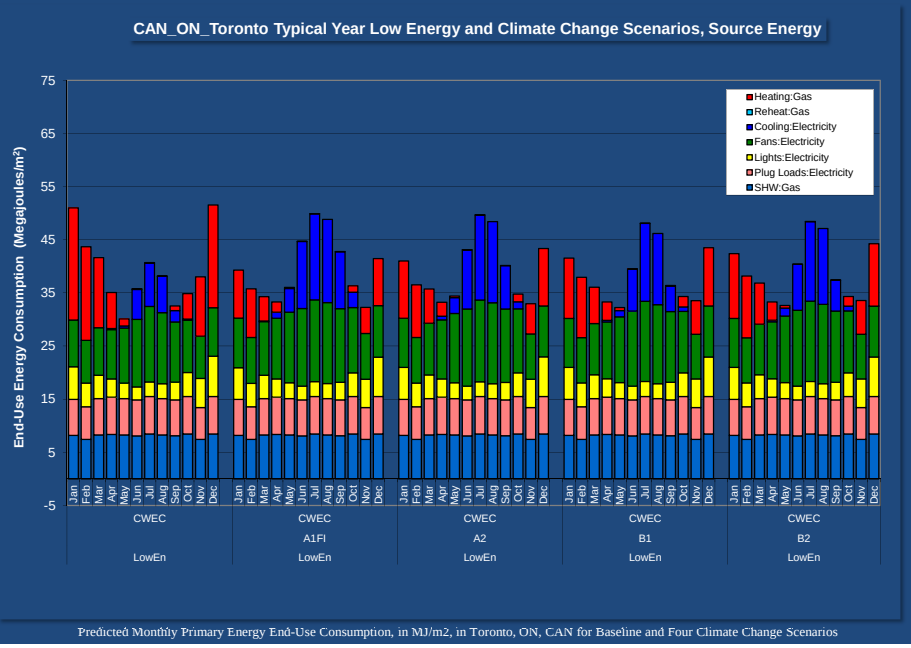
Heat Island Impacts Similar



Low-Energy Buildings Also Mitigate Heat Island Impacts

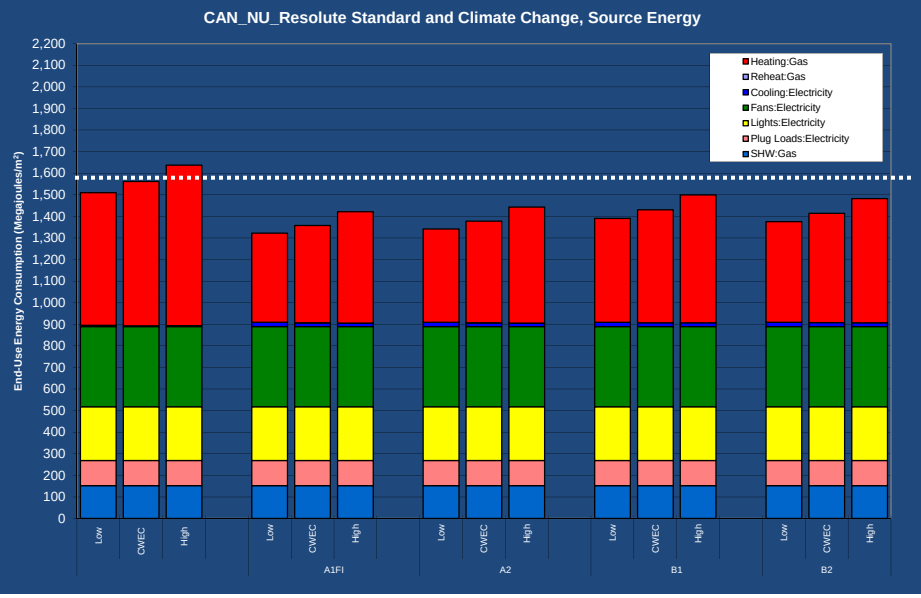


Monthly Predicted Change



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

Source Energy in Northern Canada – Even Lower

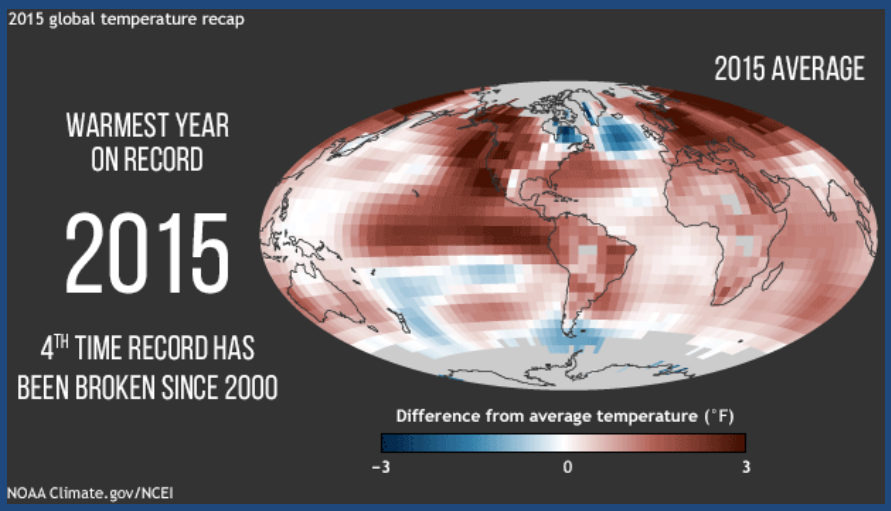


Largest Changes: Monthly End Uses

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.

2015 set a new global temperature record by wide margin



Obrigado!

Questões?

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Resources/URLs

- Building Performance Simulation for Design and Operation www.routledge.com/books/details/9780415474146/
- ASHRAE Handbook—Fundamentals 2013 www.ashrae.org
- NCDC 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 Center 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.