Simulated Impacts of Global Warming on Building Thermal Loads Throughout the 21st Century

Presented at ASHRAE Seminar 48
"Climate Change: Modeling the Weather and Its Potential Impacts on Building Performance"

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Outline

- Trends in global warming
- Models matched against global warming records
- Factors contributing to global warming
- Selection of a temperature prediction model for a case study
- Selection of a case study building and 6 cities
- Temperature plots for years 2007 and 2100
- Impacts on building air-conditioning loads
- CO-2 increases from added building a.c. loads
- Building contribution to greenhouse gases

Nomenclature

- DCV – Demand Control Ventilation
- ECM – Energy Conservation Measures
- ERV – Energy Recovery Ventilator
- EUI – Energy Utilization Index (Annual energy use per unit floor area)
- HadCM3 – Hadley Climate Model (European)
- IPCC – Intergovernmental Panel on Climate Change
- GFDL - Geophysical Fluid Dynamics Laboratory (NOAA)
- GISS – Goddard Institute for Space Studies (NASA)
- NCDC – National Climate Data Center
- NOAA – National Oceanic & Atmospheric Association.

Global warming web sites

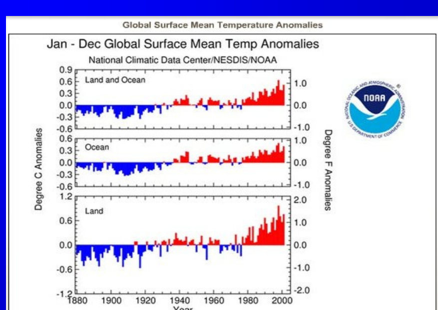
NOAA (National Oceanic and Atmospheric Administration):

- http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html

NOAA's Geophysical Fluid Dynamics Laboratory:

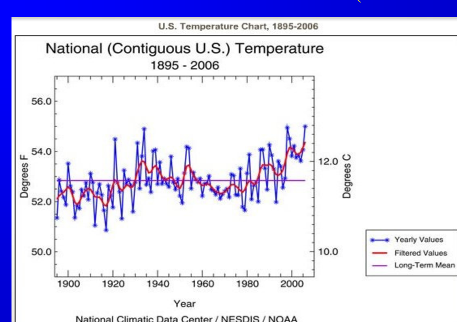
- http://www.gfdl.gov/~tk/climate_dynamics/climate_impact_webpage.html

1880-2001 Trends (source: NOAA)



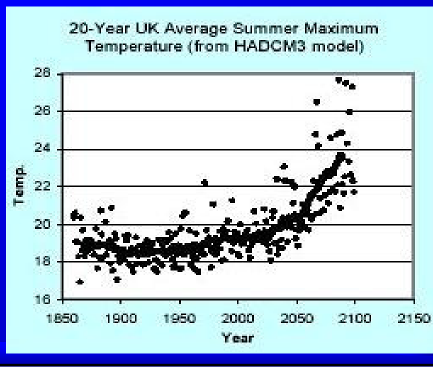
This graph shows annual mean global temperature anomalies from 1880-2001. The zero line represents the long term mean temperature and the red and blue bars show annual departures from that mean. The trend has been toward rising temperatures at least since the start of the 20th century. Land temperatures have greater anomalies than the ocean, which is to be expected since land heats up and cools down faster than water. More on Global Surface Temperatures

1895-2006 Historic trends (source: NOAA)

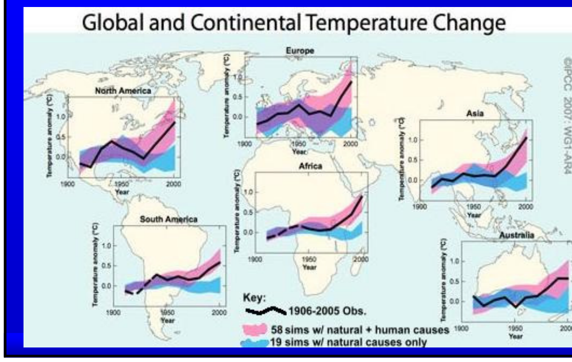


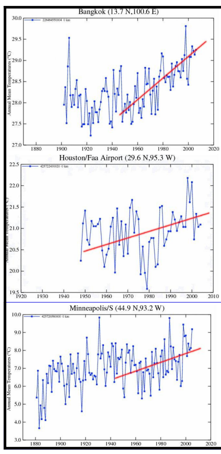
U.S. and global annual temperatures are now approximately 1.0 degrees Fahrenheit warmer than at the start of the 20th century, and the rate of warming has accelerated over the past 30 years, increasing since the mid-1970s at a rate about three times faster than the century-scale trend. The past nine years have all been among the 25 warmest years on record, a streak which is unprecedented in the historical record. 2006 Warmest on Record

Projections for the UK by the HadCM3 model

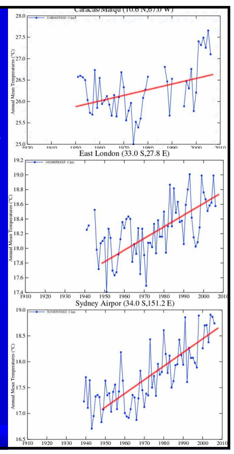


Historic records compared to predictions by 14 models (source: IPCC)





Trends shown by NCDC records



Predicted changes likely

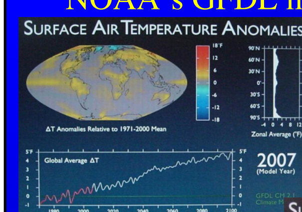
A report issued by an IPCC working group 1, "Climate Change 2001: The Scientific Basis", lists "very likely" global climate changes for the 21st century. Among those are:

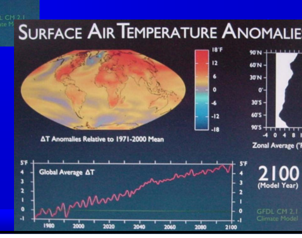
- Higher daily maximum temperatures and more hot days over nearly all of the Earth's land,
- Warmer overnight low temperatures, (minimum daily temperatures)
- Fewer cold days and frost days over nearly all the land, and
- Reduced differences between daily highs and lows over nearly all land areas (smaller diurnal ranges.)

Predicted temperatures

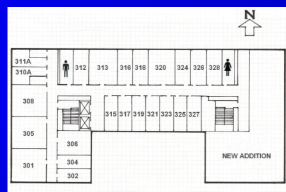
- Using the projection of doubling of atmospheric carbon dioxide over the next 70 years, experiments with NOAA's GFDL climate model reveal that the surface air temperature warming would be particularly large over the mid- and high-latitude continental regions, and lower for the low-latitude regions. Data in their report show increases of about 9F (5C) for areas in northern Europe and northern U.S., 6F (3.3C) for southern U.S. latitudes and southern Australia, and about 2.0F (1.1C) for equatorial land areas.

NOAA's GFDL model predictions





CASE-STUDY BUILDING



Engineering office/ classroom building that meets ASHRAE Std 90.1-2004

Simulation steps:

1. Simulate building as-is using today's climate data from ASHRAE 2005 HOF.
2. Simulate building using projected climate data for year 2100 from the GFDL model.
3. Simulate same as step 2 but adding occupancy sensors for lighting control and demand control ventilation and incorporating ERVs in place of standard exhaust fans.

Case study 10-story office building was simulated in 6 cities

Latitude effects on average temperature increases predicted by the GFDL model

- Higher latitude cities (London, Minneapolis), +9F by year 2100.
- Mid-latitude cities (Houston, Sydney), +6F by year 2100.
- Lower latitude cities (Bangkok,Caracas), +2F by year 2100.

Relationships between high, low, and average temperature and diurnal range

- H – L = MDR (mean diurnal range) ……... (eq. 1)
- H + L = 2 * T_{ave} …………………………...… (eq. 2)
- Or
- ΔH – ΔL = ΔMDR (mean diurnal range) . .(eq. 1A)
- ΔH + ΔL = 2 * ΔT_{ave} ………………...…. (eq. 2A)

Min-Max temperatures as a function of reduced diurnal swing (for ΔT_{ave} = 6.7F)

Change in diurnal swing (Δ MDR)	Increase in daily max. temp. (Δ H)	Increase in daily min. temp. (Δ L)
-1.8 F	5.8 F	7.6 F
-3.6 F	4.9 F	8.5 F
-5.4 F	4.0 F	9.4 F

Existing and future design temperatures for 6 case study cities

City Name	Lat. class	Lat. (deg.)	ASHRAE Design Temp. (F)		MDR (F) *	GFDL temp chg (F)	MDR chg (F) *	Year 2100 design temp. (˚F)			
			sum. #	wint #				summer		winter	
								chg	val.	chg	val.
London	High	51.2N	77.2	26.4	17.6	9	-3.6	7	84.2	11	37.4
Minn.	High	44.9N	87.8	-9.4	19.1	9	-3.6	7	94.8	11	1.6
Houston	Mid	30N	94.9	31.5	18.2	6	-2.7	4.7	99.4	7.3	38.8
Sydney	Mid	33.9S	83.4	46.3	12.1	6	-2.7	4.7	88.1	7.3	53.6
Bangkok	Low	13.7N	95	68.5	16.7	2	-1.8	1.1	96.1	2.9	71.4
Caracas	Low	10.6N	90.9	69.9	12.6	2	-1.8	1.1	92	2.9	72.8

* MDR = Mean Daily Range (F)

sum.=summer 1% desgn val.; wint.=winter 99% val (2005 ASHRAE HOF)

Energy simulation tool w/ built-in weather data generator for annual prediction

Data for Minneapolis

Year 2007

Climatic Data Summary

U.S. State Name or Country Name: MINNESOTA — City Name: MINNEAPOLIS/ST. PAUL

WMO or WBAN No.: 14922 — Latitude: 44.9 — Longitude: 93.2 — Time Zone: 90 — Elevation: 83

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Dry Bulb Ave:	12.4	18.3	31.1	46.4	59.2	68.7	73.8	70.5	60.4	48.9	33.3	18.3	Deg. F
Ave. Std. Dev:	10.3	9.2	11.5	9.5	7	6.1	7.9	8.5	7.6	7.7	9.5	9.5	Deg. F
Dry Bulb Max:	20.1	26.1	38.7	55.8	68.7	78.1	83.1	79.9	70	58.3	40.5	25.2	Deg. F
Max. Std. Dev:	11.9	10.6	14.9	11.9	8.6	7.4	7	6.8	8.8	9.2	11.2	11.7	Deg. F
Dew Point Ave:	4.1	9.1	21	33.6	45.9	56.1	61.2	59.5	51.3	39	25.3	10.8	Deg. F
DP Std. Dev:	11	9.9	13.1	10.6	7.9	6.8	7.6	7.6	8.3	8.5	10.3	10.6	Deg. F
Solar Radiation:	564	864	1190	1496	1811	1983	2011	1713	1289	885	540	438	Btu/sq.ft.
Wind Speed:	10.5	10.3	11.4	11.9	10.7	10.1	9.2	9.2	9.6	10.3	10.5	10.3	Miles/hr.

Year 2100

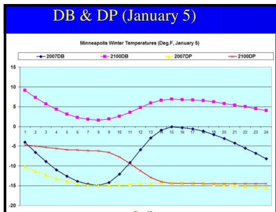
Climatic Data Summary

U.S. State Name or Country Name: MINNESOTA — City Name: gwMINNEAPOLIS/ST. PAUL

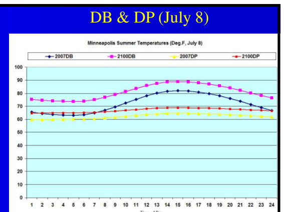
WMO or WBAN No.: 14922 — Latitude: 44.9 — Longitude: 93.2 — Time Zone: 90 — Elevation: 83

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Dry Bulb Ave:	21.2	27.1	39.9	55.2	67.8	77.5	82.6	79.3	69.3	57.7	42.1	27.1	Deg. F
Ave. Std. Dev:	10.3	9.2	11.5	9.5	7	6.1	7.9	8.5	7.6	7.7	9.5	9.5	Deg. F
Dry Bulb Max:	27.1	33.1	45.7	62.8	75.7	85.1	90.1	86.9	76.8	65.1	47.5	32.2	Deg. F
Max. Std. Dev:	11.9	10.6	14.9	11.9	8.6	7.4	7	6.8	8.8	9.2	11.2	11.7	Deg. F
Dew Point Ave:	8.4	13.6	25.5	38.1	50.2	60.6	65.7	64	55.8	43.5	29.8	15.1	Deg. F
DP Std. Dev:	11	9.9	13.1	10.6	7.9	6.8	7.6	7.6	8.3	8.5	10.3	10.6	Deg. F
Solar Radiation:	539	825	1136	1429	1730	1894	1921	1636	1231	845	516	418	Btu/sq.ft.
Wind Speed:	10.5	10.3	11.4	11.9	10.7	10.1	9.2	9.2	9.6	10.3	10.5	10.3	Miles/hr.

DB & DP (January 5)

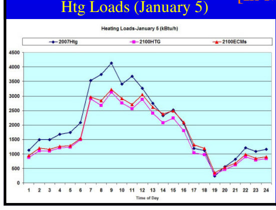


DB & DP (July 8)

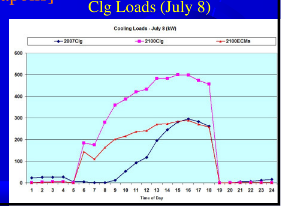


[In Minneapolis]

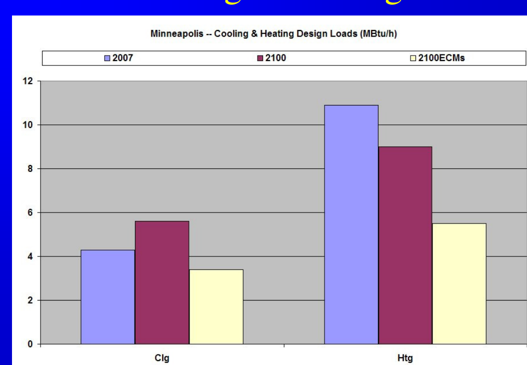
Htg Loads (January 5)



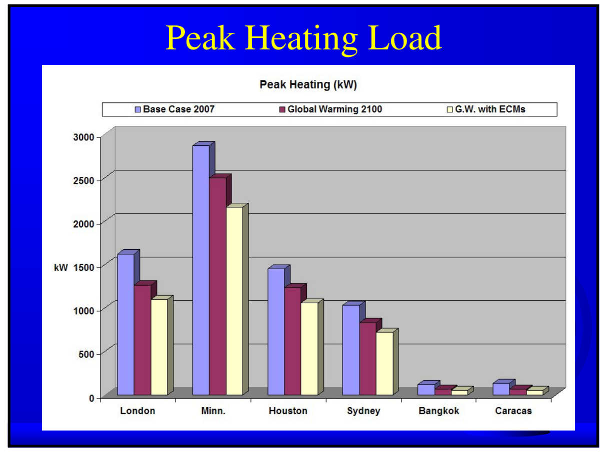
Clg Loads (July 8)

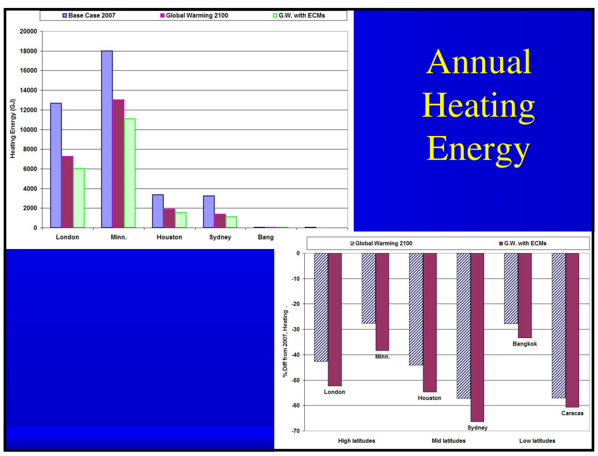


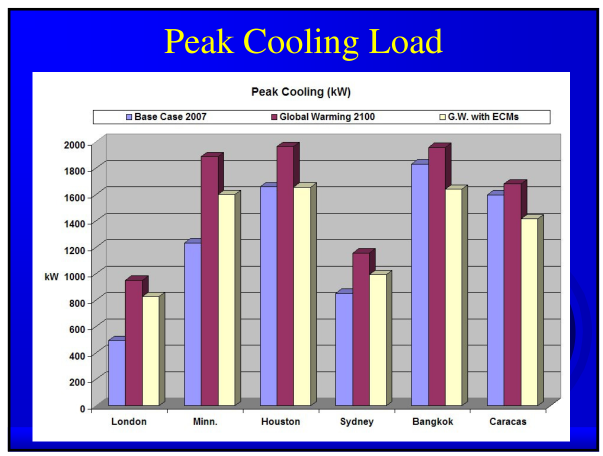
Peak Cooling & Heating Loads

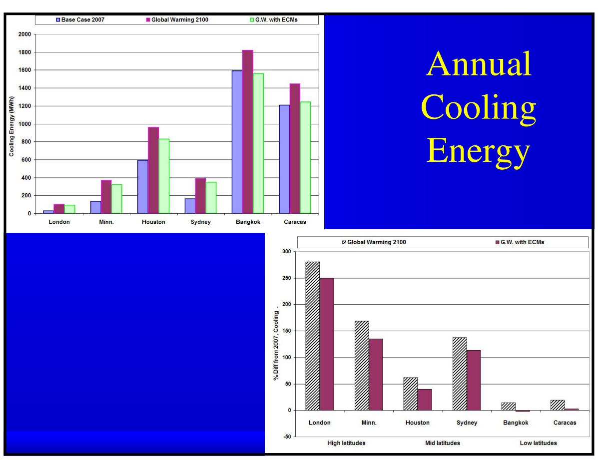


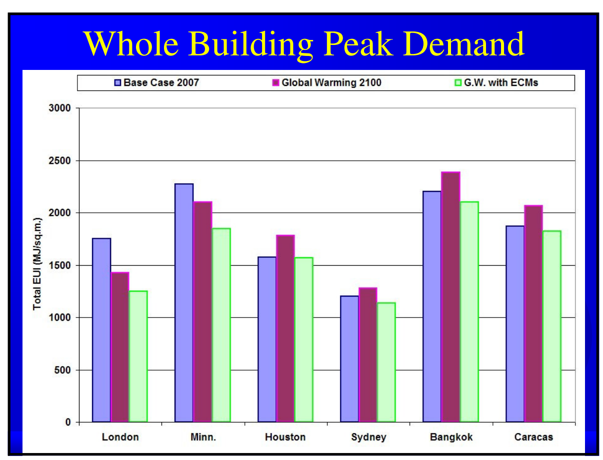

Results for all 6 cities

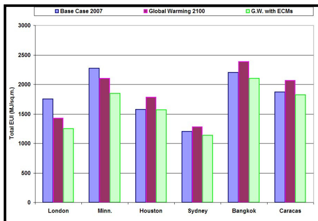

Peak Heating Load
Peak Heating (kW)
Base Case 2007
Global Warming 2100
G.W. with ECMs
kW
3000
2500
2000
1500
1000
500
0
London
Minn.
Houston
Sydney
Bangkok
Caracas


Annual Heating Energy
Base Case 2007
Global Warming 2100
G.W. with ECMs
Heating Energy (GJ)
London
Minn.
Houston
Sydney
High latitudes
Mid latitudes
Low latitudes

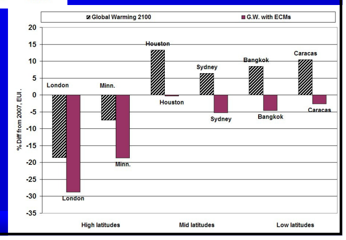

Peak Cooling Load
Peak Cooling (kW)
Base Case 2007
Global Warming 2100
G.W. with ECMs
kW
2000
1800
1600
1400
1200
1000
800
600
400
200
0
London
Minn.
Houston
Sydney
Bangkok
Caracas


Annual Cooling Energy
Base Case 2007
Global Warming 2100
G.W. with ECMs
London
Minn.
Houston
Sydney
Bangkok
Caracas
High latitudes
Mid latitudes
Low latitudes

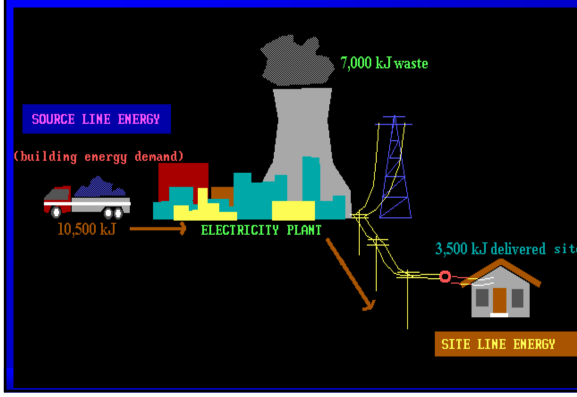

Whole Building Peak Demand
Base Case 2007
Global Warming 2100
G.W. with ECMs
Total EUI (MJ/sq.m.)
3000
2500
2000
1500
1000
500
0
London
Minn.
Houston
Sydney
Bangkok
Caracas



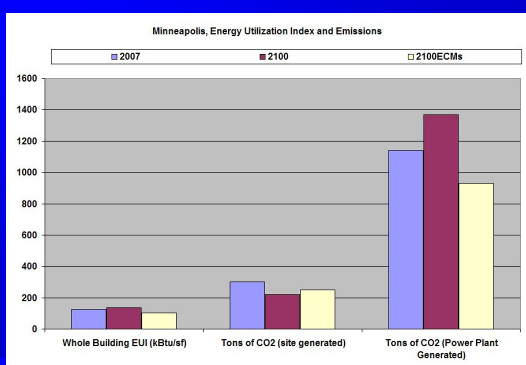
Whole-building Energy Utilization Index



How buildings impact the global environment



Greenhouse Gas Emissions



Conclusions

1. Cooling loads have far greater variations due to latitude than from expected global warming over the next century.
2. Global warming does cause increased cooling loads, the highest percentages being at high and middle latitudes.
3. Significant cooling savings at low latitudes when using motion sensors and air-to-air heat exchangers. This easily counteracts the added loads from global warming.

(cont.)

Conclusions (cont.)

4. Global warming decreases heating loads, but further decreases are possible from occupancy sensors and heat exchangers.
5. Only modest changes in EUI from global warming – due to offsetting effects of increased cooling and decreased heating.
6. Energy increases due to global warming are easily offset by use of known energy conservation measures (ECMs) like occupancy sensors for lighting control and demand ventilation.

Thank you!