Designing for Future Weather

Presented by BuildingGreen, Inc.

Russell Jones
Stratus Consulting

Chuck Khuen
Weather Analytics

Christoph Reinhart
MIT

Presenters

Russell Jones

Managing Analyst
Stratus Consulting

Chuck Khuen

Co-Founder and EVP
Weather Analytics

Christoph Reinhart

Associate Professor
MIT

Learning Objectives

- Understand the science of climate-change predictions.
- Stay abreast of changing climate models.
- Learn how to make use of future weather data in modeling tools.
- Develop strategies to adjust building designs for rising temperatures and humidity.

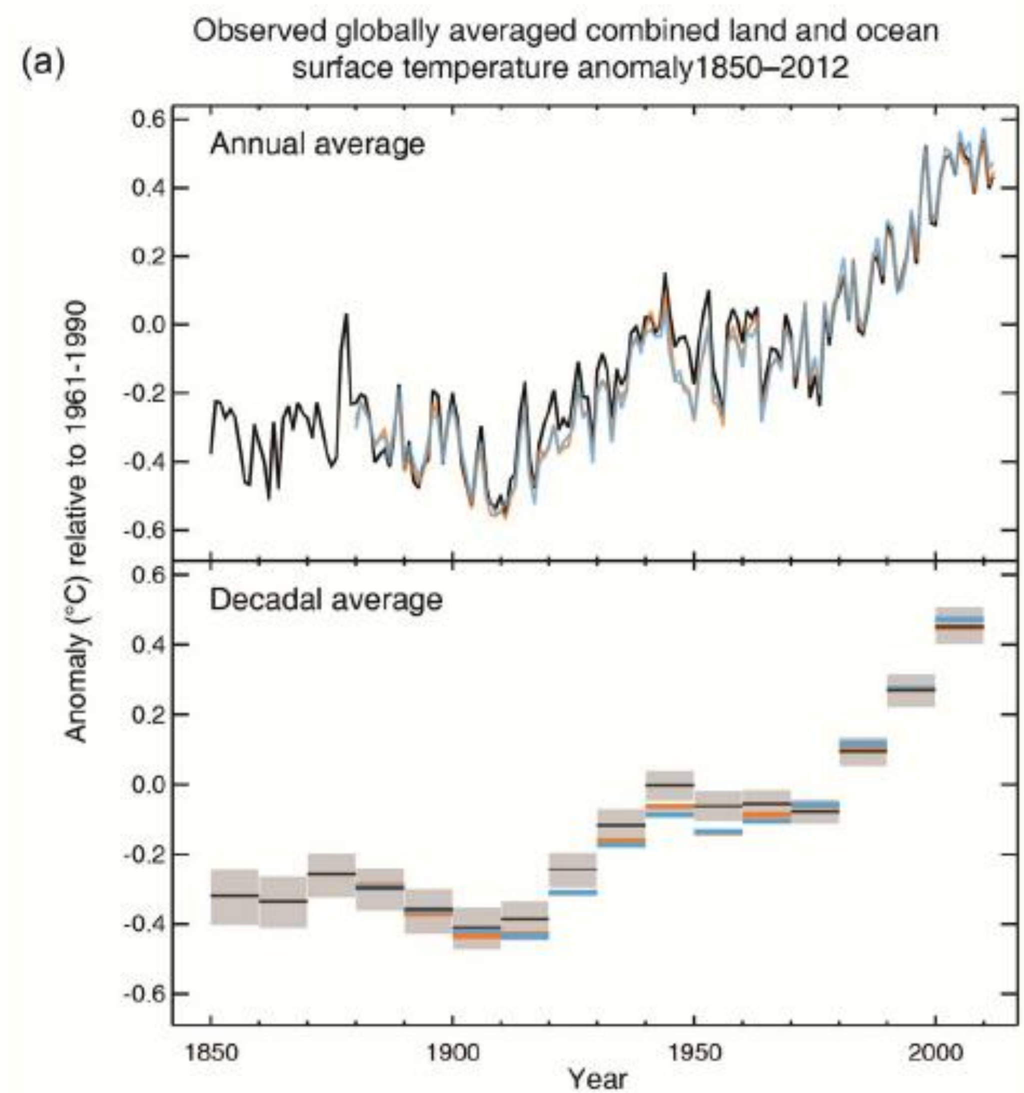
Anthropogenic Climate Change Is Happening

How we know (and what we still don't)

Photo: NOAA (public domain)

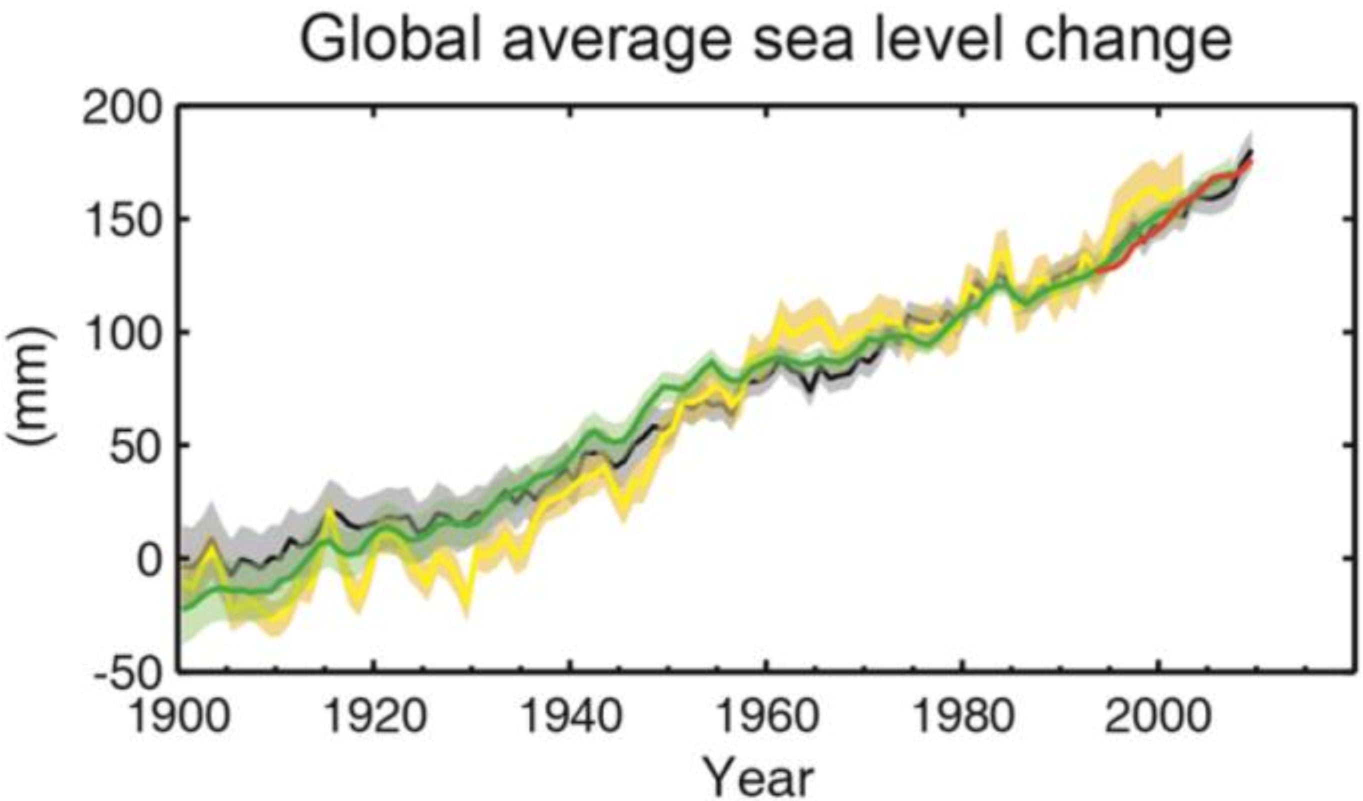
Observed Change in Global Mean Temperature

Figure SPM.1 [FIGURE SUBJECT TO FINAL COPYEDIT]



Source: IPCC WGI AR5, 2013

Observed Change in Global Sea Level



Colored lines represent different data sets

Source: IPCC WGI AR5, 2013

Climate Change Uncertainty

- Climate change is real
- So…What are the future projections?
- Uncertainties at many levels…
  - Emission scenarios
  - General Circulation Model output (GCMs)
  - Spatial scale
  - Temporal scale
  - Variable examined (e.g., precipitation, sea level)
  - – Baseline data
- Additive

Spatial Scale

- Range of projections at each scale
  - Global
  - Regional
  - Local
  - Site-specific
- Uncertainty higher with resolution
- Global average
- GCM grid cells
- Local/Site-specific (point estimates)

Climate Variable Examined

- Temperature, precipitation
- Long-term average or extreme event?
  - Change in average annual maximum/minimum/mean temperature
  - 24-hour maximum precipitation
- Length of event
  - Average number of days above 95° F
  - Average number days with no precipitation
- Recurrence of threshold event (e.g., historical 100-yr precipitation event becomes xx-yr event in future)

How to Handle Climate Change Uncertainty

- Answer questions pertinent to need (e.g., what it is that makes a difference to a building)
  - What variables are important?
  - What kinds of risk are you willing to live with?
  - What time frame is important?
  - What spatial resolution is important?
- Pick GCMs that do a better job historically in your area
  - However, historical fit is not necessarily an indication that same pattern or variability will continue.

How to Handle Climate Change Uncertainty

- Examine the range of climate output to bound estimates (pick hot/dry scenario, cool/wet scenario, and middle-of-road)
  - Allows you to know the potential range of outcomes
- Combine models into “ensemble” – average across models
- Examine the number of models in agreement

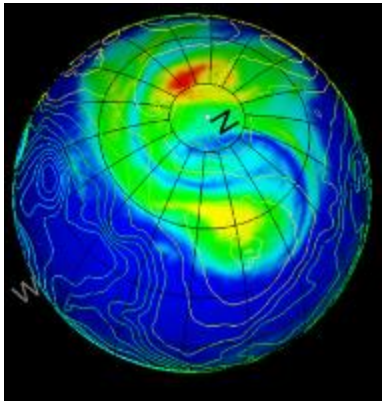
Conclusions

- Many levels of uncertainty
  - Emissions
  - Model output
  - Spatial scales
  - Temporal scales
- Simplify for what variables are important, over what time period, and what level of risk one is willing to take
- Apply reasonable range of scenarios
- Variety of CC websites and applications available to simplify analysis

How to ~~Live~~ Design with Uncertainty

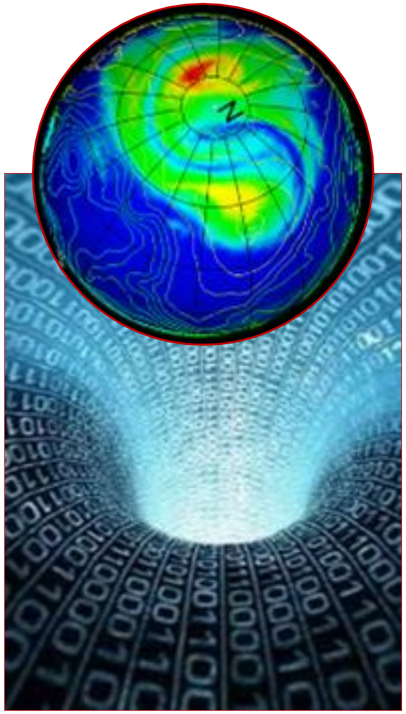
Photo: NASA (public domain)

THE PROBLEM



- **Climate models are global and continental**
  - They lose their skill as you move to the region, area, and site level
- **Design decisions, however, are local**
  - They are site- or at most area-specific
- **But the design decisions can't wait and must accommodate:**
  - Changing heating/cooling loads
  - Increased frequency of extreme conditions

INTRODUCING A NEW BIG DATA RESOURCE



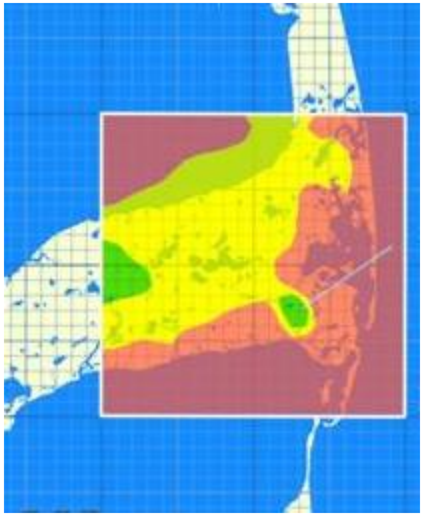
A complete, 30+ year digitized record of the weather for every 35 km^2 on the planet

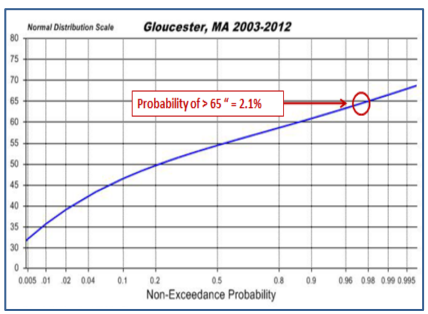
- Fused best of satellite + observed + modeled sources
- 580 variables – full coverage from the surface to altitude
- Mapped into 650,000+ geo-stable grid areas
- Cleansed, rationalized & filtered ensuring statistical stability
- Every hour from 1979 through 7-days ahead
- Kept up to date hourly (>6 Billion records a day)
- Spinning cloud database – available on-demand for any site

WHAT IS AVAILABLE NOW

- **34 Years of historical, gap-free data & short term forecasts for each grid**
  - Actual, Average, Min, Max, & Sum
  - By hour, day, daytime/nighttime, month year
- **Typical Met Year files (TMY) from the last:**
  - 30, 15, 10 & 7 years
- **Hard-to-find variables**
  - Solar radiation
  - Soil temperature
  - Snowfall

WHAT IS COMING NEXT

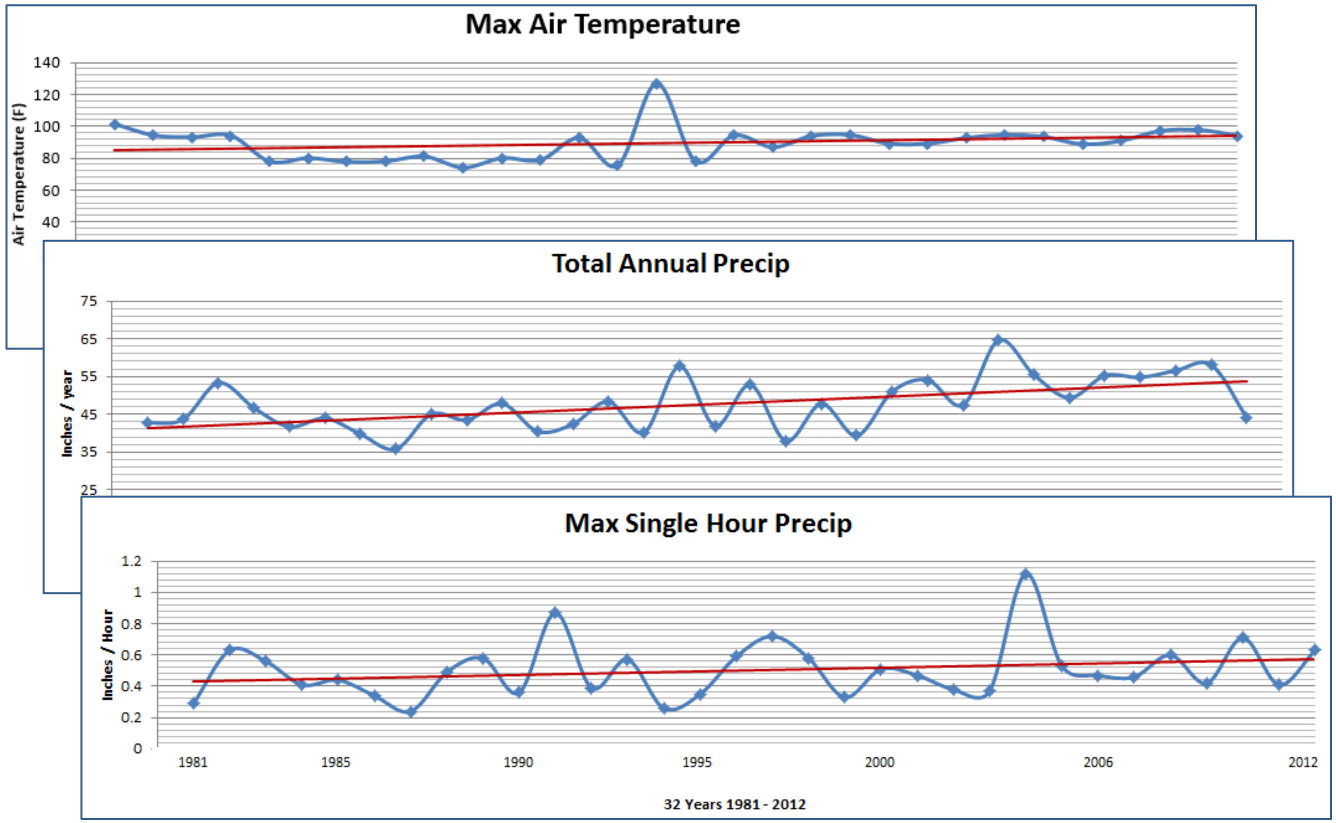




- **Augmenting the Typical TMY files with**
  - Extreme (XMY) files
  - Urban (UMY) files
  - Future (FMY) files
- **1 km downscaling**
  - Starting with US & severe events
- **Trending for any variable**
- **Frequency analysis for events and peaks**
- **Probability forecasting / comparisons**

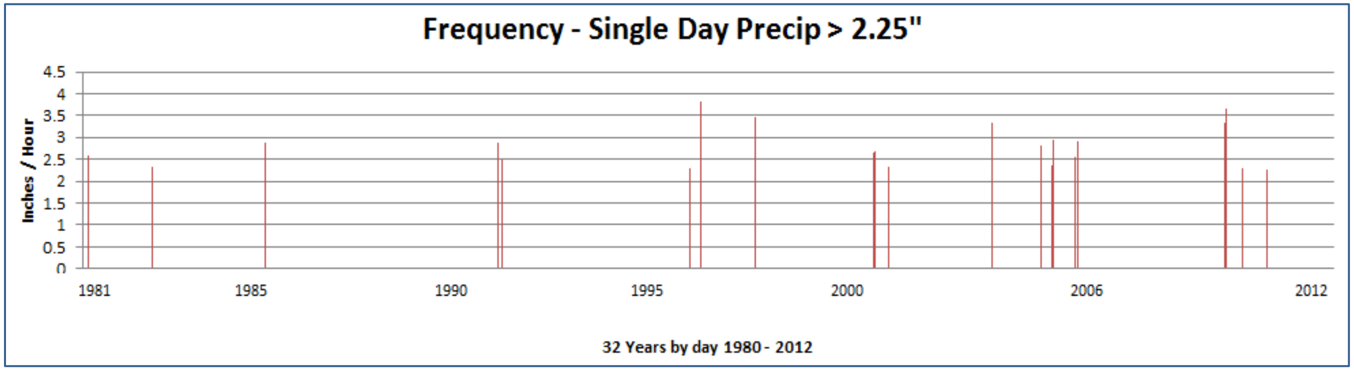
EXAMPLE: TRENDING TEMP & PRECIP

Gloucester, Massachusetts—1981 - 2012



EXAMPLE: FREQUENCY TRENDING

Gloucester Massachusetts, 1981 - 2012



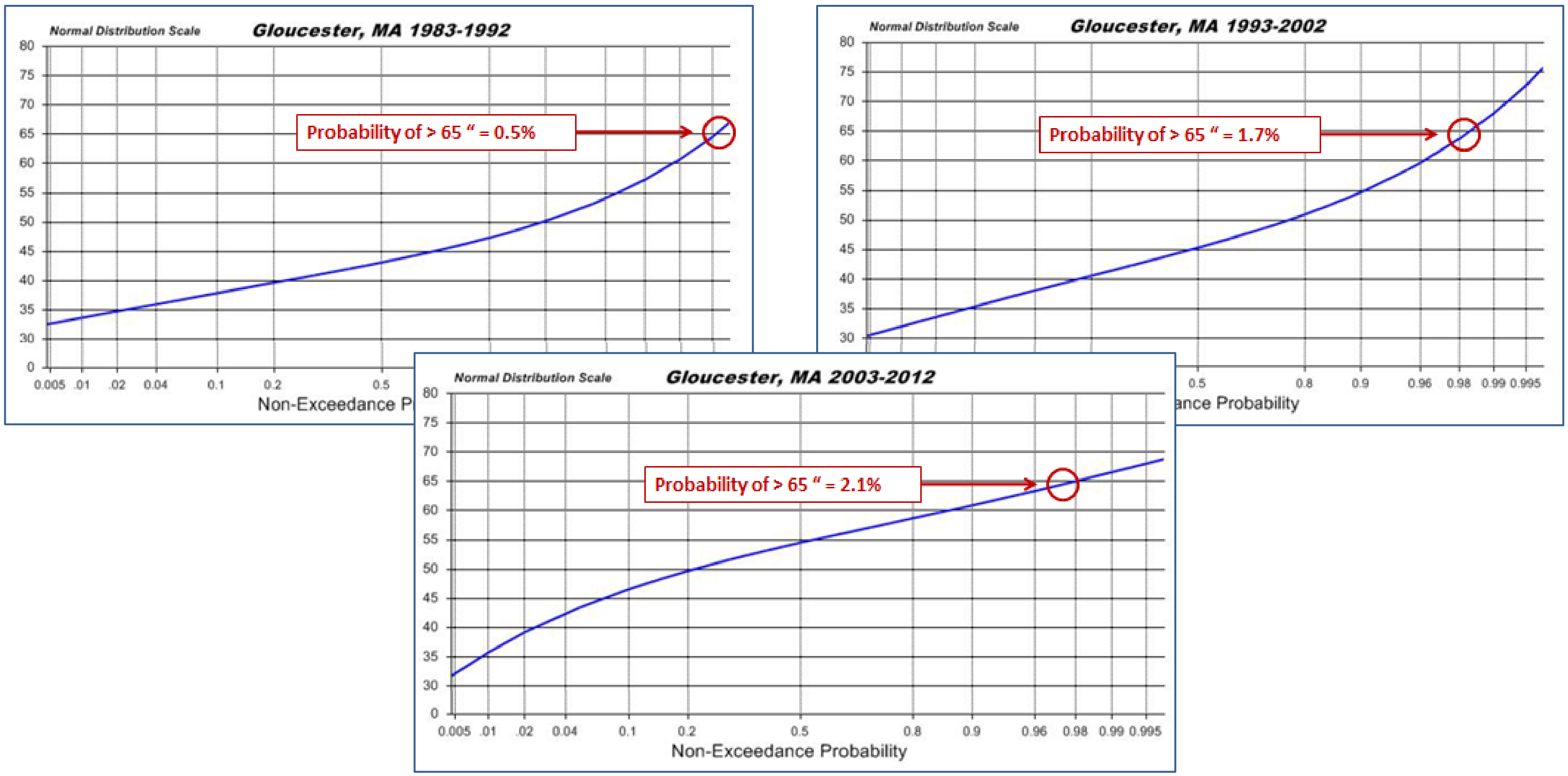
Occurrence of over 2.25" of precip in a day

- 3 times in the 1980s
- 5 times in the 1990s
- 13 times since 2000

EXAMPLE: PROBABILITY TRENDING

Decade-by-Decade Comparisons:

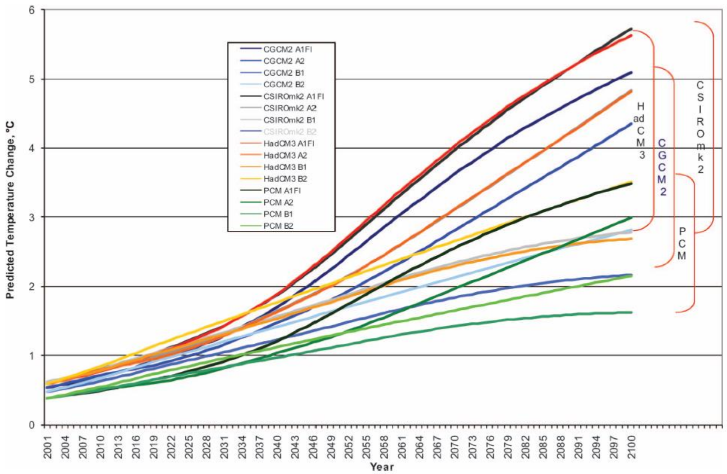
Probability of >65" annual rainfall 0.5% in 1980s to 2.1% in 2000s



Taking It to the Field

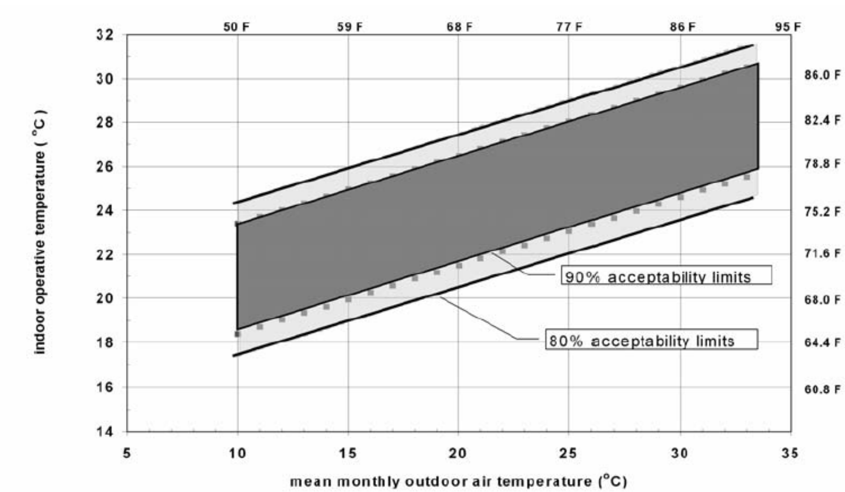
Photo: U.S. Fish and Wildlife Service (public domain)

Climate Change and Building Design



IPCC: Projected world mean temperature change

Optimized façades in Boston



Adaptive comfort

Climate Change and thermal comfort

Selected Quotes

United States Global Change Research Program

www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

Energy Supply and Use

Click here to download the Energy Supply and Use chapter from the report

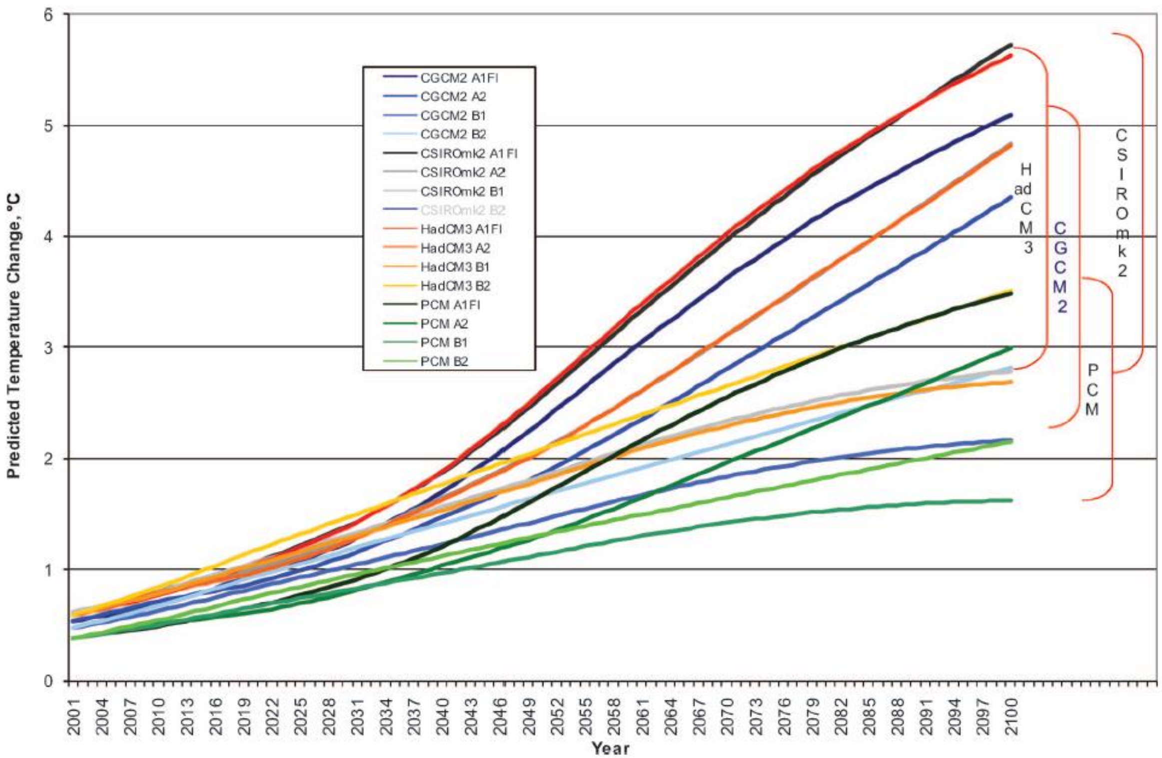
KEY MESSAGES:

- Warming will be accompanied by decreases in demand for heating energy and increases in demand for cooling energy. The latter will result in significant increases in electricity use and peak demand in most regions.
- Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions.
- Energy production and delivery systems are exposed to sea-level rise and extreme weather events in vulnerable regions.
- Climate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt.

IPCC's 3rd Assessment Report, Working Group II

"[The] impacts of climate change on human settlements are hard to forecast, at least partly because the ability to project climate change at an urban or smaller scale has been so limited."

Climate Change Predictions



A General Circulation Model (GCM) is a mathematical model of the general circulation of a planetary atmosphere or ocean. [Wikipedia]

The IPCC Working Group III developed storylines which represent a potential range of different demographic, social, economic, technological and environmental developments (IPCC 2000).

CC Modeling for Practitioners

Generating Future Climate Files

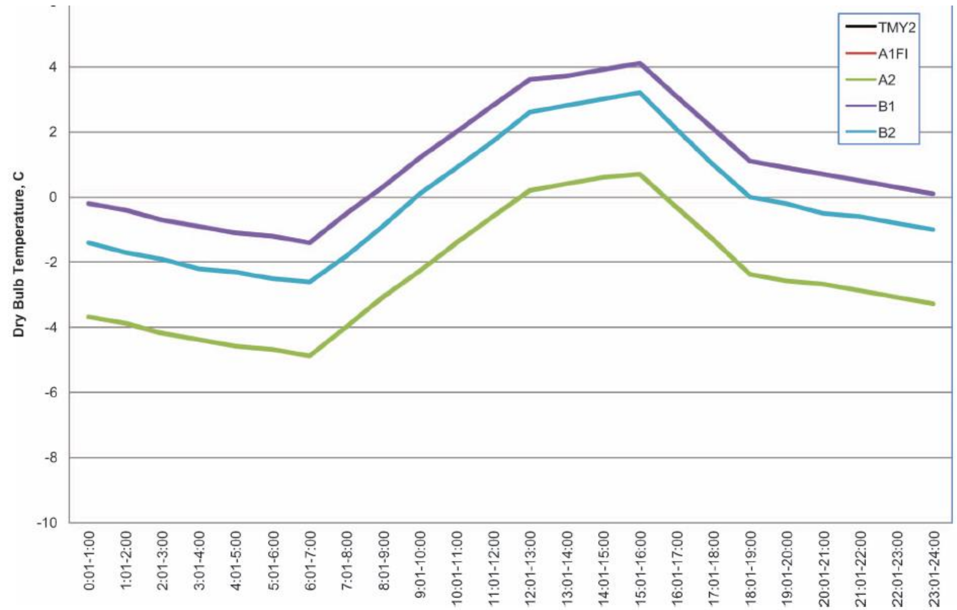


Figure 8. Hourly average TMY2 and climate change scenario drybulb temperatures for January in Washington, DC.

Crawley proposed to use a combination of current Climate Files with GMCs using hourly correction terms for dry bulb temperature, dew point temperature, rel. humidity & solar radiation. The correction terms are based on predicted monthly changes of could cover, dry bulb temperature, diurnal temperature swings, dew point temperature and relative humidity. This process is called 'morphing'.

Note: Wind data is not modified in that model.

Drury B. Crawley, "Estimating the impacts of climate change and urbanization on building performance", Journal of Building Performance Simulation, 1940-1507, Volume 1, Issue 2, 2008, Pages 91 – 115.

Climate Change Weather File Generator

http://www.serg.soton.ac.uk/ccworldweathergen/index.html

Generates future climate files for locations worldwide (with limitations) with a specific focus on the UK. It is based on the 'morphing' methodology.

Paper: Belcher SE, Hacker JN, Powell DS. Constructing design weather data for future climates. Building Services Engineering Research and Technology 2005; 26 (1): 49-61.

Paper: Jentsch MF, Bahaj AS, James PAB. Climate change future proofing of buildings - Generation and assessment of building simulation weather files. Energy and Buildings 2008; 40 (12): 2148-2168.

Climate Change Weather File Generator

CCWorldWeatherGen climate change weather file generator V1.5 manual

For transforming EPW weather files into climate change TMY2/EPW files. (Acknowledgements & disclaimer of warranties below)

Specify the HadCM3 data file pa C:\CCWorldWeatherGen\HadCM3data

Summary of combined HadCM3 A2 ensemble climate change predictions for the selected weather site

Selected scenario: A2 scenario ensemble for the 2080's

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Daily mean temperature	TEMP	(C)	4.10	4.43	4.16	4.32	4.73	4.95	5.81	5.84	5.50	5.09	4.43	3.97	4.78
Maximum temperature	TMAX	(C)	3.92	4.48	4.30	4.07	4.76	5.56	6.46	6.07	5.36	4.79	4.48	4.08	4.86
Minimum temperature	TMIN	(C)	4.39	4.56	3.83	4.42	4.77	4.62	5.52	5.88	5.68	5.27	4.30	4.02	4.77
Horizontal solar irradiation	DSWF	W/m²	-3.96	-6.05	-4.22	-0.51	11.77	17.59	14.20	10.09	11.50	6.57	-1.14	-2.35	4.46
Total cloud cover	TCLW	% points	-0.25	-0.50	-0.88	-0.13	-2.00	-3.00	-5.25	-5.00	-5.63	-4.38	-0.63	-0.88	-2.38
Total precipitation rate	PREC	%	13.41	22.11	24.97	28.96	14.52	6.39	12.84	24.38	-8.16	2.82	12.59	15.63	14.21
Relative humidity	RHUM	% points	-2.59	-4.54	-4.91	-3.85	-5.21	-7.54	-7.09	-4.63	-4.16	-3.27	-3.17	-3.15	-4.51
Mean sea level pressure	MSLP	hpa	-1.61	-1.02	-2.48	-0.52	-1.22	-1.68	-2.09	-2.54	-1.09	-0.87	-0.21	-0.95	-1.36
Wind speed*	WIND	%	-1.40	-2.22	0.70	-0.58	-1.41	-2.39	-1.79	-7.25	-6.52	-5.72	-1.20	-2.52	-2.69

* Please note that wind speed resides on a 96x72 grid whilst all the other data is on a 96x73 grid

EPW weather file selection

(1) Please specify the EPW file you want to transform

Select EPW File for Morphing

Current EPW baseline weather file for morphing:

Baltimore Blt Washngtn Intl *Latitude:* 39.17 N
Longitude: ##### W
Elevation: 45 m

HadCM3 scenario timeframe selection

(2) Please select a HadCM3 A2 scenario ensembe timeframe

○ 2020's ○ 2050's ◉ 2080's — Load Scenario

Closest four HadCM3 96x73 grid points to Baltimore Blt Washngtn		*Latitude:*	*Longitude:*
	A	40.00 N	##### W
	B	40.00 N	##### W
	C	37.50 N	##### W
A2 scenario for the 208	*D*	37.50 N	##### W

EPW weather file morphing

(3) Click button to start morphing procedure

Start Morphing Procedure

Current morphed EPW weather file:

Morphed EPW file for: Baltimore Blt Washngtn Intl, USA
HadCM3 A2 emissions senario ensemble for the 2080's

EPW/TMY2 weather file generation

(4) Click the appropriate button for EPW / TMY2 file generation

Generate Climate Change EPW Weather File

Generate Climate Change TMY2 Weather File

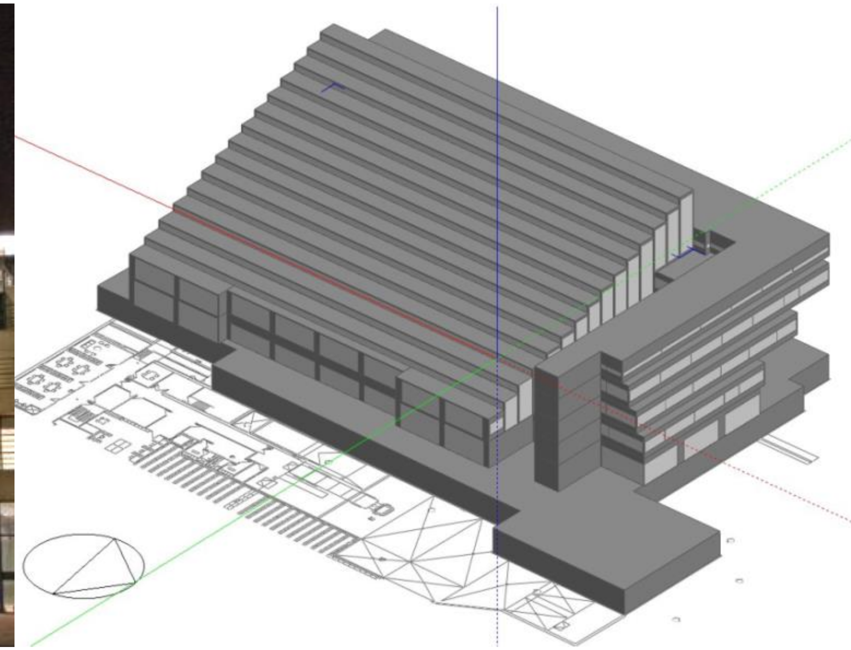
To create a TMY2 file of the original EPW file click the button below:

Generate Present-Day TMY2 Weather File form EPW data

Screenshot CCWOrldWeatherGen

How Large is the Effect?

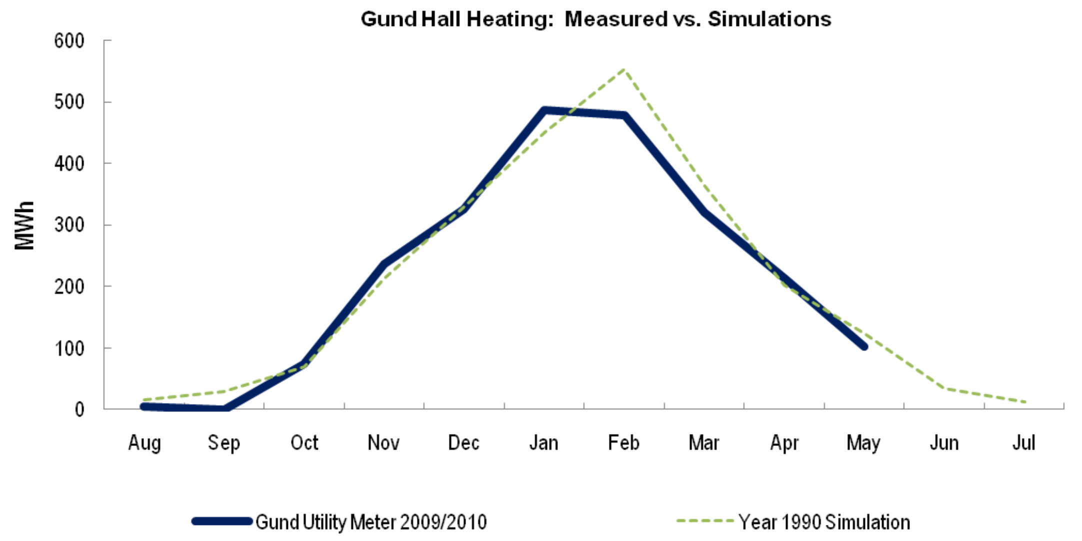
Harvard University – Gund Hall

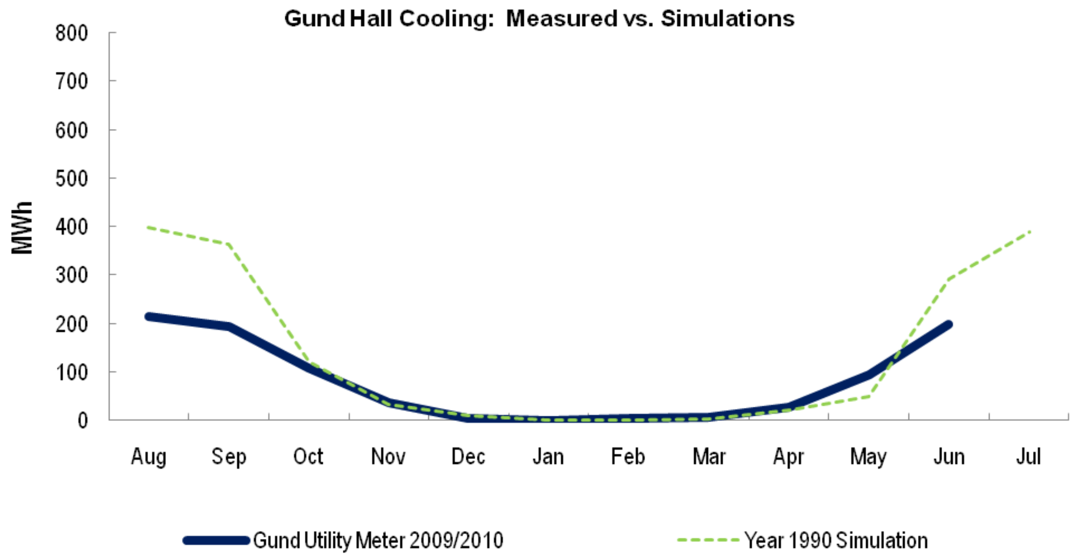


DesignBuilder model

Gund Hall now

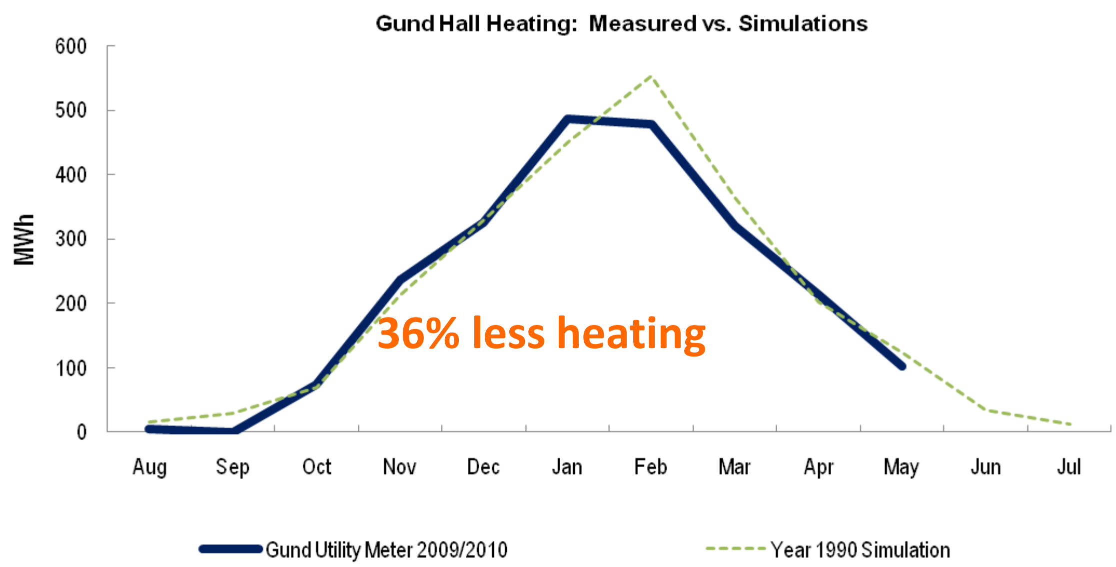
Samuelson, Holmes, Reinhart 2011

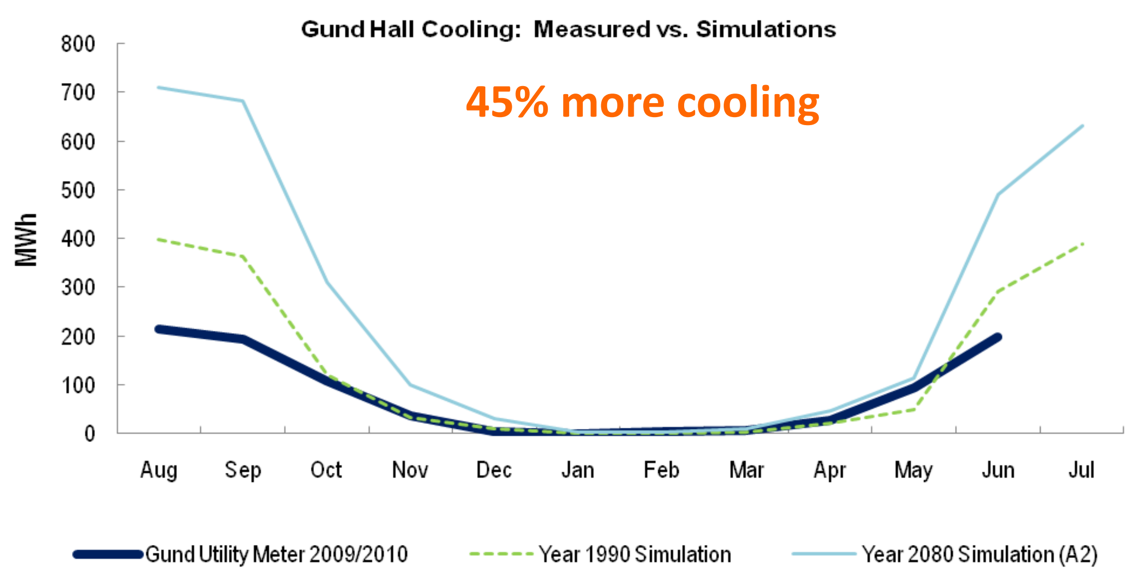




- ❑ 33 Zone E+ model
- ❑ 1990 TMY2 weather data for Boston

Case Study: Gund Hall now and then

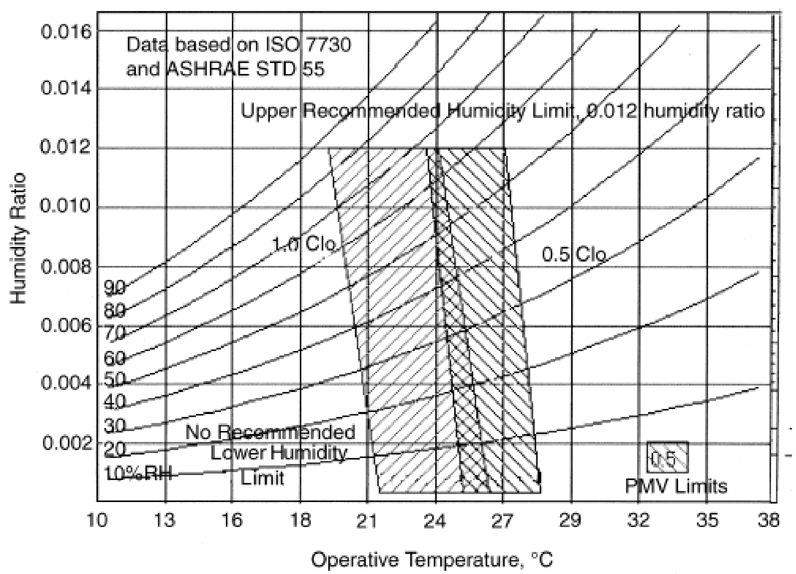


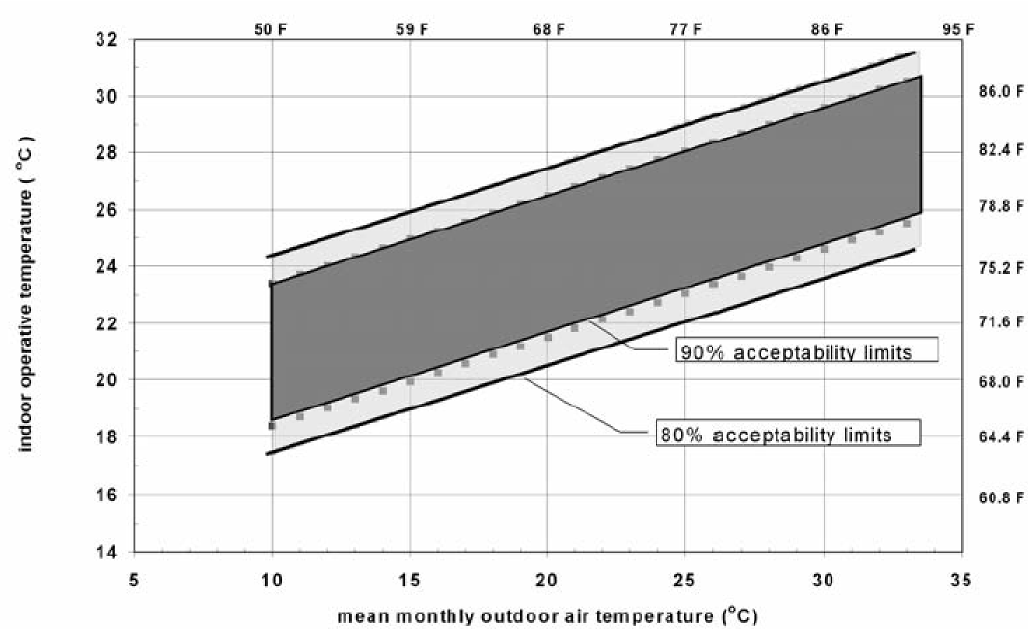


- ❑ 33 Zone E+ model
- ❑ 1990 TMY2 weather data for Boston
- ❑ predicted 2080 weather data for the IPCCCA2 scenario (medium to high emissions scenario).

CC & Thermal Comfort

Thermal Comfort





ASHRAE 55 – Thermal Environmental Conditions for Human Occupancy

De Wilde and Tian found for a mixed-mode UK building that the probability of overheating and cooling energy use varied by a factor of 2 to 5 depending on which comfort model the analysis was based.

This means that reliably predicting future climate is extremely important but occupant's reaction to warmer temperature needs to be better understood as well.

Peter de Wilde, Wei Tian (2010) “The role of adative thermal comfort in the prediction of thermal performance of a modern mixed-mode office building in the UK under climate change", Journal of Building Performance Simulation, Volume 3, Issue 2, pp. 87-101.

Case Study Being a Good Neighbor

A Case Study for the National Academy of Sciences

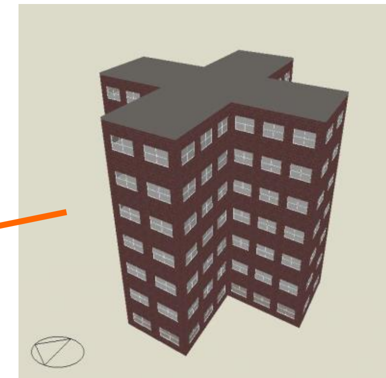
New Mixed-use condominium development project

Course Project: Changsoo Park, MAUD
Site: Halletts Cove, Astoria, New York
Model Courtesy: Studio V Architecture

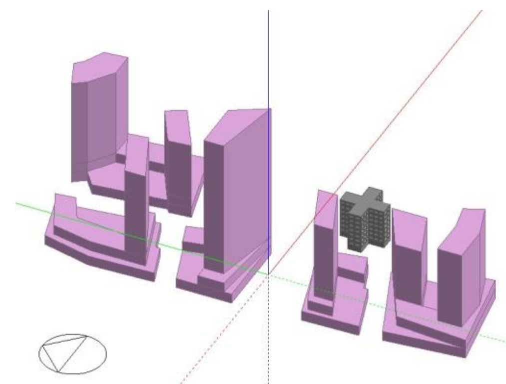
Existing Public Housing Community
by Robert Moses

Building in the City

Course Project: Changsoo Park, MAUD
Model Courtesy: Studio V Architecture

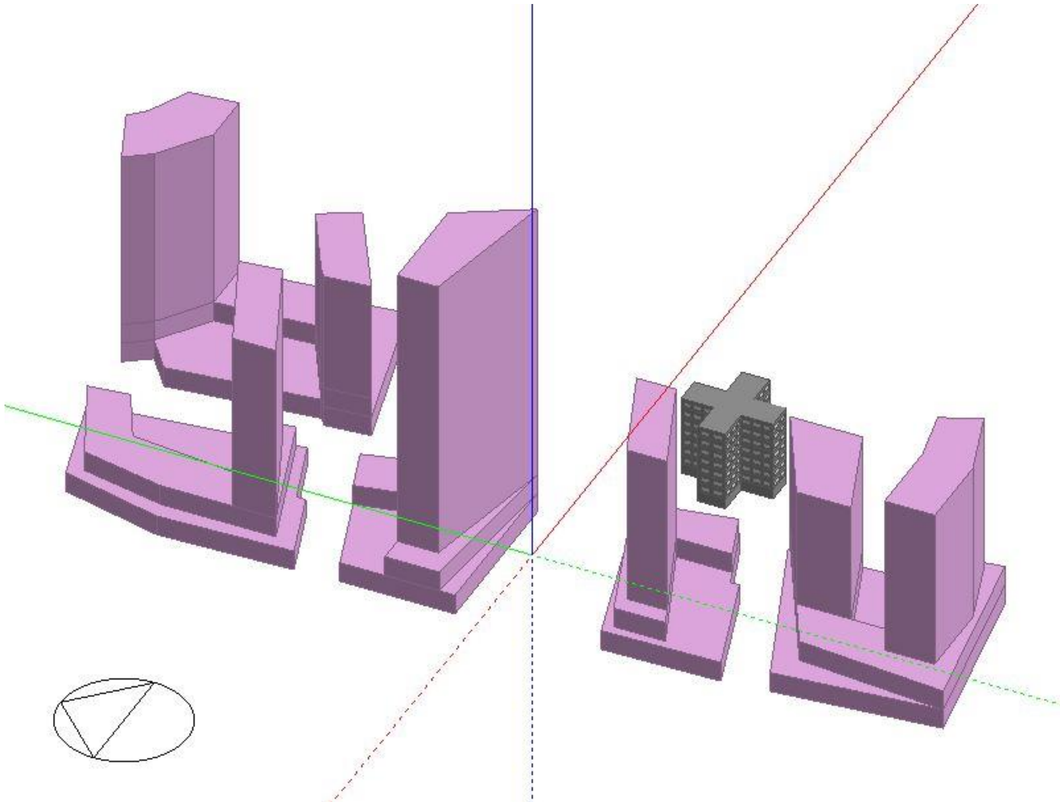


Baseline Model:
No Urban Context
JFK Airport Data



Urban Model:
Urban Context
Local Weather Data

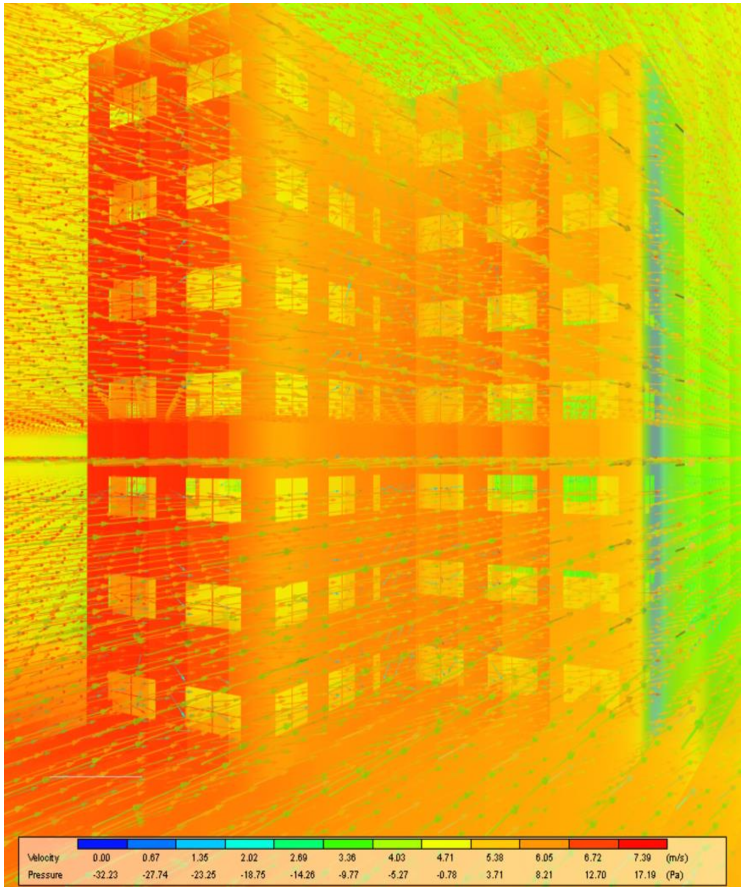
Impact of Neighboring Buildings

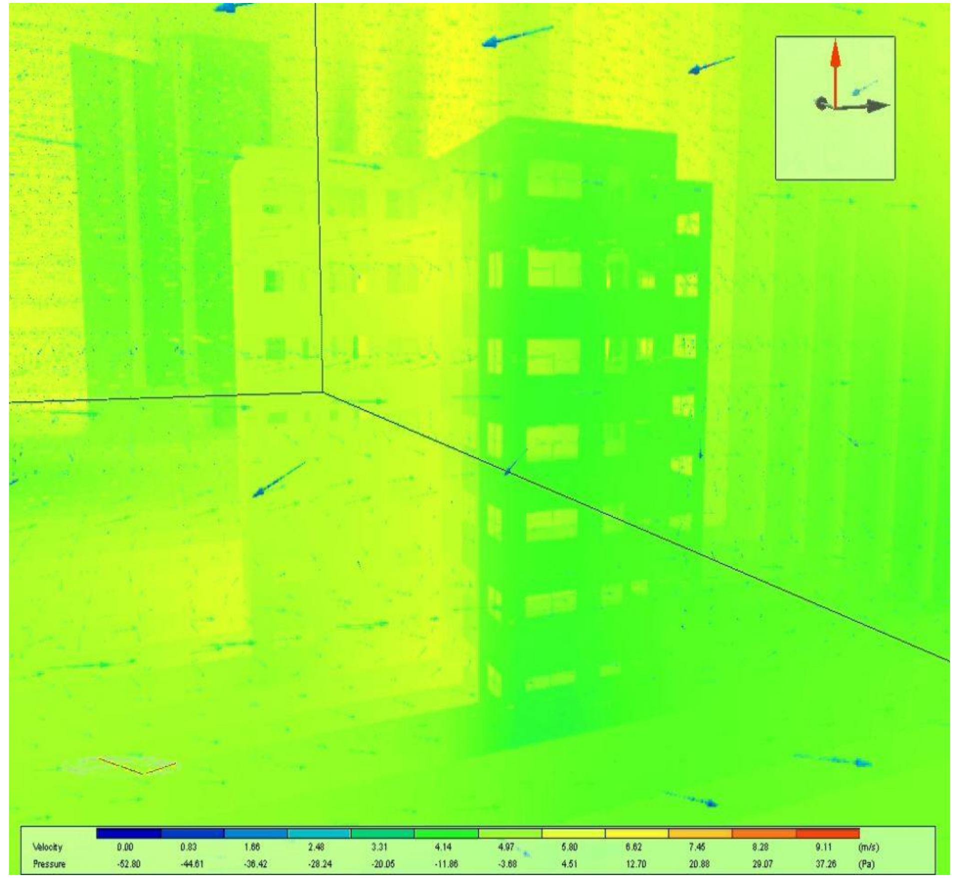


Heating Season: **Reduced solar radiation. Heating load increases by 7% (~$900).**

*Gas Cost: $ 0.043 / kWh, Jan. 2010 in New York State, US Energy Information Administration

Impact of Neighboring Buildings

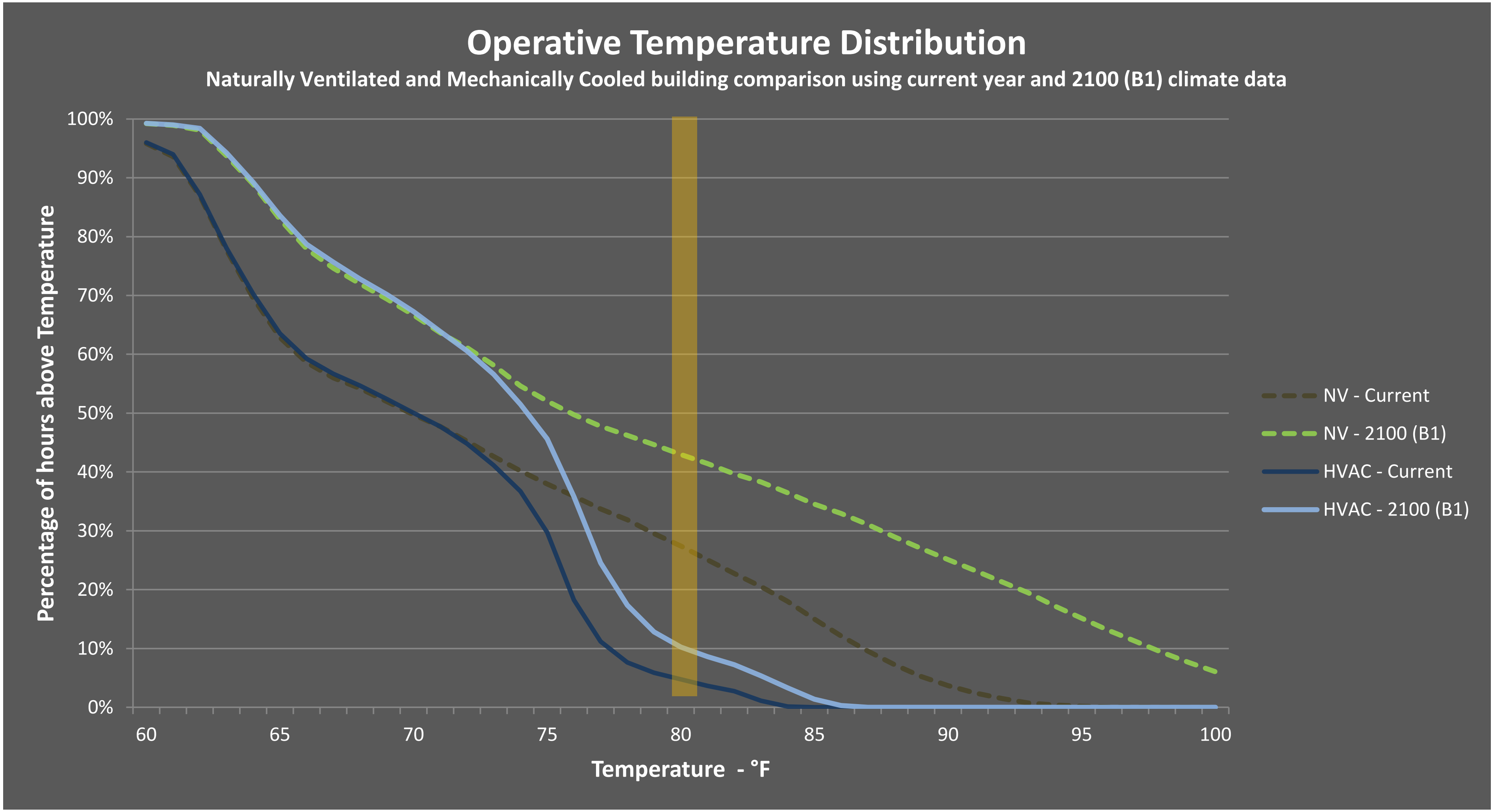




Course Project: Changsoo Park, MAUD

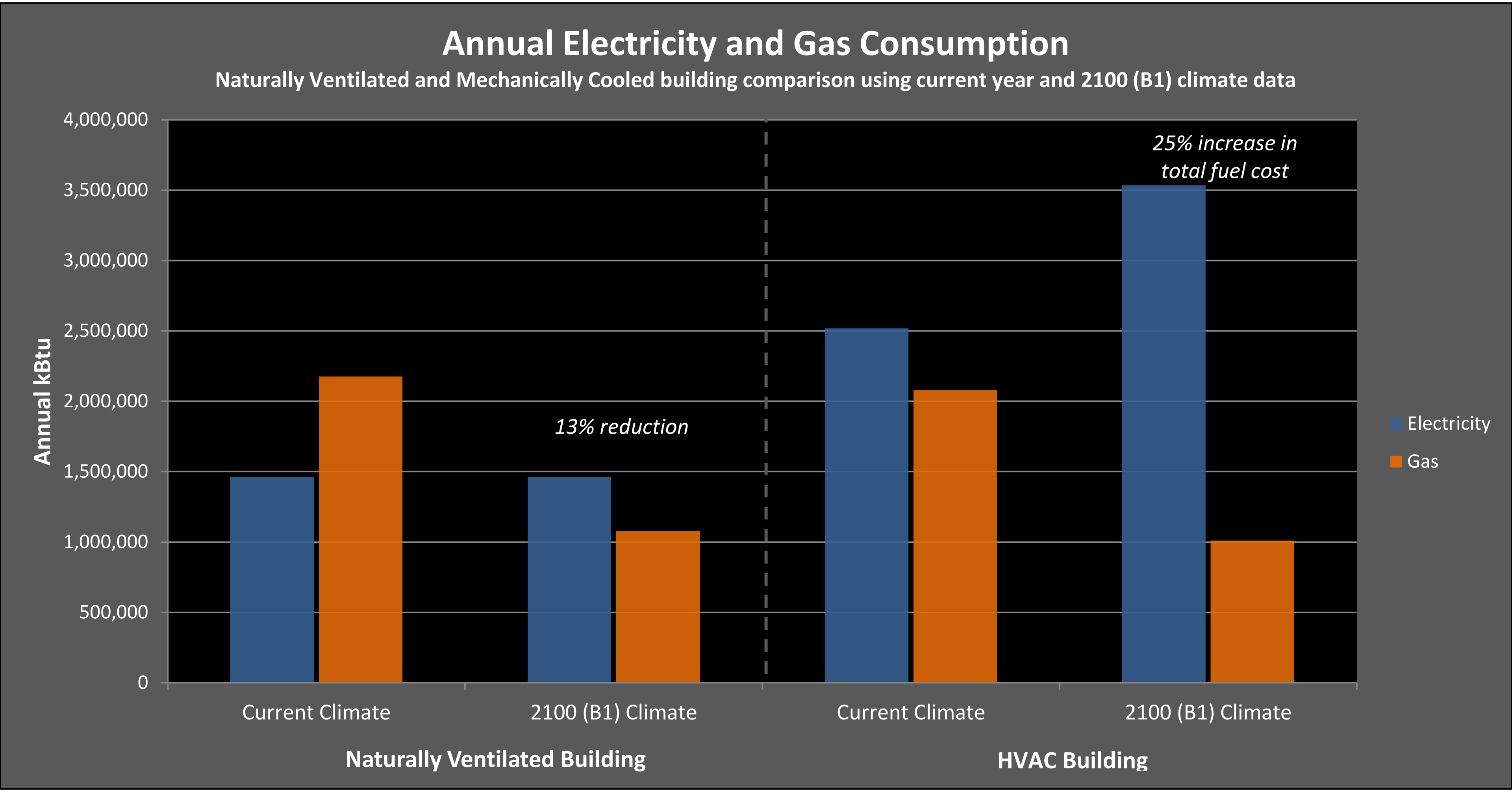
Impact of neighboring buildings: Dramatically different local wind patterns. Will lead to higher temperature during summer due to reduced natural ventilation.

Future Climate Data – Thermal Comfort



Modeling Parameters:
Type = studio apartment
Exposure = South, East, West
Elevation = 4th floor

Future Climate Data - Energy



Fuel costs
Gas = $0.043 / kwh
Electricity = $0.179 / kwh

Note: Calculation does not reflect project fuel cost increases

Source: *US Energy Information Administration*

Summary Climate Change Study

Adding a neighboring building increases annual heating bill by 7%.

Blocking local winds can dramatically reduce the potential for using natural ventilation.

A warming climate reduces heating costs by 13% but air conditioned units see a 25% increase in their annual energy bill.

CC & $

How are we reacting to this trend?

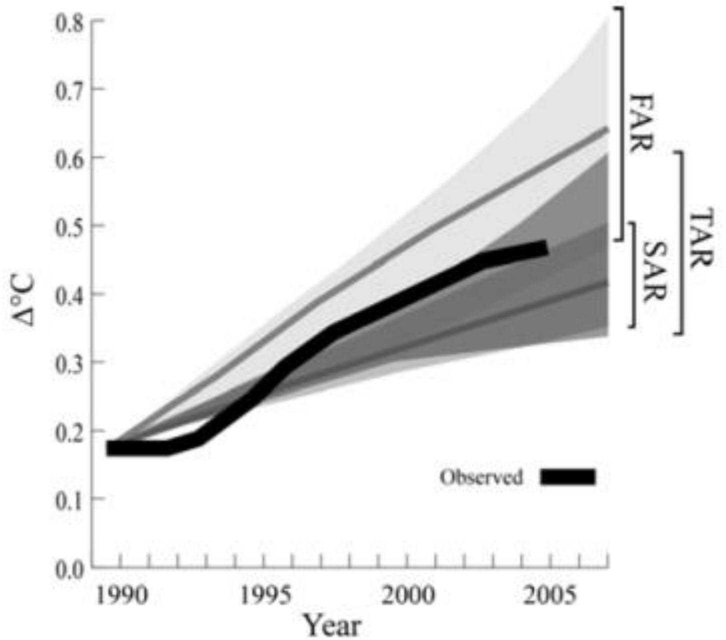
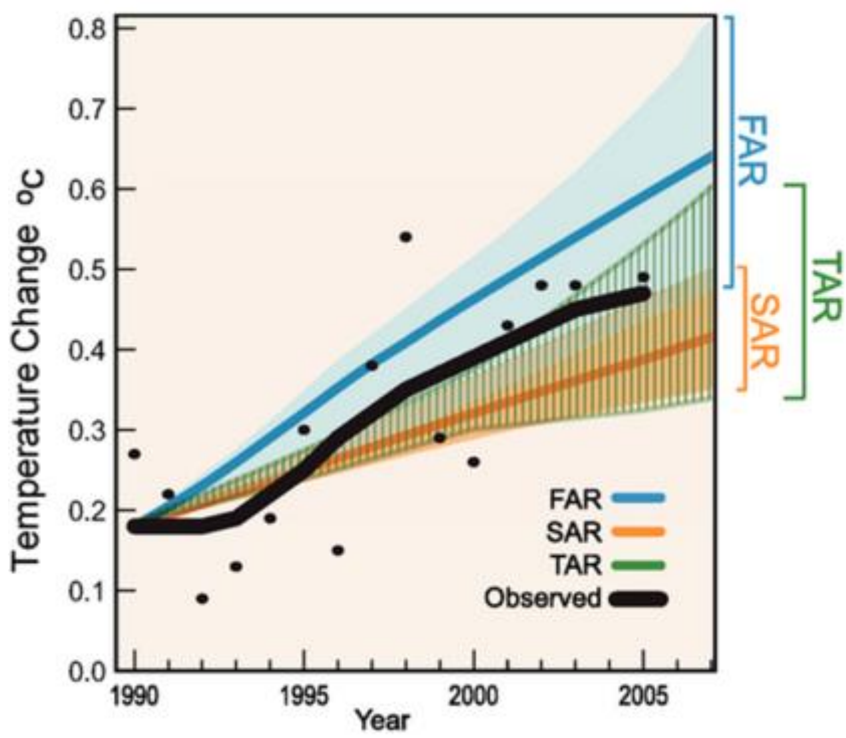
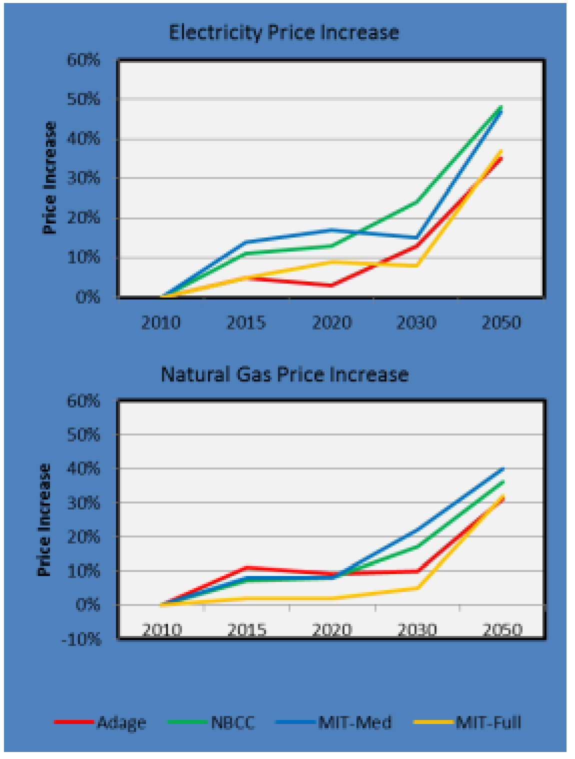


Figure 1. Climate modelling temperature comparison

Adaptation at the expense of mitigation

Linking Future Climate Files with Future Prices





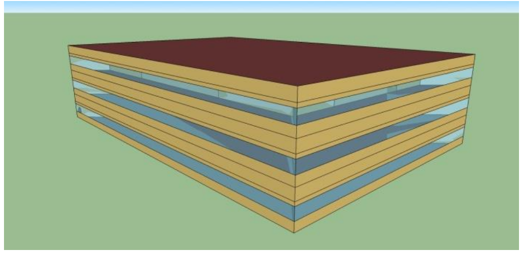
Data Source: Economic Insights from Modeling Analyses of H.R. 2454 — the American Clean Energy and Security Act (Waxman-Markey); Pew Center for Global Climate Change

- ❑ **The basic idea of the paper is to link 7 of the 22 energy price projections from the 2009 Energy modeling Forum (EMF-22) to the four climate change projections from the 3rd IPCC Assessment Report (TAR).**
- ❑ **The matching is realized via the Radiative Forcing (RF) of the different scenarios. RF is the change in net irradiance at the top of the tropopause compared to the year 1750.**

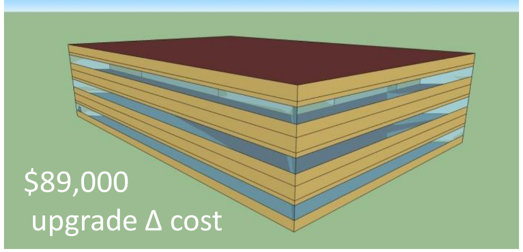
Paper: S H Holmes and C F Reinhart, 2013, "Assessing future climate change and energy price scenarios for institutional building investment and HVAC operation," *Building Research and Information*, 41:2, pp. 209-222

Case Study: Office Building in Boston

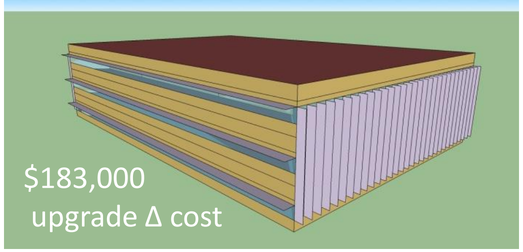
Generic 1980s office building, floor area 5000m^2, 3 stories.



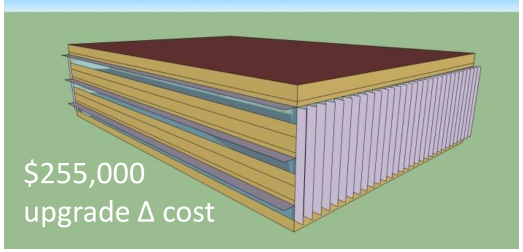
- **Baseline:** Building left as is.



- **Minimum:** Upgrade so that the building meets ASHRAE 90.1-2004 (more efficient HVAC and windows (inoperable).

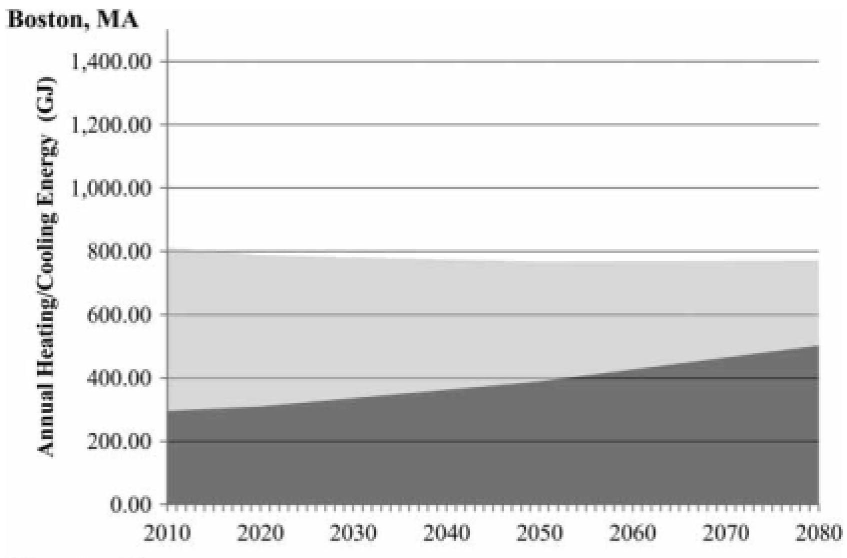


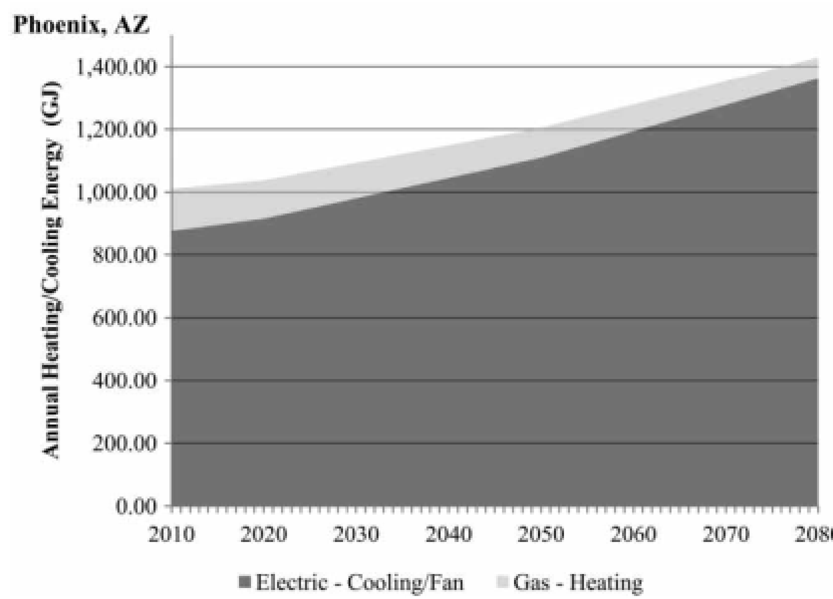
- **Medium:** Same as previous but add mixed-mode ventilation & solar shading.



- **Advanced:** Same as previous but double all insulation levels.

Case Study: Office Building in Boston

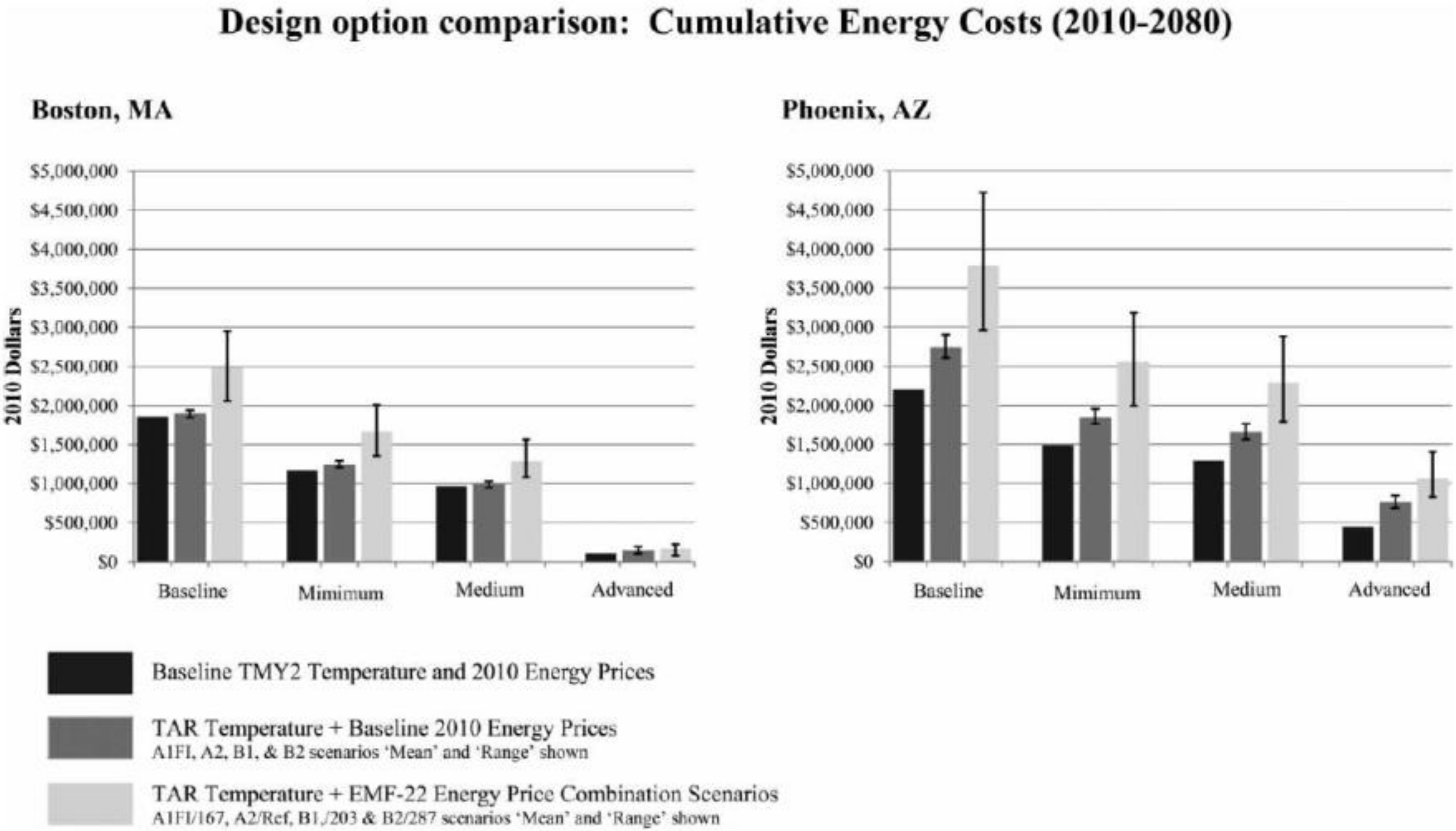




- Switch from heating to cooling dominated in Boston.

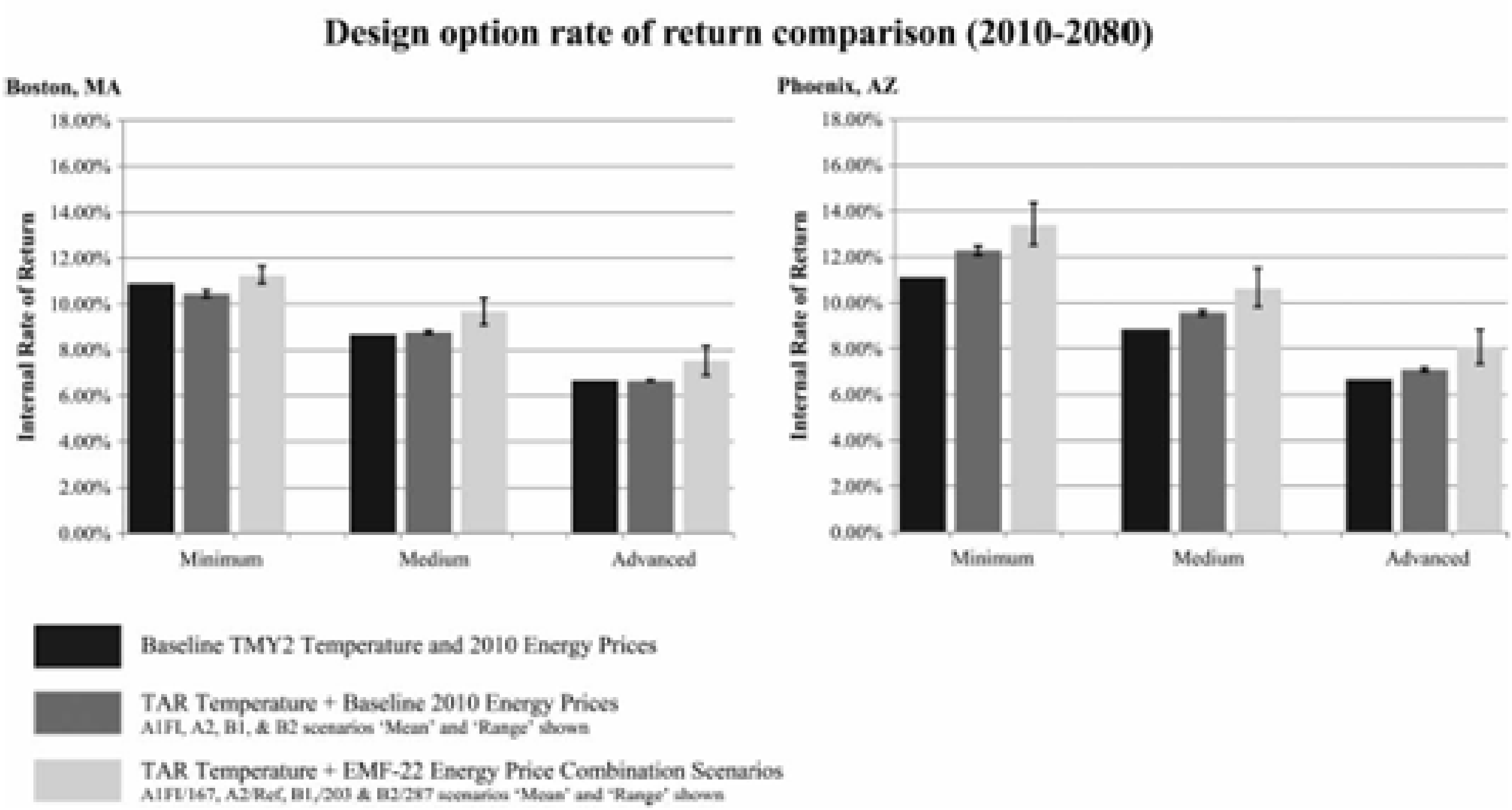
Paper: S H Holmes and C F Reinhart, Assessing future climate change and energy price scenarios for institutional building investment and HVAC operation, Building Research and Information, 41:2, pp. 209-222, 2013.

Case Study: Cumulative Energy Costs



Paper: S H Holmes and C F Reinhart, 2013, "Assessing future climate change and energy price scenarios for institutional building investment and HVAC operation," *Building Research and Information*, 41:2, pp. 209-222

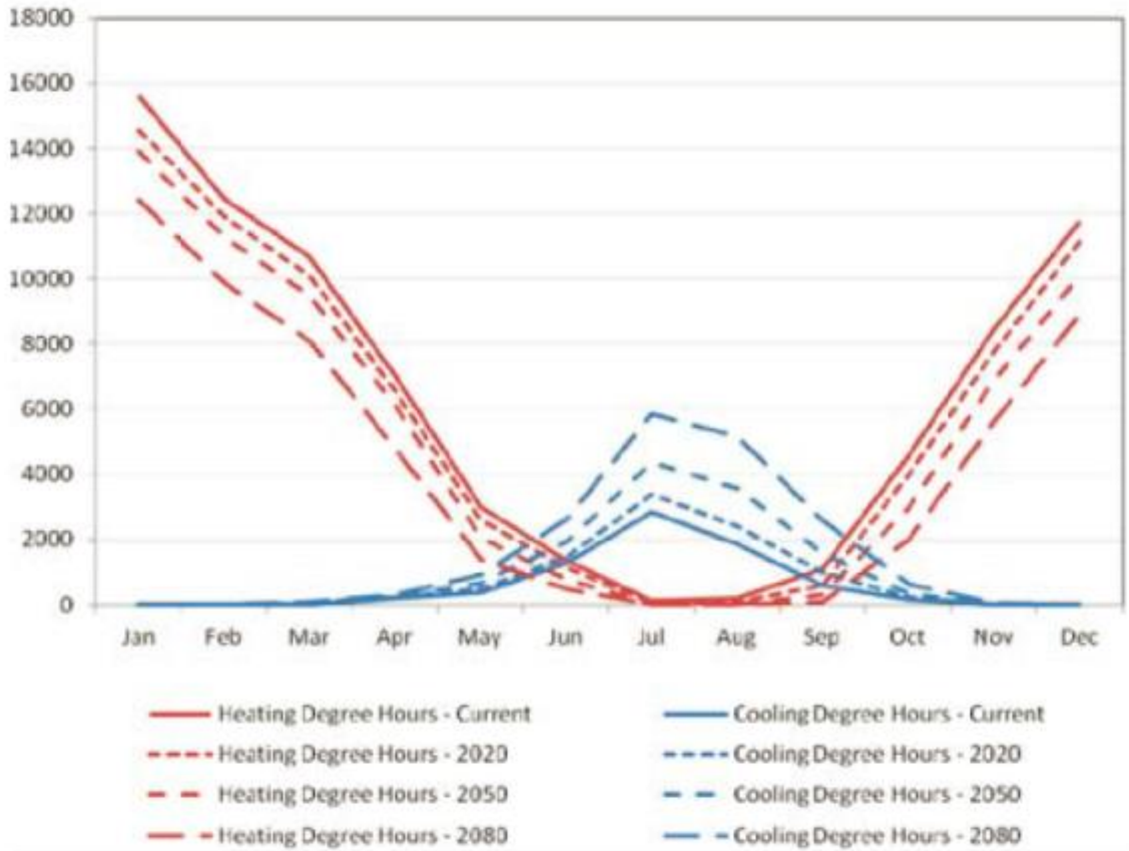
Case Study: Cumulative Energy Costs



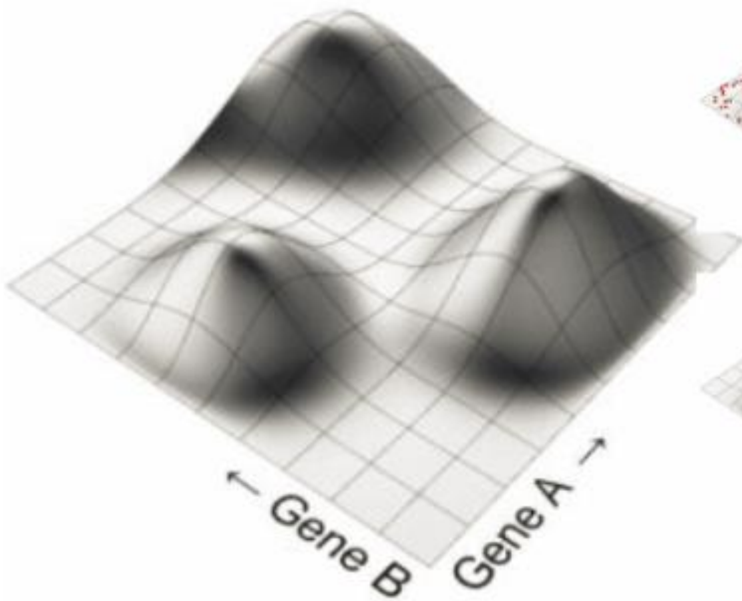
- ❑ IRR highest for minimum upgrade. (It is tough, energy is cheap in this country.)
- ❑ Cooling dominated climates have higher IRRs. This does not necessarily translate into actions today.

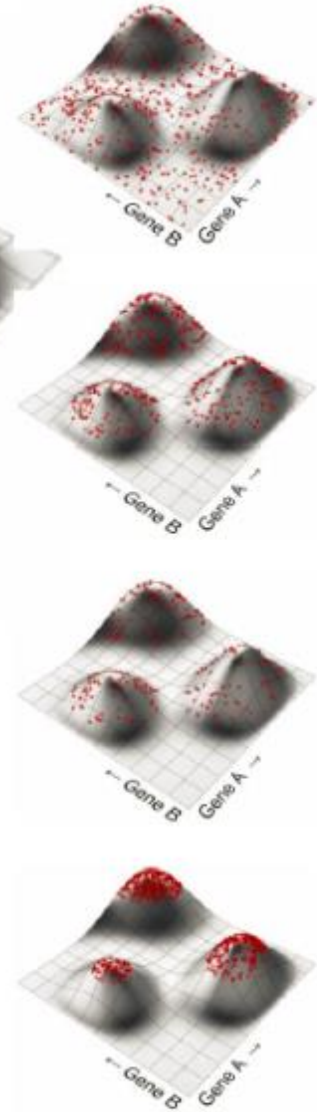
Optimized CC

How can we optimize for a changing climate?

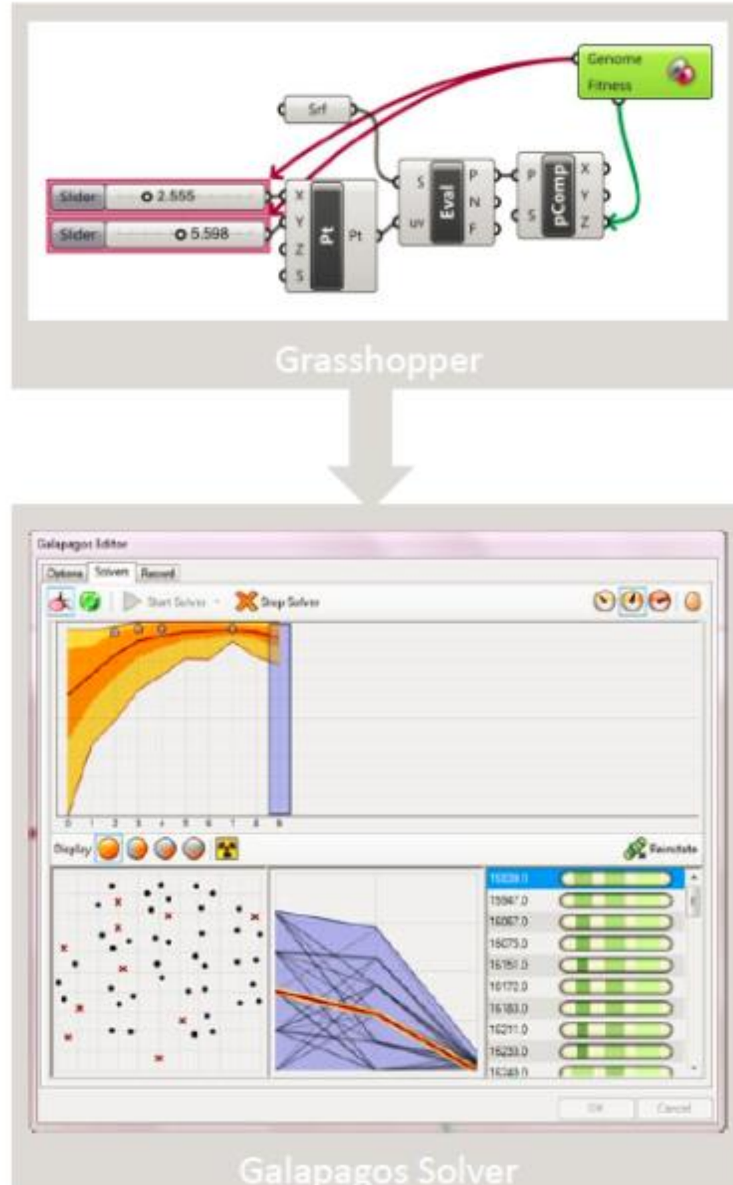


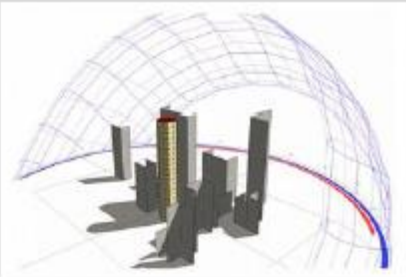
Paper: E J Glassman and C F Reinhart, 2013, "Façade Optimization Using Parametric Design and Future Climate Scenarios," Proceedings of Building Simulation 2013, Chambery, France, August 2013

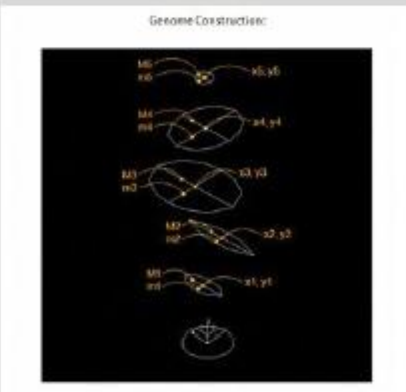


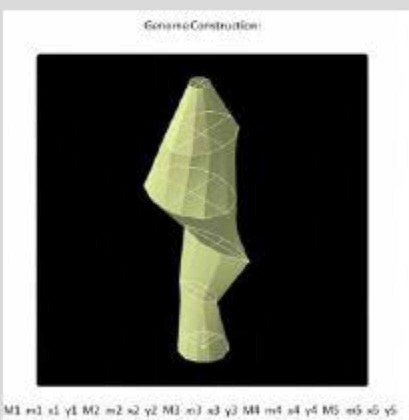


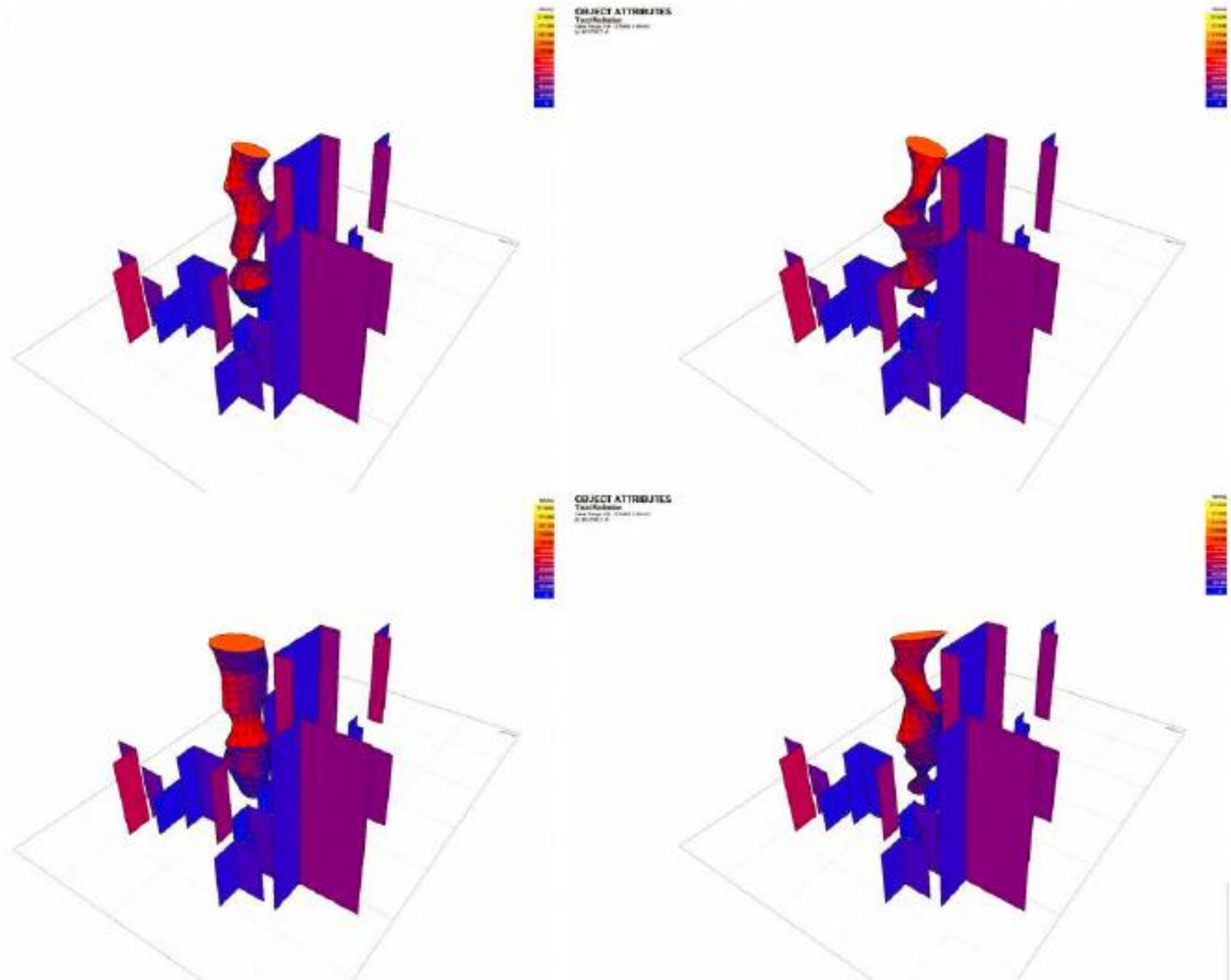
Images from David Rutten







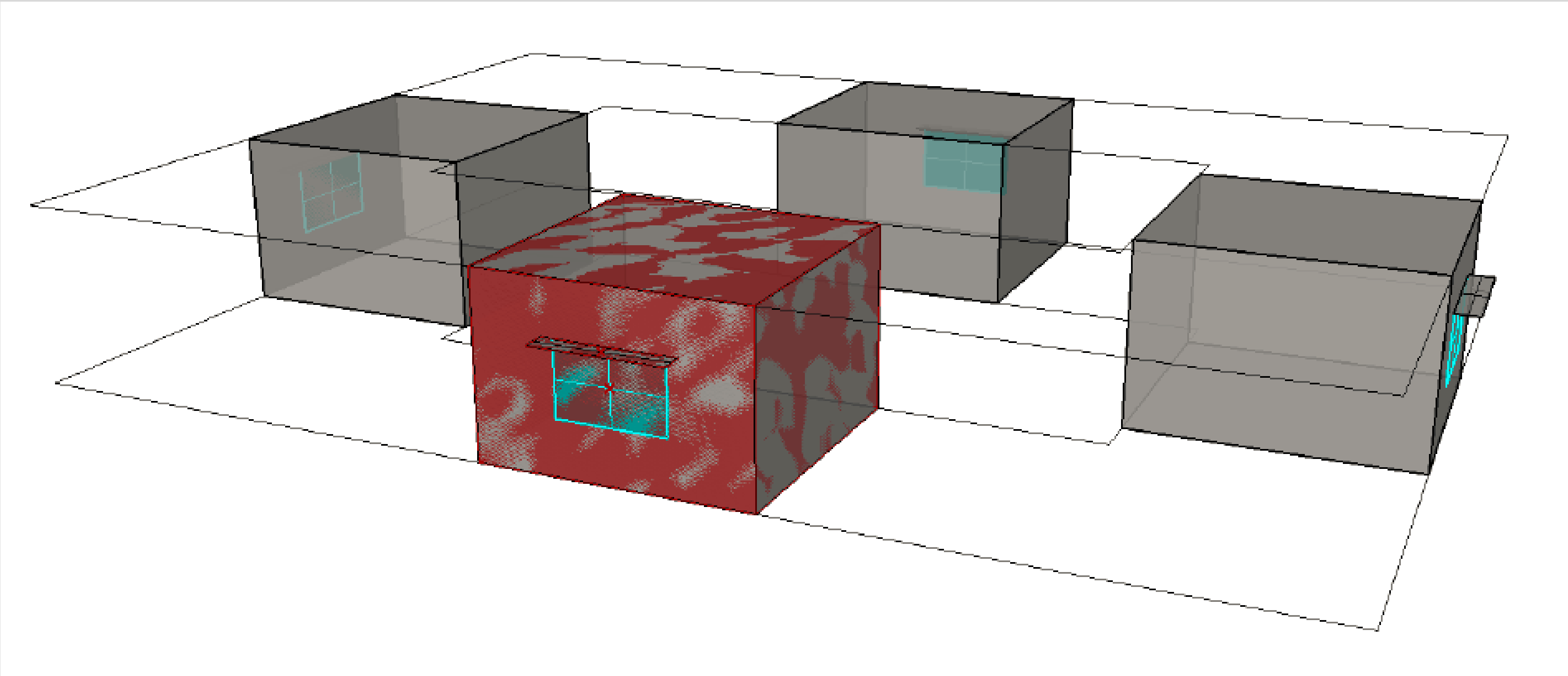




Images from SOM's Black Box Studio

Methodology

- Simulation study
- Combine future weather files with parametric optimization using Galapagos.
- Degrees of freedom are insulation levels, WWR and overhang depth.
- Performance metrics are operational costs and carbon emissions.



Boston, MA
Fairbanks, AK
Phoenix, AZ
Climates

South
West
North
East
Orientation

Current (10 years)
2020 (10 years)
2050 (10 years)
2080 (10 years)
2010 – 2080 (70 Years)
Scenarios

Cost
Carbon
Optimization

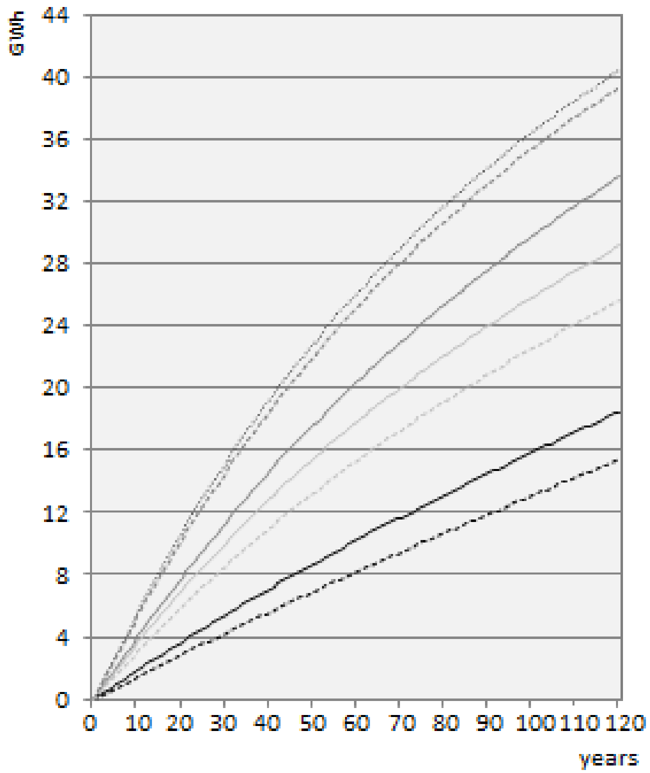
Insulation
WWR
Shading
Variables

Optimized Results for Boston

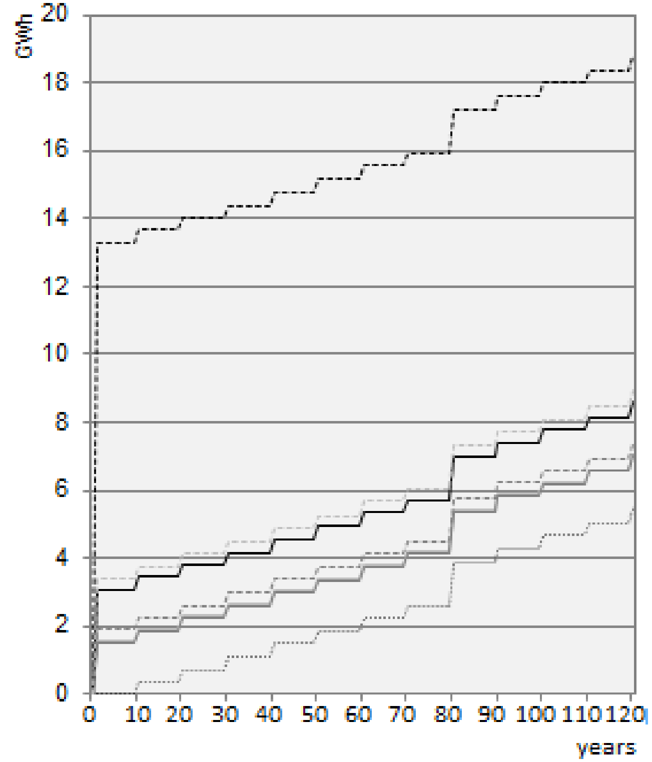
Paper: E Glassman and C F Reinhart, "Facade Optimization Using Parametric Design and Future Climate Scenarios", Building Simulation 2013, Chambery, France, August 2013.

Embodied Energy vs. Operational Energy Use

Operational Energy



Embodied Energy



Paper: C Cerezo Davila and C F Reinhart, 2013, "Urban energy lifecycle: An analytical framework to evaluate the embodied energy use of urban developments," Proceedings of Building Simulation 2013, Chambery, France, August 2013

MIT Sustainable Design Lab

Contact
Christoph Reinhart
Associate Professor
MIT
Email: creinhart@mit.edu

MIT Sustainable Design Lab
Carlos Cerezo
Timur Dogan
Diego Ibarra (GSD)
Alstan Jakubiec
Nathaniel Jones
Aiko Nagano
Krista Palen
Tarek Rakha
Julia Sokol

Solemma
Alstan Jakubiec
Kera Lagios
Jeff Niemasz
Christoph Reinhart
Jon Sargent

Our research goal is to change current sustainable design practice by developing, validating and testing workflows and metrics that lead to improved design solutions as far as occupant comfort and health as well as building energy use are concerned. The premise of this work is that an informed decision is a better decision.

www.mit.edu/SustainableDesignLab

Alumni
Seth Holmes, Karthik Dondeti, Elliot Glassman, Cynthia Kwan, Rohit Manudhane, Rashida Mogri, Azadeh Omidfar, Debashree Pal, Tiffany Otis, Holly W Samuelson, Jennifer Sze, John Sullivan, Nari Yoon

Thank you!

Russell Jones

rjones@
stratusconsulting.com

Chuck Khuen

chuck.khuen@
weatheranalytics.com

Christoph Reinhart

creinhart@
mit.edu


Questions?
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