Incorporating Climate Change into GT-NEMS

MATT COX
PAUL BAER
MARILYN BROWN

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Oak Ridge National Laboratory
Georgia Institute of Technology

A Changing Climate Will Challenge the Energy System

- Climate change could create many difficulties for the American energy system
  - changes in energy demand
  - population shifts
  - resource availability and distribution
  - transmission and distribution efficiency
  - a host of issues related to the energy/water nexus.

A Way to Incorporate Some Climate Impacts into NEMS

- NEMS adjusts space heating and space cooling for weather
  - The equation multiplies "pre-adjustment" energy consumption in year y by the ratio between DD_y and DD_{2003}

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} \cdot \frac{DegreeDays_{s,r,y}}{DegreeDays_{s,r,CBECSyear}}$$

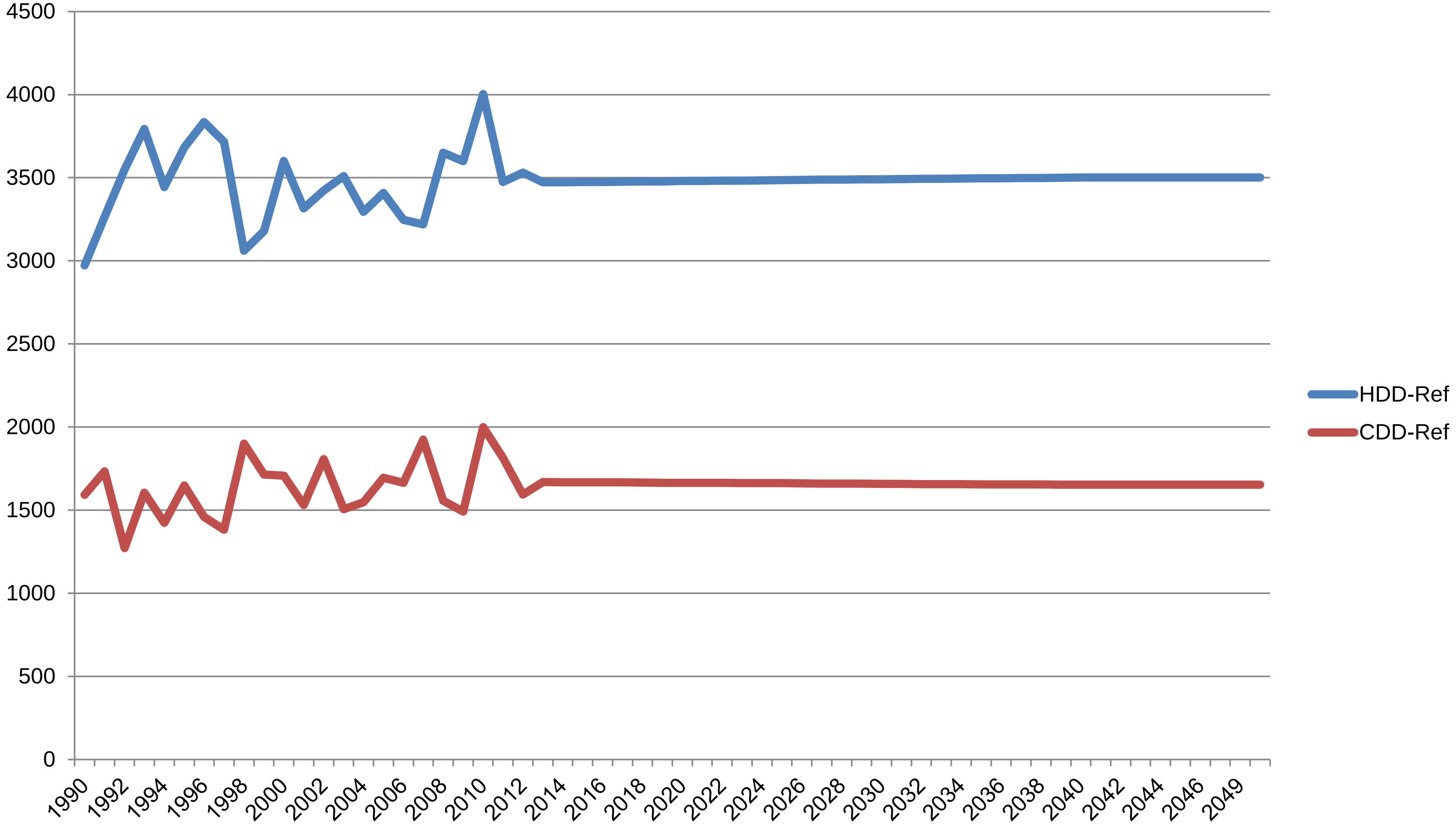
(B - 110)

  - Degree days are the only direct way to model temperature change in the current demand modules
  - NEMS uses DD as inputs only in Commercial and Residential sectors

Existing Projection of DDs in NEMS is only Affected by Population Shifts within Regions

- Current algorithm for determining HDD/CDD
  - Uses NOAA population-weighted estimates of DD for 2003-2012
  - Uses the 2003-2012 DD average to establish the 2014 "benchmark"
- Iterates values based on modeled intraregional population shifts
  - "Effective" HDD/CDD changes with population shifts and immigration
  - Projections generated for each of the nine census divisions

Example: GT-NEMS East South Central Projections



Updating the Temperature Assumptions

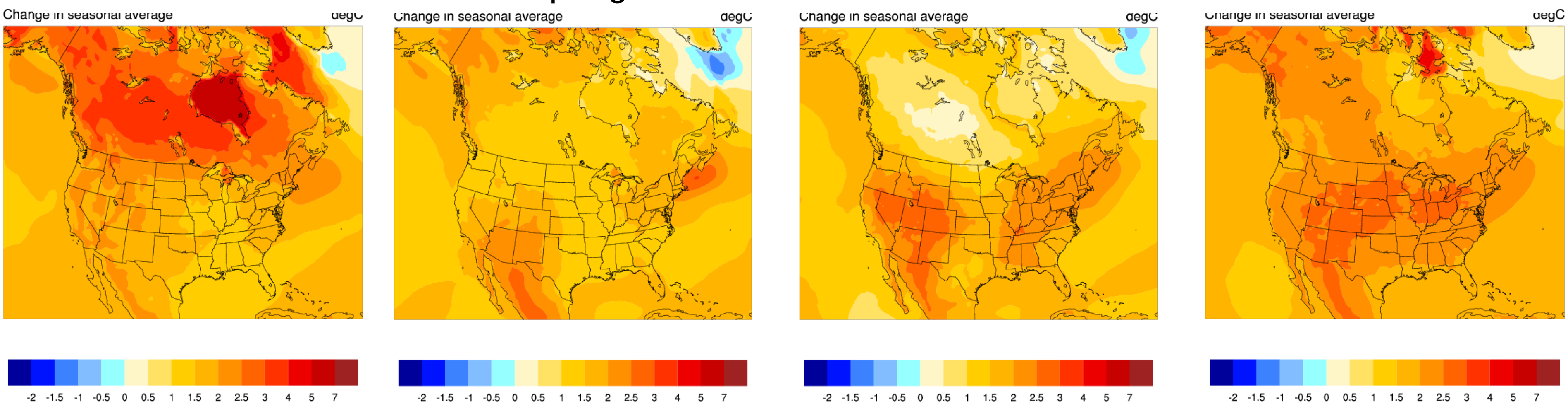
- Regional temperature projections taken from North American Regional Climate Change Assessment Program
  - Modeling community of American and Canadian research teams
- Based on SRES A2 scenario
  - Approximately a BAU scenario
  - 2050 CO_2 concentrations are 575 ppm
- We use the mean 2041-2070 anomaly for our 2050 estimate

http://www.narccap.ucar.edu/index.html

Seasonal Results from WRFG-CGCM3

2041-2070 anomaly from 1971-2000 average

Winter | Spring | Summer | Fall



	New England	Middle Atlantic	ENC	WNC	South Atlantic	ESC	WSC	Mountain	Pacific
Winter Change in T (°C)	2.5	2	1.5	1.5	1.5	1	1.5	1.5	2
Spring Change in T (°C)	1.5	1.5	1	1	1	1	1	2	1
Summer Change in T (°C)	2	2	2	1.5	1.5	2	1.5	2.5	2
Fall Change in T (°C)	2	2	2.5	2.5	2	2	2	2.5	2

Population Shifts

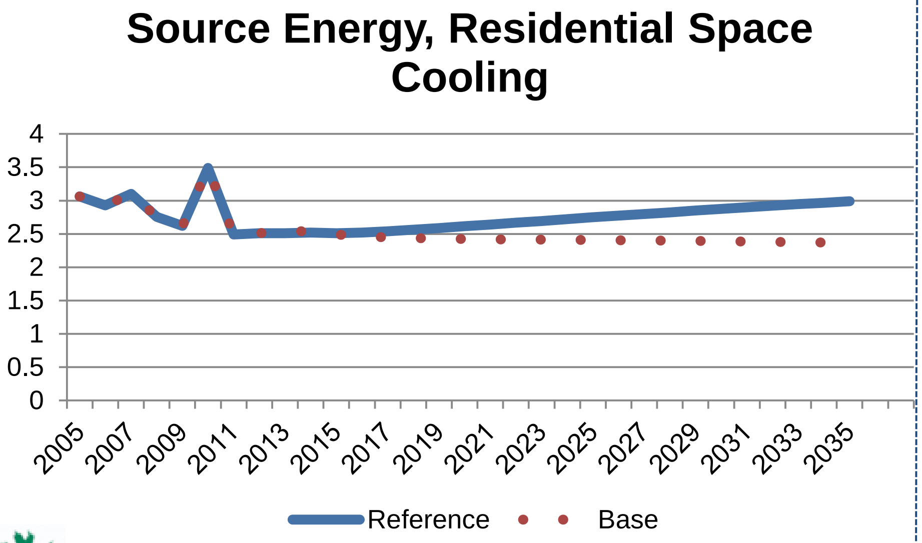
- Large migration movements are not unprecedented
  - 0.3-0.5% annual out-migration from NE states between 2000-2009
  - Up to ~2% annual out-migration from dustbowl states in between 1935-1940
- For illustrative purposes we model outmigration in proportion to average temperature
  - Highest annual out-migration from hottest decile of states at 0.7% (25% over 2014-2050 period relative to baseline)
  - Half of maximum rate from second hottest decile
- In-migration proportional to temp, gross state product (GSP)
  - 30 “coolest” states ranked based on climate suitability and GSP; suitability*GSP= weighted total (WT)
  - WT/(sum of all WT) = % of migrating population received

Interregional Migration 2010-2035 (Estimated)

REGION	BASELINE			MIGRATION CASE		
	Δ 2010 -2035	Est. Migration	Est. Ann. Migration	Δ 2010 - 2035	Est. Migration	Est. Ann. Migration
New England	8%	-10%	-0.4%	24.5%	6%	0.2%
Middle Atlantic	3%	-15%	-0.6%	16.3%	-2%	-0.1%
East North Central	9%	-8%	-0.3%	18.7%	0%	0.0%
West North Central	12%	-6%	-0.2%	14.4%	-4%	-0.2%
South Atlantic	29%	12%	0.5%	18.1%	0%	0.0%
East South Central	16%	-2%	-0.1%	4.9%	-14%	-0.5%
West South Central	19%	1%	0.1%	1.8%	-17%	-0.7%
Mountain	40%	22%	0.9%	34.9%	16%	0.7%
Pacific	19%	1%	0.0%	30.4%	12%	0.5%
United States	18%	0%	0.0%	18.5%	0%	0.0%

Differentiations from GT-NEMS Reference

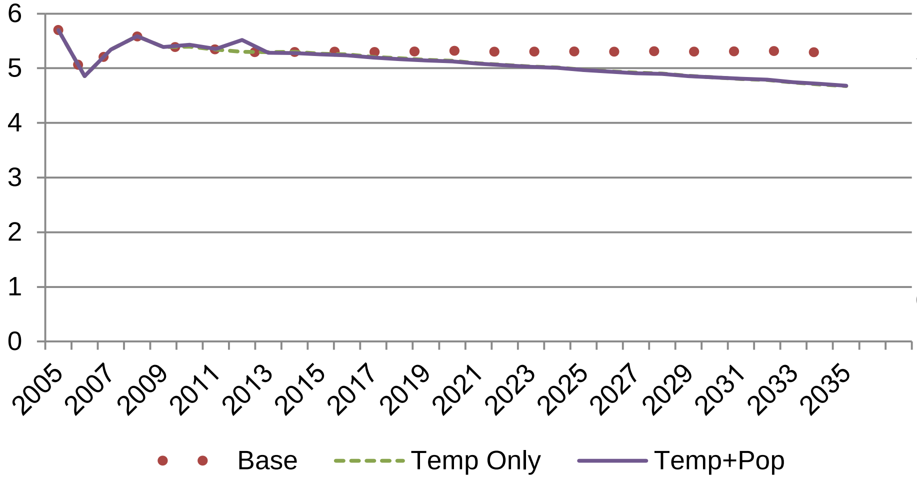
- Due to different DD baselines, our Base is not the same as the AEO 2011 reference case.



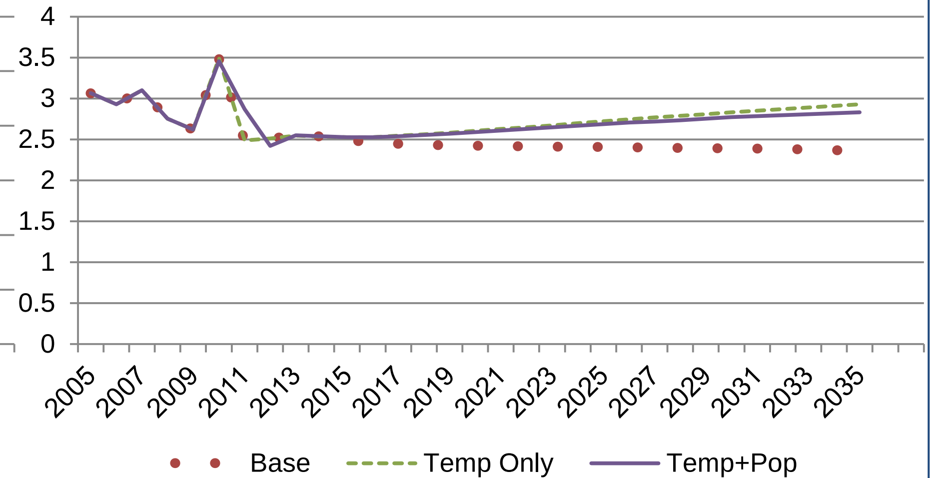
- All further calculations are based on the difference between Base and our other scenarios
- Output from migration scenario only shows the difference in intraregional population distributions
  - Such estimates do not adequately represent anticipated impacts of inter-regional population migrations

Directional Impacts Match Anticipated Results, Impacts are Modest but Significant

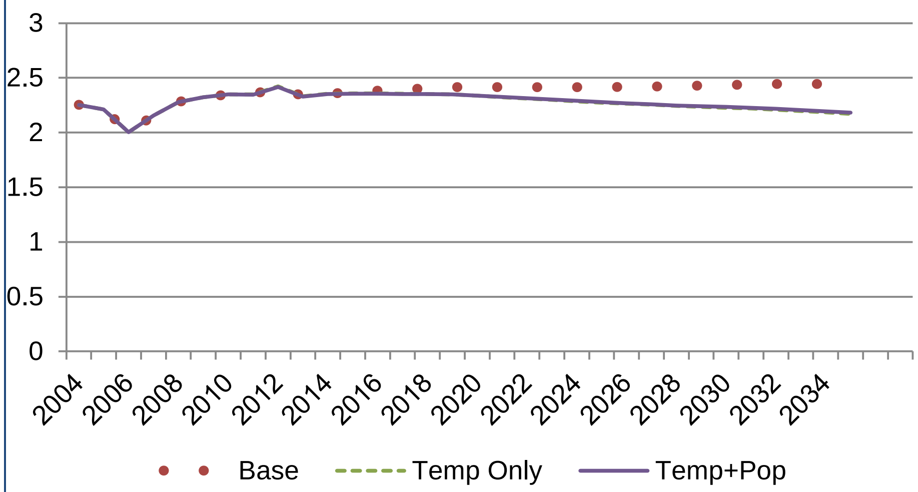
Source Energy, Residential Space Heating



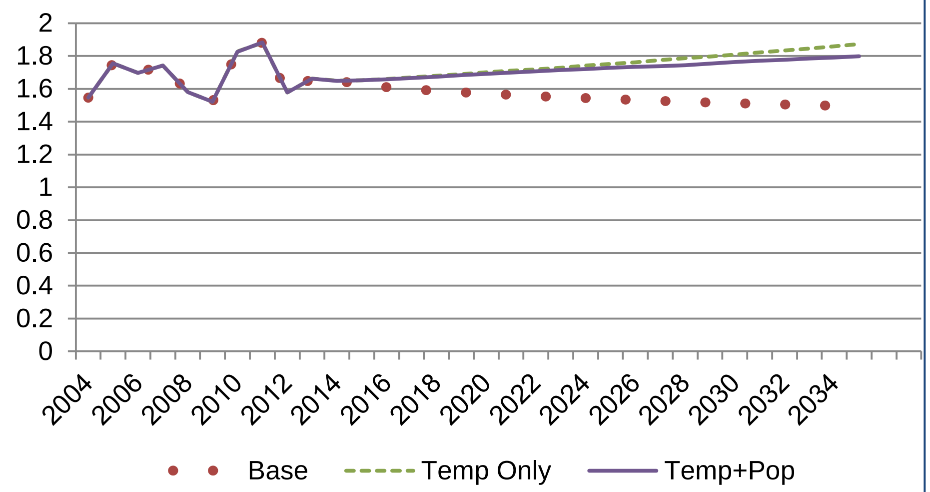
Source Energy, Residential Space Cooling



Source Energy, Commercial Space Heating



Source Energy, Commercial Space Cooling



Space Heating Reductions Offset Space Cooling Increases in 2020 and 2035

2020	Δ Temp Only	Δ Temp+Pop	%Δ 2035
Residential Space Heating Consumption (Quads)	-0.19 (-3.5%)	-0.20 (-3.7%)	→ -12/-11
Residential Space Cooling Consumption (Quads)	0.18 (7.5%)	0.17 (6.8%)	→ 24/20
Residential Expenditure ($-B)	1.40 (0.6%)	0.30 (-0.3%)	
Residential CO_2 ($MMTCO_2$)	-3.00 (-0.3%)	-3.00 (-0.3%)	
Commercial Space Heating Consumption (Quads)	-0.08 (-.3.3%)	-0.08 (-3.3%)	→ -11/-11
Commercial Space Cooling Consumption (Quads)	0.13 (8.3%)	0.12 (7.6%)	→ 26/21
Commercial Expenditure ($-B)	1.10 (0.6%)	0.40 (0.2%)	
Commercial CO_2 ($MMTCO_2$)	0.00 (0.0%)	2.00 (0.2%)	

Energy expenditures and electricity rates rise, consistent with an increase in space cooling demand that requires new capacity to meet the peak-heavy new load, without a commensurate increase in generation (EIA, 2005)

Regional Variation is Substantial

Example: Residential Electricity Use, 2035

	Change from 2010 Quads (percent)	
Division	**Δ Temp Only**	**Δ Temp+Pop**
New England	-0.029 (-4.7%)	-0.029 (-4.8%)
Mid Atlantic	0.013 (0.8%)	-0.062 (-3.7%)
East North Central	-0.049 (-2.2%)	-0.125 (-5.5%)
West North Central	-0.014 (-1.4%)	-0.04 (-4.3%)
South Atlantic	0.074 (3.8%)	0.024 (1.2%)
East South Central	-0.029 (-4.0%)	-0.043 (-6.1%)
West South Central	-0.099 (-8.2%)	-0.091 (-7.6%)
Mountain	0.016 (1.3%)	-0.054 (-4.3%)
Pacific	-0.029 (-4.7%)	-0.029 (-4.8%)
United States	-0.37 (-3.2%)	-0.39 (-3.4%)

Other Issues with Degree days, indoor temperatures, and energy consumption

Challenges to the assumed linear relationship between DDs and energy consumption:

- When outdoor temperatures are extreme, HVAC equipment operates less efficiently and the energy consumption required to achieve indoor comfort increases.

- OAT Bin

Percent of Rated Capacity	55	60	65	70	75	80	85	90	95	100	Grand Total
90%					0.0%						0.0%
80%				0.1%	0.2%	0.1%	0.3%	0.2%	0.0%		0.9%
70%		0.0%	0.1%	0.2%	0.1%	0.6%	1.1%	0.7%	0.4%	0.7%	3.9%
60%			0.2%	0.4%	0.3%	0.8%	1.6%	0.6%	0.2%	1.0%	5.3%
50%	0.0%	0.1%	0.2%	0.3%	0.7%	1.6%	2.5%	1.3%	0.4%	0.9%	8.1%
40%		0.6%	4.4%	6.6%	7.3%	6.4%	4.6%	2.1%	0.8%	0.4%	33.2%
30%		0.1%	1.4%	3.8%	8.4%	19.0%	12.5%	2.7%	0.7%	0.0%	48.6%

EER Weighted
10.50 28.00

Percent of Total Runtimebroken down by Average OAT (°F) vs. Percent of Rated Capacity. Color shows average of EER (Btu/Wh). The marks are labeled by Percent of Total Runtime.

Source:
Roderick Jackson, ORNL
(OAT = outdoor air temp.
Red = lower efficiencies
Blue = higher efficiencies)

Other Issues with Degree days, indoor temperatures, and energy consumption

Additional challenges to the assumed linear relationship between DDs and energy consumption:

- Price elasticity of demand and rebound effects from efficiency-invested customers
- Thresholds (e.g., heat storms) might lead people to cool who rarely did before; AC is often off even when standards/models assume otherwise

Regional variations in HDD/CDD set points

Inter-regional population migration effects

Alternative temperature projections

Other Issues with Degree days, indoor temperatures, and energy consumption

Climate also influences end-uses other than space conditioning (see *Climate Change and Energy Supply and Use*, 2012):

- Global warming would likely decrease residential, commercial, and industrial water heating energy consumption
- Global warming would likely increase energy consumption from residential, commercial, and industrial refrigeration energy and from industrial process cooling
    - These could be added to GT-NEMS

Food for Thought

- What besides HDD/CDD are likely to be the most important impacts to model?
- How would we approach modeling these other impacts?
- How would you rank these impacts in terms of priority for modeling?
- How would you deal with non-linearity, both behavioral and technological, related to energy demand and energy performance?

Contact Information

The research team welcomes further comments and suggestions.

Please contact
Matt Cox
matt.cox@gatech.edu
Paul Baer
Paul.baer@gatech.edu
Marilyn Brown
Marilyn.brown@pubp.gatech.edu