Climate Impact on Building Energy Use from Global (regional) to US (state)

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Outline

- Building Energy Model in GCAM
- Global (Regional Level) Building Energy Use
- US (State Level) Building Energy Use
  - Spatial and Temporal Patterns
  - Energy and Fuel Use
  - Uncertainty
  - Scale Impact
- Summary
BUILDINGS MODEL IN GCAM
Nested, service-based building energy models in the long-term global integrated assessment framework, GCAM.
Service Demands Modeling

Demand for Space Heating Service [GJ-output/m²]:

\[ Q_{H,t} = k_H \cdot (HDD_t \cdot ShellEff_t \cdot SurfaceRatio_t - \lambda_H InternalGain_t) \cdot \left[ 1 - \exp \left( -\frac{\ln 2}{\alpha_H} \cdot \left( \frac{Y_t}{P_{H,t}} \right) \right) \right] \]

Climate Change Effect

Climate Change Effect

Demand for Space Cooling Service [GJ-output/m²]:

\[ Q_{C,t} = k_C \cdot (CDD_t \cdot ShellEff_t \cdot SurfaceRatio_t + \lambda_C InternalGain_t) \cdot \left[ 1 - \exp \left( -\frac{\ln 2}{\alpha_C} \cdot \left( \frac{Y_t}{P_{C,t}} \right) \right) \right] \]

Demand for Other Services (water heating & cooking, lighting, other appliances):

\[ Q_t = k_i \cdot q_i \left[ 1 - \exp \left( -\frac{\ln 2}{\alpha_i} \cdot \left( \frac{Y_t}{P_i} \right) \right) \right] \]
Degree-days are essentially the summation of temperature differences from a human comfort level over time.

Heating degree day (HDD) and cooling degree day (CDD) are measured in “degree-days” below (HDD) or above (CDD) the set point (typically 18°C).

HDD and CDD need to be “population-weighted” (or otherwise-weighted) to reflect regional aggregated heating and cooling requirement with a changing population distribution.
HDD/CDDs (CCSM A2)

Globally averaged surface temperature change (relative to 1870-1899 baseline)

Temperature

Population

Regionalization Map

Krakatau
Santa Maria
Agung
El Chichon
Pinatubo

Gary Strand, NCAR/DOE
GLOBAL BUILDING ENERGY USE
Building Energy Use Under Climate Change

- Population
- Temperature
- HDD change
- CDD change

Ratio (Climate / no Climate)
- < 0.89
- 0.89 - 0.9
- 0.91 - 0.94
- 0.95 - 0.99
- 1 - 1.05
- 1.06 - 1.1
- > 1.1

Legend:
- HDD change:
  - < -0.05
  - [0.05, 0.005]
  - [0.005, 0.01]
  - [0.01, 0.0005]
  - [0.0005, 0.001]
  - [0.0005, 0.0005]
  - [0.0005, 0.0005]
  - [0.0005, 0.0005]
  - 0

- CDD change:
  - < -0.05
  - [0.05, 0.005]
  - [0.005, 0.01]
  - [0.01, 0.0005]
  - [0.0005, 0.001]
  - [0.0005, 0.0005]
  - [0.0005, 0.0005]
  - [0.0005, 0.0005]
  - 0
HDD/CDD Change: 2040-2005 (Population-Weighted)

Total ΔHDD: -387

Total ΔCDD: 204
US STATE BUILDING ENERGY USE
Climate Impacts (Spatial Patterns)

- Total energy use
- Energy use in sectors
- Spatial difference

Fixed Climate

A2 Climate
Climate Impacts (Temporal Patterns)

http://terpconnect.umd.edu/~yuyuzhou/GTSP/EnergyUse.html
Energy use with climate change relative to w/o climate change

Total Energy Use

(-10%, +10%)
Climate Impacts on Building Fuel Use - 21st Century

Fuel use with climate change relative to w/o climate change

**Electricity**

**Gas & Oil**

(-10%, +20% )

(-20%, -5% )
UNCERTAINTY ANALYSIS
## Sensitivity of Building Energy Use - Assumptions

Assumptions in the base case, fixed climate, and four sensitivity scenarios

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Sensitivity of Building Energy Use
SCALE IMPACT

(COMPARISON OF US MODEL WITH 50-STATE MODEL)
Scale Impact (Harmonization)

Pop

GDP

Floor Space
Scale Impact (Difference)

Percentage difference of US and 50-state model

(US – 50)/50

Energy Use

Fuel Use
Conclusions

- Climate change has a significant impact on building energy and fuel use, exhibiting a large spatial heterogeneity at the state level
  - -10% to +10% for total energy use
  - -10% to +20% for electricity use
  - -20% to -5% for oil and gas use

- Uncertainties about underlying drivers must weigh heavily on future infrastructure planning decisions as well as potential climate change

- The 50-state building model can provide detailed spatial representation and better insight for building energy use and climate change impact at the state level.

- The US regional model can achieve good national-level estimates if the key parameters are considered reasonably
Acknowledgement

➤ DOE, Office of Science
➤ DOE, PI
➤ PRIMA
➤ EPA
US Population in 2005

Change of Temperature
- >5
- (4,5]
- (3,4]
- (2,3]
- (1,2]
- (0,1]
- (-1,0]
- (-2,-1]
- (-3,-2]
- (-4,-3]
- (-5,-4]
- <=-5

Monthly Temperature in 2005

Population

2040-2005
Regional Impacts

Effect of Climate Change (Gt/person)

-6
-3
0
3

-6
-3
0
3

2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095
East North Cen East South Cen Middle Atlantic Mountain New England Pacific South Atlantic West North Cen West South Cen

Effect of Climate Change (Gt/person)

-6
-3
0
3

-6
-3
0
3

2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095 2050 2095
East North Cen East South Cen Middle Atlantic Mountain New England Pacific South Atlantic West North Cen West South Cen
Sensitivity of Building Fuel Use (1)

Sensitivity of Electricity Use

![Graph showing sensitivity of electricity use across different regions. The graph includes bars for Climate, Policy, Population, GDP, and Climate Model, showing variations in sensitivity for each region.](image-url)
Sensitivity of Building Fuel Use (2)

Sensitivity of Gas & Oil Use

- Climate
- Policy
- Population
- GDP
- Climate Model

Sensitivity of Gas and Oil Use [Percentage]

-40%  -20%  0%  20%  40%

- East North Cen
- East South Cen
- Middle Atlantic
- Mountain
- New England
- Pacific
- South Atlantic
- West North Cen
- West South Cen