Technology in the Buildings Sector—Marrying Top-Down and Bottom-Up Approaches

GTSP Technical Review Meeting
May 2005

Jae Edmonds & Leon Clarke
24 May 2005
Joint Global Change Research Institute
College Park, MD
Acknowledgements

- U.S. DOE Office of Energy Efficiency and Renewable Energy
- Sponsors of the GTSP
- Colleagues
This talk presents results from our work on implementing energy efficiency in MiniCAM.

Motivation

Building Energy Efficiency & Energy Use

Representation of building energy services

**Goal:** Develop the capability within our integrated, global model to address the potential value of renewable and energy efficiency technologies.
Motivation

The potential value of energy efficiency, for example, is large.

Increased efficiency lowers substantially the cost of achieving a specific climate stabilization target.

And if we do not achieve our baseline gains in efficiency costs increase.

We need to understand how much specific technologies can contribute to efficiency improvement.

Same for renewables.
MiniCAM

From the Top Down
MiniCAM COMPONENTS

**ATMOSPHERIC COMPOSITION**
- MAGICC Atmospheric Chemistry
- MAGICC Ocean Carbon Cycle

**CLIMATE & SEA LEVEL**
- MAGICC Climate
- MAGICC--Ocean
  - temperature
  - sea level

**HUMAN ACTIVITIES**
- ERB Energy System
- ERB Other Human Systems
- ALU Ag., L'stock & Forestry
- (none) Coastal System

**ECOSYSTEMS**
- MAGICC Terrestrial Carbon Cyc.
- Un-managed Eco-system & Animals
- ALU Crops & Forestry
- ALU Hydrology
MiniCAM Regions

1. US
2. Canada
3. W. Europe
4. Australia & New Zealand
5. Japan
6. Eastern Europe
7. Former Soviet Union
8. China
9. Mid-East
10. Africa
11. Latin America
12. Korea
13. Southeast Asia
14. India
Agriculture, Land-use and Energy in MiniCAM

Energy Module

Regional GDP

Regional demographics

Demand
- Crops
- Livestock and fish
- Forest products
- Urban land

Demand for Biomass Energy

Supply
- Crops
- Livestock and fish
- Forest products
- Urban land

Technology

Water

Fertilizer

CO₂

Climate

Commercial Biomass

Production
- Crops
- Livestock and fish
- Forest products
- Biomass energy

Markets
- Land rent
- Crop prices
- Livestock prices
- Forest product prices
- Biomass prices

Land Use
- Crops
- Livestock and fish
- Forest products
- Urban
- Unmanaged

Land Use Change Emissions

Policies
- Taxes
- Subsidies
- Parks
- Regulation
MiniCAM Energy Markets

Liquids Market
Solids Market
Natural Gas Market
Hydrogen Market
Electricity Market

Residential Sector
Commercial Sector
Industrial Sector
Transport Sector

Residential Technologies
Commercial Technologies
Industrial Technologies
Transport Technologies
MiniCAM

Buildings Sector
**ObjECTS 1.0 Structure**

Data Determines:
- Sectors
- Linkages
- Markets

**1990 Energy System Structure**

Implemented for 14 World Regions
Buildings: Building energy use is central to future energy demand and energy efficiency.

Key Question: What is the magnitude & structure of future building energy demand? (fuels, load-cycle, etc.)

Key Question: What is the potential contribution of energy efficiency in buildings?

The contribution of this sector in both reference and policy cases is of interest.
Building Modeling Status

1. Data review for trend development
   - Complete
2. Model conceptual structure
   - Complete
3. Initial Data development
   - Complete
4. Coding
   - Complete
5. Testing & Troubleshooting
   - Complete
6. Ongoing efforts to refine technology and other data and assumptions
   - Ongoing
Overview of General Structure of Building Sector in ObjECTS

Regions are characterized by variables such as heating degree days, cooling degree days, population, and GDP.

Multiple building sectors, each representing a particular type of building (e.g., type of use, shell efficiency, daylighting characteristics). The floor space demanded for each sector is based on regional characteristics such as population and GDP and the costs of building types.

Each building sector has service demands such as heating, cooling, lighting, and hot water. Demands are based on building characteristics (e.g., shell thermal efficiency), regional characteristics (e.g., heating degree days), and service prices.

Each service demand can be met by a range of service technologies. The model allocates between these technologies using a price-based logit function to capture heterogeneity in applications. Service technologies are characterized by non-fuel costs and efficiencies.
Approach to U.S. Version 1.0

A single U.S. region.

U.S. Region

Two buildings sectors: Residential and Commercial

Residential Buildings
- Heating
- Lighting*
- Appliances & Other*
- Cooling
- Hot Water

Commercial Buildings
- Heating
- Lighting
- Office Equip*
- Other*
- Non-Comm Other*
- Cooling

Five residential service demands

Six commercial service demands

* Several services suffer from substantial data limitations.
Residential Service Demands

Indexing to floor space

Residential Buildings

- Heating
  \[ D_H = \alpha_H u (\sigma F) H_{DD} \left( \frac{P_H}{P_{H,0}} \right)^{-\beta_H} - I \]

- Cooling
  \[ D_C = \alpha_C u (\sigma F) C_{DD} \left( \frac{P_C}{P_{C,0}} \right)^{-\beta_C} + I \phi_C \]

- Lighting
  \[ D_L = \alpha_L F \left( \frac{P_L}{P_{L,0}} \right)^{-\beta_L} \text{ - daylighting} \]

- Hot Water
  \[ D_W = \alpha_W F \left( \frac{P_W}{P_{W,0}} \right)^{-\beta_W} \phi_W \]

- Appliances & Other
  \[ D_A = \alpha_A F \left( \frac{P_A}{P_{A,0}} \right)^{-\beta_A} \phi_A \]

- Price of Heating Service
- Internal Gains
- Internal Gains

Thermal Energy
Lumens
Thermal Energy
Unitless

Building Design
Saturation Factor

Calibration Parameter
Heat Transfer Coefficient
Building Shell Area
Heating Degree Days

Residential Buildings

- Heating
- Cooling
- Lighting
- Hot Water
- Appliances & Other
**Characterizing Technologies**

Technologies are characterized by (1) efficiencies and (2) non-energy costs in the model.

More detailed data is used to develop the estimate of non-energy costs.

Looking out over a century-long time scale, it is critical to consider highly advanced technologies.

<table>
<thead>
<tr>
<th>Year</th>
<th>Incandescent</th>
<th>Fluorescent</th>
<th>Solid-state</th>
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<tr>
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<tr>
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<td>Efficiency (lumens/watt)</td>
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<td>120</td>
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The Role of Technology

Increasing Floor Space Drives Service Demands

There is a strong historical record of increasing per-capita floor space.

Simply following trends, residential per capita floor space could reach 1600 ft² in 2100!

Advances in technology provide a lever to mitigate associated energy demands

Approximately 750 ft² per capita residential in 2000

Approximately 270 ft² per capita commercial in 2000
Scenarios confirm a shift toward electrification

- Increases in electric demands in appliances and information technologies
- Shifts to more efficient electric technologies (e.g., heat pumps)
- Rising natural gas prices in some scenarios

1990 and 2005 represent historical data
Service Demands/Energy Demands

- **Floor Space per Capita**
- **Shell Characteristics (Heating & Cooling)**
- **Service Penetration/Growth** (Appliances, Office Equipment)
- **Internal Gains (Heating & Cooling)**
- **Advances in Service technologies**
- **Shifts in Technology Choice (across Fuels & Technologies)**

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**Per-Capita Residential Heating**
- Years: 1990 to 2095
- Graph shows fuel consumption and service demand over time.

**Per-Capita Residential Lighting**
- Years: 1990 to 2095
- Data normalized to 1 in 1990.

**Per-Capita Residential Cooling**
- Years: 1990 to 2095
- Graph shows fuel consumption and service demand over time.
Relative Contributions to Total Energy Demand

- Major service demand growth for appliances and other services
- Decreases in per-capita heating through a range of forces.
- Relatively flat per-capita energy demand in lighting, water heating, and cooling.

Residential Per-Capita Energy Consumption

- Cooling
- Lighting
- Heating
- Water heating
- Appliance and others
Understanding the Benefits of Today’s R&D

Illustrative Results of Scenario of Commercial Lighting Sector Development

Commercial Sector Lighting Shares

Benefits Accruing from Advanced Technology

Research and Development

Year

Technology Share

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

1990 2005 2020 2035 2050 2065 2080 2095

Cost ($ Billions)

Total Policy Cost

-0.25% EEffic Base_Stab +0.25% EEffic Cost ($ Bil)
The ability to analyze the building sector in the context of energy services and the technologies that provide energy services enables insights unavailable at an aggregated level.

This detail, coupled with the ability to do long-term analysis, provides the capability to understand the benefits of R&D investments in new building technologies.

Demonstration of capability in Version 1.0
- Internal gains, even in the residential sector, are increasingly important.
- As expected, the buildings sector experiences increasing electrification.
A range of extensions might be explored to increase the detail of the model or to capture important technological options.

**Extension to other world regions**

**Low or Zero Energy Buildings** represents a combination of building shell technologies, service technologies, and on-site generation.

- In the model, shell characteristics and service technologies could be bundled to represent zero-energy buildings
- PNNL is currently exploring rooftop solar as part of our solar modeling expansion
- Methodologies will be explored on how to integrate with a zero-energy building.
Other Extensions/Expansions to Version 1.0

- Combined heat and power
- Hydrogen applications
- Daylighting – Utilizing the capabilities in the model
- Combined heating and cooling technologies (e.g., heat pump)
- Further disaggregations (e.g., by building type, regional, technological)
  - Must balance data needs and ability to develop coherent century-scale assumptions.