

# Metrics and Tools for Sustainable Buildings



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# What is NIST?

NIST, founded in 1901 as the National Bureau of Standards (NBS), is part of the Department of Commerce

**Mission:** To promote **U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology** in ways that enhance economic security and improve our quality of life.

## NIST's Labs:

Center for Nanoscale Science and Technology (CNST)

Communications Technology Laboratory (CTL)

**Engineering Laboratory (EL)**

Information Technology Laboratory (ITL)

Material Measurement Laboratory (MML)

NIST Center for Neutron Research (NCNR)

Physical Measurement Laboratory (PML)



# EL's Core Areas of Expertise



Fire protection,  
fire physics,  
materials  
flammability



Structural  
analysis, disaster  
and failure studies



Building and  
renewable energy,  
indoor environment,  
and building systems  
performance  
measurement



Intelligent  
sensing, control,  
robotics and  
automation



Sustainability,  
durability, and  
service life  
prediction of  
engineered  
materials



Systems integration,  
information modeling,  
model-based  
engineering



# Applied Economics Office

The Applied Economic Office (AEO) conducts research and provides technical assistance and economic products to decision makers in the public and private sectors:

## Staff Backgrounds:

- Economics
- Engineering
- Software development
- Law & Policy

## Core Competencies:

- Econometrics
- Statistics & mathematical modeling
- Simulation methods
- Spatial analysis (GIS)

## Research Areas:

- Sustainability
- Energy conservation
- Community resilience
- Construction
- Manufacturing
- Fire
- Safety

## Staffing

9 Economists  
2 Engineers  
1 IT Specialist



# Products & Outputs

- **Draft Standards** – guides, practices, and terminology that provide a comprehensive approach for measuring and managing the economic performance of buildings and infrastructure
- **Technical Publications** – original research focused on the economic measurement of engineered systems
- **Decision Support Tools** – software, data and metrics, and guidance documents to facilitate cost-effective decision-making regarding the use and application of engineered systems



# Strategic Goals

- ① Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure
- ② Smart Manufacturing, Construction, and Cyber-Physical Systems
- ③ Disaster-Resilient Buildings, Infrastructure, and Communities





# Metrics and Tools for Sustainable Buildings Project

## Objectives

- Develop and implement science-based metrics for measuring sustainability performance in buildings
  - Economics - *Life-Cycle Costing (LCC)*
  - Environment - *Life-Cycle Assessment (LCA)*
  - Other – Occupant-related metrics (e.g. IEQ)
- Educate and assist stakeholders in decision-making
  - Standards/Codes/Certification Organizations , Government Agencies, Industry and Trade Groups, Private Sector Entities, Academics, Educators, and General Public
  - *Publications and Software Tools (3)*



# Measuring Sustainability Performance of Building Products

## Building for Environmental and Economic Sustainability (BEES)

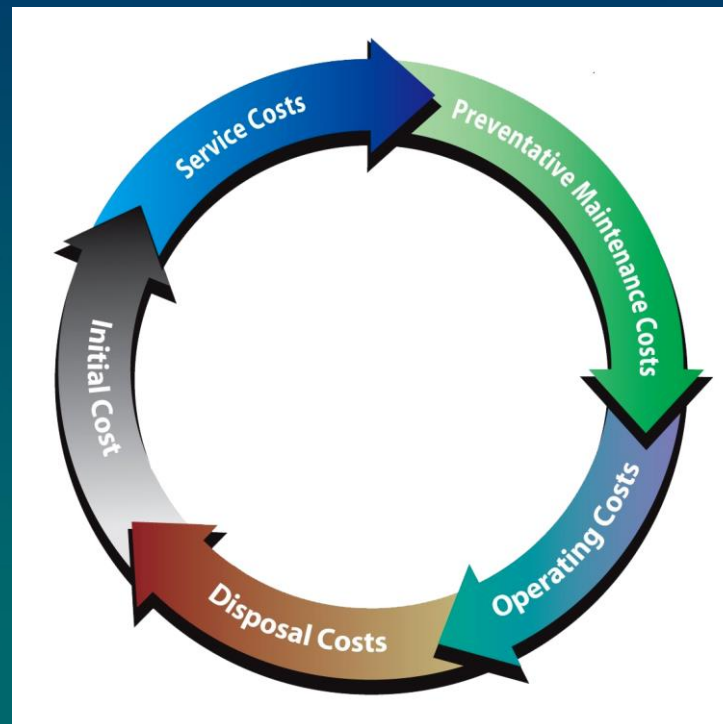
- Scientifically estimates sustainability performance of 250 individual building products
- Product Life-Cycle Costs
- Cradle-to-Grave LCA
  - TRACI
- Assist Designers and Acquisitions





# Life-Cycle Costing

- LCC is an important economic analysis approach used in the selection of alternatives that impact both pending and future costs.
- Based on **ASTM Standards of Building Economics**



Source: <http://bgwservices.com/bgw-supply/>



# Life-Cycle Assessment

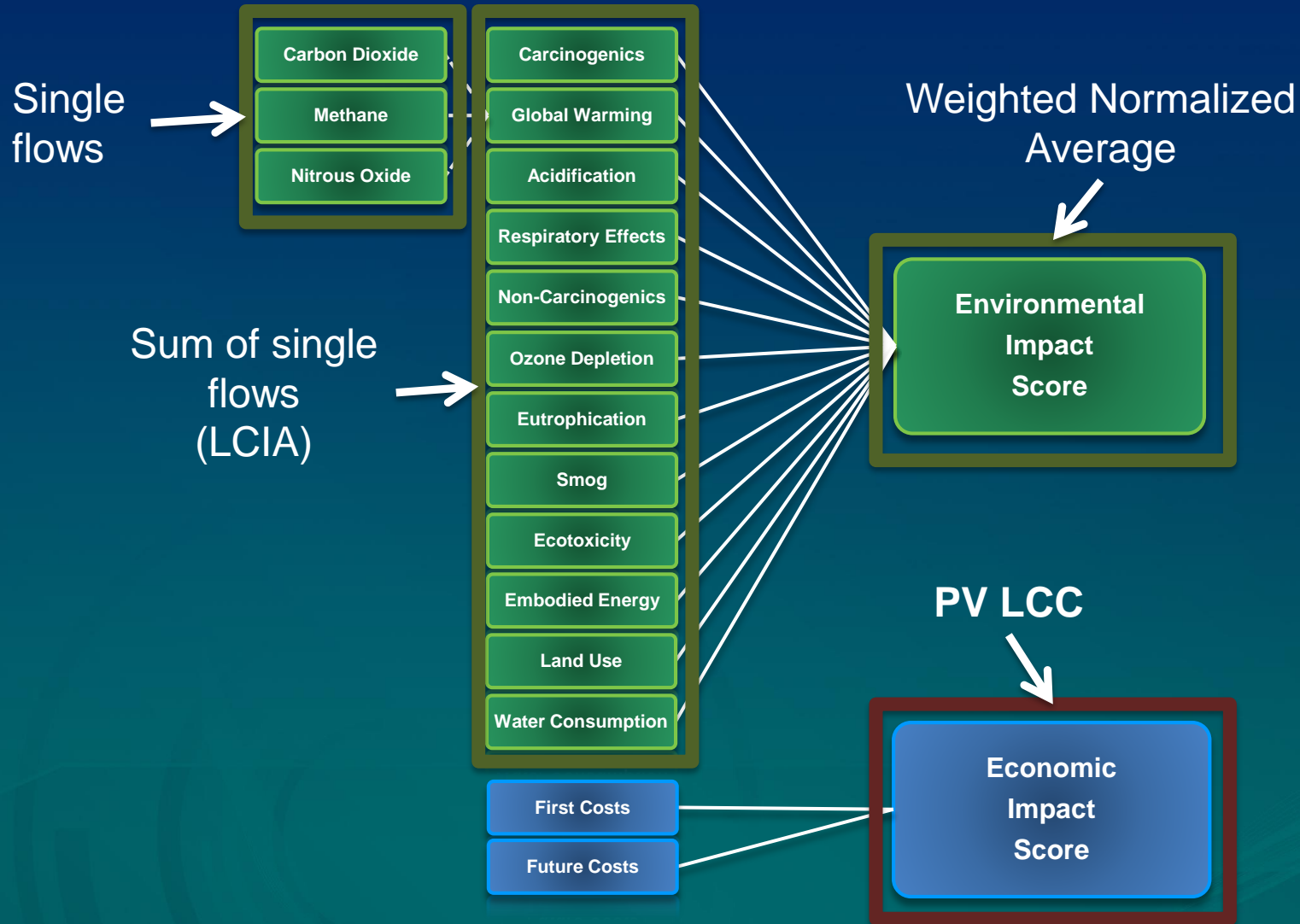
- LCA is a tool used to quantify environmental impact throughout the life-cycle of a product.
- Based on **ISO 14040** series of standards for LCA.



Source: [our-envi.blogspot.com](http://our-envi.blogspot.com)



# BEES Online Sustainability Metrics





# BEES Online (2011)



## Allows comparison of similar building products



Life Cycle Analysis for Building Products

### Building for Environmental and Economic Sustainability

BEES Online implements a powerful technique for selecting cost-effective, environmentally-preferable building products. Developed by the NIST (National Institute of Standards and Technology) Engineering Laboratory's [Applied Economics Office](#), the tool is based on consensus standards and designed to be practical, flexible, and transparent. The BEES Online web application, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 230 building products.

BEES Online measures the environmental performance of building products by using the life-cycle assessment approach specified in the ISO 14040 series of standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES Online analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMAT II.

Analyze Building Products

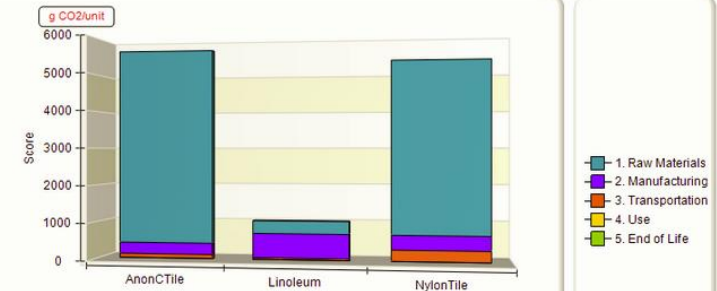


View Tutorial

- Summary Graphs
- ☒ Life-Cycle Stage Graphs
- Environmental Flow Graphs
- Embodied Energy Graphs

Global Warming

### Global Warming



Note: Lower values are better

Category	AnonCTile	Linoleum	NylonTile
1. Raw Materials	5234.7272	343.8419	4632.4248
2. Manufacturing	306.2365	653.8358	391.8796
3. Transportation	107.7307	44.2780	300.3960
4. Use	0.0000	0.0000	0.0000
5. End of Life	0.0000	0.0000	0.0000
Sum	5648.6944	1041.9557	5324.7004

<http://ws680.nist.gov/Bees/>



# BEES Online 2.0 Beta (FY 2018)



1. Updated Web Interface
  - Started with Flooring Category
2. Ability to filter based on Product Type, Characteristics, and Certifications
3. LCIA Methodology Options
  - BEES, TRACI 2, and PCR categories
4. Includes the Social Cost of Carbon (SCC)
5. Weighting option removed



# Bottom-Up LCA Data

BEES uses a “Bottom-up, Process-Based” LCA Approach

- (1) Start with an individual product
- (2) Determine their inputs
- (3) Estimate the environmental flows associated with those inputs
- (4) Sum all input flows for the product
- (5) Repeat for all products in the building
- (6) Sum flows for all products in the building

Not feasible due to required time, effort, and funding



# Top-Down LCA Data

## Input-Output (I-O) Tables

- 1) Start with Economic Supply Chain I-O Tables
- 2) Associate Environmental Flows for each industry
  - By NAICS code
- 3) Flow/\$ by Building Type (e.g. Single Family, Office)
  - Average Emissions
  - “Fuzzy Number”



# “Picture” Reflections on Energy Flows Optimal Picture of LEA Flows





# Hybrid LCA Required for Whole Buildings

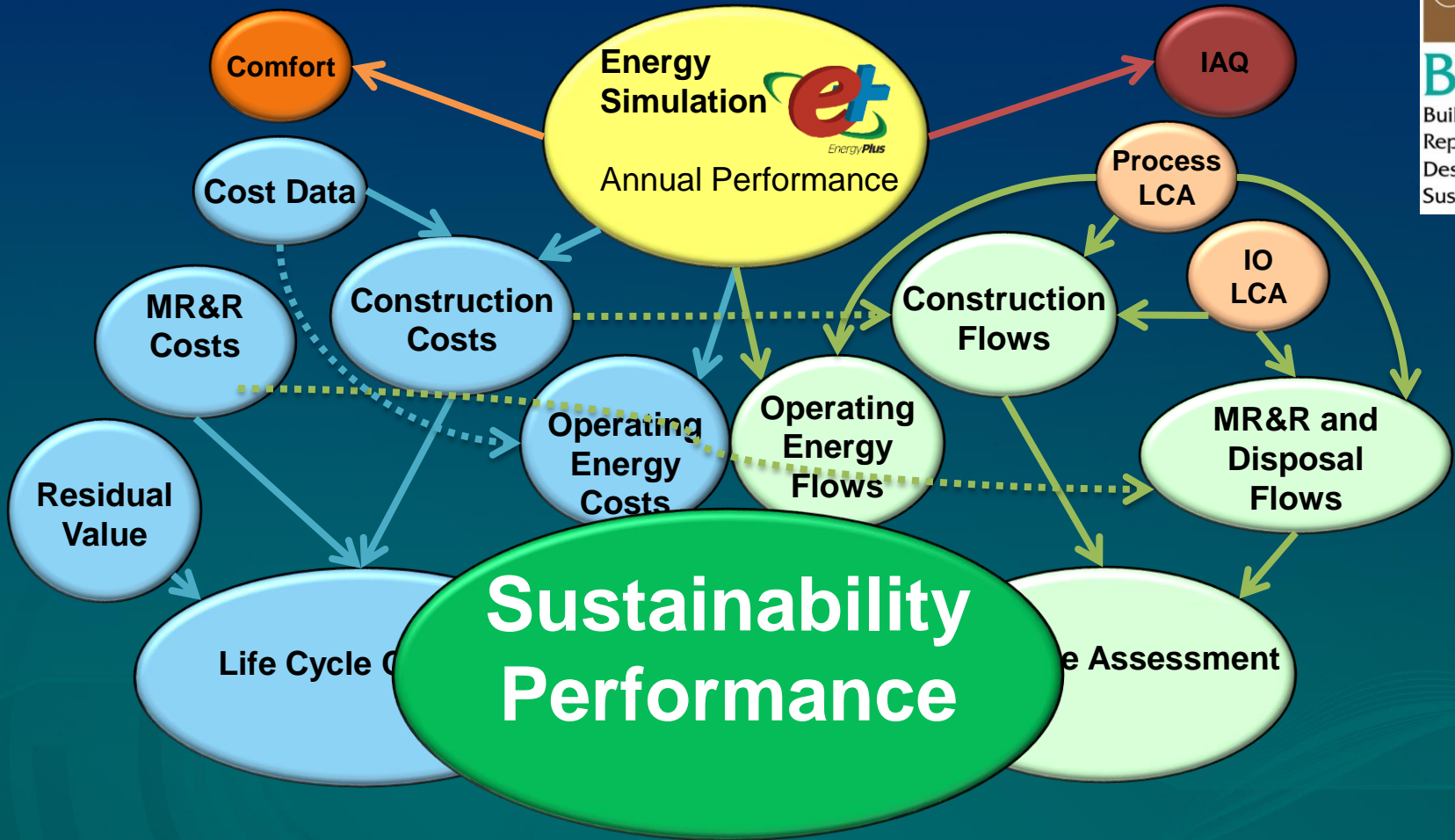
## Combination of Data

- Use the available Bottom-Up data (Process)
- Use Top-Down Data (Input-Output) for the rest
- For Buildings...
  - “Baseline” Building uses I-O tables
  - Individual energy efficiency measures use process data
    - Added insulation
    - Lower air infiltration
    - More efficient windows
    - More efficient heating and cooling equipment



# Building Industry Reporting and Design for Sustainability (BIRDS)

## Expands the BEES Framework to whole buildings





# BIRDS Applications

## Target Audience

- Building Officials, Rating System/Code/Standard Developers, and Policymakers
  - Anyone interested in sustainability in buildings at a high level

## Purpose

- Make science-based building decisions to improve sustainability performance of a whole building
  - Create a “business case” for investment choices in high performance green buildings
  - Based on industry consensus energy and green construction standards





# BIRDS v3.1

- BIRDS v3.1 includes 3 building sustainability databases
  - Commercial
    - 11 prototype commercial buildings; 5 building designs based on **ASHRAE 90.1**; 228 locations
  - Residential
    - 10 single-family prototype buildings; 4 building designs based on **IECC**; 228 locations
  - Low-Energy Residential
    - 480,000 incremental building designs (based on NIST NZERTF); 150 million records; covers building requirements from 2003 IECC to Net Zero+ Designs in Gaithersburg, MD; IEQ Metrics and alternative exterior wall finishes
- Consideration of ASHRAE and IECC building energy codes by the Commercial and Residential databases allow for more generalized analyses of building sustainability.



# BIRDS Home Page: <http://ws680.nist.gov/Birds>

## Residential Buildings

Compare sustainability performance of a residential building type.

[Start Analysis »](#)

## Commercial Buildings

Compare sustainability performance of a commercial building type.

[Start Analysis »](#)

## Low Energy Residential

Compare sustainability performance of a low energy building type.

[Start Analysis »](#)

NEW

## News

[Updating State Energy Codes for New Homes Would Deliver Significant National Savings \(09/2015\)](#)

[Go Figure: What Is the Most Efficient Design for New Single-Family Home?\(05/2015\)](#)

[Federal News Radio Interview with Dr. Kneifel](#)

[BIRDS Is for Sustainability: New](#)

## More about BIRDS...

Building stakeholders need practical metrics, data, and tools to support decisions related to sustainable building designs, technologies, standards, and codes. The Applied Economics Office (AEO) of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST) has addressed this high priority national need by extending its metrics and tools for sustainable building products, known as Building for Environmental and Economic Sustainability (BEES), to whole buildings. Whole building sustainability metrics have been developed based on innovative extensions to life-cycle assessment (LCA) and life-cycle costing (LCC) approaches involving whole building energy simulations. The measurement system evaluates the sustainability of both the materials and the energy used by a building over time. It assesses the "carbon footprint" of buildings as well as 11 other environmental performance metrics, and integrates economic performance metrics to yield science-based measures of the business case for investment choices in high-performance green buildings.



# BIRDS – Future Capabilities

## BIRDS v4.0 (2018)

- Updated Residential Database with 2015 IECC
- Update of Commercial Building
  - DOE Reference Buildings
  - New editions of ASHRAE 90.1

## Beyond BIRDS v4.0

- Designed to be additive
  - New Standards and Codes
  - New Metrics
  - New Options
    - Gas Space and Water Heating; Foundation Types
    - Occupancy, Building Types, Construction Types, Financing Options, etc.
- User Feedback will drive focus



# BIRDS Framework for Custom Building Designs

## Custom, “Real-Time” Building Design Sustainability Calculation Tool

- Target Audience
  - Building Designers and Architects
- Interconnection to existing tools to add sustainability calculations
  - NREL’s EnergyPlus Open Studio
  - Parametric Analysis Tool (PAT) Measure
- BIRDS Calculation API is Generic
  - Could be used by other software tools
  - Examples: Any simulation, CAD, or BIM software





# BIRDS – OpenStudio Measure

NZERTF.osm\*

File Preferences Components & Measures Help

NZERTF.osm\*

File Preferences Components & Measures Help

Results Summary

Reports: ReportingMeasure

Open ResultsViewer for Detailed Reports

## Lifecycle Impact Analysis Results

Category	Subcategory	Ecotoxicity (CTUe)	Smog (kg O3 eq)	Water (kg)	Non carcinogenics (CTUh)	Respiratory effects (kg PM10 eq)	Eutrophication (kg N eq)	Ozone depletion (kg CFC-11-Eq)	Land (acre)	Acidification (mol H+ eq)	Global warming (kg CO2 eq)	Energy (thousand BTU)	Carcinogenics (CTUh)
Construction	Baseline	61593.92	31117.8	11603367.31	0.01	485.82	63.35	0.24	127.68	85964.07	290643.05	4410025.79	0.0
Construction	EEM Construction	1625.47	893.43	678470.78	0.0	4.51	1.52	0.77	0.01	4400.19	117932.21	256982.05	0.0
Construction	All Construction	63219.39	32011.22	12281838.09	0.01	490.33	64.87	1.01	127.7	90364.26	408575.26	4667007.84	0.0
MRR	Replacement	13498.49	974.81	98585.9	0.0	6.67	28.99	0.0	0.01	5319.83	17026.71	152579.02	0.0
MRR	Baseline M&R	3258.89	1794.71	671549.87	0.0	15.5	3.57	0.01	5.39	4822.19	15941.0	267196.6	0.0
MRR	EEM M&R	534.42	68.78	4980.35	0.0	0.29	0.69	0.0	0.04	465.96	9837.92	15900.3	0.0
MRR	Total M&R	3793.31	1863.5	676530.22	0.0	15.79	4.26	0.01	5.42	5288.15	25778.92	283096.91	0.0
MRR	Total MRR	17291.8	2838.31	775116.13	0.01	22.45	33.25	0.01	5.44	10607.98	42805.63	435675.92	0.0
Energy	Electricity	7144.97	16761.21	24400.61	0.0	30.05	38.89	0.0	0.0	125657.52	289055.52	3572488.08	0.0
Energy	Total Energy	7144.97	16761.21	24400.61	0.0	30.05	38.89	0.0	0.0	125657.52	289055.52	3572488.08	0.0
Energy	Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

## MRR - Total MRR

Year	Ecotoxicity (CTUe)	Smog (kg O3 eq)	Water (kg)	Non carcinogenics (CTUh)	Respiratory effects (kg PM10 eq)	Eutrophication (kg N eq)	Ozone depletion (kg CFC-11-Eq)	Land (acre)	Acidification (mol H+ eq)	Global warming (kg CO2 eq)	Energy (thousand BTU)	Carcinogenics (CTUh)
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Primary HVAC System Type

Resid\_AirtoAirHeatPump



# BIRDS in “Real-Time”

## Future Plans

- BIRDS Residential LCIA API
- BIRDS Commercial LCIA API
- BIRDS NEST (Neutral Environment Sustainability Tool)
  - Could be used by other software tools
  - Any simulation, CAD, or BIM software
  - Example: AutoDesk’s Revit





# Publications Developed using BIRDS

More than 50 publications related to evaluating the sustainability performance of residential and commercial buildings developed using BIRDS data.

- *Kneifel, J. and E. O'Rear (2015). "Sustainability Performance of the NIST Net-Zero Energy Residential Test Facility Relative to a Maryland Code-Compliant Design." NIST Special Publication 1187.*
- *Kneifel, J., et al. (2016). "Evaluating the Sustainability Performance of Alternative Residential Building Designs using the BIRDS Low-Energy Residential Database." NIST Special Publication 1205.*
- *Kneifel, J. and E. O'Rear (2017). "Reducing the impacts of weather variability on long-term building energy performance by adopting energy-efficient measures and systems: a case study." Journal of Building Performance Simulation 10(1): 58-71.*
- *Kneifel, J., et al. (2017). "An Exploration of the Relationship between Increases in Energy Efficiency and Life-Cycle Energy and Carbon Emissions using the BIRD Low-Energy Residential Database." Submitted to Energy and Buildings*



# BIRDS and Policy

Regulatory policymakers may find the suite of sustainability measurement tools useful for the following:

1. Comparing residential and/or commercial building energy codes for insight on possible code adoption at the municipal/local/state level
2. Establishing energy and/or environmental performance benchmarks for whole-buildings
3. Revealing potential prescriptive pathways for building energy code compliance
4. Gauging compliance with existing or future green building codes targeting environmental performance



# For further information...

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**NIST EL Applied Economics Office**

<http://www.nist.gov/el/economics/>

**NIST NZERTF**

<http://www.nist.gov/el/nzertf/>

**BEES Online**

<http://ws680.nist.gov/Bees/>

**BIRDS**

<http://ws680.nist.gov/Birds>

**OpenStudio**

<https://www.openstudio.net/>





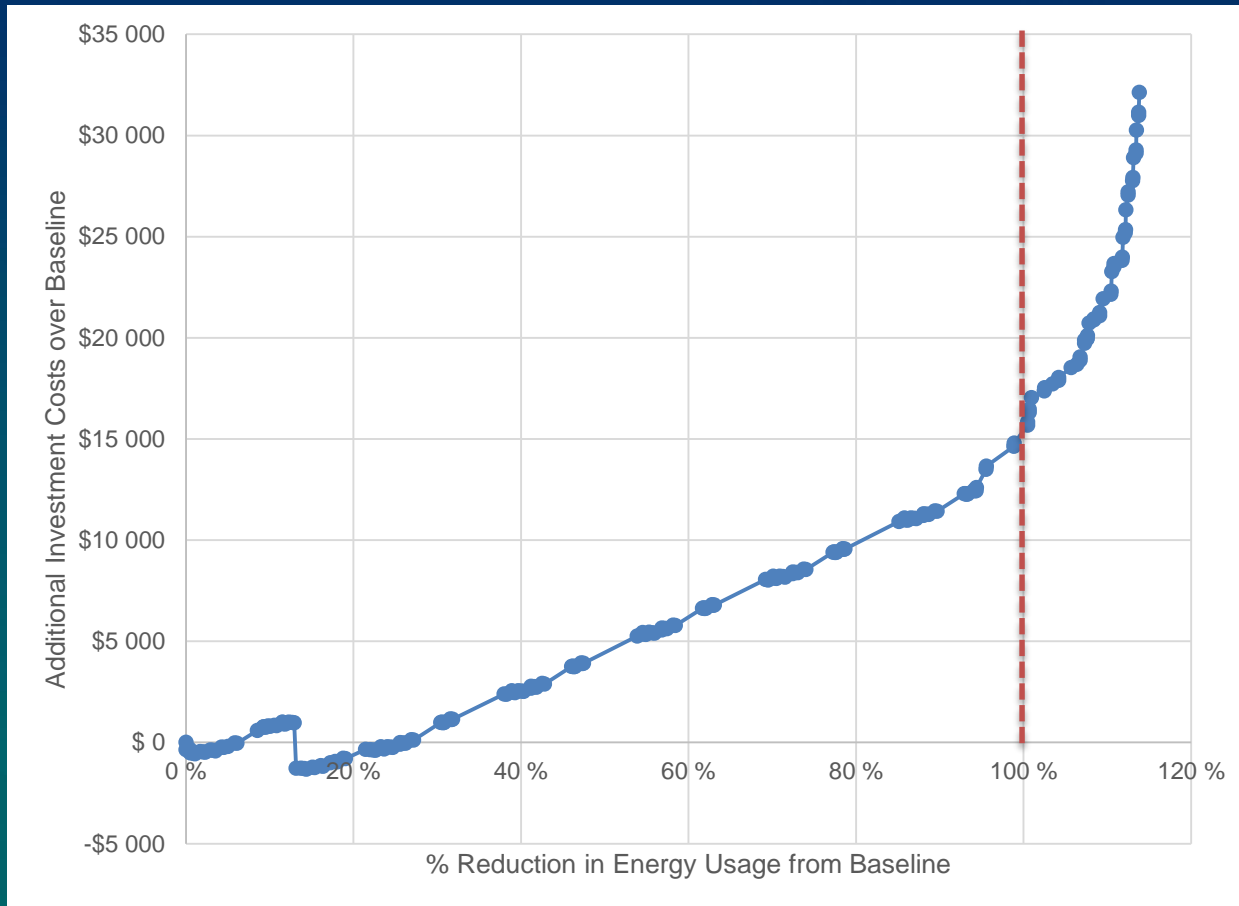
# *Supplemental Slides:*





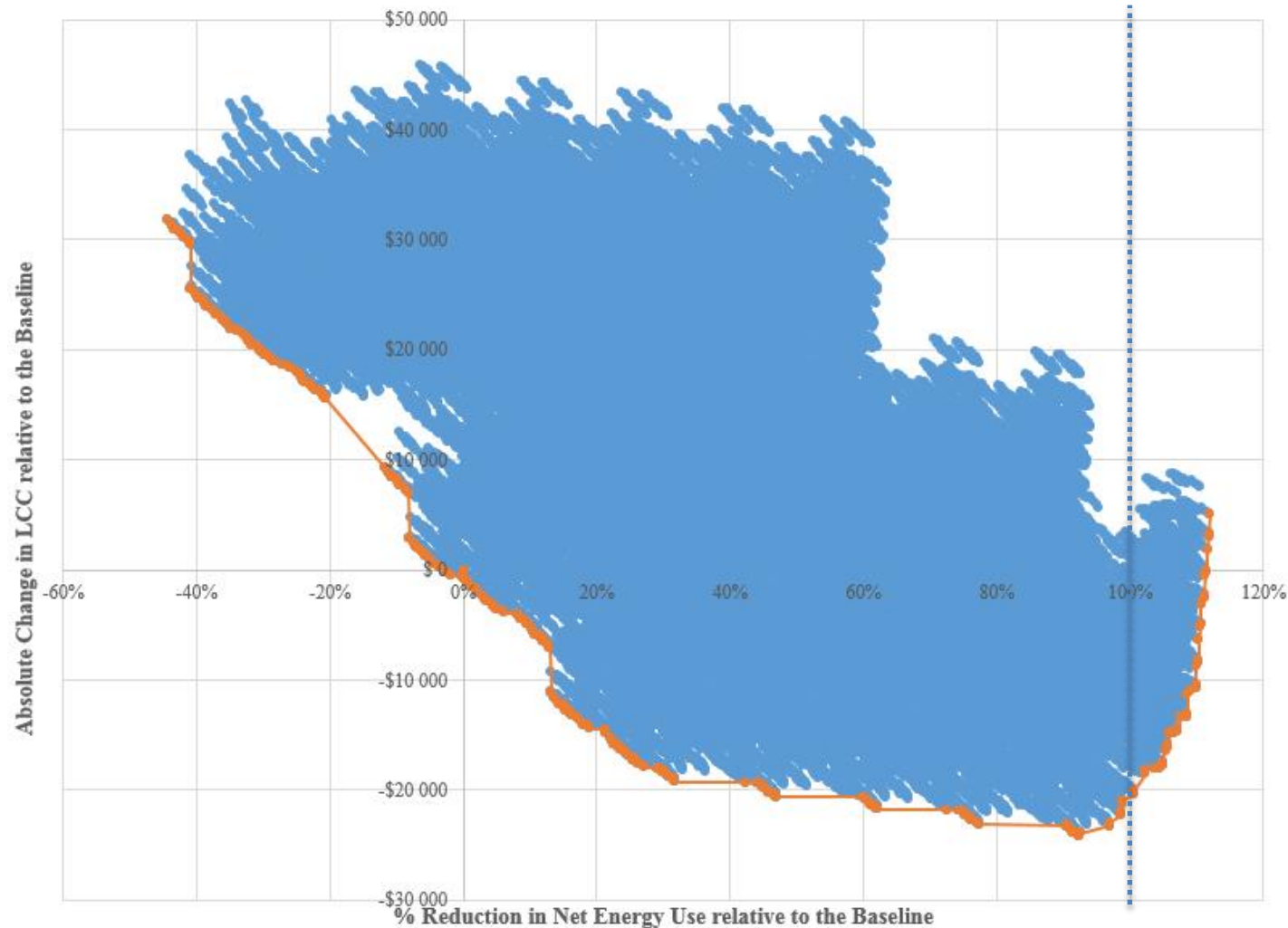
# BIRDS-based Economic Analysis

How much does it cost up front?



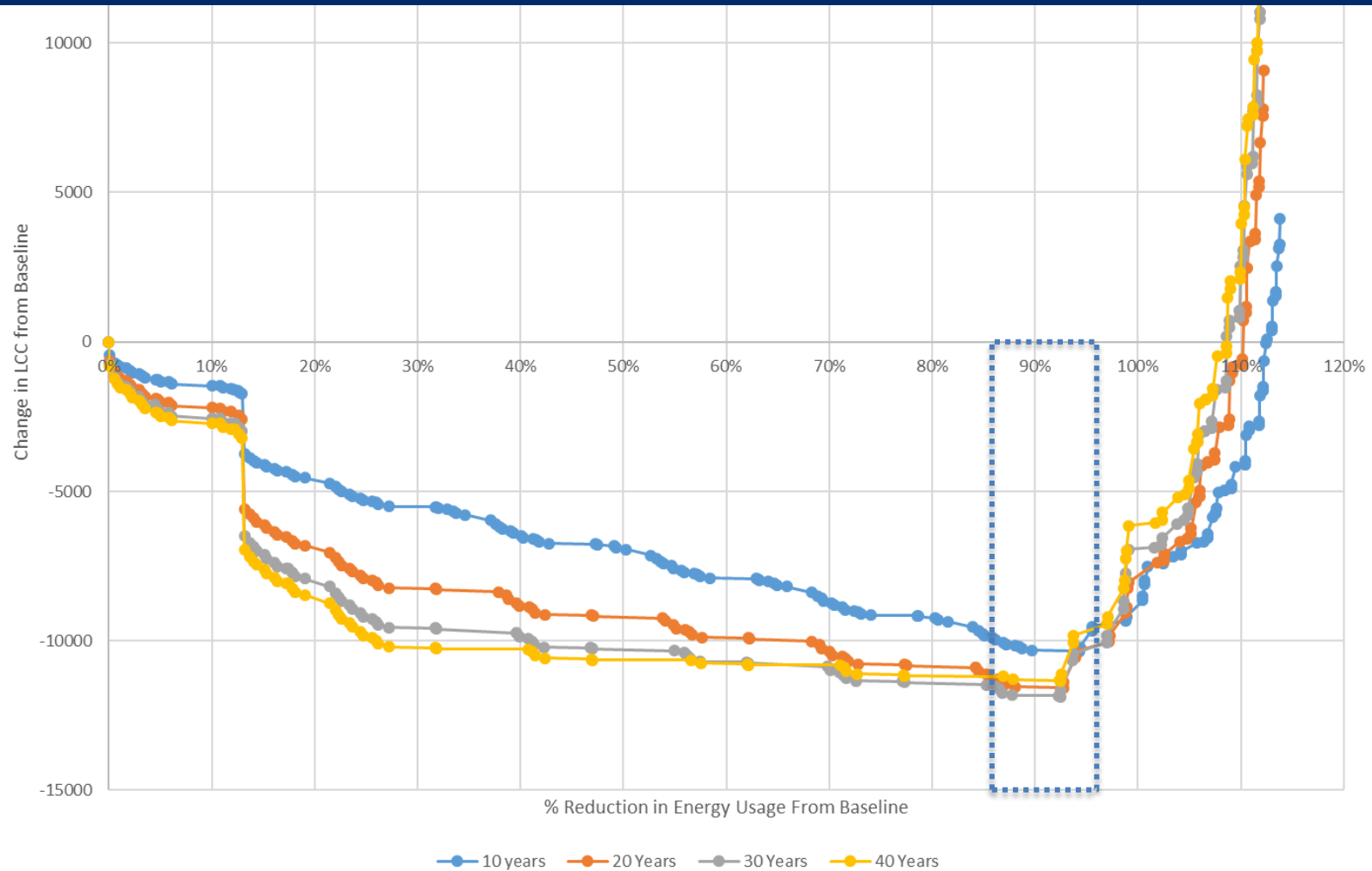


# Cost-effective Designs to increase Efficiency



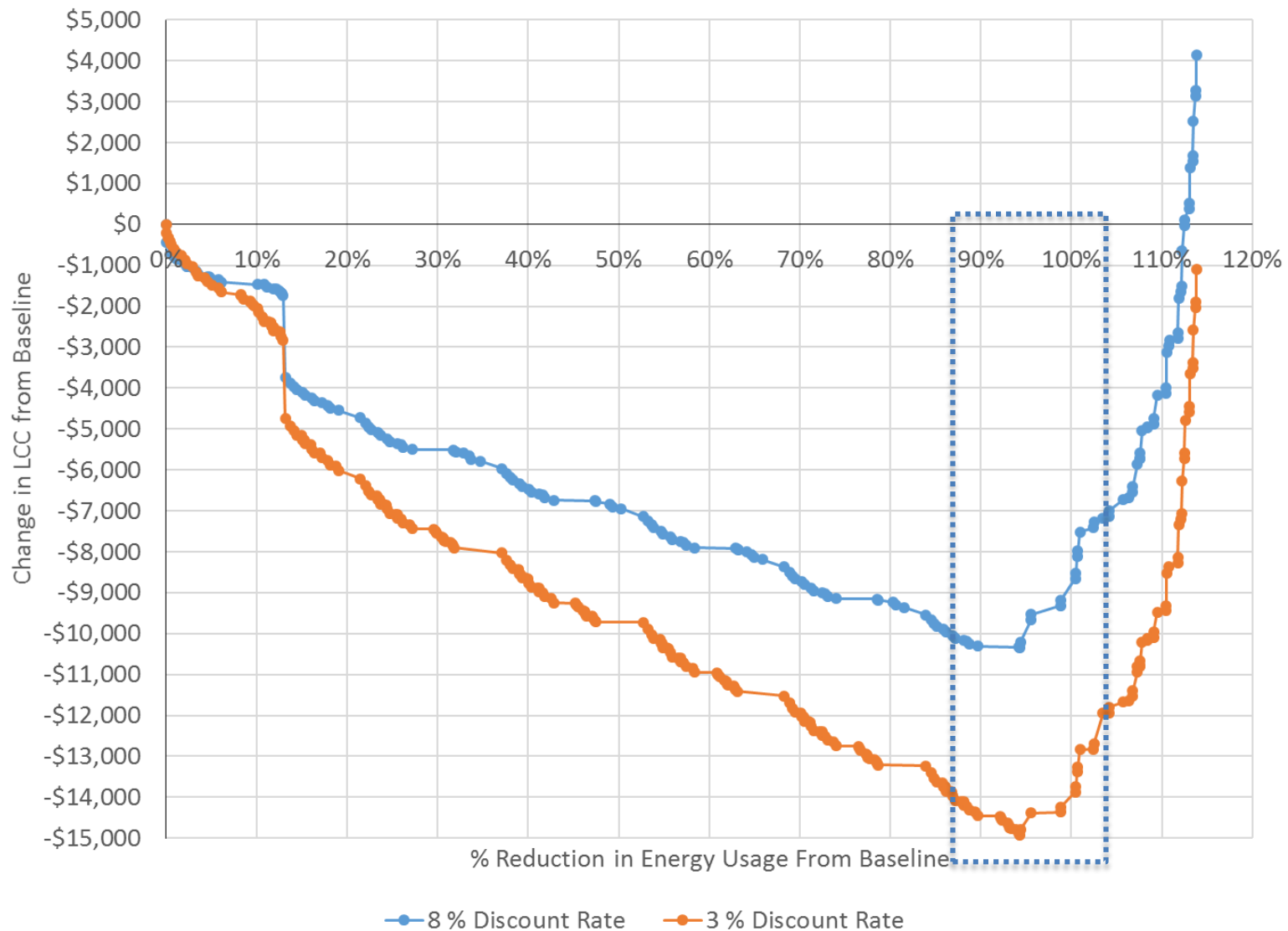


# Variation across study period



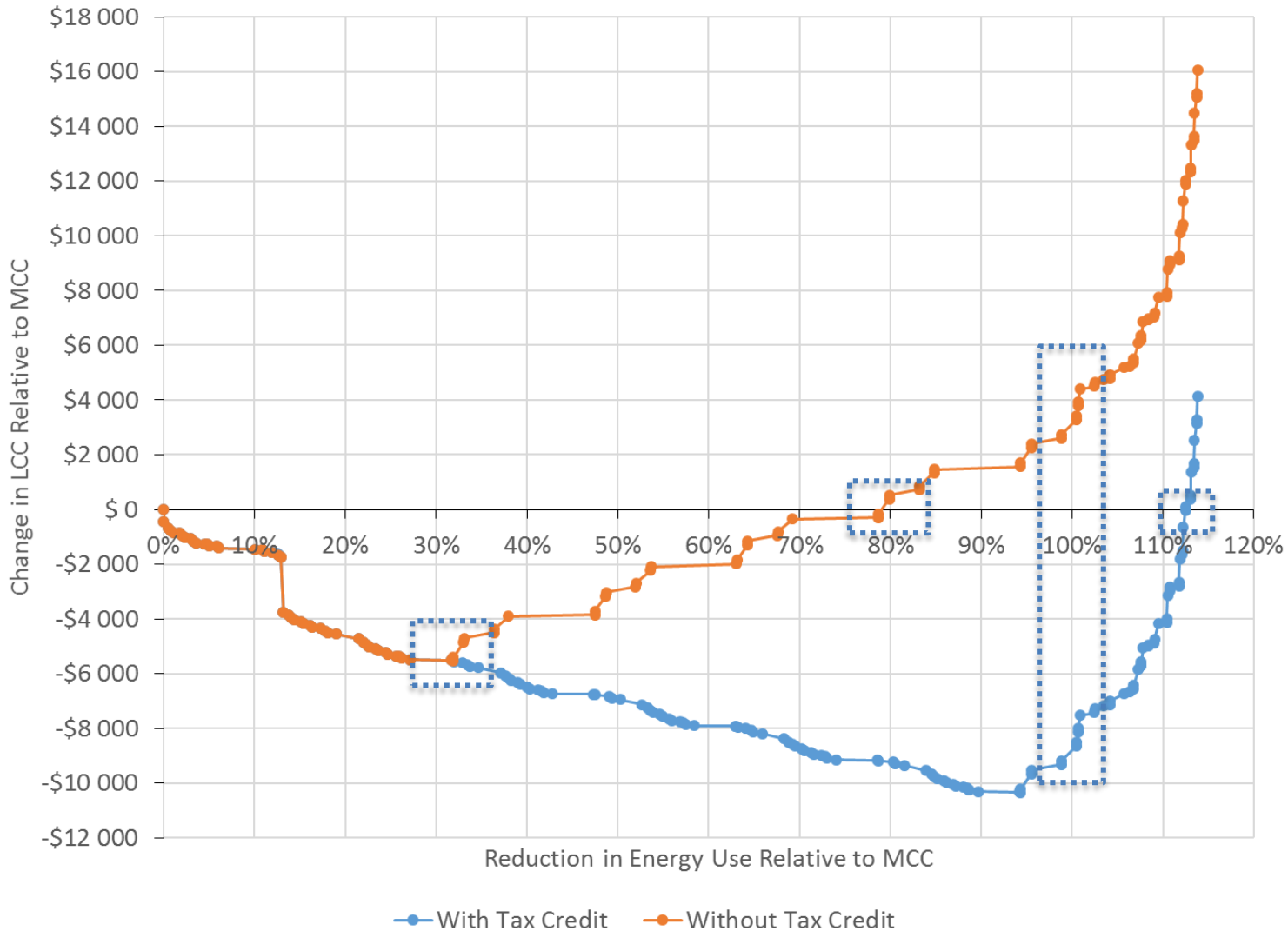


# Variation across discount rates





# Variation due to 30% Federal Solar Tax Credit





# SNEAK PEEK: Natural Gas Heating

