Applying State-of-the-Art Analysis to Utility Billing Data

Ohio Board of Regents

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April 26, 2006 Columbus, OH

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Go Sustainable Energy, LLC

Dayton, OH

Go Sustainable Energy

My Experience

- Bachelor and Master's in Mechanical Engineering from UD
- Several years of experience working with Ohio/New England/New York state and utility energy efficiency programs
  - Energy assessments
  - Demand reduction (permanent, load-shedding, peak generation)
  - Technical assistance
  - Program consulting (measure life, lean manufacturing & energy)
  - Commissioning teams and retro-commissioning studies
  - Industrial ecology
- Approx. 100 facilities evaluated

GO Sustainable Energy

- Core services
  - Utility & energy data statistical regression analysis
  - Energy assessments
  - Technical assistance (focused projects)
  - Instructional
- Also,
  - Incentive packages - GHG emissions credits; federal tax incentives; state loans & grants; utility rebates
  - Next generation - Industrial ecology, biomimicry, sustainable product design
  - Long-term demand-side management

HB 251 – For State Institutions of Higher Education

- Goal to reduce building energy consumption by 20% by 2014
  - 2004 is benchmark year
- Creation of energy efficiency standards for new buildings >$100,000 in cost
- Each board must have a 15-year plan for phasing in energy efficiency projects

HB 251 – It makes sense!

- Goal to reduce building energy consumption by 20% by 2014
  - 2.7% reduction per year from now until then
  - No big deal…
    - Refrigerators 5.5% improvement per year for past 30 years – standards
    - Economy 2.25% improvement with high prices - incentives

HB 251 – For State Institutions of Higher Education

- Creation of energy efficiency standards for new buildings >$100,000 in cost
- Each board must have a 15-year plan for phasing in energy efficiency projects
  - $250 million project….$0.00 spent on evaluating energy operating cost

Our Analysis: How Does It Help These Efforts?

- Benchmark energy use
  - Measure energy savings, track improvements
  - Normalize weather, occupancy, enrollment, other
- Identify energy savings
  - Evaluate energy signatures
  - Past-performance benchmarking
  - Multi-facility benchmarking

Our Analysis

- State-of-the-art analysis
  - Complementary to EnergyStar – 6 metrics+ instead of one
  - Expert analysis – highest quality returns - good advice will save you time and money in the long run
  - Clean database – trustworthy results
- Our higher education clients
  - California State University
    - Campus level
    - Facility level

State-of-the-Art Analysis: What is it?

- Energy Informatics
  - Extracting useful information from energy data sets
- Multi-variable change-point statistical regression (MVR) models
  - We call them Energy Signatures for short
  - Graphical and mathematical model
  - Regression beyond Excel
- Inverse Modeling
  - Interpreting the physical significance of the energy signature parameters

Who Uses It?

- EModel: Texas LoanSTAR Program
- Advanced PRISM: Princeton Center for Energy and Environmental Studies
- IMT: ASHRAE Guideline 14 on Measurement and Verification
- ETracker: U.S. EPA Energy Star Buildings Program
- Regression Method: International Performance Measurement and Verification Protocols

MVR, What is it Good for?

- Baselining energy use
- Normalizing energy use
- Forecasting energy use
- Identifying energy reduction opportunities
- Past-performance and multi-building benchmarking
- Continual monitoring
- Measurement of energy savings

Why use it?

- Powerful analysis tool
- Next generation temperature normalization
  - HDD/CDD → Actual temperature data and TMY2
- Its There! – Data is readily available
  - Utility data (except for un-metered buildings!)
  - Temperature data – free on web
    - engr.udayton.edu/weather
    - Weatherunderground.com

MVR Analysis of Utility Billing Data: Overview

- 1. Characterize performance with
  ‘**Energy Signature**’ model
- 2. Remove noise with
  ‘**Normalized Annual Consumption**’ NAC
- 3. Track performance with
  ‘Past Performance Benchmarking’ -
  ‘Sliding NAC’ analysis
- 4. Compare performance with
  ‘**Multi-Facility Benchmarking**’ analysis

Data Requirements

Monthly electricity and fuel use: utility bills

Actual outdoor air temperature

Typical outdoor air temperature

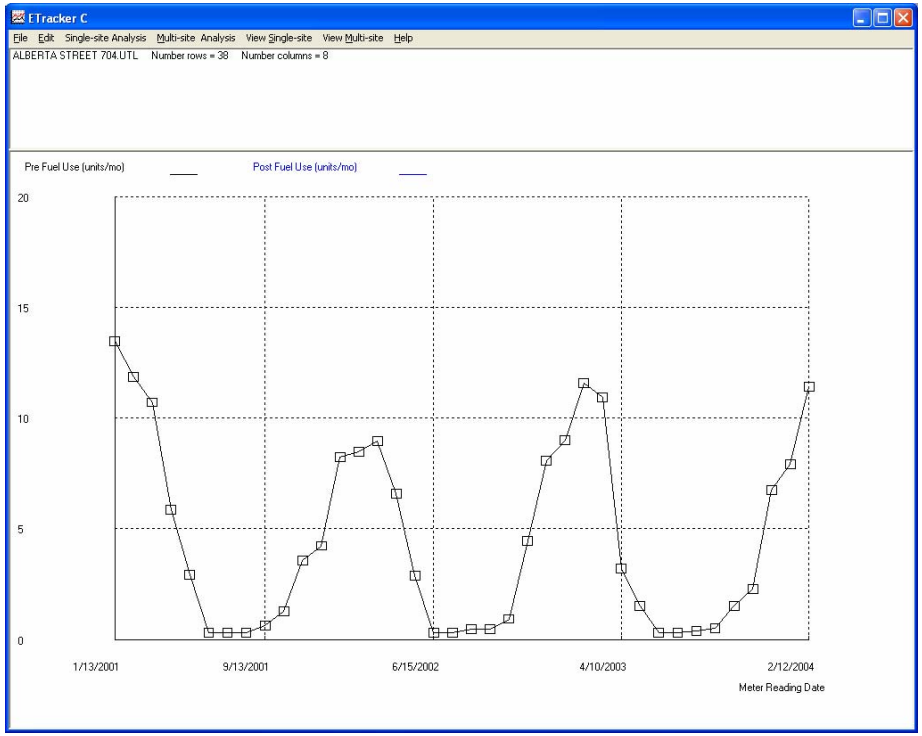
Influential variables (optional)

- Floor area, occupancy, sales, production, etc.

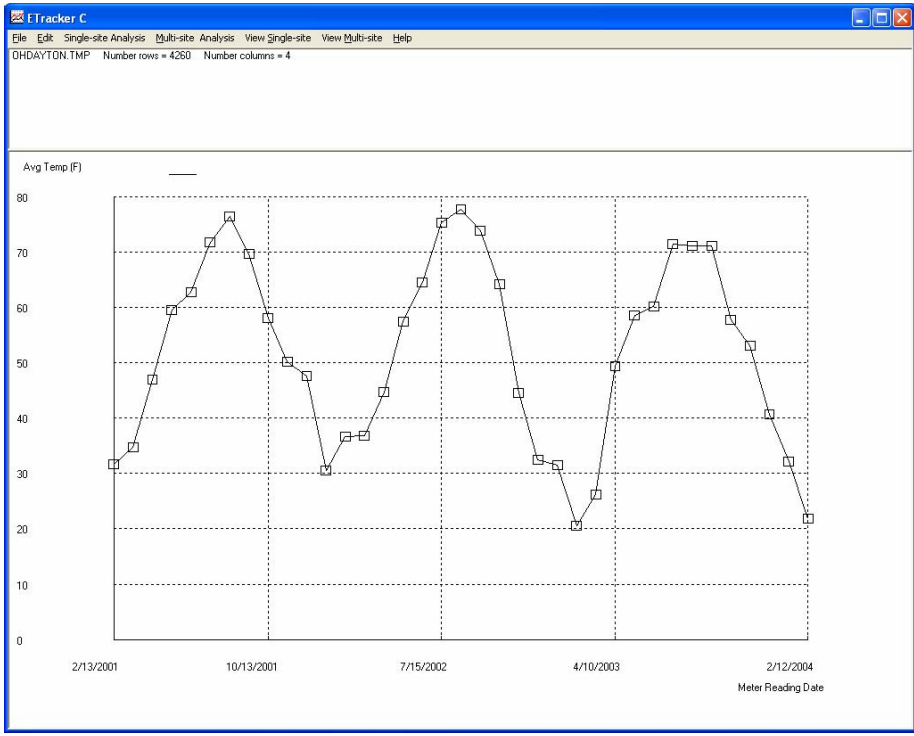
1. Characterize Performance with 'Energy Signature' Model

- Develop 3PC or 3PH energy signature model
- Disaggregate energy use
- Identify energy saving opportunities
  - Expected shape
  - Coefficient analysis
  - Fit analysis

Load Gas and Temperature Data

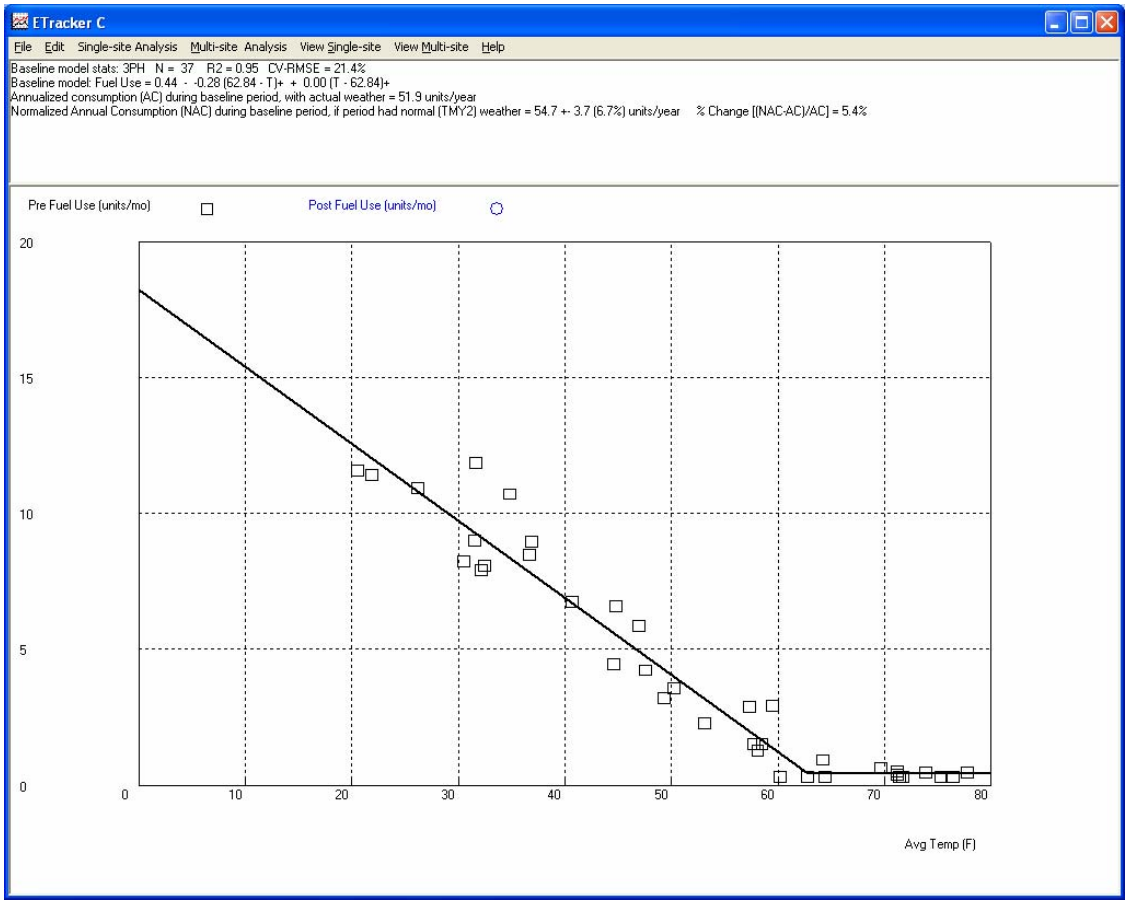


3 Years of Gas Bills

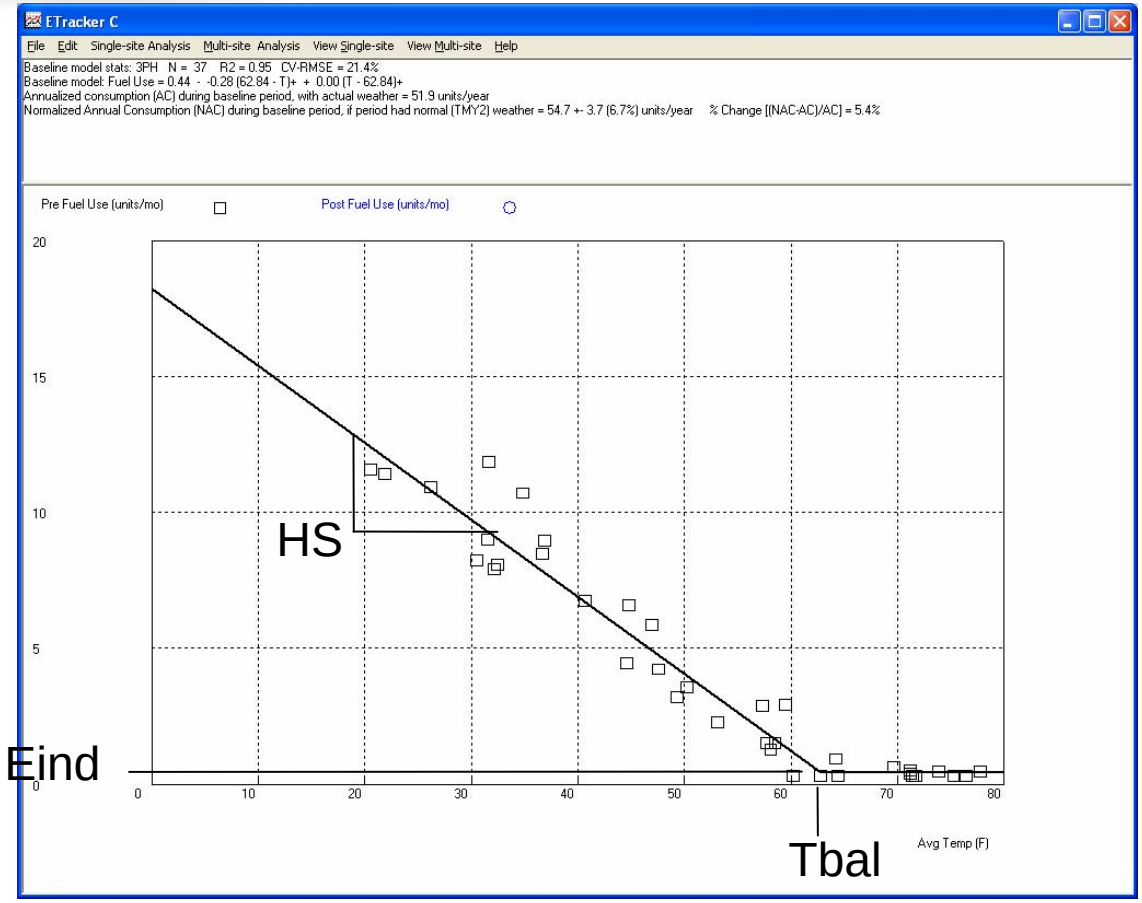


3 Years of Temperature Data

Three-parameter Heating (3PH) Model

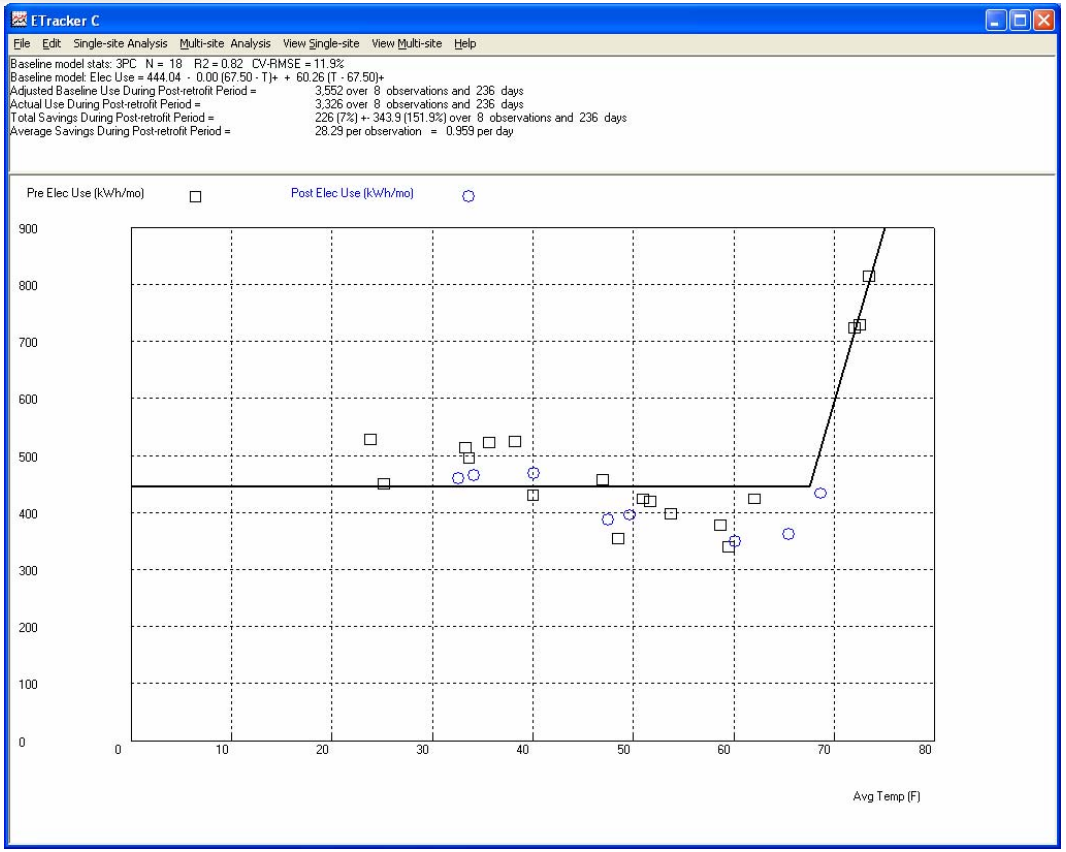


Three-parameter Heating (3PH) Model

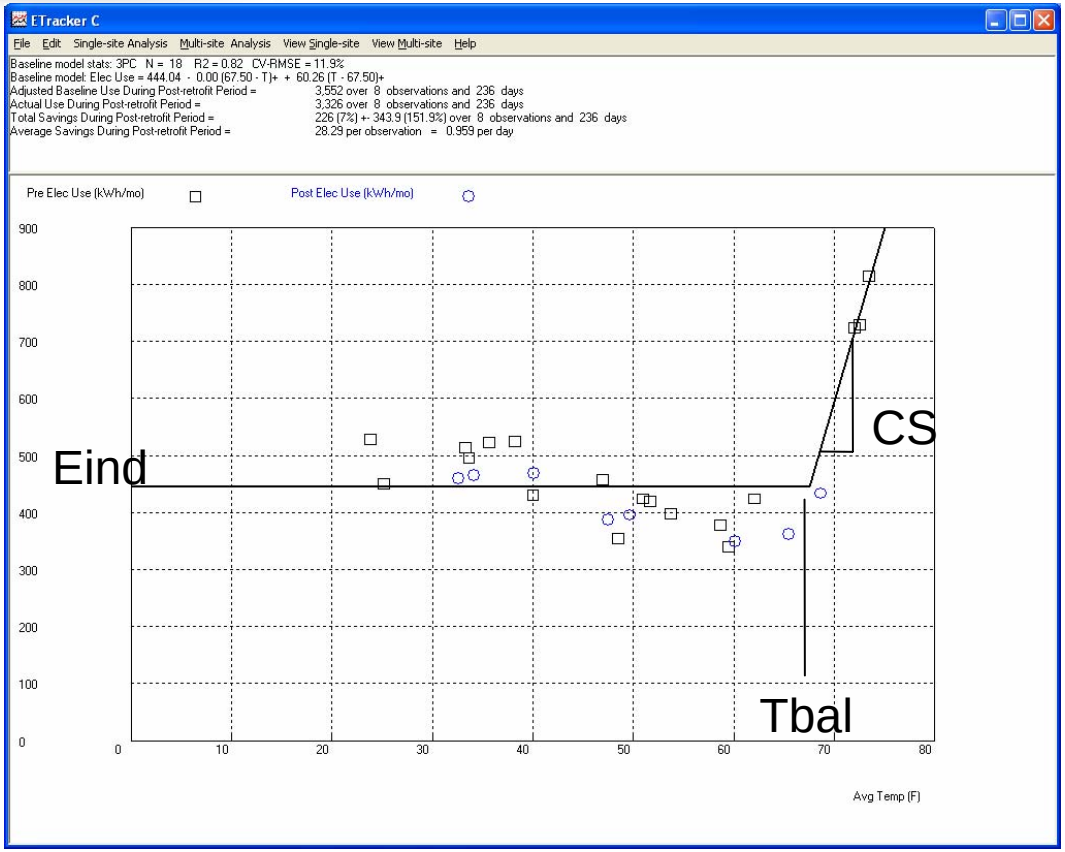


Gas Use = Eind – HS (Tbal – Toa)$^{+}$

Three-parameter Cooling (3PC) Model



Three-parameter Cooling (3PC) Model



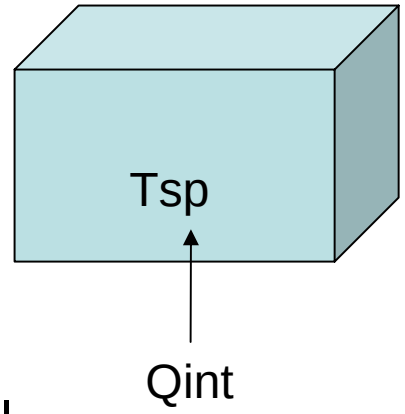
$$\text{Elec Use} = \text{Eind} + \text{CS}\,(\text{Toa} - \text{Tbal})^{+}$$

Physical Meaning of Coefficients

- Eind = Temperature-independent energy use

- Tbal = Balance temperature
  = Outdoor temperature where heating/cooling begins
  = Tsp – Qint/UA

UA = building conductance x are



- HS = Heating Slope
  = Heating energy per degree below Tbal
  = UA/Eff_Heater

- CS = Cooling Slope
  = Cooling energy use per degree above Tbal
  = UA/Eff_AC

Add Additional Variables For Industrial, Commercial, Retail Facilities

- Add additional independent variables (IV) to make 3P-MVR models

- Gas Use = Eind
  + HS x (Tcp -Toa)+
  + (IV1 x Occupancy) + (IV2 x Sales) ...

- Elec Use = Eind
  + CS x (Toa - Tcp)+
  + (IV1 x Occupancy) + (IV2 x Sales) ...

Energy Saving Opportunities: ‘Lean Energy’ Breakdowns

- Lean Manufacturing: Any ‘activity’ that does not directly add value to the product is waste
- Lean Energy: Any ‘energy’ that does not directly add value to the product is waste.
- Hence, ‘independent’ energy use is energy that does not vary with production or weather, and may be waste.
- Target independent energy use for savings opportunities.

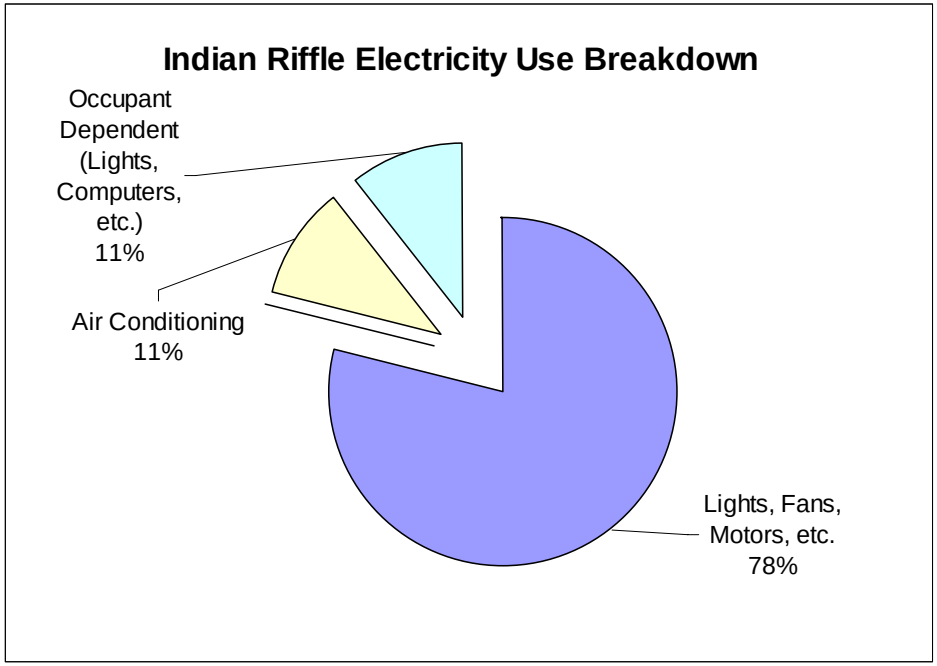
Lean Energy Breakdown:
High Independent Electricity Use

Equipment left on when not in use

- Lights
- Computers
- Vending machines

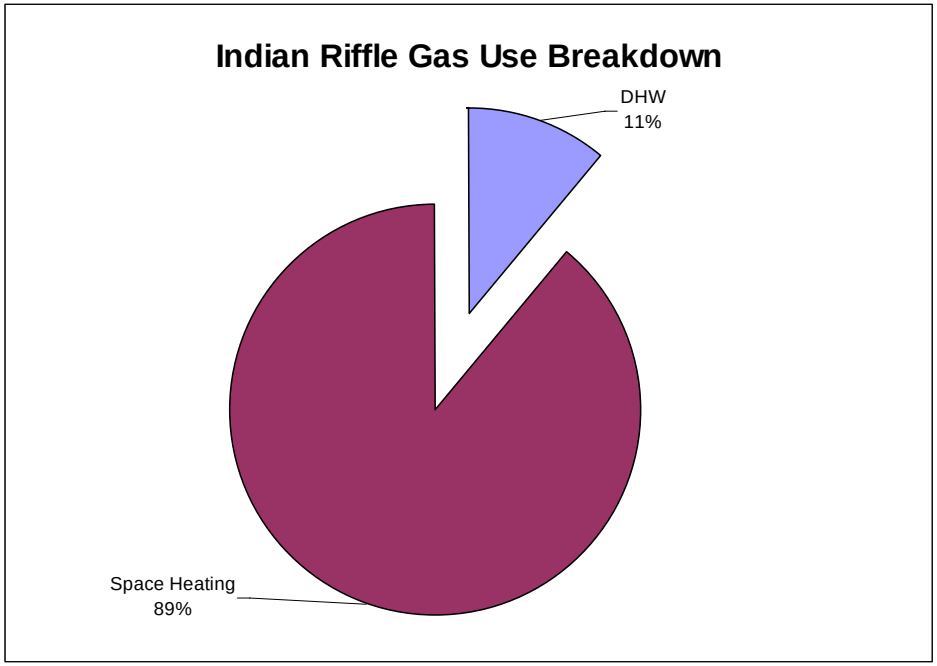
- Poor load-following behavior
  - Un-staged air compressors
  - Throttled pumps
  - Part-loaded chillers

- No load-following behavior
  - Constant-volume pumping
  - Constant-volume air flow
  - Compressed air leaks

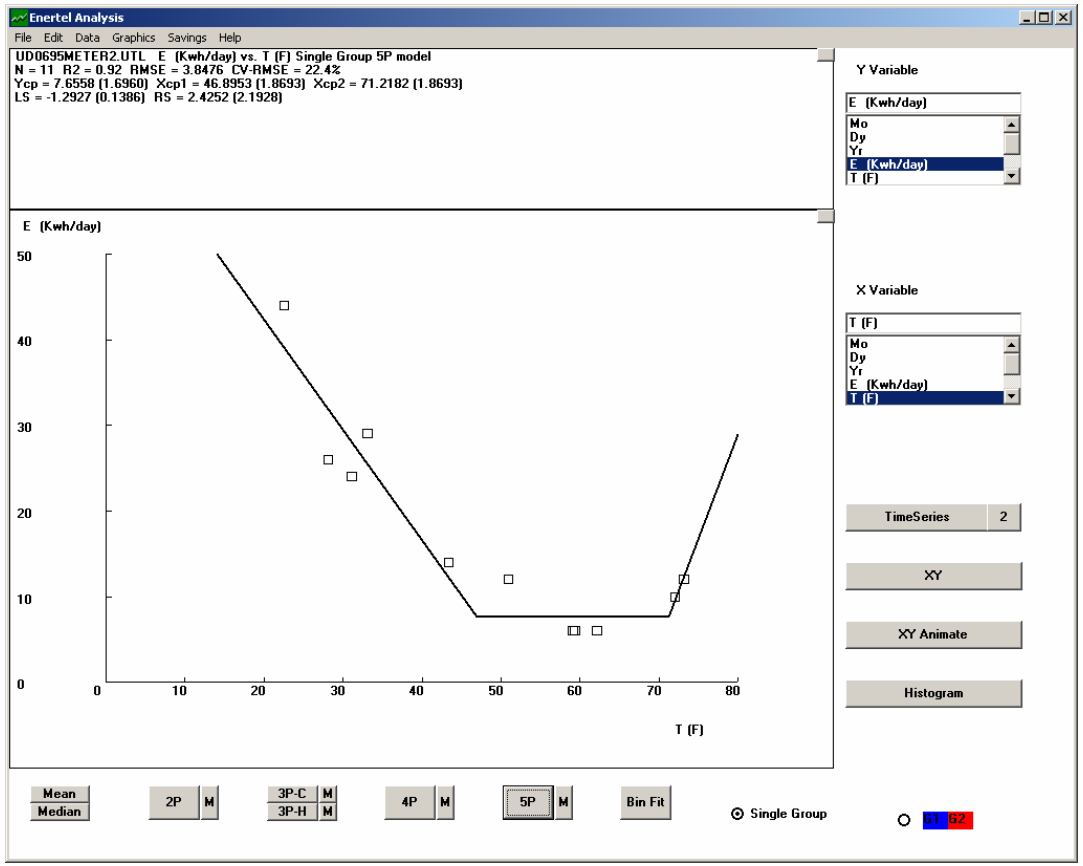


Lean Energy Breakdown:
High Independent Fuel Use

- Equipment left on when not in use
  - Ovens, furnaces, boilers
- Poor load-following behavior
  - Boilers with load/unload control
- No load-following behavior
  - Reheat/cooling interaction

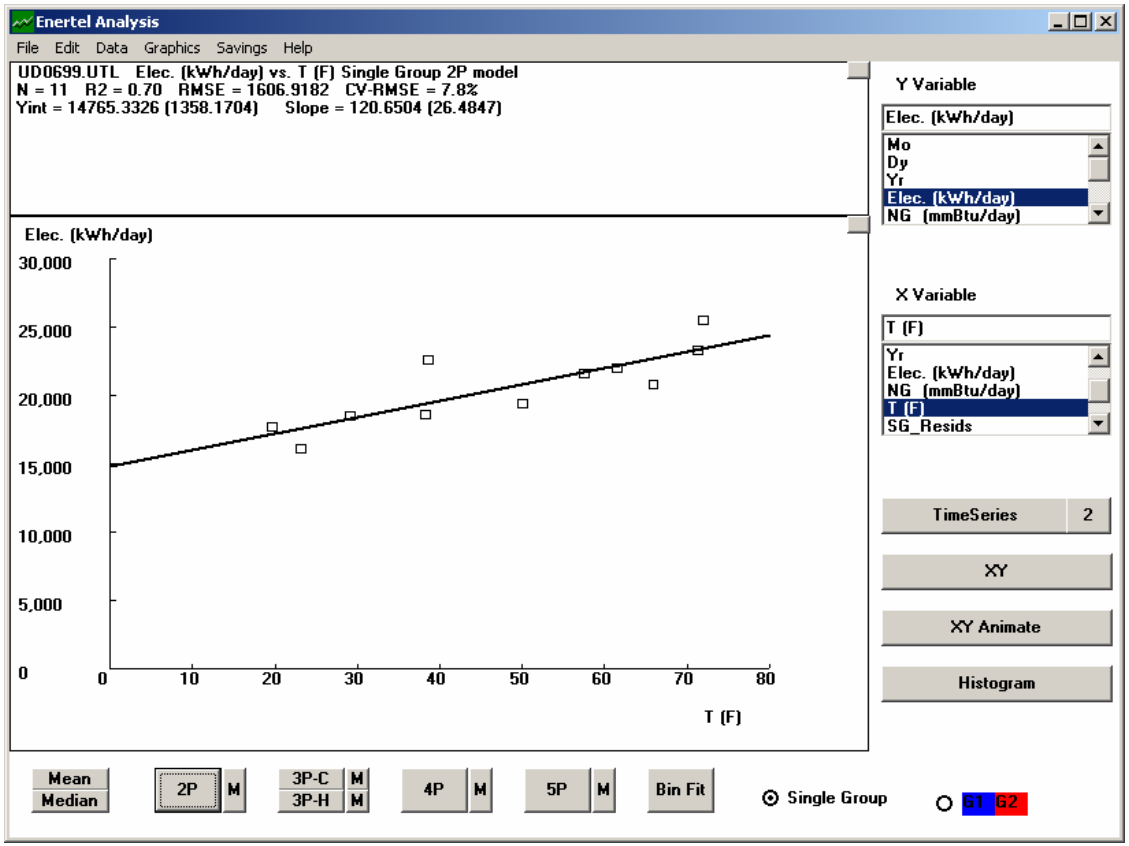


Using Models to Identify Problems: Chillers Left On



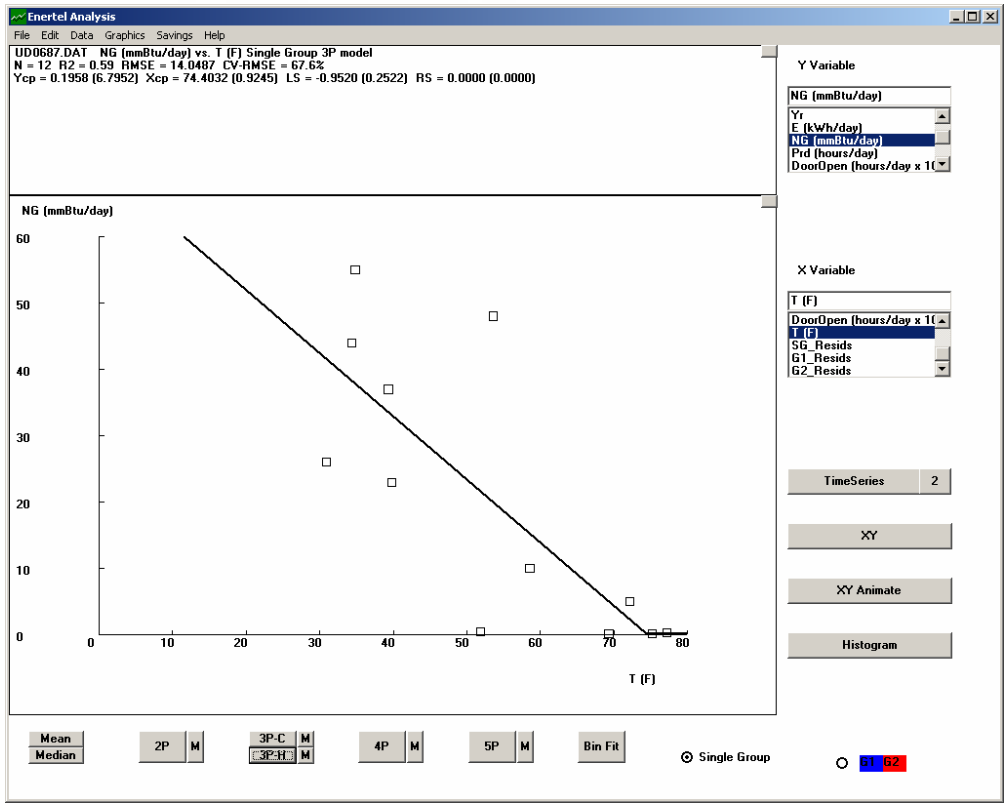
$R^2 = 0.92$ CV-RMSE = 22.4%

Using Models to Identify Problems: Malfunction Economizer



$R^2 = 0.70$ CV-RMSE = 7.8%

Using Models to Identify Problems: High Scatter = Poor Control



<u>Observation</u>

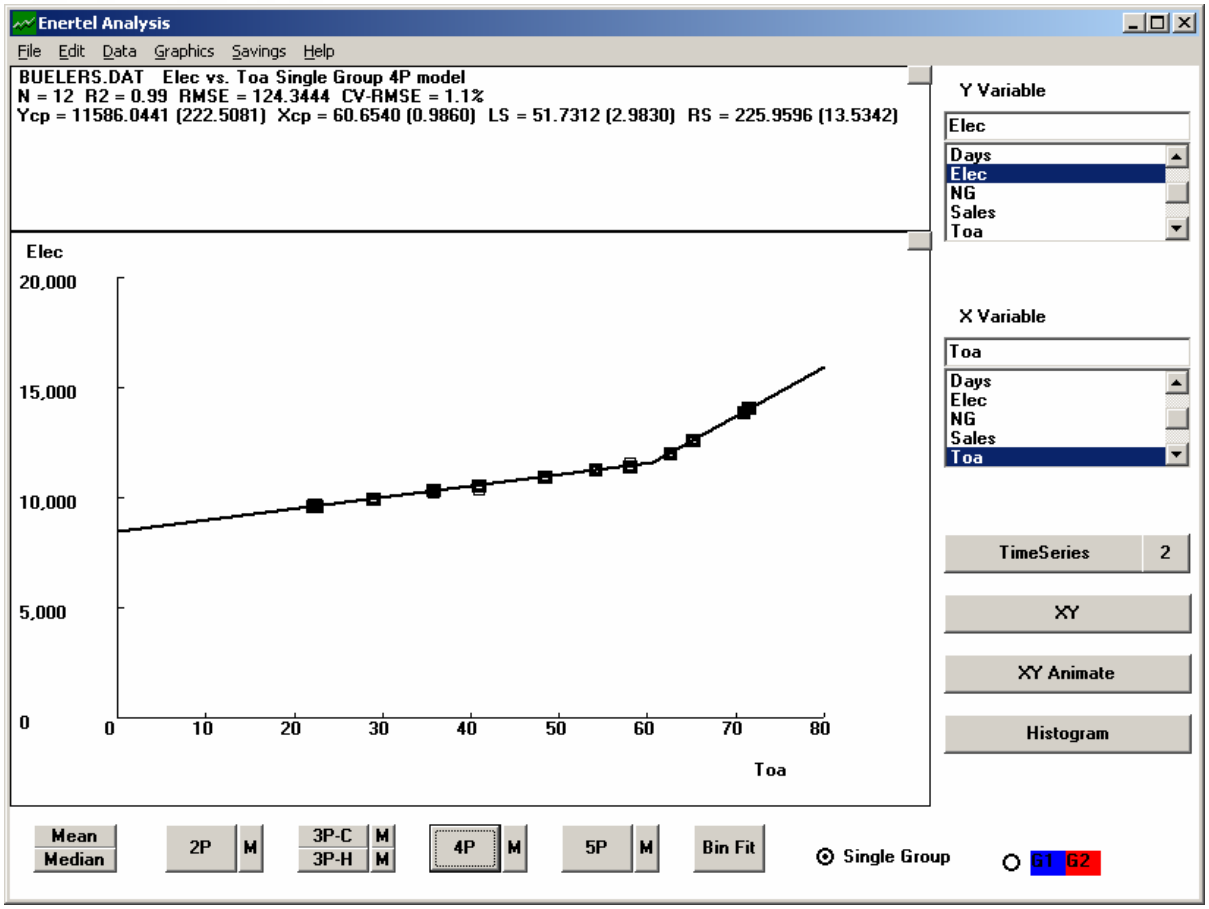
Heating energy varies by 3X at same temp!

<u>Discovery</u>

Didn't close shipping doors!

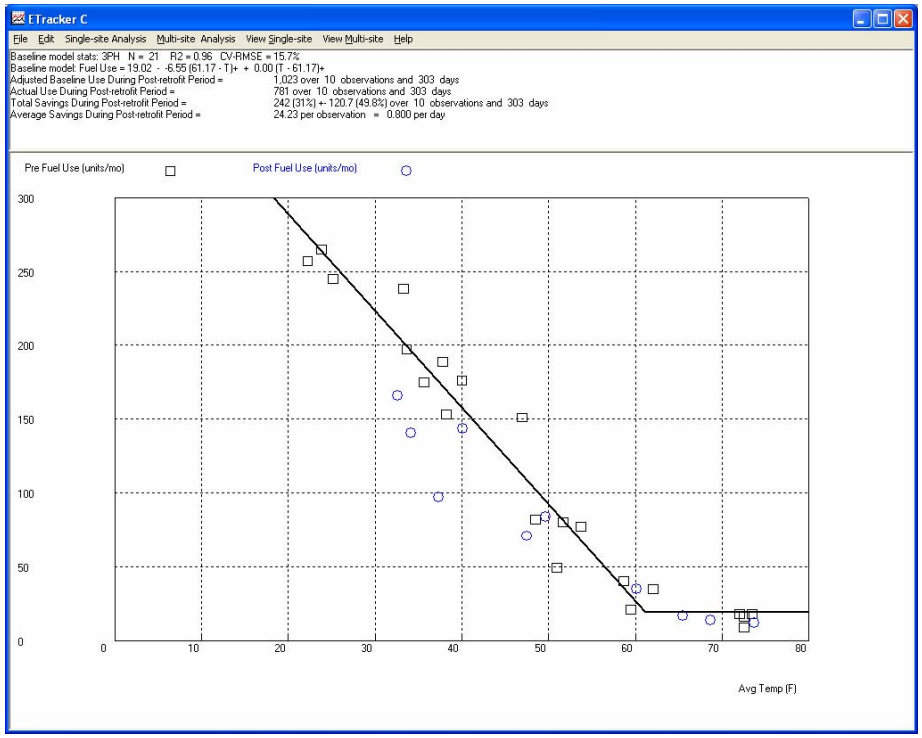
$R^2 = 0.59$ CV-RMSE = 68%

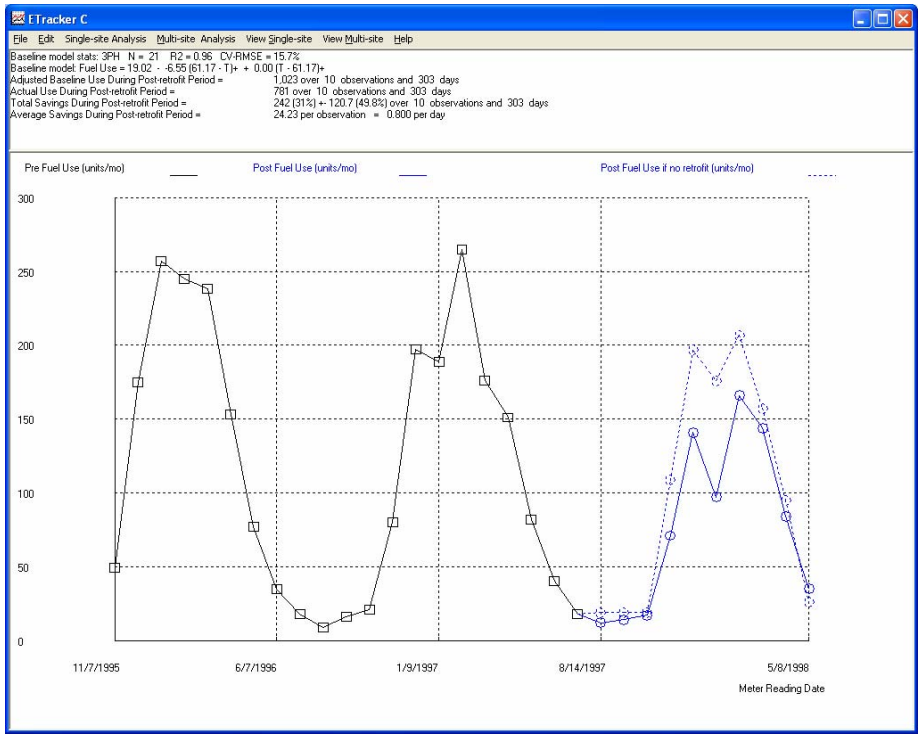
Using Models to Identify Success: Low Scatter = Good Control



R^2 = 0.99 CV-RMSE = 1.1%

Measuring Actual Savings: Insulation



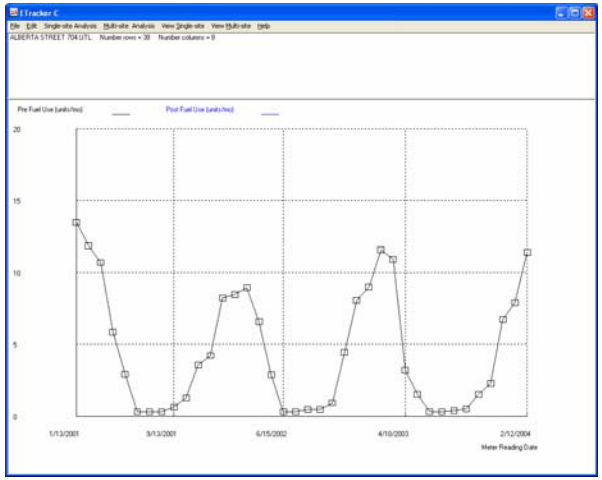


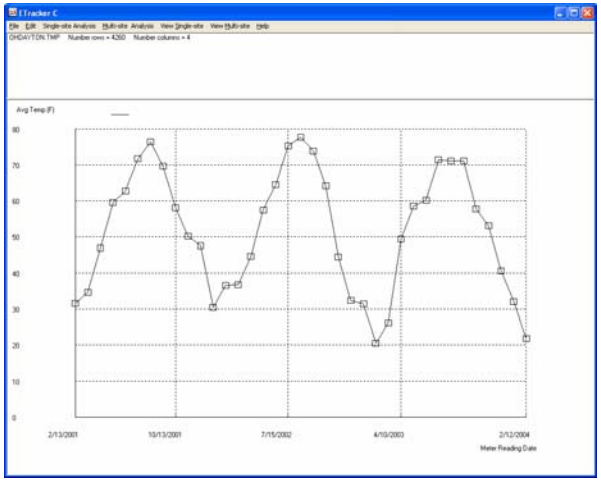
Average savings = 24.2 ccf/month = 290 ccf/yr

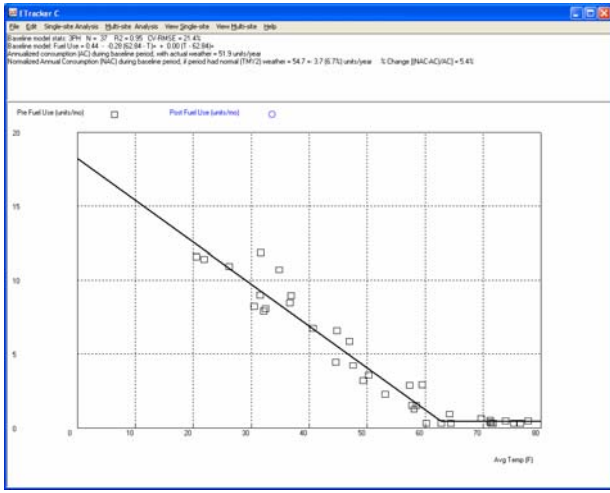
Normalized Annual Consumption: NAC

- Utility bills tells us ‘Annual Consumption’, which how much energy facility consumed with weather, sales, production, etc. that actually occurred
- We want to know how much energy building would have consumed during ‘normal’ weather, sales, production, etc.
- This is called ‘Normalized Annual Consumption’ NAC
- Calculating NAC is a two step process.

Calculating NAC:
Step 1 of 2:

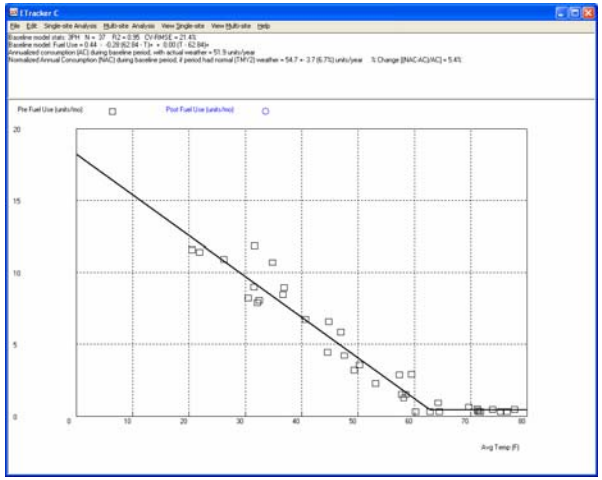


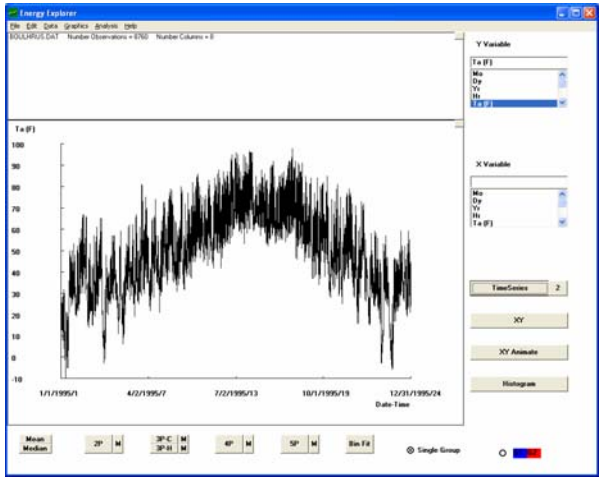


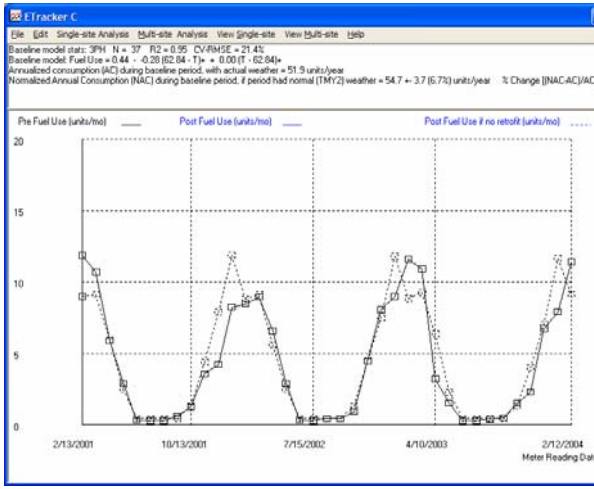


Actual gas bills + Actual weather data = Energy signature model

Calculating NAC:
Step 2 of 2:



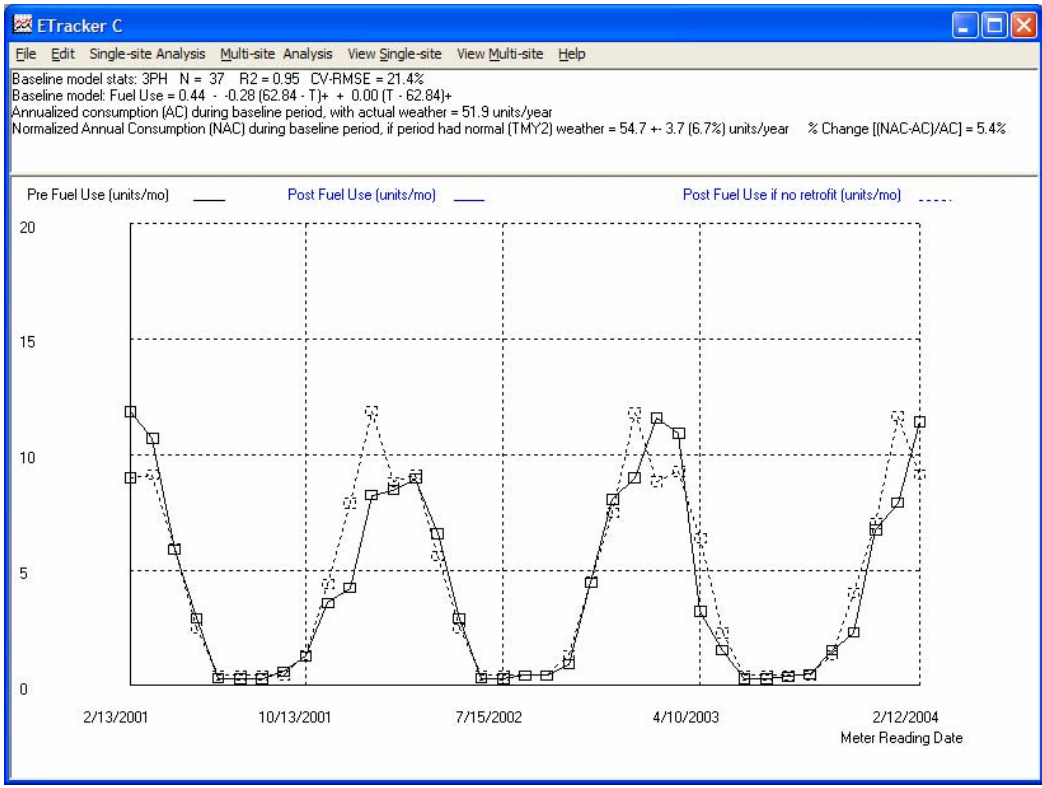




Energy signature model + Typical weather = NAC

NAC is “Noisefree” Energy Consumption

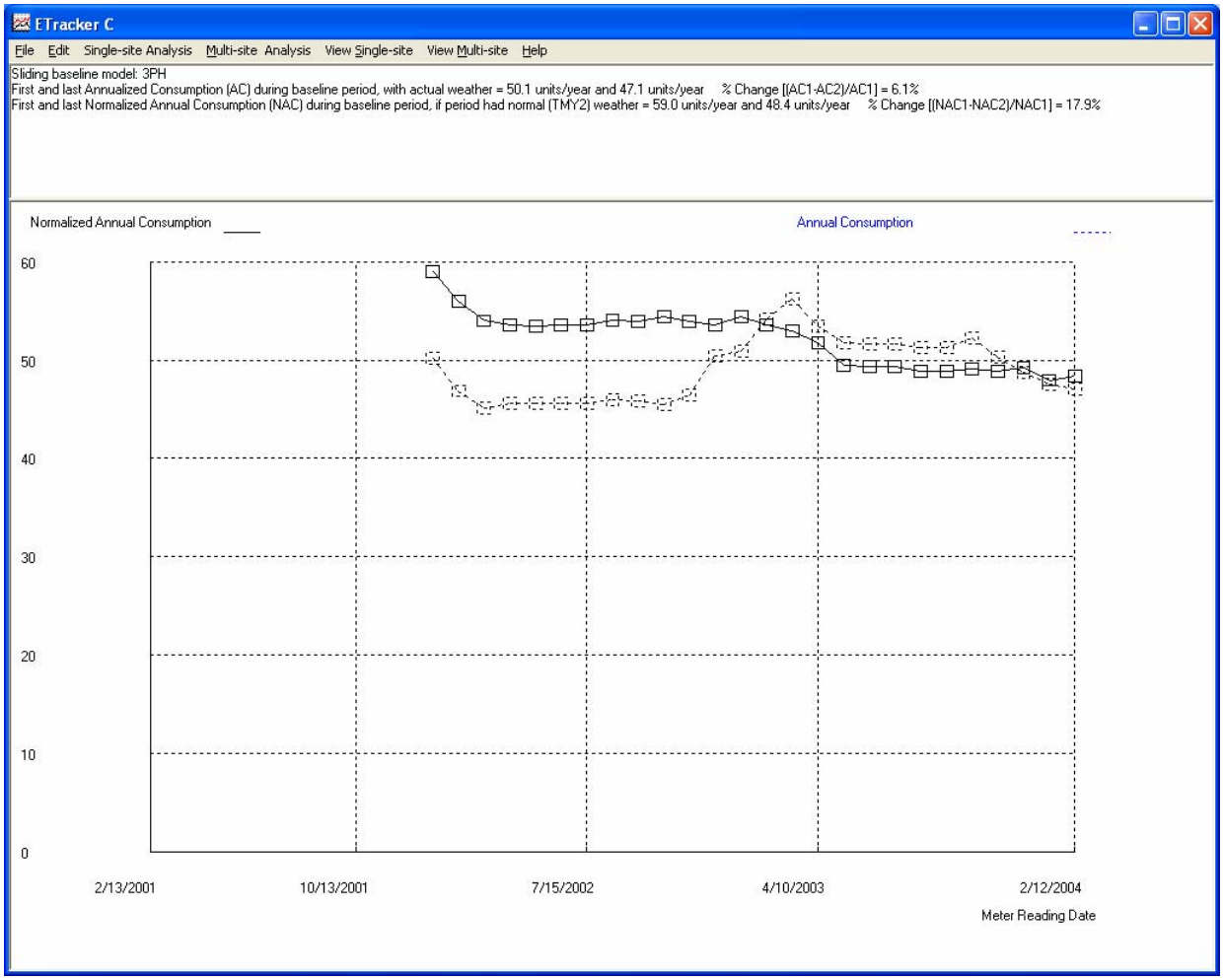
- NAC removes ‘noise’ from variable weather
- NAC reveals true energy use characteristic of facility
- NAC allows comparison of sites with different weather



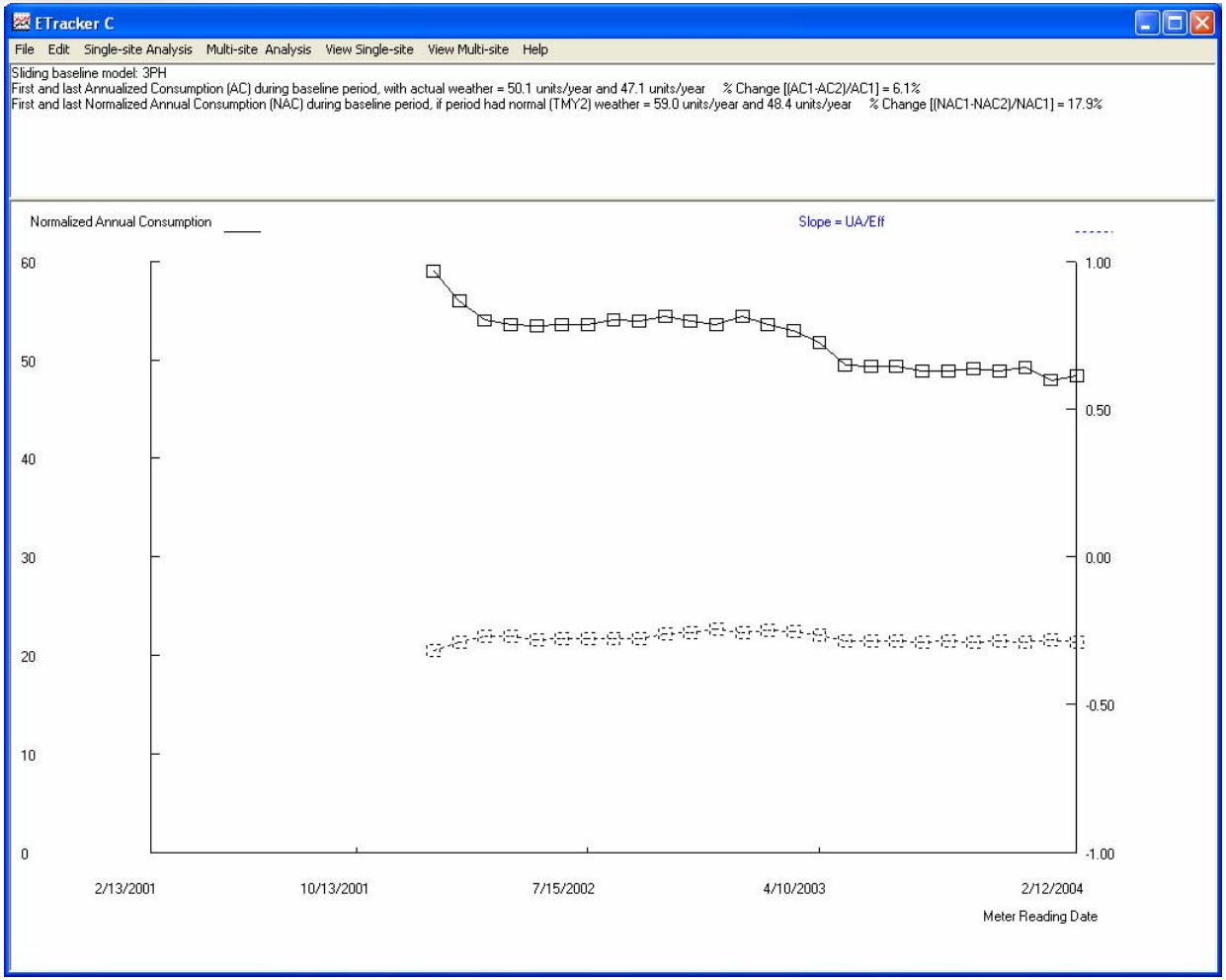
Past-Performance Benchmarking

- Track ‘Noiseless’ Performance with ‘Sliding NAC’ Analysis
- Calculate NAC for every twelve month period in data set.
- Change in NAC indicates change in building energy use characteristic
- Understand change in NAC by examining change in energy signature coefficients

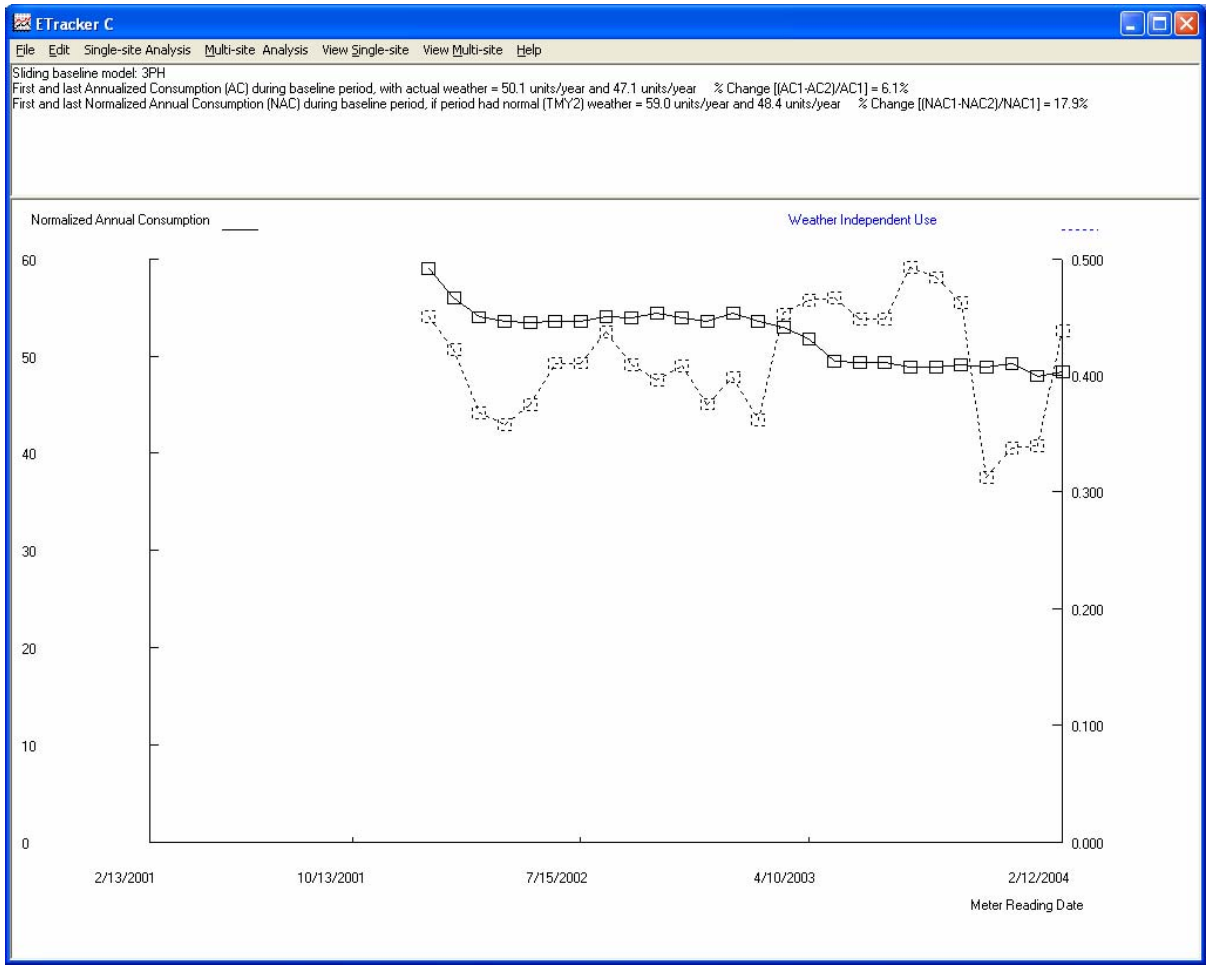
Sliding NAC:
Calc NAC for Every 12-month Period



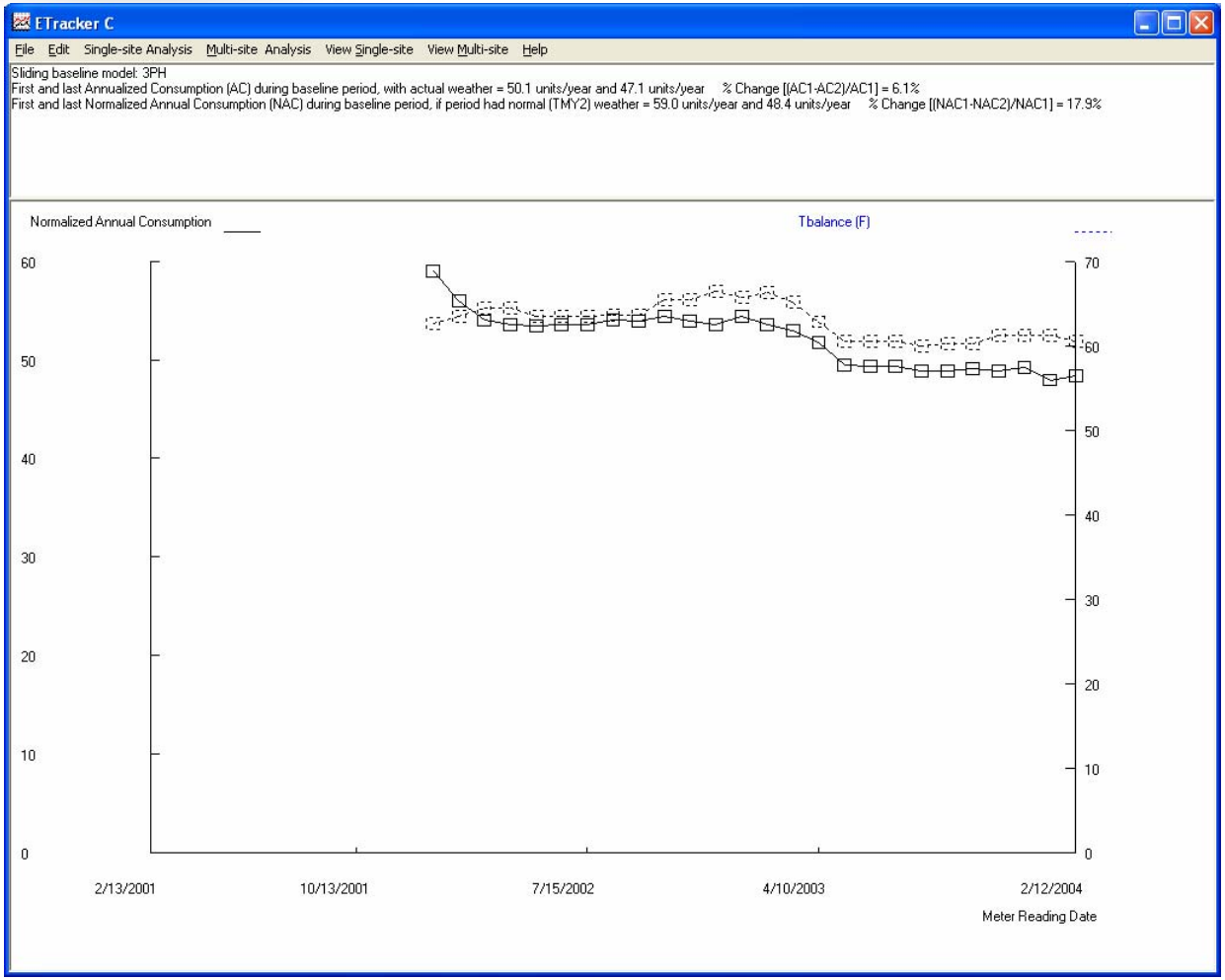
Sliding NAC and Heating Slope



Sliding NAC and Independent Fuel Use



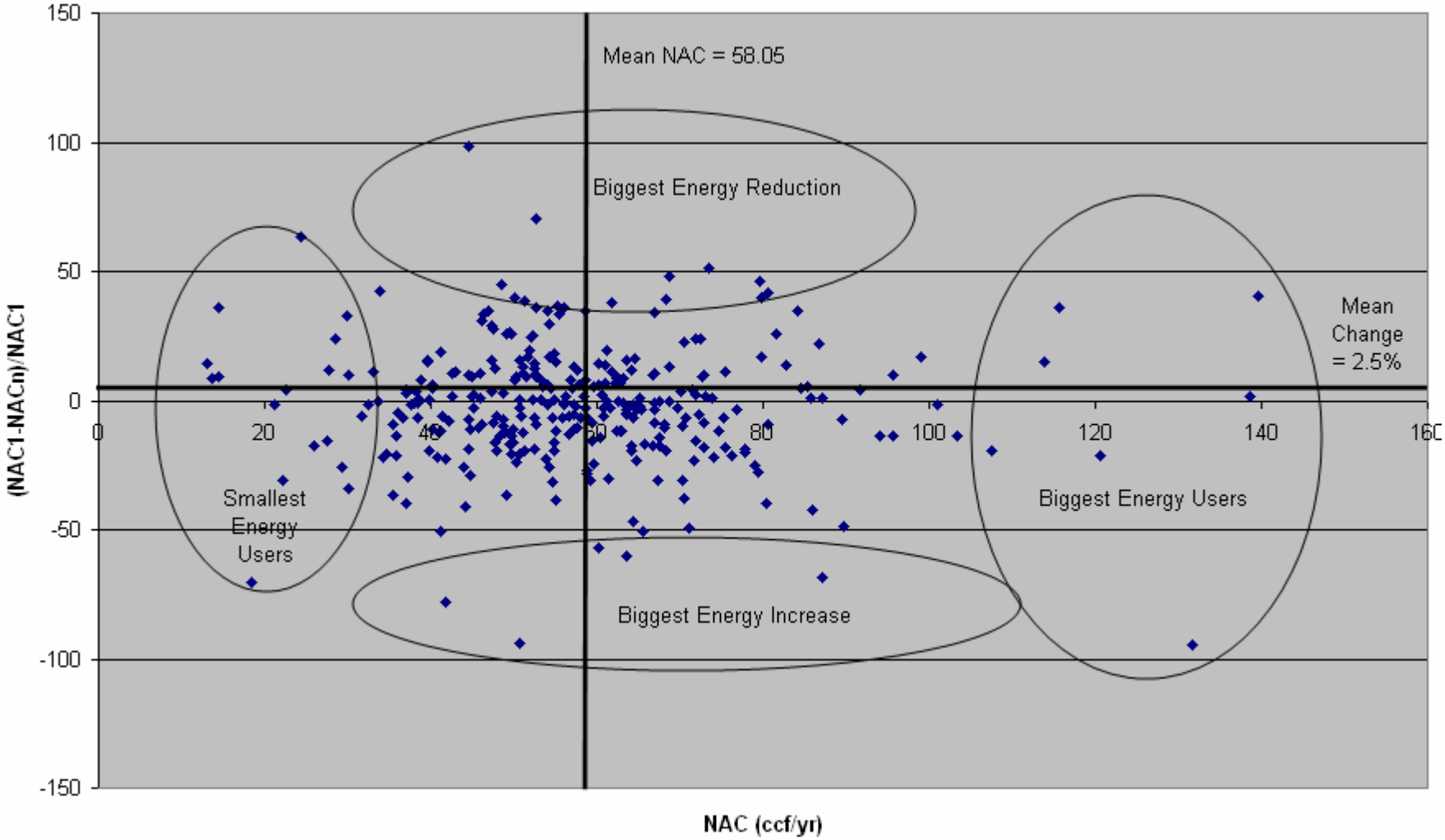
Sliding NAC and Balance Temperature



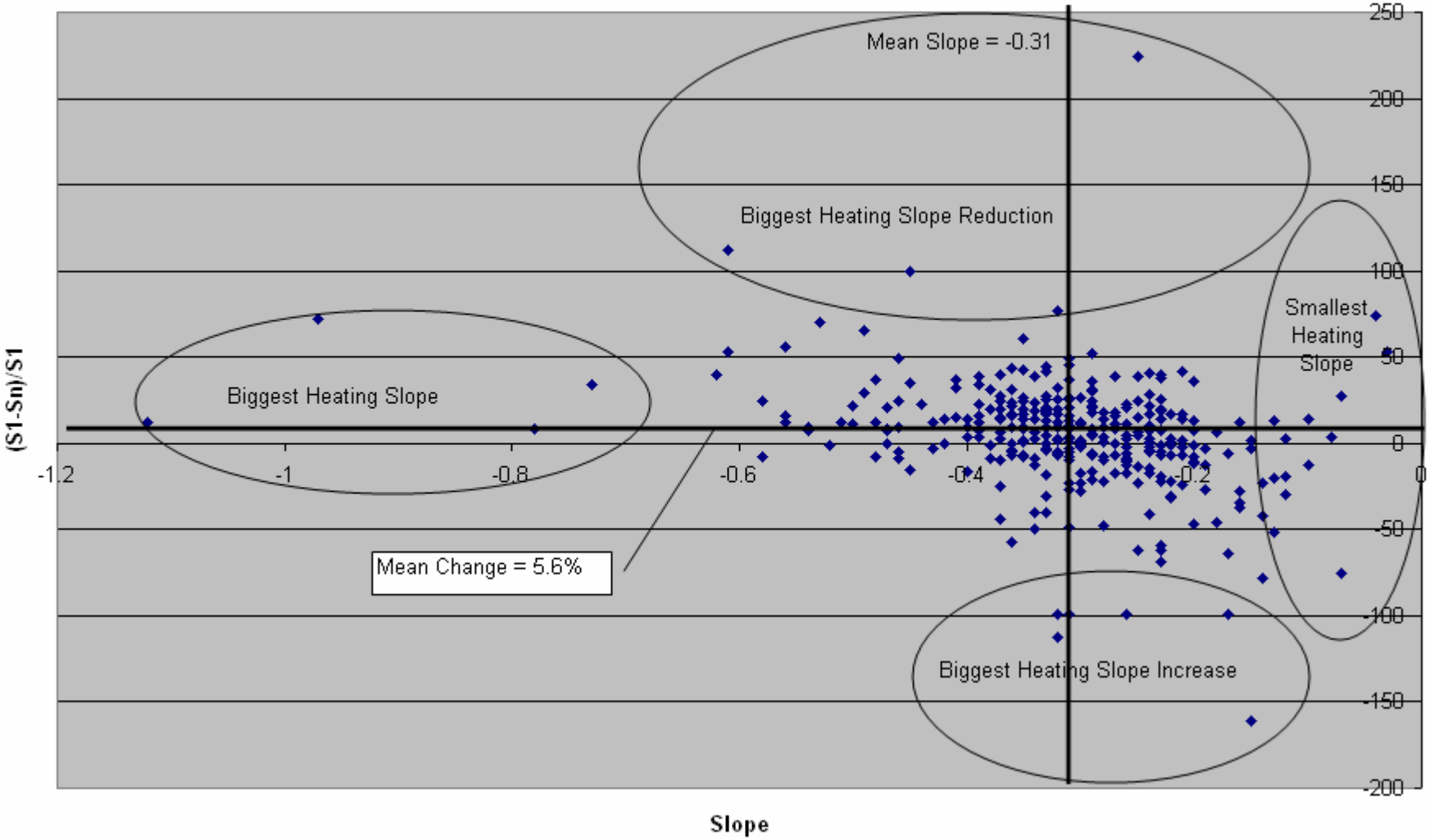
Multi-Facility Benchmarking

- Quantify average energy performance and distribution of energy performance across all sites
- Benchmark best/worst NAC and change in NAC
- Benchmark best/worst coefficients and change in coefficients

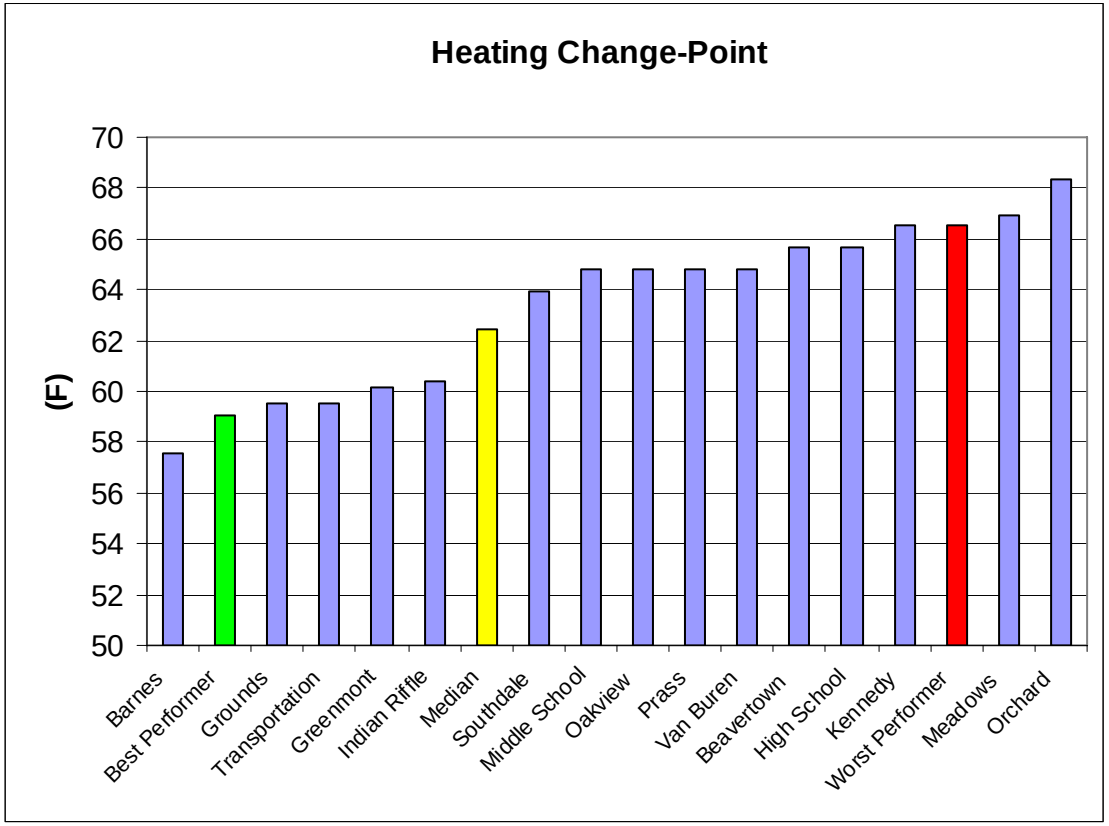
NAC and Change in NAC for 355 Sites



Slope and Change in Slope for 355 Sites



Benchmark Disaggregated Energy Performance



Let the Data Speak: Summary

- Characterize Performance with '**Energy Signature**' Model
  - 3PC-MVR or 3PH-MVR baseline model
  - Disaggregate energy use (Lean Energy Analysis)
  - Identify energy saving opportunities
  - Measure 'actual' savings

- Remove Noise with '**Normalized Annual Consumption**' NAC
  - Reveals true energy use characteristic of facility
  - Allows comparison of sites with different weather, sales, prod, etc.

- Track Performance with '**Sliding NAC**' Analysis
  - Identify problems/improvements when they happen
  - Understand nature of change with coefficient analysis

- Benchmark Performance with '**Multi-site Sliding NAC**' Analysis
  - Determine center and spread of NAC and coefficients
  - Benchmark best/worst NAC and change in NAC
  - Benchmark best/worst coefficients and change in coefficients

GO Sustainable Energy

Thank you!

questions to

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