



# Seminar 57 – Multiscale Building Energy Modeling

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Building Modeling and District System Optimization at Scale

# Learning Objectives

- Provide an overview of Urban Building Energy Model (UBEM) techniques and data sources
- Describe the use of regional building modeling as a forecasting tool
- Demonstrate the ability of 3D mapping techniques to provide wide-area geometrical information over urban and foliated scenes with evaluation of critical infrastructure (e.g. power line damage and flooding)
- Describe an approach for community-scale modeling using detailed whole-building energy models with use cases for district system optimization

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# Acknowledgements

US Army Corps of Engineers,  
Construction Engineering Research Laboratory (CERL)

- Dr. Michael Case
- Dr. Richard Liesen
- Dr. Matthew Swanson
- Dr. Alexander Zhivov

# Outline/Agenda

- Background
- Major Features
- Implementation and User Interface
- Demonstration Projects
- Conclusion

# Background

*SMPL Tool*

(System Master Planning Tool)

*NZP / Net Zero Planner*

US Army Corps of Engineers  
Construction Engineering Research Laboratory

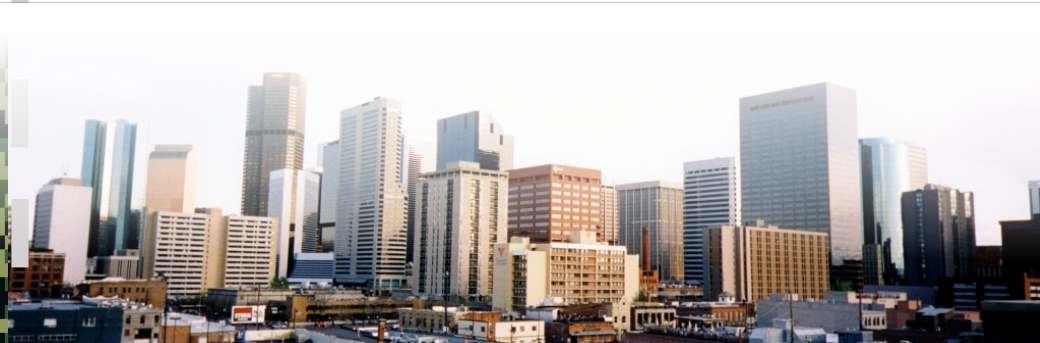
US Department of Defense



*District Zero*

Big Ladder Software LLC

Everyone else!



# Background

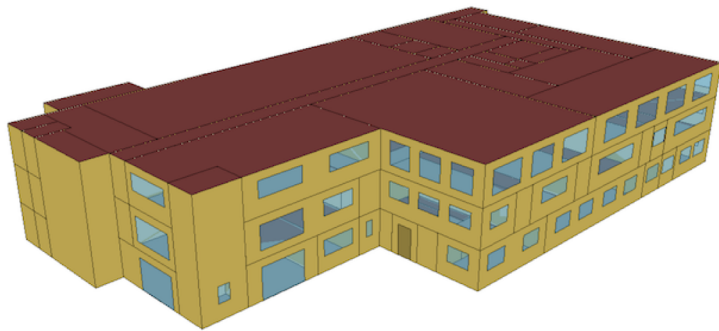
- Funded by DoD: 2011 – 2016
- Energy master planning
  - Army energy managers
  - Used on 60+ DoD installations
- Army bases and installations
  - 10,000 – 50,000 residents
  - Sparse building density
  - Standardized building designs
- Collaborative R+D: 2017 –

# Federal Energy Drivers

- EPAAct 2005
  - 30% site energy vs. ASHRAE 90.1-2004
- EISA 2007
  - By 2010: 55% source energy
  - By 2020: 80% source energy
  - By 2030: net zero energy
- 2017 –
  - Resiliency, security, reliability

# Major Features

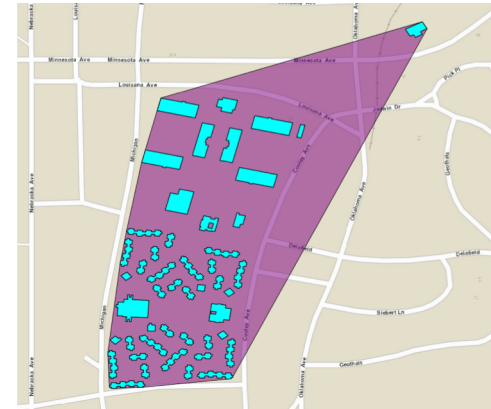
## Detailed Prototype Modeling



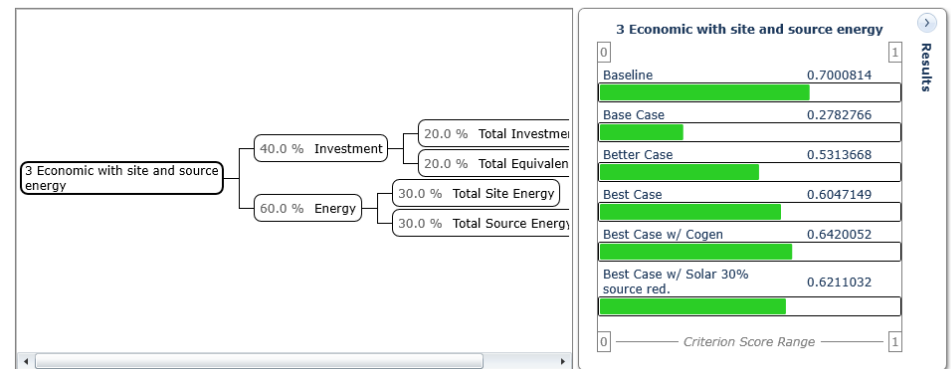
## Energy + Water + Waste



## District/Cluster Optimization

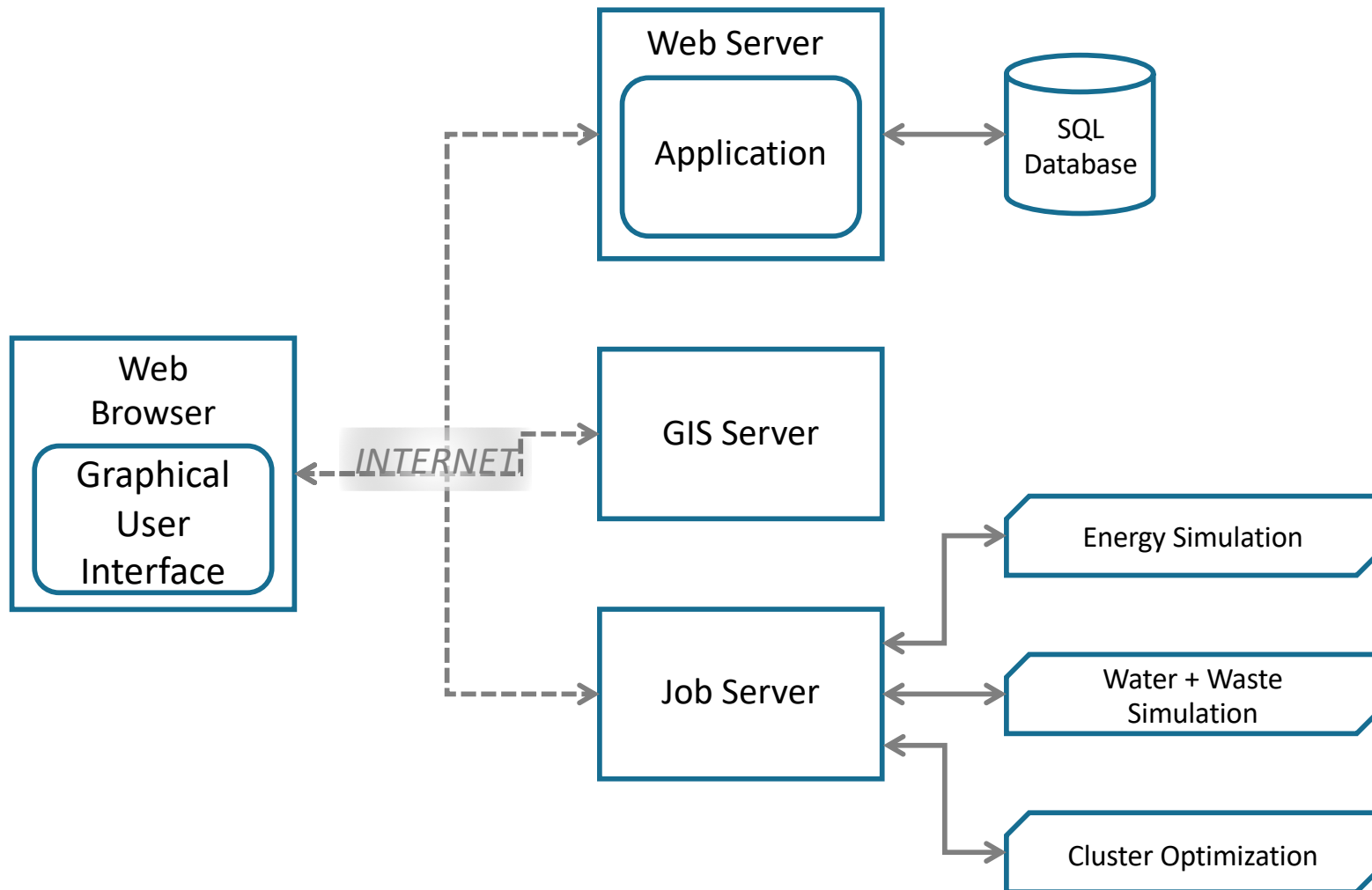


## Multi-Criteria Decision Analysis





# Software Architecture



# GIS View of Facilities

Available Facilities

New Selection Add to Selection Remove from Selection Clear Selection Delete Building Add Building Cancel Edits Save Edits

Street

Visually Group Plan Facilities Only

Facility Groups

Name	# Facilities	New
COF_2015021_1_10:30		
BNHQ_201502_11_10:30		
BdeHQ_20150_211_10:30		
Misc_2015021_1_10:30		
DFAC_201502_11_10:30		
BNHQ_201502_11_10:30		
Misc_2015021_1_10:30		
UEPH_201502_11_10:30		
Misc_2015021_1_10:30		
TEMF_201502_11_10:30		

Cancel Save

World Street Map ArmySiteLayer

# Table View of Facilities

[Study List](#)
[Study Information](#)
[Facility Loads](#)
[Installation or Subsection](#)
[Decision Analysis](#)
[Generate Reports](#)

[Details](#)
[Facilities](#)
[Rates](#)
[Consumption](#)
[Manage Users](#)
[Results](#)

## Study Inventory Facilities



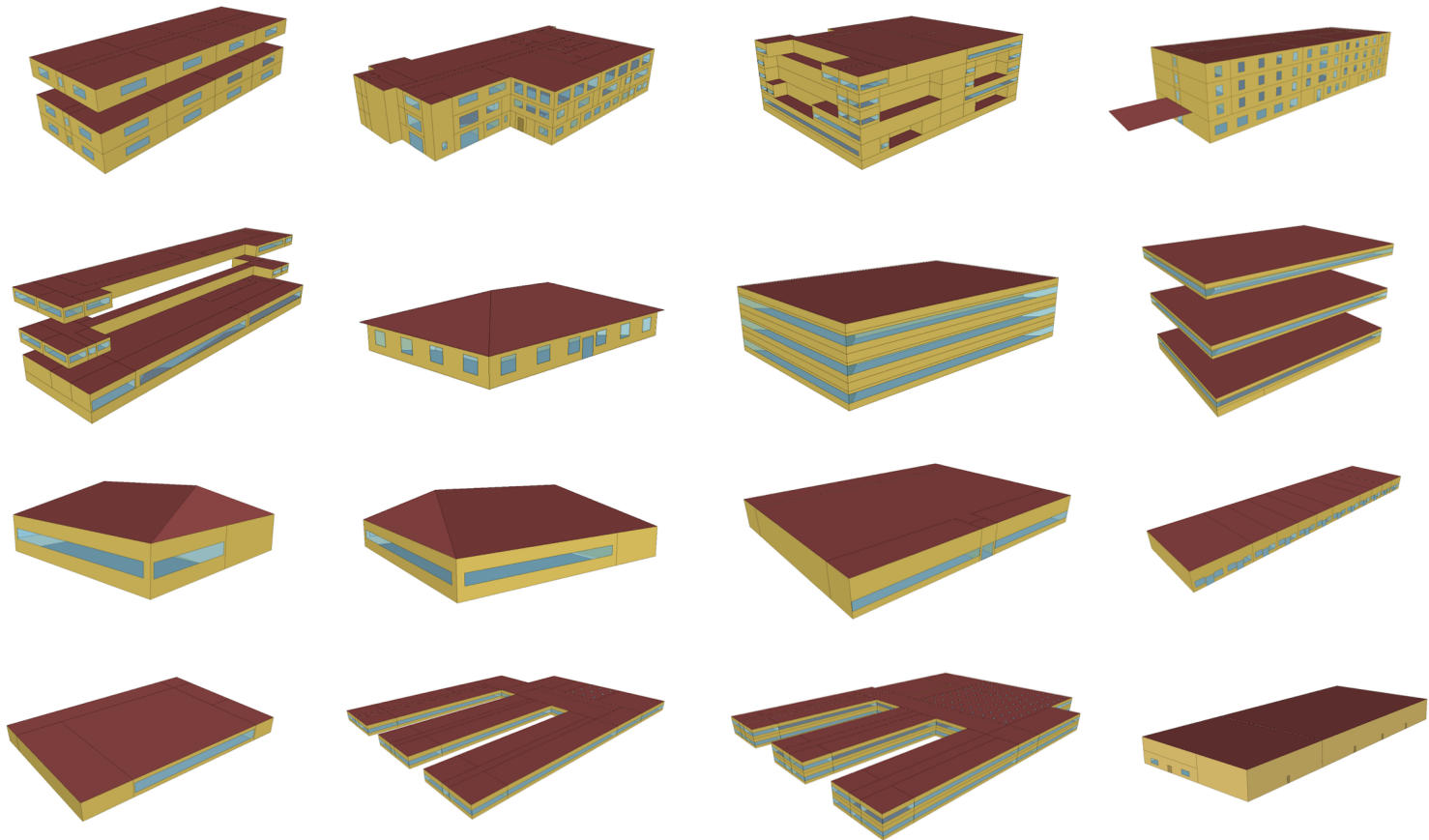
Master Facility List ▾

[Facility Group Summary](#)
[Facilities Summary](#)

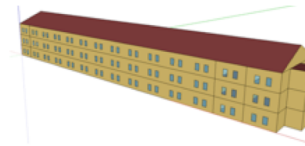
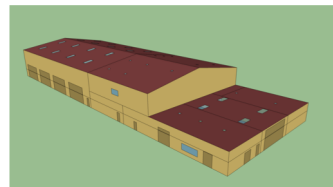
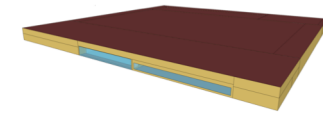
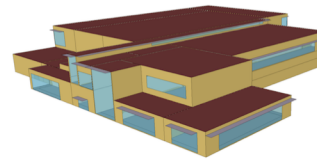
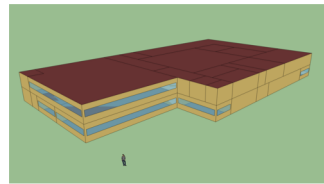
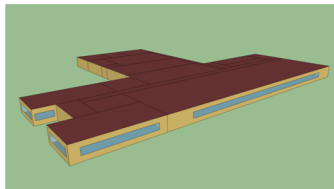
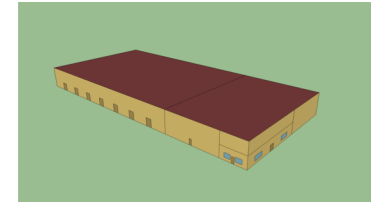
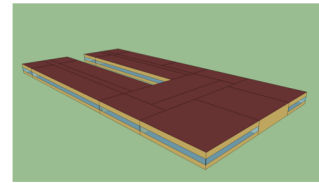
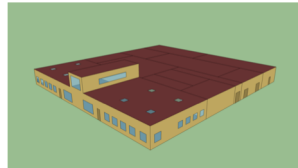
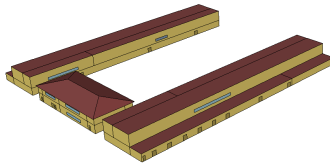
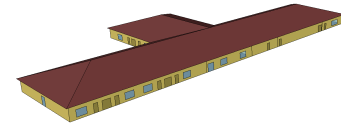
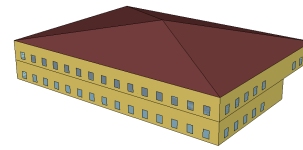
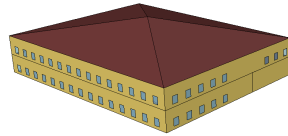
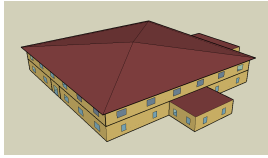
Drag a column header and drop it here to group by that column

Facility Group	Name	Number	Facility Type	Status	Active	Construction Date	Cond. Area (ft <sup>2</sup> )	Floors	Lif
BNHQ Existing Pre1980	ADMIN SPACE	1703	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	19,096	1	40
BNHQ Existing Pre1980	ADMIN SPACE FOR MARINE	1702	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	23,411	1	40
BNHQ Existing Pre1980	ADMIN GEN PURP	1705	BNHQ	Existing	<input checked="" type="checkbox"/>	1979	23,411	1	40
BNHQ Existing Pre1980	ADMIN	1706	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	23,437	1	40
BNHQ Existing Pre1980	ADMIN AREA FOR NAVY	1770	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	2,002	1	40
BNHQ Existing Pre1980	CALL FOR FIRE CLASSROOM	1750	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	12,929	1	40
BNHQ Existing Pre1980	CLASSROOM FOR MARINES	1721	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	2,002	1	40
BNHQ Existing Pre1980	ADMIN AREA FOR MARINES	1772	BNHQ	Existing	<input checked="" type="checkbox"/>	1979	2,002	1	40
BNHQ Existing Pre1980	CLASSROOM FOR MARINES	1760	BNHQ	Existing	<input checked="" type="checkbox"/>	1978	2,002	1	40
BdeHQ Existing Pre1980	GYMNASIUM	1714	BdeHQ	Existing	<input checked="" type="checkbox"/>	1979	16,784	2	40
DFAC Existing Pre1980	FAST FOOD BAR	1711	DFAC	Existing	<input checked="" type="checkbox"/>	1978	4,739	1	40
DFAC Existing Pre1980	ENL PERS DINE, EDP	1740	DFAC	Existing	<input checked="" type="checkbox"/>	1979	22,919	1	40
DFAC Existing Pre1980	DINING FACILITY	N/A	DFAC	Existing	<input checked="" type="checkbox"/>	2015	41,764	1	40
BNHQ Existing Post1980	UNIT CHAPEL	1712	BNHQ	Existing	<input checked="" type="checkbox"/>	1980	9,050	1	40
UEPH Existing Pre1980	ITRO TRAINEE BKS, NAVY	1768	UEPH	Existing	<input checked="" type="checkbox"/>	1978	11,343	3	40
UEPH Existing Pre1980	MARINE ITRO BARRACKS	1726	UEPH	Existing	<input checked="" type="checkbox"/>	1979	11,343	3	40
UEPH Existing Pre1980	PERM PARTY BARRACKS	1730	UEPH	Existing	<input checked="" type="checkbox"/>	1978	11,343	3	40
UEPH Existing Pre1980	ITRO TRAINEE BKS, AIR FOR	1725	UEPH	Existing	<input checked="" type="checkbox"/>	1978	11,343	3	40
UEPH Existing Pre1980	RESERVE COMP BARRACKS	1722	UEPH	Existing	<input checked="" type="checkbox"/>	1978	11,343	3	40
UEPH Existing Pre1980	ITRO STUDENTS, AIR FORCE	1729	UEPH	Existing	<input checked="" type="checkbox"/>	1978	24,664	3	40
UEPH Existing Pre1980	PERM PARTY BKS, 1 ENG BDE	1731	UEPH	Existing	<input checked="" type="checkbox"/>	1979	11,343	3	40

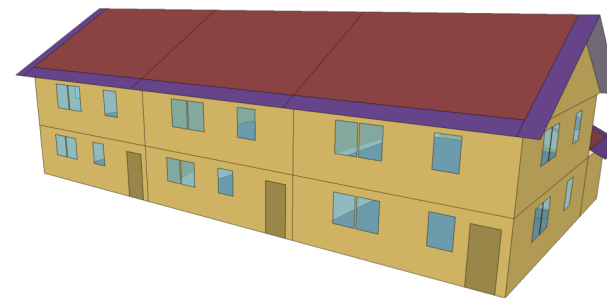
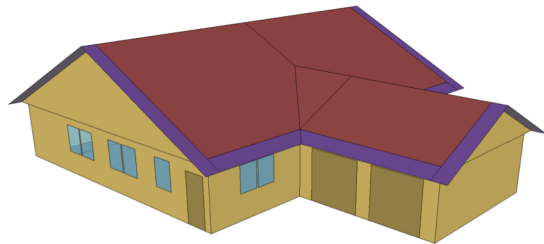
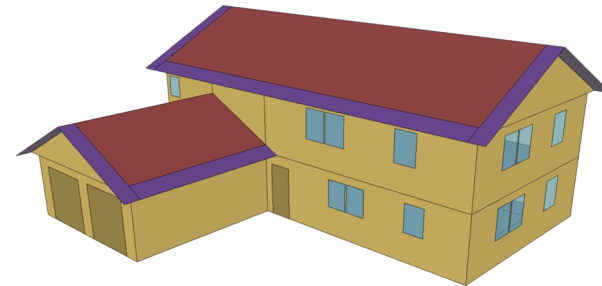
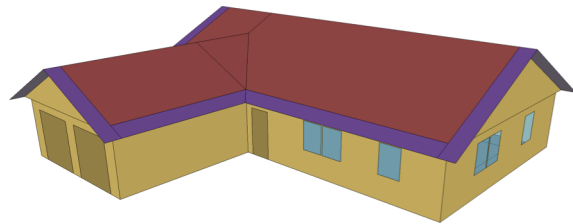
# Commercial Prototype Models



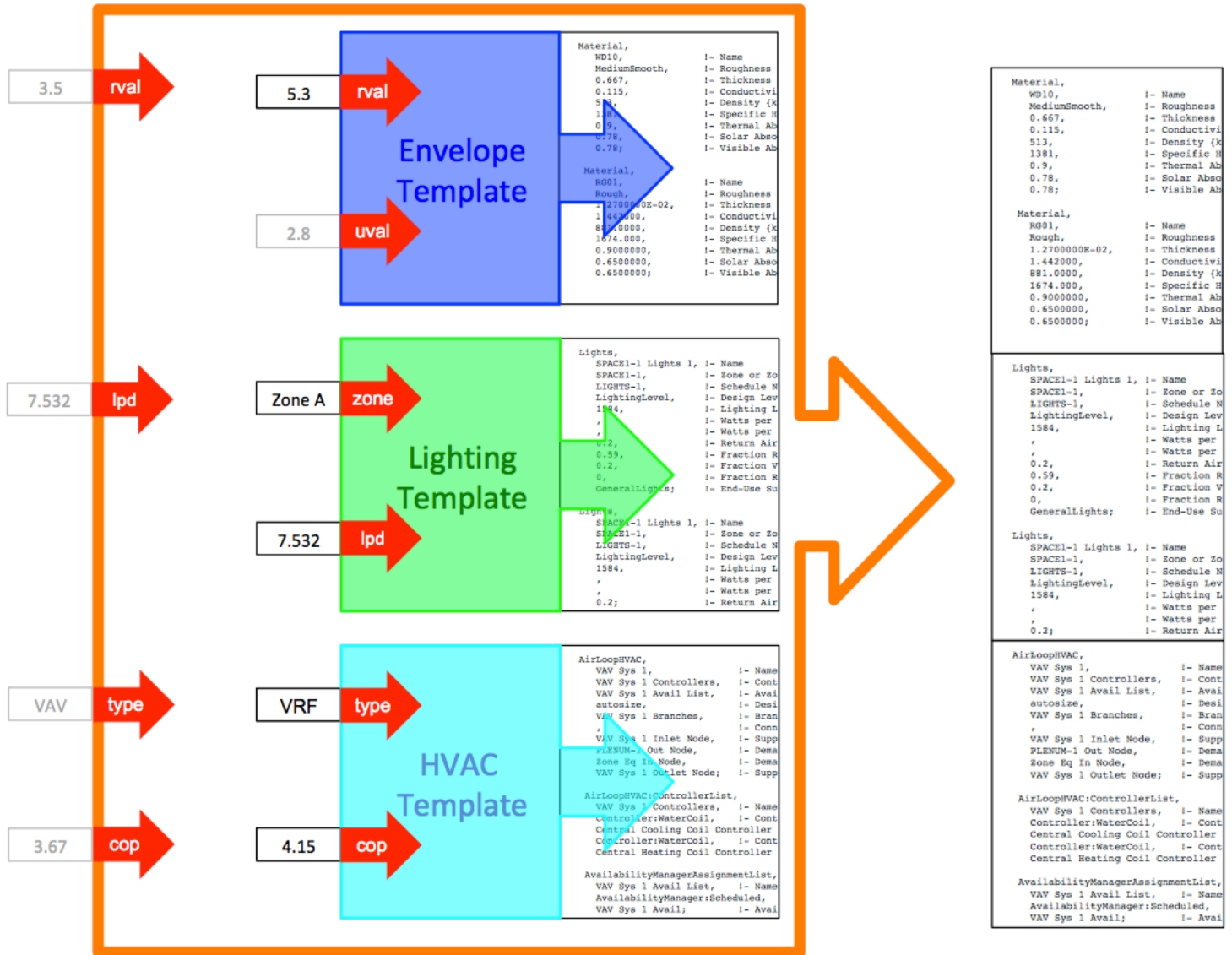
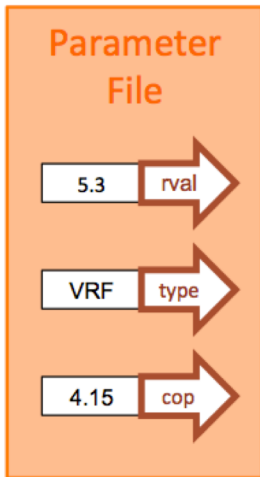
# US Army Prototype Models



# Residential Prototype Models



# Parametric Template System



# Flexible Template Library

## Zone Loads

- Classroom
- Corridor
- Fitness
- Kitchen
- Lobby
- Office
- Residence
- Restroom
- Retail
- Storage
- and more...

## Zone HVAC

- Air-Source HP
- Baseboard Heat
- Chilled Beam
- DOAS Terminal
- Fan Coil Unit
- PTAC
- Radiant Slab
- VAV Terminal
- VRF Terminal
- Window AC
- and more...

## Systems

- CAV
- Chilled Water
- DHW
- DOAS
- Dual Duct
- Ground HX
- Heat Rejection
- Hot Water
- VAV
- VRF
- and more...



# Parameter Values for Baseline Models

Study List | Study Information | **Facility Loads** | Installation or Subsection | Decision Analysis | Generate Reports

Details | **Input** | Simulation | Package Selection | Results

● Packages Defined ● Custom Spaces Defined Focus: Energy Alternative: Baseline

Baseline BdeHQ Existing Pre1980 Baseline Cost

Install Cost 0.00 \$/sqft

Baseline BdeHQ Existing Pre1980 Baseline Parameters

Enhancements & Cost

Save Changes

Enhancements

- BdeHQ Existing Pre
- BNHQ Existing Post
- BNHQ Existing Pre1
- COF Existing Pre19
- DFAC Existing Pre1
- TEMF Existing Pre1
- UEPH Existing Pre1

Name	Default Value	Value	Unit	Description
> Full-Slab Insulation	0.0	0.0	R	Full-slab insulation R-value
Slab Horizontal Insulation	0.0	0.0	R	Slab horizontal insulation R-value
Slab Horizontal Insulation Width	2.0	2.0	ft	Slab horizontal insulation width
Slab Vertical Insulation	0	0	R	Slab vertical insulation R-value
Slab Vertical Insulation Depth	2.0	2.0	ft	Slab vertical insulation depth
Roof Base Type	Insulation Entirely Above Deck	Insulation Entirely Above Deck		Roof base type
Roof Reflectance	0.3	0.3		Reflective property of roof surface
Roof Emittance	0.85	0.85		Emittance property of roof surface
Roof Base Cavity Insulation	0	0	R	Roof base cavity insulation R-value
Roof Base Continuous Insulation	10.848	10.848	R	Roof base continuous insulation R-value
Roof Exterior Type	Roof Membrane	Roof Membrane		Roof exterior type
Roof Interior Type	Metal Decking	Metal Decking		Roof interior type
Wall Base Type	Concrete MW Solid Grouted	Concrete MW Solid Grouted		Wall base type
Wall Base Cavity Insulation	0	0	R	Wall base cavity insulation R-value

# Parameter Values for Efficiency Packages

Study List | Study Information | **Facility Loads** | Installation or Subsection | Decision Analysis | Generate Reports

Details | **Input** | Simulation | Package Selection | Results

● Packages Defined ● Custom Spaces Defined Focus: Energy Alternative: Basecase

Basecase BdeHQ Existing Pre1980 Envelope Package Cost

Install Cost 4.00 \$/sqft

Basecase BdeHQ Existing Pre1980 Passive House Insulation Parameters

Name	Default Value	Value	Unit	Description
Wall Base Type	Steel Framing at 16 in. on center	Steel Framing at 16 in. on center		Wall base type
Wall Base Cavity Insulation	19	19	R	Wall base cavity insulation R-value
Wall Base Continuous Insulation	25	25	R	Wall base continuous insulation R-value
Roof Base Type	Insulation Entirely Above Deck	Insulation Entirely Above Deck		Roof base type
Roof Base Cavity Insulation	0	0	R	Roof base cavity insulation R-value
Roof Base Continuous Insulation	45	45	R	Roof base continuous insulation R-value
Slab Vertical Insulation	15	15	R	Slab vertical insulation R-value
Slab Vertical Insulation Depth	2	2	ft	Slab vertical insulation depth
Window U-Value	0.35	0.35	U	Window U-value
Window SHGC	0.35	0.35	SHGC	Window solar heat gain coefficient

Enhancements & Cost

- BdeHQ Existing Pre
  - Lighting Package
    - High-Efficiency...
  - Equipment Package
    - High-Efficiency...
  - Infiltration Package
    - Reduced Infiltration Vestibule
  - HVAC Package
    - High-Efficiency Chiller
    - High-Efficiency Boiler
    - High-Efficiency...
    - Supply Temperature...
    - Reduced Duct...
  - CoolRoof Package
    - Cool Roof
  - Daylighting Package
    - Daylighting Controls
  - Envelope Package
    - Passive House...

# Building Energy Results

[Study List](#)
[Study Information](#)
[Facility Loads](#)
[Installation or Subsection](#)
[Decision Analysis](#)
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[Details](#)
[Input](#)
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Instructions

Energy Reports

- Cost Optimization Curve
- Debug Report
- Demand By End Use
- Demand Intensity By End Use
- Energy By End Use
- Energy Intensity By End Use**
- Load Duration Curve
- Package Parameter Summary
- Package Parameters
- Site Summary
- Source Summary

Facilities

- BdeHQ Existing Pre1980
- BNHQ Existing Post1980
- BNHQ Existing Pre1980
- COF Existing Pre1980
- DFAC Existing Pre1980
- TEMF Existing Pre1980
- UEPH Existing Pre1980

Energy Utilities

- Electric Company
- Gas Company

Water Utilities

Waste Utilities

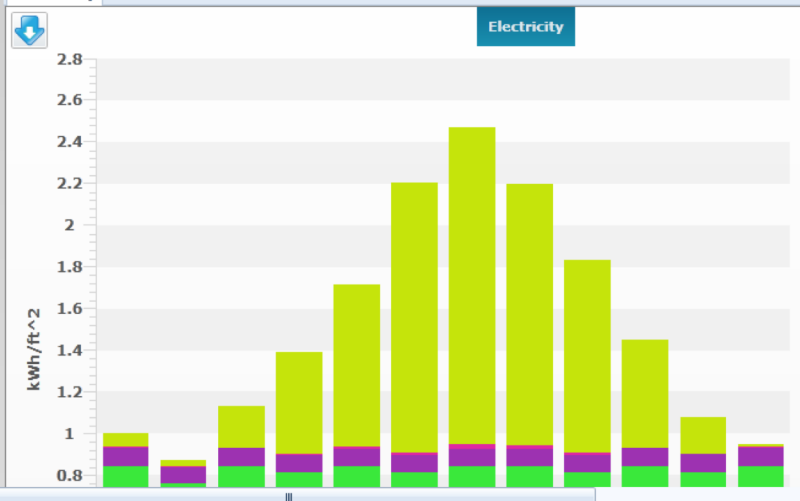
Area: 
 Electricity: 
 Gas: 
 Common:

Alternative	Facilities	Total Area (ft^2)	Annual EUI (kWh/ft^2)
Baseline	46	704,622	31.76
Basecase	46	704,622	31.76

Details Site Use

Facility Group	Facilities	Total Area (ft^2)	Annual EUI (kWh/ft^2)
BdeHQ Existing Pre1980	1	16,784	20.87
BNHQ Existing Post1980	1	9,050	15.56
BNHQ Existing Pre1980	10	119,840	16.58
COF Existing Pre1980	2	37,458	15.20
DFAC Existing Pre1980	2	27,658	82.55
TEMF Existing Pre1980	2	16,527	18.50
UEPH Existing Pre1980	28	477,305	35.07

Electricity Gas Details Total Resource Breakdown



# Building Energy Results

Study List | Study Information | Facility Loads | Installation or Subsection | Decision Analysis | Generate Reports

Details | Input | Simulation | Package Selection | Results

Instructions

Energy Reports

Cost Optimization Curve

Debug Report

Demand By End Use

Demand Intensity By End Use

Energy By End Use

Energy Intensity By End Use

Load Duration Curve

Package Parameter Summary

Package Parameters

Site Summary

Source Summary

Facilities

BdeHQ Existing Pre1980  
 BNHQ Existing Post1980  
 BNHQ Existing Pre1980  
 COF Existing Pre1980  
 DFAC Existing Pre1980  
 TEMF Existing Pre1980  
 UEPH Existing Pre1980

Energy Utilities

Electric Company  
 Gas Company

Water Utilities

Waste Utilities

Area: ft^2 | Electricity: kWh/ft^2 | Gas: therm/ft^2 | Common: kWh/ft^2

Alternative	Facilities	Total Area (ft^2)	Annual EUI (kWh/ft^2)
Baseline	46	704,622	31.76
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Details | Site Use

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Electricity | Gas | Details | Total Resource Breakdown

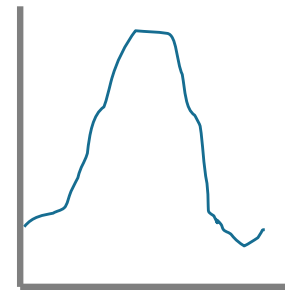
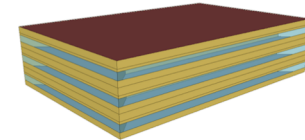
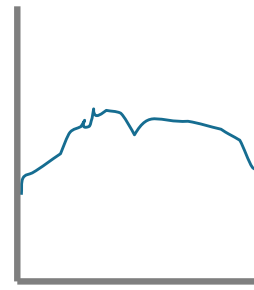
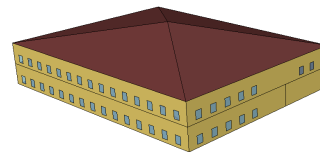
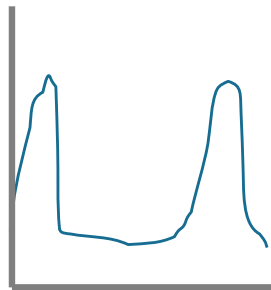
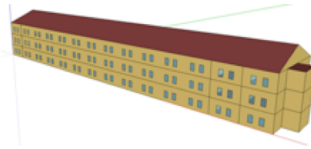
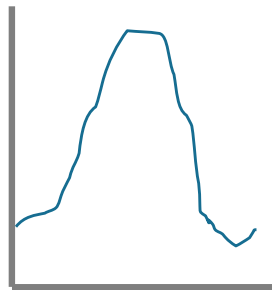
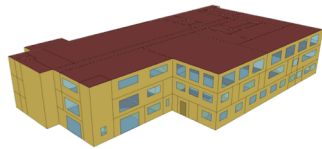
Legend

- INTERIORLIGHTS
- INTERIOREQUIPM
- FANS
- PUMPS
- COOLING
- HEATING
- WATERSYSTEMS

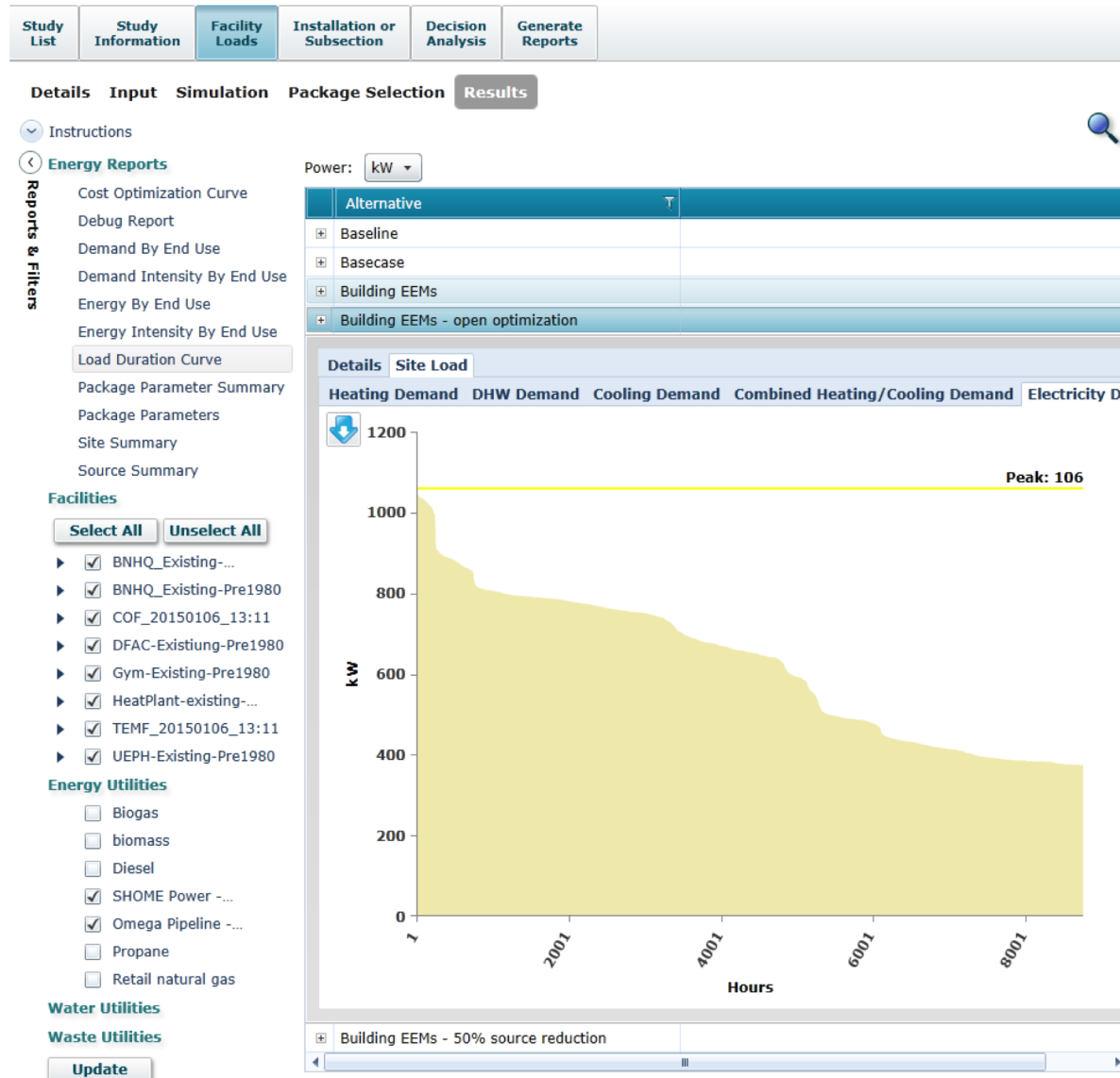
Annual Total: 35.07 kWh/ft^2

46	704,622	31.76
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# Load Profile Aggregation



# Load Duration Curve

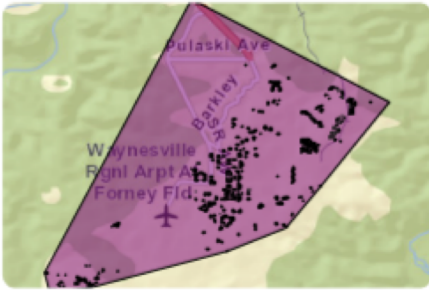

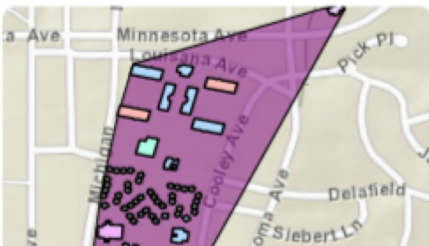


# District/Cluster Selection

List View Grid View Facility Report Map View

Page 1 of 1

Search

	<p><b>Remaining Buildings</b> N/A Number of Buildings: 403 Ground Coverage: 311,912,512 sqft Total Electrical Load: 65,161,264 kWh/Yr Total Space Heating Load: 29,428,604 kWh/Yr Total DHW Load: 24,905,866 kWh/Yr Total Cooling Load: 41,729,232 kWh/Yr Total Heating Load Density: 0.17 kWh/Yr/sqft Total Cooling Load Density: 0.13 kWh/Yr/sqft</p>	<p><a href="#">View</a></p> <p><a href="#">Delete</a></p>
	<p><b>South Cluster</b> N/A Number of Buildings: 23 Ground Coverage: 6,570,904 sqft Total Electrical Load: 7,428,096 kWh/Yr Total Space Heating Load: 4,669,444 kWh/Yr Total DHW Load: 3,631,677 kWh/Yr Total Cooling Load: 4,612,399 kWh/Yr Total Heating Load Density: 1.26 kWh/Yr/sqft Total Cooling Load Density: 0.70 kWh/Yr/sqft</p>	<p><a href="#">View</a></p> <p><a href="#">Delete</a></p>
	<p><b>Specker Cluster</b> N/A Number of Buildings: 46 Ground Coverage: 2,917,875 sqft Total Electrical Load: 8,502,343 kWh/Yr Total Space Heating Load: 5,107,636 kWh/Yr Total DHW Load: 6,083,471 kWh/Yr Total Cooling Load: 6,002,746 kWh/Yr Total Heating Load Density: 3.84 kWh/Yr/sqft</p>	<p><a href="#">View</a></p> <p><a href="#">Delete</a></p>

# Equipment Selection for Optimization

Study List   Study Information   Building Optimization   **Installation or Subsection**   Decision Analysis   Generate Planning Forms   Developmental User

Details   Cluster   Networks   **Equipment & Measure**   Constraints   Optimization   Results

### Building EEMs Realistic with AIT Barracks added Alternative Clusters

● Equipment Defined (Input\Output Device)   ● Equipment Defined (Storage Device)

Instructions

Baseline   Base Case   Building EEMs High   Building EEMs Realistic   **Building EEMs Realistic with AIT Barracks added**   Building EEM

Save Changes

Clusters

- Remaining Buildings
- South Cluster
- Specker Cluster**
- West Cluster

Equipment	Type	Name	Max Num.	Max Power	Input
Click here to add new item					
45	ORC	ORC_LOW	10	280	200_
46	ACBus	ACBus1	5	20000	EtoBt
47	HeatE	HeatE1	10	10000	800_
48	CoolLoad	CoolingLoad1	1	9999999	Distri
49	HeatLoadHotwater	HWFedHeatingLoad1	1	9999999	Distri
50	Boilers	DistBoilersSolution	1	999999	Retai
51	Elec_Chill	DistElec_Chills	1	999999	Efron
52	PhotoVolt	PhotoVolt14kW	10	100000	Solar
53	PhotoVolt	PhotoVolt140kW	10	100000	Solar
54	PhotoVolt	PhotoVolt1400kW	10	100000	Solar



# Equipment Types



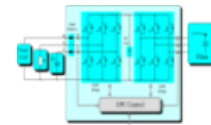
Electric Chiller



Diesel Generator



Photovoltaic



AC Bus



Absorption Chiller



Fuel Cell



Gas Boiler



Wind Turbine



Organic Rankine Cycle



Gas Turbine



Electric Heater

# Constraints for Optimization

Study List | Study Information | Facility Loads | **Installation or Subsection** | Decision Analysis | Generate Reports

Details | Cluster & Networks | Equipment & Measures | **Constraints** | Optimization | Results

## Baseline Clusters

● Constraints Defined

▼ Instructions



**Baseline** | Base Case | Base Case Buildings with Specker Replacement | Building EEMs High | Building EEMs Realistic | Building EEMs I

Clusters

Save Changes

- Remaining Building
- South Cluster
- Specker Cluster
- West Cluster

### Baseline Remaining Buildings Constraints and Basic Economic Values

#### Energy Security

Critical Electric Maximum Load: 0.00 kW

#### Environmental / Renewable (Annual)

Renewable Target (disabled): 0.00 %

Max. Carbon Footprint: 100,000,000.00 metric tons of CO2

#### Basic Economic Values

Project Lifetime: 0.00 YY

Int. Rate: 5.00 %

#### Electrical Requirements

Net Metering Allowed:

#### Miscellaneous

Maximum Investment Cost: 1,000,000,000.00 \$

Maximum Source Energy: 10,000,000,000.00 kWh

Maximum Combustables: 10,000,000,000.00 kWhs (~1.23 kWhs/lb or 2460 kWhs/Ton)

#### Redundancy Type

##### Heating

N + 1 Redundancy

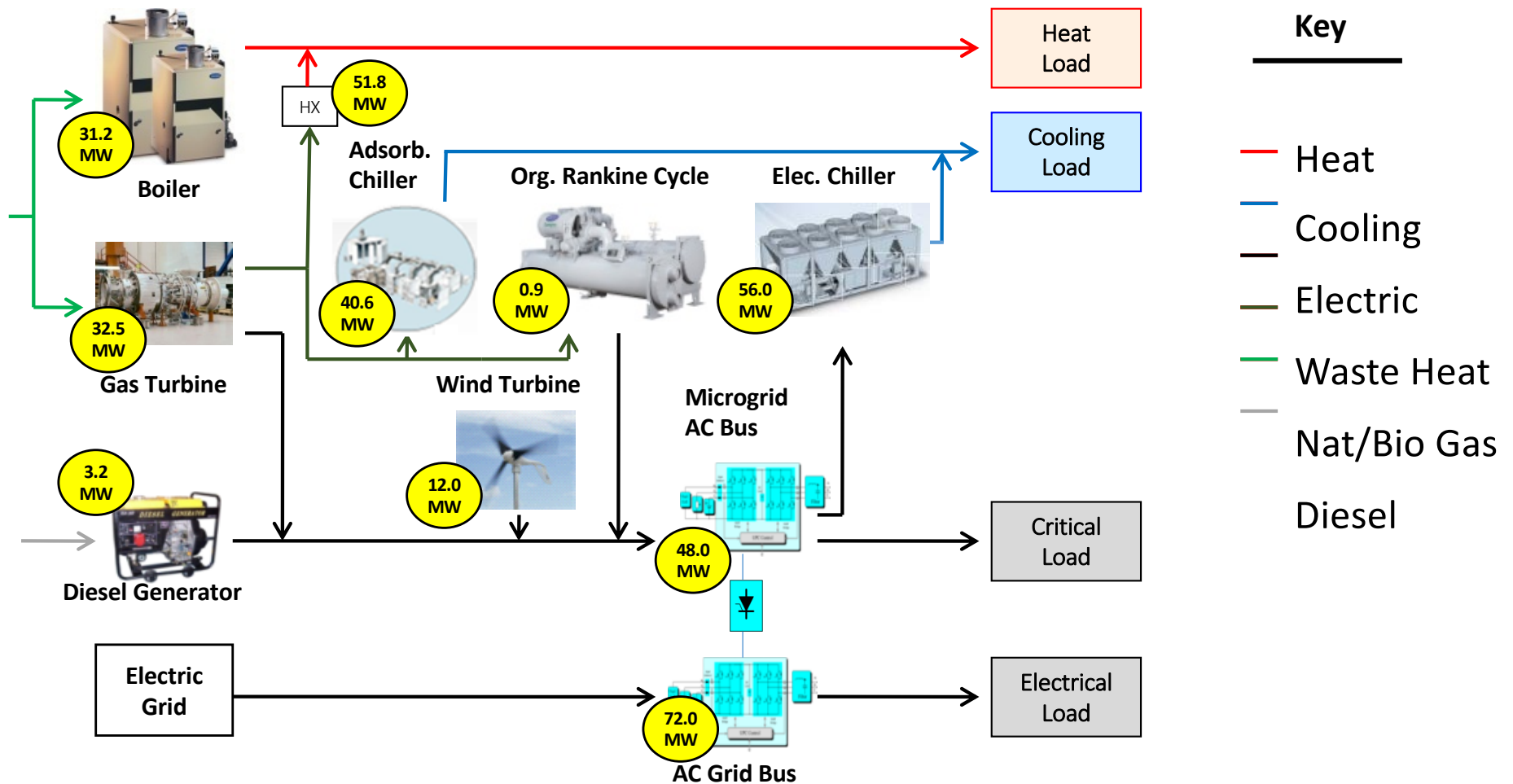
Additional Capacity: 1.00

##### Cooling

N + 1 Redundancy

Additional Capacity: 1.00

# Equipment Selection and Sizing



# District/Cluster Energy Results

Study List Study Information Building Optimization **Installation or Subsection** Decision Analysis Generate Planning Forms

Details Cluster Networks Equipment & Measure Constraints Optimization **Results**

## Installation Results - Energy Comparison

Instructions

Reports

Reports

Annual Energy Comparison

Energy Overview

Equipment Overview

Energy: kWh Power: kW

	Study Plan	Natural Gas (kWh)	Peak Natural Gas (kW)	Electricity (kWh)	Pe
+	Base Case	123,771,232	139,420	140,980,944	34
+	Baseline	110,828,536	128,586	114,134,760	29
+	Building EEMs High	74,824,808	83,670	97,613,848	25
+	Building EEMs Realistic	110,502,064	119,182	113,842,288	28
+	Building EEMs Realistic with AIT Barracks added	110,455,888	117,735	113,228,744	28
+	Building EEMS Realistic with AIT Barracks MTHW	145,015,104	123,478	113,307,272	27

# District/Cluster Equipment Results

Study List   Study Information   Building Optimization   **Installation or Subsection**   Decision Analysis   Generate Planning Forms

Details   Cluster   Networks   Equipment & Measure   Constraints   Optimization   **Results**

## Installation Results - Equipment Overview

Instructions

Reports

Reports

Annual Energy Comparison

Energy Overview

Equipment Overview

Alternative	Devices
Base Case	20
Baseline	20
Building EEMs High	113
Building EEMs Realistic	110
Building EEMs Realistic with AIT Barracks added	116

Cluster	Devices
Remaining Buildings	64
South Cluster	17
Specker Cluster	21

Equipment	Max Power	Unit	Devices
ACBus1	20,000	kW	1
Air_Elec_Chill_2	352.00	kW	1
Air_Elec_Chill_4	1,055	kW	1
Boil0	100.00	kW	2
Boil2	2,500	kW	2
ExistingBoilers	6,956	kW	2
ExistingElChillers	3,340	kW	2

# Multi-Criteria Decision Analysis

## Decision Analysis - MCDA Model Details

Close the MCDA Model

MCDA Model: 3 Economic with site and source energy

Name: 3 Economic with site and source energy

Description:

Created: Liesen, Richard (5/26/2016 11:14)

Modified: Liesen, Richard (6/28/2016 15:54)

Access Level: Edit Model Structure, Value Functions and Weights

Rank	Alternative Name	MCDA Score
1	Baseline	0.7000814
2	Best Case w/ Cogen	0.6420052
3	Best Case w/ Solar 30% source red.	0.6211032
4	Best Case	0.6047149
5	Better Case	0.5313668
6	Base Case	0.2782766

Criteria Tree

Properties | Sensitivity Analysis | Rename | Move Up | Cut | Delete | Paste as a Sub Criterion | Add New | Move Down | Copy | Paste

\* Display Local Weights  Highlight Errors

3 Economic with site and source energy

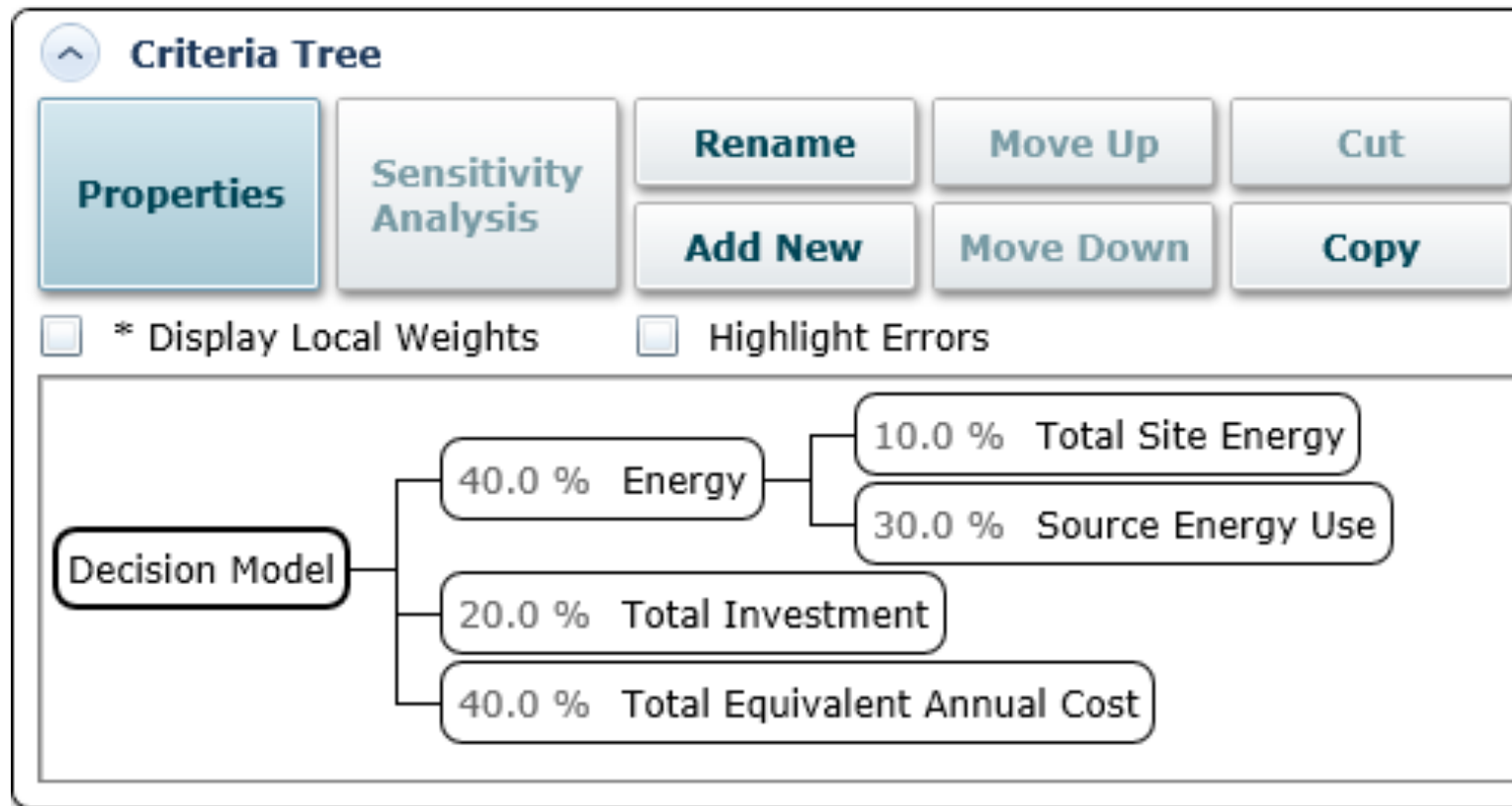
- 40.0 % Investment
  - 20.0 % Total Investment
  - 20.0 % Total Equivalent
- 60.0 % Energy
  - 30.0 % Total Site Energy
  - 30.0 % Total Source Energy

3 Economic with site and source energy Results

Baseline	0.7000814
Base Case	0.2782766
Better Case	0.5313668
Best Case	0.6047149
Best Case w/ Cogen	0.6420052
Best Case w/ Solar 30% source red.	0.6211032

0 — Criterion Score Range — 1

# Criteria Tree



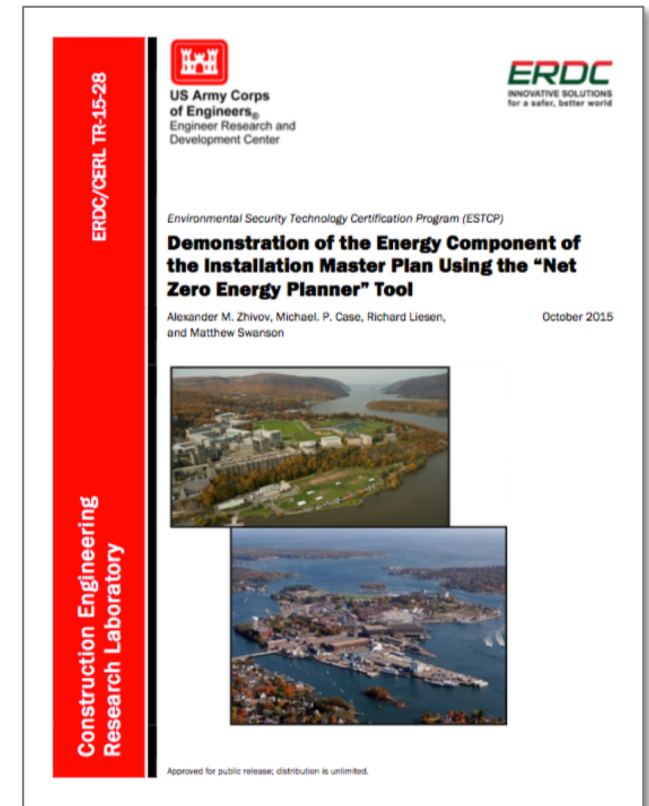
# Demonstration Projects

US Military Academy, West Point (New York)  
 Portsmouth Naval Shipyard (Maine)

- 60-70% Cost Savings
- 68-75% Time Savings

Table 6-1. Cost summary for analysis using the SME and NZP.

Installation	Number of Buildings	Number of Building Categories	Time Required		Cost of Data Analysis Using, \$1000	
			SME	NZP	SME	NZP
USMA, West Point	45	11	5 months	5 wks	167	50
PNSY	127	22	4 months	5 wks	130	50





# Beta Testing

- Master Planning Client
- Marine Corps Installation
  - 100+ Buildings in Study
  - Energy Audit Data
  - GIS Data Import
- Successful Result for Client
  - Learning and Feedback
  - Bumps in the Road

# Current Activities

- Complete Redesign + Rewrite of User Interface
  - Environmental Security Technology Certification Program (ESTCP) grant
  - Microsoft Silverlight → Modern JavaScript
- Adding Resiliency Analysis
  - IEA Energy in Buildings and Communities, Annex 73 – Towards Net Zero Energy Public Communities
- More Beta Testing

# Conclusion

- Functional, Research-Grade Tool
  - 60+ Installations
  - Demonstrated Cost/Time Savings of 60-70%
- Deficiencies and Gaps
  - Must Be Domain Expert
  - Not User Friendly
  - Missing Features
  - Addressing These in Redesign + Rewrite

# Bibliography

- Case, Michael, Richard Liesen, Alexander Zhivov, Matthew Swanson, and James Stinson. 2014. “NY-14-011 – A Computational Framework for Low Energy Community Analysis and Optimization.” *ASHRAE Transactions* 120 (1).
- Liesen, R.; Ellis, P.; Zhivov, A.; Herron, D. 2012. “CH-12-008 – Extremely Low Energy Design for Army Buildings: Barracks.” *ASHRAE Transactions* 118 (1).
- Swanson, M., Barnes, B.; Liesen, R.; Case, M.; Zhivov, A. 2014. “NY-14-012 – Community-Scale Energy Supply and Distribution Optimization Using Mixed-Integer Linear Programming.” *ASHRAE Transactions* 120 (1).
- Zhivov, A.; Case, M.; Liesen, R.; Swanson, M. 2015. *Demonstration of the Energy Component of the Installation Master Plan Using the “Net Zero Planner”*, ERDC/CERL TR-15-28. Construction Engineering Research Laboratory: Champaign, IL.

# Questions?

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