

# An Enhanced Sequential Search Methodology for Identifying Cost-Optimal Building Pathways



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# Objectives

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Develop strategies to improve speed and robustness of the basic sequential search optimization methodology

Construct packages of strategies for potential implementation in the *BEopt* software.

# Motivation

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## Robustness

- Lower-cost building designs

## Speed

- Increasing size of parameter search space
- DOE-2, TRNSYS -> EnergyPlus

## I. Background

# BEopt – Building Energy Optimizer

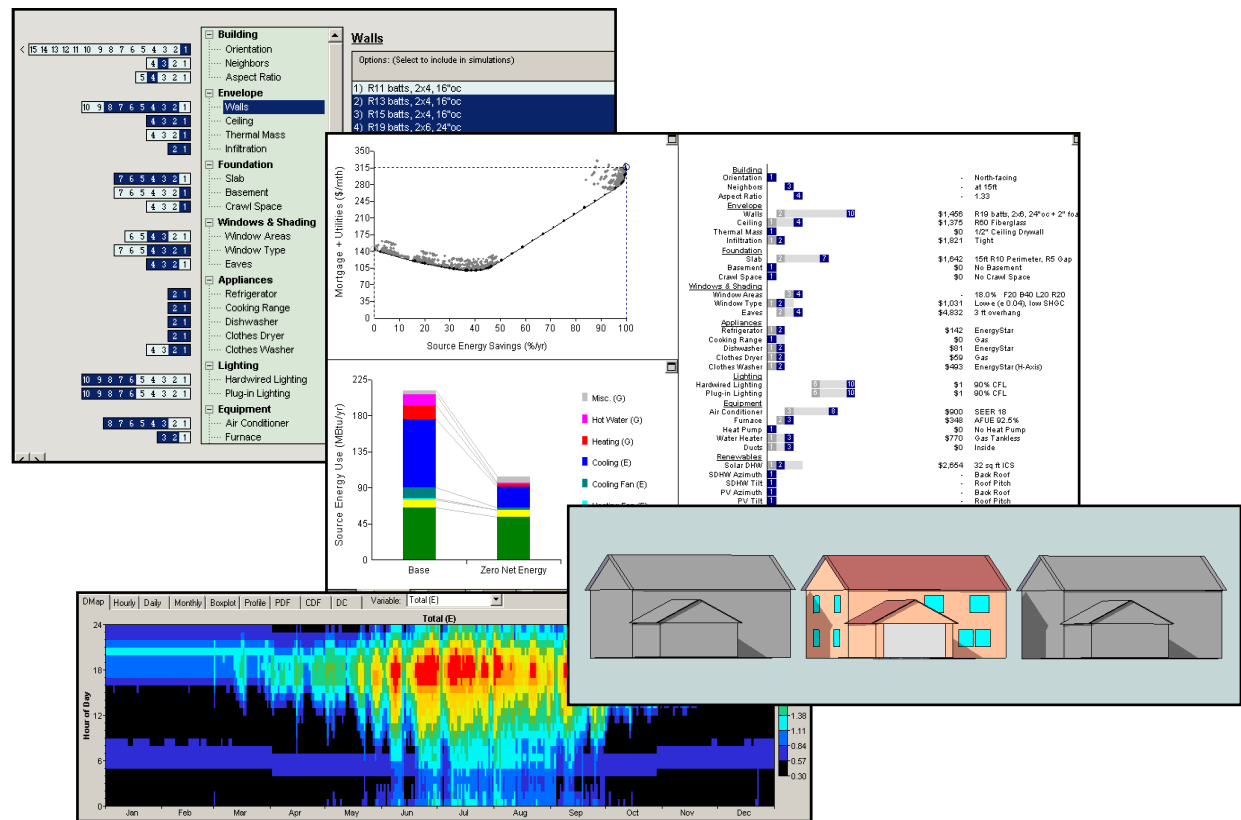
Identifies cost-optimal building designs over a range of energy savings from base case to zero net energy

Accurately accounts for interactions between measures (e.g. glass type and HVAC)

Evaluates realistic (discrete) measures

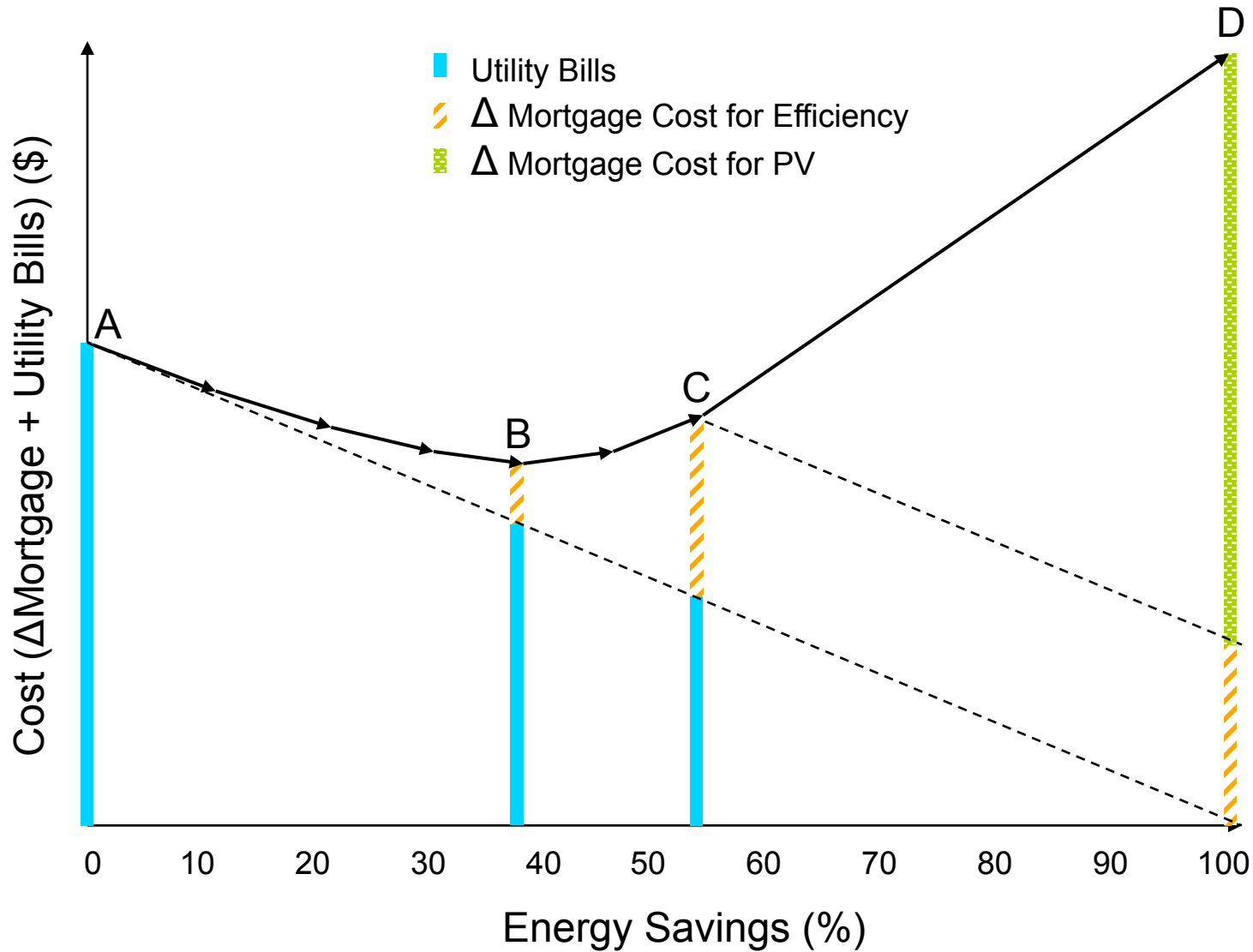
Runs hour-by-hour simulations (DOE2 and TRNSYS)

Employs sequential search optimization technique



## I. Background

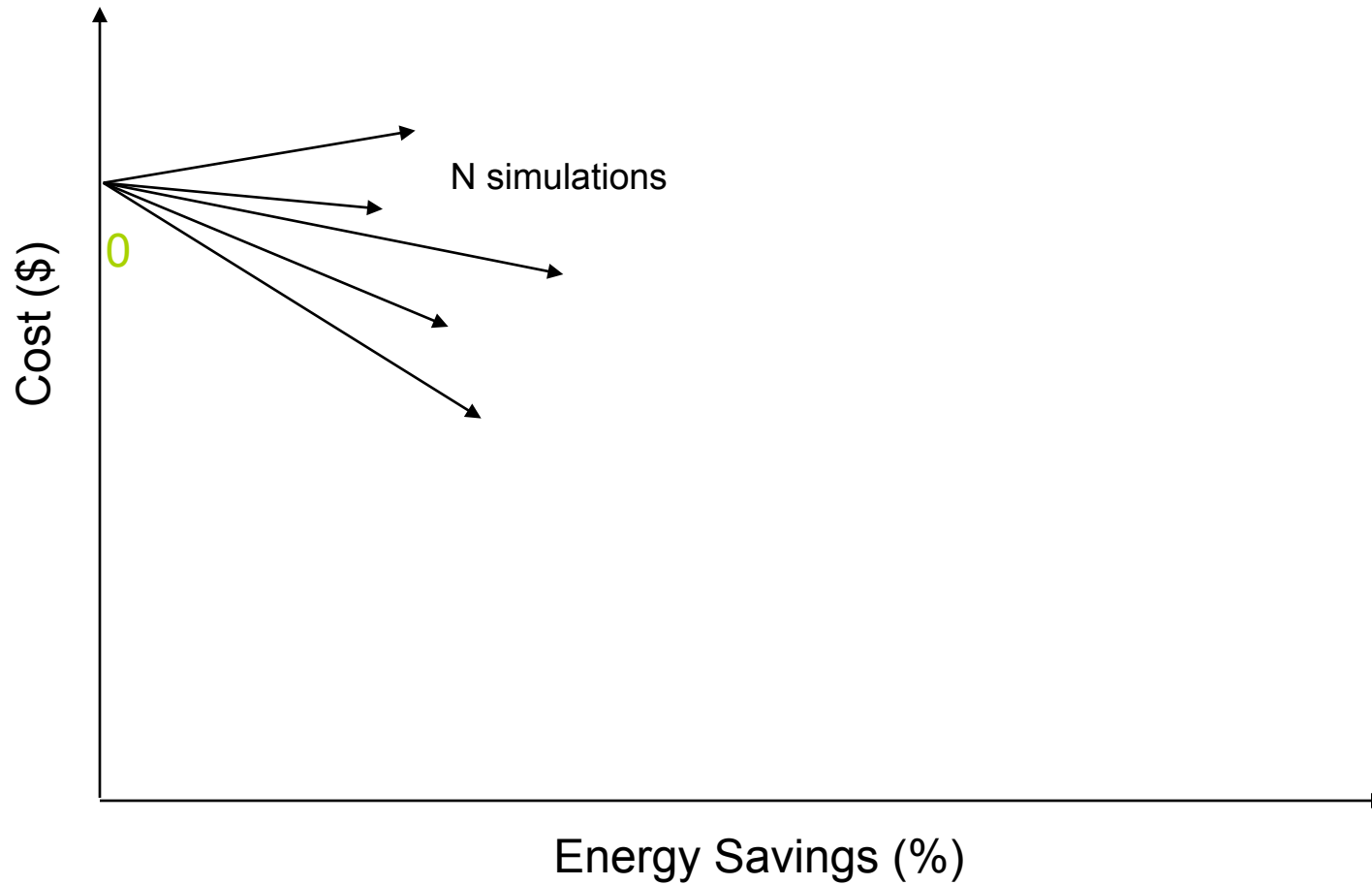
# BEopt - Cost/Energy Graph



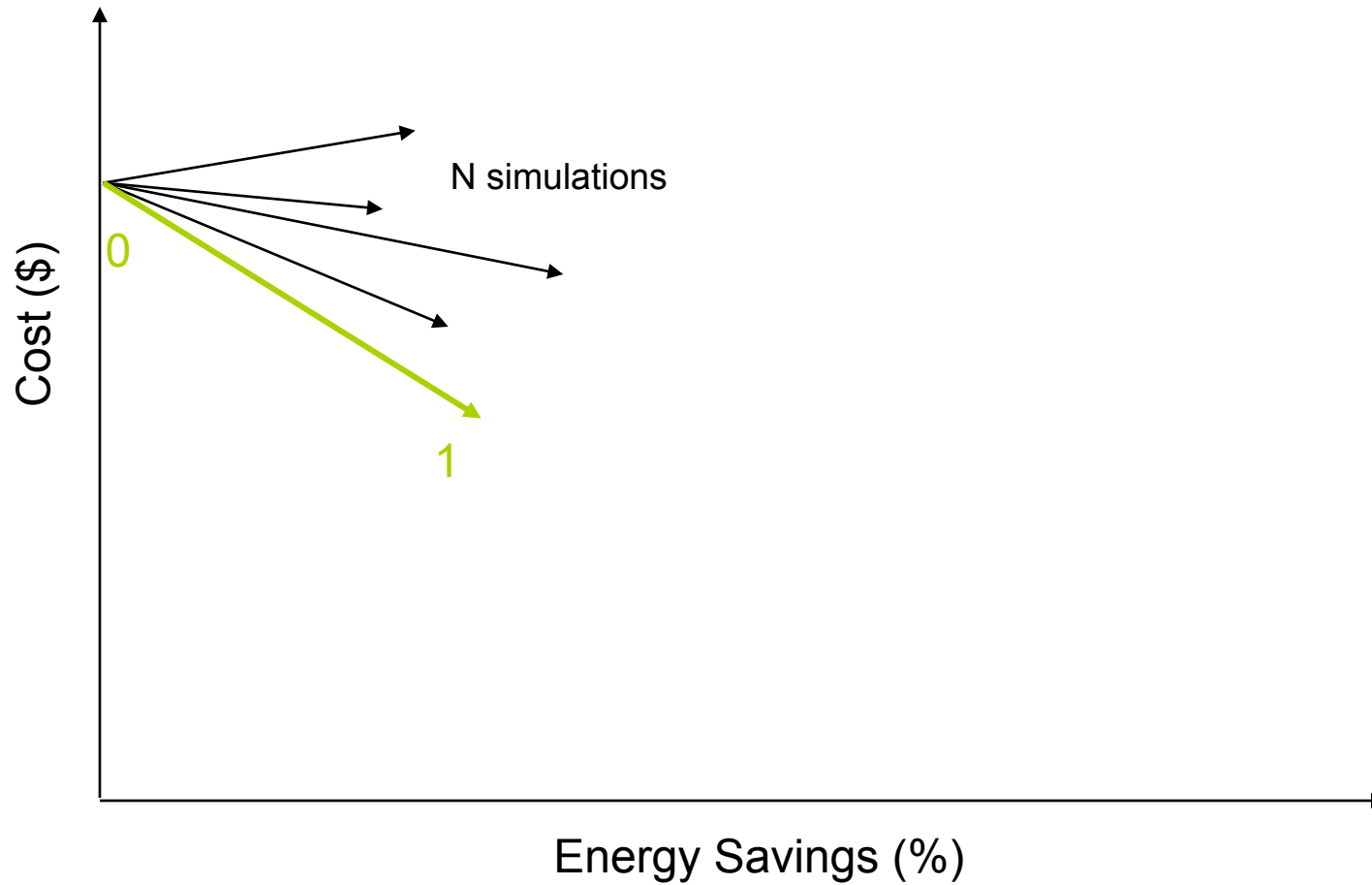
## I. Background

# Basic Sequential Search

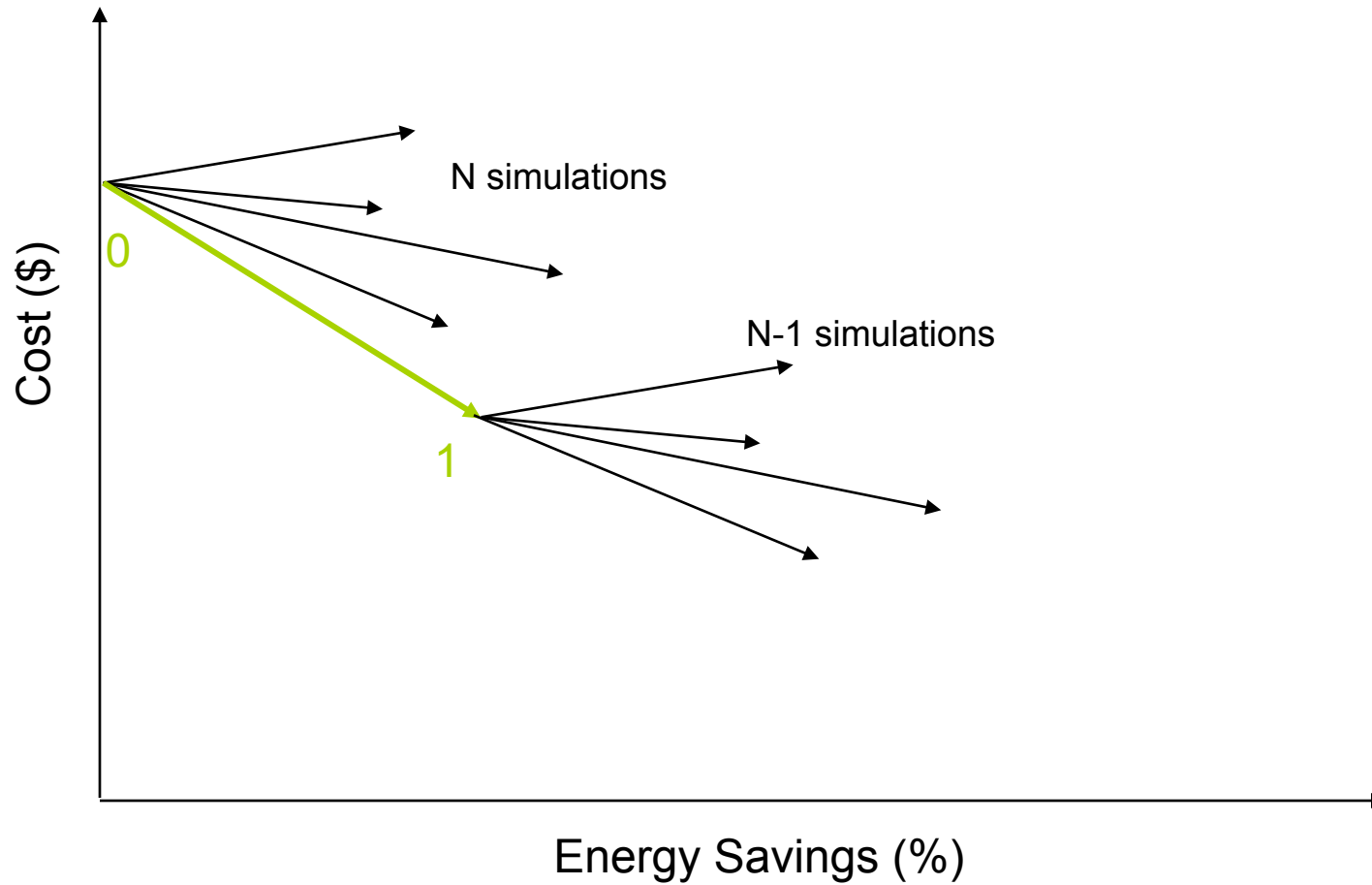
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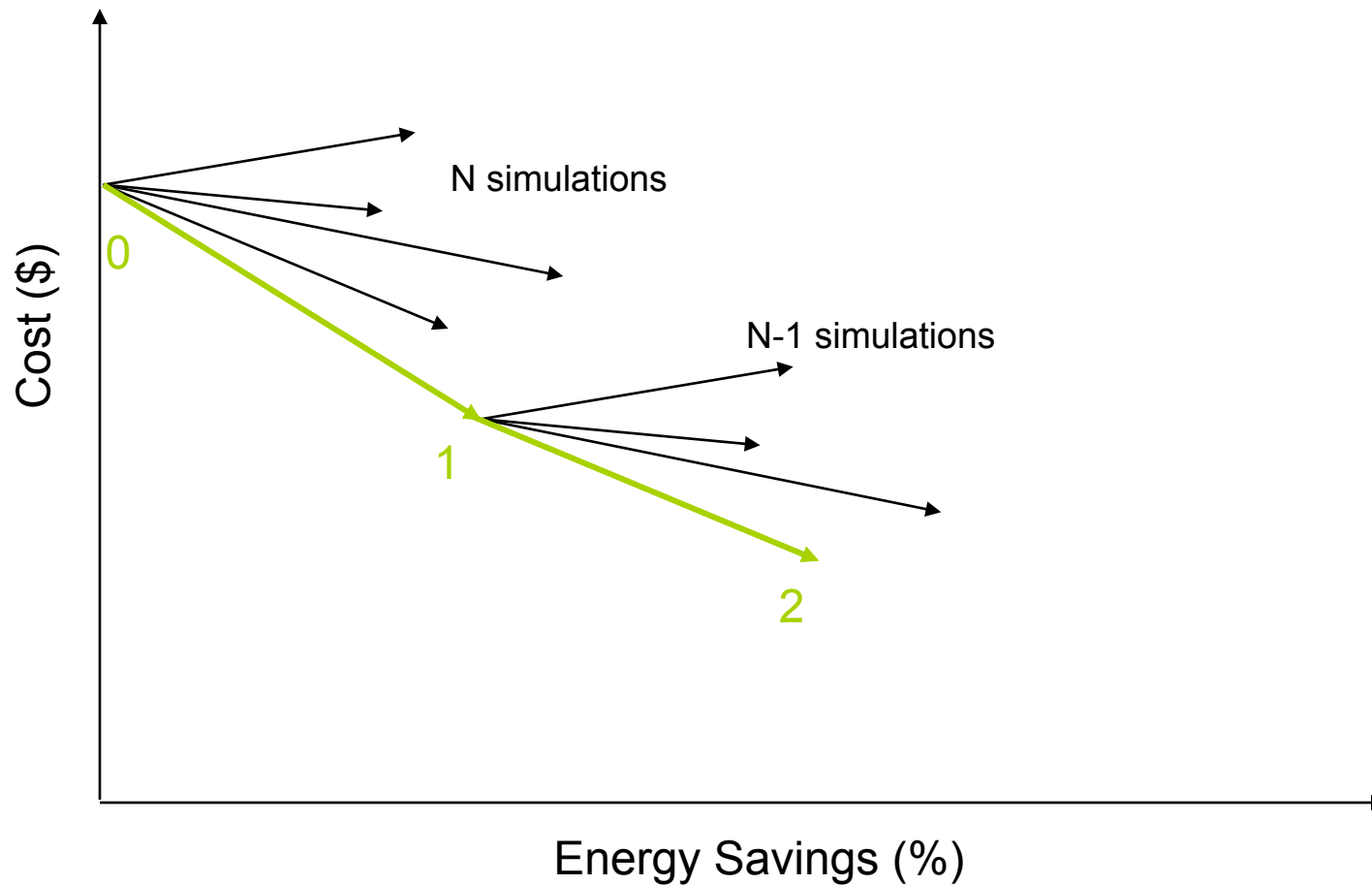
# Basic Sequential Search



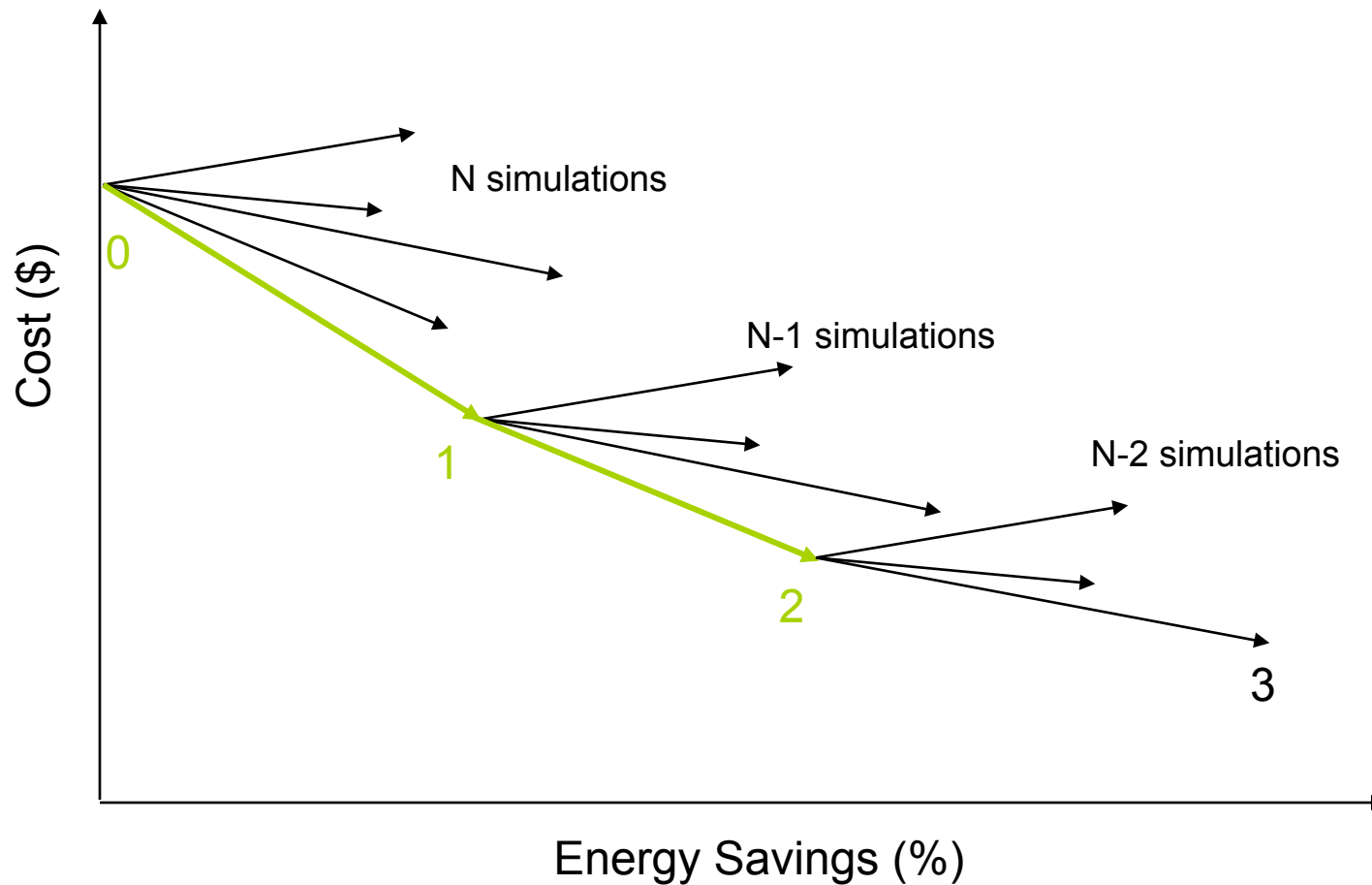
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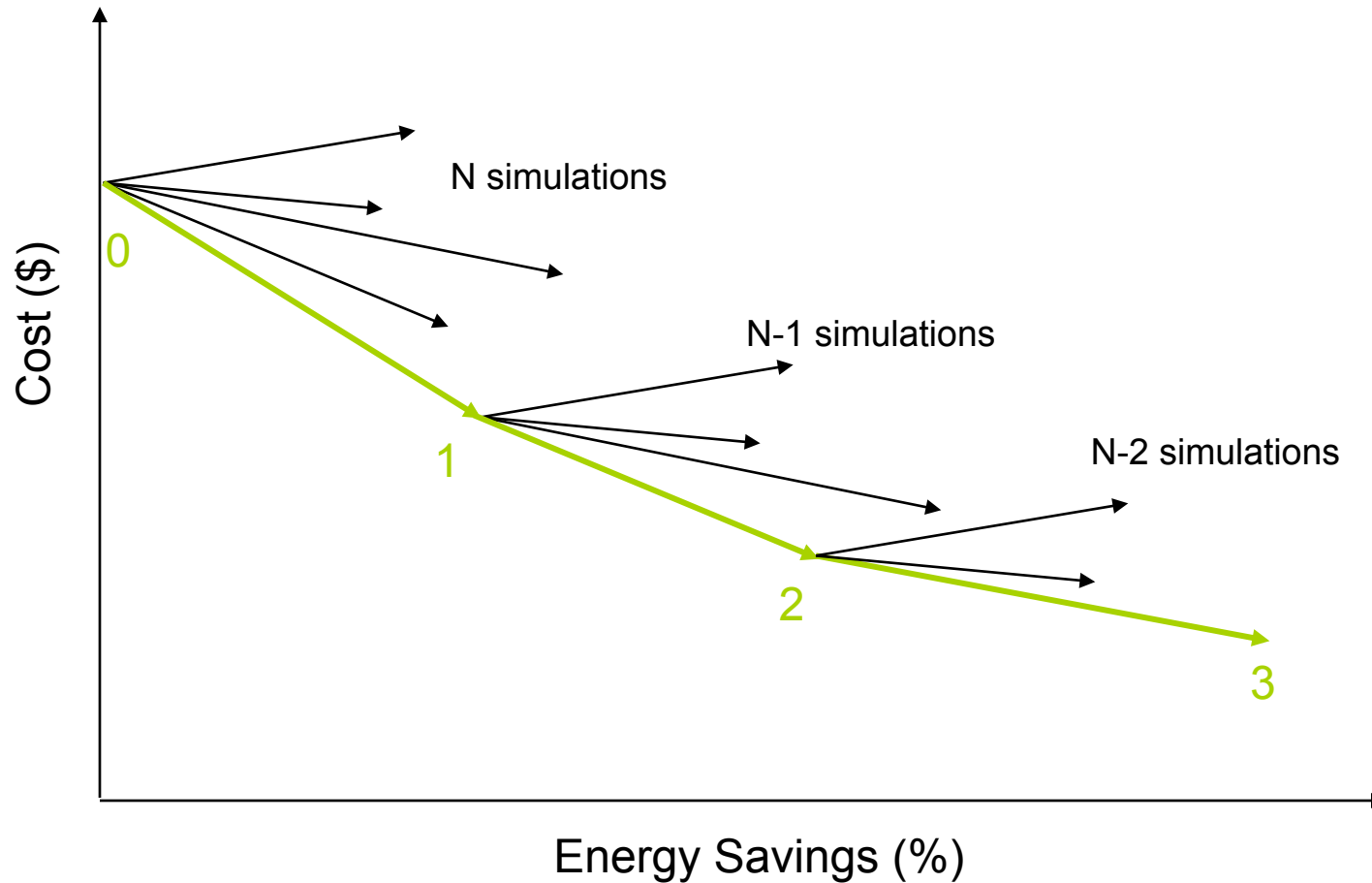
# Basic Sequential Search



# Basic Sequential Search



# Basic Sequential Search



# Basic Sequential Search

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Three goals:

- Discrete, realistic building designs
- Optimal designs for a range of energy savings
- Alternative near-optimal designs

## II. Robustness Strategies

# Overview of Strategies

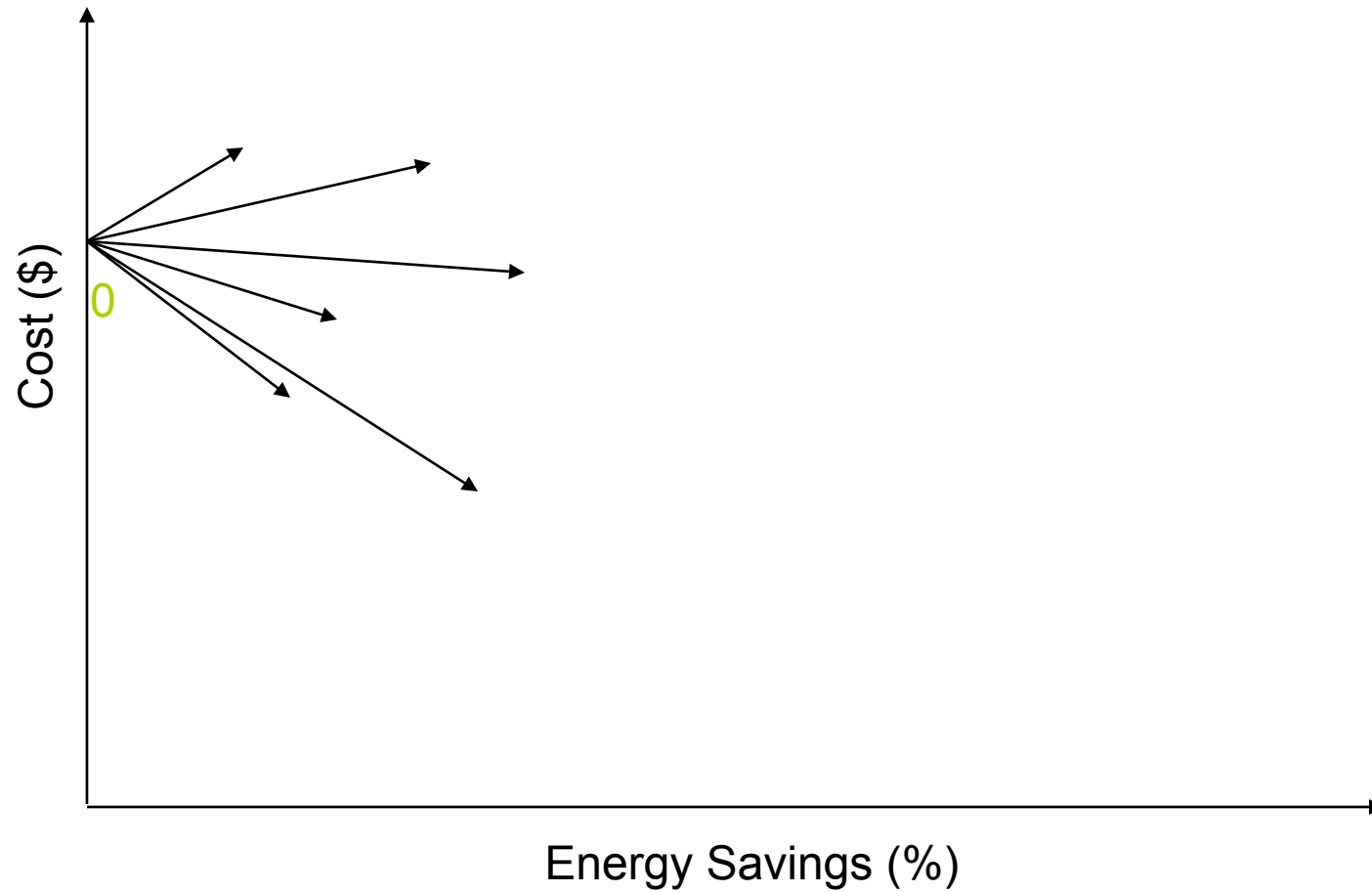
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### Special Cases

1. Large-Step
2. Invest/Divest
3. Positive Interactions

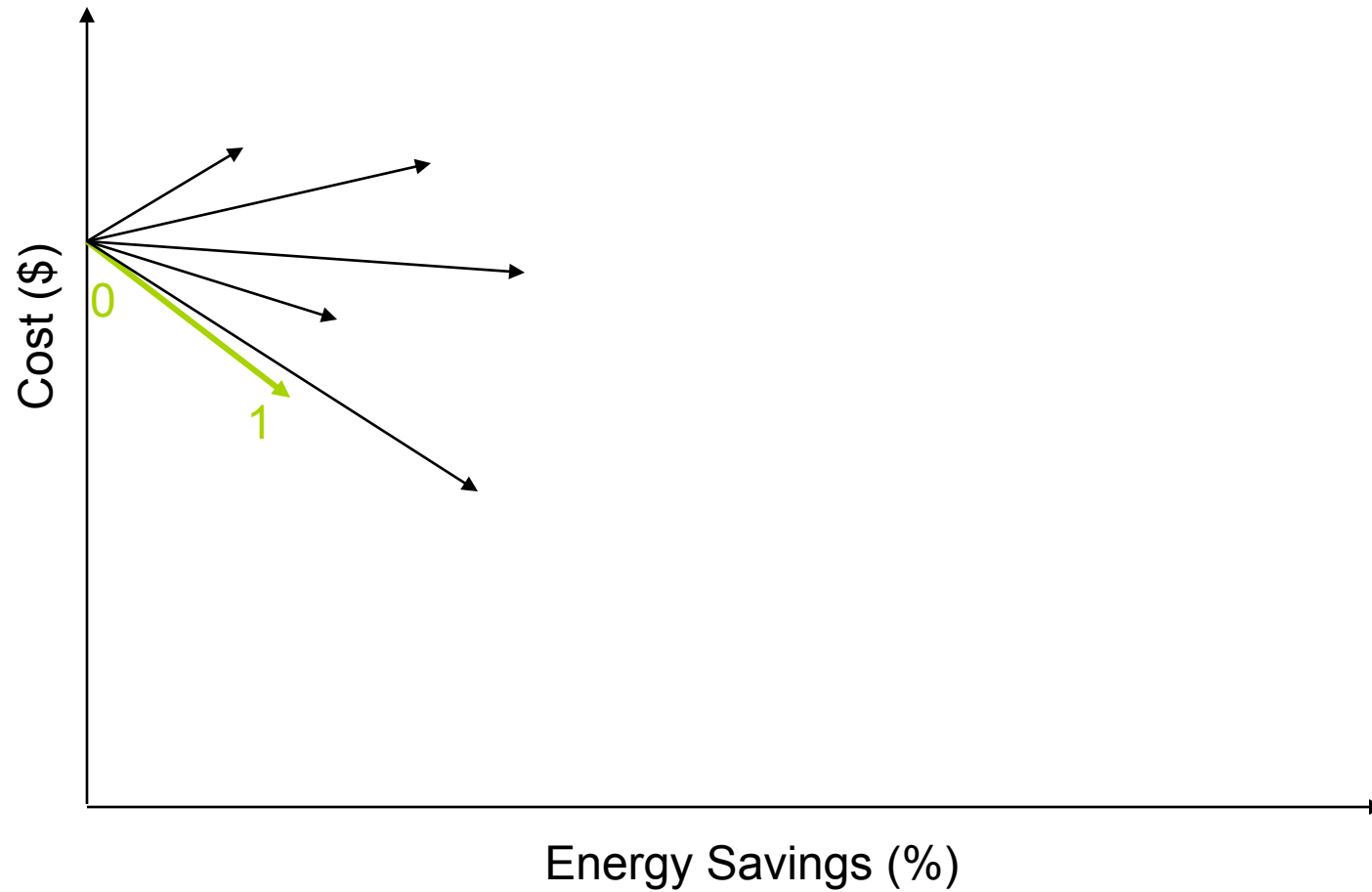
# Large-Step Special Case

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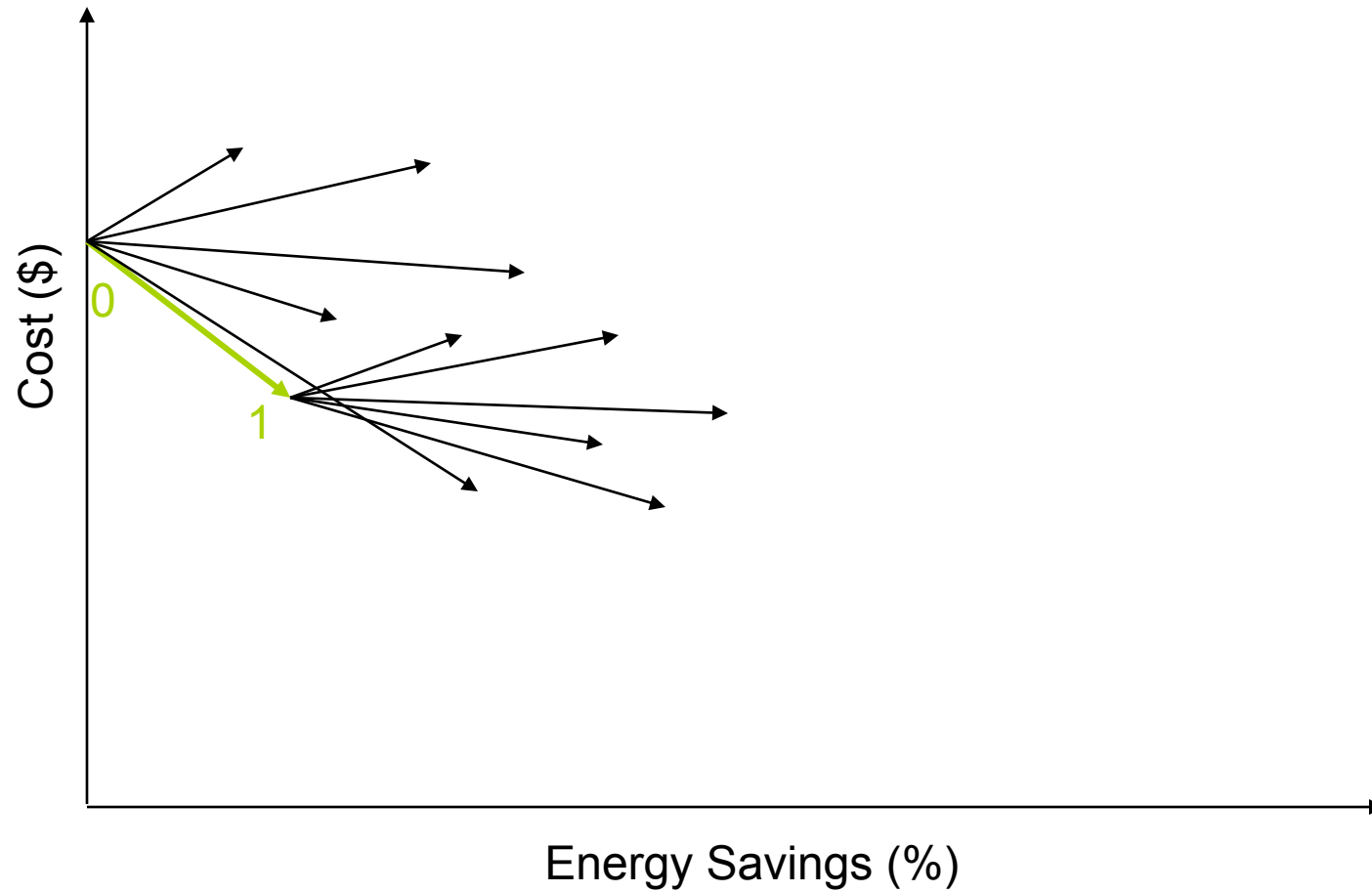


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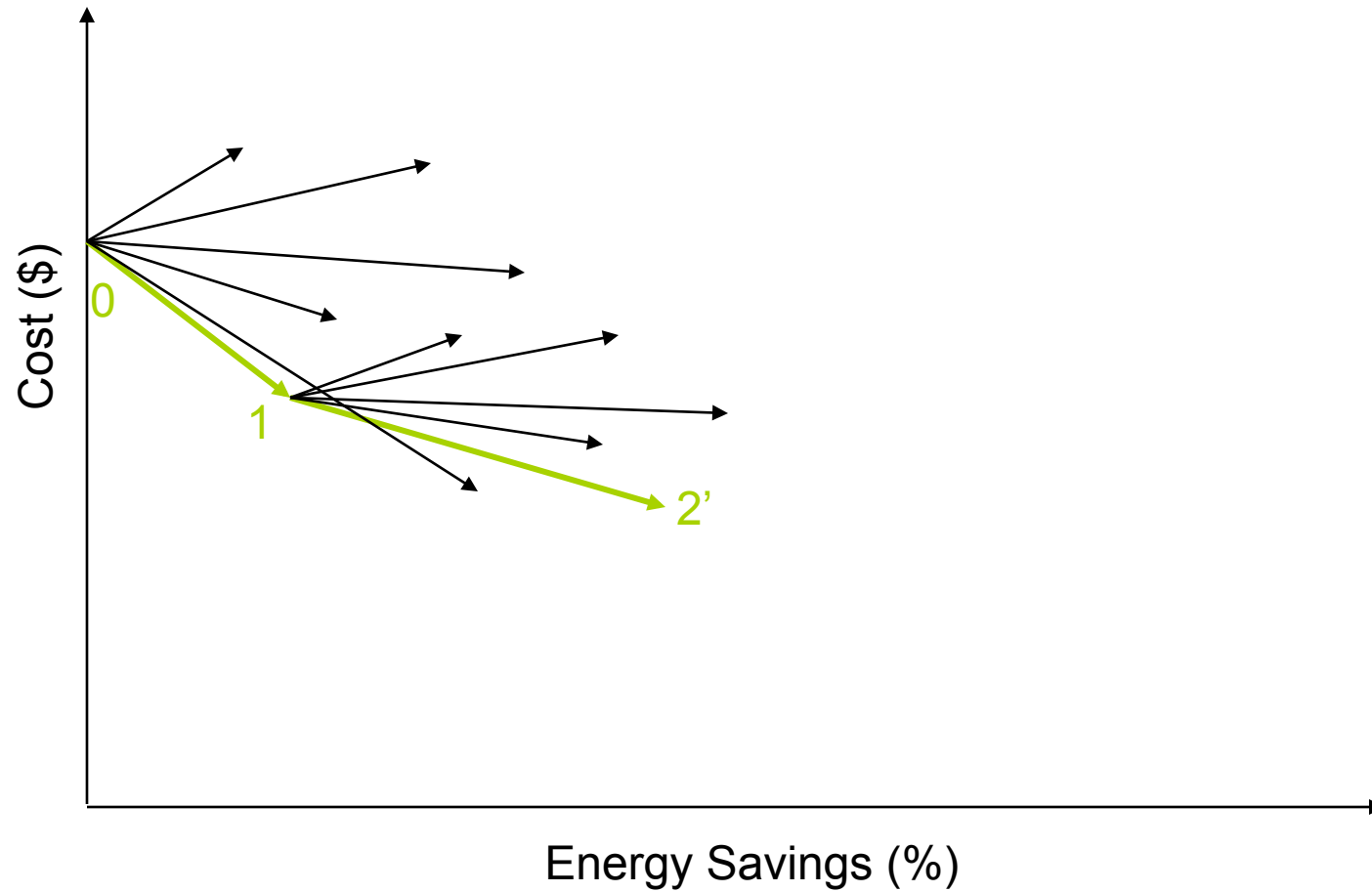
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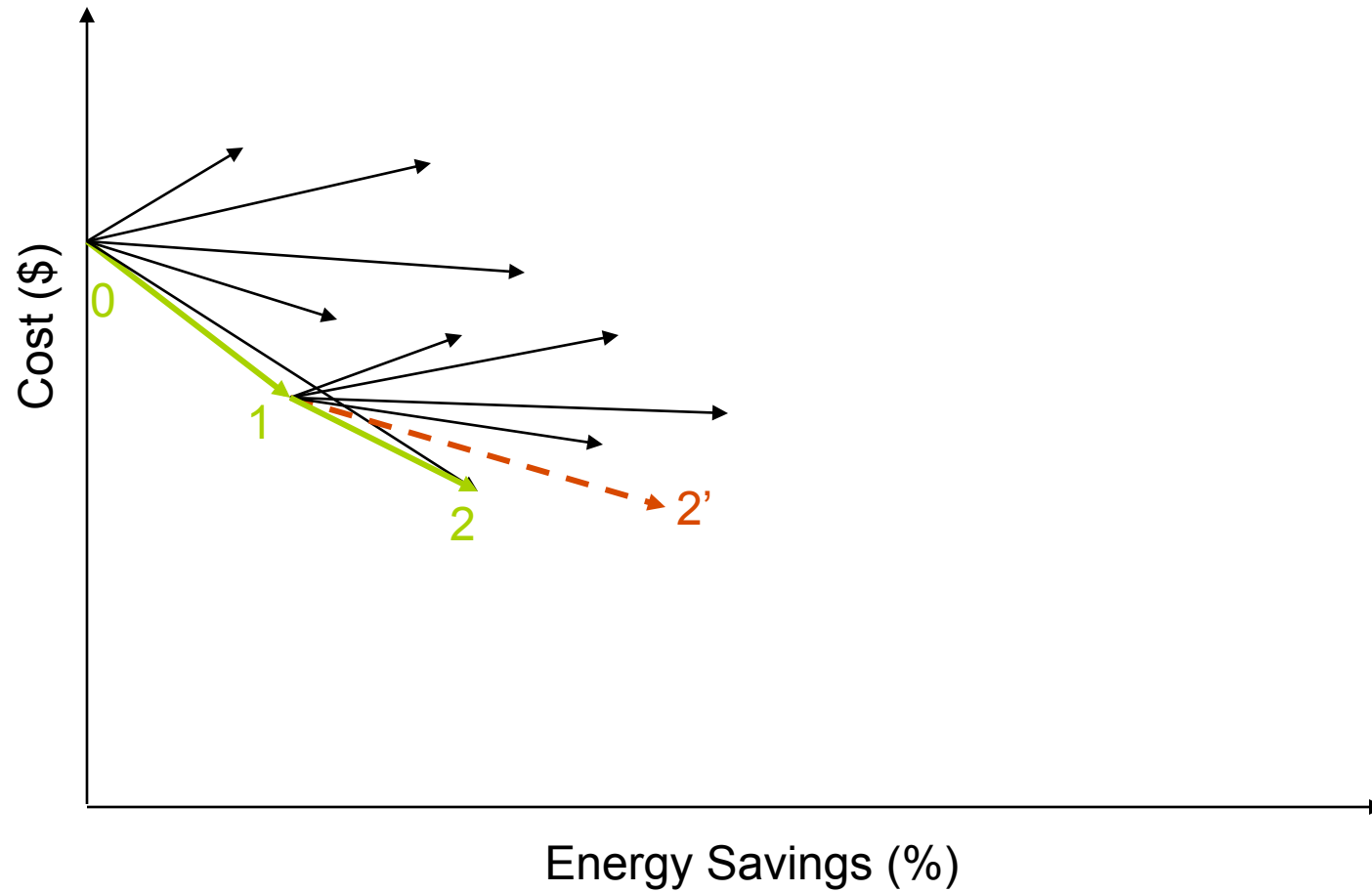
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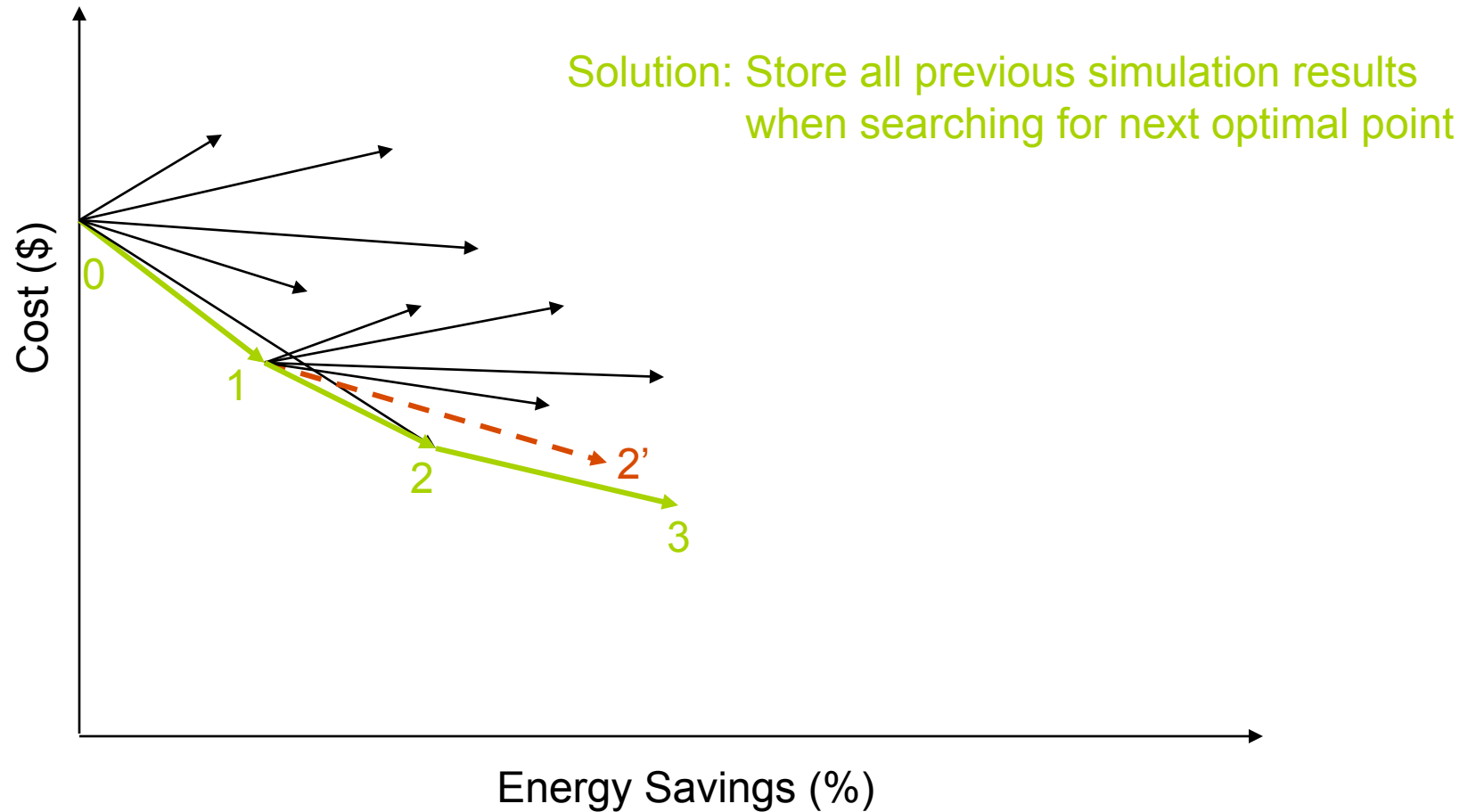
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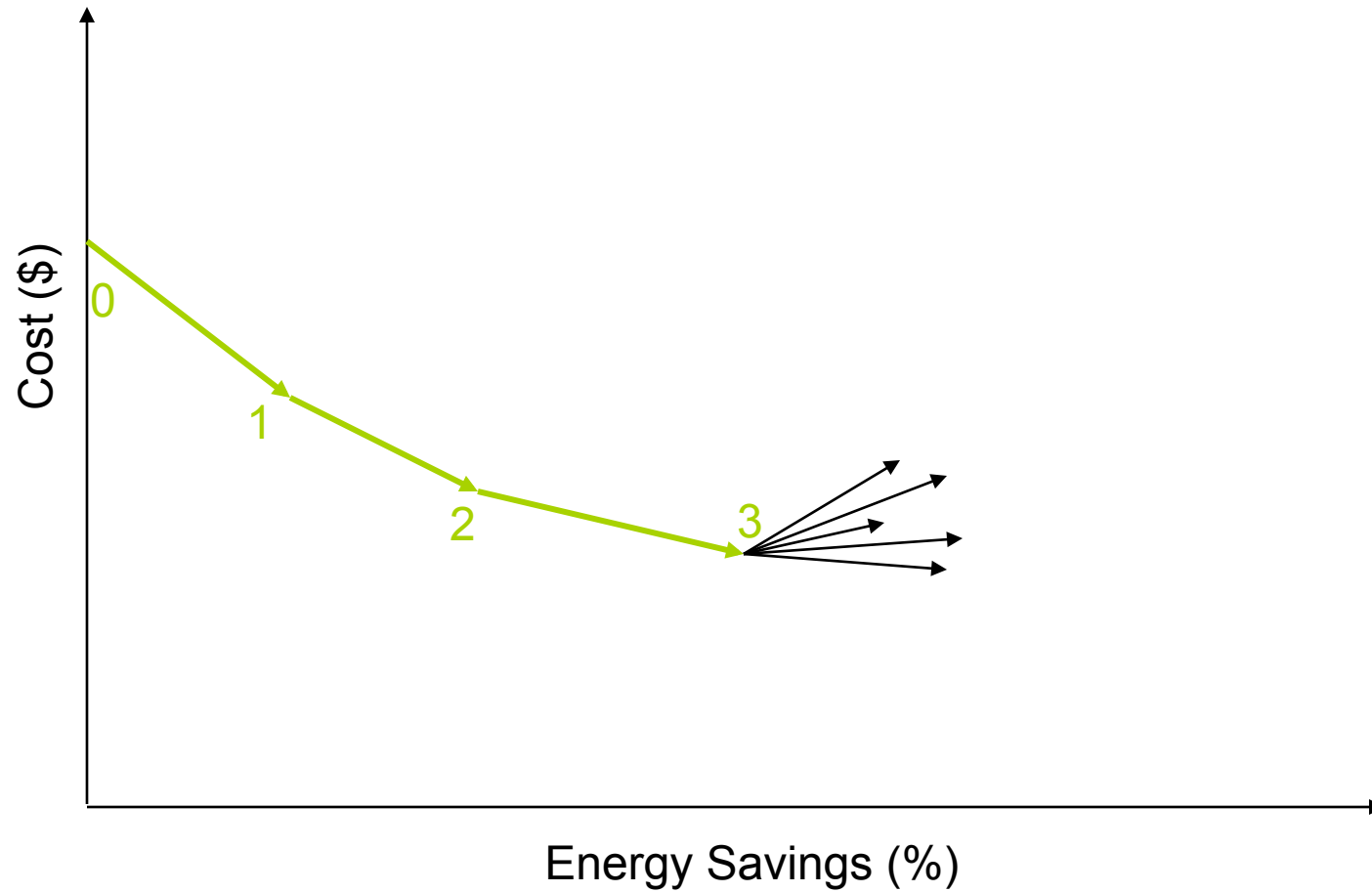
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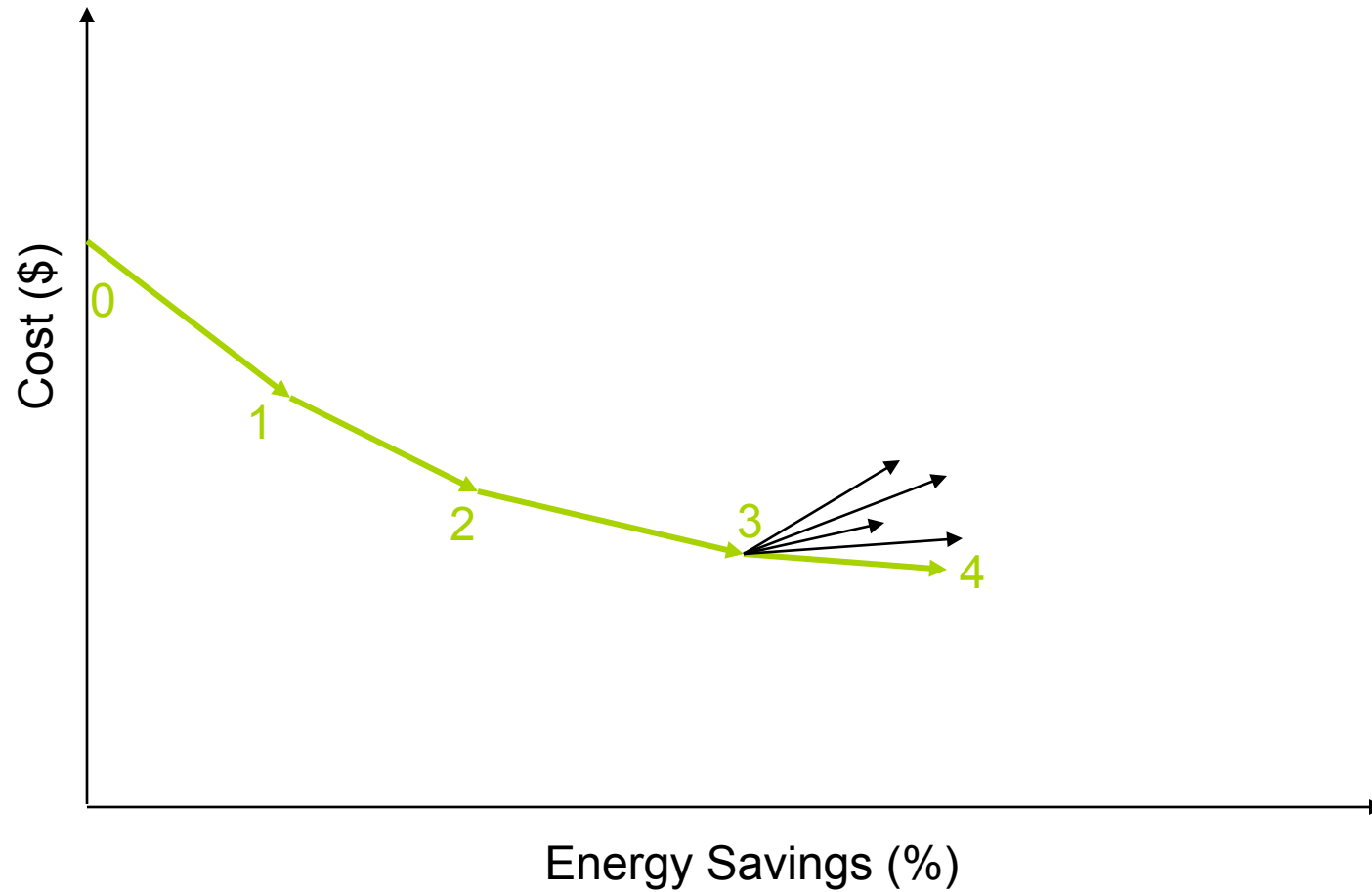
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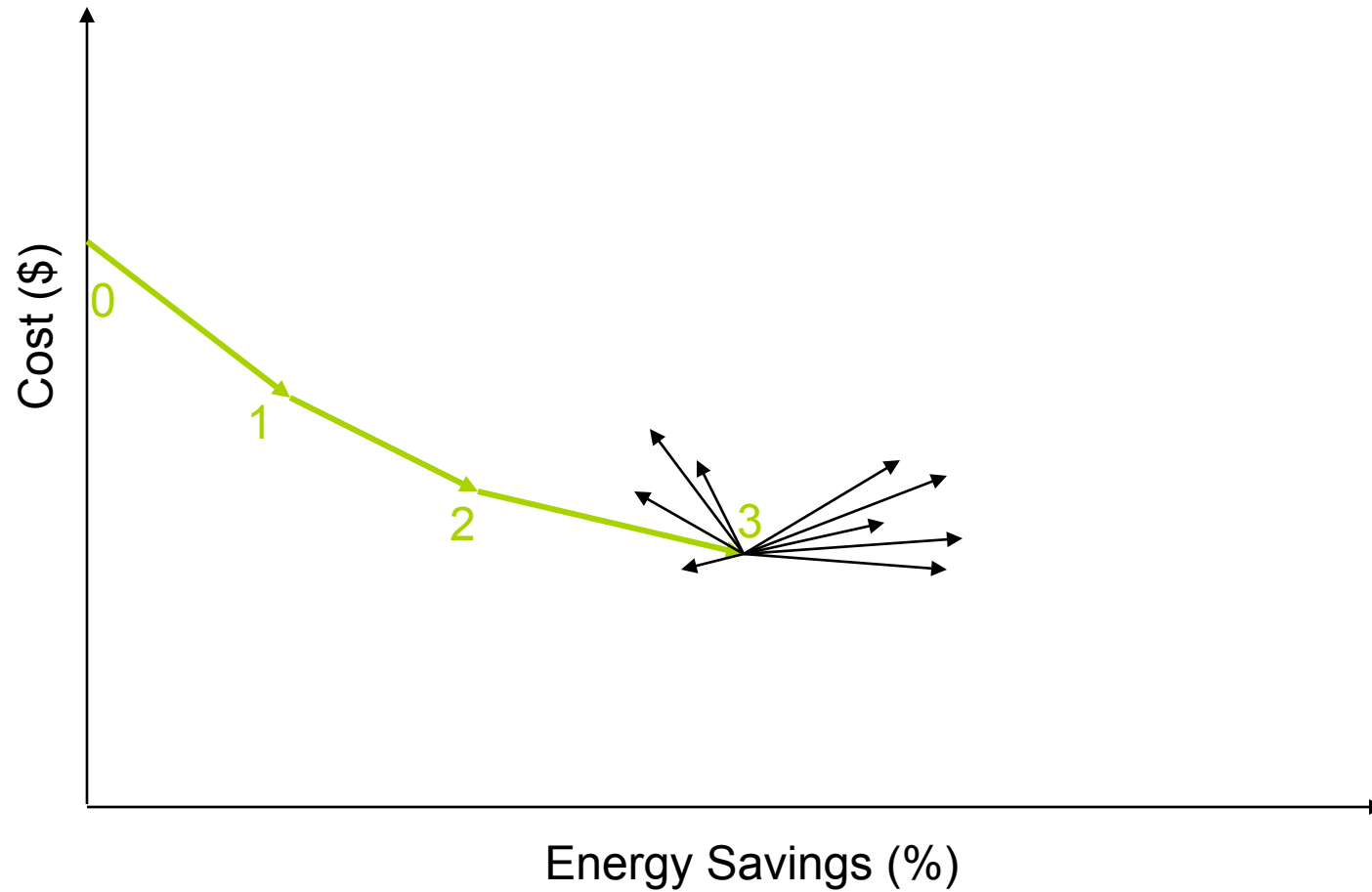
# Invest/Divest Special Case



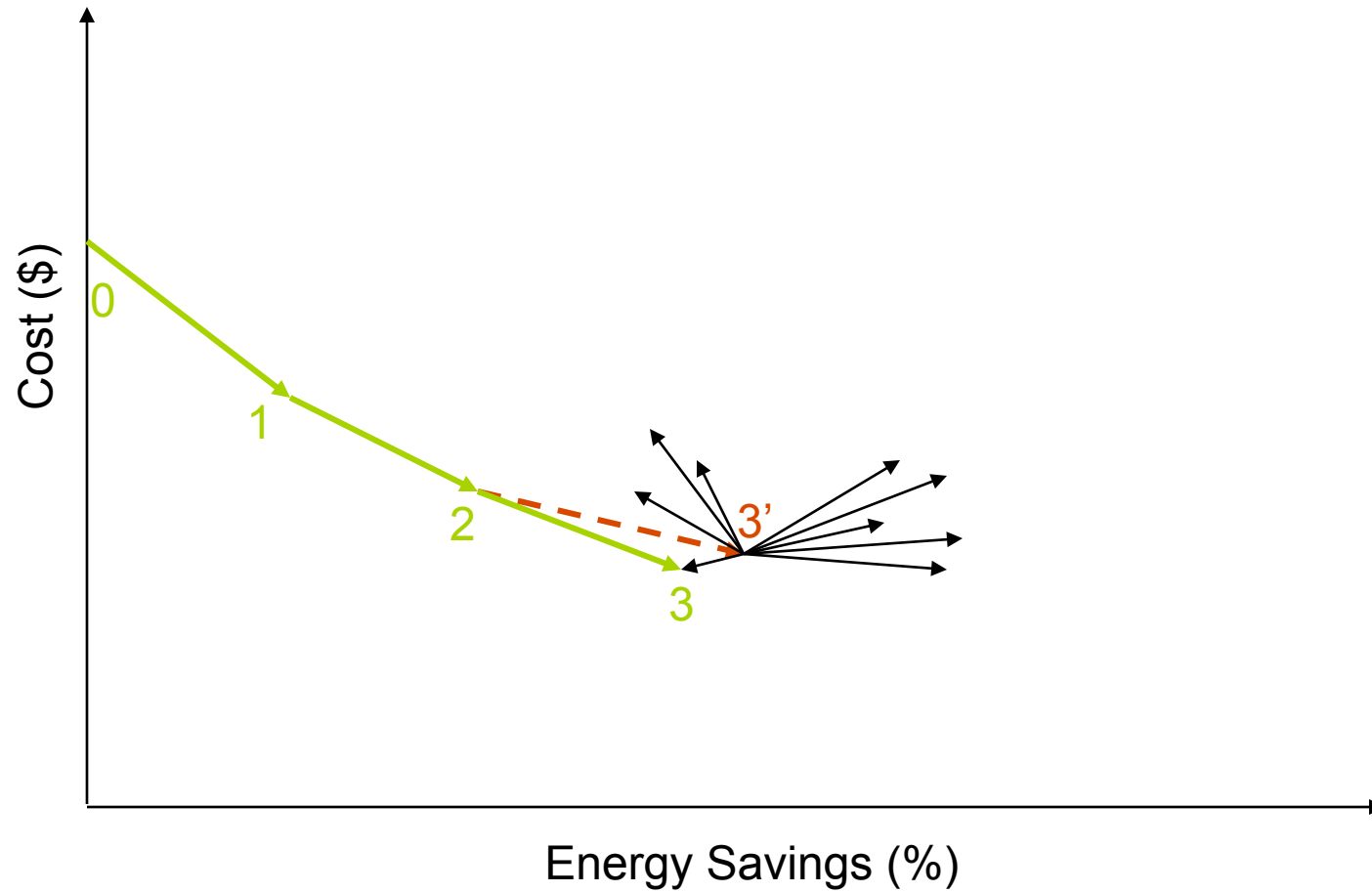
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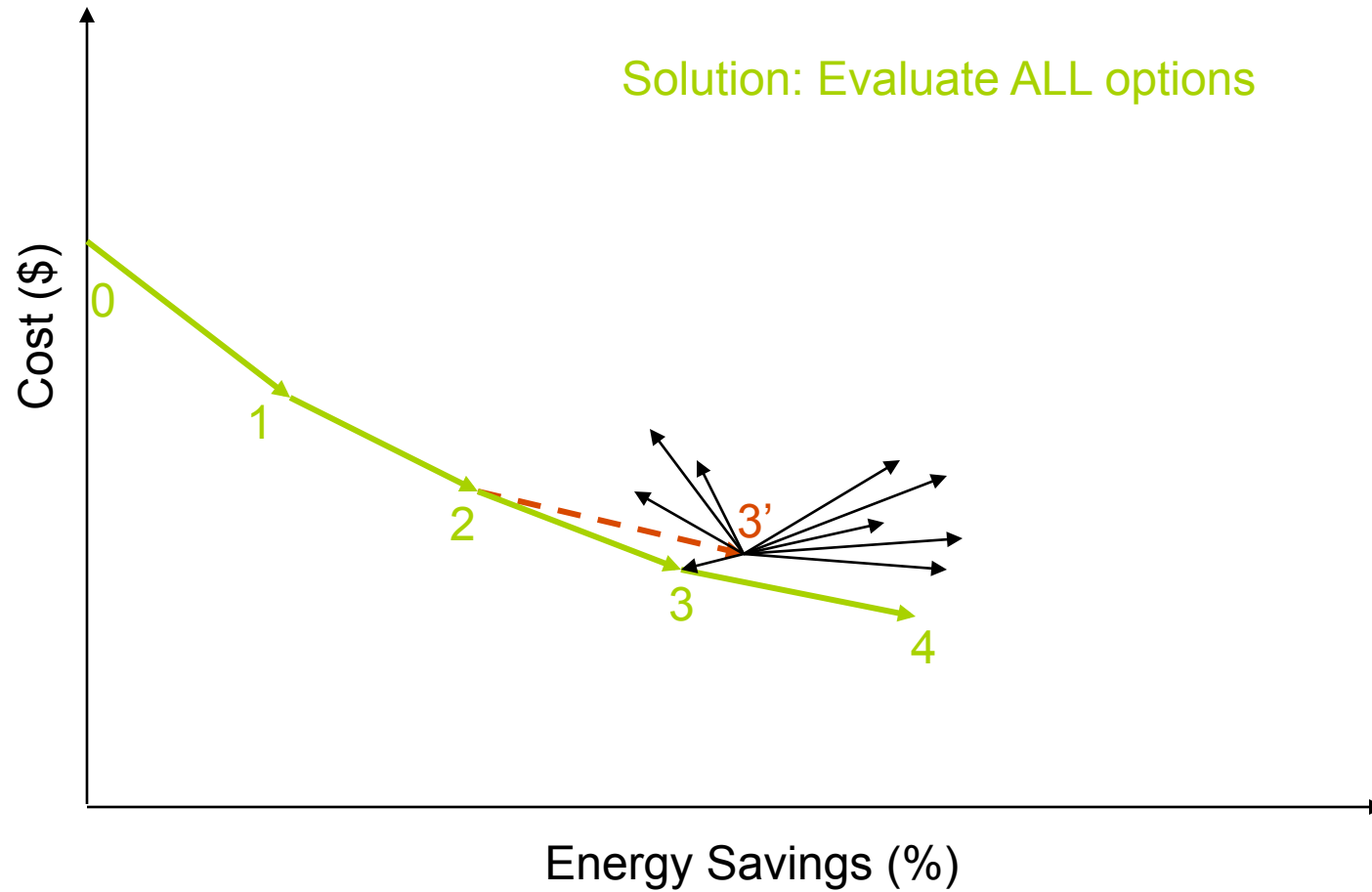
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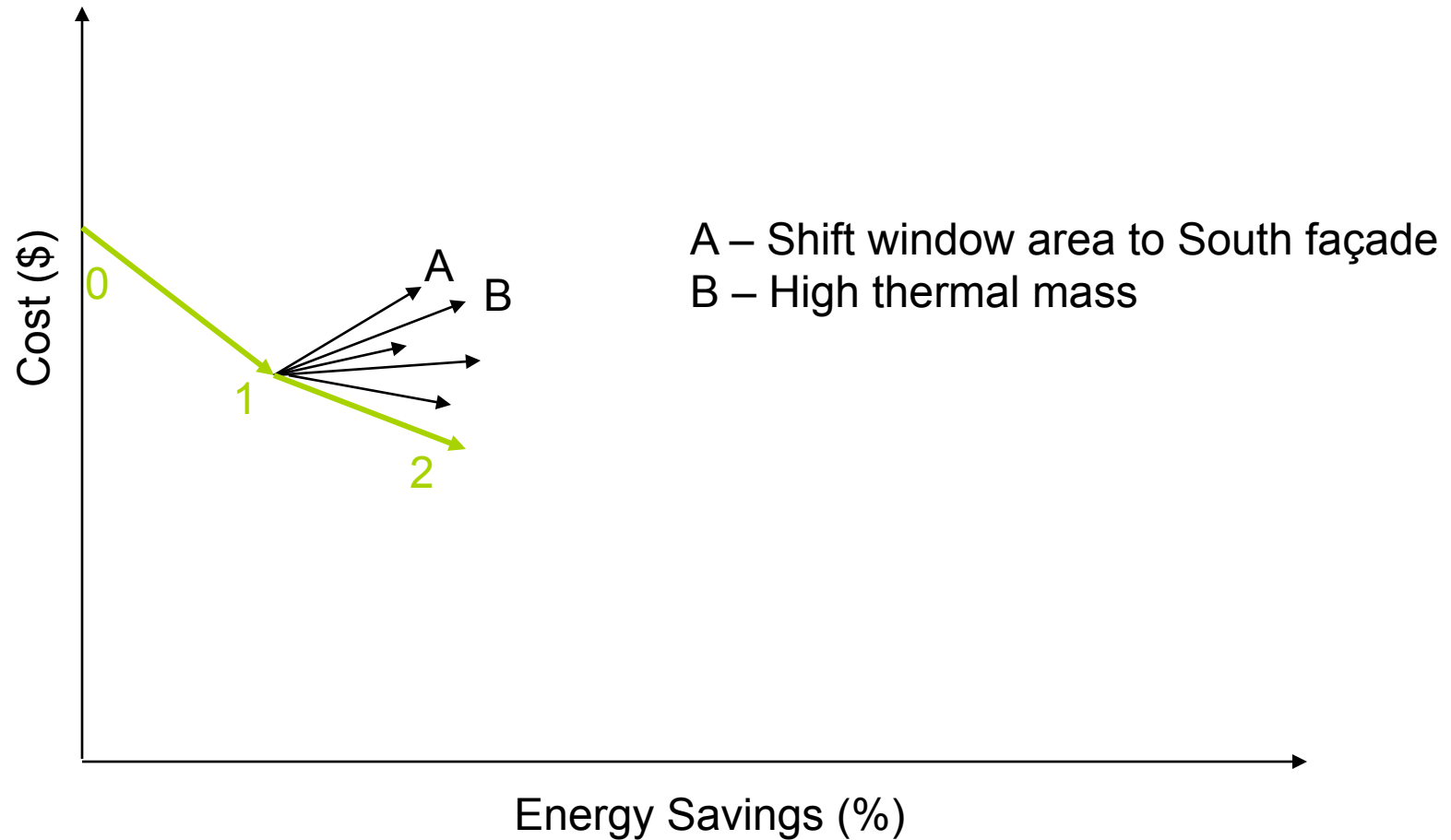
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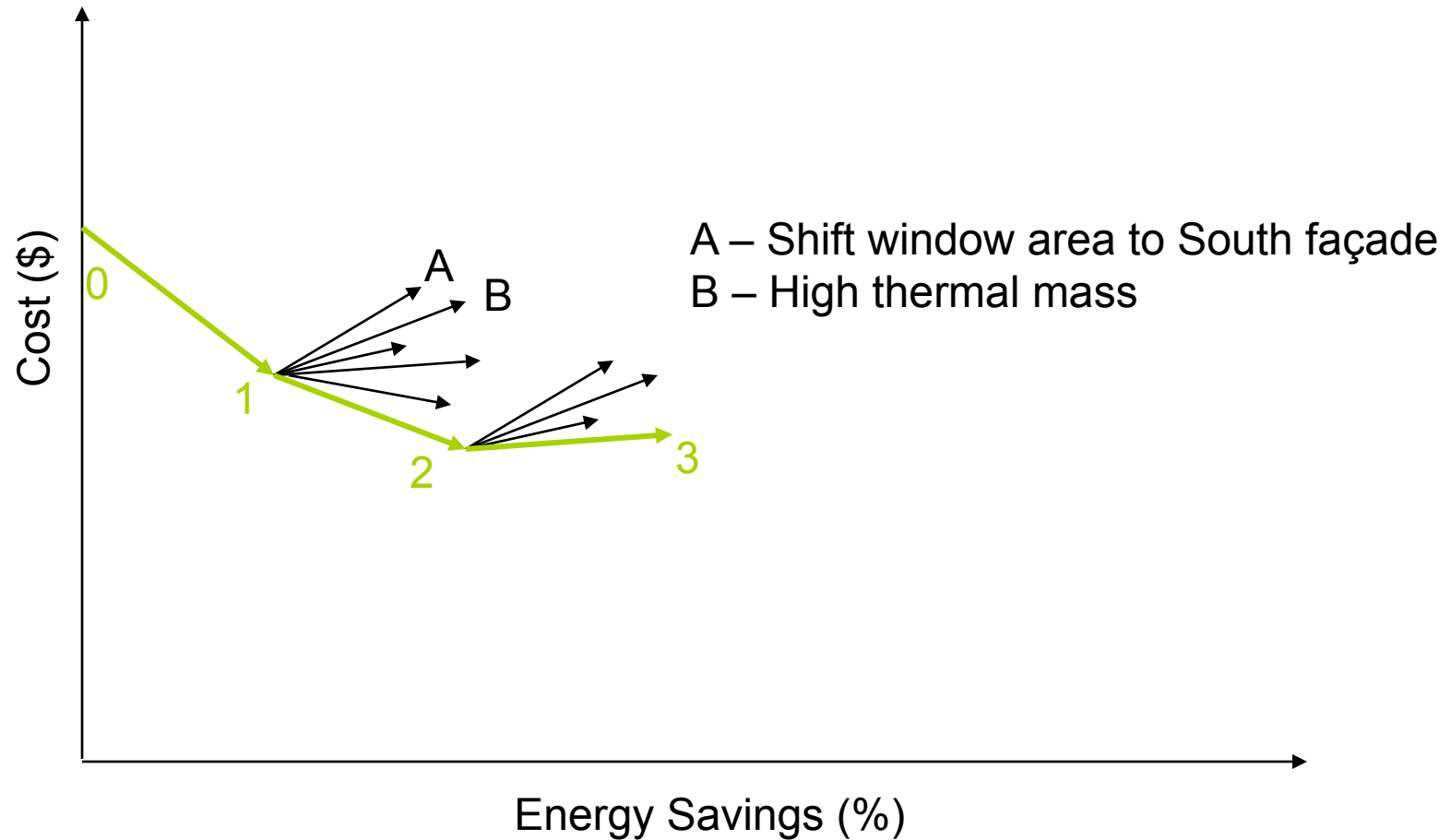
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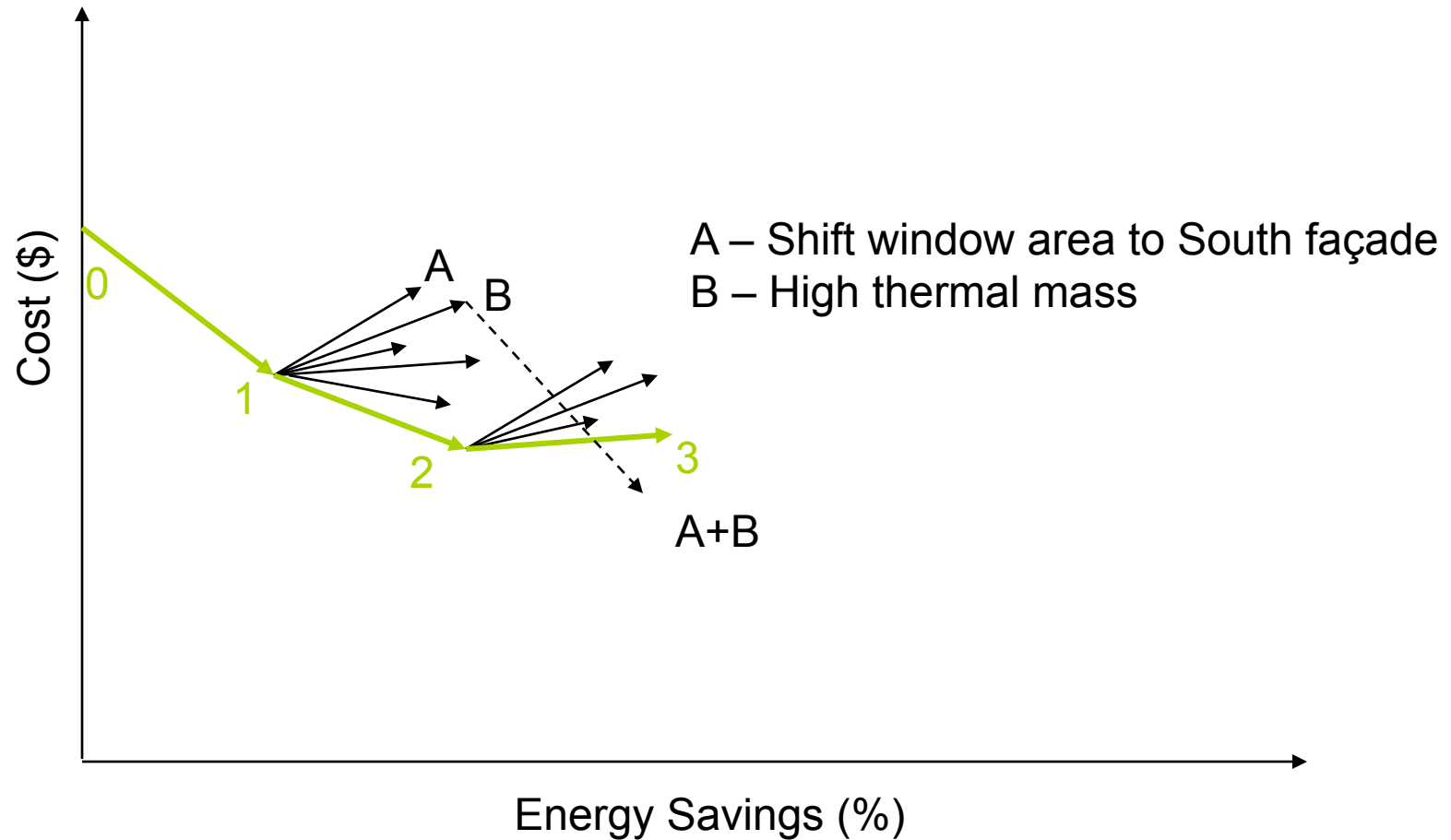
# Positive Interactions Special Case



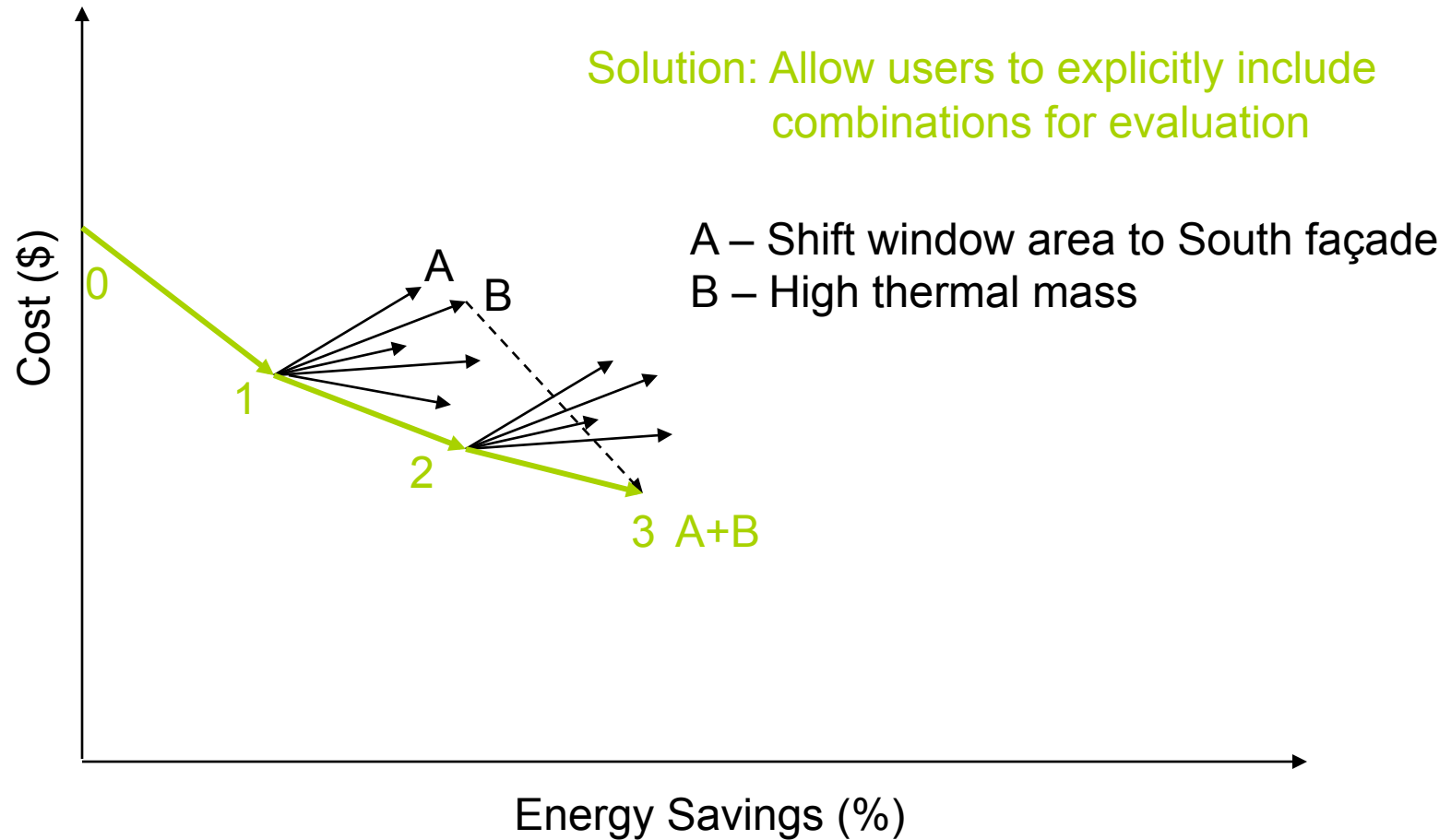
# Positive Interactions Special Case



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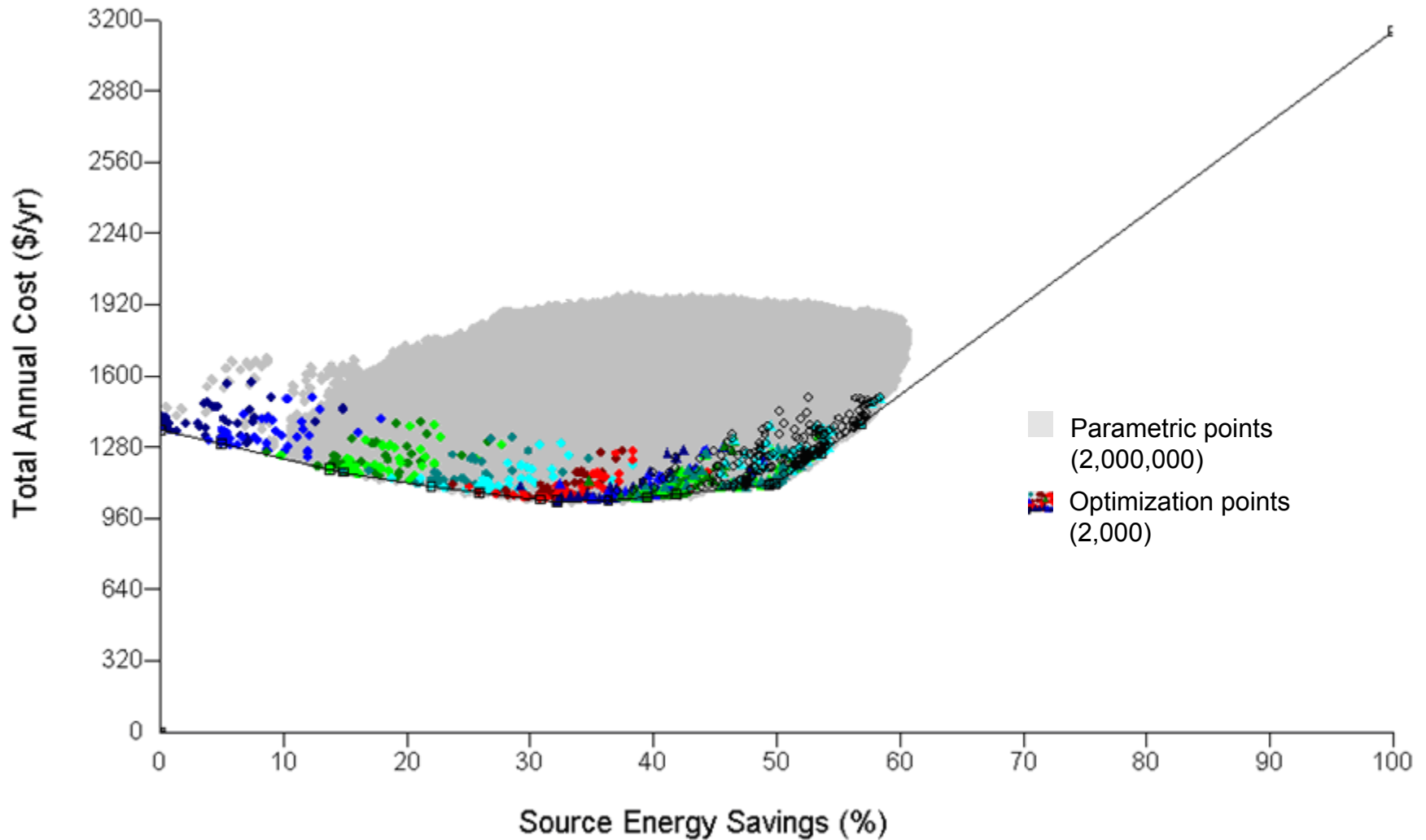


# Positive Interactions Special Case



## II. Robustness Strategies

# Parametric Validation



### III. Speed Strategies

# Overview of Strategies

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## Reducing Number of Simulations per Iteration

1. Modularized simulations
2. Skip superseded options (3)
3. Skip less efficient options (5)
4. Skip predicted outliers (4)
5. Mathematically filter points (3)
6. Skip fine points (2)
7. Skip extraneous options (2)
8. Simulate best ranked option (4)

## Reducing Number of Iterations

9. Option lumping (5)
10. Forward progression
11. Build up simulations
12. Pre-optimization of child categories

( ) Number of variants

### III. Speed Strategies

# Overview of Strategies

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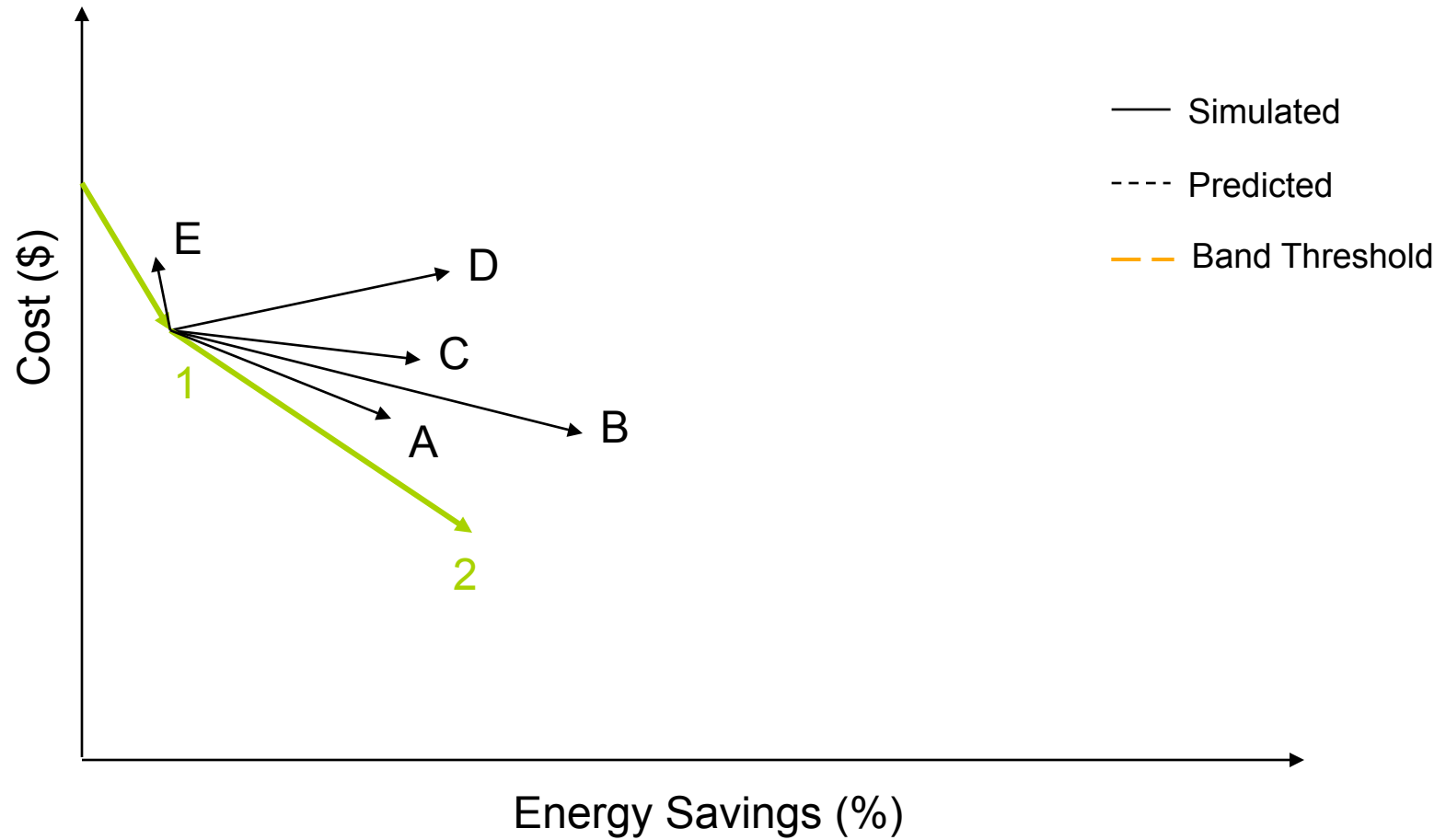
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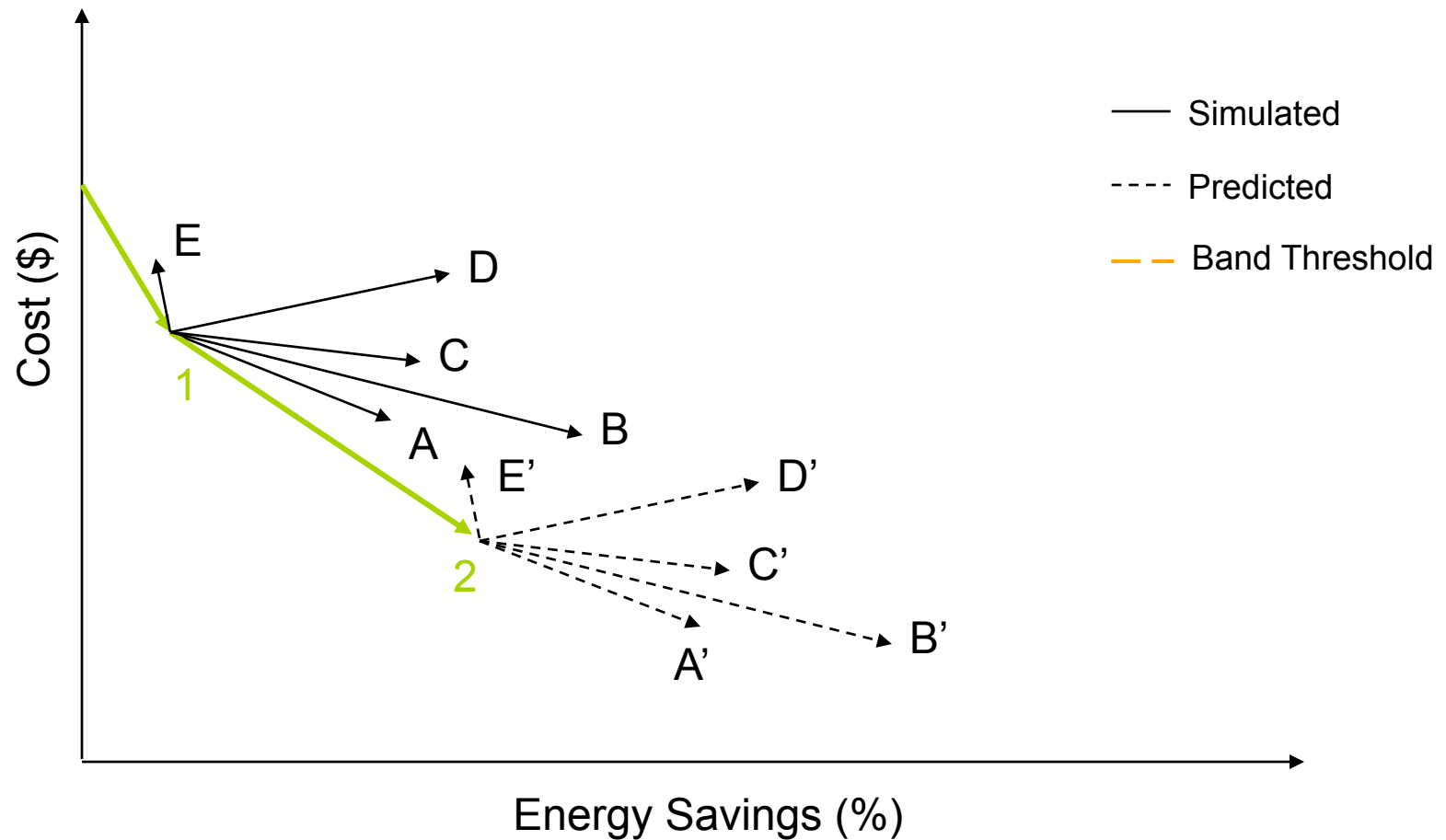
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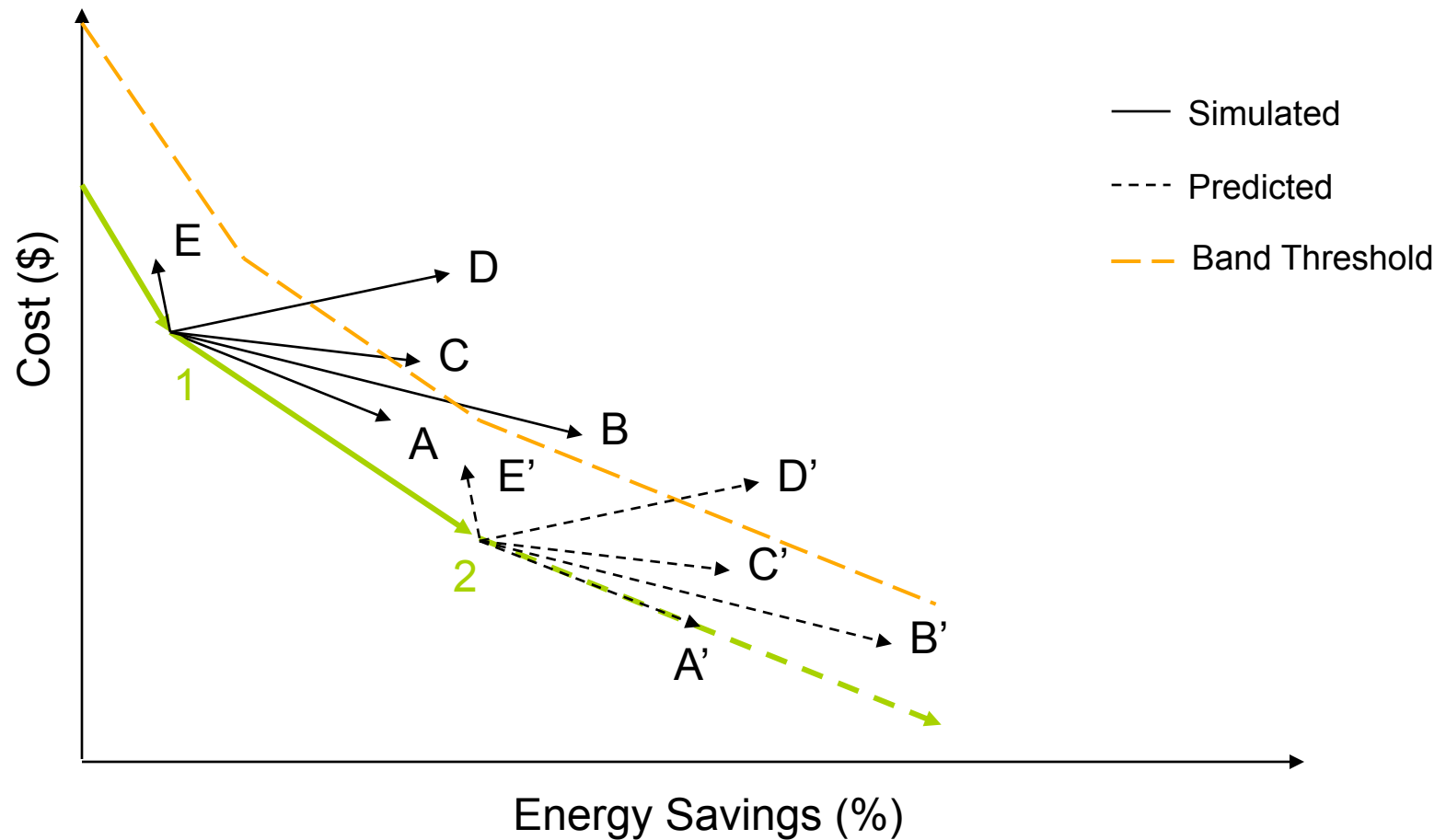
# Skip Predicted Outliers



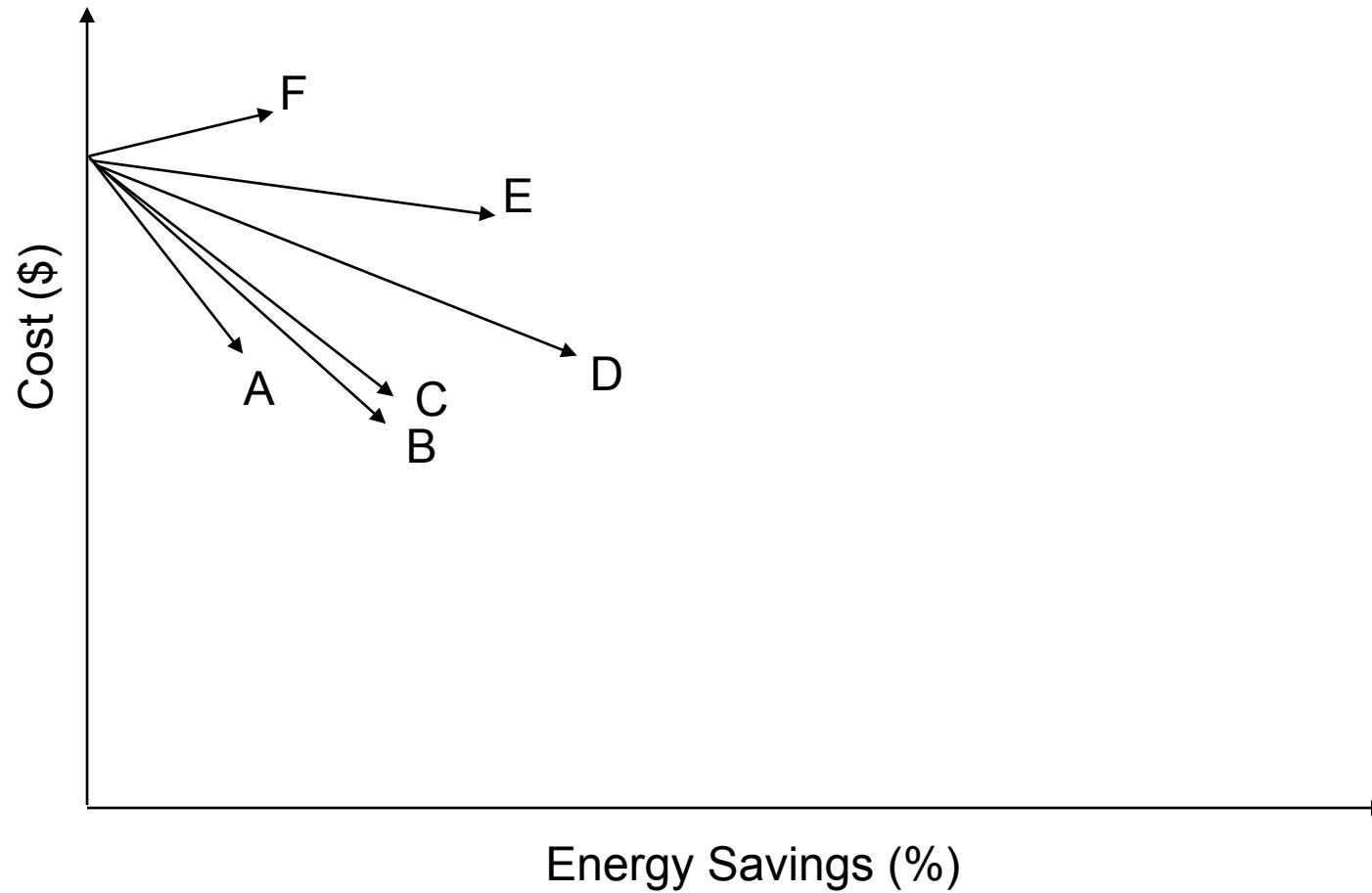
# Skip Predicted Outliers



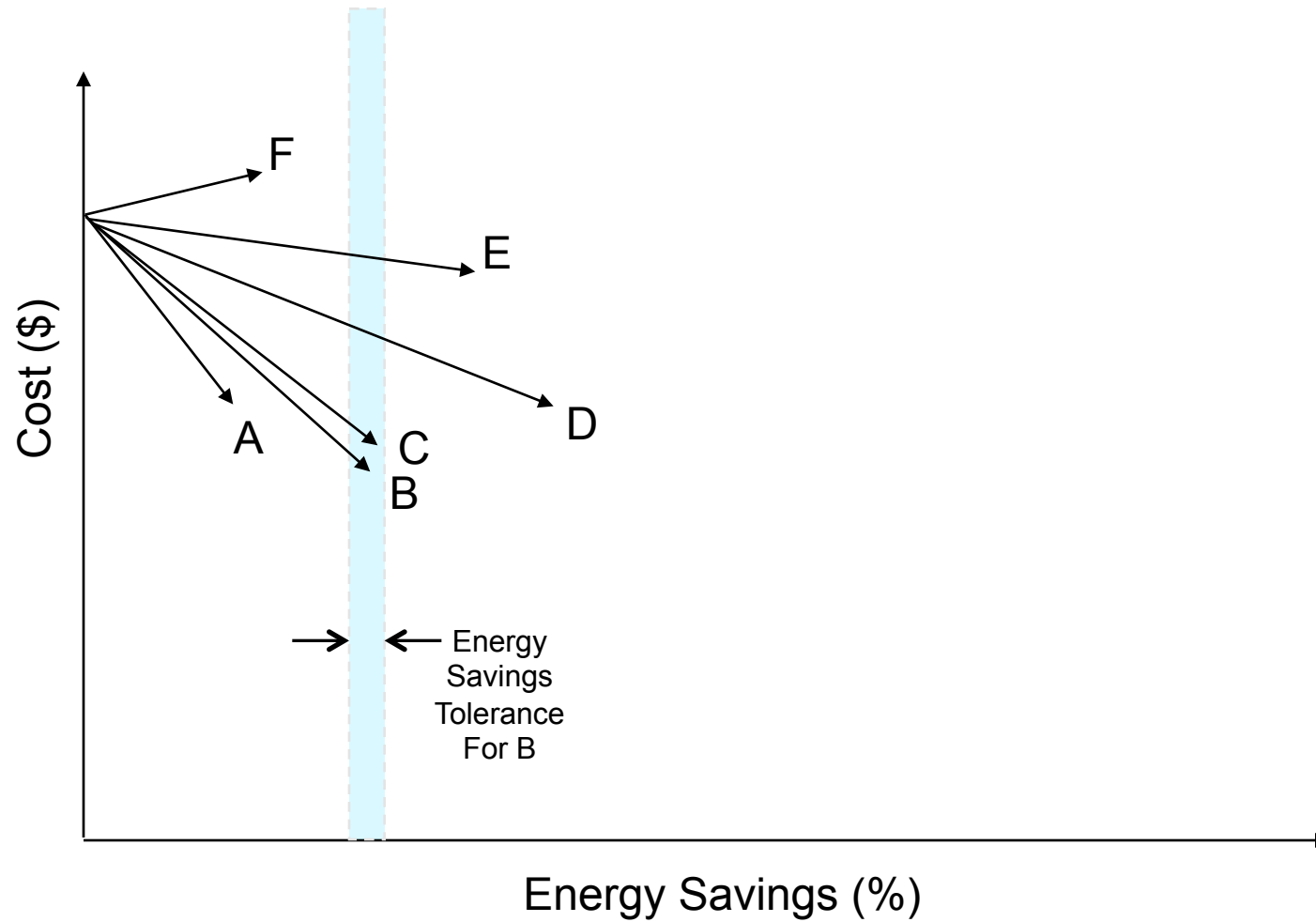
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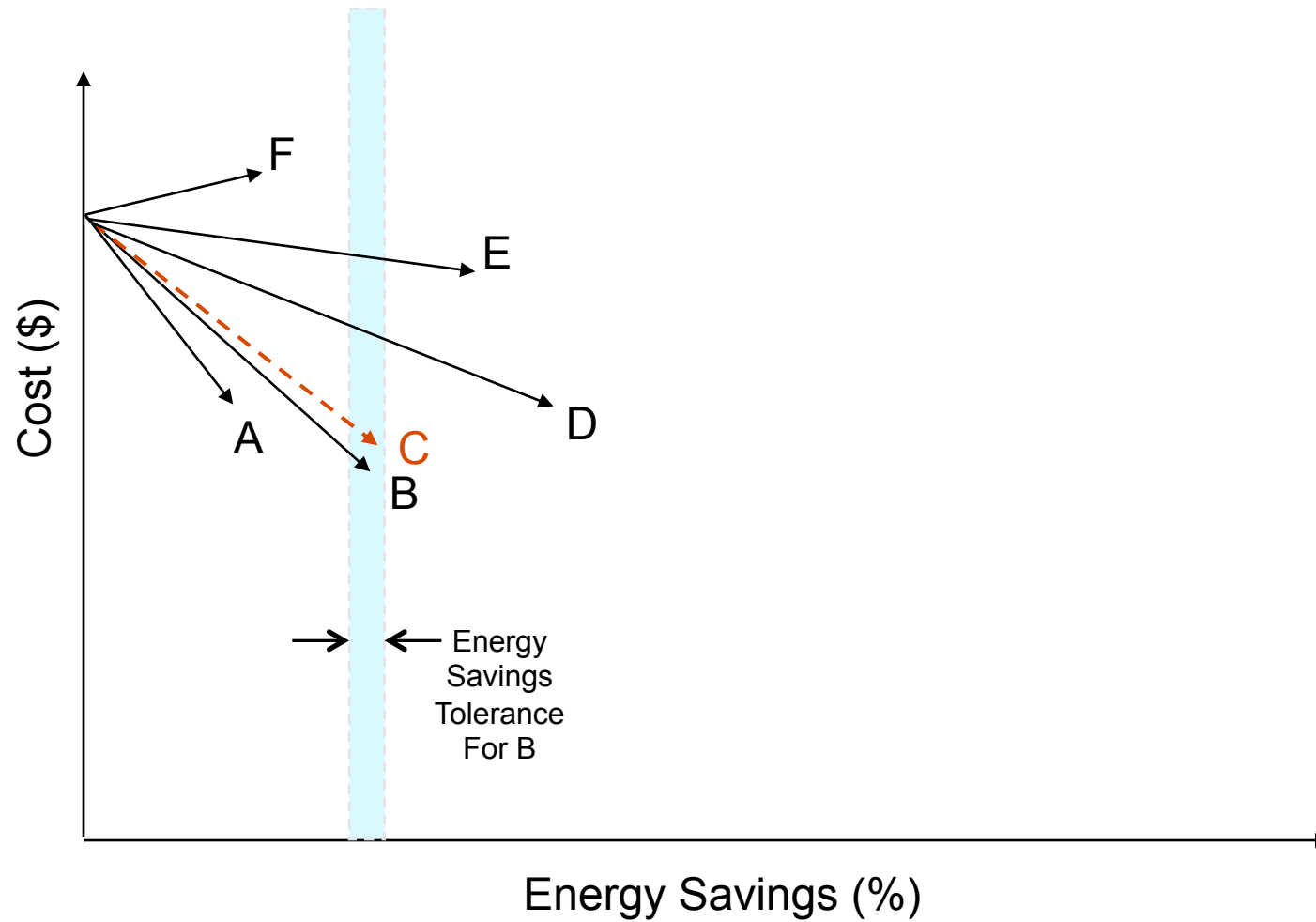
# Skip Fine Points



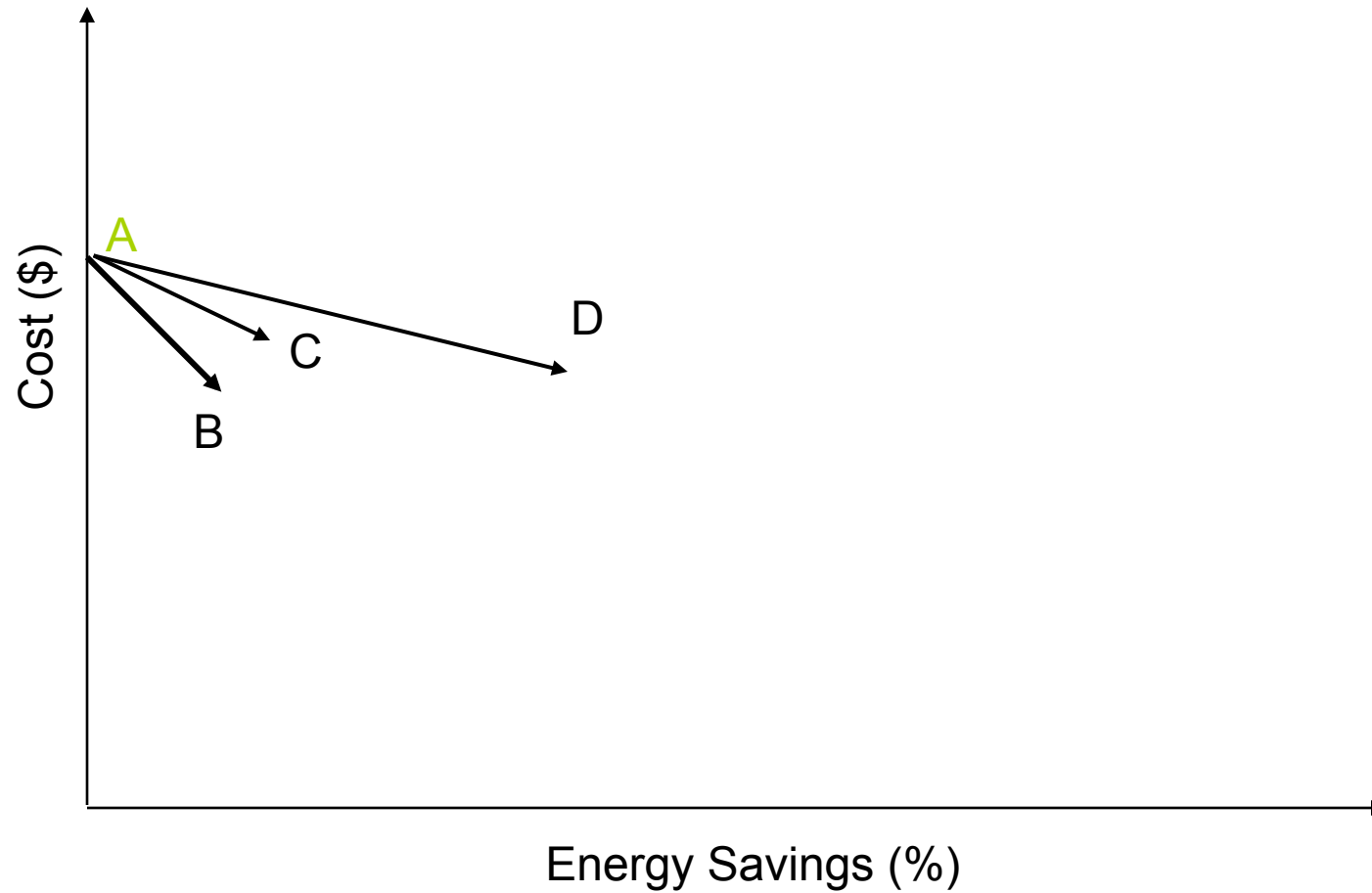
# Skip Fine Points



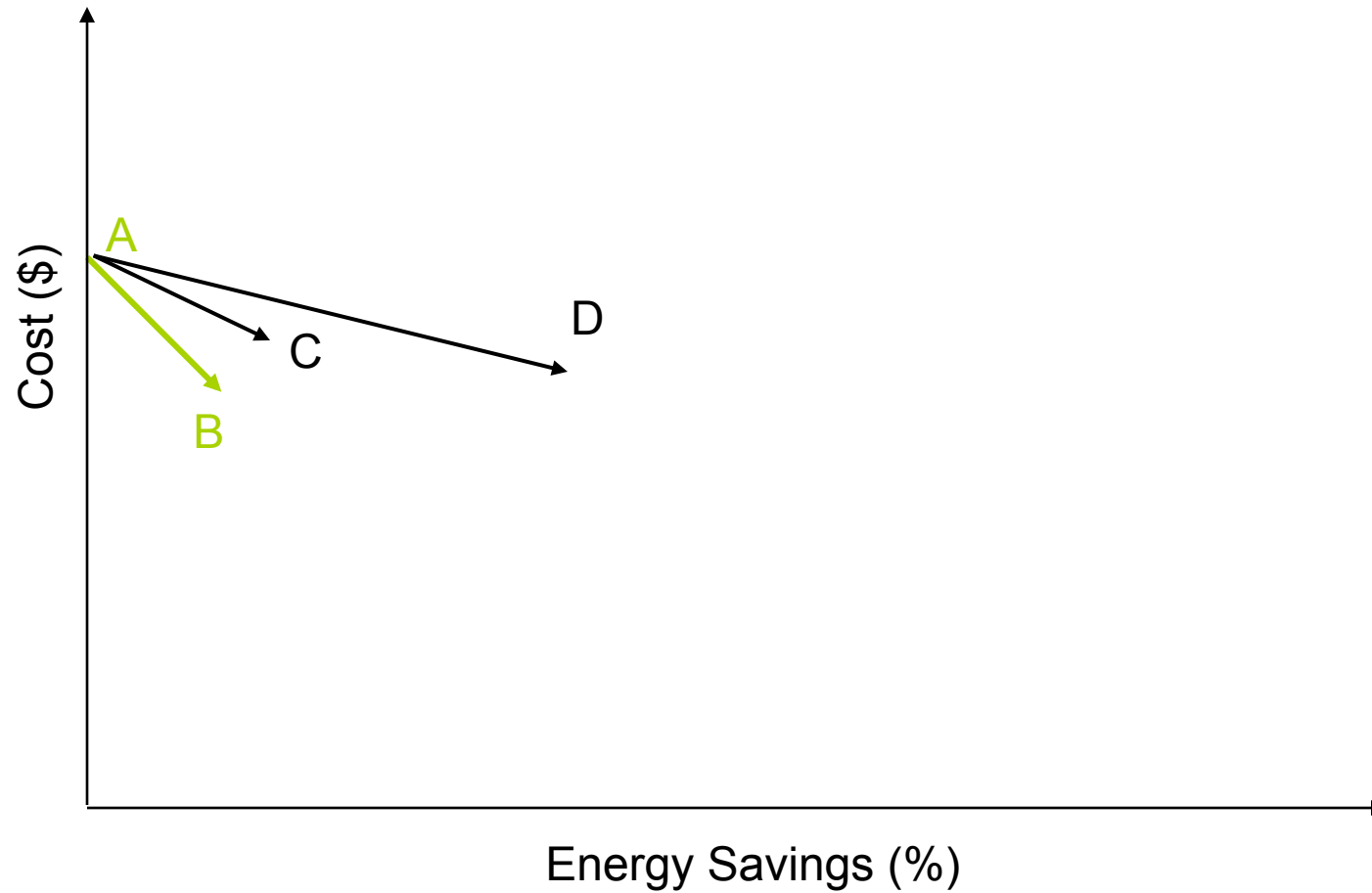
# Skip Fine Points



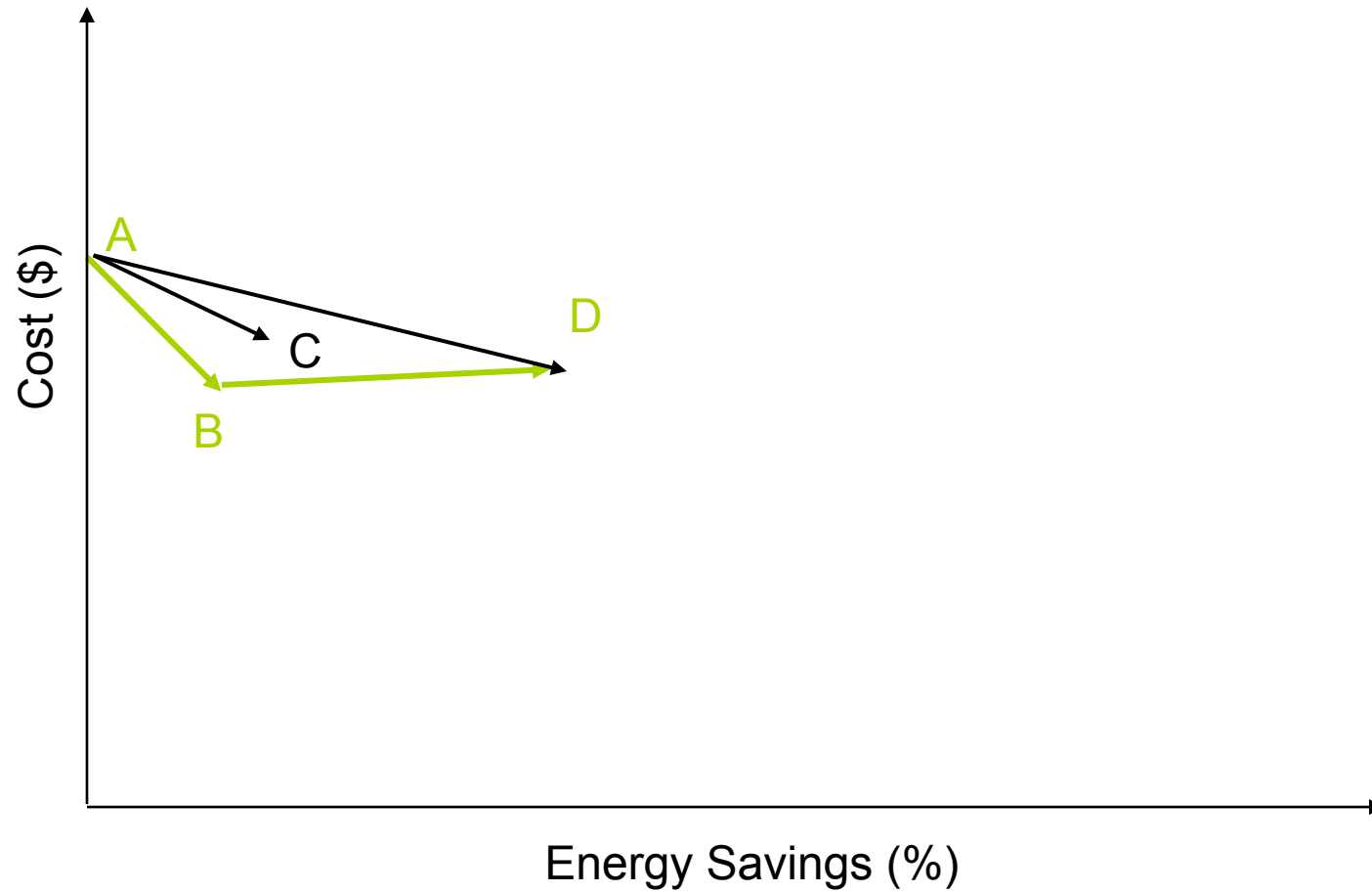
# Skip Extraneous Points



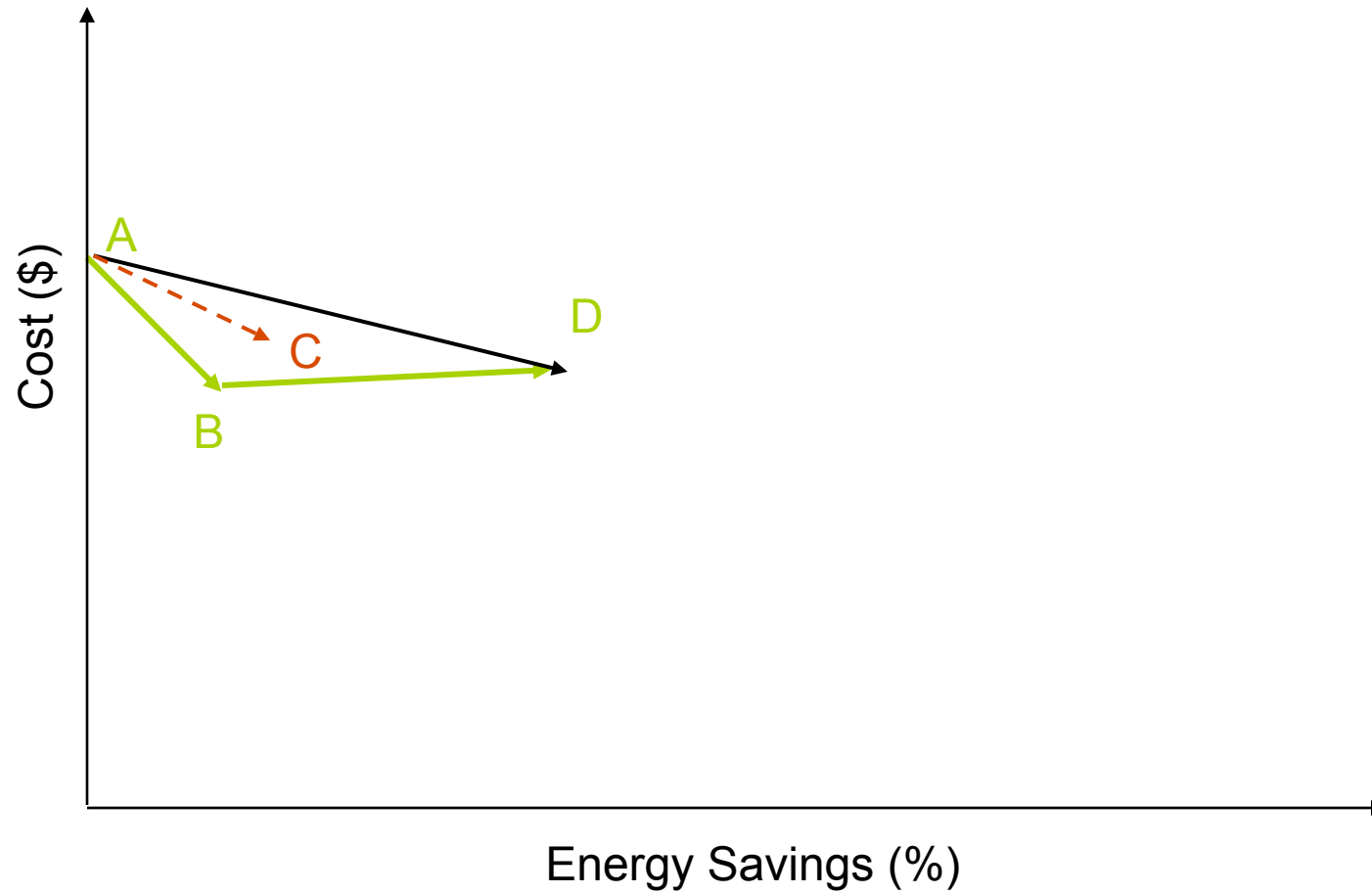
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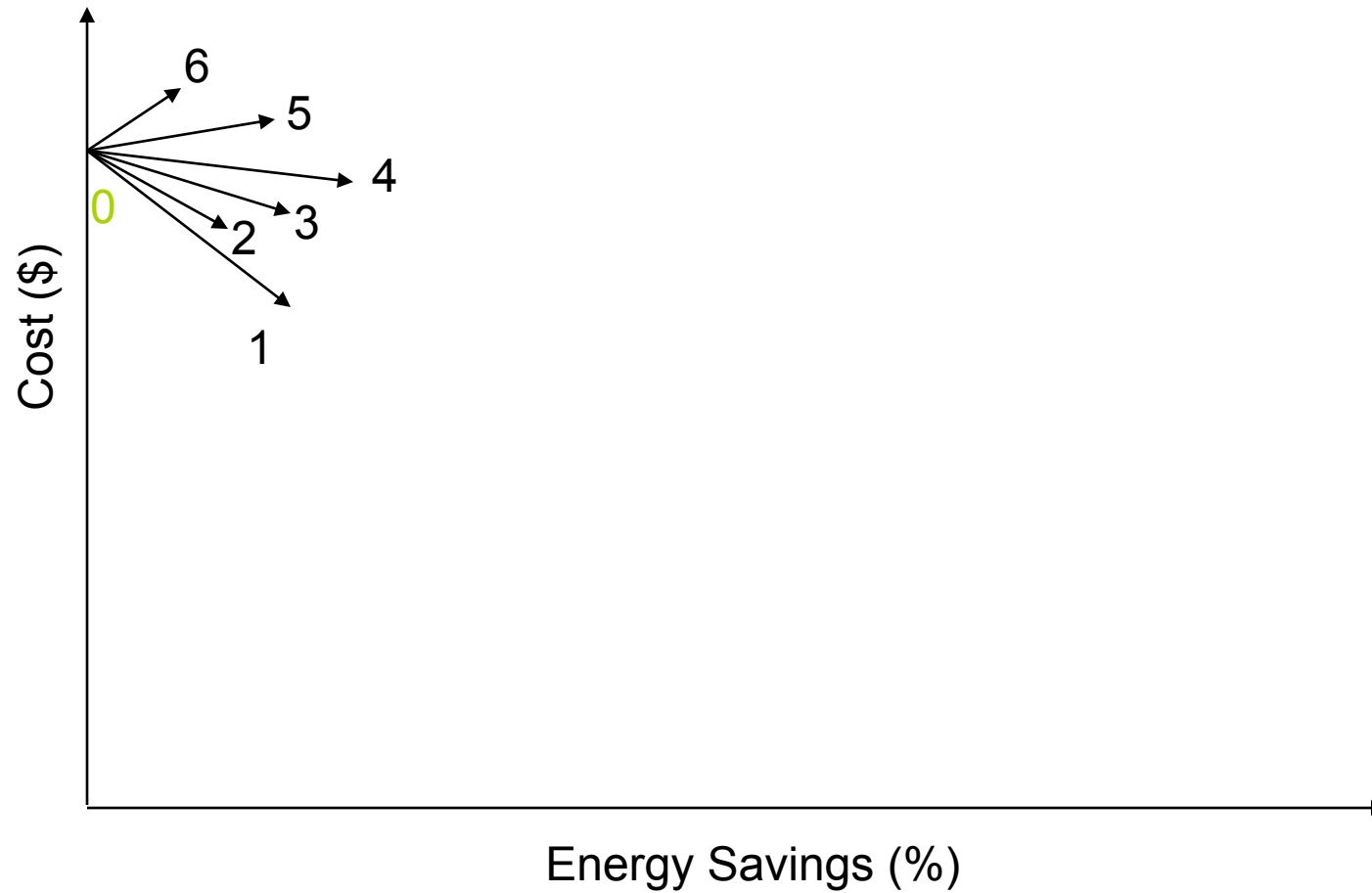
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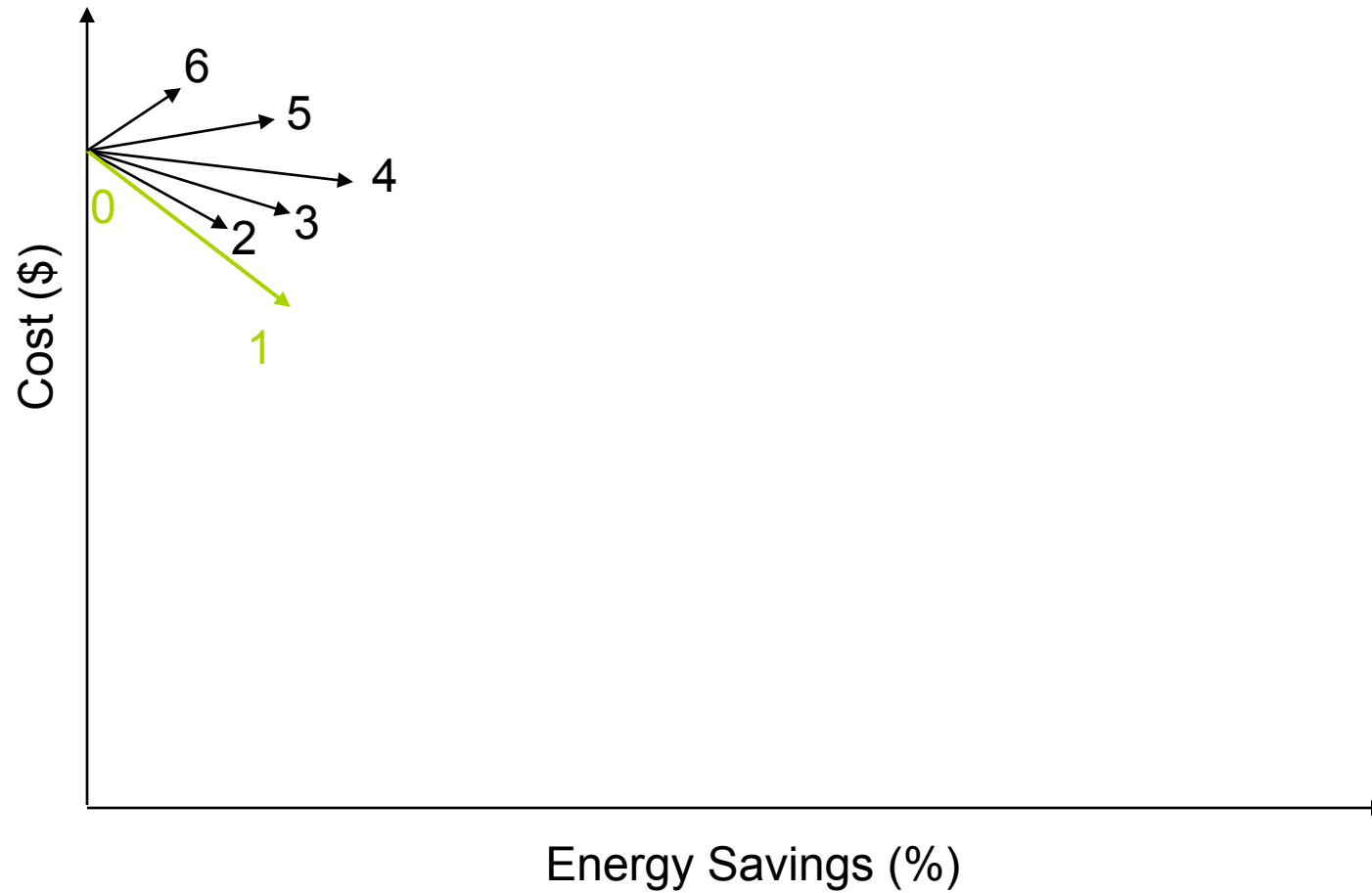
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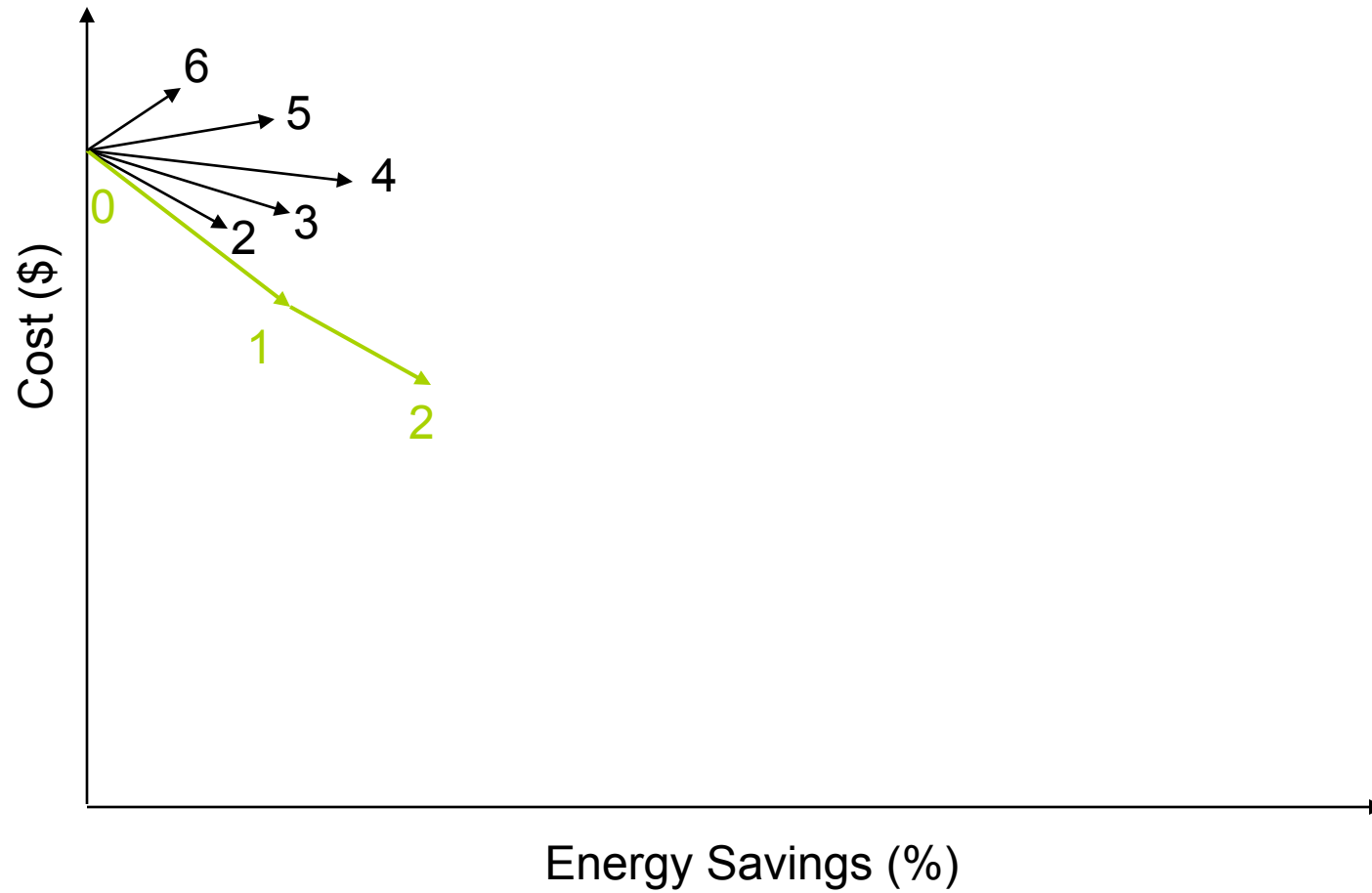
# Option Lumping



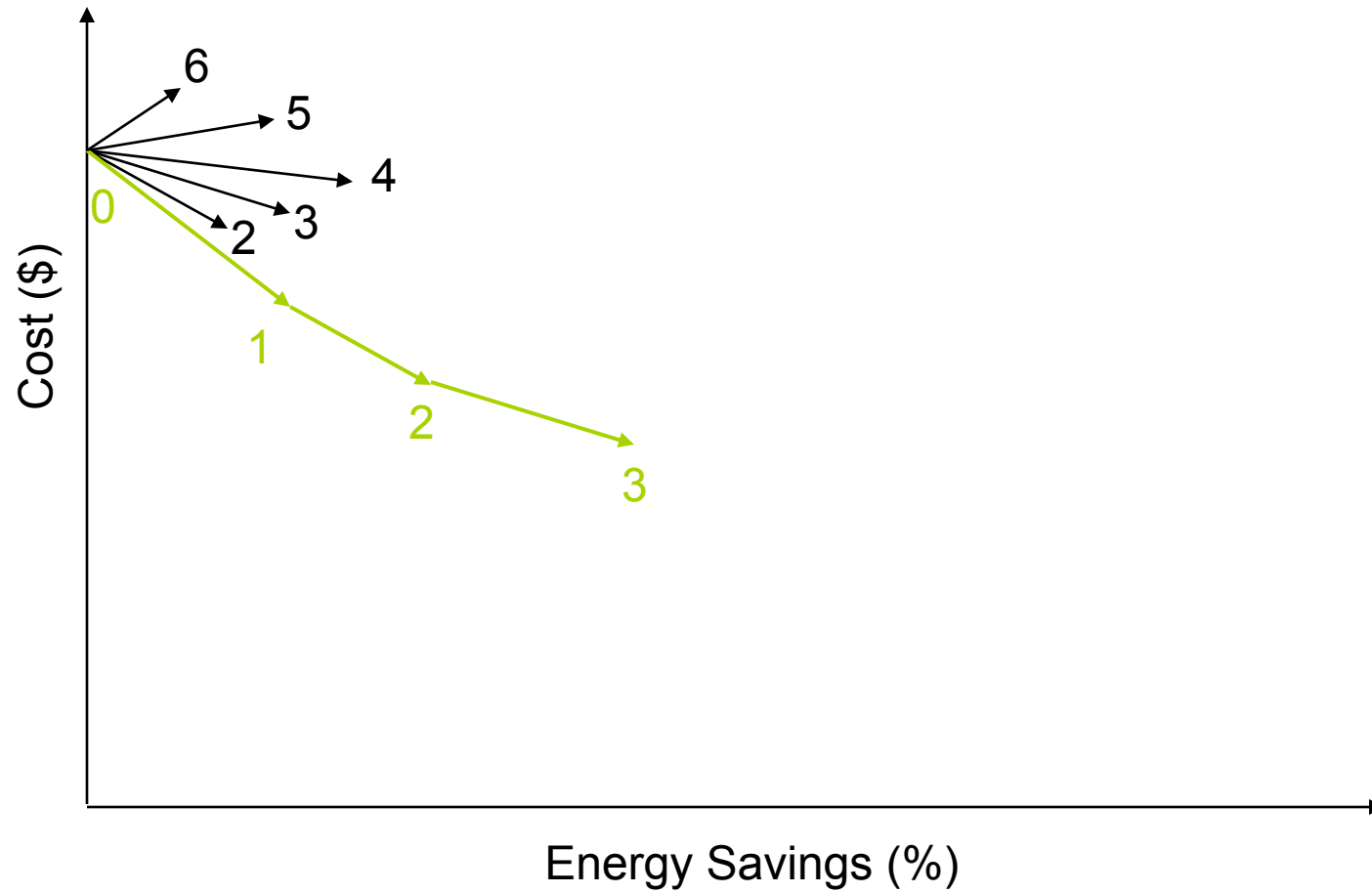
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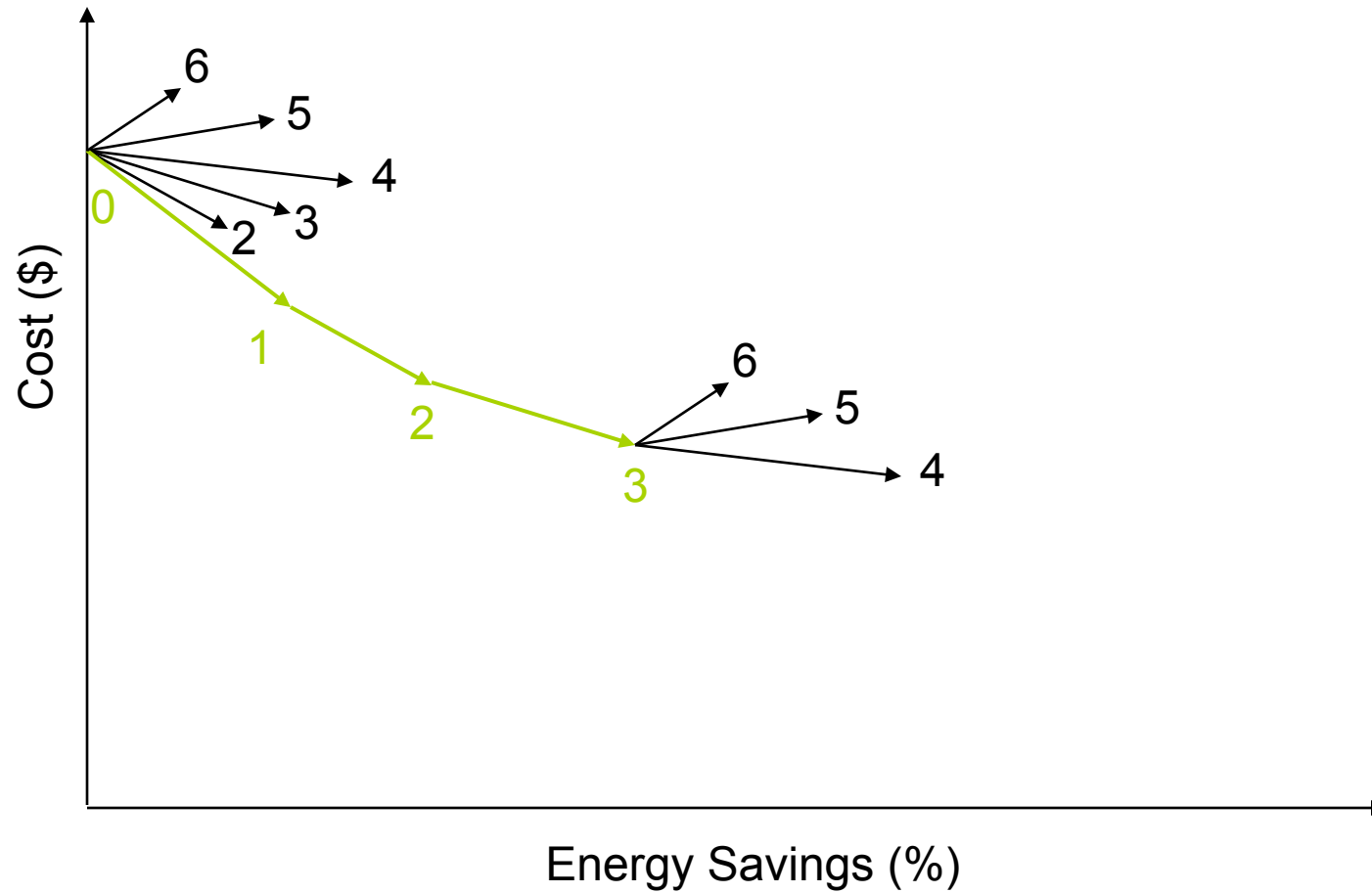
# Option Lumping



# Option Lumping



# Option Lumping



## IV. Test Suite

# Details for Test Suite

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2500 sqft building, 2 stories, 2-car garage

Standard BEopt costs

- RS Means, manufacturer's data, etc.

18 optimizations

- 6 climates
  - Phoenix, Houston, Atlanta, San Francisco, Boulder, Chicago
- 3 optimization sizes
  - Large ~ 2100 simulations, 8 hours
  - Medium ~ 300 simulations, 1.5 hours
  - Small ~ 50 simulations, 10 minutes

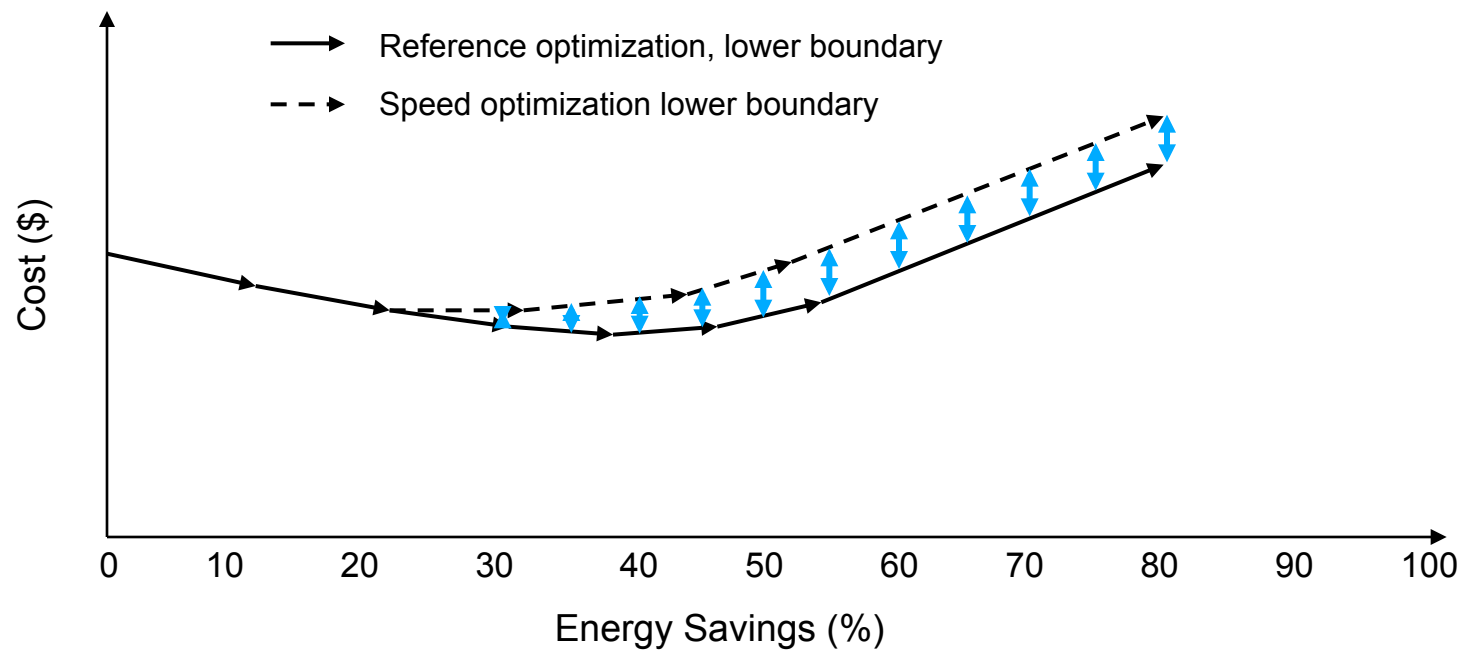
# Results

## Speed Gains

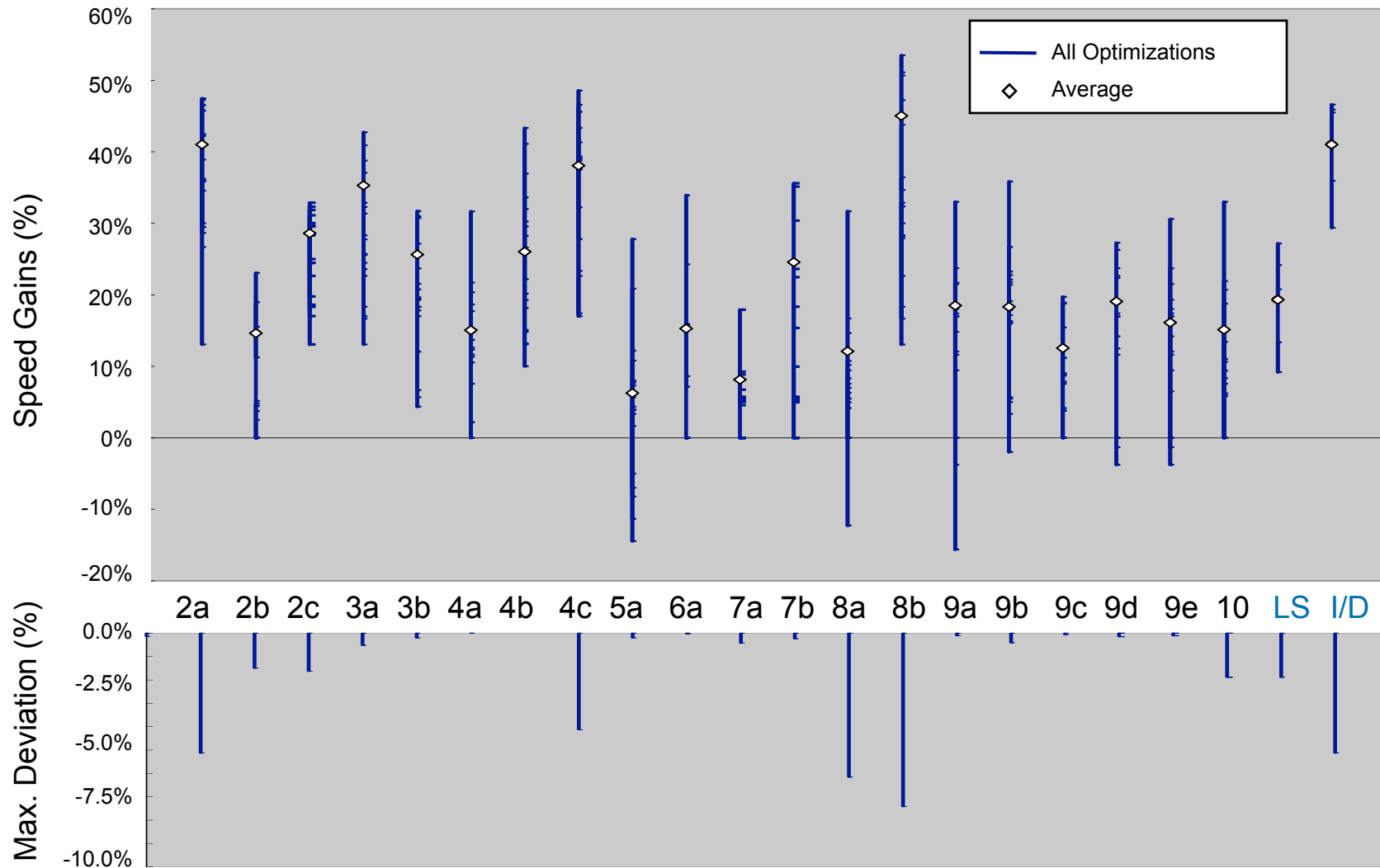
Percent reduction in number of simulations, relative to reference optimization

## Robustness

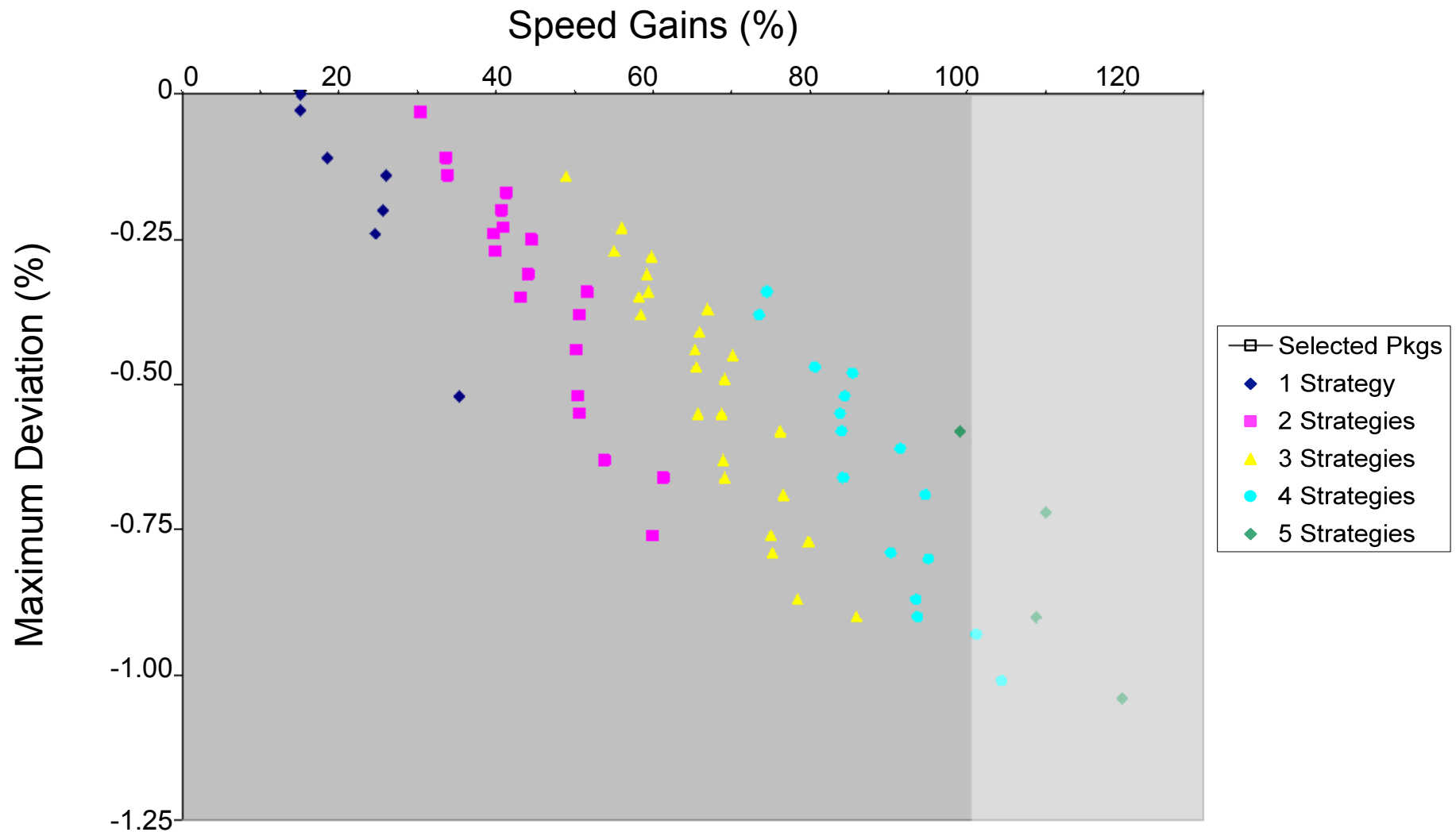
Percent maximum deviation in cost-optimal path, relative to reference optimization



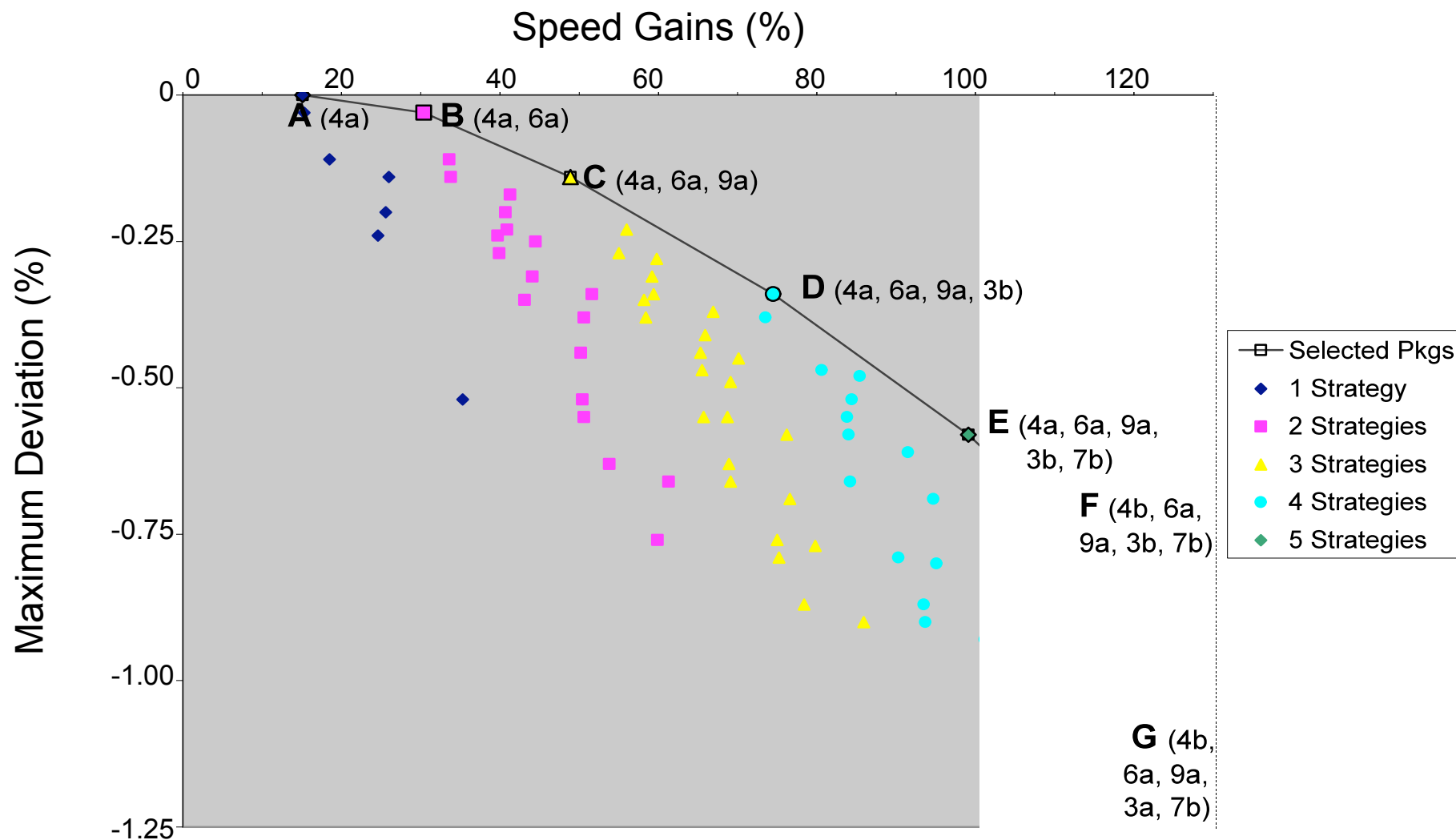
# V. Packages Results



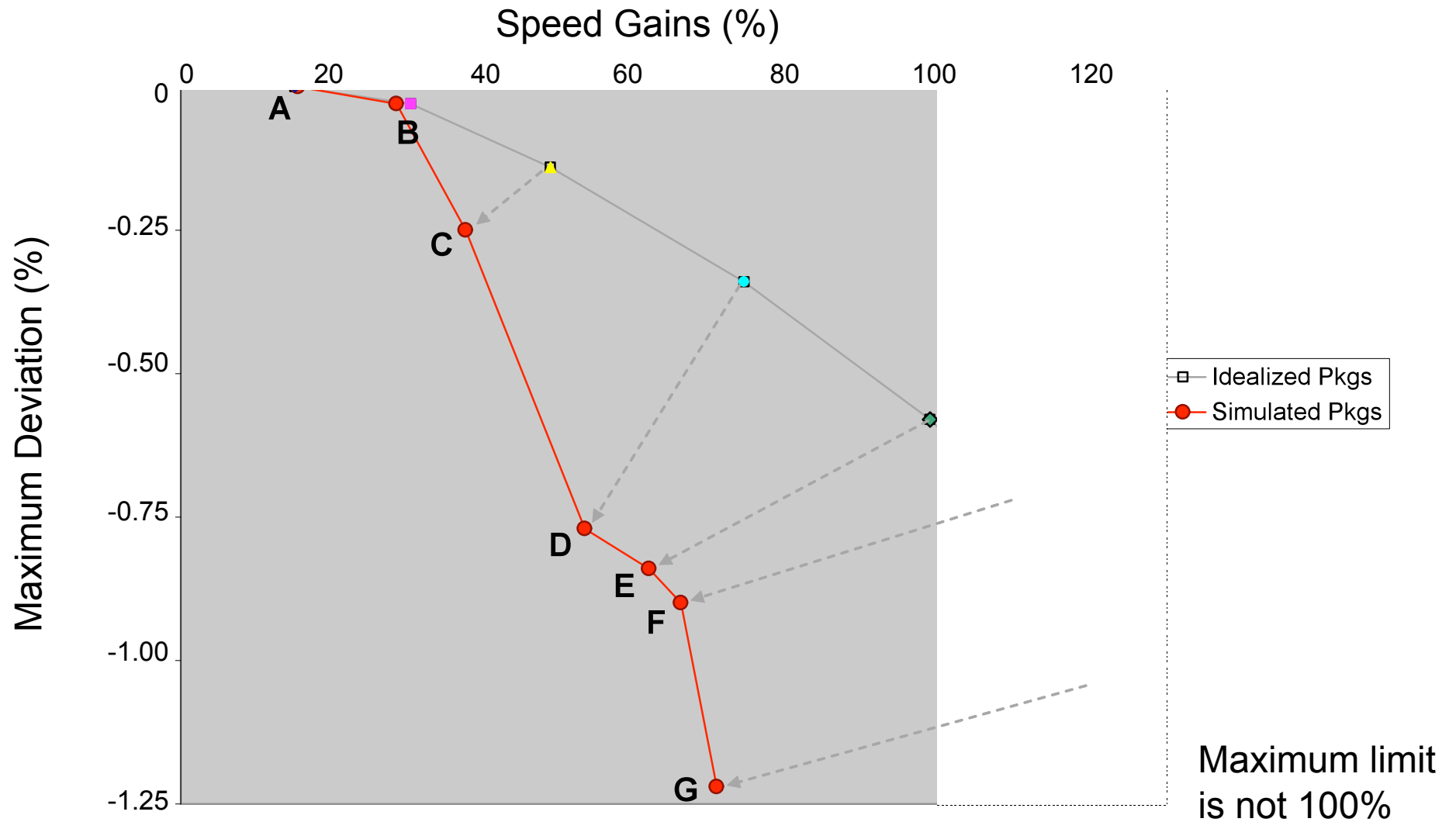
# Package Selection



# Package Selection



# Final Results



## V. Packages

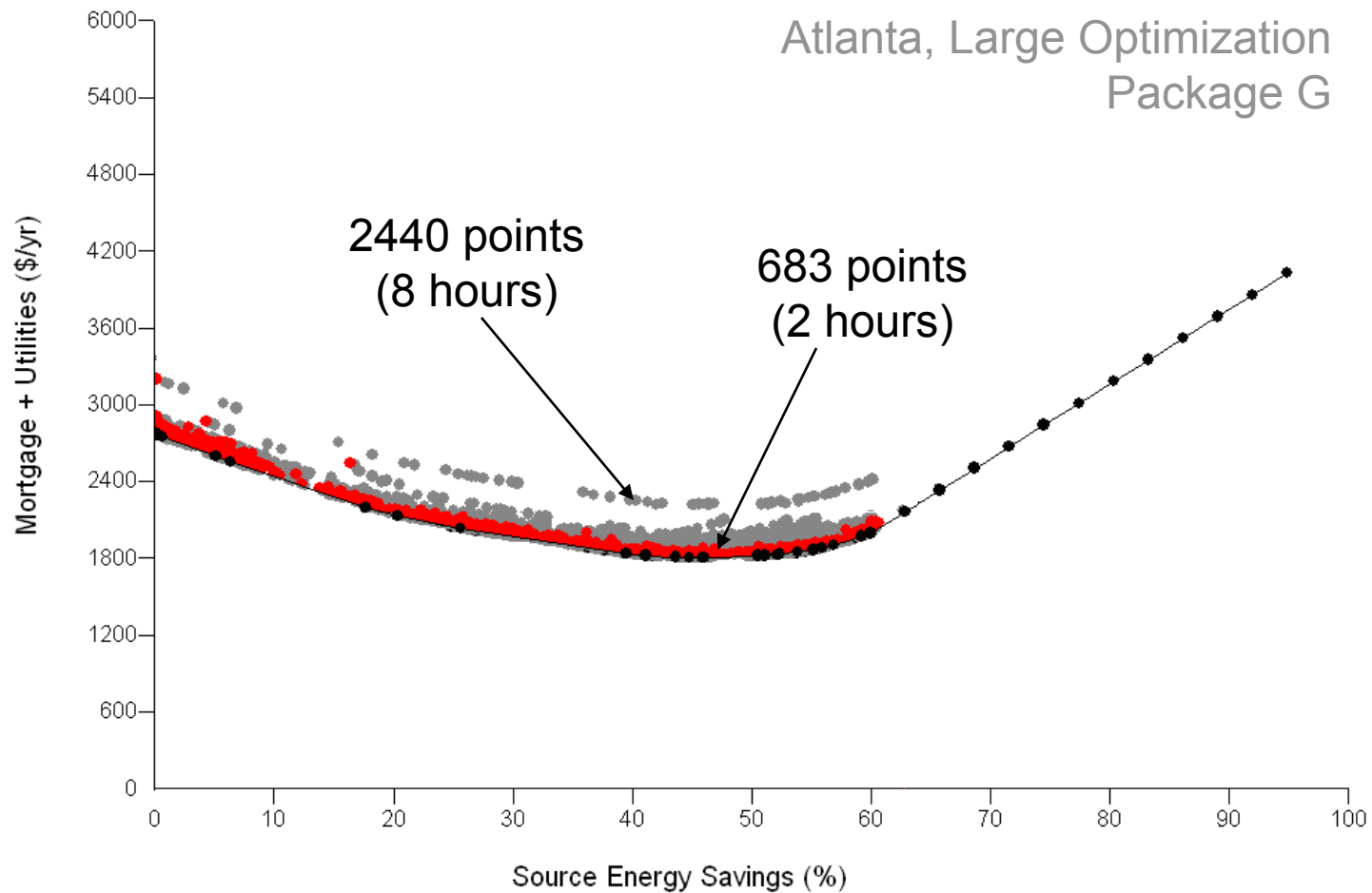
# Final Results

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Pkg	Speed Gains (%)				Max Deviation (%)
	Small Only	Medium Only	Large Only	33/33/33 Use Profile	
<b>A</b>	10.2	16.7	15.5	15.5	0.00
<b>B</b>	10.2	16.7	30.5	28.5	0.03
<b>C</b>	15.6	25.3	40.0	37.6	0.25
<b>D</b>	26.9	42.1	55.5	53.4	0.77
<b>E</b>	29.7	45.7	64.8	61.9	0.84
<b>F</b>	38.4	54.2	68.3	66.2	0.90
<b>G</b>	44.0	58.4	73.0	70.9	1.22
<b>H</b>	45.1	64.5	78.6	76.6	6.21

## V. Packages

# Final Results



# Conclusions

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## Robustness

- Three deficiencies identified/implemented
- Validated against large parametric runs

## Speed

- 11 strategies (31 variants) documented; 20 variants evaluated
- Better to supplement robustness strategies with speed strategies than to deactivate robustness strategies
- Most effective strategies: skip predicted outliers, skip fine points, option lumping, skip less efficient options, skip extraneous points

## Packages

- 7 packages selected
- Range from 15% speed gains (0% maximum deviation) to 71% speed gains (1.2% maximum deviation)

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Thank You!