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A Data-Driven Approach to Nation-Scale Building Energy Modeling

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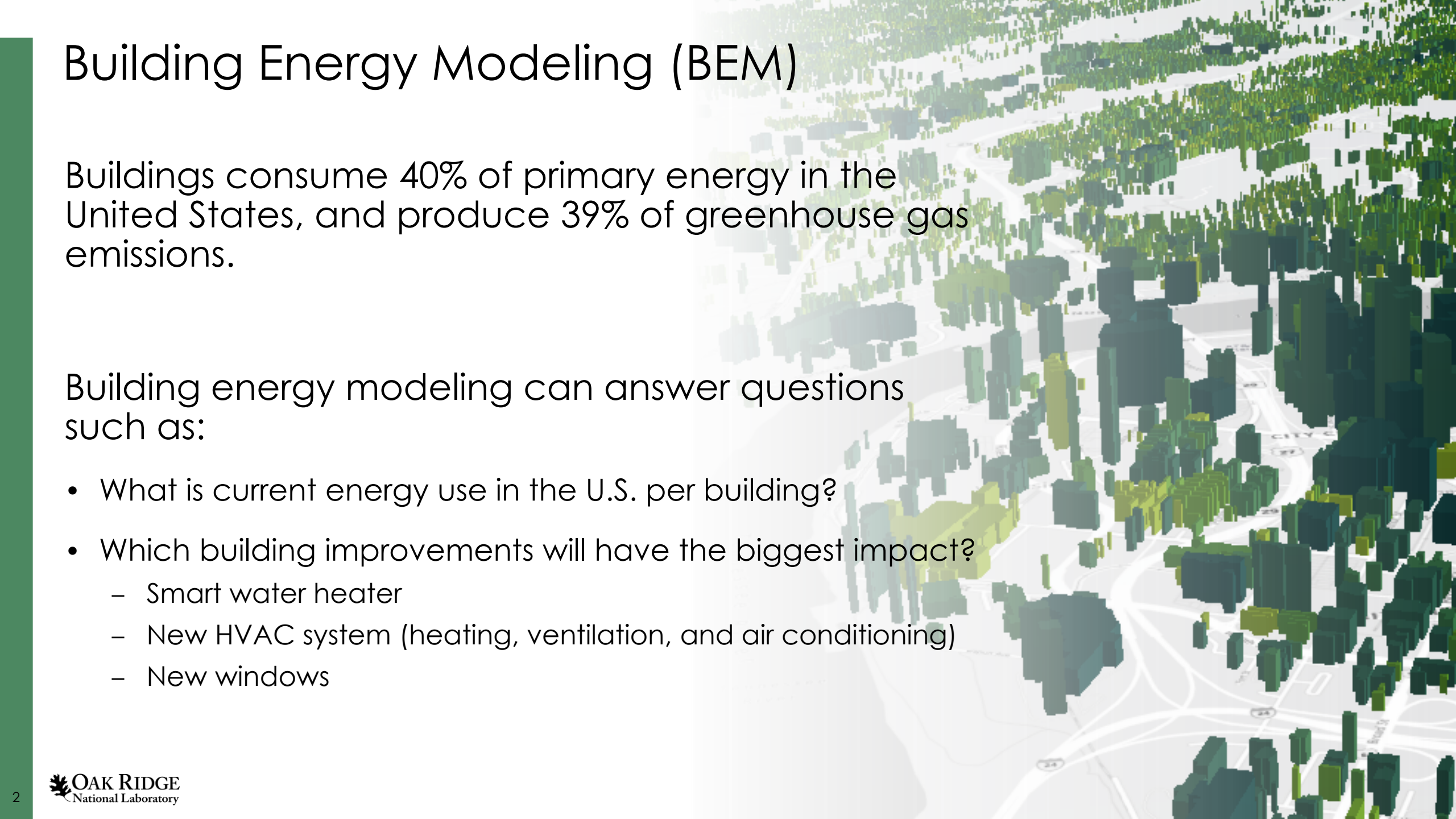
U.S. DEPARTMENT OF ENERGY

Building Energy Modeling (BEM)

Buildings consume 40% of primary energy in the United States, and produce 39% of greenhouse gas emissions.

Building energy modeling can answer questions such as:

- What is current energy use in the U.S. per building?
- Which building improvements will have the biggest impact?
  - Smart water heater
  - New HVAC system (heating, ventilation, and air conditioning)
  - New windows



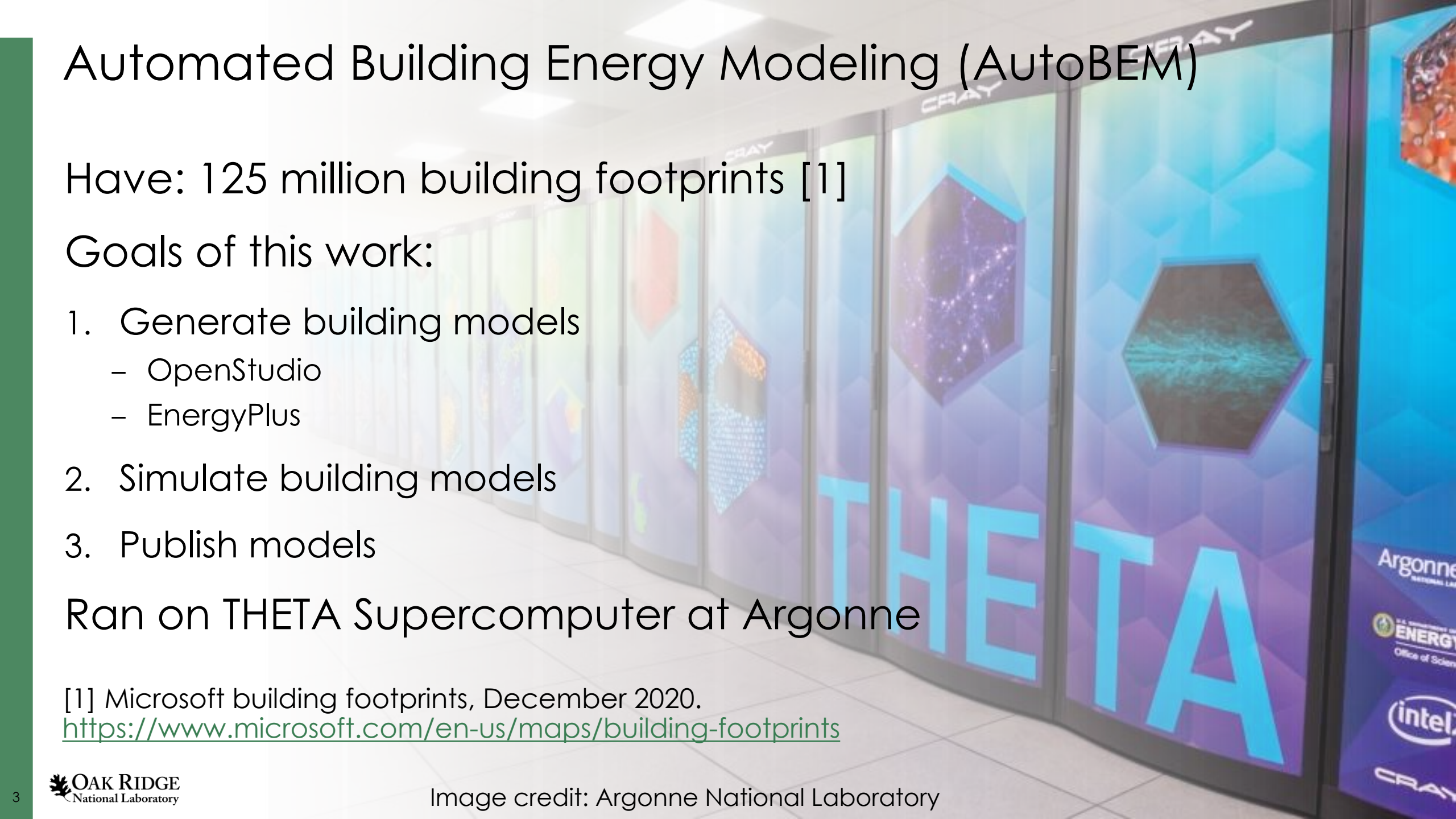
Automated Building Energy Modeling (AutoBEM)

Have: 125 million building footprints [1]

Goals of this work:

1. Generate building models
   - OpenStudio
   - EnergyPlus
2. Simulate building models
3. Publish models

Ran on THETA Supercomputer at Argonne



[1] Microsoft building footprints, December 2020. https://www.microsoft.com/en-us/maps/building-footprints

Image credit: Argonne National Laboratory

Required Building Information

- Footprint
- Height
- Number of Floors
- Area
- Window-to-wall ratio
- Building Type
- Building Vintage

Data Preparation

- Direct Building Data
  - 2D Footprint
  - Height
  - Year built
- Derived Building Data
  - Number of floors
  - Vintage
  - Area
  - *Building type*
  - Climate zone

Table 13 Reference Building Form Assignments

Building Type	Floor Area		Aspect Ratio	No. of Floors	Floor-to-Floor Height		Floor-to-Ceiling Height		Glazing Fraction
	ft^2	m^2			ft	m	ft	m	
Small Office	5,500	511	1.5	1	10	3.05	10	3.05	0.21
Medium Office	53,628	4,982	1.5	3	13	3.96	9	2.74	0.33
Large Office	498,588	46,320	1.5	12*	13	3.96	9	2.74	0.38
Primary School	73,960	6,871	E-Shape	1	13	3.96	13	3.96	0.35
Secondary School	210,887	19,592	E-Shape	2	13	3.96	13	3.96	0.33
Stand-Alone Retail	24,962	2,294	1.3	1	20	6.10	20	6.10	0.07
Strip Mall	22,500	2,090	4.0	1	17	5.18	17	5.18	0.11
Supermarket	45,000	4,181	1.5	1	20	6.10	20	6.10	0.11
Quick Service Restaurant	2,500	232	1.0	1	10	3.05	10	3.05	0.14
Full Service Restaurant	5,500	511	1.0	1	10	3.05	10	3.05	0.17
Small Hotel	43,200	4,013	3.0	4	11** 9	3.35** 2.74	11** 9	3.35** 2.74	0.11
Large Hotel	122,120	11,345	3.8** 5.1	6	13** 10	3.96** 3.05	13** 10	3.96** 3.05	0.27
Hospital	241,351	22,422	1.3	5*	14	4.27	14	4.27	0.15
Outpatient Healthcare	40,946	3,804	1.4	3	10	3.05	10	3.05	0.19
Warehouse	52,045	4,835	2.2	1	28	8.53	28	8.53	0.006
Midrise Apartment	33,740	3,135	2.7	4	10	3.05	10	3.05	0.15

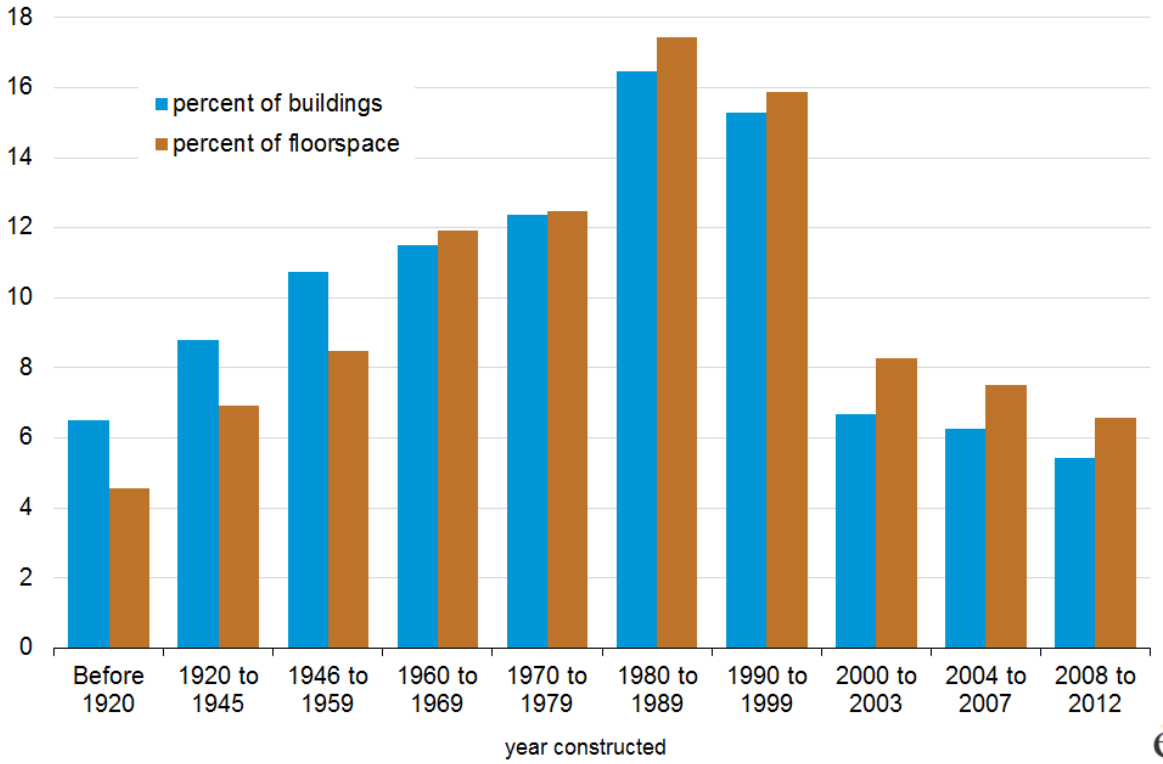
* Plus basement (not included in the table number)

** First floor

Deru, M, Field, K, Studer, D, Benne, K, Griffith, B, Torcellini, P, Liu, B, Halverson, M, Winiarski, D, Rosenberg, M, Yazdanian, M, Huang, J, and Crawley, D. 2011. "U.S. Department of Energy Commercial Reference Building Models of the National Building Stock". United States. https://doi.org/10.2172/1009264. https://www.osti.gov/servlets/purl/1009264.

Missing Data

Figure 3. About half of all commercial buildings were constructed before 1980



Source: U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey

- Missing height data imputed with median of nearest 20 buildings
- Missing year-built data classified with *Commercial Buildings Energy Consumption Survey (CBECS)* distribution of building age

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Building Type

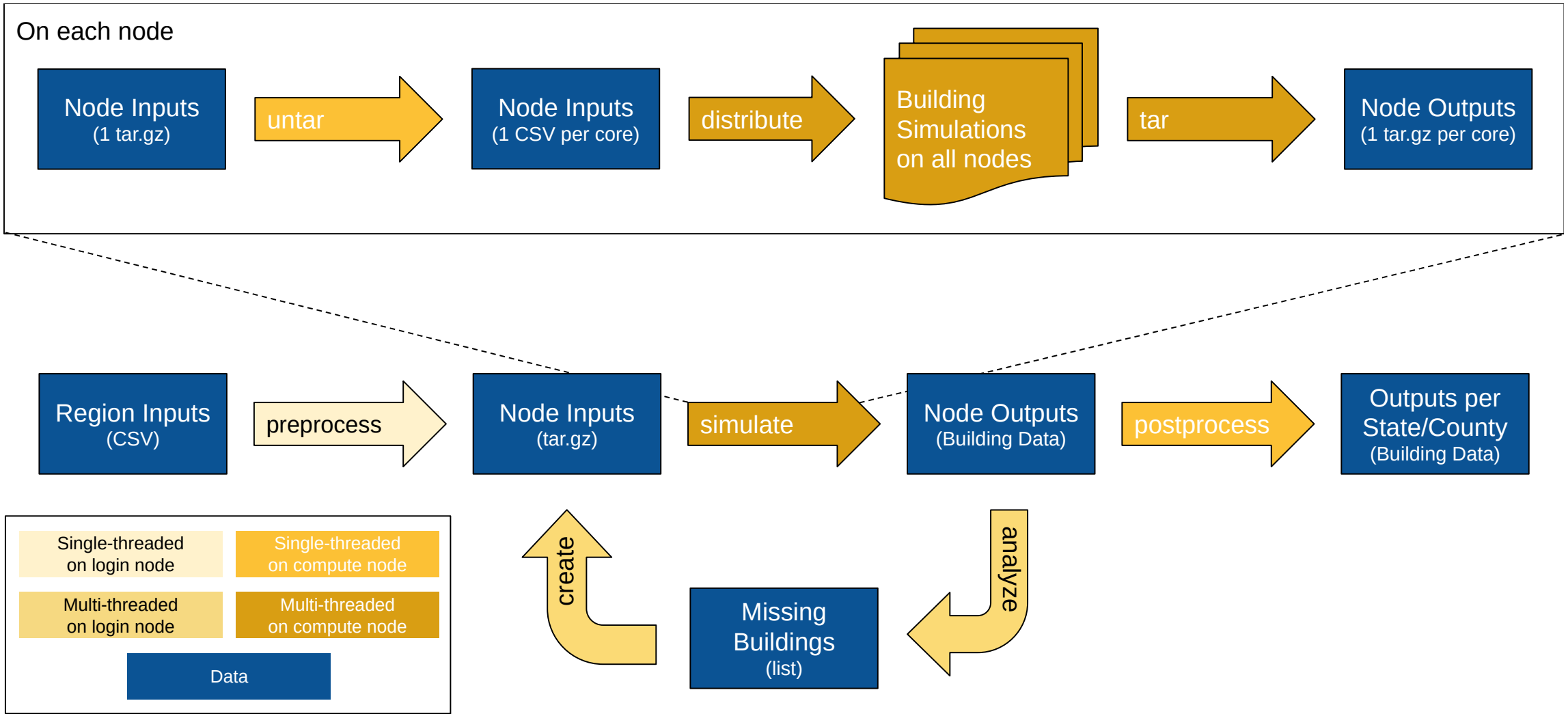
- Physical properties used to classify each building into bins
- Buildings further classified within bin using PNNL 2003-2006 distributions on commercial construction area
- Residential building percentages factored into weights using surveyed floorspace data per climate zone

Physical Bin Parameters	Prototype Buildings
<40ft Height <6,000ft^2 (2D) Area	Full Service Restaurant Quick Service Restaurant Small Office Residential
<40ft Height >6,000ft^2 (2D) Area <15,000ft^2 (2D) Area	Retail Standalone Retail Stripmall Outpatient
<40ft Height >15,000ft^2 (2D) Area	Primary School Secondary School Warehouse
>40ft Height <80ft Height <18,000ft^2 (2D) Area	Medium Office Small Hotel Midrise Apartment
>40ft Height <80ft Height >18,000ft^2 (2D) Area	Hospital Large Hotel
>80ft Height	Highrise Apartment Large Office

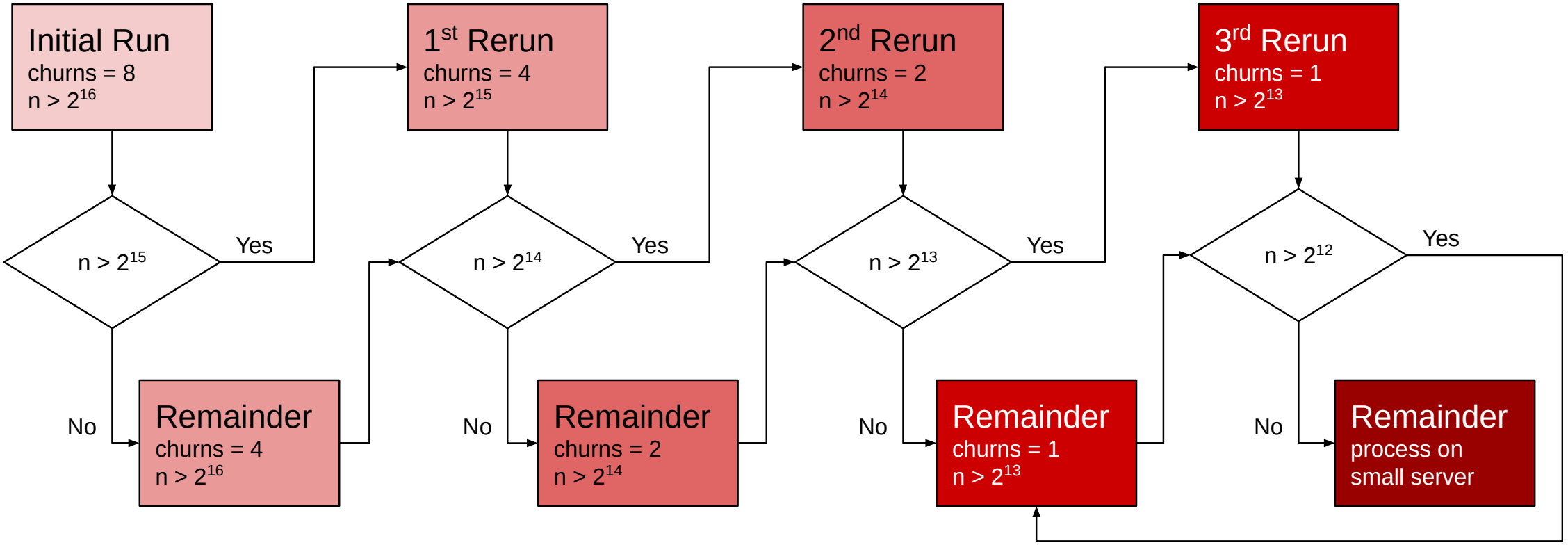
U.S. Census Regions

Region	Region Name	States	Total Buildings
1	New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	5,435,392
2	Middle Atlantic	New Jersey, New York, Pennsylvania	12,637,184
3	East North Central	Illinois, Indiana, Michigan, Ohio, Wisconsin	22,528,155
4	West North Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota	12,463,109
5	South Atlantic	Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	23,558,752
6	East South Central	Alabama, Kentucky, Mississippi, Tennessee	9,977,403
7	West South Central	Arkansas, Louisiana, Oklahoma, Texas	15,480,692
8	Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming	7,551,785
9	Pacific	Alaska, Hawaii, Oregon, Washington	5,149,591
10	California	California	10,933,546

Overall Workflow



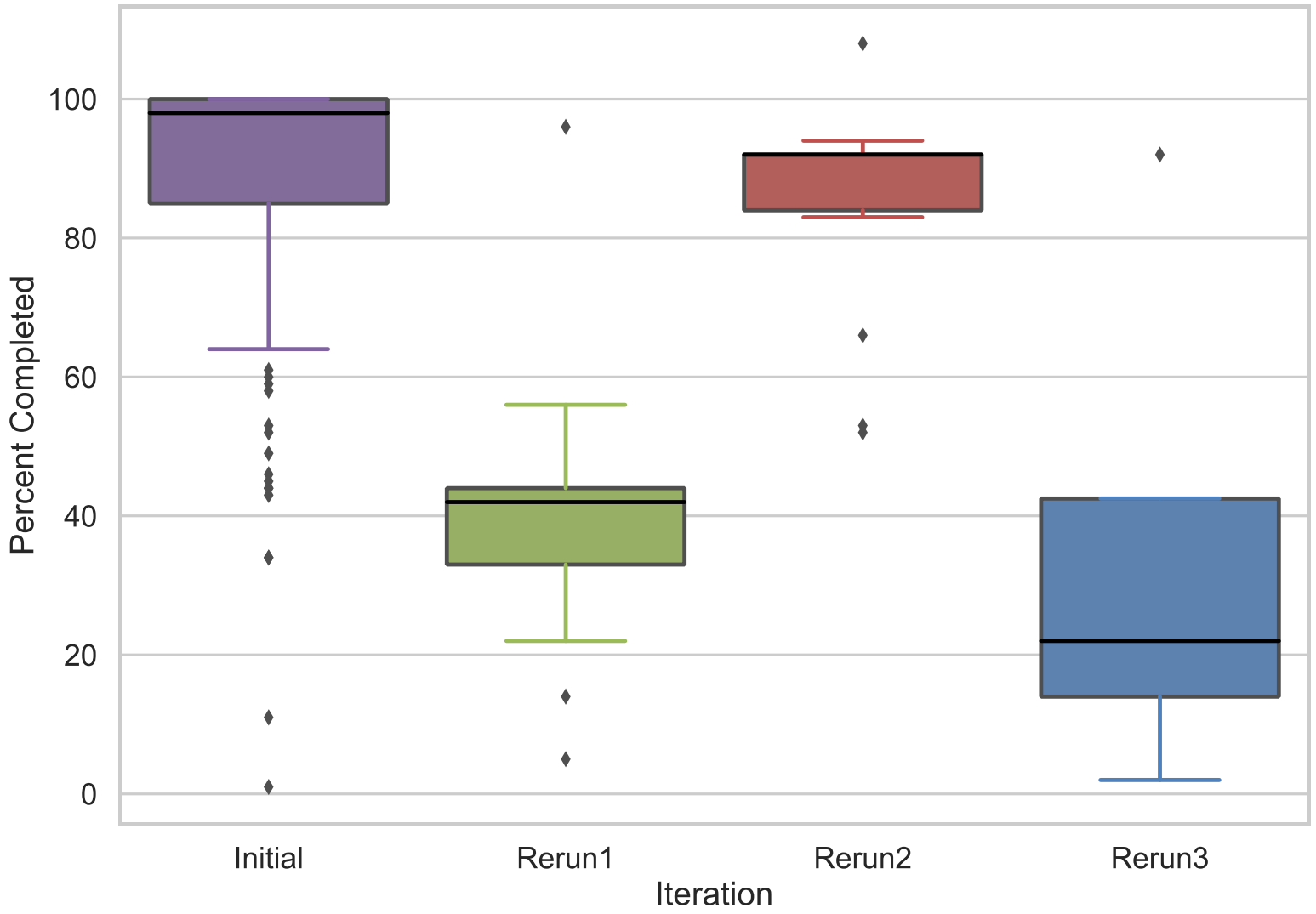
Checkpointing/Resubmission Strategy



Results: Successful Buildings per Round

#	Buildings	Initial	Rerun1	Rerun2	Rerun3
1	5,435,392	4,362,202	518,576	291,327	207,103
2	12,637,184	9,019,214	1,358,741	1,821,282	
3	22,528,155	22,467,370			
4	12,463,109	10,748,054	791,385	820,444	
5	23,558,752	23,207,301			
6	9,977,403	4,517,672	1,442,752	3,046,398	97,638
7	15,480,692	15,452,216			
8	7,551,785	7,531,113			
9	5,149,591	5,051,863			
10	10,933,546	10,781,507			
R			742,174		
$\sum$	125,716,992	113,138,512	4,853,628	5,979,451	305,741
%		89.99%	3.86%	4.76%	0.16%

Results by Submission Round



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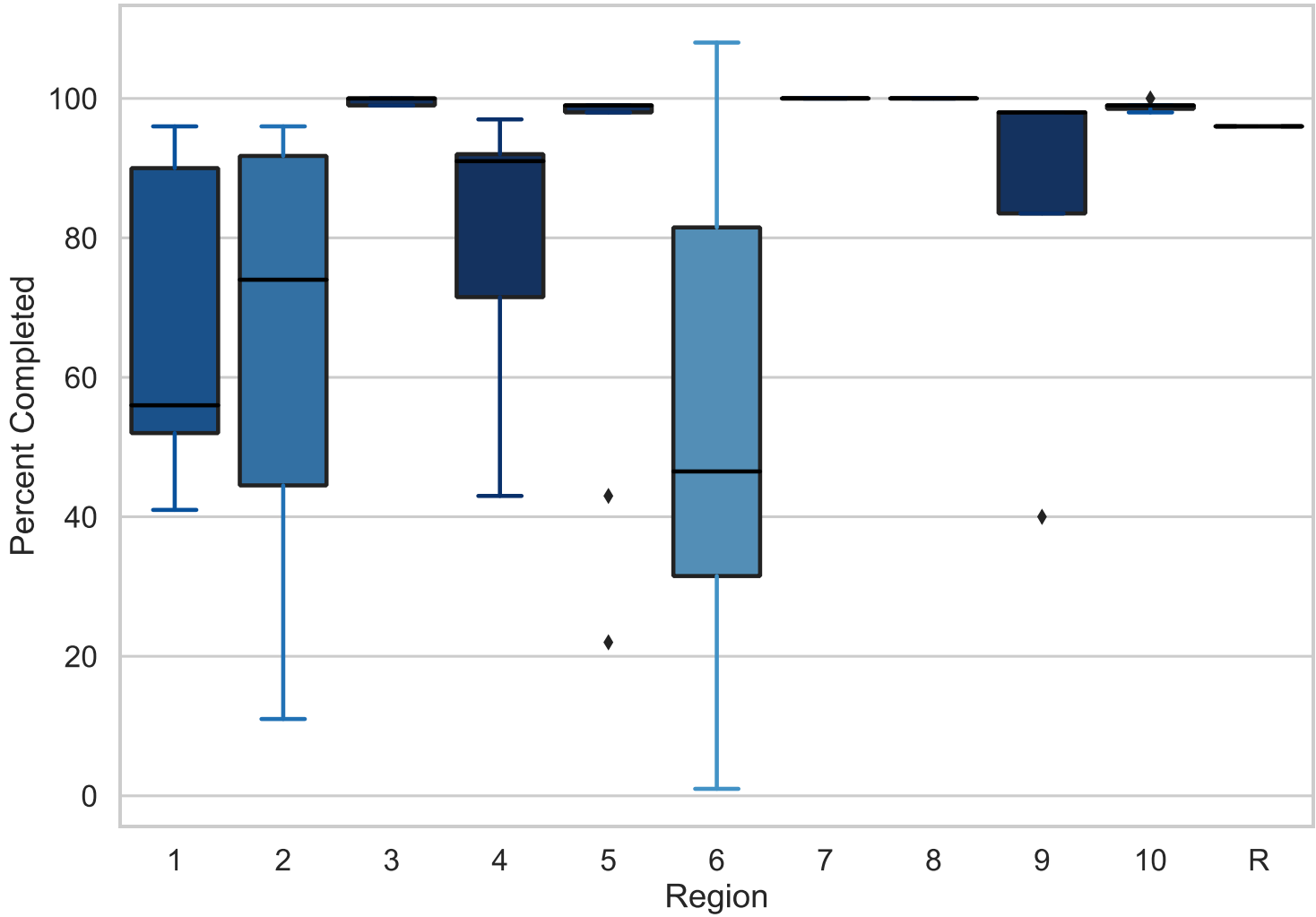
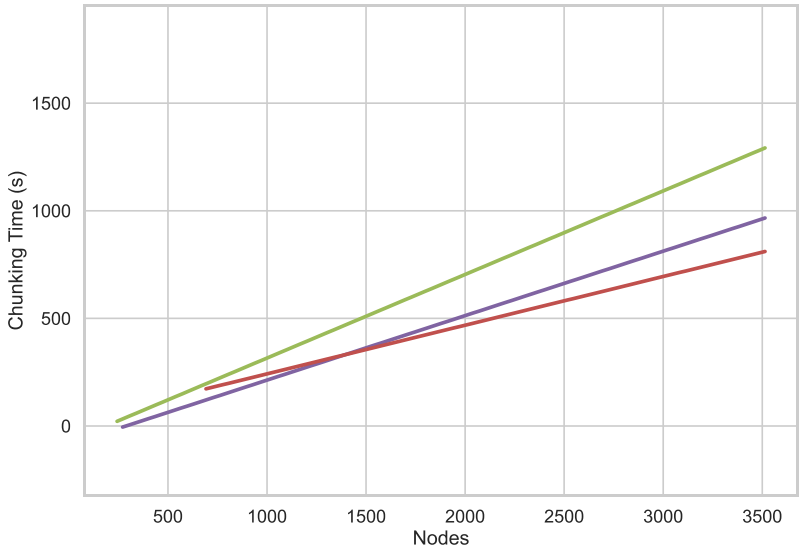
Results by Region



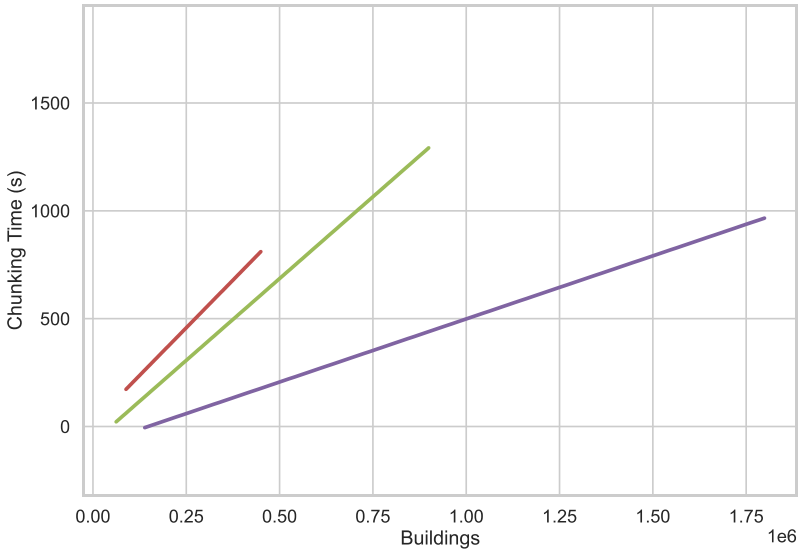
Preprocessing Results

Chunk

Nodes

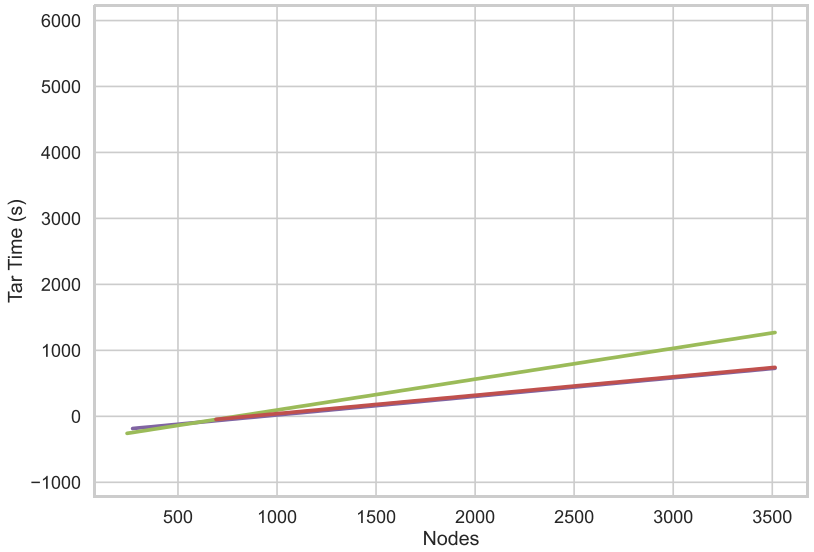


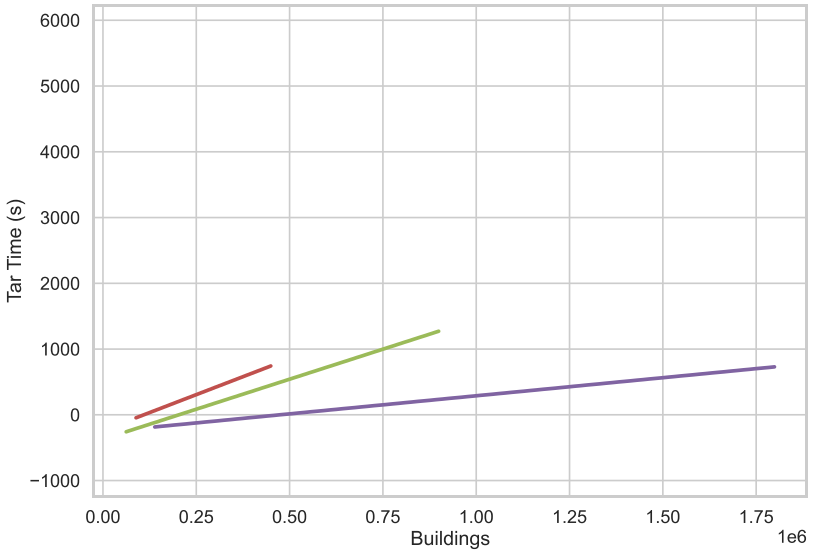
Buildings



Initial
Rerun1
Rerun2
Rerun3

Tar





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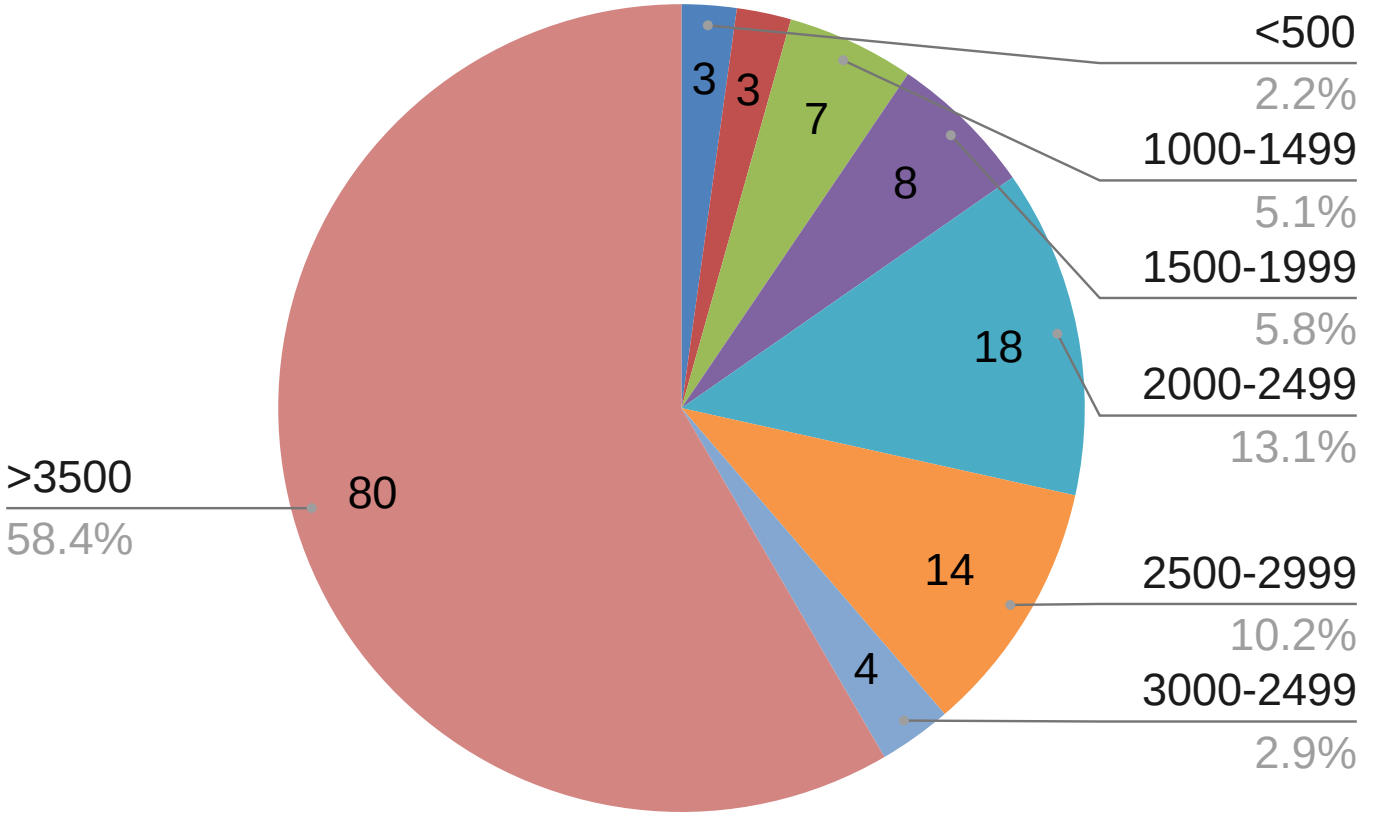
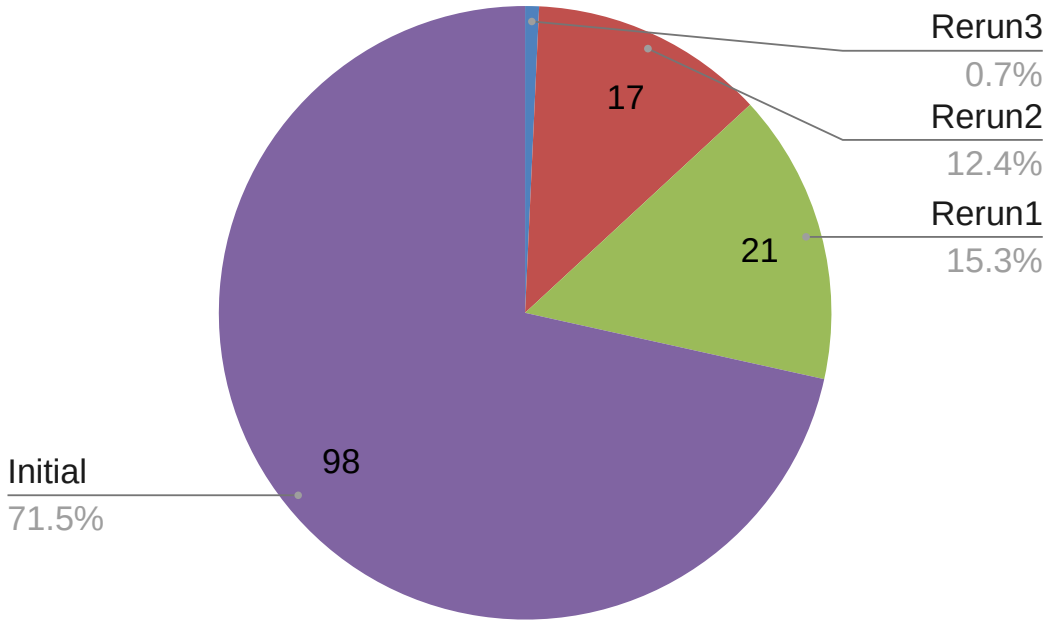
Submitted Job Sizes

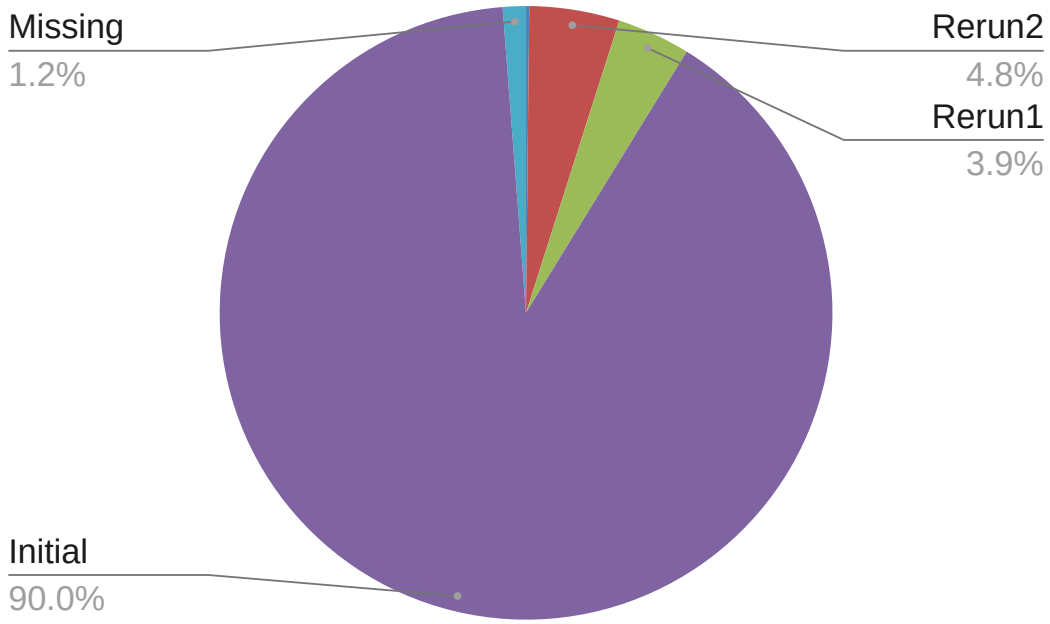


Job Completion

Jobs submitted during each round



Buildings completed during each round



Summary

- Generated and simulated ~124.4 million building energy models on THETA supercomputer at Argonne National Lab
  - 10 days of walltime on Theta
  - 752k node hours or 48 million core hours
    - 64-core server: almost 86 years
    - Average 8-core desktop 687 years
- Generated ~90TB of building related data
- Made 122.9 million models publicly available → bit.ly/AutoBEM

Future Work

- Detailed analysis of results
  - What is current energy use in the U.S. per building?
  - Which variables and other factors contribute to extremely long model generation and simulation times?
- Improvements on input data
  - Better height information
- We now have the baseline data for building energy use. Now, focusing on evaluating building improvement options
  - Which building improvements will have the biggest impact?
    - Smart water heater
    - New HVAC system (heating, ventilation, and air conditioning)
    - New windows

Acknowledgments

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Thank you!

- Questions?