Environmental 4D Benchmarking of Buildings

Towards 4D Visualization of Urban Building Environmental Performance: Analysis of Manhattan's Residential Energy and Water Use Performance Data

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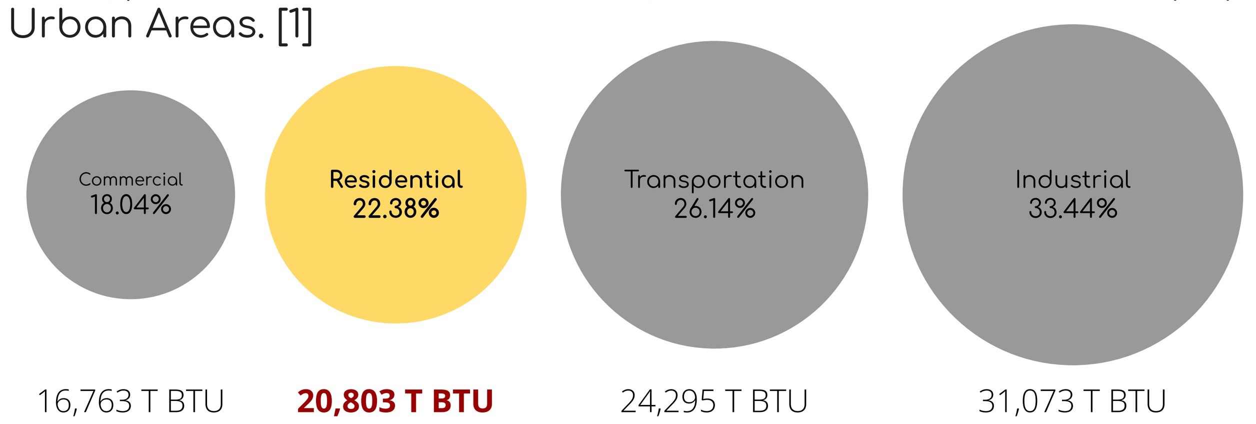
Introduction

Buildings remain one of the largest consumers of energy - around 40.4% of all energy used in the U.S.According to census 2010 - 80.7% of population resides in Urban Areas. [1]



In addition, the UN projects 68% of the world population would live in urban areas by 2050. [2]

88% of the domestic water is public-supply, 12% is self supplied. Water and wastewater utilities account for 35 % of typical US municipal energy budget. [3] Electricity use accounts for 25-40% of the operating budgets for wastewater utilities and 80% of drinking water processing and distribution. Drinking water and wastewater systems account for 3-4% of energy use in the U.S., resulting in 45M tons of greenhouse gases annually. [4]

Unnecessarily higher energy and water consumption

- Environmental degradation due to greenhouse gas emissions
- Unnecessary development of additional energy infrastructure
- Energy insecurity and inequitable cost burdens

Environmental benchmarking Benefits include - (but not limited to)

- Enhanced environmental performance of buildings
- Optimized need for additional energy infrastructure
- Results in energy security and equitable cost of utilities
- Informed decision making
- Decelerates anthropogenic climate change
- Paves the path for future improvements

Objectives and Methodology

Hypothesis

1. Energy benchmarking ordinances are essential for improving the environmental performance of existing buildings.
2. Bigger buildings result in higher environmental degradation.

Research questions

1. How effective are NYC's Local Laws (or benchmarking ordinances) in lowering the energy and water consumption, and reducing greenhouse gas emissions of residential buildings in the borough of Manhattan?
2. How does the energy, water and GHG emissions from buildings of different age and size differ?
3. What are the gaps in the existing benchmarking data and visualization used by NYC?

1 Assess Effectiveness of Benchmarking Ordinances → 2 Identifying the patterns wrt. building size and year built → 3 Identifying the gaps

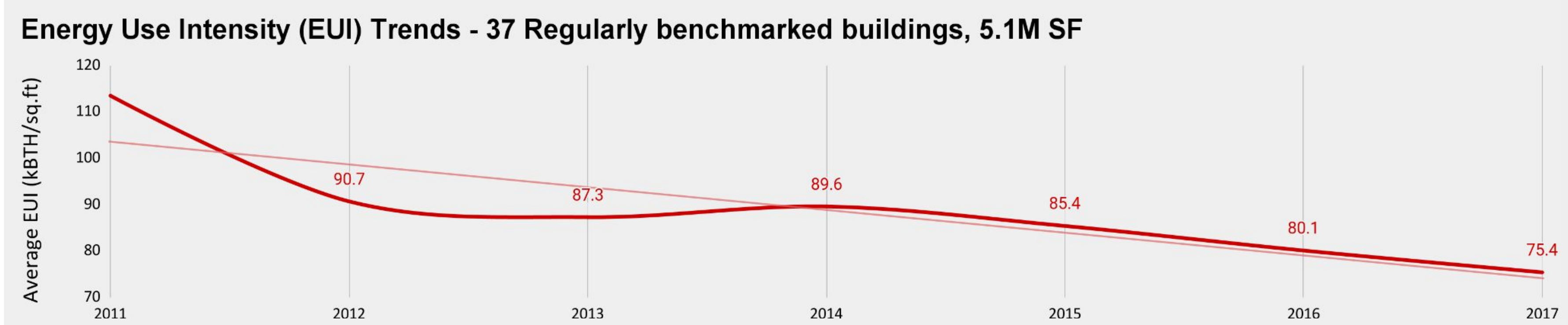
1. NYC's Energy and Water Performance Map
2. Review of Local Law 84 and 133
3. Review of NYC Energy and Water Use Reports
4. Review of related published articles

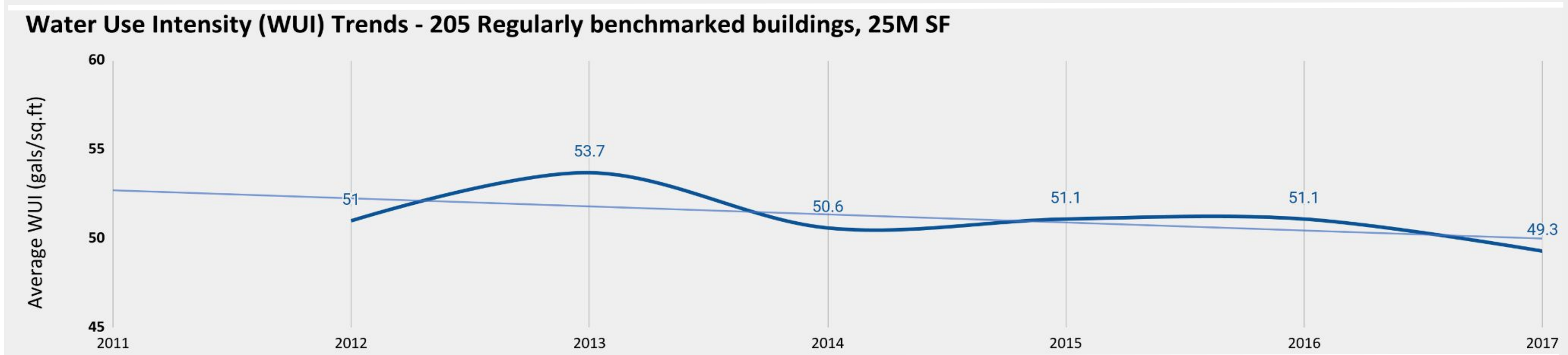
Use of descriptive and inferential statistics to identify patterns from the large data set.

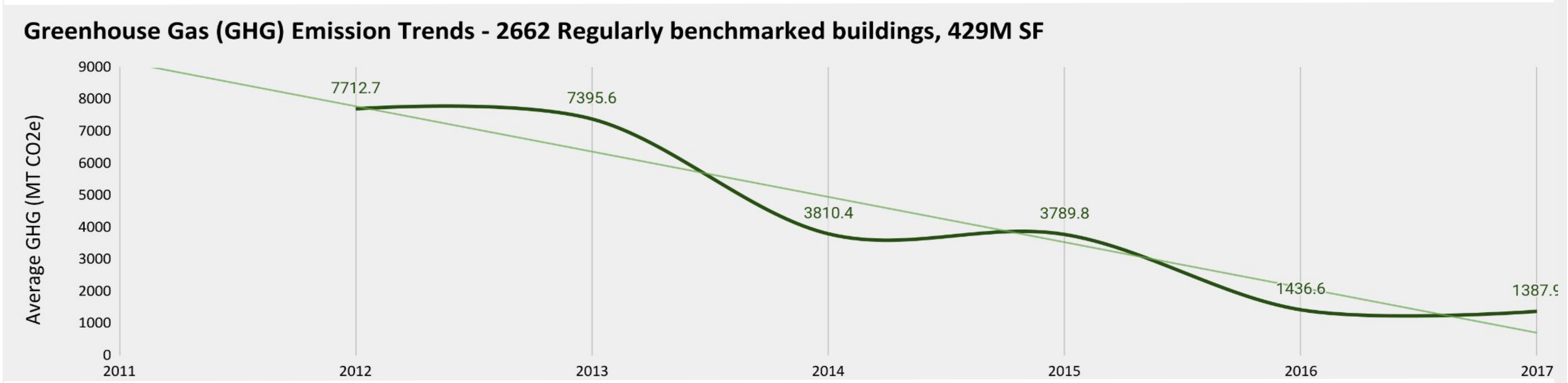
Methodology used for the results presented in this poster

Carnegie Mellon University

Results







The analysis suggests that from 2011 to 2017, average EUI, WUI and GHG emissions from residential buildings have decreased considerably.

Energy Use Intensity (EUI) Data

	<1900	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
>700k SF				63.5	72.2	52.6*	80.45	67.45	71.8	103*	84.3*	78.05	76.3
600-700k					76.6*		76.6	74.8	89.9	85.7*	67*	89.7*	77.2*
500-600k	63.6*		80.9*	53.3*	85.6*		83.25	73.9	75.5*	64.7*	81.8*	77.3	53.2
400-500k	63.4*	88.5*	92.8*	82*	62*	116.3	81.5	71.1	81.95	76.25	84.7	78.6	64.9
300-400k	55.1	119	70.2*	68.9	71.2	64.2*	96.4	78.4	79.85	82.7	88.4	94.05	55.5
200-300k	67.3*	56.5*	74	64.4	74.3	65.7	80.8	83.3	90.9	84.3	88.6	85.65	60.5
100-200k	82.3	68	67.95	69.05	73.1	68.1	78.9	85.6	85.7	82.9	79.8	76.5	66.7
10-100k	78.3	81.6	82.1	83.4	85.3	86.3	86.4	80.75	72.35	84.35	84.45	78.65	62.1

100+ kBTU per sq.ft.
80 kBTU per sq.ft.
60 kBTU per sq.ft.
40 kBTU per sq.ft.
No Data

The EUI analysis by building age and size indicate that buildings built in the six decades from 1950 to 2009 are the most energy intensive.

Water Use Intensity (WUI) Data

	<1900	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
>700k SF					29.3*	49.4*	28.54	41.8*	47.1	43.2*	29.8*	24*	27.8*
600-700k	21.5*		37.9*		27.7*		29.2*	53.61	115*	34.2*	29.9*	31.2*	
500-600k					20.7*		30.7*	35.5*	74.2*	47.7*	48.6*	44.09	20.9*
400-500k		30.6*		42.8*	32.4*		33.81	43.08	43.22	40.2*	53.6*	33.24	71.3*
300-400k	24.7*	47.1*	29.9*	29.01	31.28	14.7*	38.3*	45.65	43.31	35.26	34.9*	40.45	37.5*
200-300k	39.6*	67.48	34.7	29.75	32.14	26.29	38.97	39.15	48.26	48.39	41.18	42.36	26.61
100-200k	52.71	32.07	29.27	30.08	35.96	27.58	41.44	44.52	44.37	49.85	45.3	35.25	36.82
10-100k	36.13	44.13	50.08	51.82	43.33	39.88	45.53	42.45	65.64	45.44	46.86	40.57	29

70+ gal per sq.ft.
50 gal per sq.ft.
30 gal per sq.ft.
10 gal per sq.ft.
No Data

The WUI analysis by building age and size indicate that buildings built in the 1970s are most water intensive.

GHG Emissions Data

	<1900	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
>700k SF				3340*	4576		4668	4438	6963	5681*	5200*	4296	5323
600-700k	2476*		3524		3062*		4486*	3411	4268*	3795	2674*	3115*	2498*
500-600k	2601*			2162*	2812*		2851	2570	3114	2882	2939*	3165	2305
400-500k		3212*	2542*	2450	1913*	2961*	2512	2152	2351	2746	2756	2464	1925
300-400k	1340*	1880*	1857	1305	1630	1295*	2020	1878	1757	2071	2240	2008	1310
200-300k	1030*	1147	1364	1061	1140	945	1312	1404	1645	1482	1373	1480	1022
100-200k	773	630	620	631	623	603	707	838.2	774	750	753	691	705
10-100k	244	241	275	284	287	301	352	309.5	293	334	290	260	240

4.5k+ Metric Tons CO_2e.
3.0k - 4.5k Metric Tons CO_2e.
1.5k - 3.0k Metric Tons CO_2e.
<1.5k Metric Tons CO_2e.
No Data

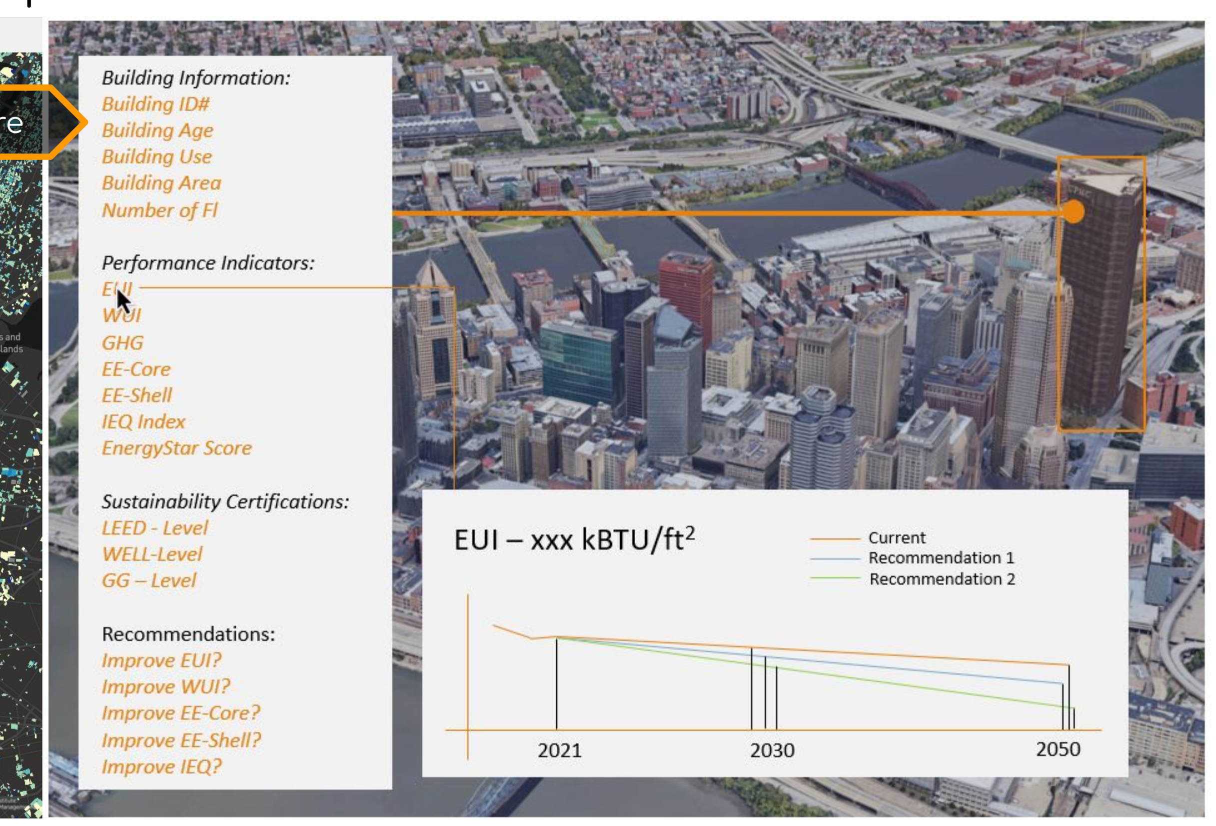
The GHG analysis by building age and size indicate a direct relation of greenhouse gas emissions with building size.

Year/building age figures are adapted from New York City's Energy and Water Use 2014 and 2015 Report 2017, Urban Green, NYU CUSP

Conclusion & Future Work

1. The analysis of NYC's energy and water performance disclosure data suggests that from 2011 to 2017, average energy use intensity (EUI), average water use intensity (WUI) and average greenhouse gas (GHG) emissions from residential buildings have decreased considerably. Supporting the hypothesis emphasizing on the need of benchmarking ordinances.
2. The EUI analysis by building age and size indicate that buildings built in the six decades from 1950 to 2009 are the most energy intensive. The WUI analysis by building age and size indicate that buildings built in the 1970s are most water intensive. The GHG analysis by building age and size indicate a direct relation of greenhouse gas emissions with building size.
3. Continuous improvements in WUI and GHG emissions were observed. However, it is not clear if the benchmarking laws are the sole reasons behind the improving trends.
4. The data will be used for performing additional correlational studies to suggest retrofit strategies (missing in the existing tool) for buildings of different sizes and ages to improve their energy and water use performance.
5. Holistic environmental assessment of buildings should also include embodied carbon data and indoor environmental quality (IEQ) data. IEQ and Embodied carbon data would help guide retrofit/rehabilitation vs. demolition decisions.
6. 3D building representation couple with future predictions (4th dimension) can enhance user experience letting people take informed decisions.

NYC's Energy and Water Use Map [5]



Schematic map showing the concept of 4D visualization of the benchmarking data

2D Representation
Time Series (based on past performance)
Operational Energy, Water and Greenhouse Gas Data

4D representation with recommendations (3D building visualization)
Future Projections (fourth dimension = Time)
Operational Data w/ Retrofit Recommendations + Embodied Carbon + IEQ Data

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[2] UN. (2018, May 16). 68% of the world population projected to live in urban areas by 2050, says UN. Retrieved from United Nations Department of Economic and Social Affairs: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html#:~:text=News-,68%25%20of%20the%20world%20population%20projected%20to%20live%20in,areas%20by%202050%2C%20says%20UN&text=Today%2C%2055%25%20of%20the%20
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[5] Sustainability, N. M. (n.d.). NYC Energy & Water Performance Map. Retrieved from https://energy.cusp.nyu.edu/#/

Additional references that contributed to this work are sited in the following conference presentation -
Varma K., Cochran E., Ken Opurum B. (2021, April). Effects and Impacts of Sustainability Initiatives on the Environmental Performance of Residential Buildings in the Borough of Manhattan: A comparative Study and a Model for Future. Eleventh International Conference on the Constructed Environment. (Online): University of Calgary, Canada. https://cgscholar.com/cg_event/events/V21/proposal/55659
[Presentation recording] https://youtu.be/aC4s8EPdL3Q

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