Optimizing Energy Burden to Incorporate into Building Decarbonization Pathways to Retrofit Existing Buildings

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Introduction

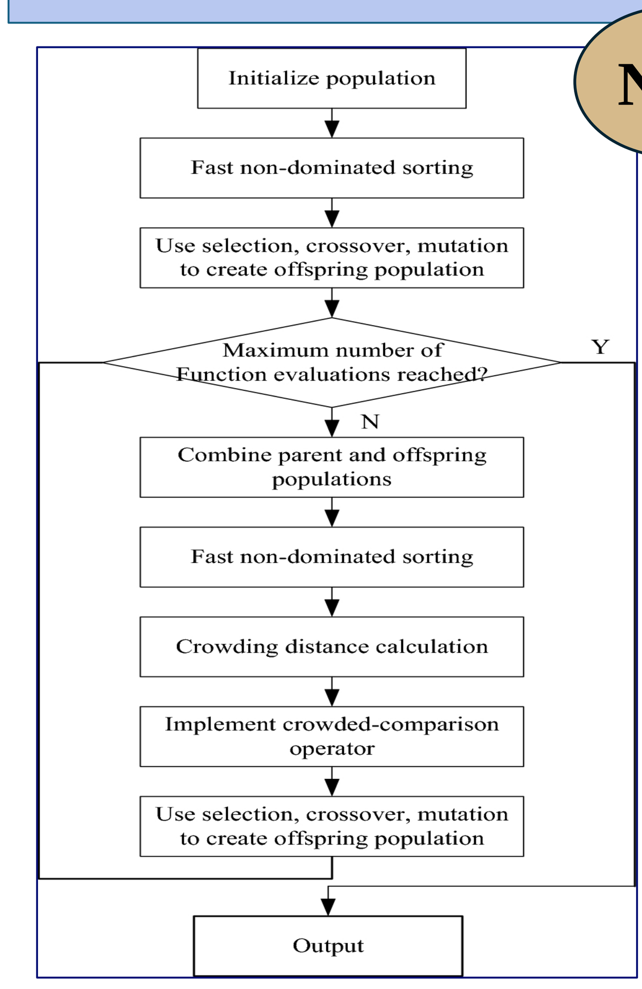
Buildings account for two thirds of New York City's greenhouse gas emissions[1] which calls for the necessity of transforming the urban building stock to deliver on climate change goals. Whilst climate change policies seek to address climate change mitigation, they also seek to address additional societal challenges such as alleviating energy burden.[2,3,4] Energy burden, which is the proportion of annual household income that is spent on energy utility costs, remains to be a persistent issue amongst low-income households. Low-income households spend a higher percent of their income on electricity and gas bills than any other income group.[2]

To begin to address this inequity issue, energy burden was incorporated as a metric into an optimization to determine how building decarbonization pathways changes the "optimal" way to retrofit existing buildings.

Methods

- Five building models were simulated in EnergyPlus with retrofits to its walls, roof, and windows
- Used the multi-objective optimization algorithm Non-dominated Sorting Genetic Algorithm II (NSGA-II)
- Objectives included: minimize greenhouse gas emissions, minimize capital and operational costs, and minimize the number of energy burdened units.

NSGA II Algorithm



NSGA-II is a popular multi-objective optimization algorithm that uses genetic algorithm principles to find a set of solutions that are not dominated by any other solution in terms of multiple objectives. The hyperparameters used for implementation include: population size of 250, simulated binary crossover, random sampling, three generations, and the algorithm was terminated after 2500 evaluations.

Flowchart source: A comprehensive survey on NSGA-II for multi-objective optimization and applications, Volume 56, pages 15217–15270, (2023).

Objective Functions

1.) Greenhouse Gas Emissions

The goal of this objective was to minimize the greenhouse gas emissions produced during operation. Average emissions coefficients from the EIA New York state database were used to convert operational costs to annual greenhouse gas emissions.

2.) Capital and Operational Costs

The goal of this objective was to minimize the operational and capital costs of the retrofit measures. The capital costs of the retrofit measures were taken from the construction cost estimation repository RS Means.

3.) Energy Burden

The goal of this objective was to minimize the number of units with energy burden > 6%. Energy burden was calculated using the annual operational energy costs divided by the income.

Acknowledgements

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References

[1]NYC Greenhouse Gas Inventories - NYC Mayor's Office of Climate and Environmental Justice (cityofnewyork.us)
[2]Sage Kime *et al* 2023 *Environ. Res. Lett.* 18 123003
[3]NYSERDA (2022). CEF Annual Performance Report: Final Report March 2023. NYSERDA
[4]The White House (2023). Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action.
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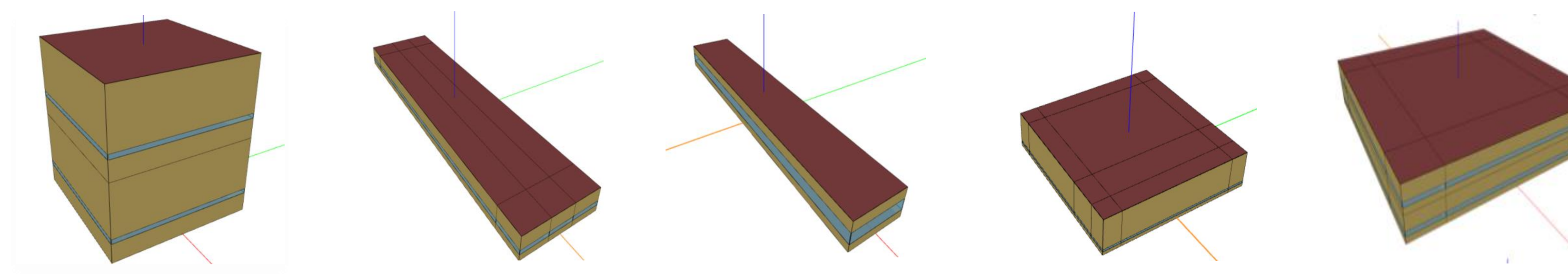
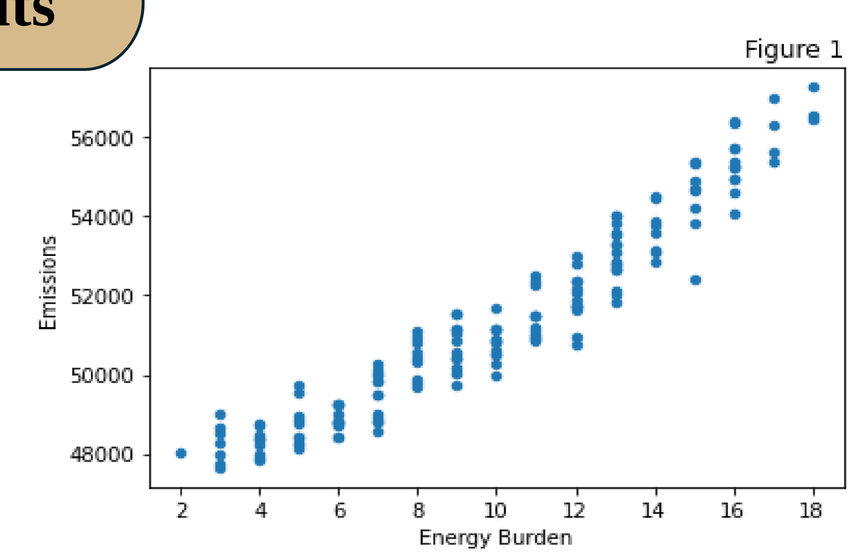
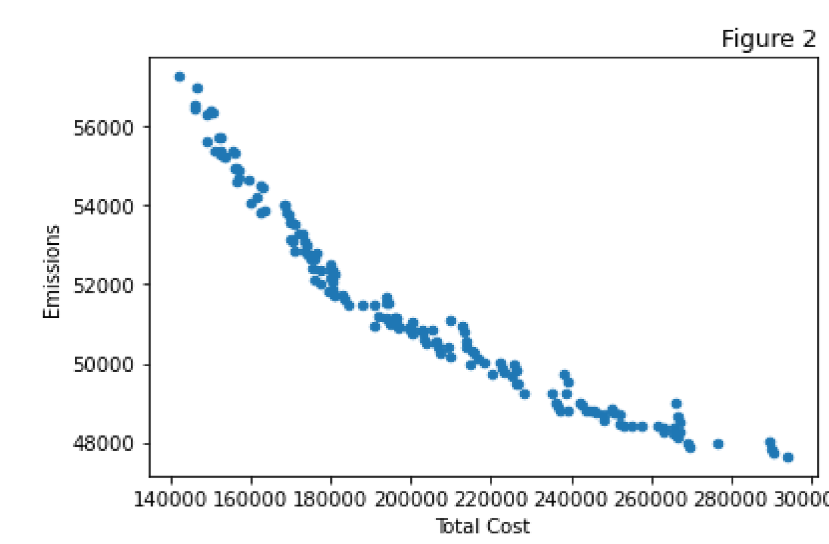
Building Data

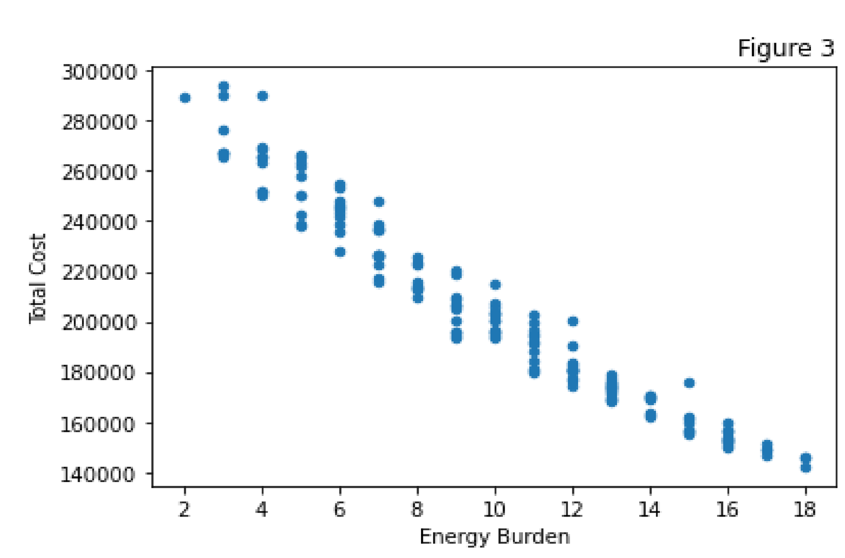


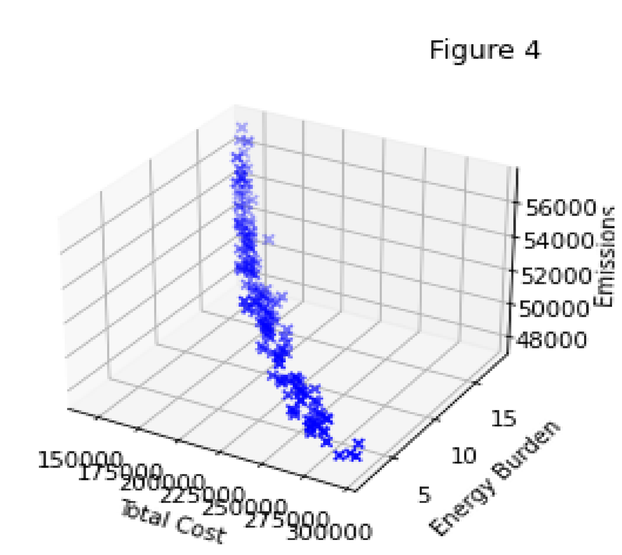
Building	Bldg1229 4% Emissions, 3.2% Cost	Bldg1408 8% Emissions, 17% Cost	Bldg339 10% Emissions, 15% Cost	Bldg1603 18% Emissions, 39% Cost	Bldg1250 60% Emissions, 26% Cost
Total Operations Cost ($) (max energy consumption)	4699	10799	13101	23106	80063
Total Operations Cost ($) (min energy consumption)	3812	9555	11298	20896	60542
# OF UNITS	2	4	5	7	10
Income range ($)	31,770- 39158	39,812-45,000	37,000 - 44,000	49,752- 55013	100,000 - 134,000
Walls	Mass Walls	Mass Walls	Mass Walls	Metal Walls	Mass Walls
Areas (ft^2)	Window Area: 107, Wall Area: 1681, Roof Area: 500	Window Area: 779, Wall Area: 3550, Roof Area: 7500	Window Area: 1189, Wall Area: 1940, Roof Area: 3000	Window Area: 965, Wall Area: 15123, Roof Area: 17500	Window Area: 1346, Wall Area: 6136, Roof Area: 8749

Results



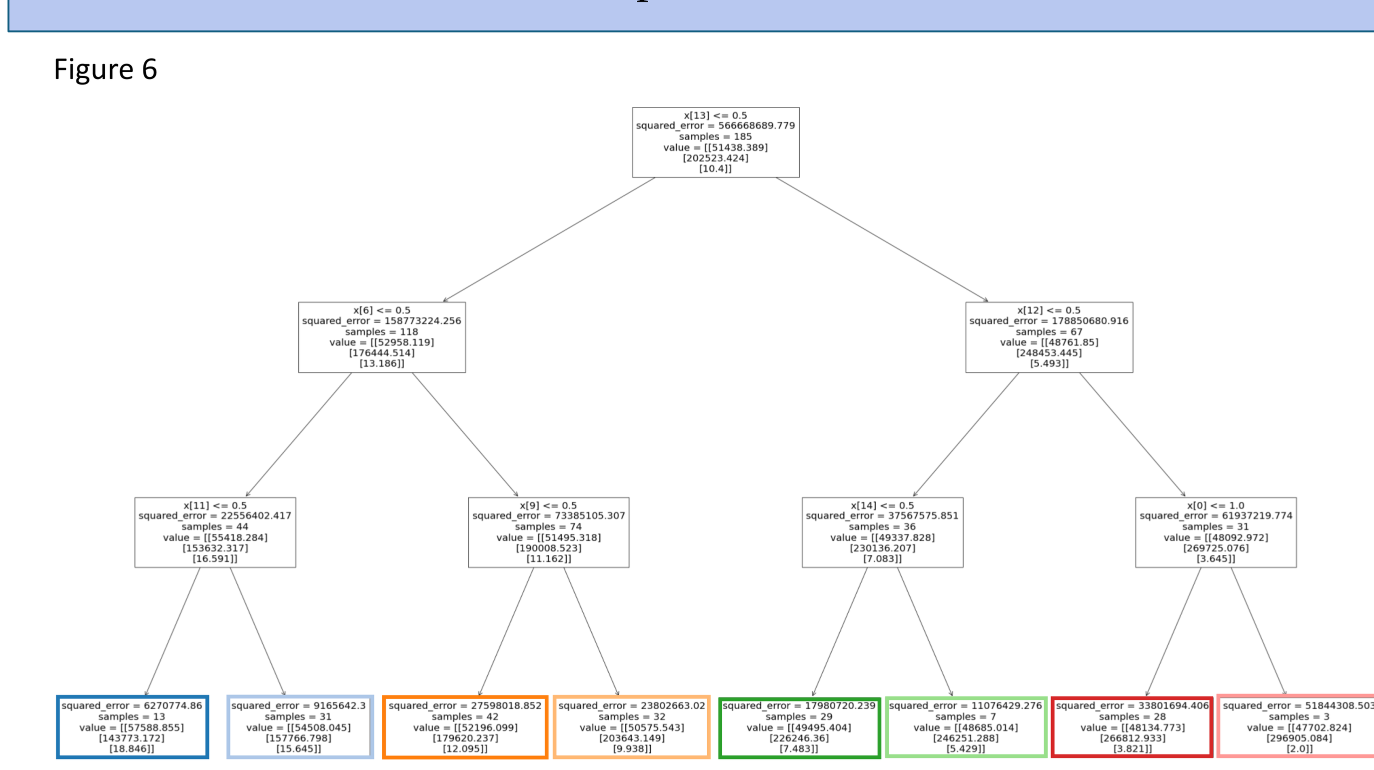


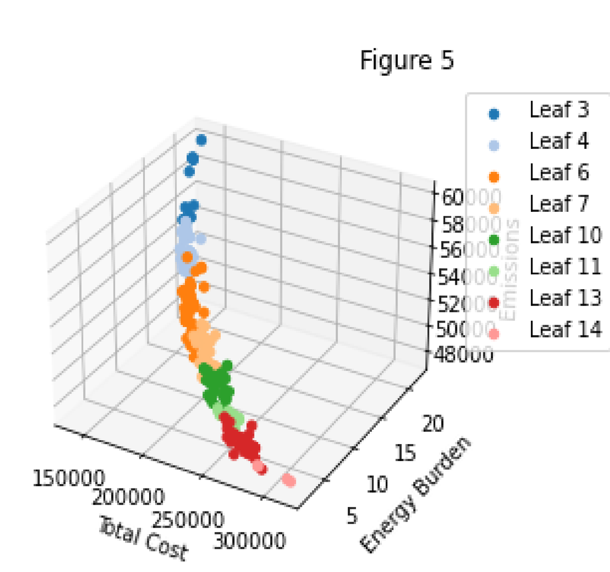




Effects on Objectives

- Reducing Greenhouse gas emissions reduces the number of energy burdened units
- The discrete nature of the measure of energy burden lead to multiple emission and cost options to deliver the same level of energy burden
- The examined incomes are close to the NYC Poverty Line ($44,000 for a family of 4) indicating that the affects of passive measures investigated here can alleviate energy burden for the lowest incomes if the costs of retrofit are not passed on to the units





Which Passive Measures Contributed most

- Four different retrofit options for the windows, walls, and roof
- Changing the roof greatly impacts the level of emissions and energy burden as a result
- Changing Bldg1603 windows is important to obtaining low emissions

Conclusions

Our findings revealed that an additional co-benefit to climate initiatives is the energy burden which disproportionately affects low-income households. Optimizing metrics such as energy burden to include in building decarbonization pathways raises awareness to the additional benefits that greatly impact marginalized communities whilst mitigating climate change.