Decarbonizing the Building Sector:

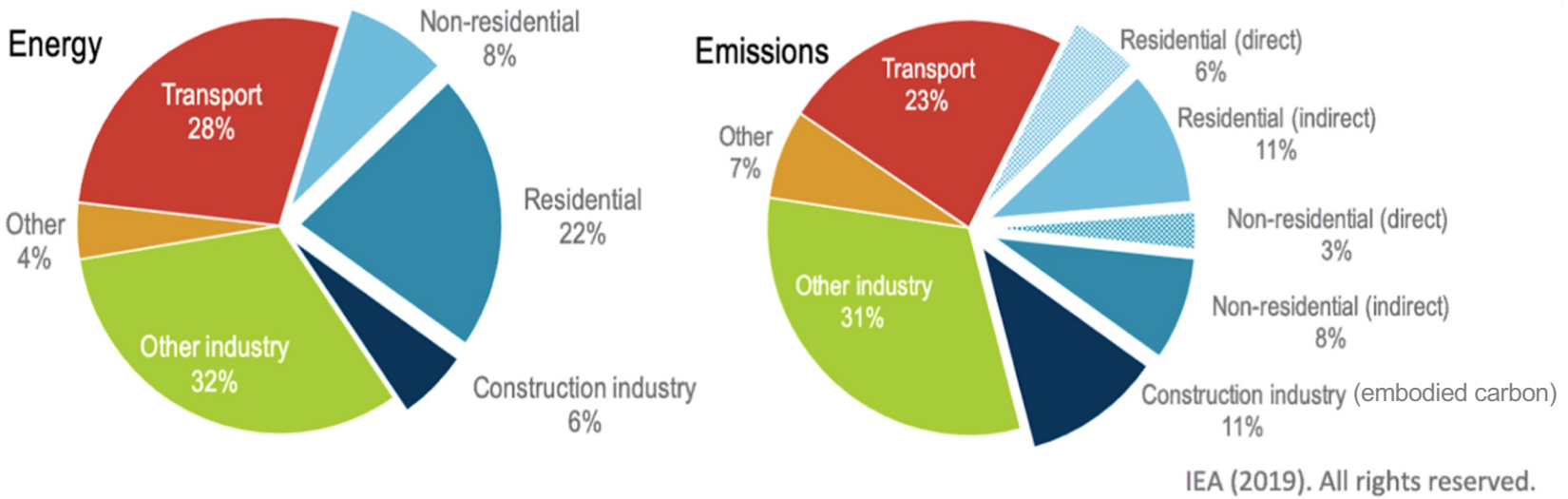
Engineering + Economics

Siqi Zheng

January 30, 2023

(MIT Center for Real Estate)

Building sector is a key target for decarbonization



Notes: *Construction industry* is the portion (estimated) of overall industry devoted to manufacturing building construction materials such as steel, cement and glass. Indirect emissions are emissions from power generation for electricity and commercial heat.

Global Alliance for Buildings and Construction , "The 2019 Global Status Report for Buildings and Construction"

Policy Pressure to Decarbonize across the Globe

Australian Government launches net zero building standard with GBCA

European Green Deal: Commission proposes to boost renovation and decarbonisation of buildings

Decarbonizing Mumbai's grid and building energy-resilient infrastructure

Mexico and Mexico City Introduce Energy Efficiency Standards for Buildings

December 22, 2016 Cover Image by: Lars Plougmann, Flickr

eatures

Inflation Reduction Act Doubles Tax Credits for Building Retrofits

Proptech VC fund says $5/SF deduction will spur energy-saving fixes previously deemed too costly.

By **Jack Rogers** | August 19, 2022 at 08:08 AM

European Green Deal: Renovation Wave

“Renovation Wave”

15%
Of worst-performing buildings must be upgraded by 2027

100%
Of **new** buildings must be zero emission by 2030

0%
Fossil fuel heating in all (new and existing) buildings by 2040

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European Commission

New York City Local Law 97

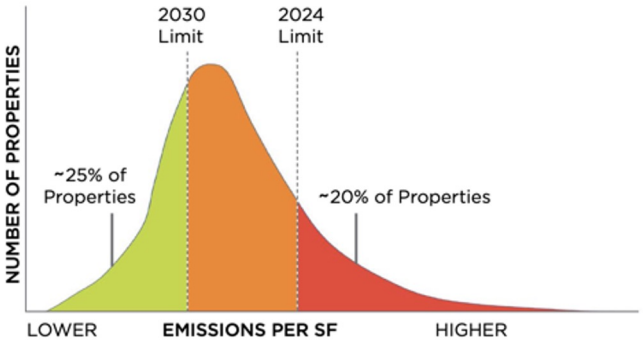
LL97

Buildings Mandate

Requires all buildings larger than 25,000 square feet to meet ambitious carbon reduction targets

- With the current building stock, building owners face sizeable fines
- Strong need to retrofit properties to meet targets

Emissions Distribution of Covered Properties

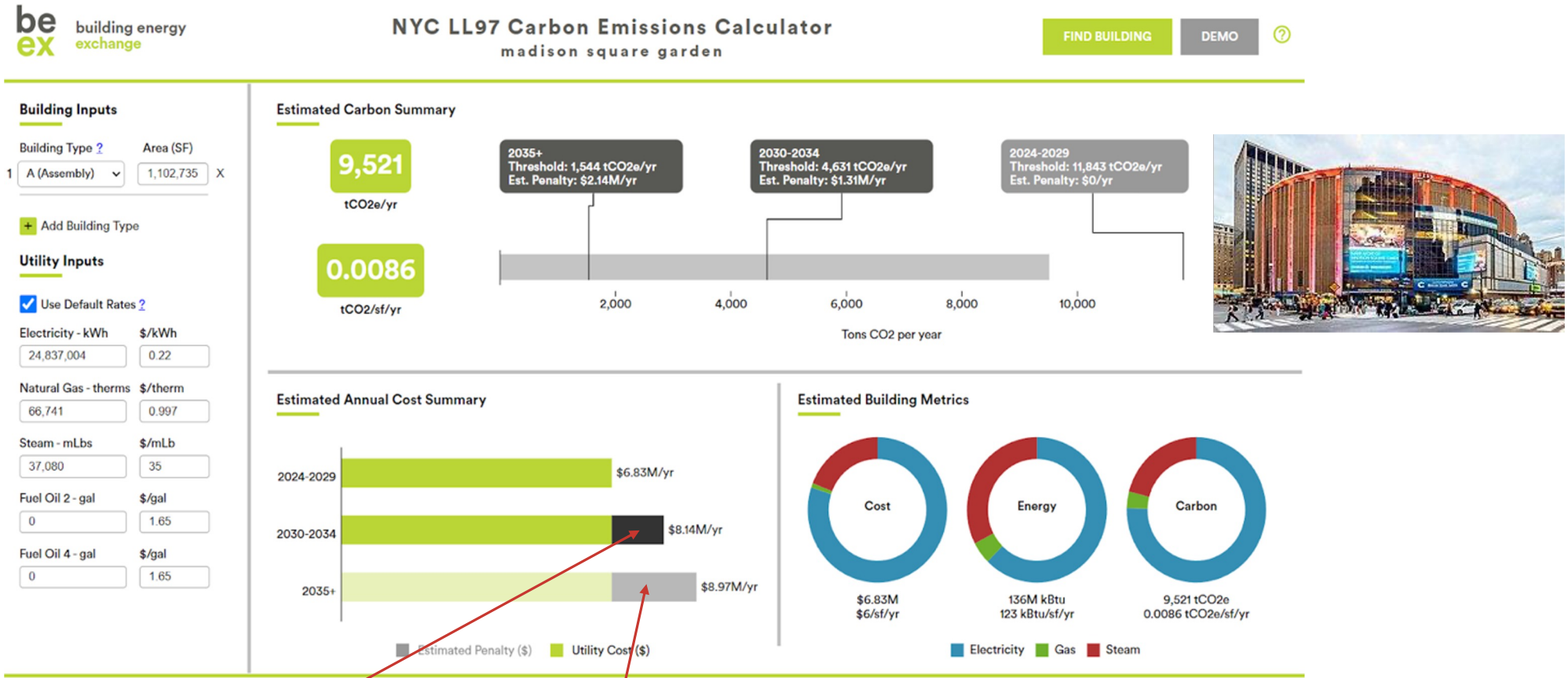


This graph is meant as a conceptual aid and does not represent actual properties or emissions limits.

Carbon Emission Standard

OCCUPANCY CLASSIFICATION	2024-2029 LIMIT (kg CO2 eq/sf/year)	2030-2034 LIMIT (kg CO2 eq/sf/year)
B - Ambulatory health, emergency response, and other critical applications listed in LL97 H - High Hazard I 2 & I 3 - Institutional	23.81	11.93
M - Mercantile	11.81	4.03
A - Assembly	10.74	4.20
R 1 - Residential (Hotels)	9.87	5.26
B - Business	8.46	4.53
E - Educational I 4 - Institutional	7.58	3.44
R 2 - Residential (Multifamily)	6.75	4.07
F - Factory	5.74	1.67
S - Storage U - Utility & Miscellaneous	4.26	1.10
I 1 - Institutional	11.38	5.98

The penalty for emissions above the limit is $268/year/metric ton.



Center for Real Estate

Example: Madison Square Garden

Data from 2019 As Required by LL84

https://be-exchange.org/ll97-calculator/

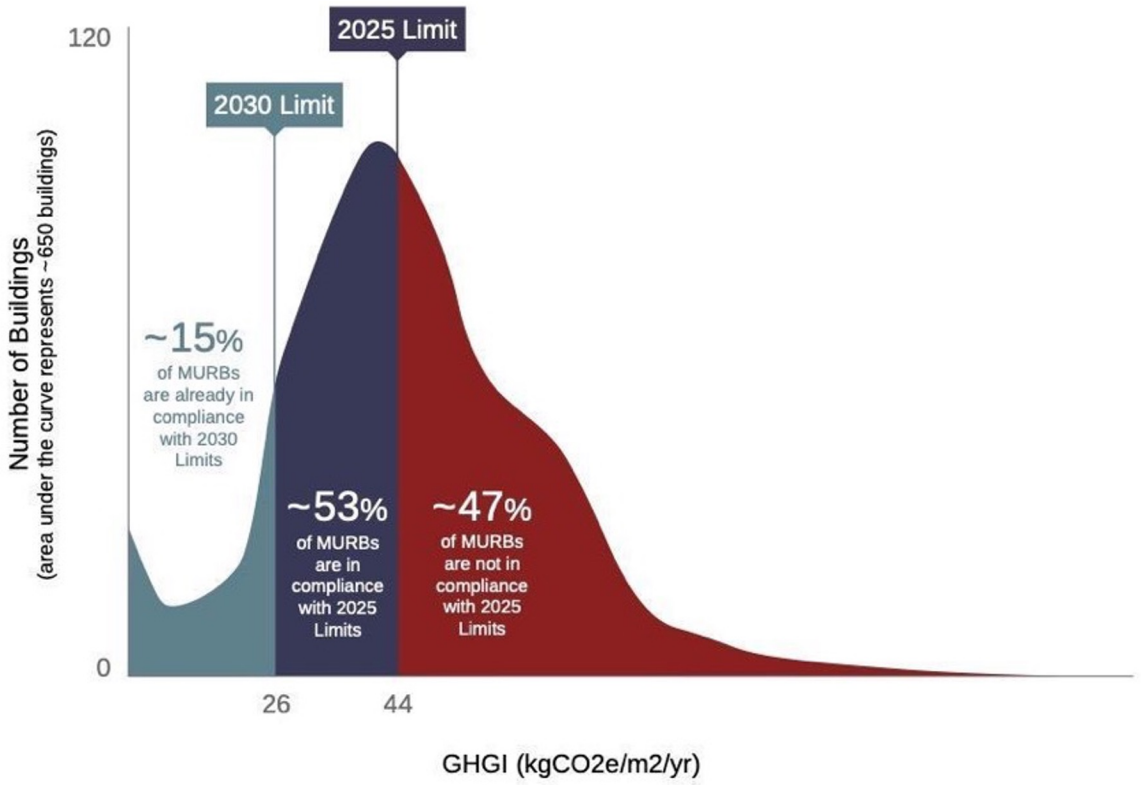
Boston BERDO 2.0

Boston BERDO 2.0

-

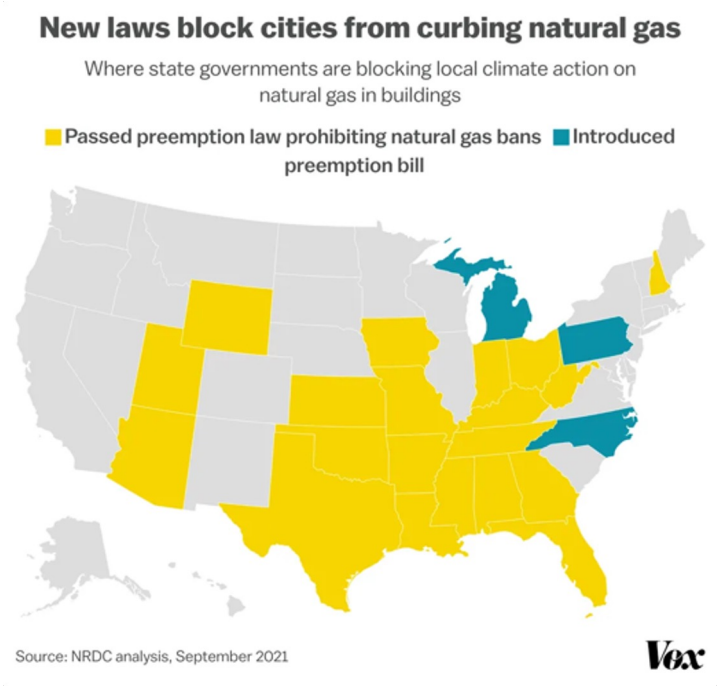
Sets emissions standards for buildings greater than or equal to 20,000 sq.ft.

Failure to meet standards results in payments of $234 per metric ton of CO2e



On the other side…

… Social and political backlashes to decarbonization efforts can present new challenges:



DeSantis prohibits Florida state-run fund managers from considering ESG factors

BY JULIA MUELLER - 01/17/23 2:45 PM ET

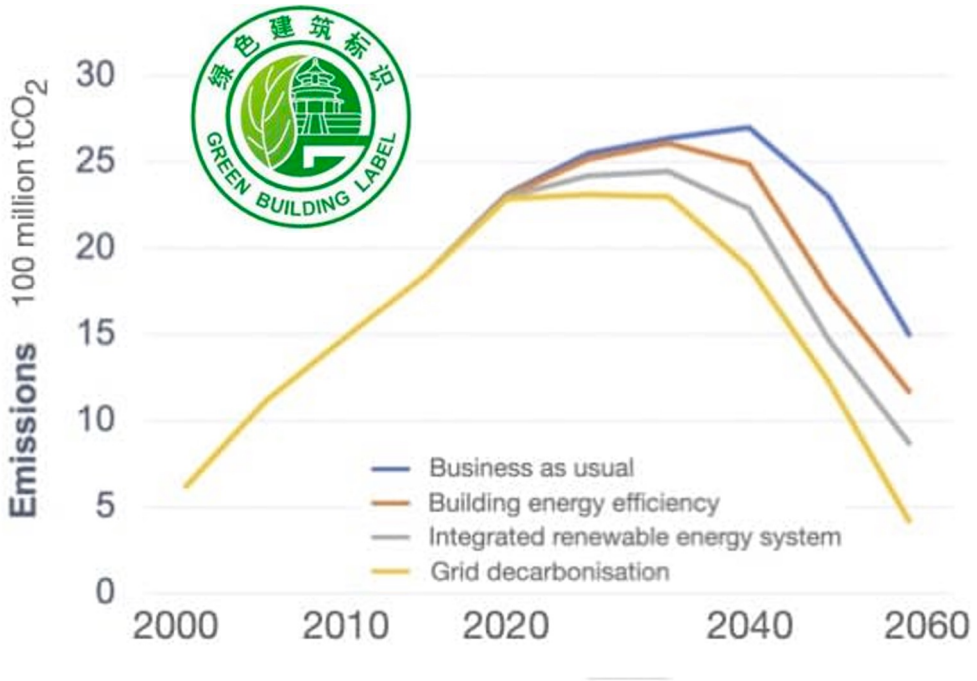
SHARE TWEET

The Economist explains

How gas stoves became part of America's culture wars

A proposal to ban them has inflamed some Republicans

China: Top-down, aspirational but also cyclical



Scenarios for China's building-related CO2 reductions.
Adapted from: China Association of Building Energy Efficiency (2020)

China is Currently Building Over Half of The World's New Coal-based Power Plants.

Helsinki-based Center for Research on Energy and Clean Air (CREA), 2022

Graphic by Stacy Smedley, 2021

Understanding a Building's Carbon Footprint

Embodied Carbon

Manufacturing Emissions
(extraction through manufacturing of building product)

Transportation Emissions
(transportation of product to the construction site)

Installation Emissions
(installation of products to create the building)

Operational Carbon

Operational Emissions
(emissions from energy consumed to operate the building: lighting, plug loads, heating and cooling, equipment, etc)

Use Phase Emissions
(replacement cycles of products during the building's life)

End of Life Emissions
(demolition and disposal of building products, ie to landfill, recycled, etc.)

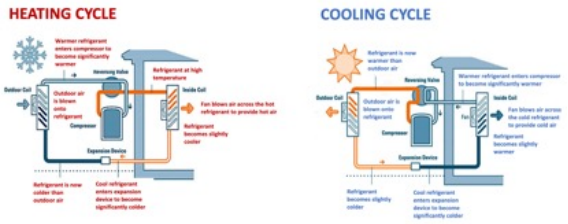
Three major strategies for building decarbonization
(operational carbon)

Improve energy efficiency

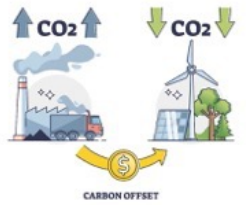
- Better energy conservation (insulation) and more efficient operations, e.g., passive house.

Switch to renewable energy: onsite and offsite

- Solar panels, offsite renewable energy procurement
- Electrification: gas-based heating → electricity-based heating (heat pump)



Purchase carbon offsets



Passive House Technology

Additional Cost

(Estimated cost premium +3-10%)

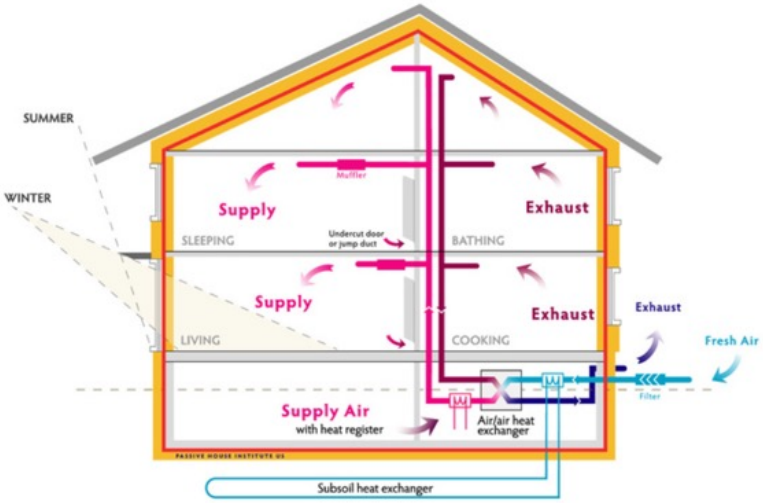


Image source: Passive House Alliance.

- **Highly Insulated Building Envelope**

(Continuous layer and high-performance and double/triple-glazed windows)

- **Continuous Air Sealed Layer**

(Add air barriers such as high-performance tapes to control heat energy loss, unwanted heat gain, and infiltration of pollutants)

- **Eliminate Thermal Bridges**

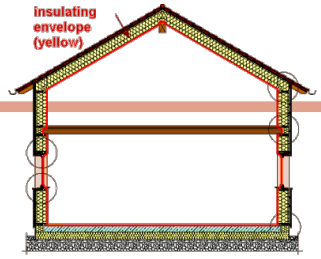
(Use double stud walls to reduce pathway of heat energy to travel through the envelope from inside to outside)

- **Heat Recovery Ventilation**

(controlled ventilation and heat exchanger to remove smell, air pollutants, excess humidity)

- **Window Orientation**

(Orientation of windows depending on the location, e.g., south-facing for heat gain)



Passive House: Benefits

Benefit

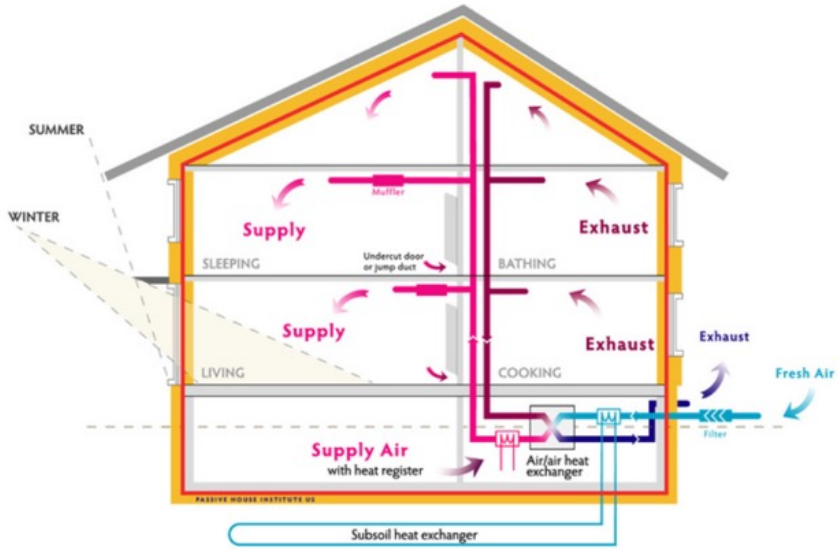


Image source: Passive House Alliance.

- **Energy Saving**

90% reduction in heating energy
(due to insulation, air tight, and high performance window)

- **Resilience**

Lower energy demand means better resilience to power outages during climate disasters.

- **Health**

Not living in a plastic bag just controlled ventilation! The balanced ventilation systems supply filtered fresh air.

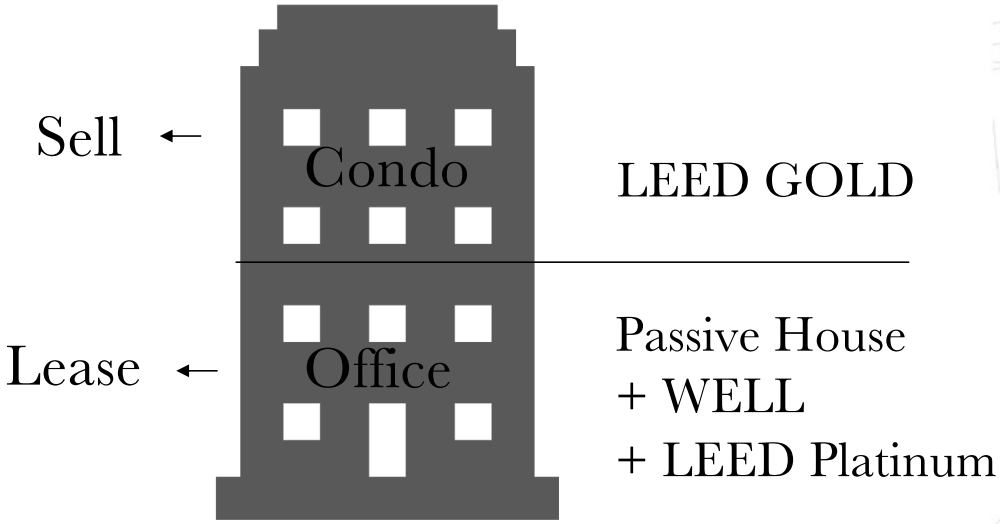
- **Comfort**

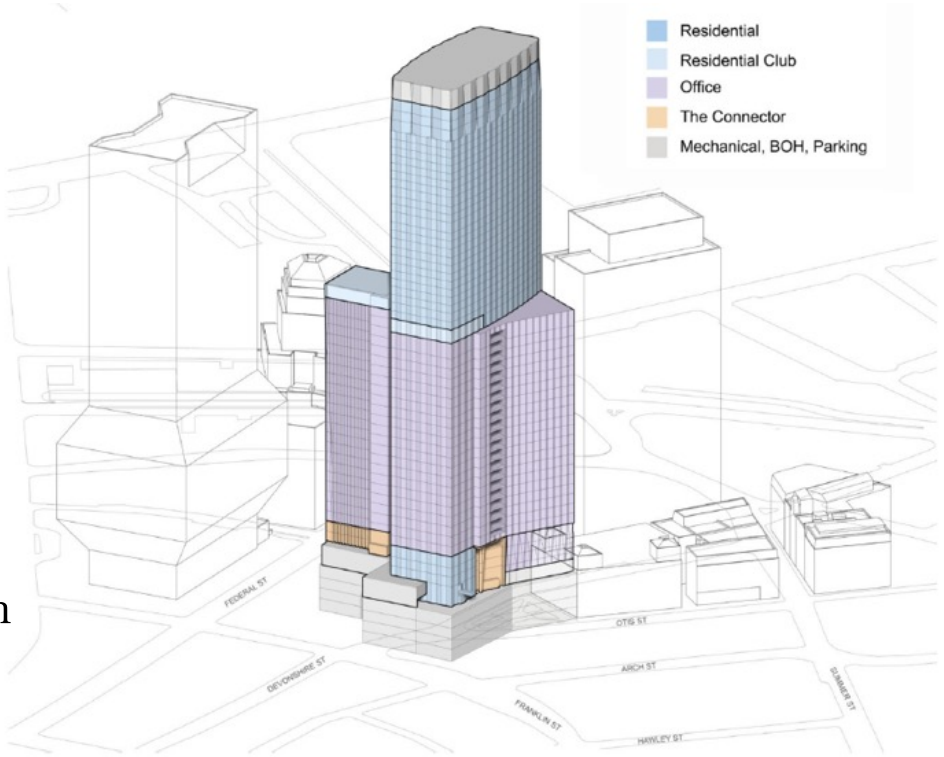
Stable indoor temperature, fresh air, quiet, dust free, no unwanted moisture …

- **Reputation**

If you move earlier and get a certificate :)

Winthrop Center (Boston MA)



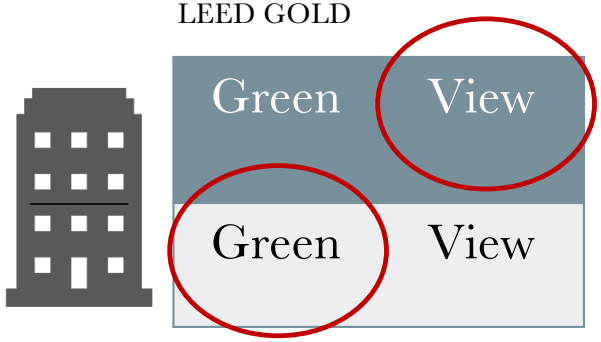


Source: Millennium Partners Boston

Winthrop Center

Comparative Advantage

LEED GOLD



Passive House
+ WELL
+ LEED Platinum

Increased rent and occupancy rate

Effective Rent (rent, occupancy)
($44.7M/yr)

Tenancy

Operation

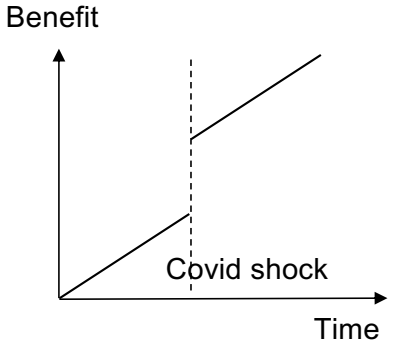
30 Years

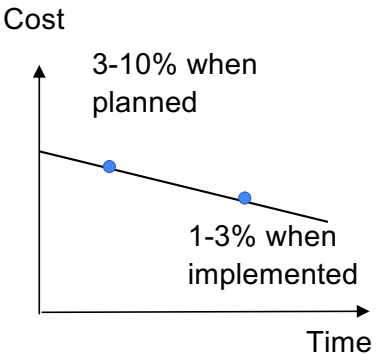
Upfront Cost
($1.3 B)

+ 3-10%
(1-3%)

Reduced utility cost
(~$300k)

Operation Cost
($7.3M/yr)

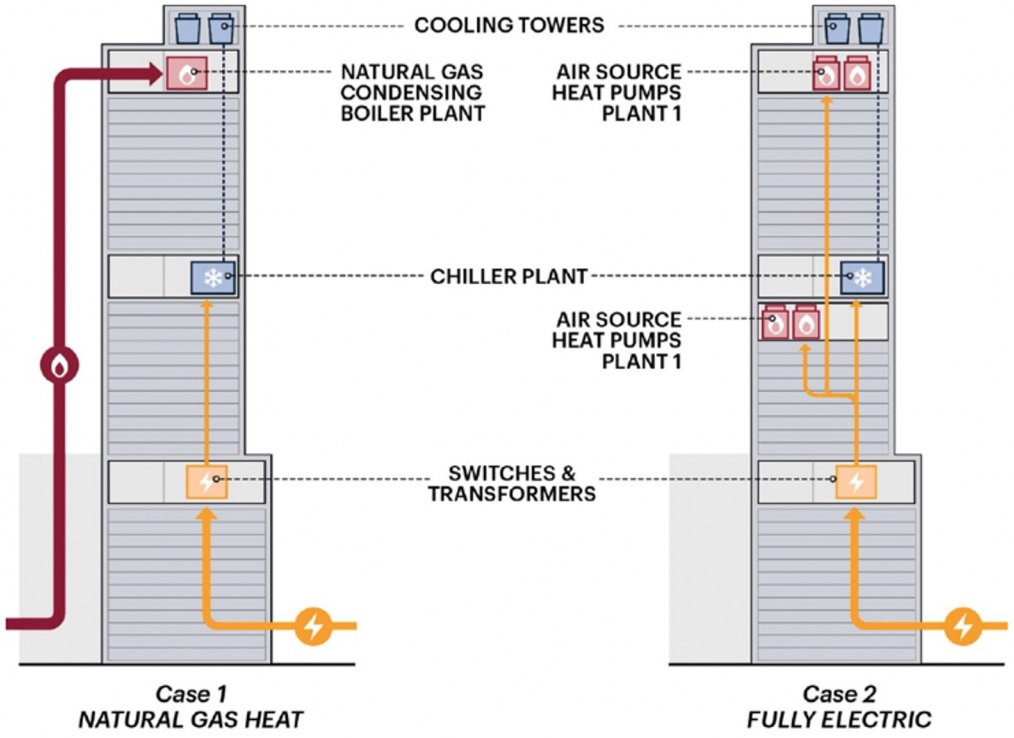




Electrification: Pathway to Net Zero

Coolin
g

Figure 3. Schematic floorplan and axonometric view of the tower

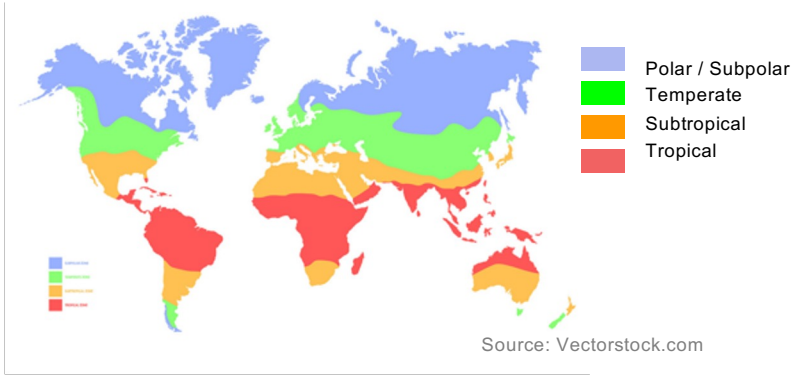


Heatin
g

Heat pump technology

Temperate Climates

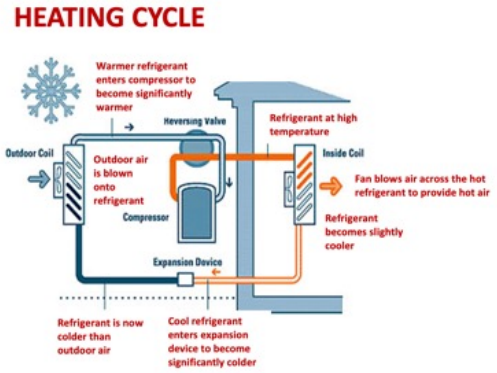
- Highly efficient heating and cooling
- Eliminates need for separate heating + cooling systems
- Health benefits from reduced natural gas use
- Improved occupant comfort from reduced noise and better humidity control

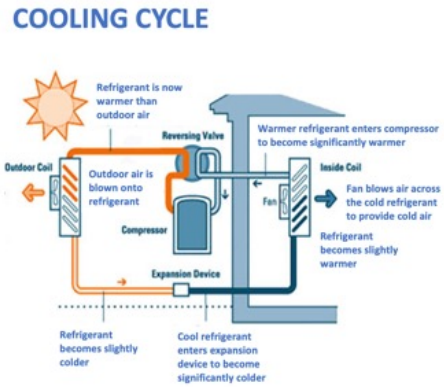


Source: Vectorstock.com

Subtropical / Tropical Climates

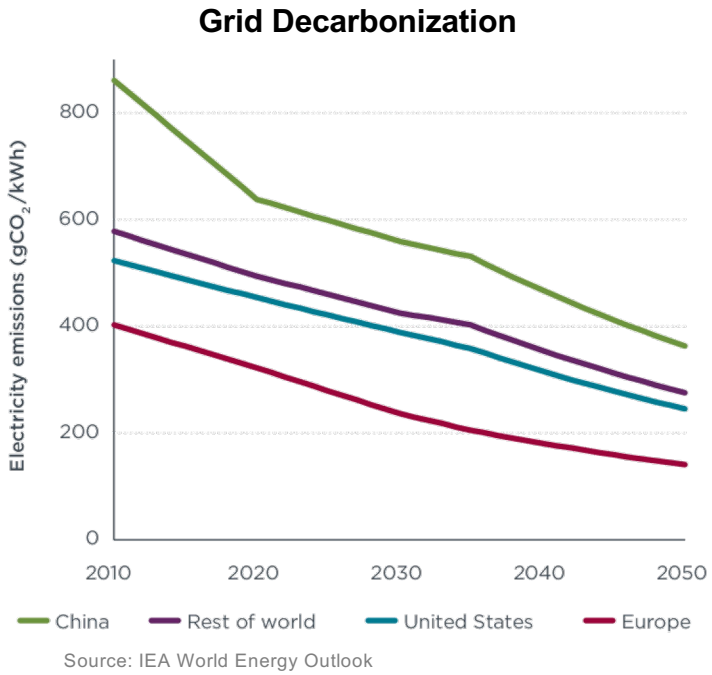
- Highly efficient cooling (especially as compared to window ACs)
- Improved occupant comfort from reduced noise and better humidity control



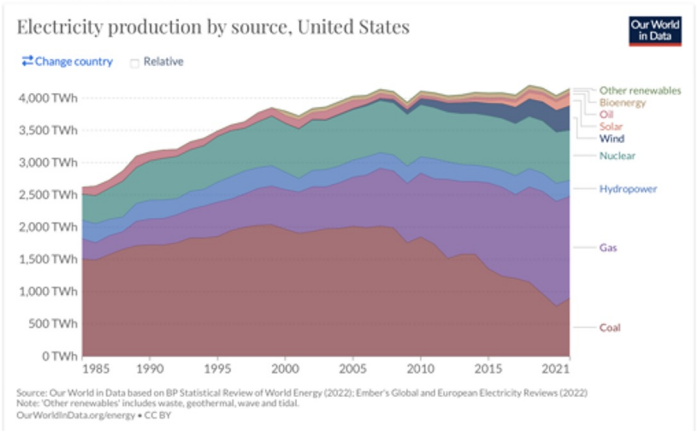


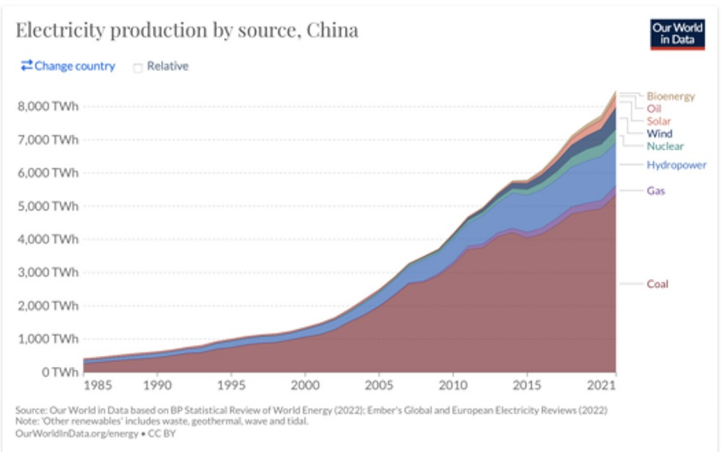
Source: https://goblueox.com/how-does-a-heat-pump-work/

… Also depends on the grid decarbonization speed



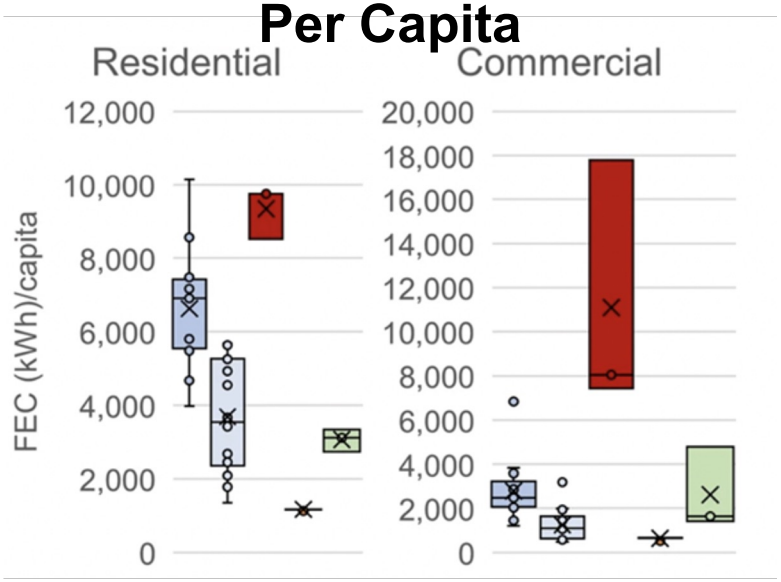
Source: IEA World Energy Outlook



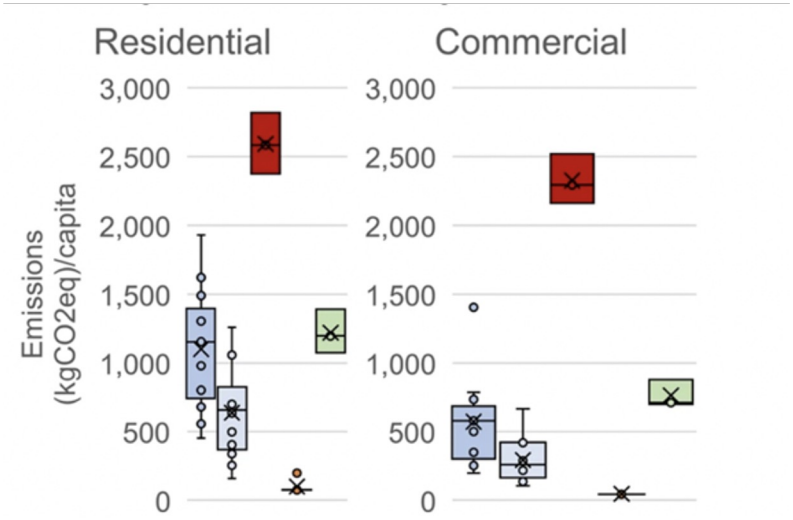


As well as cultural and social behaviors

Energy Consumption Per Capita

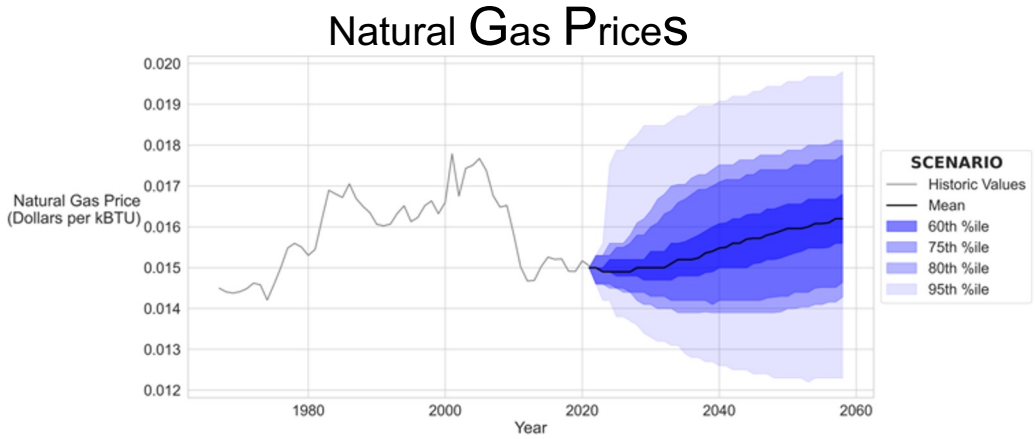


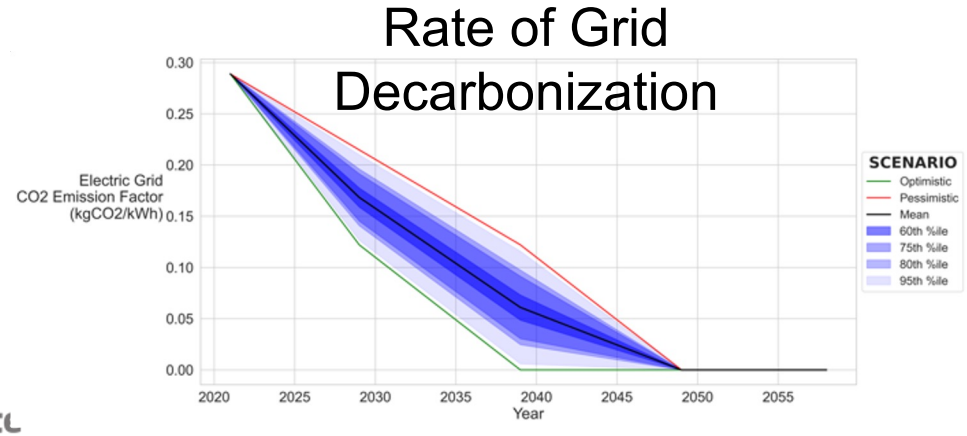
Emissions Per Capita



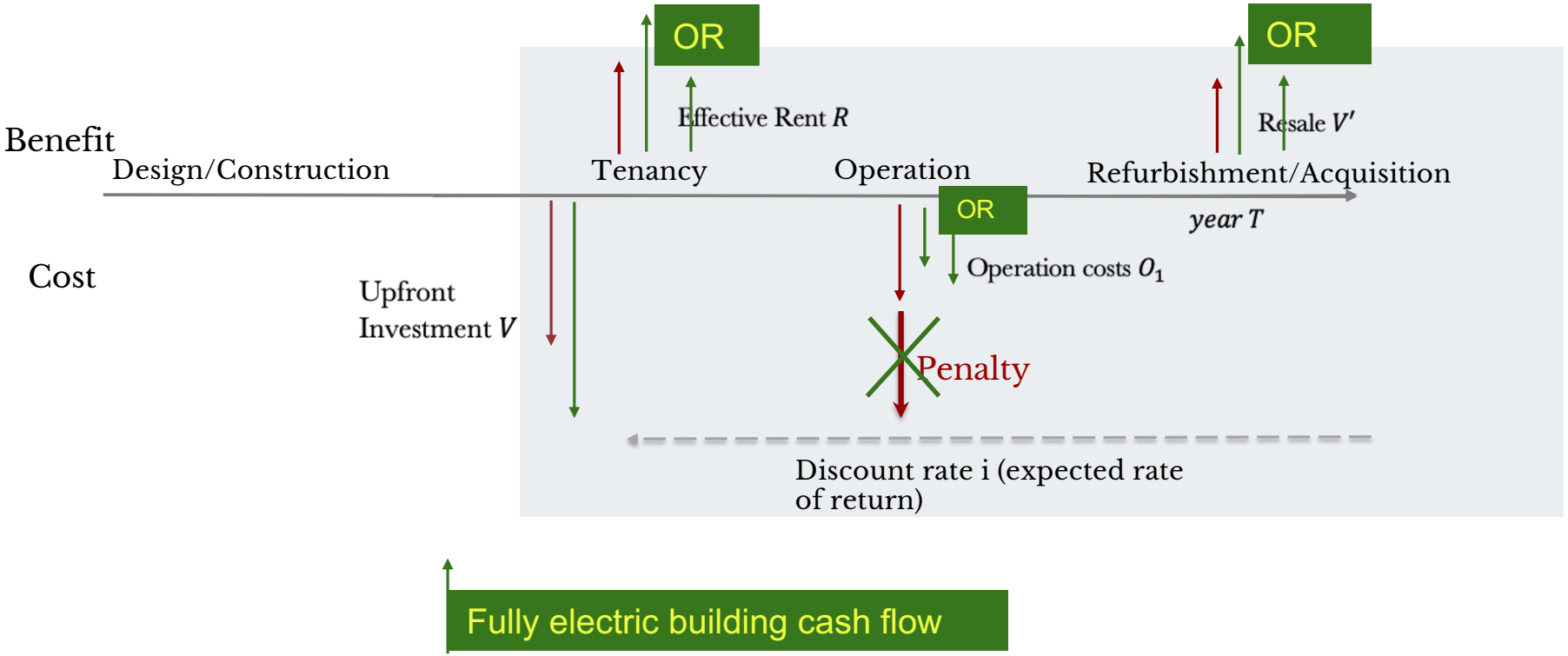
Camarasa et al. 2022

More Uncertainties

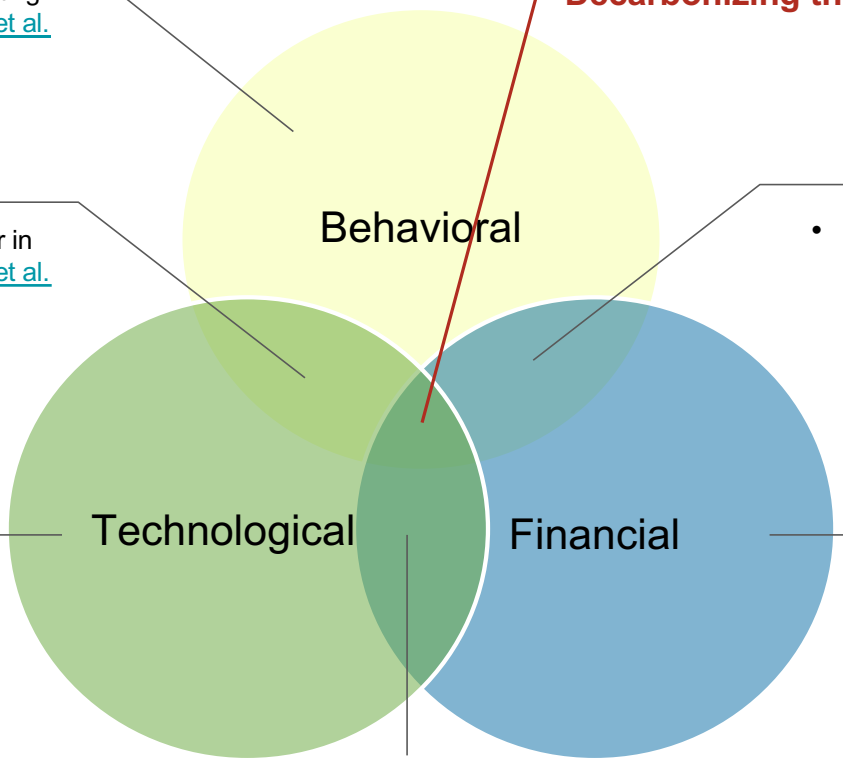




How to understand the adoption of decarbonization technologies



…But decarbonization requires an interdisciplinary approach

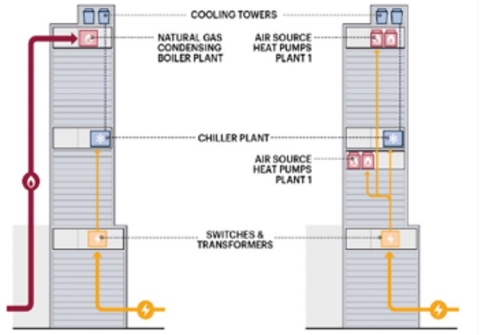


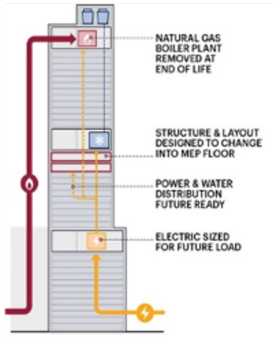
- What are the social barriers to adopting decarbonization technology? (Cole et al. 2018, Energy Efficiency)
- How to account for tenant behavior in building energy models? (Laurent et al. 2017, Building Simulation)
- How does energy efficiency affect tenant behavior? (Allcott and Greenstone 2012, Journal of Economic Perspectives)
- How can we model a building's energy performance? (Ang et al. 2020, Applied Energy)
- What is the value of investing in decarbonization from a risk management perspective? (Geltner and de Neufville 2018, Book)
- How can we model the range of costs and benefits? (Geltner and de Neufville 2018, Book), (Burhenne et al. 2014, Building and Environment)

Our Working Paper I

Quantifying the financial value of building decarbonization technology under uncertainty

Three design options:





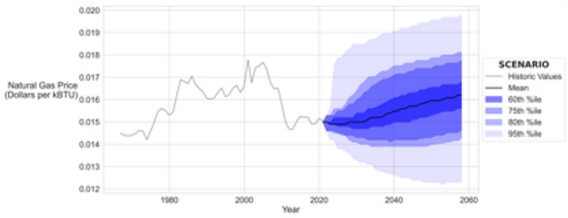
Option A
Building with natural gas heating systems

Option B
Building with *fully electric* heating systems

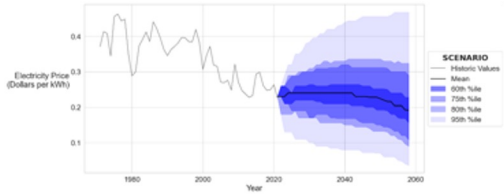
Option C
Building with the flexibility to fully electrify in the future

And a whole lot of uncertainty:

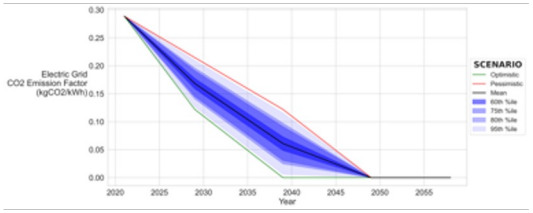
Natural Gas Prices



Electricity Prices



Rate of Grid Decarbonization



… and more

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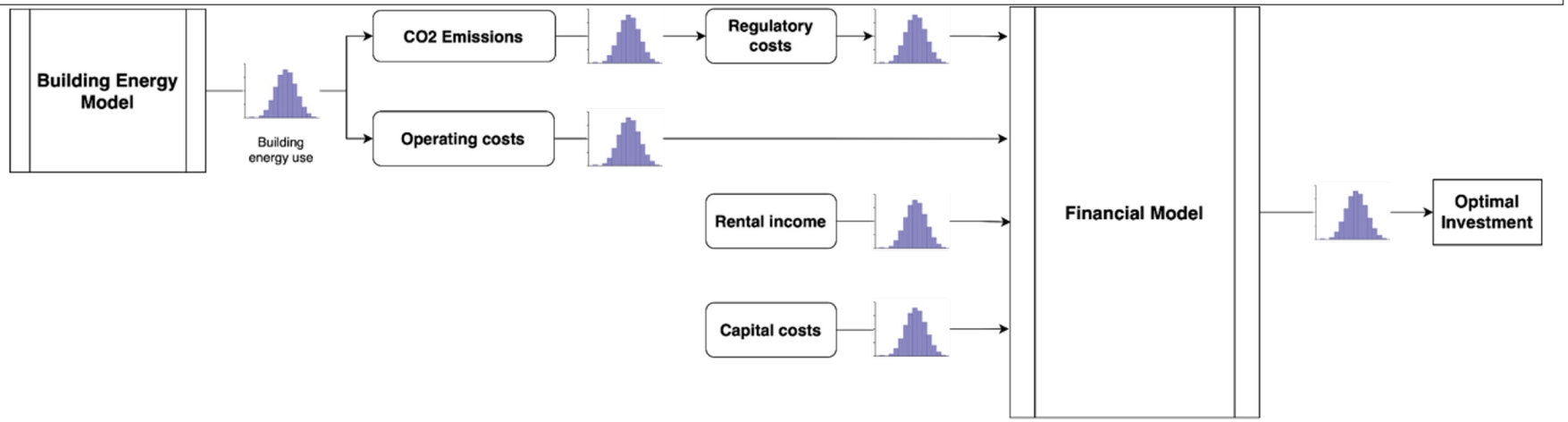
Our Working Paper

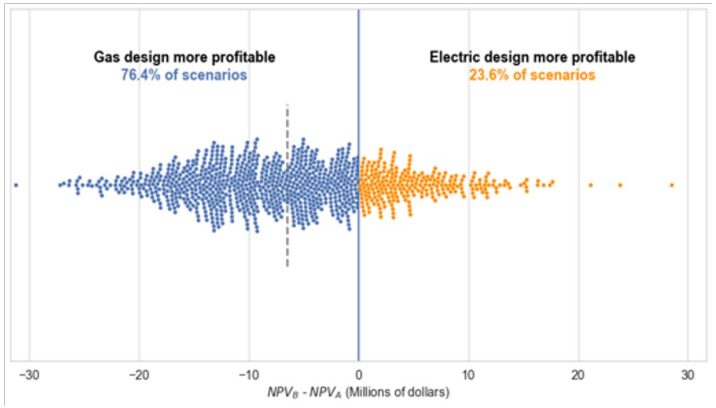
In 10,000 different future scenarios, which design option is most profitable most often?

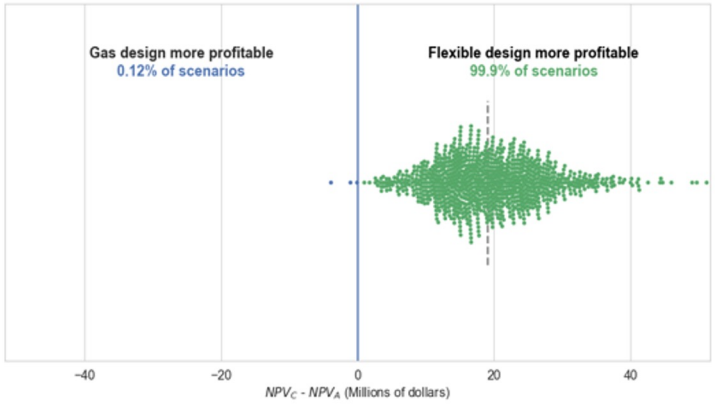
Our framework at a high-level: Combining building energy modeling, financial modeling, and uncertainty analysis



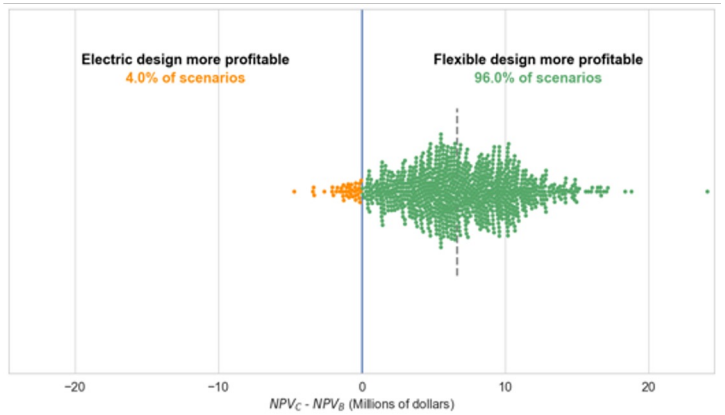
Our Working Paper

Our results





Each point represents the **difference in NPVs** of two design options in **one scenario**



The greater the number of points on one design option's side, the higher the probability that it will be more profitable across different

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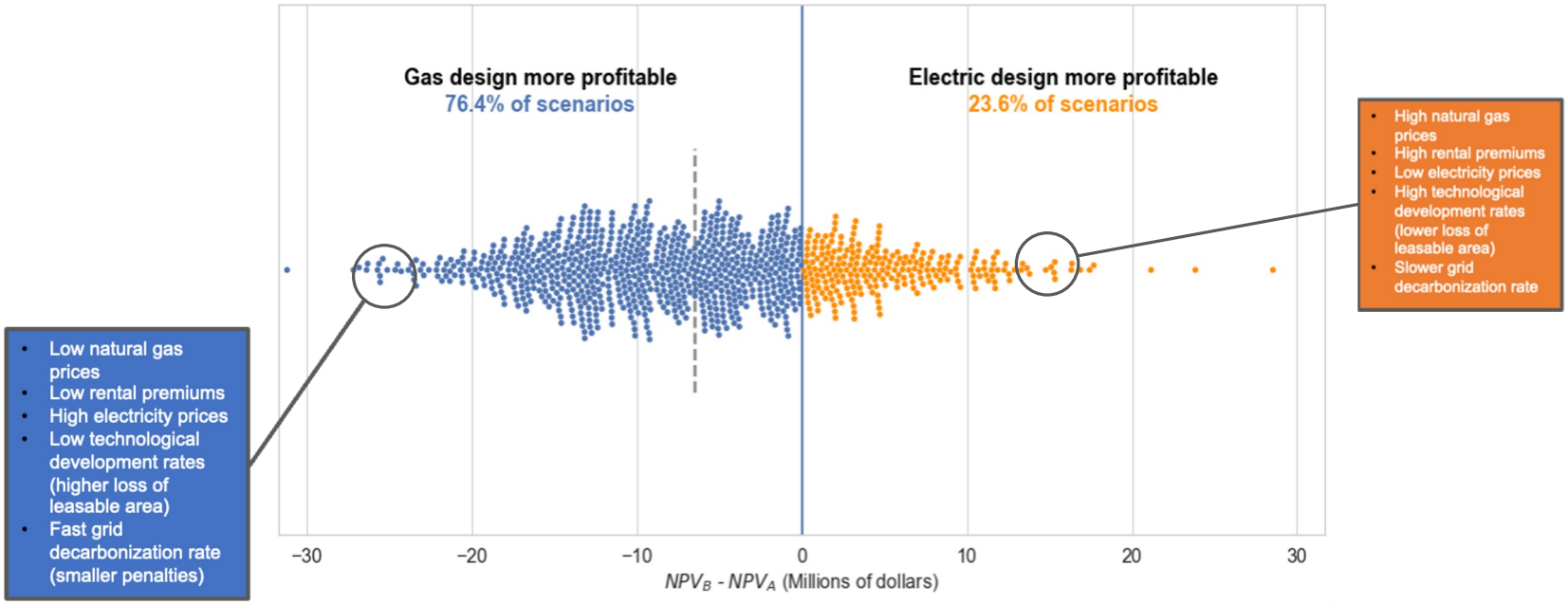
Zooming into the results

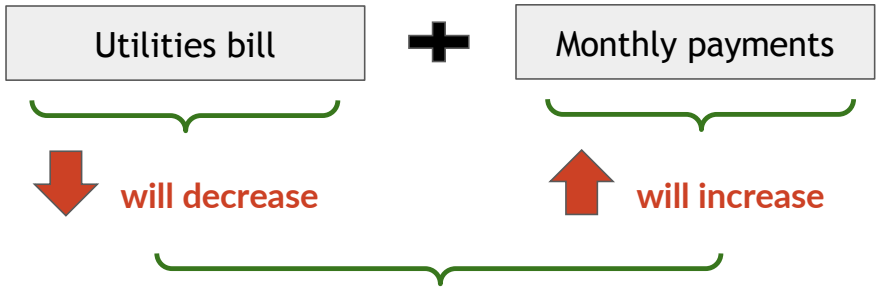


Our Working Paper II

Understanding the Impact of Net-Zero Policy on Housing Affordability

Total housing costs can be broken down into*:

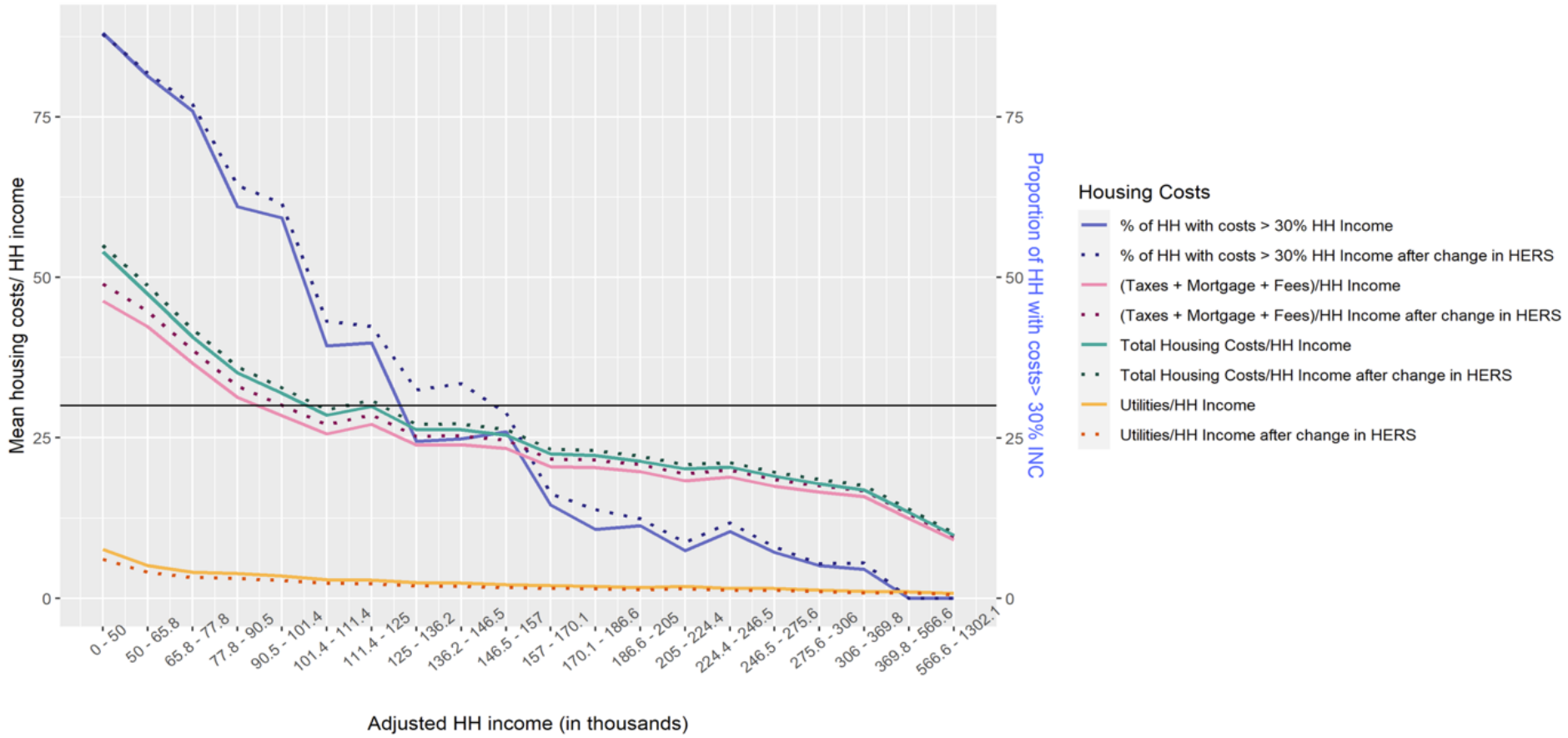
If HERS score decreases from 56 to 42:



Owners: mortgage + taxes + insurance
Renters: rent

- *Empirical question: Which effect will dominate?*
- *Heterogeneous effects depending on income groups, submarkets and housing types.*

HERS SCORE 56 TO 42 (Massachusetts)



Potential Policy Tools

Relax land use regulation

- Combine opt-in energy codes (such as stretch code) adoption with land use changes to enable more affordable and energy efficient construction, e.g., More development units per acre, Smaller minimum unit sizes, Larger height limits, More multifamily zoning, Potentially unwind forced merger of non-conforming lots.

Expedite permitting

Expand and extend incentives

- Streamline application process for incentives; provide workforce training for small builders

Expand financing sources

- Climate Bank (support in Inflation Reduction Act); Reduce financing costs for energy efficient construction; Expansion of HEAT Loan and other programs; Allow the incremental cost of net zero construction to be financed secured by an incremental property tax assessment. Ongoing savings to the owner cover the financing payments.

Thank You!