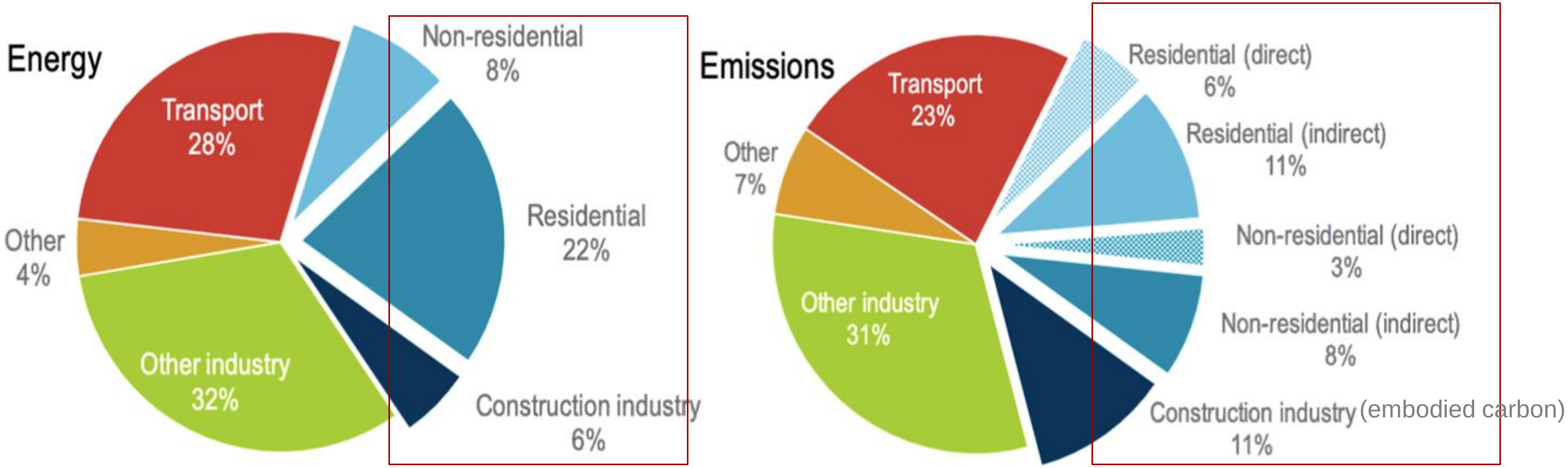
The Economics of Building Decarbonization

Siqi Zheng

November 2024

(MIT Center for Real Estate)

Buildings: 1/3 of total energy use and carbon emissions



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”

WORLD GREEN BUILDING COUNCIL

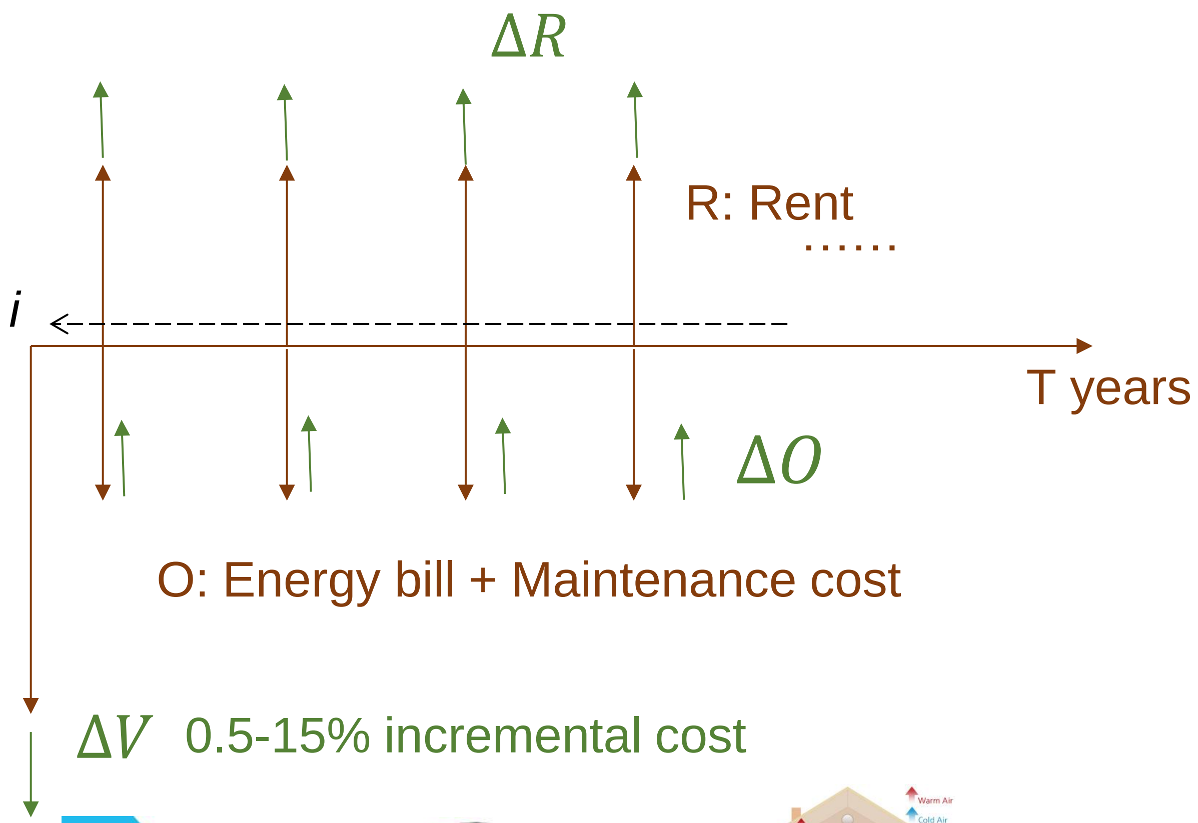
Outline

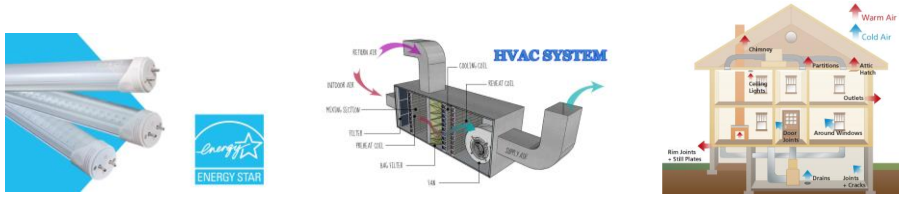
- The evidence for green premium
- Drivers and barriers of building decarbonization

The evidence for green premium

The economics of green buildings:

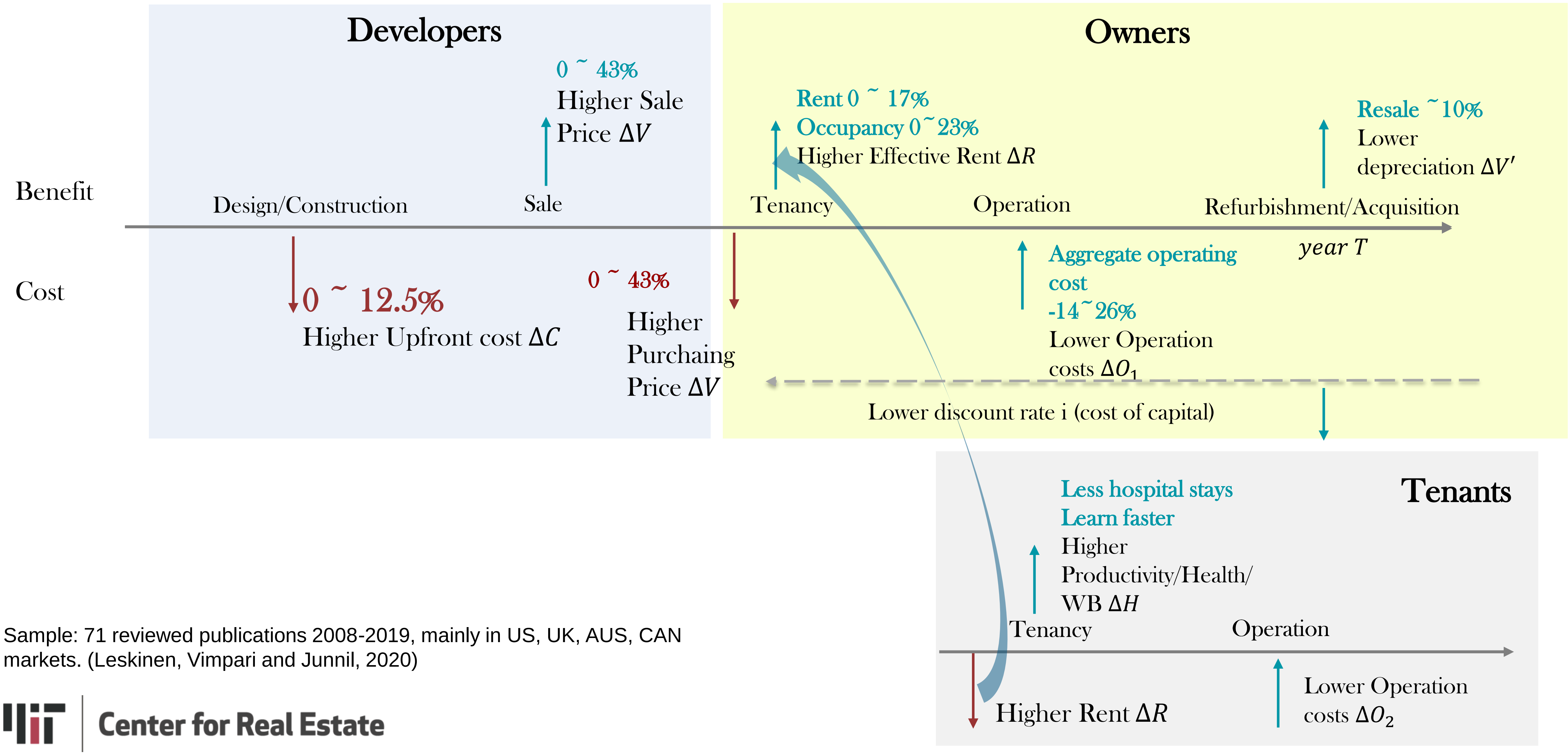
Doing well by doing good





Green Building Brown Building

Is there a business case for green buildings?



Sample: 71 reviewed publications 2008-2019, mainly in US, UK, AUS, CAN markets. (Leskinen, Vimpari and Junnil, 2020)

Green building certificates

- **The role of certificates: Solving information asymmetry.**

- LEED: Checklist based process
- Ratings: Certified (40-49); Silver (50-59); Gold (60-79); Platinum (80+)

ENERGY STAR

BREEAM
A SUSTAINABLE BUILT ENVIRONMENT CODE FOR

U.S. GREEN BUILDING COUNCIL LEED CERTIFIED USGBC
U.S. GREEN BUILDING COUNCIL LEED SILVER USGBC
U.S. GREEN BUILDING COUNCIL LEED GOLD USGBC
U.S. GREEN BUILDING COUNCIL LEED PLATINUM USGBC

PH
Passive House Institute

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name: Cambridge Crossing

Y	?	N			
1			Credit	Integrative Process	1
13	**3**	**0**		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
1			Credit 1	Sensitive Land Protection	1
	2		Credit 2	High Priority Site	2
5			Credit 3	Surrounding Density and Diverse Uses	5
5			Credit 4	Access to Quality Transit	5
1			Credit 5	Bicycle Facilities	1
	1		Credit 6	Reduced Parking Footprint	1
1			Credit 7	Green Vehicles	1
9	**1**	**0**		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
1			Credit 1	Site Assessment	1
1	1		Credit 2	Site Development - Protect or Restore Habitat	2
1			Credit 3	Open Space	1
3			Credit 4	Rainwater Management	3
2			Credit 5	Heat Island Reduction	2
1			Credit 6	Light Pollution Reduction	1
6	**3**	**2**		**Water Efficiency**	**11**
Y			Prereq 1	Outdoor Water Use Reduction	Required
Y			Prereq 2	Indoor Water Use Reduction	Required
Y			Prereq 3	Building-Level Water Metering	Required
2			Credit 1	Outdoor Water Use Reduction	2
2	2	2	Credit 2	Indoor Water Use Reduction	6
1	1		Credit 3	Cooling Tower Water Use	2
1			Credit 4	Water Metering	1
13	**4**	**16**		**Energy and Atmosphere**	**33**
Y			Prereq 1	Fundamental Commissioning and Verification	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
6			Credit 1	Enhanced Commissioning	6
5	3	10	Credit 2	Optimize Energy Performance	18
	1		Credit 3	Advanced Energy Metering	1
		2	Credit 4	Demand Response	2
		3	Credit 5	Renewable Energy Production	3
		1	Credit 6	Enhanced Refrigerant Management	1
2			Credit 7	Green Power and Carbon Offsets	2
2	**6**	**6**		**Materials and Resources**	**13**
Y			Prereq 1	Storage and Collection of Recyclables	Required
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required
		6	Credit 1	Building Life-Cycle Impact Reduction	5
	2		Credit 2	Building Product Disclosure and Optimization - Environmental Product Declarations	2
	2		Credit 3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
	2		Credit 4	Building Product Disclosure and Optimization - Material Ingredients	2
2			Credit 5	Construction and Demolition Waste Management	2
6	**7**	**3**		**Indoor Environmental Quality**	**16**
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
1	1		Credit 1	Enhanced Indoor Air Quality Strategies	2
2	1		Credit 2	Low-Emitting Materials	3
1			Credit 3	Construction Indoor Air Quality Management Plan	1
	2		Credit 4	Indoor Air Quality Assessment	2
1			Credit 5	Thermal Comfort	1
	2		Credit 6	Interior Lighting	2
		3	Credit 7	Daylight	3
	1		Credit 8	Quality Views	1
1			Credit 9	Acoustic Performance	1
6	**0**	**0**		**Innovation**	**6**
5			Credit 1-5	Innovation	5
1			Credit 6	LEED Accredited Professional	1
1	**2**	**2**		**Regional Priority**	**4**
	1		Credit 1	Regional Priority: Renewable Energy Production (2 point threshold)	1
		1	Credit 2	Regional Priority: Optimize Energy Performance (8 point threshold)	1
	1		Credit 3	Regional Priority: High Priority Site (2 point threshold)	1
		1	Credit 4	Regional Priority: Building Life-Cycle Impact Reduction (2 point threshold)	1
1			Credit 5	Regional Priority: Rainwater Management (2 point threshold)	
	1		Credit 6	Regional Priority: Indoor Water Use Reduction (4 point threshold)	
57	**26**	**29**		**TOTALS** Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED CERTIFICATION TARGET - SILVER
(57 POINTS)

Source: link

Estimate green premium: Hedonic model

American Economic Review 100 (December 2010): 2492–2509
http://www.aeaweb.org/articles.php?doi=10.1257/aer.100.5.2492

Doing Well by Doing Good? Green Office Buildings

By Piet Eichholtz, Nils Kok, and John M. Quigley*

The behavior of the building and real estate sectors is quite important in matters of environmental sustainability. It is reported, for example, that buildings account for approximately 40 percent of the consumption of raw materials and energy. In addition, 55 percent of the wood that is not used for fuel is consumed in construction. Overall, buildings and their associated construction activity account for at least 30 percent of world greenhouse gas emissions (Royal Institution of Chartered Surveyors, RICS 2005). The impact of energy costs directly affects tenants and building owners. Energy represents 30 percent of operating expenses in a typical office building; this is the single largest and most manageable operating expense in the provision of office space.

Hedonic regression

Building and location controls

$$Log(Price_{ijt}) = \boldsymbol{X_{1i}\beta_1} + \boldsymbol{X_{2j}\beta_2} + U_{ijt}$$

$$\boldsymbol{X'_{1i}\beta'_1 + \beta_g Green}$$

Green Premium

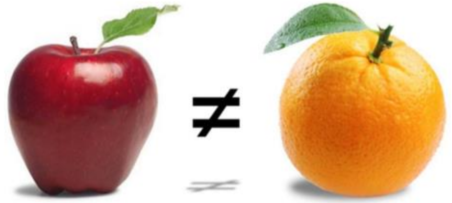
Dummy (green = 1, otherwise = 0)
Or categorical variables, such as LEED {Silver, Gold, Platinum}

How to make an “apple-to-apple” comparison

TABLE 2.—COMPARISON OF GREEN-RATED BUILDINGS AND NEARBY CONT
PROPENSITY-SCORE WEIGHTED OBSERVATIONS (STANDARD DEVIATIONS

	Rental Sample		
	Rated Buildings	Control Buildings	PSM Controls
Sample size	1,943	18,858	18,858
Contract rent (dollars/sq. ft.)	25.83	26.75	29.28
	(9.67)	(12.48)	(12.12)
Effective rent[a] (dollars/sq. ft.)	22.28	22.70	25.24
	(9.61)	(12.39)	(10.89)
Sales price (dollars/sq. ft.)			
Size (thousands sq. ft.)	299.83	155.65	282.88
	(292.40)	(245.73)	(176.74)
Occupancy rate (%)	85.80	83.45	85.32
	(13.11)	(16.39)	(31.54)
Building class (%)			
Class A (1 = yes)	75.75	26.9	71.94
	(42.87)	(44.34)	(37.53)
Class B (1 = yes)	23.21	52.73	26.90
	(42.23)	(49.93)	(12.57)
Class C (1 = yes)	1.04	20.37	1.16
	(10.15)	(40.27)	(1.31)
Age (years)	24.65	53.22	25.93
	(17.36)	(34.33)	(7.56)
Renovated building (%)	24.25	40.31	26.20
	(42.87)	(49.05)	(18.39)
Stories (number)	13.71	10.24	13.67
	(12.64)	(10.05)	(6.95)
On-site amenities (%)[b]	53.53	28.8	51.88
	(49.89)	(45.28)	(31.82)
Public transport (%)[c]	12.75	11.55	12.46
	(33.37)	(31.96)	(15.84)
Employment growth, 2006–2008 (%)	1.18	−0.07	−1.47
	(4.56)	(5.86)	(3.33)
Rental contract (%)			
Triple net (1 = yes)	22.11	14.74	22.94
	(41.51)	(35.45)	(42.05)
Modified gross (1 = yes)	1.31	7.94	2.58
	(11.39)	(27.04)	(15.85)
Plus all utilities (1 = yes)	8.81	9.51	9.86
	(28.36)	(29.37)	(29.81)
Gross (1 = yes)	69.07	75.76	67.20
	(46.23)	(42.86)	(46.95)

[a]Effective rent equals the contract rent multiplied by the occupancy rate.
[b]One or more of the following amenities are available on-site: banking, convenience store, dry cleaner, exercise facilities, food court, foo

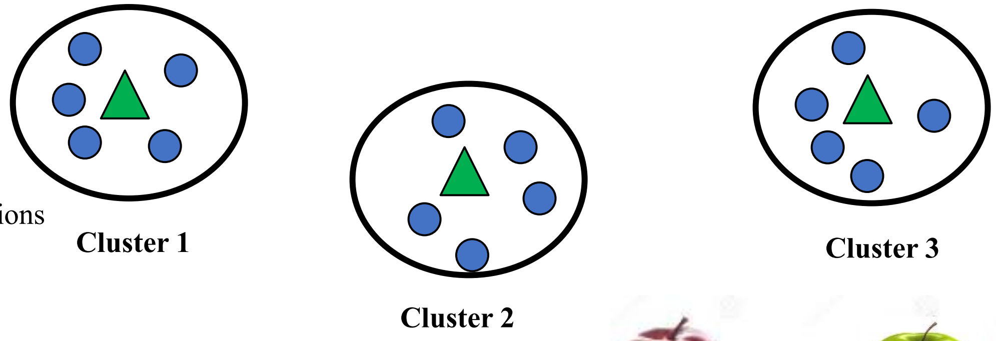


Matching:

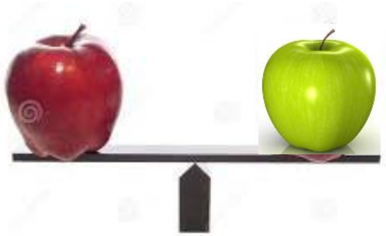
- Geographic matching

0.2 square miles

20,801 observations
1,943 clusters



- Propensity score matching (PSM)

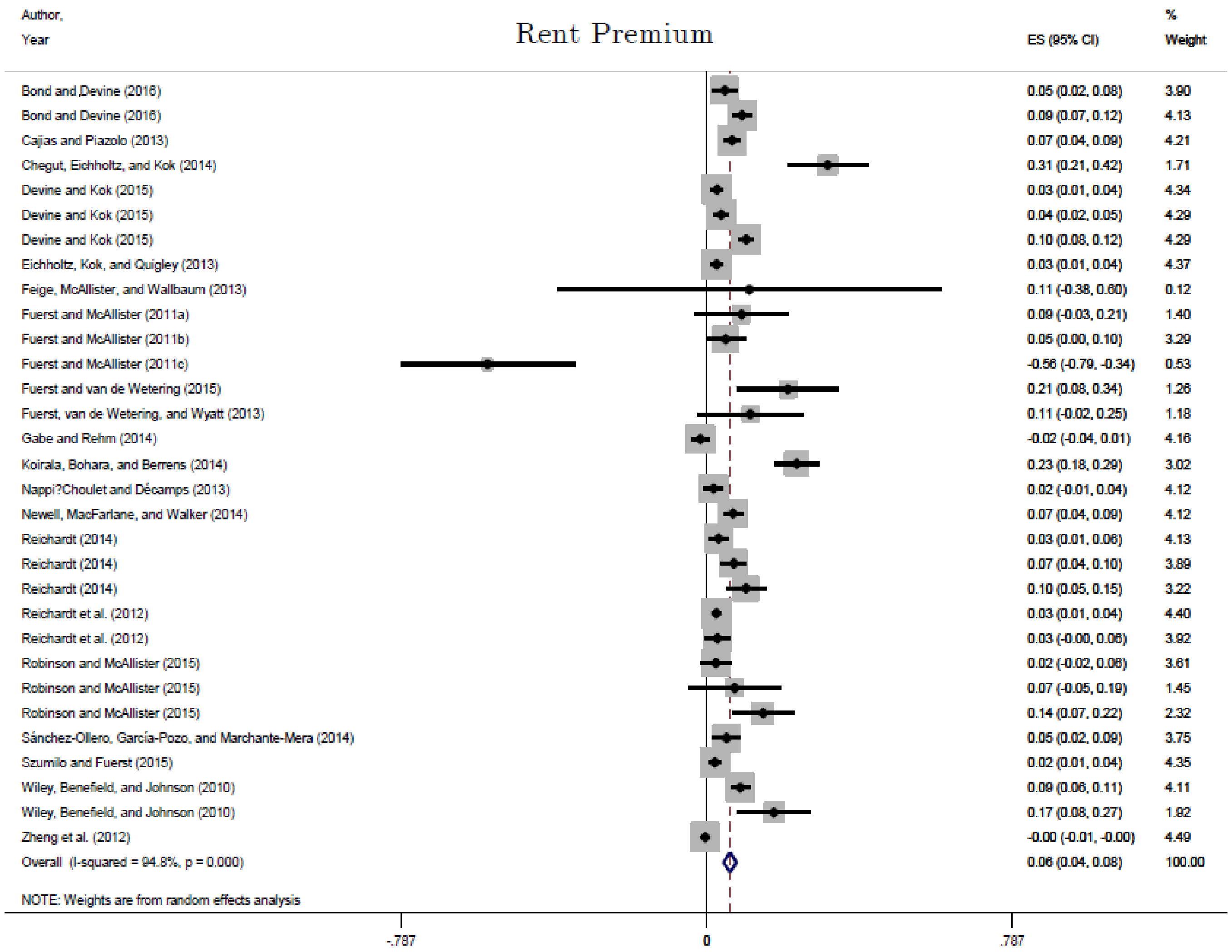


Eichholtz, P., Kok, N., & Quigley, J. M. (2013). The Economics of Green Building. *The Review of Economics and Statistics, 95*(1), 50-63.

Table 3.—Green Ratings, Rents, and Sales Prices
Propensity-Score Weighted Observations, 2009 Sample Frame

	Rent (per square foot)		Effective Rent# (per square foot)		Sales Price (per square foot)	
	(1)	(2)	(3)	(4)	(5)	(6)
Green rating (1 = yes)	0.026***		0.076***		0.133***	
	[0.007]		[0.010]		[0.017]	
Green rating × gross (1 = yes)	−0.011		−0.037***			
	[0.008]		[0.012]			
Green rating × modified gross (1 = yes)	−0.024		0.016			
	[0.035]		[0.053]			
Green rating × plus utilities (1 = yes)	−0.001		−0.049**			
	[0.013]		[0.019]			
Energy Star (1 = yes)		0.021***		0.065***		0.129***
		[0.005]		[0.007]		[0.0191]
Label vintage (years)		−0.004**		−0.010***		−0.017*
		[0.002]		[0.002]		[0.011]
LEED (1 = yes)		0.058***		0.060***		0.111***
		[0.010]		[0.015]		[0.0419]
Building size (millions of square feet)	0.034***	0.034***	0.076***	0.076***	−0.049***	−0.049***
	[0.003]	[0.003]	[0.004]	[0.004]	[0.010]	[0.010]
Fraction occupied	−0.000	−0.000				
	[0.000]	[0.000]				

Rental premium for green buildings



Dalton and Fuerst (2018): Meta analysis of green real estate rents

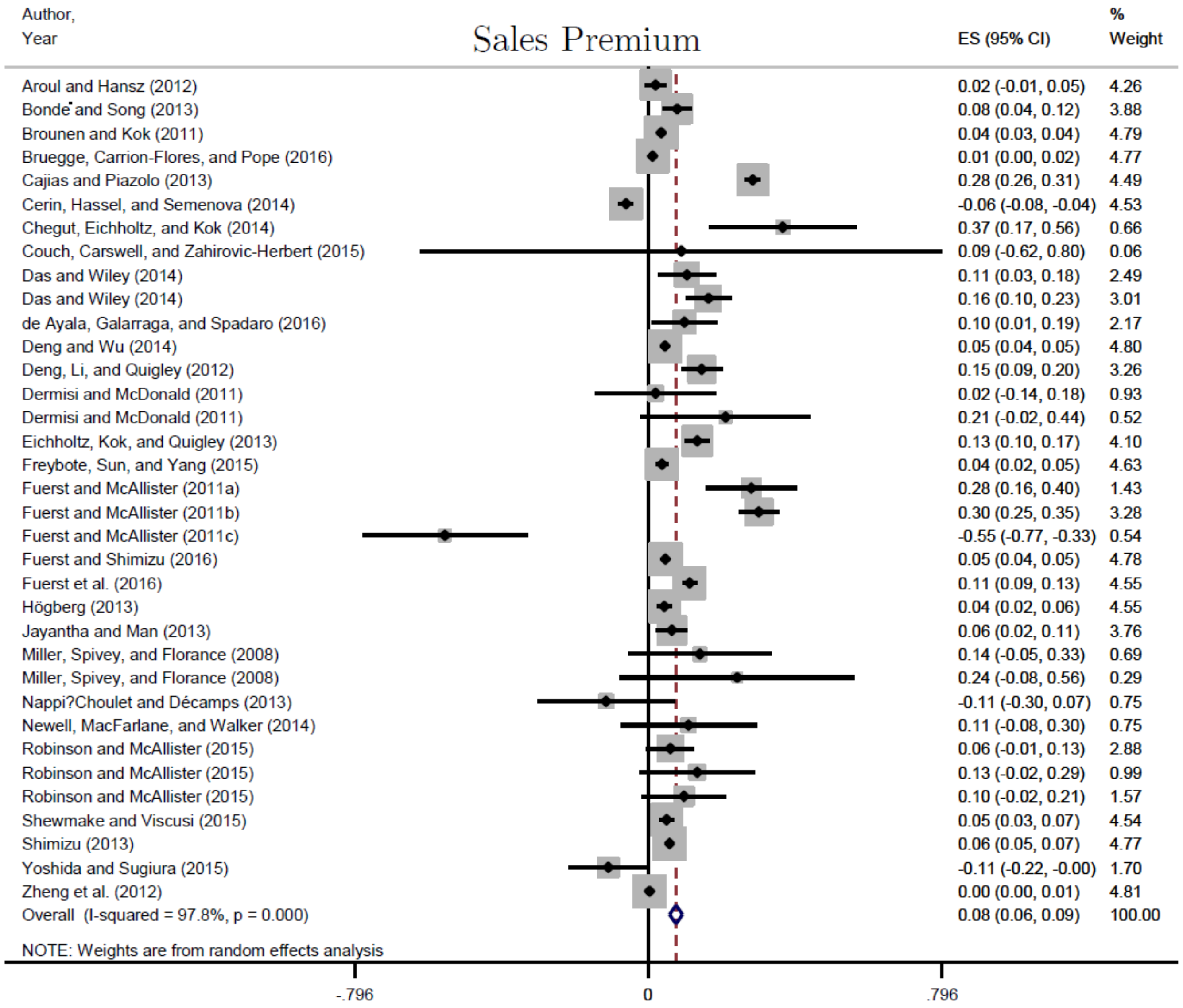
Overall significant rent premium of 6%

- 5.4% commercial
- 8.2% residential

Studies also find 5% - 9% higher occupancy rates for commercial real estate.

Fuerst, Dalton And. 2018. *The Green Value Proposition in Real Estate: A Meta-Analysis.* Routledge.

Price premium for green buildings



Dalton and Fuerst (2018) also look at evidence sales prices

Overall price premium of 7.6%

- For commercial 11.5%
- For residential 5.5%

Fuerst, Dalton And. 2018. *The Green Value Proposition in Real Estate: A Meta-Analysis.* Routledge.

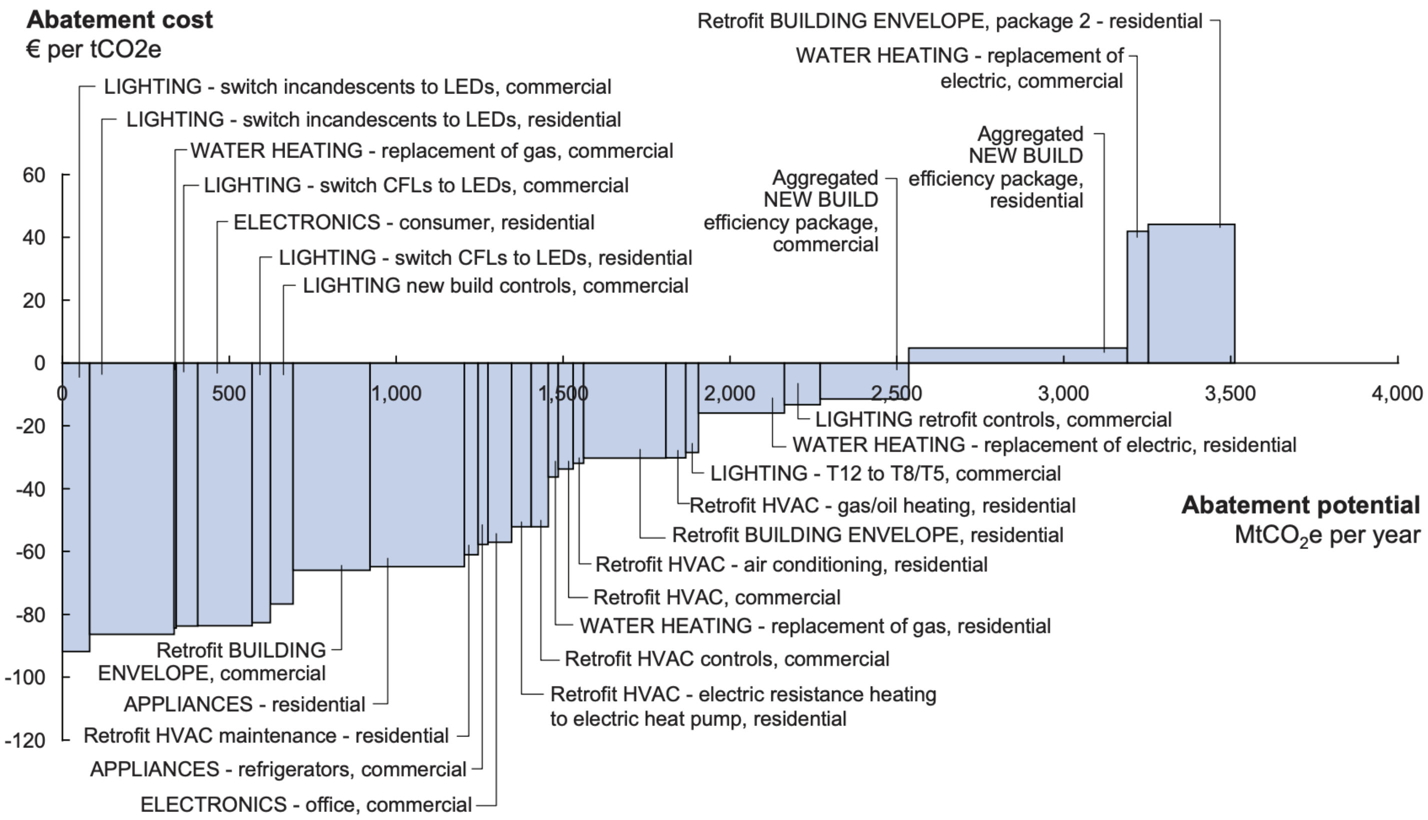
Drivers and barriers for building decarbonization

Negative Lifecyle Cost: Market Opportunity Unexploited

Exhibit 8.7.2

Global GHG abatement cost curve for the Buildings sector

Societal perspective; 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO$_2$e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

McKinsey Curve:
"Carbon emissions in the Building sector can be substantially reduced, either with net economic benefits or at low cost."

Why are the vast negative cost green opportunity unexploited?

Energy efficiency gap: Investment in energy efficient technologies/products is below (privately) optimal level.

What could explain this gap?

An easy-to-read piece: Jaffe, A. B., R. G. Newell, and R. N. Stavins. 2004. “Economics of Energy Efficiency.” *Encyclopedia of Energy* 2: 79–90.

A good review piece: Allcott, H., & Greenstone, M. (2012). Is there an Energy Efficiency Gap? *The Journal of Economic Perspectives: A Journal of the American Economic Association, 26*(1), 3–28.

Market failures

- Environmental externalities: regulations and subsidies (e.g. LL97 in NYC)
- Inadequate information

Davis, Lucas W., and Gilbert E. Metcalf. 2016. “Does Better Information Lead to Better Choices? Evidence from Energy-Efficiency Labels.” *Journal of the Association of Environmental and Resource Economists* 3 (3): 589–625.
Zhang, Li, Cong Sun, Hongyu Liu, and Siqi Zheng. "The role of public information in increasing homebuyers' willingness-to-pay for green housing: Evidence from Beijing." *Ecological Economics* 129 (2016): 40-49.

- Split incentive in the rental sector

Aydin, Erdal, Piet M. A. Eichholtz, and Rogier Holtermans. 2024. “Split Incentives and Energy Efficiency Investment: Evidence from the Housing Market.” *Social Science Research Network.* https://doi.org/10.2139/ssrn.4944953.

Non-market failure explanations

- Heterogeneity in energy users
- Under-estimated costs and over-estimated energy savings
  - **Performance gap**

Information, learning and WTP for green buildings

- "The Role of Public Information in Increasing Homebuyers' Willingness-to-Pay for Green Housing: Evidence from Beijing." Zhang, Sun, Liu and Zheng 2016, *Ecological Economics*

Information & knowledge matter!

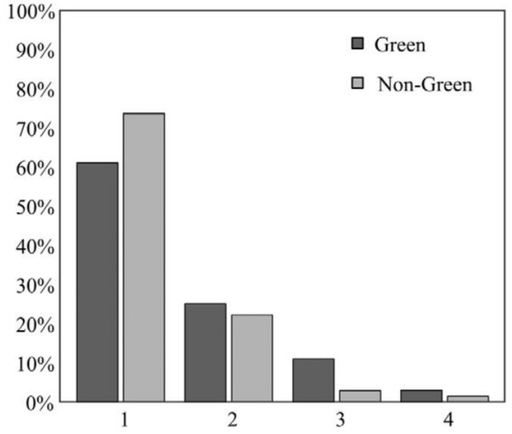
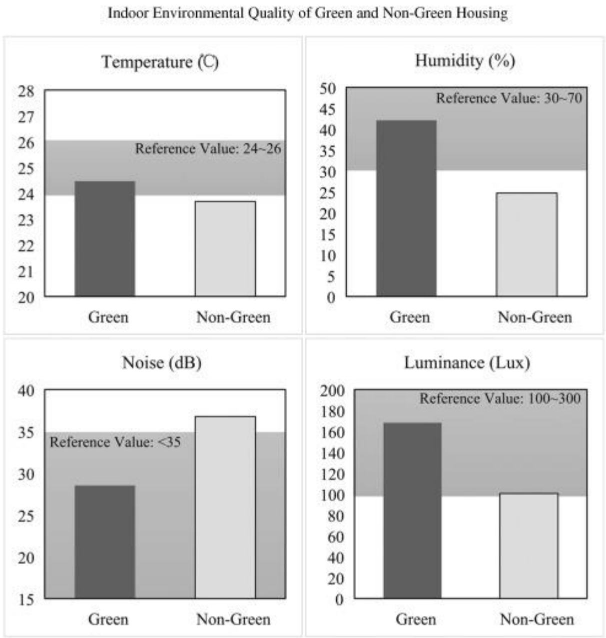
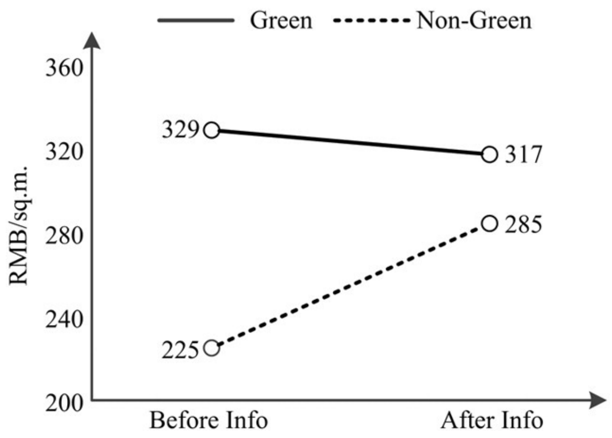


Fig. 3. Respondents' knowledge of Chinese green building label. Notes: 1 = "Do not know it"; 2 = "Only heard of it"; 3 = "Familiar. Know its logo"; 4 = "Very familiar. Has specialized knowledge about it".

Low awareness among residents in non-green buildings



Intervention: information card



Significant increase in the WTP for green buildings for non-green building residents

Split incentive in rental properties

If tenants pay the bill (such as the "triple net lease", NNN)

Net Lease

Owner
Does not pay the energy bill thus will not benefit if they pay for energy efficiency upgrades

Tenants
Do pay the energy bill but do not own the building, thus usually hesitant to make long-term investment on someone else's building.

Similarly, for buildings with a full-service lease structure (i.e., no additional expenditure for utility):

- The owner wants to keep the energy cost down
- Tenants have no incentive to save energy as they pay the flat rate.

Gross Lease

Aydin, E., Eichholtz, P. M. A., & Holtermans, R. (2024). Split incentives and energy efficiency investment: Evidence from the housing market. In *Social Science Research Network*. https://doi.org/10.2139/ssrn.494495

Dutch housing market covering 3.8 million homes. Rental properties exhibit approximately 7.7% lower energy efficiency compared to similar owner-occupied homes.

- the transition from rental to owner status leads to a reduction in subsequent energy consumption of up to approximately 6%.

Performance gap

Realized savings are 58% (Allcott and Greenstone, 2017), 30% (Fowlie et al., 2018), 51% (Christensen et al., 2021) of predicted savings.

Fowlie, M., Greenstone, M., & Wolfram, C. (2018). Do energy efficiency investments deliver? Evidence from the weatherization assistance program. *The Quarterly Journal of Economics*, *133*(3), 1597-1644.

The weatherization Assistant Program in Michigan – Upfront costs are about twice the actual energy savings. The rate of return = -7%

Non-monetary costs:

Fowlie, M., Greenstone, M., & Wolfram, C. (2015). Are the non-monetary costs of energy efficiency investments large? Understanding low take-up of a free energy efficiency program. *American Economic Review*, *105*(5), 201–204.

Explained by

- Rebound effect – 6%
- Bias in engineering models – 41% (over-estimated savings in wall insulation)
- Heterogeneity in workmanship/installation – 43%

Christensen, P., Francisco, P., Myers, E., & Souza, M. (2023). Decomposing the wedge between projected and realized returns in energy efficiency programs. *Review of Economics and Statistics*, *105*(4), 798-817.

Research directions

- RCT to test mechanisms and the effectiveness of policy instruments
  - Energy audits and energy conservation

Akesson, J., Hahn, R. W., Kochhar, R., & Metcalfe, R. D. (2023). *Do Water Audits Work?* https://www.nber.org/papers/w31831

  - Information acquisition value

La Nauze, A., & Myers, E. (2023). *Do Consumers Acquire Information Optimally? Experimental Evidence from Energy Efficiency.* https://www.nber.org/papers/w31742

  - Peer effects

Carattini, S., Gillingham, K., Meng, X., & Yoeli, E. (2024). Peer-to-peer solar and social rewards: Evidence from a field experiment. *Journal of Economic Behavior & Organization, 219*, 340–370.

Research directions

- ## Machine learning for targeting

  Christensen, P., Francisco, P., Myers, E., Shao, H., & Souza, M. (2024). Energy efficiency can deliver for climate policy: Evidence from machine learning-based targeting. *Journal of Public Economics, 234*(105098), 105098.

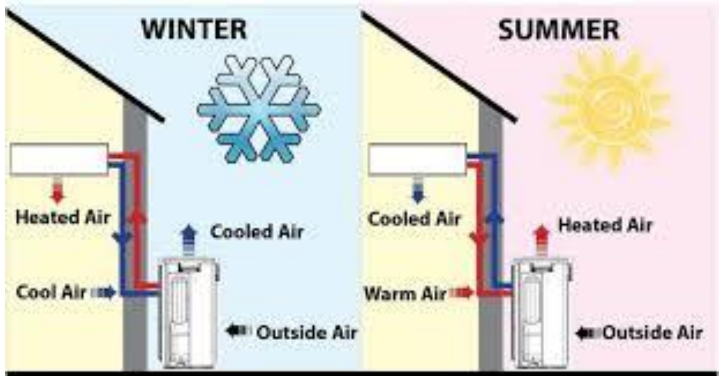
  A data-driven approach to predicting retrofit impacts based on previously realized outcomes is more accurate than the status quo engineering models. Targeting high-return interventions based on these predictions dramatically increases net social benefits.

  Gerarden, T., & Yang, M. (2022). Using targeting to optimize program design: Evidence from an energy conservation experiment. *Journal of the Association of Environmental and Resource Economists.* https://doi.org/10.1086/722833

- ## New "green" technologies

  Davis, L. W. (2023). *The Economic Determinants of Heat Pump Adoption* (No. 31344). National Bureau of Economic Research. https://doi.org/10.3386/w31344

  Knittel, C., Ontiveros J., Palacios, J. Zheng, S. (2024). Learning by Doing: Contractors' Learning in Heat Pump Installations



Energy Performance Criteria – LL97 in NYC

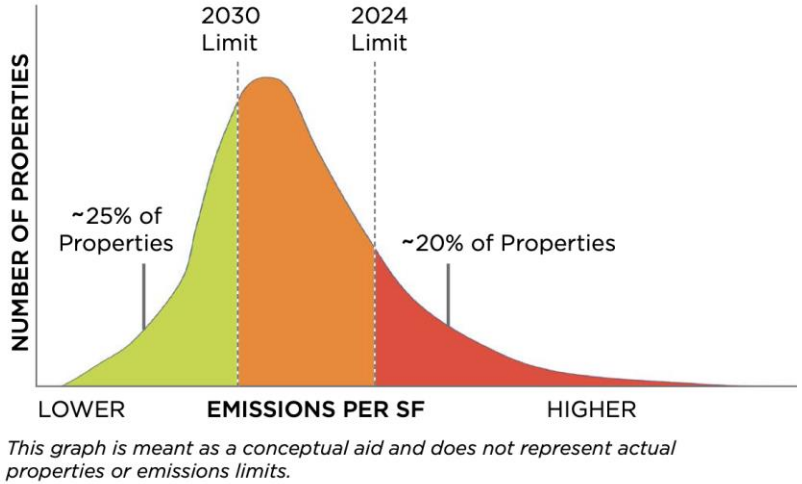
LL97

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

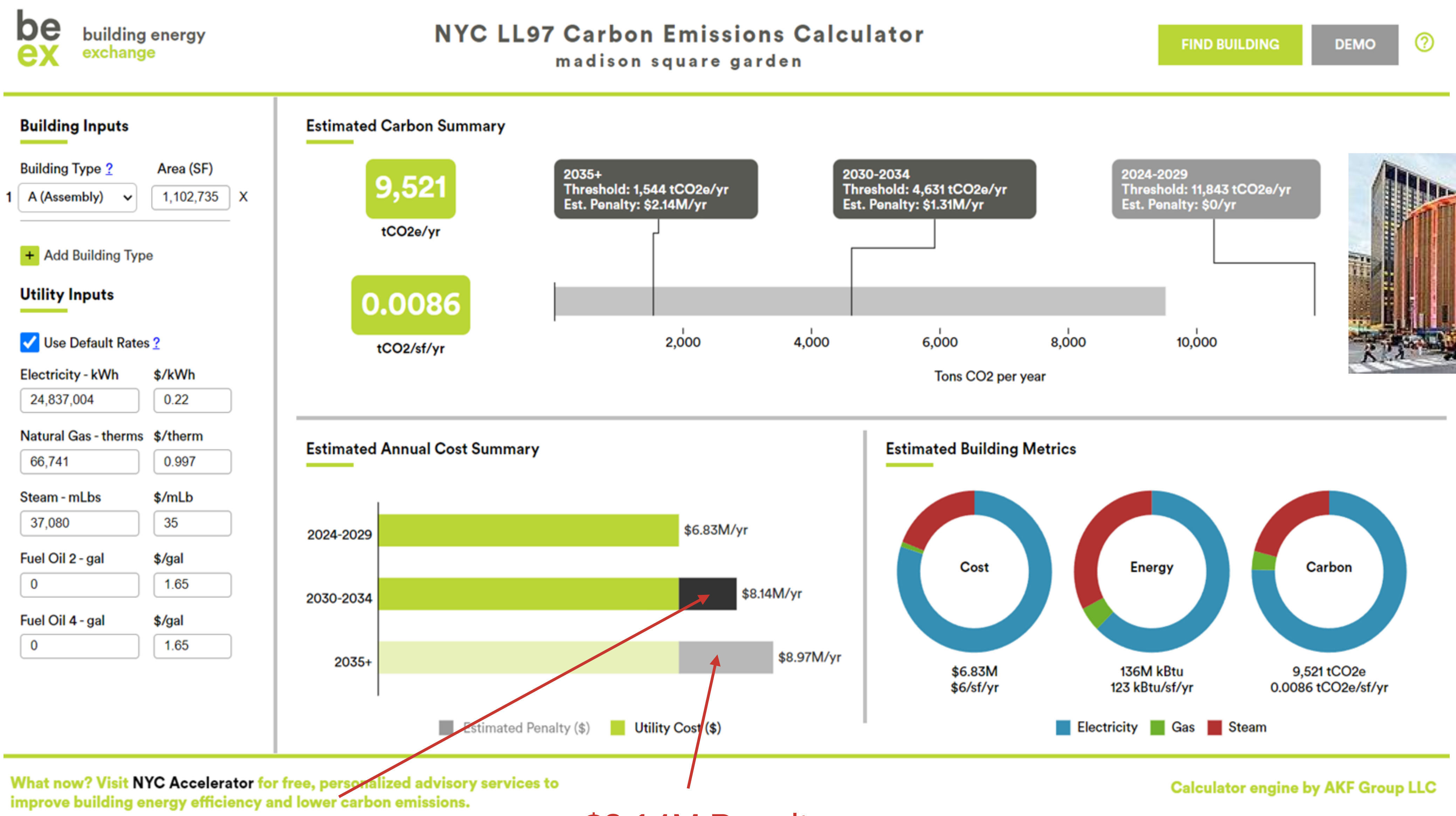


This graph is meant as a conceptual aid and does not represent actual properties or emissions limits.

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.



$1.31M Penalty

$2.14M Penalty

Example: Madison Square Garden

Data from 2019 As Required by LL84

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

MIT Center for Real Estate

The Role of Future Uncertainties

Building Completed

Annual Cash Flows

End Investment

Design/Construction

Tenancy

Operation

Decision Date

↑ Construction cost

Rent Income

Operation costs

Year 40

? Rent × ↓ Leased space

? ↓ Energy costs
+
? ↓ Emission Penalties

2

Energy prices:

- Prices subject to high volatility for fossil fuels

1

Rent premiums for fully-electric buildings:

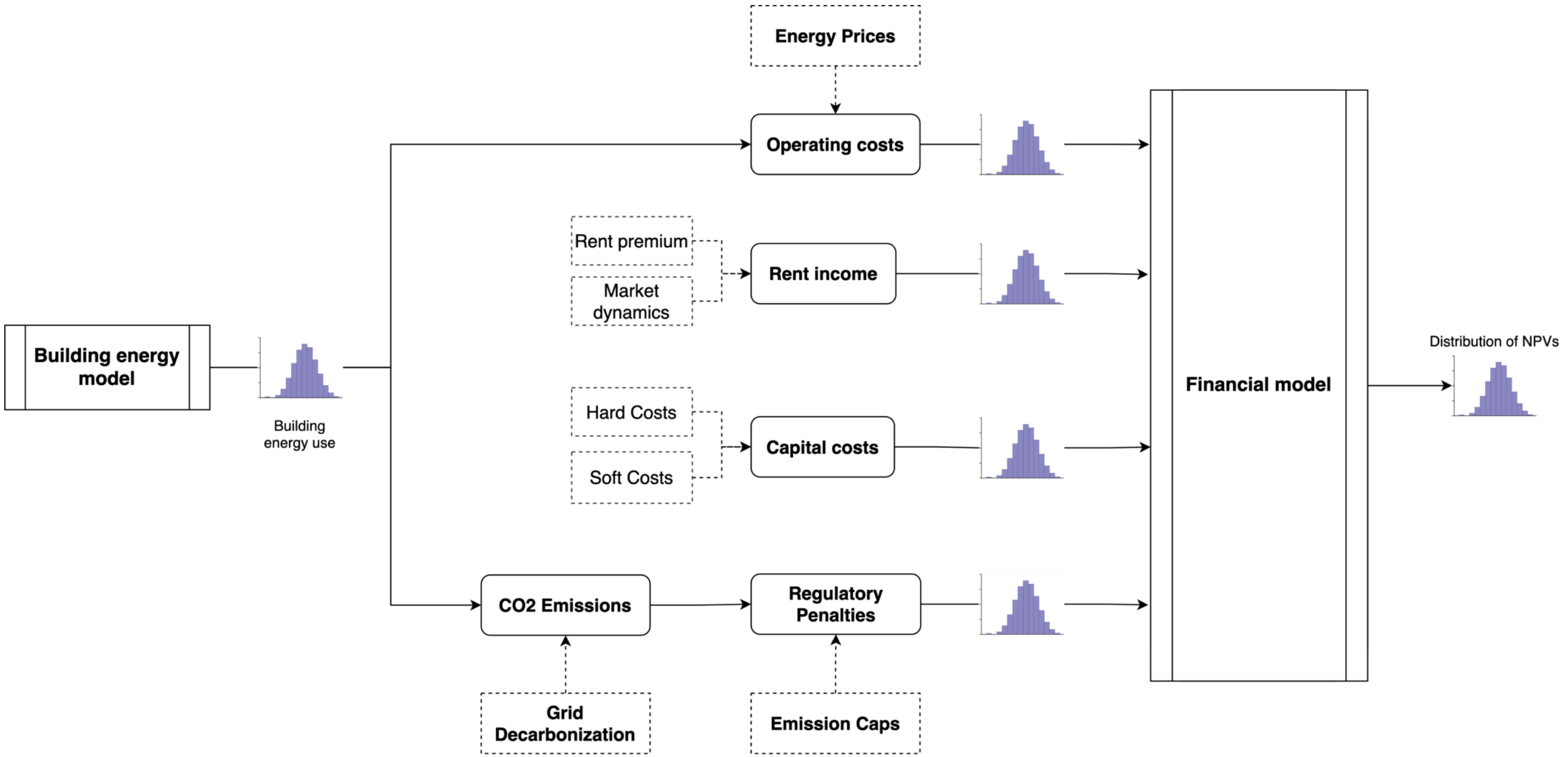
- **LL97, and LL 154** newly constructed buildings to be fully electric in 2027
- **Corporate tenants**

3

100% dependent on NYC electric grid

- Plan to decarbonize grid by year 2040
- **Local Law 97** fines owners with $268 per metric ton of emissions above caps from 2024

Building Energy Model + Financial Model: Incorporating uncertainties



Echeverria, A. J. V., Palacios, J., Davila, C. C., & Zheng, S. (2023). Quantifying the financial value of building decarbonization technology under uncertainty: Integrating energy modeling and investment analysis. *Energy and Buildings*, *297*, 113260.

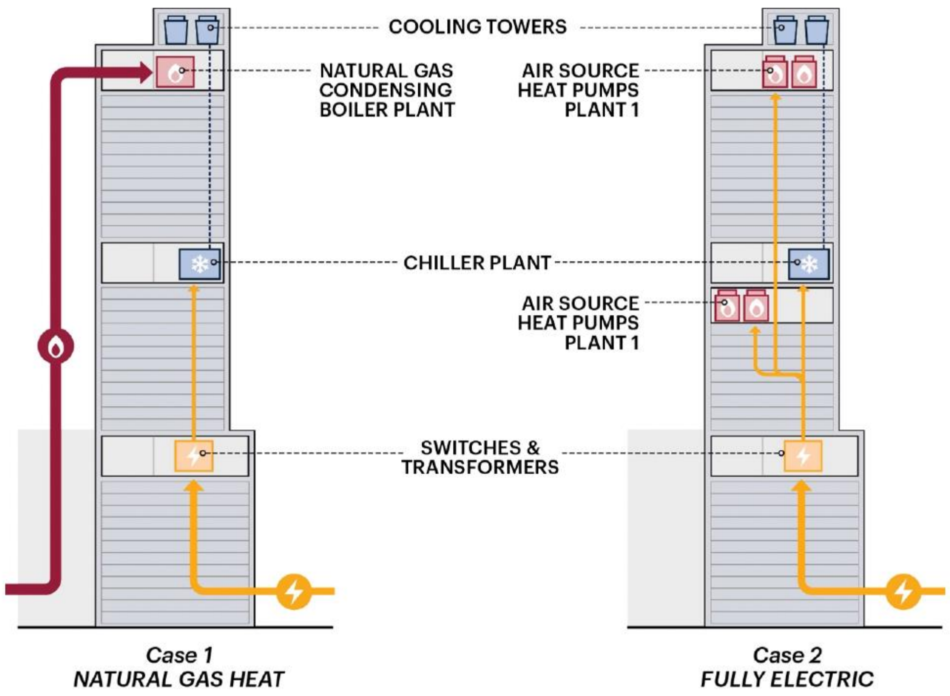
Case Study: Office building in Manhattan

- 920,000 ft^2 office building in Manhattan
- **Challenge:** *Do we construct a building that uses **natural gas** or a building that is **fully electric**?*
- **Tradeoffs:**

NYC LOCAL LAW 97

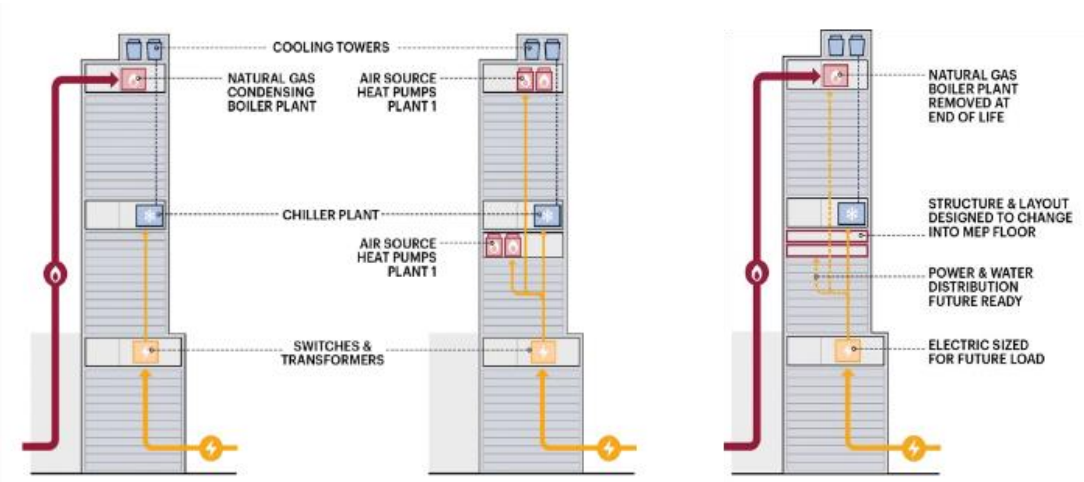
Gas boiler (heating, DHW) Gas kitchens Efficiency <1	EQUIPMENT	Heat pumps (heating) HP / electric boiler (DHW) Efficiency 2.5-4.0
Boiler room anywhere in the building	SPACE	Larger; Scales with floor area Requires roof / louvered facades
Lower initial cost	CAPITAL $	Higher initial cost + 7-10 $/sf (new office)
Usually lower today (0-10%) Energy prices VS efficiency	OPERATION $	Usually higher today (0-10%) Energy prices VS efficiency
Today depends on the grid Lower in the future	CARBON	Today depends on the grid Lower in the future
Some cities start to fine Risk of obsolete asset	MARKET / POLICY	Some cities require by 2030 Might become market advantage

Figure 3. Schematic floorplan and axonometric view of the tower



Three design options

Three design options:



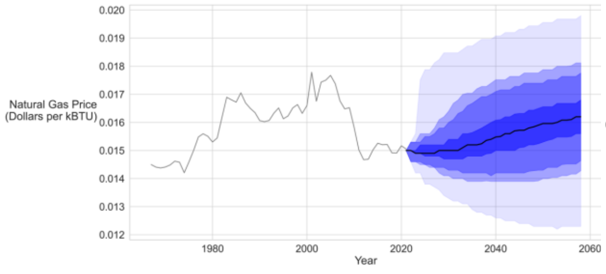
Option A
Building with natural gas heating systems

Option B
Building with fully electric heating systems

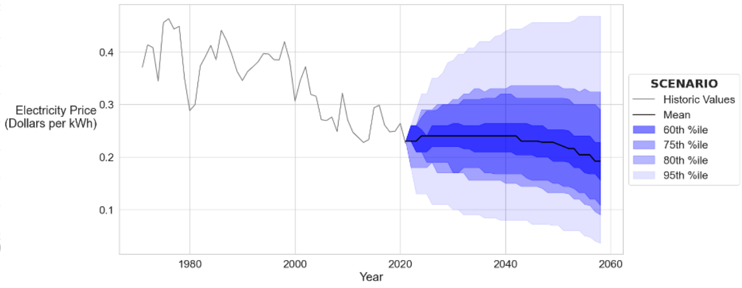
Option C
Building with the flexibility to fully electrify in the future

And a whole lot of uncertainty:

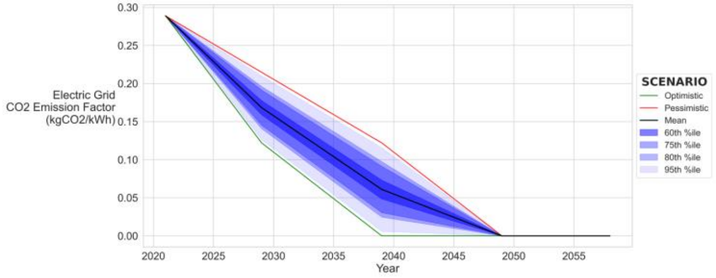
Natural Gas Prices



Electricity Prices



Rate of Grid Decarbonization

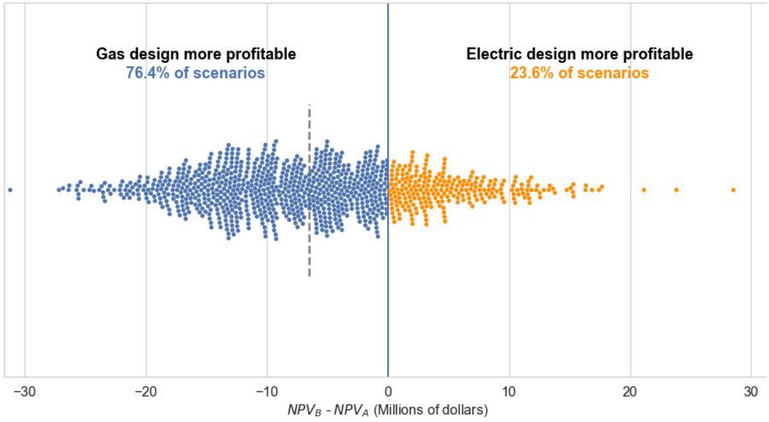


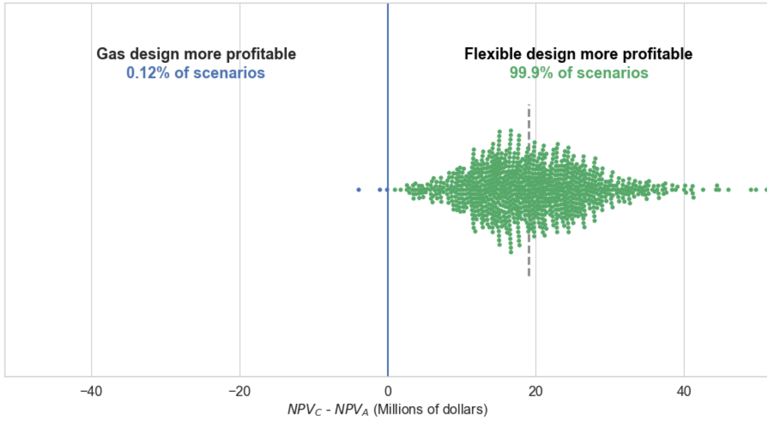
- Building energy use
- Technological development
- Energy efficiency market premiums
- Equipment performance / costs
- And more...

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

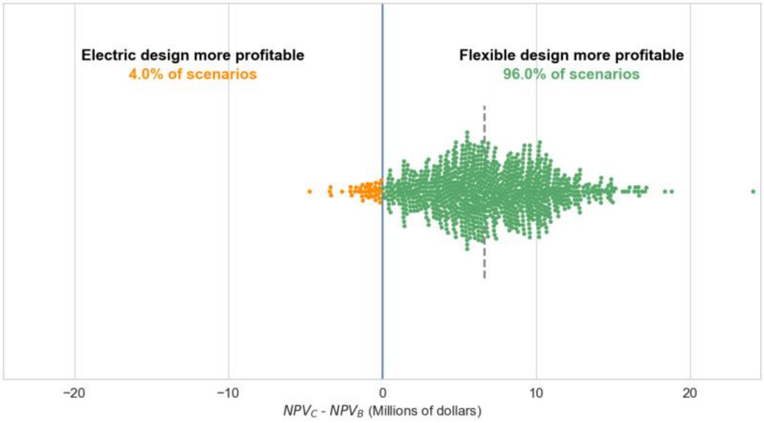
The flexibility option always wins!

Results



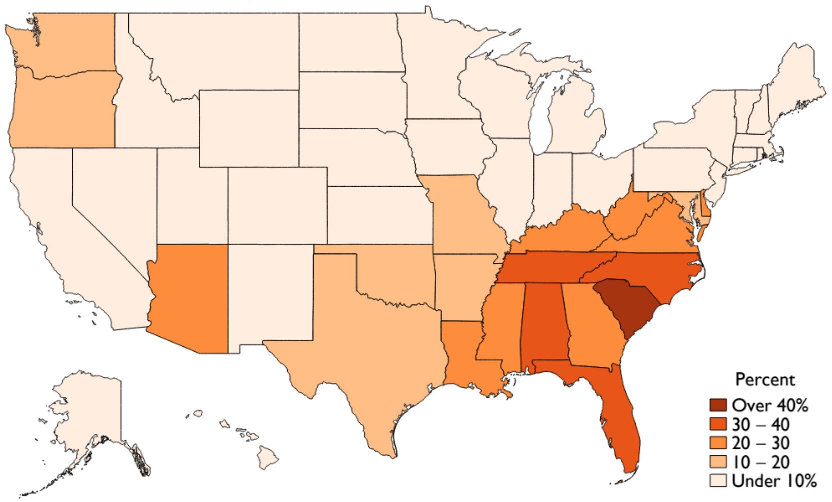


Each point represents the **difference in NPVs** of two design options in **one scenario**



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

Residential sector:
Where are today's residential heat pumps cost effective?



Heat Pump Adoption Rates by State

Davis, L. W. (2023). *The Economic Determinants of Heat Pump Adoption* (No. 31344). National Bureau of Economic Research. https://doi.org/10.3386/w31344

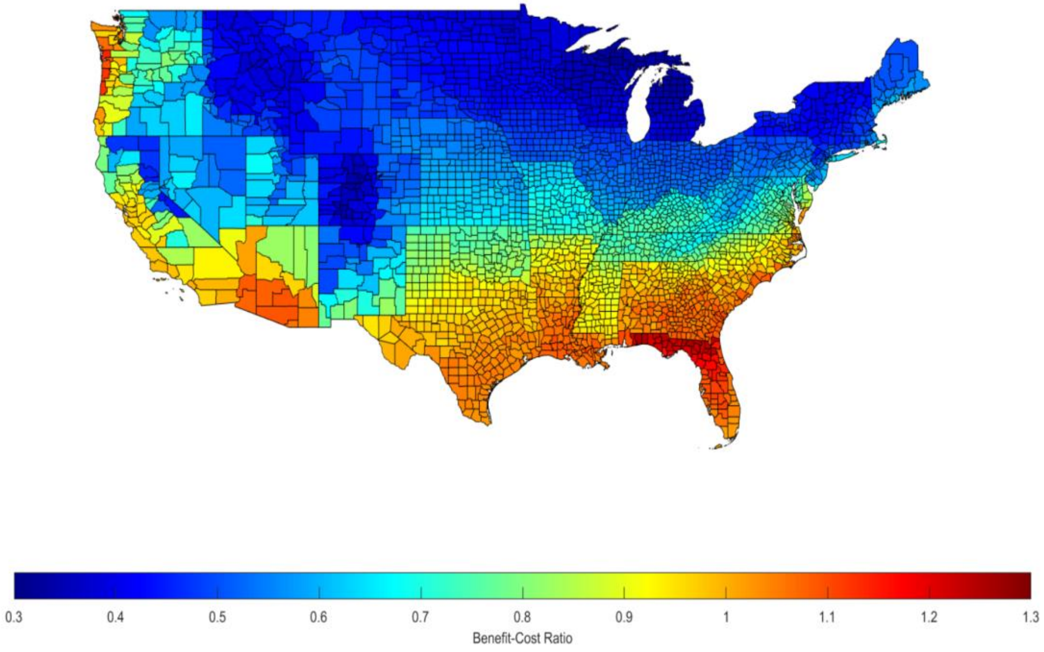


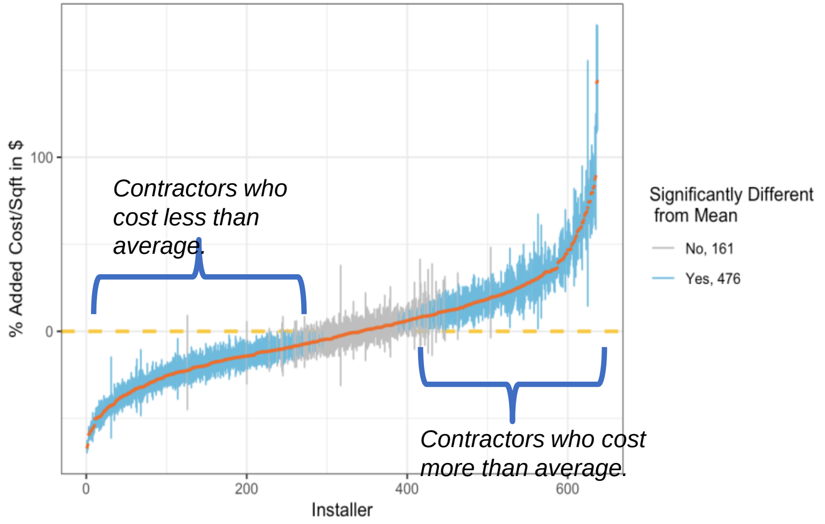
Figure 2 Benefit-cost ratio of an air-source heat pump with an electric resistance heating backup compared to a central AC with a natural gas furnace.

Benefit-cost ratio of (heat pump + backup heating) compared to (AC + natural gas heating)

Johnson, B., & Krishnamoorthy, S. (2021). Where are Today's Residential Heat Pump Technologies Cost-Effective?. *ASHRAE Transactions*, 127(1).

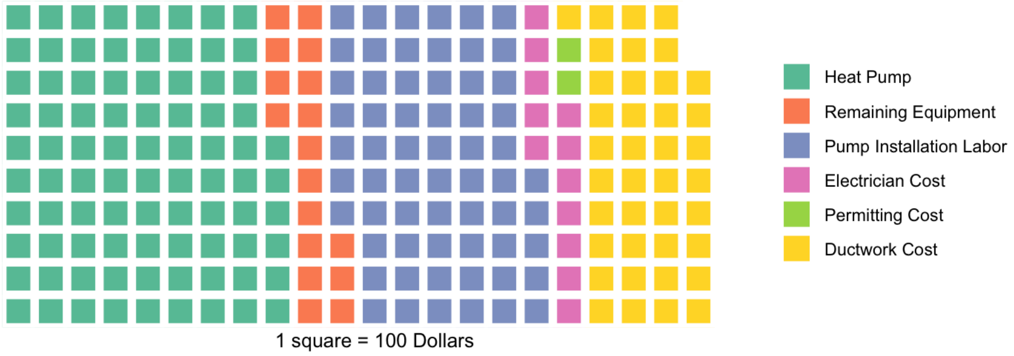
Further challenge: shortage of qualified contractors

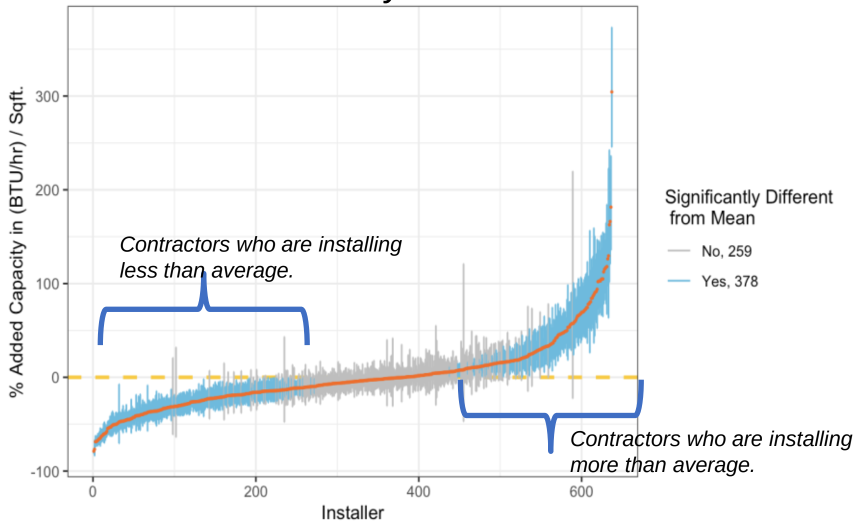
- Global demand for heat pump installers requires over 1.3 million workers by 2030, nearly triple the current amount, raising the potential for skilled labor shortages, especially for installers.
- Lack of heat pump installation skills lead to vast variations of total cost and installed capacity (MassCEC, MA homes that installed heat pumps in 2014-2019)



Total cost variation by contractor

Mean Costs of Heat Pump Installation w/ Ductworks





Installed capacity variation by contractor

Knittel, C., Ontiveros, J., Palacios, J. & Zheng, S. (2024). Learning by doing: Contractors' Learning in Heat Pump Installations. *Working Paper.*

Controlling for: MOY, Year; Footage; Zillow value; Current Fuel Source; Num Heat Pump Units; Installed Capacity; Retrofit; Year Built; Home Type; Town; Bedrooms; Bathrooms; Number of Previous Installations

Learning effect on cost and capacity

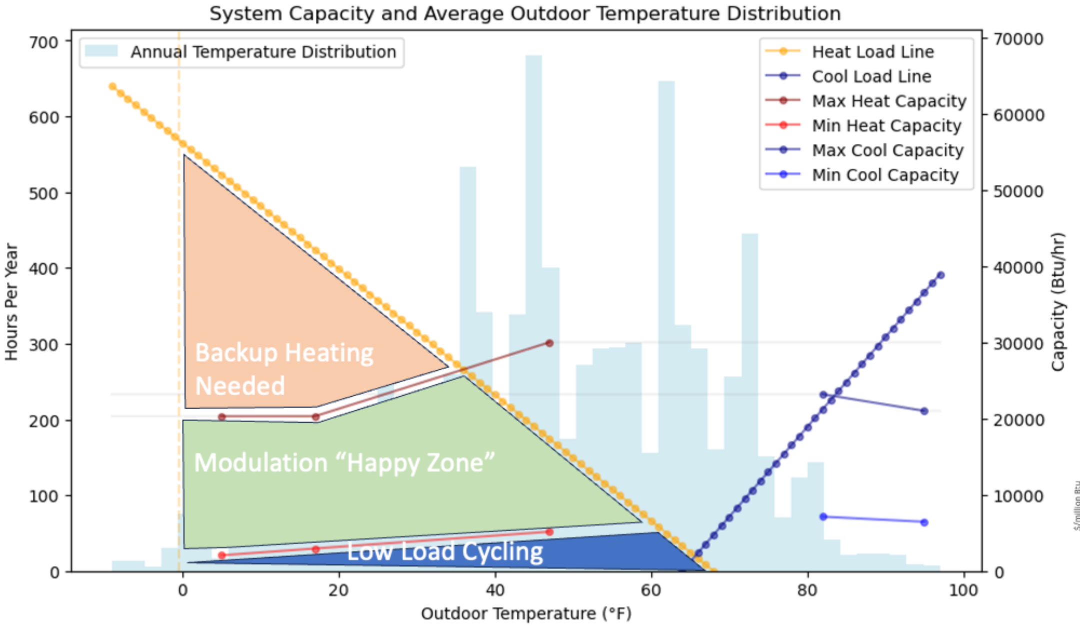
- As contractors install more heat pumps, they are reducing the size of the systems.
  - Interpretation: for every doubling in experience, contractors are downsizing systems by 2.3%.
- A large amount of cost is described through the sizing of the system.
  - Larger system = higher total cost.
- Learning leads to installation behavior shifts, but is it going to the right direction?

Knittel, C., Ontiveros, J., Palacios, J. & Zheng, S. (2024). Learning by doing: Contractors' Learning in Heat Pump Installations. *Working Paper*.

Table 3: Relationship between installer experience, installed capacity, and installation costs

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
	(A) Installed Capacity Models				
Ln(Number Past Installations)	-0.026**	-0.029**	-0.031**	-0.033***	-0.033***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
DF Residuals	13,503	13,017	12,992	12,990	12,990
R-Squared	0.27	0.33	0.36	0.36	0.36
	(B) Total Cost of Installation Models				
Ln(Number Past Installations)	-0.011	-0.018	-0.020	-0.021	0.011
	(0.013)	(0.014)	(0.014)	(0.014)	(0.0072)
Ln(Installed Capacity)	-	-	-	-	0.94***
					(0.0093)
DF Residuals	13,503	13,017	12,992	12,990	12,989
R-Squared	0.34	0.38	0.4	0.4	0.84
	Controls				
Installer FEs	Yes	Yes	Yes	Yes	Yes
Year Installed FEs	Yes	Yes	Yes	Yes	Yes
Month Installed FEs	Yes	Yes	Yes	Yes	Yes
Hedonic Controls	Yes	Yes	Yes	Yes	Yes
Town FEs	No	Yes	Yes	Yes	Yes
Previous Heating Controls	No	No	Yes	Yes	Yes
Heat Pump Brand	No	No	No	Yes	Yes

Trade-offs: private benefit vs. environmental benefit



Finding the right size with National Renewable Energy Laboratory (NREL)' ResStock tool

Comparison of learning effect across outcomes

	(1) Ln(Total Cost)	(2) Backup Hours	(3) Modulation Hours	(4) Ln(Backup/ Mod Ratio)
Ln(Number Past Installs)	-0.024** (0.012)	56.46* (33.49)	-22.70 (22.48)	0.053** (0.022)
Observations	12844	11424	11424	11424

Downsizing comes at the cost of of using the backup heat source more hours out of the year.

What might explain this behavior in downsizing?

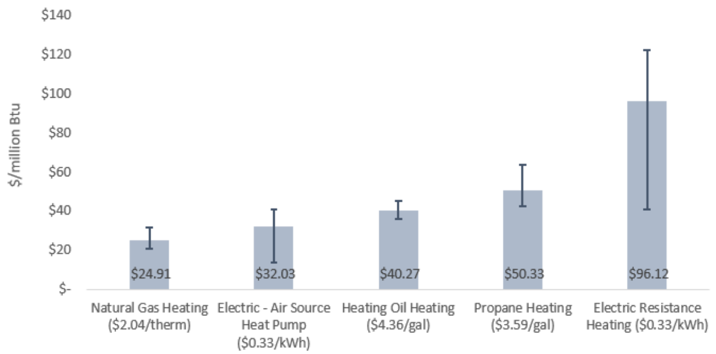
Knittel, C., Ontiveros, J., Palacios, J. & Zheng, S. (2024). Learning by doing: Contractors' Learning in Heat Pump Installations. *Working Paper.*

Trade-offs: private benefit vs. environmental benefit

	(1) All Types	(2) Natural Gas	(3) Oil	(4) Other
	(A) Outcome: Installed Capacity			
Ln(Number Past Installations)	-0.031*** (0.012)	-0.045** (0.021)	-0.026 (0.016)	-0.014 (0.031)
Observations	12825	4409	5001	2025
R-Squared	0.36	0.79	0.76	0.90
	(B) Outcome: Installation Cost			
Ln(Number Past Installations)	-0.021 (0.014)	-0.046** (0.021)	-0.0076 (0.020)	-0.0081 (0.033)
Observations	12825	4409	5001	2025
R-Squared	0.41	0.80	0.78	0.91

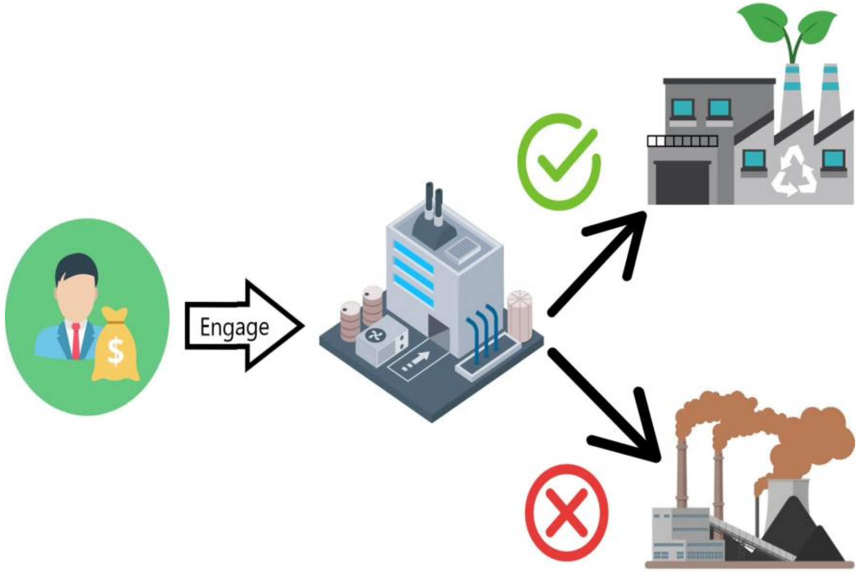
Knittel, C., Ontiveros, J., Palacios, J. & Zheng, S. (2024). Learning by doing: Contractors' Learning in Heat Pump Installations. *Working Paper.*

Natural gas is the cheapest source of heat, followed by electricity for heat pumps.
Keeping natural gas heating as the backup has a clear private benefit, with potential environmental cost.
Aligning private benefit and environmental benefit with technological advances is important and possible.



Average Cost to Produce Heat this Winter (2023/24) for Different Technologies, Source: MassGov DOER

ESG push from the capital market: sustainable engagement



Van der Kroft, B., Palacios, J., Rigobon, R., & Zheng, S. (2024). *Timing sustainable engagement in real asset investments* (No. w32646). National Bureau of Economic Research.

- S&P 1500 firms 14,689 times engaged from 2006 to 2022
- 58% Governance; 42% Environmental & Social topics
- Shareholder engagement affects financials (Dimson, Karakas, & Li, 2015) and is correlated with CO2 level reductions (Bauer, Derwall,& Tissen, 2022)
- Hedge fund activism (Akey & Appel, 2019) and Boardroom Accountability Project (Naaraayanan, Sachdeva, & Sharma, 2021) reduced pollution in US manufacturing plants
- Challenge in identification: endogenous selection in targets
    - Both profitable and environmental improvements?
    - Investors have limited engagement personnel (Bebchuk, Cohen, Hirst, 2017)
    - Impact optimization through target selection - target low-hanging fruits
    - Economic rationale: Investors selectively engage, imposing a positive selection bias on the impact of engagement.

Engagement Process: Shareholder Proposal

SHAREHOLDER PROPOSALS

UNITED STATES
SECURITIES AND EXCHANGE COMMISSION
WASHINGTON, D.C. 20549

SCHEDULE 14A

PROXY STATEMENT PURSUANT TO SECTION 14(a) OF THE SECURITIES EXCHANGE ACT OF 1934
(AMENDMENT NO.)

Filed by the Registrant ☒ Filed by a Party other than the Registrant ☐

Check the appropriate box:

☐ Preliminary Proxy Statement

☐ **Confidential, for Use of the Commission Only (as permitted by Rule 14a-6(e)(2))**

☒ Definitive Proxy Statement

☐ Definitive Additional Materials

☐ Soliciting Material under §240.14a-12

SHAREHOLDER PROPOSALS

ITEM 11—SHAREHOLDER PROPOSAL REQUESTING A REPORT ON CERTAIN COMMUNITY IMPACTS

Beginning of Shareholder Proposal and Statement of Support:

WHEREAS:

"Environmental racism" occurs when pollution is disproportionately concentrated in communities of color. "Environmental justice" occurs when pollution is borne equitably across communities regardless of their racial profile.

Popular and governmental attention to environmental justice increased in 2019:

- **First Presidential forum held on environmental justice** (https://www.theguardian.com/environment/2019/nov/09/warren-booker-environmental-justice-forum-south-carolina)
- **Senator Cory Booker introduced "The Environmental Justice Act of 2019" and co-founded an "Environmental Justice Caucus" within the Senate** (https://www.booker.senate.gov/?p=press_release&id=966)
- **House Natural Resources Committee Chair Raul Grijalva and Rep. McEachin began a process to draft an environmental justice bill** (https://naturalresources.house.gov/media/press-releases/chair-grijalva-rep-mceachin-launch-historic-effort-to-draft-environmental-justice-bill-based-on-public-feedback-at-environmental-justice-convening)
- **California passed Assembly member Robert Rivas's environmental justice bill** (https://a30.asmdc.org/press-releases/20190912-state-legislature-approves-assemblymember-robert-rivas-environmental-justice)
- **A New School report counted 40 local policies aimed at achieving environmental justice** (https://static1.squarespace.com/static/5d14dab43967cc000179f3d2/t/5d5c4bd0e1d5150001a5a919/1566329811163/NRDC_FinalReport_04.15.2019.pdf).

Evidence suggests Amazon's logistics operations may have an environmentally racist impact. Beyond carbon dioxide which drives climate change, diesel trucks also emit other dangerous substances:

- **Nitrogen dioxide and microscopic particles permanently stunt lung development in children.** (https://www.citylab.com/environment/2019/04/air-pollution-data-health-effects-child-asthma-choked-book/587545/)
- **Heat causes nitrogen oxides to combine with volatile organic compounds to become ozone. Ozone causes breathing problems and premature death.** (https://www.lung.org/our-initiatives/healthy-air/outdoor/air-pollution/ozone.html)

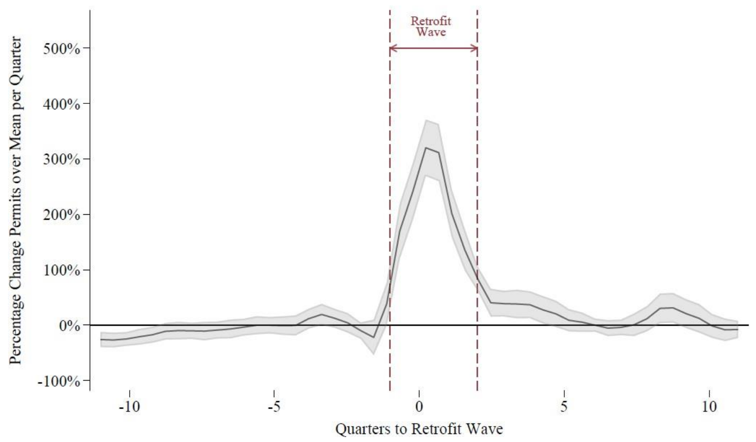
San Bernardino, California is a major logistics hub for Amazon and has some of the worst air quality in the country. Children in this region have many

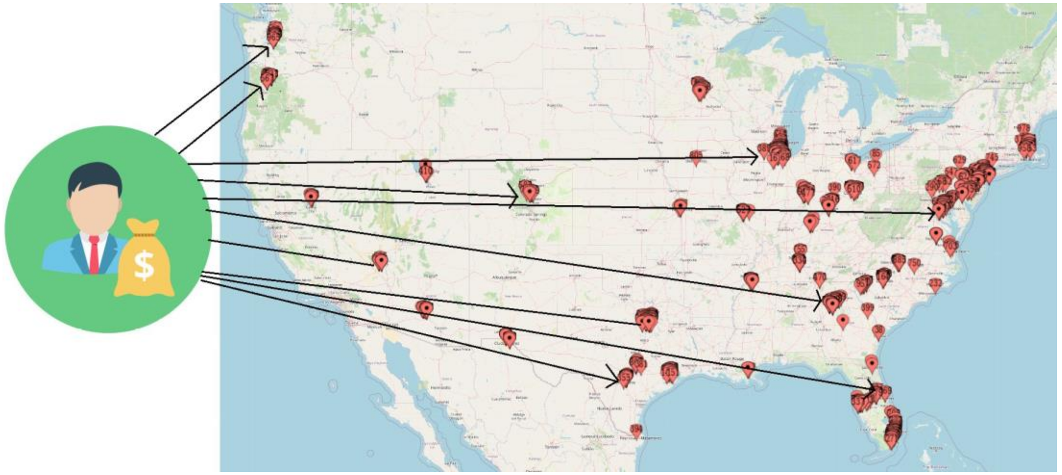
Van der Kroft, B., Palacios, J., Rigobon, R., & Zheng, S. (2024). *Timing sustainable engagement in real asset investments* (No. w32646). National Bureau of Economic Research.

Real estate: engagement timing exogenous of retrofit waves

- We have the entire sample of 207 REITS in the US, with combined marketcap of $1.3 trillion. We exact each building's attributes from CoStar %SNL, 1990-2023, in total 61,870 properties
- We also collect all US building new construction and retrofit permits., 1990-2022.
- Investors do not know the exact physical depreciation rhythms and thus the retrofit timing for each building, they also face legal constraints (SEC regulations) for engagement timing.

Figure 5: Timing of retrofit waves





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Right-timing engagements boost sustainable performance

$$\text{Sustainable retrofits } (\%)_{i,t} = \alpha + \beta_1 * \text{Sustainable Engagement}_{i,t} + \beta_2 * \text{Retrofit Wave}_{i,t} + \\ + \beta_3 * \text{Sustainable Engagement}_{i,t} * \text{Retrofit Wave}_{i,t} + \gamma_{i,t} + \psi_i + \psi_t + \varepsilon_{i,t} \quad (1)$$

Table 4: Sustainable engagement, sustainable investments, and physical depreciation

	Share sustainable permits (%)			
VARIABLES	(1)	(2)	(3)	(4)
Sustainable Engagement	-1.223	-4.992***		
	(4.781)	(0.656)		
Wave X Sustainable Engagement		9.902***		
		(1.323)		
Sustainable Engagement successful			-3.191***	
			(0.919)	
Wave X Sustainable Engagement successful			17.528***	
			(1.136)	
Sustainable Engagement unsuccessful				-5.631***
				(0.661)
Wave X Sustainable Engagement unsuccessful				-0.961
				(4.671)
Wave	-0.190	-0.243**	-0.385**	-0.208***
	(0.124)	(0.113)	(0.128)	(0.095)
Average share sustainable permits (%)	21.71	21.71	21.71	21.71
Marginal Effects: Sustainable Engagement during wave (%)	-	4.67	13.95	-6.80
Observations	3,076	3,076	3,025	3,025
Adjusted R-squared	0.162	0.162	0.163	0.166
REIT controls	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
REIT fixed effects	YES	YES	YES	YES

Past returns, size, leverage, net income, revenue. REIT and quarter fixed effects and clustered s.e.

Van der Kroft, B., Palacios, J., Rigobon, R., & Zheng, S. (2024). *Timing sustainable engagement in real asset investments* (No. w32646). National Bureau of Economic Research.

Thank You!
Questions?