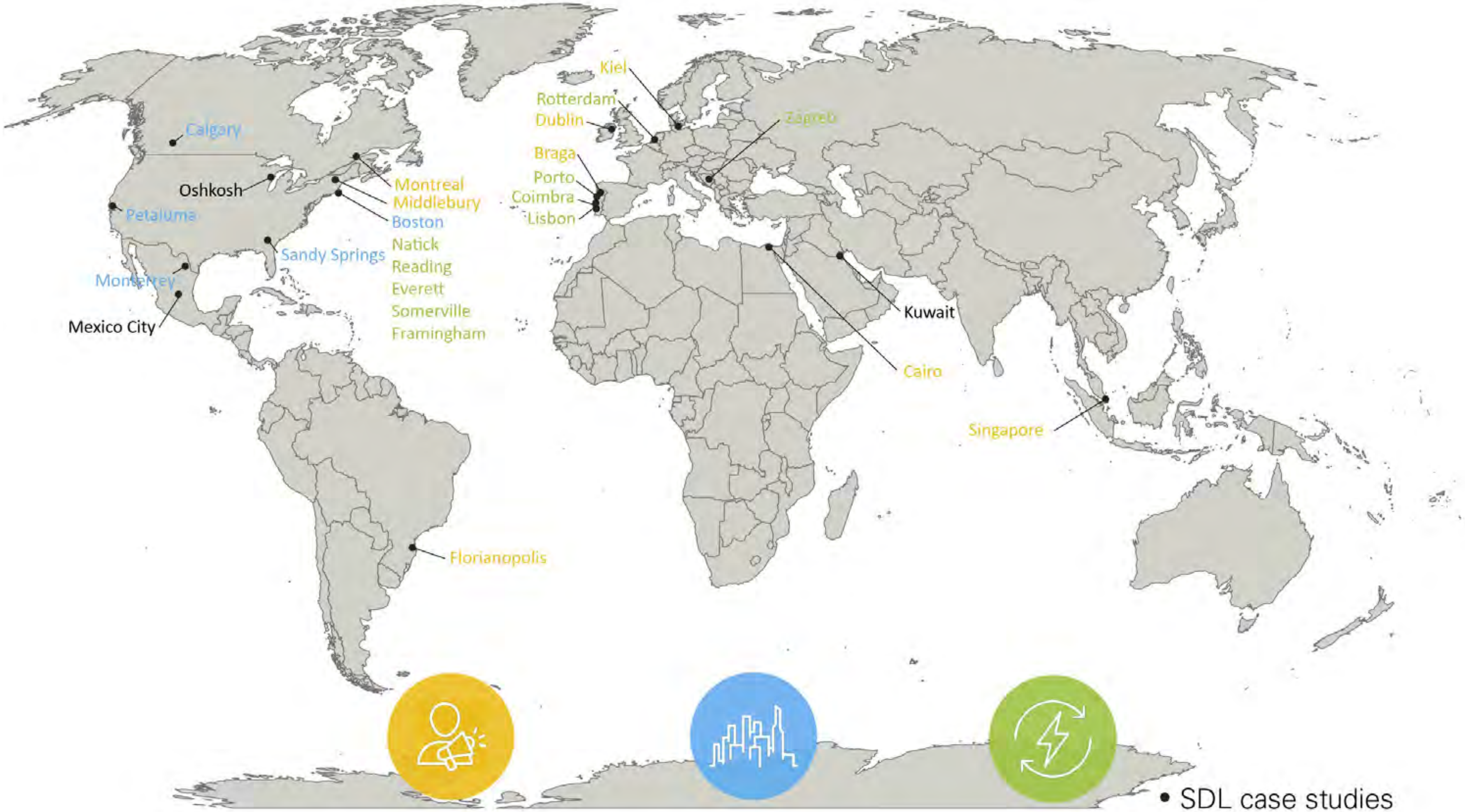
Carbon Reduction Strategies For Cities



Christoph Reinhart

International Building Physics Conference Toronto, July 25 2024

MIT SUSTAINABLE DESIGN LAB

MIT SUSTAINABLE DESIGN LAB

SOLEMMA

Christoph Reinhart MIT Sustainable Design Lab Khadija Benis + Ata Chokhachian + Ali Irani + Cody Rose+ Nada Tarkhan + Ben Taube + Sam Wolk Solemma Demi Chang + Timur Dogan + Alstan Jakubiec + Violetta Jusiega + Violeta Lialios-Buwman +Jeff Niemasz + Brandon Pachuca + Jon Sargent SDL/G(SD)^2 Alumni Yu Qian Ang + Alpha Arsano + Jamie Bemis + Zack Berzolla + Carlos Cerezo + Lukas Debiasi + Zoe De Simone + Timur Dogan + Karthik Dondeti + Jay Dhariwal + Jamie Farrell + Elliot Glassman + Jeff Geisinger + Jared Hanson + Svenja Herb + Seth Holmes + Diego Ibarra + Alstan Jakubiec + Nathaniel Jones + Amanda Kirkeby + Cynthia Kwan + Kera Lagios + Zoe Le Hong + Sam Letellier-Duchesne + Mariana Liebman-Pelaez + Rohit Manudhane + Rashida Mogri + Lauren Moore + Azadeh Omidfar + Aiko Nagano + Shreshth Nagpal + Debashree Pal + Krista Palen + Tiffany Otis + Tarek Rakha + Ellen Reinhard + Cody Rose + Holly W Samuelson + Manos Saratsis + Tristan Searight + Devon Sparks + Julia Sokol + Leilah Sory + Jiamin Sun + Jennifer Sze + John Sullivan + Bradley Tran + Irmak Turan + Ramon Weber + Elizabeth Young

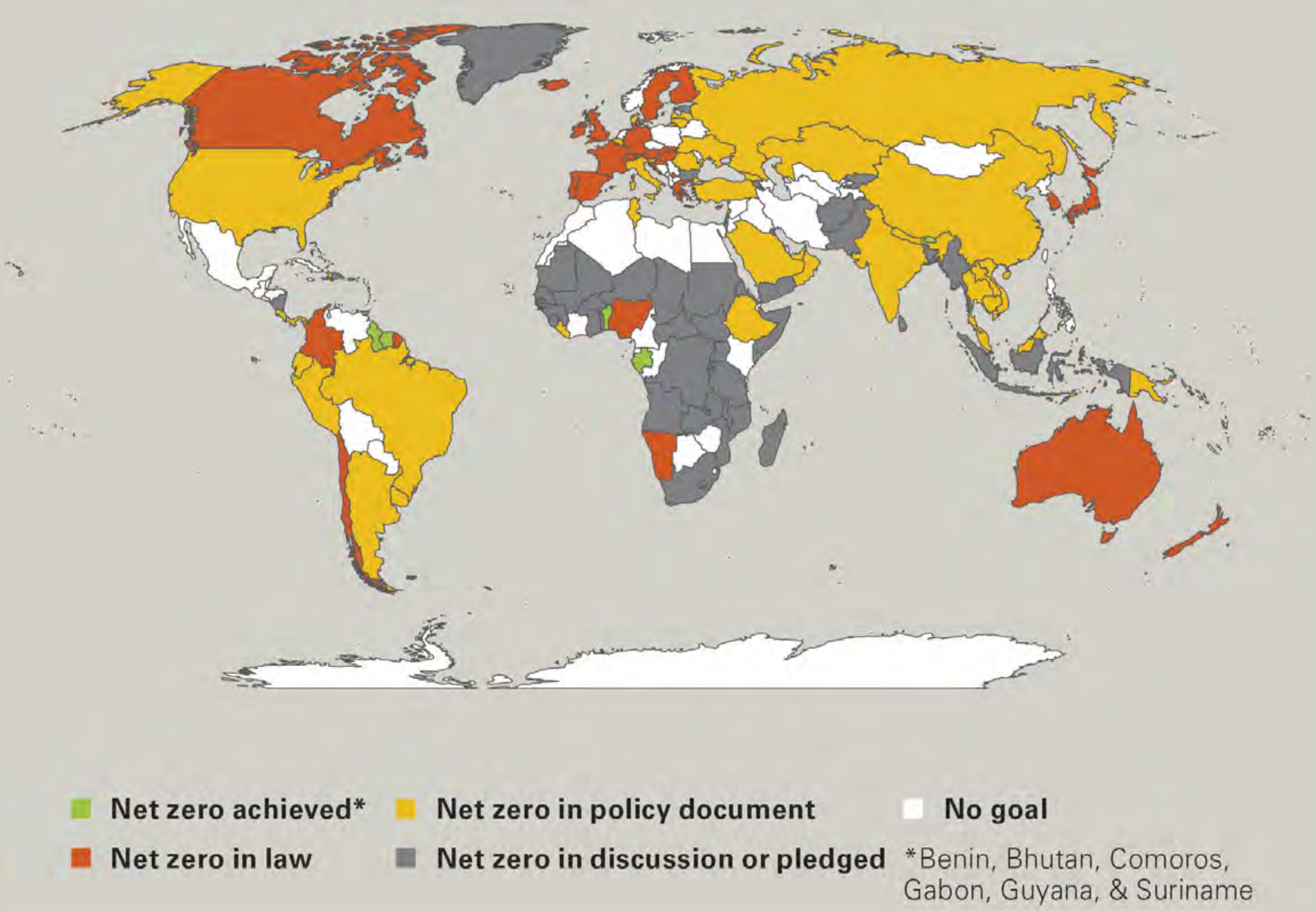
We develop design workflows, planning tools and metrics for education and practice to evaluate the environmental performance of buildings and neighborhoods. Our expertise lies in computational Environmental Performance Analysis.

SDL's Goal

To use building technology concepts to support an equitable global energy transition.

Carbon Neutrality Goals by Country

Figure: Climate Driven Design I



- ❑ In April 2024, 148 countries representing 90% of the world's population and GDP achieved, committed or proposed to fully decarbonize their economies by 2070

April 2024; Data sources: Energy and Climate Intelligence, Carbon Neutrality Coalition, Climate Action Tracker

What are the drivers behind these unprecedented goals?

Changing Societal Attitudes

Survival - Coastal Cities are disappearing

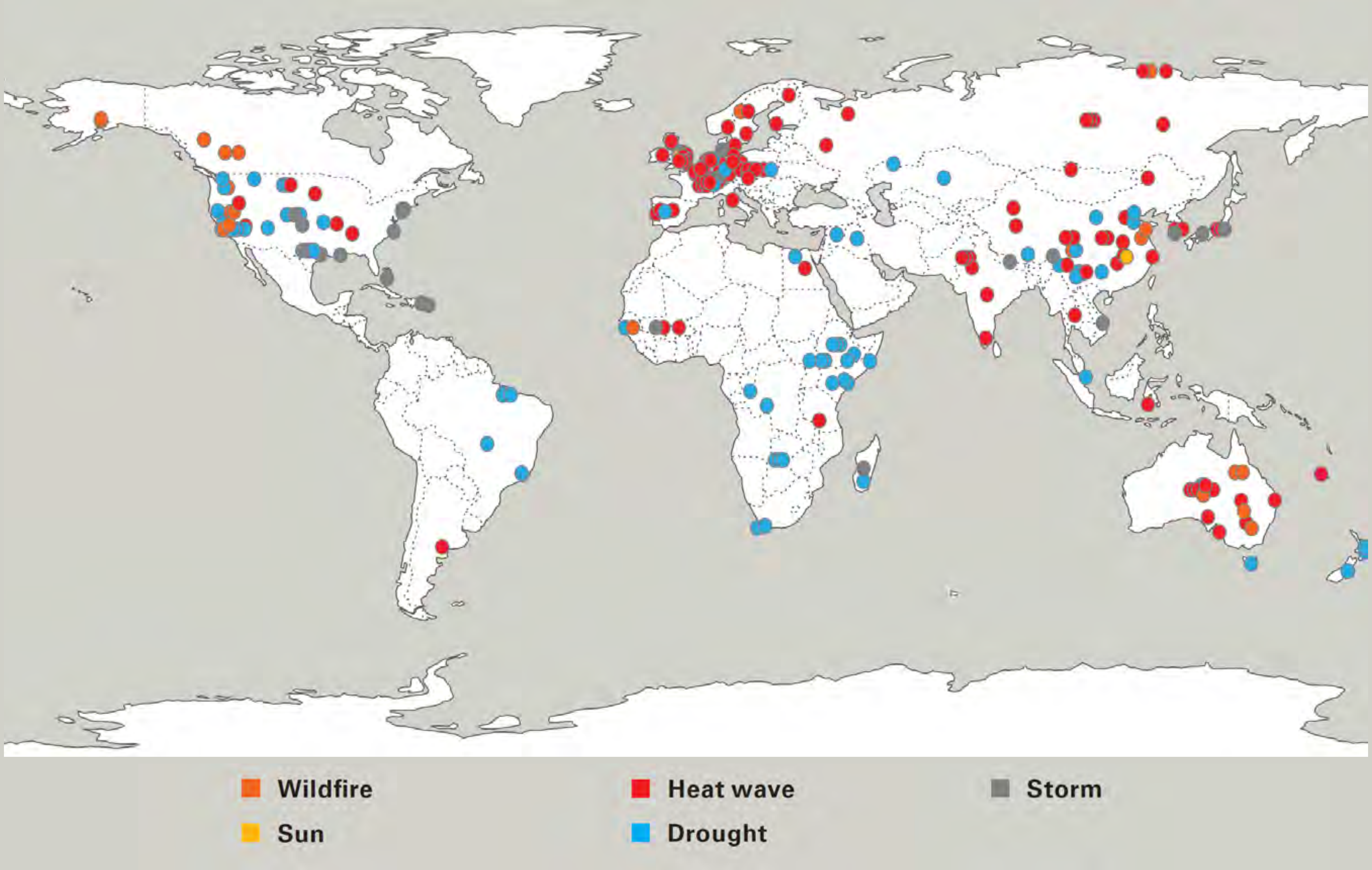
Source: May 2023 The New York Times

More frequent extreme weather events

Source: Flooding in Toront, July 2024, https://www.reuters.com/world/americas/torrential-rains-flood-toronto-causing-power-outages-traffic-disruption-2024-07-16/

Extreme Weather Events between 1950 and 2020

Figure: Climate Driven Design I



- 92% of events happened during the last out of seven decades

Data sources: U.S. National Oceanic and Atmospheric Administration (NOAA)

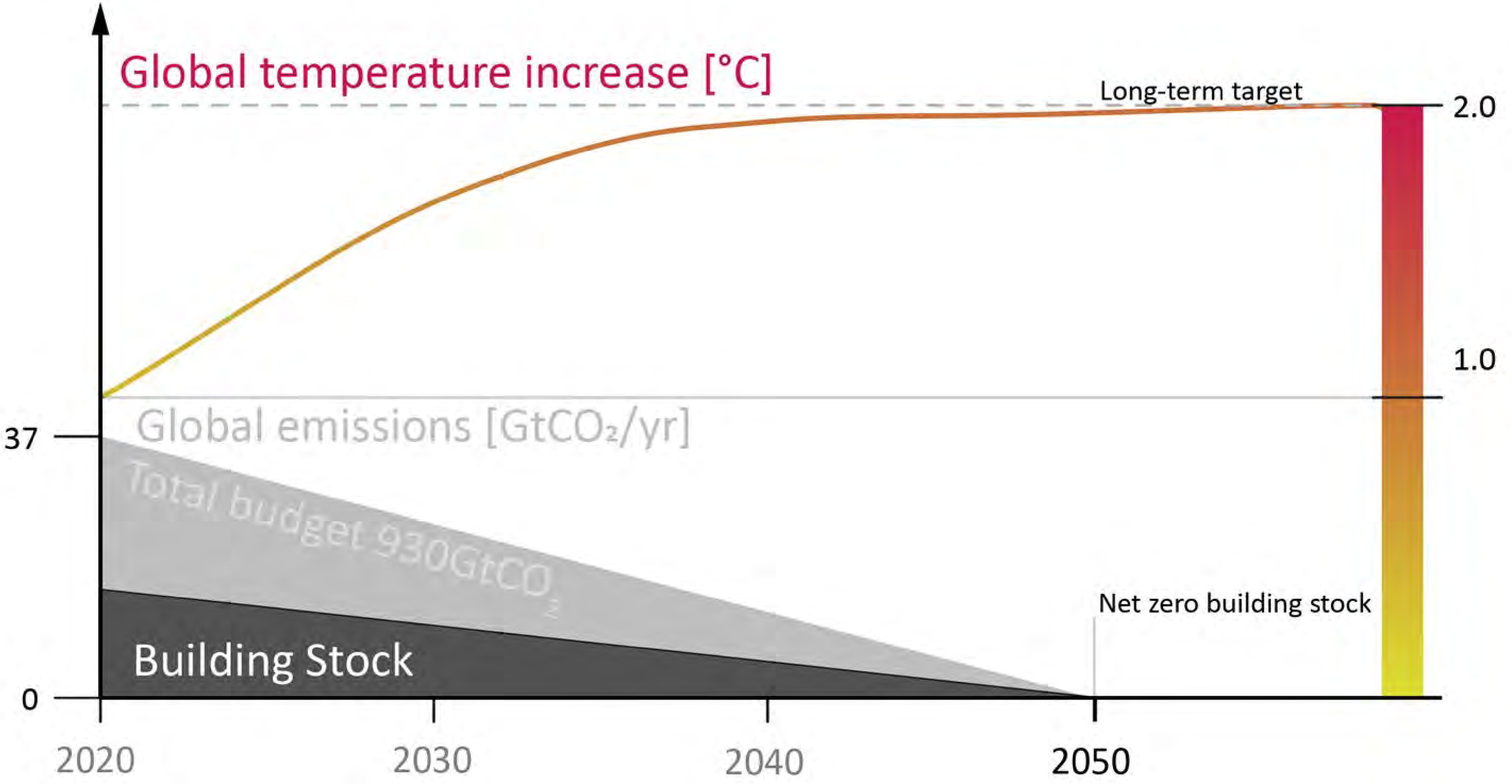
Changing Geopolitical Realities

IEA Ten Point Plan (March 2022)

1. No new gas supply contracts with Russia.
2. Replace Russian supplies with gas from alternative sources
3. Introduce minimum gas storage obligations
4. Accelerate the deployment of new wind and solar projects
5. Maximize power generation from bioenergy and nuclear
6. Enact short-term tax measures
7. Speed up the replacement of gas boilers with heat pumps
8. Accelerate energy efficiency improvements in buildings
9. Encourage a temporary thermostat reduction of 1 °C
10. Diversify and decarbonize sources of power system flexibility

Sources https://www.iea.org/news/how-europe-can-cut-natural-gas-imports-from-russia-significantly-within-a-year; https://www.nytimes.com/2022/02/22/business/nord-stream-russia-putin-germany.html

Climate Change and the Building Sector



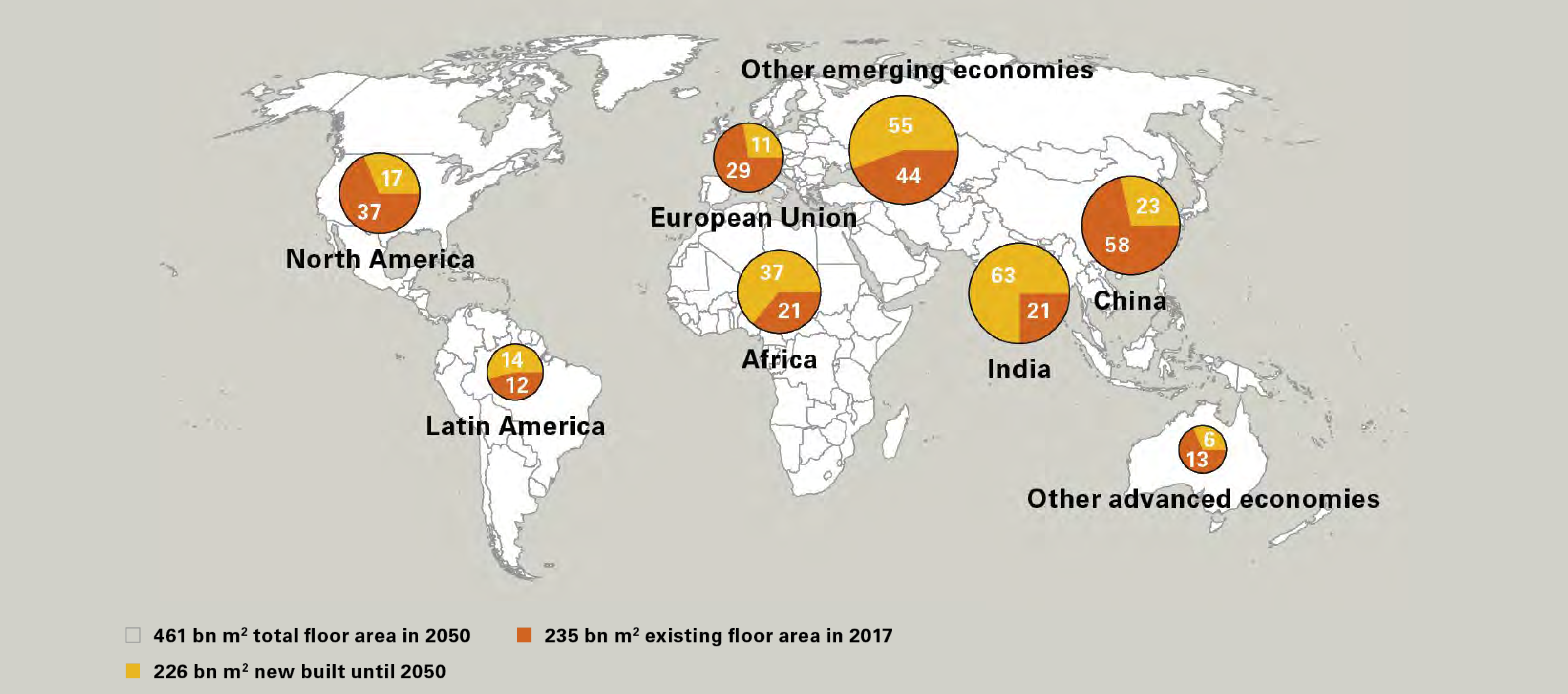
R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

Our Challenge

We have 340 $GtCO_2$ and 30 years left to make the global building stock carbon neutral.

The building stock is projected to double by 2050

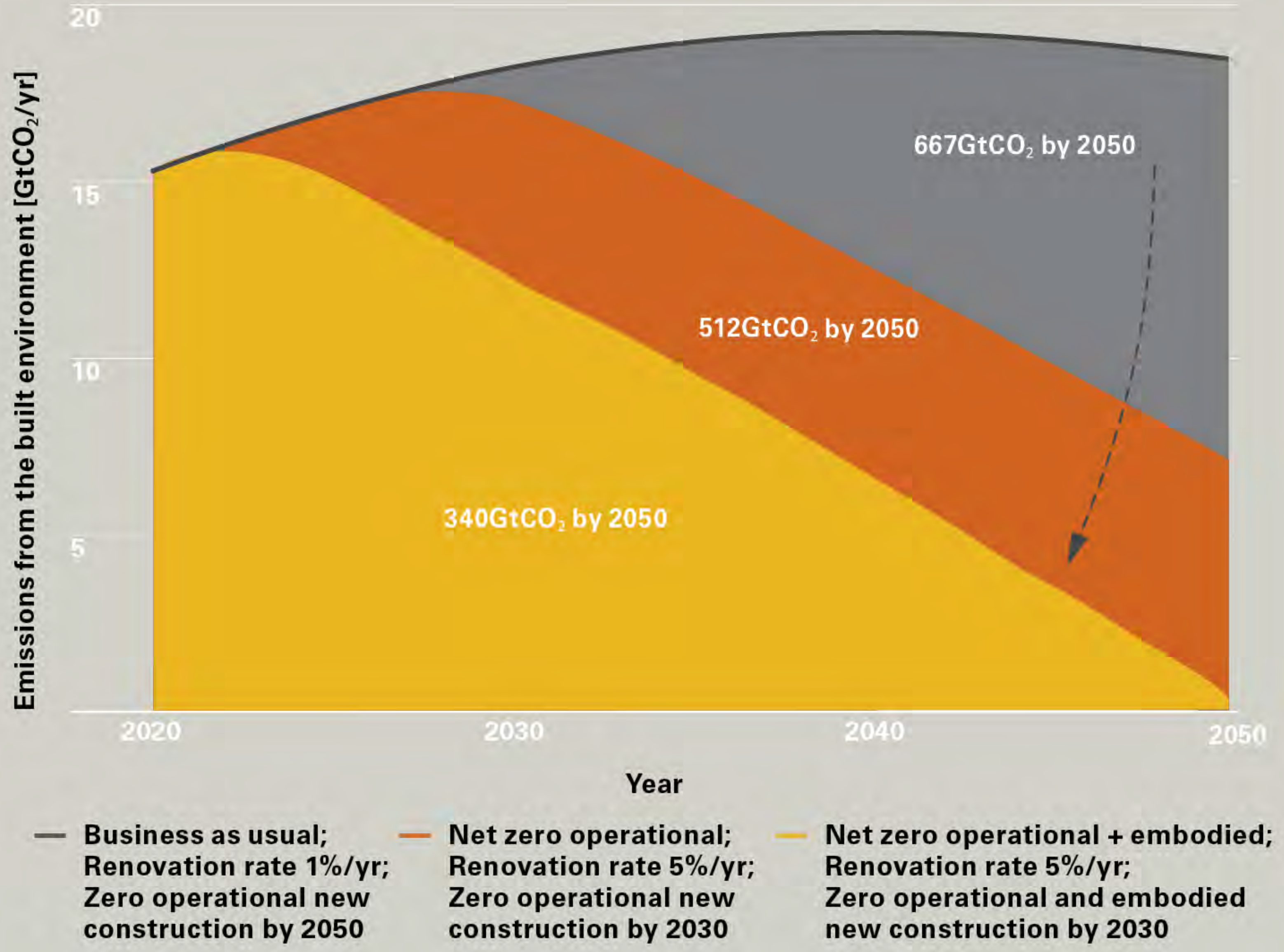
Figure: Climate Driven Design I



R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

Total annual carbon emissions from buildings

Figure: Climate Driven Design I



R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

Our goals for 2030

- ❑ Increase annual retrofitting rate to 5%
- ❑ All new construction is carbon neutral
- ❑ More efficient space use.

What technology pathways lead to net zero retrofits?

Case Study - New England Home

- ❑ Detached single-family 1350ft² home in Boston, constructed during the 1920s.
- ❑ How can our residents get to net zero while living in the house?

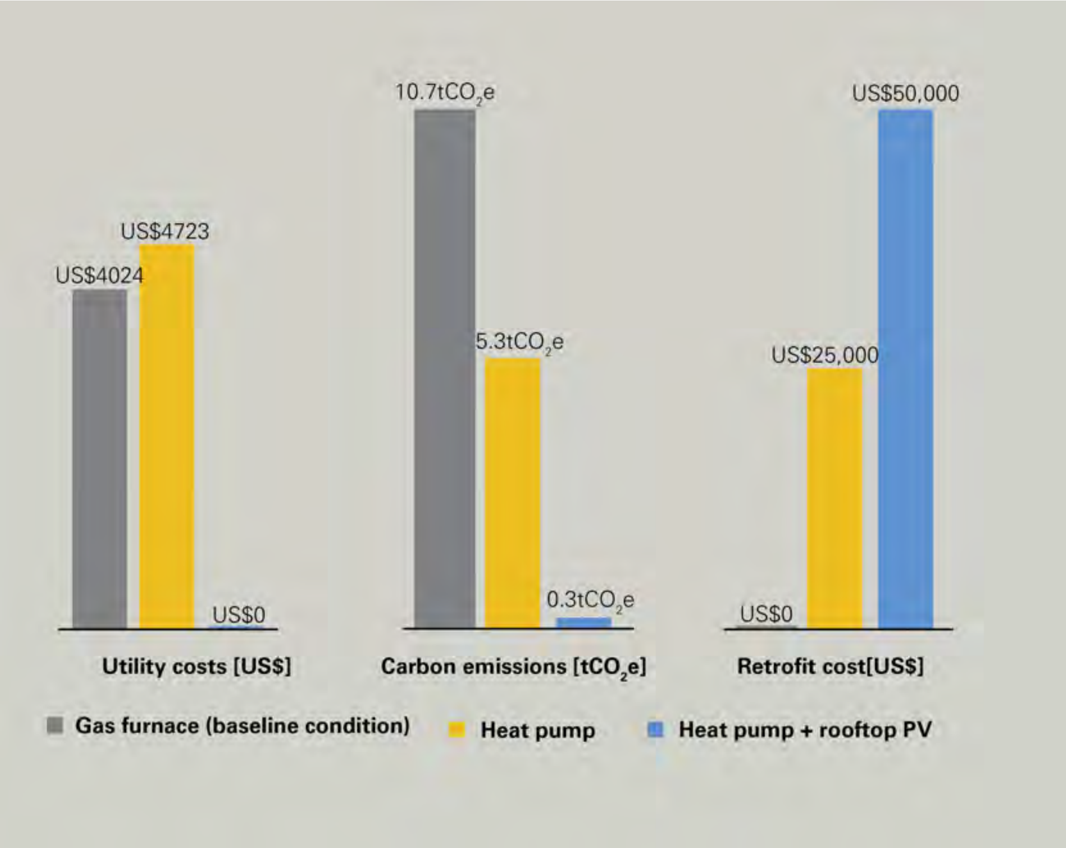
Scenario 1: Going "All electric"

Rooftop PV

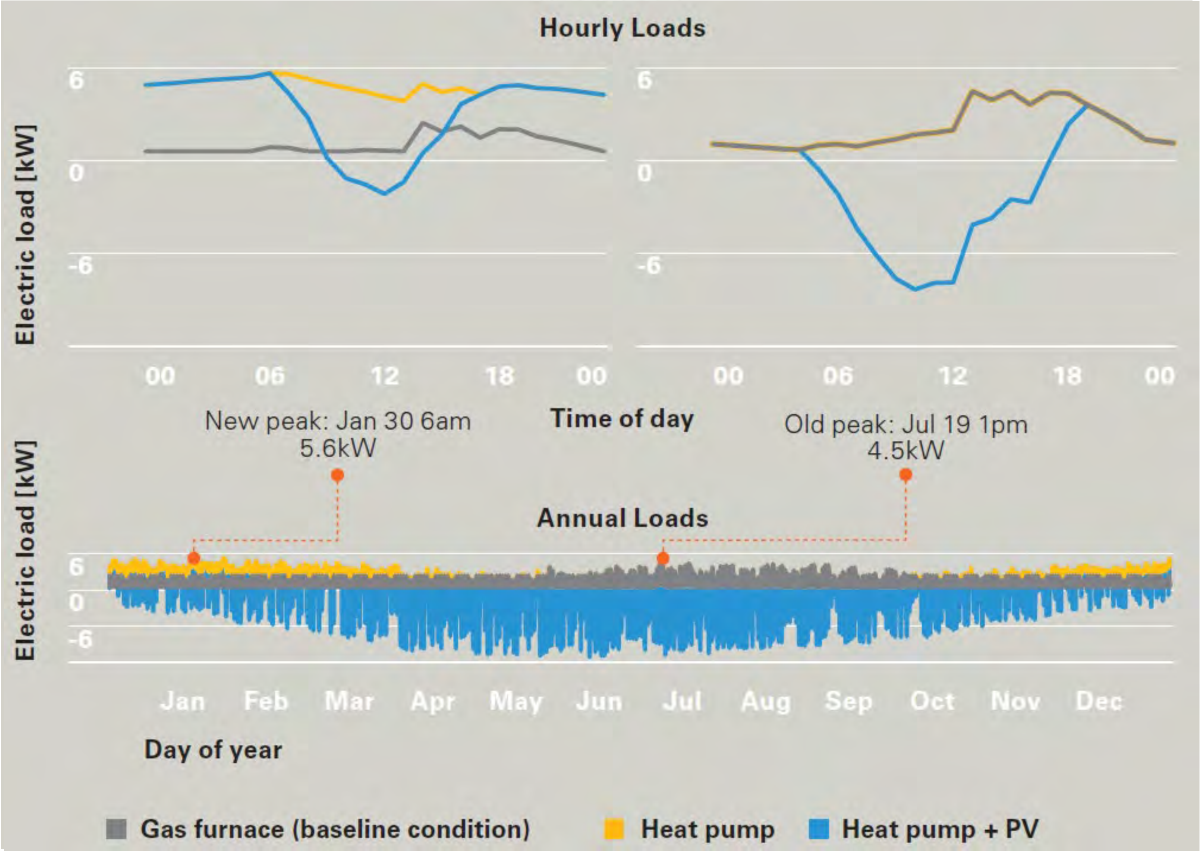
Air Source Heat Pump

Scenario 1: Going "All electric"

Owner perspective



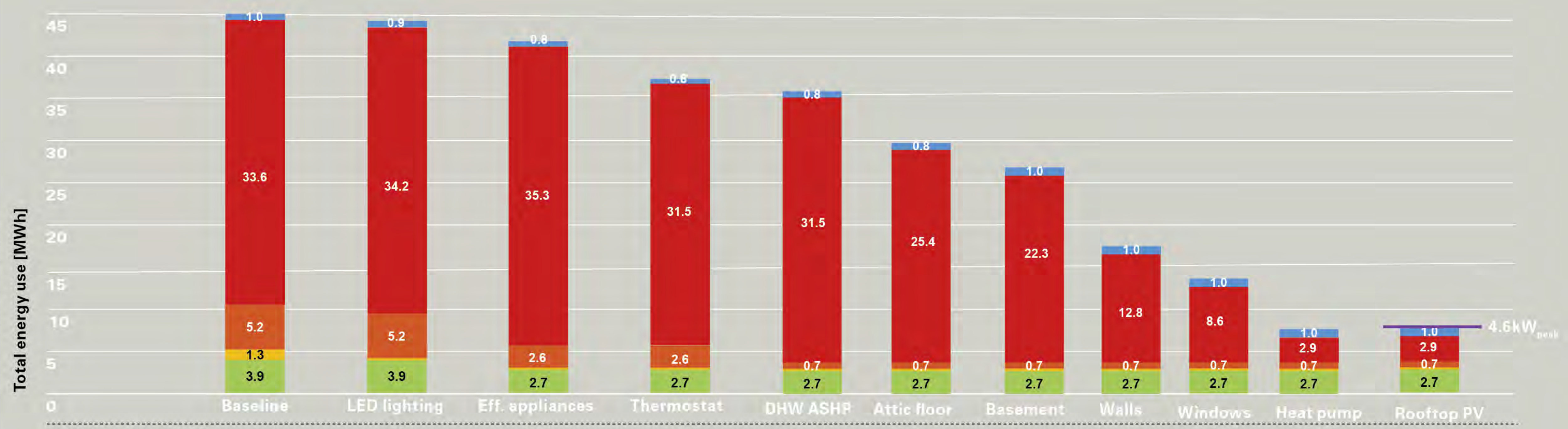
Utility perspective



- ❑ Heat pump only has negative payback.
- ❑ Heat pump + rooftop PV pays for itself in 12 years buts uses the grid as a free battery.

- ❑ Installing a heat pump increases the peak by 25%
- ❑ Peak reductions if on-site storage is installed.

Scenario 2: Deep Retrofit + HP + PV



	Baseline	LED lighting	Eff. appliances	Thermostat	DHW ASHP	Attic floor	Basement	Walls	Windows	Heat pump	Rooftop PV
Total upgrade cost [US$]	-	0*	1050	1150*	2000	2935	5320	19,320	26,900	44,900	61,400
Utility Cost [US$/yr]	4024	3806	2961	2786	2361	2095	2008	1609	1424	3488	0
Emissions [tCO_2e]	10.7	10.6	9.7	8.9	8.4	7.0	6.4	4.2	3.2	0.3	0.3
Overall payback [yr]	-	0	1	1	2	2	2	7	10	85	15

*) after rebate

Cooling | Heating | Hot Water
Lighting | Equipment

- ❑ A longer payback time but a future-proof and comfortable home.
- ❑ We need to conduct a comparable analysis for every building in the world.

Figure: Climate Driven Design I (C Reinhart)

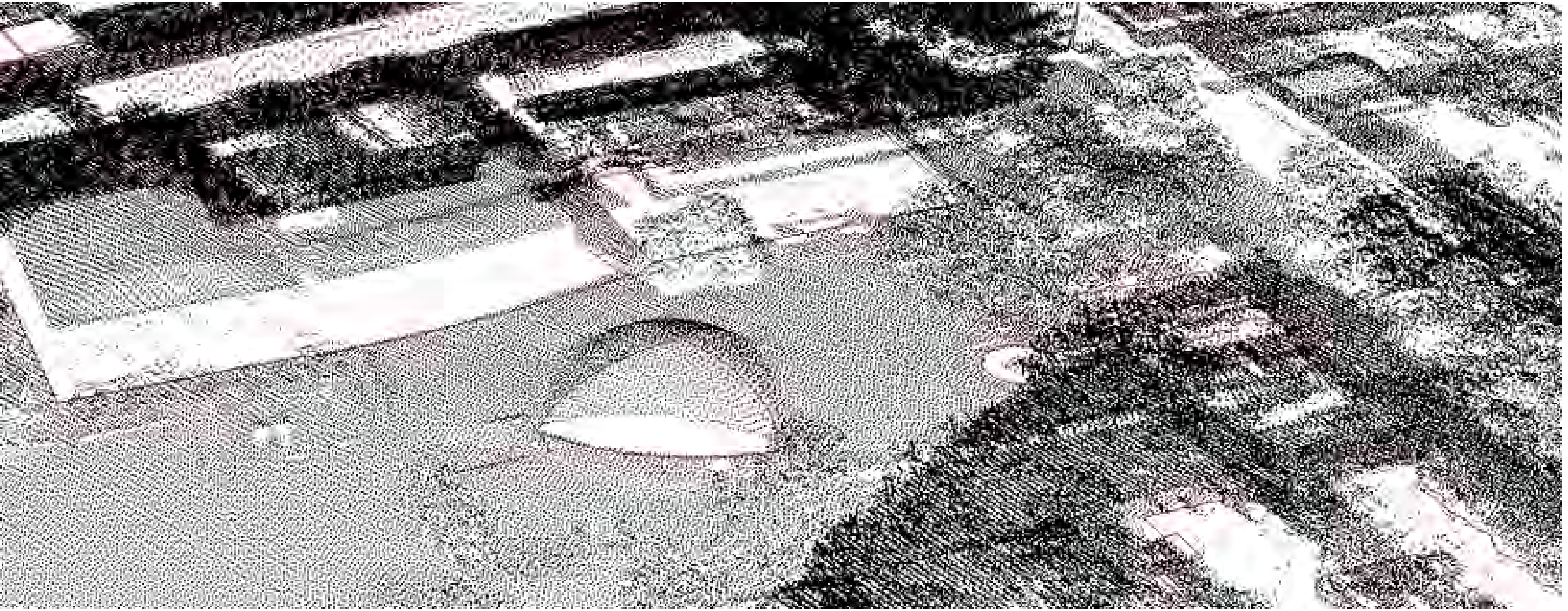
How can city governments convince their constituents to energy retrofit/add PV to their homes?

Modeling Rooftop PV Potential

Photo of the MIT Campus (Google Maps)

A Jakubiec and C F Reinhart, 2013, "A Method for Predicting City-Wide Electricity Gains from Photovoltaic Panels Based on LiDAR and GIS Data Combined with Hourly DAYSIM Simulations," Solar Energy 93, pp. 127-143

LIDAR Data of the MIT Campus

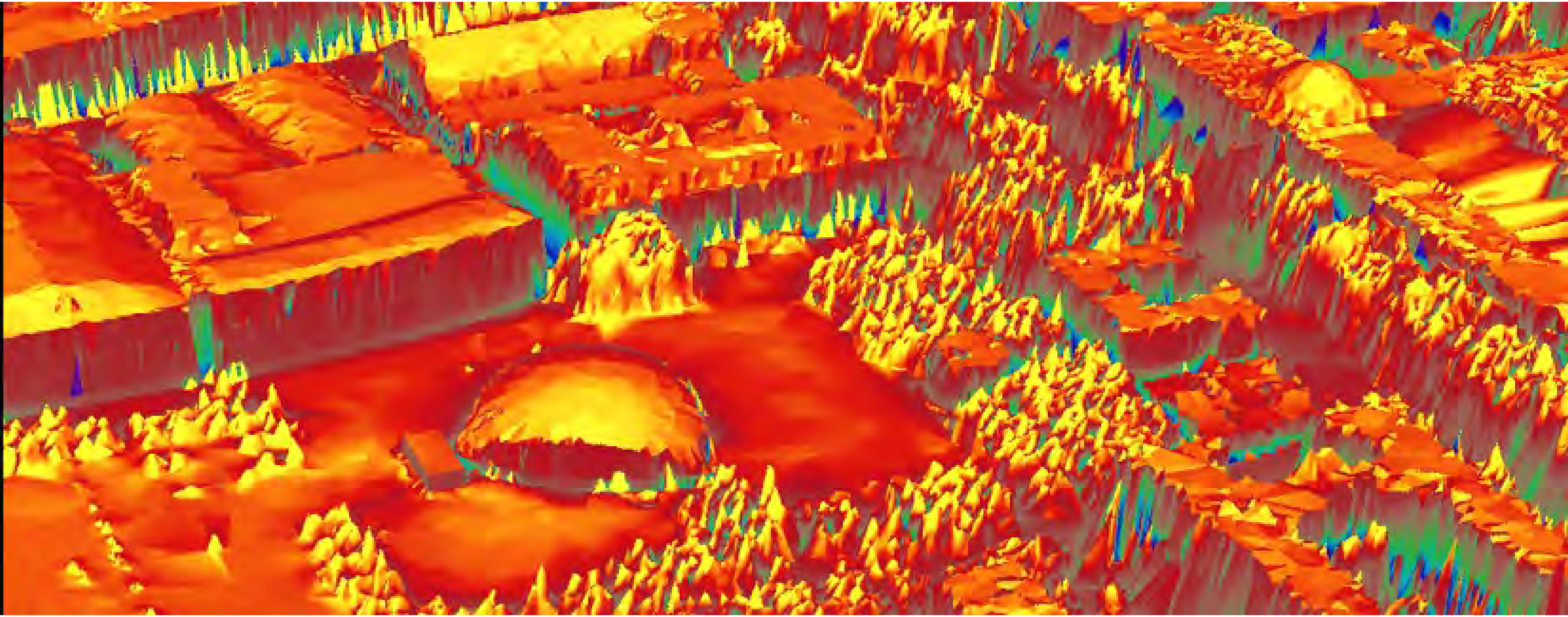


3 dimensional point cloud (126 million points)

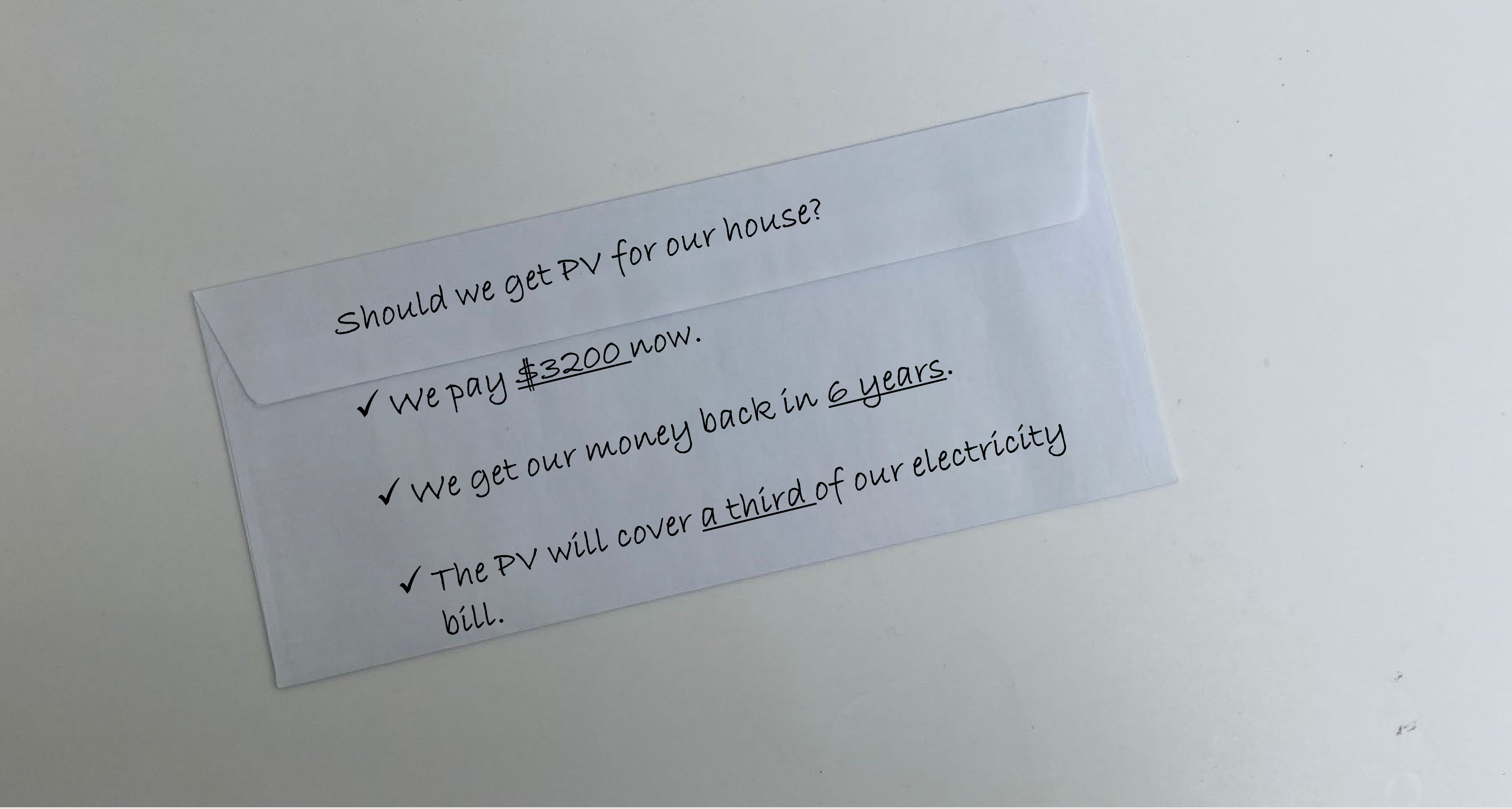
3D Model of the MIT Campus

- ❑ Generation of a 3D model through surface triangulation

Solar Radiation Map



- In 2013 we formed an MIT spinoff called mapdwell that develops interactive maps to predict the potential to install PV on urban rooftops.
- In 2021 mapdwell merged with Palmetto. In 2023 we covered over +119 million US homes (84% coverage)


Should we get PV for our house?
✓ We pay $3200 now.
✓ We get our money back in 6 years.
✓ The PV will cover a third of our electricity bill.

Case Study Wellfleet, MA

- ❑ In 2014 the mapdwell map of Wellfleet, MA, successfully supported a community-driven solarize program: Within 4 months 10% of all households went solar.

Source: Palmetto Mapdwell

Urban Building Energy Modeling (UBEM)

Link: https://www.youtube.com/watch?v=O46GkHSYvYE

- ❑ Combing big urban data with building performance simulation

C F Reinhart and Cerezo, 2016, “Urban Building Energy Modeling – A Review of a Nascent Field,” Building and Environment, 97:196–202

2016 - Boston Building Energy Study

- In collaboration with the Boston Redevelopment Authority with support from the Massachusetts Clean Energy Center we created an UBEM with has over 80,000 buildings.
- Together with Lincoln Laboratory we applied the model to explored new energy supply technologies such a micro-grids and district heating/cooling.

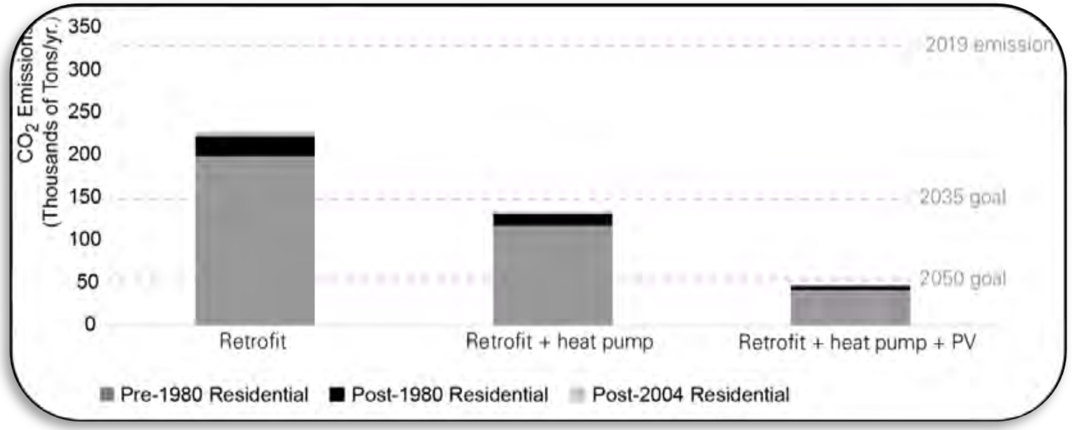
C Davila Cerezo, J Bemis and F Reinhart, “Modeling Boston: A workflow for the efficient generation and maintenance of urban building energy demand models from existing geospatial datasets,” Energy, 117, pp. 237-250, 2016

Four use cases for UBEM

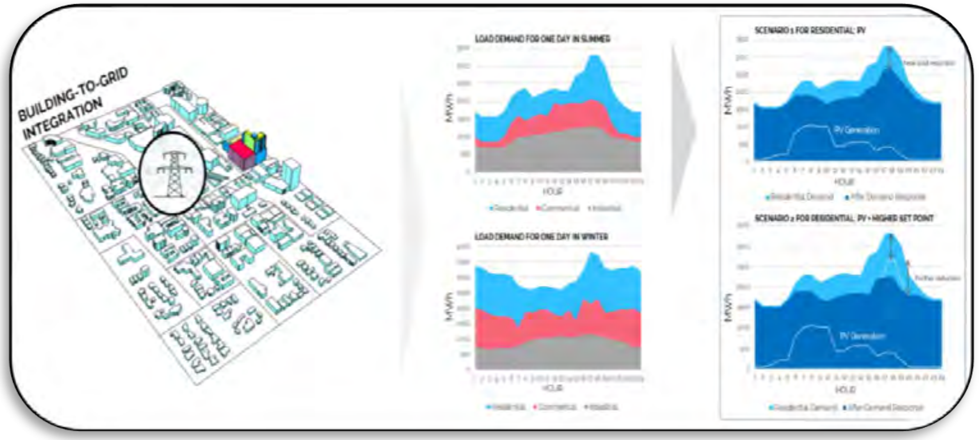
1 Urban Planning & New Neighbourhood Design

3 Building-Level Recommendations

2 **Stock-Level Carbon Reduction Strategies**



4 Buildings-to-Grid Integration

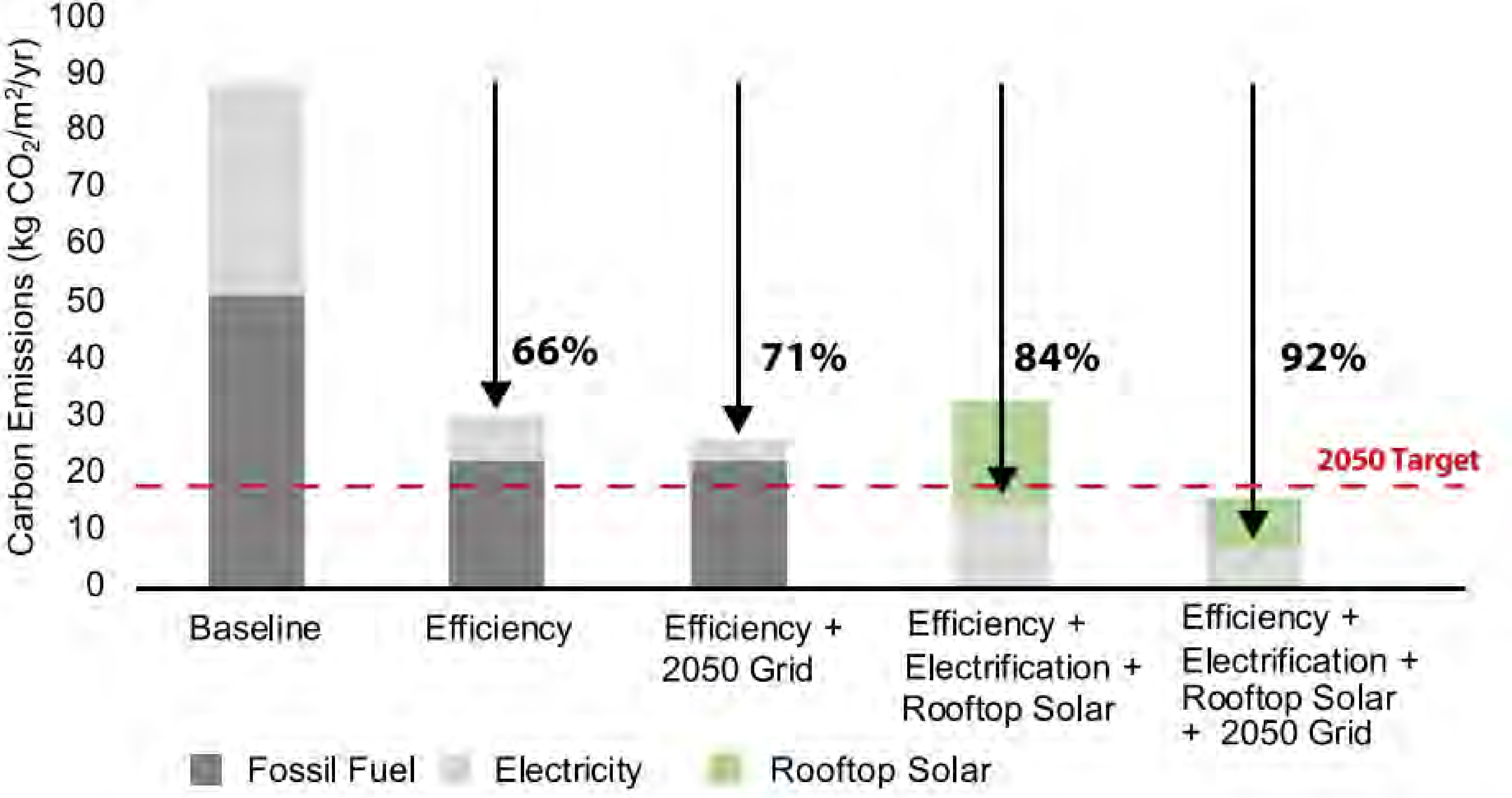


Y Q Ang, Z M Berzolla and C Reinhart, 2020, From concept to application: A review of use cases in urban building energy modeling, Applied Energy

Case Study Carbon Reduction Pathways | Oshkosh, WI

Z M Berzolla, Y Q Ang , S Letellier-Duchesne and C Reinhart, 2023, An eight-step simulation-based framework to help cities reach building-related emissions reduction goals, Environmental Research: Infrastructure and Sustainability

Three upgrade strategies for Oshkosh to meet its emissions reduction goals



Z M Berzolla, Y Q Ang , S Letellier-Duchesne and C Reinhart, 2023, An eight-step simulation-based framework to help cities reach building-related emissions reduction goals, Environmental Research: Infrastructure and Sustainability

Outreach to residents

Z M Berzolla, Y Q Ang , S Letellier-Duchesne and C Reinhart, 2023, An eight-step simulation-based framework to help cities reach building-related emissions reduction goals, Environmental Research: Infrastructure and Sustainability

How can we help cities anywhere to conduct a carbon reduction pathway analysis of their building stock?

UBEM.IO

Sustainability Champion

GIS Manager

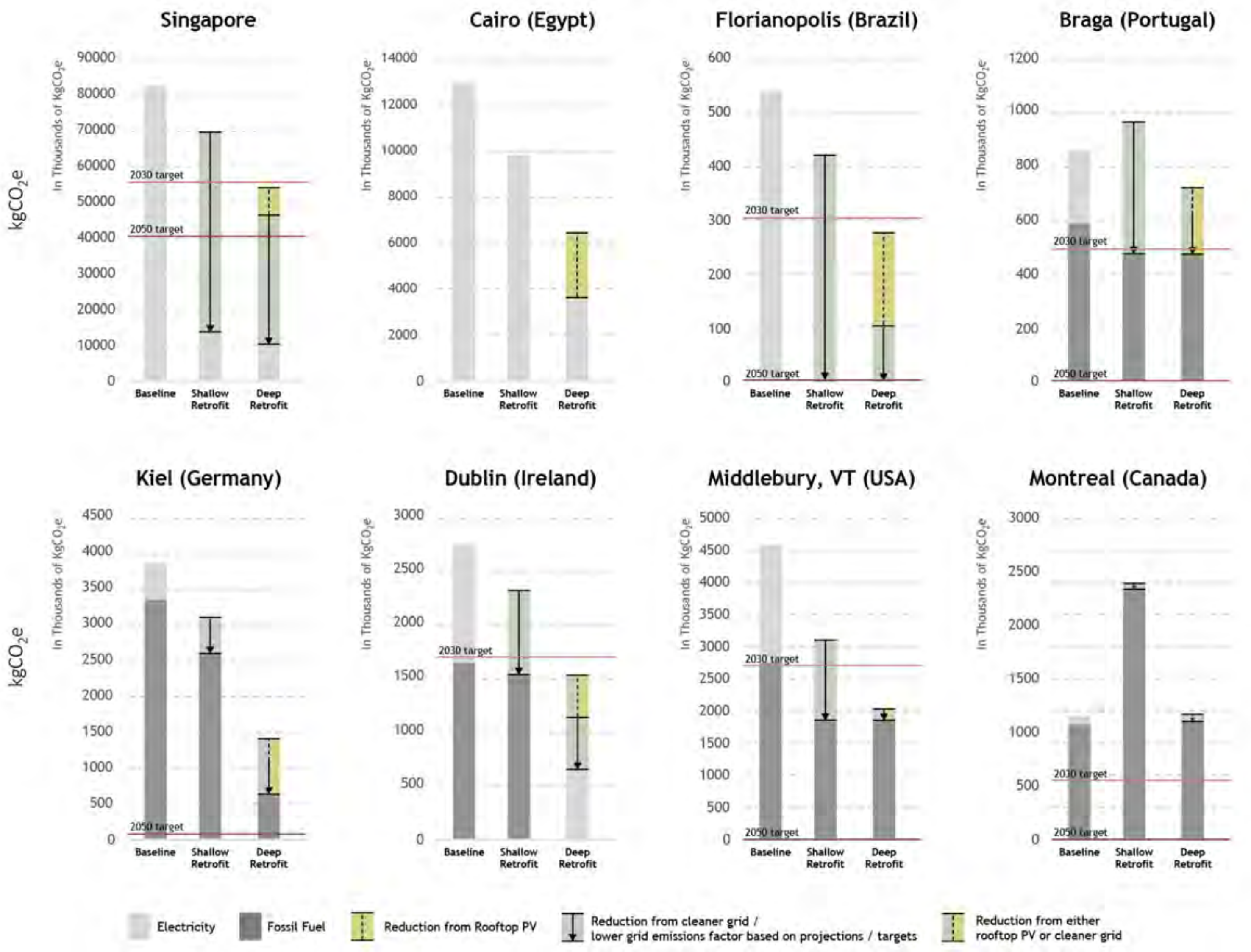
Energy Modeler

Y Q Ang, Z Berzolla, S Letellier-Duchesne, V Jusiega and C Reinhart, 2021, “UBEM.io: A web-based Framework to Rapidly Generate Urban Building Energy Models for Carbon Reduction Technology Pathways” Sustainable Cities and Society

Testing the 8 Step Framework Globally

Y Q Ang, Z M Berzolla, S Letellier-Duchesne and C F Reinhart, Carbon reduction pathways for buildings in eight cities, Nature Communications, 14, 1689, 2023

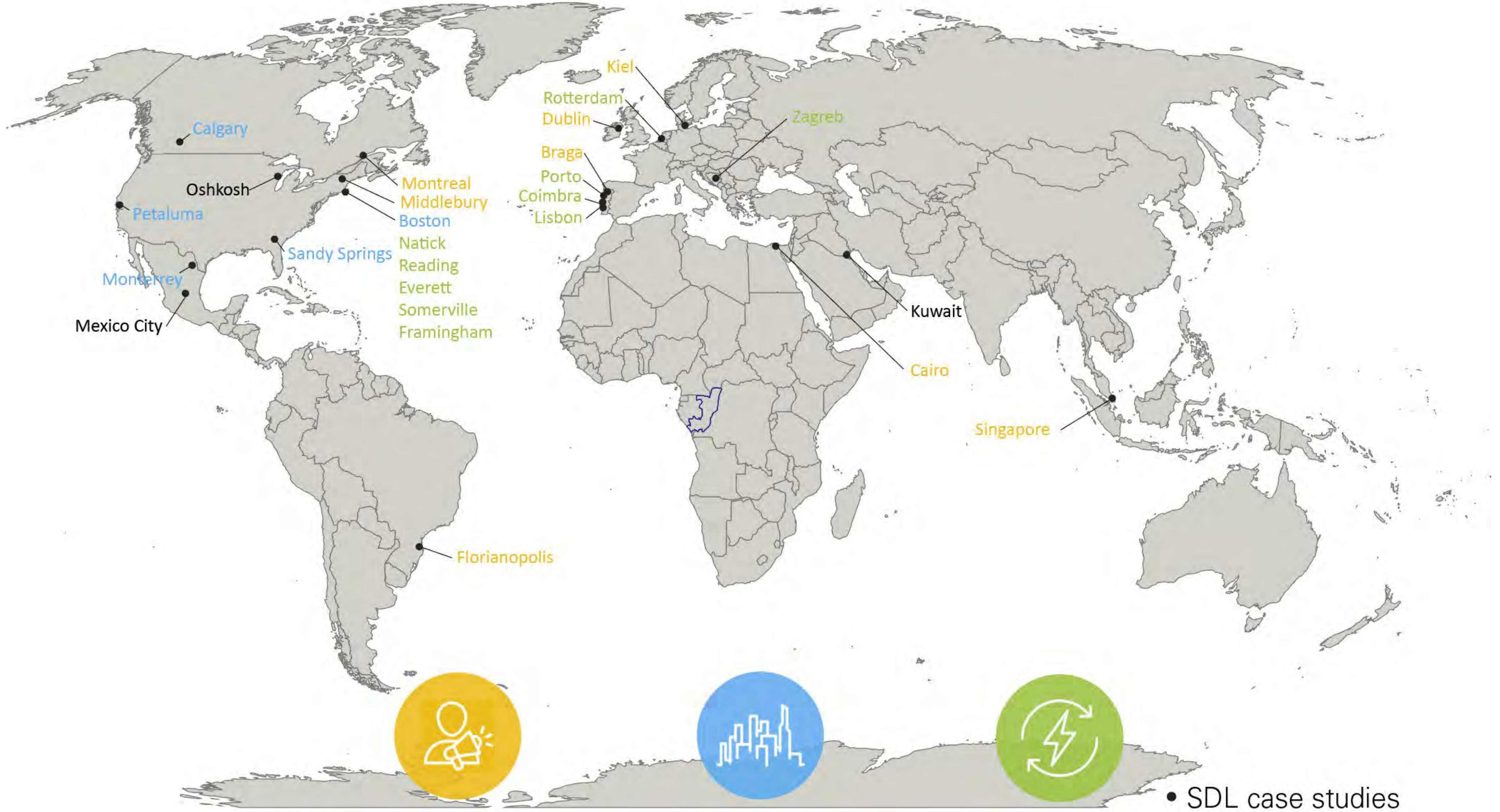
Carbon emissions for shallow, and deep retrofits



- Every city is different. Justifiable effort. Need more template libraries for different countries.

Y Q Ang, Z M Berzolla, S Letellier-Duchesne and C F Reinhart, Carbon reduction pathways for buildings in eight cities, Nature Communications, 14, 1689, 2023

Testing the 8 Step Framework Globally



Y Q Ang, Z M Berzolla, S Letellier-Duchesne, V Jusiega and C Reinhart, 2022, UBEM.io: A web-based framework to rapidly generate urban building energy models for carbon reduction technology pathways, Sustainable Cities and Society

Who within a community is most likely to upgrade their home?

Outreach to residents

Do You Own a Home Built Before 1980…

…and want to lower your energy bills, reduce emissions, and be more comfortable?

What can you do and how much would it cost?*

Energy Retrofit	or	Energy Retrofit + Heat Pump + Solar
$1,000/Year	Save	$1,600/Year
$10,000	Pay Now	$23,000
10 Years	Break Even	15 Years
-30% CO_2 Emissions	Save the Planet	-85% CO_2 Emissions

*for the average home

Contact us here! 555-5555

Ownership

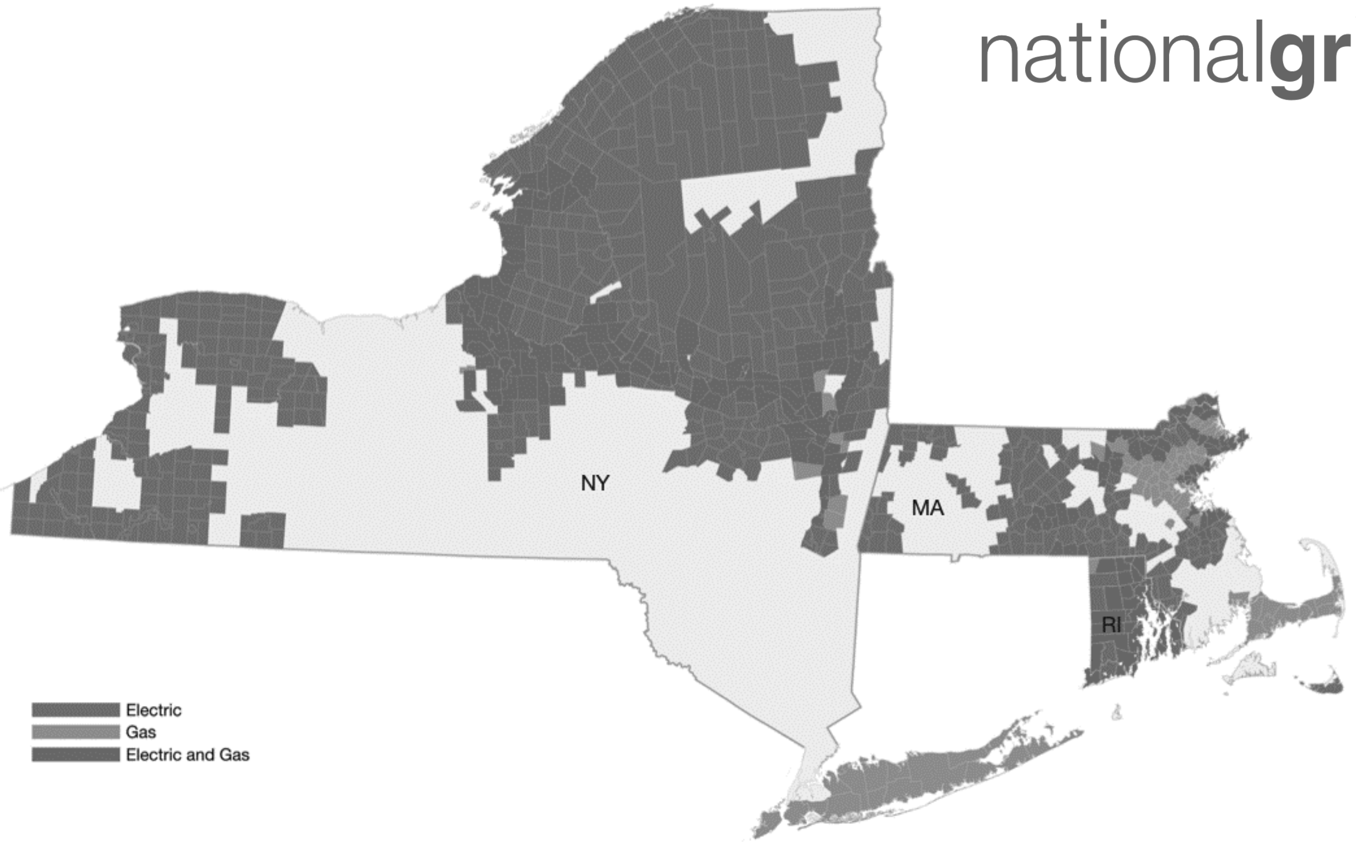
1^{st} cost

Payback time

Z Berzolla, YQ Ang, C Reinhart, 2022, "Combining Urban Building Energy Models with Retrofit Adoption Models for Time-Dependent Carbon Emission Projections," 2022 ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA, August 2022

Would owners pay this kind of money?

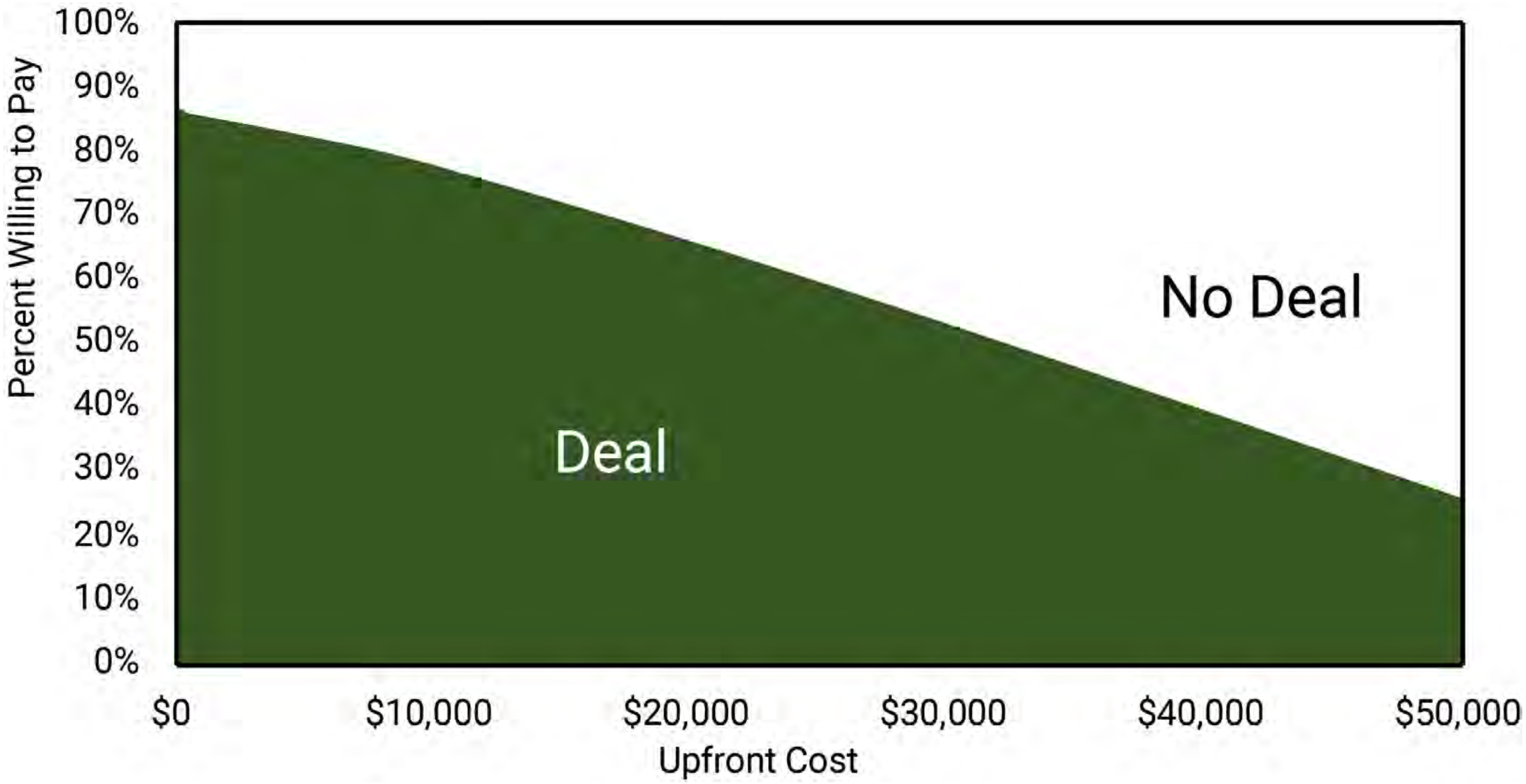
Willingness to Pay Survey + Regression Model



What is the minimum payback time that you would accept for a retrofit upfront cost of $x, or is it too expensive?

Z. Berzolla, T. Meng, and C Reinhart, 2023, “Homeowners’ Willingness to Pay for Residential Building Retrofits.” Available at SSRN: http://dx.doi.org/10.2139/ssrn.4536734

Willingness to Pay | Deal or No Deal



- ❑ Key input variables are household income, upfront cost and concern about emissions

Z. Berzolla, T. Meng, and C Reinhart, 2023, "Homeowners' Willingness to Pay for Residential Building Retrofits." Available at SSRN: http://dx.doi.org/10.2139/ssrn.4536734

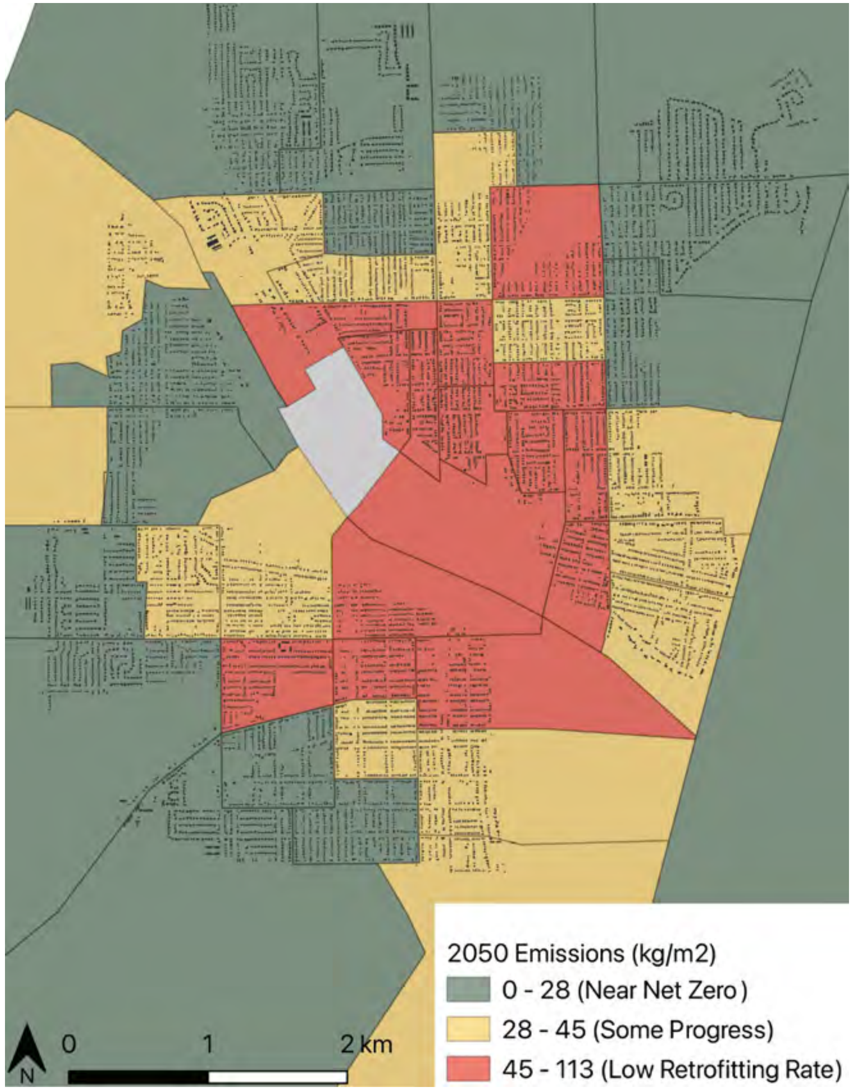
Willingness-To-Pay Regression Model

Individual building: Depending on demographics, our New England Home Owner's willingness to pay for a deep retrofit range between 36% and 87%.

Municipal level: In Oshkosh 68% of households are willing to pay for some upgrades. 74% of residential buildings are owner occupied.

Z. Berzolla, T. Meng, and C Reinhart, 2023, "Homeowners' Willingness to Pay for Residential Building Retrofits." Available at SSRN: http://dx.doi.org/10.2139/ssrn.4536734

Upgrade Distribution

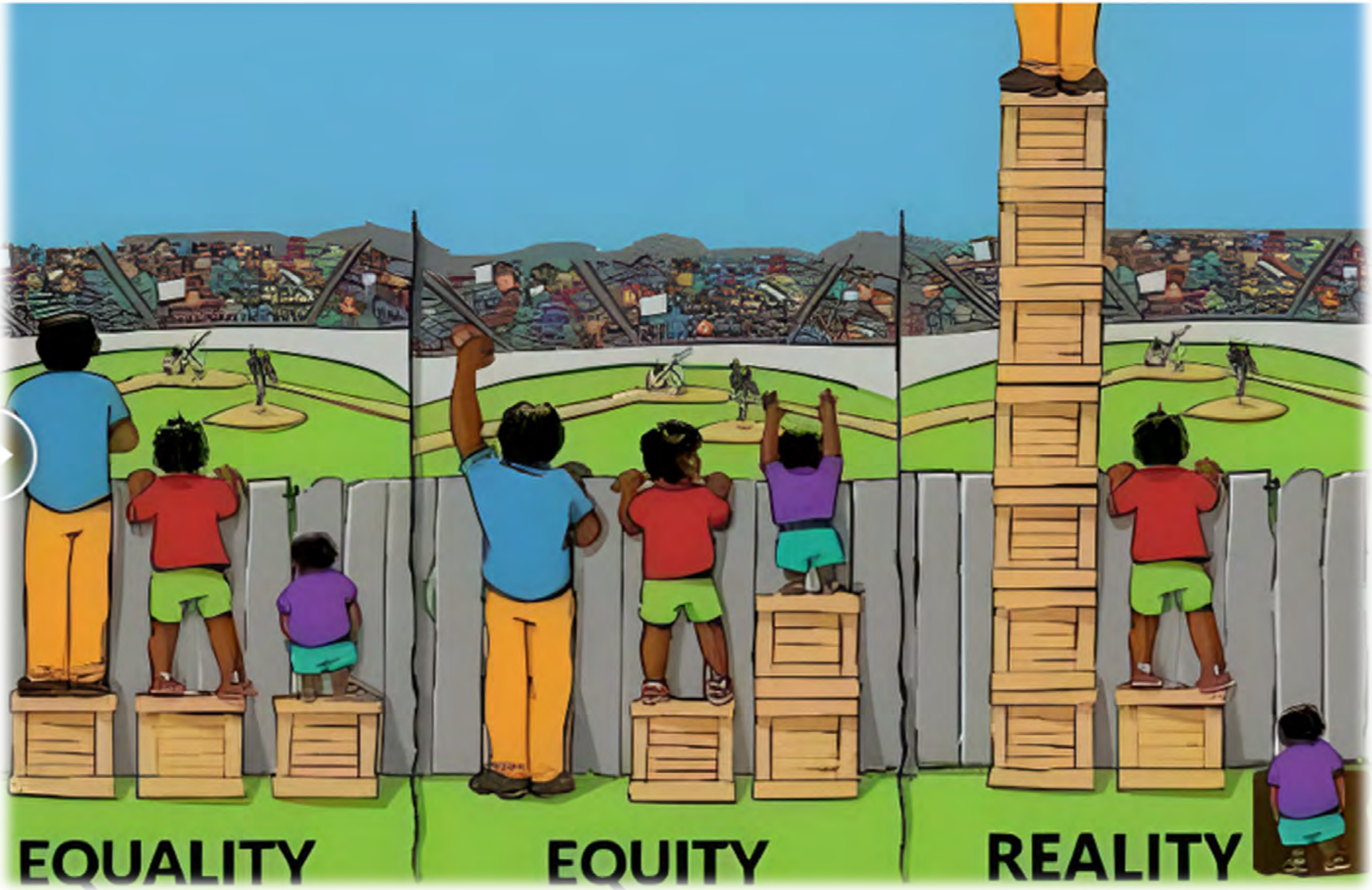


- ❑The Landlord/Tenant Challenge
- ❑Those in high-income, high-ownership (i.e. affluent neighborhoods) adopt
- ❑Low-income neighborhoods left behind
- ❑Tale of two Americas

Z. Berzolla, Y. Q. Ang, S. Letellier-Duchesne, and C Reinhart, 2023, “An eight-step simulation-based framework to help cities reach building-related emissions reduction goals” Environmental Research: Infrastructure and Sustainability.

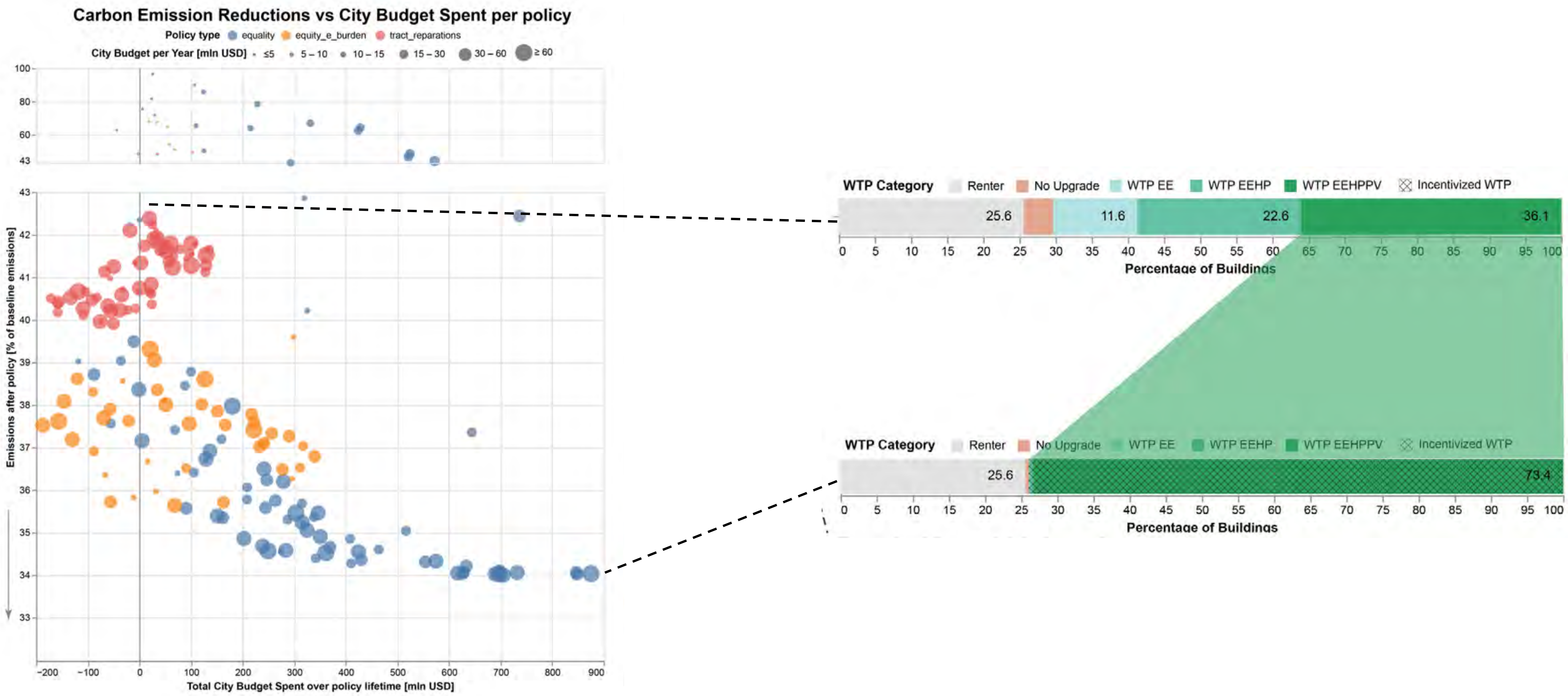
What incentives should governments provide to encourage more equitable building retrofits?

Notions of Fairness



Slide: Z De Simone
Image Credit: Interaction Institute for Social Change | Artist: Angus Maguire

Evidence-based Incentive Structures

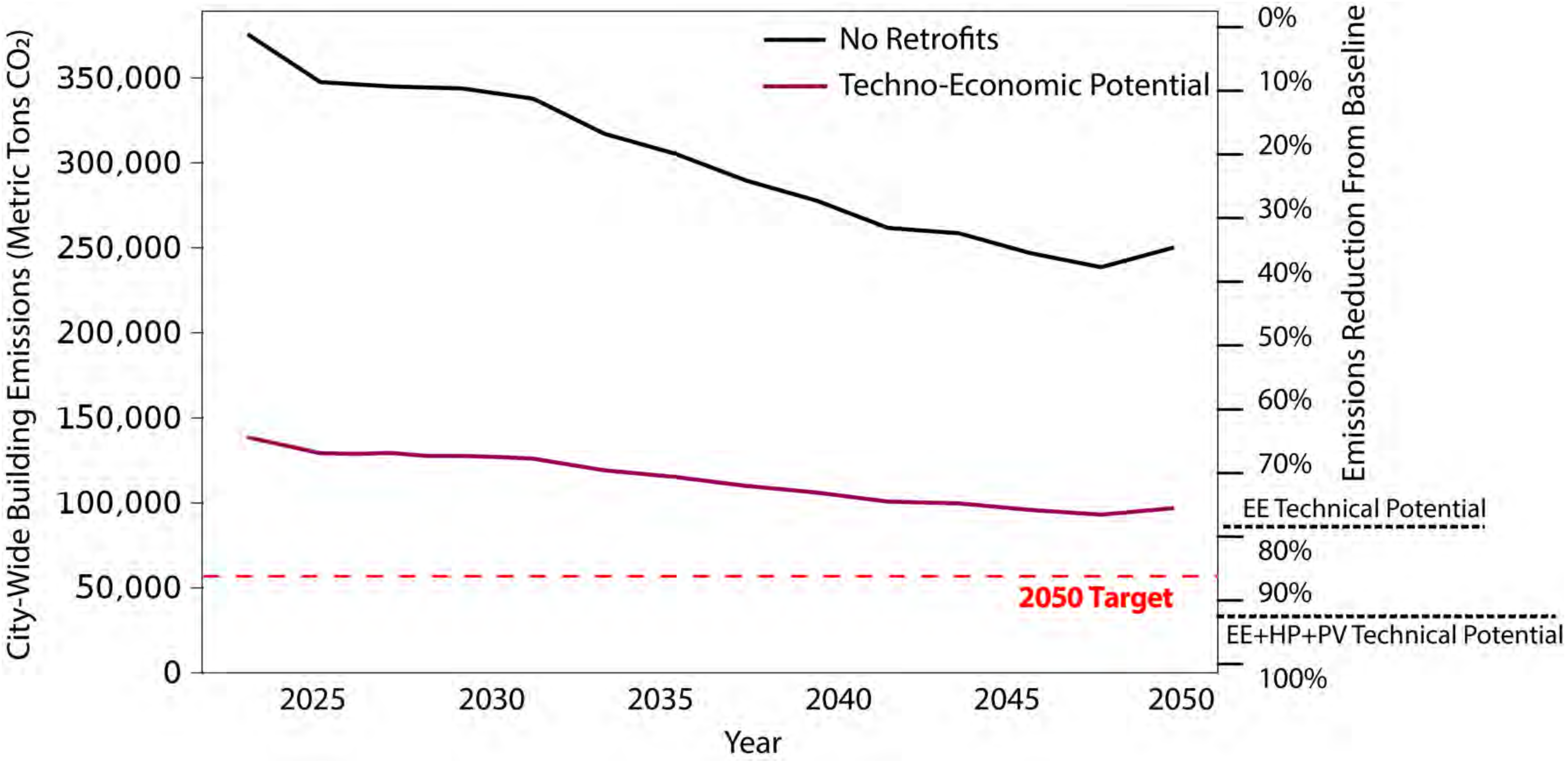


- ❑ More incentive $ lead to higher carbon reductions.
- ❑ Equity programs do not compromise carbon reductions.
- ❑ Reduction differences stem from upgrade package chosen.

Z De Simone, M Arcaya and C Reinhart, Energy transition and equity: Quantifying pathways to building decarbonization based on notions of fairness, in preparation

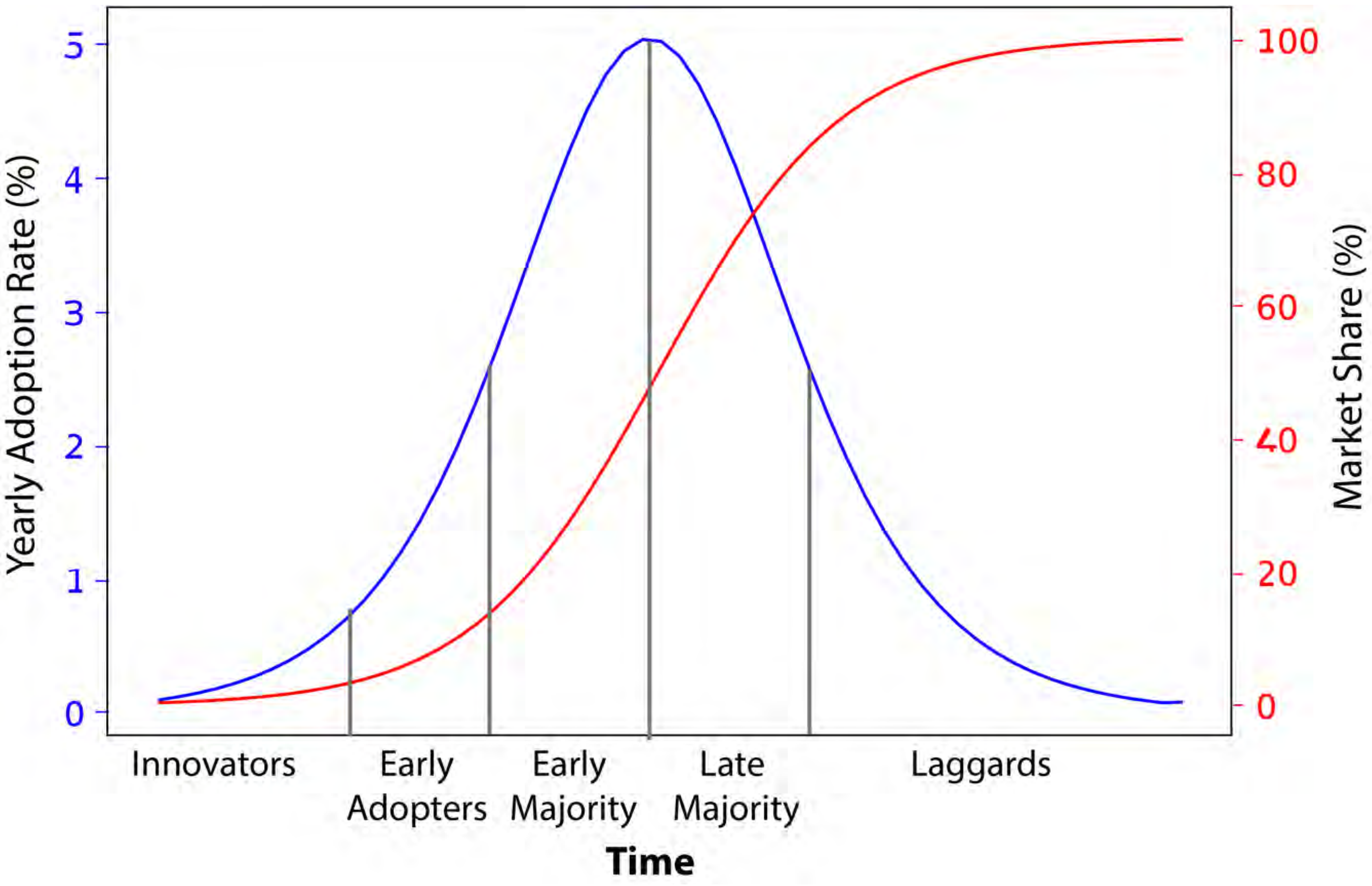
How fast will households adopt retrofits?

Techno-Economic Potential to 2050



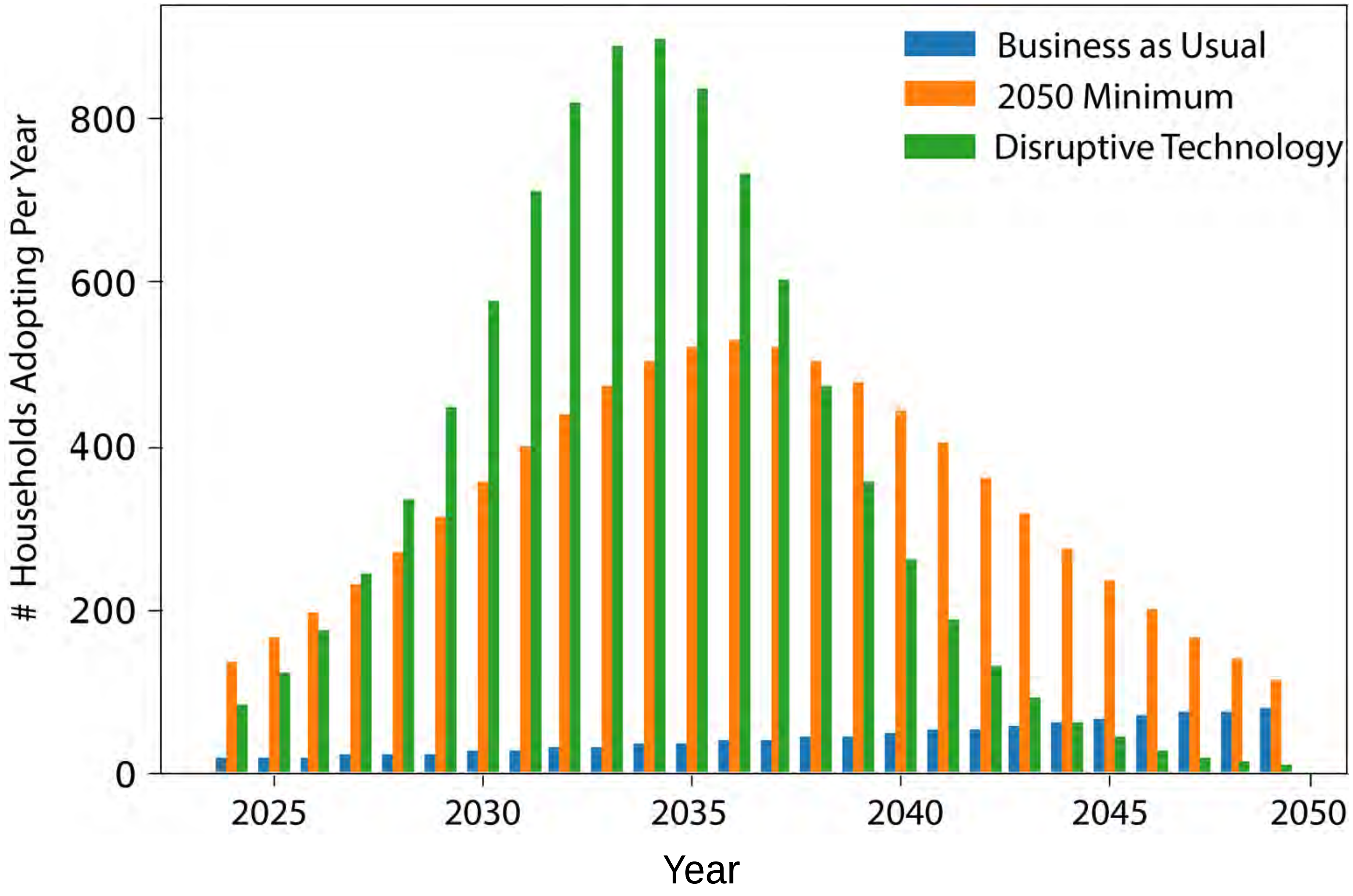
Z. Berzolla, Z. De Simone, and C. Reinhart. "Modeling techno-economic adoption of building energy retrofits at the city-scale." *In preparation.*

Technology Adoption



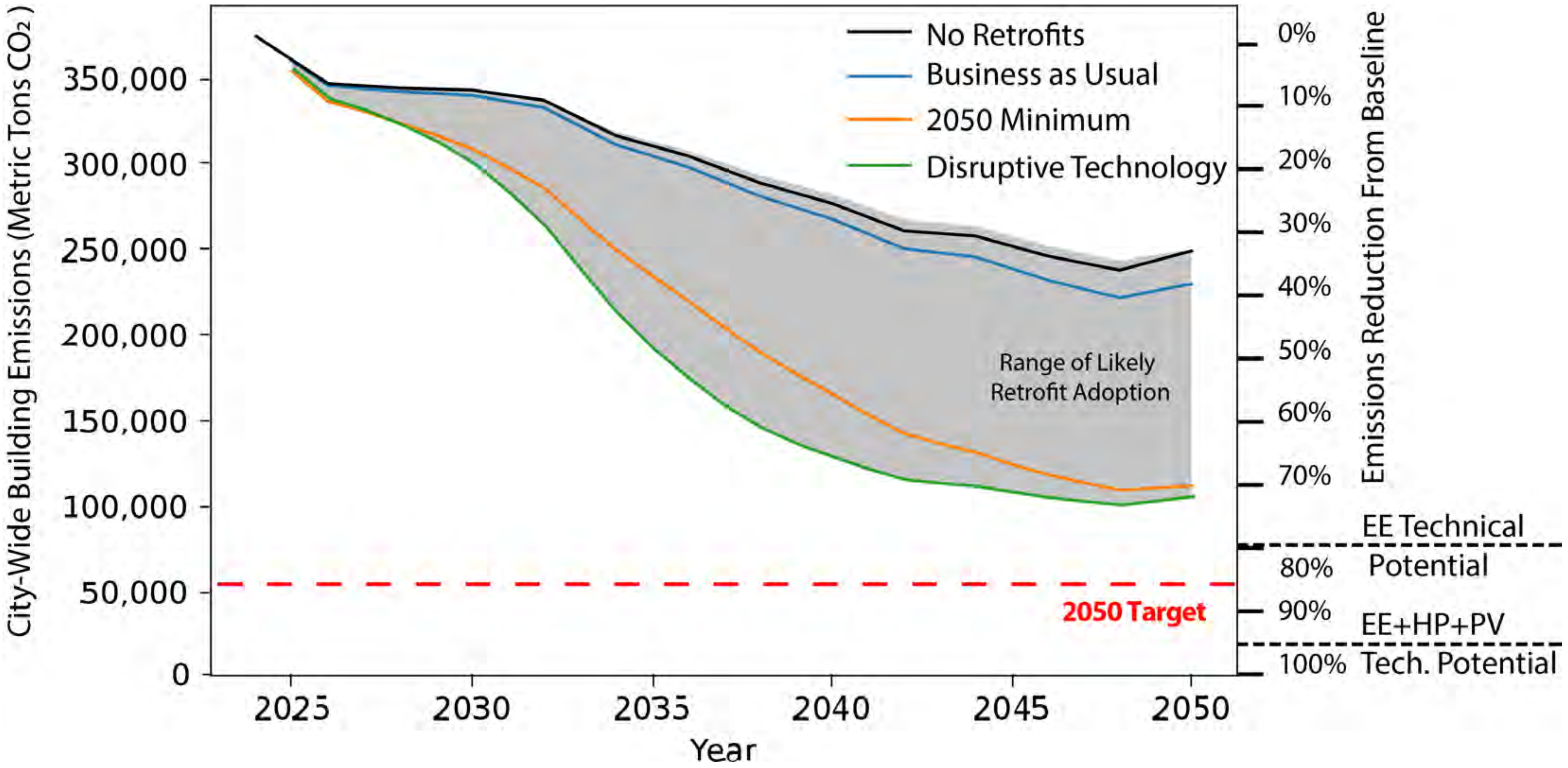
Diffusion of Innovation, Everett M. Rogers, 1976

Technology Adoption



Z. Berzolla, Z. De Simone, and C. Reinhart. "Modeling techno-economic adoption of building energy retrofits at the city-scale." *In preparation.*

Oshkosh Emissions Projections



Z. Berzolla, Z. De Simone, and C. Reinhart. "Modeling techno-economic adoption of building energy retrofits at the city-scale." *In preparation.*

”Disruptive Technology” Adoption

Desirability-Driven

TIME **“Best Inventions of 2022”**

Regulation-Driven

https://time.com/collection/best-inventions-2022/6224874/gradient/
BPS data from: https://www.energycodes.gov/BPS

Our goals for 2030

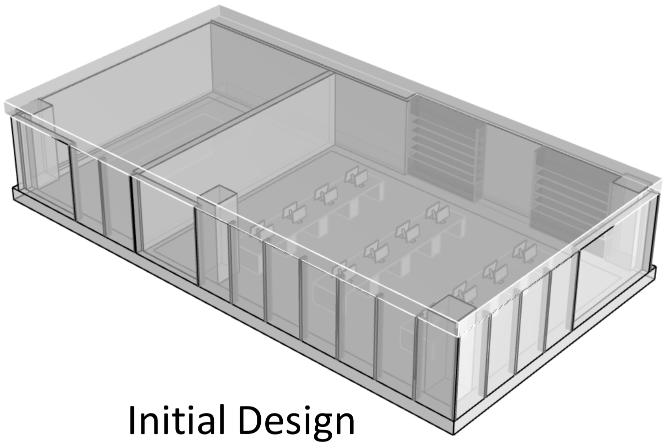
- ❑ Increase annual retrofitting rate to 5%
- ❑ All new construction is carbon neutral
- ❑ More efficient space use.

How can we educate the construction industry to design to net zero buildings?

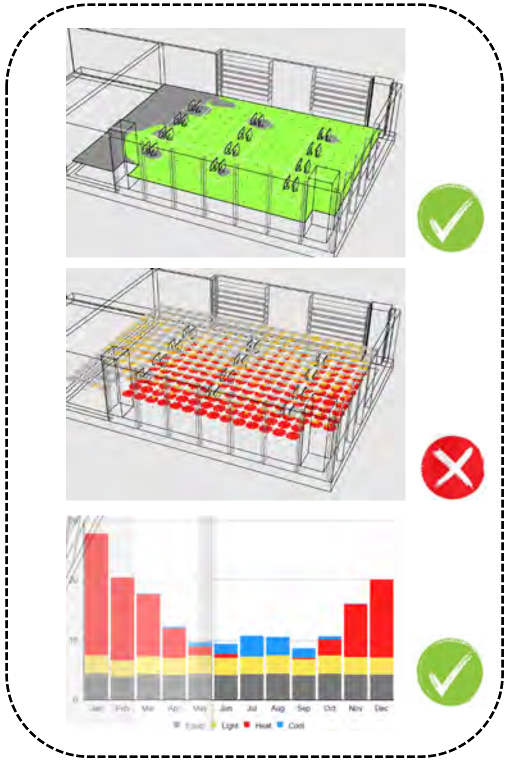

ClimateStudio
Software for advanced daylight and energy simulation.
About ClimateStudio

SOLEMMA

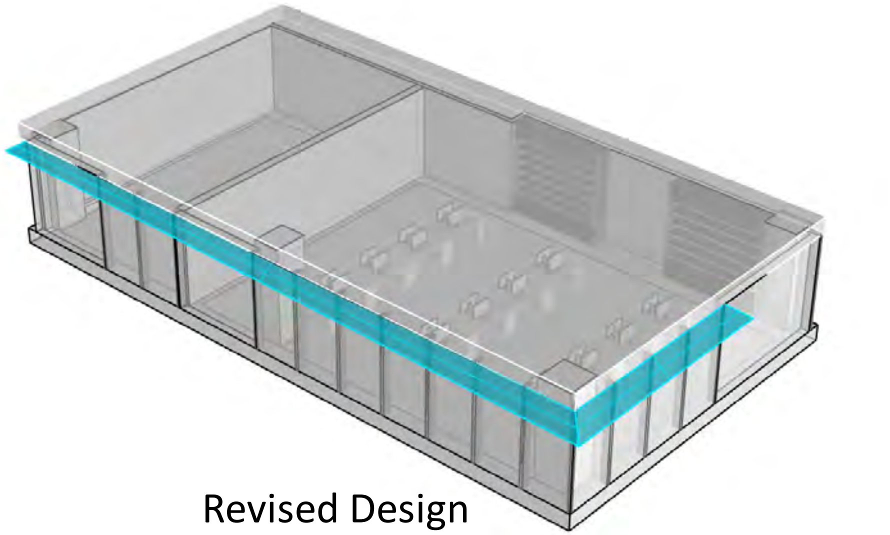
Environmental Performance Analysis in Design



Initial Design



Environmental Analysis



Revised Design

Solemma Product Advisory Group

KALWALL®
high performance translucent building systems

KPF

h+k

SHIMIZU CORPORATION
SHIMZ

PERKINS EASTMAN

TAKENAKA

atelier ten

STUDIO MA

Snøhetta

Lam Partners

NIKKEN

INTEGRAL

Gensler

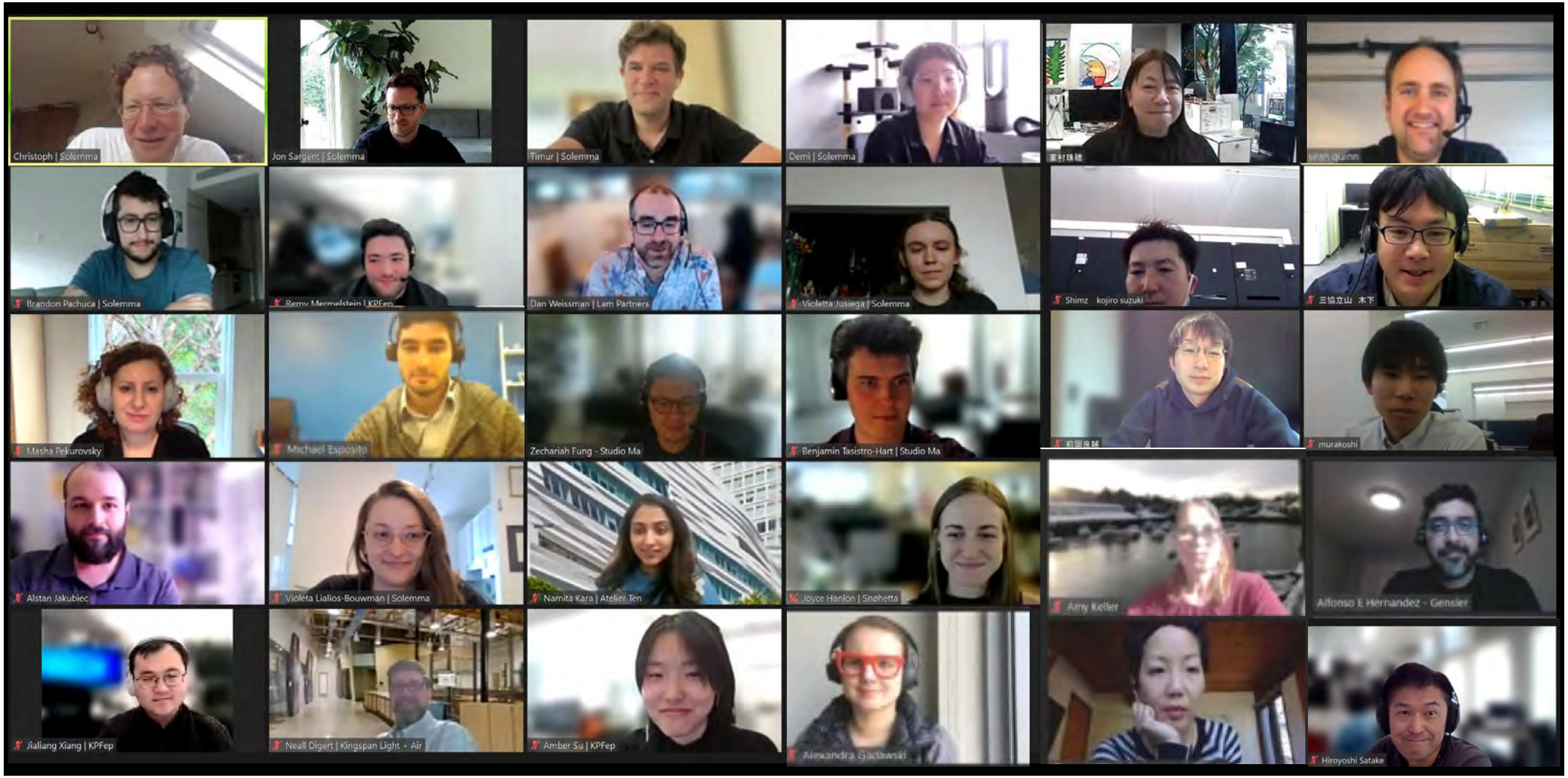
BEHNISCH ARCHITEKTEN

HMFH

SAINT-GOBAIN

SOLATUBE®

Product Advisory Group



- ❑ Present new concept ideas
- ❑ Share test installers
- ❑ Survey and respond to member interests

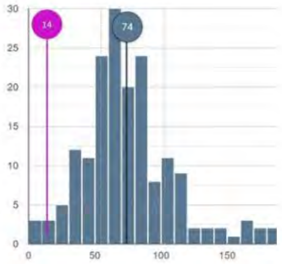
ClimateStudio Ambassador Program

~400 Ambassadors train an estimated 20,000 students per year (Solemma, 2022)

ClimateStudio in Ghana

Courage (Dzidula) Kpodo teaching CS at Kwame Nkrumah University of Science and Technology

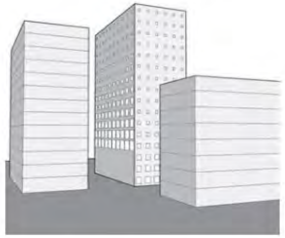
SDL Net Zero Buildings in eight steps



Climate, Benchmark & PV

Three initial environmental analysis steps for any net zero building project

o to exercise



Precedence & Massing Study

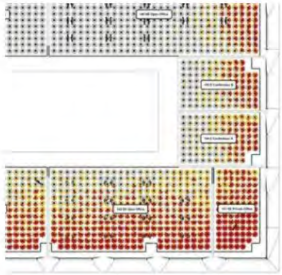
Develop an initial daylight concept using rules of thumb

Go to exercise

Daylight Availability Study

Refine daylight massing and set window-to-wall-ratio and glazing type

Go to exercise



Visual Comfort

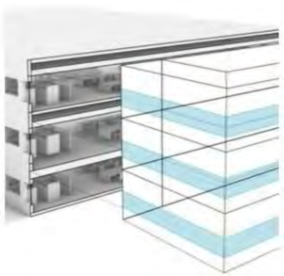
Develop a shading strategy by balancing glare, view and solar gains

Go to exercise

Electric Lighting

Explore the dynamic interactions between daylight and electric lighting

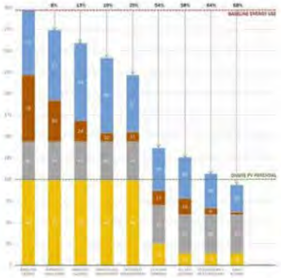
Go to exercise



Thermal Model Setup

Ceate a baseline model and adjust internal gains schedules

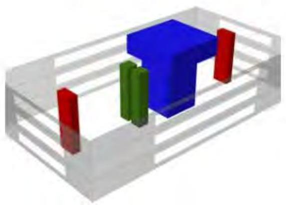
Go to exercise



EUI Study

Upgrade the envelope and optimize ventilation

Go to exercise

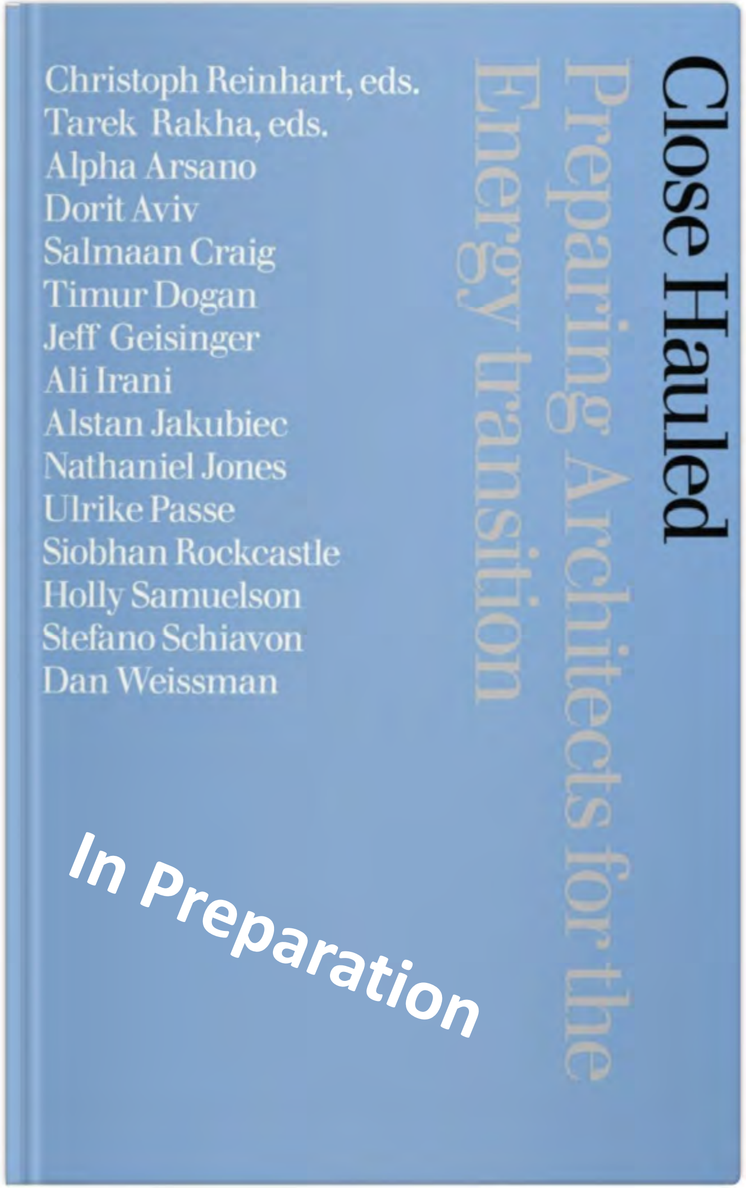


HVAC Selection and Layout

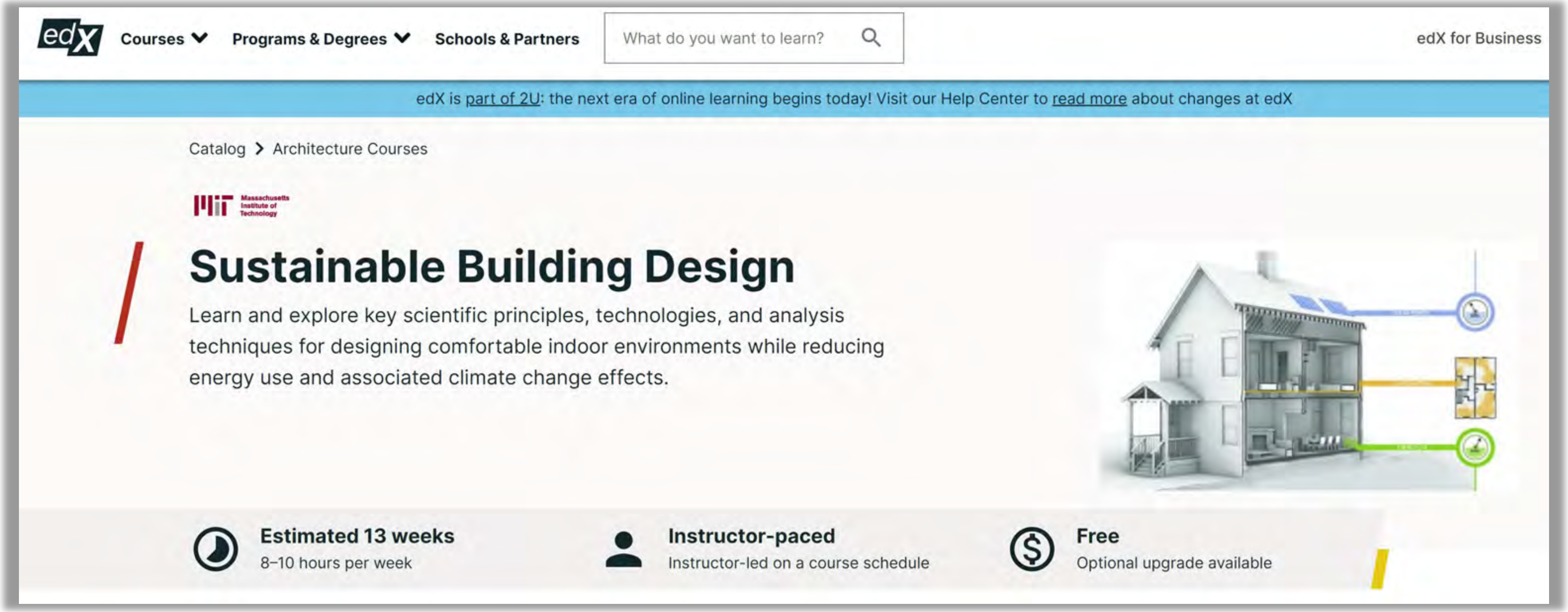
Select a system type and Description goes here locate system components

Go to exercise

Close Hauled Symposium – Sep 14/15 2023 @ MIT



Massive Open Online Course (MOOC)




A Arsano


E Elowe


P Freeman


C Reinhart

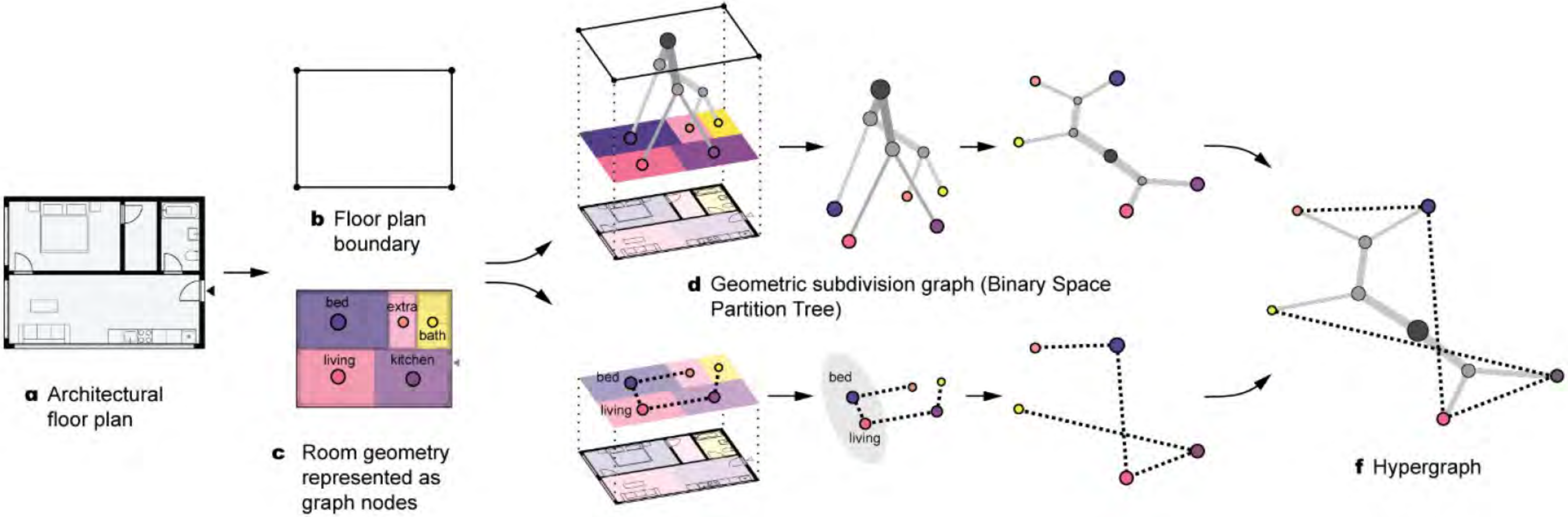
https://www.edx.org/course/environmental-technologies-in-buildings

Our goals for 2030

- ☐ Increase annual retrofitting rate to 5%
- ☐ All new construction is carbon neutral
- ☐ More efficient space use.

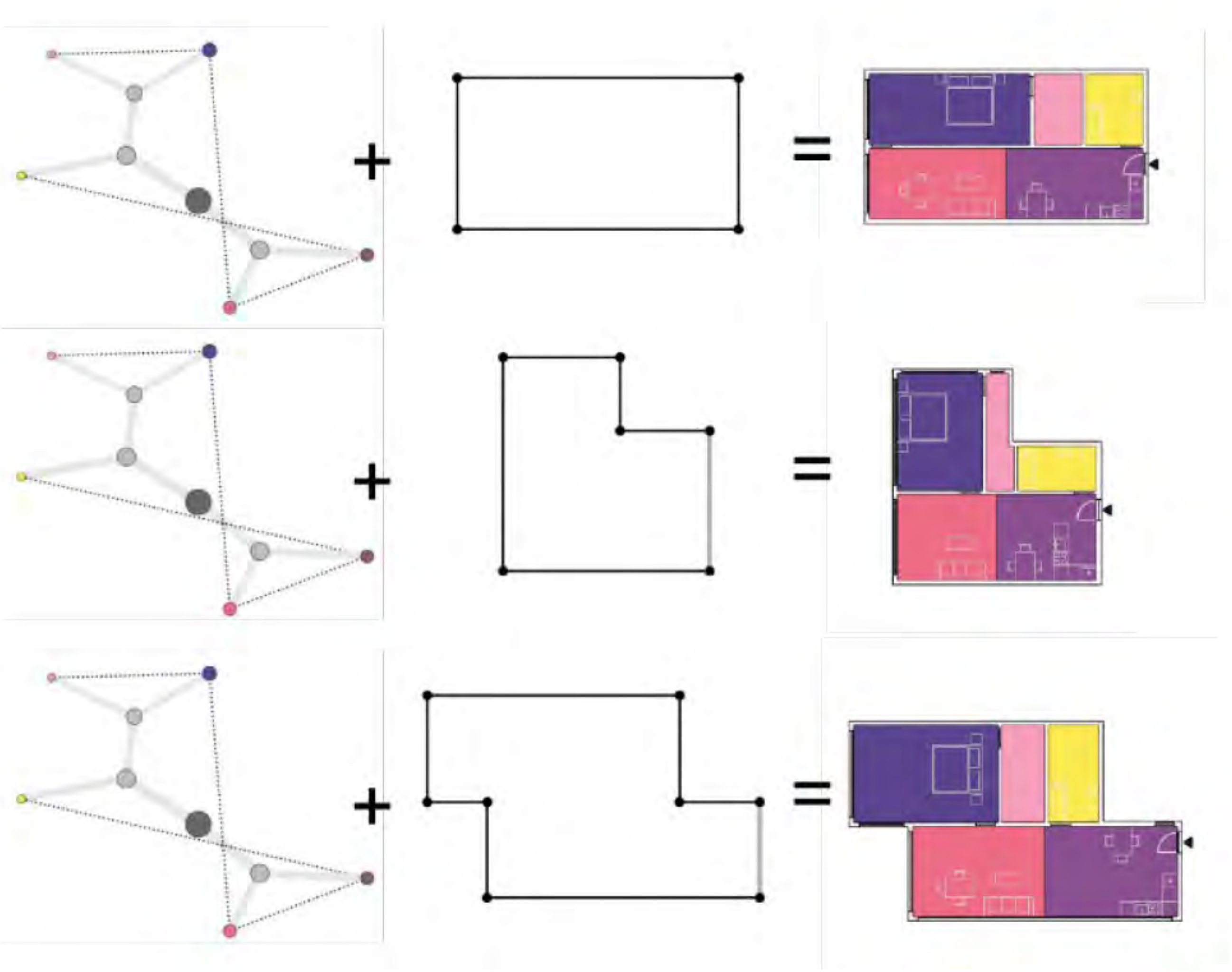
How can we design more adaptive buildings faster?

Hypergraph Mapping

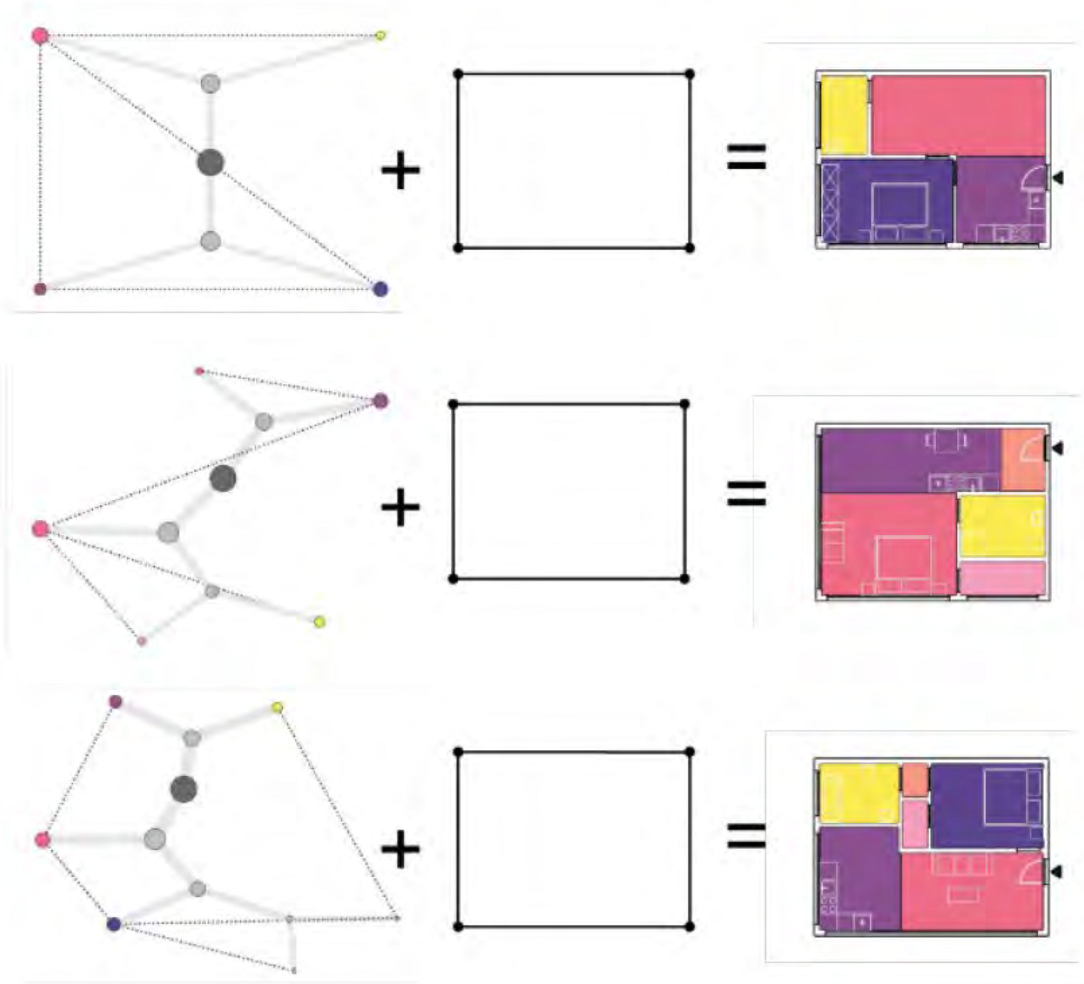


R E Weber, C Mueller, C Reinhart, A hypergraph model shows the carbon reduction potential of effective space use in housing, http://arxiv.org/abs/2405.01290

Hypergraph Mapping



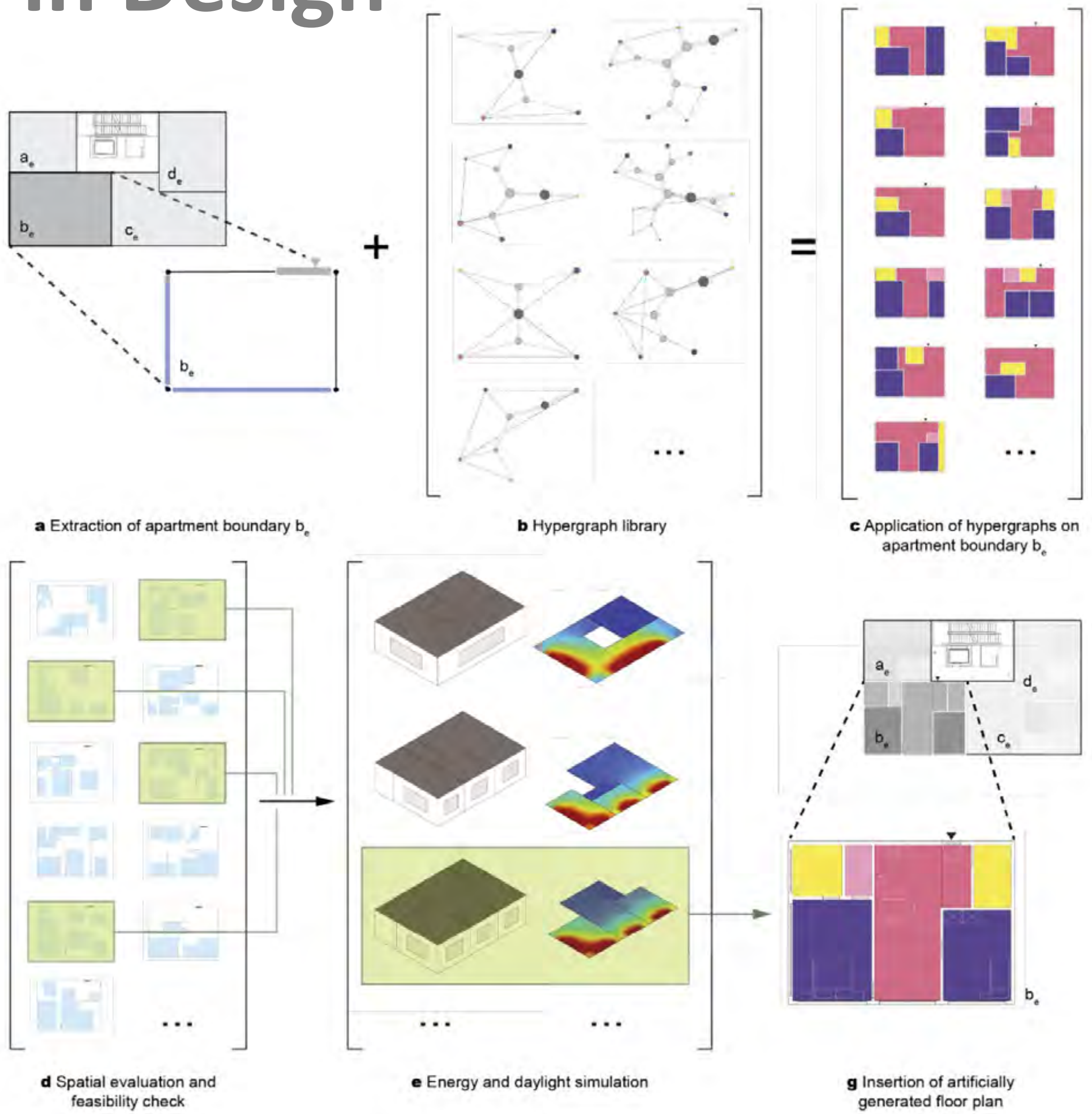
Same hypergraph applied to different floor plan boundaries



Different hypergraphs applied to the same floor plan boundary

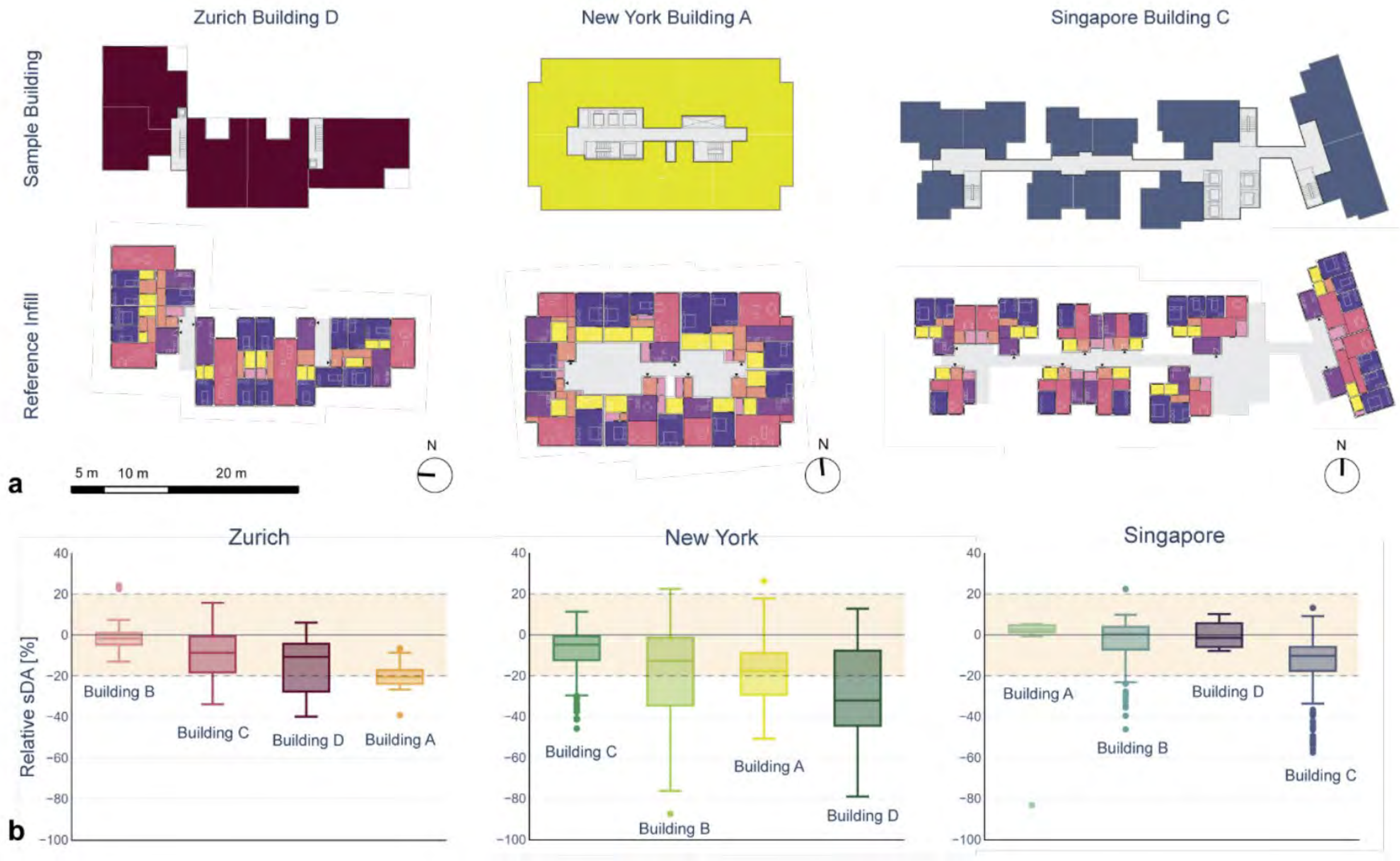
R E Weber, C Mueller, C Reinhart, A hypergraph model shows the carbon reduction potential of effective space use in housing, http://arxiv.org/abs/2405.01290

Application in Design



R E Weber, C Mueller, C Reinhart, A hypergraph model shows the carbon reduction potential of effective space use in housing, http://arxiv.org/abs/2405.01290

Autogenerated versus Actual Apartment Layouts



- ❑ Methods provide an indication of the daylighting potential of an apartment floorplan
- ❑ Hypergraph usually finds some better performing layouts for inspiration

R E Weber, C Mueller, C Reinhart, A hypergraph model shows the carbon reduction potential of effective space use in housing, under review

Closing Thoughts

IABP's goals are to "promote research and best practice in the field of building physics in order to improve new and existing buildings and the surrounding infrastructure."

- ❑ Reach out for a wider audience starting with your local community.
- ❑ Be definitive. People have no patience for endless disclaimers and caveats.
- ❑ Aim for impact. Try every year to identify at least one building project that partially happened because of you.
- ❑ Shows the world that building physics is fun.

Thank You

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