SUSTAINABLE UPGRADES

OF NEW BUILDINGS IN ANN ARBOR

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EGLE
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The City of Ann Arbor is committed to achieving carbon neutrality by 2030 through its A2ZERO Climate Action Plan.

This goal cannot be met without addressing emissions from buildings, which account for 17% of total emissions in Michigan.

The City Council instructed the City to find incentives for residents and businesses to enhance emissions reductions by transitioning to sustainable heating and beneficial electrification.

INTRODUCTION

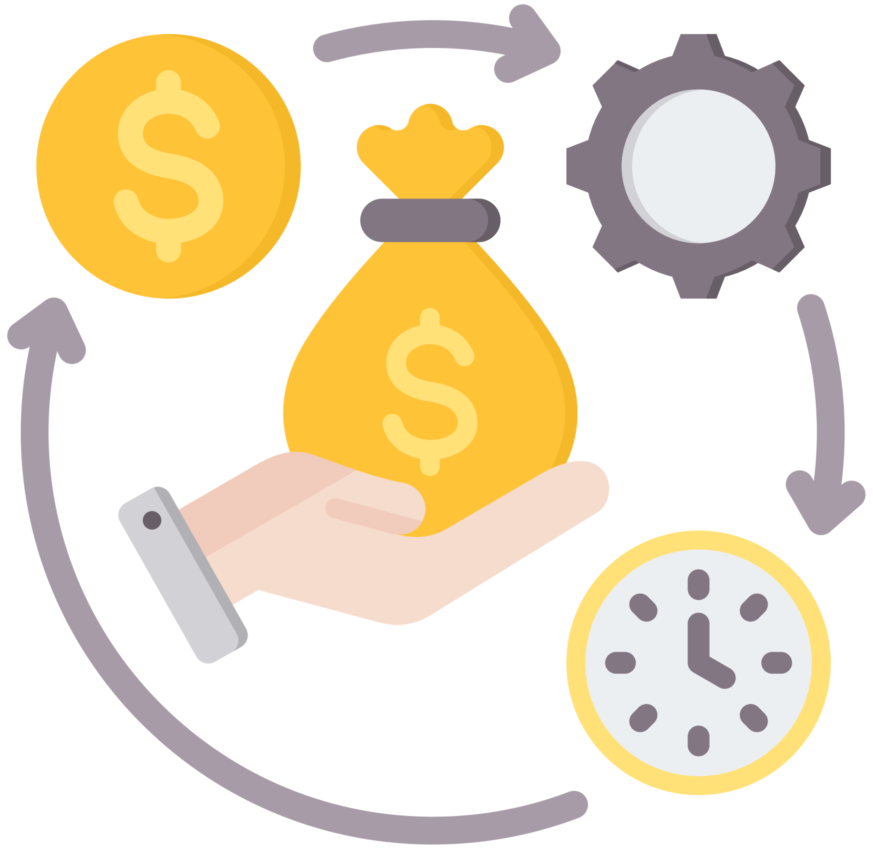
What are **cost**-effective heating and cooling systems to achieve **net zero** in new buildings?

Carbon Emissions + **Cost** = **Sustainable Upgrade of New Buildings Policy Recoemmdations**

RESEARCH QUESTIONS

1 LIFE CYCLE ANALYSIS (LCA)

The LCA describes the estimated CO_2 equivalent emission for building construction and building operation for a given time.



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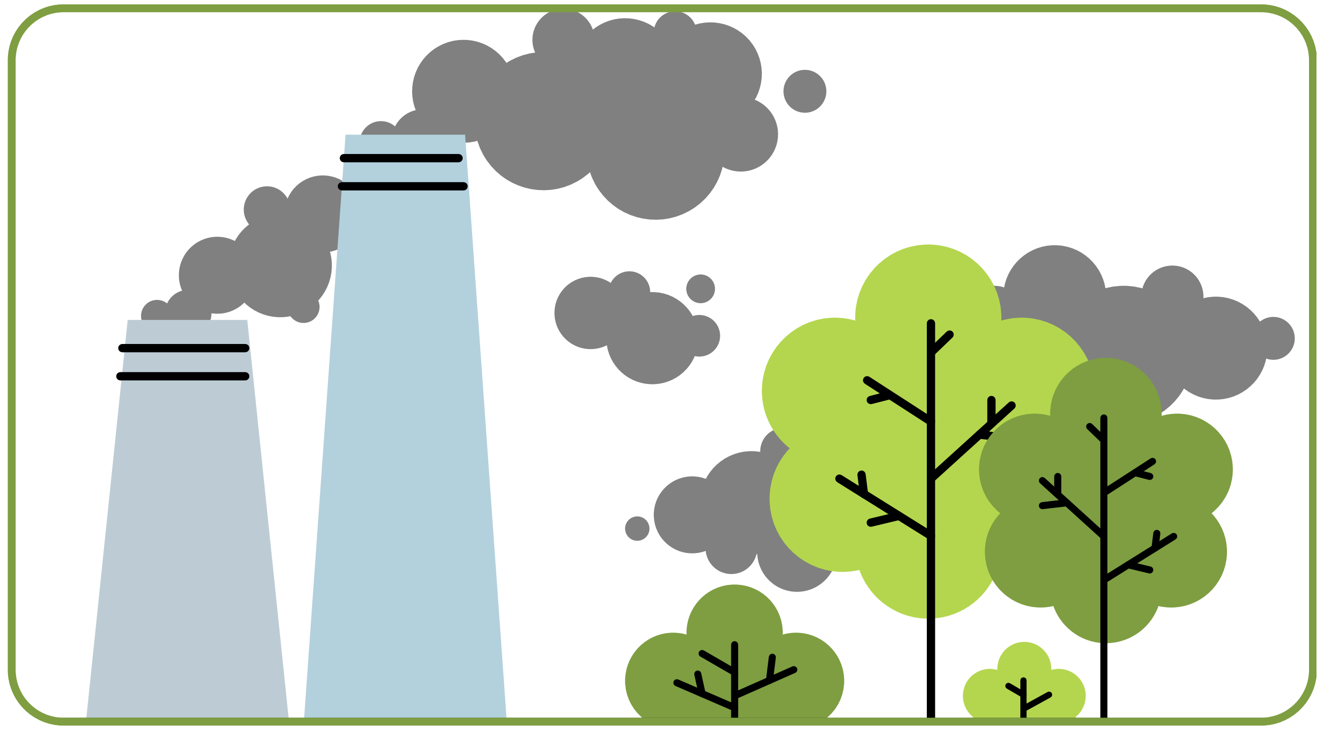
LIFE CYCLE COST (LCC)

The LCC describes the estimated cost for building construction and building operation for a given time



METHODS

This section elaborates on the methodologies employed, the (1) Heating and Cooling Systems Survey, which facilitated data collection for the case studies used to model (2) LCA, and (3) LCC.

Heating and Cooling Systems Survey

1

Collected information about the residential and office buildings used to build LCA and LCC models

2

LCA

Cumulative emissions over the lifetime of the building

Solutions

Optimal Heating and Cooling Systems

Initial Costs

Return on Investment

CO_2 emissions saved per $1 invested in upgrades

3

Cumulative costs over the lifetime of the building

METHODS

SINGLE FAMILY HOUSE

- Meets energy code for zone 5A
- Area 2400 sq ft,
- 4 bedrooms
- well-insulated structure, medium-quality windows, and standard HVAC
- but no renewable energy.

CASE STUDY

THE CASE STUDY

Characteristic	Description
Area	2400 sqft
Bedrooms	4
Construction Type	Stick platform framing (timber)
External Wall	Drywall, vapor retarder, 2x6 framing, fiberglass insulation (R20), OSB sheeting, weather membrane, Vinyl siding
Roof	Drywall, vapor retarder, 2x8 framing, fiberglass insulation (R38), OSB sheeting, weather membrane, Asphalt shingle roofing
Floor	Basement unconditioned (concrete), XPS insulation (R20), OSB sheeting
Windows	Casement windows (medium quality), U value 0.29, SHGC 50%
Flooring	Carpet, Hardwood floor, tiles
Internal Walls	Timber stick frame, acoustic insulation, drywall
Heating Unit	Furnace (gas)
Cooling Unit	AC unit integrated into enforced ventilation system (electric)
Warm Water Heating	Warm Water Tank (gas)
Mechanical Ventilation	Recirculation air ventilation for furnace and AC. No Heat Recovery technology
Renewable Energy	No
Equipment	Kitchen large size medium grade. 3.5 Bathrooms, no elevator

LCA AND LCC EQUATIONS & ASSUMPTIONS

LCA describes the estimated CO_2 equivalent emission for building construction and building operation for a given time.

$$LCA = Em,I + Em,Op * year$$

Em,I = CO_2 equivalent emission for building construction
Em,Op = CO_2 equivalent emission for building operation
Year = Number of years of observation

Assumptions: The LCA used in this study is based on a static method (no dynamic changes like specific CO_2 emissions).

LCC describes the estimated cost for building construction and building operation for a given time.

$$LCC = Cost,I + Cost,Op * year$$

Cost,I = CO_2 equivalent emission for building construction
Cost,Op = CO_2 equivalent emission for building operation
Year = Number of years of observation

Assumptions: The LCC used in this study is based on a static method (no dynamic changes in energy cost).

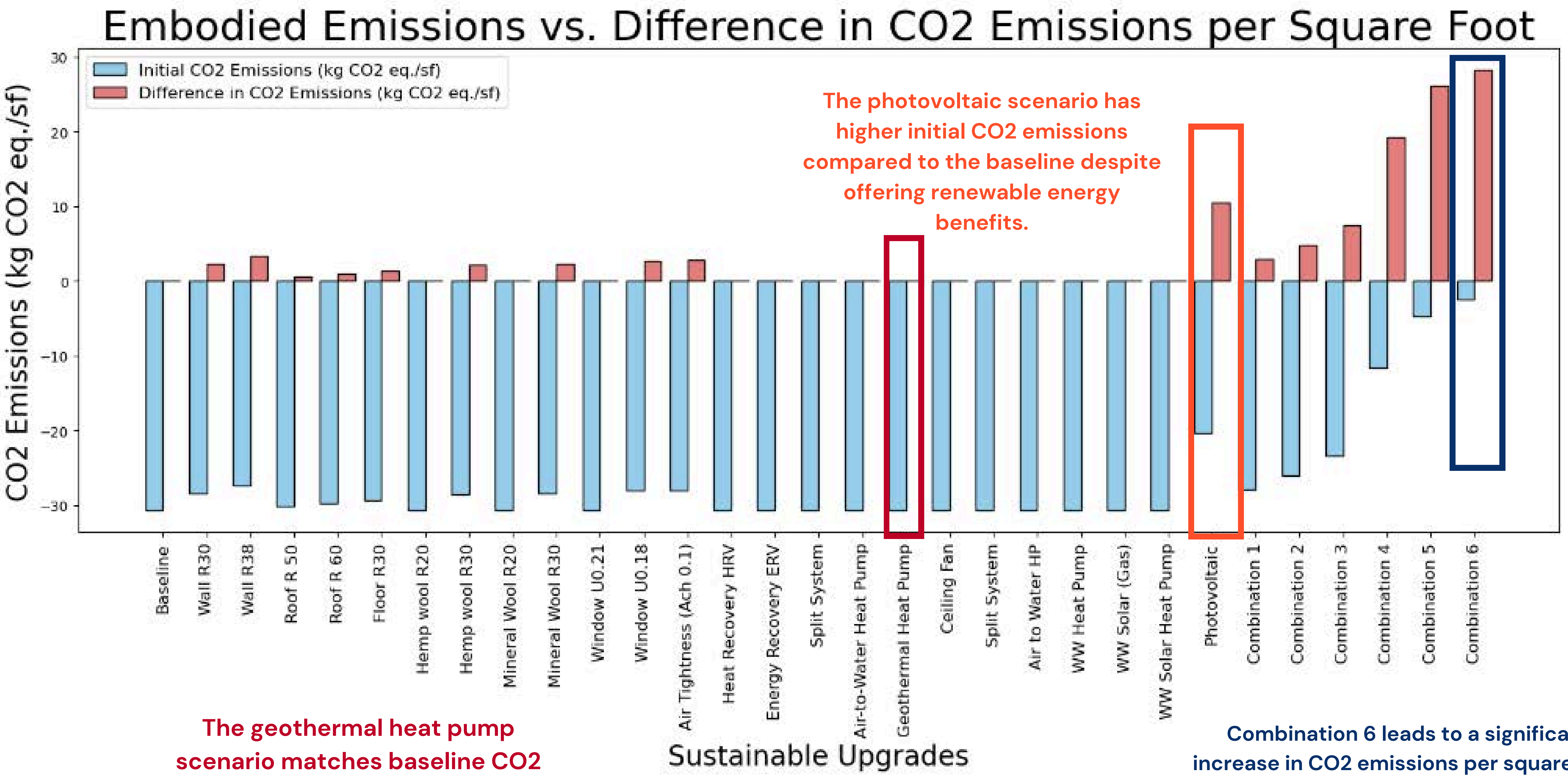
- The cost includes estimations for materials and labor costs.
- The soft construction cost is not included.
- The cost of financing is not included in the calculation.

METHODS

THE LCA AND LCC VALUES FOR EACH SUSTAINABLE UPGRADE FOR 10, 20, AND 30 YEAR SCENARIOS.

		LCA (Co2 equ/sf)			LCC ($/sf)		
#	Sustainable Upgrade	10	15	20	10	15	20
1	Baseline	81.61	119.06	156.51	245.49	255.00	264.50
2	Wall R30	77.56	112.89	148.22	246.60	255.66	264.72
3	Wall R38	75.96	110.43	144.89	246.92	255.79	264.67
4	Roof R 50	80.81	117.79	154.78	246.09	255.49	264.90
5	Roof R 60	80.42	117.16	153.90	247.08	256.43	265.79
6	Floor R30	79.31	115.56	151.80	245.66	254.92	264.17
7	Insulation Material Hemp wool R20	81.52	118.94	156.35	248.07	257.57	267.07
8	Insulation Material Hemp wool R30	77.55	112.90	148.25	249.65	258.71	267.77
9	Insulation Material Mineral Wool R20	81.61	119.06	156.51	246.37	255.87	265.38
10	Insulation Material Mineral Wool R30	77.56	112.89	148.22	248.46	257.52	266.57
11	Window U0.21	81.61	119.06	156.51	248.30	257.39	266.48
12	Window U0.18	76.27	111.03	145.80	250.97	259.91	268.85
13	Air Tightness (Ach 0.1)	76.05	110.72	145.39	251.88	261.38	270.89
14	Night Ventilation						
15	Heat Recovery HRV	62.78	90.81	118.85	250.75	258.07	265.39
16	Energy Recovery ERV	56.34	81.15	105.96	249.27	255.72	262.17
17	Split System	55.18	79.42	103.65	251.73	260.87	270.01
18	Air-to-Water Heat Pump	48.45	69.32	90.18	250.85	258.71	266.57
19	Geothermal Heat Pump	45.10	64.29	83.48	252.36	259.59	266.81
20	Ceiling Fan	74.93	109.04	143.15	235.86	244.10	252.34
21	Split System	83.89	122.48	161.07	240.85	250.79	260.73
22	Air to Water HP	80.78	117.82	154.85	245.18	254.53	263.87
23	WW Heat Pump	81.45	118.81	156.18	246.38	255.93	265.47
24	WW Solar (Gas)	80.95	118.07	155.19	247.40	256.83	266.27
25	WW Solar Heat Pump	80.92	118.02	155.13	248.23	257.67	267.12
27	Photovoltaic	67.38	96.60	125.82	244.14	251.58	259.01
30	Combination 1	76.79	111.68	146.57	247.20	256.17	265.13
31	Combination 2	73.09	106.12	139.14	250.05	258.62	267.19
32	Combination 3	67.88	98.30	128.72	250.93	258.89	266.85
33	Combination 4	44.27	62.88	81.49	250.76	255.84	260.93
34	Combination 5	30.51	42.25	53.98	253.44	257.83	262.22
35	Combination 6	26.16	35.72	45.28	279.63	289.14	298.64

RESULTS

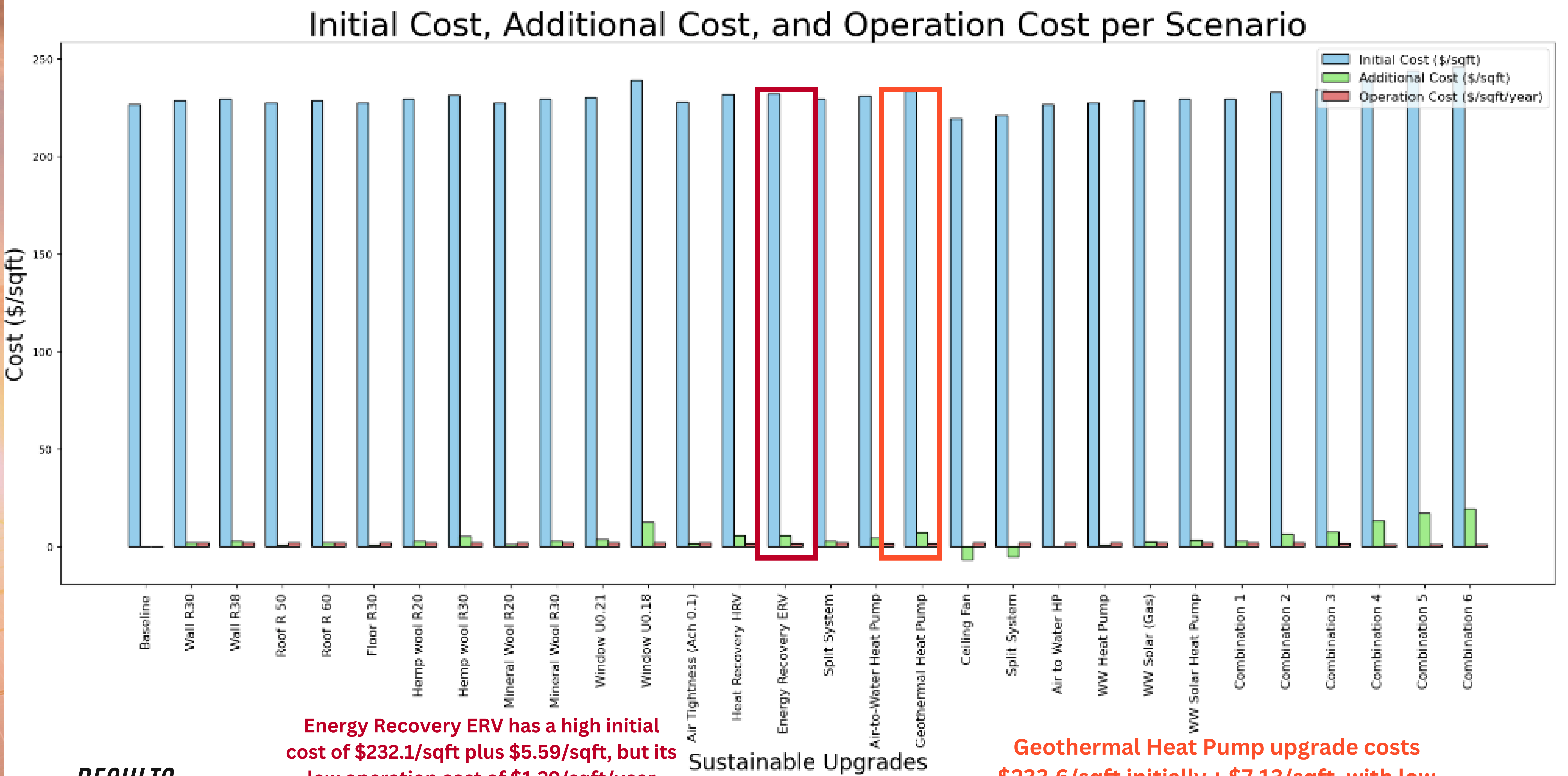


The photovoltaic scenario has higher initial CO2 emissions compared to the baseline despite offering renewable energy benefits.

The geothermal heat pump scenario matches baseline CO2 emissions with potential operational benefits.

Combination 6 leads to a significant increase in CO2 emissions per square foot, indicating a substantial environmental impact despite potential benefits.

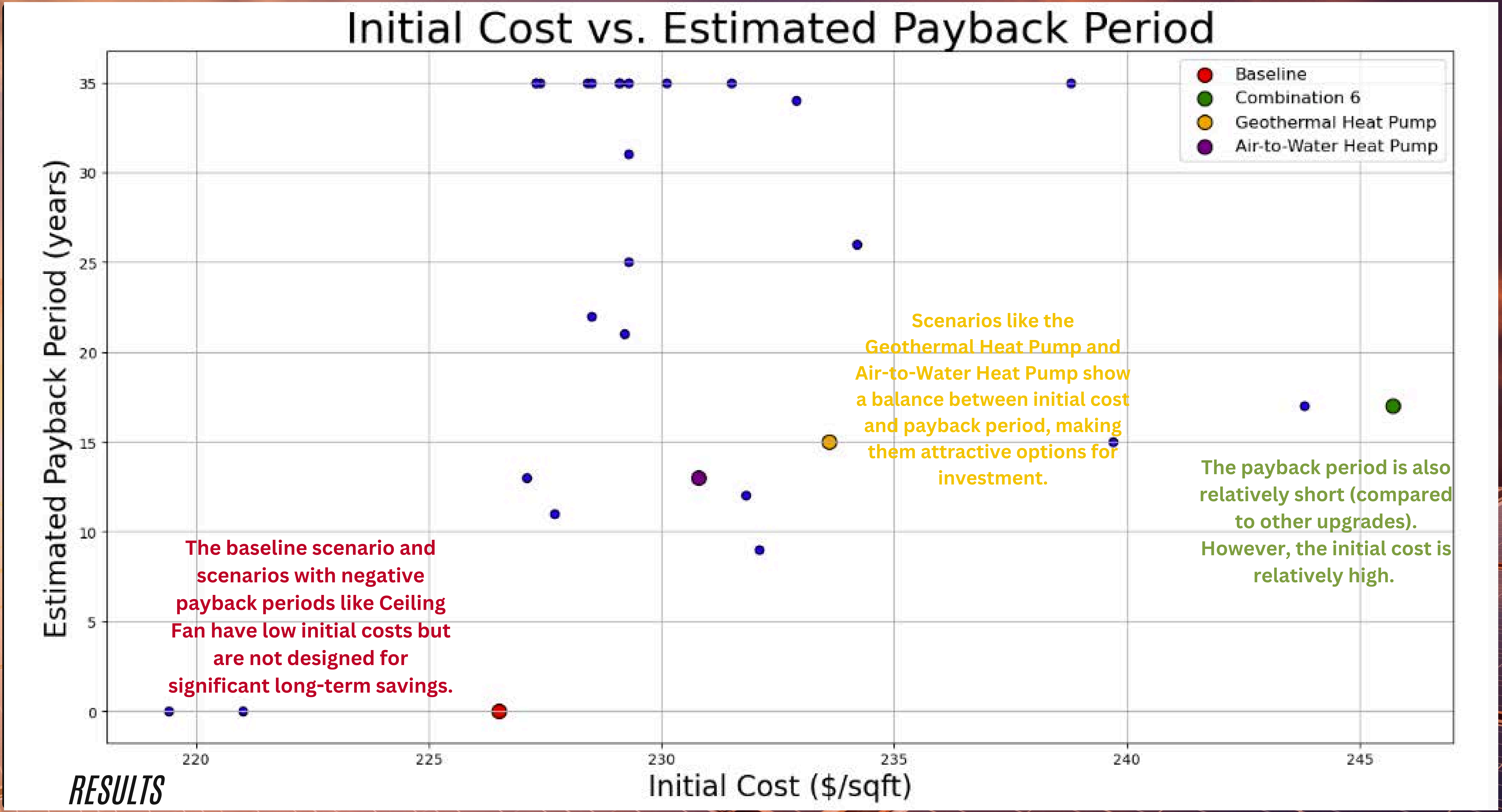
RESULTS



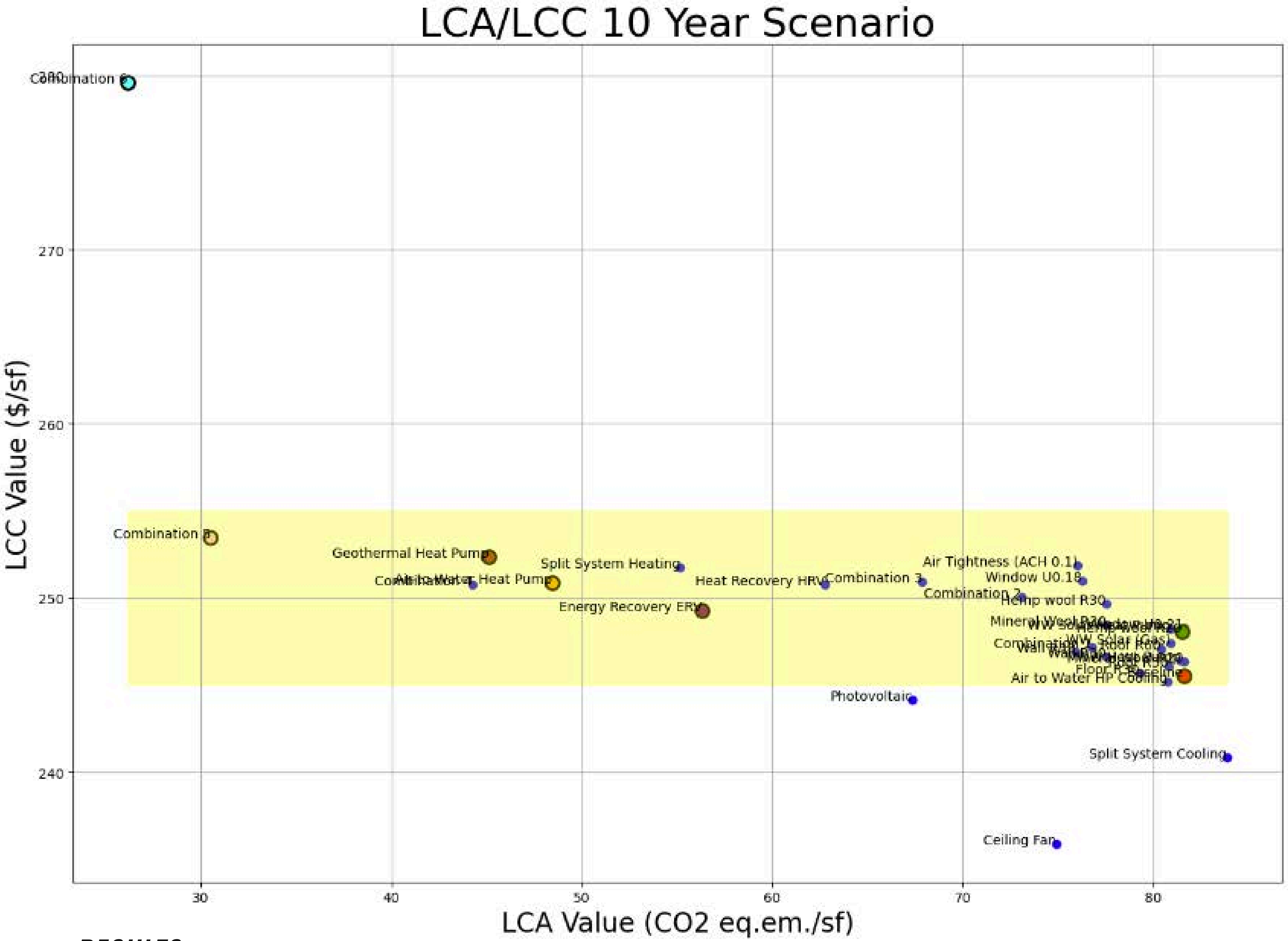
Energy Recovery ERV has a high initial cost of $232.1/sqft plus $5.59/sqft, but its low operation cost of $1.29/sqft/year makes it potentially cost-effective in the long term.

Geothermal Heat Pump upgrade costs $233.6/sqft initially + $7.13/sqft, with low yearly operation cost of $1.45/sqft.

RESULTS


Initial Cost vs. Estimated Payback Period
Estimated Payback Period (years)
Initial Cost ($/sqft)
0
5
10
15
20
25
30
35
220
225
230
235
240
245
Baseline
Combination 6
Geothermal Heat Pump
Air-to-Water Heat Pump
The baseline scenario and scenarios with negative payback periods like Ceiling Fan have low initial costs but are not designed for significant long-term savings.
Scenarios like the Geothermal Heat Pump and Air-to-Water Heat Pump show a balance between initial cost and payback period, making them attractive options for investment.
The payback period is also relatively short (compared to other upgrades). However, the initial cost is relatively high.

RESULTS



RESULTS

Geothermal heat pump scenario **reduces environmental impact by 44.73%** compared to baseline but is **2.80% more expensive**.

The hemp wool R20 scenario shows a **2.82% lower environmental impact** but is **1.05% more costly** compared to the baseline scenario.

The air-to-water heat pump has a **higher environmental impact than the geothermal heat pump by 7.42%.** However, it is **0.60% less expensive** than the geothermal heat pump.

The plot indicates that most technologies have LCC values between 245 and 255 $/sf, suggesting similar financial returns. Decisions on choosing technologies may be driven more by factors like environmental impact or operational benefits rather than cost differences.

FINDINGS

1. The investment into the geothermal heat pump is relatively high. The air-to-water heat pump has a shorter payback period and a smaller initial cost.
2. The use of insulation materials made of a natural material like hemp wool reduces the initial CO2 emission. However, the CO2 emission from building operations is not reduced.
3. The ERV system is strongly advised for its effective reduction in emissions and cost associated with building operation energy recovery ventilation.
4. The investment into an air-to-water heat pump has a relatively short payback time
5. Combinations of sustainable upgrades (Combination 5+6) have a significant reduction in CO2 emission for building operation. The payback period is also relatively short (compared to other upgrades). However, the initial cost is relatively high.
6. The use of a ceiling fan instead of an AC unit reduces initial cost, operation cost, and emission. It reduces thermal comfort in the cooling season
7. Window upgrades show moderate improvements in LCA but at a slightly higher cost.
8. The return on investment for upgrades is not significant. Therefore, the main incentives may be reducing emissions and improving health benefits.

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Acknowledgements

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REFERENCES AND SOFTWARES

01

Cost calculation: RS Means Database (University of Michigan)
RS Means is a tool to estimate the construction cost in the US

02

Material Data Emission:
Hegger, Auch-Schwelg, Fuchs, Rosenkranz, “Construction Materials Manual”, Birkhäuser Architecture; 2006th edition (July 21, 2006)
ISBN-10 : 3764375701
https://www.ubakus.de/bauteilkatalog/

03

The data for the embodied CO2 equivalent emission is based on the internationally respected standard EN 15804. The data is updated in the year 2022