Energy Efficiency Upgrades & Lifecycle Carbon
The Association for Energy Affordability, Inc. is dedicated to achieving energy efficiency in new and existing buildings in order to foster and maintain affordable and healthy housing and communities, especially those of low-income.

With locations in NY, CA, and IL, AEA representatives engage in a broad range of educational, technical and construction management activities and services to promote this mission and develop the industry that advances and sustains it.

• Energy Efficiency Program Design and Implementation
• Energy Research & Demonstration Projects
• Energy Audits and Green Building Design for New Construction and Existing Buildings
• Provider of Weatherization Assistance Program Services
• National Weatherization Training Center
Tackling the Biggest Carbon Sources in Existing Buildings
Building emissions in California

Fragmented view of building sector emissions:
- Residential
- Commercial
- Electricity
- Industry

Ignores out-of-state methane leakage

Demand view of building emissions, including:
- Direct onsite emissions
- Emissions from electricity generation
- Fugitive methane from extraction, distribution, use

Source: Vukovich, Delforge, NRDC blog, The Real Climate Impact of California’s Buildings, 9/18/2018
As electricity is getting cleaner, emissions from burning natural gas are becoming the majority of energy-related emissions from buildings.

![Average Household CO2 emissions from energy use](chart.png)

- Note including emissions from methane and other high global warming potential gases
Heat Pumps Can Do It

Mostly

CA Residential Natural Gas Consumption

- Water Heating 49%
- Space Heating 37%
- Pool/Spa/Misc 4%
- Cooking 7%
- Dryer 3%

Data: 2010 California Residential Appliance Saturation Survey. Images: Mitsubishi, Frigidaire, Hayward, Electrolux, Sanden
Water heater CO2 emissions*
As CA grid gets cleaner, HPWH offer pathway to very low-GHG hot water

![Graph showing CO2 emissions comparison for different water heaters]

- Electric resistance (COP 0.96)
- Gas, storage tank (COP 0.6)
- Gas, tankless condensing (COP 0.95)
- Electric heat pump (COP 2.7)

1) Not including fugitive methane emissions
2) 45%-efficient combined cycle gas plant (build margin)
But what about the high-GWP refrigerants?

- Many heat pumps, air conditioners, and refrigerators use refrigerants with high GWP.
- Regulations and technical advances should bring these lower.
- Reducing system size and complexity based on energy efficient load reductions reduces volume of refrigerant.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R404a</td>
<td>3,922</td>
</tr>
<tr>
<td>R410a</td>
<td>2,088</td>
</tr>
<tr>
<td>R22</td>
<td>1,810</td>
</tr>
<tr>
<td>R407c</td>
<td>1,774</td>
</tr>
<tr>
<td>R134a</td>
<td>1,430</td>
</tr>
<tr>
<td>R32</td>
<td>675</td>
</tr>
<tr>
<td>R290 (propane)</td>
<td>3</td>
</tr>
<tr>
<td>R744 (carbon dioxide)</td>
<td>1</td>
</tr>
</tbody>
</table>

Typical Space Heating

Typical Heat Pump

Water Heater

750: CARB’s Proposed 2023 regulations for A/C

CO2 based heat pumps (ex. Sanden)
Is All Efficiency Equal through the Lens of Carbon?
Not all electricity usage is equal. Therefore, not all EE is equal. Emissions intensity will change over time.

Grid-interactive heat pump water heaters can help integrate renewable energy

NRDC and Ecotope study, ACEEE Aug. 2018
Lifecycle Carbon of Existing Building Upgrades
Annual Emission: Operational Only

- Highest efficiency first time
- Moderate efficiency needing re-upgrade
Annual Emission: Operational + Embodied Carbon

- Highest efficiency first time
- Moderate, then re-upgrade
Cumulative Emission: Operational + Embodied Carbon

- Highest efficiency first time
- Moderate, then re-upgrade
Stranded Assets of Gas Equipment

- **Gas Lines**
  - Meter to Equipment
  - For New Construction, utility hookups to meter
  - Both can be $$$

- **Combustion Venting Equipment**
  - Metal, PVC, or stainless steel venting to remove combustion gasses from equipment

- **Envelope Penetrations**
  - For venting (roof or wall) and gas lines (walls or floors)
Carbon Perspective on Energy Loading Order:

- Reduce loads as small as possible, to make equipment smaller, easier and cheaper

- High Performance Envelopes and Ventilation systems can mean
  - Smaller Heat Pumps for Space Heating
  - Possibly Low-Cost Electric resistance for heating (no refrigerant GHGs)

- Efficient Plumbing Fixtures and Distribution Systems
  - Smaller, simpler heat pump water heaters

- Smaller Renewable Energy Systems to offset overall energy use
Empire State Building Case Study


For more information, please visit www.esbsustainability.com
I. MOTIVATION

1) Prove or disprove the economic viability of whole-building energy efficiency retrofits.

Prior to 2008, the Empire State Building’s performance was average compared to most U.S. office buildings.

**Annual utility costs:**
- $11 million ($4/sq. ft.)

**Annual CO2 emissions:**
- 25,000 metric tons (22 lbs/sq. ft.)

**Annual energy use:**
- 88 kBtu/sq. ft.

**Peak electric demand:**
- 9.5 MW (3.8 W/sq. ft. inc. HVAC)
**WINDOWS**
Remanufacture 6,500 existing dual glazed windows
Add suspended film between panes, fill with argon gas
R-2 to R-8

**RADIANT BARRIERS**
Install more than 6,000 radiant barriers behind existing radiators at perimeter of building
CHILLER PLANT RETROFIT
Retrofit + controls, variable speed drives and primary loop bypass

VAV AIR HANDLING UNITS
Replace existing constant volume units with Variable Air Volume units using 2 floor mounted instead of 4 ceiling mounted
III. KEY FINDINGS

1) Eight interactive levers ranging from base building measures to tenant engagement deliver these results.

Energy and CO2 savings in the optimal package result from 8 key projects.

Annual Energy Savings by Measure

Embodied carbon investment

38% Reduction = 8.3 metric Tons/year
III. KEY FINDINGS

1) Eight interactive levers ranging from base building measures to tenant engagement deliver these results.

Though it is more informative to look at financials for the package of measures, capital costs and energy savings were determined for each individual measure.

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Projected Capital Cost</th>
<th>2008 Capital Budget</th>
<th>Incremental Cost</th>
<th>Estimated Annual Energy Savings*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows</td>
<td>$4.5m</td>
<td>$455k</td>
<td>$4m</td>
<td>$410k</td>
</tr>
<tr>
<td>Radiative Barrier</td>
<td>$2.7m</td>
<td>$0</td>
<td>$2.7m</td>
<td>$190k</td>
</tr>
<tr>
<td>DDC Controls</td>
<td>$7.6m</td>
<td>$2m</td>
<td>$5.6m</td>
<td>$741k</td>
</tr>
<tr>
<td>Demand Control Vent</td>
<td>Inc. above</td>
<td>$0</td>
<td>Inc. above</td>
<td>$117k</td>
</tr>
<tr>
<td>Chiller Plant Retrofit</td>
<td>$5.1m</td>
<td>$22.4m</td>
<td>-$17.3m</td>
<td>$675k</td>
</tr>
<tr>
<td>VAV AHUs</td>
<td>$47.2m</td>
<td>$44.8m</td>
<td>$2.4m</td>
<td>$702k</td>
</tr>
<tr>
<td>Tenant Day/Lighting/Plugs</td>
<td>$24.5m</td>
<td>$16.1m</td>
<td>$8.4m</td>
<td>$941k</td>
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<tr>
<td>Tenant Energy Mgmt.</td>
<td>$365k</td>
<td>$0</td>
<td>$365k</td>
<td>$396k</td>
</tr>
<tr>
<td>Power Generation (optional)</td>
<td>$15m</td>
<td>$7.8m</td>
<td>$7m</td>
<td>$320k</td>
</tr>
</tbody>
</table>

*Note that energy savings are also incremental to the original capital budget.*
Consider Carbon Payback

Embodied carbon “investment”

Reduced operational carbon “savings” or “return”

Energy efficiency measures can have short or long “payback”
high or low ROI