Urban Energy Consumption

MINIMIZING HVAC CONSUMPTION THROUGH URBAN RETROFITS

Across different climate zones, HVAC (Heating, Ventilation and Air Conditioning) usage constitutes 43–59% of US building energy consumption. A notable portion of this energy, though, is wasted due to inefficiencies. Since over 81% of the US population lives in urban areas, state and federal agencies have funded initiatives for cities to reduce this waste. With limited funds available to them, CSHub has developed methods for cities to pinpoint buildings with the greatest saving potential to minimize carbon emissions from HVAC usage.

Instead of using traditional rating tools that measure efficiency in relation to a local average, our methods combine data from gas bills, building footprints and physical simulations. The result is a more scalable understanding of building energy saving potential that can readily inform targeted urban retrofits.

CASE STUDY: CAMBRIDGE MASSACHUSETTS

Our research looks at almost 6200 individual residential buildings in Cambridge, MA using billing data gathered over a three-year period (2007-2009). This data, taken from a utility company, was measured in kilowatt-hours (kWh) per parcel and focused entirely on gas consumption. Gas consumption per square meter was then matched with monthly mean weather data gathered from the closest weather station at Logan International Airport in East Boston and Winthrop, Massachusetts.

Analyzing Gas Consumption

- We found that gas bills provide a direct means to quantitatively determine thermal efficiency of buildings at city scale.
- A building with high thermal efficiency uses less gas in the winter than a building of low thermal resistance in the summer.
- Gas consumption exhibits a linear form with respect to the outdoor temperature separated by a cut-off temperature. The slope of the linear form is the inverse of the thermal efficiency of a building. (See Fig. 1)
- The cut off temperature indicates the point at which consumers feel the need to turn on their heating systems to maintain indoor spaces at a desired comfort temperature.
- Below this cut-off temperature, gas consumption does not vary significantly. This provides a baseline of gas usage which is likely generated by hot water production.

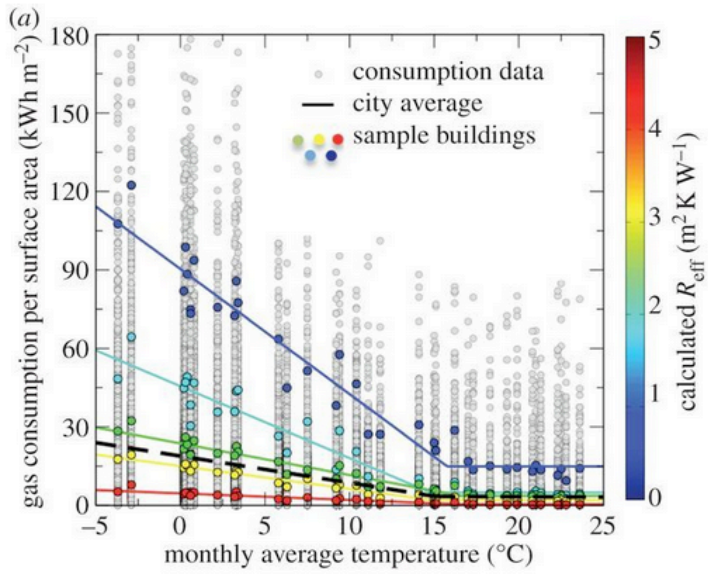

Fig. 1 – Gas consumption per surface area as a function of monthly average temperature for more than 6200 buildings. Five sample buildings are highlighted based on their effective thermal resistance.

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Comfort Temperature

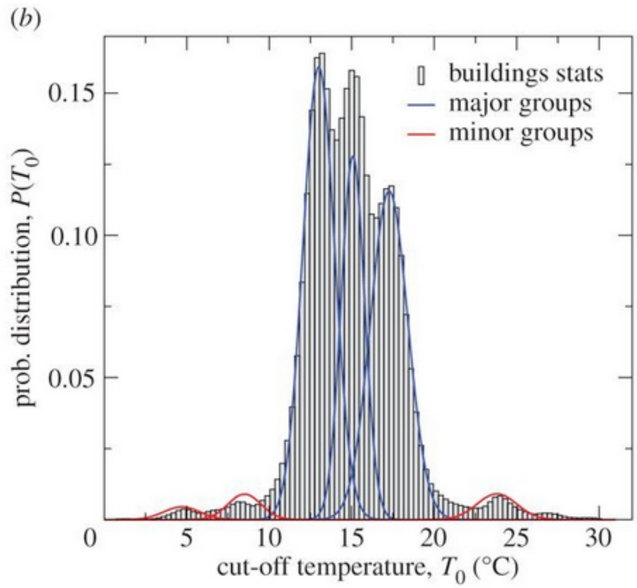

Fig. 2 – Distribution of the cut-off temperature.

- One issue that has challenged the implementation of large-scale retrofits is a quantitative understanding of the comfort temperature of the occupants of buildings.
- Instead of focusing on random factors like as age, humidity, and health, to determine comfort temperature, we chose to look at fuel consumption and outside temperature data.
- <u>We actually found that comfort temperature is quite predictable if it is stated in terms of the outside temperature, not the inside temperature.</u>
- 93% of recorded cutoff temperatures fell between outside temperatures of 13°C to 17°C. This relative lack of variance (See Fig. 2) suggests that comfort temperature relates not only to random factors like occupancy, humidity etc., but foremost to the temperature outside and the thermal efficiency of the building.
- <u>If comfort temperature can be quantified as an outside temperature threshold, then we can attribute excess gas consumption primarily to a building's thermal efficiency. This in turn enables retrofitting on an urban scale.</u>

The Parameters of Fuel Consumption

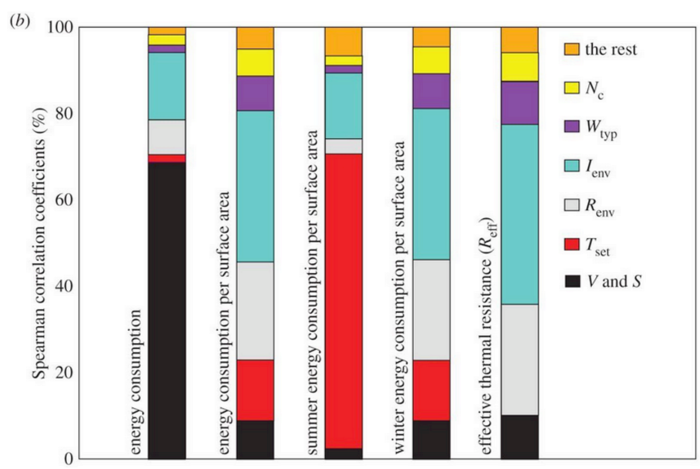

Fig. 3 – This figure describes the impacts of different parameters on energy consumption and effective thermal resistance.

- For cities to retrofit their building stock, they must be able to quickly and accurately determine which factors influence a building's fuel consumption. We have broken down these primary factors and determined which ones should be used to identify retrofits.
- Using an hourly energy simulation, we found 7 parameters (See Fig. 3) that had a significant impact on monthly heating energy consumption. These are:
  1. Building volume (*V*)
  2. Building envelope surface area (*S*)
  3. Number of neighbors sharing a wall with the building (N_c)
  4. Effective thermal resistance of the building envelope (R_{env})
  5. Air infiltration rate (I_{env})
  6. Average temperature set point (T_{set})

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7. Window type indicating the number of glazing (W_{typ}).

- During the winter months the temperature set had less influence on energy consumption due to the difference in interior and exterior temperatures. That is, the inside-outside temperature differential dominates over the variability of set temperatures from one building to another.
- While these 7 factors are all significant when retrofitting on a building by building basis, for the sake of identifying which buildings to retrofit, they can be further reduced to the three most impactful factors. These are:
  1. Effective thermal resistance of the building envelope (R_{env})
  2. Window type indicating the number of glazing (W_{typ})
  3. HVAC efficiency (η_H)

Implementing Retrofits on an Urban Scale

- Numerous strategies exist by which to identify and target potential buildings for retrofit. (See Fig. 4)
- The black line in **Fig. 4** represents the conventional method by which owners volunteer to retrofit their buildings to receive tax incentives. This method is effectively random.
- Using the metric of E^{-}, or overall building energy consumption, to target potential retrofits has a far greater energy saving potential than every other scenario except for ΔE. (See Fig. 4)
- ΔE represents the energy saving potential of a building after retrofitting; that is the difference of energy consumption before and after retrofitting.
- Using ΔE, we found that if Cambridge were to retrofit only 16% of its building stock, it could see a 40% reduction in overall gas consumption.

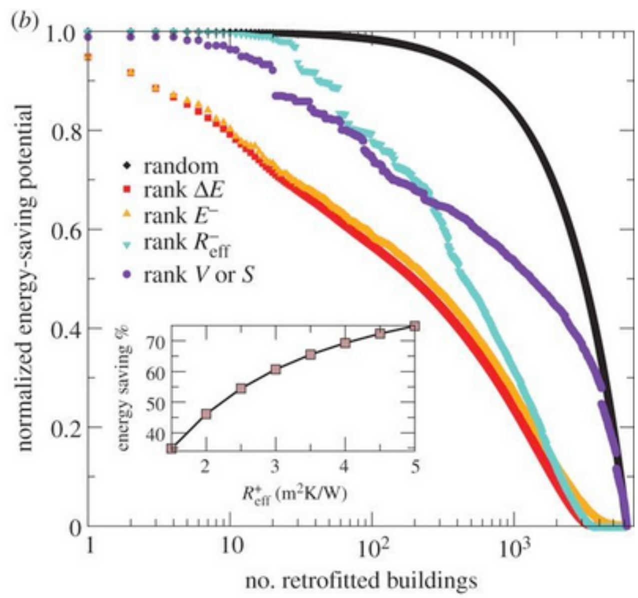

Fig. 4 – A comparative study between different retrofit scenarios in comparison with random (blind retrofit) on the city scale.

- By contrast, if using the random selection procedure, Cambridge would need to retrofit 67% of its building stock to see a similar reduction in overall gas consumption.
- After targeting buildings to retrofit using ΔE, municipalities could incentivize these retrofits by:
  1. Employing mortgage underwriting programs that require owners to account for the gas consumption of their building.
  2. Setting a target for an effective R_{eff} for new construction in order to meet a city-wide target.
  3. Providing tax incentives to buildings with high R_{eff}.

References:

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