Building Energy Simulation Paper Title

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1 Abstract

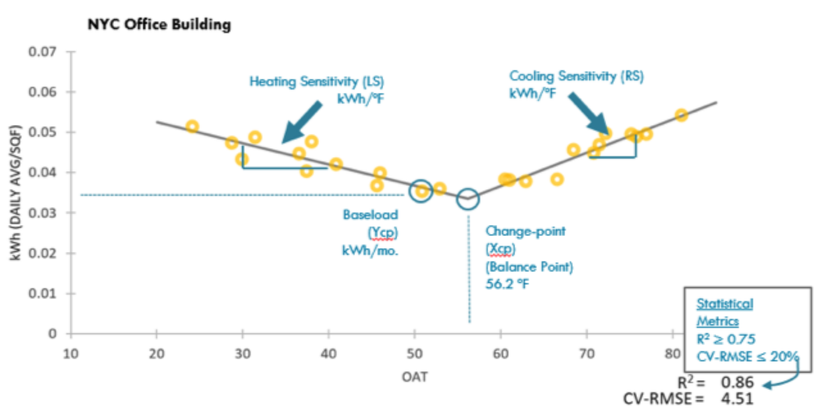
2 Introduction

The U.S Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS) estimates that there were 5.6 million commercial buildings in the United States in 2012, comprising 87 billion square feet of floorspace. These buildings consumed 6,963 trillion Btu in site energy. In 2014, New York City buildings were responsible for 73 percent of citywide greenhouse gas (GHG) emissions through the use of natural gas, electricity, heating oil, steam, and biofuel.

We propose to build on the methodology described in the papers below on change-point regression modeling of building energy use to investigate energy use in New York City. The practice of using inverse modeling to analyze historical facility energy consumption has been widely researched and employed in the industry since the late 1990s; however, the proposed inverse simulation methodology is a relatively new concept and has not been widely reviewed in the literature. As the research in question was developed on industrial facilities and single-family homes, it is unclear as to whether the methodology is applicable to the commercial real estate sector (i.e., office buildings) in New York City.

3 Literature Review

4 Methodology



4.1 Data Sources & Preparation

4.2 Building Comparison (Sonya)

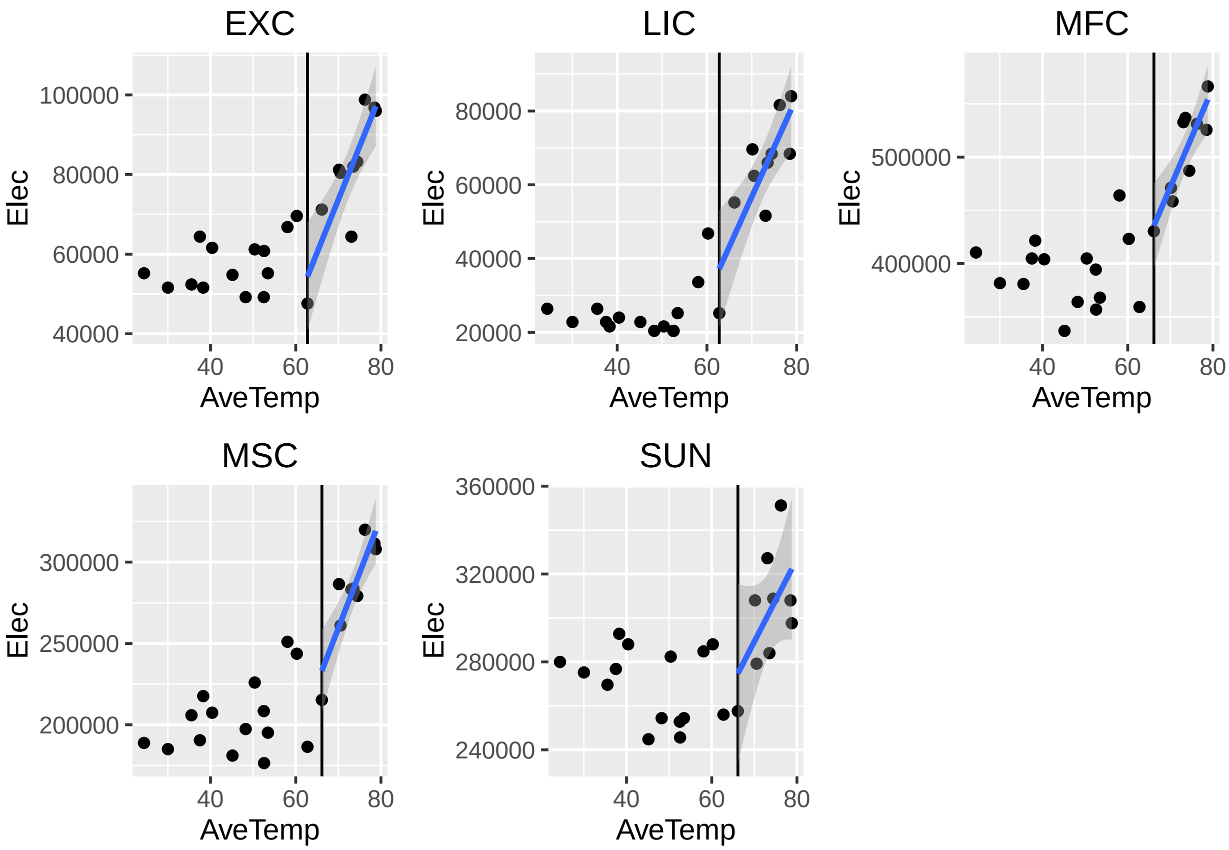
4.3 Change-point Regression

Heating and cooling energy consumption varies according to ambient air temperature in addition to baseline use for non-temperature regulating consumtion like cooking (gas) or lighting (electricity). A changepoint analysis was preformed on both electricty and fuel data using the R package *changepoint* (Killick and Eckley, 2014).

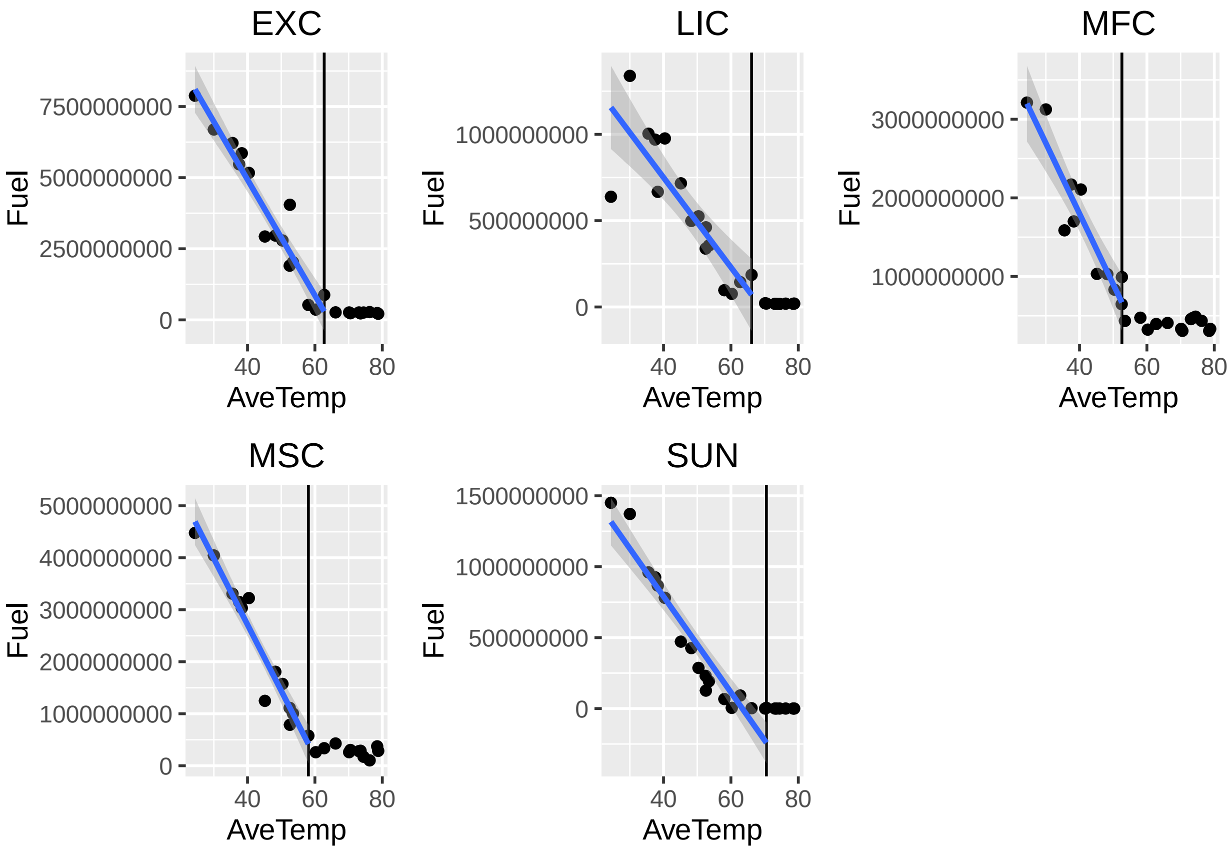
The changepoint analysis utilized the AMOC method (At Most One Change) to specify a single changepoint for each electricity and fuel consumption series with no loss function. For electricty, the changepoint was determined using the mean of the electricty load data. Given the wide range of electricity loads over the observed temperature range, the change in mean at warmer temperatures leads to an identifiable changepoint. For fuel, both mean and variance changes were incorporated to determine the changepoint, as at warmer temperatures there is very little change in the fuel load (i.e. the baseline load has very little variance, but the load during warming temperatures does).

After determining the changepoints, a linear regression model was fit to the electricty load observations at temperatures greater than or equal to the changepoint. For fuel load the linear regression model was fit to observations less than or equal to the changepoint. These two linear models represent the observed response rates of energy load to changes in average monthly outside air temperature.

	EXC	LIC	MFC	MSC	SUN
Elec	47600	25200	430400	215323	257600
AveTemp	62.75806	62.75806	66.13548	66.13548	66.13548



	EXC	LIC	MFC	MSC	SUN
Fuel	876396000	185900000	992214000	578397958	4776000
AveTemp	62.75806	66.13548	52.57667	58.06452	70.53




```
##
## Call:
## lm(formula = Elec ~ AveTemp, data = df %>% filter(Facility ==
##     bldg) %>% filter(AveTemp >= elec.changepoints["AveTemp",
##     ]$bldg))
##
## Coefficients:
## (Intercept)      AveTemp
##     -131947         2695
```

```
##               LIC
## AveTemp 62.75806
##         LIC
## Elec 25200
```

```
##        1
## 83687.98
```

4.3.1 Building:LIC Model

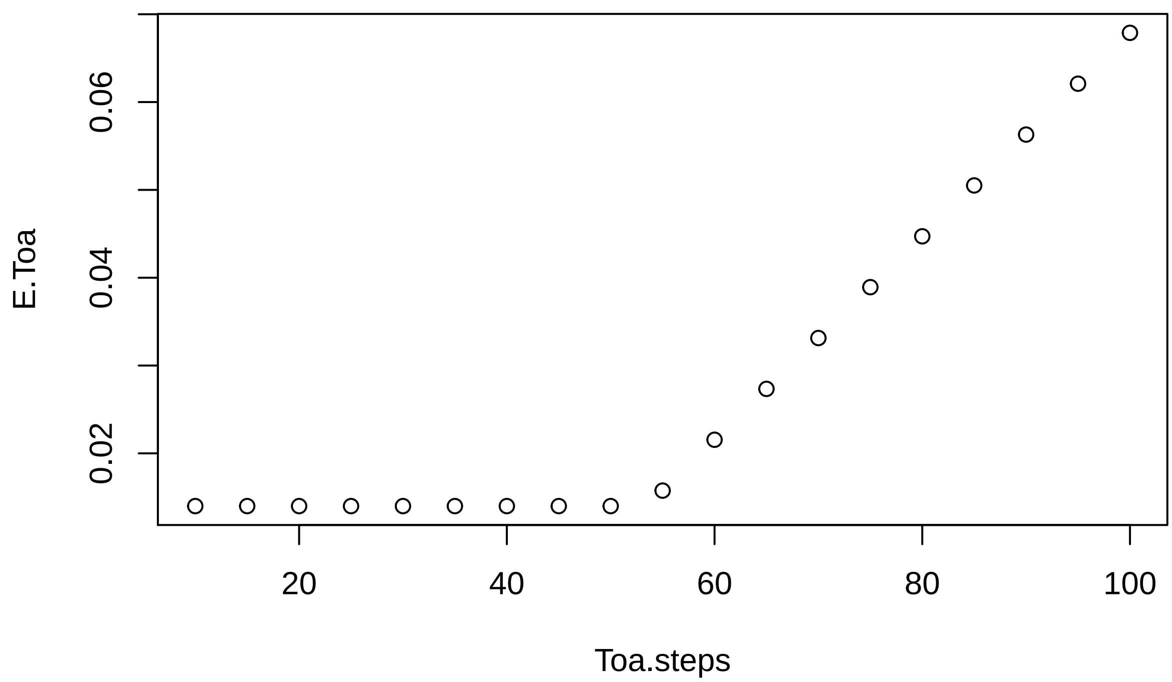
```
## Expected kWh at Toa: 0.04471509
```

```
## Cooling Coefficient: 15502.5
```

```
## Cooling efficiency: 13383842

## Internal loads: 178588.9

##           parameters
## 1         0.31000000
## 2     50000.00000000
## 3         2.00000000
## 4         1.19600000
## 5         1.04700000
## 6         0.00115830
## 7        53.48000000
## 8        65.00000000
## 9         0.01399697
## 10       80.00000000
## 11        0.04471509
## 12    15502.50442400
## 13 13383842.20322887
## 14   178588.85096448

##                U              A              V            rho             cp
##          0.31000    50000.00000        2.00000        1.19600        1.04700
##               CS           TcpC           Tset             Ei            Toa
##          0.00116       53.48000       65.00000        0.01400       80.00000
##                E             CC           Effc             Qi
##          0.04472    15502.50442 13383842.20323   178588.85096

## Expected kWh at Toa: 0.04471509

## Cooling Coefficient: 15502.5

## Cooling efficiency: 13383842

## Internal loads: 178588.9
```

Assumptions made for model can be simulated:
- Sim #1: Toa – use CP Model Equation and simulate Toa from 10-100 degrees F in steps of 5 degrees
- Sim #2: Tset – substitute other values from 50 to 75, in steps of 5 degrees – this simulates setting the thermostat lower or higher
- Sim #3: U – substitute other values: 0.25, 0.18, 0.12, 0.09 – this simulates adding insulation, etc. to tighten building envelope
- Sim #4: V – substitute other values: 1 to 3, in steps of 0.5 – this simulates improved/worse ventilation/infiltration flow rate (lower is)

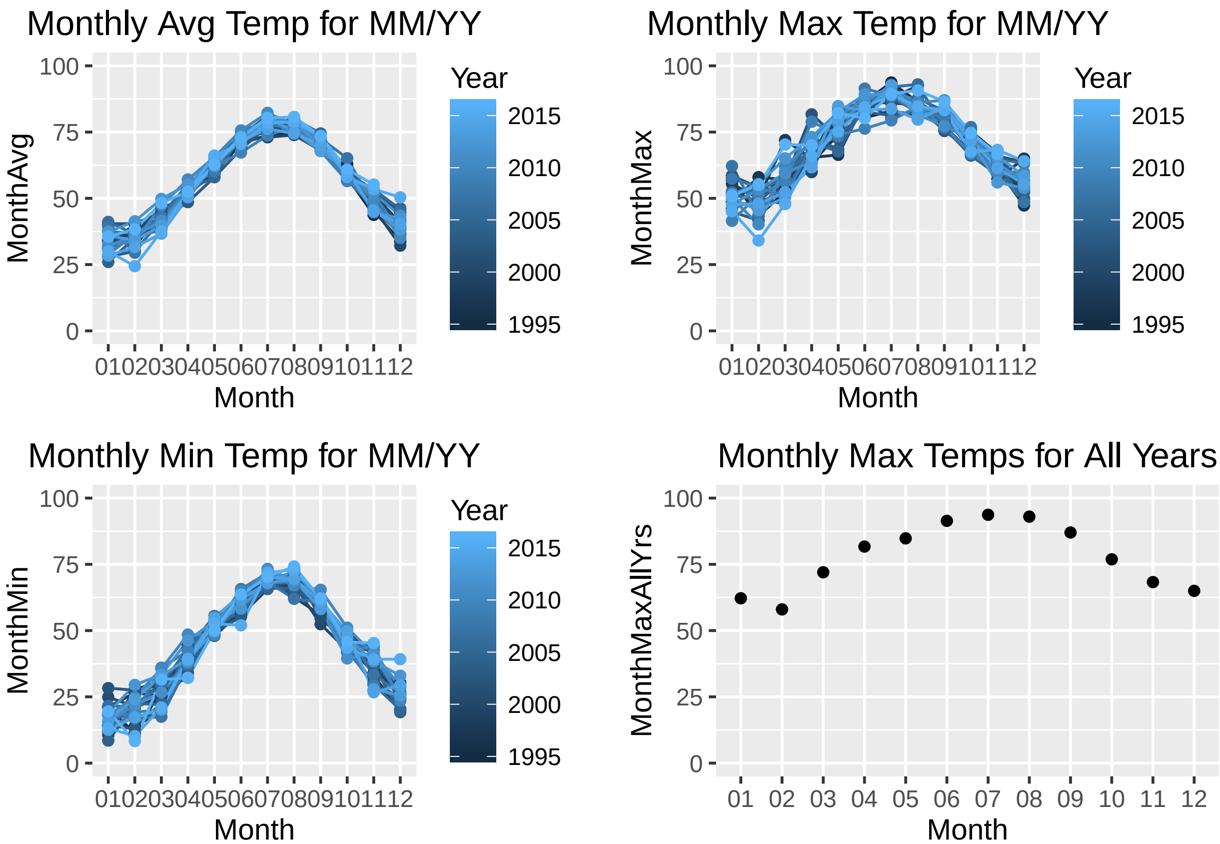
5 Sim 1: Toa



5.0.1 Weather Sampling Utilities:

We need a single temperature per month, but that single temperature can be chosen in a variety of ways. Various strategies could include the following:

- The mean temperature for the specified month and year
- The maximum temperature for the specified month and year
- The minimum temperature for the specified month and year
- The maximum temperature for the specified month for ALL years



5.0.2 Random Sampled Temperatures by Month

We will sample a random day per month for the specified year as our sampling strategy. Below is an example of the output:

```
##    [1995 Month] [1995 Sampled Temps]
## 1            01                 56.9
## 2            02                 31.3
## 3            03                 47.6
## 4            04                 52.2
## 5            05                 50.7
## 6            06                 76.8
## 7            07                 81.2
## 8            08                 73.2
## 9            09                 68.3
## 10           10                 61.7
## 11           11                 46.3
## 12           12                 41.5

##    [1997 Month] [1997 Sampled Temps]
## 1            01                 36.4
## 2            02
## 3            03                 37.5
## 4            04                 51.4
## 5            05                 57.3
```

```
## 6            06                 55.8
## 7            07                   76
## 8            08                 74.7
## 9            09                 75.1
## 10           10                 72.6
## 11           11                 35.2
## 12           12                 47.2

##    [1999 Month] [1999 Sampled Temps]
## 1            01                 25.5
## 2            02                   36
## 3            03                 43.4
## 4            04                   53
## 5            05                 60.8
## 6            06                 78.8
## 7            07                 83.1
## 8            08                   65
## 9            09                 65.9
## 10           10                 50.9
## 11           11                 59.9
## 12           12                 30.2
```

5.1 Sensitivity Analysis and Temperature Sampling

6 Results

7 Conclusions

8 Citations

Killick, R., Eckley, I., changepoint: An R Package for Changepoint Analysis. Journal of Statistical Software, June 2014 58:3.

9 Appendix I - Figures & Tables