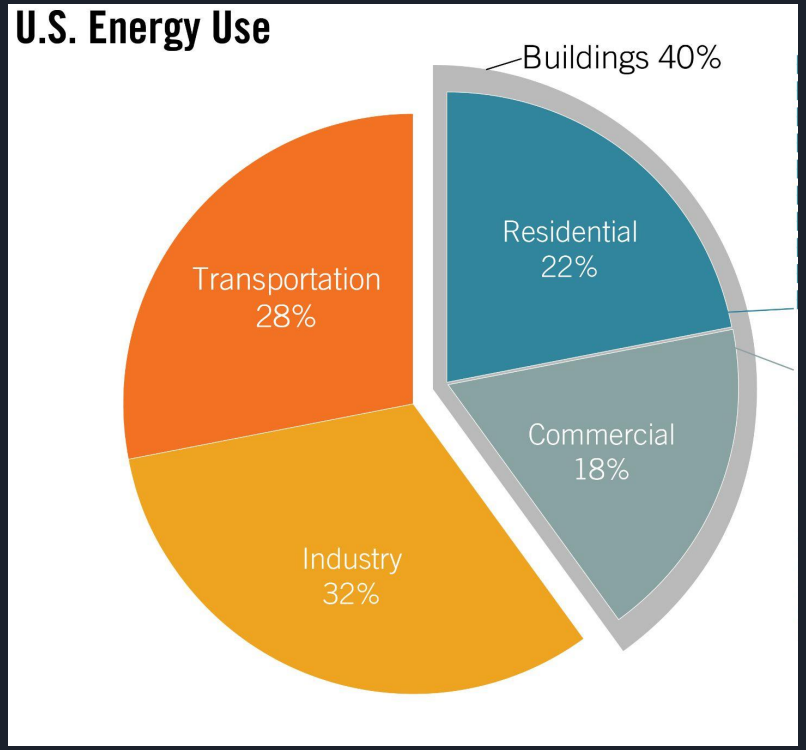
Modeling Energy Efficiency

SDS 322E

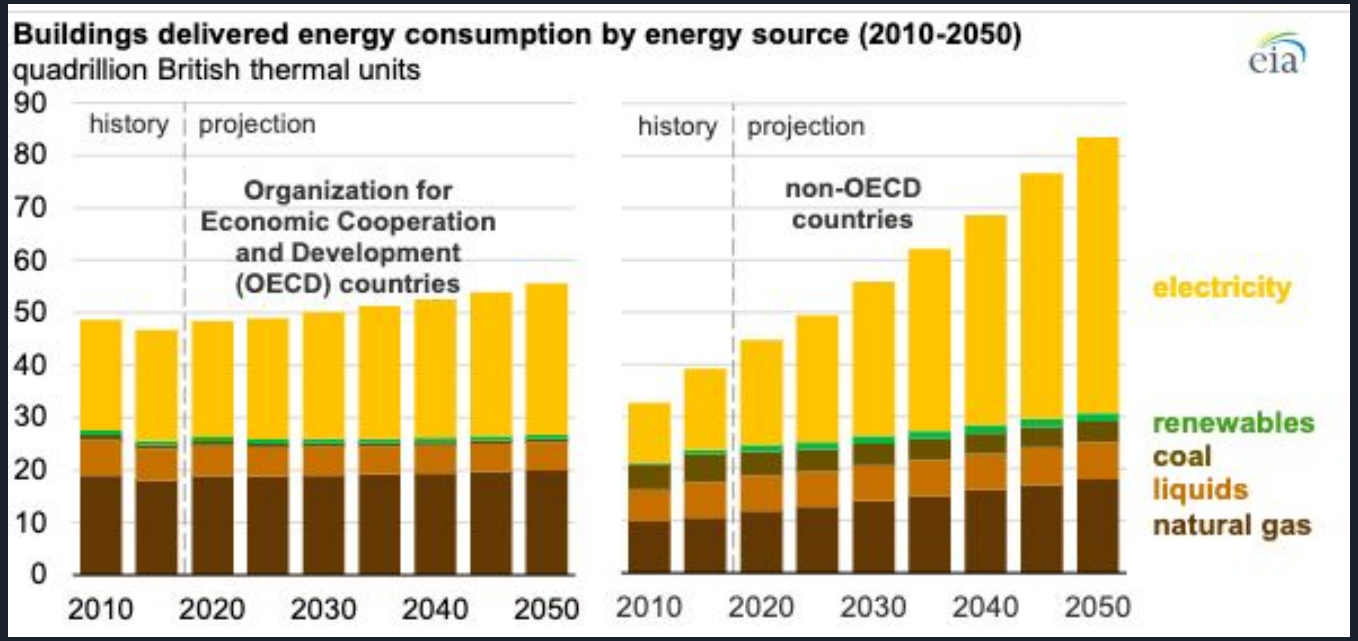
By: Ahad Kesaria, Michael Kobrosky, Mike Truong, Naima Sagar, Naila Hajiyeva, Rahul Ranganath, Varunika Selvakumar

Introduction



- Our project is about the energy performance of buildings
- Governments around the world are looking to reduce their energy wastage and carbon footprints
- Many nations have implemented laws which require all buildings to meet a minimum energy efficiency requirement

Motivation



- Building energy consumption has been steadily increasing worldwide
- Most of most this energy use can be accounted for by HVAC systems
- Nations can reduce their carbon footprints and reduce power costs by designing more energy efficient buildings

Data Description

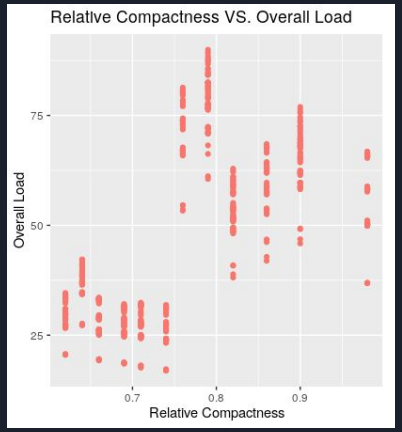
- Our dataset is from a study of 768 simulated residential buildings based in Athens, Greece
- 8 building attributes were measured and their effects on cooling load, heating load and overall load were analyzed
  - Relative compactness - buildings surface area to volume ratio
  - Surface area, Wall area, Roof area, and Overall height - measured in meters
  - Orientation - was the building facing North, South, East, or West?
  - Glazing area - the amount of glass in the building expressed as a percentage (0%, 10%, 25% or 40%)
  - Glazing area distribution - one of six different scenarios: uniform, north, east, south, west, and no glazing (uniform had 25% glazing on each side while NSEW had 55% on the main side and 15% on each of the other sides)
- Heating, Cooling, and Overall Load were the measured response variables

Cleaning Procedures

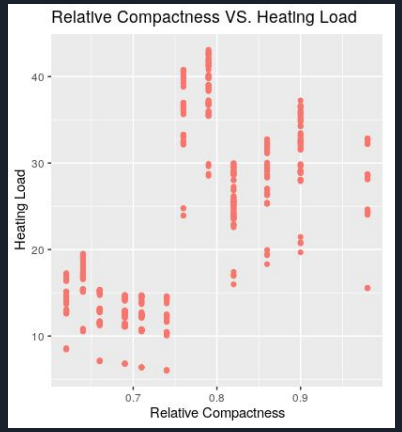
Mathematical Representation	Input or Output Variable	Number of Possible Values
X1	relative compactness	12
X2	surface area	12
X3	wall area	7
X4	roof area	4
X5	overall height	2
X6	orientation	4
X7	glazing area	4
X8	glazing area distribution	6
y1	heating load	586
y2	cooling load	636
y3	overall load	786

- Data was generated via targeted simulations
  - Did not require any data cleaning operations on the sample
- Y3 variable of Overall Load was created by adding the heating and cooling loads together
  - Allows for a better understanding of energy efficiency of each of the 8 attributes

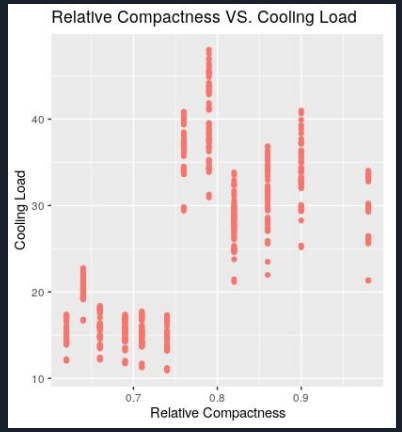
Exploratory Analysis - Relative Compactness (X1)



Relative Compactness and Overall Load Linear Regression Score: 0.3994



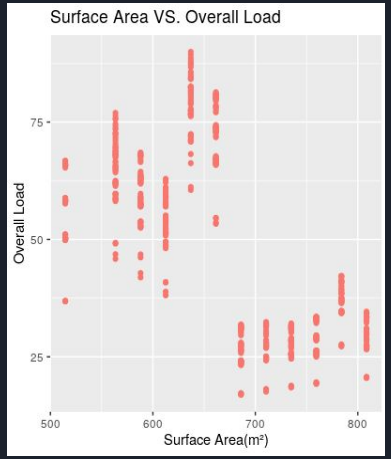
Relative Compactness and Heating Load Linear Regression Score: 0.3442



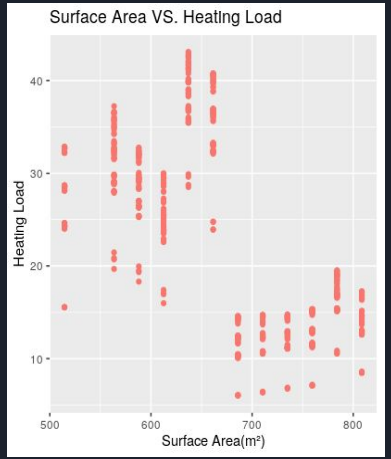
Relative Compactness and Cooling Load Linear Regression Score: 0.4024

As the relative compactness of a building increases, cooling load, heating load and overall load will increase as well, resulting in a positive regression coefficient in all three cases.

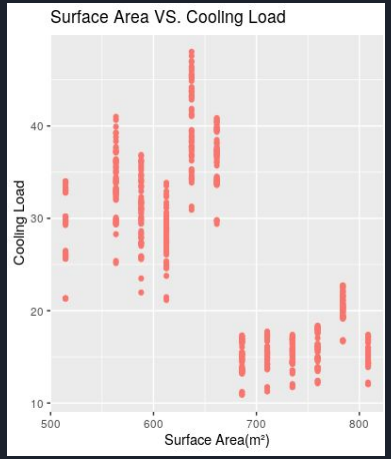
Exploratory Analysis - Surface Area (X2)



Surface Area and Overall Load Linear Regression Score: 0.4481



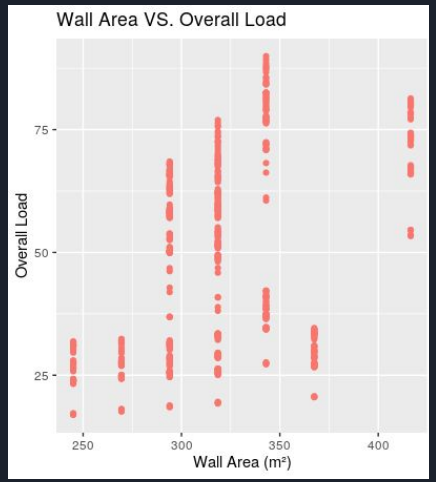
Surface Area and Heating Load Linear Regression Score: 0.4331



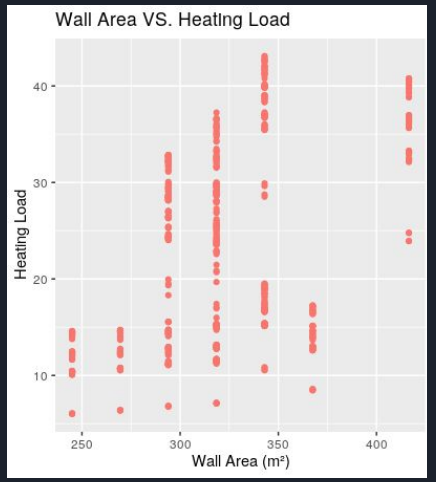
Surface Area and Cooling Load Linear Regression Score: 0.4529

As the surface area of a building increases, cooling load, heating load and overall load will decrease, resulting in a negative regression coefficient in all three cases.

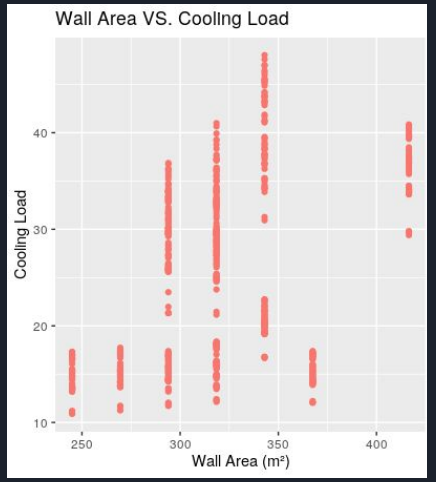
Exploratory Analysis - Wall Area (X3)



Wall Area and Overall Load Linear Regression Score: 0.1975



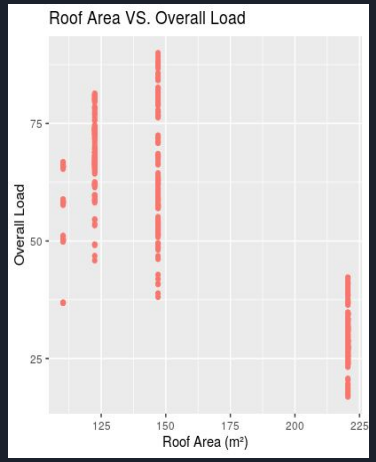
Wall Area and Heating Load Linear Regression Score: 0.2076



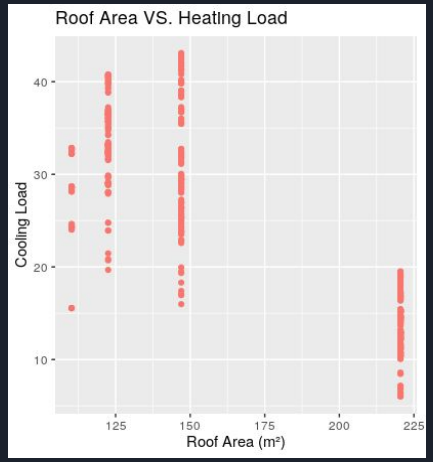
Wall Area and Cooling Load Linear Regression Score: 0.1824

As the wall area of a building increases, cooling load, heating load and overall load will increase as well, resulting in a positive regression coefficient in all three cases.

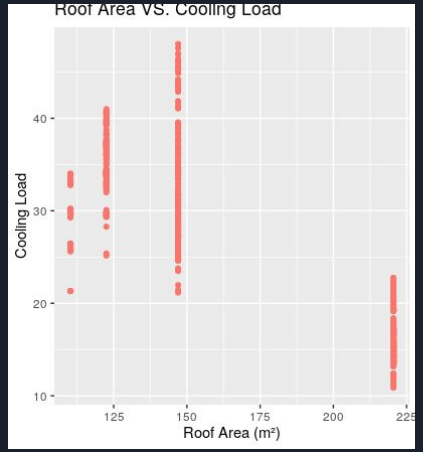
Exploratory Analysis - Roof Area (X4)



Roof Area and Overall Load Linear Regression Score: 0.7524



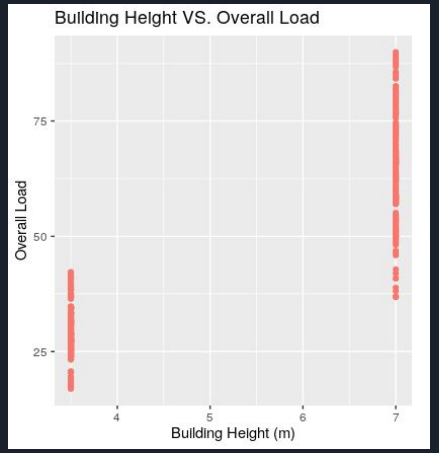
Roof Area and Heating Load Linear Regression Score: 0.7427



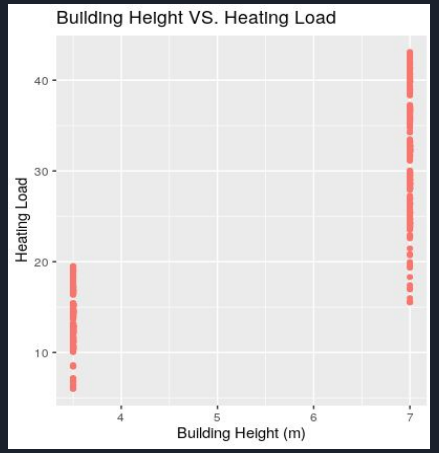
Roof Area and Cooling Load Linear Regression Score: 0.7439

As the roof area of a building increases, cooling load, heating load and overall load will decrease, resulting in a negative regression coefficient in all three cases.

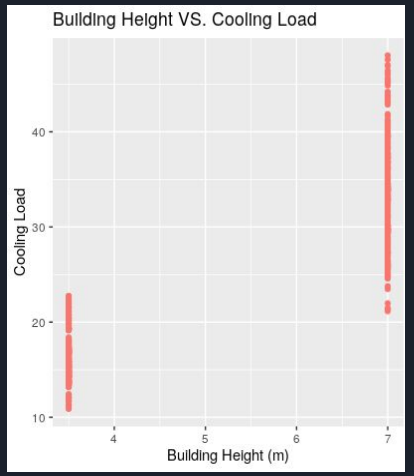
Exploratory Analysis - Overall Height (X5)



Overall Height and Overall Load Linear Regression Score: 0.8063



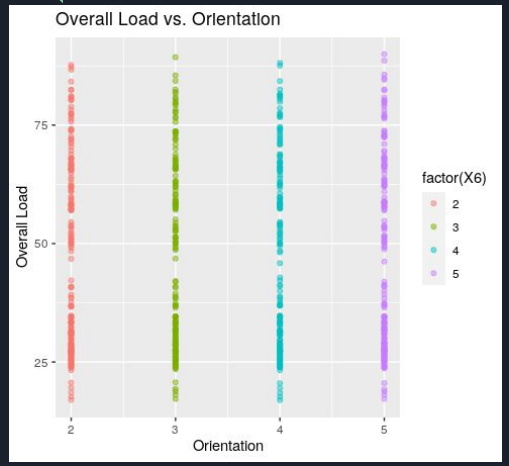
Overall Height and Heating Load Linear Regression Score: 0.7911



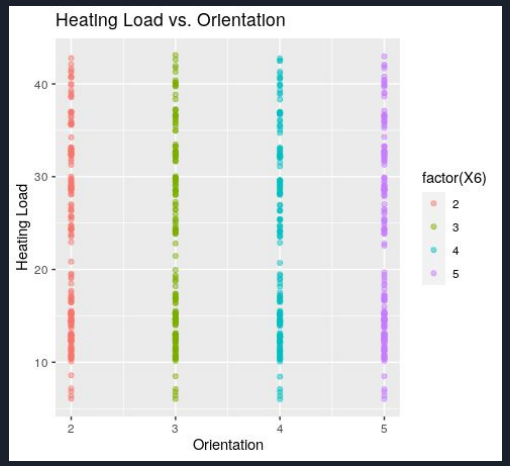
Overall Height and Cooling Load Linear Regression Score: 0.802

As the overall height of a building increases, cooling load, heating load and overall load will increase as well, resulting in a positive regression coefficient in all three cases.

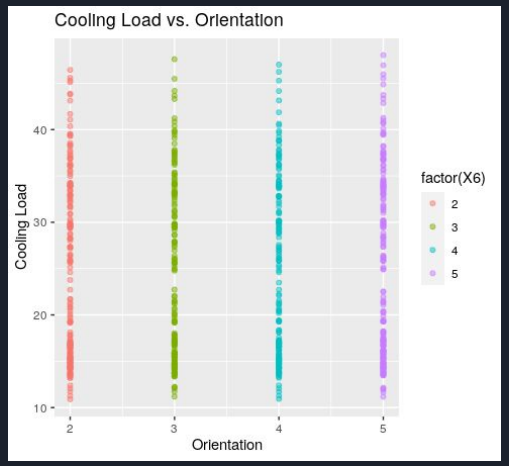
Exploratory Analysis - Orientation (X6)



Orientation and Overall Load
Linear Regression Score: ~0



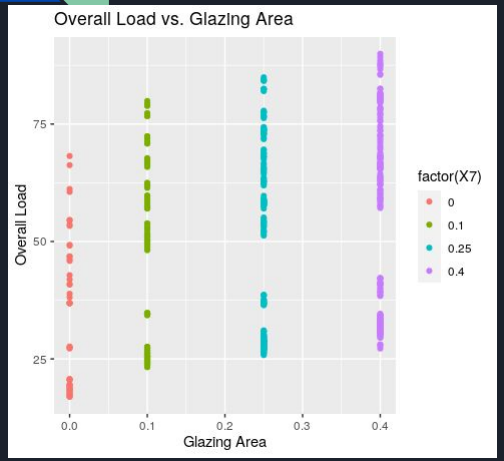
Orientation and Heating Load
Linear Regression Score: ~0



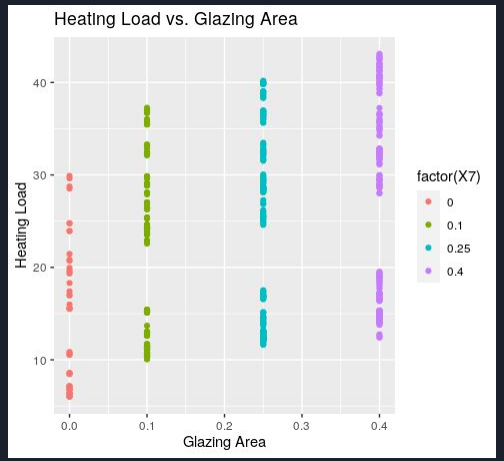
Orientation and Cooling Load
Linear Regression Score: ~0

The orientation of the building will have little effect on cooling load, heating load and overall load. Thus the regression coefficient will be close to 0 for each orientation in all three cases.

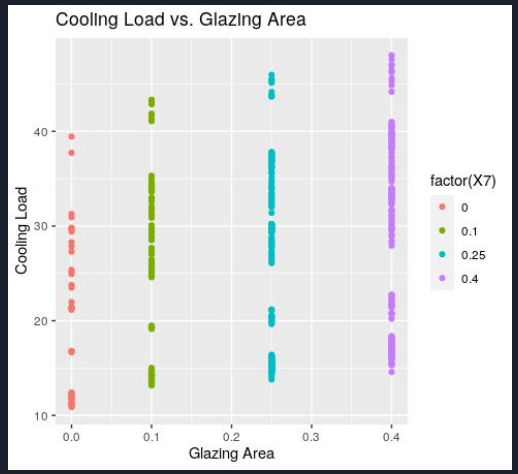
Exploratory Analysis - Glazing Area (X7)



Glazing Area and Overall Load
Linear Regression Score: 0.0581



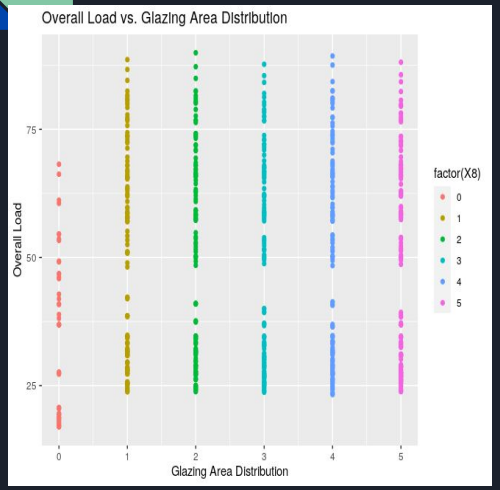
Glazing Area and Heating Load
Linear Regression Score: 0.0728



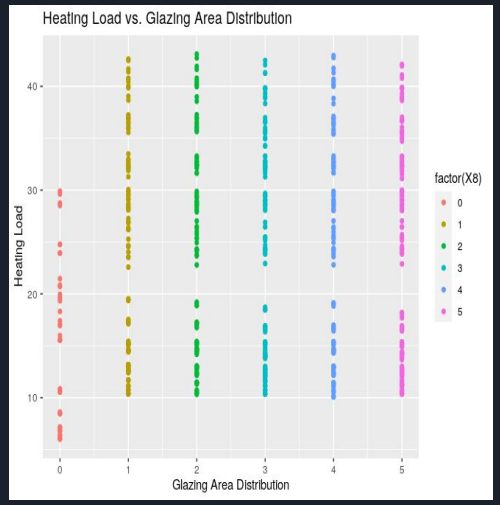
Glazing Area and Cooling Load
Linear Regression Score: 0.0431

As the glazing area of a building increases, cooling load, heating load and overall load will increase slightly as well, resulting in a positive regression coefficient in all three cases.

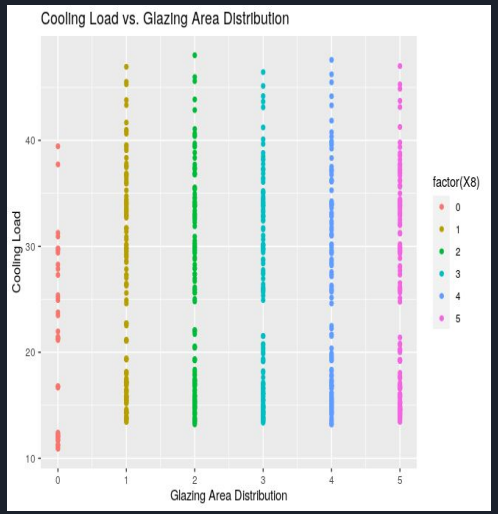
Exploratory Analysis - Glazing Area Distribution (X8)



Glazing Area Distribution and Overall Load Linear Regression Score: 0.0049



Glazing Area Distribution and Heating Load Linear Regression Score: 0.0076



Glazing Area Distribution and Cooling Load Linear Regression Score: 0.0026

The glazing area distribution in a building will have little effect on its cooling load, heating load and overall load. Thus the regression coefficient will be close to 0 for each distribution model in all three cases.

Feature Importance Analysis

Random Forest

	Features	Average
0	Relative Compactness	0.259388
1	Surface Area	0.249057
2	Overall Height	0.195562
3	Roof Area	0.167655
4	Glazing Area	0.063145
5	Wall Area	0.044405
6	Glazing Area Distribution	0.014132
7	Orientation	0.006656

ADABoost on Heating

	Features	Average
0	Relative Compactness	0.277283
1	Surface Area	0.237258
2	Overall Height	0.172648
3	Roof Area	0.112012
4	Glazing Area	0.108610
5	Wall Area	0.069239
6	Glazing Area Distribution	0.022062
7	Orientation	0.000889

ADABoost on Cooling

	Features	Average
0	Relative Compactness	0.277283
1	Surface Area	0.237258
2	Overall Height	0.172648
3	Roof Area	0.112012
4	Glazing Area	0.108610
5	Wall Area	0.069239
6	Glazing Area Distribution	0.022062
7	Orientation	0.000889

XGBoost

	Features	Average
0	Relative Compactness	0.875137
1	Glazing Area	0.055404
2	Roof Area	0.053369
3	Wall Area	0.007079
4	Glazing Area Distribution	0.004952
5	Orientation	0.004052
6	Surface Area	0.000000
7	Overall Height	0.000000

Regular Gradient Boost on Heating

	Features	Average
0	Surface Area	0.316170
1	Roof Area	0.258993
2	Relative Compactness	0.171860
3	Overall Height	0.160812
4	Glazing Area	0.044685
5	Wall Area	0.031186
6	Glazing Area Distribution	0.010437
7	Orientation	0.005857

Regular Gradient Boost on Cooling

	Features	Average
0	Surface Area	0.316170
1	Roof Area	0.258993
2	Relative Compactness	0.171860
3	Overall Height	0.160812
4	Glazing Area	0.044685
5	Wall Area	0.031186
6	Glazing Area Distribution	0.010437
7	Orientation	0.005857

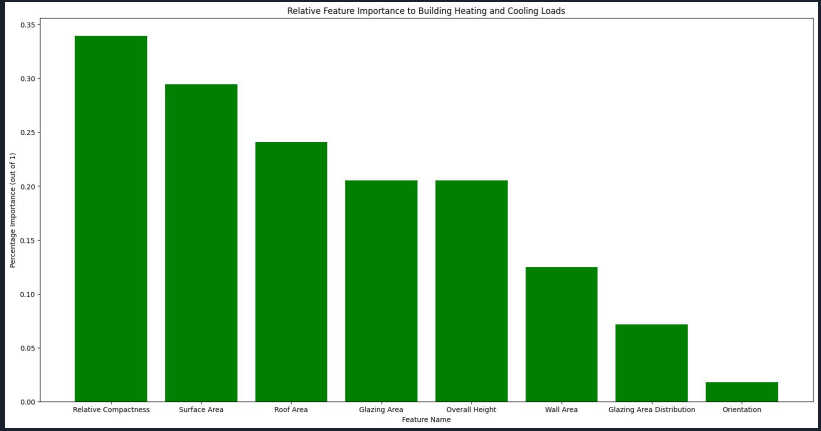
Results

Regressors used:

- Random Forest
- AdaBoost
- XGBoost
- Regular Gradient Boosting

Feature Importance Across of Dataset Across Four Different Regressor Algorithms, Six Different Regression Models

	Random Forest	RegularGradientBoosting on Heating	RegularGradientBoosting on Cooling	AdaBoost on Heating	AdaBoost on Cooling	XGBoost
0	Relative Compactness	Surface Area	Surface Area	Relative Compactness	Relative Compactness	Relative Compactness
1	Surface Area	Roof Area	Roof Area	Surface Area	Surface Area	Glazing Area
2	Overall Height	Relative Compactness	Relative Compactness	Overall Height	Overall Height	Roof Area
3	Roof Area	Overall Height	Overall Height	Glazing Area	Glazing Area	Wall Area
4	Glazing Area	Glazing Area	Glazing Area	Roof Area	Roof Area	Glazing Area Distribution
5	Wall Area	Wall Area	Wall Area	Wall Area	Wall Area	Orientation
6	Glazing Area Distribution	Glazing Area Distribution	Glazing Area Distribution	Glazing Area Distribution	Glazing Area Distribution	Surface Area
7	Orientation	Orientation	Orientation	Orientation	Orientation	Overall Height



Matrix points:

Relative Compactness: 38
Surface Area: 33
Roof Area: 27
Glazing Area: 23
Overall Height: 23
Wall Area: 14
Glazing Area Distribution: 8
Orientation: 2

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Limitations

- Our data is generated from simulated buildings which may not accurately represent actual data in the real world.
  - A Random Sample can be used to understand the effect of building attributes on the loads in their subsequent geographic location
- While modeling, it was hard for us to **cluster** our model because there are too many conflicting variables that account for all of the overall heating and cooling load.
- To simplify the data, many attributes were measured in discrete numerical categories rather than continuously

Conclusion

- By creating less compact buildings with lower surface areas after a critical point, the heating and cooling systems would require less energy in order to cover the building due to the lower surface area to volume ratio
- Variables that contribute least to energy efficiency are orientation and glazing area distribution, indicating these factors should not be considered as significant when designing energy efficient buildings
- Future studies should compare simulated data and real data from residential buildings in Athens
- Future studies can also compare residential energy usage to commercial energy usage