Ocean_challenge_byVS

November 6, 2022

0.1 Helping Scotland Towns to a better and cheaper energy performance future

0.1.1 Background

The issue of the steep rise in cost of living has been at the first and foremost of minds of all citizens, especially so now that winter is upon us and fuel costs to stay warm will be at a all-time high. The local authorities are doing the best they can to assist. Some of the local government initiatives include extending energy advice to businesses via Business Energy Scotland, and also the Winter Heating Payment allowance to low income households, in order to combat the issue aforementioned. Through an analysis of the energy performance data used in the production of Energy Performance Certificates in Scotland, we hope to identify the key insights why some towns or buildings seemed to have better energy efficiency and are better at cutting energy costs. We will also propose a basic recommender model where using given roof and wall materials, the recommender model can make suggestions on what wall or roof improvements can be made for better energy efficiency. We will also look at what are the building factors that could contribute to the total cost of energy, and how one's costs can be lowered if switch to other materials instead. The information can be shared to others in making improvements to their buildings for reduction in fuel costs and lower emissions.

0.1.2 Overview on the energy performance in Scotland by towns

Here we provide a Top 10 list of local towns ranked by the following criterias:

Towns by current efficiency rating

Towns by potential energy efficiency rating

Towns by current environmental impact rating and note if there have been periods where houses were more or less environmentally friendly

Towns by potential environmental impact rating

Towns by Current Emissions (T.CO2/yr)

Towns by Potential Reduction in Emissions (T.CO2/yr)

Towns by potential savings in heating costs (£) over three years

Towns by potential savings in hot water costs (£) over three years

For reference, these ratings are based on the following scale:

Current efficiency rating: higher ratings indicate better efficiency.

Potential energy efficiency rating: higher ratings indicate better efficiency.

Current environmental impact rating: higher ratings indicate better environmental impact.

Potential environmental impact rating: higher ratings indicate better environmental impact.

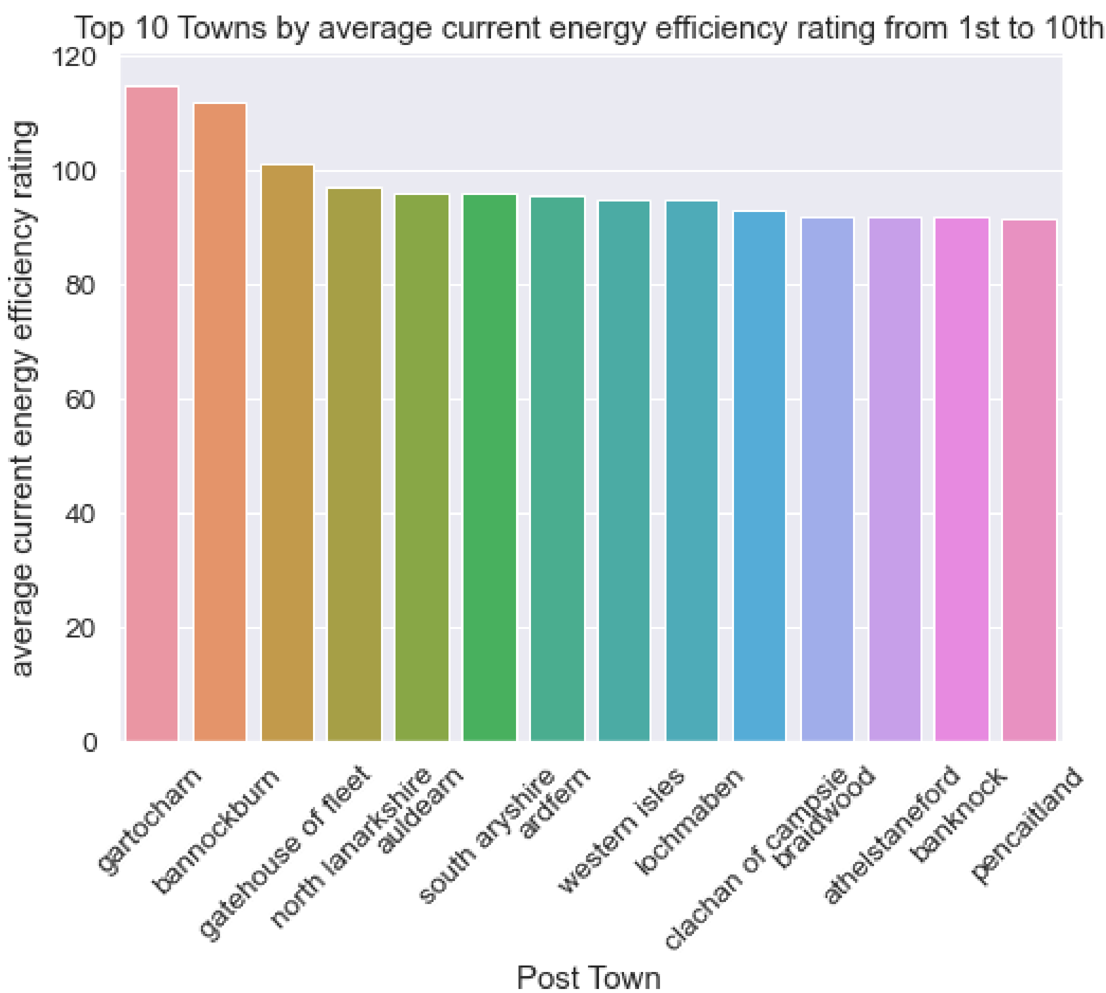
Current Emissions (T.CO2/yr): higher ratings indicate lower emissions.

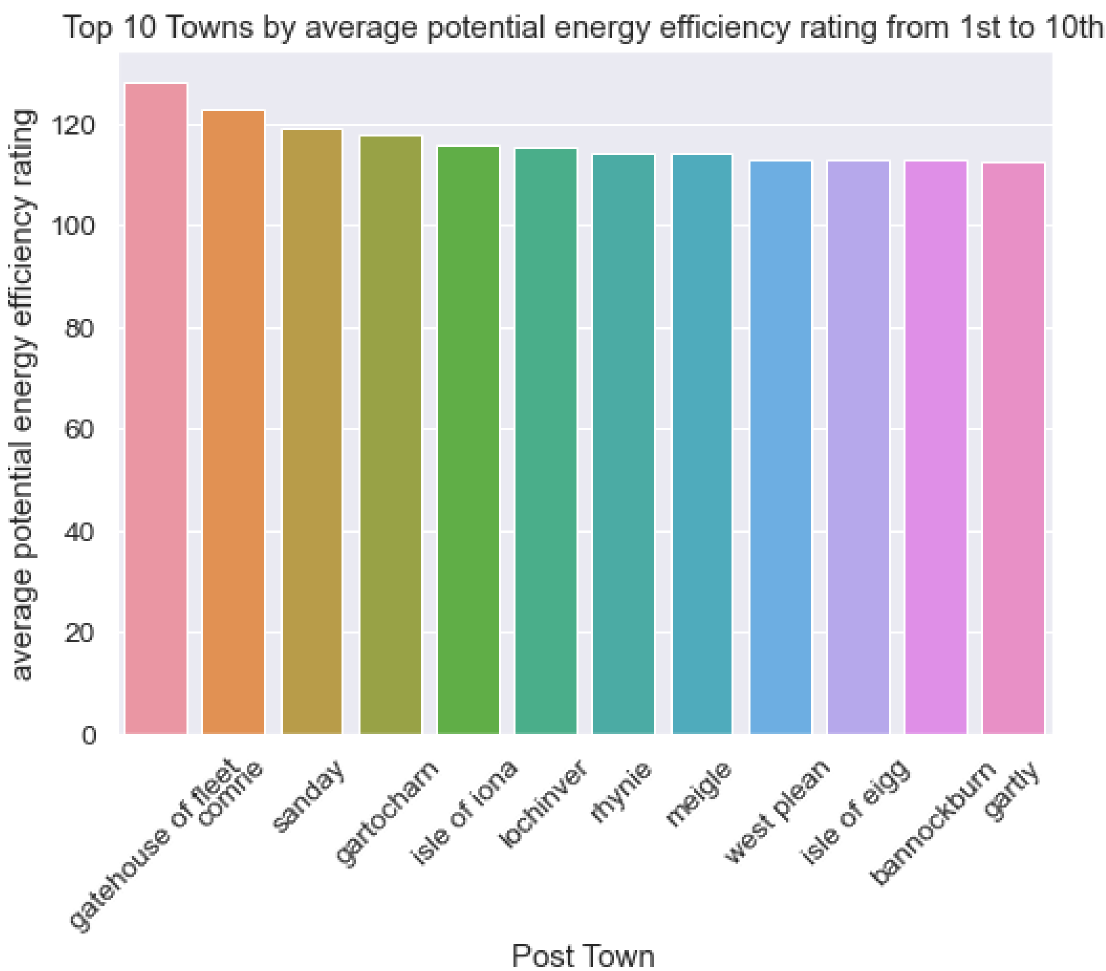
Potential Reduction in Emissions (T.CO2/yr): higher ratings indicate higher potential reductions.

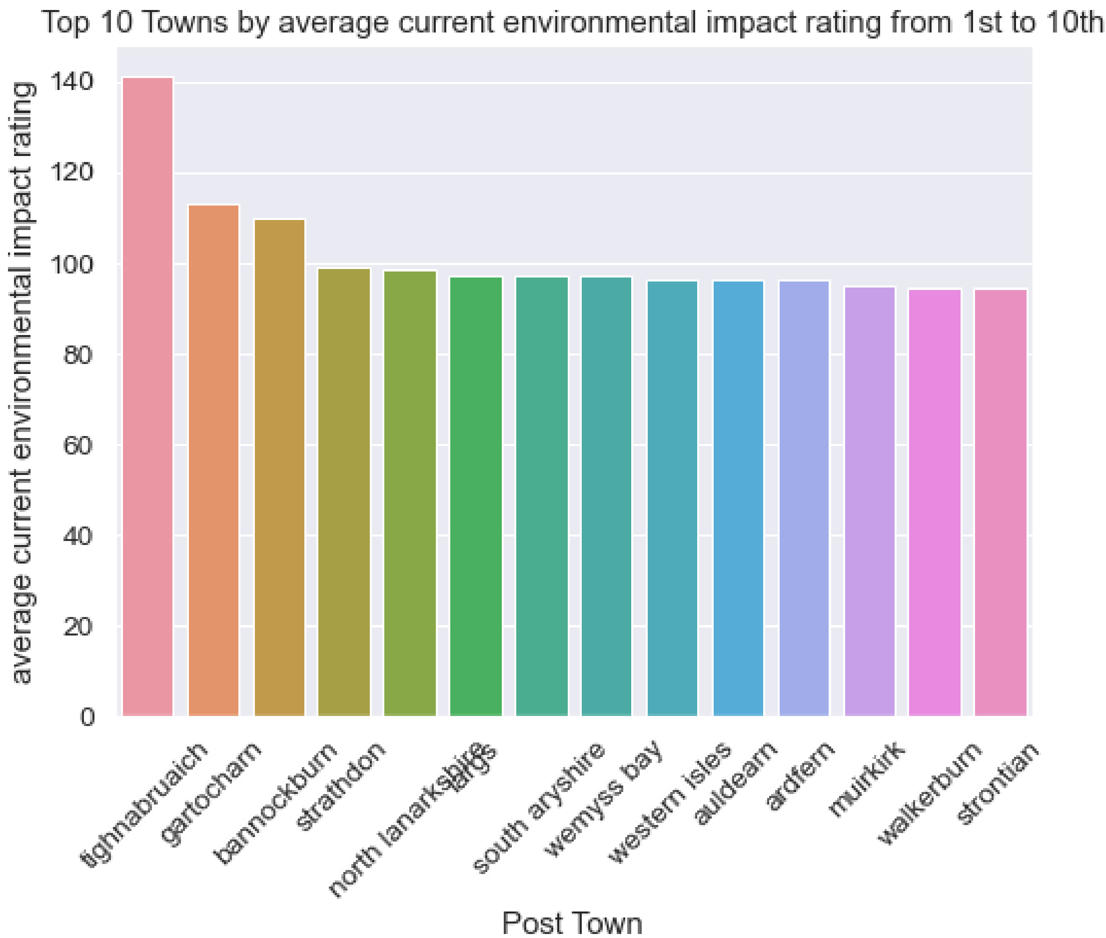
Potential savings in heating costs (£) over three years: Calculated from current heating costs (£) over three years - potential heating costs (£) over three years. Higher numbers indicate more savings in costs.

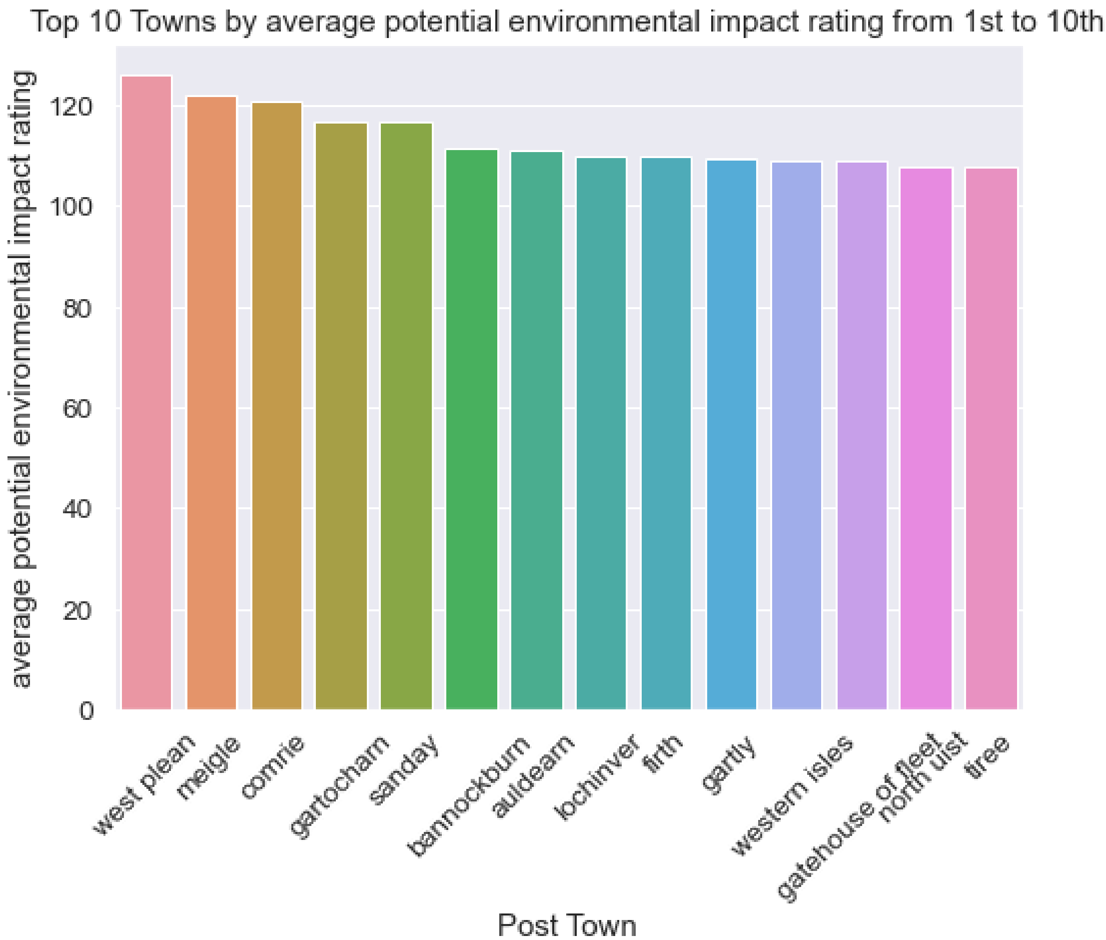
Potential savings in hot water costs (£) over three years: Calculated from current hot water costs (£) over three years - potential how water costs (£) over three years. Higher numbers indicate more savings in costs.

Note: Some of these rankings may show more than 10 towns since there are some towns tied at the same position

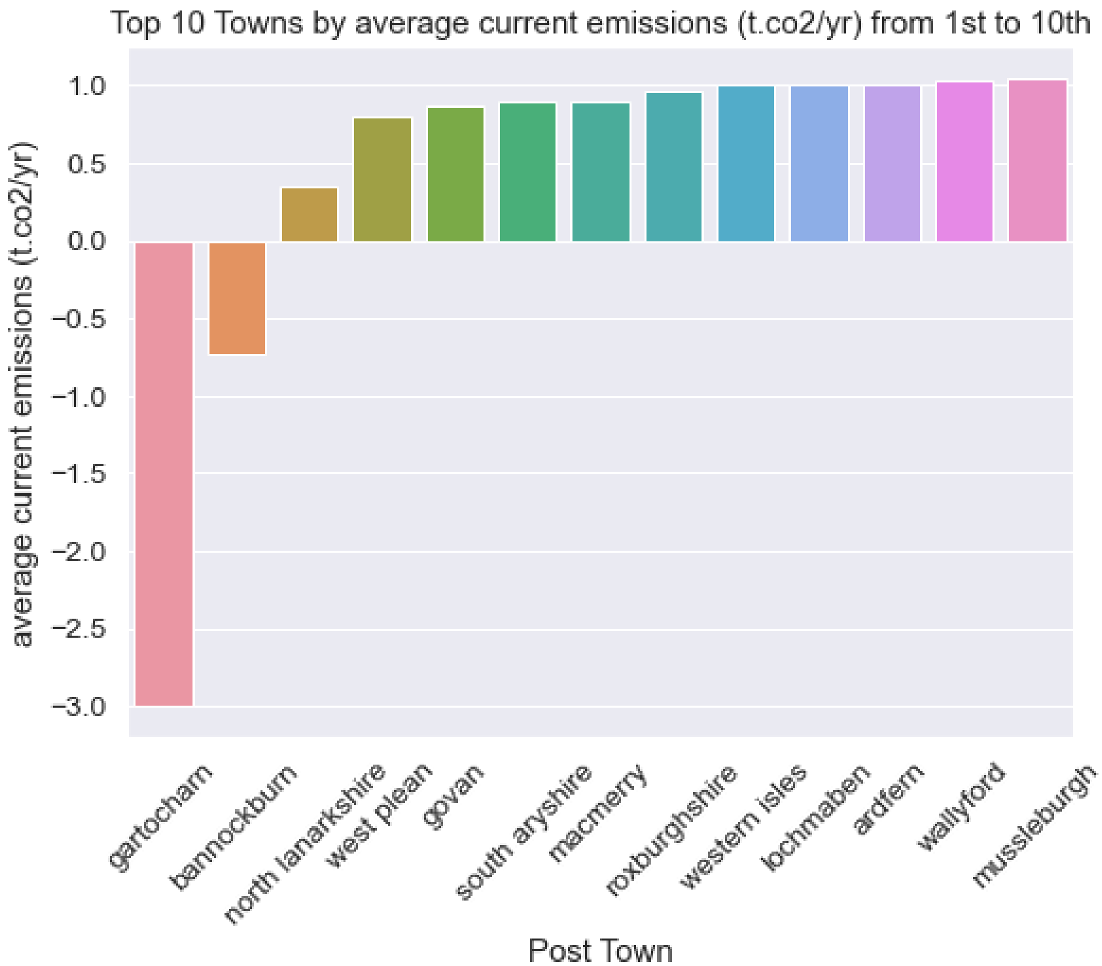


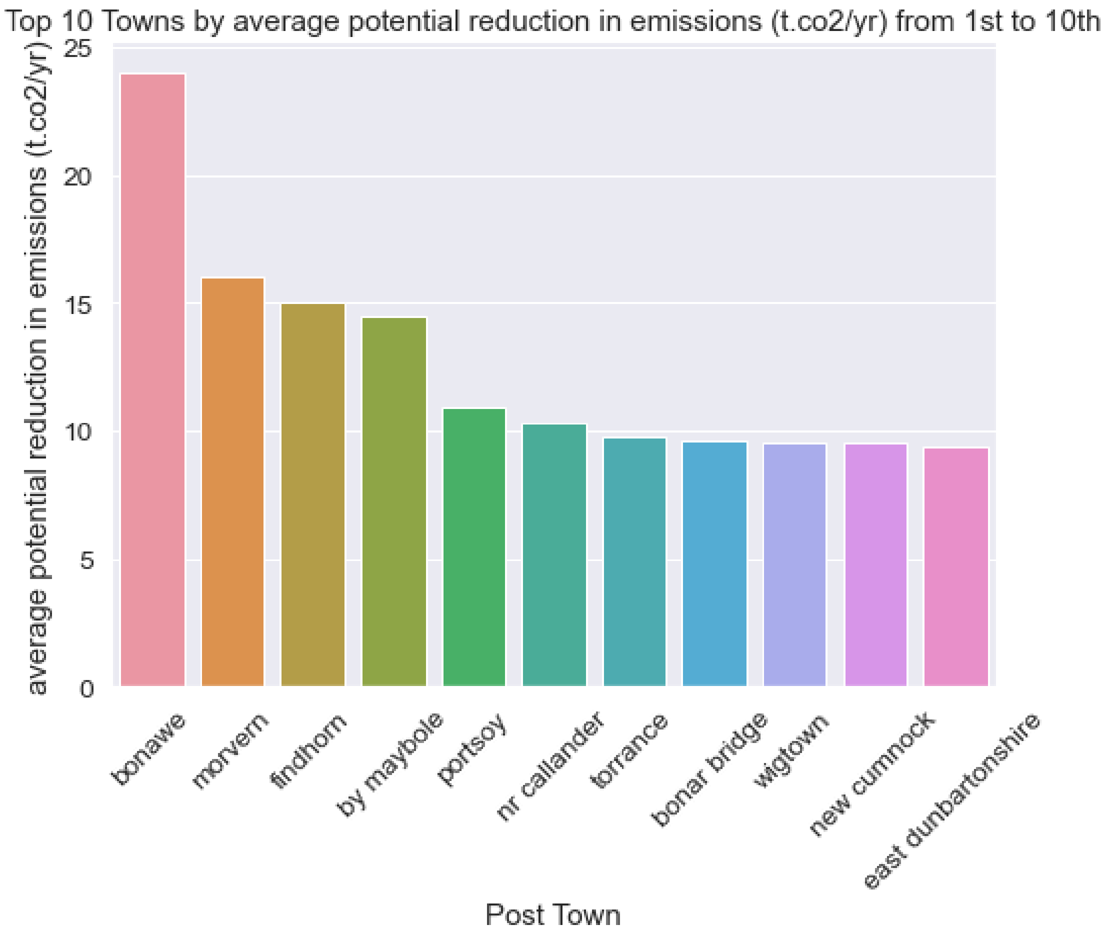

Top 10 Towns by average potential energy efficiency rating from 1st to 10th
average potential energy efficiency rating
0
20
40
60
80
100
120
gatehouse of fleet
comrie
sanday
gartocharn
isle of iona
lochinver
rhynie
meigle
west plean
isle of eigg
bannockburn
gartly
Post Town


Top 10 Towns by average current environmental impact rating from 1st to 10th
average current environmental impact rating
0
20
40
60
80
100
120
140
tighnabruaich
gartocharn
bannockburn
strathdon
north lanarkshire
largs
south aryshire
wemyss bay
western isles
auldearn
ardfern
muirkirk
walkerburn
strontian
Post Town

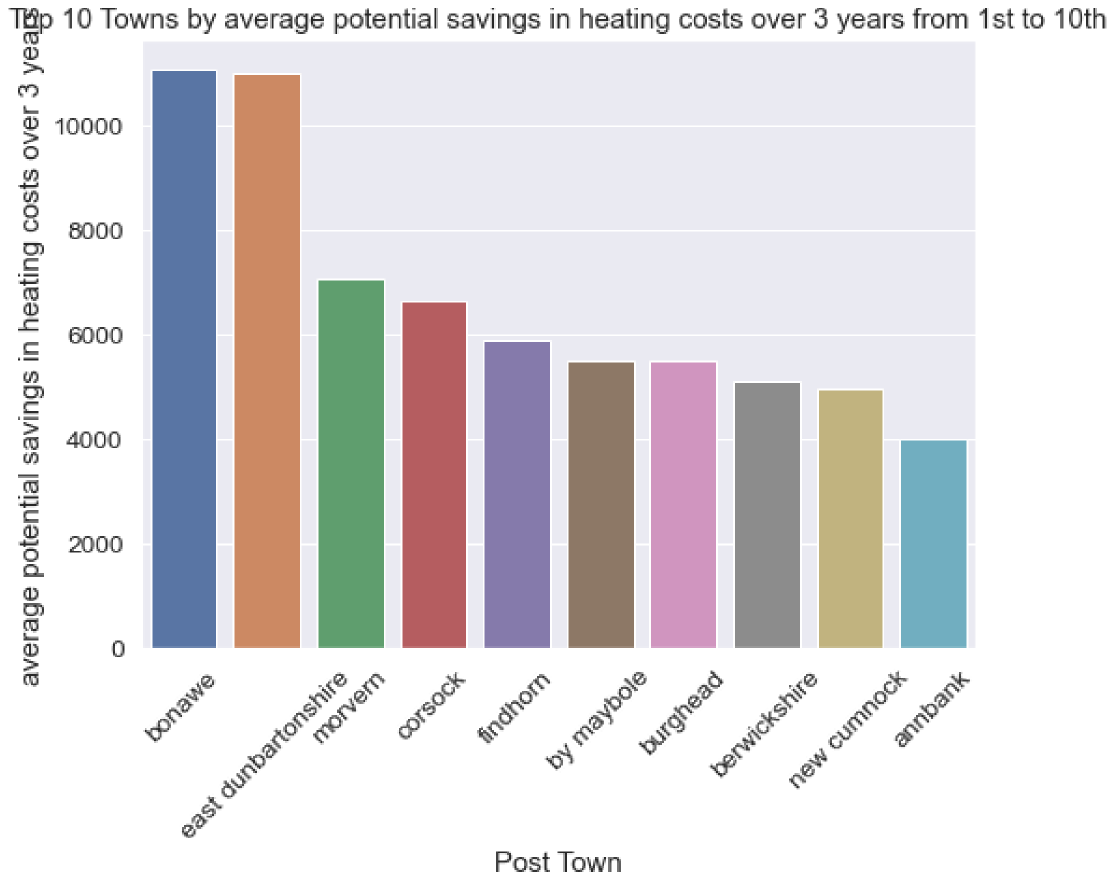


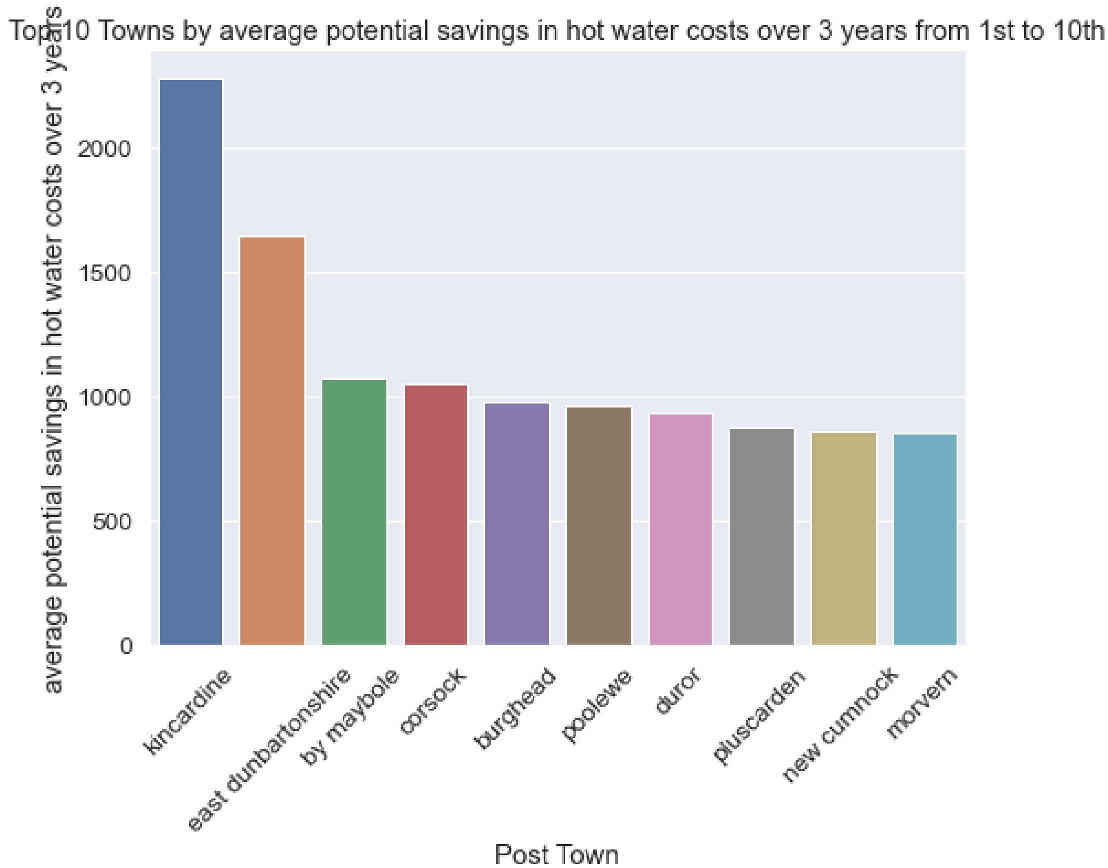
Top 10 Towns by average potential environmental impact rating from 1st to 10th
average potential environmental impact rating
0
20
40
60
80
100
120
west plean
meigle
comrie
gartocharn
sanday
bannockburn
auldearn
lochinver
firth
gartly
western isles
gatehouse of fleet
north uist
tiree
Post Town


Top 10 Towns by average current emissions (t.co2/yr) from 1st to 10th
average current emissions (t.co2/yr)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
gartocharn
bannockburn
north lanarkshire
west plean
govan
south aryshire
macmerry
roxburghshire
western isles
lochmaben
ardfern
wallyford
mussleburgh
Post Town



Top 10 Towns by average potential reduction in emissions (t.co2/yr) from 1st to 10th
average potential reduction in emissions (t.co2/yr)
0
5
10
15
20
25
bonawe
morvern
findhorn
by maybole
portsoy
nr callander
torrance
bonar bridge
wigtown
new cumnock
east dunbartonshire
Post Town


Top 10 Towns by average potential savings in heating costs over 3 years from 1st to 10th
average potential savings in heating costs over 3 years
0
2000
4000
6000
8000
10000
bonawe
east dunbartonshire
morvern
corsock
findhorn
by maybole
burghead
berwickshire
new cumnock
annbank
Post Town



0.1.3 Correlations Analysis

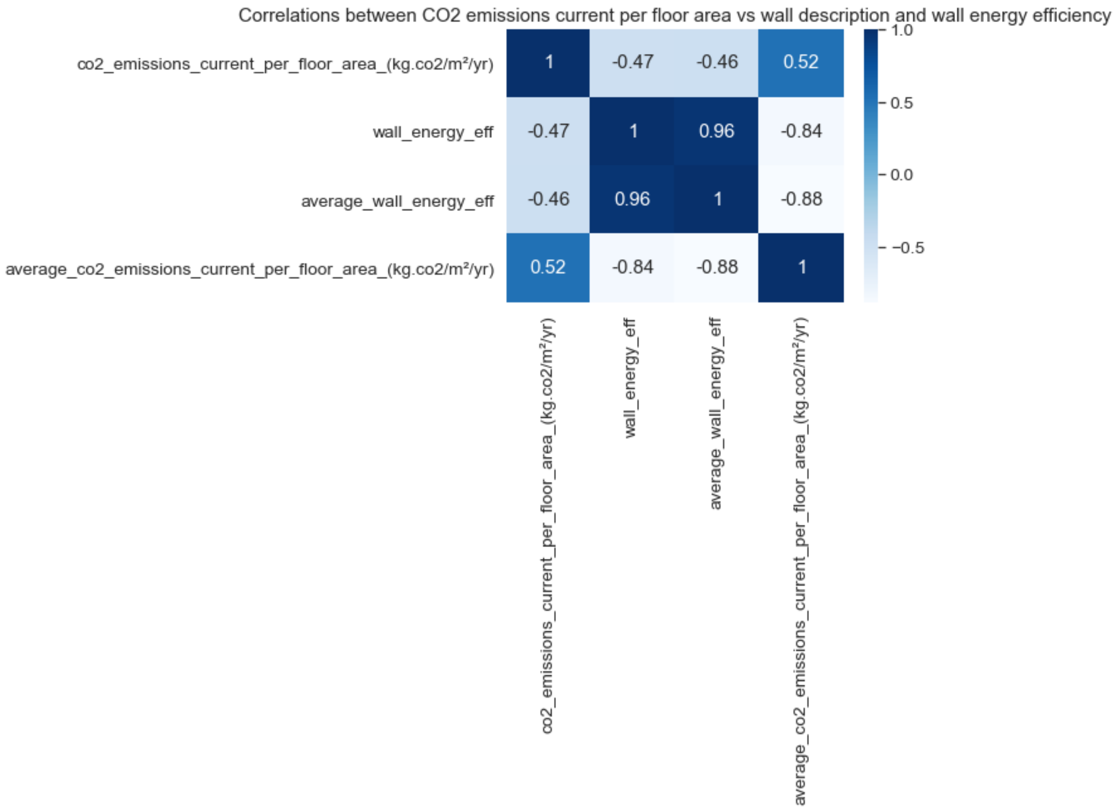
We dive further into analysing some of the building characteristics that may be correlated with the energy performance data, in particular,

Correlations between CO2 emissions current per floor area vs wall description and wall energy efficiency

Correlations between CO2 emissions current per floor area vs roof description and roof energy efficiency

Correlations between construction age band vs current energy efficiency and current emissions (T.CO2/yr)

0.1.4 Correlations between CO2 emissions current per floor area vs wall description and wall energy efficiency



0.1.5 Findings

As a guide, the numbers above are in the scale from -1 to 1, where negative numbers indicate negative correlations and likewise for positive numbers. The strength of correlations are measured by how close these numbers are towards -1 (strong negative correlation) and 1 (strong positive correlation). The correlation matrix above shows that:

Co2 emissions current per floor area decrease when the wall energy efficiency ratings increase, indicating a moderately negative correlation.

The wall energy efficiency ratings and its average ratings are strongly positively correlated.

The co2 emissions current per floor area and its average re moderately positively correlated.

To create a single rating combining CO2 emissions and wall energy efficiency, first:

Rank the average CO2 emissions current per floor area, where lower emissions will be ranked higher (1 - Best).

Rank the average wall energy efficiency rating, where higher efficiency will be ranked higher.

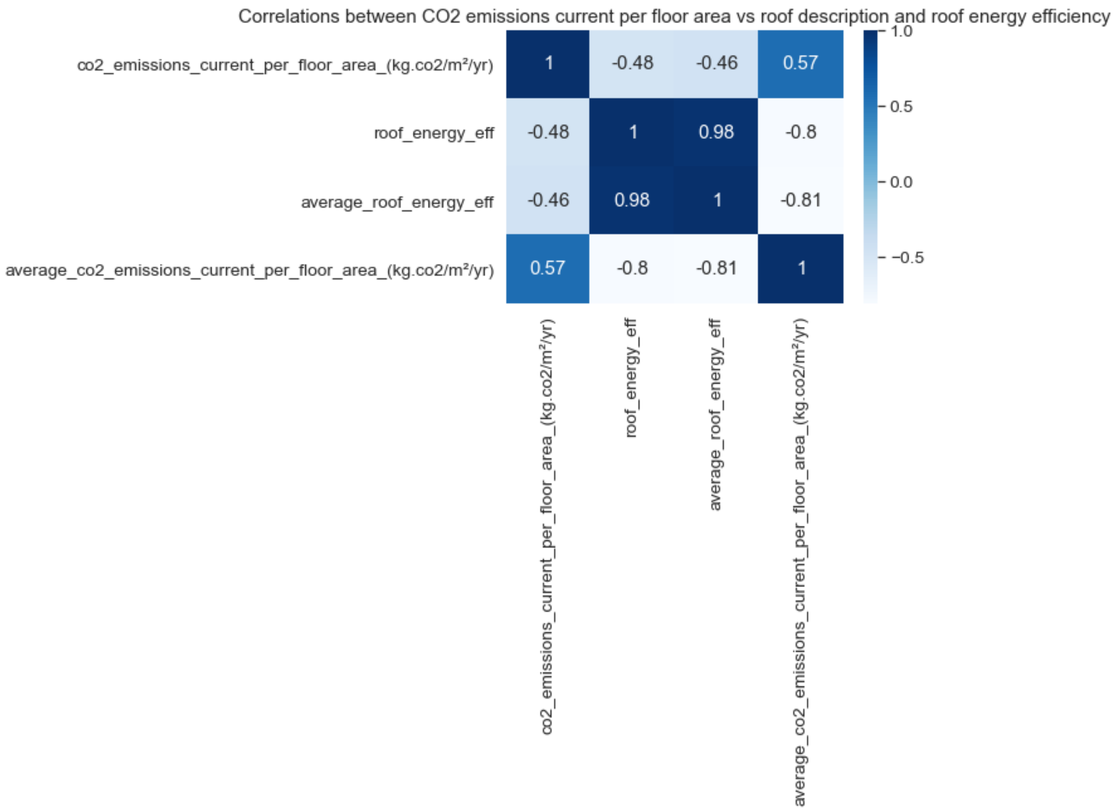
The ranks generated from (1) and (2) are then combined for a single rating across all wall materials.

Top 5 wall materials by CO2 emissions current per floor area and wall energy efficiency

[35]:

	rank_wall_overall	wall_description
89	1	Average thermal transmittance 0.09 W/m²K
29	2	Average thermal transmittance 0.14 W/m²K
67	3	Average thermal transmittance 0.10 W/m²K
37	4	Average thermal transmittance 0.17 W/m²K
44	5	Average thermal transmittance 0.11 W/m²K

0.1.6 Correlations between CO2 emissions current per floor area vs roof description and roof energy efficiency



The correlation matrix above shows that:

Co2 emissions current per floor area decrease when the roof energy efficiency ratings increase, indicating a moderately negative correlation.

The roof energy efficiency ratings and its average ratings are strongly correlated.

The co2 emissions current per floor area and its average are moderately positively correlated.

To create a single rating combining CO2 emissions and roof energy efficiency, first:

Rank the average CO2 emissions current per floor area where lower emissions will be ranked higher (1 - Best).

Rank the average roof energy efficiency rating when higher efficiency will be ranked higher.

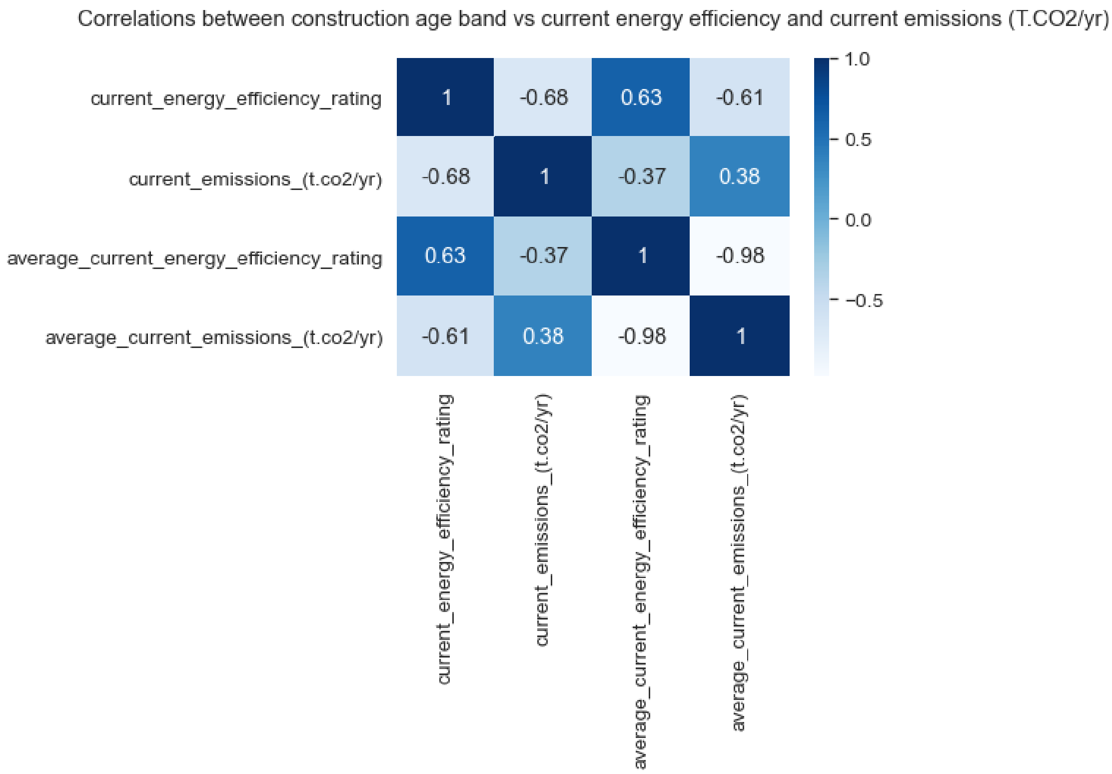
Ranks from (1) and (2) are then combined for a single rating across all roof materials.

Top 5 roof descriptions by CO2 emissions current per floor area and wall energy efficiency

[45]:

	rank_roof_overall	roof_description
59	1	Average thermal transmittance 0.06 W/m²K
16	2	Average thermal transmittance 0.11 W/m²K
39	3	Average thermal transmittance 0.08 W/m²K
38	4	Average thermal transmittance 0.09 W/m²K
15	5	Average thermal transmittance 0.10 W/m²K

0.1.7 Correlations between construction age band vs current energy efficiency and current emissions (T.CO2/yr)



The correlation matrix above shows that:

Current emissions (t.co2/yr) decrease when the current energy efficiency rating increase, indicating a moderately negative correlation.

The average current emissions (t.co2/yr) and the average current energy efficiency rating are strongly negatively correlated.

The current emissions (t.co2/yr) and its average are moderately positively correlated.

The current energy efficiency rating and its average are moderately positively correlated.

We're interested to see how the construction's age would relate to the current emissions (t.co2/yr) plus current energy efficiency rating. To do so, we adopt a single rating combining current emissions(t.co2/yr) plus current energy efficiency rating. First:

Rank the average current emissions(t.co2/yr) where lower emissions will be ranked higher (1 - Best).

Rank the average current energy efficiency rating when higher efficiency will be ranked higher.

Results from (1) and (2) are then combined for a single rating for the construction age band.

Construction age band vs Current energy efficiency and Current emissions (t.co2/yr)

[52]:

	rank_construction_overall	part_1_construction_age_band
11	1	others
8	2	2008 onwards
9	3	2003-2007
3	4	1999-2002
10	5	1992-1998
7	6	1984-1991
5	7	1976-1983
6	8	1950-1964
2	9	1965-1975
0	10	1930-1949
1	11	1919-1929
4	12	before 1919

We conclude that the construction age band is strongly correlated to a higher energy efficiency rating and lower emissions overall, where new-builts are more energy efficient as compared to older-builts.

0.2 Recommender model for wall and roof materials

Using characteristics of a wall/roof as input, the recommender model identifies the closest match in the data and recommends a list of more energy efficient suggestions. With this, users could consider their options available in improving the energy efficiency of their building and save on fuel costs over time.

A demonstration of the basic recommender model

Example search phrase for wall: "Average thermal transmittance 0.13" Search result:

```
Closest match result: average thermal transmittance 0.13 w/m²k
Average wall energy efficiency for average thermal transmittance 0.13 w/m²k: 5.0

Recommendations:
```

	wall_description	average_wall_energy_eff
18	average thermal transmittance 0.20 w/m²k	5.0
38	average thermal transmittance 0.16 w/m²k	5.0

```
72  average thermal transmittance 0.00 w/m²k                      5.0
68  average thermal transmittance 0.27 w/m²k                      5.0
67  average thermal transmittance 0.10 w/m²k                      5.0
46  average thermal transmittance 0.12 w/m²k                      5.0
45  average thermal transmittance 0.13 w/m²k                      5.0
44  average thermal transmittance 0.11 w/m²k                      5.0
42  average thermal transmittance 0.23 w/m²k                      5.0
37  average thermal transmittance 0.17 w/m²k                      5.0
19  average thermal transmittance 0.21 w/m²k                      5.0
36  average thermal transmittance 0.18 w/m²k                      5.0
35  average thermal transmittance 0.19 w/m²k                      5.0
30  average thermal transmittance 0.15 w/m²k                      5.0
29  average thermal transmittance 0.14 w/m²k                      5.0
24  average thermal transmittance 0.24 w/m²k                      5.0
21  average thermal transmittance 0.25 w/m²k                      5.0
20  average thermal transmittance 0.22 w/m²k                      5.0
89  average thermal transmittance 0.09 w/m²k                      5.0
```

A demonstration of the basic recommender model (for roof)

Example search phrase for roof: “thatched, roof” Search result:

```
Closest match result: roof room(s) thatched
Average roof energy efficiency for roof room(s) thatched: 4.0

Recommendations:

                            roof_description  average_roof_energy_eff
68  average thermal transmittance 0.05 w/m²k                 5.000000
38  average thermal transmittance 0.09 w/m²k                 5.000000
34   average thermal transmittance 0.1 w/m²k                 5.000000
32  average thermal transmittance 0.13 w/m²k                 5.000000
31           pitched 400+ mm loft insulation                 5.000000
27                  (another dwelling above)                 5.000000
26            pitched 350 mm loft insulation                 5.000000
20  average thermal transmittance 0.14 w/m²k                 5.000000
39  average thermal transmittance 0.08 w/m²k                 5.000000
18  average thermal transmittance 0.12 w/m²k                 5.000000
40            pitched 400 mm loft insulation                 5.000000
16  average thermal transmittance 0.11 w/m²k                 5.000000
15  average thermal transmittance 0.10 w/m²k                 5.000000
11            pitched 300 mm loft insulation                 5.000000
59  average thermal transmittance 0.06 w/m²k                 5.000000
65          pitched 400+  mm loft insulation                 5.000000
35  average thermal transmittance 0.07 w/m²k                 5.000000
48      thatched with additional insulation                  4.818182
2           roof room(s) insulated (assumed)                 4.232880
4             pitched 250 mm loft insulation                 4.000000
54  average thermal transmittance 0.25 w/m²k                 4.000000
```

```
66  average thermal transmittance 0.29 w/m²k                    4.000000
5             pitched 200 mm loft insulation                    4.000000
64                     roof room(s) thatched                    4.000000
61  average thermal transmittance 0.23 w/m²k                    4.000000
7             pitched 270 mm loft insulation                    4.000000
58  average thermal transmittance 0.21 w/m²k                    4.000000
52  average thermal transmittance 0.22 w/m²k                    4.000000
19  average thermal transmittance 0.18 w/m²k                    4.000000
49  average thermal transmittance 0.17 w/m²k                    4.000000
9             pitched 150 mm loft insulation                    4.000000
47  average thermal transmittance 0.16 w/m²k                    4.000000
44  average thermal transmittance 0.19 w/m²k                    4.000000
43  average thermal transmittance 0.24 w/m²k                    4.000000
17  average thermal transmittance 0.15 w/m²k                    4.000000
37  average thermal transmittance 0.20 w/m²k                    4.000000
```

0.3 Total cost of energy prediction model

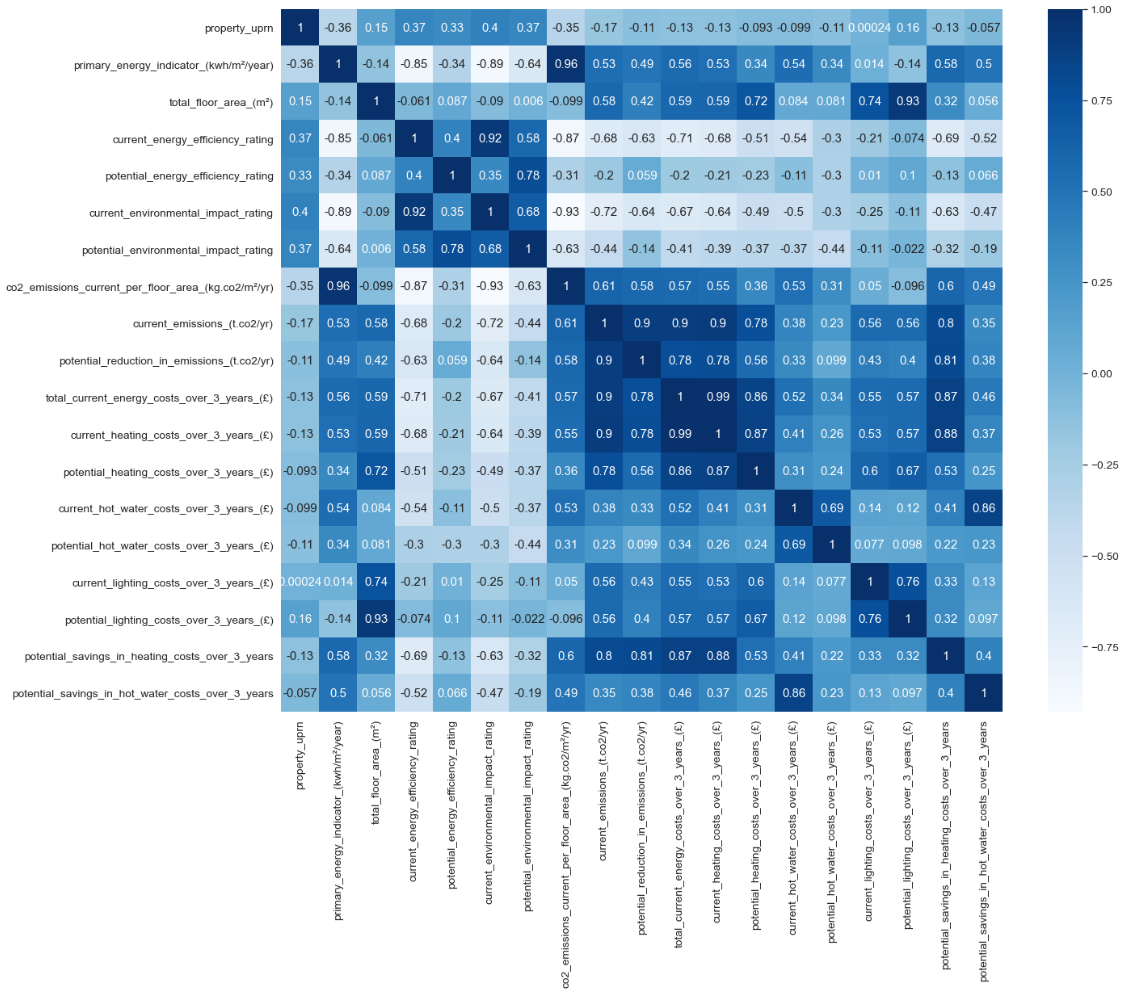
Upon close inspection, it was found that the total current energy costs over 3 years is a sum of the following:

Current heating costs over 3 years (£)

Current hot water costs over 3 years (£)

Current heating costs over 3 years (£)

Therefore, we will train separate ML models to predict these three individual cost breakdowns, which helps to predict the total cost of energy over 3 years.



We start with identifying building criterias which have moderate to strong correlations for each type of costs. Current heating costs over 3 years (£):

Positive correlations with primary energy indicator (kwh/m²/year), total floor area (m²).

Negative correlations with current energy efficiency rating, mainheat description, mainheat energy efficiency, mainheat environment efficiency.

Current hot water costs over 3 years (£):

Positive correlations with primary energy indicator (kwh/m²/year), total floor area (m²)

Negative correlations with current energy efficiency rating, hot water energy efficiency, hot water environment efficiency.

Current lighting costs over 3 years (£):

Positive correlations with primary energy indicator (kwh/m²/year), total floor area (m²)

Negative correlations with current energy efficiency rating, lighting description, lighting energy efficiency, lighting environment efficiency.

With the above information in mind, we built three separate Machine Learning Models to predict individual costs. Below is a breakdown on the model's performance on prediction on a scale of 0 to 1, 1 being the highest.

```
Model performance for predicting current heating costs over 3 years:
0.9418734153228135

Model performance for predicting current hot water costs over 3 years:
0.8505996402862955

Model performance for predicting current lighting costs over 3 years:
0.9851809581929017
```

0.3.1 Summary

The energy performances of Scottish towns tells us how well some of them have done so far, and how some others carry great potential for better energy performance if they carry out improvement suggestions. Rankings such as top 10 towns in potential savings in various costs (heating, hot water) show us how improvements could reduce costs by a huge amount over 3 years, for example, Bonawe and East Dunbartonshire could save all together over 22000 pounds in 3 years potentially in heating, that is a huge amount of costs and imagine how these savings could be put towards other improvements locally.

The wall and roof materials tell us another story on materials that are more environmental-friendly are also easyier on the pocket, and it pays to invest in greener materials for building improvements and constructions likewise. This in particular has never been more obvious as we looked at the correlations between a building's construction age and how their associated energy performance looked like overall.

0.3.2 Final Thoughts

We hope that you find our analysis very insightful. There are a few recommendations for suggestions of improvement and future work:

The wall and roof recommender model can be extended into a online energy performance improvement recommendations system, which allows input for various building materials, and then outputs recommendations on materials that perform better.

The energy costs prediction models can also be combined into the energy performance improvement system as above, which allows input for various energy consumption sources (heating, hot water, lighting) to predict total costs for users.

The combination of the two suggestions above, could lead to a user feature which not only outputs recommendations on materials that perform better, but also calculate the potential total energy costs based on such recommendations.