Does the London urban heat island affect electricity consumption of small supermarkets?

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Introduction

Urban warming in large cities is broadly observed as a temperature gradient decreasing away from the centre. Using hourly electricity demand data from small supermarkets, we have conducted a pilot study to understand if it may be possible to observe the Urban Heat Island (UHI) effect on energy consumption. Typically the UHI has been quantified using bespoke sensor systems with a modest number of sites.

The difficulty of quantifying the UHI effect on the electricity consumption of retail premises is the requirement to compare consumers with similar features. We have performed clustering and other statistical analyses of the electricity consumption of small supermarkets located across the Greater London area.

The data set

- The whole data-set consists of electricity readings of more than 150 British supermarkets belonging to a single company.
- There are 40 supermarkets located in the Greater London area.
- The resolution is one-hour, and the sampling period is July 2014 to June 2015.
- Meta-data available: location (postcode), sales area and opening times.

Analysis of the electricity consumption by floor area

We analysed the relationship between the normalised consumption by floor area of each store with its location.

- The average of the hourly electricity consumption is computed for each store.
- This average is normalised by the sales floor area of the store.

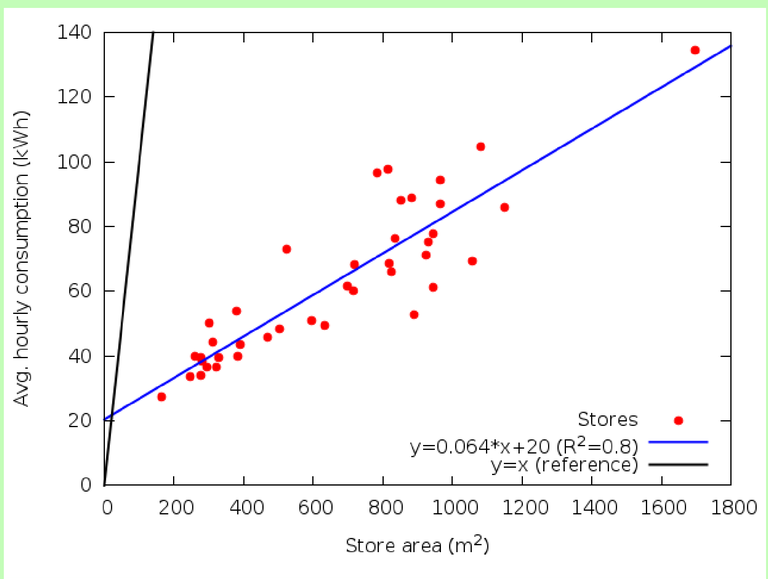
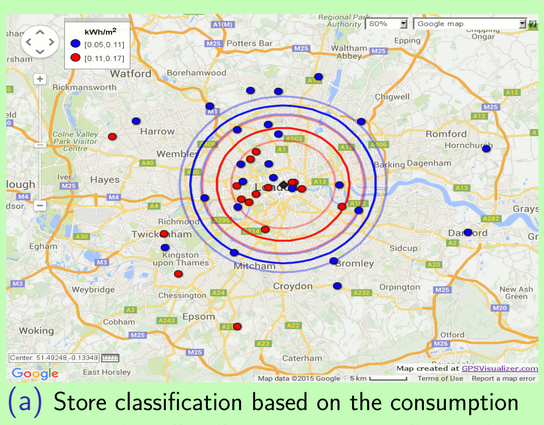
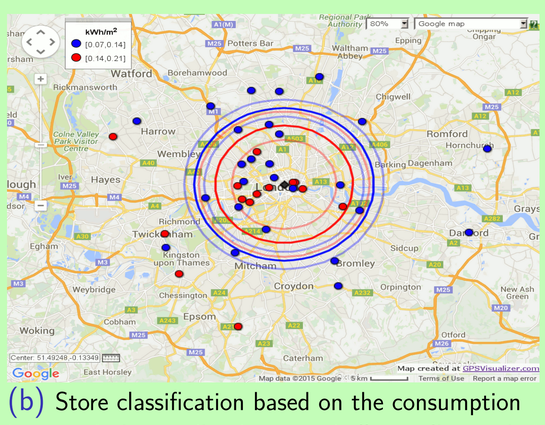


Figure : Store area against average hourly consumption and the ordinary least squares (OLS) regression model

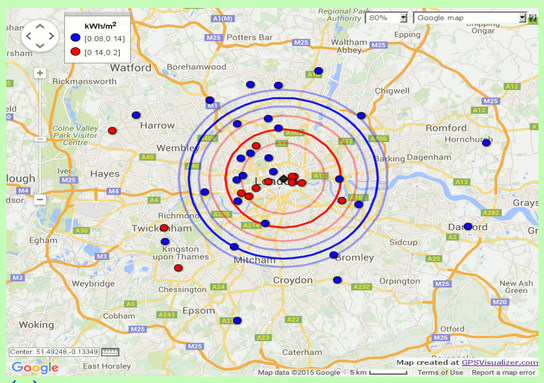
- All stores are classified between low or high consumption using two equal-size intervals.
- The distance of each store with London city centre is computed. For the city centre we used the grid coordinates: 51°30'37.6"N, 0°6'56.3"W, Victoria Embankment in front of King's College London.
- The average and standard error of the store distance from the centre for each class are then computed. Three rings per class are plotted on the maps.



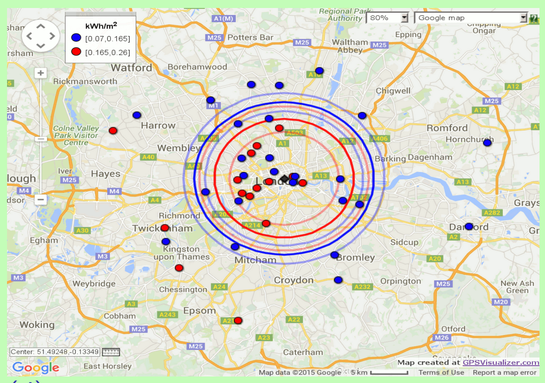
(a) Store classification based on the consumption by area during all daily hours and sampling period



(b) Store classification based on the consumption by area during trading hours and all sampling period



(c) Store classification based on the consumption by area during trading hours and July 2014



(d) Store classification based on the consumption by area during trading hours and January 2015

Analysis of the consumption with outdoor temperature

To discover the relationship of consumption with respect to the external temperatures of the supermarket we used temperature data from three meteorological stations.

- We compute the heating degree days (HDD) using a base temperature of 18.5C°.
- For each store we compute the linear regression model (OLS) obtained by computing the area normalised daily average consumption during trading hours against the HDD of the closest meteorological station.
- Stores are classified by the sign of the OLS, and the average and standard error of the store distances of each group are computed.

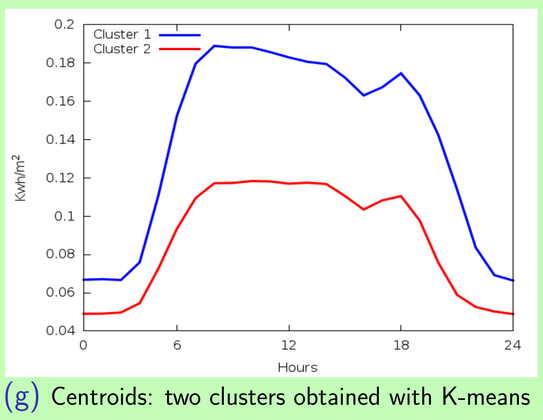
(e) Example HDD against daily consumption for a single store, a positive slope

(f) Classification of the stores by the sign of the OLS slope

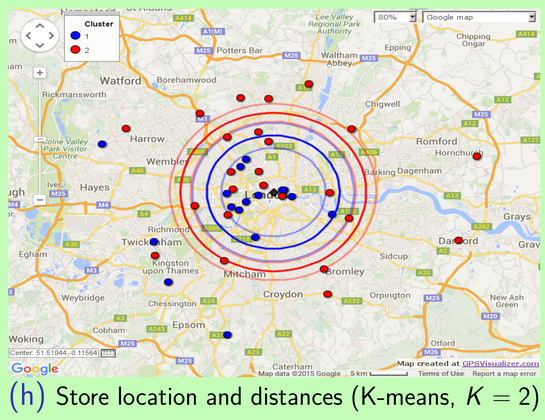
Clustering the daily profiles

For each store we compute the daily load profile for the usual trading days (Monday to Saturday), normalised by area. We have used two different algorithms to cluster these profiles:

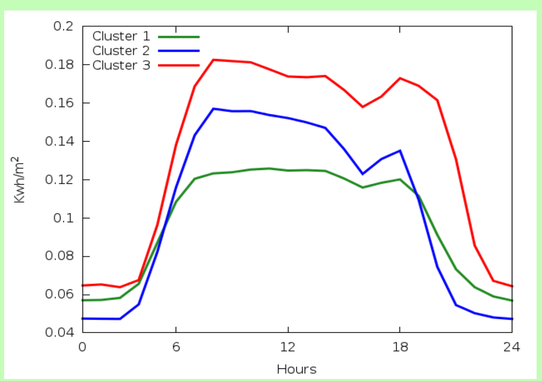
- **The K-means algorithm:** we have selected the partition for $K = 2$ that maximises the Clustering Dispersion Indicator over 100 repetitions with different random initialisations.
- **The Dirichlet Process Mixture Model (DPMM):** the DPMM is a Bayesian non-parametric algorithm where the number of clusters depends on parameters that can be estimated from the real data. The number of clusters is not pre-selected.



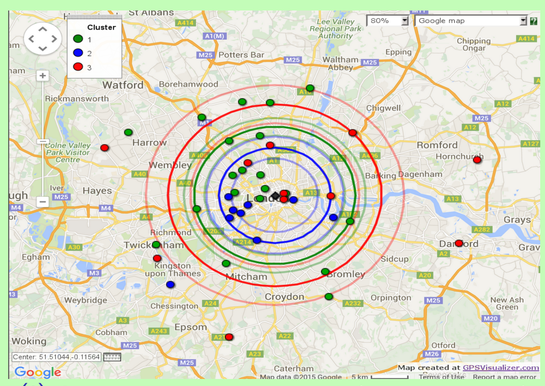
(g) Centroids: two clusters obtained with K-means



(h) Store location and distances (K-means, $K = 2$)



(i) Centroids: the DPMM found three clusters



(j) Store location and distances (DPMM, $K = 3$)

	K-means			DPMM		
Clust	No. Stores	Mean (km)	SE (km)	No. Stores	Mean (km)	SE (km)
1	16	8.3	1.8	20	10.1	1.3
2	24	9.1	1.1	11	13.4	2.8
3	-	-	-	9	7.0	1.6

Table : Mean and standard error (SE) of the distances of the stores from the London centre.

Conclusions

- We have shown that the UHI effect can be observed in power consumption of small supermarkets.
- Stores closer to the centre have a statistically-significant higher area-normalised energy consumption than those further from the centre. These consumption differences are higher during Summer, suggesting that the cooling system may be the responsible.
- Location differences are also found when we compare the stores by their profile behaviour.

Acknowledgements

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