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# Relationship between specific energy consumption and size of supermarket stores

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**ABSTRACT**

Energy consumption data for 2017 were analysed for 190 retail (supermarket) stores from one retailer in the UK. The relationship between energy consumption and store size was investigated. The mean energy intensity defined by the ratio of electrical energy consumption across the sales floor area was 866 $kWh.m^{-2}.yr^{-1}$ for an average sales floor area of 469 $m^2$. Plotting energy intensity against store size showed that smaller stores had a higher energy intensity. Measuring energy intensity using electrical energy consumption, total energy consumption, sales or gross floor area, perimeter area of the store and store volume all showed a similar trend. Electrical energy consumption is well correlated with refrigeration capacity ($r^2$ = 0.779), however, it is has a slightly better correlation with sales floor area ($r^2$ = 0.883). . When including these data with other data from previous studies, it can be seen that large stores (supermarkets) had an approximately constant energy intensity (decreasing slightly with increased floor area) and smaller stores (convenience) had a much higher energy intensity which increases strongly with decreasing floor area. Therefore to represent stores ranging from small to large a power law relationship is required.

Key words: Benchmarking, supermarket, energy consumption, retail

## 1 INTRODUCTION

In the UK, the retail sector accounts for 4.3 million tonnes of oil equivalent (MTOE) per year or 9.9 $MtCO_{2e}$ emissions (Lee *et al*., 2009). Seventy per cent of this energy use is from electricity. Foster *at al.* (2018) showed that refrigeration accounts for an average of 33% of total electrical energy for a UK retailer (based on 565 stores).

Comparing energy consumptions between different stores is not sensible unless the size of the store is taken into account, e.g. a large store should use more energy than a smaller store. Therefore, energy intensity, sometimes called specific energy consumption, is considered a useful metric to compare the energy efficiency of different size retail stores. Energy intensity is calculated by taking a metric of the energy consumption (the dividend) and dividing by another metric of the size of the store (the divisor) which normalises the data to allow comparisons between different size stores. The two dividends used are either the electrical energy consumption (EEC) or the total energy consumption (TEC), which includes natural gas. The two divisors used are either the gross floor area (GFA) or the sales floor area (SFA). There is no standard measurement and therefore data is often presented using either a dividend or divisor, making it difficult for comparisons.

Tassou *et al.* (2011) showed that energy consumption and emissions from supermarkets varies widely and can depend on many factors such as the type and size of the store, business and merchandising practices and refrigeration and environmental control systems used. Their data showed that electrical energy intensity plotted against SFA followed a power law with almost constant electrical intensity at high sales area and electrical intensity rising rapidly for small sales area. For small (convenience) stores with self-contained 'integral' refrigeration equipment, energy intensities were approximately 300 $kWh.m^{-2}.yr^{-1}$ higher than stores using predominantly centrally located 'remote' refrigeration equipment. They also showed the standard deviation of the stores with integral refrigeration was also slightly higher than the stores with remote refrigeration. Other factors that were considered to have an important influence on the electrical energy intensity of convenience stores, were the balance between temperature controlled (refrigerated) and ambient products and the balance between frozen and chilled food cabinets.

Chung *et al* (2006) showed energy intensity was affected by building age, floor area, operation schedule, number of customers and occupants' behaviour. Foster *et al.* (2018) showed energy intensity was related to store age and opening hours. In data from one UK retailer's stores Foster *et al.* (2018) showed energy intensity decreasing linearly with floor area and energy intensities which were significantly lower than those presented by Tassou *et al.* (2011).

This paper analyses recent, so far unpublished, UK supermarket energy intensities from a retailer with predominantly smaller stores than those previously analysed by Foster *et al.* (2018).

Different ways of calculating energy intensity and the relationship between the size of stores' refrigeration systems and energy intensities are investigated. The paper also compares the new data on smaller stores with previously published data on mainly larger stores to better ascertain the relationship of energy intensity over a large range of store sizes.

## 2 METHOD

Energy consumption data for 2017 was analysed for 190 retail stores from one retailer in the UK.

Energy intensity was calculated using both EEC and TEC as the dividend and SFA and GFA as the divisor. Energy intensities were also calculated using two other divisors, perimeter area (PA) and store volume (SV)

As the heat flow due to conduction into and out of a building through the walls is generally proportional to the total surface area of all sides of the building (including floor and roof), it was considered that energy consumption may better correlate with the perimeter surface area, which in this analysis was termed PA. The height of each of the stores was unknown, however the retailer approximated that convenience stores (SFA < 280 $m^2$) had a celling height of 3.2 m and that supermarkets (SFA > 280 $m^2$) had a celling height of 5 m.

It was also considered that energy consumption may also correlate well with store volume, so both sales volume (SV) (SFA x height of store) and gross volume (GV) (GFA x height of store) were used in the analysis.

In smaller stores, refrigerated food typically takes up a greater proportion of floor area than it does in larger stores as larger stores will merchandise more non-grocery products. As refrigeration is responsible for a large part of the energy used by stores (33% of electrical consumption according to Foster *et al.*, 2018), refrigeration capacity (RC) was considered to assess whether it correlated well with energy intensity.

## 3 RESULTS

### 3.1 Relationship between energy consumption and size of store

**Table 2** shows the mean and standard deviation (SD) of the different energy consumptions and floor areas for the supermarket stores.

**Table 1. Mean and standard deviation of energy consumption and store areas.**

| | Mean | SD |
|---|---|---|
| Gross floor area ($m^2$) | 738 | 741 |
| Sales floor area ($m^2$) | 469 | 493 |
| Electrical energy consumption ($MWh.year^{-1}$) | 327 | 283 |
| Total energy consumption ($MWh.year^{-1}$) (gas+electrical) | 371 | 352 |

EEC was plotted against SFA in Figure 1. A good linear relationship is shown ($r^2 = 0.870$). However, the linear regression does not go through zero, with an offset of 75.8 ± 20.2 $MWh.yr^{-1}$ within a 95% confidence band.

This offset did not seem significant when looking at all the total data set, however, when examining only the smaller stores (Figure 2), it is obvious that the offset was a significant part of the energy consumption for smaller stores.

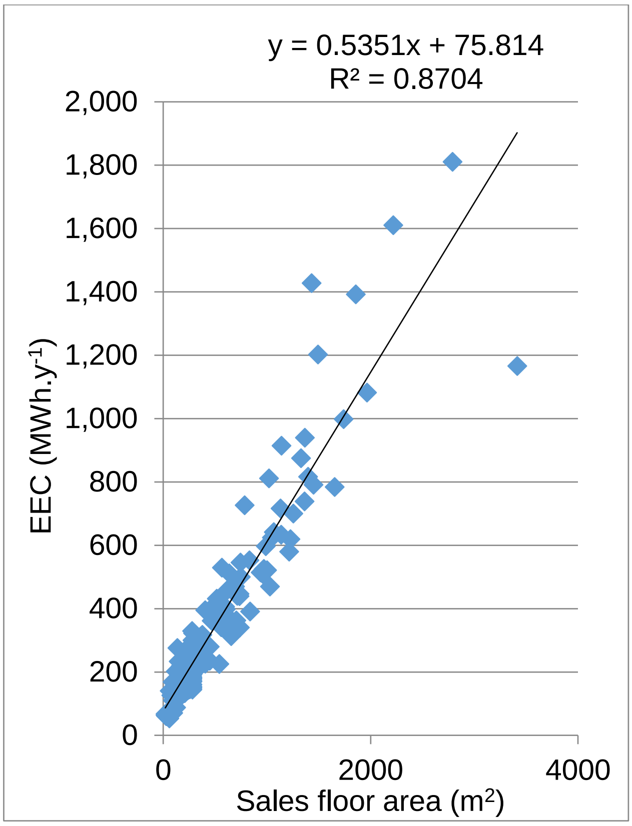


**Figure 1. EEC against SFA for all stores.**

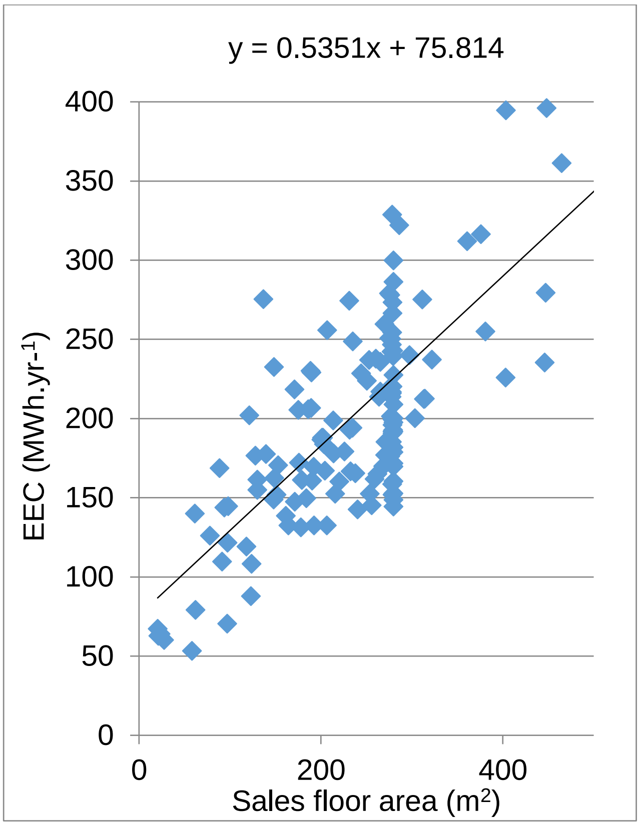


**Figure 2. EEC against SFA for the smaller stores.**

### 3.2 Relationship between energy intensity and size of store

**Table 2** shows the mean and standard deviation (SD) values for the different energy intensities examined. As can be seen there is a large standard deviation of all of the energy intensities. The two energy intensities based on store volume had standard deviations larger than 50% of the mean. The lowest standard deviation as a proportion of the mean (33%) was based on perimeter area.

**Table 2. Mean and standard deviation of supermarket store parameters.**

| | Mean | SD | % SD/mean |
|---|---|---|---|
| EEC/SFA (kWh.year$^{-1}$.m$^{-2}$) | 866 | 408 | 47 |
| EEC/GFA (kWh.year$^{-1}$.m$^{-2}$) | 533 | 239 | 45 |
| TEC/GFA (kWh.year$^{-1}$.m$^{-2}$) | 568 | 244 | 43 |
| EEC/PA (kWh.year$^{-1}$.m$^{-2}$) | 193 | 64 | 33 |
| EEC/SV (kWh.year$^{-1}$.m$^{-3}$) | 243 | 143 | 59 |
| EEC/GV (kWh.year$^{-1}$.m$^{-3}$) | 157 | 84 | 54 |

In cases where there is so much variance around the mean, it is common in the literature to plot the energy intensity against the divisor. If the results give a flat line then the energy intensity is an ideal way of comparing stores of different sizes, as the value is constant for different store sizes. If the energy intensity is not constant then a relationship between the energy intensity and the size of store can be shown by line fitting (regression analysis).

Figure 3 shows energy intensities plotted as EEC/SFA, EEC/GFA, TEC/GFA, EEC/PA, EEC/SV and TEC/GV. All energy intensities show a similar power law relationship to that given by Tassou *et al.* (2011).

A better correlation coefficient ($r^2$) is shown when the energy intensity is based on volume rather than area. EEC/SV and TEC/GV give $r^2$ values of 0.77 and 0.63 respectively, which are higher than the $r^2$ of 0.54 from the usually reported EEC/SFA.

If we wish to compare energy intensities between stores there is clearly less variance between the predicted and actual values if we use a power law relationship, and this relationship shows less variance when volume is used as the divisor. If we wish to use mean data and not consider energy intensity varying with size, then it is better to use perimeter area as the divisor, as this gives the lowest %SD/mean.

### 3.3 Effect of refrigeration

RC values were not available for all stores and therefore the number of samples in the analysis was reduced to 139. When RC was plotted against SFA (Figure 4), a slope with a statically significant (P>0.95) positive offset is shown, much like when EEC is plotted against SFA. This shows that smaller stores have proportionally more refrigeration capacity as can be seen when RC/SFA is plotted against SFA ( Figure 5). As a significant part of the energy consumption of the store is through refrigeration, this indicates that this is a reason for increased energy intensity in smaller stores.

Figure 6 shows EEC vs RC and EEC vs SFA for the reduced (139 samples) data set. There was a good correlation between EEC and RC ($r^2$ = 0.779), however, this was not as high as that for EEC vs SFA ($r^2$ = 0.883). This was due to the quality of the data, where SFA is more accurately known than RC and also because RC is not the actual refrigeration capacity of the store but a nominal value specified when the refrigeration system was contracted.

A multiple regression of EEC using both SFA and RC was carried out. This only reduced the standard error from 80.3 to 79.6 (MWh.m$^{-2}$.yr$^{-1}$) compared to a single regression using SFA as the factor and therefore was not considered useful.

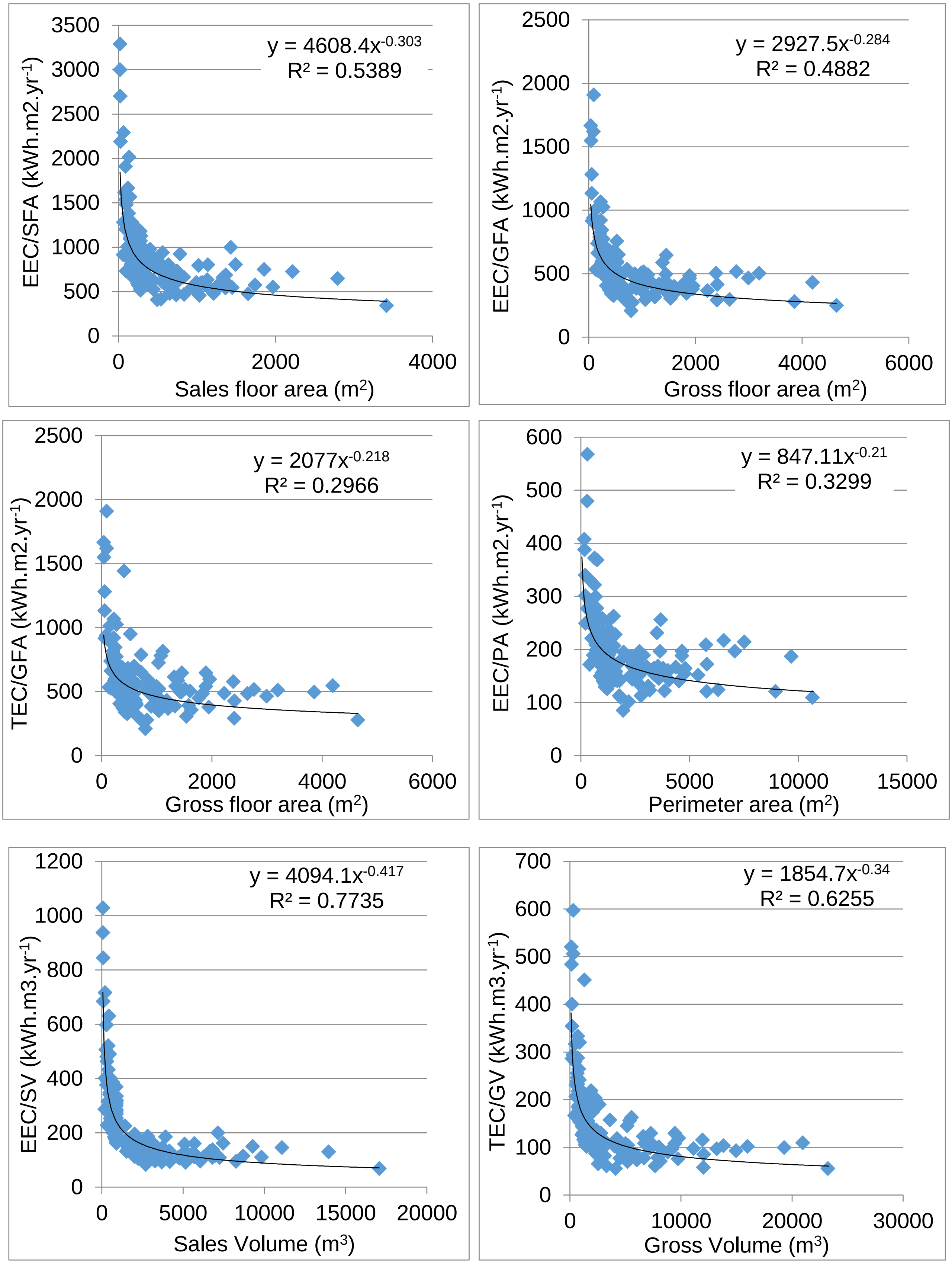


**Figure 3. Power law regression for energy intensity intensities plotted as EEC/SFA, EEC/GFA, TEC/GFA, EEC/PA, EEC/SV and TEC/GV.**

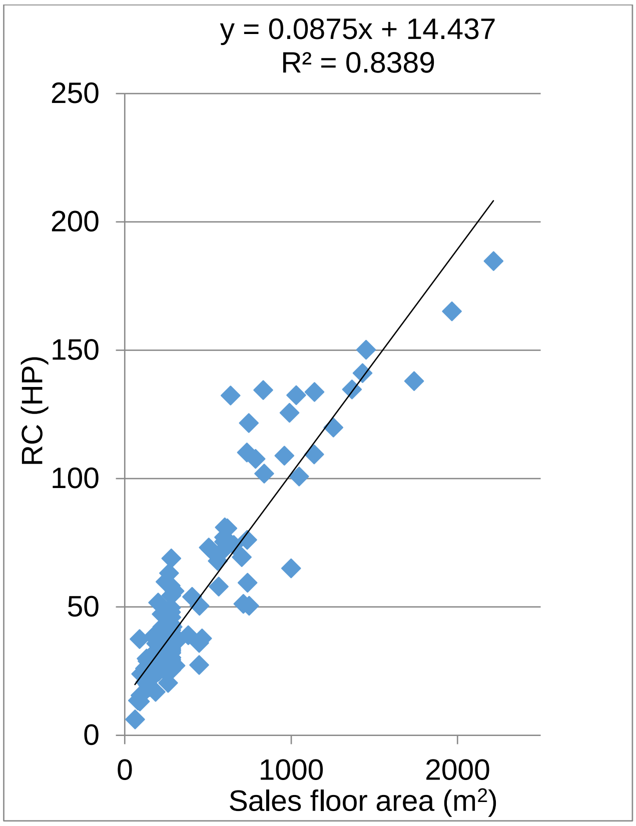


**Figure 4. RC plotted against SFA.**

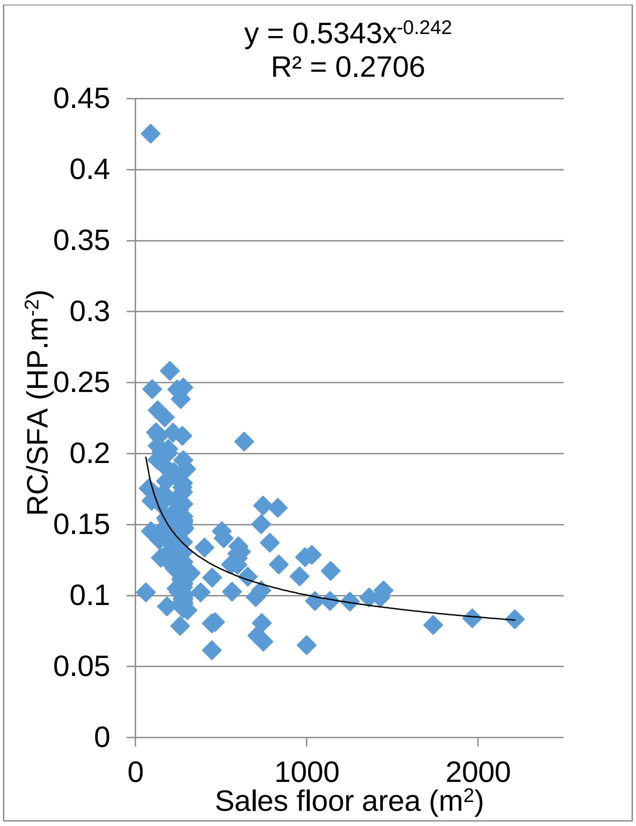


**Figure 5. RC/SFA plotted against SFA.**

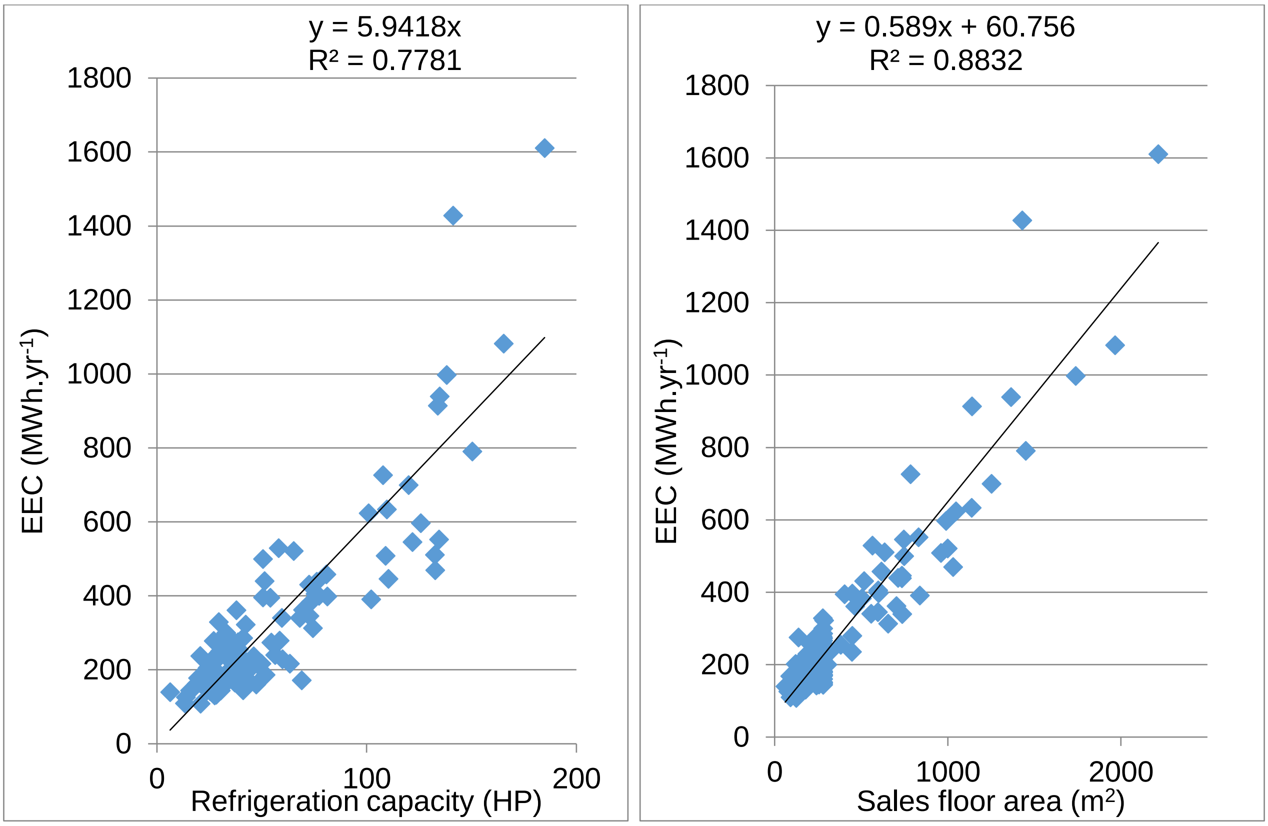


**Figure 6. EEC vs RC (left) and EEC vs SFA (right).**

### 3.4 Comparison with other studies

Data from a different UK retailer's stores (Foster *et al.*, 2018) showed a linear relationship between EEC/SFA and SFA, with EEC/SFA reducing slightly with increasing SFA. Average EEC/SFA was 566 kWh.m$^{-2}$.yr$^{-1}$ and average SFA was 3,306 m$^2$. This was very different to the data presented in this paper with an average EEC/SFA of 866 kWh.m$^{-2}$.yr$^{-1}$ and a non-linear relationship with SFA. However, the average SFA for this study was 469 m$^2$ and as we have shown the EEC/SFA is very dependent on SFA. Figure 7 shows EEC/SFA plotted for both data sets, the figure on the right includes all data and the figure on the left only stores below 4,000 m$^2$ SFA.

It can be seen that when EEC/SFA values from this study are plotted with those from Foster *et al.* (2018) there is a good match between stores with similar SFAs. This study covers the small SFAs where there is a power law relationship and Foster *et al.* (2018) covers large SFAs where there is a linear relationship.

The inverse power relationship observed by Tassou *et al.* (2011) was seen in this study. For SFA below 280 m$^2$ Tassou *et al*. (2011) showed an average EEC/SFA of 1480 kWh.m$^{-2}$.yr$^{-1}$. Data from this study showed a similar EEC/SFA at the very low SFAs but once SFA reached approximately 280 m$^2$ the EEC/SFA dropped to approximately 750 kWh.m$^{-2}$.yr$^{-1}$ which is about half that in the Tassou *et al.* (2011) study. As stated in Foster *et al.* (2018) the reason for this difference is not obvious.

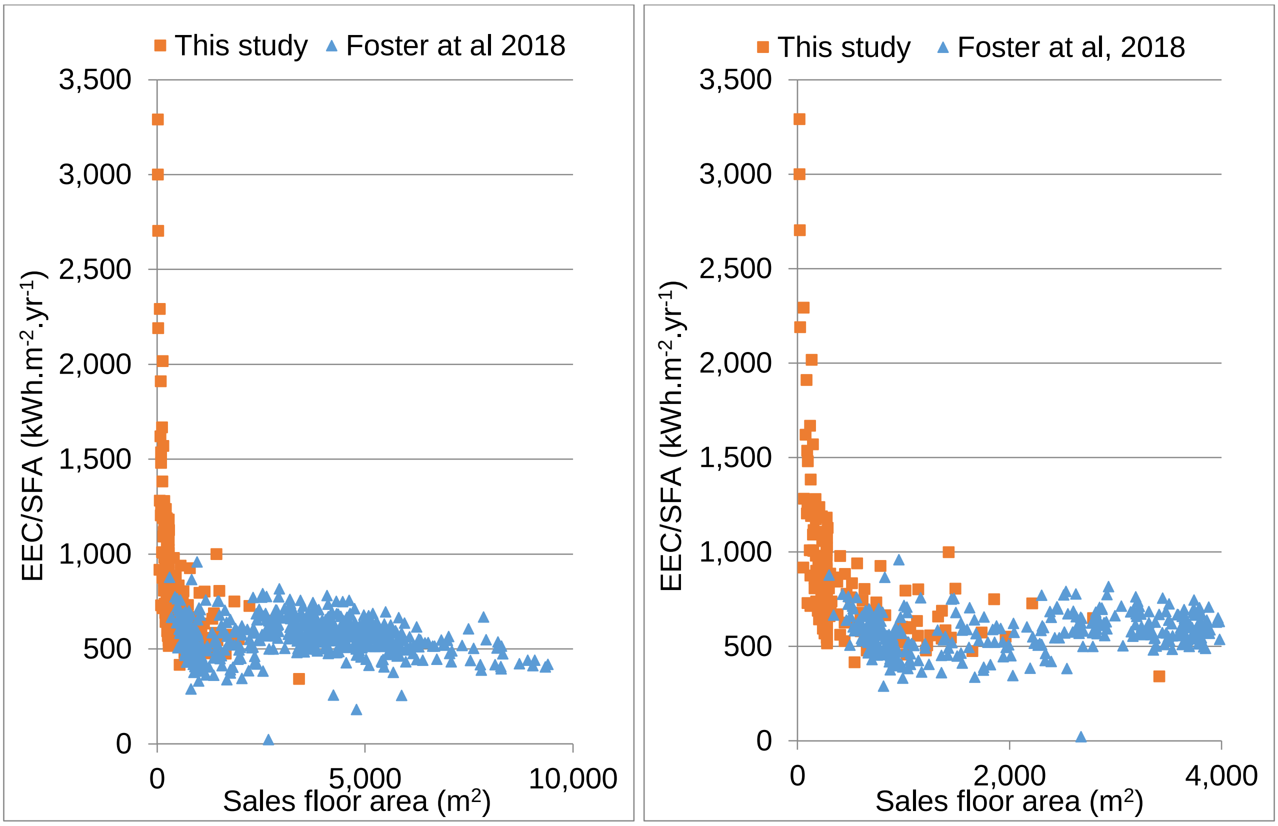


**Figure 7. SEEC v SFA for this study and a previous study. Left figure includes all SFAs and right figure SFAs below 4000 m$^2$.**

## 4 DISCUSSION AND CONCLUSIONS

This study of small supermarket stores complements a previous study on larger stores (Foster *et al.* 2018) and thus provides recent energy consumption data to allow benchmarking comparisons.

Large 'supermarket' stores have been shown to have an approximately constant energy intensity (decreasing slightly with increased floor area). Smaller 'convenience' stores have a much larger energy intensity which increases strongly with decreasing floor area. This can be represented by a power law relationship between energy intensity and store size or a linear relationship with a positive offset between energy consumption and store size.

Calculating energy intensity using electrical or gross energy and sales, floor, perimeter or volume shows a similar pattern. When looking at the energy intensity irrespective of store, using the PA as the divisor gives the smallest variance in the data. When using a power law relationship between energy intensity and store size, using store volume as the divisor gives the smallest variance.

EEC is well correlated with RC, however, it is has a slightly better correlation with SFA.

## 5 ACKNOWLEDGEMENTS

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## NOMENCLATURE

EEC Electrical energy consumption ($MWh.yr^{-1}$)

PA Perimeter area ($m^2$)

RC Refrigeration capacity (Horse power)

SFA Sales floor area ($m^2$)

TEC Total energy consumption ($kWh.m^{-2}.yr^{-1}$)

TFA Total floor area ($m^2$)

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