Energy Usage Analysis

An Analysis of Solar Generation Effectiveness

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Introduction (20 marks)

(20 Marks)

- Origin
- Why is it important to me
- Show first 5 or 6 lines of data to help understanding

Objectives

This report looks at the use of solar energy during September 2024 in a domestic property in the southern highlands of Scotland. The property previously used oil for heating and electricity for lighting plus cooking but this was changed in order to reduce running costs and the carbon-footprint of the property. A solar array, battery and ground source heat pump were installed in order to attempt to rely solely on solar generated electricity and supplemented with import from the electricity grid only to compensate for short-falls.

The main aims of this data analysis is to answer the following questions:

1. How effectively does the solar generation cover energy consumption?
2. When specifically does the solar generation fall short and require grid import?
3. Would additional battery storage capacity cover these shortfalls?
4. Does the installation meet the expectations at the time of purchase?

Summary of The Data

The data was collated from three original sources and combined into a single .txt file, then imported as an R dataframe.

```r
# Import all data from the tab-separated data file which is held in the data sub-folder
file_path <- './Data/Energy_September_2024.txt'
energy_df <- read.delim((file_path))
# Convert the string date to a valid date format
energy_df$Date <- as.Date(energy_df$Date, '%d/%m/%Y')
```

The data analysed comprises four parts, all daily data, 30 observations, for each day in September 2024:

- Weather: Temperature and solar irradiance readings

- Energy Use: Electricity consumption
- Energy Source: The source of electricity: solar, battery or import from the grid
- *Occupied*: The approximate number of hours the house is occupied each day

All data and supporting files can be found online at Github[1].

Weather

Weather data is sourced from the Balquhidder Weather Station[2] and consists of:

- *Temp* - the mean daily temperature in °C and is derived from 6 readings taken at 4 hourly intervals over a 24 hour period
- *Irrdnce* - irradiance, a measure of the solar energy experienced over a specified area, units are W/m^2 and is used to calculate the theoretical power generated from an array of solar panels[3]

Energy Use & Source

The distribution of power for the house is managed by a Tesla Powerwall and Controller and an iPhone app is used to monitor this, see Figure 1. All electricity data was downloaded via this app. Electricity is measured in Wh.

Electricity used and where it is sourced from:

- *Home_Total* - total energy used by the house
- *From_Solar* - solar power generated by an array of 36 solar panels
- *From_PWall* - battery storage
- *From_Grid* - the national power grid

Electricity generated by the solar panels and where it is used (the controller intelligently makes the routing decisions):

- *Solar_Total* - total energy generated by the solar panels
- *To_Home* - consumption by the house
- *To_PWall* - for battery storage
- *To_Grid* - export to the national power grid

TO DO: *Tidy up table columns display .... look at Pandoc options etc to change layout for table and whole document? https://pandoc.org/MANUAL.html#synopsis*

Once the sources of data have been collated and loaded the dataset consists of 30 observations and 12 columns. The first 6 rows are shown below:

```r
# Display the first 6 rows of the data
#head(energy_df)
kable(head(energy_df), caption = 'First 6 Rows of the source dataset')
```

[1] https://github.com/StuartG24/Home-Solar-Usage-Analysis
[2] https://www.blscc.org/weather
[3] Wikipedia: https://en.wikipedia.org/wiki/Solar_irradiance

Table 1: First 6 Rows of the source dataset

Date	Home_Total	From_Pwall	From_Solar	From_Grid	Solar_Total	To_Home	To_Pwall	To_Grid	Temp	Irrdnce	Occupied
2024-09-01	19048	11652	2180	5217	2360	2180	172	9	12.9	365.9	24
2024-09-02	11304	5224	1171	4909	1232	1171	50	11	13.4	335.4	6
2024-09-03	13867	7062	3690	3115	6372	3690	2664	18	9.9	1346.8	0
2024-09-04	16241	9315	4380	2546	6768	4380	2378	10	9.5	1722.5	0
2024-09-05	17960	9127	5744	3090	11036	5744	5204	88	14.5	1681.8	12
2024-09-06	16015	10998	4617	400	14726	4617	9152	957	16.6	1489.4	24

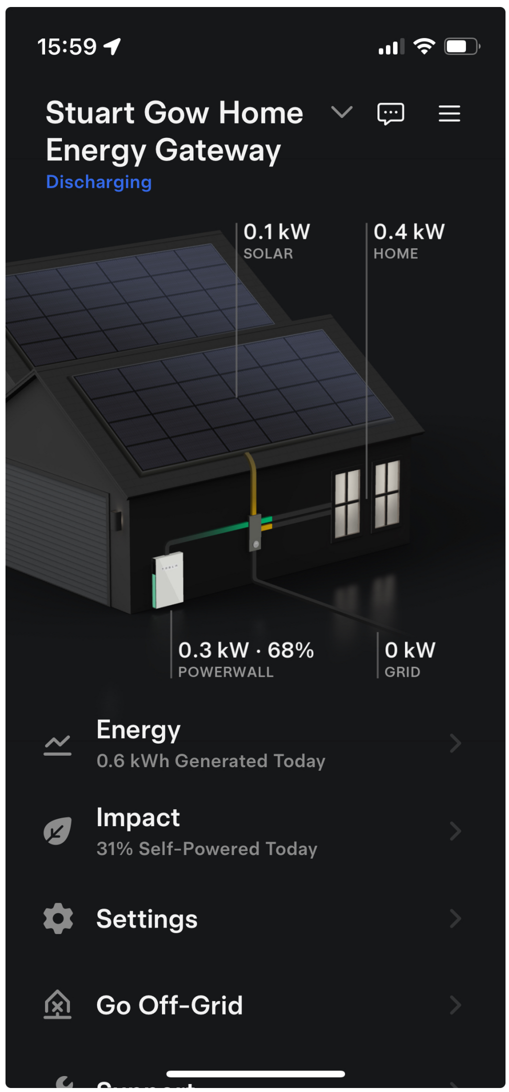


Figure 1: Tesla Powerwall

Methods and Results - (40 marks)

The data was analysed in several groups and themes, in summary:

- House Demand & Solar Energy Sufficiency
- xxx
- xxx

WIP - Analysis, expected conclusions:

1) Consumption is covered by solar .. or not? how much? how much grid still needed
2) Consumption is linked to temperature and house occupancy
3) Solar generation is linked to irradiance .. but how much?
4) Any other links such as temperature? .. probably not usage or occupancy though?
5) ?? Cannot account for £ cost and different costs at times of day .. battery importing then for example
6) ?? Battery timing in and out complicates the analysis?
7) Increased battery will smooth out across days? forecast storage/impact .. but can't see the intra-day detail to better analyse
8) Solar generation meets the forecasts at purchase .. need original data/estimates!?

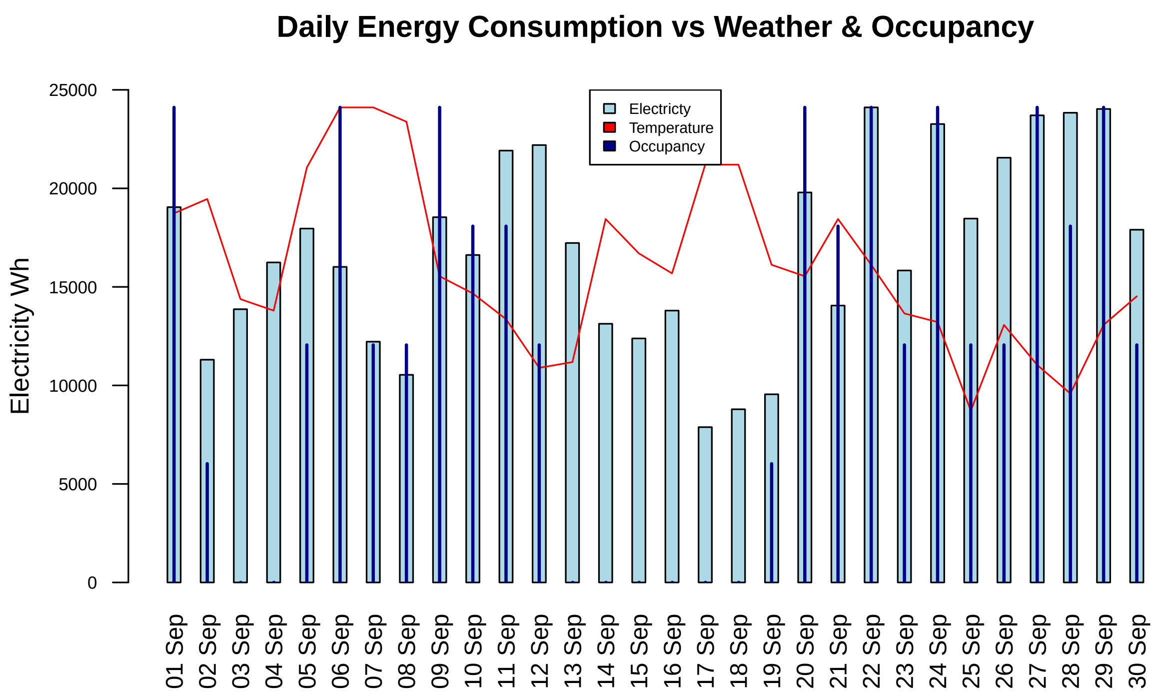
To Do.

- ?? overlay temp, irradiance, solar generation
- ?? Overlay temperture and occupation over house usage
- ?? Overlay irradiance and solar generation

House Demand & Solar Energy Sufficiency

Energy Demand

The energy consumption of the house can be compared to the weather and its occupancy and the figure below shows this (NB: the temperature and occupancy values have been scaled to only show the relationships and so no values are displayed). At first glance, there does not appear to be a strong link between the energy demand and the outside temperature but potentially there is with occupancy.



The first bar plot below shows the total energy consumed per day by the house and a breakdown of where this energy is sourced from. It appears that the energy generated by the solar panels only meets a small proportion of the total daily consumption, on average 26%.

```
average_solar_percent <- mean(c(energy_df$From_Solar / energy_df$Home_Total)) * 100
print(paste("Straight percentage:", average_solar_percent))
```

```
## [1] "Straight percentage: 26.0395444324628"
```

However, this is misleading as generated solar energy is often first stored in the battery for later use or exported to the gird if the battery becomes full. The second bar plot shows this more clearly. With solar energy distributed to the home, the battery or exported to the grid on average: 62%, 30% and 8% respectively.

```
solar_home_percent <- mean(c(energy_df$To_Home / energy_df$Solar_Total)) * 100
solar_powerwall_percent <- mean(c(energy_df$To_Pwall / energy_df$Solar_Total)) * 100
solar_grid_percent <- mean(c(energy_df$To_Grid / energy_df$Solar_Total)) * 100
print(paste("To Home:", solar_home_percent, "To Powerwall:", solar_powerwall_percent,
            "To Grid:", solar_grid_percent))
```

```
## [1] "To Home: 62.0971977996547 To Powerwall: 29.9891405679381 To Grid: 7.91530834160956"
```

A good measure of how well the solar generation meets the needs of the house's energy consumption is to simply look at how much usage is catered for without any import from the grid, and this is 80% on average.

```
adjusted_solar_percent <- mean(c((energy_df$Home_Total - energy_df$From_Grid) /
                                    energy_df$Home_Total)) * 100
print(paste("Without Grid Imported:", adjusted_solar_percent))
```

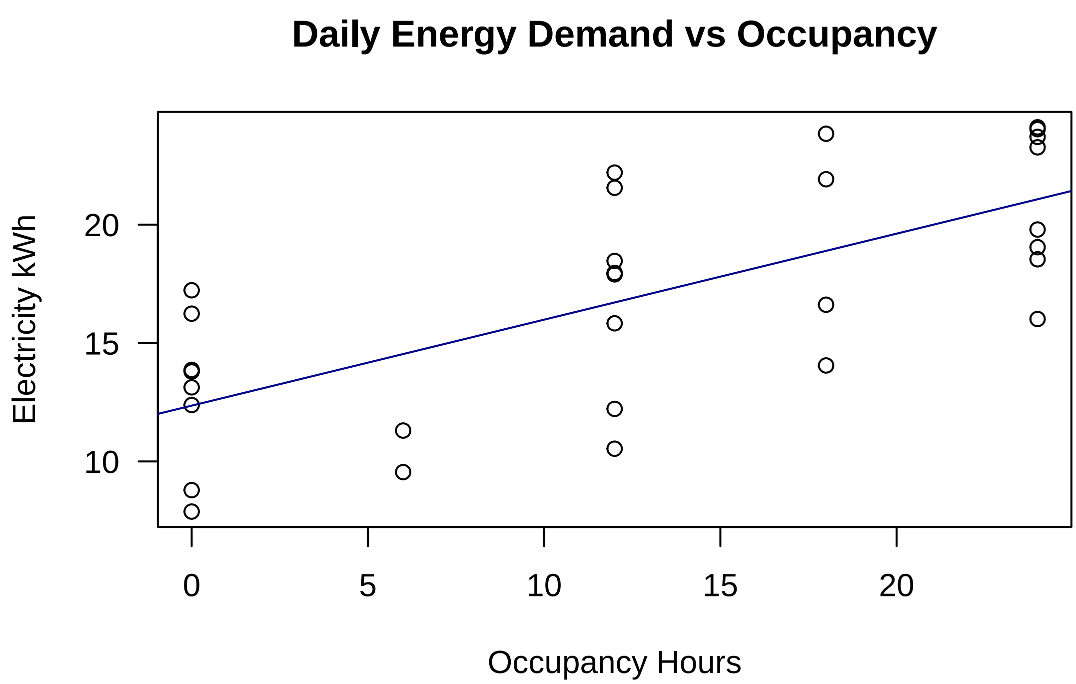
```
## [1] "Without Grid Imported: 79.9652308577059"
```

It is expected that the energy demand from the house should be related to the occupancy and also the temperature. So three linear regressions were carried out. The null hypothesis for these are that energy demand is not linked to occupancy or to temperature.

First looking at the relationship between energy demand and occupancy.

```r
# Plots and linear regression for energy and occupancy
regression_model <- lm(energy_df$Home_Total/1000 ~ energy_df$Occupied)
regression_summary <- summary((regression_model))
alpha <- regression_summary$coefficients["(Intercept)", "Estimate"]
beta <- regression_summary$coefficients["energy_df$Occupied", "Estimate"]
p_value <- regression_summary$coefficients["energy_df$Occupied", "Pr(>|t|)"]
adj_r_squared <- regression_summary$adj.r.squared

plot(energy_df$Home_Total/1000 ~ energy_df$Occupied, main="Daily Energy Demand vs Occupancy",
     xlab="Occupancy Hours", ylab="Electricity kWh", las=1)
abline(regression_model, col="darkblue")
```



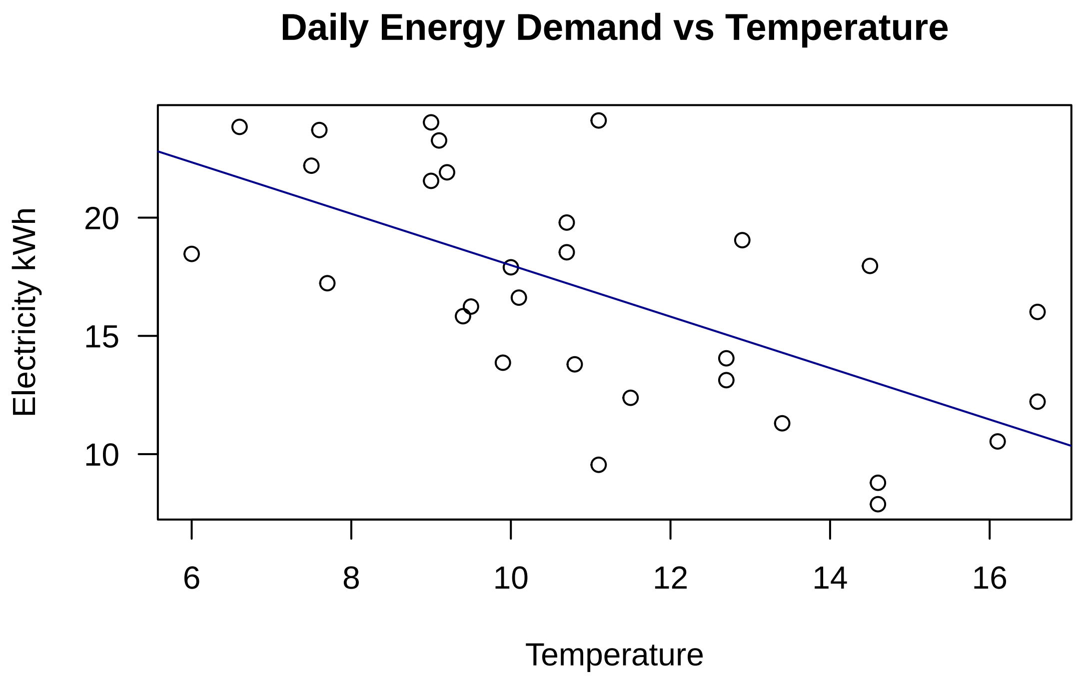

```r
print(sprintf("Alpha: %.3f, Beta: %.3f", alpha, beta))
```

```
## [1] "Alpha: 12.356, Beta: 0.363"
```

```r
print(sprintf("p-value: %.4f, Adj R-Squared: %.3f", p_value, adj_r_squared))
```

```
## [1] "p-value: 0.0000, Adj R-Squared: 0.461"
```

Then looking at the relationship between energy demand and temperature (NB: same R Code so not printed to save space).




```
## [1] "Alpha: 28.868, Beta: -1.088"
```

```
## [1] "p-value: 0.0001, Adj R-Squared: 0.397"
```

Additionally a multi-linear regression was completed to look at the relationship between energy demand and occupancy plus temperature (NB: A three dimensional plot was not completed). The p-value for this is near zero and below the 5% crical value and we can reject the null hypothesis and can infer that energy demand is linked to occupancy and temperature. In addition the high adjusted r-squared value of 0.8 suggest that there is a strong correlation between energy demand and with the combined occupancy and temperature. It is worth noting that the seperate relationships were not very strongly correlated.

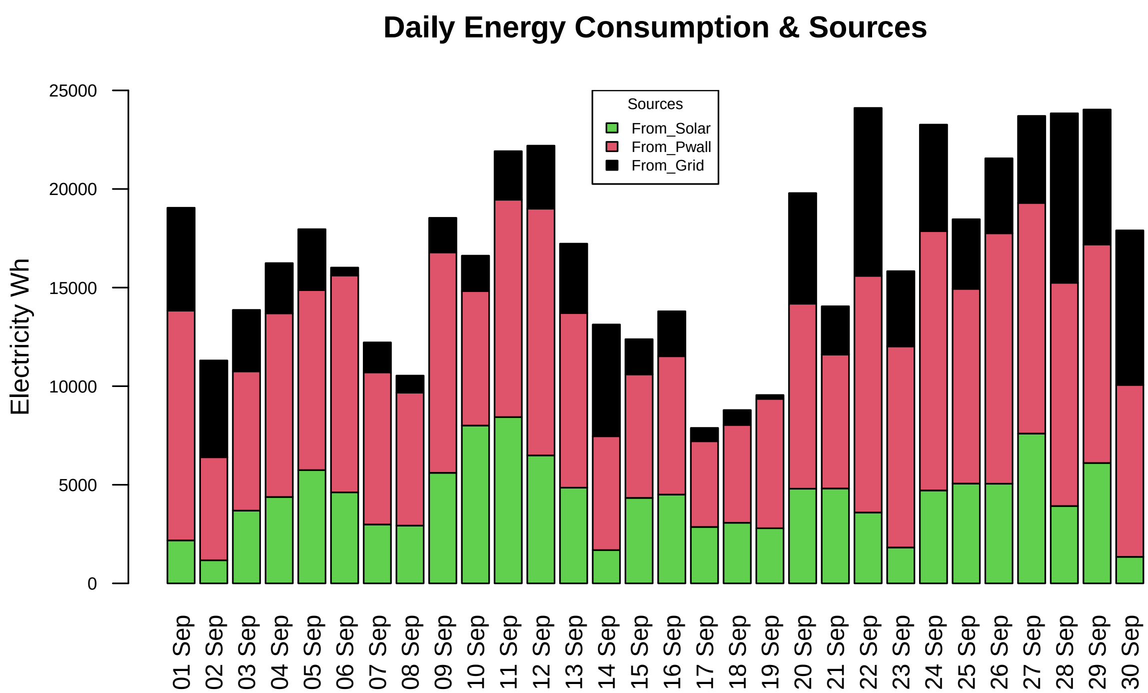
!! TO DO: For conclusions section

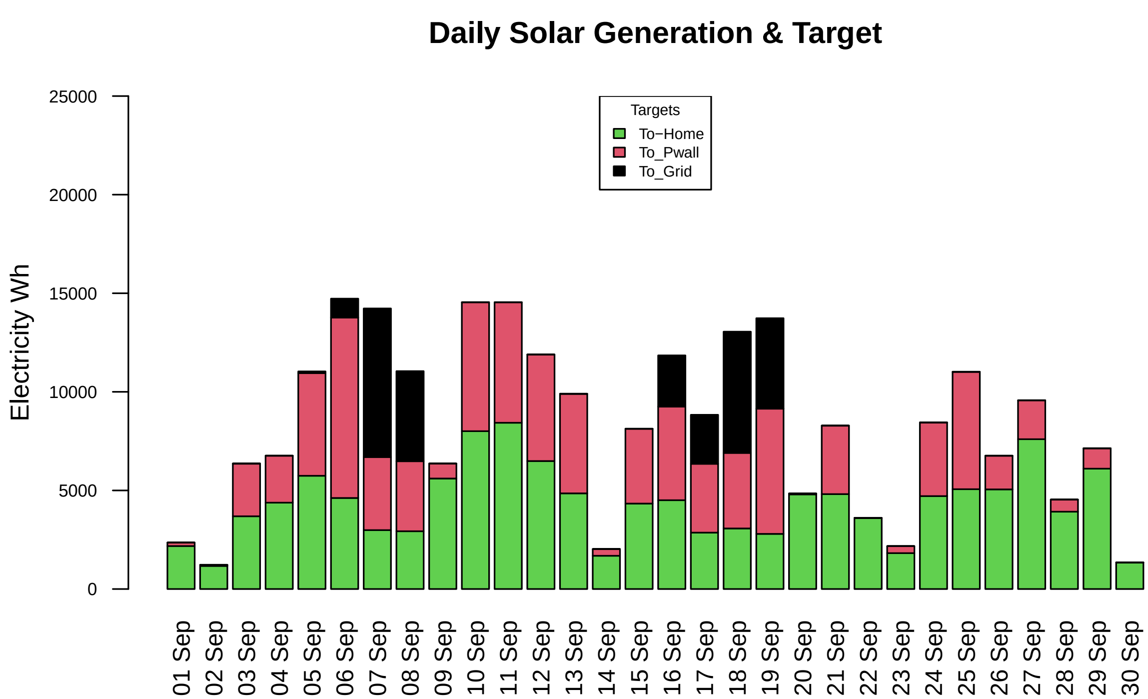
```
## [1] "Alpha: 23.448, Beta Occupancy: 0.328, Beta Temp: -0.965"
```

```
## [1] "p-value Occp: 0.0000, p-value Temp: 0.0000, Adj R-Squared: 0.789"
```

!! So a conclusion is that

?? ***Energy Consumption . . . .***





```
plot(energy_df$To_Home ~ energy_df$Date, type = 'l', col = 'red')
lines(energy_df$Date, energy_df$Temp, type = 'l', col = "blue")
lines(energy_df$Date, energy_df$Occupied*20, type = 'h', col = "green")
legend("topright", legend = c("Home", "Temp", "Occupied"),
       col = c("red", "blue", "green"), lty = 1)
```

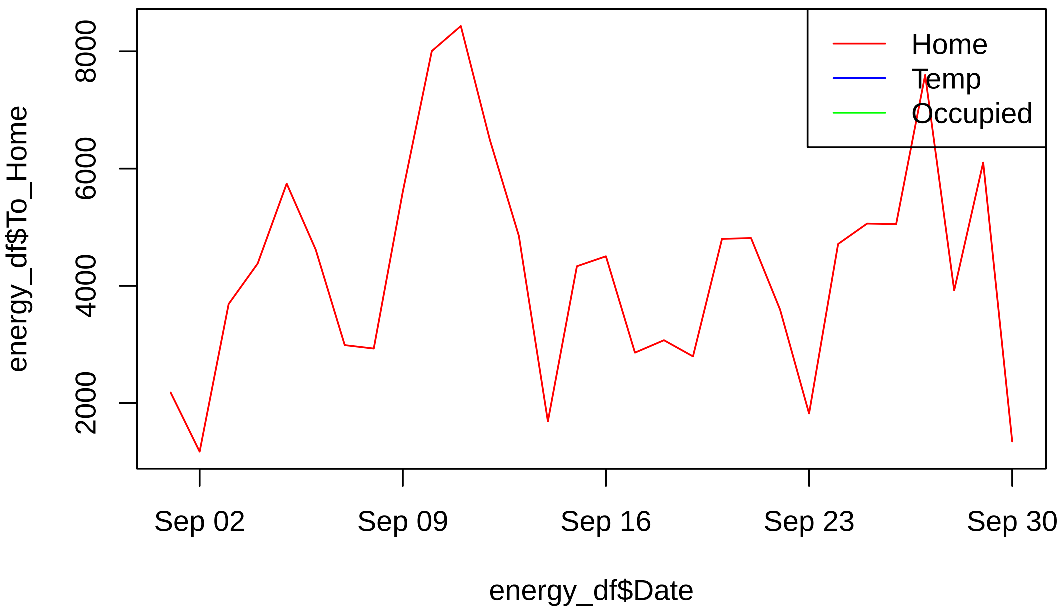


Figure 2: First plot

```
plot(energy_df$Date, energy_df$From_Solar, type = 'l', col = "red")
lines(energy_df$Date, energy_df$Irrdnce/150, type = 'l', col = "blue")
legend("topright", legend = c("Solar", "Irradiance", "xx"),
       col = c("red", "blue", "green"), lty = 1)
```

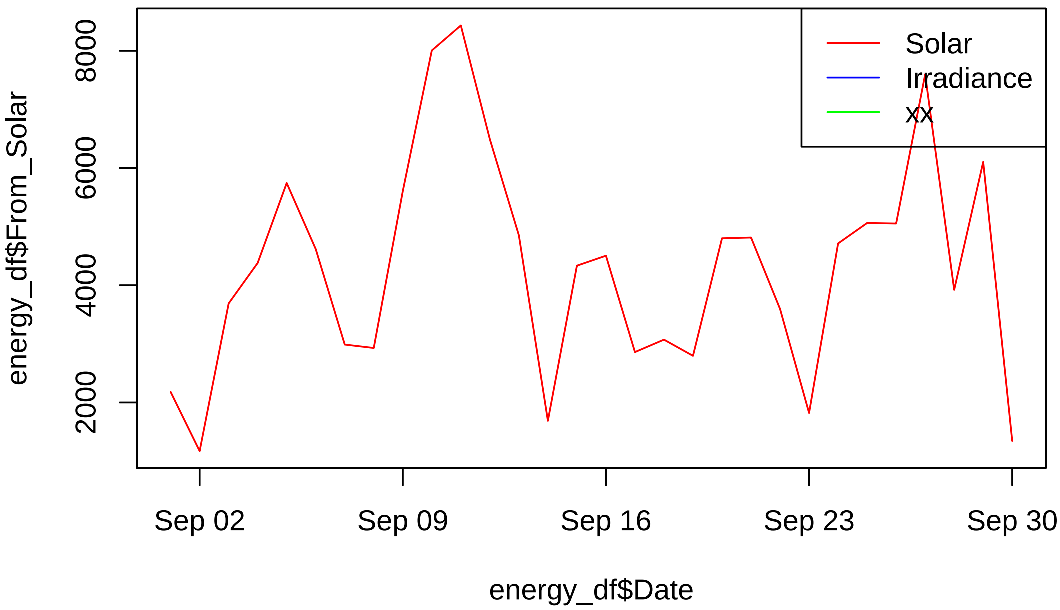


Figure 3: Second plot

Methods and Results

(40 marks)

Method

TO DO: Should data introduction and visualisation be here instead?

Results

TO DO: Have a look back at the Bran Lab report for Spring 2018, for how to present means, SD etc etc

Conclusions

(20 marks)

##?? Discussion

TO DO: Structure into two sections

##?? Conclusion

Test citations (Crawley, 2014) and as Fraix-Burnet (2016)

Spiegel and Schiller (2012)

References

Crawley, M.J. (2014) *Statistics: An introduction using R*. 2nd Edition. John Wiley & Sons.

Fraix-Burnet, D. (2016) 'Introduction to R', *Statistics for Astrophysics: Clustering and Classification*, Volume 77(2016), pp. 3–12. Available at: https://doi.org/10.1051/eas/1677002.

Spiegel, M.R. and Schiller, J. (2012) *Schaum's outline probability and statistics.* 4th edn. McGraw Hill.