POWERVAULT – Analytic test

Result

The estimated electricity cost before and after installed battery are £236.50 and £130.20 respectively, as shown below. Based on the assumption that the battery will be charged using excess energy from solar generation and also charged from the grid when the agile tariff is low, then discharged when the tariff is high. MATLAB and Excel were used in this analysis.

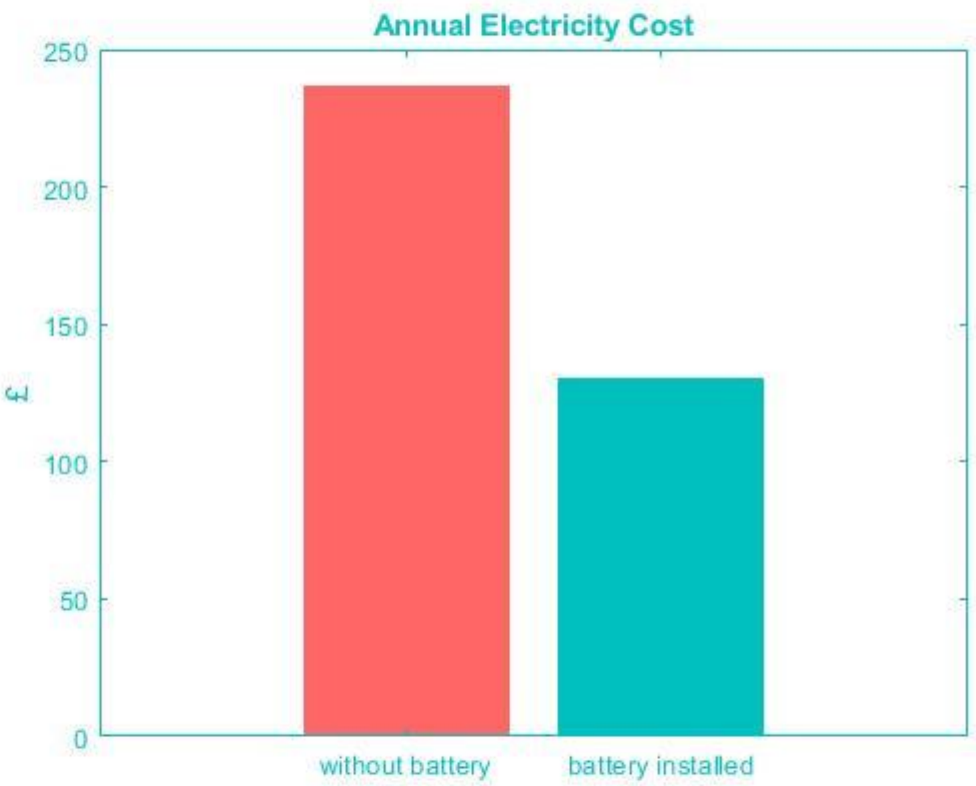


Figure 1 Annual electricity cost

Question 1 Analytic approach

The data given is listed below,

- Electricity demand profile every 30 minutes, gross 1 kWh
- Solar generation profile every 30 minutes, gross 1 kWh

Though, the agile tariff has not been given, it is available for download on Octopus website. The tariff is recorded every 30 minutes in the past 2 years. The same range of dates of tariff was chosen to match the energy profiles.

Step 1: Adjust electricity demand to 3,100 kWh by multiplying 3,100 to electricity demand profile.

$$Energy\ demand = Energy\ shape\ \times 3{,}100$$

Based on rough estimation, generally 3 kWp-solar panels can generate 2,264 kWh annually if installed in south-western England. Similar to electricity demand, solar profile was multiplied by 2,264. Then all data was transformed into the same format (17,520 rows x 1 column)

$$Solar\ generation = Solar\ shape\ \times 2{,}264$$

Step 2: Calculate the energy used from the grid by subtracting solar generation from electricity demand

$$Energy\ used\ from\ grid = Energy\ demand - Solar\ generation$$

Step 3: Calculate the electricity cost by multiplying tariffs to the energy used from grid each 30 minute period. The sum of these electricity costs is the annual electricity cost.

$$Electricity\ cost = Energy\ used\ from\ grid\ \times Agile\ tariffs$$

$$Annual\ electricity\ cost = \sum Electricity\ cost$$

Question 2 Analytic Approach

The analysis is based on the assumption that the battery will be charged the excess energy from solar and when the tariff is the lowest during the day. Battery will release energy when the tariff is high. From figure 2, tariff is low between 2:00 to 5:00 and rising from 15:30 then drops again after 20:00. Therefore, in this analysis,

- Battery will be charged between 2:00 – 5:00
- Battery will release energy from 15:30

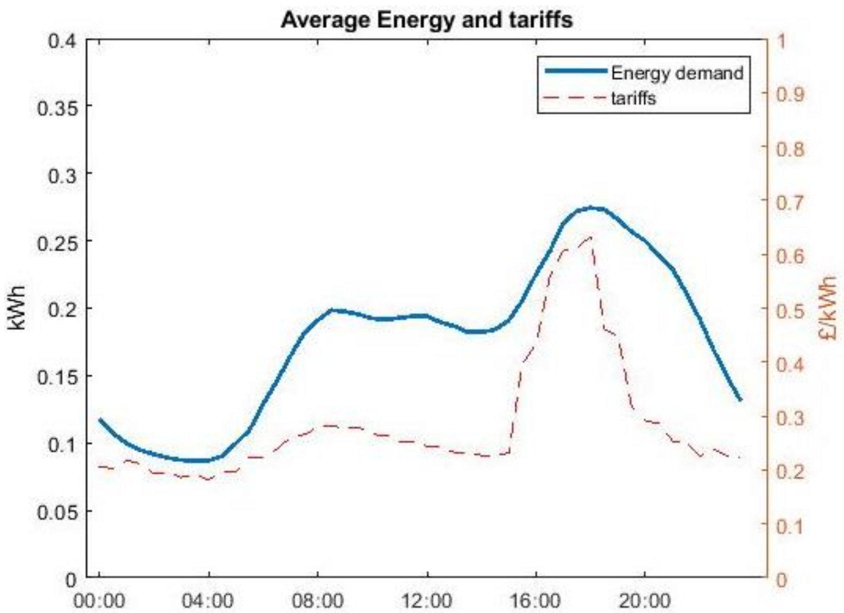


Figure 2 Average energy and tariffs

Battery efficiency is also considered based on Powervault 3 datasheet on the website.

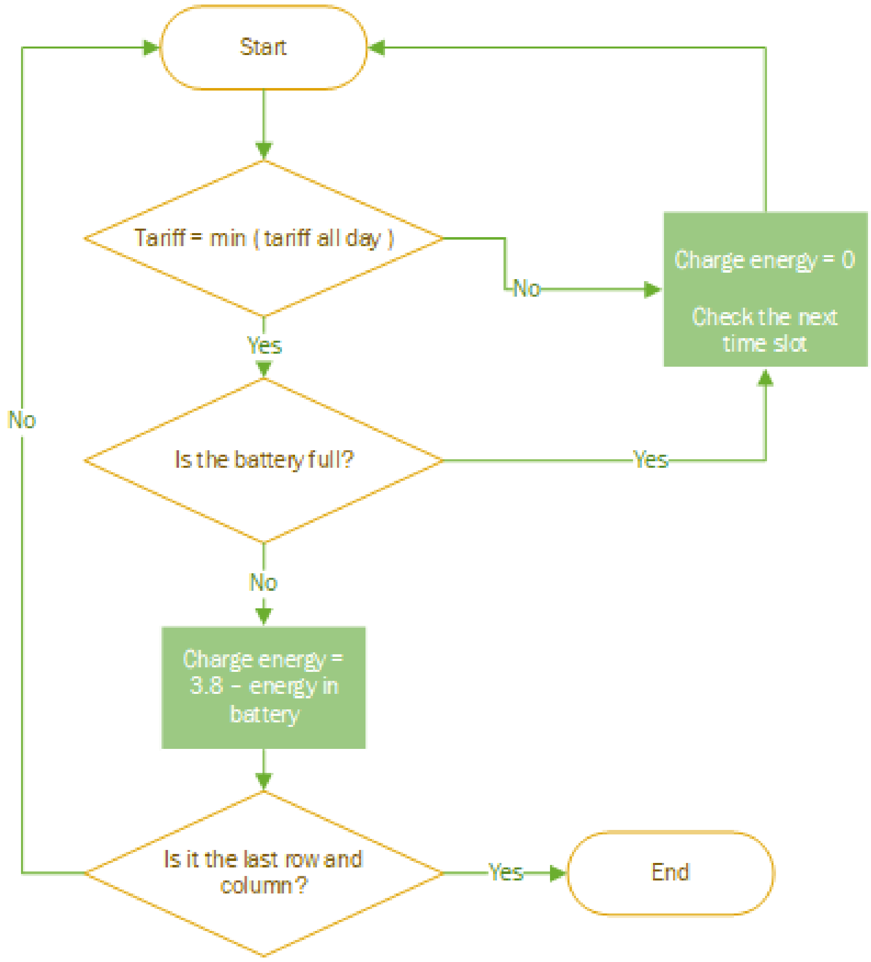
- Usable capacity, 3.8 kWh
- Battery efficiency, 95%
- Depth of discharge, 100%

The aim is to find the discharge energy from battery and subtract from energy left in question 1 then find the energy that charge from grid to battery and add it to the energy used from grid.

Step 1: Find charge energy from solar energy that exceeds energy demand at specific time.

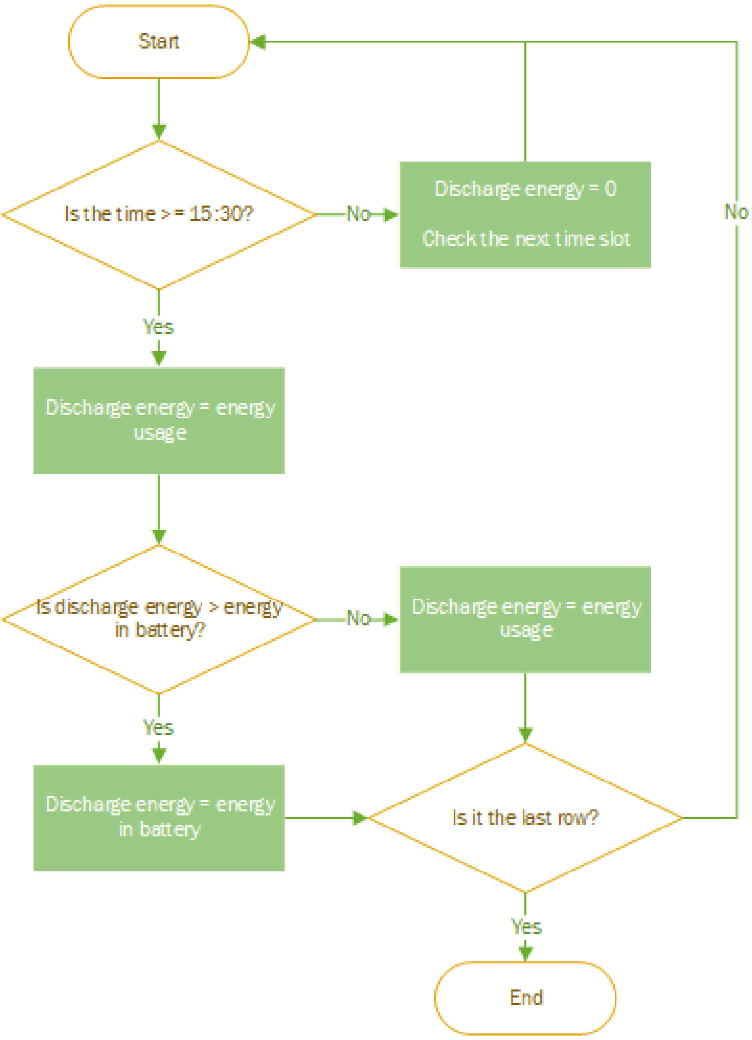
$$Charge\ from\ solar(kWh) = \int_0^t (Solar\ energy - Energy\ demand)\,dt$$

Step 2: Set the battery to charge only when the tariff is the lowest during the day and if the battery is not full.



Step3: Combine charge energy from solar and grid to model state of charge

Step 4: Find discharge energy from 15.30, where the tariff tends to be high.



Step 5: Calculate the total energy used from the grid from below equation.

$$Energy_{used\ grid} = \left(Energy_{demand} - Solar_{gen}\right) + Energy_{charge\ grid} - Energy_{discharge,batt}$$

Step 6: Similar to question 1, calculate the electricity cost by multiplying tariffs to the energy used from grid each 30 minute period. The sum of these electricity costs is the annual electricity cost.

For example, as shown in figure 3, the battery is charged when the tariff is the lowest between 2:00 to 5:00. Then when solar panels start to generate power at 7:30, use of grid energy decreases. At 11:00, when the solar panels generate more power than energy demand, the surplus energy charges the battery. Then the battery starts to discharge when the tariff is high from 15:30. Figure 4 shows that the battery helped to shift the peak.

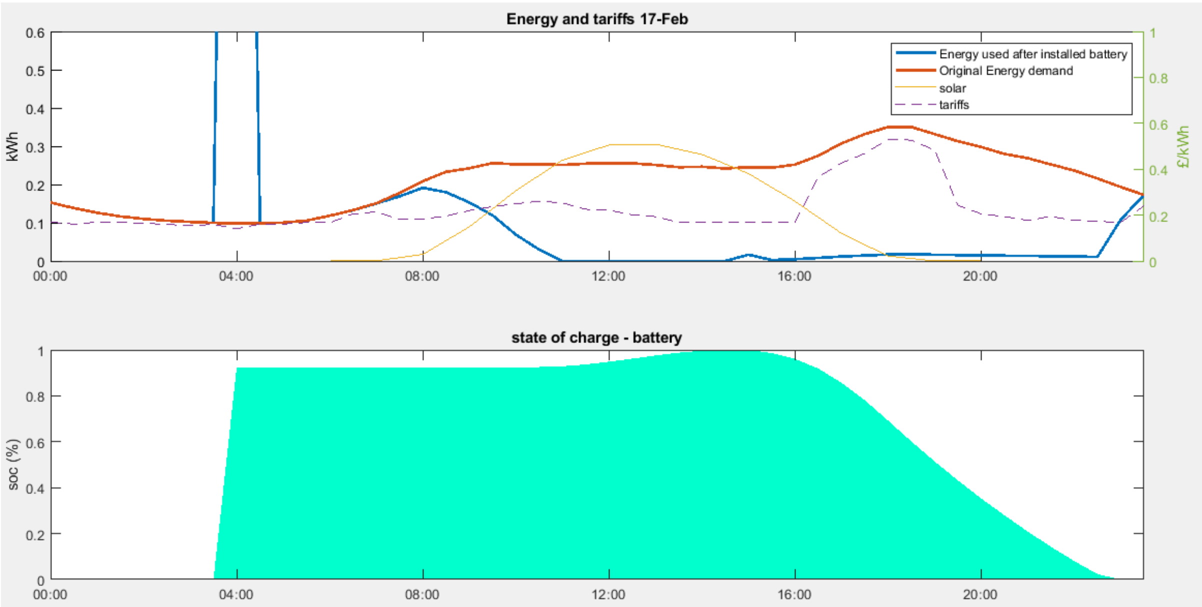


Figure 3 Energy and tariffs on 17-Feb-2019

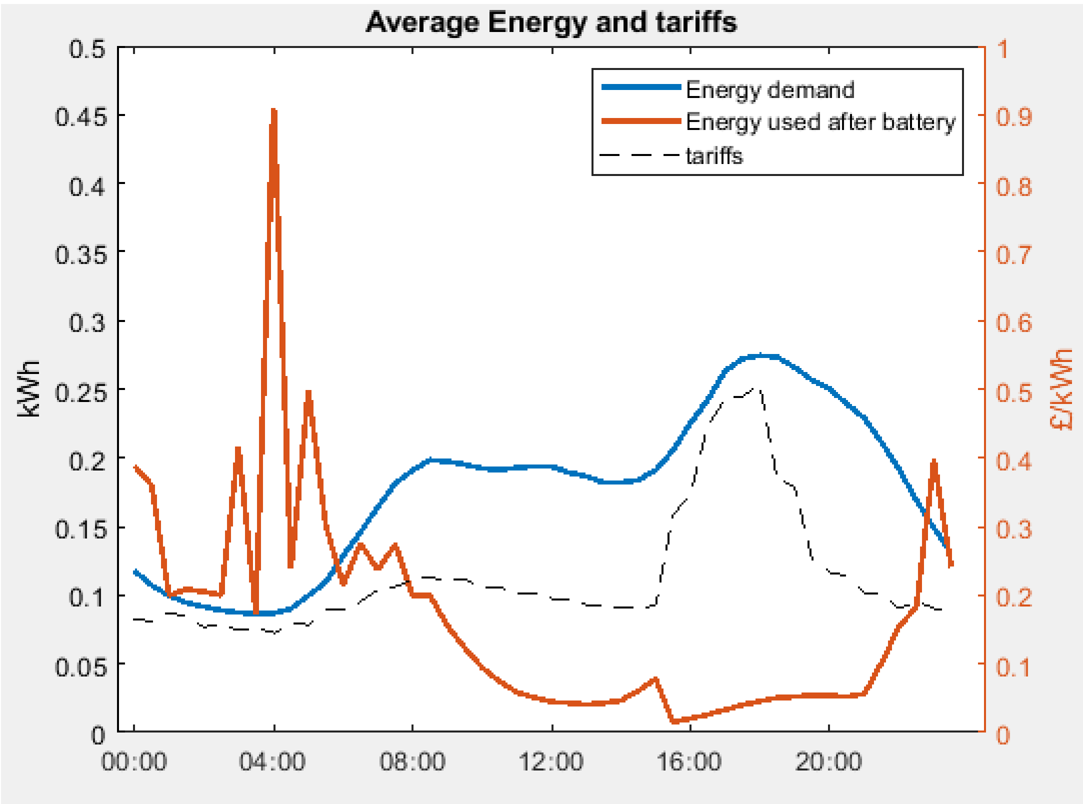


Figure 4 Average energy and tariffs

MATLAB code

```
%-----------------------------------------------------------------------------
%                          Load data
%-----------------------------------------------------------------------------
% index %
%pw(row,1) = agile tariffs
%pw(row,2) = energy demand
%pw(row,3) = solar generation
%pw(row,4) = energy_usage (2-3)
%pw(row,5) = energy from solar charge to battery
%pw(row,6) = hourly electricity cost
%pw(row,7) = charge accumulate
%pw(row,8) = discharge energy from 15.30
%pw(row,9) = state of charge
%pw(row,10) = charge from grid to battery
%pw(row,11) = charge from solar + charge from grid to battery
%pw(row,12) = refine discharge energy from battery
%pw(row,13) = energy_usage - discharge energy + charge grid
%pw(row,14)=hourly electricity cost after battery

ag_tariff=xlsread('agile_tariff','Sheet2');
energy_demand=xlsread('Energy profiles (exercise 1)','Demand_PC1_shape');
solar_gen=xlsread('Energy profiles (exercise 1)','Solar_shape');

%Adjust energy_demand to meet the annual use 3,100 kWh
energy_demand=energy_demand*3100;

%Solar 3kWp approximately produce 2,264 kwH per year
solar_gen=solar_gen*2264;

%Transform data to the same format
i=1;
for row = 1:365
    for col = 1:48
        pw(i,1)=ag_tariff(row,col);
        pw(i,2)=energy_demand(row,col);
        pw(i,3)=solar_gen(row,col);
        i=i+1;
    end
end

avg_en_demand=average_array(energy_demand);%avarage energy demand
avg_solar_gen=average_array(solar_gen);%avarage solar gen

%-----------------------------------------------------------------------------
%                          Question 1
%-----------------------------------------------------------------------------

%Find energy left to charge grid after solar power generation
%=energy_use=energy_demand - solar_gen
for row=1:17520
    pw(row,4)=pw(row,2)-pw(row,3);
    if pw(row,4)<0
        pw(row,5)= pw(row,4)*-1;
        pw(row,4)=0;
    else
        pw(row,5)=0;
    end
end
```

```
%transform to 48 col
energy_usage=tran_to_timeslot(pw,4);

%avarage energy_usage
avg_en_usage1=average_array(energy_usage);

%find electricity cost by ag_tariff * energy charge from grid
%pw(row,6)=hourly electricity cost
%pw(row,1)=ag_tariffs
for row= 1:17520
    pw(row,6)=pw(row,4)*pw(row,1);
end

%annual electricity cost
annual_cost=sum(pw(:,6))/100;

%-------------------------------------------------------------------------
%                        Question 2
%-------------------------------------------------------------------------
%Transform solar charge energy from pw to timeslot
charge=tran_to_timeslot(pw,5);

%charge energy to battery between 2.00-5.00 when tariffs is the lowest
for row=1:365
    for col=1:48
        if ag_tariff(row,col)==min(ag_tariff(row,:))
            charge_grid(row,col)=3.8-sum(charge(row,:));
            if charge_grid(row,col)<0
                charge_grid(row,col)=0;
            end
        else
            charge_grid(row,col)=0;
        end
    end
end

%Transform back to pw
%pw(row,10)=charge from grid to battery
i=1;
for row = 1:365
    for col = 1:48
        pw(i,10)=charge_grid(row,col);
        i=i+1;
    end
end

%combine charge from solar (5) and from grid (10)
for row=1:17520
    pw(row,11)=pw(row,5)+pw(row,10);
end

%Calculate the accumulate charge energy to battery
pw(1,7)=pw(1,11);
for row=2:17520
    pw(row,7)=pw(row-1,7)+pw(row,11);
    if pw(row,7)>3.8;
        pw(row,7)=3.8;
    end
end
```

```
%Investigate the ag_tariffs to select the windows to discharge
%see average tariff for each 30 mins
avg_tariffs=average_array(ag_tariff);


%From the graph the tariff is getting high on 15.30 and low again after
%20.00. So battery will be discharge from 15.30

%Transform data structure of batt_charge_acc
batt_charge_acc=tran_to_timeslot(pw,7);

%Find discharge energy every 30 mins from 15.30 (col=32)
for row=1:365
    for col=1:48
        if col>31
            discharge(row,col)=energy_usage(row,col);
        else
            discharge(row,col)=0;
        end
    end
end

%add to pw
%pw(row,8)=discharge energy from 15.30
i=1;
for row = 1:365
    for col = 1:48
        pw(i,8)=discharge(row,col);
        i=i+1;
    end
end

%pw(row,9)=Discharge from battery(batt_discharge)
pw(1,9)=pw(1,11);
for row=2:17520
    pw(row,9)=pw(row-1,9)-pw(row,8)+pw(row,11);
    if pw(row,9)<0
        pw(row,9)=0;
    elseif pw(row,9)>3.8
        pw(row,9)=3.8;
        pw(row,11)=pw(row,9)-pw(row-1,9);
    elseif pw(row,9)>0 && pw(row,8)==0 && pw(row,9)<3.8;
        %pw(row,8)=pw(row,4);
        pw(row,9)=pw(row-1,9)-pw(row,8)+pw(row,11);
    end
end

%redefine charge from grid (10)
for row=2:17520
    if pw(row,10)>0 && pw(row-1,9)>0;
        pw(row,10)=0;
    end
end
for row=1:17520
    pw(row,10)=pw(row,10)/0.95;
end

%pw(row,12)=refine discharge energy from battery
```

```
for row=2:17520
    if pw(row,9)==0 && pw(row-1,9)<3.8 && pw(row-1,9)~=0 && pw(row,8)>0
        pw(row,12)=pw(row-1,9);
    elseif pw(row,9)==0 && pw(row-1,9)==0 && pw(row,8)>0
        pw(row,12)=0;
    else
        pw(row,12)=pw(row,8);
    end
end
%Discharge efficiency 95%
for row = 1:17520
    pw(row,12)=pw(row,12)*0.95;
end

%pw(row,13) = energy_usage - discharge from battery +charge from
%grid
for row=1:17520
    pw(row,13)=pw(row,4)-pw(row,12)+pw(row,10);
end

%Transform charge energy from pw to timeslot
energy_usage_batt=tran_to_timeslot(pw,13);

%average energy usage after installed battery
avg_en_usage=average_array(energy_usage_batt);

%find electricity cost by ag_tariff * energy charge from grid
%pw(row,14)=hourly electricity cost after battery
%pw(row,1)=ag_tariffs
for row= 1:17520
    pw(row,14)=pw(row,13)*pw(row,1);
end
%annual electricity cost
annual_cost_wbatt=sum(pw(:,14))/100;

%-------------------------------------------------------------------------
%                        Graph
%-------------------------------------------------------------------------
figure(1);plot(avg_tariffs)
title('average tariffs every 30 mins');ylabel('p per kWh')
set(gca,'XTick',1:8:48)
set(gca,'XTickLabel',{'00:00','04:00','08:00','12:00','16:00','20:00'})
%-------------------------------------------------------------------------
figure(2);h=bar([annual_cost annual_cost_wbatt])
title('Annual Electricity Cost','Color',[0 0.75 0.75]);ylabel('£')
set(gca,'XTicklabel',{'without battery','battery installed'});
set(h(1),'facecolor',[0 0.75 0.75],'edgecolor',[0 0.75 0.75]);
set(gca,'XColor',[0 0.75 0.75],'YColor',[0 0.75 0.75]);
%-------------------------------------------------------------------------
figure(3);plot(avg_en_demand,'linewidth',2);%ylim([0 0.4]);
set(gca,'XTick',1:8:48)
set(gca,'XTickLabel',{'00:00','04:00','08:00','12:00','16:00','20:00'})
yyaxis left
ylabel('kWh')
hold on;
plot(avg_en_usage,'color',[0.8500, 0.3250, 0.0980],'linewidth',2)
plot(avg_tariffs/100);
title('Average Energy and tariffs');yyaxis right;ylabel('£/kWh');
legend('Energy demand','Energy used after battery','tariffs');
%-------------------------------------------------------------------------
```

```
x=769:816;
date='17-Feb';
figure(4);subplot(2,1,1);
plot(pw(x,13),'linewidth',2);ylim([0 0.5]);xlim([1 48]);ylim([0 0.6]);
title(sprintf('Energy and tariffs %s',date));
hold on;
plot(pw(x,2),'linewidth',2);
plot(pw(x,3));
plot(pw(x,1)/100,'--');

set(gca,'XTick',1:8:48);yyaxis right;ylabel('£/kWh');yyaxis
left;ylabel('kWh')
set(gca,'XTickLabel',{'00:00','04:00','08:00','12:00','16:00','20:00'})
legend('Energy used after installed battery','Original Energy
demand','solar','tariffs');

subplot(2,1,2);
h=area(pw(x,9)/3.8,'EdgeColor','none');
title('state of charge - battery');ylim([0 1]);xlim([1 48]);
set(gca,'XTick',1:8:48);ylabel('soc (%)');
set(gca,'XTickLabel',{'00:00','04:00','08:00','12:00','16:00','20:00'})
h.FaceColor=[0 1 0.8];

%-----------------------------------------------------------------------
%                          Function
%-----------------------------------------------------------------------
function avg = average_array(file_name)
i=1;
for col = 1:48
    avg(i,1)=mean(file_name(:,col));
    i=i+1;
end
end

%-----------------------------------------------------------------------
function time_slot = tran_to_timeslot(file_name,j)

%Transform data from 1 column to 48 column
%j is the column number that you want to transform
i=1;
for row=1:366
    if i<17521
        for col=1:48
            time_slot(row,col)=file_name(i,j);
            i=i+1;
        end
    end
end
%-----------------------------------------------------------------------
```