Smart cities use information and communication technology to improve operational efficiency without impacting citizen welfare. In this project, we will focus on energy management which emerged as a necessity because the ever growing consumption demands will eventually surpass the supply of critical resources. For this purpose, we will develop a basic model of a Smart City with a battery system deployed in each house. The main objective is to take advantage of this battery in order to minimize the total electricity cost required by the household as well as to minimize the maximum instantaneous power consumption required by the utility supplier.

1. Household Model

The typical consumption of a household is the result of the use of light, heater, boiler, television, refrigerator, cooking equipment, vacuum cleaner, dishwasher, washing machine, ventilation, etc. In this project, we do not consider the power consumption of each appliance separately, but the required power consumption of a household is aggregated into a single vector that is provided as an input.

Furthermore, we investigate this problem assuming a time-variable pricing scheme where the electricity tariffs are allowed to change every 10 minutes. Under this configuration, the energy to power conversion ratio is equal to 1/6.

Date Time	15/01/2015 6:00	15/01/2015 6:10	15/01/2015 6:20	15/01/2015 6:30	15/01/2015 6:40	15/01/2015 6:50	15/01/2015 7:00
Tariff	€ 2.686E-05	€ 2.462E-05	€ 2.379E-05	€ 3.074E-05	€ 4.718E-05	€ 4.752E-05	€ 3.835E-05
Required Power	100 W	100 W	100 W	100 W	100 W	200 W	200 W

2. Battery Model

The considered household is equipped with a rechargeable battery pack. A rechargeable battery pack is characterized by:

- The full capacity of the battery = 14000 Wh,
- The maximum charging power of the battery = 3300 W,
- The maximum discharging power of the battery = 4500 W,
- The charging efficiency coefficients = 93 %,
- The discharging efficiency coefficients = 95 %,
- The maximum state of charge of the battery = 0.98,
- The minimum state of charge of the battery = 0.02.

In other words, the energy level in the battery should be kept, at any time, between minimum state of charge × capacity = 0.02 × 14000 = 280 Wh and maximum state of charge × capacity = 0.98 × 14000 = 13720 Wh. During a timeslot of 10 minutes in the charging phase, the battery can consume a maximum of P_{ch} = maximum charging power × energy to power conversion ratio = 3300 × 1/6 = 550 W from the power grid. This will allow the battery to accumulate a maximum of P_{ch} × charging efficiency = 550 × 0.93 = 511.5 W of energy. Similarly, during a timeslot of 10 minutes in the discharging phase, the battery can deliver a maximum of P_{dis} = maximum discharging power × energy to power conversion ratio = 4500 × 1/6 = 750 W. This will allow to reduce the power consumption from the power grid by P_{dis} × discharging efficiency = 750 × 0.95 = 712.5 W.

It is assumed that the battery pack is initially empty, thus, at the beginning of the simulation, it contains only 280 Wh of energy. Furthermore, the battery pack can only be used to provide the necessary energy for the household and the energy excess can never be provided back to the power grid. Finally, the number of charging/discharging cycles of the rechargeable battery pack is limited to one single cycle per day.

3. Problem Formulation

a. Variables

In order to solve this problem, you need to determine the values to be assigned to some decision variables Q_i. The decision variable Q_i represents the quantity of energy accumulated in/drawn from the battery pack during the i^{th} epoch. In order to keep the problem formulation simple, we will also introduce some intermediate variables B_i. The intermediate variable B_i represents the energy level of the battery pack at the end of the i^{th} epoch. Finally, we will denote by O_i the overall power that is consumed by the household during the i^{th} epoch.

Date / Time	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Epoch 5	Epoch 6	Epoch 7
Tariff (T_i x 10^{-5} €)	$T_1 = 2.686$	$T_2 = 2.462$	$T_3 = 2.379$	$T_4 = 3.074$	$T_5 = 4.718$	$T_6 = 4.752$	$T_7 = 3.835$
Required Power (P_i W)	$P_1 = 100$	$P_2 = 100$	$P_3 = 100$	$P_4 = 100$	$P_5 = 100$	$P_6 = 200$	$P_7 = 200$
Decision Variables (Q_i Wh)	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
Intermediate Variables (B_i Wh)	$B_1 = 280 + Q_1$	$B_2 = B_1 + Q_2$	$B_3 = B_2 + Q_3$	$B_4 = B_3 + Q_4$	$B_5 = B_4 + Q_5$	$B_6 = B_5 + Q_6$	$B_7 = B_6 + Q_7$
Consumed Power (O_i W)	If ($Q_1 \geq 0$) $O_1 = P_1 + Q_1 / 0.93$ Else $O_1 = P_1 + Q_1 \times 0.95$	If ($Q_2 \geq 0$) $O_2 = P_2 + Q_2 / 0.93$ Else $O_2 = P_2 + Q_2 \times 0.95$	If ($Q_3 \geq 0$) $O_3 = P_3 + Q_3 / 0.93$ Else $O_3 = P_3 + Q_3 \times 0.95$	If ($Q_4 \geq 0$) $O_4 = P_4 + Q_4 / 0.93$ Else $O_4 = P_4 + Q_4 \times 0.95$	If ($Q_5 \geq 0$) $O_5 = P_5 + Q_5 / 0.93$ Else $O_5 = P_5 + Q_5 \times 0.95$	If ($Q_6 \geq 0$) $O_6 = P_6 + Q_6 / 0.93$ Else $O_6 = P_6 + Q_6 \times 0.95$	If ($Q_7 \geq 0$) $O_7 = P_7 + Q_7 / 0.93$ Else $O_7 = P_7 + Q_7 \times 0.95$

b. Constraints

The decision variables Q_i are real numbers. In order to take into account the maximum charging and discharging power of the battery, Q_i are allowed to vary in the range [-750, 511.5]. Moreover, in order to ensure one single charging/discharging cycle per day, the variables Q_i are allowed once to change their sign from positive to negative.

The intermediate variables B_i are positive real numbers. In order to take into account the maximum and the minimum states of charge of the battery, B_i should always be in the range [280, 13720].

The consumed power O_i are non-negative real numbers ($O_i \geq 0$). This is needed in order to ensure that the energy excess in the battery can never be provided back to the power grid.

c. Objective Function

The main objective of the problem is to take advantage of the battery pack in order to minimize the total electricity cost required by the household as well as to minimize the maximum instantaneous power consumption required by the utility supplier. The total electricity cost can be expressed mathematically as:

$$Cost = O_1 \times T_1 + O_2 \times T_2 + O_3 \times T_3 + O_4 \times T_4 + O_5 \times T_5 + O_6 \times T_6 + O_7 \times T_7$$

The maximum instantaneous power consumption can be expressed mathematically as:

$$Peak = \max(O_1, O_2, O_3, O_4, O_5, O_6, O_7)$$

The objective function to minimize is given by:

$$Objective = \alpha \times Cost + \beta \times Peak$$

where α and β are two parameters of the problem.

4. Example 1

In this example, we will set α to 1 and β to 0. This will correspond to the case where we focus on minimizing only the total cost of electricity. In this case, the optimal solution is the following:

Date / Time	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Epoch 5	Epoch 6	Epoch 7
Tariff (T_i x 10^{-5} €)	T_1 = 2.686	T_2 = 2.462	T_3 = 2.379	T_4 = 3.074	T_5 = 4.718	T_6 = 4.752	T_7 = 3.835
Required Power (P_i W)	P_1 = 100	P_2 = 100	P_3 = 100	P_4 = 100	P_5 = 100	P_6 = 200	P_7 = 200
	Charging			Discharging			
Decision Variables (Q_i Wh)	Q_1 = 0	Q_2 = 120.078947	Q_3 = 511.5	Q_4 = -105.26316	Q_5 = -105.26316	Q_6 = -210.52632	Q_7 = -210.52632
Intermediate Variables (B_i Wh)	B_1 = 280	B_2 = 400.078947	B_3 = 911.578947	B_4 = 806.315789	B_5 = 701.052632	B_6 = 490.526316	B_7 = 280
Consumed Power (O_i W)	O_1 = 100	O_2 = 229.117148	O_3 = 650	O_4 = 0	O_5 = 0	O_6 = 0	O_7 = 0

The minimum value of the objective function is equal to 2379.03642 x 10^{-5} €.

5. Example 2

In this example, we will set α to 0 and β to 1. This will correspond to the case where we focus on minimizing only the maximum instantaneous power consumption. In this case, the optimal solution is the following:

Date / Time	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Epoch 5	Epoch 6	Epoch 7
Tariff (T_i x 10^{-5} €)	T_1 = 2.686	T_2 = 2.462	T_3 = 2.379	T_4 = 3.074	T_5 = 4.718	T_6 = 4.752	T_7 = 3.835
Required Power (P_i W)	P_1 = 100	P_2 = 100	P_3 = 100	P_4 = 100	P_5 = 100	P_6 = 200	P_7 = 200
	Charging					Discharging	
Decision Variables (Q_i Wh)	Q_1 = 28.9832489	Q_2 = 28.9832489	Q_3 = 28.9832489	Q_4 = 28.9832489	Q_5 = 28.9832489	Q_6 = -72.458122	Q_7 = -72.458122
Intermediate Variables (B_i Wh)	B_1 = 308.983249	B_2 = 337.966498	B_3 = 366.949747	B_4 = 395.932996	B_5 = 424.916245	B_6 = 352.458122	B_7 = 280
Consumed Power (O_i W)	O_1 = 131.164784	O_2 = 131.164784	O_3 = 131.164784	O_4 = 131.164784	O_5 = 131.164784	O_6 = 131.164784	O_7 = 131.164784

The minimum value of the objective function is equal to 131.164784 W.

6. Instructions

- In order to solve this problem, you need first to select a metaheuristic algorithm. The list of known metaheuristic algorithms is available here: [Table of metaheuristics - Wikipedia]
- This project must be worked in a group of 2 students only. Once you identify the algorithm that you will implement as well as your teammate, you need to fill in this information no later than the **16th of May, 2021** using this link:
  https://doodle.com/poll/htcrtyz2r7r3uxyz?utm_source=poll&utm_medium=link

- If you select an algorithm other than the ones listed in the doodle form, please drop me an email at elias.doumith@ul.edu.lb in order to add the algorithm for you.
- The main objective of this project is to design and implement an extensible software application following a proper scientific approach. The software needs to run in a concurrent environment while taking into account the proper handling of the shared data and the critical sections. You should be able to assess the performance improvement of your selected algorithm when you try to run it using additional threads. For this purpose, the number of used threads should be a parameter to be passed to your software.
- The input data of your software should be read from a file and not hard coded in your source code. If you need more input samples other than the ones provided in this document, please let me know.
- You are allowed to customize your software as long as it fulfills the main objective of the project.
- Your submission must be done on Microsoft Teams no later than the **16th of June, 2021** and should contain the following files:

  1) The compressed project file/source code (ZIP/RAR). You are not allowed to use any implementation that may be available on the internet.
  2) A report detailing the steps of the project including some results. This report should briefly explain the selected metaheuristic algorithm as well as the approach used to make it work in a concurrent environment. The description of the algorithm should not be copied from online resources. The code must not be copied in this report.
  3) A short video showing the execution of your software with several input data and different values of α and β. You should comment the obtained results.

- The date of the defense will be fixed later on.
- Sending the project by e-mail will not be accepted.
- No projects shall be accepted after the deadline.
- Plagiarism will not be tolerated!