Building Net Zero Carbon (NZC) Retrofit Optimizer

Retrofitting buildings to Net Zero Carbon (NZC) is an efficient way to lower carbon emissions and prevent climate change. However, it is challenging to select the optimal retrofit strategies to maximize social, environmental, and economic sustainability while retrofitting the buildings to NZC. Therefore, this app supports deciding optimal retrofit strategies to attain NZC buildings, focusing on carbon savings, economic profitability, and occupant satisfaction.

Available Analysis Methods

This app consists of two optimization methods.

1. **Life Cycle Analysis (LCA) based Optimization**
    - Considers the life cycle performance of retrofit measures.
    - Optimization is based on the life cycle carbon saving, economic profitability, and occupant dissatisfaction.
2. **Annual based Optimization**
    - Considers the annual performance of retrofit measures
    - Optimization is based on annual carbon saving, economic profitability, and occupant dissatisfaction.

Basic Details Required to Use the App

- Simulated data for the building's annual energy consumption, annual carbon emissions, and predicted percentage of dissatisfaction (PPD), before retrofitting.
- The building's gross floor area and the expected lifetime after retrofitting.
- Simulated data for the building's annual energy consumption, annual carbon emissions, and PPD, after retrofit using the suggested strategies.
- The embodied carbon and the initial costs associated with the retrofit strategies.
- Electricity billing rates, to calculate the annual average cost per energy unit of the building.

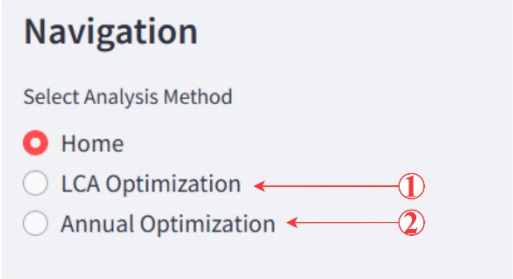
How to Use

1. Select your desired analysis method from the sidebar.
2. Upload your data (the app can be tested using the sample data from the data selection on the right side of the app).
3. Configure parameters and run optimization.
4. Analyze results and download reports

Detailed User Manual

Step 1 – Select the analysis method

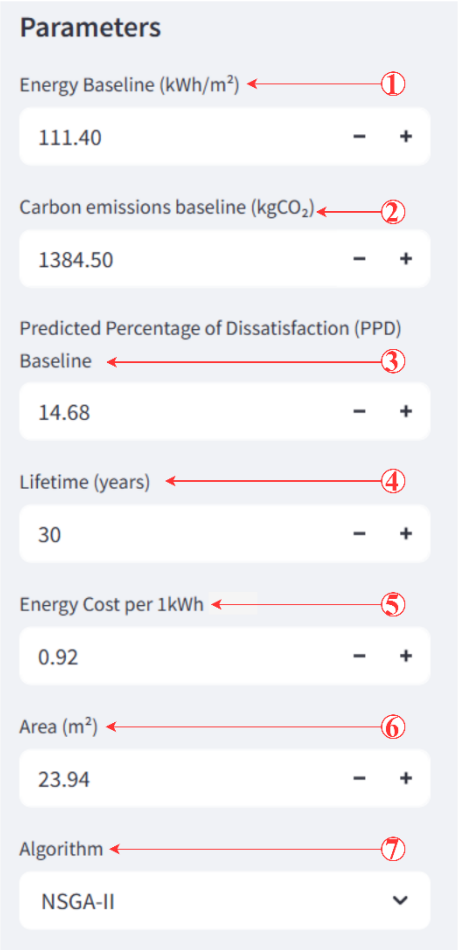
Select the analysis method from the "Navigation" at the top of the left side of the app.



1. ***LCA Optimization*** – Proposes optimized retrofit strategies focusing on the lifecycle performances of the retrofitted building.
2. ***Annual Optimization*** – Proposes optimized retrofit strategies focusing on the yearly performance of the retrofitted building.

Step 2 – Enter the basic parameters of the existing building

Enter the basic parameters of the existing building under the relevant rows representing "Parameters" on the left side of the app.



1. ***Energy Baseline (kWh/m²)*** – Enter the simulated annual energy consumption of the building in kWh/m².
2. ***Carbon emissions baseline ($kgCO_2$)*** – Enter the simulated annual operational carbon emissions from the building in $kgCO_2$.
3. ***Predicted Percentage of Dissatisfaction (PPD) Baseline*** – Enter the simulated average percentage of occupant dissatisfaction within the building.
4. ***Lifetime (years)*** – Enter the expected lifetime of the building after retrofitting in years.
5. ***Energy Cost per 1 kWh*** – Enter the average cost per energy unit based on the electricity consumption rates.

Example to calculate the energy cost per 1kWh:

The following are the annual metered data on the energy consumption of the sample building.

Month	Energy Consumption (kWh)
January	130
February	138
March	135
April	158
May	225
June	247
July	279
August	347
September	289
October	228
November	184
December	262

The rates for electricity consumption under the first four classifications are as follows.

- For the first 150 units – 0.779 HKD
- For the next 150 units (151-300) – 0.918 HKD
- For the next 200 units (301-500) – 1.057 HKD
- For the next 200 units (501-700) – 1.293 HKD

Given that the energy consumption of the sample building surpasses the threshold of 200 and 300 units, the annual average energy cost is calculated as:

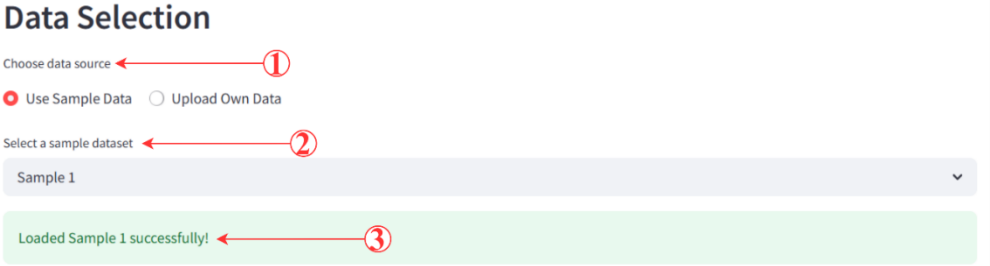
(0.779+0.918+1.057)/ 3 = 0.918 HKD

6. ***Area (m²)*** – Enter the gross floor area of the building in m².

7. ***Algorithm*** – This app is based on three optimization algorithms, namely: (1) non-dominated sorting genetic algorithm II (NSGA II), (2) non-dominated sorting genetic algorithm III (NSGA III), and (3) adaptive grid-based evolutionary algorithm (AGE-MOEA). These three are common algorithms used for multi-objective optimization. Users can choose one of these three algorithms using the dropdown menu. Further, users can compare the optimization results with these three algorithms.

Step 3 – Enter data into the model

"Data Selection" allows users to select their data or proceed with the sample data.



To proceed with the sample dataset:

1. ***Choose data source*** – Select "Use Sample Data".
2. ***Select a sample dataset*** – Users can select a sample dataset from the dropdown menu. Then the app displays the successful upload of the sample dataset ***(3)***.

To proceed with your own dataset:

- The users need to collect simulated data for annual energy consumption, annual carbon emissions, and the PPD of the building after retrofitting with the retrofit strategies.
- The users need to calculate the embodied carbon associated with the retrofit materials along with their initial costs.
- Then all the data needs to be filed in an **Excel** or **CSV** file format.
- The first columns of the datasheet should include the variables (different retrofit measures used to develop the retrofit strategies) while the **last five columns should be for the "Energy Consumption per area (kWh/m²)", "Carbon emission (kgCO_2)", "PPD", "Embodied Carbon (kgCO_2e)", "Initial Cost"**.
- There should not be empty cells or cells containing the value "0". Those cells should be filled as "no" in the dataset.
- Data format examples:

Example 1

This example considers the wall insulation, implementation of external wall shadings, replacement of windows with double and triple-glazed windows, replacement of the air conditioner, and installation of PV panels on the rooftop as the retrofit measures (variables) to develop the strategies.

Wall Insulation Thickness (mm)	External Wall Shading Length (mm)	Window Retrofitting (Thickness of glass (mm))	Replacement of Air Conditioner	Number of PV Panels	Energy Consumption per area (kWh/m2)	Carbon emission (kgCO2)	PPD	Embodied Carbon (kgCO2e)	Initial Cost (HKD)
100	100	4,4 (double glazed)	no	1	92.30	1168.80	13.81	557.63	8,132.09
75	no	4,4,4 (triple glazed)	Replaced	no	97.10	1232.10	13.83	808.91	13,233.34
50	300	6,6 (double glazed)	no	2	73.30	983.10	13.79	495.73	12,046.25
50	200	4,4 (double glazed)	Replaced	8	-22.90	-248.20	13.81	1226.64	32,694.18

According to the first row, the retrofit strategy consists of 100mm thick wall insulation, 100mm length wall shading, 4-4mm thick double-glazed windows, and installation of 1 PV panel on the rooftop. The second row represents the strategy with 75mm thick wall

insulation, 4-4-4mm thick triple-glazed windows, and replacement of the air-conditioner. The last five columns represent the post-retrofit details with the implementation of the particular retrofit strategy.

Similarly, users can represent their retrofit strategies within an Excel or CSV file.

Example 2

This example considers the wall insulation, implementation of external wall shadings, replacement of windows with different types, and installation of PV panels on the rooftop as the retrofit measures (variables) to develop the strategies.

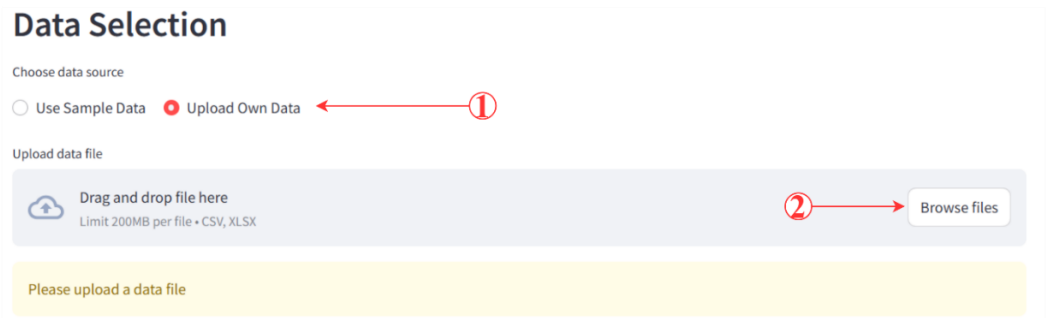
Wall insulation thickness (mm)	External wall shading length (mm)	Window Retrofitting	Number of solar panels	Energy Consumption per area (kWh/m2)	Carbon emission (kgCO2)	PPD	Embodied Carbon (kgCO2e)	Initial Cost (HKD)
100	400	Type 1 (4-4mm double glazed windows)	3	57.2	793.10	13.74	682.15	14134.92
75	100	Type 4 (6-12-6mm triple glazed windows)	9	-31.5	-336.10	13.82	1055.36	36006.42
no	300	Type 2 (4-6mm double glazed windows)	6	14.9	259.10	13.89	517.49	22976.84
50	no	Type 3 (4-12-4mm triple glazed windows)	5	32.6	432.60	13.83	681.81	22864.44

Example 3

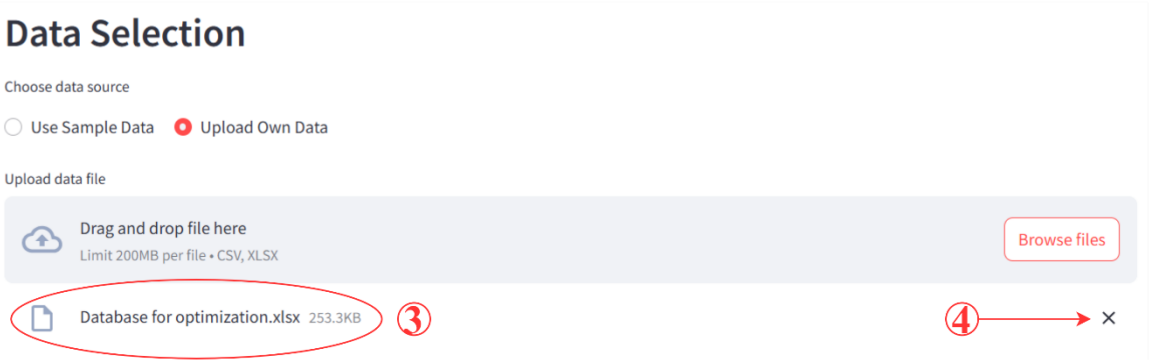
This example considers the wall insulation, replacement of windows with double and triple-glazed windows, replacement of the air conditioner, and installation of PV panels on the rooftop (variables) as the retrofit measures to develop the strategies.

External wall insulation thickness (mm)	Window Retrofitting	Replacement of air conditioner	The percentage of area used to install PV panels on rooftop	Energy Consumption per area (kWh/m2)	Carbon emission (kgCO2)	PPD	Embodied Carbon (kgCO2e)	Initial Cost (HKD)
100	Triple glazed (4-6-4 mm thick)	no	20%	61.10	793.90	13.82	713.03	17,998.30
75	no	Replaced	80%	-65.30	-812.20	13.89	1404.43	39,193.92
50	Double glazed (4-6mm thick)	Replaced	90%	-99.80	-1182.50	13.82	1545.44	51,531.73
25	Double glazed (6-12mm thick)	updated	100%	-111.60	-1360.90	13.83	1519.66	52,100.14

After preparing the data file as an Excel or CSV file, users can upload it.



1. Select “Upload Own Data”.
2. Then the app displays the option to “Browse files”. Users can click it to upload the file from their device.
3. After the successful upload, the app displays the uploaded file.
4. If the users upload the wrong file, remove it by clicking the “x” mark.



Step 4 – Configuration

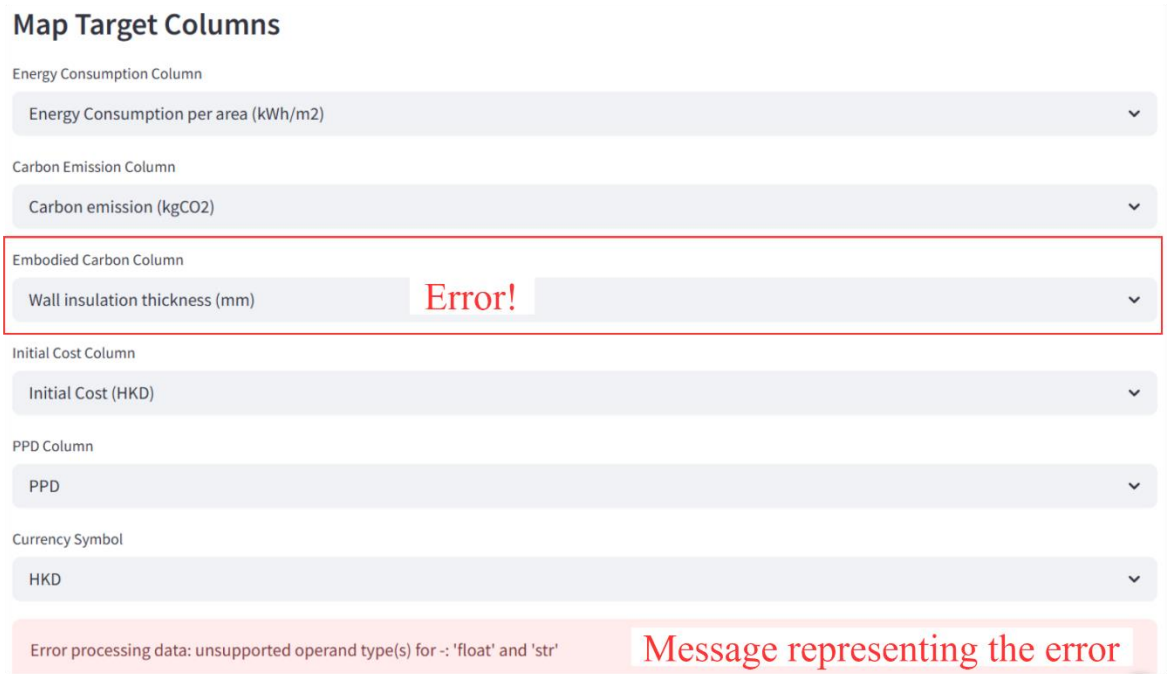
After data is selected for the model (uploaded file/sample data), users can observe decision variables displayed under "Select decision variables".

1. ***Select decision variables*** – Following the dataset selection, all decision variables are displayed. If the user has detected columns that are unrelated to the decision variables, they can remove them using the “x” mark.
2. If the users want to remove all the variables, click “x” and use the dropdown menu to add variables.

Step 5 – Map Target Columns

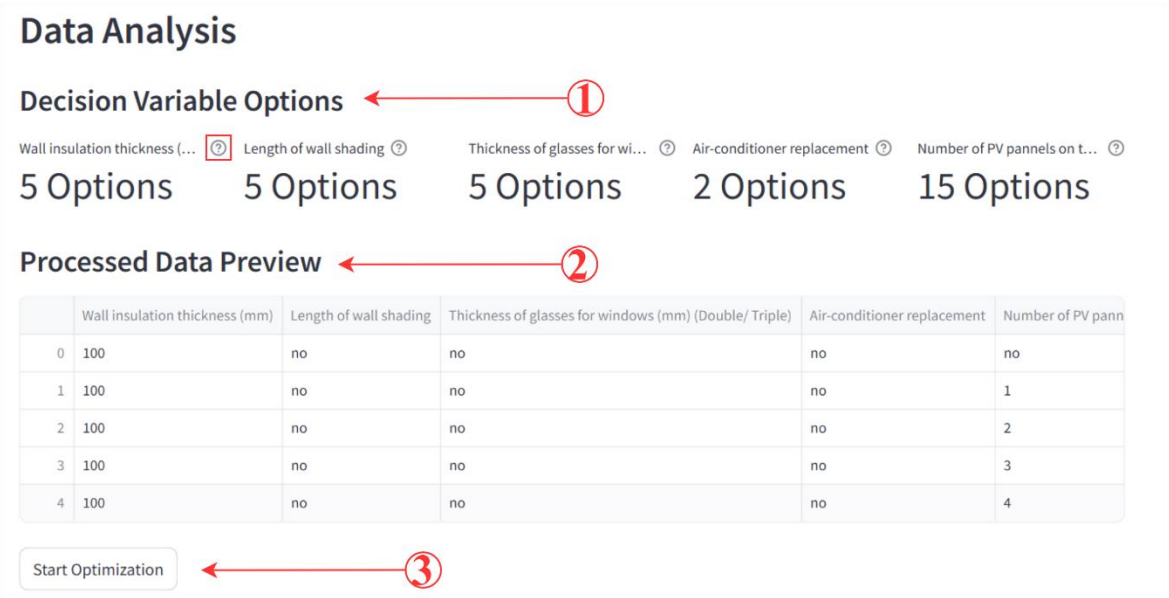
The users need to follow this step to match the suitable column from the selected data file (uploaded data file/ sample data) to the given description. Users can select the relevant column using the dropdown menu at the end of each description row. **The next steps of the app will be displayed after the successful completion of column mapping.**

When the target columns are not properly mapped with the description, **an error** notice appears: **"Error processing data: unsupported operand type(s) for /: 'str' and 'int'".**



Step 6 – Data Analysis and Optimization

This section **only appears after the successful completion of mapping the target columns**.



1. ***Decision Variable Options*** – Displays all variables within the selected data file (uploaded datafile/ sample data). In addition, displays the number of options within each decision variable. For example, 100mm thick, 75mm thick, 50mm thick, 25mm thick, and without insulation are the options under wall insulation, displayed as 5 options. Moving to the mark "?" with variables, displays the list of options under each variable.
2. ***Processed Data Preview*** - Displays only the first five rows of the data file after processing with carbon saving (Csave) and economic profitability (EP) calculations.
3. ***Start Optimization*** – Click to proceed with the optimization.

Step 7 – View and Download the Results

The model will take a few minutes to run the optimization. The results are displayed after the completion of optimization. The users can view the results under "Optimization Results".

On the list of optimization results,

click to download the results in a CSV file format.

click to search for the results.

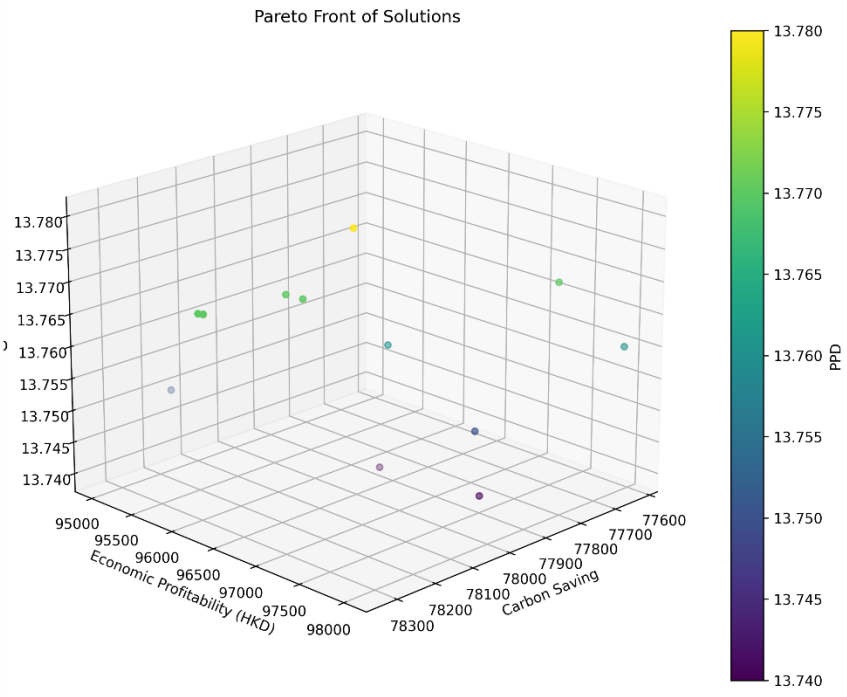
click to view the results on full screen.

Optimization Results

	Wall insulation thickness (mm)	Length of wall shading	Thickness of glasses for windows (mm) (Double/ Triple)	Air-conditioner replacement	Number of PV pann
27	75	400	6,6,6	no	14
33	100	400	6,6,6	no	14
6	100	400	4,4,4	no	14
17	50	400	6,6,6	no	14
37	75	400	6,6	no	14
7	25	400	6,6,6	no	14
16	50	400	6,6	no	14
25	100	400	6,6	no	14
81	75	400	4,4	no	14
79	100	400	4,4	no	14

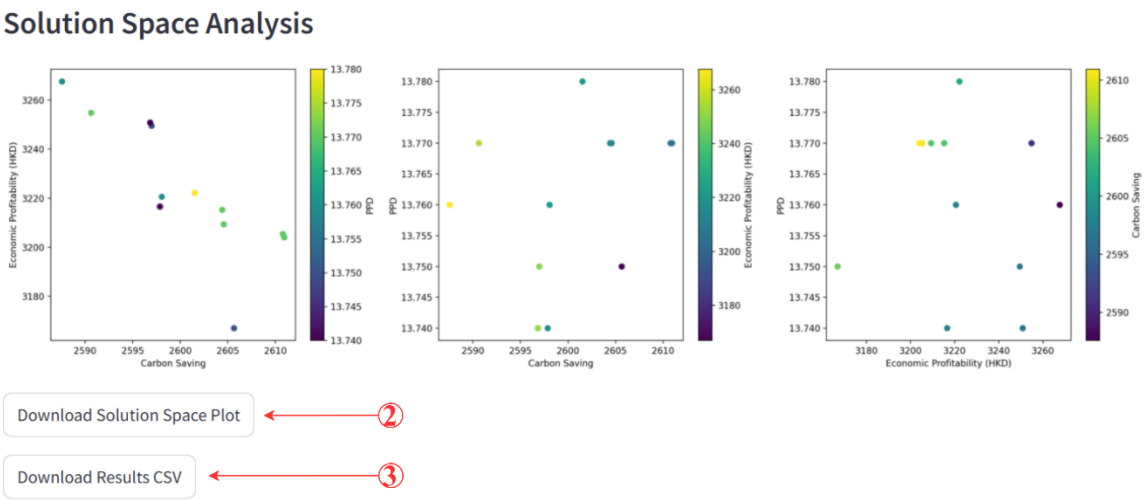
Following the list of results, the Pareto front and the 2D plots of the results are visualized under "Pareto Front" and "Solution Space Analysis", respectively.

Pareto Front



Download Pareto Front Plot ← ①

1. ***Download Pareto Front Plot*** – Click to download the Pareto Front of the optimization results.



2. ***Download Solution Space Plot*** – Click to download 2D plots of the optimization results.
3. ***Download Results CSV*** – Click to download the CSV file of the optimization results.