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# Multi-Objective Decision Making Optimization of a Residential Net Zero Energy Building in Cold Climate


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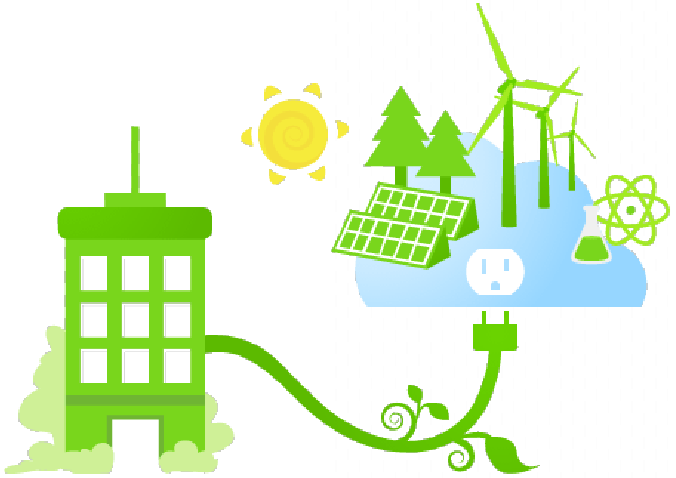
# Presentation outline

- Introduction / Objective
- Case Study Description / Simulation
- Multi-Objective Optimization / Multi-Criteria Decision making
- Results / Discussion
- Conclusion / Future Studies

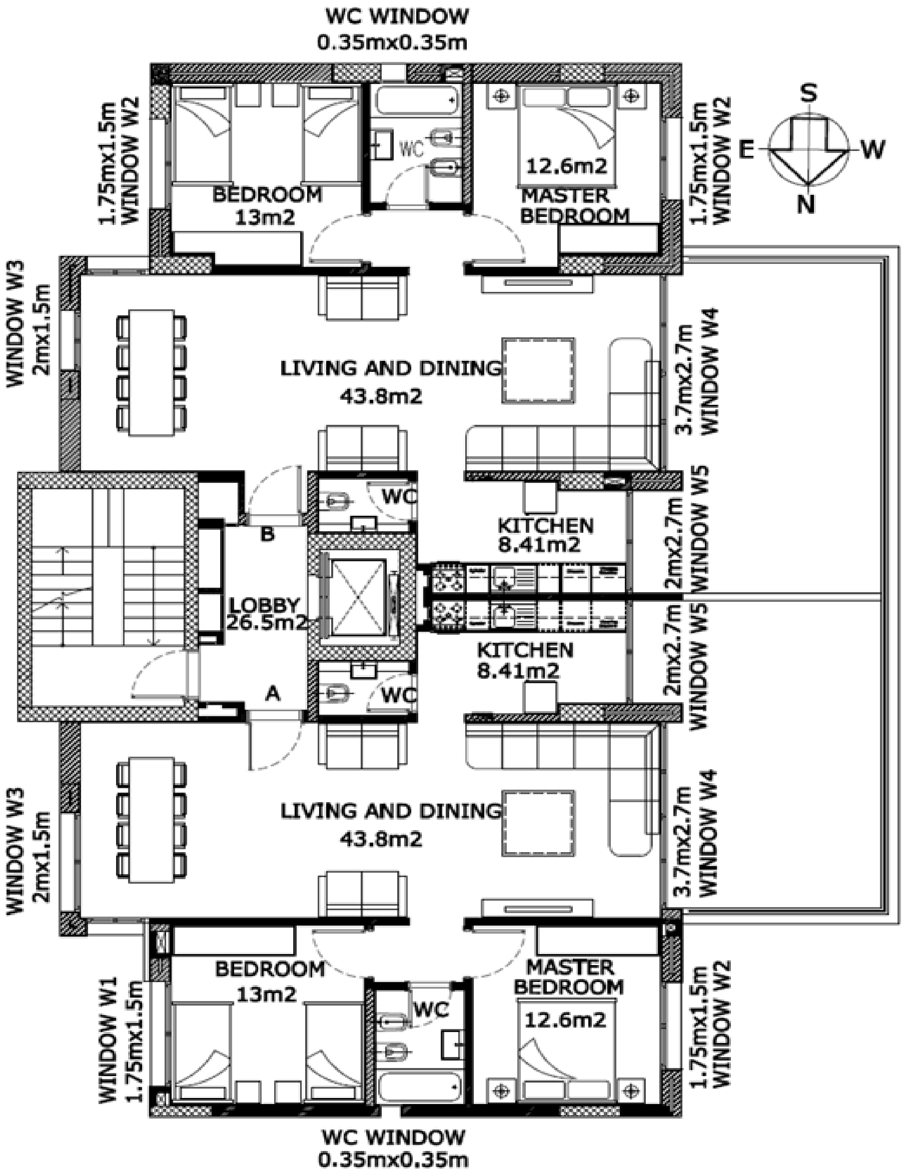
# Introduction-Objective



- Net Zero Energy Buildings (NZEBs) are suggested to limit buildings energy consumption

- Investigate Cost-effective design options of a residential NZEB in Cedars, through Multi-Objective Optimization, followed by a Decision Making

# Case Study




- Three stories building in Cedars
- Consisting of two apartments, each apartment is 102 m2

# Design conditions

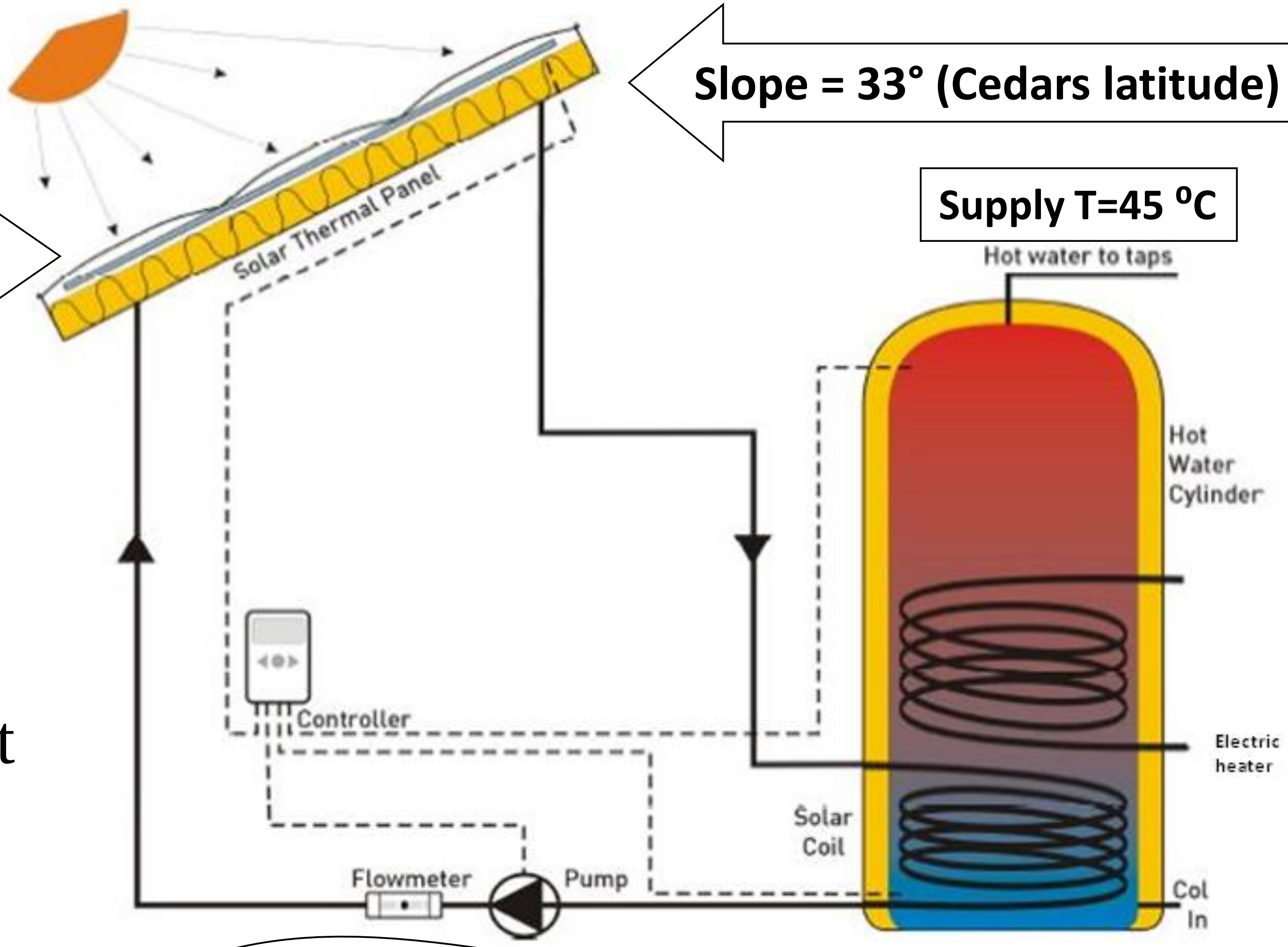
- Heating loads covered by natural gas condensing boiler, $\eta$=98.3%
- Heating set point = 20˚C
- Cooling loads covered by air source heat pump, COP= 2.9
- Cooling set point = 24˚C

# Solar Domestic Hot Water System (SDHW)

**15 South oriented collectors connected in series of total area equal to 31.35 m2**

**Slope = 33° (Cedars latitude)**

**Supply T=45 ºC**




- Flat plate active SDHW system + auxiliary Electric heater, to cover domestic hot water demands

**Circulating flow rate= 70 Kg/hr**

# Base case demands simulation

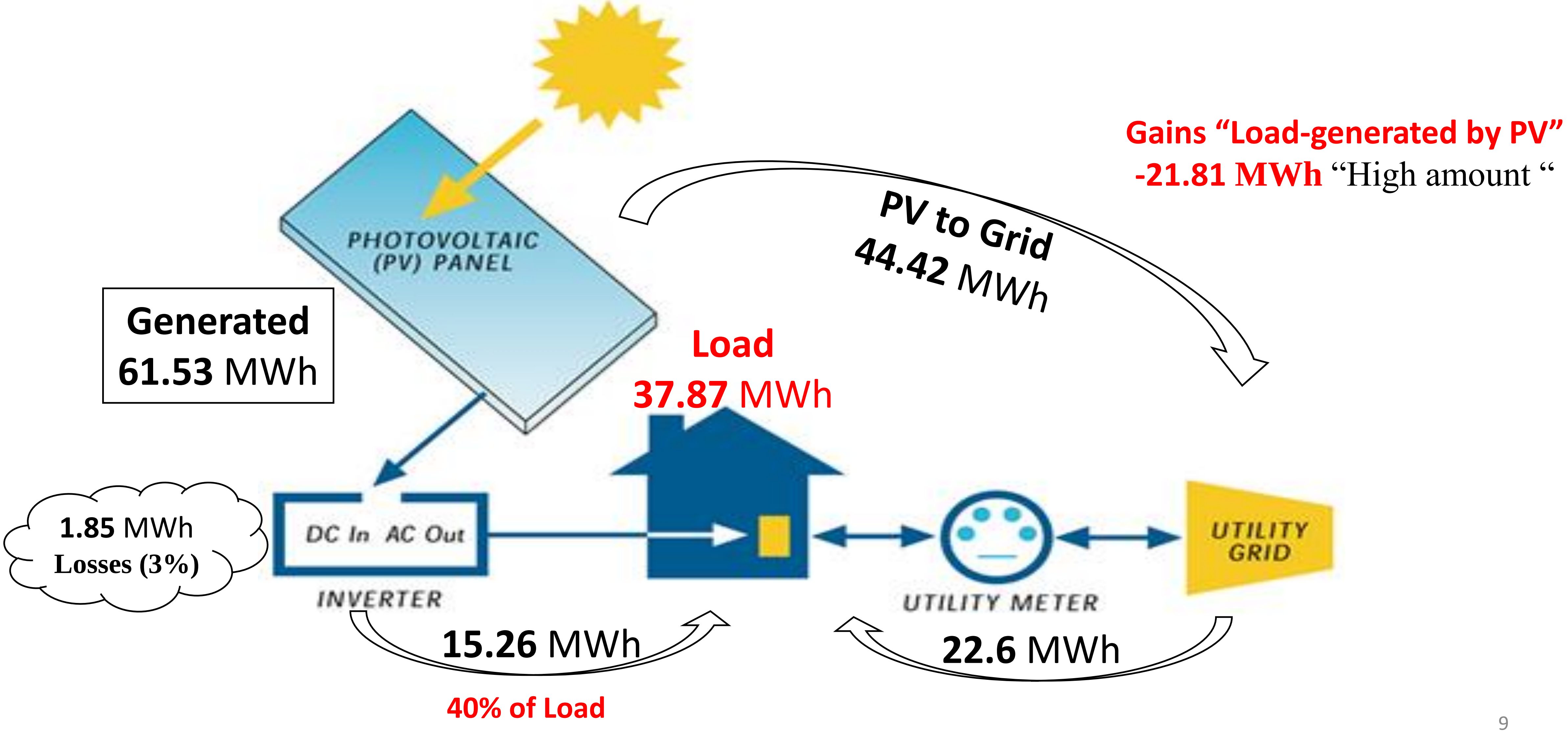
- Buildings different demands are simulated using TRNSYS
- Buildings' electrical loads are **61.57 KWh/y.m2** (37.78 MWh/y)
- Buildings' thermal loads are **73.47 KWh/y.m2** (45.19 MWh/y)

# Photovoltaic System (PV)

- South oriented PV system on rooftop to generate electricity
- Building exploits utility power grid for storage
- Analytical calculation yield to 90 PV modules (Each 1.94 m2)

(15 in series, 6 in parallel)

# Base case Annual Electric balances



# Base case Life Cycle Cost (LCC)

- Economic evaluation of projects cost effectiveness

$$\mathrm{LCC} = \mathrm{IC} + f\ (\mathrm{N}, \mathrm{rd}) \times \mathrm{EC}$$

| | |
|---|---|
| **IC** | Initial cost for implementing design features for building envelope and HVAC system ($), **"Cost of PV + SDHW + Construction cost"** |
| **rd** | Annual discount rate (%), **"5% in this study"** |
| **N** | Life period (year), **"20 years in this study"** |
| **EC** | Annual energy cost required to maintain building indoor comfort for the selected design and operating features ($), **"Cost of Electricity from grid + Cost of fuel for boiler"** |

- LCC, life period 20 years, is 181180 $ (125 $/month/ apartment)

# Formulation of the optimization problem

- Multi-Objective Optimization (MOO) an effective technique to get the perfect design solution for a specific intention
- To start MOO, define the following:

1-Objective functions to Minimize/ Maximize

2- Decision variables

3-Constraints

# Objective functions to Minimize/ Maximize

- Electrical consumption = consumption of (cooling+ heating + appliances+ lighting+ SDHW (“Auxiliary electric heater + Pump”))
- Consumption from appliances and lighting not concerned in this study
- f1=Min (“Auxiliary electric heater + Pump” consumptions)
- f2=Min (Thermal demand)
- f3=Min (Difference between load and generation)
- f4=Min (LCC)

# Decision variables

| Description | Type | Values | Step |
|---|---|---|---|
| External walls, Roof insulation thickness (cm) | D | 1,3,5,7,10 | - |
| Type of double glazing: Krypton or Argon, U-value (W/m².K) | D | 0.86, 1.4 | - |
| Cooling set point (˚C) | D | 24, 25, 26 | - |
| Heating set point (˚C) | D | 19, 20 | - |
| Width window bedroom, master bedroom, kitchen, (m) | C | 1 to 2 | 0.25 |
| Width window Living and dining, (m) | C | 1 to 3 | 0.25 |
| Width window Living and dining, (m) | C | 1 to 3.7 | 0.25 |
| Number of solar collectors in series | C | 1 to 20 | 1 |
| SDHW pump flow rate (Kg/h) | C | 50 to 120 | 5 |
| Number of solar panels in series | C | 1 to 20 | 1 |
| Number of solar panels in parallel | C | 1 to 40 | 1 |

D: Discrete, C: Continuous

# Constraint

- Keep Comfort -> Average Predicted Mean Vote $|PMV| \leq 0.5$

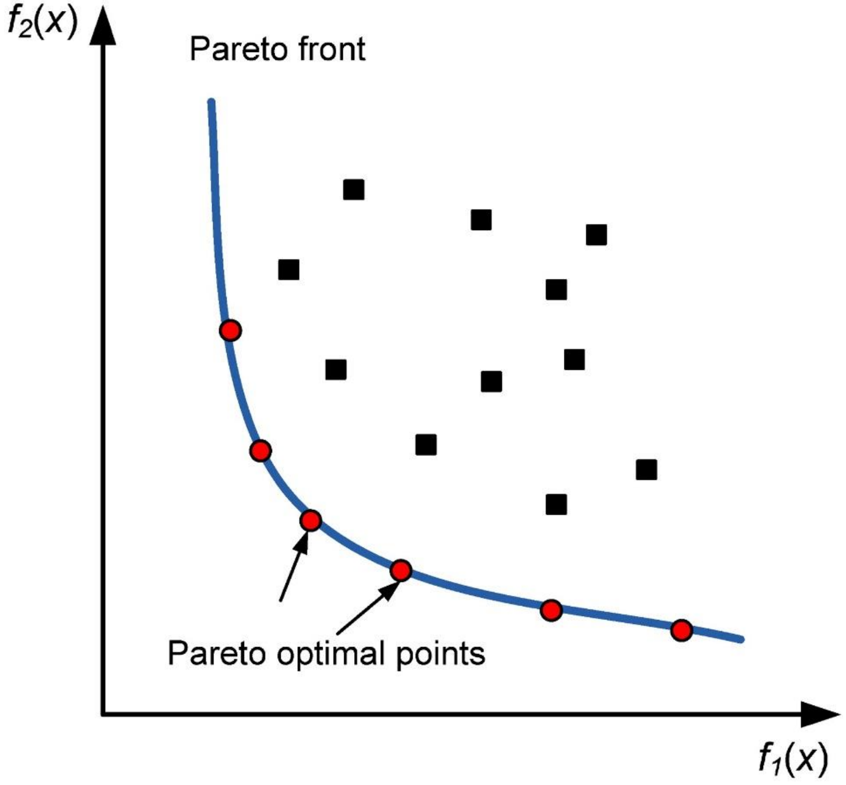
# Optimization tool / Algorithm

- Optimization using TRNSYS coupled with MOBO “Multi-Objective Building Optimization Tool”
- The non-sorting genetic algorithm (NSGA-II), is adopted
- The used parameters’ setting of NSGA are:

1- Population size = 40

2- Generation number = 25

# Pareto Front

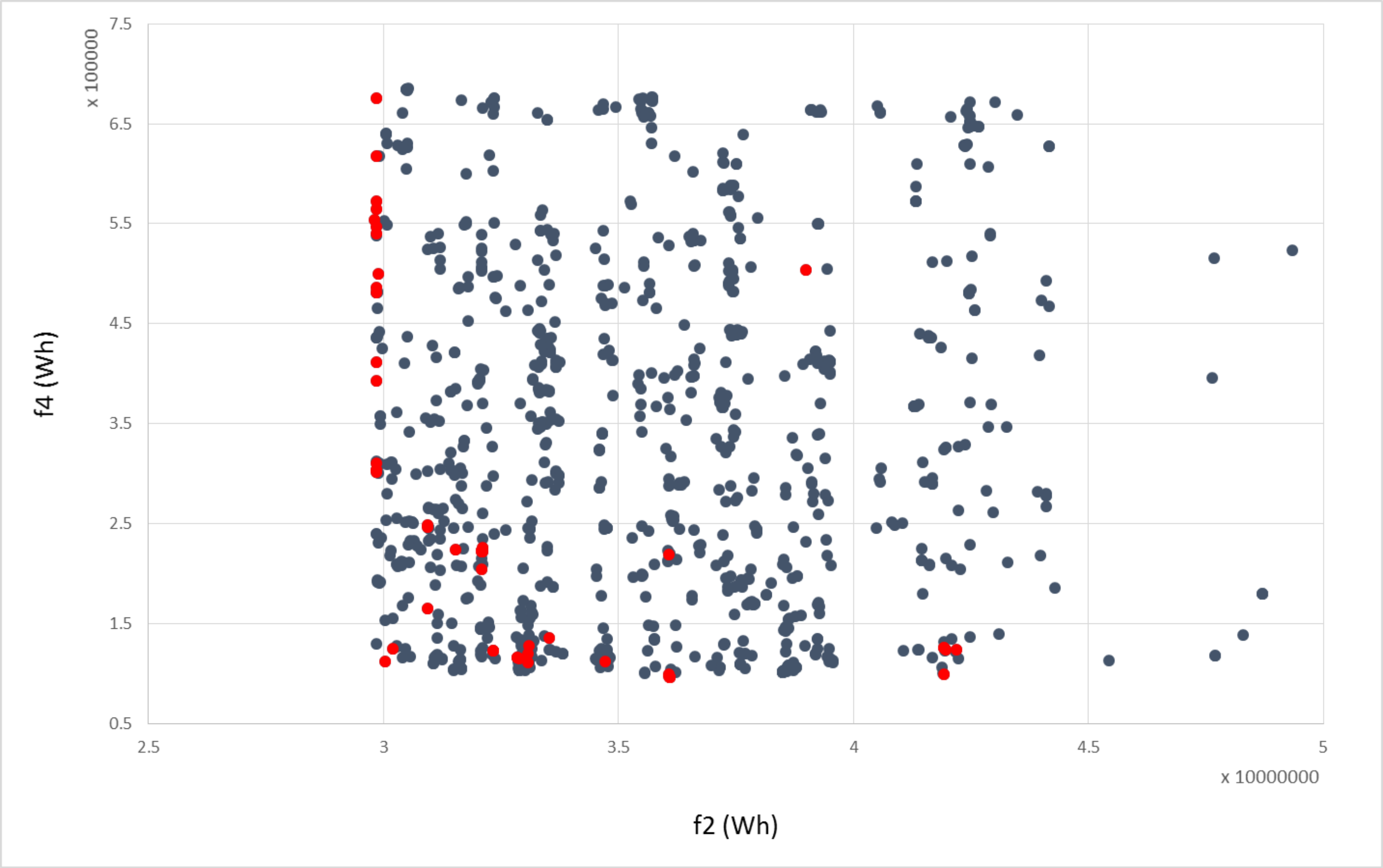



**Black:** design Variable Space, Dominated Variants

**Red:** Possible Solutions, Non-Dominated Variants

- MOO results are sets of non-dominated solutions called Pareto optimal solutions represented as a Pareto Front
- Each point of the Pareto Front is a possible best solution

# Pareto Front




f2: Thermal Load, f4: LCC

**Blue:** Dominated Variants , **Red:** Non-Dominated Variants

- Four-objective optimization generates Four-dimensional (4D) problem space
- Projecting 4D-Pareto-front on 2D-Graph, points belonging to Pareto Front may incorrectly appear to be dominated variants

# Multi-Criteria Decision making (MCDM)

- MCDM process to select the final optimal solution among all available possibilities
- Elimination and Choice Expressing the Reality (ELECTRE III) method classifies Pareto front solutions, to choose the most adequate solution
- To start ELECTRE III, the decision maker must assign the following:

1-Indifference, Preference and Veto Thresholds

2-Weights for each objective function using Analytical Hierarchy Process (AHP)

# Multi-Criteria Decision making (MCDM)

- ELECTRE III parameters:

| Threshold | Percentage relative to objective function average |
|---|---|
| Indifference | 5% |
| Preference | 10% |
| Veto | 30% |

| | f1 | f2 | f3 | f4 |
|---|---|---|---|---|
| **Weights** | 0.25 | 0.25 | 0.25 | 0.25 |

# Decision making Results

- Best solution after ELECTRE III ranking

| | **f1 (MWh)** **"SDHW electric consumption"** | **f2 (MWh)** **"Thermal Loads"** | **f3 (MWh)** **"Load-generation"** | **f4 (1000$)** **"LCC"** |
|---|---|---|---|---|
| **Best solution** | 3.94 | 30.19 | -0.33 | 124.84 |
| **Base case value** | 4.80 | 45.19 | -21.82 | 181.18 |
| **% difference** | 17.91 | 33.19 | -98.48 | 31.09 |

# Decision making Results

- Best solution after ELECTRE III ranking

| | Walls insulation | Roof insulation | Windows U-value | Cooling set point | Heating set point |
|---|---|---|---|---|---|
| **Unit** | (cm) | (cm) | ($W/m^2.K$) | (˚C) | (˚C) |
| **Base case** | 5 | 1 | 1.4 | 24 | 20 |
| **Optimal case** | 10 | 10 | 0.86 | 25 | 19 |
| | **Solar collectors** | **Pump flow** | **Number PV** | **Eastern WWR** | **Western WWR** |
| **Unit** | - | (Kg/h) | - | (%) | (%) |
| **Base case** | 15 | 70 | 90 | 23.43 | 59.46 |
| **Optimal case** | 8 | 115 | 72 | 21.87 | 35.15 |

# Conclusion

- Significant potential to improve energy performance of residential NZEB in cold climate of Cedars by using proven passive strategies
- The optimum design parameters decreases annual thermal load and LCC by 33.19% and 31.09% respectively, compared to the baseline model
- Envelop high level of insulation is a key parameter to decrease the high heating demands

# Future studies

- Investigate other passive design, and Renewable Energy options
- Investigate different climatic zones in Lebanon and France
- Sensitivity analyses of Decision maker preferences and design parameters
- Final goal is an attempt to define certain weighting factors for the key parameters to attain NZEB