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

Fatima Harkouss\textsuperscript{a, b}, Farouk Fardoun\textsuperscript{a}, Pascal-Henry Biwol\textsuperscript{b, c}

\textsuperscript{a}University Institute of Technology, Department GIM, Lebanese University, Saida, Lebanon
\textsuperscript{b}Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal, F-63000 Clermont-Ferrand, France
\textsuperscript{c}MINES Paris Tech, PSL Research University, PERSEE - Center for Processes, Renewable Energies and Energy Systems, CS 10207, 06 904 Sophia Antipolis, France
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)

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

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

- Slope = 33° (Cedars latitude)

- Supply T=45 °C

- 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)

Slope = 33° (Cedars latitude)
Base case Annual Electric balances

Generated 61.53 MWh

Load 37.87 MWh

PV to Grid 44.42 MWh

Gains “Load-generated by PV” -21.81 MWh “High amount “

1.85 MWh Losses (3%)

15.26 MWh 40% of Load

22.6 MWh
Base case Life Cycle Cost (LCC)

- Economic evaluation of projects cost effectiveness

\[
LCC = IC + f(N, rd) \times EC
\]

<table>
<thead>
<tr>
<th>IC</th>
<th>Initial cost for implementing design features for building envelope and HVAC system ($), “Cost of PV + SDHW + Construction cost”</th>
</tr>
</thead>
<tbody>
<tr>
<td>rd</td>
<td>Annual discount rate (%), “5% in this study”</td>
</tr>
<tr>
<td>N</td>
<td>Life period (year), “20 years in this study”</td>
</tr>
<tr>
<td>EC</td>
<td>Annual energy cost required to maintain building indoor comfort for the selected design and operating features ($), “Cost of Electricity from grid + Cost of fuel for boiler”</td>
</tr>
</tbody>
</table>

- 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
- \( f1 = \text{Min (“Auxiliary electric heater + Pump” consumptions)} \)
- \( f2 = \text{Min (Thermal demand)} \)
- \( f3 = \text{Min (Difference between load and generation)} \)
- \( f4 = \text{Min (LCC)} \)
# Decision variables

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

D: Discrete, C: Continuous
Constraint

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

- 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

Black: design Variable Space, Dominated Variants
Red: Possible Solutions, Non-Dominated Variants
Pareto Front

- 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

f2: Thermal Load, f4: LCC

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

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Percentage relative to objective function average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indifference</td>
<td>5%</td>
</tr>
<tr>
<td>Preference</td>
<td>10%</td>
</tr>
<tr>
<td>Veto</td>
<td>30%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>f1</th>
<th>f2</th>
<th>f3</th>
<th>f4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Decision making Results

- Best solution after ELECTRE III ranking

<table>
<thead>
<tr>
<th></th>
<th>f1 (MWh) “SDHW electric consumption”</th>
<th>f2 (MWh) “Thermal Loads”</th>
<th>f3 (MWh) “Load-generation”</th>
<th>f4 (1000$) “LCC”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best solution</td>
<td>3.94</td>
<td>30.19</td>
<td>-0.33</td>
<td>124.84</td>
</tr>
<tr>
<td>Base case value</td>
<td>4.80</td>
<td>45.19</td>
<td>-21.82</td>
<td>181.18</td>
</tr>
<tr>
<td>% difference</td>
<td>17.91</td>
<td>33.19</td>
<td>-98.48</td>
<td>31.09</td>
</tr>
</tbody>
</table>
## Decision making Results

- Best solution after ELECTRE III ranking

<table>
<thead>
<tr>
<th></th>
<th>Walls insulation</th>
<th>Roof insulation</th>
<th>Windows U-value</th>
<th>Cooling set point</th>
<th>Heating set point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit (cm)</strong></td>
<td><strong>(cm)</strong></td>
<td><strong>(W/m².K)</strong></td>
<td><strong>(°C)</strong></td>
<td><strong>(°C)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Base case</strong></td>
<td>5</td>
<td>1</td>
<td>1.4</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td><strong>Optimal case</strong></td>
<td>10</td>
<td>10</td>
<td>0.86</td>
<td>25</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Solar collectors</th>
<th>Pump flow</th>
<th>Number PV</th>
<th>Eastern WWR</th>
<th>Western WWR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit (Kg/h)</strong></td>
<td>-</td>
<td>(Kg/h)</td>
<td>-</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td><strong>Base case</strong></td>
<td>15</td>
<td>70</td>
<td>90</td>
<td>23.43</td>
<td>59.46</td>
</tr>
<tr>
<td><strong>Optimal case</strong></td>
<td>8</td>
<td>115</td>
<td>72</td>
<td>21.87</td>
<td>35.15</td>
</tr>
</tbody>
</table>
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