
Master’s Thesis Defence Presentation
by
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Under Supervision of
Prof. Dr. U. Eicker
What is happening Energy-wise?

Statistics Canada & Canada Energy Regulator:

- 20% of Quebec’s total energy use in Residential buildings

Quebec’s Energy end-use

Quebec Households’ Primary Heating System

- Heat pump
- Heating stove
- ELECTRICITY
- NATURAL GAS
- OIL PRODUCTS
- Forced air furnace
- Other

Planned emission reduction by 2030

BOSTON
NEW YORK
QUEBEC
LONDON

CONCORDIA
Urban Energy System Modeling (UESM)

- Strategic Energy Planning
- Greenhouse Gas Emission reduction
  - Sustainable Design

Single Building Energy Modeling

District Scale Energy Modeling

City Scale Energy Modeling
Frameworks for energy modeling, planning and policy making

- Different applications/focus (Demand, Supply, Waste,...)
- Various Capabilities (Scale, Temporal Resolution, Technology,...)
- Different approaches (Benchmarking, Optimization, Simulation, ...)

Names of commonly used UESMs:

AURORAxmp, EnergyPLAN, ETM, HEAT+ INSEL, OpenDSS, PyPSA, SimStadt, SynCity, Urbs, CityInSight, CYME, PRIMES, EnergyPlus eTransport, HOMER, INVERT/EE-Lab, MESSAGE, MODEST, NEMS, PLEXOS, RETScreen, STAR, TRACE, SAM, SWITCH, STREAM, TRNSYS, COMPOSE, EMCAS, E-OPT, City Energy Analyst, GEMIS, IKARUS, LEAP, Network Planner, SIMPOW, UMI.
## Literature review – UESM

<table>
<thead>
<tr>
<th>Author</th>
<th>Overview</th>
<th>Focus/ Finding/ Suggestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connolly et al. 2010 [9]</td>
<td>Explored 37 UESMs</td>
<td>Proposing best UESMS fit for every application</td>
</tr>
<tr>
<td>Sinha et al. 2014 [10]</td>
<td>19 UESMs discussed in detail</td>
<td>Highlighted capabilities, limitations and future research areas of different UESMs</td>
</tr>
<tr>
<td>Yazdanie et al. 2021 [8]</td>
<td>Explored 30 review studies including 61 UESMs</td>
<td>Fundamental review of gaps and improvement point in current tools</td>
</tr>
<tr>
<td>Hall et al. 2016 [12]</td>
<td>Review of 22 implemented UESMs</td>
<td>model purpose and structure, technological detail and mathematical approach</td>
</tr>
</tbody>
</table>
Issues to be addressed in UESMs:

- Lack of adjustable temporal resolution regarding the problem and available data
- Lack of transparency and flexibility
- Not modeling demand (demand is an input)
- Inability to practice demand-side management strategies
- Energy system sizing is not automatized / Input by the user
- Not capturing Energy System Performance fluctuations in high temporal resolution
Research Focus- Objectives

- Proposing an automated, flexible and transparent workflow Capable of:
  - Adjusting temporal resolution
  - Integrating demand and supply side
  - Selecting and sizing detailed energy system model components to supply heating, cooling and domestic hot water
  - Practicing demand-side management strategies
  - Performing Optimization and sensitivity analysis
Proposed Workflow
Roof Area (PV)
Number of PV Panels
AC & DC Power Generation

Heating & Cooling & DHW Demand Profiles
Heat Pump Heat Output
Number of HPs
HP Electricity Consumption
HP Supply Temperature
HP Seasonal COP
Heating Seasonal Factor
Heat Pump Heat Output

Electrical & Thermal Balance
Heat Surplus/ Deficit

Hot Water Supply Temp.
Return Temp
Return & Supply Flow rate

Elec. Heater consumption

Domestic Hot Water / Thermal Storage Tank

Heating- 40°С
Hot water

City Water

Energy Meter

Maximum Power Point Tracker

Inverter

Panel & Inverter

Inverter Efficiency

Battery

Terminal Units

Buffer Tank / Ideal Heat Exchanger

Heat Pump- Outdoor Unit

Introduction
Literature
Methodology
Case Study
Conclusion
Future Works
References
Case study 1 – Dominion Bridge 1\textsuperscript{st} Objective

- Dominion Bridge district, Lachine, Montreal
  - 6 mixed-use buildings, 277,000 sqm, 90% residential, 10% office

- Energy system design parameters
  - Low-temp heating / High-temp cooling
  - PV covers 65% roof area, Slope 31 degree

- Objectives
  - Energy positivity potential
  - Air Source & Ground Source HP

<table>
<thead>
<tr>
<th>Borehole Temp °C</th>
<th>Outdoor Air Temp °C</th>
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<tbody>
<tr>
<td>-5</td>
<td>-30</td>
</tr>
<tr>
<td>-4.2</td>
<td>-25</td>
</tr>
<tr>
<td>-3.9</td>
<td>-15</td>
</tr>
<tr>
<td>-3</td>
<td>-10</td>
</tr>
<tr>
<td>-2</td>
<td>-5</td>
</tr>
<tr>
<td>-1.1</td>
<td>0</td>
</tr>
<tr>
<td>1.7</td>
<td>5</td>
</tr>
<tr>
<td>4.4</td>
<td>10</td>
</tr>
<tr>
<td>7.2</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>
Case study 1—Results & findings

- Sizeable floor area vs. limited PV space
  - Foreseeable outcome: Energy Positivity
  - Exception: building E, Smallest floor area
  - PV penetration: 75-100% and as low as 30-40% in small and large buildings

- ASHP vs GSPH
  - Relatively similar performance despite harsh weather
  - Lower Elec. consumption and Higher SCOP for GSHPs
Case study 2– Dominion Bridge 2nd Objective

Decentral GSHPs

vs

Central district heating and cooling (DHC) with GSHPs

- Energy system design parameters
  - Single Stage GSHPs
  - System sizing for Peak demand and P=98%

- Objectives
  - Comparing Energy systems performance
  - Energy system sizing - different demand percentiles
  - Network design – Heat loss calculation
  - Economic assessment

Central GSHP

Decentralized GSHP
Case study 2 – Results & findings

- 17% less electricity consumption in Central scenario
- 18% lower import from the grid in Central scenario (Higher resiliency)
- 3 HPs less for DHC

LCOE = \frac{\sum \text{Lifetime cost of investment}}{\sum \text{Energy generation by the investment}}

![Graph showing demand and supply in the Central Scenario]
Case study 3

Objectives

- 1st: DHW: (HP only) vs. (HP+electrical heater)
- 2nd: Finding optimum slope for PV system using Python
- 3rd: Sensitivity analysis of heating supply temperature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Number of stories-units</td>
<td>3-20</td>
</tr>
<tr>
<td>Total floor area (m²)</td>
<td>2161</td>
</tr>
<tr>
<td>Total Roof area (m²)</td>
<td>667</td>
</tr>
<tr>
<td>(23x29)</td>
<td></td>
</tr>
<tr>
<td>Occupant density (m²/person)</td>
<td>27</td>
</tr>
<tr>
<td>DHW demand (liter/day/person)</td>
<td>120</td>
</tr>
<tr>
<td>DHW storage factor</td>
<td>1</td>
</tr>
<tr>
<td>DHW demand factor</td>
<td>0.3</td>
</tr>
<tr>
<td>DHW set point</td>
<td>40°C</td>
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</table>
Case study 3– Hot water generation–Results

- DHW usage profile generated using DHW-Calc
  - 1.5 cubic meter hot water tank
  - City water temperature of 10°C

- Higher SCOP and seasonal performance factor for HP ONLY Scenario

- Despite having heat loss, higher COP of HP makes the difference

\[
SPF = \frac{\sum \text{Demand}}{\sum \text{Energy Consumed for Meeting Demand}}
\]

\[
SCOP = \frac{\sum \text{Energy Produced}}{\sum \text{Energy Consumed}}
\]

<table>
<thead>
<tr>
<th></th>
<th>HP + Electric Heater</th>
<th>HP Only</th>
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<tbody>
<tr>
<td>Total EXCESSIVE ENERGY (kWh)</td>
<td>0</td>
<td>139,704</td>
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<tr>
<td>DHW HP Seasonal COP</td>
<td>3.22</td>
<td>3.55</td>
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<tr>
<td>HP Electricity Consumption (kWh/yr) (DHW)</td>
<td>68,558</td>
<td>128,113</td>
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<tr>
<td>Aux. Electric. Heater Consumption (kWh/yr)</td>
<td>94,116</td>
<td>0</td>
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<tr>
<td>Number Of Heat Pumps (DHW)</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Seasonal Performance Factor</td>
<td>2.45</td>
<td>2.67</td>
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Case study 3 – Optimum slope – Results

INSEL and Python
- Text file, PyCharm and DEAP library

65% roof area for PV

Optimizing AC electricity generation
- Considering inverter efficiency

Result: 31 degree
- Despite 30,34,35,37 in literature

<table>
<thead>
<tr>
<th>Slope (degree)</th>
<th>AC Electricity Generation (kWh/yr)</th>
<th>Inverter Efficiency (%)</th>
<th>Total PV Generation (kWh/yr)</th>
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<tr>
<td>0</td>
<td>70802</td>
<td>91.50</td>
<td>73809</td>
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<td>75641</td>
<td>92.41</td>
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<td>25</td>
<td>71808</td>
<td>93.14</td>
<td>74694</td>
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<td>28</td>
<td>80336</td>
<td>93.26</td>
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<td>29</td>
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<td>80</td>
<td>9706</td>
<td>90.54</td>
<td>10233</td>
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<td>86</td>
<td>error</td>
<td>error</td>
<td>3125</td>
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<tr>
<td>90</td>
<td>error</td>
<td>error</td>
<td>error</td>
</tr>
</tbody>
</table>

Azimuth Angle 180
Ground reflectance 0.2
Latitude 45.5
Longitude 73.62
Nominal Power (W) 300
MPP Voltage (V) 53.76
MPP Current (A) 5.54
Efficiency (%) 17.24
Width (mm) 1072
Height (mm) 1623
Case study 3– Sensitivity Analysis - Results

- Heating supply temperatures
  - 30-55°C – 5°C increment

- Min, max and average increase in consumption for 5 degrees
  - 4%, 20%, and 13%
  - COP drops, average 11%

![Graph showing heating seasonal COP and electricity consumption (kWh/yr) for heating vs temperature.](image)
Conclusion

- UESMs contributing to existing and future energy strategies and policies
  - Gaps: transparency, flexibility, low temporal resolution, etc.

- Automated flexible workflow introduced
  - Demand calculation and energy system sizing
  - Complete solution for heating, cooling and DHW
  - Detailed model, applicable to various studies and scenarios
  - Sophisticated analyses (Optimization, Sensitivity analysis) using Python libraries
Suggestions for Future works

- Adding other energy systems (PV/T, Wind, CHP, Boiler, etc.)
- Considering inverter HPs
- Improving battery and thermal storage models
Thank You!

CONCORDIA.CA


