METHODOLOGY FOR COMMERCIAL BUILDINGS THERMAL LOADS PREDICTIVE MODELS BASED ON SIMULATION PERFORMANCE

Dimitrios-Stavros Kapetanakis\textsuperscript{1,2}, Eleni Mangina\textsuperscript{3} and Donal Finn\textsuperscript{1,2}

\textsuperscript{1}School of Mechanical & Materials Engineering
\textsuperscript{2}UCD Energy Institute / Electricity Research Centre
\textsuperscript{3}School of Computer Science and Informatics

24.08.2015
Outline

- Context and Motivation
- Research Aim
- Contribution
- Research Questions
- State of the Art
- Methodology
- Expected Outcomes
- Future Work
Context and Motivation

- Buildings account for $\sim41\%$ of total final energy consumption (Eurostat, 2013)
- Retrofit of existing buildings offers significant opportunities for energy savings (European Commission, 2009; 2010)

Diagram:
- Envelope Upgrade
- Installation of more efficient HVAC systems
- Improvement of the control of HVAC systems
Research Aim

- Development of a data-driven modeling approach for predicting the thermal loads of commercial buildings
Contribution

Scalability of the approach to any commercial building type at any climate zone, while maintaining high accuracy.
Research Questions

Main Question

- Can BEMS historical data be used to predict the thermal load of any global commercial building using regression or machine learning techniques?

Sub-questions

- Is it possible to generate consistent databases of historical BEMS data from different categories of commercial buildings?
- Which BEMS variables should be utilised as inputs to predictive models?
- Which method, machine learning or regression, is the most accurate for generating predictions of building heating and cooling loads?
- How scalable is the proposed methodology?
State of the Art

Building Energy Performance

White-box Models
- Variable-base degree-day
- Bin method
- Computer Simulation
- Computer emulation

Grey-box Models
- Thermal networks
- Hybrid models

Black-box Models
- Simple linear regression
- Multiple regression
- Artificial neural networks
- Genetic algorithms
- Support Vector Machines

Steady-state
Dynamic
Methodology

- **Reference Buildings**
  - Different Building types
  - Various Climates

- **Dataset**
  - Simulation of Reference Buildings
  - Generation of Synthetic Database

- **Data Analysis**
  - Analysis of Linear and Monotonic Correlation
  - Selection of Input Variables

- **Model Development**
  - Development of multiple Regression, SVM & ANN predictive models

- **Model Evaluation**
  - Evaluation of Predictive Models based on Accuracy

- **Application**
  - Application of the Selected Predictive Model to Real Buildings

**Input Variable Selection**

- Auto-Regression
- Polynomial Kernel
- Feedback Network

**Comparison**

**Model Selection based on Accuracy**

- Regression
- SVM
- ANN

**Synthetic Database**

- Weather Data
  - Zone T
  - Zone RH
  - Zone CO₂
  - Zone Occupancy
  - Gas Consumption

- Normality Tests
- Pearson Correlation (Linear relationship)
- Spearman Correlation (Monotonic relationship)
## Reference Buildings

Selection of representative commercial buildings:

<table>
<thead>
<tr>
<th>i.</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>ii.</td>
<td>Large Hotel</td>
</tr>
<tr>
<td>iii.</td>
<td>Large Office</td>
</tr>
<tr>
<td>iv.</td>
<td>Strip Mall</td>
</tr>
<tr>
<td>v.</td>
<td>Secondary School</td>
</tr>
<tr>
<td>vi.</td>
<td>Supermarket</td>
</tr>
</tbody>
</table>
## Climate Zones

Selection of representative cities for different climates:

<table>
<thead>
<tr>
<th>Zone</th>
<th>EnergyPlus W.D.</th>
<th>Equivalent City</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Miami</td>
<td>Rio de Janeiro, Brazil Luxor, Egypt</td>
<td>Very Hot, Humid or Dry</td>
</tr>
<tr>
<td>1B</td>
<td>Riyadh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>Houston</td>
<td>Tel Aviv, Israel</td>
<td>Hot, Humid</td>
</tr>
<tr>
<td>2B</td>
<td>Phoenix</td>
<td>Cairo, Egypt</td>
<td>Hot, Dry</td>
</tr>
<tr>
<td>3A</td>
<td>Memphis</td>
<td>Valencia, Spain</td>
<td>Warm, Humid</td>
</tr>
<tr>
<td>3B</td>
<td>El Paso</td>
<td>Larnaca, Cyprus</td>
<td>Warm, Dry</td>
</tr>
<tr>
<td>3C</td>
<td>San Francisco</td>
<td>Rome, Italy</td>
<td>Warm, Marine</td>
</tr>
<tr>
<td>4A</td>
<td>Baltimore</td>
<td>London, UK</td>
<td>Mild, Humid</td>
</tr>
<tr>
<td>4B</td>
<td>Albuquerque</td>
<td>Madrid, Spain</td>
<td>Mild, Dry</td>
</tr>
<tr>
<td>4C</td>
<td>Salem</td>
<td>Shannon, Ireland</td>
<td>Mild, Marine</td>
</tr>
<tr>
<td>5A</td>
<td>Chicago</td>
<td>Berlin, Germany</td>
<td>Cold, Humid</td>
</tr>
<tr>
<td>5B</td>
<td>Boise</td>
<td>Bucharest, Romania</td>
<td>Cold, Dry</td>
</tr>
<tr>
<td>5C</td>
<td>Vancouver</td>
<td>Dublin, Ireland</td>
<td>Cold, Marine</td>
</tr>
<tr>
<td>6A</td>
<td>Burlington</td>
<td>Oslo, Norway</td>
<td>Cold, Humid</td>
</tr>
<tr>
<td>6B</td>
<td>Helena</td>
<td>Moscow, Russia</td>
<td>Cold, Dry</td>
</tr>
<tr>
<td>7</td>
<td>Duluth</td>
<td>Helsinky, Finland</td>
<td>Very Cold</td>
</tr>
<tr>
<td>8</td>
<td>Fairbanks</td>
<td>----</td>
<td>Subarctic</td>
</tr>
</tbody>
</table>

ANSI / ASHRAE Standard 90.2 - 2007
Selection of Input Variables

Selection of input variables based on data analysis:

- Data analysis procedure applied to all reference buildings for all the selected climates
- Examine the linear and monotonic correlation between “possible” input variables with heating and cooling loads

<table>
<thead>
<tr>
<th>Weather Data</th>
<th>Indoor Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td>Zone Air Temperature</td>
</tr>
<tr>
<td>Ambient Relative Humidity</td>
<td>Zone Relative Humidity</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>Zone Occupancy</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>Zone CO₂ level</td>
</tr>
<tr>
<td>Sky Clearness</td>
<td></td>
</tr>
</tbody>
</table>
Simulation Tools

- EnergyPlus:

- IBM SPSS Modeler:
Testbed Building (NIMBUS)

- NIMBUS building – 2 storey quadrangle-type office building located in Cork

- Heating system incorporates a 50 kW electrical / 82 kW thermal CHP unit, 2 gas boilers of 175 kW and a 2000 lt water calorifier

- Extensive monitoring and data collection
Testbed Building (SLLS)

- SLLS building – Student Learning Leisure and Sports building located in University College Dublin

- Heating system incorporates 2 CHP units, 2 gas boilers and an Air Cooled Chiller

- Multipurpose building with extensive monitoring and data collection
Expected Outcomes

- Novel selection of input variables for predictive models
- Comparison of Regression, ANN and SVM
- Investigation of the existence of a global solution for predicting building thermal loads
- Evaluation of the scalability of the most accurate model
- Application of the predictive models to real testbed buildings
## Progress Summary

### Reference Buildings
- Different Building types
- Various Climates

### Dataset
- Simulation of Reference Buildings
- Generation of Synthetic Database

### Data Analysis
- Analysis of Linear and Monotonic Correlation
- Selection of Input Variables

### Model Development
- Development of multiple Regression, SVM & ANN predictive models

### Model Evaluation
- Evaluation of Predictive Models based on Accuracy

### Application
- Application of the Selected Predictive Model to Real Buildings

---

**NIMBUS, Cork**

**SLIS, UCD**
Thank you for your attention