A study of building thermal models for use in the analysis of energy sector coupling

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8th International Scientific Conference on Energy and Climate Change
Athens, October 7-9th, 2015
Agenda

• Introduction
• Residential Energy Demand Modelling Techniques at City Scale
• Methodology:
  – Complex EnergyPlus Building Model
  – RC Model
• Results and Discussion
  – Base Case Scenario
  – Effects of Solar Heat Gains
  – Effects of Internal Heat Capacity
  – Effects of Internal Heat Gains
Introduction

To make cities more energy-efficient and carbon neutral through better understanding of the urban energy systems.

Analysing interaction between different urban energy components at city district level
Introduction

Residential Electricity model (REM) - GIS

START

Select and export area to be analyzed

Create characterization matrix for smallest possible characterized region

Run REM

Electricity consumption matrix [HH_Timeline]

Assign household values to characterization matrix

Synthetic households

Visualize in ArcGIS

Extract characterization matrix for selected region

Build attributes

GIS Data

Available statistics

Population

Total number of households [HH]

Distribution of households by size [size_perc]

Distribution of households by size and area

ArcGIS + Python

END

Smallest possible characterized region

Area to be analyzed

8th International Scientific Conference on Energy and Climate Change – Athens, October 7-9th, 2015
Introduction

Residential Electricity model (REM) - GIS
Residential Energy Demand Modelling at City Scale

Modelling Techniques

Residential Energy Modelling

- Top-Down
  - Technological
  - Econometric
- Bottom-up
  - Neural Network
  - Archetype
  - RC-Model

adapted from (Swan & Ugursal, 2009)
Residential Energy Demand Modelling at City Scale

Simplified RC Modelling

+ Low number of required parameters
+ Simplified computation
+ High temporal resolution
+ Accurate representation of building dynamics

- Further improvement required for:
  • parametrization method
  • representation of user behavior
  • integration of technical equipment

- Model integration between software
Methodology

Case Study Building

- construction year class: 1958 – 1968
- building typology: DE.N.TH.05.Gen (TABULA)
- un-renovated, existing state
- heating system: central gas boiler, low temperatures
- conditioned area: 297 m²
Methodology

Complex EnergyPlus model

Building parameters
• Thermal properties: Construction-year-class
• Occupancy patterns: realistic, schedules for the day, week and year
• Appliance usage: realistic, schedules for the day, week and year
• Internal heat gains: with fractions of sensible, latent and radiant heat dissipation
• Window-to-wall ratio of 16%
• Internal thermal mass: indoor partitions (50m²) and furniture (14m²)
• Weather data of Munich in an hourly basis
Methodology

2R2C Model

\[ T_a \quad \text{Indoor air temperature [}^\circ\text{C}] \]
\[ T_w \quad \text{Temperature of the thermal mass [}^\circ\text{C}] \]
\[ T_e \quad \text{External temperature [}^\circ\text{C}] \]
\[ C_i \quad \text{Internal heat capacity of constructions and room air [J/K]} \]
\[ C_{eff} \quad \text{Effective heat capacity of thermal mass [J/K]} \]
\[ R_{se} \quad \text{Resistance of external constructions [K/W]} \]
\[ R_{sw} \quad \text{Resistance between heat capacity in construction and internal surfaces [K/W]} \]
\[ Q_s \quad \text{Windows Total Transmitted Solar Radiation Rate [W]} \]
\[ L \quad \text{Internal Load [W]} \]
Methodology

2R2C Model

L:
- $Q_s$: Internal Heat Gains from appliances and occupants
- $T_a$, $T_r$, $T_c$, $T_w$, $T_s$: Temperatures
- $C_i$: Internal Partitions, Furniture and Zone Air

Solar Gains $Q_s$
Results and Discussion

R2C2 Model vs. EnergyPlus

• Base Case Scenario
• Solar Radiation
• Internal Heat Capacity
• Internal Heat Gains
Results and Discussion

R2C2 Model vs. EnergyPlus

- Base Case Scenario

Comparison of modelled indoor temperatures (November-Feb)

Indoor Temp - R2C2
Indoor Temp - EnergyPlus
Outdoor Temp

Model run: Nov-Dec
Model run: Jan-Feb
Results and Discussion

R2C2 Model vs. EnergyPlus

• Base Case Scenario
### Results and Discussion

#### R2C2-model vs. EnergyPlus

- **Base Case Scenario**

<table>
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<tr>
<th></th>
<th>R²</th>
<th>EnergyPlus</th>
<th>Average T°</th>
<th>Δ</th>
<th>RMS Δ</th>
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Results and Discussion

R2C2-model vs. EnergyPlus

- Base Case Scenario
Results and Discussion

R2C2-model vs. EnergyPlus

• Solar Radiation
  i) removing the north-facing windows
  ii) removing the south-facing windows

Effect of solar radiation on the heating load (EnergyPlus Model):
  i) decrease of 4.8%
  ii) increase of 10.5%
Results and Discussion

R2C2-model vs. EnergyPlus

• Solar Radiation

![Graph showing solar radiation comparison between R2C2 and EnergyPlus](image-url)
Results and Discussion

R2C2-model vs. EnergyPlus

• Internal Heat Capacity

\[ C_i = C_a + C_f + C_{ip} \]

With
\( C_a \) = heat capacity of room air \([J/K]\)
\( C_f \) = heat capacity of furniture, assume heated to the internal air temperature \([J/K]\)
\( C_{ip} \) = heat capacity of interior partition walls, assumed heated to the internal air temperature \([J/K]\)

i) omitting the heat capacities of internal walls and interior furnishing in the calculation of \( C_i \)
ii) doubling the surface area of internal walls and interior furnishing

Effect of Internal Heat Capacity on Heating Load (EnergyPlus Model) < 0.1%
Results and Discussion

R2C2-model vs. EnergyPlus

- Internal Heat Capacity

![Comparison of modelled indoor temperatures (a week in November)](image-url)
Results and Discussion

R2C2-model vs. EnergyPlus

• Internal Heat Gains
  
i) using the DIN 4108-6 recommended constant 5W/m²
  ii) assuming no internal heat gains

Effects of the Internal Heat Gains on the heating loads (EnergyPlus Model):
  i) increase by 11%
  ii) increase by 23%
Results and Discussion

R2C2-model vs. EnergyPlus

- Internal Heat Gains
  i) using the DIN 4108-6 recommended constant 5W/m²

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Results and Discussion

R2C2-model vs. EnergyPlus

- Internal Heat Gains
  ii) assuming no internal heat gains

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<td>Jan</td>
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Results and Discussion

Conclusion and next steps

Summary

• Overall good RC-Model performance with $R^2 > 0.8$ in most cases
• Simplifications may undermine the performance -> further improvement is required
• RC-Model sensitive to variations in the internal heat capacity

Further Work on the RC Model

• Advance to operational capacity
• Include the heating load
• Increase the temporal resolution to sub-hourly levels
• Interface with a GIS-Database system
• Integrate the Heat Model with the Electricity Model
Energy Efficient and Smart Cities

Research Group

Established in 2013 within the ‘Energy Valley Bavaria’ programme of the Munich School of Engineering
Current projects

Holistic Urban Energy Planning

Intelligent Solar thermal Heating Network

Polymer-Based Solar Thermal Drain Back Systems

Geothermal Applications in Urban Areas
Thank you for your Attention

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