CITIES
Centre for IT Intelligent Energy Systems

DTU

WP3: Intelligent Energy System Integration

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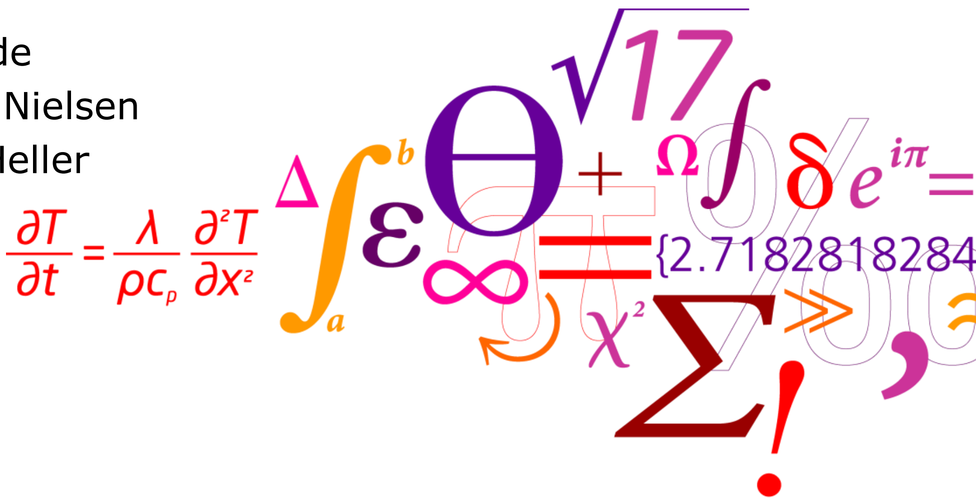

DTU Civil Engineering
Department of Civil Engineering

Agenda

- Introduction

- Theoretical Background
- Problem Statement
- Aggregating Building Energy Demands
- Main Objective
- Implementation of City Energy Model
- Results-Conclusions

MSc Project

- Next steps-Future work
- CITIES project-structure
- Similar projects worldwide

PhD Project

Introduction

- **Diploma** in Mechanical Engineering, Aristotle University of Thessaloniki, Greece (Energy Production and Utilization specialization)

- **MSc** in Sustainable Energy, DTU, Denmark (Energy Savings study line)

- **MSc Thesis**: 'Development of Aggregation Models for Building Energy Demands applied to Smart Cities', DTU Byg

- **PhD** project (September 2014): 'Buildings for Smart Energy Cities', DTU Byg

MSc Project

Theoretical Background

- **Building stock energy modelling approaches**

- Bottom-up → Calculate energy demand based on **individual** buildings and **extrapolate** the results to a whole region/country → data intensive

- Top-down → Refer to **aggregate** level, while typically represent a historical time series of national energy consumption data → Require up-to-date well-distributed data for **large** groups of buildings

- **Parametric modelling**
  - Creates a plethora of outcomes and design alternatives in a **dynamic** manner
  - Inputs/**parameters** control the design
  - **Automates** city modelling and helps generate bottom-up urban structures

- **Load modelling of buildings**
  - ✓ Building energy simulation methods
  - ✓ Statistical analyses
  - ✓ Intelligent computer systems

Problem Statement

❖ **How can buildings contribute to the development of Smart Cities?**

- Integration of smart energy solutions
- Increase of building-energy efficiency → high energy & CO_2 savings

• Energy demand of building sector plays an important role on national energy balances

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• Many efforts to estimate energy demand of neighborhoods, districts or cities

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Aggregation

Aggregating building energy demands

❖ First aggregation way

- Energy estimates of **individual** buildings are added up to calculate the total energy use of the building stock

$$Y = \sum_{i=1}^{n} X(i)$$

Y = total energy demand of the examined building stock [kWh]

n = number of individual buildings

X = energy demand per building [kWh]

❖ Second aggregation way

- **Reference** buildings are used → representative for the whole stock and weighting factors are used proportionally for every category

$$Y = \sum_{j=1}^{N} EUI(j)\, A(j)$$

EUI = energy demand per floor area [kWh/m^2] for each building type

A = total floor area [m^2] of all buildings included in the respective type

Main objective

- Investigate the existing aggregation ways by **implementing** them on a real case-study

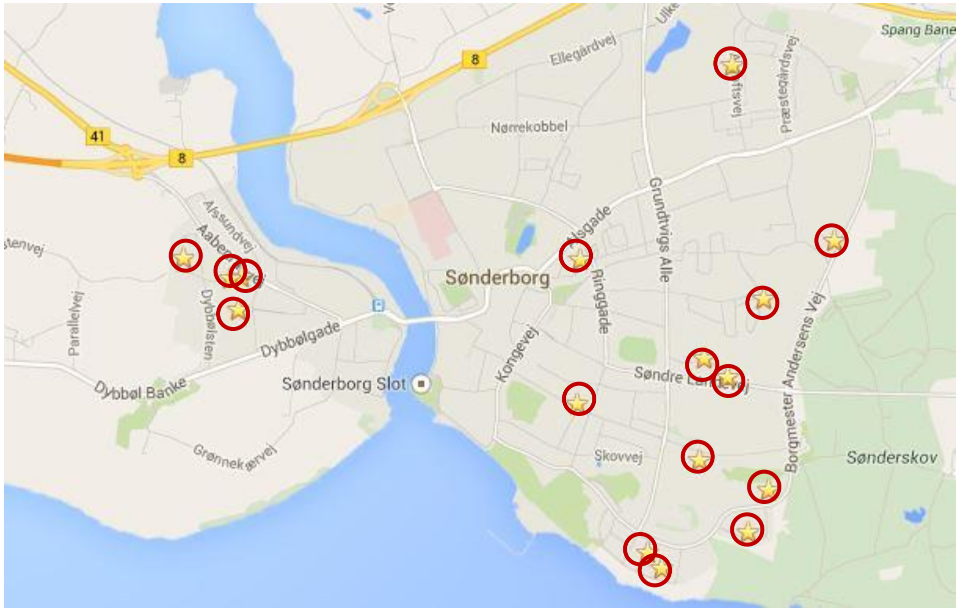
- Propose a **methodology** for estimating realistic energy demand models for districts or cities

Implementation of city energy model

Description of the case study

- **16** one-floor **single-family houses**
- Located in Sønderborg, Denmark
- Constructed mainly in 1960s
- Floor areas: 85 - 175 m²
- Connected to local district heating network
- No solar heating panels
- No mechanical cooling

Figure 1. Typical design of the single-family house



Implementation of city energy model

➢ Sources of information

- Danish Building Register (BBR)
- TABULA project (WebTool)
- Google Maps-StreetView
- Questionnaires
- Measurements

➢ Simulation tool

• Termite

- Developed by PhD student **Kristoffer Negendahl**, DTU Civil Eng.
- Based on **Rhinoceros®** (CAD design environment) and **Grasshopper™** (visual parametric programming interface)
- Uses **Be10** for energy simulations

Implementation of city energy model

➢ Information levels

A. Simple typological data (TABULA)
B. Online public databases (BBR)
C. Google Maps, Street View
D. Personal visits, on site measurements
or distributed questionnaires to the occupants

Number of occupants
Energy refurbishments

- 6 different scenarios were created based on these information levels

Information level	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
A	X	X	X	X	X	X
B	X	X	X	X	X	X
C		X		X		X
Di				X	X	X
Dii			X		X	X

Design based on generic means

Scenario 1	BBR
Scenario 2	BBR & Google Maps/Street View
Scenario 3	BBR & Refurbishment
Scenario 4	BBR & Google Maps/Street View & Occup. Loads
Scenario 5	BBR & People Loads & Refurbishments
Scenario 6	BBR & Google Maps/StreetView & Occup. Loads & Refurbishments

Implementation of city energy model

➢ Information levels

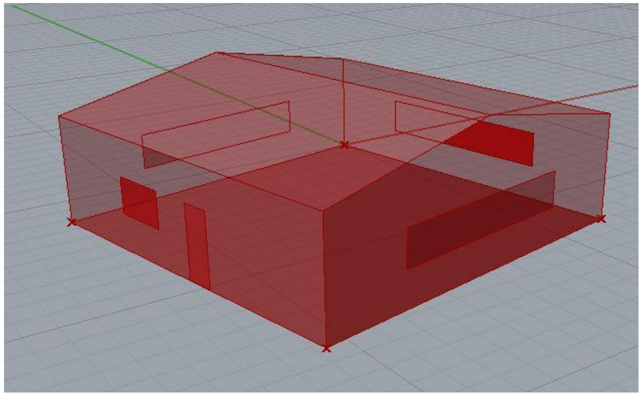


Figure 6. Design of House no.1 based on Scenario 1

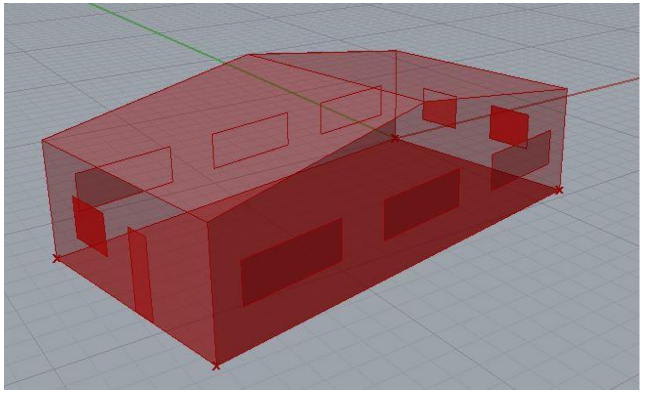


Figure 7. Design of House no.1 based on Scenario 6

- Initially aggregation of building energy demands was made based on the individual summing up (first way)

❑ Aggregation based on reference buildings

Example buildings →

Building type	Construction period	No. of incl. buildings	Total floor area [m^2]
A	1931-1950	2	238
B	1951-1960	2	180
C	1961-1972	10	1,530
D	1973-1978	1	117
E	1979-1998	1	122

Results - Conclusions

➢ First aggregation way

- Knowing the energy **refurbishment** state → improved the model's results by **24%** compared to the model including information only from BBR database
- Benefits of energy renovations **depend** highly on the building's age → usual renovation measures can have impressive reductions of energy demand in **older** buildings
- Most representative: model with **highest** information level (Scenario 6) → 12% deviation from measured values (annual aggregate heat demand)

➢ Second aggregation way

- Example buildings represented quite well the **individual** houses' performance, but not so well the **real** heat demands as measured
- Error increased when the houses had undergone energy **renovations**
- Example buildings did not include improved U-values → different classification **differentiating** between renovated and not renovated buildings may be more effective

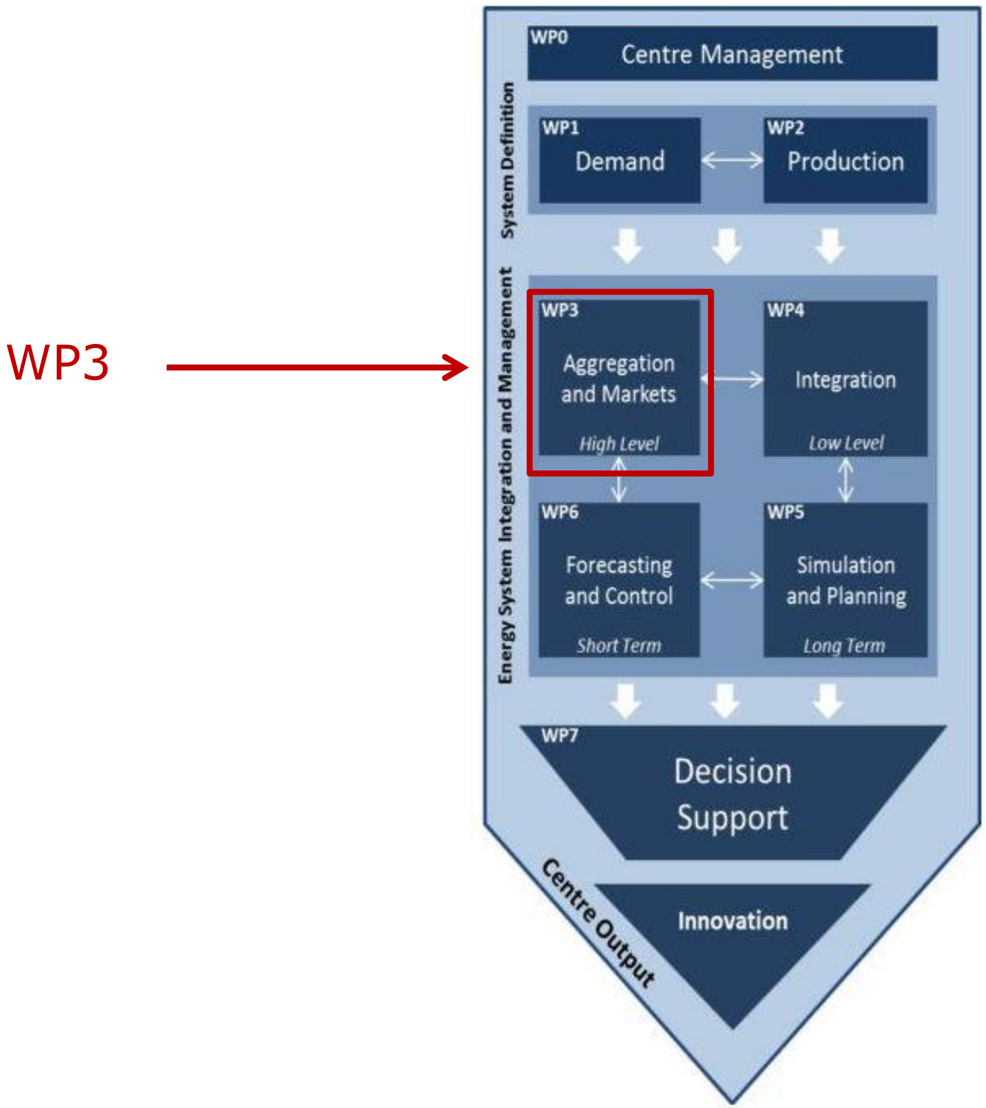
Proposal: Include information about current energy **refurbishment** state of buildings in most national estate databases

PhD project

Next steps – Future work

- Expand the sample to a **larger** building population → collect case studies
- Implement a **dynamic** energy simulation tool
  ↓
  study domestic flexibility → Electricity-thermal solutions
  → Thermal building masses
- **Challenges** to be met at **national** scale:
  - ✓ Data availability: critical
  - ✓ **Parametric** modelling tools
  - ✓ Vast computation times → use '**autotuning**' methods
  - ✓ Combine building energy simulation tools with **statistical** models (regression analysis)
  - ✓ City-scale models: **less** homogeneous → use 'system-types' categorization

CITIES project - structure



Work Package 3

- **WP3.1** :
  - ✓ Investigate novel methods for **aggregate** modelling and simulation techniques
  - ✓ Address any **interoperability** issues between different energy modelling and optimisation tools
  - ✓ Investigate the capabilities of individual **tools** for modelling energy systems with multiple energy flows.

- **WP3.2**:
  - ✓ Study low level aggregation techniques

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➢ Collect evidence and experiences from real world cases of **demand modelling and demand flexibility** demonstration projects and state of the art literature, methods and tools for aggregation models.

Similar projects around the world

- **IssyGrid**: the 1st smart district energy network in France
- **Kalasatama**: a model district of smart urban development with the help of open data in Helsinki
- **Celsius**: Combined Efficient Large Scale Integrated Urban Systems (smart district heating & cooling) in Gothenburg
- **FEEB&D**: Future Energy Efficient Buildings & Districts project by ETH Zurich
- **Zernez** (Switzerland): independent of fossil fuels by 2020

Thank You!

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