CITIES
Centre for IT Intelligent Energy Systems

DTU

WP3: Intelligent Energy System Integration

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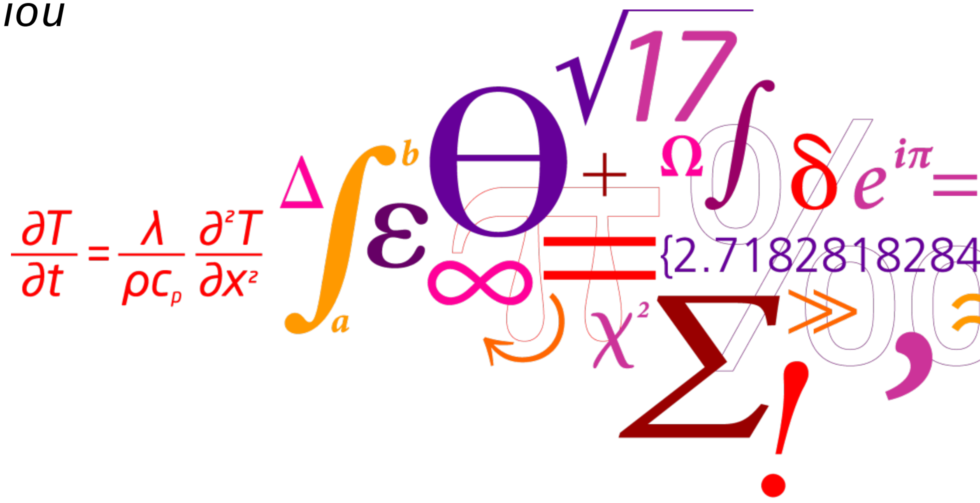

DTU Civil Engineering
Department of Civil Engineering

Agenda

- CITIES – WP3
- Theoretical Background
- Problem Statement
- Main Objectives
- Background-Tools
- Implementation of City Energy Model (example)
- Next steps-Future work

WP 3 Description

WP3 description from the CITIES proposal:

Together with WP4, WP3 will investigate interactions between energy flows and system components, and mechanisms to incentivise them on scales from the individual component to the entire energy system.

WP3 – Intelligent Energy System Integration

[DTU Civil Engineering (C. Rode)] [2 PhDs, 2x0.5 PDs]

This WP will explore possibilities to optimise the interaction and complementarity between low level PTSC resources, and consumers or groups thereof. Prosuming buildings (capable of consumption, storage and production) and their models will play an important role in this WP, reflecting their central role in an integrated city energy system. Efficient control mechanisms to achieve the identified interactions will be developed. A focus will be placed on developing more aggregate forms of modelling and simulation techniques than seen to date.

WP3 Work items

WP3.1: *Investigate novel methods for aggregate modelling and simulation techniques. This study should furthermore address any interoperability issues between different energy modelling and optimisation tools, and investigates the capabilities of individual tools for modelling energy systems with multiple energy flows.*

WP3.2: *Study low level aggregation techniques which facilitate the grouping of consumers with similar (or dissimilar) characteristics and consumption profiles.*

WP3.3: *Detailed models from WP1 and WP2 will be employed to identify interactions between system components (PTSC and demand) on various spatiotemporal scales. Synergies will be identified at the component level and between aggregations of similar resources.*

WP3.4: *Control, forecasting and optimisation tools will be developed based on data and models to optimise the interactions identified in WP3.3. Adaptive tools will be favoured to ensure relevance as the system evolves.*

WP3.5: *ICT solutions will be developed to support monitoring, validation, analysis, optimisation and control capabilities at the system component level.*

WP5 - Forecasting and Control

Effective forecasting and control methodologies are critical to ensure the secure operation of an energy system, particularly one with high penetrations of stochastic energy sources, where deviations between long- and short-term predictions for the system can be significant and must be dealt with in a robust and economically efficient manner. WP5 will investigate and develop various hierarchical forecasting and model predictive control techniques for a wide variety of energy system participants and components. Operational strategies will be devised and the required regulations to ensure the reliability of the system will be identified.

- **WP5.1:** Statistical characterisation of resources will be conducted with a focus on the possibilities for forecasting. **The interactions, dynamics, dependencies and correlations between resources will be specified (with contributions from WP3 and WP4).**
- **WP5.2:** Establish methods for probabilistic forecasting of consumption and production. Multi-variate forecasts will account for the relationships between, e.g. wind and solar.
- **WP5.3:** Develop controllers and operational strategies for direct control of system states (e.g. temperature control in district heating systems), taking probabilistic forecasts as an input.
- **WP5.4:** Develop controllers and operational strategies for economic based control for an indirect control of the system states, for example, by sending out a price signal.
- **WP5.5:** An operations and forecasting portal will be developed to provide forecasts and set-points to devices and subsystems operating as defined in WP5.3 and WP5.4. A special focus will be placed on solutions for demand side management.

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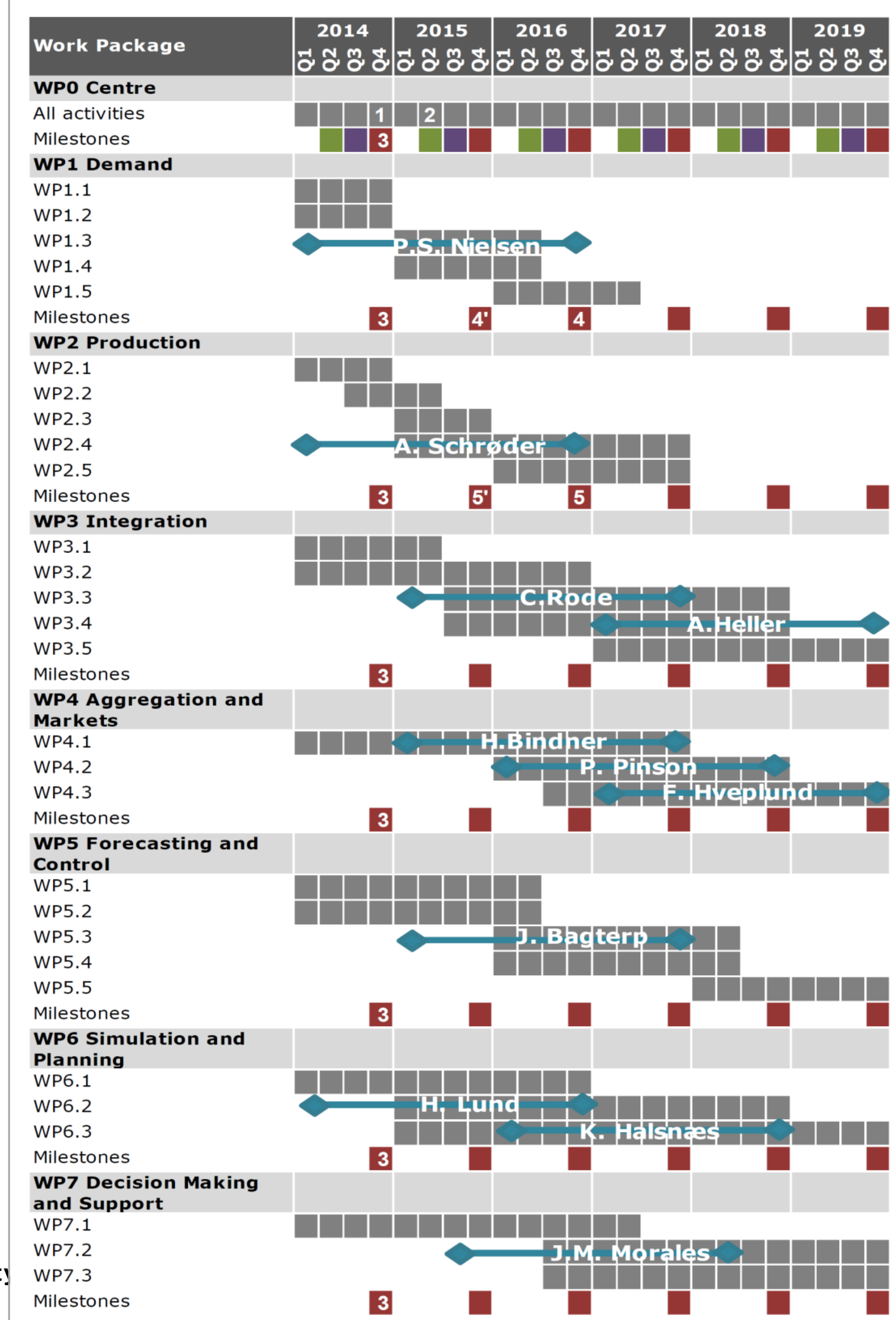
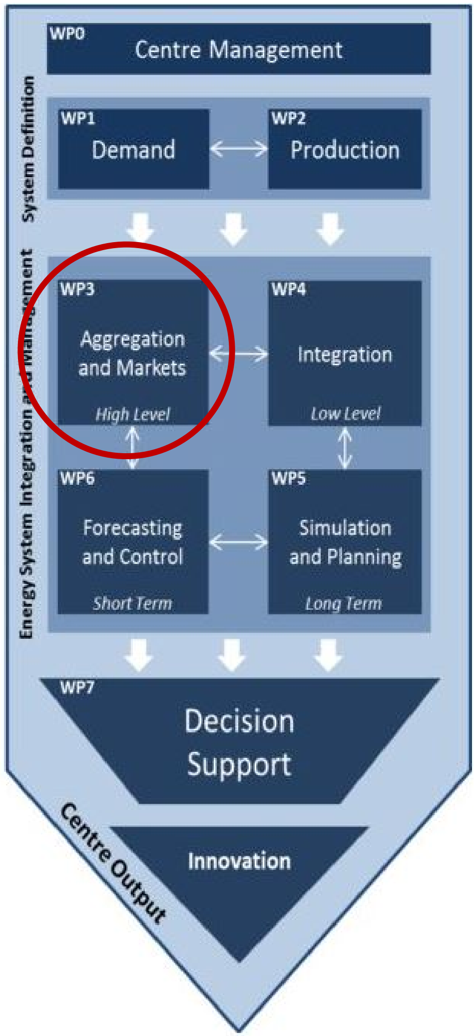
TIMELINE

Gannt diagram showing

- Work packages
- PhD’s and PostDocs and their supervisors
- Milestones:
  - PhD summer schools
  - Annual conferences
  - Steering group meetings
  - International advisory board meeting



CITIES - 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

⇩

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

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

➢ **Building energy simulation methods**

o Calculate energy demand and use
o Differentiate mainly upon:
  ▪ element conduction solution method
  ▪ interior surface convection
  ▪ human thermal comfort
  ▪ design day sizing calculations

Theoretical Background

➢ Building energy simulation methods

- **Heat balance** calculation
  - Quasi-steady-state methods → Monthly and seasonal results
  - Dynamic methods
    - Simple hourly results
    - Detailed simulation results

- **Heat transfer** modelling
  - Mathematical models → Euler/Fourier series methods
  - Physical models
    - Explicit solutions of the heat diffusion equation
    - Model reduction techniques
    - Model simplification techniques

Problem Statement

❖ **How can buildings contribute to the development of Smart Energy 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

⇩

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

⇩

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 objectives

- Investigate the existing ways of aggregating building energy demands by **implementing** them on a real case-study
- Propose a **methodology** for estimating realistic energy demand models for districts or cities
- Increase domestic **flexibility** and contribute to the overall stabilization of the energy grid

Background - Tools

➢ **Urban simulation tools**

Program-based approaches towards modelling buildings at city scale

❑ ***SUNtool*** (developed by Prof. Darren Robinson & his team)

- Early stage decision making tool for **sustainable urban design**
- Simulates a **set** of single-zone/multi-zone buildings or a sub-set of them
- Simulates shortwave and longwave **radiation** exchange and interior daylight
- **Simplified** thermal model
- Uses **stochastic** models (e.g. occupance presence/behavioural patterns, their interaction with windows etc.)
- High solver speed (simulates 100 single-zone buildings in max. 10 min)

❑ ***CitySim***

- Simulates and optimizes building-related **energy flows**
- Model are simulated based on the **resistor-capacitor** network
- Considers **water** consumption in buildings, **transport** related energy use and **urban heat island**
- Considers HVAC systems and energy conversion systems (ECS)

Background-Tools

➢ **Urban simulation tools**

- ***Umi*** (developed by Prof. Reinhart, MIT Department of Architecture)
  - Aims at **converting** GIS city maps to CAD data
  - Uses **Rhinoceros** (CAD), **EnergyPlus** (thermal & energy simulations), **Daysim** (daylight analysis) and **Python** scripts (walkability evaluations)
  - Creates EnergyPlus files for every building **individually**
  - Runs yearly energy simulations in **sequence** or **parallel**

- ***CityGML*** (developed by Special Interest Group 3D, Thomas H. Kolbe)
  - International **standard** for the representation, storage and exchange of virtual 3D city and landscape models
  - Defines 5 **levels** of detail in geometric representation of buildings
  - Based on **GML** (Geography Markup Language)
  - Focuses on the **semantical** aspects of 3D virtual city models (taxonomies, structures, aggregations etc.)

Example of implementation

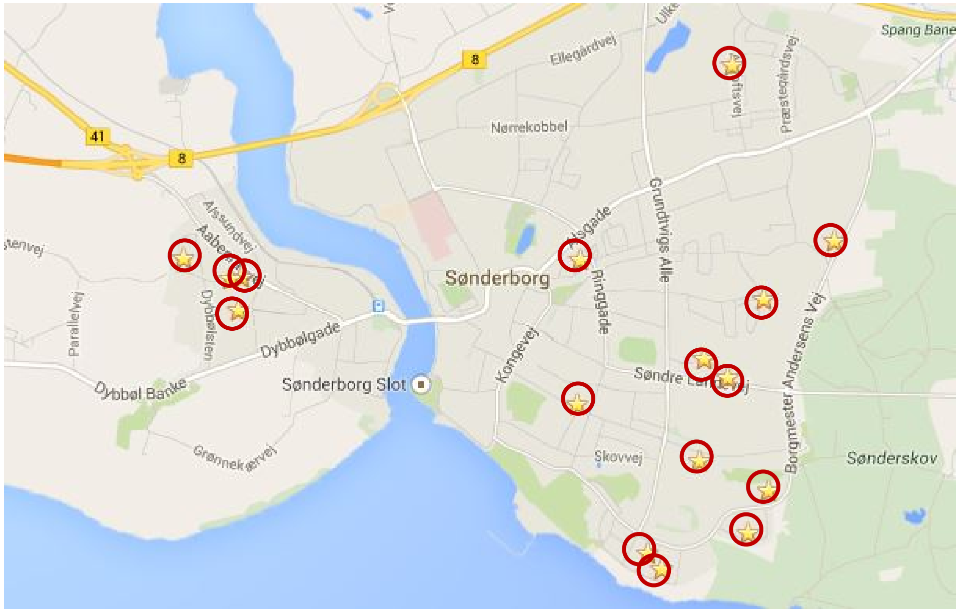
(part of MSc Project)

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 m^2
- 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

➢ Model setup

- A building model was created for house number 0 in Grasshopper
- Rest of houses: number of **lists** containing input data
- All lists connected with a main **controller**

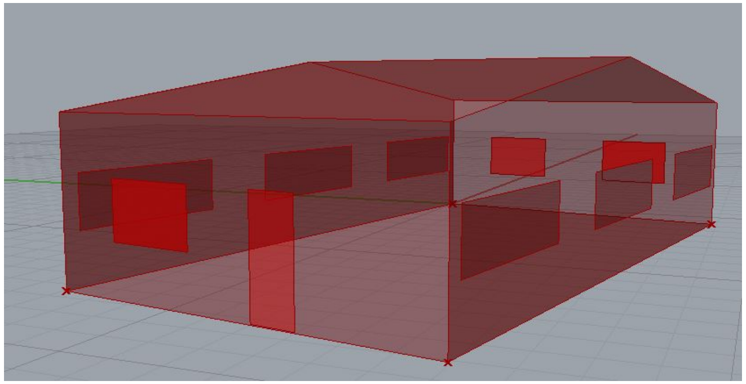


Figure 3. 3D perspective of the building model in Rhino

- **Room** temperature: **20ºC**
- **Outdoor** dimensioning temperature: **-12ºC** (according to Danish Standard DS418)
- Building **envelope**: divided into walls, floor and roof
- Transmission **losses** & thermal bridges: calculated based on DS418

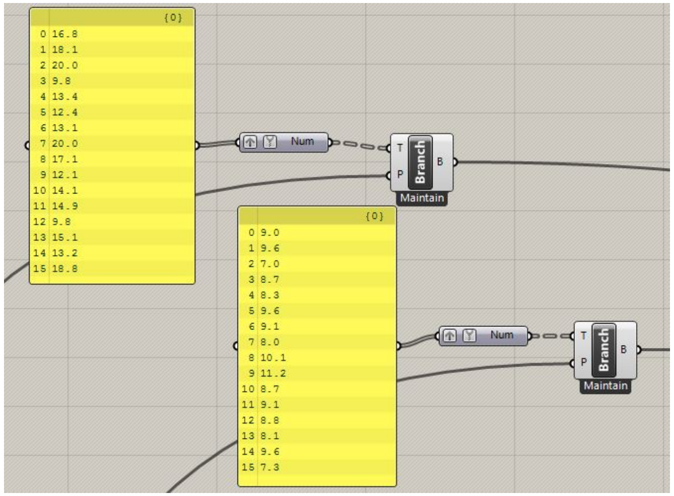


Figure 4. Inputs' lists for the 16 houses in Grasshopper

Implementation of city energy model

➢ **Model setup**

❑ **Windows**

- Glazing area
- Orientation & inclination
- U-values
- g-values
- Window-to-frame ratio

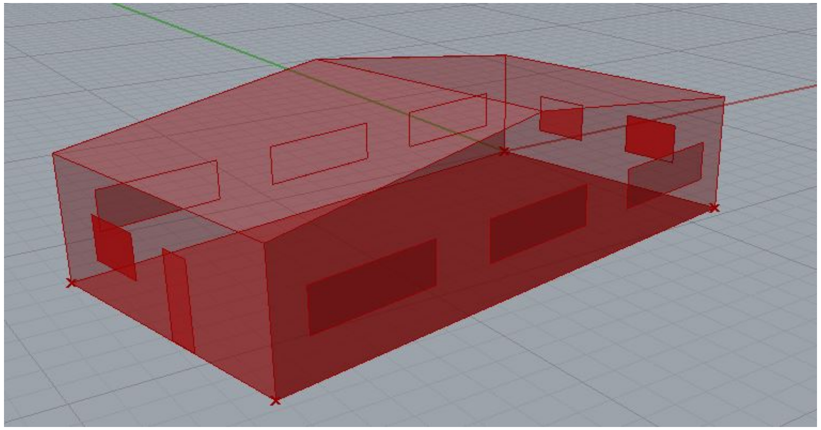


Figure 5. 3D perspective of the building model’s windows in Rhino

- Shading → horizon, overhangs, geometry of openings
  ↓
  interaction among neighboring houses

❑ **System’s parameters**

- Occupancy loads from people → heat production: 100 W/person (EN 13779)
- Natural ventilation (average airflow in winter: 0.3 l/s m^2
  summer: 0.9 l/s m^2)
- Heating system: connected to local DH network, radiators
- Hot water tanks [200 liters]

Implementation of city energy model

➢ Sources of information

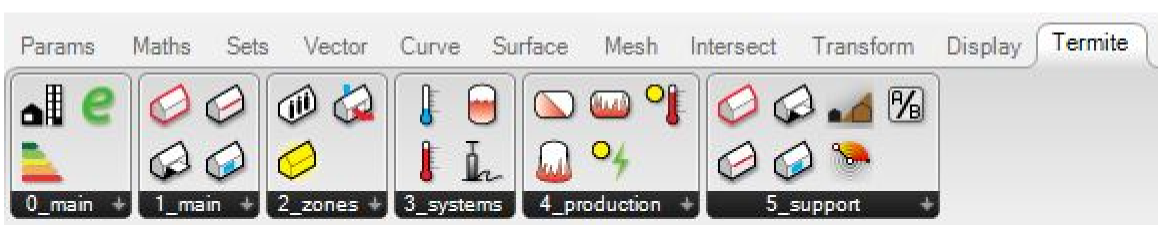
- **A** - Danish Building Register (BBR)
- **B** - TABULA project (WebTool)
- **C** - Google Maps-StreetView
- **D** - Questionnaires
  - Measurements

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

➢ 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



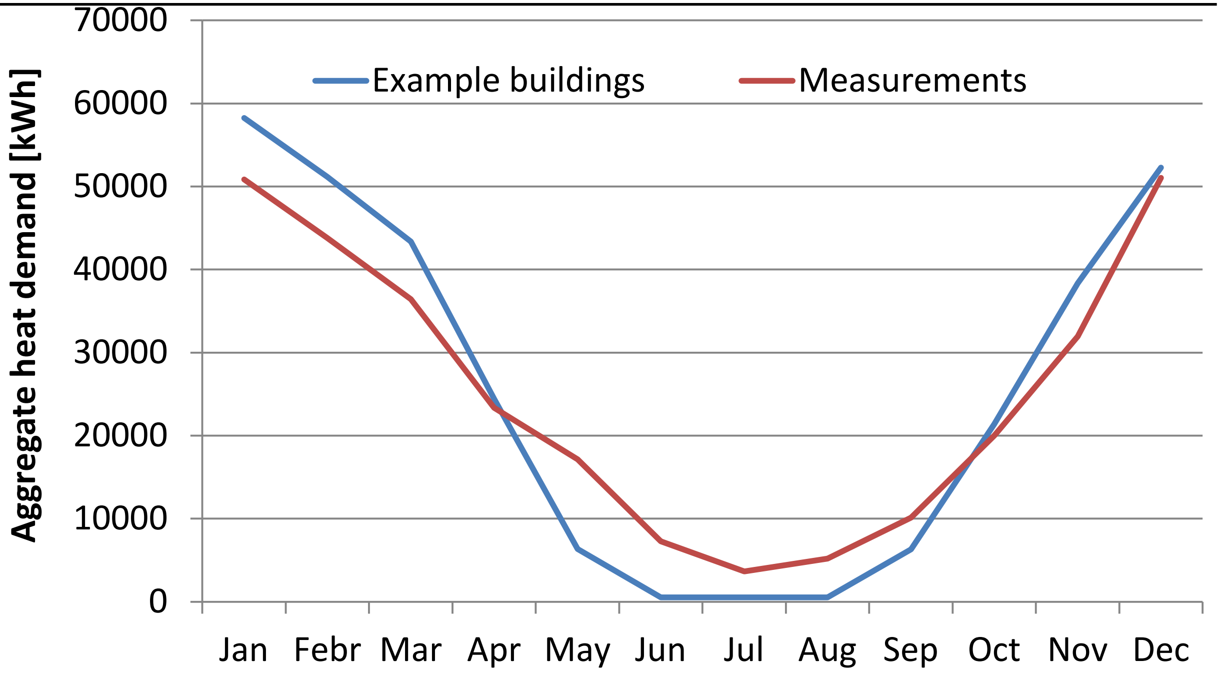
Results

➢ Information levels

Building type	EUI [kWh/m²]	Total floor area [m²]	Energy demand [kWh]
A	82	238	19,516
B	91	180	16,380
C	158	1,530	241,740
D	118	117	13,806
E	104	122	12,688

Aggregated = 304,130 kWh

1% deviation from measured heat consumption



Future work

Next steps

- Expand the sample to a **larger** building population → collect case studies
  - ✓ *Sønderborg* case: collect data for hundreds of buildings
    - ✓ Electricity, district heating measurements

- Implement **dynamic** energy simulation tools to study domestic **flexibility**
  - demand shifting through thermal building masses
  - electricity-thermal solutions

- **Challenges** to be met at **national** scale:
  - Data availability:critical
  - Simplify building models
  - Reduce simulation times
  - Majority of buildings are old
  - Lack of smart energy systems (energy metering) in most buildings
  - User profiles differentiate every building

Next steps – To be answered

- Where to **focus**?
  - Building level / city level
  - Residential / commercial / educational etc. sector
- What is the **minimum** possible level of **information** to model building stock?
- How much can building **typologies** contribute to this?
- Which **time step** is the optimum for building energy simulations?

Pic: Anna See

Thank You!

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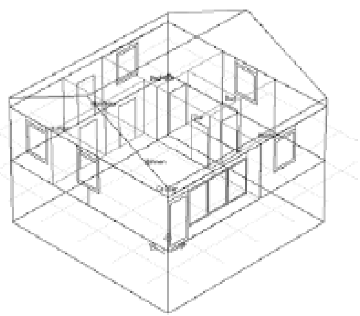
Summary of works in DTU for CITIES project

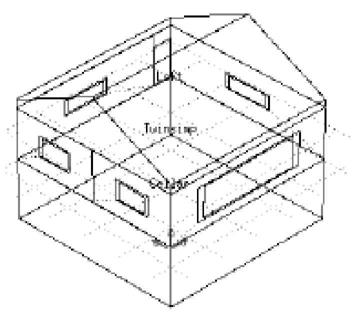
Kyunghun Woo,
Senior Researcher, Samsung C&T

Comparison between simplified and Detailed Model

- Simulation model for City is usually made with one zone model to reduce the building and running time
- To investigate how much accuracy an simplified model can achieve, a comparison study with detailed model was done, which is based on the real TwinHouse in Germany



Detailed Model



Simplified one zone Model

	DM	SM
No. of Zone	7 Zone(As built)	1 Zone
Windows	as built	% of Walls on each façades
Thermal bridges	Thermal bridges between walls and slabs calculated and applied	No thermal brides Only 1-dimentional calculated U-value is applied
Thermal and optical Properties of window	Calculated value in Winodow6. Thermal bridges around glazing edges was considered	Calculated value in Winodow6. No thermal bridge considered
Ventilation rate	Supply 120 m^3/hr fresh air into living room and extract 60 m^3/hr each at bathroom and children's room on the south part	Supply 120 m^3/hr and extract 120 m^3/hr (0.56 ach/hr)
Thermal properties of wall	Thermal properties supplied by manufacturer	Same as DM
Infiltration rate	0.08 ach/hr	Same as DM
Occupancy	No human input(as tested)	Same as DM
Equipment	No equipment in the house(as tested)	Same as DM
Simulation date	21^{st} of August ~ 30^{th} of September	

Why needs multi domain simulation software

- To perform an energy analysis of a city and maximize the efficiency through demand and supply matching, these items are required

  1. Prediction of Energy supply in near future.

  2. Prediction of Energy Demand in the forecasted weather condition taking into account user behavior

  3. With two data above, Control logics which will regulate supply and demand site to get a best performance

- With conventional single domain simulation software it is not possible to do this type of complex analysis

- Ptolemy II is an object oriented programing language. It support very simplified measures to exchange data with other software via XML format
  - BCVTB is building oriented customizied version of Ptolemy

Purpose of this study

- In the future energy grid the flexibility of heating demand will be an important factor to increase the efficiency of district energy grid
  - Due to the fluctuating nature of renewable energies
- Comprehensive sensitivity analysis is required to find out which factors are most important for the flexibility of demand
  - There are some sensitivity analysis regarding demand shifting but the number of parameters considered are very limited

Parameters which affect on demand shifting

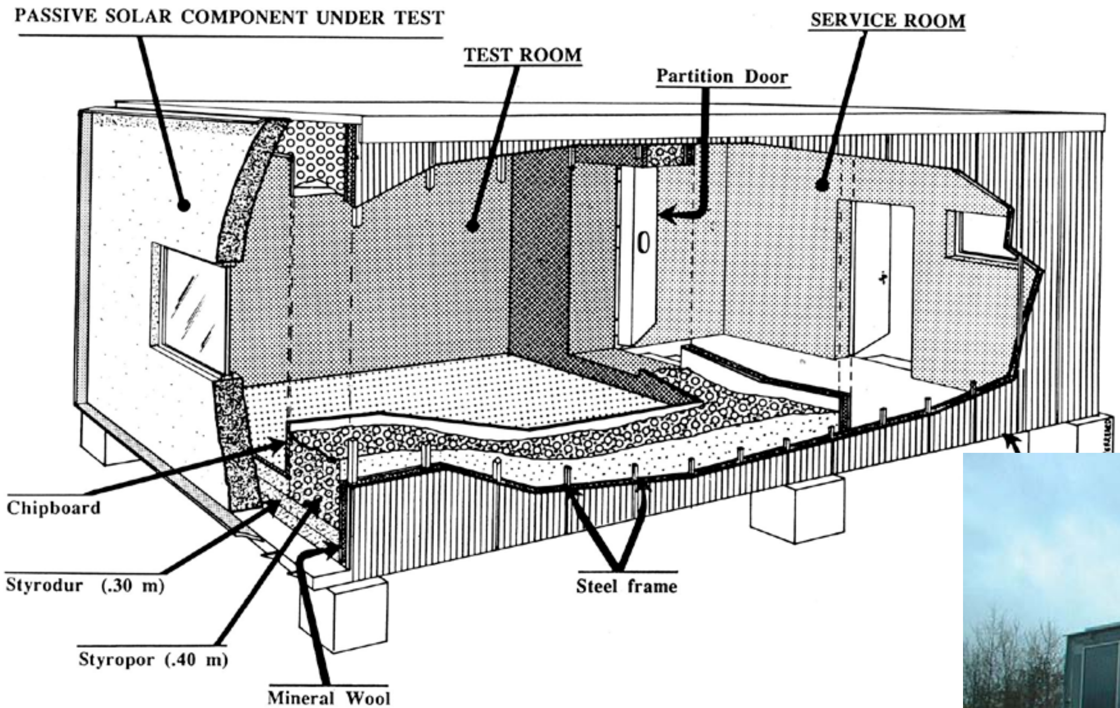
1. Insulation level of building fabric (Wall, Floor, Ceiling, Window)
2. Amount of Thermal mass (All the part in a building)
3. Ventilation and Infiltration rate
4. Overheating duration time
5. Position of insulation (Inside – outside of wall)
6. Solar radiation absorbed inside face of a building fabric (G-value)
7. Types of heater
8. outside boundary condition of ceiling and floor of a floor

Definition of parameter range

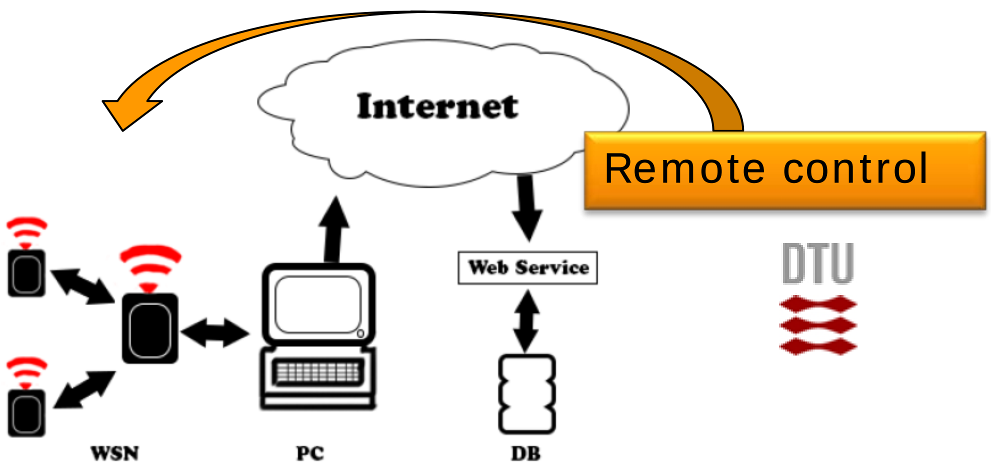
- Input for sensitivity analysis

Category	Item	Unit	Data Type	max	min	mode		
insulation	wall	W/m²k	Triangular	2.8	0.12	1.6		
	floor	W/m²k	Triangular	1.21	0.12	0.6		
	ceiling	W/m²k	Triangular	1.9	0.11	1.03		
	window	W/m²k	Discrete	0.8	1.7	2.7	4.2	5.1
g-value	window		Discrete	0.5	0.63	0.76	0.85	
Thermal mass	wall	(J/°C)	Triangular	816000	9576	510000		
	floor	(J/°C)	Triangular	585000	49875	96787.5		
	ceiling	(J/°C)	Triangular	195000	49875	49875		
infiltration		ac/h	Triangular	0.4	0.03	0.2		
Overheating time		hour	Discrete	1	2	3	4	5
Position of Insulation			Discrete	internal	middle	exterior		

PASSYS Test Cells

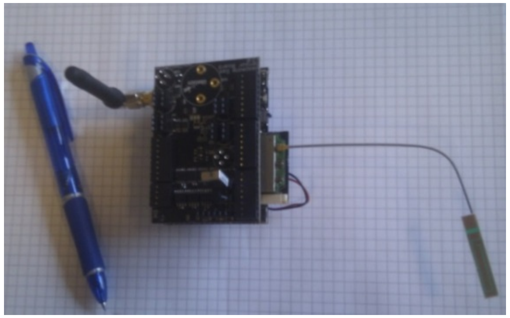


Data collection <-> control



Apisseq, Sisimiut - Greenland

- Communication sensors transfer data to databases
  - E.g. a local database (PC)
  - E.g. over the internet to a central database (DB, collection)
  - E.g. over the internet to a “cloud database”
  - Control and remote control



WSN for Smart Buildings

- Adjustment of various parameters
  - ✓ Ventilation
  - ✓ Heating
  - ✓ Pumping
  - ✓ Duct systems etc.

- When WSN is applied to **one** building floor

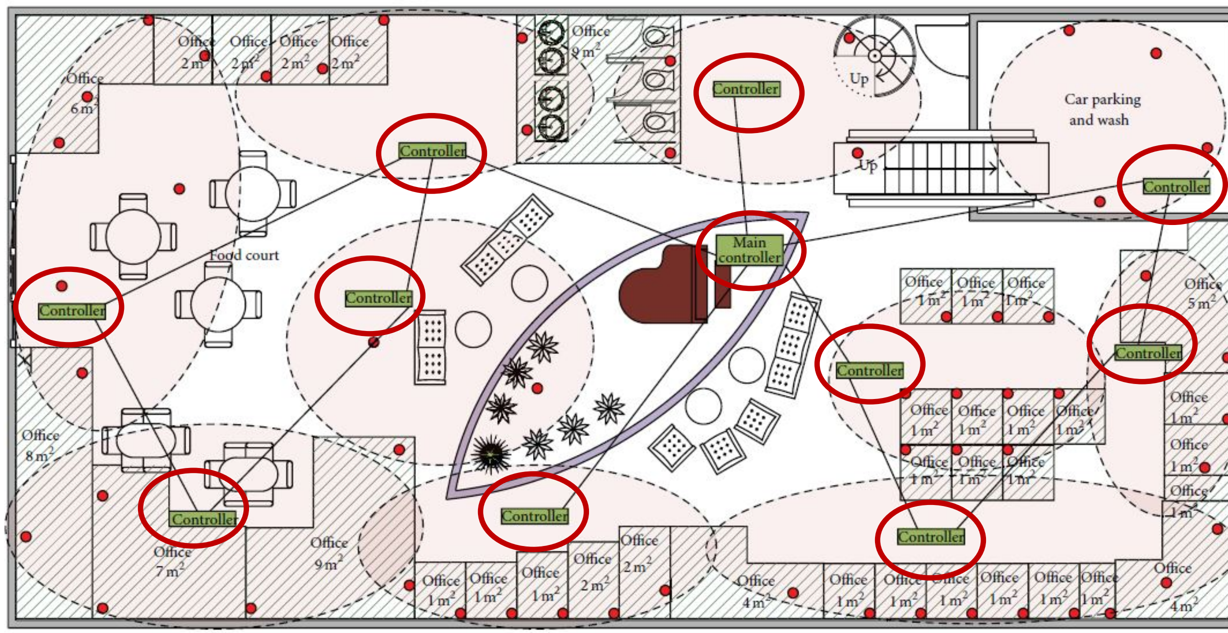


Figure 3. WSN architecture for one floor of a shopping centre (Source: Stojkoska et al.)