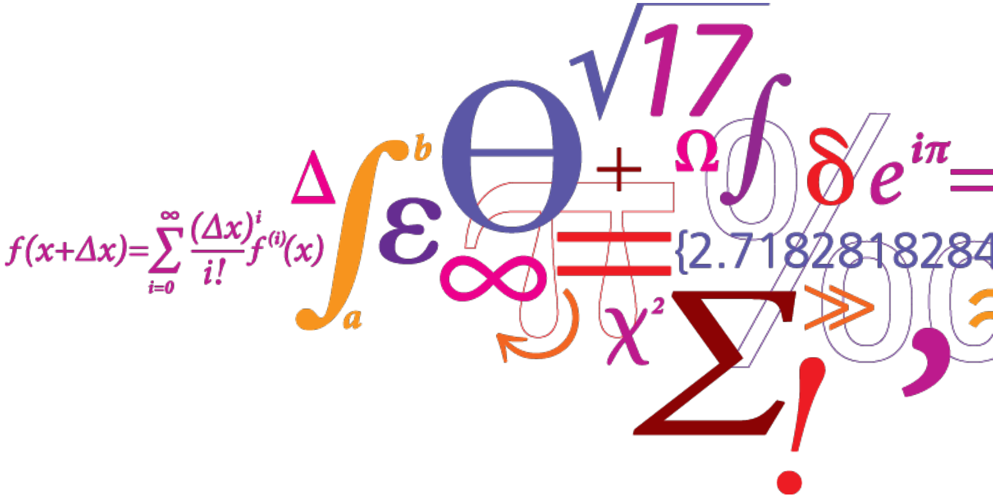
Energy Flexible Buildings

Prof. Carsten Rode, DTU Byg

CITIES Consortium Meeting, May 30-31, 2017, Aarhus

Pic: Anna See



DTU Civil Engineering
Department of Civil Engineering

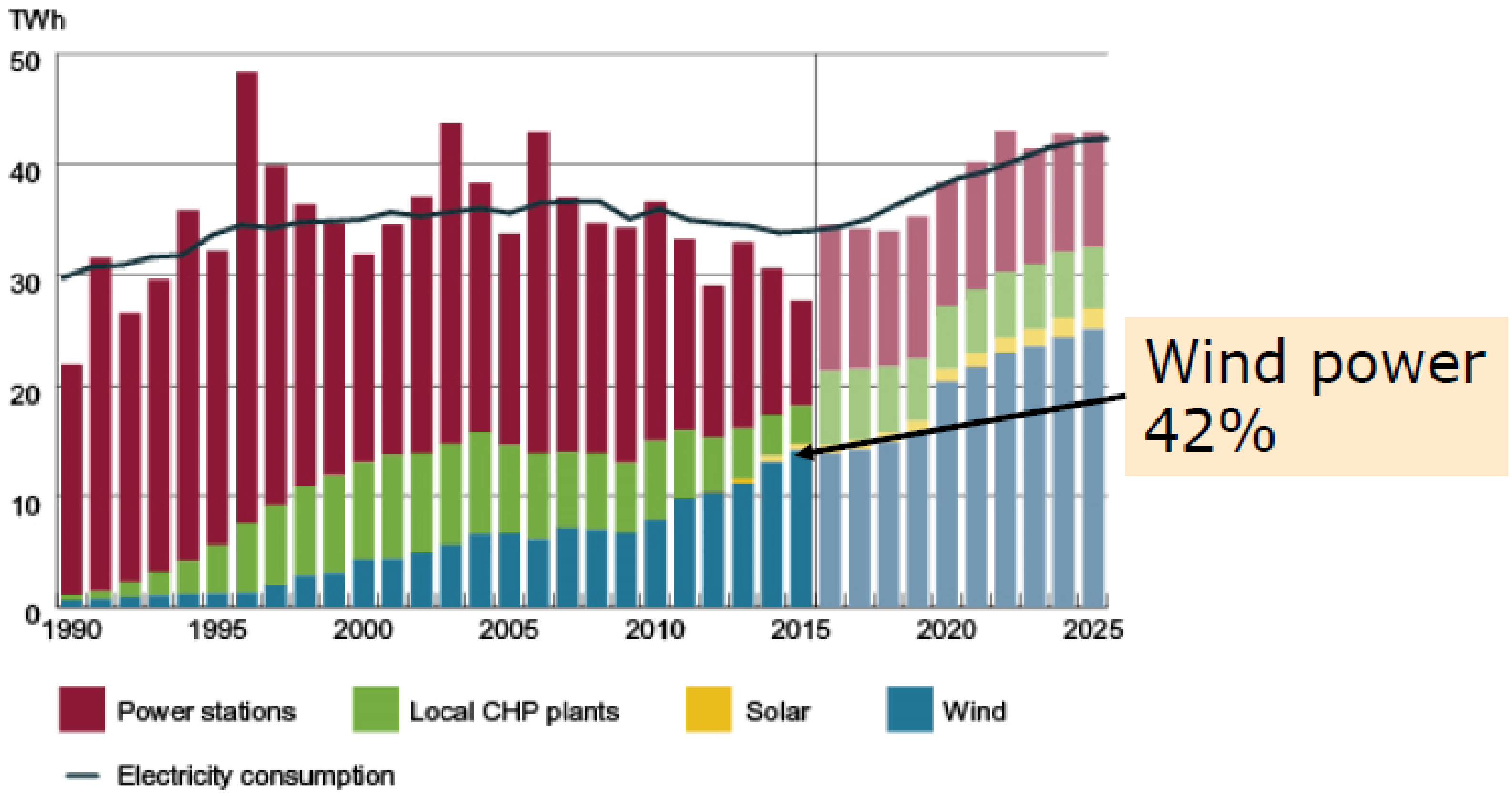
Need for Flexibility

The future energy system will be characterized by a significant penetration of **renewable energy:**

→ Challenge for the stability of the system, as both the production and the consumption side would have fluctuating patterns.

→ The concept of **energy flexibility** will be necessary in order for the consumption to match the production patterns.

Renewable Energy in the Danish Energy System



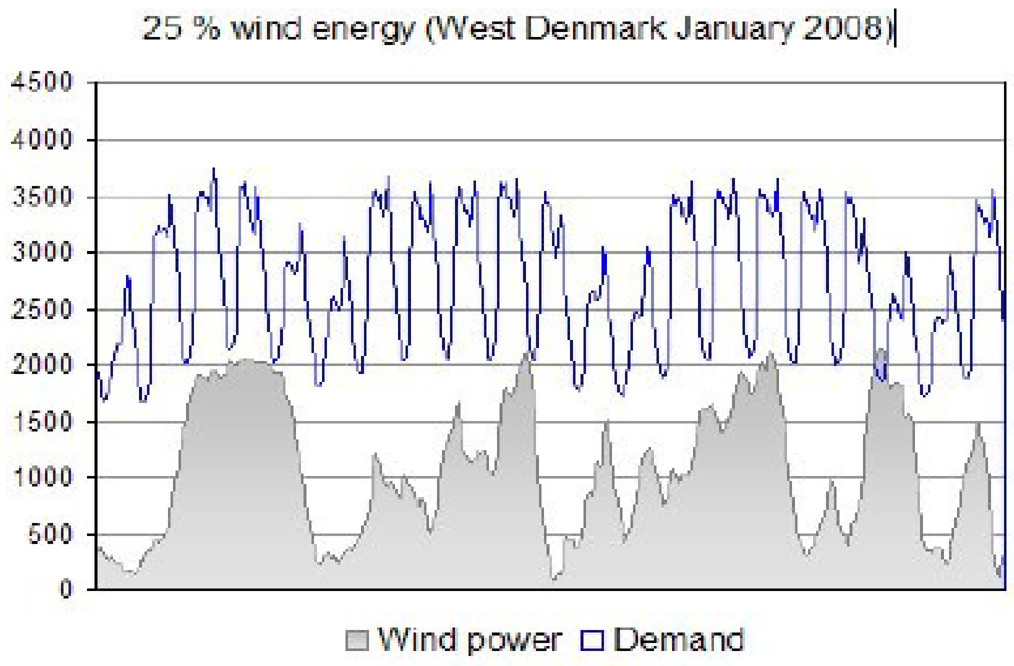
By Energinet.dk, last update in Sep. 2016

http://www.energinet.dk/EN/KLIMA-OG-MILJOE/Miljoerapportering/Elproduktion-i-Danmark/Sider/Elproduktion-i-Danmark.aspx

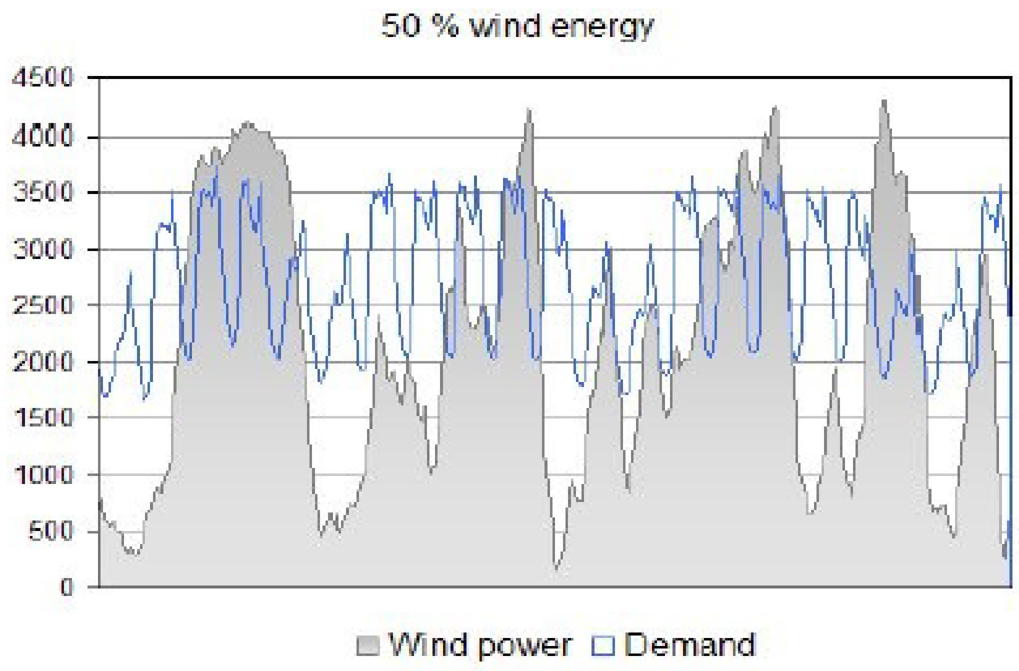
Gathered by: Rongling Li

The Danish Wind Power Case

.... balancing of the power system



Wind power covers the entire demand of electricity in 200 hours (West DK)

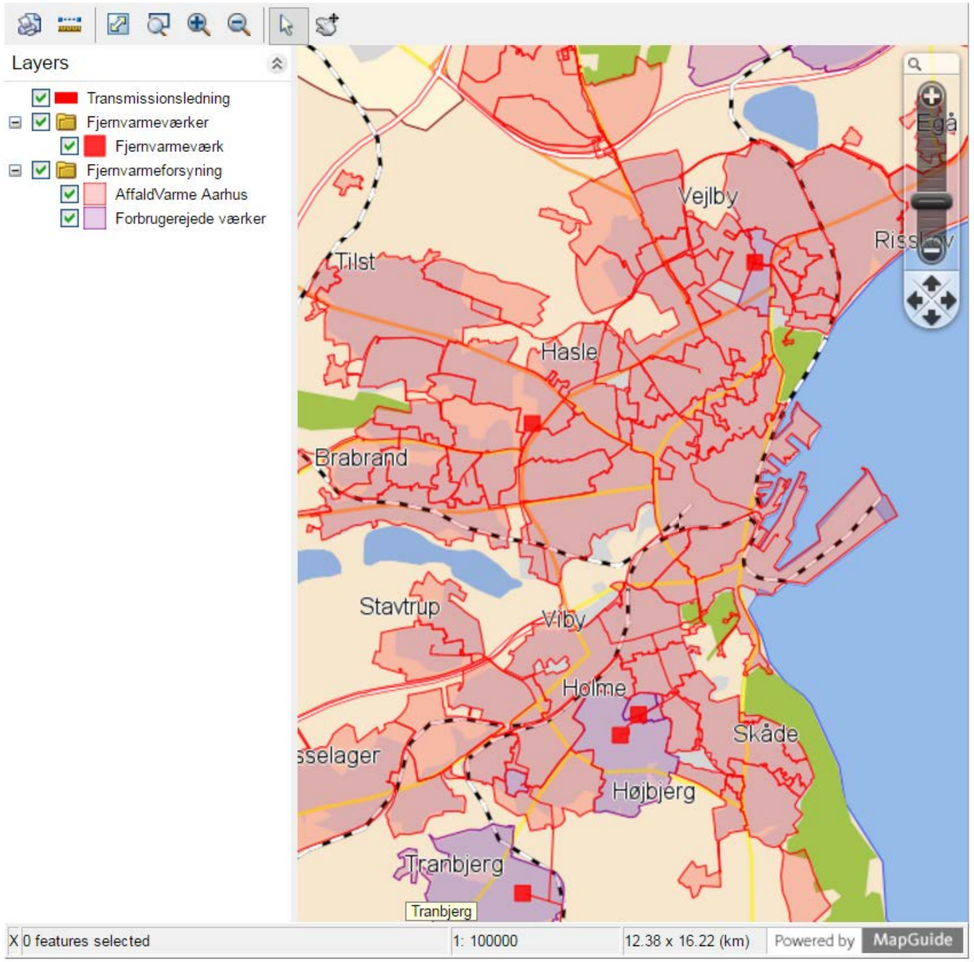


In the future wind power will exceed demand in more than 1,000 hours

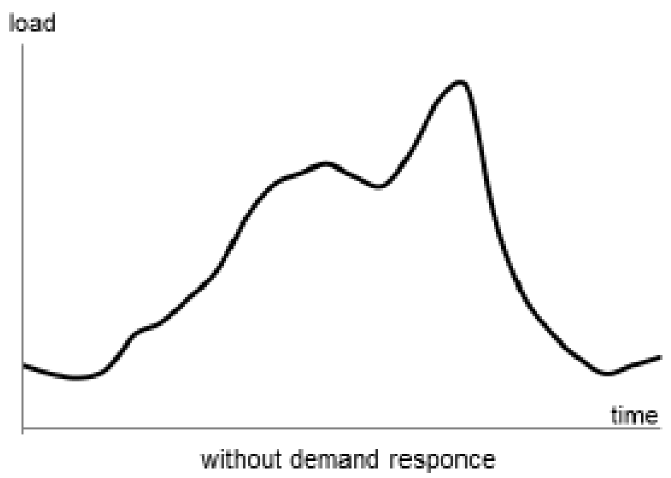
Source: Henrik Madsen

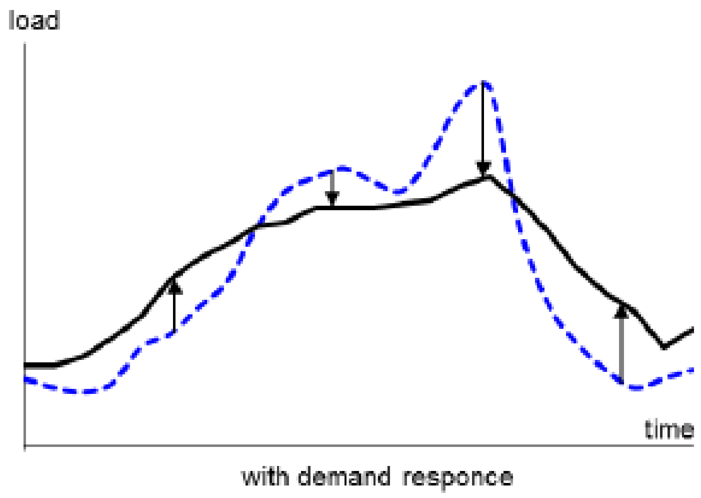
For District Heating

- District heating companies also need flexibility
- They can avoid ”turning on” a power plant in situations with peak heating demand – possibly saving on the need for fossil energy!



Most Buildings Have the Ability to Become Energy Flexible





Building thermal mass

Building energy systems

Gathered by: Rongling Li

Why Flexible Buildings?

The building sector is dominating in terms of energy demand:
In most European countries 32% of the total final energy use or 40% of the primary energy use are related to buildings.

→ Ideal platform to integrate **smart energy solutions** for the future.

Hypothesis:

Buildings could provide energy flexibility to the system, thus facilitating the integration of a larger share of renewable energy.

Interconnection of buildings with the energy network is crucial to form **energy hubs.**

Energy Flexibility in Buildings

Techniques:

- Demand-Side Management (DSM) → any activity adopted on the demand side that ultimately changes the utility's system load profile

- Demand Response (DR) → a set of techniques to induce the customer to change their energy demand

- Electric Load Management (ELM) → any policy devised to manage a set of electric loads to obtain the desired goal, such as peak load reduction or energy usage optimization

[Benetti et al., 2015]

Demand-Side Management includes:

- Reduce peak loads
- Shift load from on-peak to off-peak
- Increase the flexibility of the load
- Reduce energy consumption in general

[Müller et al., 2015]

Energy Flexibility in Buildings

Aspects:

- Technical parameters of buildings:
  - Thermal mass: Building thermal properties
  - HVAC: System characteristics
- Occupants
- Micro-climate and other external influences

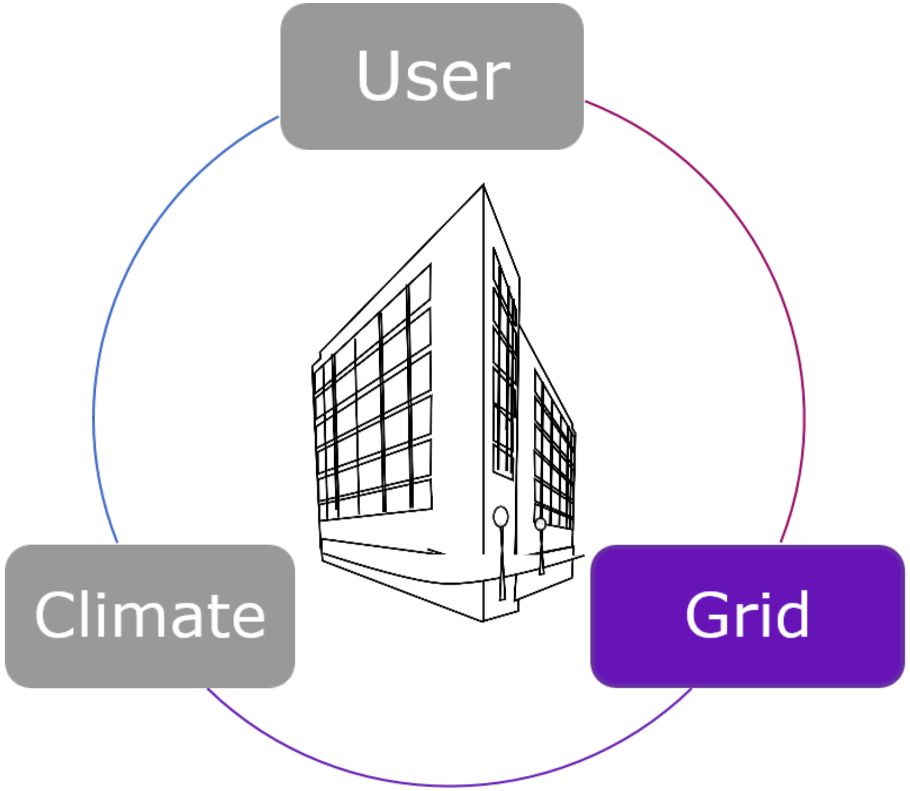
Storage in the thermal mass of the buildings:

- Store energy during periods with high availability of RE
  → No additional CO_2
- No investments required for this method, apart from controllers

Flexible users:

- Informed and motivated users
- A building management system (BMS) will be extended with smart energy management.

Grid need and flexibility potential in buildings



District heating grid

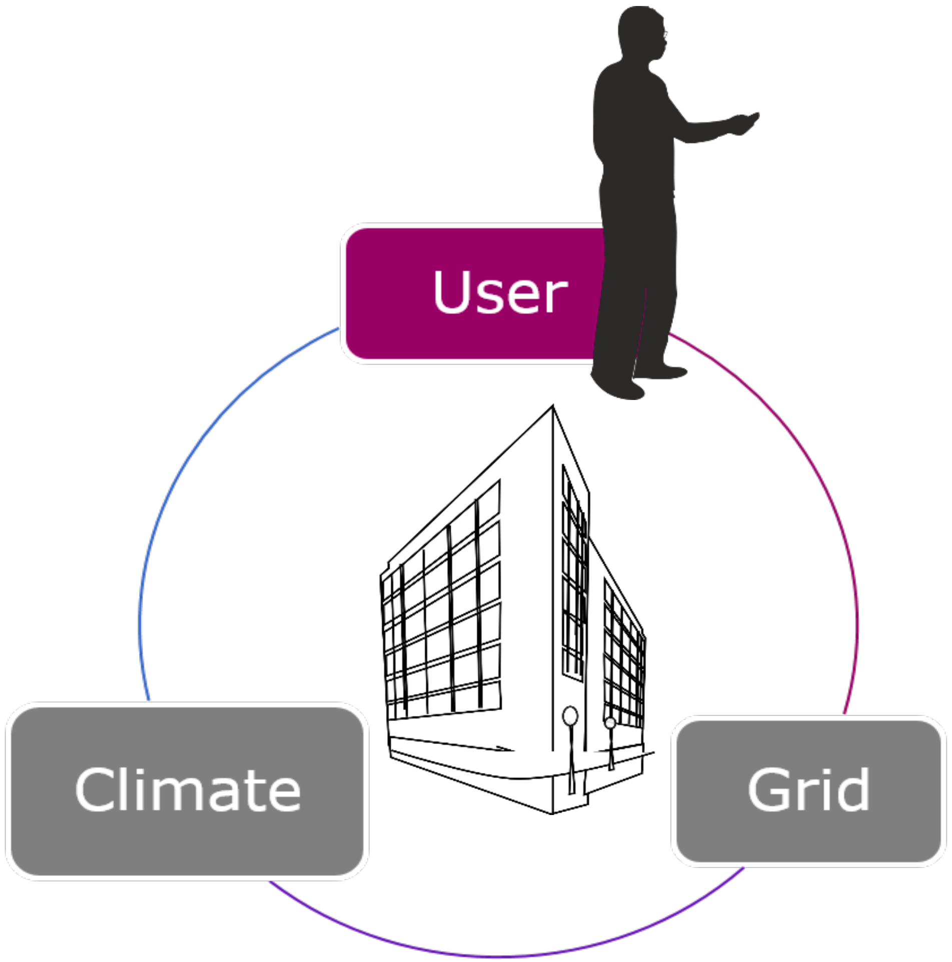
- Reduction of peak load
- Reduction of heat generation costs
- Reduction of GHG emissions

Heat demand flexibility in buildings

- Building thermal mass
- Hot water storage tank
- Heat pump

Source:
Rongling Li

User behaviour



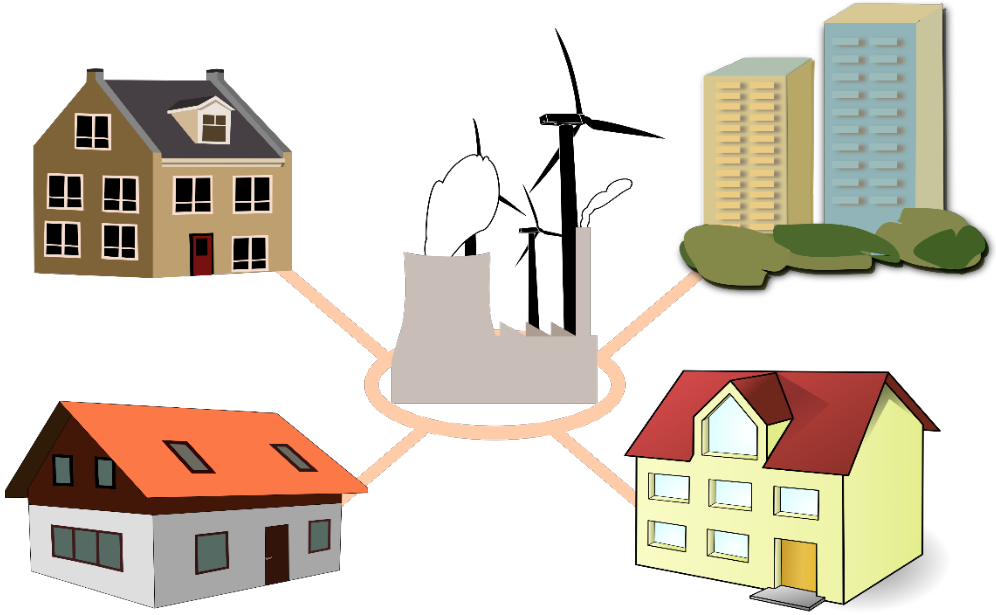
Stochastic daily activities

- Occupancy
- Lighting
- Thermostat adjustment
- Use of white goods
  - o Window opening
  - o Blinds adjustment
  - o etc.

Building performance simulation

- Occupancy
- Lighting
- Thermostat adjustment
- Use of white goods
  - o Window opening
  - o Blind adjustment

Categorization of heating energy flexibility for thermal flexibility integration



- Heat flexibility quantification for different building types
- Applicable indicator development
- Flexibility integration to district level

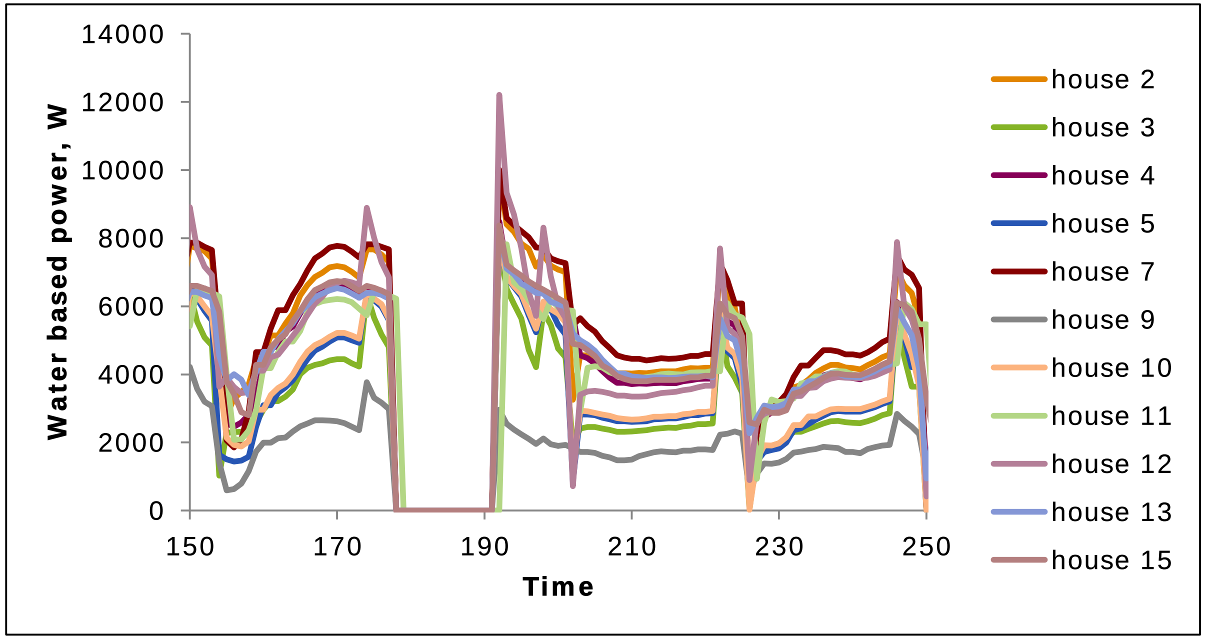
Example 1
Energy flexibility potential of building stock

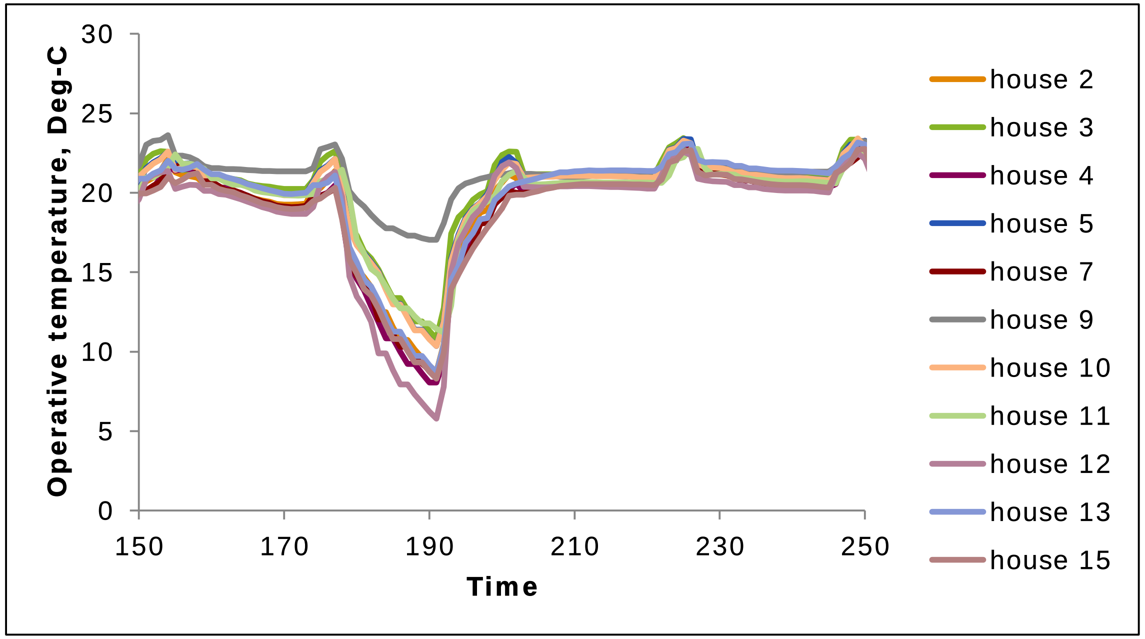
- 11 archetypes of buildings
- Mainly built in 1950-1970s
- Heating cut-off experiment applied on a winter day with reduced solar radiation
- Pre-heating strategy up to 25^{o}C for 4h was applied followed by heating cut-off

Source:

Panagiota Gianniou

Energy flexibility potential of building stock





Findings

- Reduced energy flexibility potential: mean thermal autonomy duration after cut-off= 1 h
- Operative temperature falls below 10° C in some cases, which is indicative of poor building envelope and cold ambient temperatures

Building typologies
Types of Danish houses

Approx. 1900

1920s

1930s

1940s

1950s

1960s

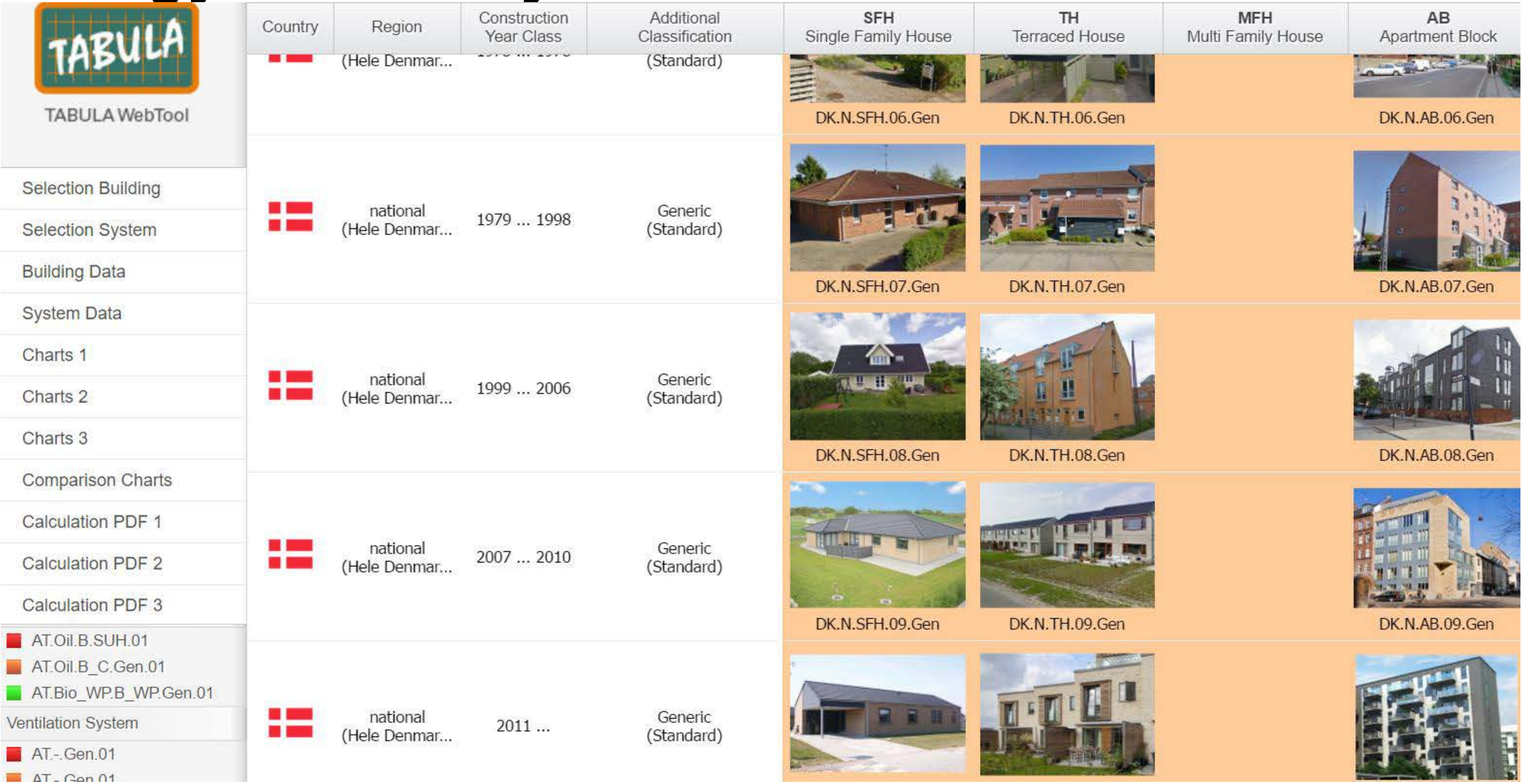
1970s

1980s

1990s

Source: SBi 2012:04

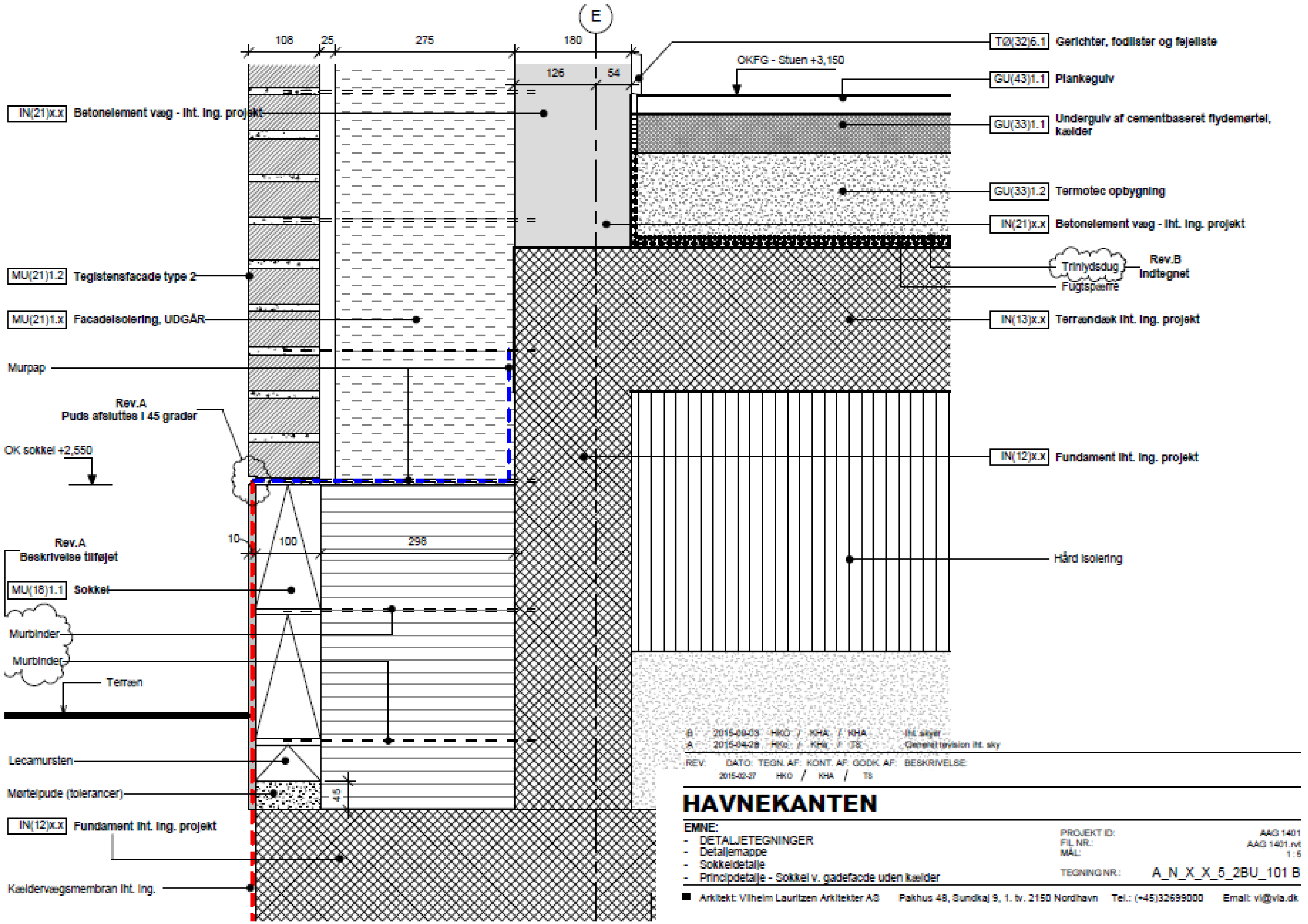
Categorization of Buildings for Heating Energy Flexibility



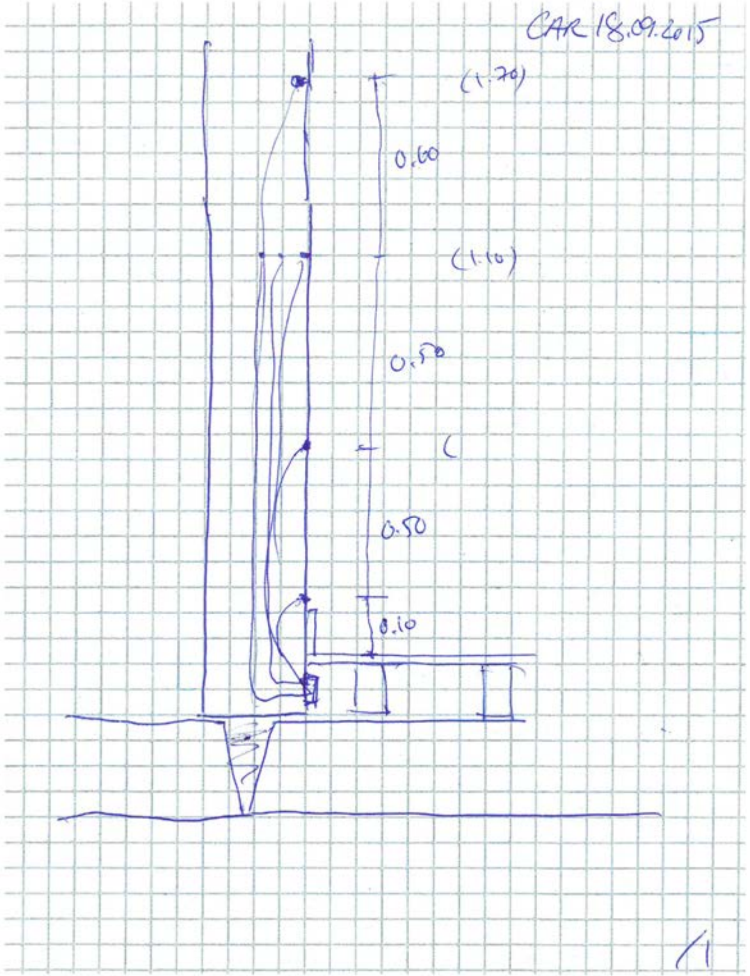
Example 2 – more modern buildings

From EnergyLab Nordhavn Project:

Case Terra Nova


E
108
25
275
180
126
54
OKFG - Stuen +3,150
TØ(32)6.1 Gerichter, fodlister og fejeliste
GU(43)1.1 Plankegulv
GU(33)1.1 Undergulv af cementbaseret flydemørtel, kælder
GU(33)1.2 Termotec opbygning
IN(21)x.x Betonelement væg - iht. ing. projekt
Trinlydsdug
Fugtspærre
Rev.B
Indtegnet
IN(13)x.x Terrændæk iht. ing. projekt
IN(12)x.x Fundament iht. ing. projekt
Hård isolering
IN(21)x.x Betonelement væg - iht. ing. projekt
MU(21)1.2 Teglstensfacade type 2
MU(21)1.x Facadeisolering, UDGÅR
Murpap
Rev.A
Puds afsluttes i 45 grader
OK sokkel +2,550
10
100
298
Rev.A
Beskrivelse tilføjet
MU(18)1.1 Sokkel
Murbinder
Murbinder
Terræn
Lecamursten
Mørtelpude (tolerancer)
45
IN(12)x.x Fundament iht. ing. projekt
Kældervægsmembran iht. ing.
B 2015-09-03 HKO / KHA / KHA Iht. skyer
A 2015-04-28 HKo / KHa / TS Generel revision iht. sky
REV: DATO: TEGN. AF: KONT. AF: GODK. AF: BESKRIVELSE:
2015-02-27 HKO / KHA / TS
HAVNEKANTEN
EMNE:
- DETALJETEGNINGER
- Detaljemappe
- Sokkeldetalje
- Principdetalje - Sokkel v. gadefacde uden kælder
PROJEKT ID: AAG 1401
FIL NR.: AAG 1401.rvt
MÅL: 1 : 5
TEGNING NR.: A_N_X_X_5_2BU_101 B
Arkitekt: Vilhelm Lauritzen Arkitekter AS Pakhus 48, Sundkaj 9, 1. tv. 2150 Nordhavn Tel.: (+45)32699000 Email: vl@vla.dk

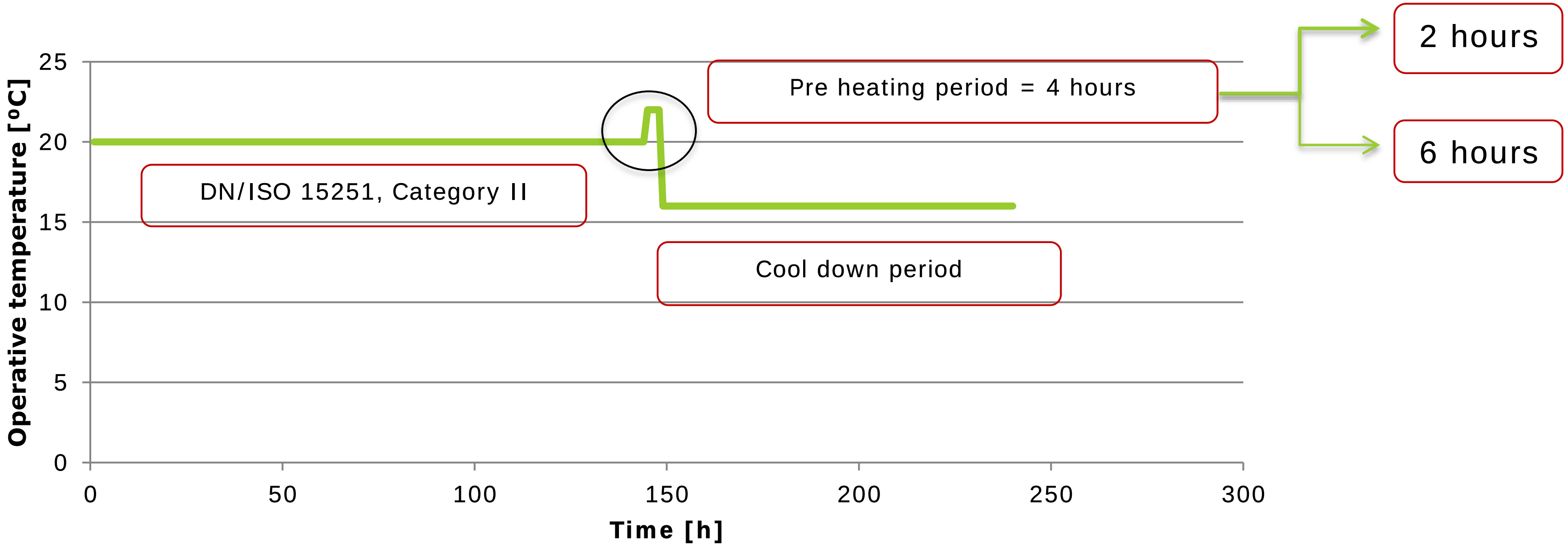
Sensors in Structures to Study Flexibility with Thermal Mass



Scenario

- For the Danish District Heating system, the main goal to be achieved is to avoid the utilization of peak load boilers.

  → Scenario examined: When there is limited/no availability of RES, heat supply needs to stop at specific city districts for certain time intervals.



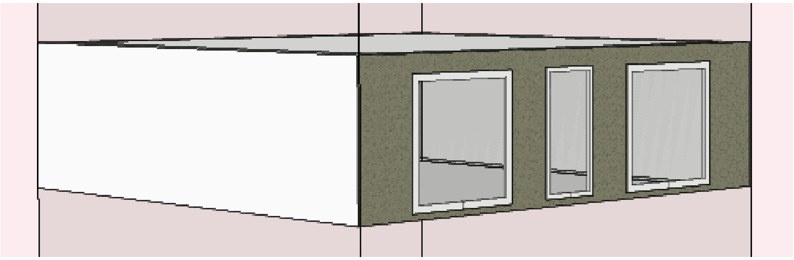
Source:

Kyriaki Foteinaki

Methodology

Building simulation tool IDA ICE

- An apartment belongs to a multi-family house low-energy building
  - 81 m^2 area; 2.6 m height; North and South walls exposed to the ambient; East and West walls, floor and ceiling attached to similarly heated spaces.

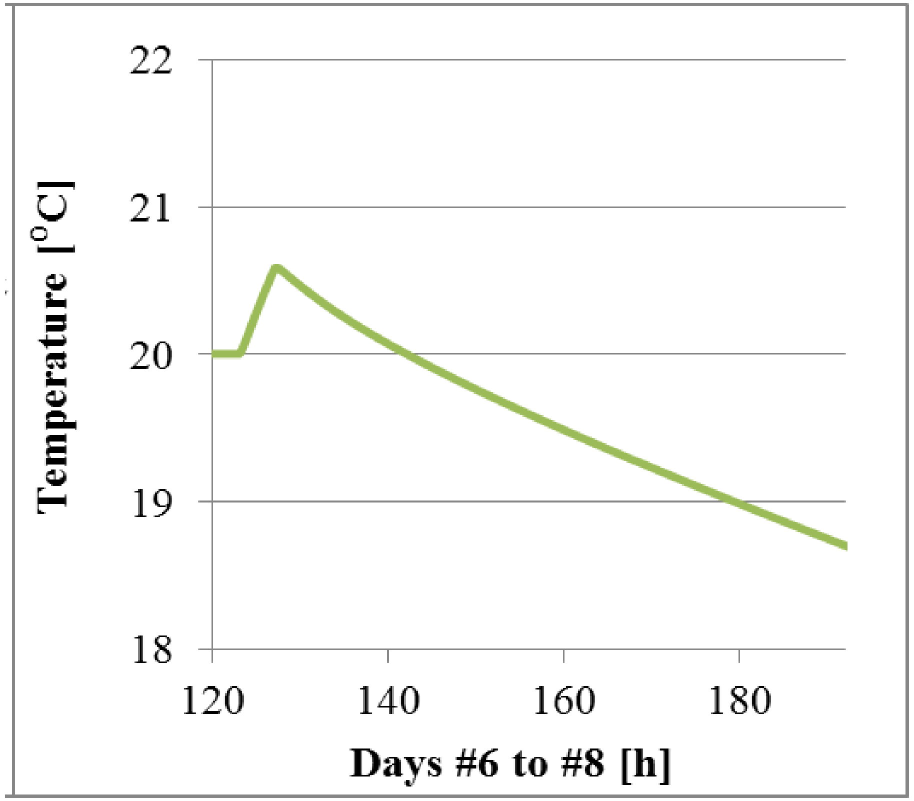


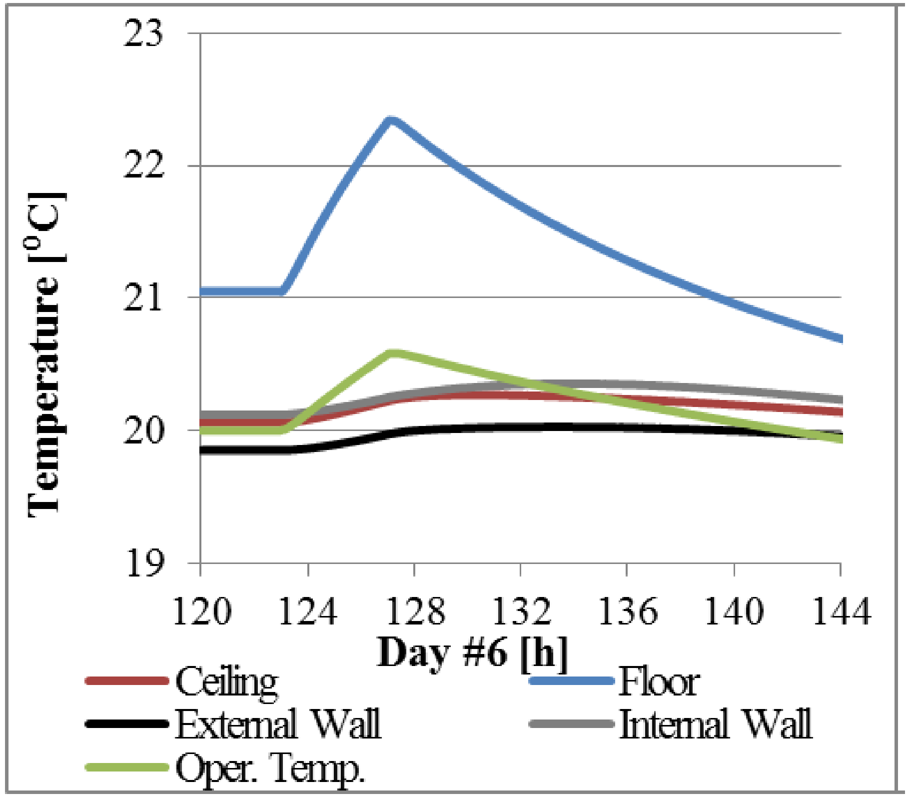
- Connected to the DH system; Floor heating system
- Mechanical ventilation with heat recovery
- Low Infiltration

Objective

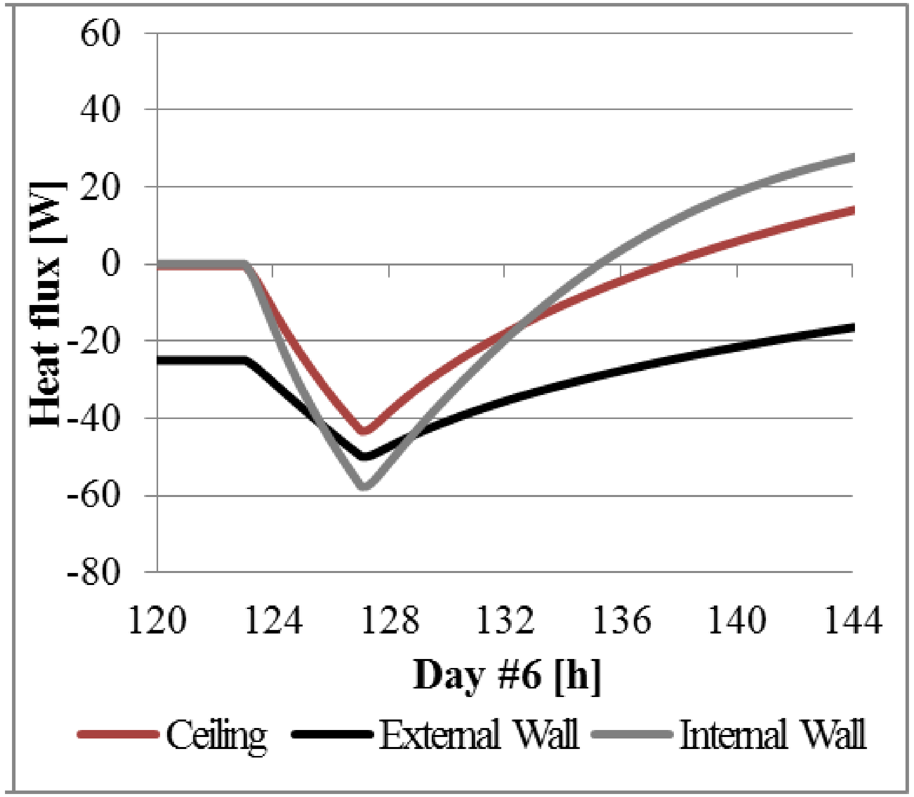
- The purpose of the study is to identify the effect of such a stop on an apartment.
  - Focus on impact of thermal mass on the apartment's thermal behaviour.
  - Key parameter is the duration of preheating period before the stop, in order to maintain thermal comfort.

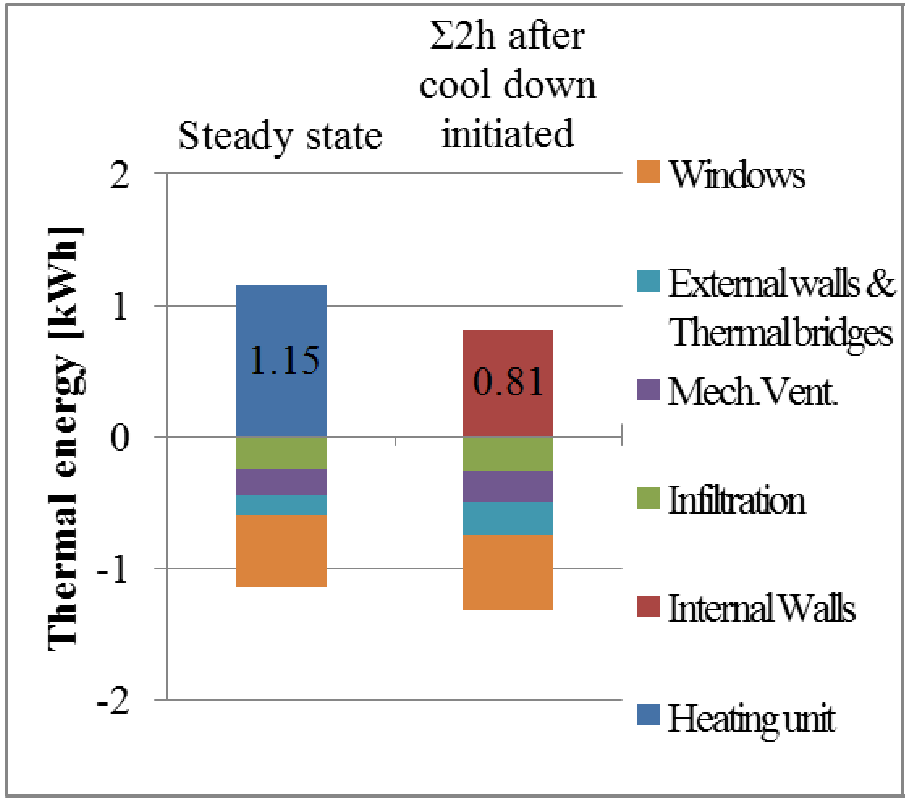
Results


Temperature [°C]
22
21
20
19
18
120
140
160
180
Days #6 to #8 [h]


Temperature [°C]
23
22
21
20
19
120
124
128
132
136
140
144
Day #6 [h]
Ceiling
Floor
External Wall
Internal Wall
Oper. Temp.

Results


60
40
20
0
-20
-40
-60
-80
Heat flux [W]
120
124
128
132
136
140
144
Day #6 [h]
Ceiling
External Wall
Internal Wall


Steady state
Σ2h after cool down initiated
2
1
0
-1
-2
Thermal energy [kWh]
1.15
0.81
Windows
External walls & Thermal bridges
Mech. Vent.
Infiltration
Internal Walls
Heating unit

Results

Basic case apartment	Preheating duration		
	2 h	4 h	6 h
Max operative temperature difference during preheating [^oC]	0.3	0.6	0.8
No. of hours operative temperature above 20^oC [h]	8.3	15.1	21.2

Need for Flexibility indicator

- effect of thermal capacity of the internal walls on the load shifting potential
- effect of the heat losses of the building envelope on the load shifting potential

=> Time constant: > 800 hours

Building energy flexibility

Definition by **IEA EBC Annex 67 – *Energy Flexible Buildings***

> The Energy Flexibility of a building is the ability to manage its energy demand and generation according to <u>local climate conditions</u>, <u>user needs</u> and <u>grid requirements</u>.

IEA EBC: International Energy Agency, Energy in Buildings and Communities Programme

Consequences of Use of Flexible Heating Paradigms

Flexibility causes:

- Peak shaving
- Higher energy use
- Less use of fossil fuel in energy system
- May influence occupant comfort – is it acceptable?

- More research needed (Occupant <-> City Scale)

Thank you for your attention !