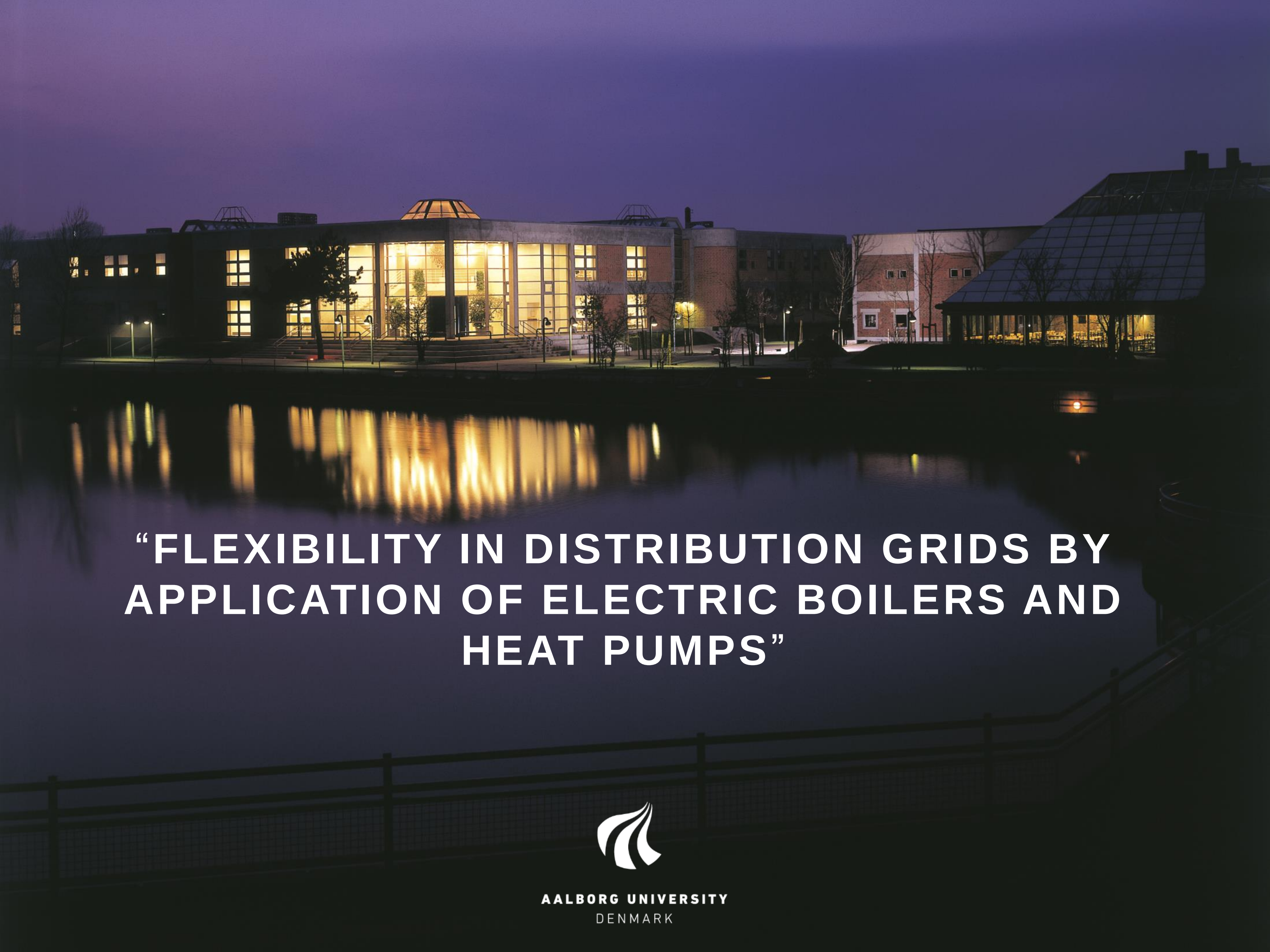

"FLEXIBILITY IN DISTRIBUTION GRIDS BY APPLICATION OF ELECTRIC BOILERS AND HEAT PUMPS"

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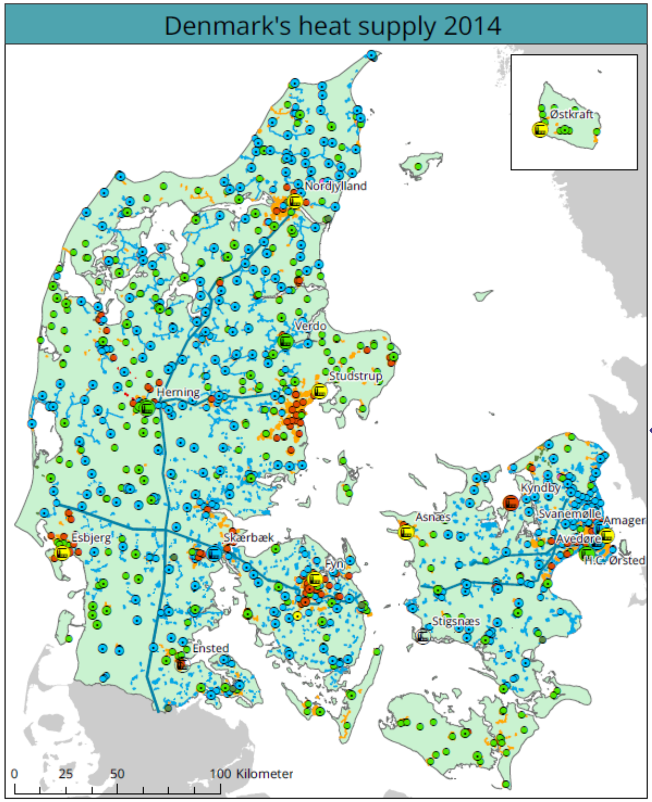
DENMARK

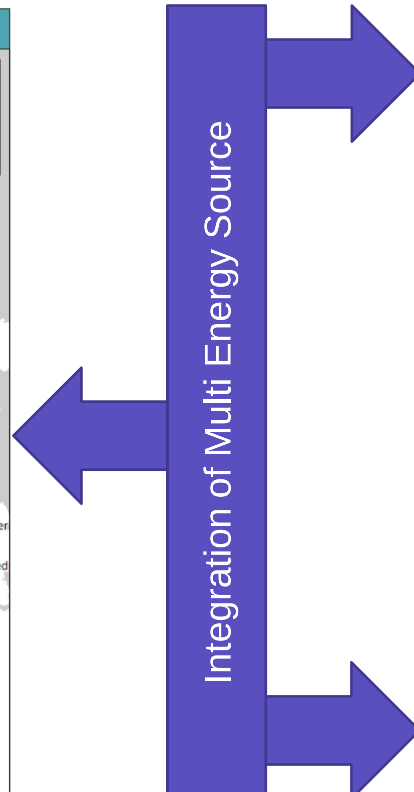
Content

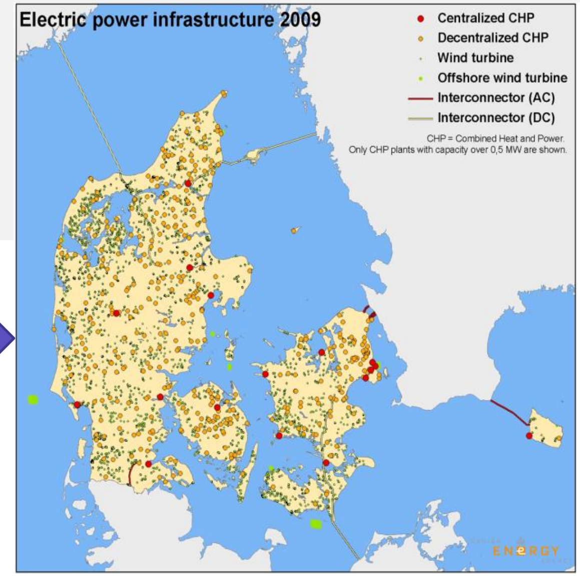
- Introduction and background
- Significant Outcome of Project
    - Analysis of Thermal Heat Demand
    - Modelling of Hot Water Storage Tank for Electric Grid Integration and Demand Response Control
    - Modelling of integrated energy systems

Abstract

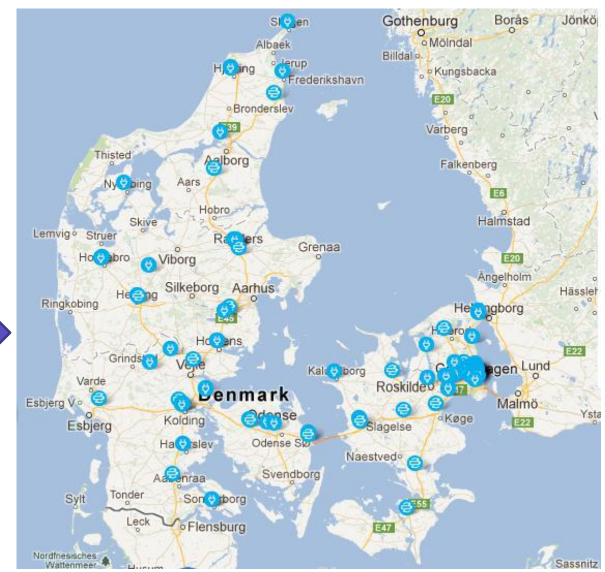


Source: [Denmark's Heat Supply 2014]





Source: [Danish Energy Agency]



Source: Danish Experiences in Setting up Charging Infrastructure for Electric Vehicles with a Special Focus on Battery Swap Stations

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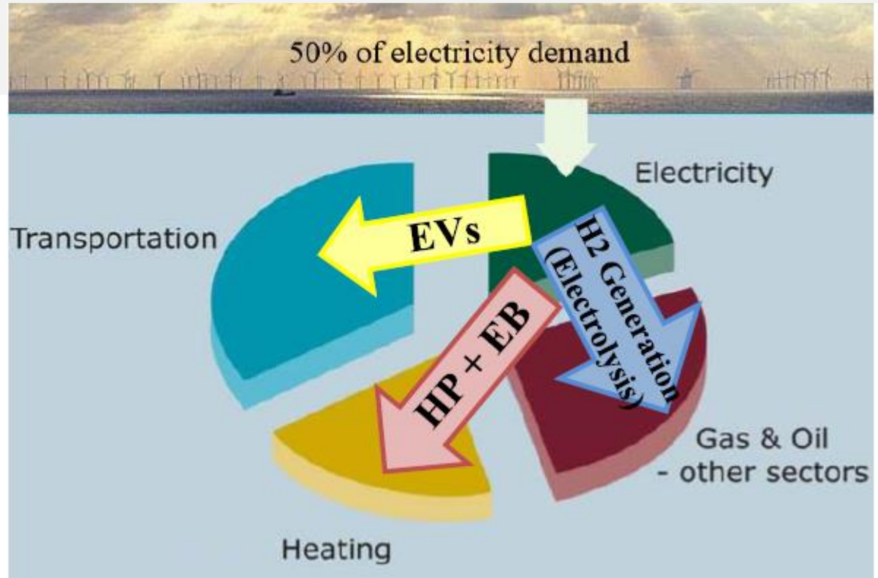
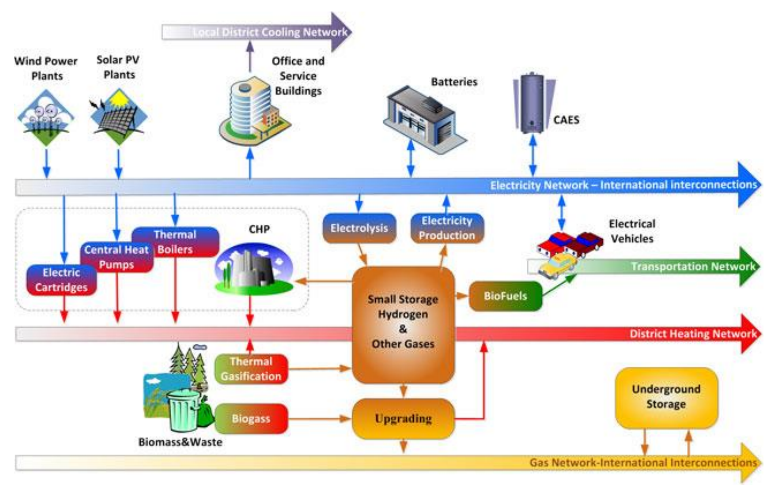
Demand response – Danish solution for smart energy system

- To counteract that 50% the electricity demand in Denmark are to be produced by wind power by 2020 the Danish solution is to integrate and make interaction between the different energy systems through the DR.
- Heating, Gas & transportations Sectors will be the main players of this Smart System.
- For that large flexible demand needs to be mobilized: Continuous development of the electric vehicle (EV) infrastructure and stimulation plans for replacing old fashion heating systems.





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THERMOSTATIC LOADS (EB & HP) INTRODUCTION / PRESENT AND FUTURE STATUS IN DENMARK

- Present Penetration of EB and HP in the Danish Households is relatively low.
- According to the Danish Energy Agency 2.45-2.5 million Households in Denmark.
- Where:
  - 320.000 households have EWHs or EB
  - 112.338 households have heat pumps
- 500.000 HPs are expected to penetrate the LV systems by 2030.

Country	Total no. of households (thousands)	No. of households using DE(S)WHs [thousands (%)]
Luxemburg	100	45 (45.0)
Germany	34 600	15 200 (43.9)
Austria	2 960	1 290 (43.6)
France	21 000	8 800 (41.9)
Finland	1 700	650 (38.2)
Belgium	3 900	1 287 (33.0)
Italy	25 021	8 257 (33.0)
UK	22 600	4 755 (21.0)
Portugal	2 710	515 (19.0)
Sweden	2 800	530 (18.9)
Spain	11 300	1 900 (16.8)
Netherlands	6 000	1 000 (16.7)
Ireland	1 070	170 (15.9)
Denmark	2 420	320 (13.2)
Greece	3 100	160 (5.2)
EU total	**141 281**	**44 879 (31.8)**

Penetration of electric water heating in European households

And Marques,L; Tonico, N and Leite, N, "Electrodomesticos" University of Coimbra, Science and Technology Faculty, 2004.

Type	Flats	Single-family houses	Terrace or double houses	Farms/ Farm houses	Summer resi-dences	Total
Air-air	1.016	35.411	6.293	1.652	33.006	77.378
Air-water	635	8.684	828	1.906	2.762	14.815
Ground-water	3.614	11.179	0	5.352	0	20.145

Estimated number of heat pumps in Danish households estimated by "Elmodelbolig"

Ref: "Stock of heat pumps for heating all-year residences in Denmark" Technical Report. Danish Energy Agency. November 2011

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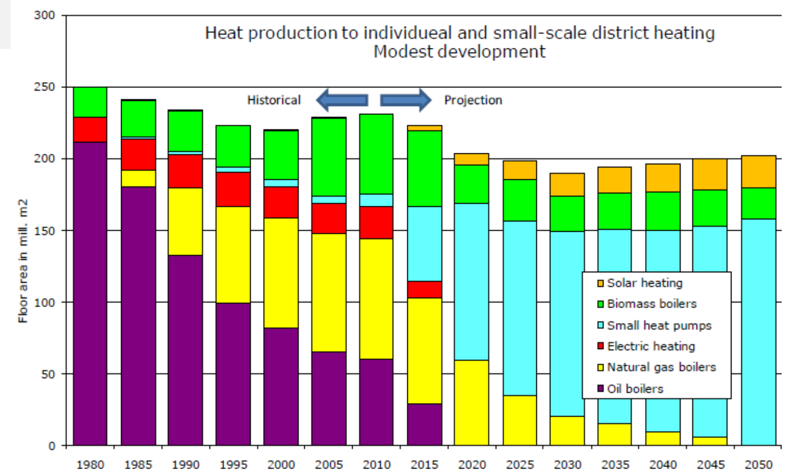
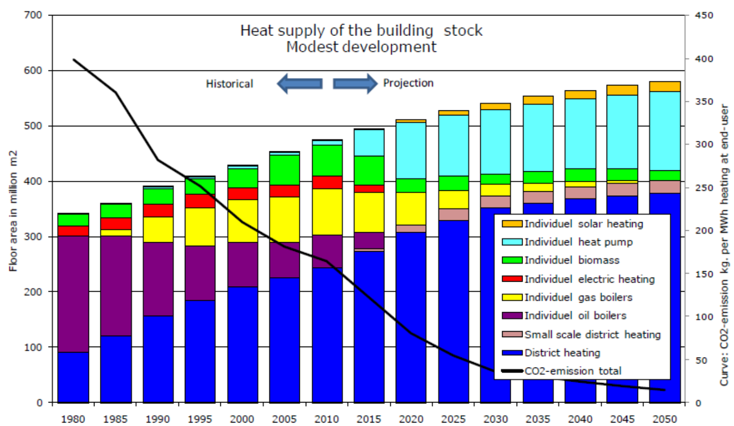
Domestic energy consumption

- Forecasted scenario of EWH and HP penetration by Rambøll
- EB, SH and HP seems to be the future solution at individual household level
- HP are expected to cope most of the heating service in a short term and mid term
- The electrical power demand for the residential heating purpose will be most covered by HP

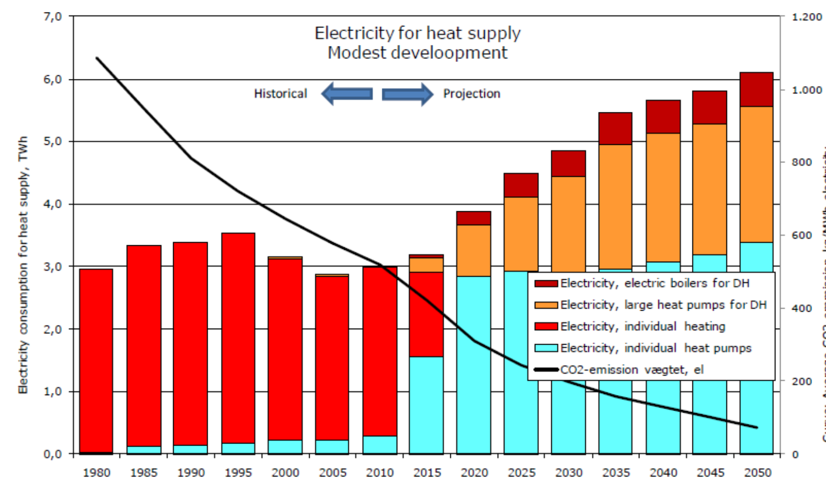
Individual heat sources



Heat demand devided on heat sources



Consumption of electricity



Ref: Dyrelund, A "Heat Plan Denmark 2010 – Low Carbon Urban Heating"
Presentation. Ramboll. 2010

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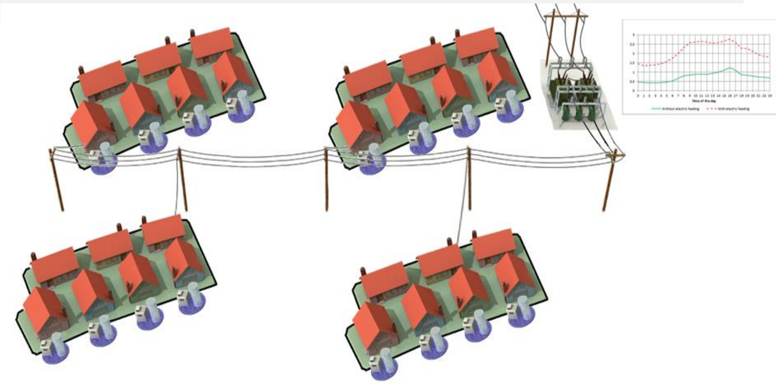
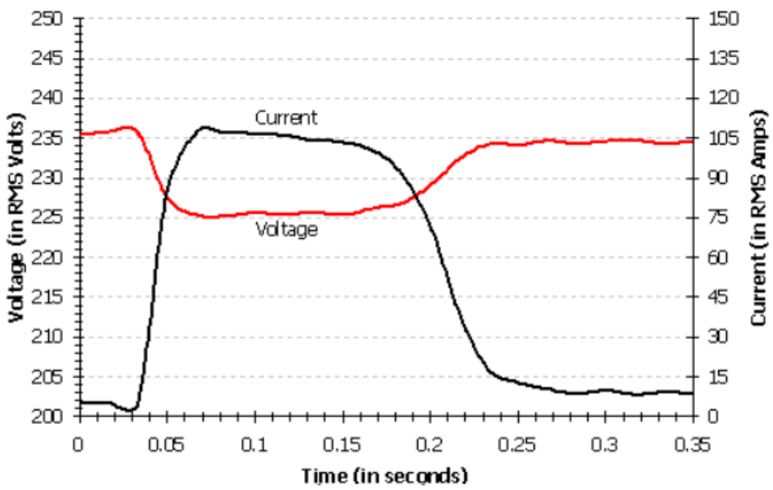
Impact of thermostatic loads integration in LV grids

- Energinet.dk expects 500.000 HPs to penetrate in low voltage distribution networks by 2030.
- Considering that the rated power:
  - From a Domestic EB: 1-15 kW
  - From a Domestic HP+EB: 0.7-8kW
- Some distribution grids may not be designed to host such a high power rating loads.
- The main issues related with their impact are:
  - Large and continuous voltage drops.
  - Overloading of the power infrastructure (transformers, cables…).
  - Power congestions with long durations.
  - Power unbalances in single phase connections.
  - Flicker issues due to the voltage variations when heat pumps start-up.



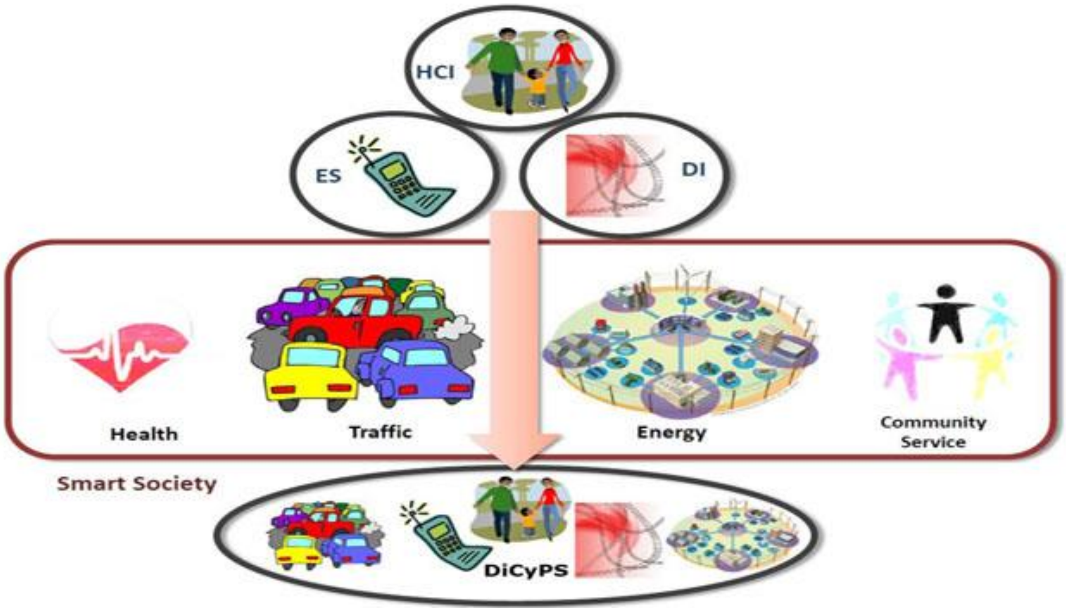


RMS voltage and current waveforms of a typical residential compressor starting event on a nominal 240V, 60 Hz system.

Ref: Fox, J.C.; Collins, E.R., "A Voltage Flicker Suppression device for residential air conditioners and heat pumps," Harmonics and Quality of Power (ICHQP), 2010 14th International Conference on , vol., no., pp.1,8, 26-29 Sept. 2010

DiCyPS

DiCyPS
CENTER FOR DATA-INTENSIVE CYBER-PHYSICAL SYSTEMS



- Linking Heating, Transportation and Electricity System
- Electricity, transportation and thermal energy systems are complex and offer numerous opportunities for deep integration

Reference: https://www.iea.org/publications/freepublications/publication/LinkingHeatandElectricitySystems.pdf

Partners: 20+ Partners across Denmark and Europe

Link to project website: DiCyPS

Funding

Innovationsfonden

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Significant Outcome of Project

ANALYSIS OF THERMAL HEAT DEMAND

Analysis of Thermal Heat Demand

The consumption of heat energy circulated through hot water by district heating (Q_{DHW}) has been analysed to know the pattern of usage

SPACE HEATING

DOMESTIC HOT WATER

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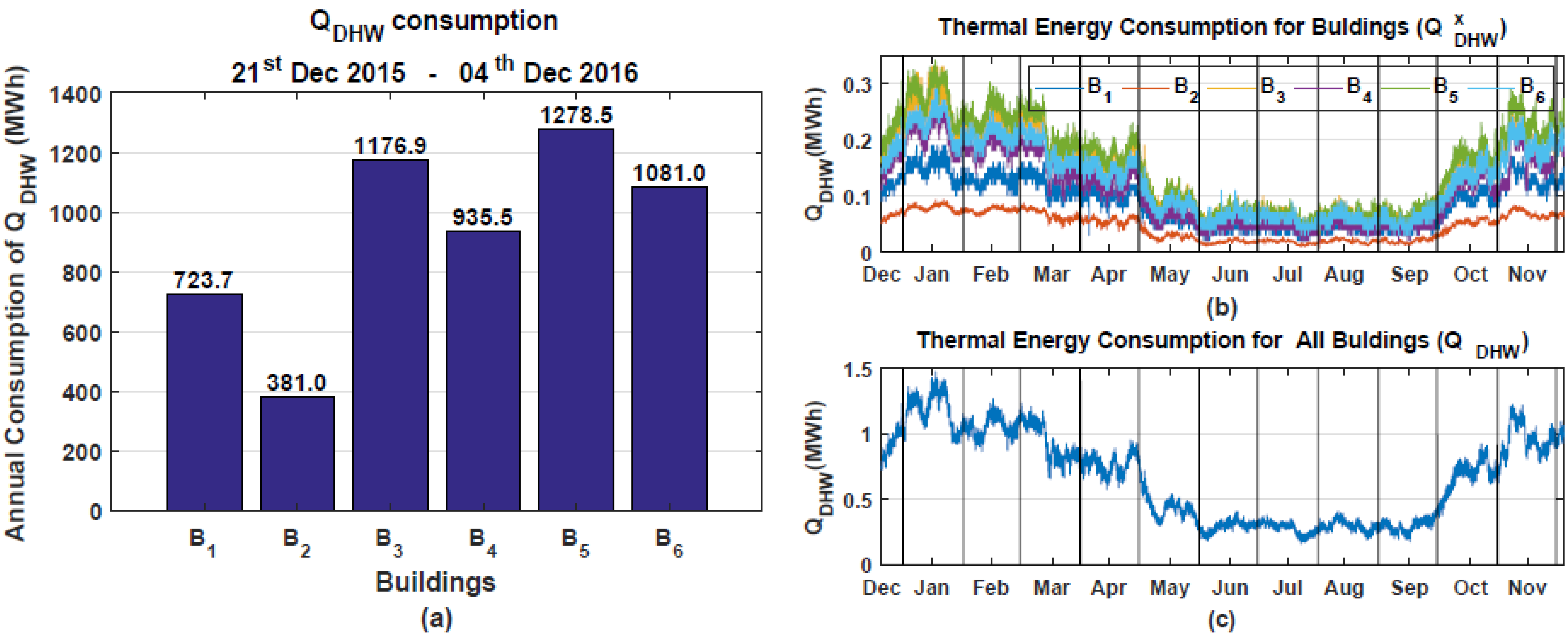
Thermal Heat Demand (Q_{DHW}) Data for Analysis



(a) Yearly consumption of Q_{DHW} in different buildings. (b) Yearly Q_{DHW} consumption pattern of all buildings (c) Total yearly Q_{DHW} consumption pattern of all six buildings

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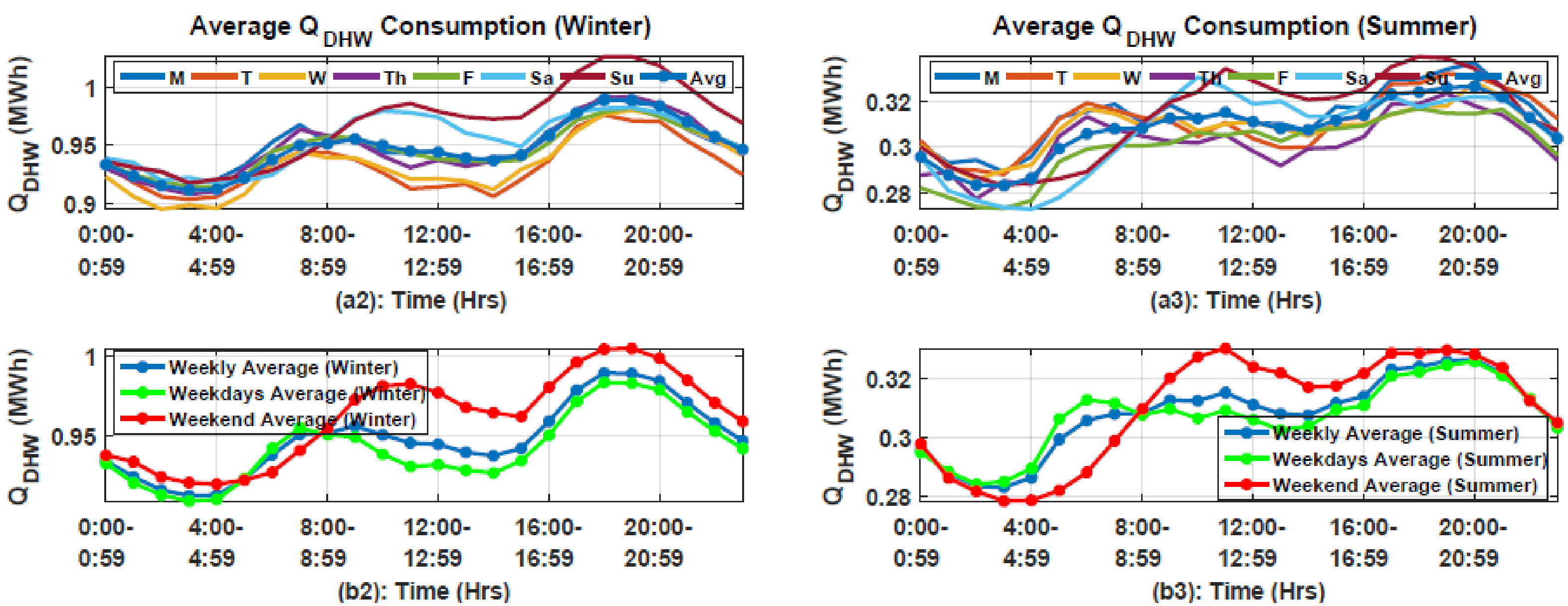
Analysis and Result

Winter consumption is 208% more than Summer consumption



(a2), (a3): Analysis of average Q_{DHW} consumption in hourly basis for different days of week during winter and summer respectively
(b2), (b3): Analysis of average Q_{DHW} consumption in hourly basis for a week, weekdays and weekends winter and summer respectively

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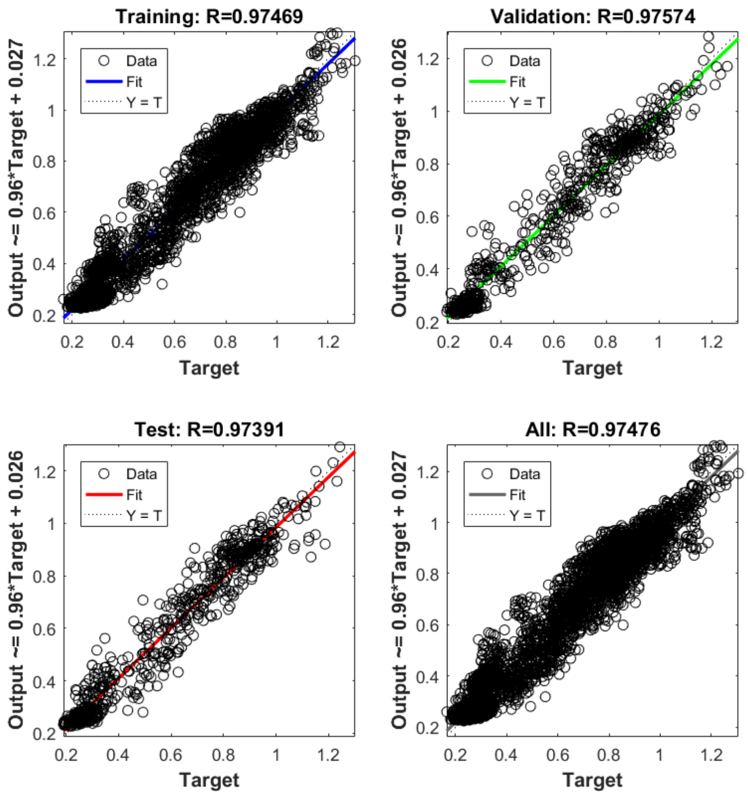
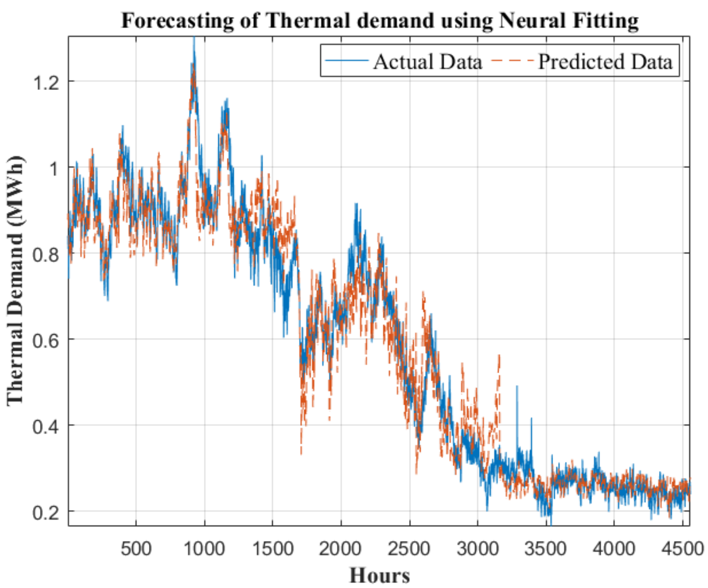
Neural Network-Levenberg Marquardt training



- Input = Hour, AT, Day, season
- Output = Thermal demand
- MAPE = 9.2634



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Significant Outcome of Project

MODELLING OF INTEGRATED ENERGY SYSTEMS

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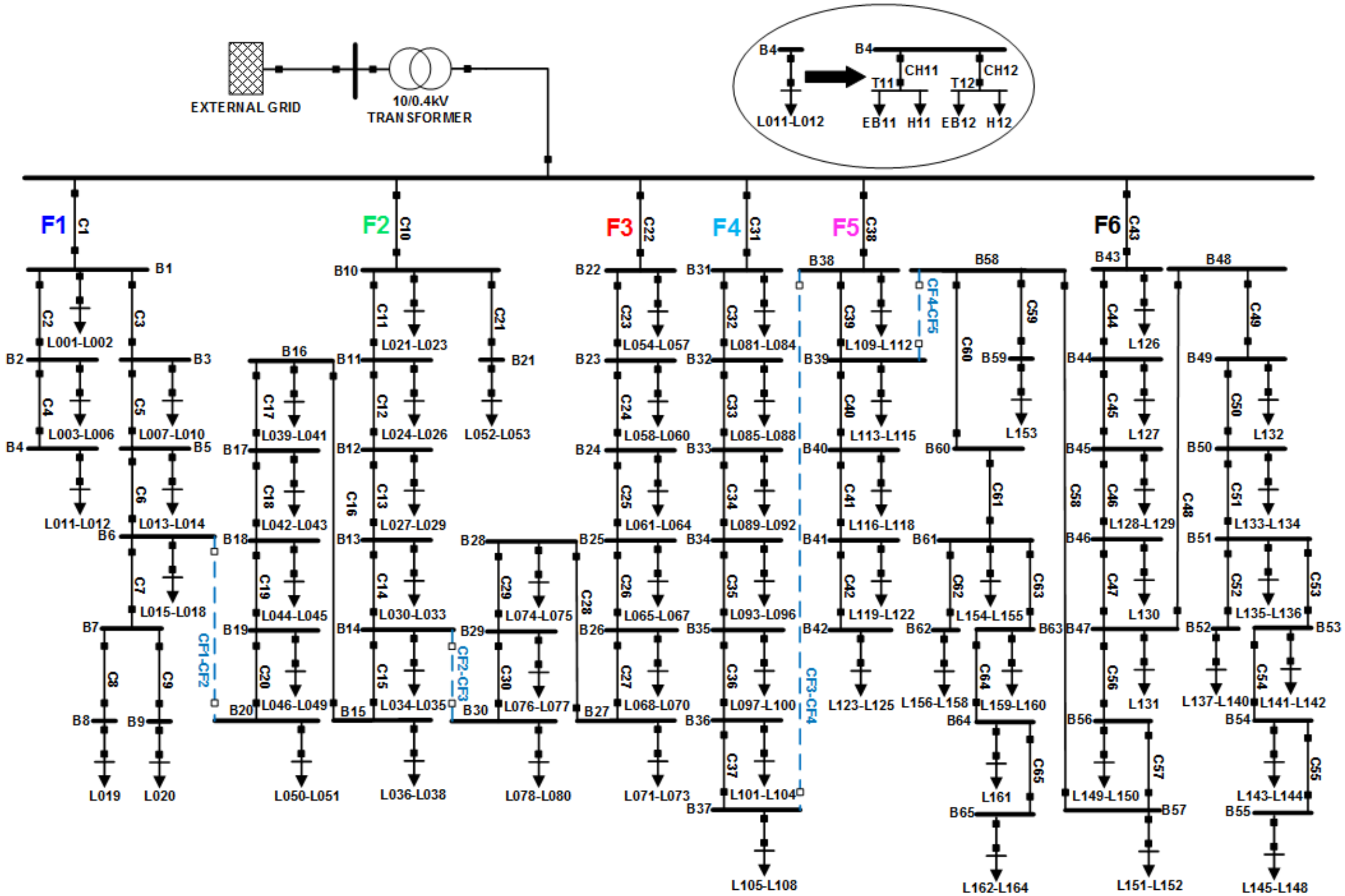
LV Distribution Network



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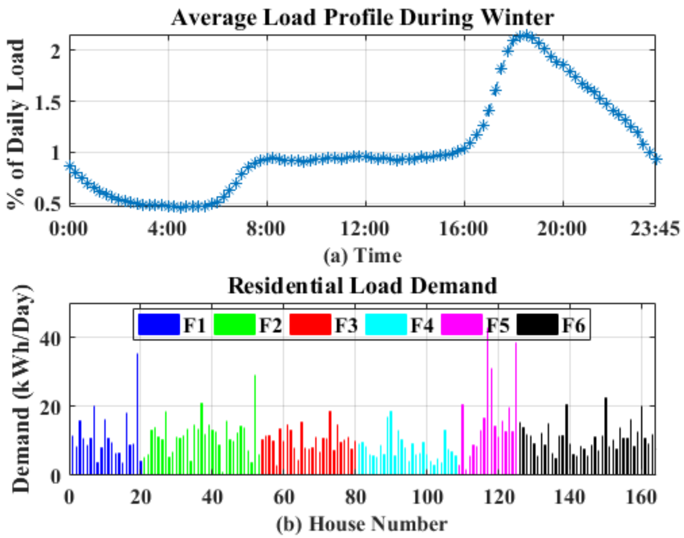
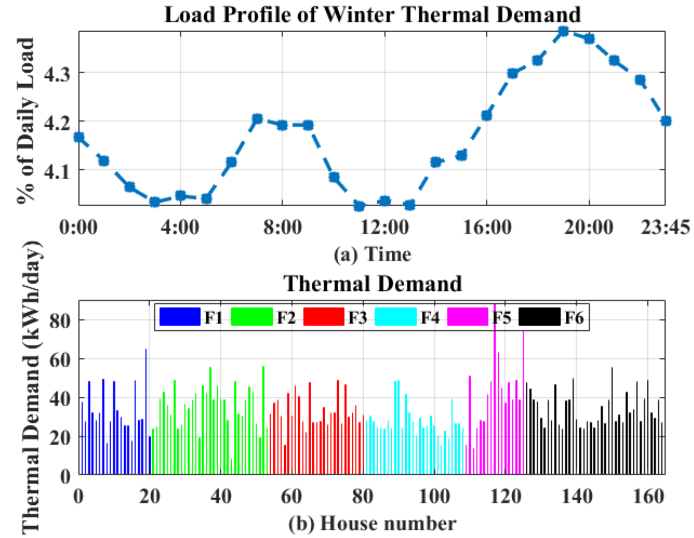
Demand Profile of Electrical and Thermal Load

Electricity Demand Profile



Thermal Demand Profile



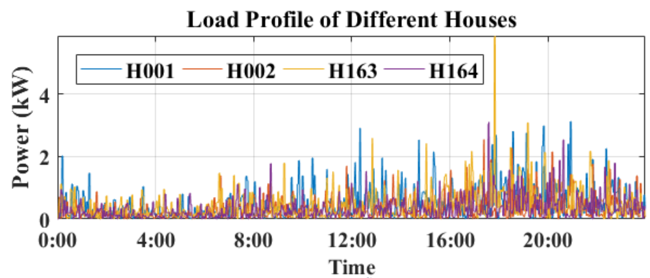


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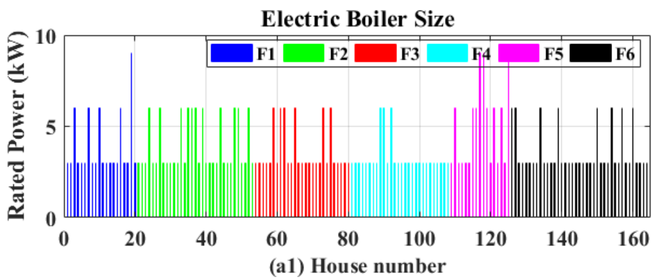
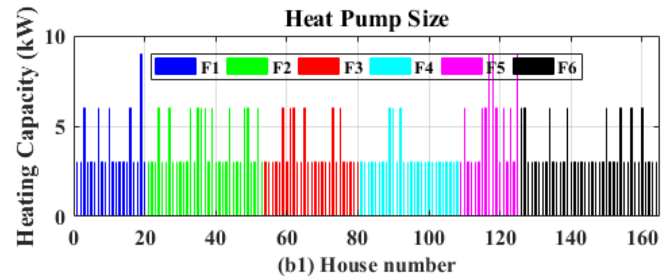
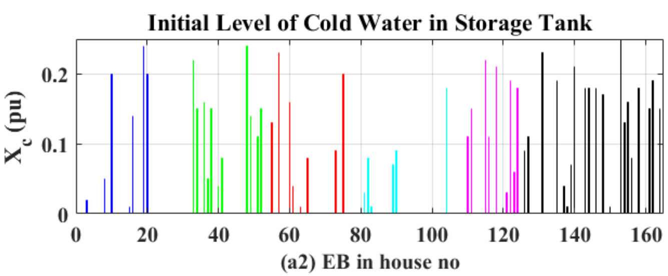
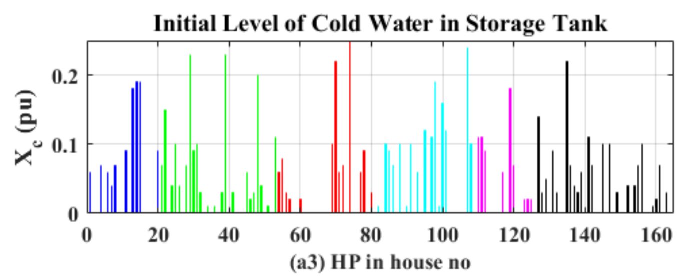
Table I: EB and HP Size allocation

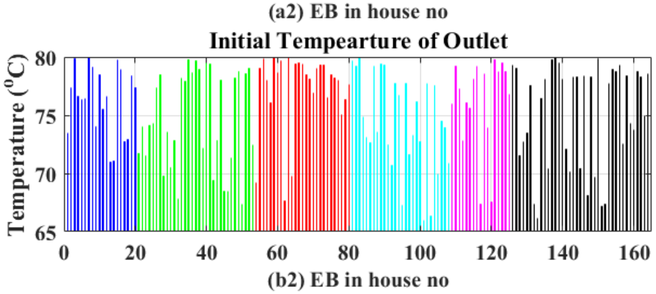
Thermal Demand (kWh)	Storage Size (m^3)	EB Rated Power (kW)	HP Heat Capacity (kW)	No of Units
<40	0.5	3	3	122
40-60	0.75	6	6	38
60-90	1	9	9	4

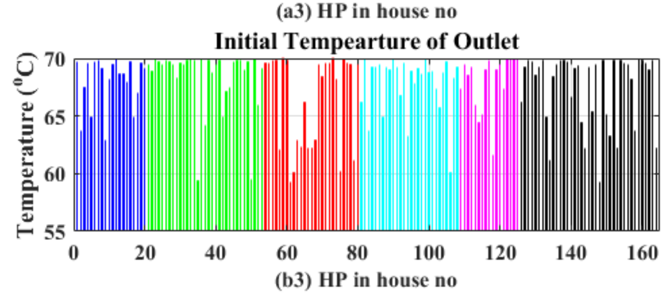












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Control of EB and HP

Two different approaches are taken into consideration to unleash the flexibility from the EB or HP to support grid voltage when integrated in the LV residential network.

- **Type I control:** Hysteresis control of the heating unit based on temperature of hot water or accumulation of cold water in the storage tank.

- **Type II control:** Hysteresis control of the heating unit primarily based on grid voltage and secondarily based on hysteresis control of temperature of hot water or accumulation of cold water in the storage

Table II: control variables of heating unit

	T_{max} (°C)	T_{min} (°C)	V_{min} (pu)	$V_{recovery}$ (pu)	X_{cold} (%)
EB	80	70	0.92	0.98	25%
HP	70	55	0.92	0.98	25%

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Case Studies

- Case I : With only residential load
- Case II: Residential load with only EBs or HPs in each individual houses respectively based on **Type I control:** temperature control.
- Case III: Residential load with only EBs or HPs in each individual houses respectively based on **Type II control:** voltage and temperature control
- Case IV: Case II with non-stratified storage tank in EB.

Results of Case I and Case II

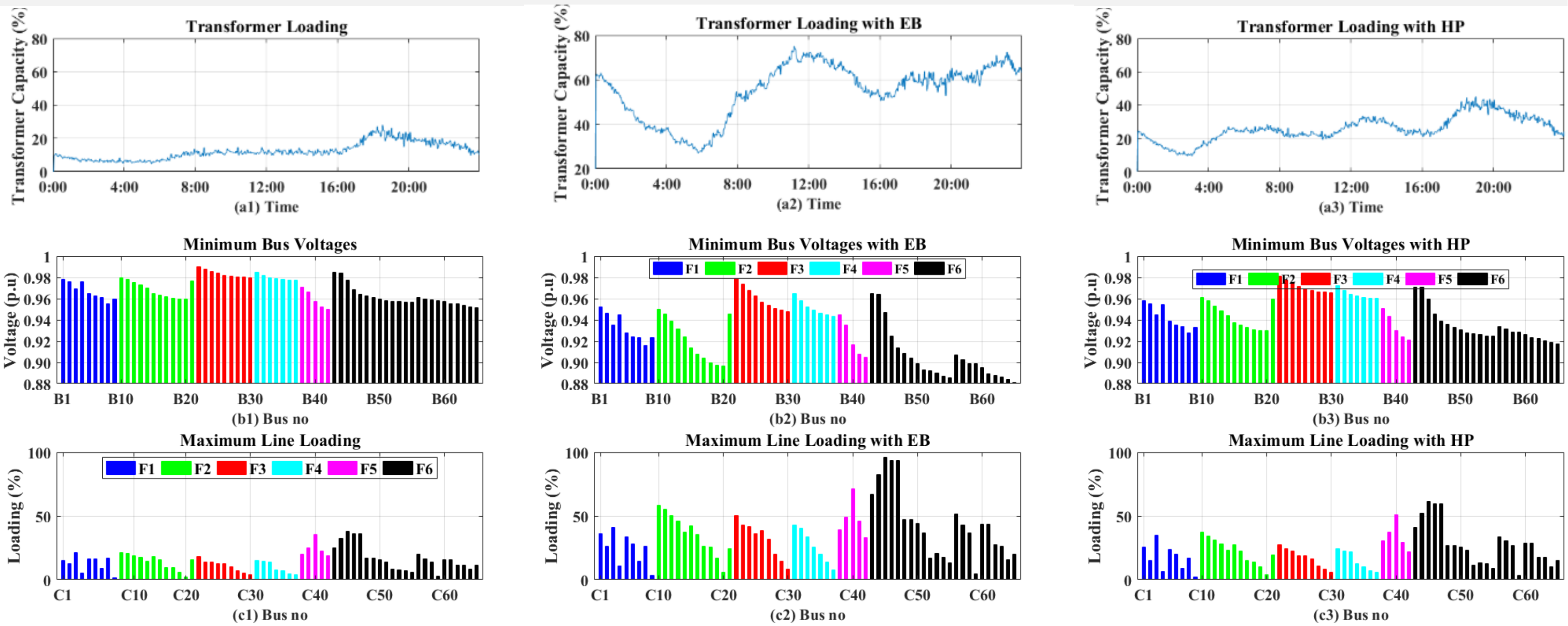

Figure: Results of case I and II; **(a1), (a2), (a3):** tranformer loading for residential load, with EBs connected and with HPs connected respectively; **(b1), (b2), (b3):** Minimum bus voltages at different busbars with residential load, with EBs connected and with HPs connected respectively; **(c1), (c2), (c3):** Maximum line loadings in cable with residential load, with EBs connected and with HPs connected respectively

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Results of Case III

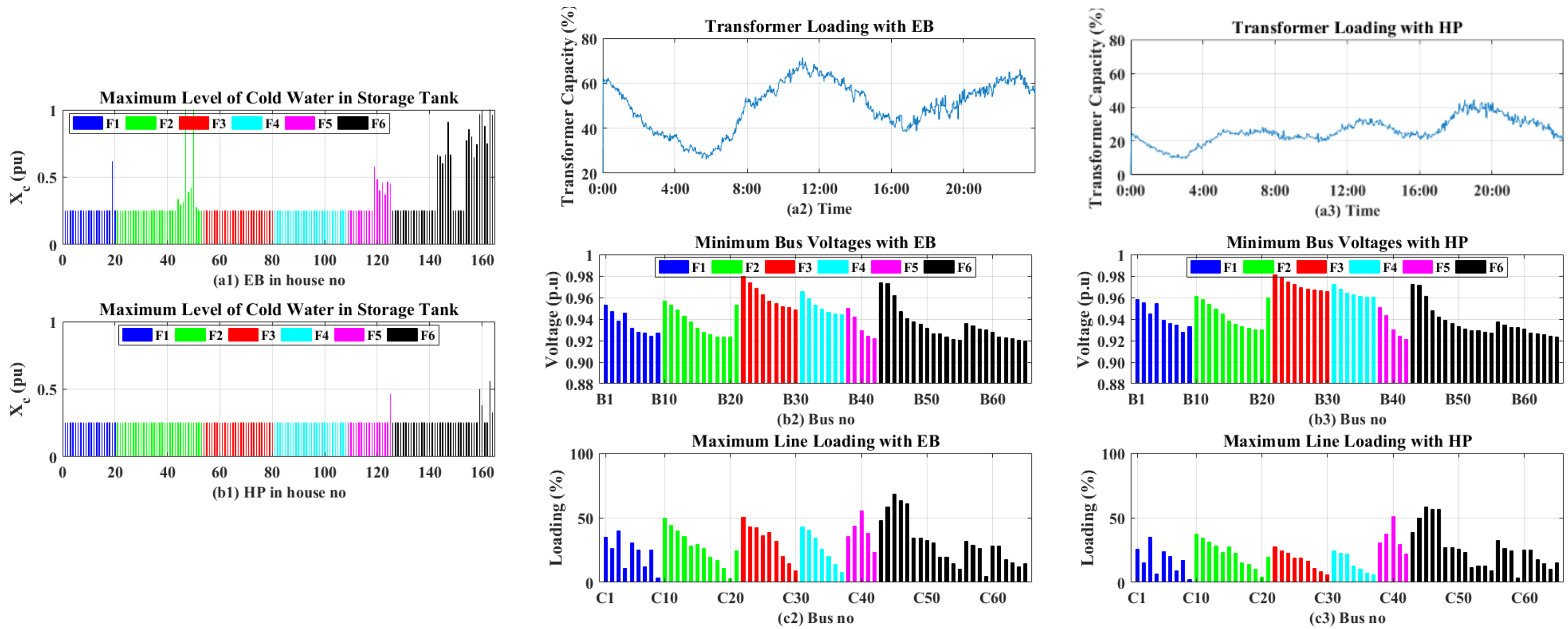

Figure : Results case III; **(a1),(b1)**: maximum level of cold water attained in storage tank associated with EBs and HPs respectively; **(a2), (a3): ,** tranformer loading, with EBs and with HPs respectively **(c2), (c3):** Minimum bus voltages at different busbars, with EBs and with HPs respectively; **(d2), (d3):** Maximum line loadings in cable, with EBs and with HPs respectively

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Conclusion: Modelling of integrated energy systems

- The concept of using EBs and HPs as flexible thermal loads in Denmark’s low voltage distribution network with its significance on storage of electrical energy is presented in brief.
- Study on the consumption pattern of electrical and thermal demand are used in a simulation model with different case studies for analysis on grid limitation (based on grid congestion and voltage drop).
- A strategy based on temperature and voltage control associated with flexible control of the thermal unit are discussed to mitigate the problems with low voltage in week feeders and satisfying the end user need simultaneously.