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#SESAAU2019

STORM
Testing and evaluation of the STORM controller in two demonstration sites

Ed Smulders, Tijs van Oevelen, Christian Johansson, Dirk Vanhoudt
SES conference, September 11th , Copenhagen

STORM
DISTRICT ENERGY CONTROLLER

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STORM project – general info

Self-organizing **T**hermal **O**perational **R**esource **M**anagement.

- **Aim:**
  Developing, **D**emonstrating and performance **A**ssessing of a generic intelligent self-learning DHC network controller
- **Research period:**
  March 2015 => March 2019

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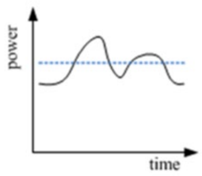
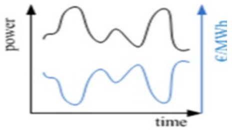
STORM control features

1. Peak Shaving (PS)



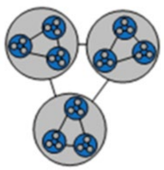
- Reduction of running hours of expensive and fossil fuel consuming peak boilers
- System capacity improvement

2. Market Interaction (MI)



- Optimizing operation of CHP-plants or heat pumps with respect to fluctuating electricity prices

3. Cell Balancing (CB)



- Aligning heat and cold demands and/or production, stimulating self-consumption, integrating excess energy).

Offset of outdoor temperature

Demo sites:

- **Rottne**-Sweden
- **Heerlen**-The Netherlands

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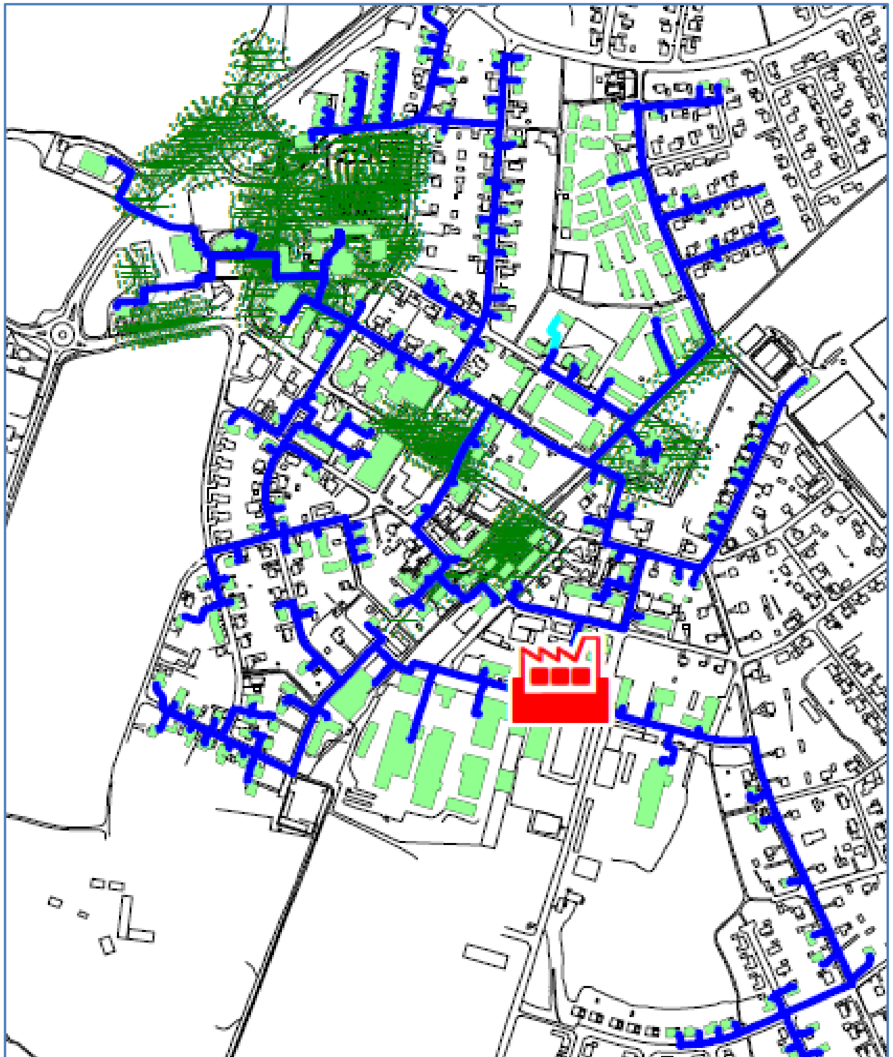
Demo site Rottne, Sweden



- 3rd generation DH
- 175 consumers
- 2 wood chips boilers (1.5 + 1.2 MW) + biofuel peak boiler (3 MW)
- Design temperature 90-60°C
- **Testing**:
  - Peak Shaving
    - eliminate the operation of the expensive peak boiler
  - Market Interaction
    - Focus on earnings:
      - Avoiding high costs
      - Premier low costs

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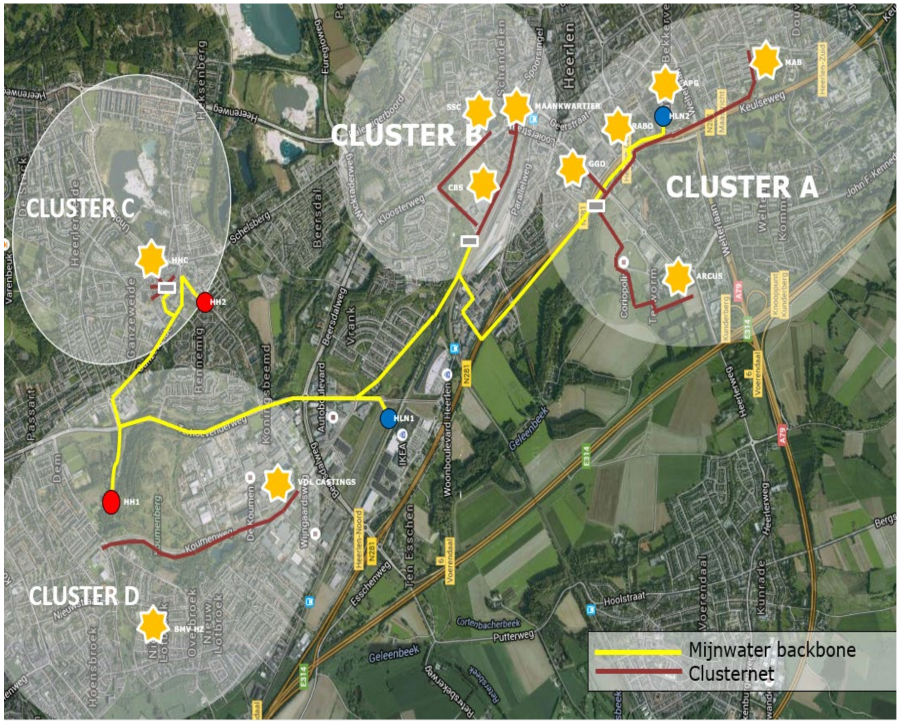
Demo site Mijnwater Heerlen, The Netherlands



- 4th generation DHC system
- 200,000 m2 connected
- Very low temperatures (28°C – 16°C)
- Simultaneous provision of heating + cooling
- Exchanging energy (prosuming)
- Underground storage in abandoned mines
- **Testing**:
  - Cell Balancing
    - balancing of heat/cold producers and consumers
  - Peak shaving
    - Strive for an average consumption

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Peak shaving – Evaluation methodology

- Approach: Comparison of heat load patterns between
  - Reference heat load model (historic data without STORM)
  - Results during testing period
- Hourly data profiles:
  - Heat load of the total network
  - Heat load of the controllable part
  - Outdoor temperature
- Test period Rottne:
  - March 2018 - January 2019 (excl. summer months with low loads)
- Evaluation criterion:
  - Peak heat production energy
  - Part of the heat load above 2.5 MW

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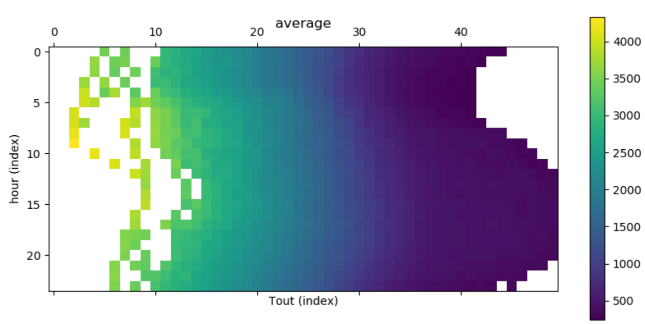
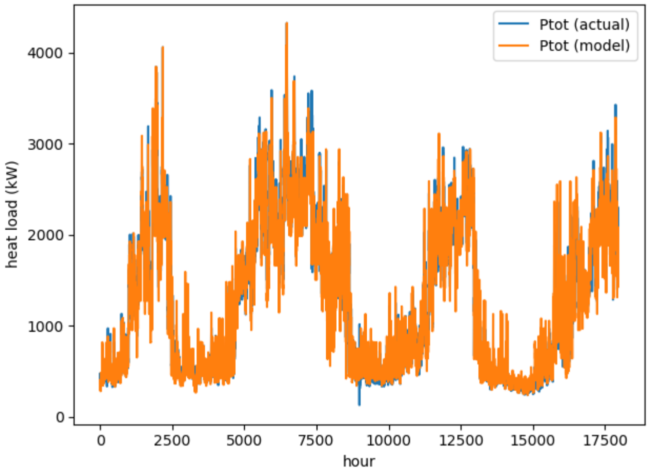
Peak shaving – Reference heat load modeling

Approach:

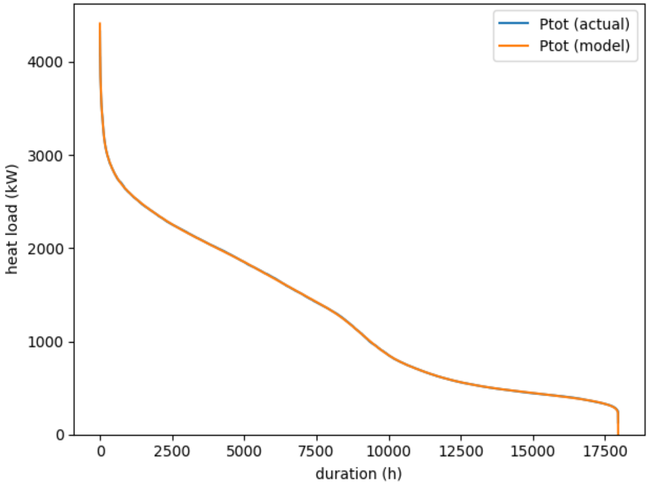
- Look-up table with outdoor temperature and hour of the day as input variables
- Filled using historic reference data: July 2015 – January 2019 (excl. control actions)
- Recorded statistics: average, minimum, maximum, count, standard deviation
- Average heat load is used to model the reference behavior



Validation:



MAE:
79.5 kW



MAE:
7.9 h

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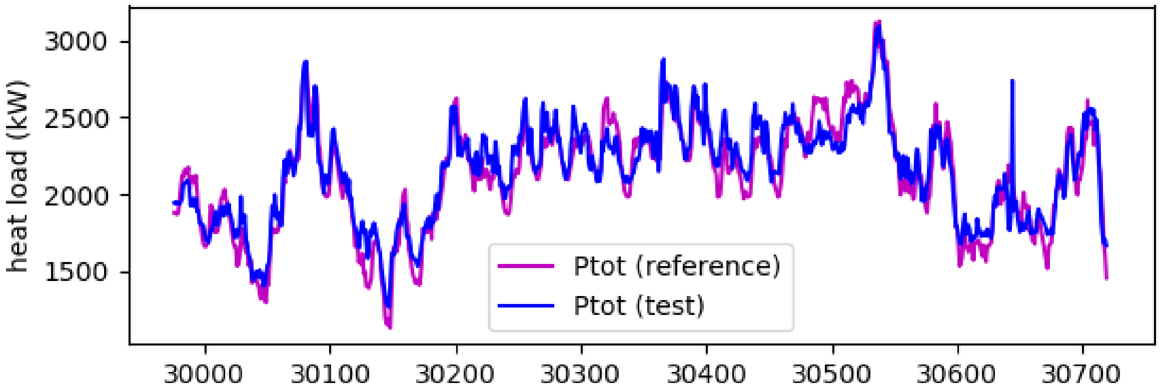
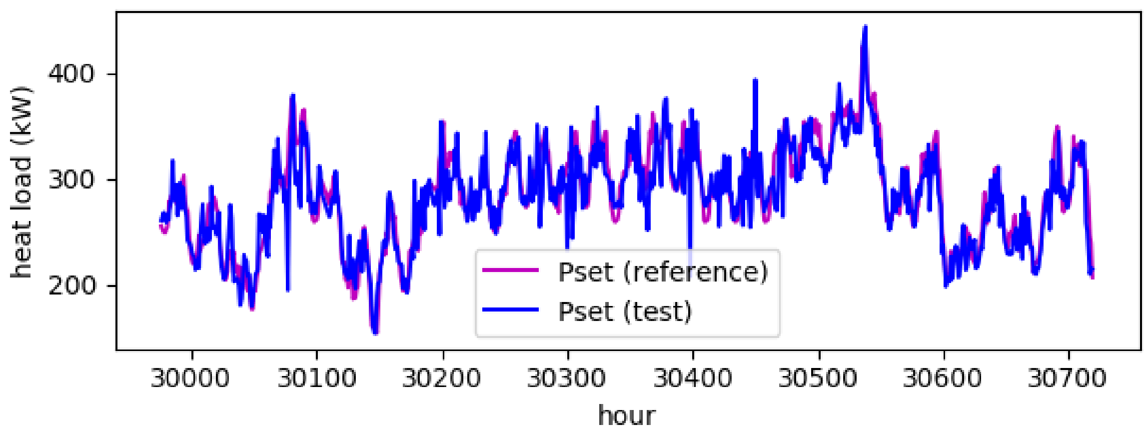
Peak shaving - Example

- Demo-site Rottne, December 2018
- Comparison of heat load profiles:

Total network



Controllable part



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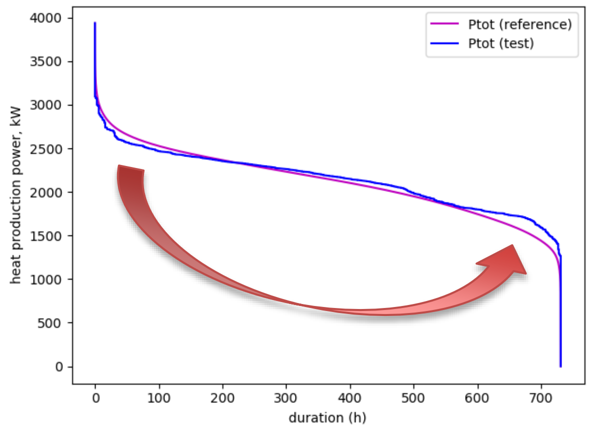
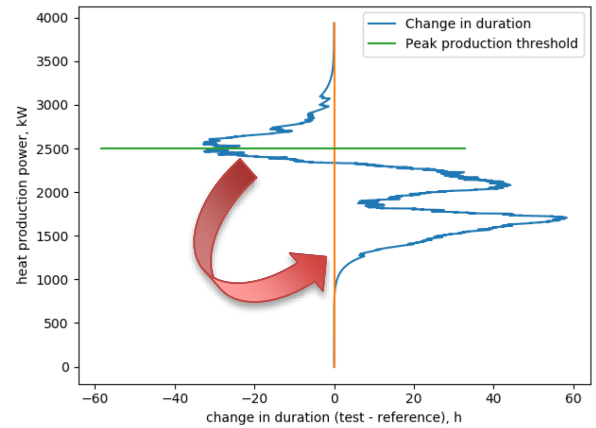
Peak shaving - Example

- Demo-site Rottne, December 2018
- Comparison of load-duration curves:

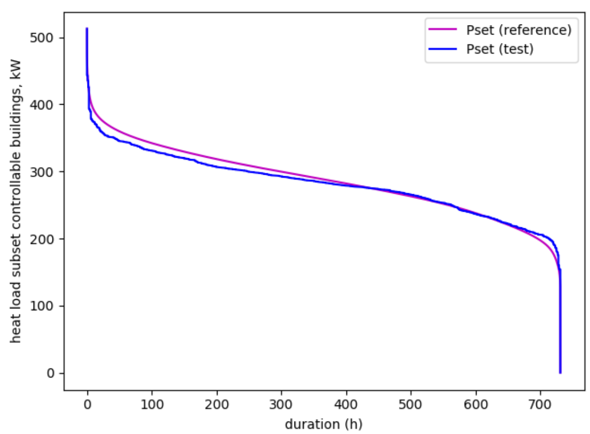
Total network

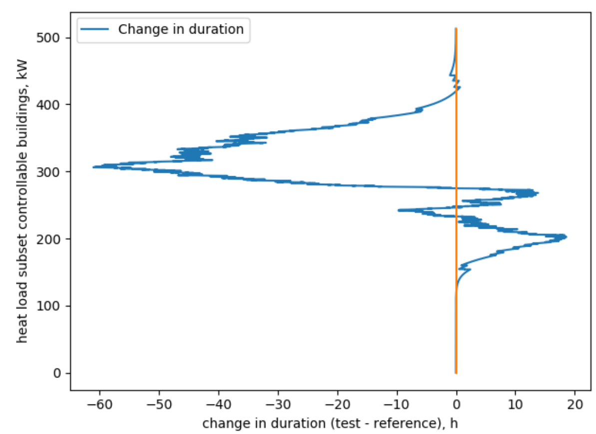




Heat load moved from peak boiler to baseload boiler

Controllable part





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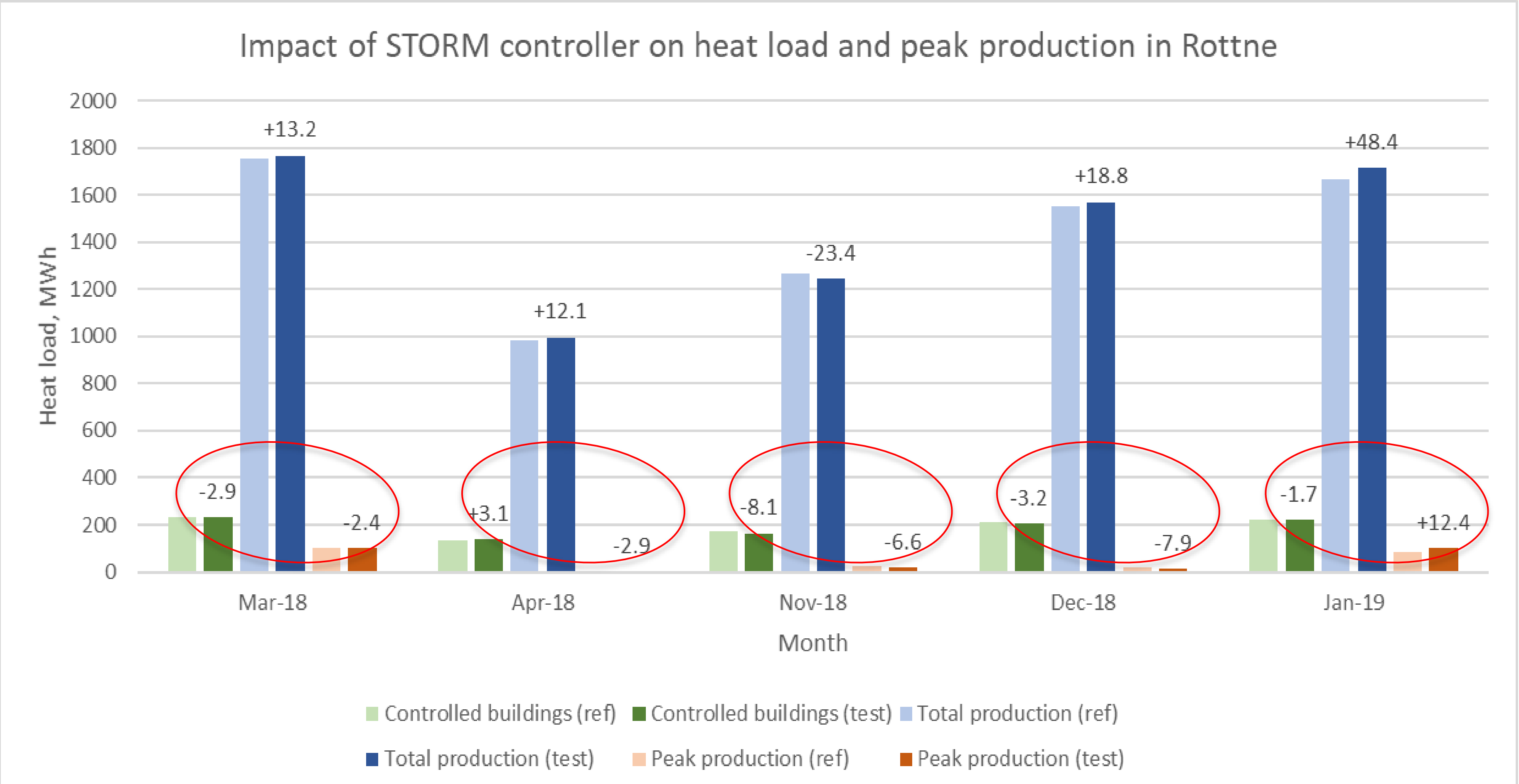
Peak shaving – Summary of results

- Demo-site Rottne, March 2018 - January 2019



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Peak shaving - Conclusions

- Peak shaving
  - Tested in Rottne (March 2018 to January 2019)
  - Test results compared with the behavior of a validated historical reference model
- Disturbances:
  - Weather
  - User behavior
    - Increase in uncontrollable heat load
    - One customer that connected more buildings without notice
- Reduced peak heat production:
  - -3.1% to -12.7% (excluding Jan. ’19)
  - -1.3% controllable part consumption

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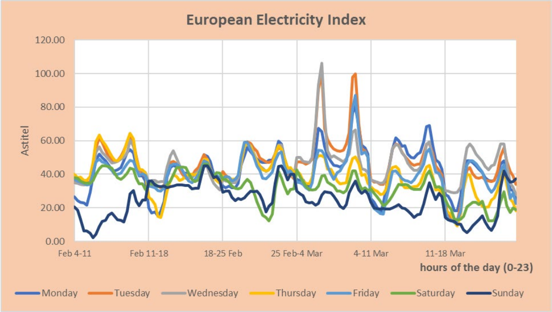
Market Interaction - Strategy



1. **Combined Heat & Power** (CHP)

- Charging and discharging
- Forecast of spot-prices for electricity
- Focus on earnings:
  - increase heat demand (charge) during times of high spot-prices
  - decrease heat demand (discharge) during low spot-prices.

2. **Heat Pumps** (HP):

- Focus on costs:
  - avoiding high costs and premier low costs.

3. **Zero-sum functionality**.

- Ensuring no overall increase of energy usage for customers

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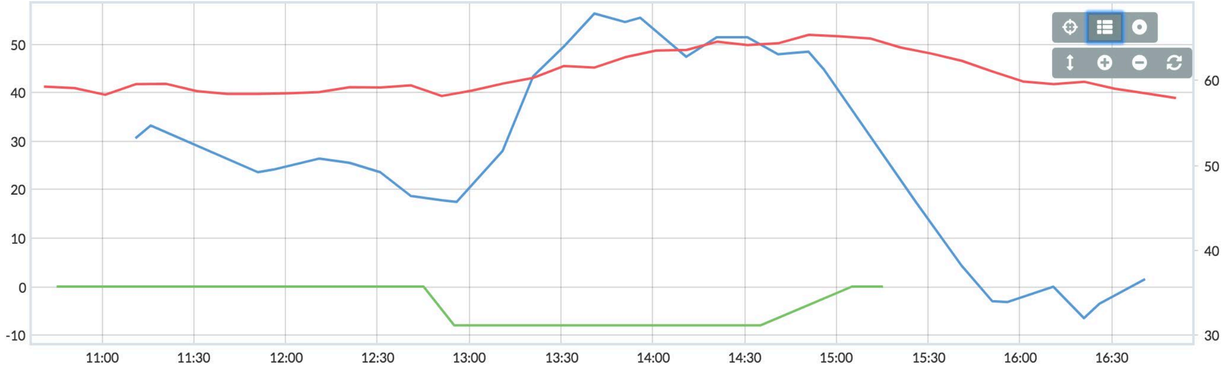
Market Interaction - Charging

Group of buildings

Individual building



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Market Interaction - Results and Conclusions

Average results:

- number of control actions for charging

Offset [°K]	Reference [kW]	Charged level [kW]	Difference [kW]	Quota [%]
5	805	1176	371	31
6	700	1080	380	35
8	582	1141	559	49

- discharging has been tested extensively through peak load management

Conclusions:

- MI has the ability to charge and discharge (depending on requested behaviour)
- Results of charging are in line with the results of discharging
- maximum impact of 50% of the instantaneous demand.
- Impact on short-term demand ranges between 30–50% on individual building level.
- zero-sum functionality achieved in Rottne 5.8%.
- MI is a powerful control strategy
- several commercial spin-off projects based on STORM technology

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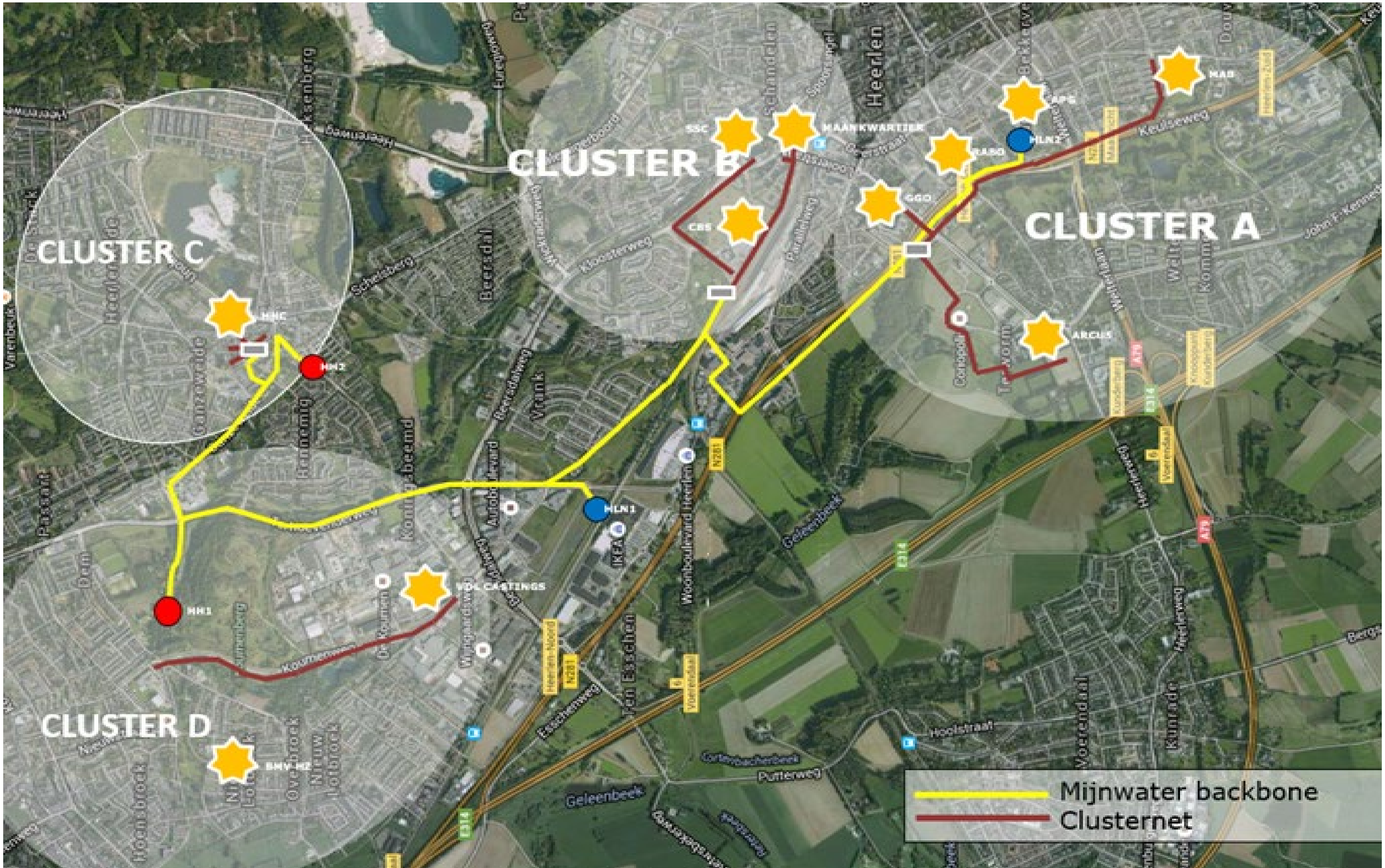
Cell Balancing - Strategy



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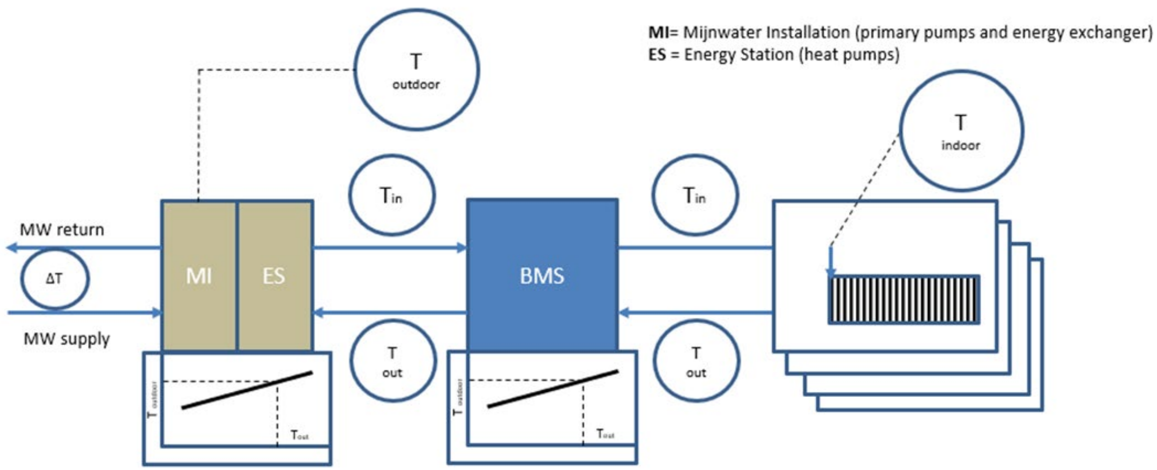
Cell Balancing - Strategy

- The outdoor temperature offset was:
  - Not used to influence the indoor energy demand, but:
  - Used to influence the flow going to the cluster- or customer installations (i.e. implementing PS)
- With less flow, the activity of the HP's increases, leading to a larger dT, thus to more energy per m3 of water;



- Optimisation process performed over 3*24 hour time horizon (24 hours in the past to 48 hours into the future)
- The process is repeated every hour

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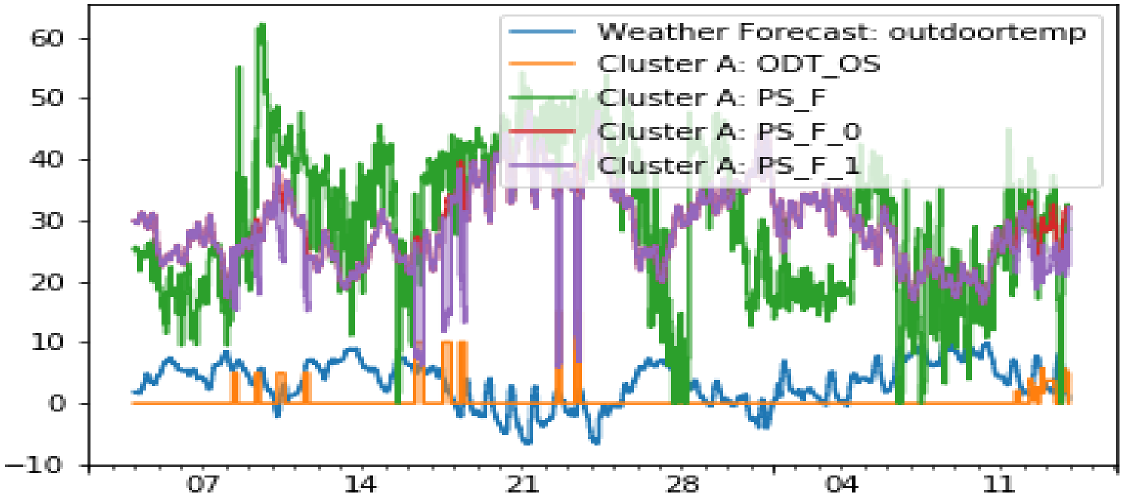
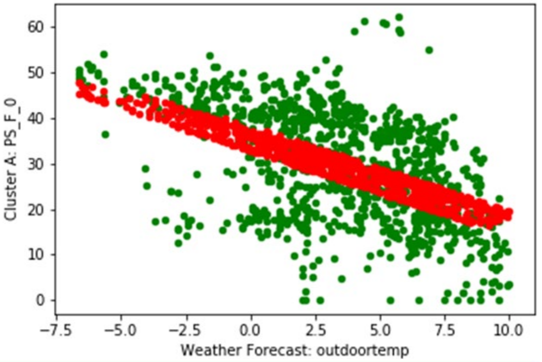
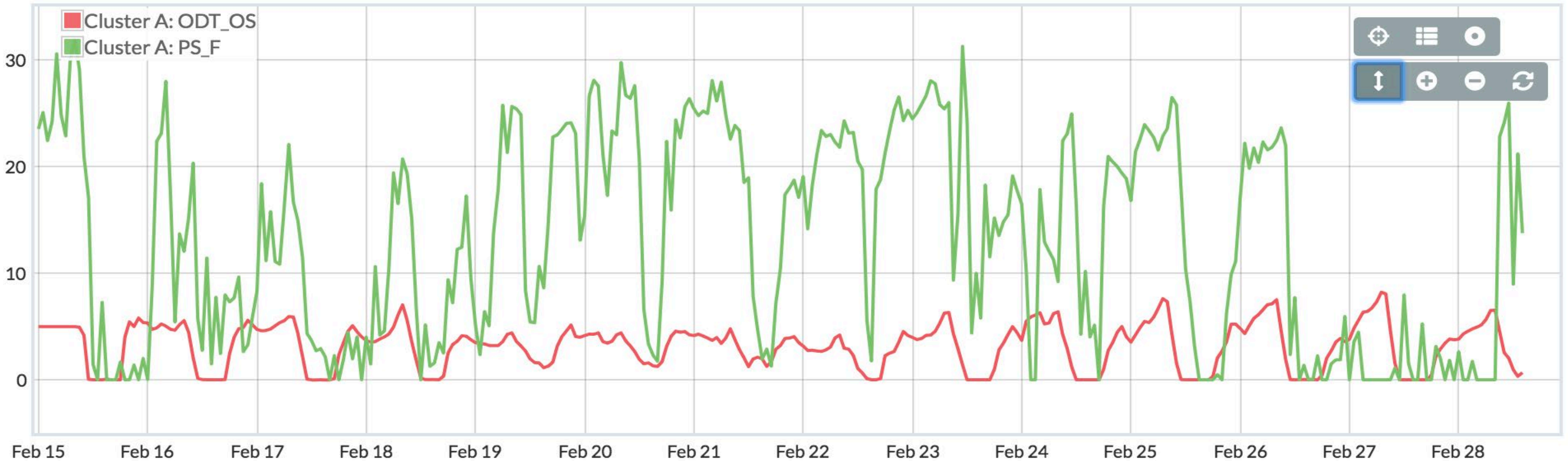
Cell Balancing - Performance



ODT_OS =outdoor temperature offset
PS_F =measured flow
PS_F_0 = predicted flow
PS_F_1 = optimised flow





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Cell Balancing - Results

- The average **dT** increased with 3.13°C (cluster A) and 2.55°C (cluster B)
- The average **flow** could be decreased with 7.5% (cluster A) to 34.1% (cluster B); =PS-potential.
- The **capacity** of the system (the weighted product of the flows times the increased dT) increased with 36.9% (cluster B) to 49.4% (cluster A); =CB-potential

		Cluster A			Cluster B			
		Reference	STORM	dT/%	Reference	STORM	dT/%	
backbone	supply temperature [°C]	20.23	21.26	1.03	22.71	23.96	1.25	
	return temperature [°C]	13.9	11.8	-2.1	15.8	14.5	-1.3	
	dT [°K]	6.33	9.46	3.13	6.91	9.46	2.55	
	Flow [m^3/h]	*14.97*	*13.85*	-7.5%	25.9	17.06	-34.1%	Peak Shaving
	capacity [$GJ/m^3.h$]	0.03	0.04	49.4%	0.03	0.04	36.9%	Cell Balancing

- combining CB and PS leads to system's **capacity improvement of 52%**

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STORM - Final results

Evaluated results of the STORM controller	
Peak Shaving	up to 12.75% (Rottne) on peak heat load up to 17.3% (Heerlen; median values) on flow
Market Interaction	up to 49% influence on instantaneous demand, leading to: • 15% reduction on electricity purchase price • 6% reduction on electricity procurement costs
Cell Balancing	up to 42.1% (Heerlen; median values) capacity improvement through improved energy exchange potential
Sustainability	Up to 15% of annual energy savings of connected buildings, especially in combination with the Smart Heat Building service, Avoided CO_2 emissions per year: • Rottne: another 10,880 tonnes • Heerlen: an additional amount of 12,816 tonnes

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STORM – Benefits for DHC operators

- **Economical:**
  - Positive annual operating result by:
    - Reduced costs of energy production
    - Reduced costs of electricity purchase
    - connecting more customers to the system
    - installing less capacity
  - Reduced TCO
- **Environmental:**
  - Reduced energy demand
    - Improved energy exchange
    - Integration of excess energy
  - Reduction on GHG emissions
- **Other:**
  - Improved supply security

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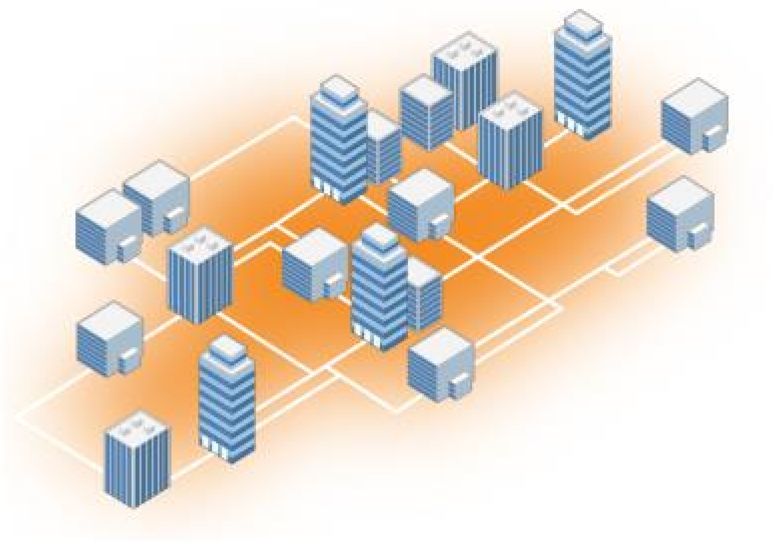
Questions?



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THANK YOU!

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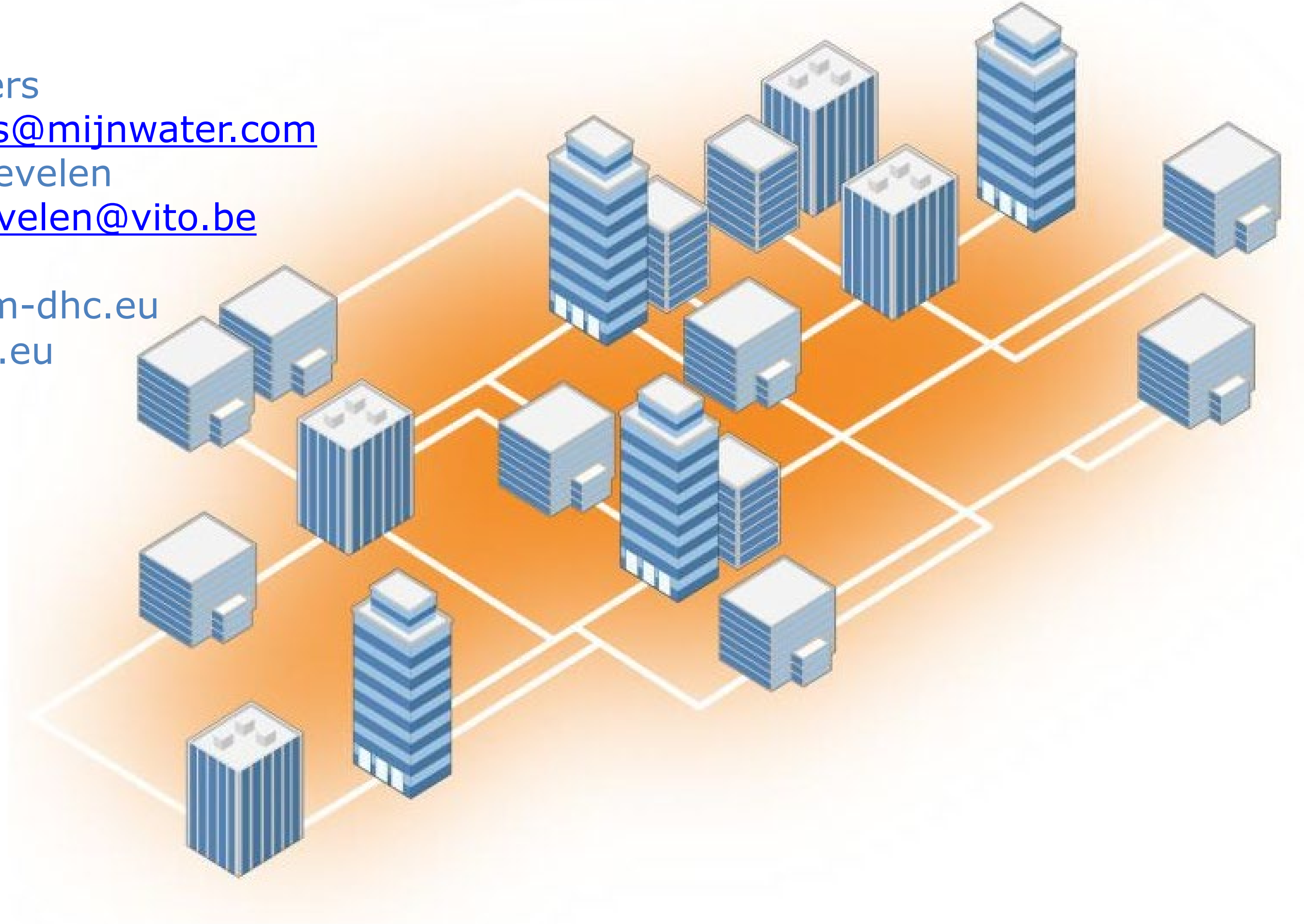

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