RESIDENTIAL HEAT PUMPS AS FLEXIBLE LOADS FOR DIRECT CONTROL SERVICE WITH CONSTRAINED PAYBACK

E. Georges
B. Cornélusse
D. Ernst
Q. Louveaux
V. Lemort
S. Mathieu
Table of content

• Introduction
• Flexibility service and optimization
• Thermal models
• Results
• Conclusions
Introduction

• **Who?**
  Aggregator with direct control of heat pumps

• **What?**
  from the consumption of its portfolio, proposes a consistent modulation service

• **How?**
  • Optimize baseline to minimize energy cost for end-user
  • Maximize amount of modulation available for given payback

• **Why?**
  • Relieve congestions in distribution network
  • Solve an imbalance
Table of content

• Introduction
• **Flexibility service and optimization**
• Thermal models
• Results
• Conclusions
Flexibility service

- Flexibility service with a modulation in a given period $\tau$ and a payback in $k$ following periods
Flexibility service

- Flexibility service with a modulation in a given period $\tau$ and a payback in $k$ following periods

Deviations from baseline

⇒ Imbalance
⇒ Other congestions?
Definition of a baseline

- Reference: baseline which **minimizes** the **electricity cost** for the **consumer**
  - the use of flexible heat pumps should benefit the **end-user** as an **incentive to enroll** in flexibility programs
  - if an aggregator is a **BRP**, then it has to **state its positions** to the **TSO** in the form of baselines
Thermal state transition model

- In the optimization problem, the thermal states transition model and the state constraints are summarized by

\[ x_{t+1} = f(x_t, u_t, W_t) \]

\[ x_{t,min} \leq x_t \leq x_{t,max} \]

and detailed in a few slides.

Where
- \( x_t \) state variables
- \( u_t \) model parameters
- \( W_t \) modulable variables
Optimization of the baseline

Solve

Min energy cost

Subject to

- thermal state transition model
- state constraints
- power limitations
- heat pump constraints
Optimization of the modulation

To obtain the maximum upward modulation in a period $\tau$ with a payback effect in the $k$ following periods, solve

$$\text{Max} \text{ amount of modulation available in period } \tau$$

Subject to

- thermal state transition model
- state constraints
- power limitation
- heat pump constraints
- payback limited on $k$ periods
Table of content

• Introduction
• Flexibility service and optimization
• Thermal models
• Results
• Conclusions
Thermal model: building

- Building thermal behavior modeled by an equivalent single zone 5R3C thermal network
- Parameters identified from detailed validated models
- Zone temperature constrained to remain within thermal comfort

\[ T_t^a \quad R_1 \quad T_t^m \quad R_2 \quad T_t^i \quad R_3 \quad T_t^f \quad R_4 \quad \bar{T}_t^a \]

\[ R_4 \quad C_1 \quad R_2 \quad C_2 \quad R_3 \quad C_3 \]

\[ Q_t^s, Q_t^g, Q_t^{sol} \]
Thermal model: heat pump

- Variable-speed air-to-water heat pumps used to cover domestic hot water and space heating needs

- Modeled using a linear empirical model with a coefficient of performance function of:
  - the ambient temperature
  - full-load / part-load performance

- The heat pump can only supply either the domestic hot water tank or the direct space heating emitters
Table of content

• Introduction
• Flexibility service and optimization
• Thermal models
• Results
• Conclusions
Results: single house

- Modulation in quarter 53 with a payback of 1 hour
- 2.5 kW of modulation provided by space heating
- Domestic hot water counterbalances space heating to limit deviations during payback
Results: 100 houses

- Freestanding houses built > 1971
- Average nominal power: 4.3 kW (heat pump + resistance)

- Modulation amplitude increases with $k$
- Potential for upward higher than for downward activation
- Potential dominated by set point profiles and tariff structure
Results: 100 houses

- Freestanding houses built > 1971
- Average nominal power: 4.3 kW (heat pump + resistance)

Winter: 80% of the flexibility from space heating
Mid-season: 50%/50%
Summer: 100% from domestic hot water
Results: 100 houses

- Average results per house depending on the payback
- Overconsumption $\sim= \frac{1}{2}$ of energy of upward modulation
  $\sim= \frac{3}{4}$ of energy of downward modulation
Conclusion

• Definition of a flexibility service provided by a load aggregator controlling domestic heat pumps
• Heat pumps used to supply domestic hot water production and space heating needs
• Consists in upward or downward activation of heat pumps at certain time-periods with a pay-back effect over a fixed number of periods
• Sequential optimization scheme to determine maximum modulation amplitude from an optimized baseline
• Application to a case-study with 100 houses:
  • Up to 1.2kW / 0.5kW for upward / downward modulation
  • Quantification of overconsumption and costs
Contact

Emeline Georges
emeline.georges@ulg.ac.be

B49 Thermodynamics Laboratory
Quartier Polytech 1
Allée de la Découverte 17
4000 Liège

http://www.labothap.ulg.ac.be/cmsms/