Heat FlexOffers: a device-independent and scalable representation of electricity-heat flexibility.

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Flexibility

- Flexibility is the capability to change energy loads in time and amount.
- Among the models that describe flexibility from devices, not many handle energy conversion.
- We want to create a model with the following desirable properties:
  - Representing multiple device types in a unified format.
  - Being scalable with respect to long time horizons and many loads.
  - Capturing most of the available flexibility.
  - Handling conversion between different energy vectors.
- We created the FlexOffer (FO) model in the past: it complies to the first three points, but refers specifically to electric energy.
- This work has the goal to extend FOs in order to model heat, and support heat-electricity conversion.

State of art

- There are models that describe flexibility with accuracy (exact models); however, they may become unfeasible for optimization within long time horizons/many devices.
- FOs are an approximate model, i.e., they represent flexibility for a device in a simple and device-independent format, but the representation may not be exact because of the format itself.
- The simplicity of FOs representation allows them to trade a slight amount of accuracy of flexibility representation in exchange for much faster optimization.
- The current models for heat-electricity are not many, and are exact.
- In this presentation we will show FOs generated for a heat pump in a $5 \times 4 \times 3$m room, with internal temperature 22°C and external temperature 2°C, which will be our running example. Temperature thresholds are $T_{min} = 20$°C and $T_{max} = 24$°C respectively.

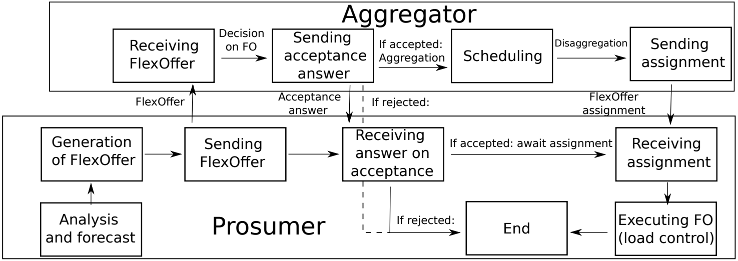
Contributions

- We extend FOs to Heat FlexOffers (HFOs), in order to model other energy vectors and conversion between them.
- We are mainly targeting heat pumps. Many heat pumps comply to a standard (SG-Ready), and we want HFOs to be aware of the SG-Ready standard.

This work has the following contributions:

1. Create HFOs and use them to represent flexibility for heat pumps.
2. Show how HFOs can adapt to different consumption patterns.
3. Prove that HFOs are compliant to SG-Ready for heat pumps.
4. Describe how HFOs handle heat-electricity conversion.
5. Show how HFOs retain almost all flexibility for heat pumps, and provide a very fast method to combine their flexibility.

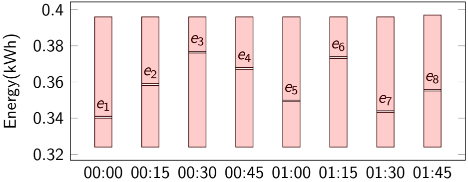
FlexOffers



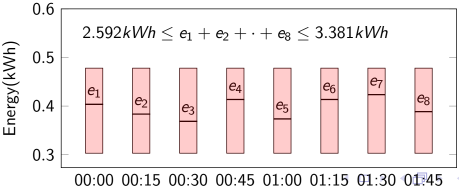
- FOs are defined as sets of constraints approximating flexibility for a certain device. In the figure we can see the life-cycle of an FO.
- The main actors are the prosumer, who issues and executes the FO via an automatic agent, and the aggregator, who processes it.

Types of FlexOffer

- **Standard FOs** (SFOs) have *slice constraints*: they determine the minimum and maximum amount of energy consumable at each time. They provide an accurate representation for flexiblity for wet devices.

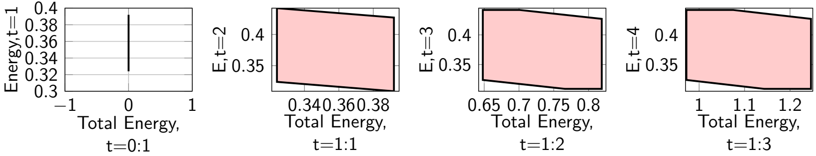


- **Total energy constraint FOs** (TECFOs) have slice constraints, plus a constraint on the total amount of energy consumed. They offer good flexibility approximations for charging batteries.



Types of FlexOffer

- **Dependency FlexOffers** (DFOs) have constraints describing how much energy can be used (y-axis), depending on how much has been consumed until that time (x-axis). They support batteries that operate freely.



- Flexibility can have *inner* and *outer* approximations. Inner approximations describe less flexibility than the actual amount, while outer approximations describe more.

SG-Ready standard

- SG-Ready is an interface designed to allow flexibility exploitation from heat pumps.
- There are more than 1200 heat pump models adopting this interface.
- According to this standard, heat pumps may operate in the following modes:

Operating mode	**Description**
Off	Heat pump is switched off.
Normal	Heat pump operates in an energy-efficient mode.
Recommended On	Heat pump operates on an enhanced heating mode.
Forced On	Heat pump operates at its maximum power.

- The operating mode cannot switch more than 4 times per hour.

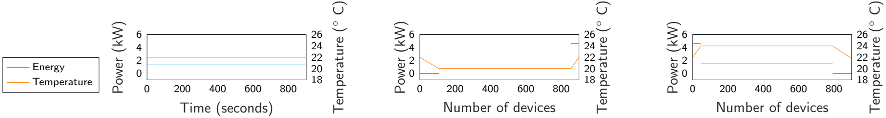
Power curves

- Energy is the integral of power over time; however, dispersion of heat depends on the current temperature, and so different functions that describe power over time may result in different temperatures obtained by spending the same amount of energy. We refer to those functions as *power curves*.
- HFOs have the same flexibility representation as DFOs, but the amount of flexibility represented by them depends on the considered power curve inside each considered time slice.

Different power curves allow for pursuing different objectives. We have identified the following:

- Minimizing energy consumption.
- Maximizing upwards flexibility.
- Maximizing downwards flexibility.
- Maximizing bidirectional flexibility.

Power curves



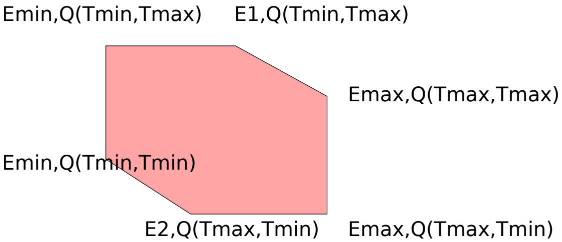
(a)Bidirectional maximization (b)Upwards maximization (c)Downwards maximization

- The figure shows the power curves (blue) that meet the desired requirements, and the respective temperatures (orange) of the room.
- Those curves are all SG-Ready compatible, as they are obtained by alternating the *Off*, *Normal* and *Forced On* modes.
- The curve (b) also solves the energy consumption minimization problem.

HFO creation

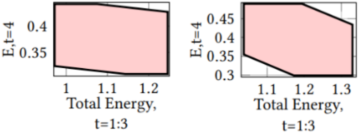
- Once the power curve is chosen, we can create the HFO. HFOs have the same form of DFOs, i.e., consumable energy depends on the amount of energy consumed up to the considered time.
- In order to create the HFO slices, we need the function $Q(T_i, T_f)$, that calculates the amount of energy needed to bring the room temperature from temperature T_i to T_f in the considered time slice.
- Q only depends on the chosen power curve.
- $Tmin$ and $Tmax$ define the temperature constraints for the room.

The $t-$th HFO slice is then as follows:

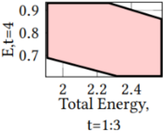


HFO aggregation

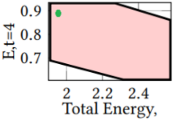
- Aggregating N FOs means generating M FOs, with $M \ll N$, which represent their combined flexibility, with some losses.
- HFOs represent flexibility the same way as DFOs, and therefore they are aggregated the same way.



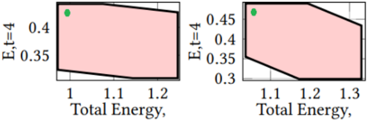
Aggregate to



- We implemented a new analytic algorithm for HFO aggregation, which is much faster than the current DFO aggregation algorithm.
- Disaggregation splits the schedule for one single HFO to schedules relative to the initial HFOs, proportionally to the flexibility of each HFO.

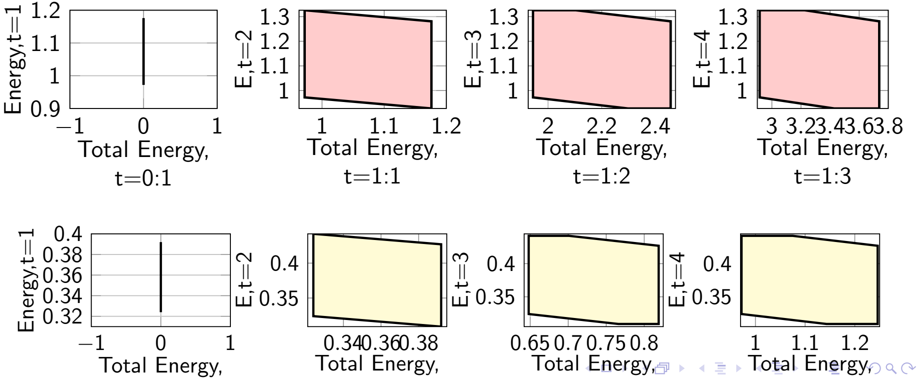


Disaggregates to



Heat-electricity conversion

- HFOs can be reversed: given an HFO representing heat for a heat pump, a DFO representing electricity consumed by the heat pump can be generated, and vice versa.
- In the figure, our example for a heat pump with coefficient of performance (COP) 3.



Simulations - scenarios

- We model flexibility for the next 12 time slices every time.
- The objective is profit maximization, and the idea for obtaining it is *buying low, selling high*.
- The baseline for single device optimization is a theoretical optimum approach (**Theo.Opt**), while for aggregation we compare to **Minkowski** sum, an approximate Minkowski sum (**App.Mink.**), another exact approach (**LTIAgg**) and the old **DFO** aggregation.
- Data for spot and imbalance prices are from Nordpool, and refer to the day-ahead spot market in Denmark in the year 2018, January 1st to December 31st.

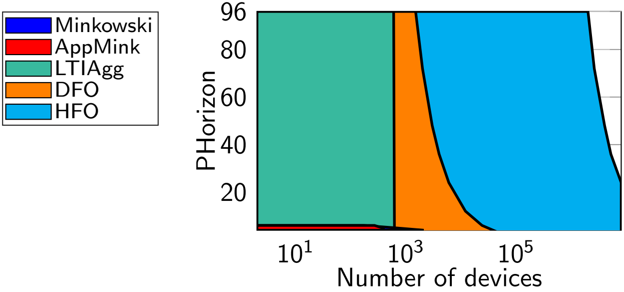
Results - Single heat pump

Type	Pre-Imb(€)	Imb.Pen.(€)	Cost(€)
Theo.Opt.-C	131.86	0	131.86
HFO-Constant	130.75	3.21	133.96
Theo.Opt.-O	131.83	0	131.83
HFO-Optimal	130.33	2.99	133.32

	0	1	2	3	4+
Hours	8112	333	273	42	0

- HFOs retain 98.9% of flexibility for heat pumps, compared ot the theoretical optimum.
- The heat pump complies to the SG-Ready requirements, as its mode does not change more than 3 times per hour, which is in itself a very rare event (less than 0.5% of the total hours).

Results - Aggregation



- HFOs can aggregate up to $2 \cdot 10^6$ heat pumps for 96 time slices, while DFOs stop at 1500.
- This is because of analytic aggregation, that allows for much faster aggregation/disaggregation despite the constraints being the same.

Conclusions

- We expanded FOs to HFOs, a device-independent and scalable model that models heat and handles conversion to/from electricity.
- HFOs are compliant to SG-Ready, and can adapt to different power curves.
- HFOs are very accurate in modeling flexibility for heat pumps, as only 1% of flexibility is lost.
- Analytic aggregation of HFOs is much faster than exact approaches and DFO aggregation, and outperforms the latter by 3 orders of magnitude.
- Future work will include more energy vector such as gas, and also integration with Uncertain FOs.