Energy Informatics.Academy Conference 2022

Probabilistic FlexOffers in Residential Heat Pumps Considering Uncertain Weather Forecast

AALBORG UNIVERSITET

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FEVER

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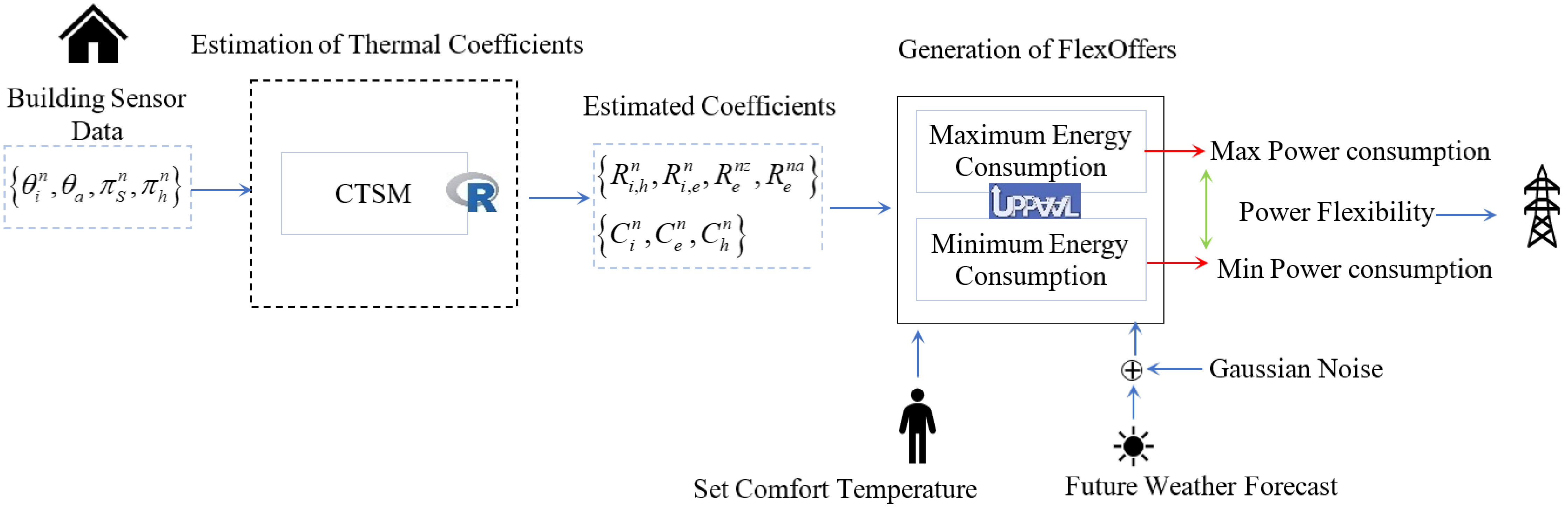
Purpose and Contributions

- Integration of the thermal dynamic model of residential buildings with multi-temperature zones from R language into UPPAAL software. The building's input data are used to train the data-driven approach, i.e., the CTSM.

- Generating FlexOffers through calculation of minimum and maximum flexibility potentials of heat pumps in pessimistic and optimistic energy consumption patterns in UPPAAL-STRATEGO.

- Investigating the impacts of the uncertain weather forecast on the flexibility potential of heat pumps.

General Structure

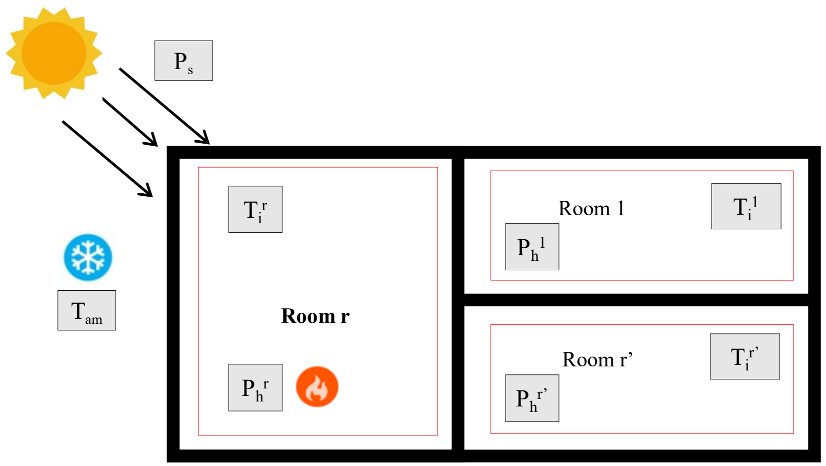


Thermal Dynamics of Buildings

$$\frac{dT_i^r}{dt} = \frac{1}{C_i^r} \times \left(\frac{1}{R_{ih}^r} \times \left(T_h^r - T_i^r \right) + \frac{1}{R_{ie}^r} \times \left(T_e^r - T_i^r \right) + \left(A_w^r \times P_s^r \right) \right)$$

$$\frac{dT_e^r}{dt} = \frac{1}{C_e^r} \times \left(\frac{\left(T_i^r - T_e^r \right)}{R_{ie}^r} + \sum_{\substack{r'=1 \\ r' \neq r}}^{R} \frac{\left(T_i^{r'} - T_e^r \right)}{R_e^{rr'}} + \sum_{a=1}^{A} \frac{\left(T_{am} - T_e^r \right)}{R_e^{ra}} \right)$$

$$\frac{dT_h^r}{dt} = \frac{1}{C_h^r} \times \left(\frac{(T_i^r - T_h^r)}{R_{ih}^r} + P_h^r \right)$$



Thermal dynamic Estimation: CTSM-R

- The CTSM is a grey-box model developed by DTU Compute and publicly available
- The input is the buildings' sensor data:

$$\Psi = \{\theta, \pi\}$$

$$s.t. \quad \forall n = 1,\dots,N: \quad \theta \in \{\theta_i^n, \theta_h^n, \theta_a\}, \quad \pi \in \{\pi_S^n, \pi_h^n\}$$

- The output is the constant thermal parameters:

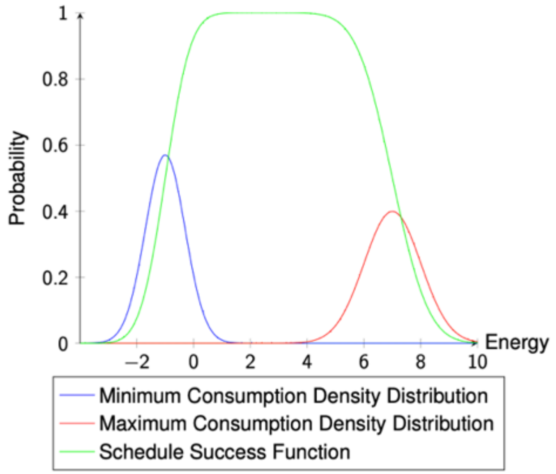
$$\Phi = \{R, C, \rho\}$$

$$s.t. \quad \forall n = 1,\dots,N: \quad R \in \{R_{i,h}^n, R_{i,e}^n, R_e^{nz}, R_e^{na}\}, \quad C \in \{C_i^n, C_e^n, C_h^n\}$$

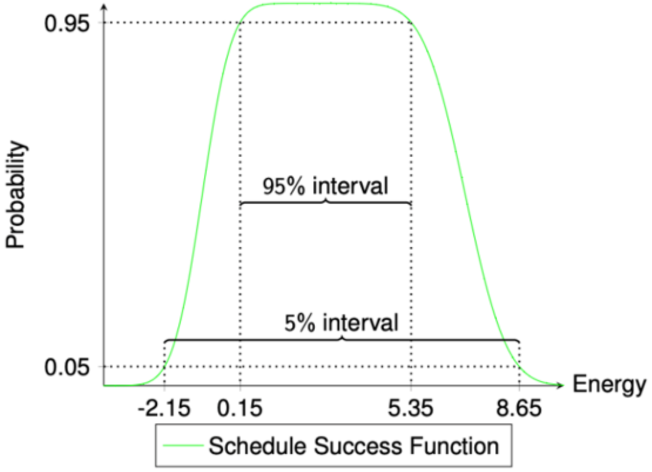
Probabilistic FlexOffers

- Uppaal Stratego is free and non-profit tool for modeling, validation and verification of real-time systems developed by Uppsala and Aalborg University.
- A Success Function evaluate the CDF of optimistic and pessimistic energy input x:

$$Succ(x) = Min_{CDF}(x) - Max_{CDF}(x)$$



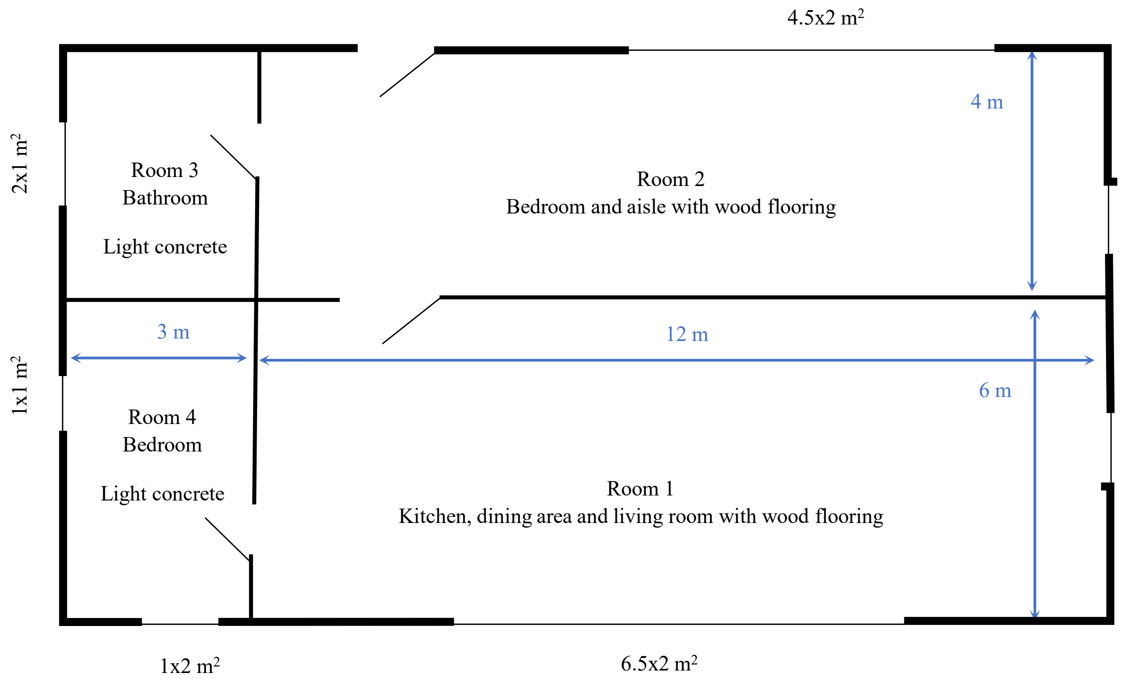
Example of a slice of a Probabilistic FlexOffer.



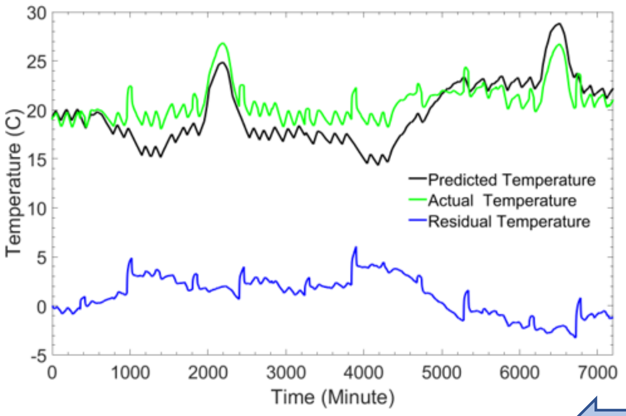
95% and 5% success interval for the scheduling success function.

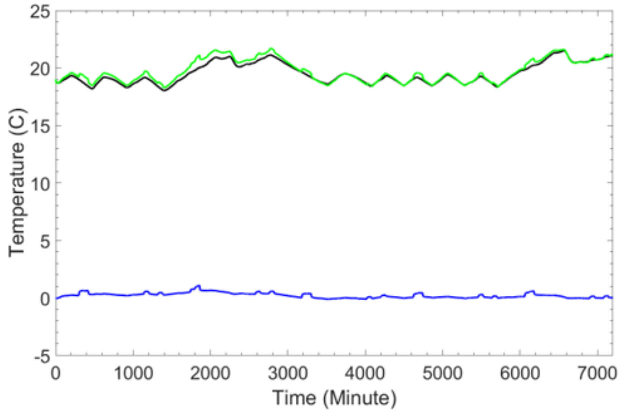
Building Case Study

- 150 m² 4-room residential building with floor heating extracted from Modelica.

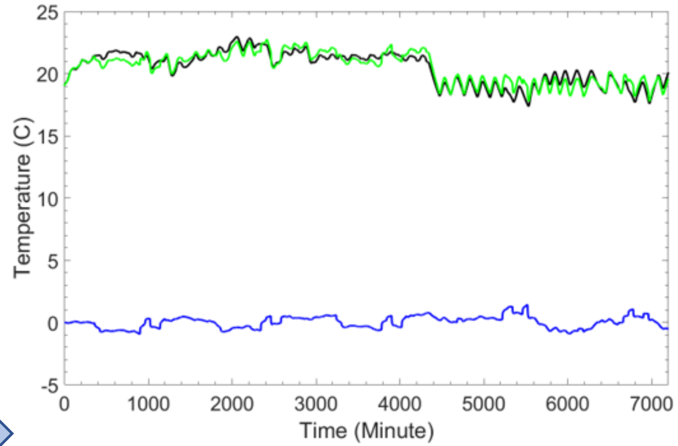


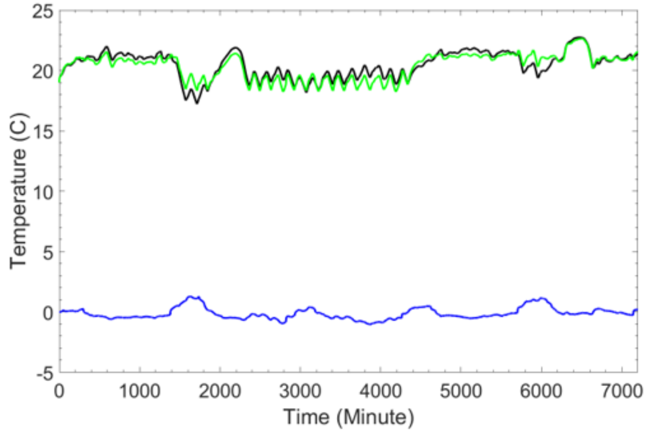
Estimated Coefficients





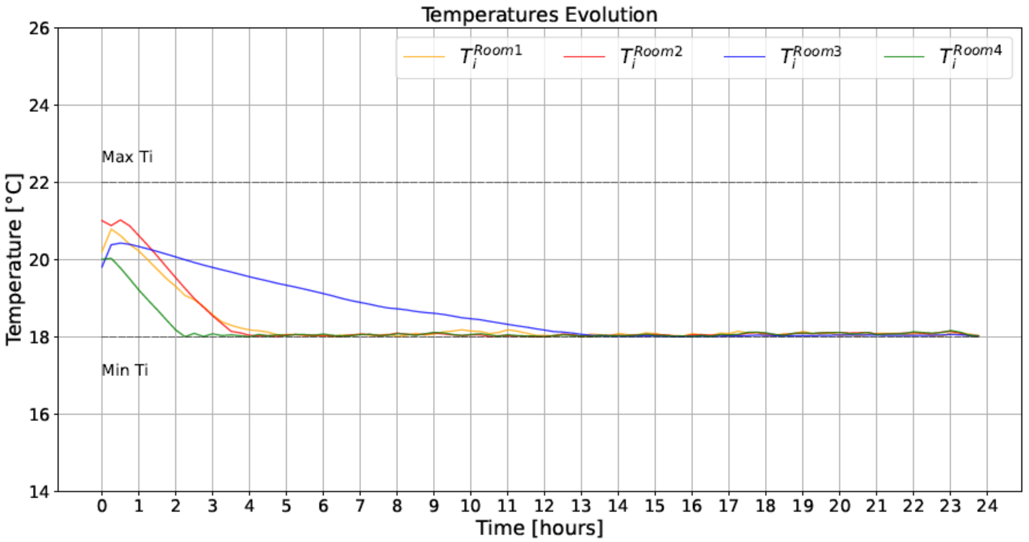
Coefficients	Room 1	Room 2	Room 3	Room 4
A_w	2.3158×10^{-2}	4.1767×10^{-7}	1.2852×10^{-2}	8.5950×10^{-3}
MF	2.3472	6.4206	2.8651	1.7252×10^{1}
Ω^{r}_{ie}	9.9841×10^{1}	1.1452×10^{1}	4.4957×10^{-1}	1.2048
Ω^{r}_{ih}	3.1201×10^{1}	4.8226	4.2024	2.6110
Ψ_e	1.5355	1.2926	4.5021×10^{1}	1.0343×10^{2}
Ψ_h	5.2051×10^{1}	2.7054	2.5162×10^{1}	3.057
Ω^{ra}_{e}	1.7904	2.3561×10^{-1}	2.1670×10^{1}	8.0429
$\Omega^{rr'}_{e}$	1.9805×10^{-1}	4.1671×10^{-1}	4.8035	2.1611
$\Omega^{rr'}_{e}$	5.3296×10^{-1}	3.8123×10^{-1}	8.2707×10^{-1}	1.7462×10^{1}

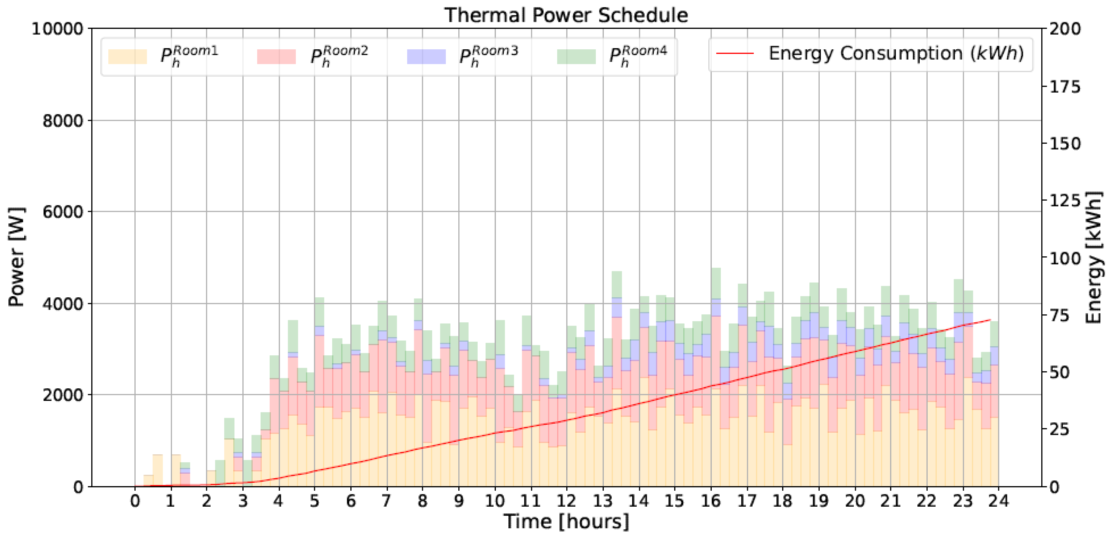




Generated FlexOffers

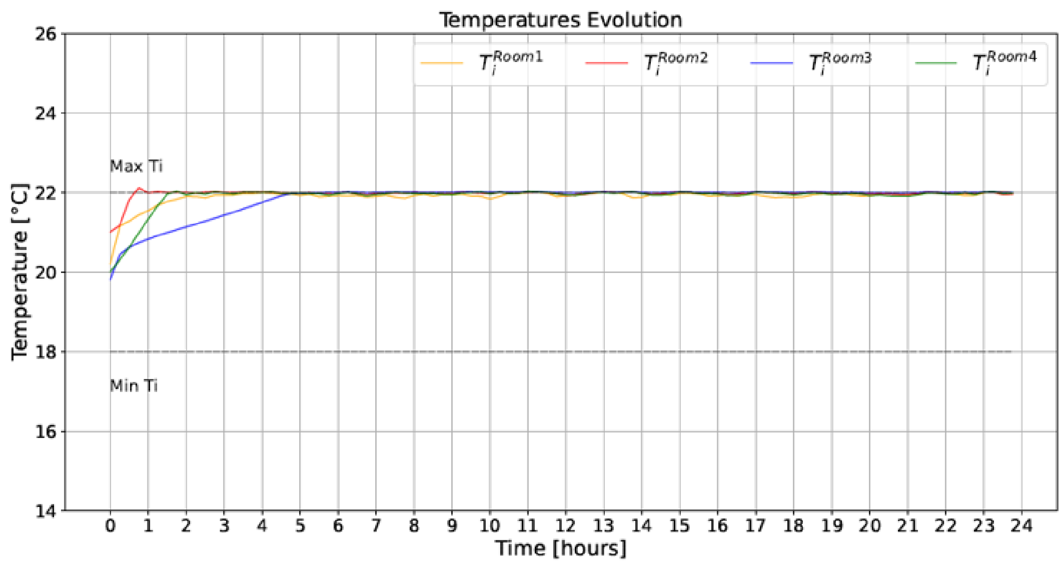
Minimum Energy Consumption

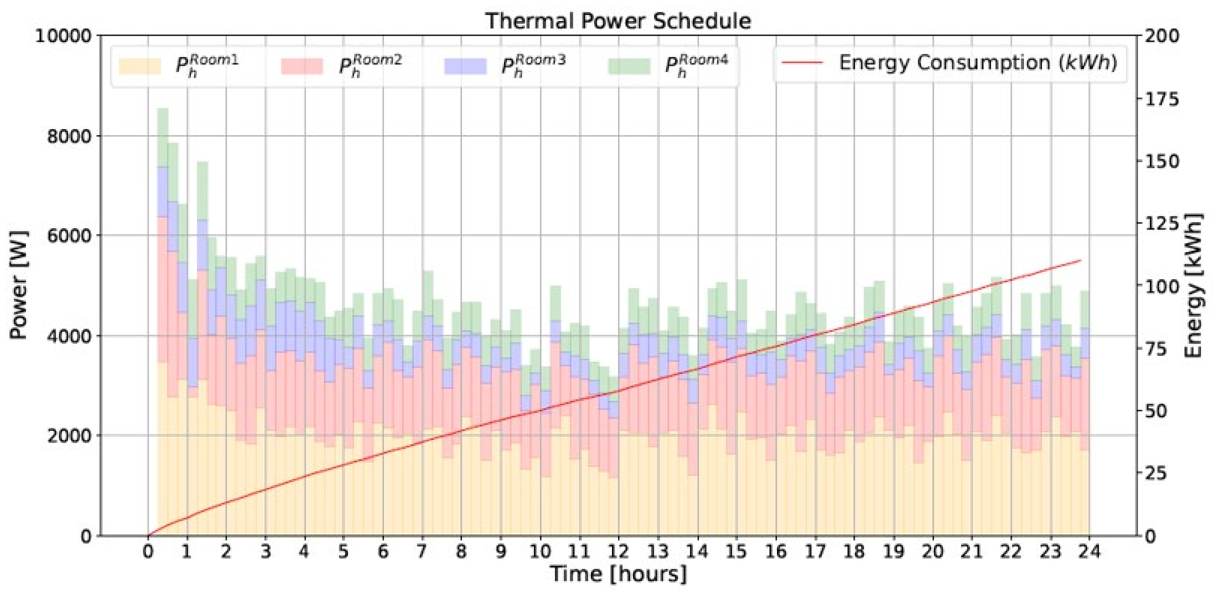




Generated FlexOffers

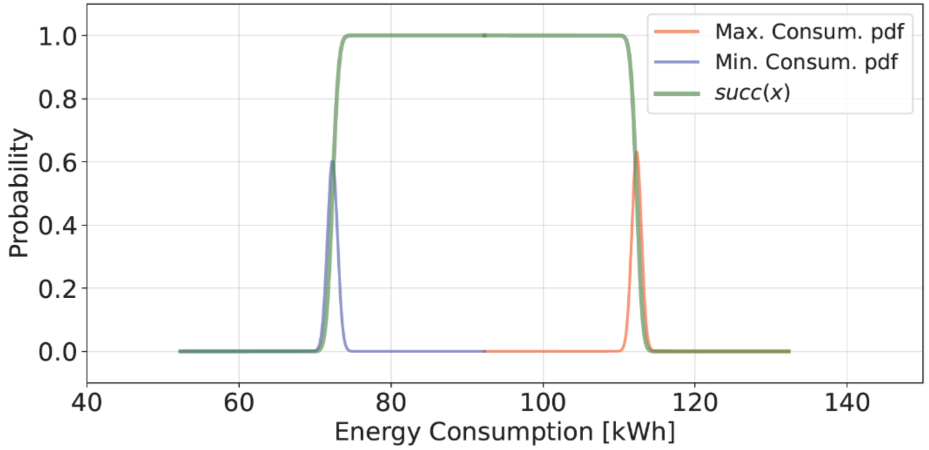
Maximum Energy Consumption





Generated FlexOffers

Available Energy Flexibility



Max. Avg. Consumption	30.36 [kWh]
Optimal Consumption	24.96 [kWh]
Min. Avg. Consumption	19.55 [kWh]
Available Flexibility	10.81 [kWh]
% Of Available Flexibility	43.3 %

Max Energy

Energy Flexibility

Min Energy

Thank You for Your Attention

Hessam Golmohamadi, SMIEE, has BSc, MSc, and Ph.D. in Power Electrical Engineering. He joined the Department of Energy, AAU, Denmark in 2018 to finalize his Ph.D. thesis. His research interests are intelligent energy systems, energy/demand flexibility, and smart grids. In 2020, he joined the Department of Computer Science, AAU as a postdoctoral fellow. Currently, he is working on Danish and EU projects, including FED and FEVER. The projects discuss flexibility potentialls of energy management systems, especially in residential heating systems.

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