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Demand Response for Ancillary Services: Thermal Storage Control

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Abstract:

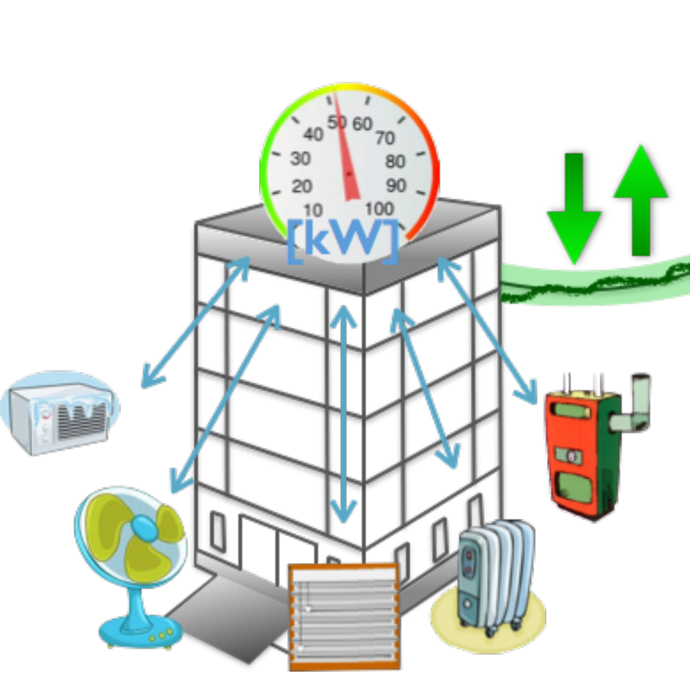
• In power grids, demand and supply must always be balanced, which is achieved by *ancillary services*. In Switzerland, these services are provided by generators, mainly hydro power plants.

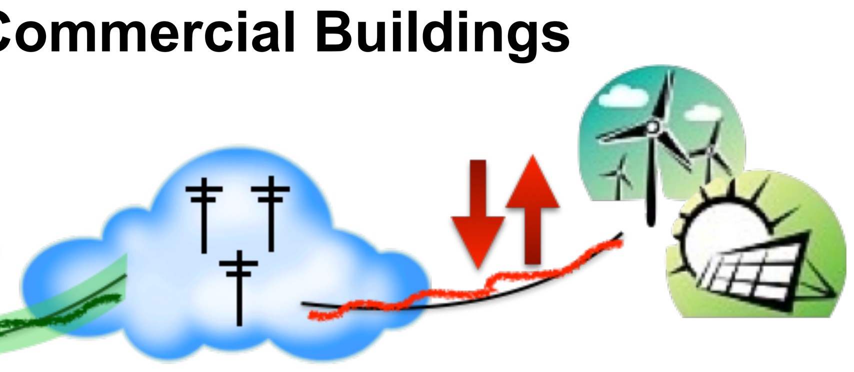
• The increase in renewable energy sources leads to an increase in uncertainty of power supply. Therefore, *additional ancillary services* are required to balance supply and demand.

Key Ideas:

- Control *demand side* to provide ancillary services through:
  - Control of HVAC systems of commercial buildings.
  - Control of appliances of thousands of households.
- Benefits of controlling the above thermal loads:
  - Integration of more renewable energy sources.
  - Higher quality and lower cost of ancillary services.

Reserve Provision of Commercial Buildings



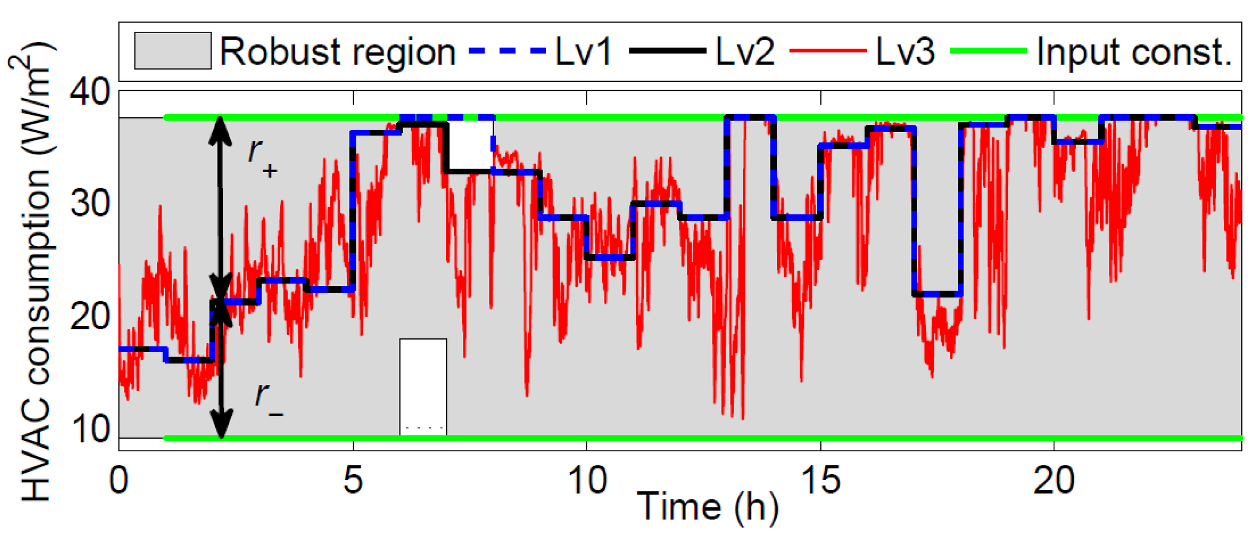


- To provide reserves, the buildings' flexibility is used, incurring higher operating costs.
- However, provision of the reserves is financially compensated.
- Challenge: find the optimal trade-off.

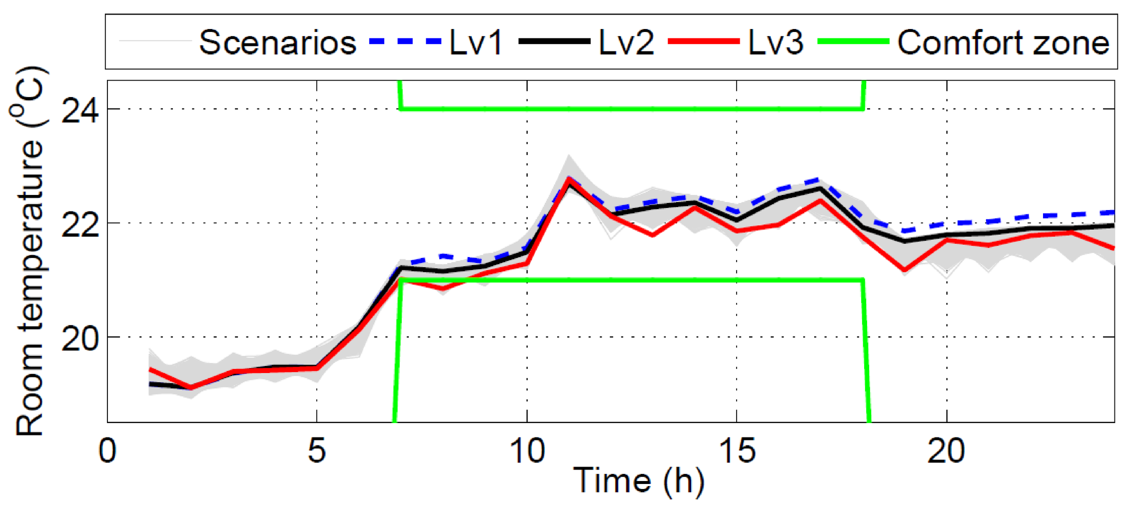
- Formulation as a tractable Convex Program [1]

minimize nominal operating cost of HVAC systems — maximize reward for offering frequency reserve capacity

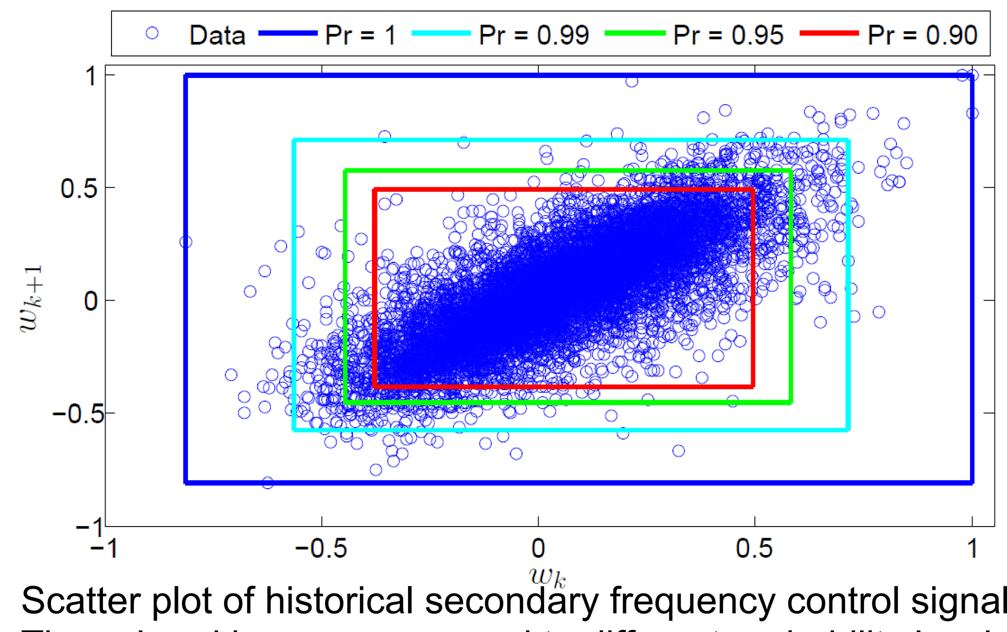
$$\begin{aligned}\min\ & \max_{\mathbf{w}\in\mathcal{W}} \{\mathbf{c}^\top \mathbf{e}(\mathbf{w})\} - \lambda \varrho(\mathcal{W})\\ \text{s.t.}\ & \boldsymbol{\pi}(\cdot)\in\mathcal{C}_s,\ \boldsymbol{\kappa}(\cdot)\in\mathcal{C},\\ & \mathcal{W} = \times_{k=0}^{N-1}[-Y_k, Y_k],\ \mathbf{Y}\geq 0\\ & \left.\begin{aligned} &\mathbf{x}(\mathbf{w}) = \mathbf{A}x_0 + \mathbf{B}(\boldsymbol{\pi}(\mathbf{w})+\boldsymbol{\kappa}(\mathbf{w})) + \mathbf{E}\mathbf{v},\\ &\mathbf{F}\,\mathbf{x}(\mathbf{w}) \leq \mathbf{f},\ \mathbf{G}(\boldsymbol{\pi}(\mathbf{w})+\boldsymbol{\kappa}(\mathbf{w}))\leq \mathbf{g},\\ &\mathbf{e}(\mathbf{w}) = \boldsymbol{\eta}^\top\boldsymbol{\pi}(\mathbf{w}),\ \mathbf{w} = \boldsymbol{\eta}^\top\boldsymbol{\kappa}(\mathbf{w}),\end{aligned}\right\}\ \forall \mathbf{w}\in\mathcal{W}.\end{aligned}$$



Building operation with a three-level hierarchical controller for frequency regulation. The first level computes the reserve capacity, the second level determines the HVAC system setpoints, and the third level modulates the power consumption to track the frequency regulation signal [3].



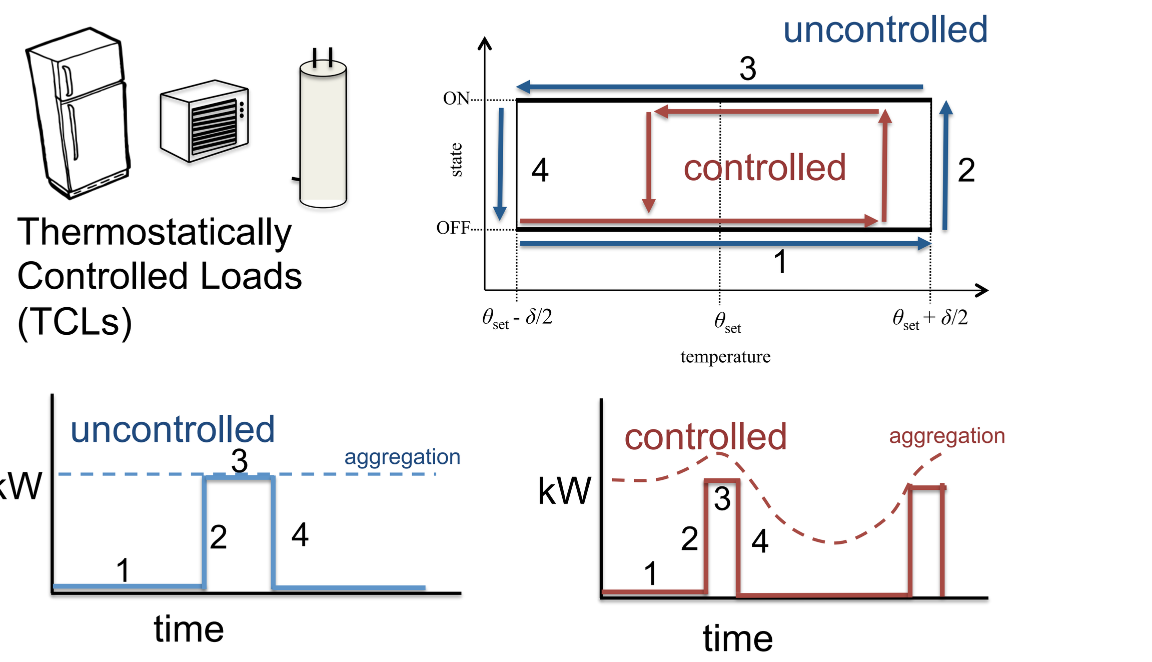
Trajectories of room temperature in the three levels of control. With proper control design, frequency reserves can be provided while respecting occupant comfort (staying within the comfort zone) [3].



Scatter plot of historical secondary frequency control signals. The colored boxes correspond to different probability levels. The larger the box, the more robust the solution, but the higher the cost [2].

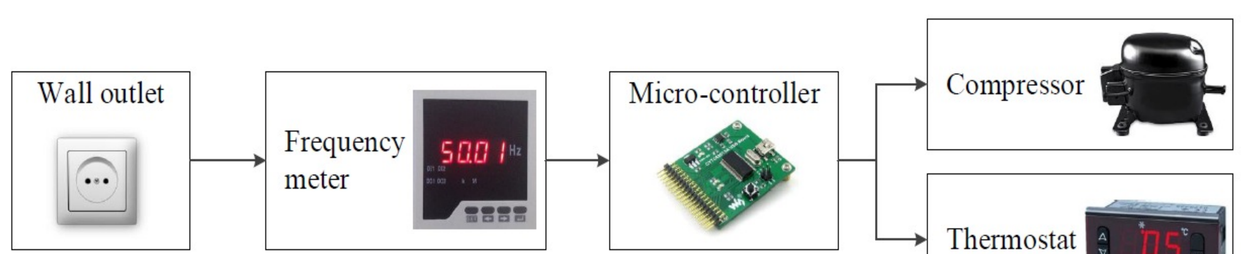
Reserve Provision of TCLs

Household appliances, referred to as thermostatically controlled Loads (*TCLs*), provide thermal storage and therefore can shift their demand. They operate within a temperature dead-band. An aggregation of large number of TCLs can be controlled by turning them on/off prematurely or by adjusting their temperature dead-band so to provide frequency reserves.

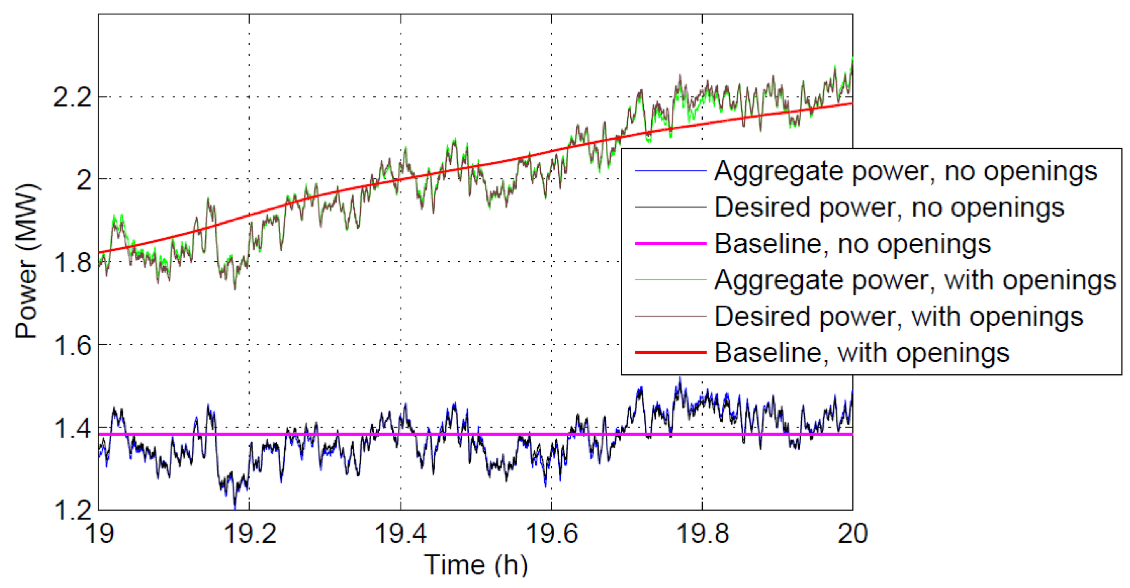


Thermostatically controlled loads, their dynamics modeled as on/off switches around a temperature dead-band, and the effects of switching control on individual and aggregate power consumption.

- Primary frequency control from refrigerators



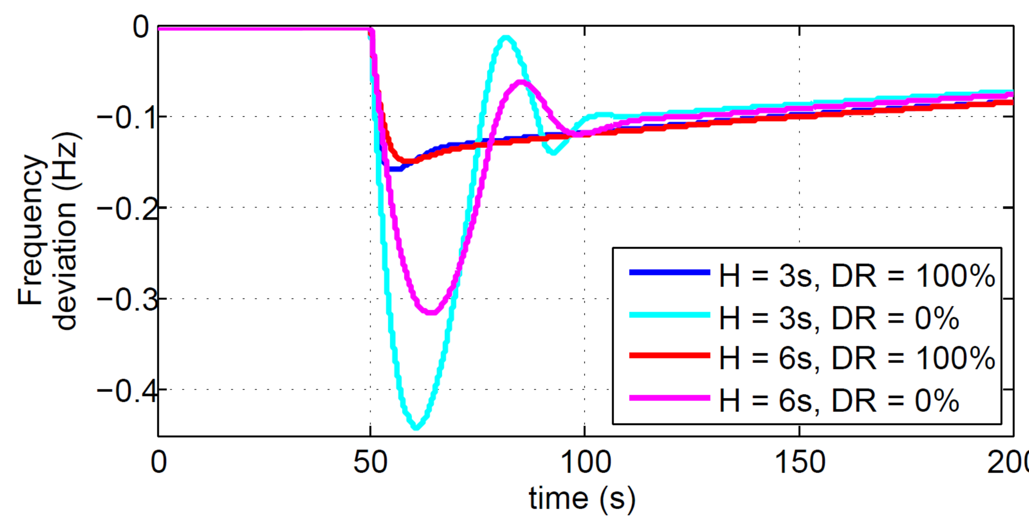
A large population of refrigerators can provide primary frequency control reserves in a decentralized way. The required hardware at the device level consists of a frequency meter, and a micro-controller to control the compressor's switch and modify the thermostat's temperature limits [4].



Activation of primary frequency control around the baseline consumption of a large refrigerator population subject to random door openings [5].

Additional topics addressed:

- Modeling approaches for TCL aggregations [6]
- State estimation to reduce communication in secondary frequency control [8]
- Effects of large penetration of loads in frequency control on power system dynamics [7]



Frequency trajectory after a sudden loss of 3 GW of generation in a two-area power system with and without demand response and for two inertia levels [7].

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[4] E. Vrettos, C. Ziras, and G. Andersson: Fast and Reliable Primary Frequency Reserves from Refrigerators with Decentralized Stochastic Control – Part I: Control Design and Benchmarking, IEEE Transactions on Power Systems (in review).
[5] E. Vrettos, C. Ziras, and G. Andersson: Fast and Reliable Primary Frequency Reserves from Refrigerators with Decentralized Stochastic Control – Part II: Robustness and Sensitivity Analysis, IEEE Transactions on Power Systems (in review).
[6] M. Kamgarpour, et al.: Modeling Options for Demand Side Participation of Thermostatically Controlled Loads, IREP Bulk Power System Dynamics & Control Symposium, Crete, Greece, August 2013.
[7] E. Vrettos, C. Ziras, G. Andersson: Integrating Large Shares of Heterogeneous Thermal Loads in Power System Frequency Control, IEEE PowerTech Conf., Grenoble, France, June 2015.
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