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Control of Residential Air-conditioning Loads to Provide Regulation Services under Uncertainties

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Background

Modern renewable energy generation by source, World
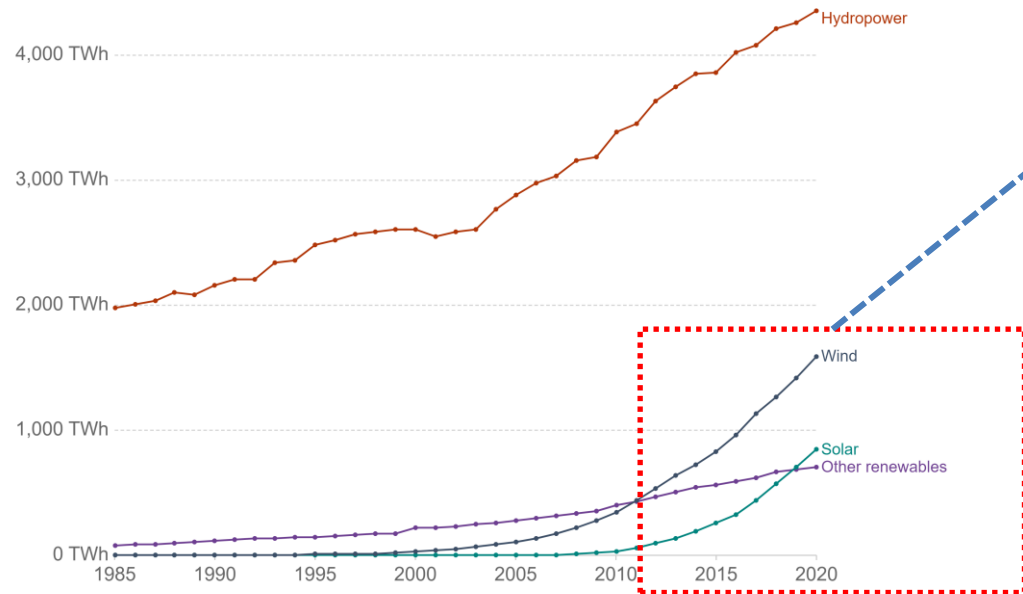
Source: Our World in Data based on BP Statistical Review of World Energy & Ember

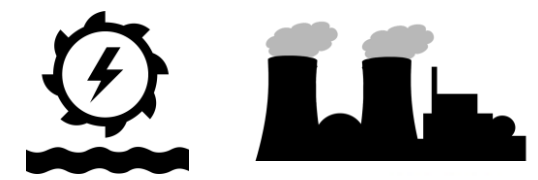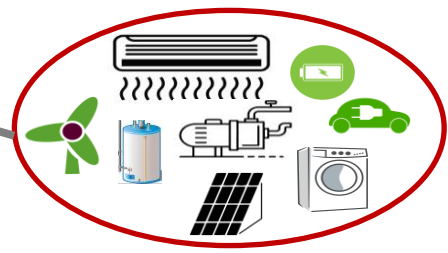OurWorldInData.org/renewable-energy • CC BY

Strong uptake of renewable generation

↓

Highly intermittent nature

↓

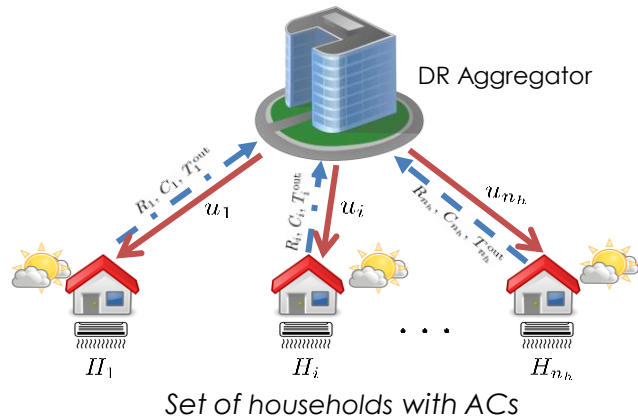Additional requirement of ancillary services

Alternative forms (e.g. DERs)

Conventional generation

HVAC is a potential candidate due to the presence of high thermal inertia.
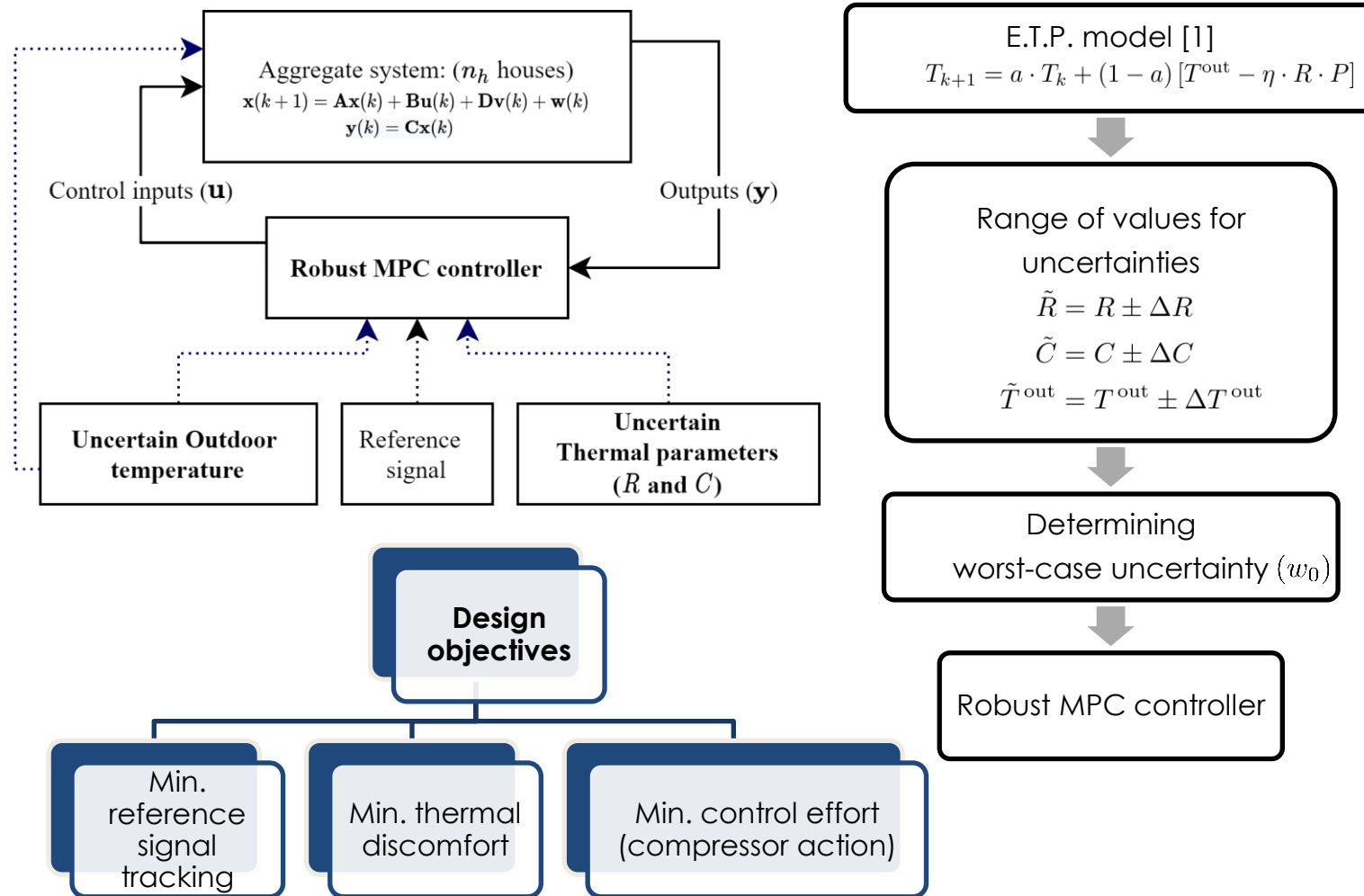
[1] https://ourworldindata.org/grapher/modern-renewable-prod

Existing work

DR Aggregator

Set of households with ACs
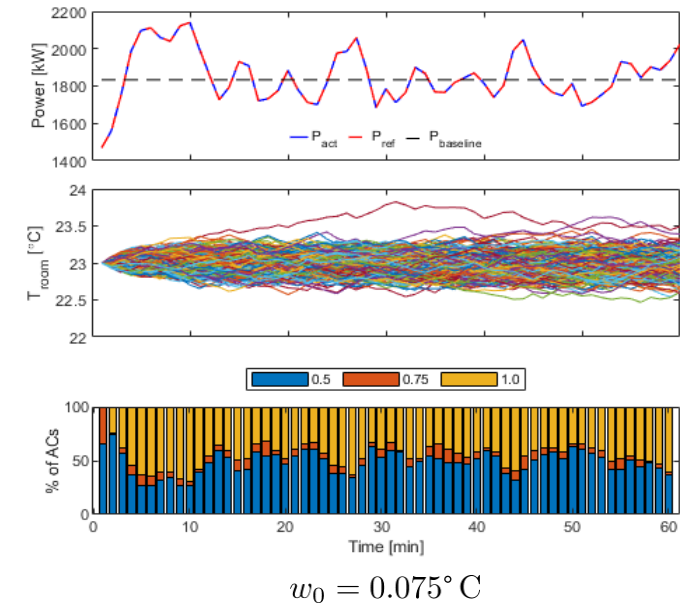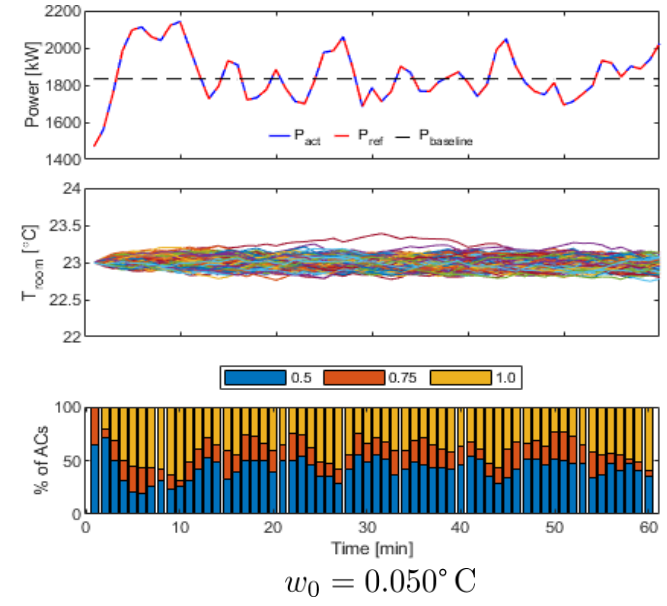
Challenges

- Handling uncertainties in,

  ✓ Household thermal parameters (R, C)

  ✓ Outdoor temperature forecasts (T^{out})

- Consistency with modern inverter-type air conditioners

- Compliance with existing DR standards

Proposed approach

Aggregate system: (n_h houses)
$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{B}\mathbf{u}(k) + \mathbf{D}\mathbf{v}(k) + \mathbf{w}(k)$$
$$\mathbf{y}(k) = \mathbf{C}\mathbf{x}(k)$$

Control inputs ($\mathbf{u}$)　　　　Outputs ($\mathbf{y}$)

Robust MPC controller

| **Uncertain Outdoor temperature** | Reference signal | **Uncertain Thermal parameters (R and C)** |

Design objectives

- Min. reference signal tracking
- Min. thermal discomfort
- Min. control effort (compressor action)

E.T.P. model [1]
$$T_{k+1} = a \cdot T_k + (1 - a)\left[T^{\text{out}} - \eta \cdot R \cdot P\right]$$

Range of values for uncertainties
$$\tilde{R} = R \pm \Delta R$$
$$\tilde{C} = C \pm \Delta C$$
$$\tilde{T}^{\text{out}} = T^{\text{out}} \pm \Delta T^{\text{out}}$$

Determining worst-case uncertainty (w_0)

Robust MPC controller

[1] J. Mathieu, S. Koch and D. Callaway, "State estimation and control of electric loads to manage real-time energy imbalance," 2013 IEEE Power & Energy Society General Meeting, Vancouver, BC, 2013, pp. 1-1, doi: 10.1109/PESMG.2013.6672144.

Results

Parameter	Description
R	1.5-2.5 °C/kW
C	1.5-2.5 °C/kW
η	2.5
P_{rated}	2.5 kW
$[\underline{T}, \overline{T}]$	[22, 24]°C
T_{set}	23 °C
ΔT	1-min
N	3-mins
T_{duration}	1-hour
n_h	1000

- Reference signal obtained from PJM markets

AS 4755 DR standards [1]

Mode	Action
DRM- 1	Compressor off
DRM- 2	Limit to 50% rated
DRM- 3	Limit to 75% rated

$w_0 = 0.050°\,\text{C}$

$w_0 = 0.075°\,\text{C}$

As the degree of uncertainty increases, the majority of the ACs operate at their extreme limits to avoid temperature violations.

Trade-off between tracking performance and thermal comfort

$w_0 = 0.020°\,\text{C}$
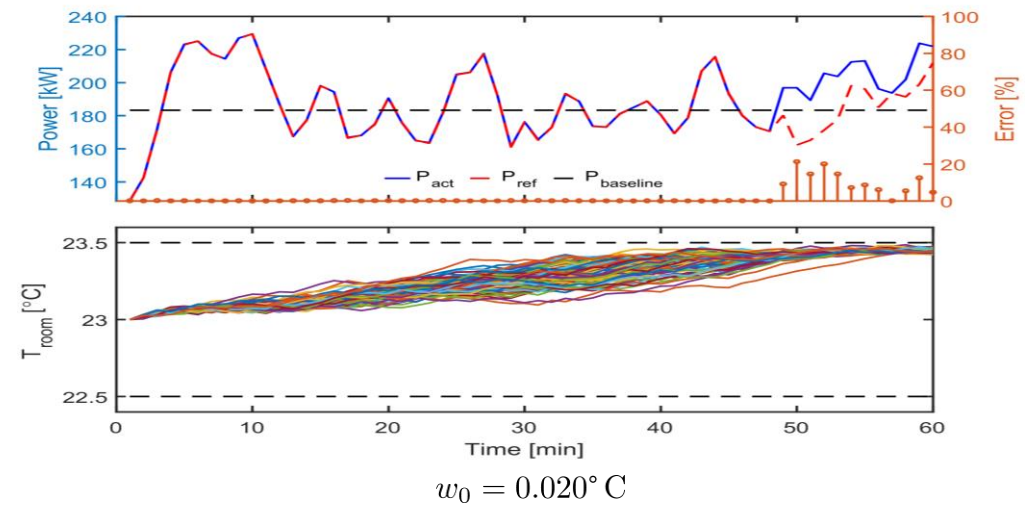
Towards the end of the event, the tracking performance is compromised to maintain thermal comfort.

[1] https://www.energex.com.au/home/control-your-energy/positive-payback-program/positive-payback-for-business/air-conditioning-rewards

Conclusion

- A real-time control approach to provide regulation services from residential inverter-type air conditioners under uncertainties.

- The approach under discrete power consumption levels is consistent with existing DR standards.

- Future work includes developing distributed control schemes to preserve end-user data privacy.