

# Empowering Smart Energy Communities: Connecting Buildings, People, and Power Grids



## Background and Motivation

- In today's interconnected world, over half of the population (54%) lives in urban areas.
- While cities only cover 2% of global land area, they consume about 75% of global primary energy and account for 70% of greenhouse gas emissions.
- Smart energy communities can significantly enhance the reliability of the smart grid, reduce energy consumption, GHG emissions, and improve the quality of life for building occupancy.

## Definition of Smart Energy Communities

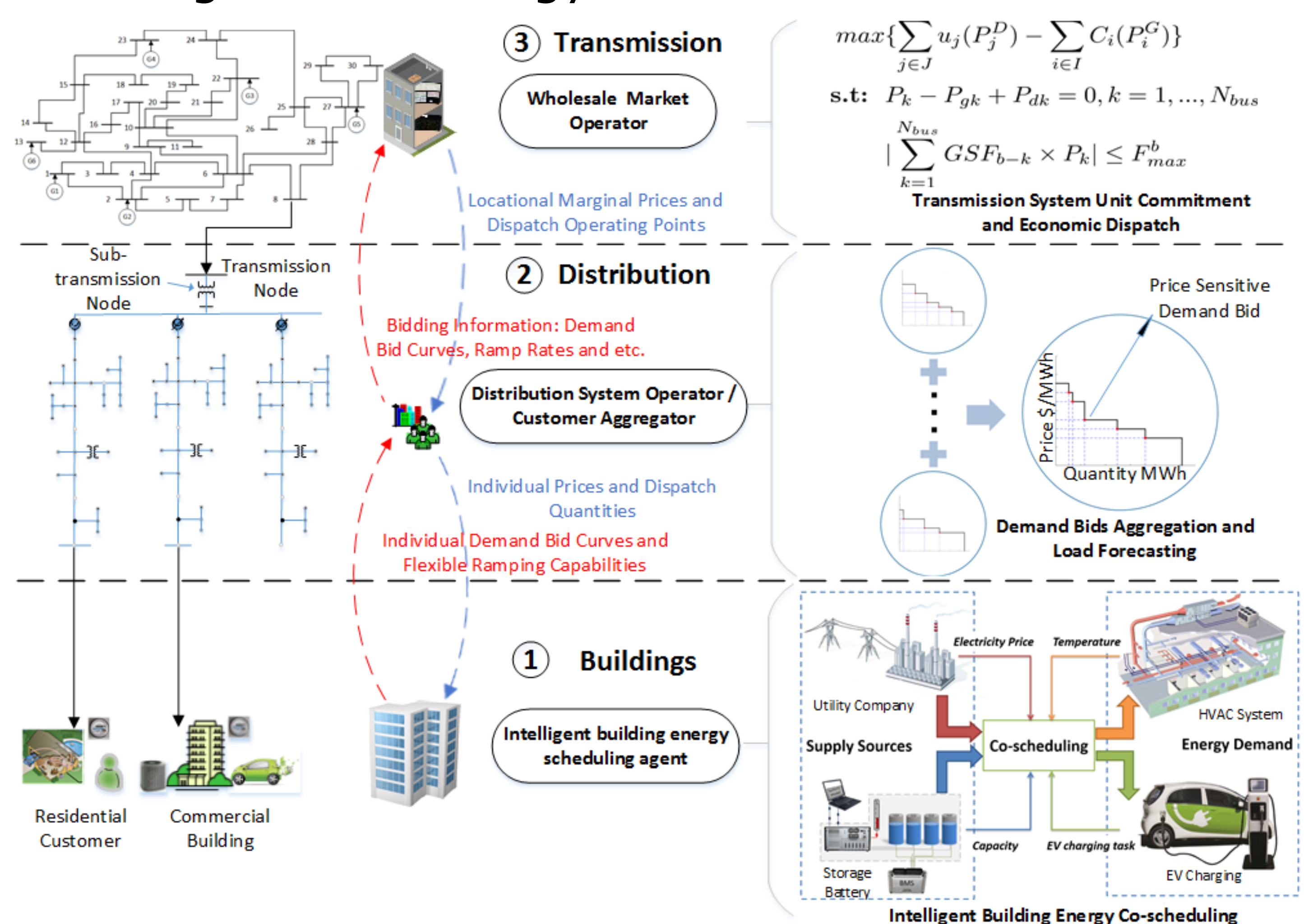
- *Seamless connection* of smart buildings, smart grid, and people facilitated by rapid deployment of ubiquitous sensor networks, two-way communication networks, and intelligent devices in smart buildings and electric grids.

Smart Energy Communities



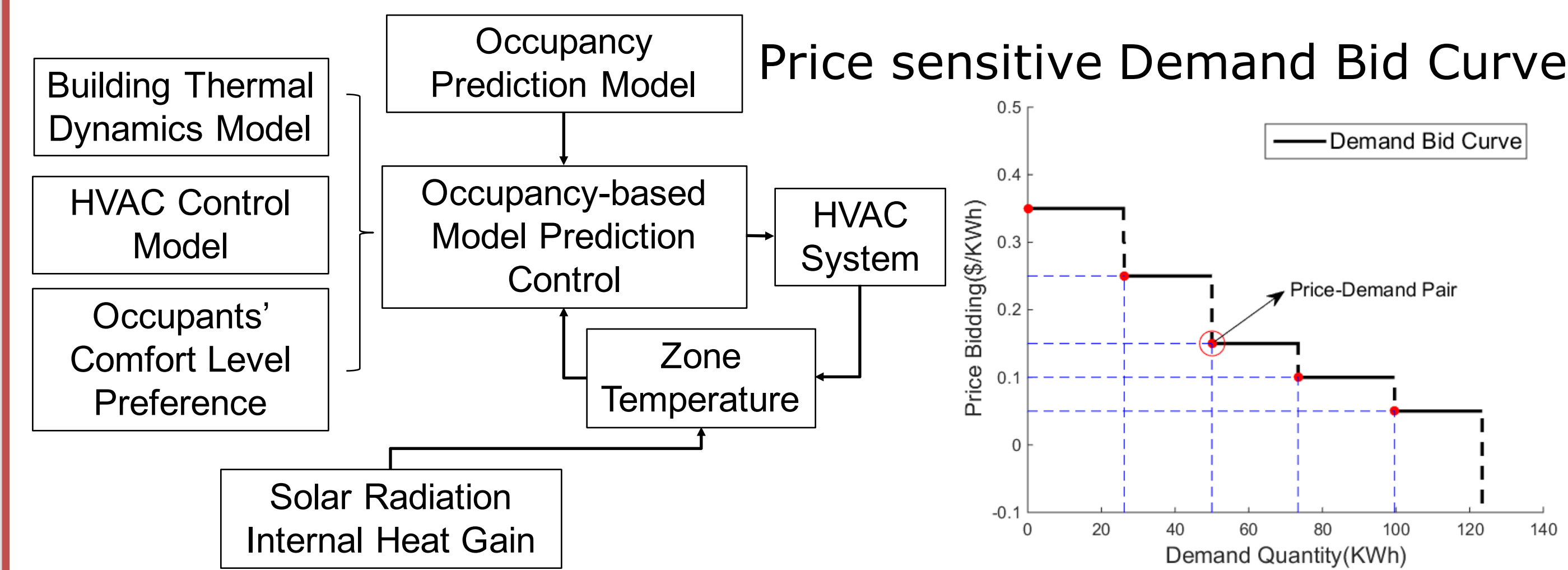
## Problems & Overall Framework

- There is no *holistic framework* to analyze and manage smart energy communities.



## Energy Efficient Building Control with Real-time Occupancy Prediction

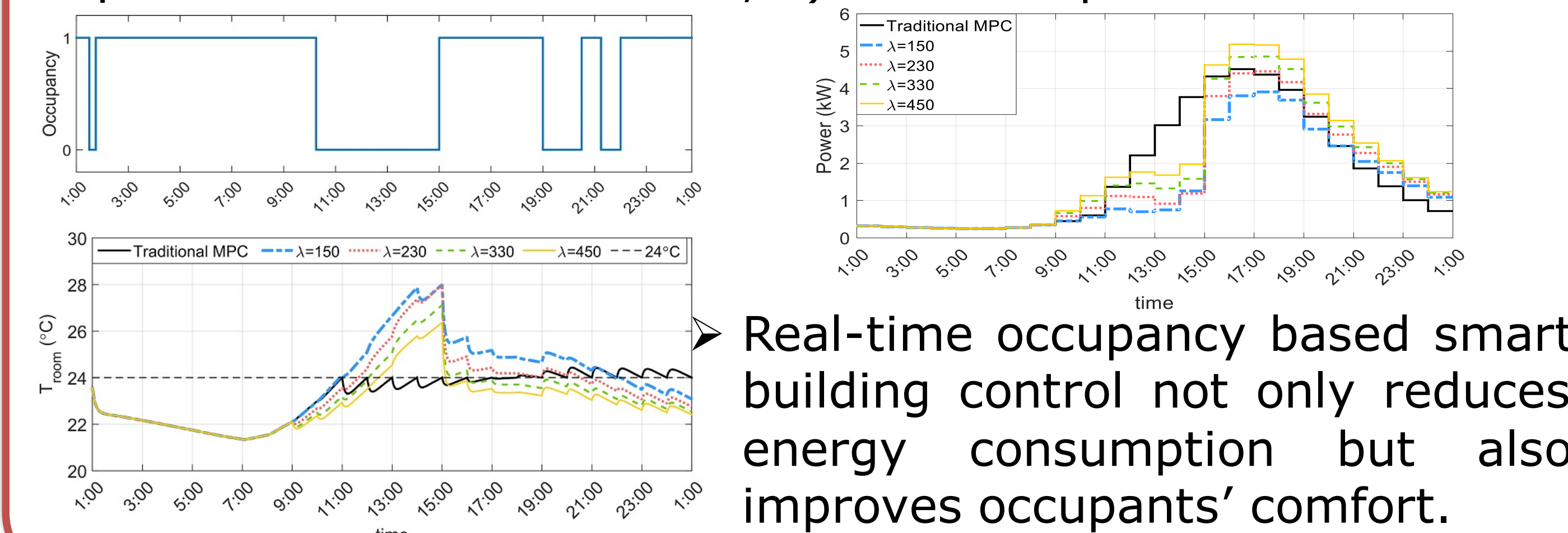
How to convert building occupants' preferences, objectives, and building control models into electricity market compatible bidding information?



Minimize energy cost and building occupant discomfort

$$\min \sum_{t=i}^{i+\omega-1} [p_g(t) \cdot e_g(t) + \lambda P(y(t) = 1)(T_{room}(t) - T_{desire})^2]$$

Subject to 1) building thermal dynamic model constraints, 2) air flow volume constraints, 3) energy storage and demand response resource constraints, 4) room temperature constraints.



➢ Real-time occupancy based smart building control not only reduces energy consumption but also improves occupants' comfort.

## DERs and Smart Buildings Operation Coordination with Three-phase OPF

- The deployment of distributed energy resources (DERs) in the power distribution system has grown exponentially in the past ten years.
- The operations of millions of smart buildings and DERs need to be coordinated.
- A distribution system operator (DSO) managed electricity market seems to be a viable solution.
- Three-phase optimal power flow (OPF) algorithm enabling DSO market is still in its infancy.

## Three-phase ACOPF

- Highly non-linear and nonconvex
- Semidefinite Programming Relaxation Method only works for single-phase tree networks.

$$\min_X C(X) \quad \text{Minimize total power purchase cost}$$

Subject to

$$P_{G_k}^p - P_{D_k}^p = \text{Tr}\{Y_k^p X\}, k \in N \setminus G \quad Q_{G_k}^p - Q_{D_k}^p = \text{Tr}\{\bar{Y}_k^p X\}, k \in N \setminus G$$

$$\text{Tr}\{Y_{ik}^p X\}^2 + \text{Tr}\{\bar{Y}_{ik}^p X\}^2 \leq (S_{ik}^{p, \max})^2, i, k \in N$$

$$(\underline{V}_k^p)^2 \leq \text{Tr}\{M_k^p X\} \leq (\bar{V}_k^p)^2, k \in N \quad X = VV^T$$

$$X \succeq 0 \text{ and } \text{rank}(X) = 1$$

## Chordal Conversion based Convex Iteration Algorithm

- The convex iteration technique solves the rank-1 conundrum by expressing the original problem as iteration of convex problem sequence.

Convex Problem 1      Convex Problem 2

$$\min_X C(X) + \omega \text{Tr}(XW^*) \quad \min_{W \in S^N} \text{Tr}(X^*W)$$

$$\text{s.t. } X \in B \quad X \succeq 0 \quad \text{s.t. } 0 \preceq W \preceq I \quad \text{Tr}(W) = N_X - 1$$

- The chordal based conversion algorithm exploits the sparsity of radial network by converting the large SDP problem into another form with smaller-sized positive semidefinite variables.

- The proposed three-phase OPF algorithm is computationally efficient and highly scalable. It is also capable of finding global optimal solutions for all IEEE distribution circuit test cases.

## Numerical Results

- Feasibility and Optimality of Proposed Algorithm

Test System	Method	Rank of Solution	Objective value (\$/hour)
4-bus test feeder	SDP relaxation	3	3085.6
	Convex iteration	1	3121.9
13-bus test feeder	SDP relaxation	3	2319.5
	Convex iteration	1	2345.4
37-bus test feeder	SDP relaxation	1	1739.5
	Convex iteration	1	1739.5
123-bus test feeder	SDP relaxation	6	2413.6
	Convex iteration	1	2413.6
906-bus test feeder	SDP relaxation	6	38.219
	Convex iteration	1	38.149

- Scalability of Proposed Algorithm

Test System	Computation time (s)	Number of iterations	Number of nonzero elements
4-bus test feeder	0.373	4	$2.95 \times 10^4$
13-bus test feeder	8.714	16	$3.61 \times 10^5$
37-bus test feeder	3.261	1	$2.06 \times 10^6$
123-bus test feeder	27.128	3	$4.93 \times 10^6$
906-bus test feeder	217.099	11	$1.19 \times 10^7$