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

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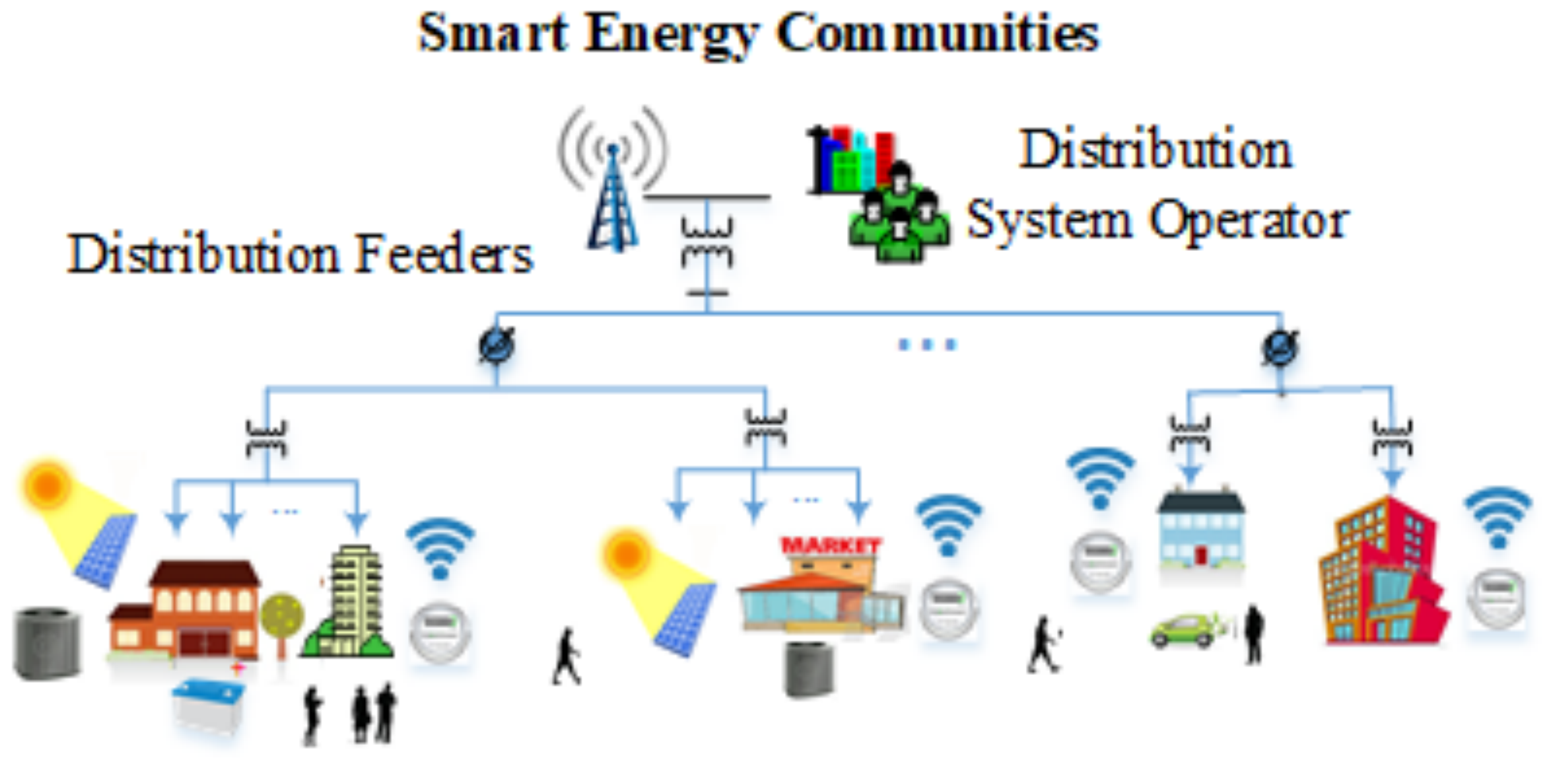
Background and Motivation

- 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.

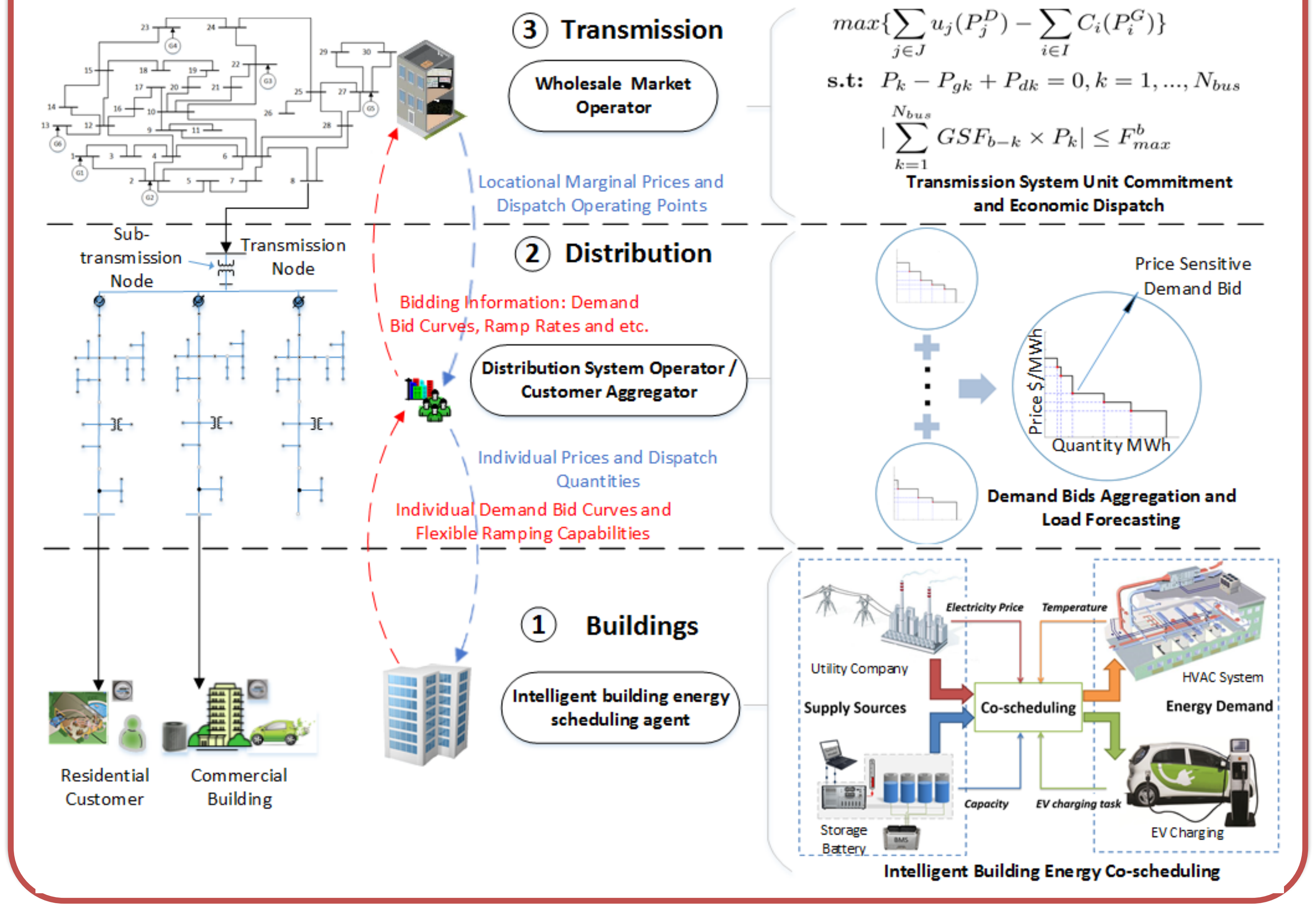
Definition of Smart Energy Communities

- *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.



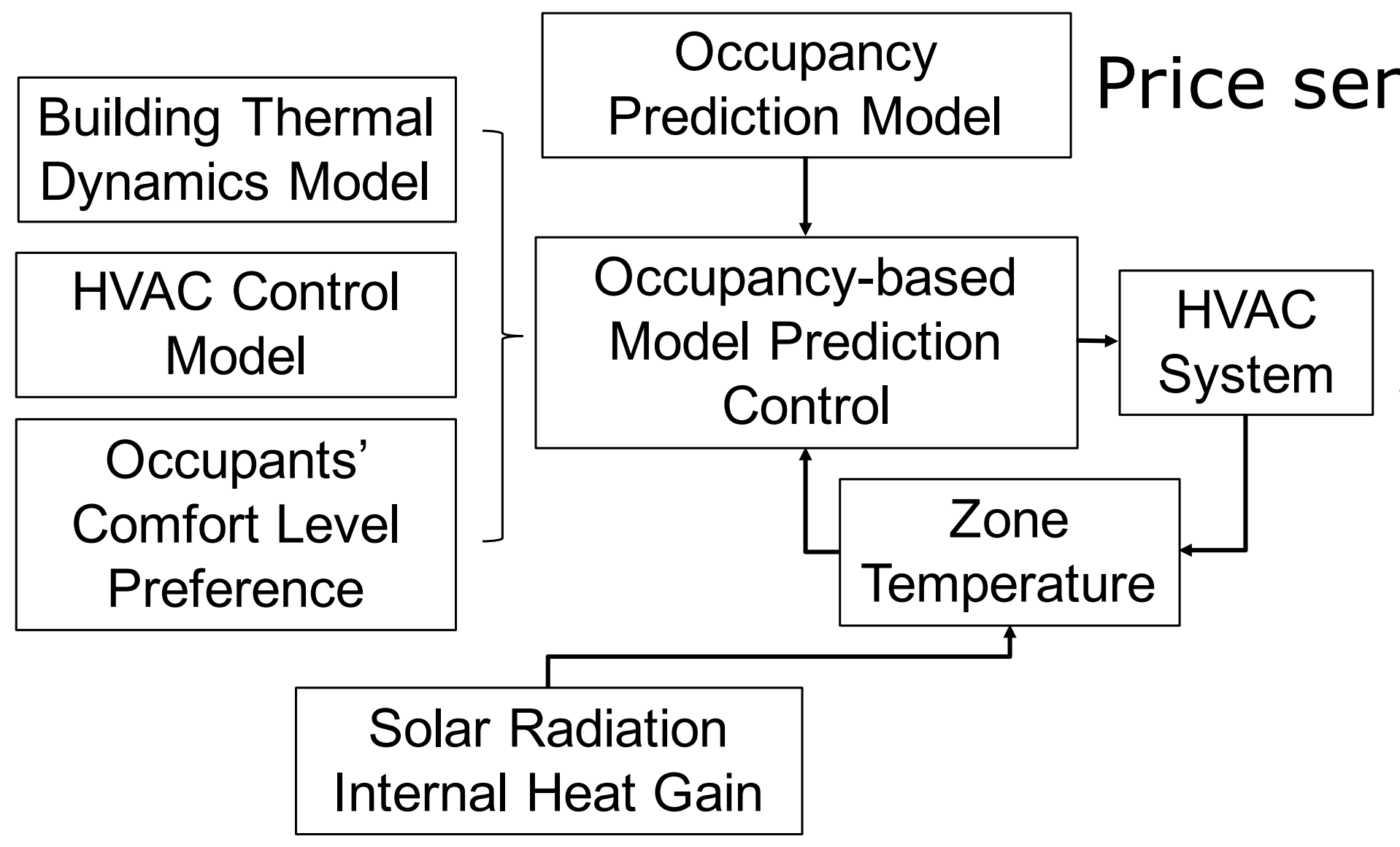
Problems & Overall Framework

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

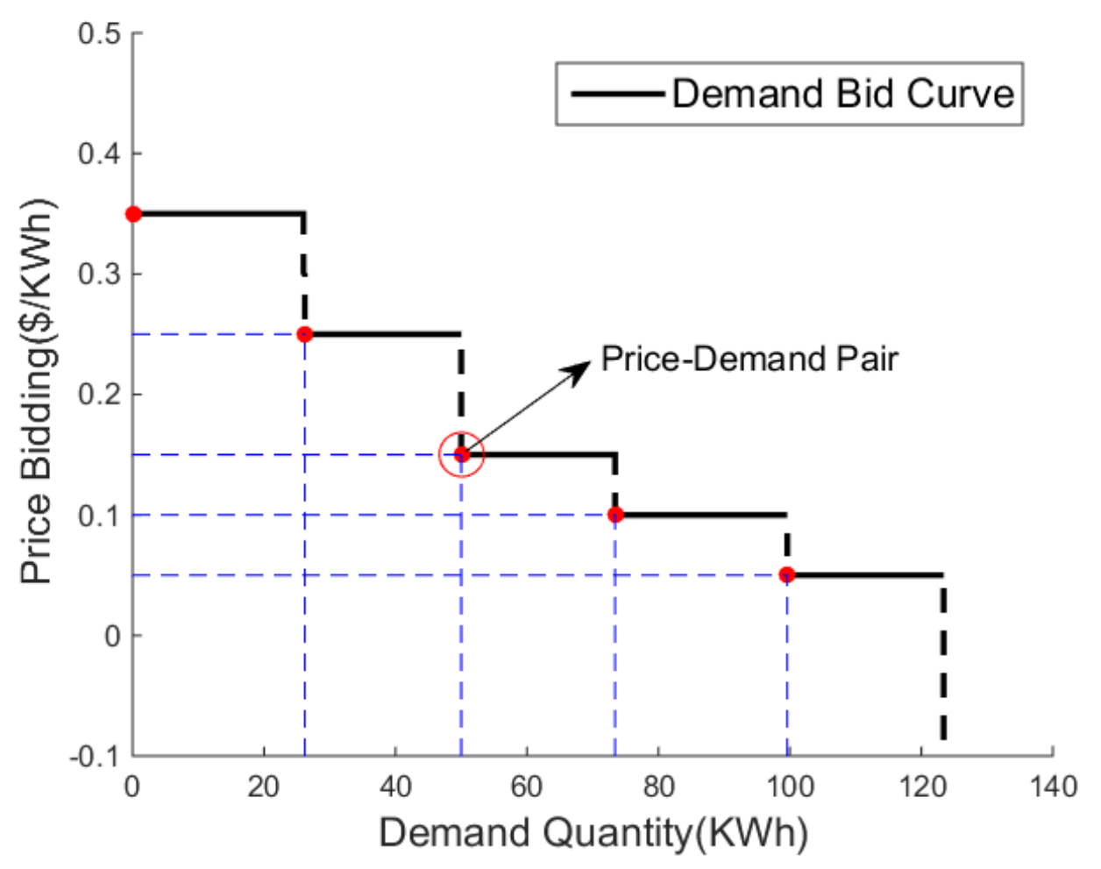


Energy Efficient Building Control with Real-time Occupancy Prediction

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



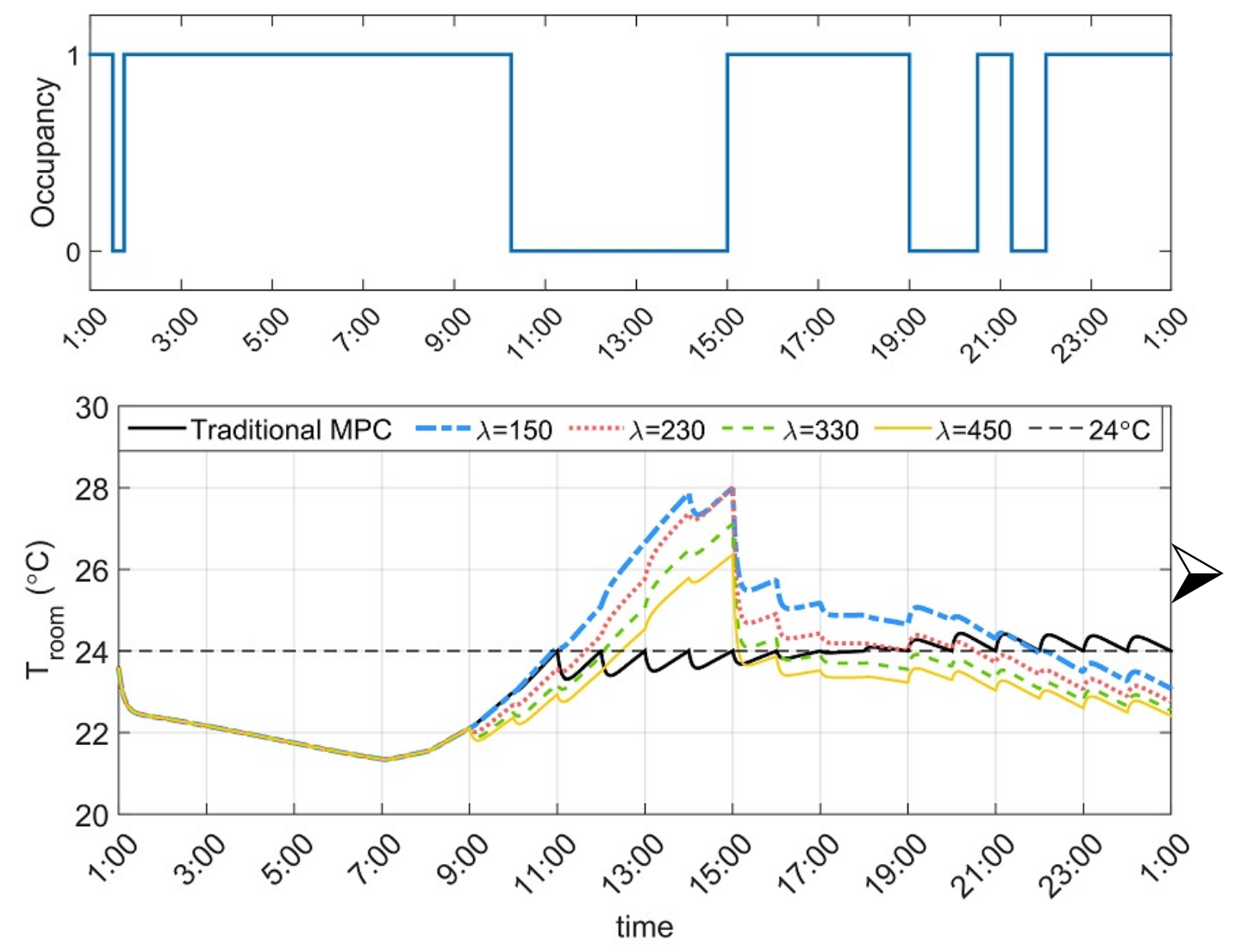
Price sensitive Demand Bid Curve

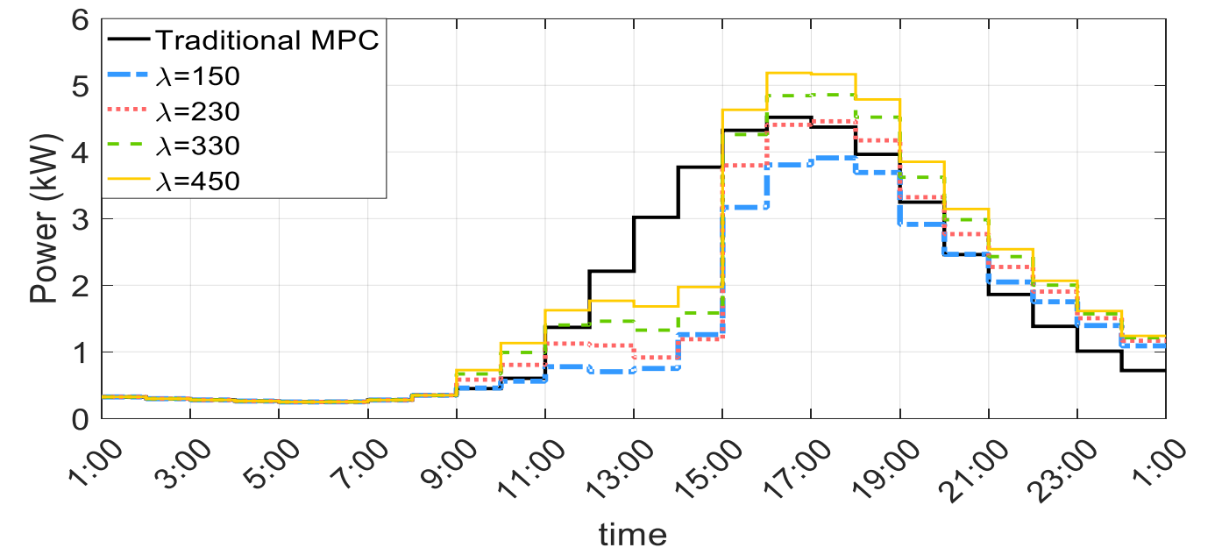


Minimize energy cost and building occupant discomfort

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

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.

Numerical Results

- Feasibility and Optimality of Proposed Algorithm

Test System	Method	Rank of Solution	Objective value ($/hour)
4-bus test feeder	SDP relaxation Convex iteration	3 1	3085.6 3121.9
13-bus test feeder	SDP relaxation Convex iteration	3 1	2319.5 2345.4
37-bus test feeder	SDP relaxation Convex iteration	1 1	1739.5 1739.5
123-bus test feeder	SDP relaxation Convex iteration	6 1	2413.6 2413.6
906-bus test feeder	SDP relaxation Convex iteration	6 1	38.219 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 × 104
13-bus test feeder	8.714	16	3.61 × 105
37-bus test feeder	3.261	1	2.06 × 106
123-bus test feeder	27.128	3	4.93 × 106
906-bus test feeder	217.099	11	1.19 × 107

DERs and Smart Buildings Operation Coordination with Thee-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.

$\min_X C(X)$ Minimize total power purchase cost

Subject to

$$P_{G_k}^p - P_{D_k}^p = Tr\{Y_k^p X\}, k \in N\backslash G \qquad Q_{G_k}^p - Q_{D_k}^p = Tr\{\overline{Y_k^p} X\}, k \in N\backslash G$$

$$Tr\{Y_{ik}^p X\}^2 + Tr\{\overline{Y_{ik}^p} X\}^2 \leq \left(S_{ik}^{p\,max}\right)^2, i,k \in N$$

$$(\underline{V_k^p})^2 \leq Tr\{M_k^p X\} \leq (\overline{V_k^p})^2, k \in N \qquad X = VV^T$$

$$\updownarrow$$

$X \succcurlyeq 0$ and $rank(X) = 1$

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

$$\min_X C(X) + \varpi Tr(XW^*)$$

s.t. $X \in B \quad X \succcurlyeq 0$

Convex Problem 2

$$\min_{W \in S^N} Tr(X^* W)$$

s.t. $0 \preccurlyeq W \preccurlyeq I \quad Tr(W) = N_X - 1$

- 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.