Electric Vehicles-Building Nexus: Optimal Charging and Load Management Solutions

Shanshan Liu MSc[1]; Alex Vlachokostas PhD[2]; Chen Si[3]; Eleftheria Kontou PhD[1]
1 Civil and Environmental Engineering, University of Illinois Urbana-Champaign; 2 Optimization and Controls Group, Pacific Northwest National Laboratory; 3 Computer Science, University of Illinois Urbana-Champaign | Corresponding author: kontou@illinois.edu

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INTRODUCTION

Significant office **building energy savings** can be realized through control strategies, like heating, ventilation, and air conditioning (HVAC) setpoint adjustments and daylighting control for corporate sustainability. **Workplace charging (WPC)** enables the collocation of flexible electric vehicle (EV) charging loads with office building loads.

Objectives

- **management of the EVs-Building nexus** and determining the number of EVs that corporate office building energy savings (HVAC setpoint adjustments, daylighting control) can enable charging
- **simulating building energy savings by HVAC setpoint adjustment and daylighting control** in typical medium office buildings in three US metropolises of **different climate regions**
- **a mathematical model to minimize charging costs under time-of-use electricity pricing schemes** for a given EV hosting capacity of saved office energy and patterns of roundtrip commuting

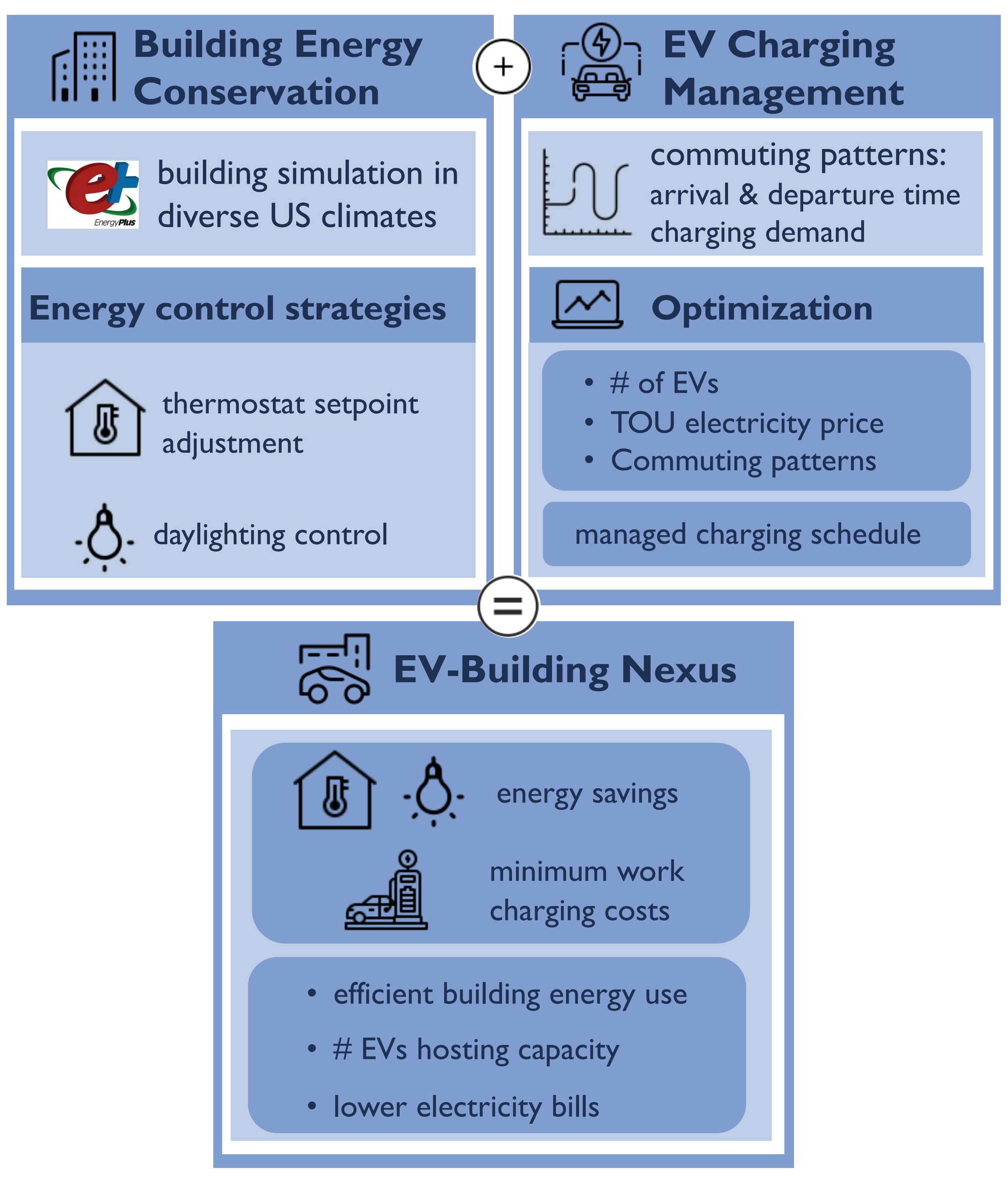

Fig 1. Research approach for managing the EVs-building nexus

Methods: Building Energy Simulation

A DOE medium office building, with a base HVAC cooling setpoint of 24°C and heating setpoint of 21°C, and lighting illuminance level of 900 lux has two control strategies to reduce total energy use:

- **Control strategy 1**: **adjust the building's thermostat temperature setpoint from 24 to 26°C**, with a step of 0.5°C during the summer period (June-August); **21 to 19°C** with a step of 0.5°C during the winter period (December-February)
- **Control strategy 2**: the daylighting control calculates the contribution of daylight and **dims the electric lighting to meet a target illuminance level** in the office (two illuminance levels of 300 and 500 lux)

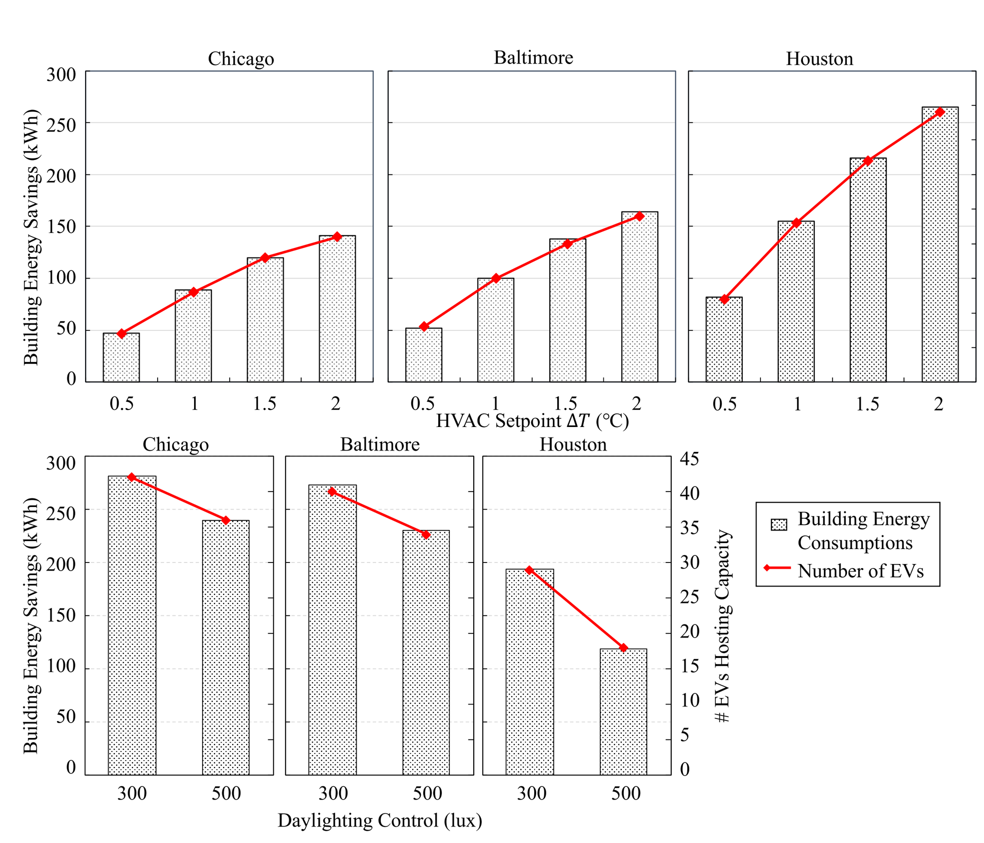

Fig 2. Building energy savings from summer office building control strategies and the corresponding EVs charging capacity in Chicago IL, Baltimore MD, and Houston TX

Methods: EV Charging Management

❑ **Input**

- Charging patterns: arrival and departure times, charging demand, and #EVs charging capacity for corporate energy efficiency
- Charger allocation: a matrix assigning EVs to a specific charger

$$\delta_{i,n} = \begin{cases} 1, & \text{if EV } n \text{ charges at charger } i \\ 0, & \text{otherwise} \end{cases}, \forall n \in N, i \in I$$

$$\sum_{i=1}^{I} \delta_{i,n} = 1, \forall n \in N$$

$$L_{i,m} = \sum_{n=1}^{m} \delta_{i,n}, \text{if } \delta_{i,m} = 1$$

- Electricity price: time-of-use electricity pricing scheme
- Charger specification: charger type and technical specifications (power levels)

❑ **Optimization Model**

- **Objective:** min EV charging costs

$$\min \sum_i \sum_t Cost(t) \cdot y_{i,t}$$

- **Constraints**:

Charging session assignment with shared chargers based on arrival/departure time, and charging demand

$$\begin{cases} \sum_{t=t_n^a}^{t_m^a} y_{i,t} \le D_n \\ \sum_{t=t_n^d}^{t_m^d} y_{i,t} \le D_m \end{cases}, \text{if } t_n^a \le t_m^a \,\&\, t_n^d \le t_m^d \,\&\, \delta_{i,n} = \delta_{i,m} = 1 \,\&\, L_{i,n} + 1 = L_{i,m}, \forall i \in I$$

$$\begin{cases} \sum_{t=t_n^a}^{t_m^a} y_{i,t} \le D_n \\ \sum_{t=t_n^a}^{t_m^d} y_{i,t} \ge D_n + D_m \end{cases}, \text{if } t_n^a \le t_m^a \,\&\, t_n^d \ge t_m^d \,\&\, \delta_{i,n} = \delta_{i,m} = 1 \,\&\, L_{i,n} + 1 = L_{i,m}, \forall i \in I$$

$$\begin{cases} \sum_{t=t_n^a}^{t_n^d} y_{i,t} \ge D_n \\ \sum_{t=t_n^d}^{t_m^d} y_{i,t} \le D_m \end{cases}, \text{if } t_n^a \ge t_m^a \,\&\, t_n^d \le t_m^d \,\&\, \delta_{i,n} = \delta_{i,m} = 1 \,\&\, L_{i,n} + 1 = L_{i,m}, \forall i \in I$$

$$\begin{cases} \sum_{t=t_n^a}^{t_n^d} y_{i,t} = D_n \\ \sum_{t=t_m^a}^{t_m^d} y_{i,t} = D_m \end{cases}, \text{if } [t_n^a, t_n^d] \cap [t_m^a, t_m^d] = \emptyset \,\&\, \delta_{i,n} = \delta_{i,m} = 1 \,\&\, L_{i,n} + 1 = L_{i,m}, \forall i \in I$$

$$\sum_{t=t_n^a}^{t_m^d} y_{i,t} \ge D_n + D_m, \text{if } t_n^a \ge t_m^a \,\&\, t_n^d \ge t_m^d \,\&\, \delta_{i,n} = \delta_{i,m} = 1 \,\&\, L_{i,n} + 1 = L_{i,m}, \forall i \in I$$

Charging availability constraints

$$y_{i,t}\delta_{i,n} = 0, \forall t \in [t_n^a, t_n^d], i \in I, n \in N$$

EV charging demand constraints

$$\sum_{t=t_n^a}^{t_n^d} y_{i,t} = D_n, \text{if } \delta_{i,n} = 1, i \in I, n \in N$$

Charging power constraints

$$0 \le y_{i,t} \le P_{max}, \forall i \in I, t \in T$$

RESULTS

We implement building efficiency control strategies and optimal EV charging schedules in one average daily demand case, i.e., 6.71 kWh/EV, 6.76 kWh/EV, 7.06 kWh/EV in Chicago IL, Baltimore MD, and Houston TX, and one hundred synthetic demand cases.

Results with Cooling Setpoint Adjustments

- in Chicago IL, the volumetric electricity bill portion under HVAC setpoint adjustments remains constant even with increased EV charging loads
- in Baltimore MD and Houston TX, the cost savings between unmanaged and managed charging plans are on the rise, increasing from $0.42 to $0.92 in Baltimore MD, and from $3.78 to $28.87 in Houston TX, as more EVs are hosted in the workplace lot

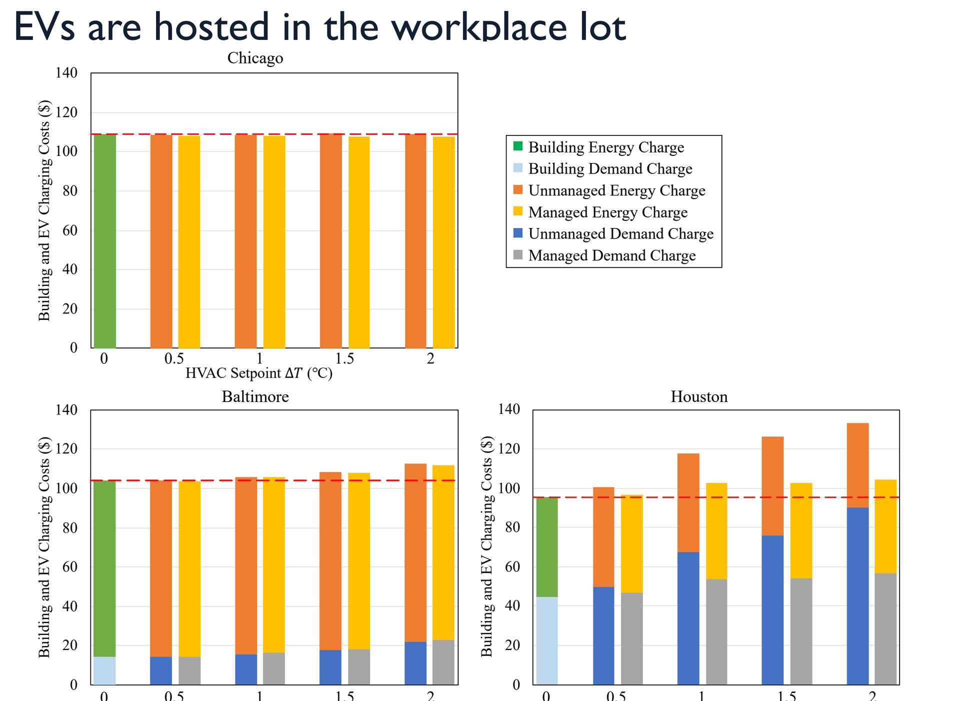

Fig 3. Building and EV charging costs

RESULTS

Results with Cooling Setpoint Adjustments

- in Houston, the managed building and EV charging costs in +1.5°C is lower than in +1°C scenarios, because the ratio of EVs to chargers is 2.875, 3.2 and 3 in the +1, +1.5 and +2°C scenarios, respectively. This suggests that fewer EVs can charge at the same time in the +1.5 °C scenario, which can make the peak load and demand charge lower.

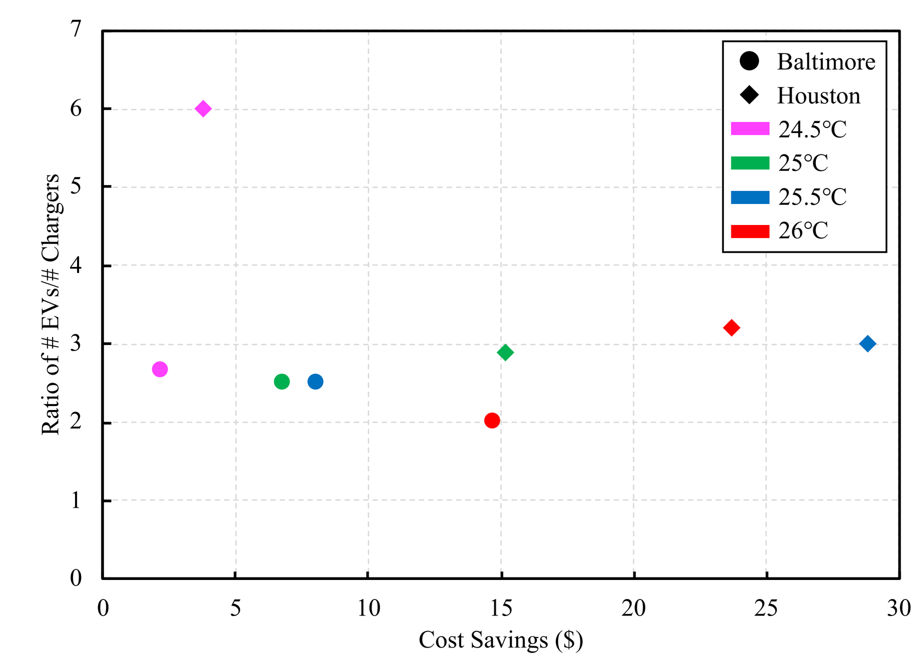

Fig 4. Relationship between the ratio of EVs to chargers and the building and EV charging saving costs

Results with Daylighting Control

- in the average demand case, the managed charging profile performs better in 300 lux scenarios in Chicago, Baltimore, and Houston than in the 500 lux scenarios;
- in the synthetic cases, the ranges of charging savings, charging savings per EV, and the ratio of savings to FCFS costs are wider in the 300 lux scenarios than in the 500 lux scenarios in all three cities.

Table 1. Comparison of management performance with daylighting control

	Lux	# EVs	Charging savings ($)	Charging savings per EV (¢/ per veh)	Savings/FCFS costs (%)	Average Savings ($)
Average Demand Cases						
Chicago	300	42	3.57	8.49	11.59	---
	500	36	2.76	7.66	10.54	---
Baltimore	300	39	2.00	5.14	9.7	---
	500	33	1.01	3.07	6.07	---
Houston	300	29	1.84	6.35	35.83	---
	500	18	1.01	5.62	33.07	---
Synthetic Demand Cases						
Chicago	300	32–43	-0.06–3.45	-0.16–9.58	-0.22–11.96	0.883
	500	27–39	-0.11–2.38	-0.36–7.35	-0.47–9.79	0.782
Baltimore	300	33–44	-0.40–1.10	-1.00–2.96	-1.99–5.06	0.262
	500	27–39	-0.17–1.08	-0.54–3.32	-1.02–5.88	0.288
Houston	300	22–33	-0.19–0.80	-0.73–3.08	-4.54–15.27	0.088
	500	14–21	-0.09–0.53	-0.63–3.04	-3.86–18.12	0.071

CONCLUSION

- Saved energy from building control strategies improvements can support up to **42 EVs to recharge**.
- Managed EV charging will not burden the office building's electricity bill. Compared to a first-come, first-served charging strategy, managed charging can **save up to 21.7% per day** with the consideration of electricity demand charges. **The monthly savings can reach up to $ 635.07 in a workplace lot in Houston TX**.
- Cost-saving performance of managed charging is influenced by model inputs. **A larger gap** between different times of the electricity price tiers **increases savings of the managed EV charging schedule**; a **longer coincident period** of low electricity prices and dwell times of commuters **makes the managed charging practice more effective**.

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