

APPENDIX

In basic electricity consumption optimization problems, a binary variable $x_{m,t}$ represents the operating status of adjustable appliance m at time t . Adjustable appliances are categorized into shiftable appliances, interruptible appliances (e.g., electric vehicles), and thermostatically controlled appliances (e.g., air conditioners). For shiftable appliances, the start time can be adjusted within a specified period, but once started, they must run for a fixed duration. This is expressed by the following constraints:

$$\sum_{i=t}^{t+T_m^r} x_{m,i} \geq s_{m,t} \cdot T_m^r \quad (1)$$

$$U_m^{\min} \cdot T_m^r \leq \sum_{t=1}^{T^{\text{total}}} x_{m,t} \leq U_m^{\max} \cdot T_m^r \quad (2)$$

where $s_{m,t}$ is an auxiliary variable indicating appliance start, T^{total} is the total number of optimization periods, T_m^r , U_m^{\min} , and U_m^{\max} represent the operating duration, minimum daily usage, and maximum daily usage of appliance m , respectively.

For electric vehicles, the battery state of charge must exceed a threshold soc^{set} before the departure time T^{ev} . The change in battery state of charge soc_t is expressed as follows [1].

$$\text{soc}_t = \text{soc}_{t-1} + (x_{\text{ev},t} \cdot P^{\text{ev}} \cdot \eta^{\text{ev}} \cdot \Delta t) / b^{\text{max}} \quad (3)$$

where P^{ev} , η^{ev} , and b^{max} represent the charging power, charging efficiency, and maximum battery capacity, respectively.

For air conditioners, the operating status is related to indoor and outdoor temperatures (TP_t^{in} , TP_t^{out}) based on the Equivalent Thermal Parameter (ETP) model, as shown below:

$$\begin{aligned} TP_t^{\text{in}} &= e^{-\Delta t/RC} \cdot TP_{t-1}^{\text{in}} + R \cdot (e^{-\Delta t/RC} - 1) \cdot P^{\text{ac}} \cdot x_{\text{ac},t-1} \\ &+ (1 - e^{-\Delta t/RC}) \cdot TP_{t-1}^{\text{out}} \end{aligned} \quad (4)$$

where R and C are the thermal resistance and thermal capacitance of the house, and P^{ac} is the air conditioner's power.

Electricity consumption optimization may aim to minimize costs, maintain indoor temperature preferences, meet appliance usage preferences, and reduce electric vehicle charging losses [2]. These objectives are combined into a single minimization target using weighted coefficients w , as shown below:

$$\begin{aligned} \text{obj} &= w_1 \cdot \sum_{m=1}^M \sum_{t=1}^{T^{\text{total}}} x_{m,t} \cdot P_m \cdot \Delta t \cdot \delta_t \\ &+ w_2 \cdot \sum_{t=1}^{T^{\text{total}}} 2 \cdot \left| TP_t^{\text{in}} - \frac{TP_{\text{max}}^{\text{in}} + TP_{\text{min}}^{\text{in}}}{2} \right| / (TP_{\text{max}}^{\text{in}} - TP_{\text{min}}^{\text{in}}) \\ &+ w_3 \cdot \sum_{m=1}^M \sum_{t=1}^{T^{\text{total}}} x_{m,t} \cdot PR_{m,t} + w_4 \cdot \sum_{t=1}^{T^{\text{total}}} c_{\text{ev},t} \cdot \beta^{\text{ev}} \end{aligned} \quad (5)$$

where M is the total number of adjustable appliances, δ is the electricity price, and $TP_{\text{max}}^{\text{in}}$ and $TP_{\text{min}}^{\text{in}}$ are the maximum and minimum indoor temperature setpoints. Besides, $PR_{m,t}$ is the user's preference weight for appliance m at time t , $c_{\text{ev},t}$ and β^{ev} are the charging state indicator and loss coefficient for the electric vehicle, respectively.

The above integer programming optimization problem can be solved with solvers like Gurobi [3] and Scipy [4].

REFERENCES

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