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:

$$\sum_{i=t}^{t+T_m^{\mathrm{r}}} x_{m,i} \geq s_{m,t} \cdot T_m^{\mathrm{r}} \tag{1}$$

$$U_m^{\min} \cdot T_m^{\mathrm{r}} \leq \sum_{t=1}^{T^{\mathrm{total}}} x_{m,t} \leq U_m^{\max} \cdot T_m^{\mathrm{r}} \tag{2}$$

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].

$$soc_t = soc_{t-1} + (x_{\mathrm{ev},t} \cdot P^{\mathrm{ev}} \cdot \eta^{\mathrm{ev}} \cdot \Delta t) / b^{\max} \tag{3}$$

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:

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

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:

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

where M is the total number of adjustable appliances, δ is the electricity price, and $TP_{\max}^{\mathrm{in}}$ and $TP_{\min}^{\mathrm{in}}$ 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_t^{ev} 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].

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