Optimal Design & Scheduling of a Supermarket Energy System

ICPE 604 Energy Systems Engineering I - Project Description

System Overview:

Given is a supermarket with on-site energy conversion and generation blocks. With an expected operating horizon of 20 years, energy will be utilized for lighting, refrigeration, and space heating. As such, the conversion block consists of two electricity-driven energy conversion technologies and one heat driven energy conversion technology to meet these demands. The efficiency (or coefficient of performance, COP), types of energy input, types of utility output, capital cost and operational cost of these technologies are summarized in Table 1.

Table 1: Technical and economic parameters of on-site energy conversion technologies

Sources	***Refrigerator***	***LED***	***Heater***
Input Resource	Electricity	Electricity	Heat
Output Resource	Refrigeration	Lighting	Space Heating
Efficiency [%]	300 (COP)	80	85
CAPEX [$/kW]	70	10	30
OPEX [$/kW·year]	4	1	3

The energy required for energy conversion is met using the on-site energy generation section. The on-site energy generation section involves two electricity generation technologies, one heat generation technology, and one co-production technology. The block includes biomass steam turbines (ST), natural gas combined heat and power (CHP), solar photovoltaic panels (PV), and wind farms. The various parameters of these processes are given in Table 2.

Table 2: Technical and economic parameters of energy generation technologies

Processes	***Biomass ST***	***Natural Gas CHP***	***Solar PV***	***Wind Farm***
Input Resource	Biomass	Natural Gas	Solar	Wind
Output Resource	Electricity	Electricity & Heat	Electricity	Electricity
Electrical Efficiency [%]	68	44	9	22
Heating Efficiency [%]	0	28	0	0
Minimum Capacity [kW]	100	800	10	10
Maximum Capacity [kW]	1×10^6	1×10^6	300	500
CAPEX [$/kW]	250	500	2000	2000
OPEX [$/kW·year]	15	15	500	1200

Primary energy resources for these processes will include natural gas and biomass. Electricity from the grid will also be considered for utilization in energy conversion. Prices for these resources and their associated CO_2 production is given in Table 3.

Table 3: Prices and CO_2 emissions of the primary energy resources and grid electricity [1GJ = 277.78 kWh]

Sources	***Natural Gas***	***Biomass***	***Grid Electricity***
Price[$/GJ]	8.89	9.72	36.11
CO_2 Generation [kg/PJ]	56	100	90

Problem Statement:

PART A: SYSTEM DESIGN

Using the information given above, formulate and solve a mixed-integer model to determine the optimal design of the energy system with the following characteristics:

1. Incorporate a single operating horizon of 20 years with the following demands:

Table 4: Energy demands for various utilities

Uses	***Lighting***	***Refrigeration***	***Space Heating***
Energy Demand [kW]	200	1000	100

2. Add integer cuts to limit utilization of the three power-production technologies in each period by selecting any one.
3. Optimize model towards multiple objectives: Maximization of efficiency and minimization of total system costs and emissions.

PART B: SYSTEM SCHEDULING

Using the design determined in the previous section, formulate and solve a multi-period based mathematical programming model to determine the optimal scheduling of the energy system with the following characteristics:

4. Multi-period component: Consider an operating horizon of 1 day with 24 time periods with varying lighting demands for each hour of the day (refer to spreadsheet on Canvas) with a single objective of minimizing total system costs.
5. Bonus (optional): Analyze the impact of time-varying emissions on the overall system. This section allows for additional points but is not a requirement for the submission.

Report Guidelines:

The project report is limited to 5 pages and should contain the following information:

1. Introduction: Project overview and a superstructure-based representation of the supermarket energy system.
2. Mathematical Model: Formulations of the models used for Part A and B.
3. Results & Analysis: Solutions of the resulting optimization problems (in Energiapy or Pyomo) along with an analysis of the optimal solutions obtained.
4. Conclusion: Brief summary of results and future considerations.
5. Appendix: Include any other information, results and, if available, the input and output files of all the optimization problems solved (Note: Appendix is not included in the 5 page limit).

Report Submission:

In-person: November 7th, 2025
Online: November 17th, 2025