Development and Performance Evaluation of a Thermal Energy Prosumer System Using EnergyPlus-Based Simulation During the Cooling

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Abstract. This study aims to develop and evaluate a thermal energy prosumer system during the cooling season using EnergyPlus-based simulation. The research focuses on J-Town, located in Chungcheongbuk-do, Korea, where multiple buildings share cooling energy via heat pumps and chilled-water storage systems. A district-level thermal energy prosumer model is implemented in a single EnergyPlus simulation environment to represent buildings that can both consume and supply cooling energy through heat exchangers. Real BEMS data from the demonstration site are utilized to reflect realistic system capacities and operating schedules. Based on the developed model, several scenario-based operation strategies are evaluated to assess their impact on energy consumption, operating cost, and carbon emissions. The results demonstrate that the performance of thermal energy prosumer systems strongly depends on the location of the main prosumer and the resulting operational characteristics of heat pump systems. The findings of this study provide insights into the design and operation of plant-level thermal energy prosumer systems and establish a simulation-based framework for future development of advanced control strategies.

Keywords. Thermal energy prosumer, EnergyPlus-based simulation, District-scale cooling, Performance assessment, Carbon emissions

1 Introduction

There has been growing interest in thermal energy prosumer systems as part of low-carbon energy strategies, in which buildings not only consume thermal energy for heating and cooling but also produce [1-3]. By combining heat pumps, renewable energy, thermal storage systems, and operating strategies, these systems enable buildings to participate in thermal energy flows, and their performance is evaluated mainly through simulation-based methods [4].

Prior studies often model thermal energy demand and production using different tools or in separate stages [5-7]. When demand, supply and operating strategy modeling are separated, the thermal load profile must be transferred between modeling stages, and assumptions regarding time resolution and parameter handling may differ across models [8-9]. These differences do not always determine the results, but they can affect the interpretation of system behavior when comparing system configurations or operating strategies.

This study uses EnergyPlus to evaluate thermal energy demand, supply, storage, and operating strategies within a single, integrated simulation framework. The case study is conducted at the J Town demonstration site in Chungcheongbuk-do, where a thermal prosumer system is configured to enable inter-building energy sharing during the cooling season. The study analyzes operating characteristics under different allocations of prosumer roles and quantifies the impacts on energy consumption, operating cost, and carbon emissions.

2 Methodology

2.1 EnergyPlus Modeling

The EnergyPlus model consists of two zones within a single simulation environment, each representing an individual building. Cooling loads are imposed exogenously on each zone based on BEMS measurements collected at the J Town. To isolate system-level interactions, a simplified model with adiabatic envelopes and externally imposed cooling loads was adopted. This approach excludes building-physics feedback, thermal comfort impacts, and load-shaping effects, focusing on

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plant-level interactions among heat pumps, thermal storage, and heat exchangers.

Regarding the system configuration, Loop 1 represents a building equipped with electric heat pump 1 (HP1) and a chilled water storage tank, while Loop 2 represents a building equipped only with electric heat pump 2 (HP2). Cooling energy exchange between the two buildings occurs exclusively through a heat exchanger (HX). Key settings for each building system and the EnergyPlus model are summarized in Table 1.

Table 1. Summary of EnergyPlus modelling settings and system configuration

Category	Item	Setting / Value
Weather data	EPW file	KOR_Cheongju_TMY
Simulation settings	Simulation tool	EnergyPlus (v24.x series)
	Simulation period	Cooling season (June 1 – September 30)
	Time step	6 timesteps/hour (10-minute resolution)
Loop 1 modeling		
Thermal energy storage (TES)	Equipment specification	200 m³ chilled-water storage tank
Heat pump1	Cpacity / COP	166,000 W / 4
	Operation strategy	Activated when TES bottom temp ≥ 9 °C
	Heat source	District cooling
Loop 2 modeling		
Heat pump2	Cpacity / COP	99,600 W / 4
	Operation strategy	Water supplied at 9 °C during cooling operation
	Heat source	District cooling

2.2 Scenario Configuration

Three case scenarios are defined to evaluate the impact of the thermal prosumer concept. Scenario A serves as the baseline without a prosumer configuration, in which both buildings operate solely as cooling consumers and the heat exchanger remains inactive. In Scenario B, HX1 is activated, allowing HP1 to operate as the primary prosumer for cooling supply, while HP2 supplements the cooling supply when total cooling demand increases or when the combined capacity of HP1 and the chilled water storage tank is insufficient. In Scenario C, HX2 is activated so that HP2 operates as the prosumer, enabling HP1 to operate as needed. Across all scenarios, the heat pump control logic, thermal storage control strategy, and indoor setpoint conditions are kept constant. The system configuration and energy flows for each scenario are illustrated in Figure 1.

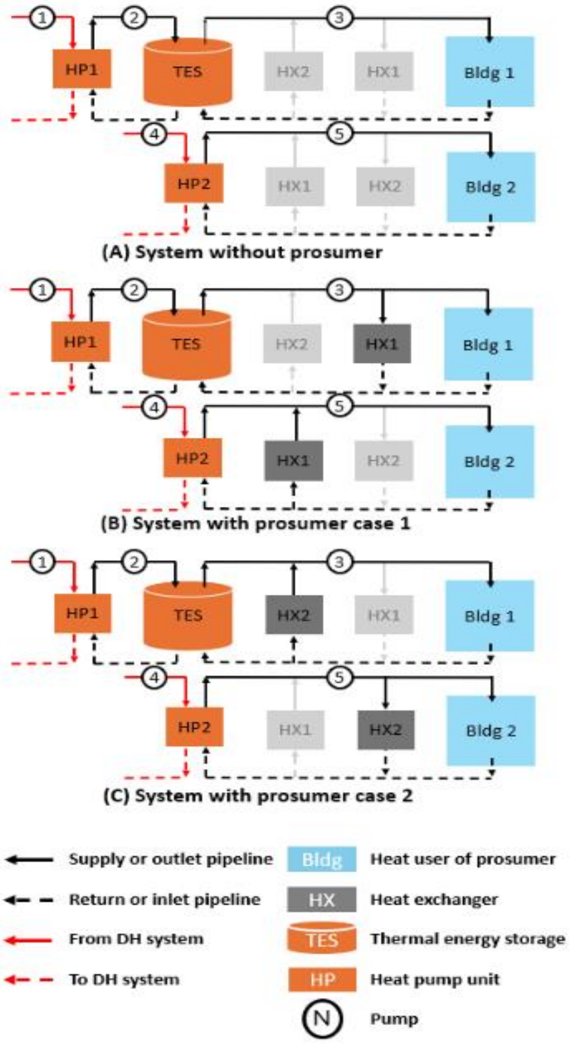

Fig. 1 . Schematic of the thermal energy prosumer system and case scenario configurations

2.3 Performance Evaluation

System performance during the cooling season is evaluated in terms of energy consumption, operating costs, and carbon emissions. The total electricity consumption is calculated as the sum of heat pump and pump electricity use, as expressed in Eq. (1).

$$E_{\text{tot}} = \sum_{t=1}^{T} [E_{\text{HP}}(t) + E_{\text{pump}}(t)] \tag{1}$$

Operating costs are calculated as the sum of the energy and the demand charges based on the KEPCO time-of-use (TOU) electricity tariff, as expressed in Eq. (4). The energy charge is computed by multiplying the electricity consumption at each timestep by the corresponding TOU

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tariff rate. The demand charge is determined based on the peak electric demand during the cooling season.

$$C_{\text{energy}} = \sum_{t=1}^{T} E(t)\, p_{\text{TOU}}(t) \quad (2)$$

$$C_{\text{demand}} = P_{\text{peak}}\, p_{\text{demand}} \quad (3)$$

$$C_{\text{op}} = C_{\text{energy}} + C_{\text{demand}} \quad (4)$$

As shown in Eq. (5). Carbon emissions are calculated by multiplying electricity consumption by a constant grid emission factor, EF_{grid}. therefore, changes in carbon emissions are proportional to changes in electricity consumption.

$$CO_2 = \sum_{t=1}^{T} E(t)\, \text{EF}_{\text{grid}} \quad (5)$$

The performance of each prosumer scenario is evaluated as the relative reduction compared to the baseline scenario, as defined in Eq. (6). Here, X denotes total electricity consumption, operating cost, or carbon emissions.

$$\eta = \frac{X_{\text{baseline}} - X_{\text{prosumer}}}{X_{\text{baseline}}} \times 100 \quad (6)$$

3 Result and Discussion

3.1 Total electricity uses by scenario

Table 2 presents the total electricity consumption for each scenario during the cooling season. In the baseline Case A, total electricity consumption is 59.0 MWh. In Case B, total electricity consumption decreases to 53.9 MWh, corresponding to an 8.6% reduction relative to Case A. In contrast, total electricity consumption in case C increases to 67.0 MWh, representing a 13.6% increase relative to the baseline. These results indicate that system-level energy performance varies significantly depending on prosumer role allocation, even under the same operating conditions

Table 2. Total electricity consumption during the cooling season and relative change compared to Scenario A

Case Scenario	Case A (Baseline)	Case B (HP1 prosumer)	Case C (HP2 prosumer)
Electricity (MWh)	58.99	53.93	67.03
Energy Change (%)	–	**-8.6**	**13.6**
Operating Cost Change (%)	–	**-6.6**	**14.6**
CO_2 Change (%)	–	**-8.6**	**13.6**

Note: Positive values indicate increases relative to the case A, while negative values indicate energy savings.

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3.2 Heat pump and circulation pump electricity use under prosumer operation

In the prosumer scenarios, changes in total electricity consumption are driven by variations in both heat pump operation and circulation pump electricity use. As shown in Figure 2.

In Case B, HP1 coupled with thermal energy storage functions as the primary cooling supplier, reducing the operating burden on HP2. As a result, HP2 operation decreases and overall heat pump electricity consumption is reduced relative to the baseline. Although activation of the heat exchanger in the prosumer scenarios increases electricity consumption by circulation pumps required for inter-building cooling transfer (Pump3, Pump4, and Pump5), the reduction in heat pump electricity leads to an overall decrease in total electricity consumption of 8.6%.

In contrast, in Case C, HP2 supplies both its own cooling demand and a portion of the load from the other building, increasing its operating hours and electricity consumption. In this case, electricity consumption increases for both the heat pump and the circulation pumps associated with heat exchanger operation, resulting in a 13.6% increase in total electricity consumption compared to the baseline.

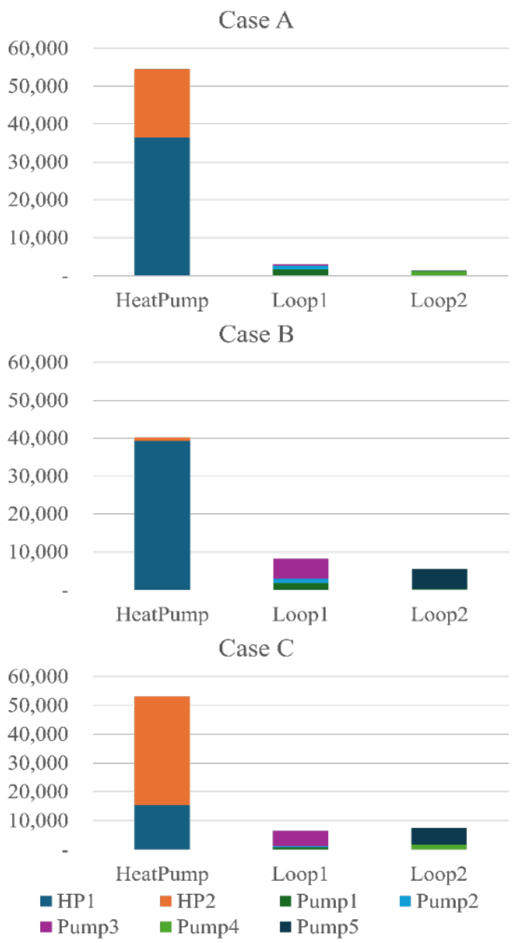

Fig. 2. Plant equipment electricity rate by case scenario. (kWh)

3.3 Sensitivity analysis

A sensitivity analysis was performed for several parameters, including storage temperature, heat exchanger type, and heat pump COP. Among these, heat pump COP showed most significant impact on system performance. Table 3 summarizes the change in total electricity consumption by case, under different COP conditions and prosumer role allocations, relative to case A.

Larger reductions in electricity consumption were observed in Case B, where HP1 operates as the prosumer, particularly when the COP of HP1 was higher than that of HP2. Case B resulted in reduced electricity consumption under all COP conditions, with relative reductions ranging from 4% to 22%. In contrast, Case C, led to increased electricity consumption in most cases, with relative changes ranging from −28% to 6%.

Table 3. Relative change in total electricity consumption under different COP combinations and prosumer allocations

HP1 COP	HP2 COP	Case B Energy Change (%)	Case C Energy Change (%)
2.5	2.5	-15	8
3	3	-13	10
3.5	3.5	-11	12
4	**4**	**-9**	**14**
4	2.5	-22	28
2.5	4	-4	-6

Note: Positive values indicate increases relative to the case A, while negative values indicate energy savings.

4 Conclusion

This study implements a thermal prosumer system within a single EnergyPlus simulation environment and quantifies differences in energy performance driven by prosumer role allocation. In the J-Town case study,total electricity consumption decreases by 8.6% in Case B, where the prosumer role is assigned to a heat pump coupled with thermal energy storage, whereas total electricity consumption increases by 13.6% in Case C, where the prosumer role is assigned to a heat pump without thermal storage. These findings indicate that implementing a thermal prosumer configuration does not necessarily guarantee energy savings, as system performance depends on heat pump COP, thermal storage availability, and overall system configuration, including circulation pump operation. This study also demonstrates that an integrated EnergyPlus-based simulation framework provides an effective approach for the development and performance evaluation of plant-level thermal energy prosumer systems.

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