Integrated Modeling and Optimization of Various Cogeneration Systems for a Zero-Energy Industrial Building Using the Combination of Renewable Energies

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Abstract: *This study aims to develop a zero-energy building (ZEB) by optimizing required energy consumption in an industrial building complex. The complex uses an electric compression chiller to meet heating and cooling demands. To achieve this goal, four multi-energy generation systems are proposed, leveraging renewable resources. Building Energy Optimization (Beopt) software is used for simulation, and the EES software is employed to design the energy-supplying systems. The results indicate that the industrial building complex consumes 50,656.29 kWh of electricity, 436,221.62 kWh of heating, and 8,073.36 kWh of cooling annually. The four systems are optimized using the Response Surface Methodology (RSM), focusing on exergy efficiency (EE) and cost rate (CR). System D emerges as the most efficient, with an average EE of 22.35% and an average CR of 8.9 $/h. This system generates 726,090.61 kWh of electricity, approximately 1.06 million kWh for heating purposes, and around 760,000 kWh for cooling needs, making it a suitable system for the complex. Ultimately, this study presents an efficient system with the best cost rate and performance for the energy supply of the studied industrial building, contributing to a more sustainable and environmentally friendly energy strategy.*

Keywords: *Multi Generation Systems, Dormitory Complex, Multi-objective Optimization, BEopt, RSM.*

1. Introduction

Buildings consume 40% of the total energy and possess considerable potential for the conservation of primary energy [1]. The generated energy from renewable resources is natural and easily reproducible. These resources are the sunlight, water, wind, tides, geothermal, and biomass resources in nature. New energy alternatives shape green buildings that are adaptive to the environment [2]. Green buildings may be offices, houses, dormitories, schools, hospitals, social centers, or any type of structures [3-4]. In this research, multiple production systems based on renewable solar and geothermal energy were evaluated to determine the most suitable and efficient system for supplying energy to buildings. The goal was to identify the system that offers the lowest cost and highest energy efficiency, taking into accounts the specific conditions and parameters of the study area. By thoroughly examining and comparing different energy supply systems, the researchers were able to make an informed decision on the most appropriate system for the given context. This approach is more comprehensive than simply proposing a single system without considering alternatives. Selecting the most suitable energy supply system, based on cost-effectiveness and efficiency, can provide several benefits:

1. **Reduced energy supply costs**: By choosing the system with the lowest cost, building owners and investors can save money on energy expenses.
2. **Improved energy efficiency**: The selected system should offer the highest energy efficiency, minimizing waste and maximizing the utilization of renewable resources.

3. **Increased investment and motivation**: By demonstrating the potential for cost savings and efficient energy supply, this research can encourage more investors to participate in renewable energy projects for buildings.

Our research builds upon the existing body of work in the field of renewable energy systems for building energy supply. By evaluating multiple systems and highlighting their innovations and applications, we have made a significant contribution to the field, providing practical recommendations for building owners and investors. Cheraghi and Jahangir (2023) investigated a hybrid renewable energy system that supplied a residential building. The system consisted of a photovoltaic panel, a wind turbine, a ground source heat pump, a diesel generator, a battery bank, and fuel cells The environmental analysis showed that CO_2 emissions decreased by 46-100% and 3-100% in the selected systems compared to coal and natural gas power plants [5]. Jafarian et al. (2023) examined a hybrid cooling, heating, power, and water system in energy, economic, and environmental terms. The results displayed that the high ratio of the sell-to-buy tariff and low inflation rate reduced costs in the system's entire lifetime and increased investment productivity [6]. Deng et al. (2024) proposed a method for renewable buildings by combining a Direct Current (DC) distributed energy system. One solution is to adopt more renewable resources to supply energy. Compared to the baselines, DC-RL conserved energy and PV consumption by 38% and improved user satisfaction by 9%. DC-RL led to nearly zero-emission buildings with a 93 % self-sufficiency rate and reduced battery dependence by 33 % [7]. Wu et al. (2023) analyzed building energy systems by combining active and passive energy-saving. Their case study on Building Energy Systems (BES) in the new Xiong'an region of China revealed that the co-optimization method saved costs by 2.2-3.4 % compared to active energy-saving [8]. To store energy, materials called phase change materials (PCM) are used, which store energy in the form of latent heat. The use of phase change materials (PCM) in buildings is used to regulate temperature and store thermal energy. These materials can absorb or release heat by changing phase (from solid to liquid and vice versa), and thus help maintain the desired temperature in the interior of the building. The use of these materials helps reduce cooling and heating energy consumption, which has received less attention in research related to zero-energy buildings. Assareh and colleagues in 2022 designed a cogeneration system that used solar and geothermal energies. The outcomes displayed that integrating battery and hydrogen storage components in the new system maximized efficiency by 90%, 60%, 23%, and 18% for the electrolyzer, fuel cell, photovoltaic panel, and electric generator [9]. Assareh et al. (2023) analyzed a heating cooling and power generation system benefitting from several renewable energies simultaneously. The results showed that the fuel cell, photovoltaic panel, and wind turbine with 75 kW, 52 kW, and 24 kW powers maximally contributed to electricity generation [10]. The use of multi-objective optimization methods such as genetic algorithm and particle swarm optimization algorithm has been carried out in various studies for the optimization of renewable systems by various researchers. However, the use of response surface methodology as a new multi-objective optimization method to find the most optimal technical and economic performance of renewable systems with the aim of increasing exergy efficiency and reducing cost rates has received less attention. Combining two complete reviews of renewable systems, which include optimization studies and case studies for setting up a study city with suitable renewable potential, as well as studying zero-energy buildings and calculating building energy consumption, requires more research that can measure the ability of renewable systems by calculating the production of renewable systems and the consumption of buildings. Since today's industry is looking for systems with high potential and capacity, for this reason, the ability of systems to supply energy to buildings should be examined. Ang et al. (2022) investigated hybrid renewable energy systems by modeling urban building energy for a sample coastal population. The results showed that although the various combinations of renewable energy systems enjoyed a long-lasting capacity, cost optimization, energy utilization, and power deficiency could be increasingly challenging due to the high estimation of annual demand hours (>90%) [11]. To improve thermal comfort and energy consumption in different climates of Iran, Aliakbari et al. (2021) investigated the effect of new transparent nano insulation in building windows. The five main parameters influencing thermal comfort were the indoor temperature, mean radiant temperature, Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), relative humidity, and consumed energy for heating and cooling [12]. Moghaddas-Zadeh et al. (2023)

followed a neural network approach to supplying the cooling energy of a factory for the purpose of estimating the optimal performance of a compression chiller network. The energy consumption of a chiller network depends on its configuration and control strategy in various circumstances [13]. Xie and Wang (2022) investigated geothermal power generation by combining three systems, including a single-flash system, a double-flash system, and a single-flash system with an Organic Rankine Cycle (ORC), to maximize efficiency and minimize cost as two objective functions. The results showed that a drop in the thermal tank's temperature considerably influenced the combined effect of the injection flow rate and tank permeability [14]. According to the studies conducted, a lot of research has been done on the use of renewable energies for energy production. In the studies conducted, most of the attention has been paid to the use of renewable energies, especially solar energy for the production of various energies. In the studies reviewed, the use of geothermal energy for the establishment of renewable systems has received less attention. On the other hand, the study of the energy produced by renewable systems for buildings requires more studies, because paying attention to zero energy buildings requires studied renewable systems that are suitable for the establishment and supply of energy to zero energy buildings. Sady et al. (2024) investigated a net-zero energy building with intelligent control of Trombe walls, underground air ducts, and an optimized micro grid consisting of renewable energy systems. The results showed that the average daily electricity demand for the base building was 86.37 kWh and for the passive building was 67.49 kWh [15]. Lu et al. (2024) investigated hybrid solar-wind renewable energy systems with energy storage for net/near-zero energy buildings. Considering the correlation of uncertainty and equipment degradation, this study proposed an uncertainty-based approach for robust design of renewable energy systems in net energy buildings. First, scenarios were randomly generated considering correlated uncertainties. Then, a novel scenario reduction technique, which considered the loss of correlation during scenario reduction, was introduced to improve the optimization efficiency [16]. Mobayen et al. (2025) investigated a multi-purpose hybrid energy system for zero-energy residential buildings. The study presents an innovative hybrid energy system that integrates wind energy and gas turbines for a four-story, 16-unit residential building. The system produces electricity, heating, cooling, and hydrogen using a proton exchange membrane electrolyzer and a compression chiller [17]. Aelenei et al. (2025) conducted a techno-economic analysis of a renewable energy-based multiple generation system for zero-energy buildings. The present study investigates the contribution and benefits of a prototype renewable energy-based multiple generation system that integrates a luminescent composite parabolic concentrator, a photovoltaic/thermal system, and thermal storage using phase-change materials. A numerical model was developed to evaluate the energy performance of the prototype, and results are presented for three different European locations [18].

The present study simulates the 210-unit dormitory complex of the Oil and Gas Company of Oslo city in Norway, using the BEopt tool to optimize energy and introduce the suitable materials for the complex. Then, it analyzes four renewable systems to estimate the requisite load of the complex and proposes the most suitable system to operate and supply the energy of the dormitory. Energy consumers in buildings need different types of energy, e.g., electricity, heating, and natural gas. Today, various types of energy resources are available. For this reason, applying new cogeneration systems in the real world is a suitable method economically and technically to supply the energy of buildings. BEopt is capable of evaluating building designs and identifying efficient cost packages at different levels of energy conservation in buildings, making them reach net zero energy. This study estimates the heating, cooling, and electric loads of the dormitory complex of the Oil and Gas Company in Oslo, with a 700,000m^2 area, two floors, and 210 units of 100m^2.

Key innovations of this research are:

- Simulation of a dormitory building in Oslo.
- The building energy optimization tool or BEopt software was used to optimize the building in order to save energy and reduce pollution. Finally, the amount of electricity and heating and cooling energy required by the building throughout the year and in an optimal state was calculated.
- Optimization of 4 new systems to increase energy efficiency and minimize costs and pollution.
- Implementation of 4 new renewable cogeneration systems to meet the building's energy needs.

- Increasing the performance of the renewable cogeneration system by maximizing the production of electricity, cooling and heating while reducing costs.
- Using response surface methodology to optimize the 4 systems.
- Introducing a suitable system for energy supply of the dormitory building.

2. Designing the dormitory complex of the Oil and Gas Company

This study calculates the heating, cooling, and electric loads of a dormitory complex of the Oil and Gas Company in Oslo. The dormitory, with a 700,000m^2 area, possesses 210 100m^2 units. Figure 1 illustrates a schematic of the dormitory complex of the Oil and Gas Company.

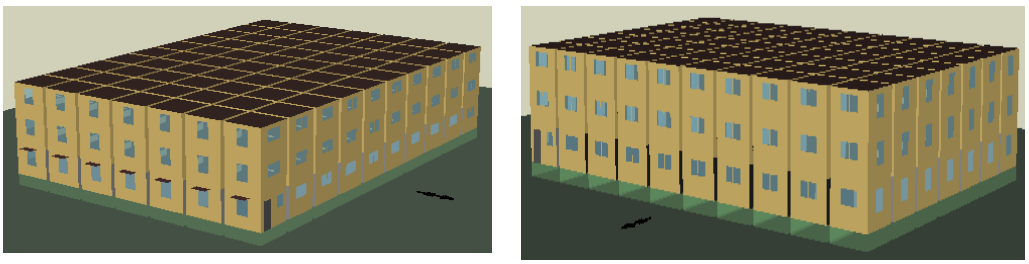

Figure 1. Schematic of the complex

The dormitory building in Oslo was designed, and the BEopt software was used to estimate the required heating, cooling, and electricity during the year. The aim was to analyze four new cogeneration renewable systems to supply these three demands of the building. The dormitory design involved selecting various sizes and types of materials to create the most optimal structure. Notably, the dormitory was oriented towards the north, which is a crucial consideration in building design. This study employs a comprehensive approach to optimize energy consumption and conservation in the dormitory by incorporating various materials and technologies. The design incorporates different materials for the door, window, lighting, pier and beam, and phase change material (PCM) in ceilings and walls. These materials are strategically selected to minimize energy consumption and maximize energy efficiency. The PCM, in particular, is used to store thermal energy during the day and release it at night, reducing the need for heating and cooling. This innovative approach helps to regulate the indoor temperature, ensuring a comfortable and energy-efficient living space. After simulating and optimizing the building parameters, the study determines the suitable combination of materials and technologies that achieve the optimum objective functions. The optimized parameters are designed to minimize energy consumption while maintaining a comfortable indoor environment, ultimately contributing to a more sustainable and environmentally friendly dormitory.
The subsequent step, the hourly fluctuations in meteorological parameters and environmental conditions in Oslo were analyzed to understand how variations in ambient temperature (AT), wind speed (WS), solar radiation (SR), snowfall, and relative humidity (RH) impact energy consumption (EC) in buildings for one year. Environmental factors have a substantial impact in influencing the EC of buildings, making it essential to consider these factors in building design and operation. Figure 2 illustrates the hourly variations in the meteorological parameters of Oslo, providing valuable insights into the effects of these environmental conditions on energy consumption. It should be noted that Oslo's weather data is extracted hourly for 8,760 hours per year from Meteonorm software.

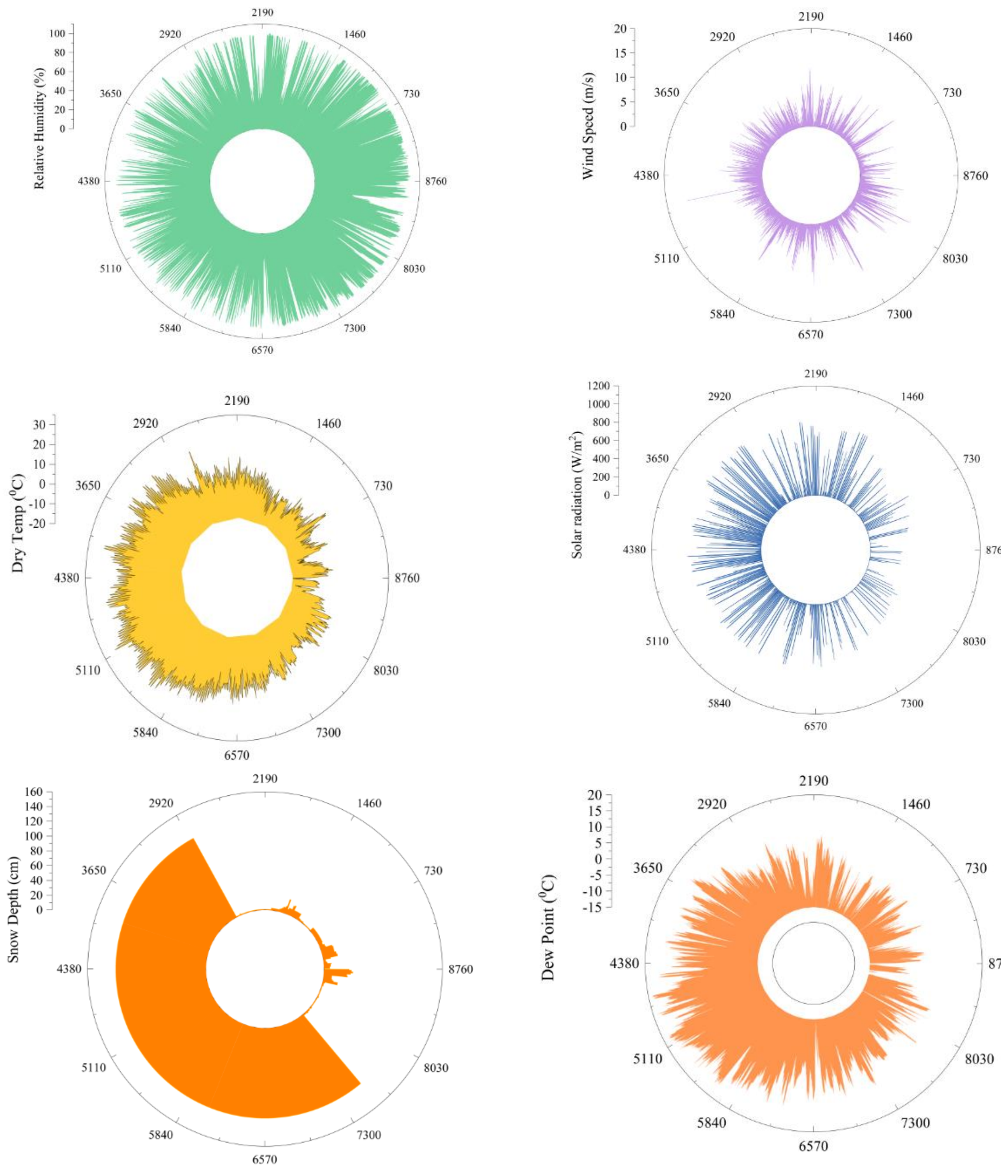

Figure 2. Hourly variations in the meteorological parameters of Oslo (Meteonorm software)

2.1. Building validation

Figure 3 validates and compares the consumed electricity of a 100m^2 unit in Oslo (a real case) and the examined model with the BEopt software. As the results display, the real model consumes excess electricity in hot seasons due to the increased consumption of the electric cooling equipment (cooler and split), and electricity consumption declines in cold seasons due to the reduced consumption of these devices in the building. For this reason, the cooling equipment in the examined model is fed by the national power grid, and a similar condition has been considered for the examined building toward an accurate validation.

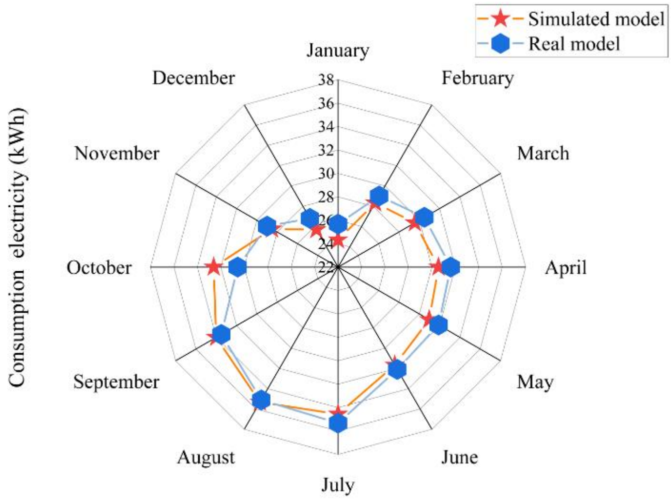

Figure 3. Validating the consumed electricity of a building unit in Oslo and the examined model

2.2. Dormitory complex Analysis

To begin the optimization process, the BEopt was employed to determine the most effective approach for minimizing energy consumption, construction costs, and CO2 emissions. Given Oslo's location and the variations in Meteorological conditions, along with the types and sizes of materials used, also influence the energy consumption, these factors were considered as input variables in the optimization outcome. The post-analysis optimization, which involved 92 repetitions, took approximately 19 hours, 22 minutes, and 16 seconds to complete. During this time, three specific scenarios were examined to address the building analysis. Table 1 compares the consumed load of the dormitory in three result modes: the optimal point, reduced construction costs, and maximum energy conservation. As shown, the main scenario selected for this research is the optimal condition, where electricity consumption, heating, and cooling are balanced, all building energies are simultaneously conserved, construction costs are reasonable and environmental pollution is minimized. In contrast, the maximum energy conservation mode focuses solely on energy savings, while the minimum construction mode prioritizes cost reduction. This study selects the optimal condition due to its simultaneous optimization of EC, pollution reduction, and construction cost.

Table 1. Comparing the consumed load of the dormitory in various conditions

Scenario	Electricity	CO2 emission	Cooling bar	Heating bar
Optimal selection	50656.29	11911.38	436221.6	8073.36
Min Cost	49118.86	11356.25	429811.39	7945.87
Max Savings	49654.34	11732.71	432769.47	7994.67

Figures 4 and 5 present the hourly heating and cooling, electricity, and CO_2 emission loads consumed by the dormitory over the course of a year. These figures illustrate the range of changes that occur throughout the year, providing valuable insights into the dormitory's energy consumption patterns. The figures demonstrate the fluctuating nature of energy consumption, with heating and cooling loads varying significantly depending on the time of year and external environmental conditions. The electricity consumption and CO2 emissions also exhibit distinct patterns, reflecting the dormitory's energy usage and environmental impact. By examining these figures, it is possible to identify trends and correlations between energy consumption and environmental factors, such as temperature and humidity. This information can be used to optimize energy efficiency, reduce energy costs, and minimize the dormitory's environmental footprint.

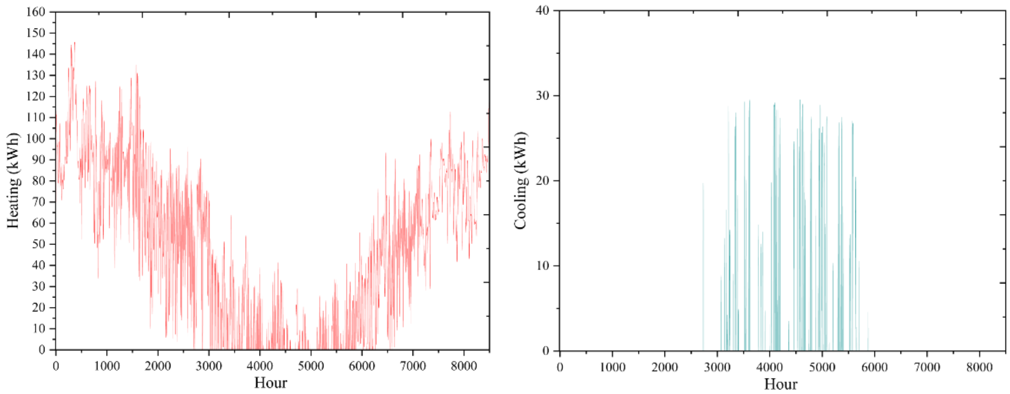

Figure 4. Consumed heating and cooling bar

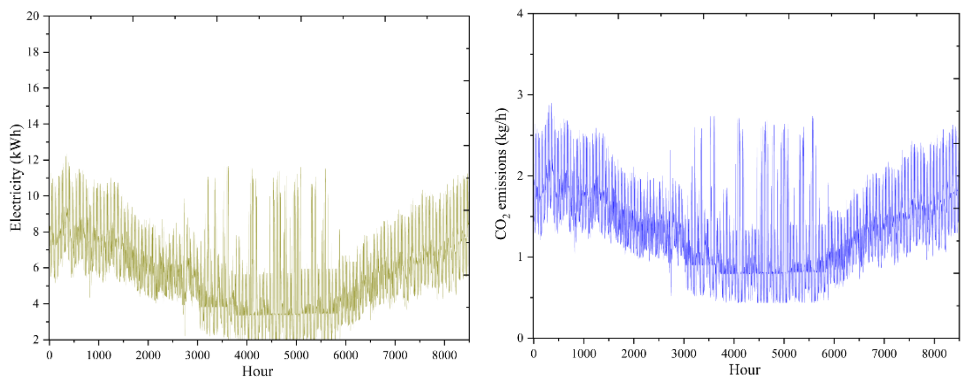

Figure 5. Consumed Electricity and CO_2 emission

3. Different cogeneration systems

The present study embarked on designing four renewable systems based on solar and geothermal energies using thermal/photovoltaic panels and thermal parabolic collectors absorbing solar energy and geothermal wells absorbing the thermal energy of the earth. Solar energy, with the most potential, is a fundamental source of renewable energy that is highly accessible in the world and not limited to a certain location. Geothermal energy, as one of the renewable energies, considerably contributes to energy generation all over the world. This energy is defined as the extraction of thermal energy from the lower substrates of the earth. Contrary to other renewable energies, it is not limited to certain seasons, times, and conditions and is exploitable ceaselessly and, hence, reliable extensively. Figure 6 displays the schematic of the systems, wherein the ORC and Steam Rankine Cycle (SRC) have been used for generating clean electricity, and a compression chiller (CC) has been employed to produce cooling and heating bar. Rankine cycle consists of four components, including an evaporator, a condenser, a pump, and a turbine, and the R123 refrigerant constitutes its fluid. The systems based on geothermal energy use a low-temperature heat source and circulate the ORC turbine to generate power. The heat source in this system is the geothermal energy extracted from a geothermal tank and inserted into the ORC evaporator. Accordingly, heat is given to the cycle, converted to power by the ORC turbine, transformed into electricity by the generator, and reinjected to the earth. The temperature and flow rate of the fluid injected by the tank to the ORC equal 180˚C and 16kg/s, respectively. This study has also utilized a CC to produce cooling for dormitory complex. A CC is a device that uses the compression refrigeration cycle to cool or heat the environment.

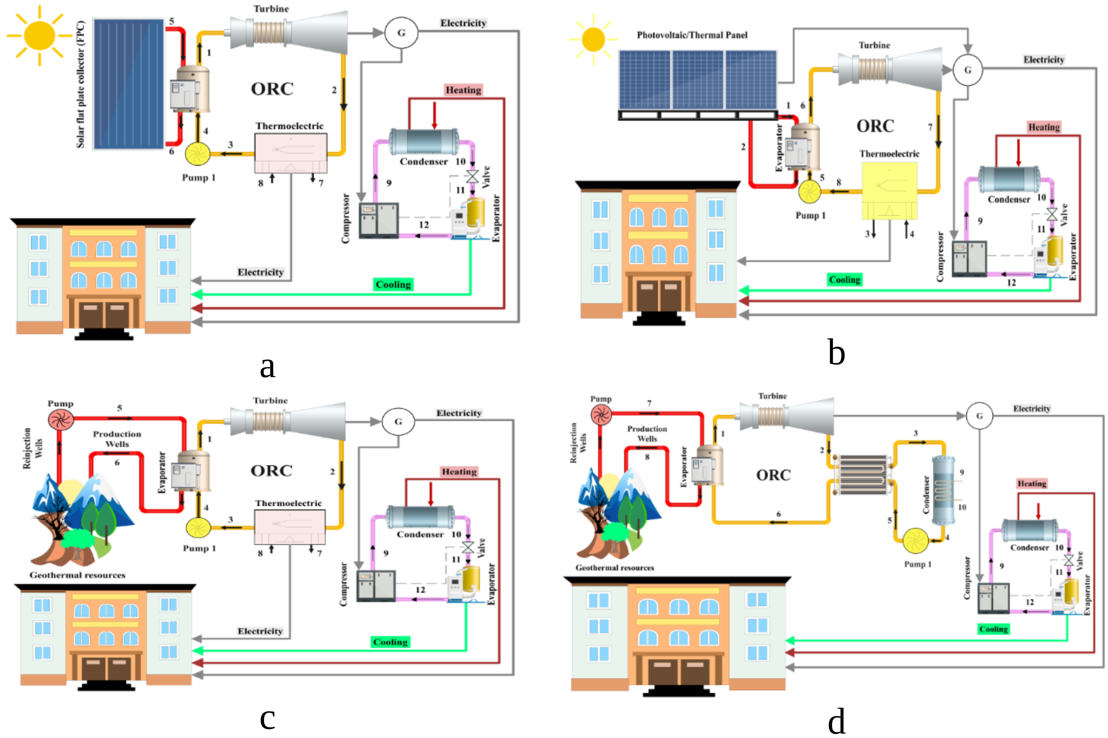

Figure 6. The proposed systems

4. Results and Discussion

4.1. Validation

Validating studies is the first step in scientific research. Since the introduced system is new, the thermoelectric unit, which is among the originalities of the renewable system, is compared for validation purposes. Therefore, the performance of the thermoelectric generator is validated by Habibollahzadeh et al.'s (2018) work [19] (Figure 7). As the results reveal, the modeling enjoys proper validity.

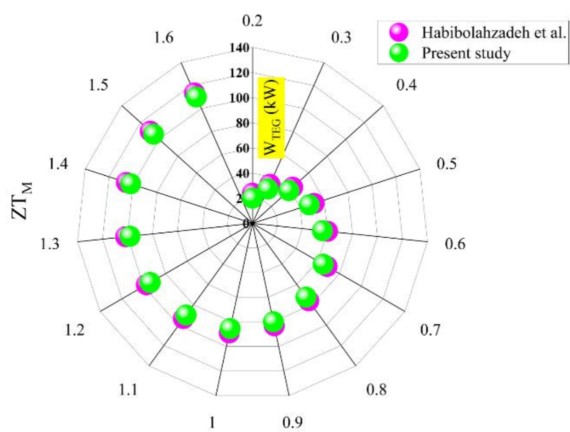

Figure 7. Validation of cogeneration system

Furthermore, the ORC was validated by the comparison of the present work with Amirirad et al.'s [20] study in Table 2. The comparison reveals a good agreement of the results with the findings of the reference study. The error that occurred in the validation of the organic Rankine cycle unit was related to the coding of the cycle. Because only the initial data was extracted from the reference article and considering that all the necessary information for coding and modeling the Rankine cycle was not available, the error that occurred, which is between 0.77% and 1.1%, occurred, and this error is very small.

Table 2. Validating the ORC

Terms	Present model	Amiri rad et al.	Error (%)
Working fluid	R152a	R152a	-
Heat source T	150	150	-
Heat source mass	15	15	-
Turbine inlet P	27.30	27.3	-
Turbine power	120.40	121.80	1.1
Net power output	106.80	105.80	0.94
Thermal efficiency	7.80	7.740	0.77

4.2. Optimization

The performance of the four renewable systems was optimized by the Response Surface Method (RSM), and the optimal values were introduced for the objective functions (OF). Figure 8 shows a flowchart of the response surface methodology. Response surface methodology is a set of mathematical and statistical techniques that aim to analyze, by means of an empirical model, the problems that have been raised. This method achieves the best response surface by discovering the optimal response surface for each of the design variables [21, 22].

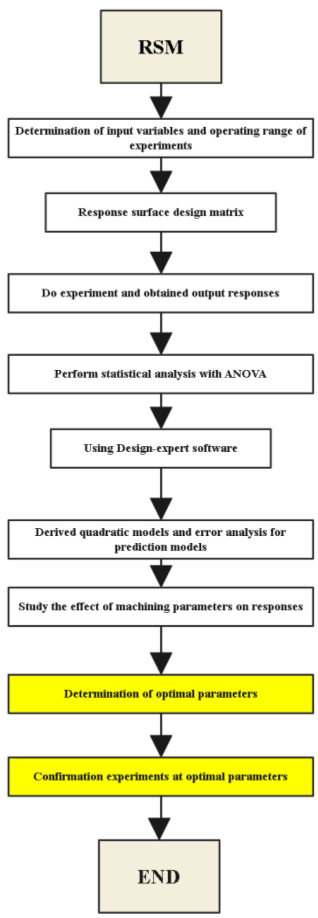

Figure 8. Response Surface Method

The optimization effort focused on improving the performance of the new systems and decreasing the cost rate. Table 3 presents the optimization variables and their ranges for the four systems.

Table 3. Optimization variables

Decision variable	lower bound	upper bound
System a		
T_1 (^{0}C)	110	130
T_3 (^{0}C)	30	50
T_5 (^{0}C)	180	200
P_5 (kPa)	900	1100
Collector [$_{\text{mass flow rate}}$ (kg/s)]	1	3
Pump[$_{\text{efficiency}}$ (%)]	0.7	0.9
Turbine [$_{\text{efficiency}}$ (%)]	0.7	0.9
Pinch point[$_{\text{evaporator}}$ (^{0}C)]	3	6
System b		
T_6 (^{0}c)	80	100
T_8 (^{0}c)	30	40
Pump[$_{\text{efficiency}}$ (%)]	0.7	0.9
Turbine[$_{\text{efficiency}}$ (%)]	0.7	0.9
Pinch point[$_{\text{evaporator}}$ (^{0}c)]	3	6
Solar panel[$_{\text{mass flow rate}}$ (kg/s)]	1	3
ZT_m (-)	0.6	0.9
System c		
T_1 (^{0}C)	110	130
T_3 (^{0}C)	30	50
T_5 (^{0}C)	180	200
P_5 (kPa)	900	1100
Geothermal[$_{\text{mass flow rate}}$ (kg/s)]	1	3
Pump[$_{\text{efficiency}}$ (%)]	0.7	0.9
Turbine[$_{\text{efficiency}}$ (%)]	0.7	0.9
Pinch point[$_{\text{evaporator}}$ (^{0}C)]	3	6
System d		
T_1 (^{0}C)	110	130
T_4 (^{0}C)	30	50
T_7 (^{0}C)	180	200
P_7 (kPa)	900	1100
Geothermal[$_{\text{mass flow rate}}$ (kg/s)]	1	3
Pump[$_{\text{efficiency}}$ (%)]	0.7	0.9
Turbine[$_{\text{efficiency}}$ (%)]	0.7	0.9
Pinch point[$_{\text{evaporator}}$ (^{0}C)]	3	6

The primary objective of this optimization study was to enhance the performance of the systems and supply the building's consumed energy in the most optimal manner. To achieve this, the study considered eight decision variables for systems 1, 3, and 4, and seven decision variables for system 2. These variables directly influence the performance of the OF, which are EE and CR. By optimizing these systems, the study aimed to improve their efficiency and reduce costs. Researchers utilized the Design Expert software to examine the outcomes of 155 RSM runs for systems 1, 3, and 4, and 89 RSM runs for system 2. This process allowed for the optimization of the systems' performance and the identification of the optimal point for the OFs. During RSM optimization in Design Expert software, 100 optimal points were determined based on the optimization variables and their final values. These 100 points represented the best optimal points for sequentially improving the systems' economic and technical performance. The selection of these points was based on the utility percentage, where a utility closer to 1 indicated a more acceptable solution. Table 4 presents the optimal solutions for the target functions, providing valuable insights into the most efficient and cost-effective configurations for the systems. By implementing these optimal solutions, the building can achieve significant improvements in energy efficiency and cost savings, ultimately enhancing its overall performance and sustainability.

Table 4. Optimal values of cogeneration systems

System a

Objective	T_1 (^0C)	T_3 (^0C)	T_5 (^0C)	P_5 (kPa)	$Collector_{mass\ flow\ rate}$ (kg/s)	$Pump_{efficiency}$ (%)	$turbine_{efficiency}$ (%)	Pinch $point_{evaporator}$ (^0C)	Exergy efficiency (%)	Cost rate ($/h)	Desirability
Value	125.532	34.054	185.735	951.331	1.406	0.859	0.859	3.608	38.26	13.441	0.879

System b

Objective	T_6 (^0c)	T_8 (^0c)	$Pump_{efficiency}$ (%)	$turbine_{efficiency}$ (%)	Pinch $point_{evaporator}$ (^0c)	Solar $Panel_{mass\ flow\ rate}$ (kg/s)	ZTm (-)	Exergy efficiency (%)	Cost rate ($/h)	Desirability
Value	96.148	38.074	0.839	0.817	5.084	2.615	0.842	33.35	3.24	0.853

System c

Objective	T_1 (^0C)	T_3 (^0C)	T_5 (^0C)	P_5 (kPa)	$Geothermal_{mass\ flow\ rate}$ (kg/s)	$Pump_{efficiency}$ (%)	$turbine_{efficiency}$ (%)	Pinch $point_{evaporator}$ (^0c)	Exergy efficiency (%)	Cost rate ($/h)	Desirability
Value	125.945	24.054	184.131	992.642	1.741	0.828	0.859	3.887	42.67	2.58	0.834

System d

Objective	T_1 (^0C)	T_4 (^0C)	$Geothermal_{mass\ flow\ rate}$ (kg/s)	$Pump_{efficiency}$ (%)	turbine efficiency (%)	Pinch $point_{evaporator}$ (^0C)	T_7 (^0C)	P_7 (kPa)	Exergy efficiency (%)	Cost rate ($/h)	Desirability
Value	125.946	28.046	1.405	0.856	0.859	4.224	184.105	1006.598	47.47	5.98	0.962

Then, to obtain the optimal condition, this research investigated the simultaneous effect of two factors on an OF.

4.3. Case study

This study selected Oslo as the case study to examine the performance of four new renewable systems. Figure 2 examined hourly variations in meteorological parameters of Oslo, i.e., variations in the ambient temperature, solar radiation, and wind speed, etc., using the meteorological data obtained by the Metronome software. Figures 9-11 shows hourly variations in the net total generated power and heating and cooling of the examined four systems regarding the changes in the meteorological parameters of Oslo. The power of the new systems is generated by the ORC turbine, steam turbine cycle, thermoelectric generator, and photovoltaic panel, and the consumed power of the pumps and compression chiller is subtracted from the net total generation power of the systems. The energy required by the Rankine cycle to produce power is provided by the heat input to the evaporator. On the other hand, increasing or decreasing the heat energy received by the evaporator has a direct effect on the power production by the turbine. An innovative idea in this study is the use of a compression chiller, where the power required by the compression chiller is supplied by the electricity generated by the system. By cogenerating heating and cooling, this chiller reduces system losses the variations in the system-produced heating are like the total system-generated power since 40 % of the produced electricity of the four examined systems is injected into the compression chiller. Oslo needs a high heating load due to the cold climate of the city.

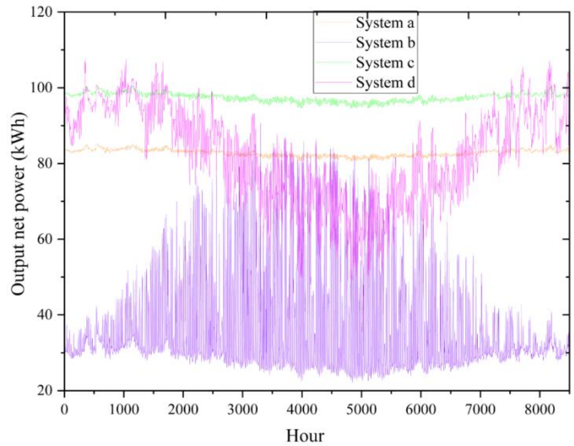

Figure 9. Variations in the generation power of four examined systems.

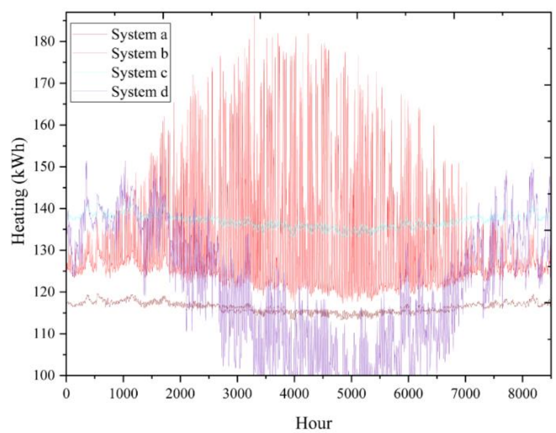

Figure 10. Variations in the heating of the four examined systems.

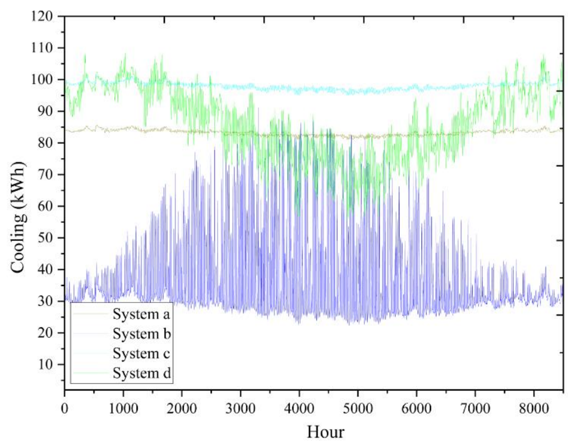

Figure 11. Variations in the produced cooling of the four examined systems.

This research also studied the effect of variations in the ambient temperature of Oslo on the performance of the four examined systems during the year. Figure 12 shows variations in the total exergy efficiency of these systems relative to the annual meteorological changes in this city.

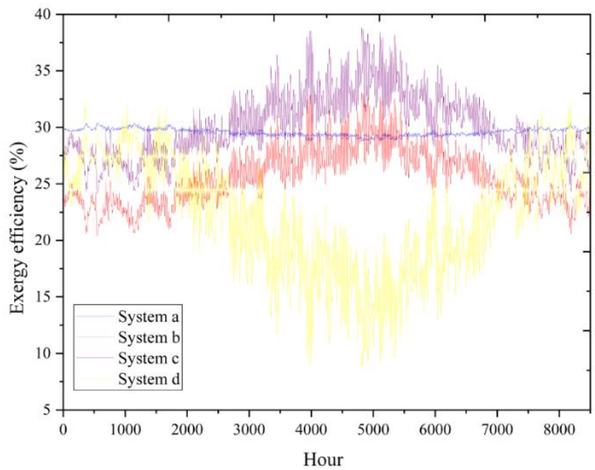

Figure 12. Variations in the exergy efficiency of the four examined systems.

Figure 13 illustrates hourly variations in the cost rate of the four examined systems in relation to the changes in the meteorological parameters of the city for a year. As the results depict, the cost rates of the systems are directly associated with their power generation. A rise or fall in the produced power of the systems makes the cost rate go up or down due to fluctuations in the repair and maintenance operations in hot months.

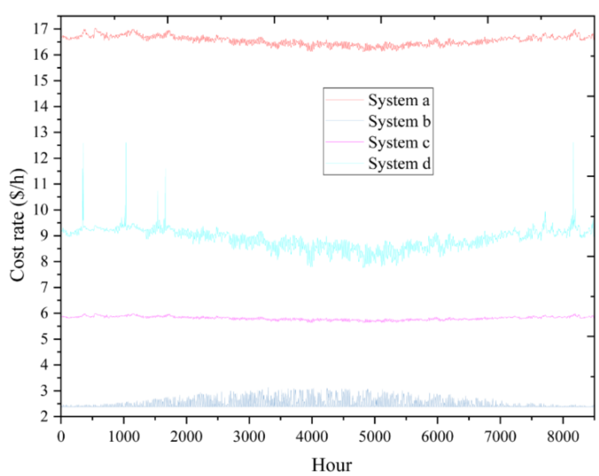

Figure 13. The cost rate of the four examined systems.

4.4 System capacity

Figure 14 presents a detailed comparison of the simulated dormitory complex's hourly electricity consumption, cooling, and heating requirements in Oslo, considering the city's climatic fluctuations and the excess electricity sold to the national grid throughout the year. The results show that the systems can efficiently meet the dormitory's electricity, cooling, and heating needs. Furthermore, the excess electricity generated can be sold to the national grid, generating revenue to offset the systems' costs. Additionally, the extra cooling and heating can be stored for later use in other applications, enhancing the overall efficiency and sustainability of the systems. This outcome highlights the potential of the systems to not only meet the dormitory's energy demands but also contribute to the national grid and reduce the building's environmental impact.

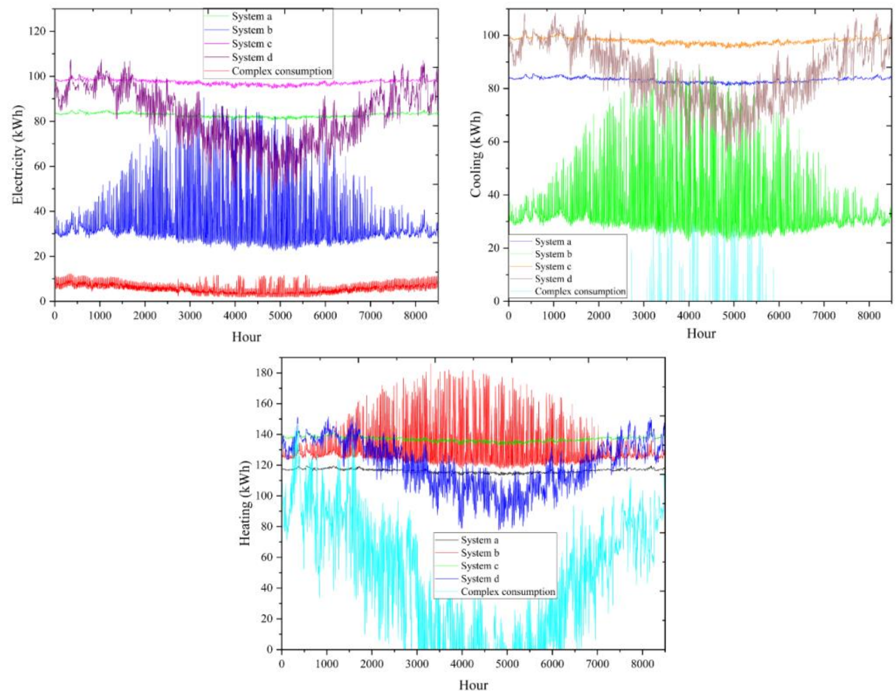

Figure 14. Comparing the consumed energy of the dormitory and the generated power of the four systems

4.5 Stored energy

Examining the capacity of four renewable systems based on solar and geothermal energies to supply the consumed energy of a dormitory complex of the Gas and Oil Company in Oslo revealed that these systems were highly capable of supplying energy, storing heating and cooling during the year, and selling a considerable amount of electricity. Figure 15 examines the stored cooling during the year hourly and obtains the consumed cooling of the dormitory complex by estimating the difference between the produced cooling of the four systems and the consumed cooling of the dormitory. As mentioned, this extra energy can be used for other purposes.

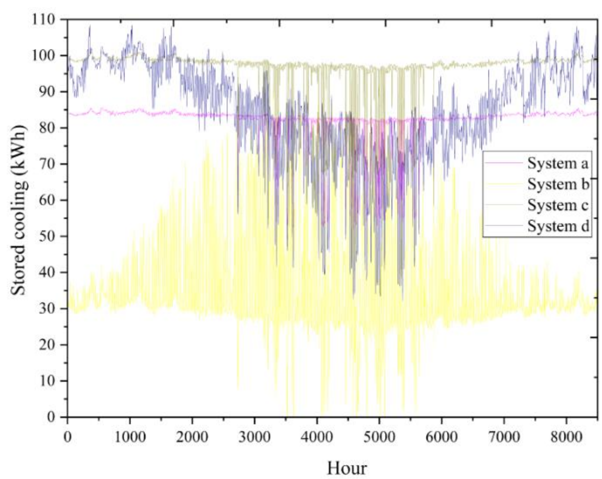

Figure 15. The volume of stored cooling

Figure 16 investigates the stored heating during the year hourly by estimating the difference between the produced heating of the four systems by the compression chiller and the consumed heating of the dormitory. As explained, this extra heating energy can be used for other purposes.

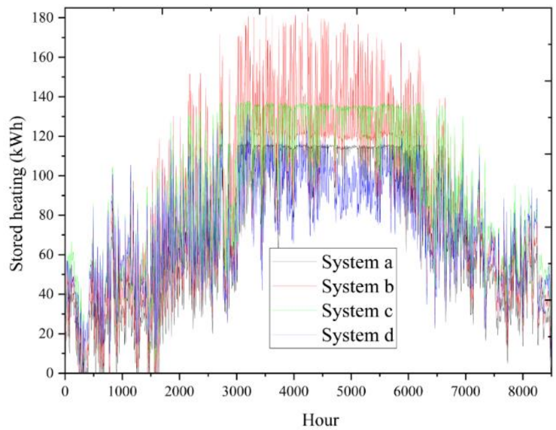

Figure 16. The volume of stored heating

Figure 17 hourly estimates the amount of the extra system-produced electricity as stored energy during the year by calculating the difference between the electricity generated by the four renewable systems and the consumed electricity of the dormitory. This extra electric energy can be sold to the power grid and cause the system to monetize.

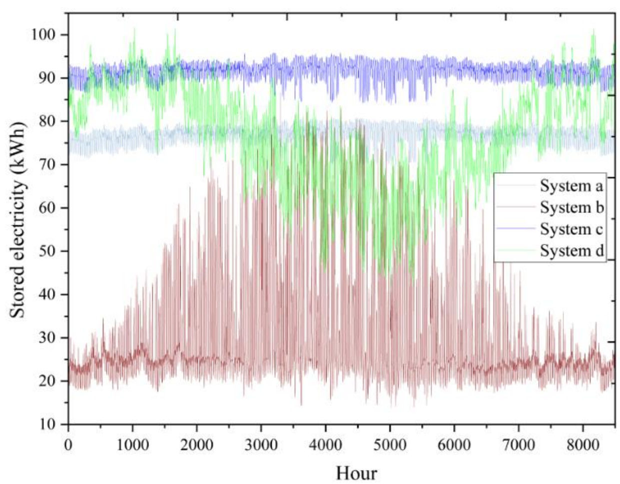

Figure 17. The volume of stored electricity

5. Comparison

In this part, the technical and economic performance of the system has been compared with related research, and results such as the amount of energy production of the system and the cost of the system have been presented. The result of comparing the results extracted in this research with the work of others is presented in Table 5.

Table 5. Comparison with the results of the conducted researches.

Research	Renewable energy	System products	Efficiency	Cost

Present work	Geothermal energy	Cooling, heating and electricity	47.47%	5.98$/h
[23]	Geothermal energy	Electricity, cooling, and hydrogen	40.3%	6.9 $/GJ
[24]	Geothermal energy	Electricity, cooling, freshwater, and hydrogen	46.44%	3.98 $/GJ
[25]	Solar energy	Electricity	36.44%	13.76$/h
[26]	Solar and geothermal energy	Electricity, domestic hot water, cooling load, and hydrogen	35.2%	37.8 $/GJ

6. Conclusion

This study proposed four new cogeneration systems to estimate the consumed energy of a dormitory complex in Oslo, with a 700000 m^2 area. An electric compression chiller was used to supply the heating and cooling demands, and the systems supplied the electric energy of the chiller. The main purpose of this research was to reach a ZEB by supplying the consumed energy of the dormitory by four new cogeneration systems based on renewable resources. The BEopt was employed for the simulation of the dormitory, and the EES software was utilized to design the energy-supplying systems of this building. The results showed that the dormitory consumed 50656.29 kWh, 436221.62 kWh, and 8073.36 kWh of energy for electricity, heating, and cooling during the year. Meanwhile, optimizing energy consumption in the dormitory paved the way for reducing 11911.37 kg/h of CO2 emissions and preventing the surge of environmental pollution. The research embarked on optimizing the four systems with the RSM by defining objective functions, i.e., efficiency and cost rate. A comparison of the outcomes revealed that system d possessed an average cost rate of 8.9 $/h and exergy efficiency of 22.35 %. The system's performance in energy production can be expressed as follows:

- 726090.61 kWh of electricity, which significantly contributed to the dormitory's energy needs.
- 1061256.69 kWh of heating energy, ensuring a comfortable and warm living environment.
- 759213.5 kWh of cooling energy, providing a refreshing and cool atmosphere during the hot summer months.

As a result, System D emerged as the premier supplier of energy in the dormitory, offering a reliable and efficient source of power. Furthermore, the system's advanced capabilities allowed it to store energy during the year, including:

- 675434.32 kWh of electricity, which could be utilized during peak demand periods or when the grid was experiencing high loads.
- 625035.07 kWh of heating energy, providing a backup source of warmth during extreme cold snaps.
- 751140.14 kWh of cooling energy, ensuring a consistent and comfortable living environment even during the hottest summer days.

Overall, the optimization of System D using the Design Expert software demonstrated its potential to provide a reliable, efficient, and cost-effective source of energy for the dormitory, while also offering the ability to store energy for future use. Finally, this research introduced an efficient system with the suitable cost and performance in supplying energy for a 210-unit dormitory of the Oil and Gas Company in Oslo.

7. Suggestions

In this section, 5 important suggestions are presented to researchers to continue and complete current research, which are:

- By combining the fuel cell system with study systems and using proton exchange membrane electrolysis to produce the hydrogen required by the fuel cell, the system stability and energy supply during peak consumption can be helped.
- The use of compressed air storage is recommended to increase the stability of the systems because renewable energy such as the sun is not available all day long.
- To start studying and setting up renewable systems, the potential of the region must first be examined, because in some places, there is the potential to use two or more renewable energies

simultaneously. For this reason, by combining renewable energies, the stability and reliability of the system can be helped. For example, solar energy is the most potential and available renewable energy in the world, which can help increase electricity production by combining solar energy and the existing geothermal system.

- By using freshwater production systems such as reverse osmosis and combining them with the proposed system, in addition to generating electricity, cooling and heating buildings, the amount of freshwater produced by the system can also be provided.
- The use of other optimization methods such as neural networks is also recommended to optimize the systems.

8. Appendix

Base equations in system analysis are used to analyze the systems economically and hemodynamically.

Table 14. Base equations

Basic relationships	*Equation*
Law of Survival of Crime	$\sum_k \dot{m}_i - \sum_k \dot{m}_e = \frac{dm_{cv}}{dt}$
Law of conservation of energy	$\dot{Q} - \dot{W} + \sum_i \dot{m}_i \left(h_i + \frac{v_i^2}{2} + gZ_i \right) - \sum_e \dot{m}_e \left(h_e + \frac{v_e^2}{2} + gZ_e \right) = \frac{dE_{cv}}{dt}$
Exergy balance	$\dot{E}x_Q + \sum_i \dot{m}_i (ex_i) = \sum_e \dot{m}_e (ex_e) + \dot{E}x_W + \dot{E}x_D$
Physical exergy	$\dot{E}x_{ph} = \sum_i \dot{m}_i \left((h_i - h_0) - T_0 (s_i - s_0) \right)$
Cost rate	$\dot{Z} = \frac{Z \times CRF \times \varphi}{T}$
CRF	$CRF = \frac{k(1+k)^n}{(1+k)^n - 1}$

The thermodynamic analysis of the present work necessitates balancing mass and energy for every control volume. The following assumptions are developed for the solution simplification:

- The variations in the kinetic-potential energy are insignificant.
- Steady-state conditions
- The output of the condenser and evaporator is a saturated liquid.
- The turbines and pumps are isentropic.

The input data for system analysis is given.

Appendix 1- The input data

Data	**Definition**	**Value**
T_0	Ambient temperature	25°C
T_1	Geothermal energy temperature	210°C
P_0	Ambient pressure	101.3 kPa
$pp_{\text{condenser}}$	Pinch point temperature of the condenser	5°C
$pp_{\text{evaporator}}$	Pinch point temperature of the evaporator	5°C
η_{turbin}	Turbine efficiency	0.85
η_{pump}	Pump efficiency	0.8

References

1) Zhang, S., et al. (2022). "Renewable energy systems for building heating, cooling and electricity production with thermal energy storage." Renewable and Sustainable Energy Reviews 165: 112560.

2) Walmsley, T. G., et al. (2023). "Hybrid renewable energy utility systems for industrial sites: A review." Renewable and Sustainable Energy Reviews 188: 113802.

3) Nkini, S., et al. (2023). "Comparative analysis of the energy performance in green and non-green office buildings in Dar Es Salaam, Tanzania." Energy and Buildings 293: 113202.

4) Noohian, M. and J. Mahmoudi (2023). "Energy simulation on how to go green buildings in an earth's dry climate." International Journal of Thermofluids 20: 100405.

5) Cheraghi, R. and M. Hossein Jahangir (2023). "Multi-objective optimization of a hybrid renewable energy system supplying a residential building using NSGA-II and MOPSO algorithms." Energy Conversion and Management 294: 117515.

6) Jafarian, M., et al. (2023). "Optimal tariffs of resources and users scale size for a combined Cooling, Heat, power and water (CCHP-RO) system from Energy, Economic, and environmental point of view." Energy and Buildings 297: 113480.

7) Deng, X., et al. (2024). "A novel operation method for renewable building by combining distributed DC energy system and deep reinforcement learning." Applied Energy 353: 122188.

8) Wu, Z., et al. (2023). "Co-optimization of building energy systems with renewable generations combining active and passive energy-saving." Applied Energy 351: 121514.

9) Assareh, E., et al. (2022). "Performance analysis of solar-assisted-geothermal combined cooling, heating, and power (CCHP) systems incorporated with a hydrogen generation subsystem." Journal of Building Engineering: 105727.

10) Assareh, E., et al. (2023). "Techno-economic analysis of combined cooling, heating, and power (CCHP) system integrated with multiple renewable energy sources and energy storage units." Energy and Buildings 278: 112618.

11) Ang, Y. Q., et al. (2022). "Multi-objective optimization of hybrid renewable energy systems with urban building energy modeling for a prototypical coastal community." Renewable Energy 201: 72-84.

12) Aliakbari, K., et al. (2021). "Investigating the impact of a novel transparent nano-insulation in building windows on thermal comfort conditions and energy consumptions in different climates of Iran." Thermal Science and Engineering Progress 25: 101009.

13) Moghaddas-Zadeh, N., et al. (2023). "ANN-based procedure to obtain the optimal design and operation of the compression chiller network – Energy, economic and environmental analysis." Journal of Building Engineering 72: 106711.

14) Xie, J. and J. Wang (2022). "Compatibility investigation and techno-economic performance optimization of whole geothermal power generation system." Applied Energy 328: 120165.

15) Sady, H., et al. (2024). "Towards a net-zero-energy building with smart control of Trombe walls, underground air ducts, and optimal microgrid composed of renewable energy systems." Energy 294: 130703.

16) Lu, M., et al. (2024). "Hybrid solar-wind renewable energy systems with energy storage for net/nearly zero energy buildings: An uncertainty-based robust design method." Energy 313: 133965.

17) Mobayen, S., et al. (2025). "Multi-functional hybrid energy system for zero-energy residential buildings: Integrating hydrogen production and renewable energy solutions." International Journal of Hydrogen Energy 102: 647-672.

18) Aelenei, L., et al. (2025). "Techno-economic analysis of a renewable energy based multigeneration system for zero energy buildings." Renewable Energy 247: 123002.

19) Habibollahzade, A, Gholamian, E, Ahmadi, P, Behzadi, A, (2018), Multi-criteria optimization of an integrated energy system with thermoelectric generator, parabolic trough solar collector and electrolysis for hydrogen production, Int. J. Hydrogen Energy.

20) Amiri Rad E, Mohammadi S, Tayyeban E. Simultaneous optimization of working fluid and boiler pressure in an organic Rankine cycle for different heat source temperatures. Energy 2019;194. https://doi.org/10.1016/j.energy.2019.116856.

21) Allaix, D. L. and V. I. Carbone (2011). "An improvement of the response surface method." Structural Safety 33(2): 165-172.

22) Li, D.-Q., et al. (2016). "Response surface methods for slope reliability analysis: Review and comparison." Engineering Geology 203: 3-14.

23) Cao, Y., et al. (2022). "Economic examination and multi-objective optimization of integrating a novel geothermal-driven combined cooling and power (CCP) system using a bi-evaporator cycle with a low-temperature electrolyzer." International Journal of Hydrogen Energy 47(46): 19955-19976, https://doi.org/10.1016/j.ijhydene.2022.04.105

24) Li, K., et al. (2022). "Multi-objective optimization and multi-aspect analysis of an innovative geothermal-based multi-generation energy system for power, cooling, hydrogen, and freshwater production." Energy 245: 123198, https://doi.org/10.1016/j.energy.2022.123198

25) Assareh, E., et al. (2025). "Optimizing solar photovoltaic farm-based cogeneration systems with artificial intelligence (AI) and Cascade compressed air energy storage for stable power generation and peak shaving: A Japan-focused case study." Applied Energy 377: 124468.

26) Mahmoudan, A., et al. (2022). "A geothermal and solar-based multigeneration system integrated with a TEG unit: Development, 3E analyses, and multi-objective optimization." Applied Energy 308: 118399, https://doi.org/10.1016/j.apenergy.2021.118399.

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