



OPEN Innovative biomass cogeneration system for a zero energy school building

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This study presents a detailed analysis of a Co-generation system specifically designed to fulfill energy (Electricity – Cooling – Heating) requirements of a Zero energy building (ZEB) school in Dubai. The proposed system integrates an electric compression chiller, which plays a crucial role in efficiently managing both heating and cooling demands within the educational facility. To generate clean electricity, the system utilizes a combination of advanced technologies, including a steam Rankine cycle turbine, an organic Rankine cycle turbine, and a gas turbine. The main goal of this research is to supply the definition of a ZEB by providing energy consumed by Zero Energy school building (ZESB) with a biomass system. To optimize energy consumption within the building, the innovative Building Energy Optimization Tool (BEopt) is employed, providing insights into energy efficiency improvements. Optimization of the biomass-based energy production system are executed applied EES software (Engineering Equation Solver) alongside the response surface methodology, ensuring a robust analytical framework for performance evaluation. The suggested co-generation consisted of modified Brayton cycle units (biogas fuel), steam Rankine cycle, organic Rankine cycle, and compression chiller for electricity generation, cooling, and heating. Annual energy consumption metrics for the school indicate a total electricity usage of 43,539.48 kWh, with a heating load of 0.94 kWh and a cooling load of 1,115.68 kWh. Through strategic optimization of energy consumption patterns, the system achieves a notable reduction in carbon dioxide emissions, amounting to 24,548.97 kg per year. The optimized energy system operates with an overall efficiency of 31.79% and incurs operational costs estimated at \$88.02 per hour. In terms of output generation, the biomass energy system is projected to yield approximately 151,746,087 kWh of electricity, 194,610,878 kWh of heating bar, and 158,962,204 kWh of cooling bar annually. Comparative analysis demonstrates that this innovative biomass-based energy system can effectively meet the school's energy demands throughout the year while contributing to sustainability goals and reducing environmental impact. A comparison of the school's consumption and the system's production showed that 151,702,547.5 kWh of electricity, 194,609,762.3 kWh of heating, and 158,774,864.1 kWh of cooling could be saved in one year to offset costs of co-generation systems. This research underscores the potential for integrating diversified renewable energy technologies in educational settings, thereby promoting sustainable practices within the context of Dubai's commitment to supplying ZEB consumption in its ZEBs by 2050.

Keywords Co-generation system, Biomass, ZESB, Building energy optimization (BEopt), Response surface method (RSM).

List of symbols

Abbreviations

T	Temperature [°C]
p	Pressure [kPa]
Q	Heat transfer rate, (kW)
A	Area (m ²)
Ex	Exergy [kW]
C _p	Specific heat of air and water at constant pressure [kJ/kg.K]
m	Mass flow rate [kg/s]
C _{air}	Capacity specific heat

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L	Panel length (m ²)
b	Panel width (m ²)
s	Specific entropy [kJ/kg.K]
U	Overall heat transfer coefficient [kW/m ² K]
h	Specific enthalpy [kJ/kg]
W	Power [kW]
x	Salinity [ppm]
Z	Investment cost [\$]
$\dot{Z}$	Cost rate [\$ /h]

Subscripts

HEX	Heat exchanger
EES	Engineering equation solver
GT	Gas Turbine
ZT _M	Figure of merit
CRF	Capital recovery factor

Abbreviations

cond	Condenser
TEG	Thermoelectric generator
Eva	Evaporator
0	Dead state
i	In
comp	Compressor
e	Out
ph	Physical
ch	Chemical
cv	Control volume

Greek symbol

η	Efficiency
φ	Maintenance factor

A critical concern for many nations worldwide is the provision of clean energy for buildings serving various purposes. As the demand for comfort, recreational amenities, and commercial spaces continues to rise, so too does the energy consumption associate with these structures. In response to this challenge, zero-energy buildings have gained considerable traction as a leading approach to environmental conservation and energy management¹. These buildings utilize renewable energy sources to meet their energy requirements, thereby minimizing reliance on fossil fuels. Achieving zero-energy status involves multiple factors, including construction practices, operational strategies, maintenance protocols, and the selection of materials such as window types and wall compositions, as well as building orientation². Each of these elements plays a crucial role in influencing the overall energy demand for heating, cooling, and the clean electricity essential for building operations. Optimizing building design through innovative tools and methodologies can significantly enhance energy efficiency, ultimately contributing to national energy goals. The integration of renewable energy sources through systems known as multi-energy production systems presents a viable solution to address these needs. Among various renewable options, biomass energy stands out as a key resource recognized for its potential as a clean energy source in numerous countries³. The implementation of a multi-production system that relies on biomass energy has demonstrated effectiveness in supplying energy to buildings while yielding practical and appealing outcomes. This approach not only supports the transition towards sustainable building practices but also aligns with global efforts to mitigate climate change by reducing greenhouse gas emissions associated with conventional energy sources. Thus, this study aims to explore the multifaceted benefits of zero-energy buildings and the role of biomass in enhancing their sustainability and operational efficiency⁴.

In 2023, Dezhdar and colleagues developed a cogeneration system to cater to the clean energy requirements of an apartment. The quantity of solar panels and wind energy systems employed had the most significant impact on the generation of clean electricity and associated costs⁵. Jafarian et al. devised a novel energy system to fulfill the entirety of the building's energy demands. The outcomes were examined in contrasting climates (Dubai and Barcelona), leading to substantial energy savings⁶. In 2020, Gholamian and colleagues assessed an energy production system (involving clean power, cooling bar and heating bar) designed to meet the energy requirements for a building. The suggested multi-system has the capability to produce and store an extra 715.32 kWh of power⁷. In 2023, Nikbakht Naserabad and co-authors developed a system aimed at supplying clean energy for a building. The outcomes indicated energy efficiency and exergy values of 55.33% and 31%, respectively⁸. In 2024, Mohammadi and colleagues assessed an energy storage and hydrogen production system for a building. The findings revealed that in systems incorporating batteries and hydrogen storage, photovoltaic panels contribute to producing 39% and 37% of the electricity needed by the building, respectively⁹. Zabihi Tari and colleagues optimized a building using innovative tools in 2023. Situated in a remote location, this building relies entirely on the electricity grid to fulfill the residents' requirements¹⁰. In 2024, Shirazi and colleagues conducted thermal energy storage for residential buildings in cold climates. The energy supply is derived from a combination of biomass and solar systems. The solar-powered system demonstrates a favorable energy cost, while the biomass fuel system proves to be highly efficient, boasting a relatively high energy efficiency of 69%¹¹. Lan and colleagues examined an extensive design strategy for net zero-energy residential structures in 2019. The study presents a holistic design approach for achieving net zero-energy in residential buildings, incorporating three key principles: social, environmental, and financial considerations¹². In 2022, Arabkoksar and colleagues

explored and assessed thermal photovoltaic panels for net zero-energy structures. Findings indicated that to fully leverage the potential of these panels in smart buildings, significant challenges like high initial costs and limited bidirectional interaction with local energy systems need to be addressed¹³. In 2023, Behzadi and colleagues examined the energy supply and demand of buildings in Stockholm, Sweden, utilizing solar and biomass systems. The analysis revealed that 70.8 MWh of renewable electricity was fed back into the local grid, while 111.5 MWh was utilized to fulfill the building's energy requirements¹⁴. Shahsavar and Khanum Mohammadi conducted a study in 2022 to explore how the quantity of objective functions influences the optimization of hybrid photovoltaic systems for supplying energy to buildings¹⁵. In 2022, Izadi and colleagues examined a building incorporating a hydrogen storage system and various fuel sources. The study focused on assessing the impact of natural gas on the proposed system, highlighting its lower CO₂ emissions compared to alternative fuels¹⁶. In 2023, Tamiz and Dincer studied a combined system involving hydrogen production and storage for building applications. Findings indicated that a 20-story building covering around 62,680 square meters requires a photovoltaic power plant ranging from 550 to 1550 kW/s in five distinct cities¹⁷. In 2022, Izadi and colleagues examined a novel hybrid renewable energy system alongside hydrogen storage systems across varying weather conditions. Their findings suggested that solar panels and wind turbines could generate between 35% and 49% of the electricity required by buildings in any given city¹⁸. Sohani and colleagues in 2023 conducted a thermal-electrical assessment of photovoltaic technology implemented on a building's rooftop. They examined the newly installed photovoltaic system on a building in Tehran. The findings indicated that employing cooling methods and centralized strategies concurrently is recommended as a highly effective approach to enhance system efficiency¹⁹. Also, new studies^{20–23} have been carried out in the field of the current research work, and their review can be of great help to the readers of the present research. Addressing environmental challenges involves reducing per capita energy consumption and minimizing the combustion of fossil fuels. Buildings contribute to about 40% of global energy consumption and 33% of greenhouse gas emissions²⁴. In 2024, Ding et al. evaluated a novel liquid air energy storage system capable of simultaneously producing electricity, cooling, heating, hot water, and hydrogen. The system demonstrated significant outputs, including 58,793.5 kW of electricity and 67.94 kg/s of hot water, with a 20.76% improvement in energy efficiency compared to traditional systems, though it experienced a 14.61% drop in exergy efficiency²⁵.

In another study, Ding et al. analyzed two solar-assisted multi-generation systems for cooling, heating, and power production, differing in their use of solar energy storage. The system with energy storage showed better primary energy utilization, exergy efficiency, and fuel savings but weaker economic performance. A rotor speed-temperature-fuel control system was developed to ensure stable and efficient power generation with minimal surplus and quick stabilization times²⁶.

Chater et al. in 2024 investigated a solar system for the hydrothermal carbonization process using photovoltaic solar panels. Systems using parabolic trough solar collectors proposed in the literature present limitations and challenges. Therefore, to overcome this issue, a new concept combining photovoltaic solar panels and a batch reactor with a heating collar is proposed²⁷.

Alomar et al. in 2024 investigated a solar photovoltaic panel. Energy and exergy analysis is used to predict the performance of three solar panels. The theoretical work includes technical, economic, and environmental analysis of the proposed 1 MW solar power plant. The results showed that the increase in electrical output power and thermal exergy output increases when using tracking systems, where the exergy losses are reduced for single-axis and dual-axis tracking systems compared to fixed solar aircraft²⁸.

Zayed et al. in 2023 designed a solar air conditioning system integrated with photovoltaic panels and thermoelectric coolers. This research introduces a microclimate solar cooling system to enhance human thermal comfort and reduce grid-based energy consumption. In this system, PV modules generate electrical power that is directly used to power SPVTEAC and lead-acid batteries for the self-service nighttime operation of the hybrid system²⁹.

Currently, the provision of energy for buildings has become a central concern for researchers, particularly as cogeneration systems emerge as a promising solution to meet the diverse energy loads of these structures. The growing apprehension regarding the finite nature of fossil fuel resources, coupled with their substantial greenhouse gas emissions, highlights the critical need for alternative energy solutions. Cogeneration systems, which facilitate the simultaneous production of electricity and useful heat from a single energy source, offer significant advantages in this context. By integrating various energy production units, these systems not only minimize exergy destruction and overall energy consumption but also enhance production efficiency. The ability to recover and utilize waste heat that would traditionally be lost in conventional energy generation processes significantly improves the overall energy yield. This integrated approach not only contributes to lower operational costs but also aligns with global sustainability goals by reducing carbon footprints. As such, cogeneration systems represent a vital component in the transition towards more sustainable building practices and energy management strategies, addressing both economic and environmental imperatives in contemporary architecture. This study investigates the optimization of energy consumption and supply for a school in Dubai City through the implementation of a biomass cogeneration system that incorporates a modified Brayton cycle utilizing biogas, along with ORC, SRC, and condensation chiller technologies. Given Dubai's hot climate, where cooling demands significantly exceed heating needs throughout the year, the research involved simulating the school's energy requirements and utilizing the Building Energy Optimization Tool (BEopt) to analyze and refine its design. The findings highlight the school's electricity load, heating, and cooling demands, leading to an optimized design that enhances energy efficiency while minimizing pollution and construction costs. The proposed biomass-based multi-generational system aims to meet the school's energy load effectively while integrating innovative cycles to improve power generation and overall system efficiency. By employing response surface methodology for system optimization, this research not only addresses the specific energy challenges

Parameter	Type			
Floor height (FH)	2.7 m	2.8 m	2.9 m	–
Building height	0.3 m	0.6 m	1 m	–
Building type	Pier & beam	Crawlspace	Salb	Basement
Roof type (RT)	Falt roof/deck	Vaulted ceiling	Finished attic	–

Table 1. Design specifications.

Senario	1	2	3	4	5	6	7	8	9	10	11
Type	Pier&Beam	Pier&Beam	Pier&Beam	Crawlspace	Pier&Beam	Crawlspace	Salb	Salb	Basement	Crawlspace	Crawlspace
H	0.3	0.6	1	0.6	0.6	0.6	0.1	0.1	0.6	0.3	1
FH	2.7	2.8	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.7	2.8
RT	Falt roof/deck	Falt roof/deck	Falt roof/deck	Finished attic	Vaulted ceiling	Vaulted ceiling	Falt roof/deck	Falt roof/deck	Falt roof/deck	Finished attic	Falt roof/deck

Table 2. Introduction of scenarios.

Scenario	Electricity	CO ₂ emissions	Heating	Cooling
1	4322.73	1016.426	0.049824	4854.513
2	4329.43	1018.049	0.052755	4872.781
3	4341.57	1020.844	0.061547	4904.736
4	4538.3	1067.213	0.052755	5413.045
5	4342.94	1021.238	0.055686	4893.898
6	4540.37	2353.984	0.17	18434.01
7	4444.65	1045.151	0.032239	5209.132
8	4433.97	2298.892	0.09	17670.66
9	4699.28	1105.049	5805.991	1157.556
10	4319.51	1015.67	0.046893	4845.574
11	4329.43	1018.049	0.052755	4872.781

Table 3. Results of Building design scenario.

faced by educational institutions in hot climates but also contributes to broader sustainability goals by reducing environmental impact and promoting renewable energy solutions.

The innovations are as follows:

- Simulation of a school in the city of Dubai.
- Using BEopt for school analysis.
- Calculation of Energy for ZESB (Electricity- cooling – heating).
- ZESB optimized with save energy & reduce pollution.
- Using a biomass-based Cogeneration to supply ZESB load.
- Optimized performance of the new proposed renewable system.
- Using RSM for optimized system.

Optimum design of the school building

This study initially explores various scenarios to determine the optimal floor height, building foundation type, foundation height, and roof design, as outlined in Table 1.

A selection of 11 scenarios for designing a room in a school in Dubai was made, showcasing different designs for the construction of the school. The details of these scenarios are outlined in Table 2.

In Table 3, the results of 11 scenarios are presented.

The findings indicated that reducing the floor height and the building foundation height led to decreased building energy consumption. In Dubai, the optimal building foundation type is identified as Pier&Beam with a Flat Roof/Deck. Given the objective of optimizing energy usage in the Dubai school, Scenario 1 was selected for the comprehensive design of the school building. The study involved calculating the thermal and cooling load, as well as the electrical load of a school in Dubai City.

The school building in Dubai (Fig. 1) was designed and evaluated using Building Energy Optimization (BEO) to establish the yearly clean power output load, heating demand, and cooling requirements for the entire school facility. BEopt software serves as a building energy optimization tool, offering cost-effective efficiency



Fig. 1. View of the school.

enhancement solutions. It evaluates buildings based on dimensions, architecture, occupancy, location, and amenities to simulate energy performance. Figure 2 illustrates the flowchart for analyzing the school building in terms of energy consumption, encompassing electricity demand, heating requirements, and cooling needs.

A range of sizes and materials were chosen for constructing the school building to identify the optimal structure. Notably, the school building is positioned facing north. The study explored various materials for walls and ceilings, featuring the innovative utilization of Phase Change Materials (PCMs), with specific details outlined in Table 4. Furthermore, diverse door products, lighting systems, and components were integrated to enhance the building design from an energy efficiency standpoint. The duration needed for analyzing the building optimization considering various influencing factors is detailed in Table 5.

The study delves into the analysis of weather conditions, concentrating on the impact of variations (weather conditions) in ambient temperature (AT), Wind Speed (WS), Solar Radiation (SR) and Relative Humidity (RH) in Dubai. These environmental factors play a significant role in the Energy usage of buildings over the course of a year. Hourly variations in T_0 for Dubai city are depicted in Fig. 3, showcasing temperature fluctuations ranging from 0 to 50 °C, with peak temperatures observed in June and July during the summer season. Furthermore, hourly fluctuations in dew point temp are illustrated, fluctuating between −5 and 35 °C. The dew point is the temperature at which air must be cooled to become saturated with water vapor, playing a crucial role in both air conditioning and meteorology. The hourly fluctuations in wind speed for Dubai are graphed to illustrate the variations in wind patterns throughout the day and year. The wind speed in Dubai experiences mild seasonal changes, with the windier period lasting from December to June and the calmest period from June to December. The windiest month is March, with an average hourly speed of 9.2 miles per hour, while the

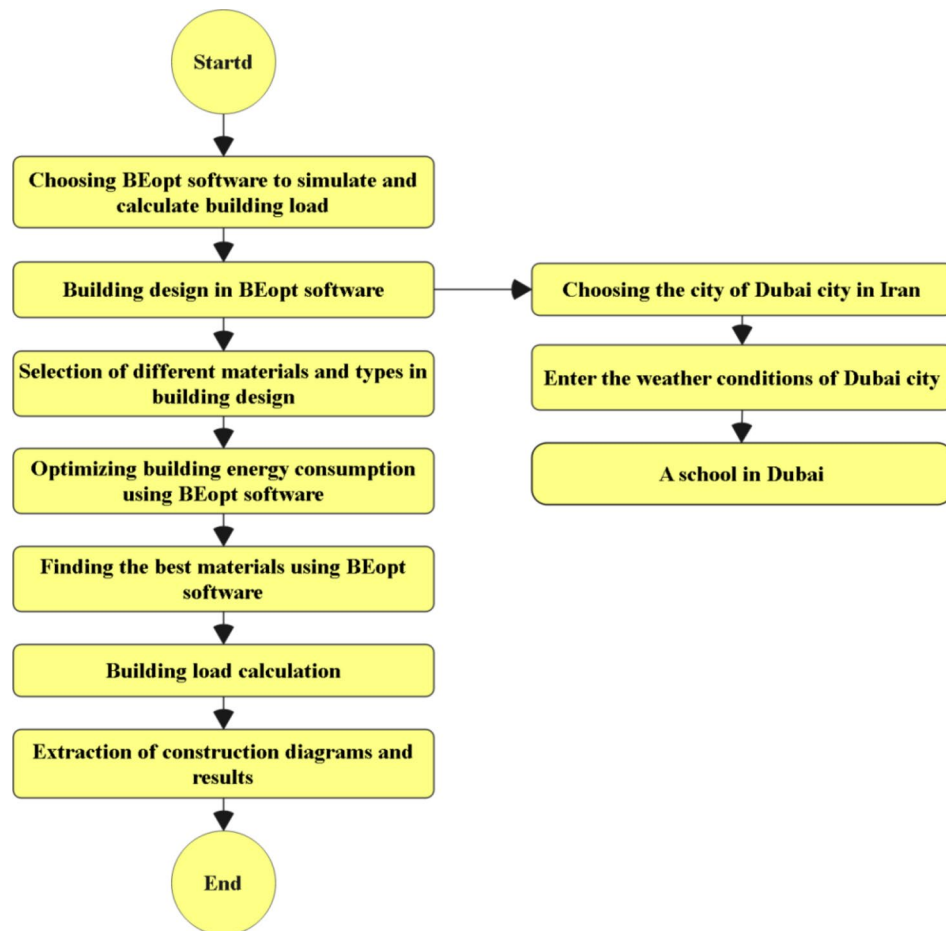


Fig. 2. Flowchart of school building analysis.

PCM	U-value (W/m ² -K)	Density (kg/m ³)	Latent heat (kJ/kg)	Specific heat (kJ/kg-K)	Thermal conductivity (W/m-K)
Solid	46.9	878	100	2.750	0.300
Liquid	15.6	898	100	1.848	0.100

Table 4. Properties of PCM materials^{30,31}.

Parameter	Description
Run time	17 h 15 min 23 s
Number of iterations	88

Table 5. Building RUN information.

calmest month is October, with an average speed of 7.0 miles per hour, the wind speed in Dubai ranges from 0 to 25 m/s, highlighting the city's significant wind energy potential. This potential can have a substantial impact on building energy consumption by providing an alternative and renewable source of energy. Additionally, the solar radiation intensity in Dubai varies throughout the year, ranging between 0 and 1200 W/h. These findings underscore Dubai's high solar energy potential, which also plays a crucial role in influencing building energy usage. Relative humidity, closely related to dew point in thermodynamics, is crucial for determining air moisture content. Represented as a percentage at a specific temperature, relative humidity reflects the proportion of water vapor pressure to saturation pressure in the air. Monitoring hourly relative humidity levels throughout the year for Dubai city is essential for understanding indoor air quality and comfort. Maintaining indoor humidity around 45% is ideal for creating a comfortable environment; levels below 30% can lead to dryness-related health issues like skin irritation and respiratory discomfort. Therefore, regulating temperature and humidity indoors is paramount for overall well-being and comfort.

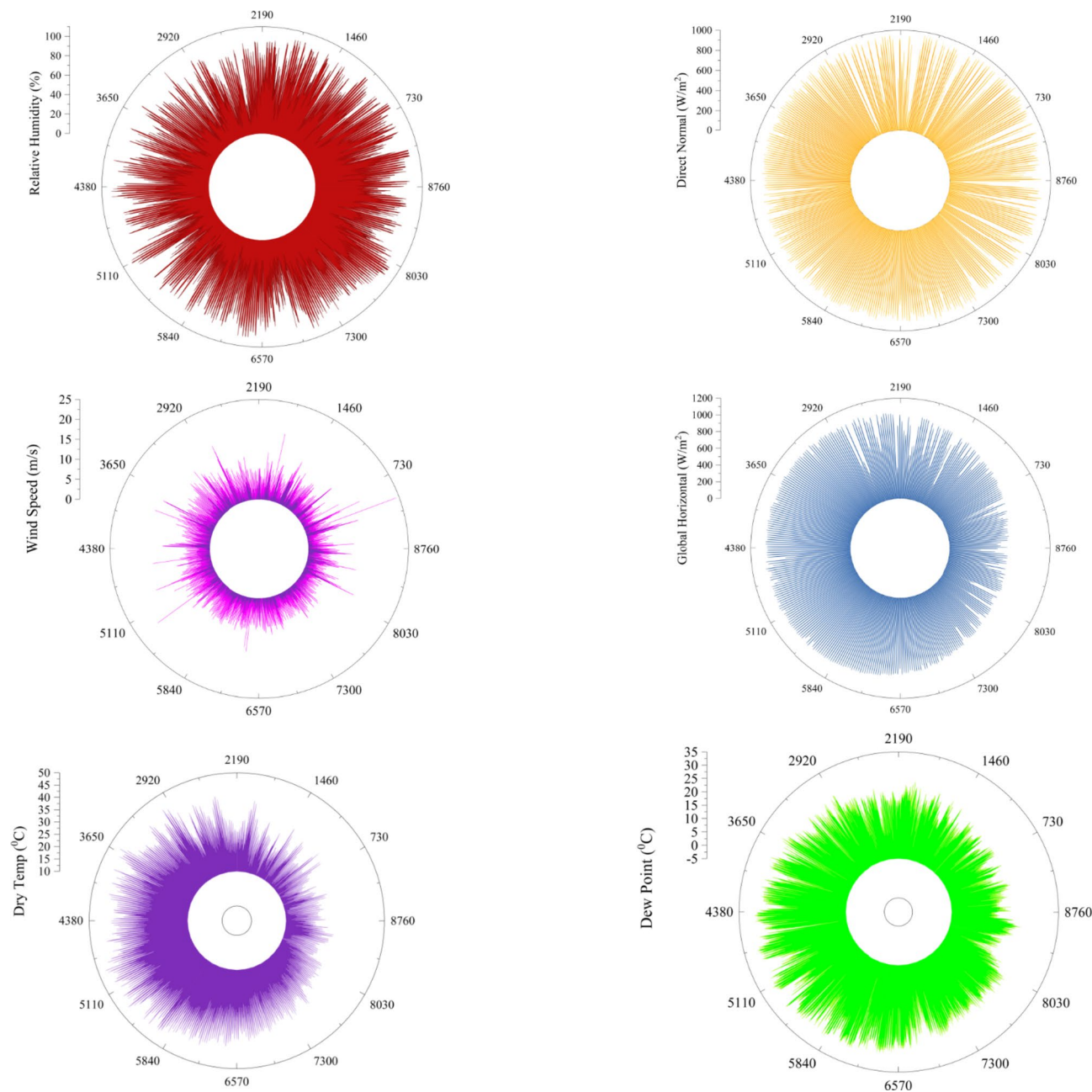


Fig. 3. Hourly changes in weather parameters.

Figure 4 illustrates the temperature levels within the living space. The recommended temperature range for the school building in Dubai is between 70 and 76 °F (21.5–24.5 °C), emphasizing the importance of utilizing central heating and other temperature control methods to establish a healthy and pleasant indoor atmosphere. The graph also displays the adjustment points for cooling and heating loads in the school to achieve the desired living space temperature. Working in excessively hot conditions can lead to physical and mental discomfort, impacting performance. Heat-related illnesses can result in a decline in athletic performance, muscle cramps, exhaustion, fainting, and even loss of consciousness. Heat stroke, a life-threatening condition, can occur due to prolonged exposure to high temperatures or physical exertion in such conditions. Therefore, maintaining an optimal temperature in the living area is crucial for enhancing overall well-being and comfort.

Validation of the building analysis

Figure 5 presents the validation and comparison of electricity consumption in a 30-meter room in Dubai between the actual model and the BEopt software-assessed model. The findings reveal that the real model shows elevated electricity usage during summer and hot seasons, primarily due to heightened utilization of cooling electrical devices. In contrast, electricity consumption decreases in colder seasons as the reliance on cooling equipment

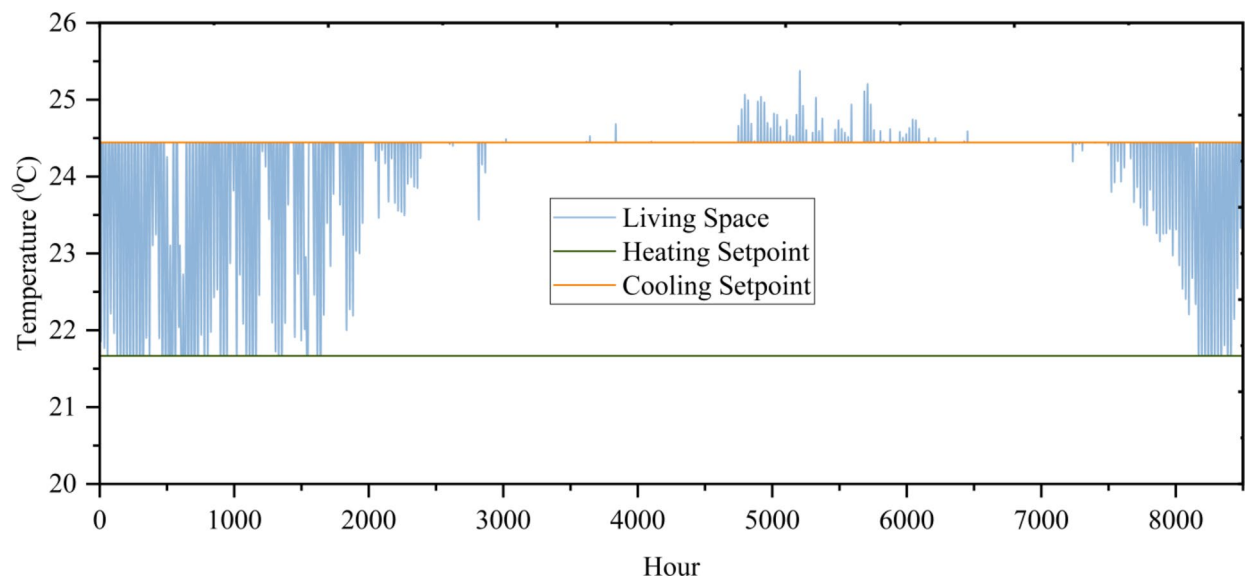


Fig. 4. Living space.

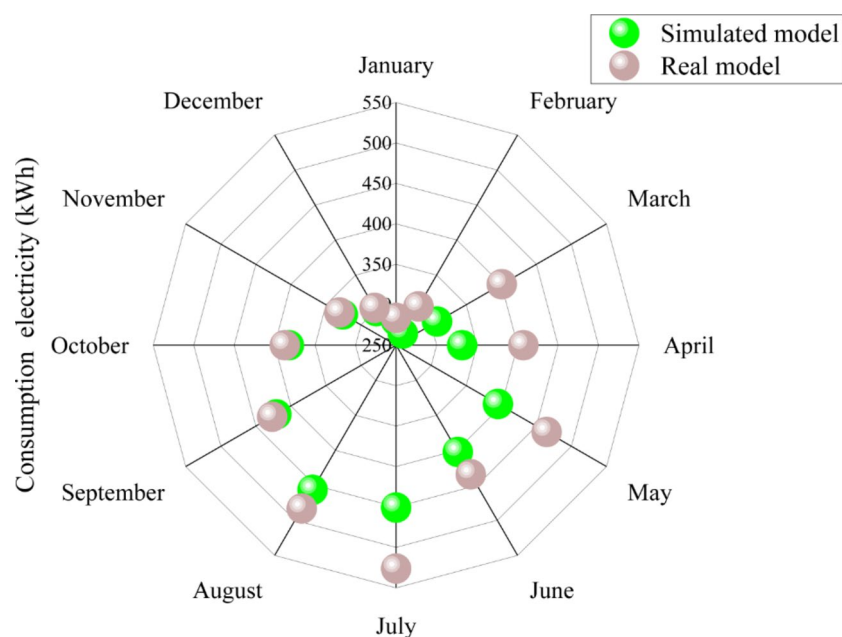


Fig. 5. Validation of electricity consumption of a school room in Dubai City and the investigated model.

diminishes. The software-modeled scenario replicates the powering of cooling equipment by national electricity, aligning with the conditions observed in the actual Dubai model to ensure a thorough validation process.

School building analysis

The initial phase of this research involved a comprehensive optimization process utilizing the Building Energy Optimization Tool (BEopt) to identify the most effective strategy for enhancing the energy consumption, construction costs, and carbon dioxide emissions reduction of a proposed school in Dubai. This optimization process considered a multitude of factors, including the specific geographic location, local weather variations, and the materials selected for construction. Over an extensive analysis period of 17 h, 15 min, and 23 s, BEopt conducted 88 simulation runs to generate a range of optimization solutions tailored to the unique requirements of the school. The BEopt methodology is particularly adept at identifying the best materials and features for building designs by evaluating various combinations of energy efficiency measures and renewable energy options. This approach not only facilitates the selection of optimal construction materials but also enhances overall building performance in terms of energy efficiency and sustainability. By systematically analyzing the

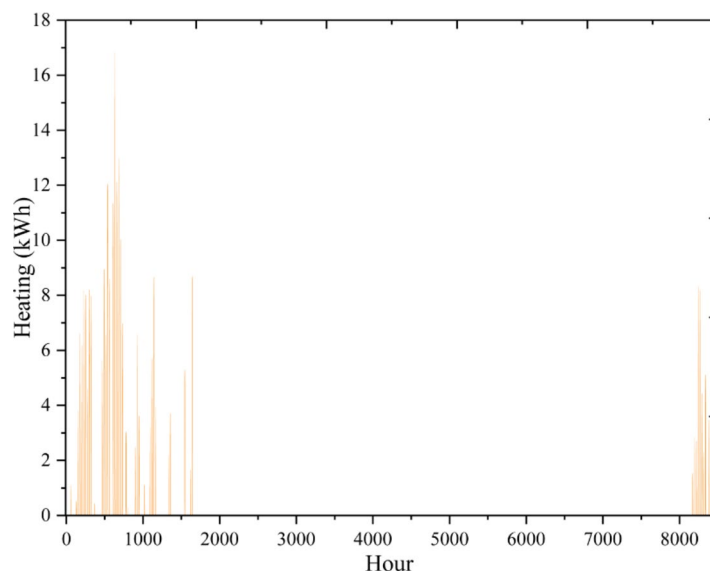


Fig. 6. Heating bar consumed by the school.

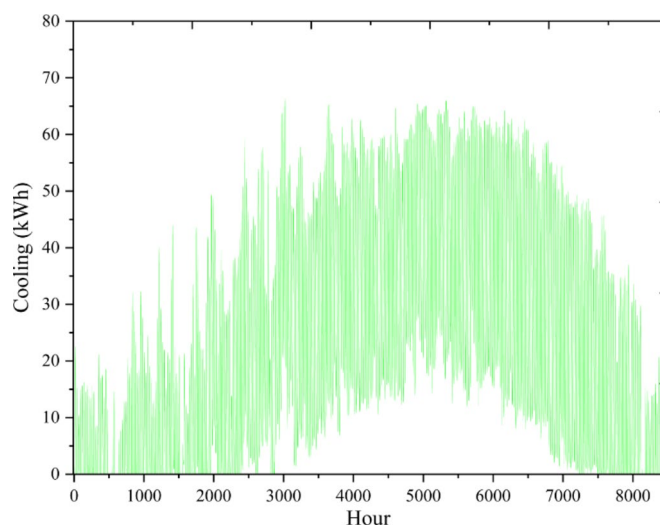


Fig. 7. The cooling load of the school.

interactions between different design elements, BEopt enables researchers to pinpoint configurations that minimize energy consumption while maximizing comfort and functionality. In this study, BEopt's capabilities were leveraged to assess how different construction strategies could lead to significant reductions in operational costs and environmental impact. The results from this optimization process will serve as a foundation for implementing a biomass-based multi-generational energy system, ensuring that the school meets its energy demands sustainably. Ultimately, this research aims to contribute valuable insights into the design and operation of zero-energy buildings in hot climates, promoting environmentally responsible practices in educational infrastructure development.

Results - optimum building

In Fig. 6 depicts the hourly heating outcomes for the school building throughout the year. In Dubai, the school's heating needs are significantly lower than its cooling demands, thanks to the region's ample solar radiation and warm air conditions. The annual heating consumption for the school building falls within the range of 0 to 18 kWh.

Figure 7 displays the hourly cooling bar data for the school over a year. The findings indicate that in Dubai, the school's cooling demand is notably high, primarily influenced by the ambient temperature (T_0). The school's cooling consumption ranges from 0 to 80 kWh throughout the year.

Figure 8 illustrates the hourly electricity consumption of the school building over the course of a year. The school's electricity usage ranges from 0 to 80 kWh annually.

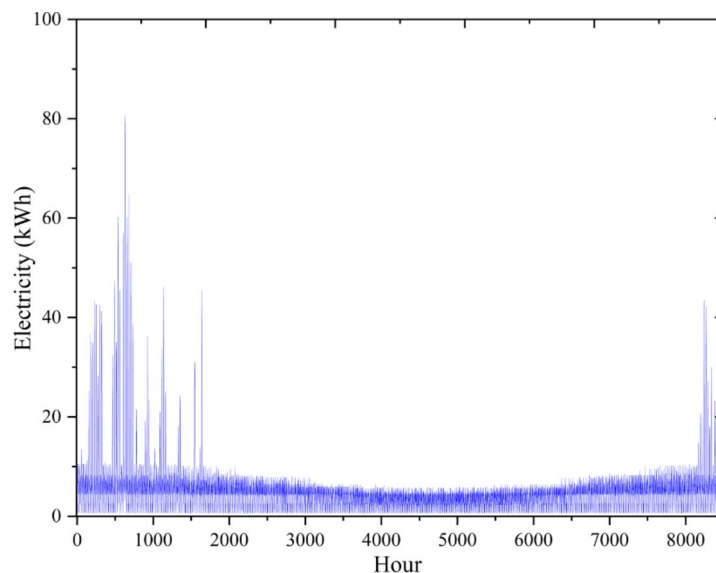


Fig. 8. Clean electricity consumed by the school building.

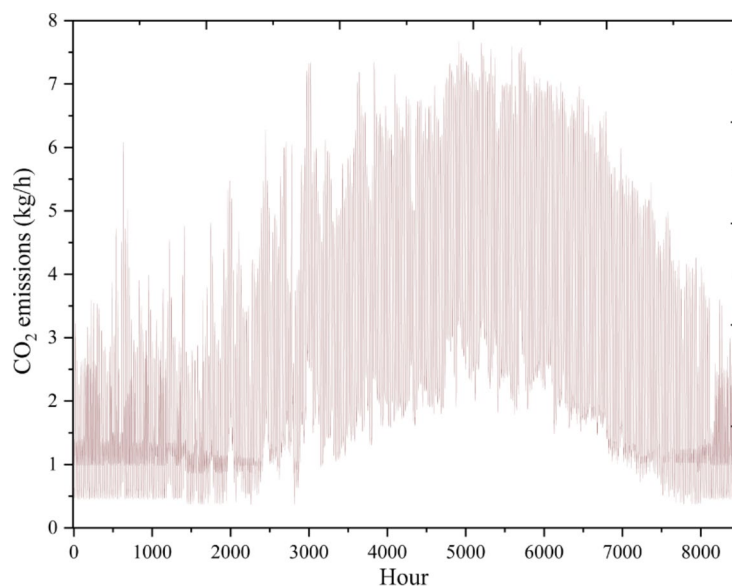


Fig. 9. Reduction - CO₂ emission.

Figure 9 presents the outcomes of reducing CO₂ emissions over the span of a year through optimizing the school's energy usage.

Figure 10 exhibits the thermal contours that represent the energy consumption of the school, illustrating the hourly energy flow and distribution. It visualizes the fluctuations in energy required by the school throughout various seasons based on the construction materials utilized. The figure displays the heating and cooling contours over the year, showcasing variations in their consumption levels influenced by environmental conditions affecting the school.

The effects of changes in environmental factors (Fig. 11) on a school's heating consumption can have significant implications for student learning and overall well-being. Research indicates that cumulative heat exposure over the school year is associated with lower levels of student learning. In school districts without air conditioning, a 1°F increase in average school year temperature is linked to a 1% decline in learning. However, the presence of classroom air conditioning systems can mitigate this negative effect, nearly eliminating the adverse impact of higher temperatures on academic achievement. Ambient Temperature (AT) & solar Radiation (SR) & wind speed (WS) & relative humidity (RH) are individually evaluated to understand their impact on heating usage throughout the year in Dubai City.

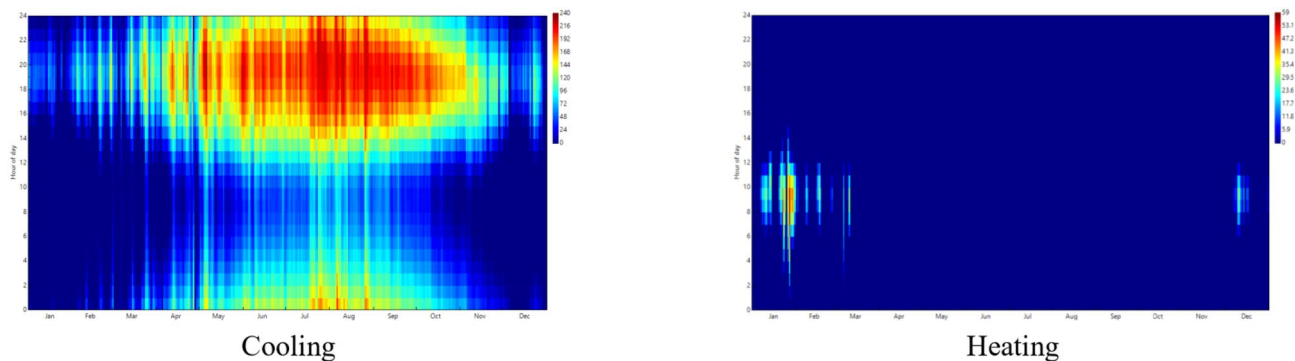


Fig. 10. Energy contours.

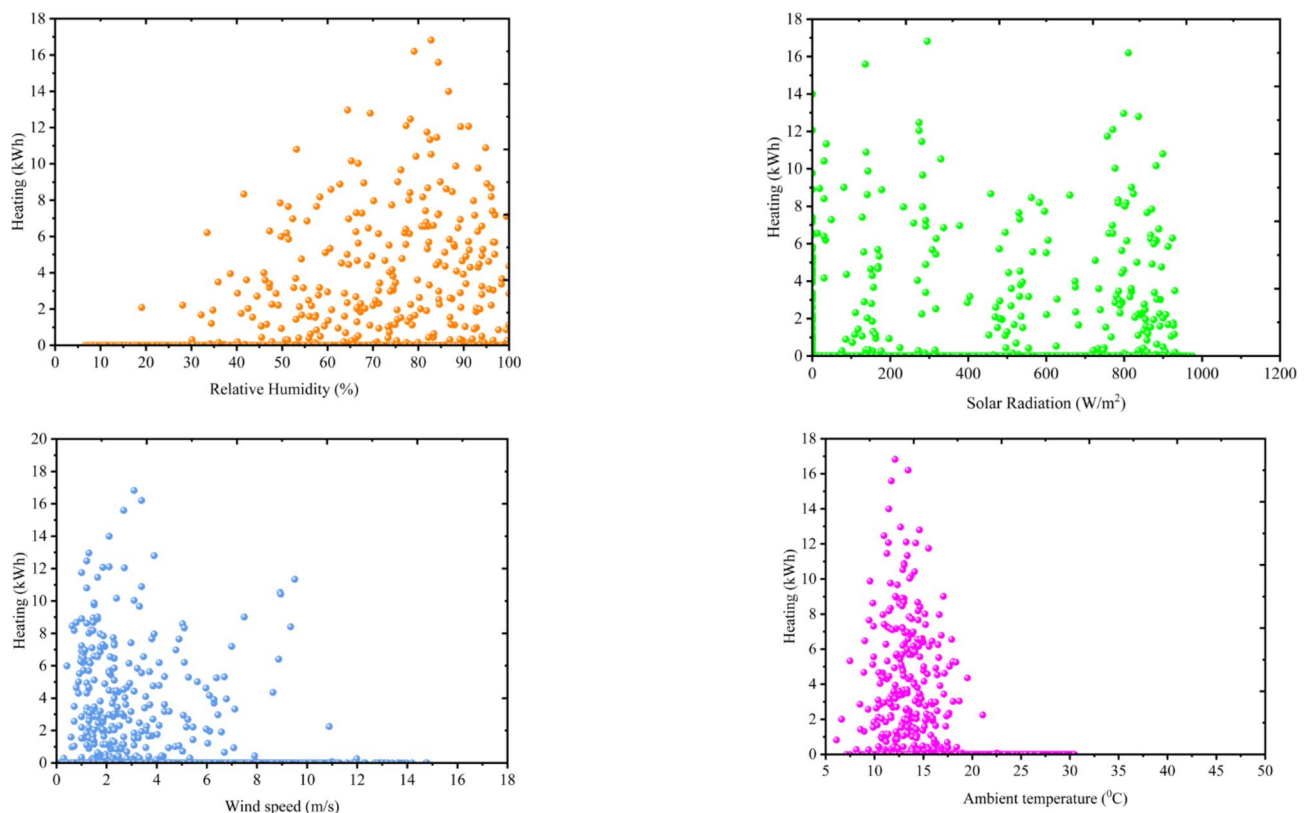


Fig. 11. Heating consumption based on weather parameters.

Relationship between variations in environmental elements and cooling usage in a school in Dubai is crucial for understanding energy consumption patterns and optimizing thermal comfort. Factors like AT, SR, WS, and RH are analyzed independently to evaluate their influence on cooling consumption over the course of the year. Research indicates that cumulative heat exposure over a school year is associated with lower levels of student learning, with higher temperatures leading to a decline in academic achievement. The presence of air conditioning systems in schools can mitigate this negative effect, emphasizing the importance of maintaining appropriate indoor thermal conditions for student performance. Furthermore, the quality of the indoor thermal environment in school classrooms is essential for students' health and performance. Studies highlight the impact of thermal comfort on students' learning experiences, emphasizing the need for conducive indoor environments to promote teaching and learning effectively. Understanding how environmental factors like temperature, solar radiation, wind speed, and relative humidity affect cooling usage in schools is crucial for optimizing energy efficiency, promoting student well-being, and enhancing academic performance (Fig. 12). By analyzing these relationships, schools can implement strategies to create comfortable learning environments that support both energy conservation and student success.

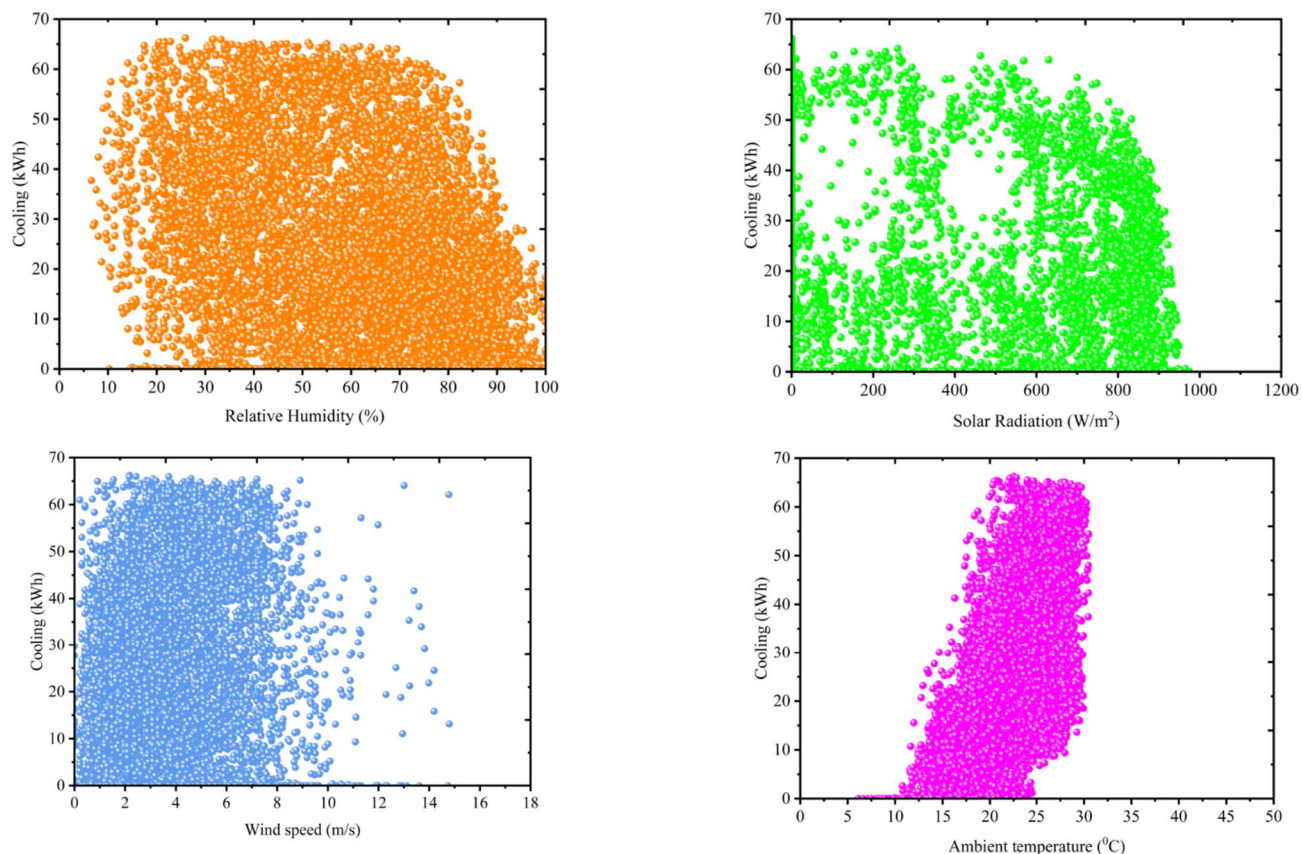


Fig. 12. Effects of weather parameters on the cooling bar.

Figure 13 shows distribution of changes in environmental factors affecting of the electricity consumption for ZESB in Dubai is a critical aspect of energy management and efficiency. Understanding how factors like temperature, solar radiation, wind speed, and relative humidity impact cooling usage is essential for optimizing energy consumption and creating comfortable learning environments for students. These factors include temperature (T_0), SR, WS, and RH. They are individually analyzed to understand their influence on electricity usage throughout the year in Dubai.

Table 6 presents the optimal amounts corresponding to the 6 points featured on Pareto figure. These six optimal points, labeled alphabetically, are aligned with the primary goals of lowering building energy optimization consumption (BEOC) and mitigating Carbon dioxide emission (CDE) linked to energy use are a significant concern globally, with implications for climate change and environmental sustainability. The school building attains an annual energy savings rate of 0.34%, resulting in annualized energy cost savings of \$18,760.35.

Optimization of cogeneration system

System description

This research discusses the design of a novel system incorporating a modified Brayton cycle unit (utilizing biogas as fuel supply), steam Rankine cycle, Organic Rankine Cycle (ORC), thermoelectric generator, and compression chiller (CC) for electricity generation, cooling bar and heating bar purposes. The Brayton cycle in this system utilizes biomass fuel (burning animal waste to generate the heat required for the cycle) and does a thermodynamic power generation cycle comprise a gas turbine, compressor, and combustion chamber. The system integrates a simple gas turbine with a biogas power plant, where biogas serves as the fuel for the gas turbine. Cow dung and water are introduced into an anaerobic digester in a 1:1 ratio, resulting in the production of biogas and fertilizer after the anaerobic process. The produced biogas is then directed into the combustion chamber. Fresh air for compression enters the compressor at point 1, while the discharge air from the compressor enters the combustion chamber at point 2. Following combustion and passage through the gas turbine (GT), electricity is generated. The GT's output heat is utilized to provide heat energy for the steam Rankine cycle. Heat is transferred from point 5 to the evaporator of the steam Rankine cycle, where it functions as a heat exchanger. Subsequently, it enters the thermoelectric generator at a lower temperature to produce electricity. In the steam Rankine cycle process, heat enters the steam turbine at point 10 with saturation temperature to generate electricity. The lower-temperature heat then proceeds to the HEX at point 11 and is utilized by the Organic Rankine Cycle (ORC) turbine to produce additional electricity. Additionally, a compression chiller is employed in this research to provide cooling and meet the cooling demands of the school building. A water-cooled compression chiller operates by utilizing the compression refrigeration cycle and consists of components such as a compressor, condenser, evaporator,

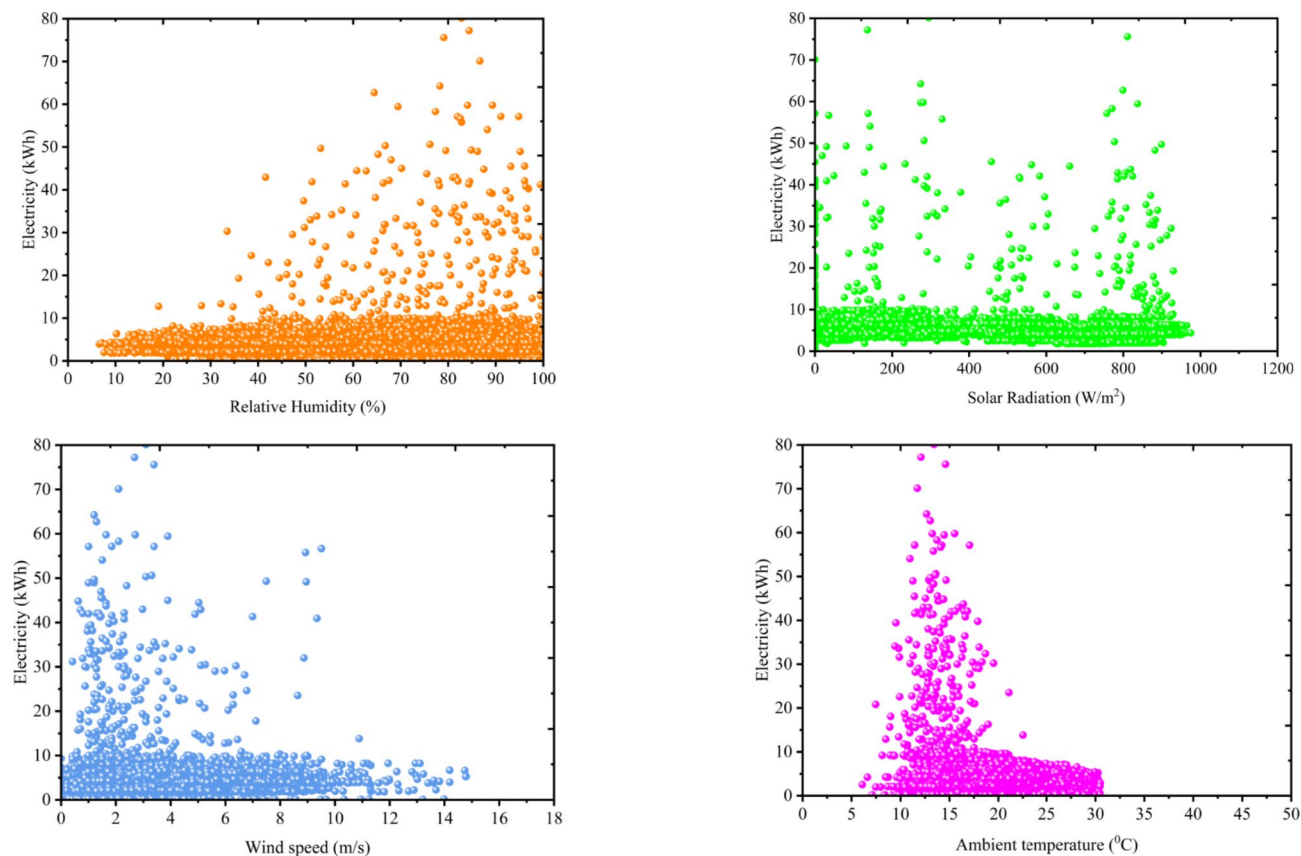


Fig. 13. Significant impact on clean electricity consumption.

Point	Objective	Amount
A	Energy saving	0.39
	Annualize	18760.35
B	Energy savings	0.39
	Net present value	1832.48
C	Energy savings	0.34
	Life cycle cost	830591.06
D	Energy savings	0.92
	Annualize	18760.35
E	CDE	85615.86
	Annualize	18760.35
F	CD savings	20527.83
	Annualize	18760.35

Table 6. Optimal values.

expansion valve, and cooling tower. Positioned alongside an air chiller that cools the condenser using a fan, this water chiller effectively cools its environment. Water-cooled chillers are known for providing superior cooling efficiency due to the heat transfer qualities of water compared to air. They are more efficient and have a longer lifespan than air-cooled chillers, although they require more maintenance and a dedicated space for the cooling tower. On the other hand, air-cooled chillers are simpler to install and maintain but are less efficient and require more space to achieve the same capacity. The choice between water-cooled and air-cooled systems depends on factors like water availability, space considerations, and environmental conditions.

Methodology

To model the system designed according to a framework, the methodology flow chart is presented in Fig. 15. The summary of the method is as follows:

- Using analysis software EES.
- Optimization with RSM and with Design-Expert software.
- Choosing the city of Dubai from the United Arab Emirates to check the performance of the new Suggested co-generation power plant.
- Weather information for case study by Meteonorm software.
- Analysis of Environmental.
- Investigating the performance of the new biomass system in providing energy consumption of the school building.
- Calculation of stored energy throughout the year.

RSM

The RSM has been used to optimize for co-generation system. In Fig. 16 shows flowchart of RSM. RSM is a set of statistical techniques and applied mathematics for constructing experimental models. This method achieves the best RS (response surface) by discovering the optimal RS of each design variable^{32,33}.

Results

Resorts Validation

Given the novelty of the introduced system, validation of the results and work conducted is essential. To validate and compare the outcomes, particular focus is placed on the thermoelectric unit, a key innovation within the proposed system (Fig. 14). In this regard, the performance of the thermoelectric generator has been scrutinized and validated by referencing the research conducted by Habibolazadeh et al.³⁴, as depicted in Fig. 17. The results indicate a strong level of validity in the modeling process.

Optimization of cogeneration system

optimized biomass system performance was carried out using Response Surface Methodology (RSM). This optimization aimed to achieve the performance of new cogeneration system while simultaneously reducing costs. optimization variables are detailed in Table 7.

The optimization goal is to improve the system's efficiency and ensure the school building's energy consumption is maximally efficient with the new energy production system. Ten parameters and 2 objectives as exergy efficiency (EE) and Cost Rate (CR) were defined for optimization. After conducting 543 runs, the outcomes were assessed using Response Surface Methodology (RSM) to enhance the performance of the new biomass system and identify the optimal point. The results of 100 optimized points by RSM are provided in Appendix 5. The optimal result is outlined in Table 8.

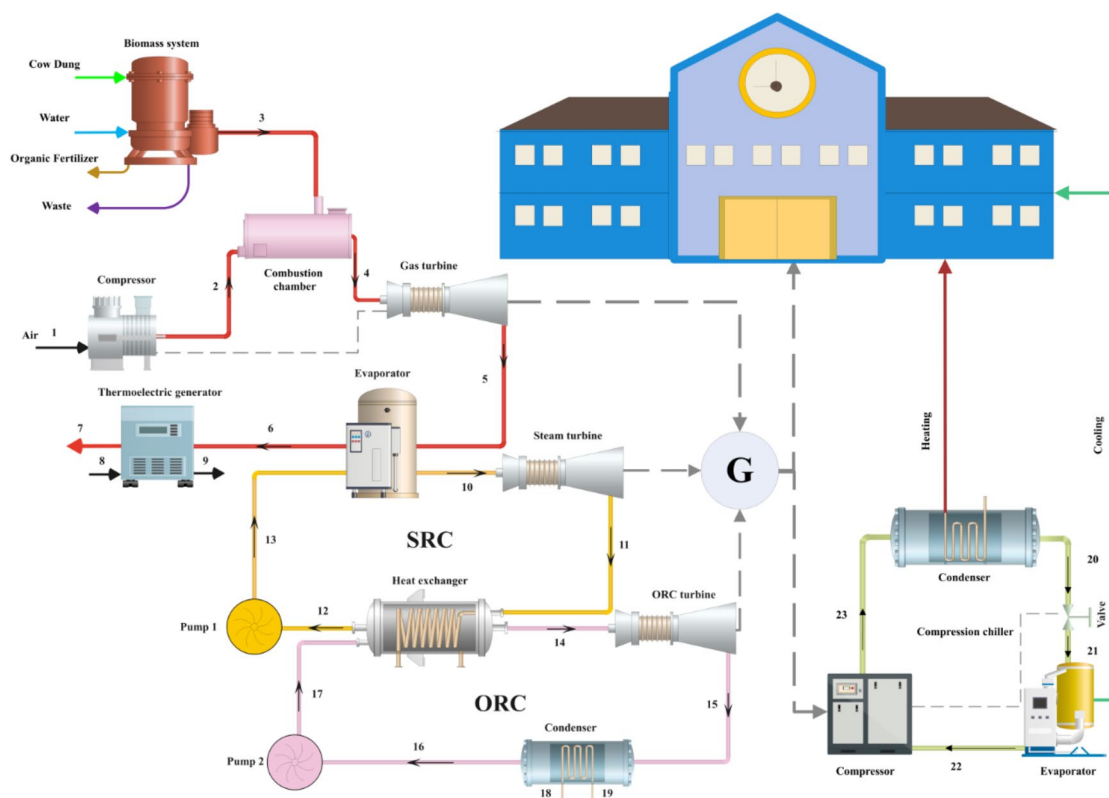


Fig. 14. Proposed system.

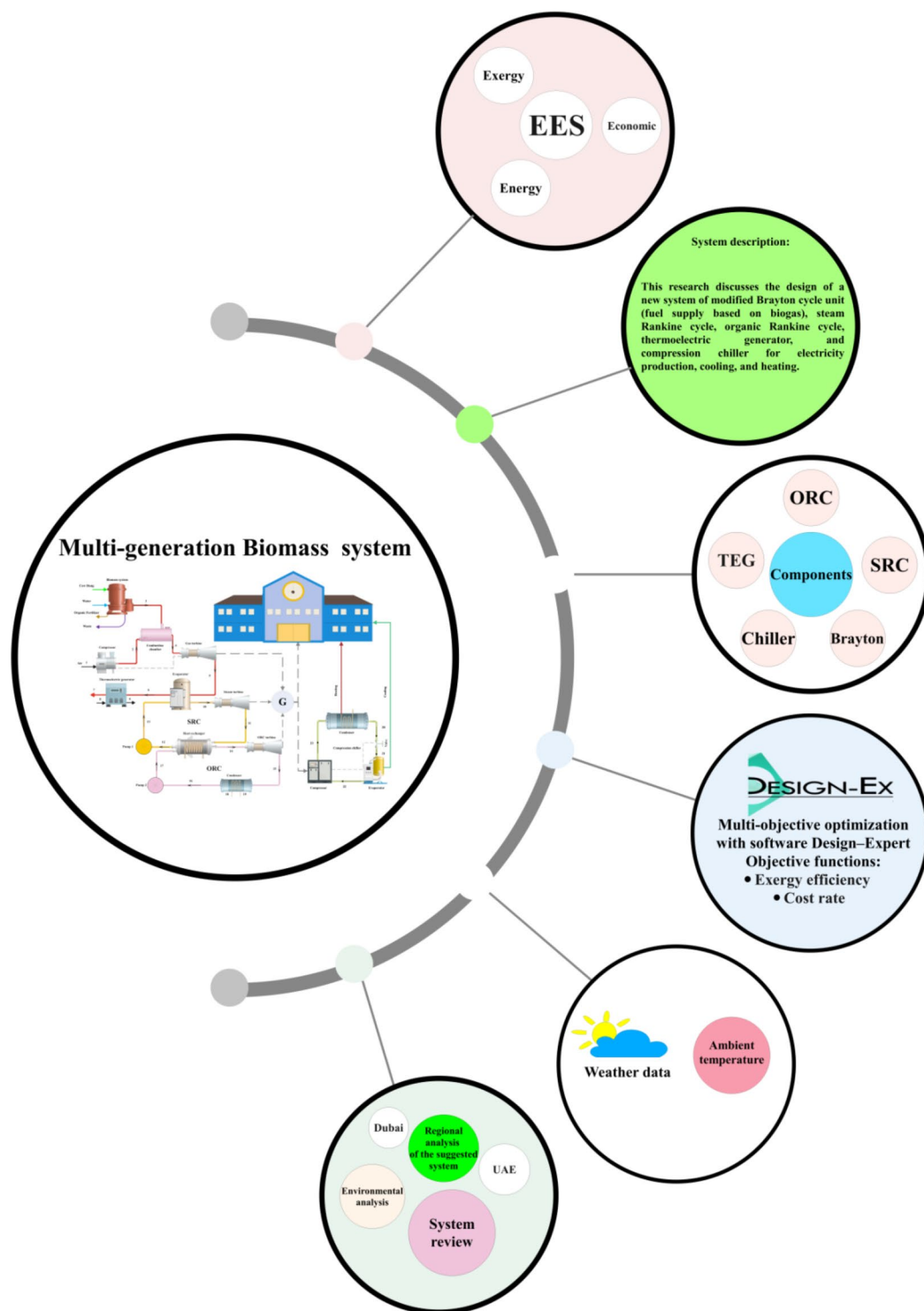


Fig. 15. Methodology.

Figure 18 depicts how changes in parameters affect exergy efficiency concurrently. The red shade in the figure indicates to compared green shade with a higher production capacity. main objective of improving EE is to raise it. Gas turbine efficiency, compressor efficiency, ORC turbine inlet temperature, steam turbine inlet pressure, pinch point evaporator, and steam pump inlet pressure are recognized as the six crucial factors pivotal in enhancing the efficiency objective function to boost the performance of the new biomass system.

Shown in Fig. 19 is the concurrent influence of parameter changes on the cost rate. The red hue in the visualization indicates a higher CR in contrast to the green hue. The analysis carried out in the optimal state investigates the collective impact of parameters on the CR objective function. findings emphasize that

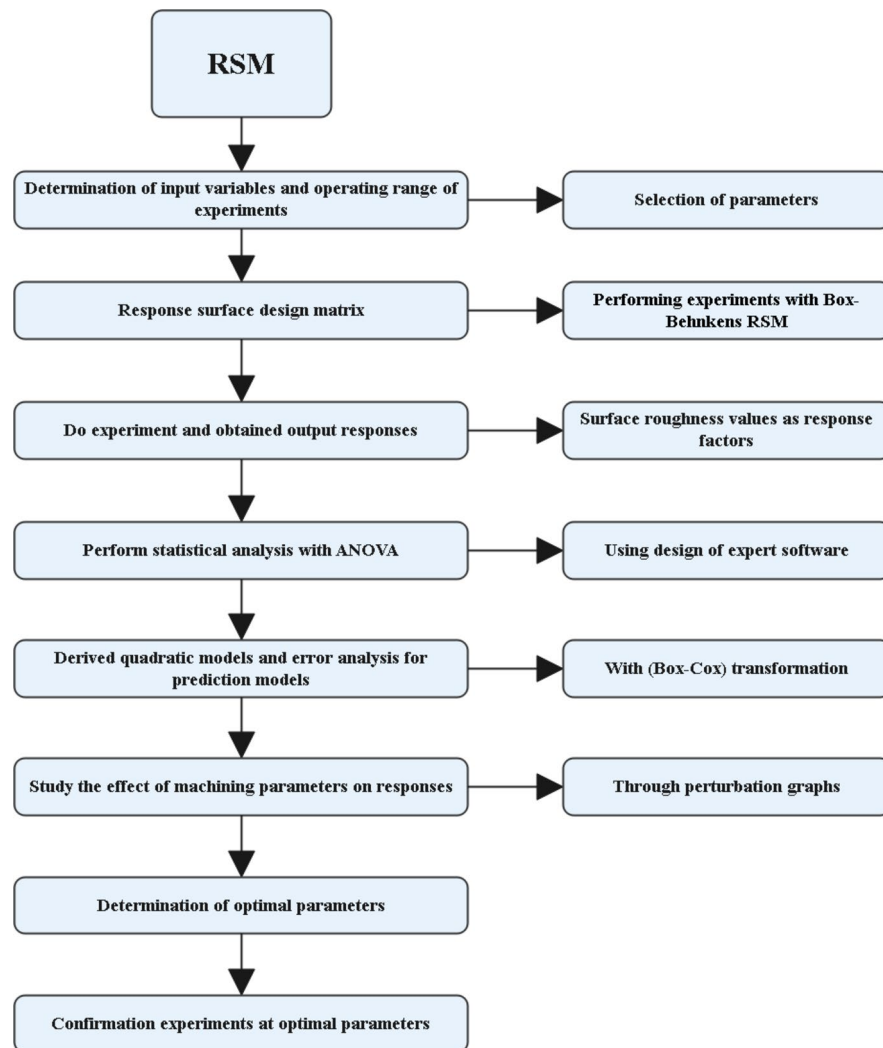


Fig. 16. Response surface methodology.

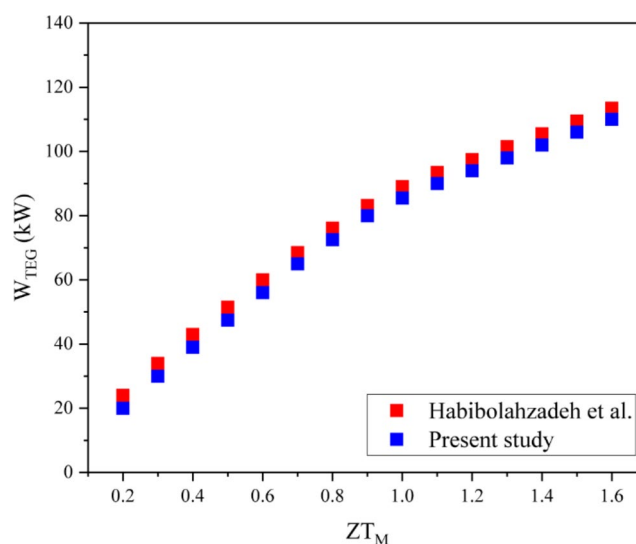


Fig. 17. Validation of cogeneration system.

Decision variable	Lower bound	Upper bound
Pressure ratio (-)	7	9
T_4 ($^{\circ}\text{C}$)	1000	1100
T_{14} ($^{\circ}\text{C}$)	80	95
P_{10} (kPa)	2900	3100
P_{12} (kPa)	90	120
Gas turbine _{efficiency} (%)	0.7	0.95
Compressor _{efficiency} (%)	0.7	0.95
Pump efficiency (%)	0.7	0.95
Turbine _{efficiency} (%)	0.7	0.95
Pinch point _{evaporator} ($^{\circ}\text{C}$)	3	9

Table 7. Optimization variables.

Objective	Value
Pressure ratio (-)	3.438
T_4 ($^{\circ}\text{C}$)	1062.685
T_{14} ($^{\circ}\text{C}$)	87.967
P_{10} (kPa)	3009.598
P_{12} (kPa)	103.944
Gas turbine _{efficiency} (%)	0.895
Compressor _{efficiency} (%)	0.82
Pump efficiency (%)	0.827
Turbine _{efficiency} (%)	0.873
Pinch point _{evaporator} ($^{\circ}\text{C}$)	5.687
Exergy efficiency (%)	31.79
Cost rate (\$/h)	88.02
Desirability	0.624

Table 8. Optimal value.

modifications in seven decision variables - Gas turbine efficiency, gas turbine inlet temperature, pressure ratio, compressor efficiency, steam turbine inlet pressure, steam pump inlet temperature, and turbine efficiency - significantly contribute to shaping the economic aspects of the new biomass system.

Case study

Dubai is well-known for its warm climate with plenty of sunny days all year round. The winters in Dubai are relatively mild, while the summers are extremely hot. As the largest and most prominent city in the United Arab Emirates, Dubai utilizes energy production from perishable waste materials, animal waste, and agricultural by-products, leading to reduced fuel preparation costs. The city has a wide range of biomass resources including animal waste, agricultural residues, wood, and convenient access to various other biomass sources. A study conducted hourly (8760 h) investigated how changes in the city's AT (T_0) impact on new proposed system. This analysis aimed to evaluate power generation, cooling and heating capabilities, as well as the CR of the new biomass system. Climate parameter T_0 plays a crucial role in influencing system performance. Figure 20 illustrates hourly fluctuations in T_0 for Dubai city, ranging between 0 $^{\circ}\text{C}$ and 50 $^{\circ}\text{C}$, with peak temperatures typically occurring during June, July, and August in the summer season. Dubai is acknowledged as one of the hottest cities globally.

A method for obtaining biomass energy involves planting fast-growing trees or shrubs on marginal lands, in addition to collecting animal waste, urban and industrial waste, and other practices. While the combustion of biomass emits carbon dioxide into the atmosphere, the permanent planting and growth of biomass sources enable the absorption of an equivalent amount of carbon dioxide from the atmosphere through photosynthesis, utilizing solar energy to produce oxygen. This process establishes a harmonized carbon cycle in nature. Biomass sources such as wood or specific wastes can be combusted to generate steam for electricity production, contributing to a sustainable energy strategy. Dubai, as a densely populated and industrially significant city with abundant access to biomass resources, holds considerable potential in this aspect.

Figure 21 illustrates the hourly Energy production of co-generation system (CGS) in relation to variations in the weather parameter T_0 . Energy production of the CGS encompasses the collective output of the steam turbine, ORC turbine, thermoelectric generator, and gas turbine. Additionally, the consumption linked to compressors, pumps, and compression chillers is subtracted from the total power production of the entire biomass system. During July and June, with an increase in T_0 , compressor consumption rises, leading to a decrease in power

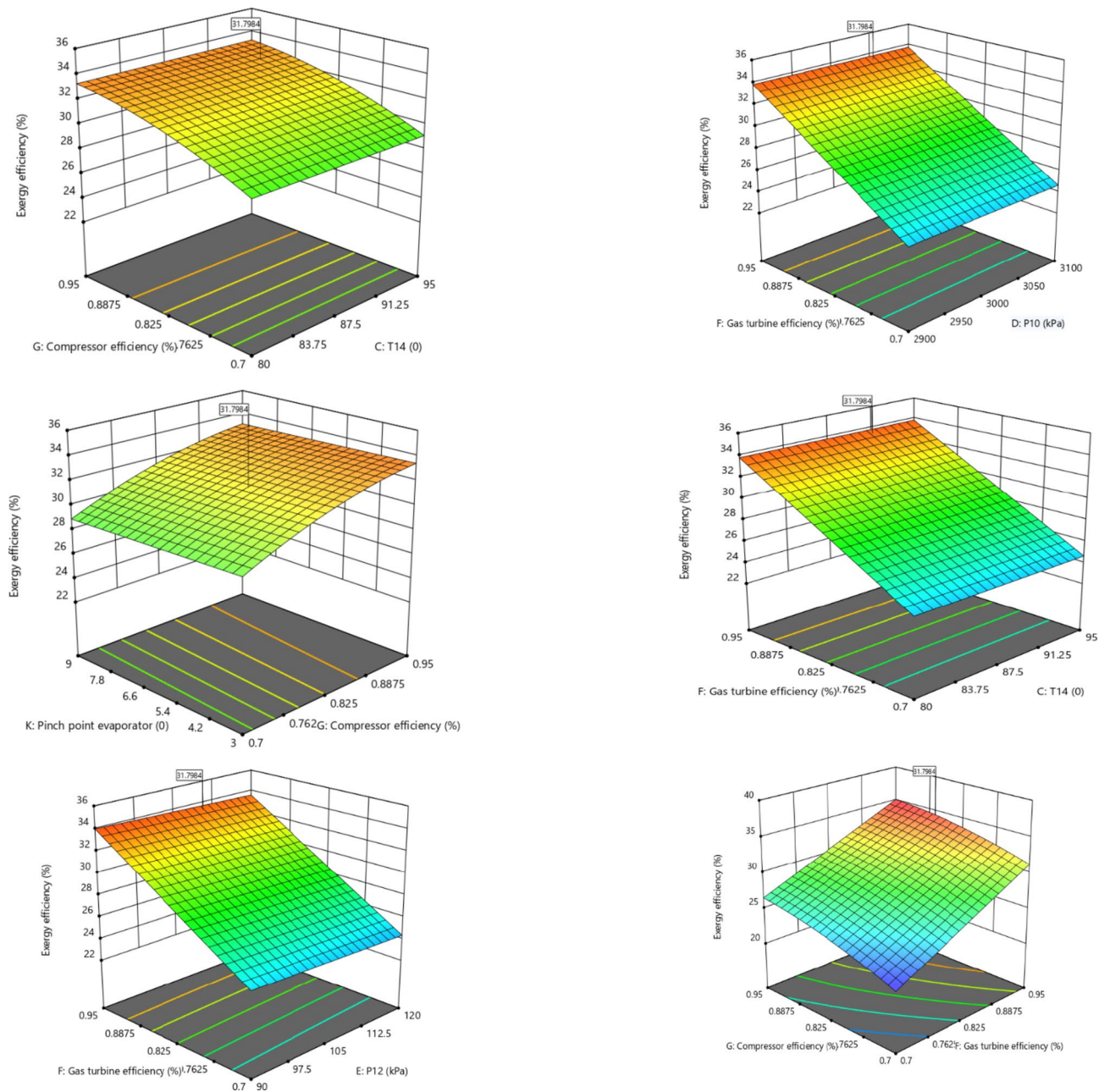


Fig. 18. The impact of parameters on exergy efficiency.

production. The heightened compressor consumption in hot months results in a reduction in gas turbine power production. This decline in gas turbine efficiency translates to a decrease in thermal energy supplied to other power generation units, subsequently reducing the power production of the steam Rankine cycle (SRC), Organic Rankine Cycle (ORC), and Thermoelectric Generator (TEG) that utilize waste heat from the gas turbine.

Displayed in Fig. 22 are the fluctuations in the heating output produced by the new biomass system that includes a compression chiller, in accordance with shifts in weather parameters. A significant advancement in current study is incorporation CC, with electricity production required for chiller being supplied by electricity generated from the CGS. This inventive method not only delivers cooling capabilities but also enhances heating production, effectively minimizing system waste.

Cooling (hourly) produced by energy production CGS with the integration of a CC unit, responding to fluctuations in weather conditions, are illustrated in Fig. 23. This figure showcases how the cooling output varies throughout the day in response to different weather conditions, highlighting the system's dynamic performance in adjusting to environmental changes. A unique concept presented in this research involves using the power generated by the new biomass system to power the compression chiller, allowing for concurrent cooling production. The clean electricity required by the cc is obtained from the system, ensuring that cooling production aligns with changes in the clean electricity output of CGS.

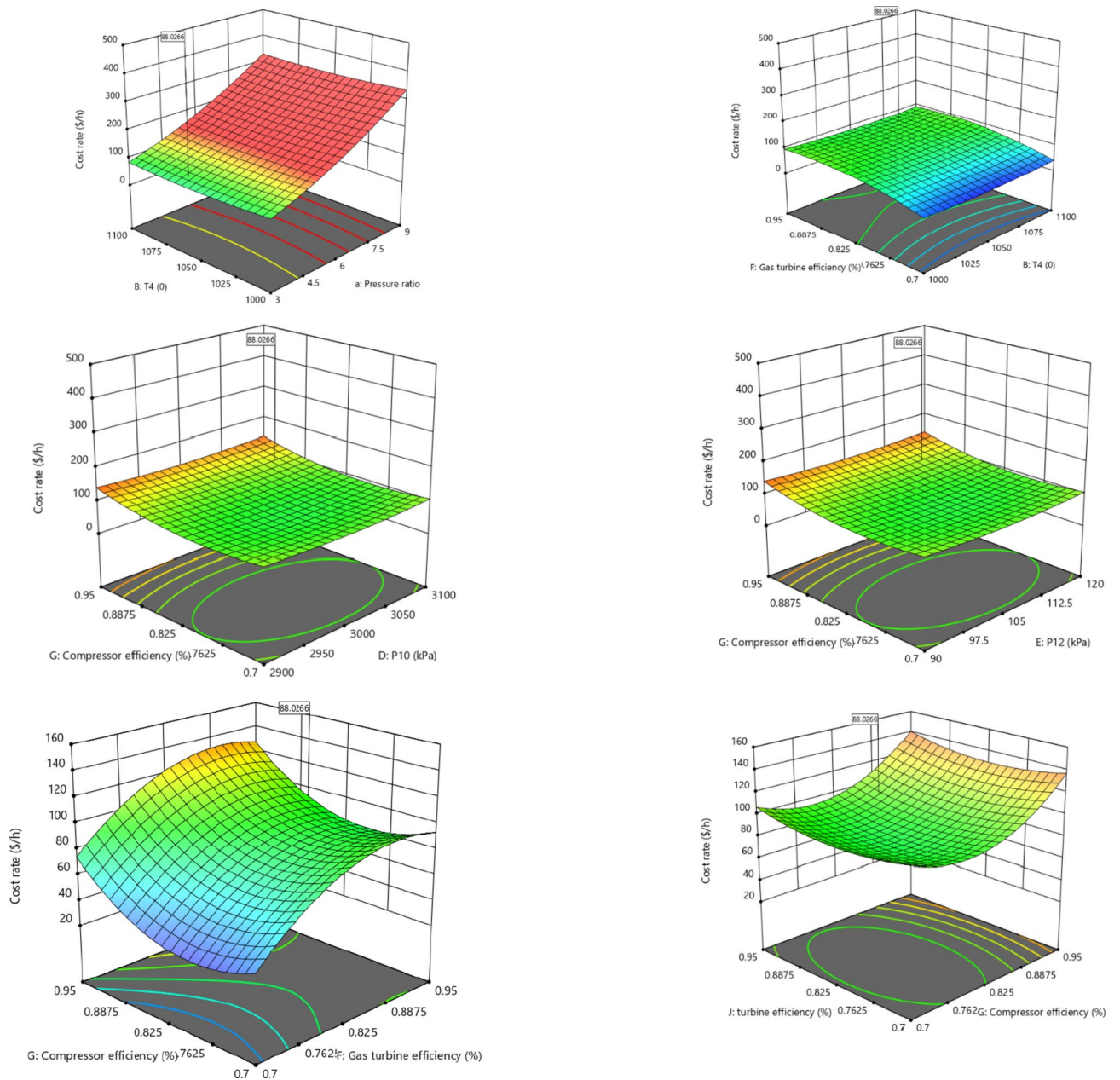


Fig. 19. Cost rate analysis.

This study delves into the hourly impact of Dubai's T_0 on the performance of the new energy production system. Figure 24 illustrates the fluctuations in the efficiency of the entire CGS concerning the annual variations in T_0 . As T_0 rises, efficiency declines during hot months due to reduced power output from the new energy production system, while it improves in winter and autumn months as a result of enhanced system performance. Efficiency, representing the maximum useful work, is directly linked to Energy production of the new energy production CGS.

Figure 25 illustrates the variations in the cost rate of the new system relative to the annual changes in T_0 . As T_0 increases and production of CGS decreases, cost rate of CGS also decreases due to reduced maintenance operations during hot months. Conversely, in colder months, as the overall energy production system output increases, the cost rate of the proposed biomass energy production system also rises.

Figure 26 illustrates the environmental benefits of the system implemented in Dubai. Typically, power plants release around 0.204 tons of CO₂ to generate one MW hour of electricity. Conventional power plants (CPP) incur an environmental cost (The environmental cost associated with air conditioning and cooling systems is a significant concern due to their impact on the environment) of 24 \$ per ton of CO₂ emissions. Through the installation of the new proposed system and the generation of clean electricity, it becomes feasible to mitigate environmental costs annually, leading to the expansion of green spaces and vegetation.

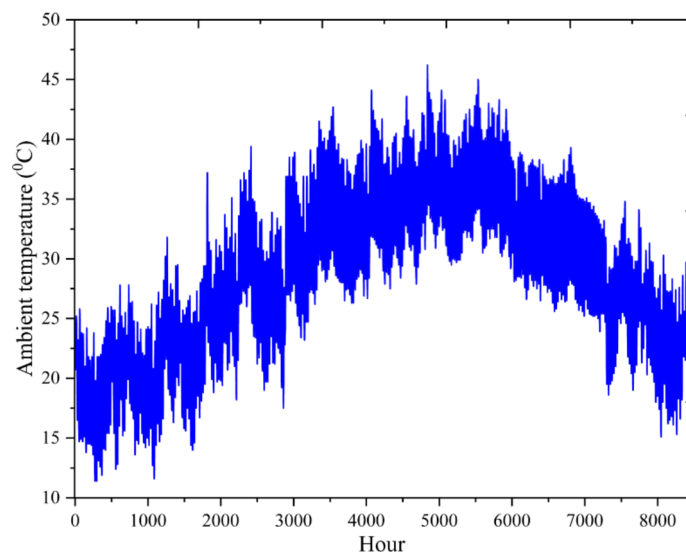


Fig. 20. T_0 changes in one year (Dubai city).

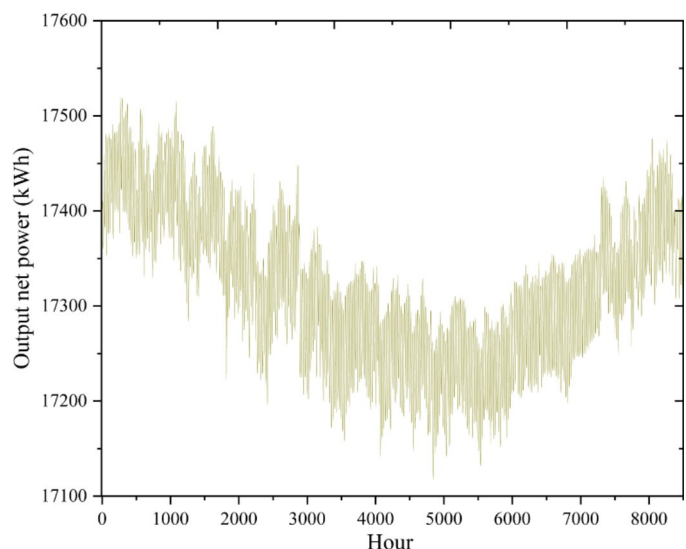


Fig. 21. Output net power of cogeneration system.

The implementation of CGS offers the opportunity to circumvent environmental costs annually, equivalent to the expansion of green spaces and vegetation. An estimated value of 4940 dollars per hectare has been allocated for the average non-waterfront bottomland habitat. Table 9 presents the annual environmental performance of the system in Dubai City relative to the production power output.

Cogeneration system abilities

Figure 27 compares the electricity usage of a simulated school building in Dubai City with the electricity generation of CGS, taking into account the climate fluctuations of the city.

Figure 28 demonstrates the contrast between the cooling energy consumption of the simulated school building in Dubai City and the cooling production from the system, taking into consideration the city's climate variations, as well as the surplus cooling energy accumulated throughout the year.

Figure 29 illustrates the comparison of the heating bar usage of the simulated school building in Dubai with the heating production from the system, taking into account the city's climate variations, and including the surplus heating energy stored in one year.

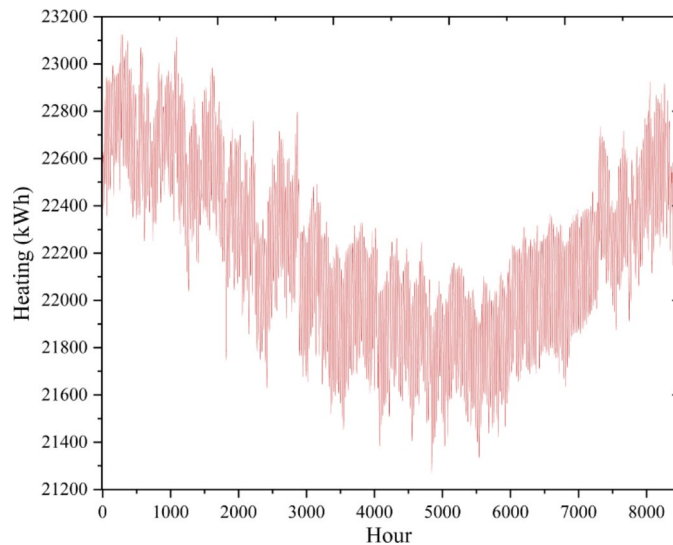


Fig. 22. Heating production of cogeneration system.

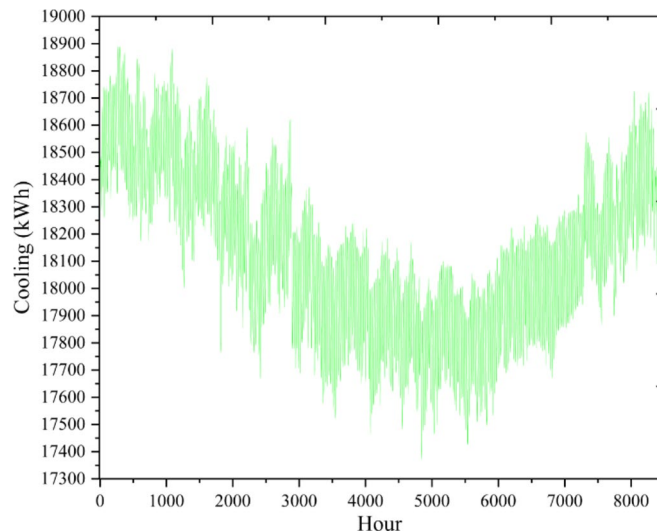


Fig. 23. Cooling production of cogeneration system.

Stored energy

Figures 30, 31 and 32 showcase the hourly monitoring of stored heating, cooling, and electricity over the year. This computation is obtained by deducting the cooling utilized by the school building from the cooling generated by the new proposed cogeneration system, leading to surplus cooling that can be employed for various purposes.

Conclusion

This study introduces a cogeneration system tailored to fulfill the energy requirements of a 12,542 m² school located in Dubai. The primary focus was on evaluating the thermal, cooling and electrical loads specific to South View School. To effectively manage the heating and cooling needs, an electric compression chiller unit was integrated into the system. Electricity generation was achieved through various technologies, including:

- Steam Rankine Cycle Turbine.
- Organic Rankine Cycle (ORC) Turbine.
- Gas Turbine.

A comprehensive analysis of the load supply system was performed using EES, ensuring efficient operation by accurately determining the maximum load demand on the power supply system. The proposed cogeneration system utilized modified Brayton cycle units powered by biogas, along with steam Rankine and ORC cycles, to efficiently provide electricity, heating, and cooling.

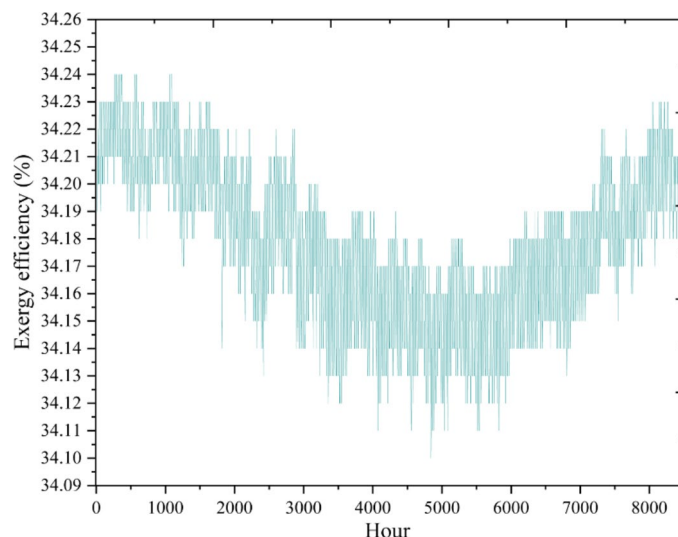


Fig. 24. Exergy efficiency of cogeneration system.

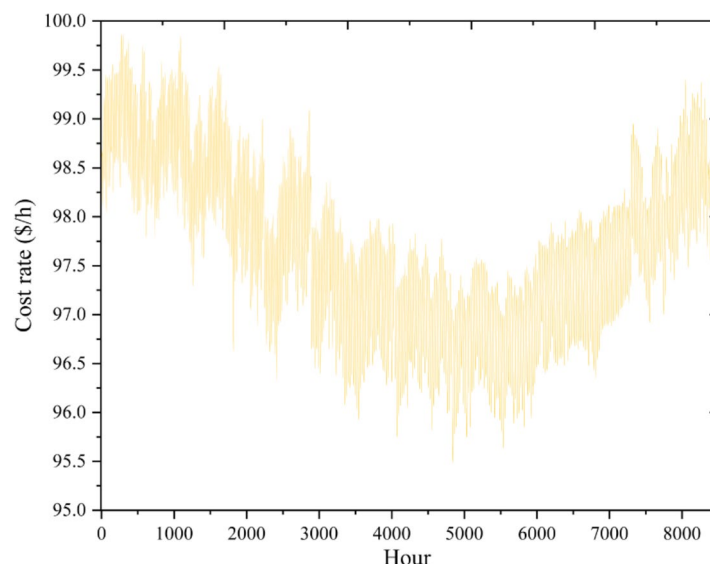


Fig. 25. Cost rate changes.

The summary of the results is as follows:

- Survey results indicated that the school's annual electricity consumption was around 43,539.48 kWh, with heating needs at 0.94 kWh and cooling demands at 1,115.68 kWh.
- By optimizing energy consumption within the school, the system significantly reduced carbon dioxide emissions by approximately 24,548.97 kg per year, contributing to environmental pollution mitigation efforts.
- The overall efficiency of the cogeneration system was recorded at 31.79%, with operational costs estimated at \$88.02 per hour.
- Performance evaluations conducted in Dubai showed that the cogeneration system could generate an impressive 151,746,087 kWh of electricity annually, along with 194,610,878 kWh of heating and 158,962,204 kWh of cooling.
- A comparative analysis of the school's energy consumption and the cogeneration system's output demonstrated its effectiveness in meeting energy needs throughout the year.
- Surplus electricity totaling 151,702,547.5 kWh could be sold back to the electricity distribution network.
- Excess heating (194,609,762.3 kWh) and cooling (158,774,864.1 kWh) could be stored for future use, further offsetting operational costs.

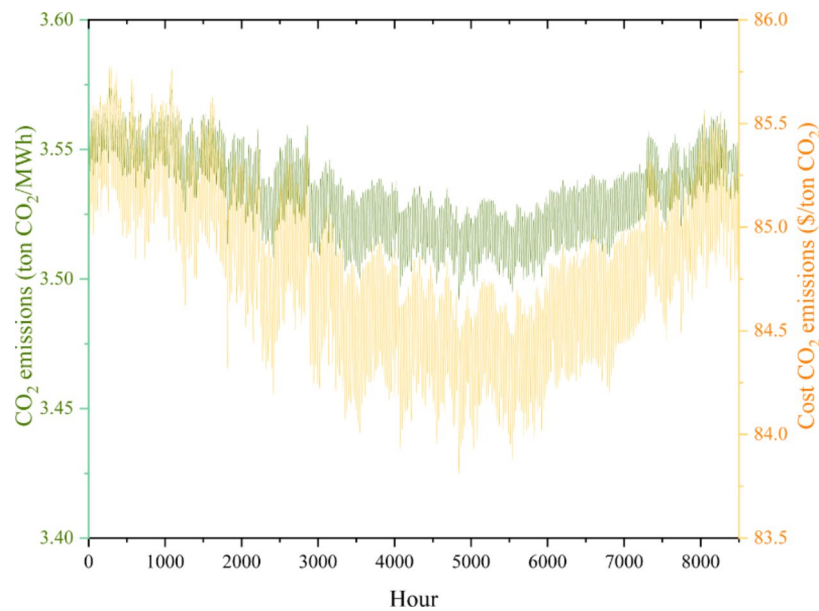


Fig. 26. CO₂ emission costs.

Output net power (MWh)	The amount of CO ₂ emissions (tonCO ₂ /MWh)	The cost of CO ₂ emissions (\$/tonCO ₂)	Hectares
151746.1	30956.2	742948.8	150

Table 9. Environmental analysis of the system.

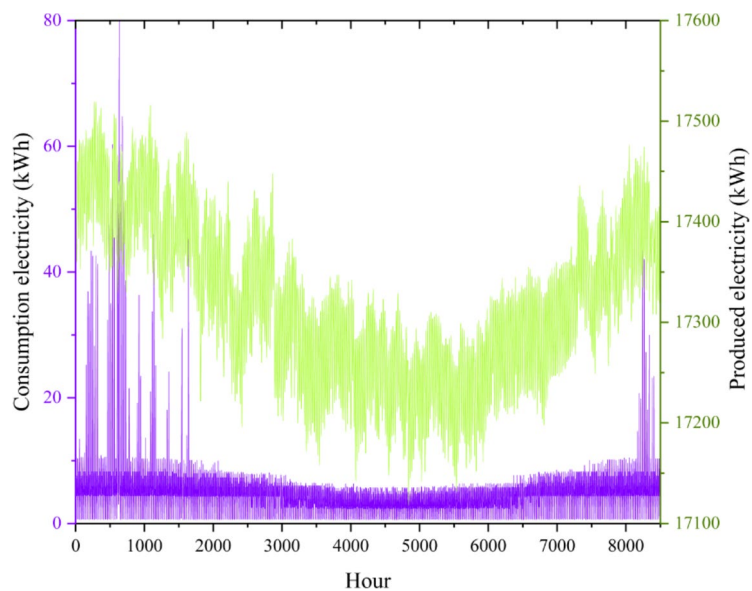


Fig. 27. Comparison of consumed and produced electricity energy.

Suggestions

In this section, researchers and researchers are given suggestions to continue the path that can help reduce environmental pollution and also preserve non-renewable resources.

- Use energy storage sources to stabilize and increase system performance, such as the compressed air energy storage system (CAES).

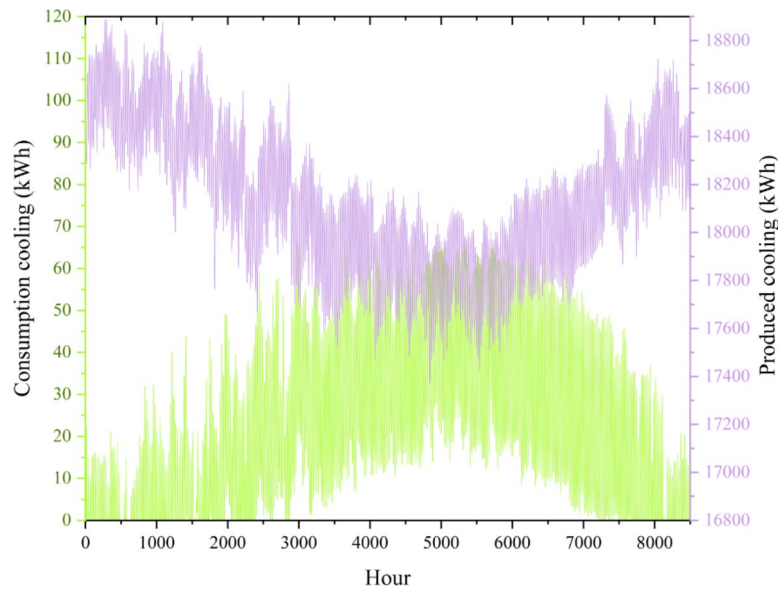


Fig. 28. Comparison cooling bar.

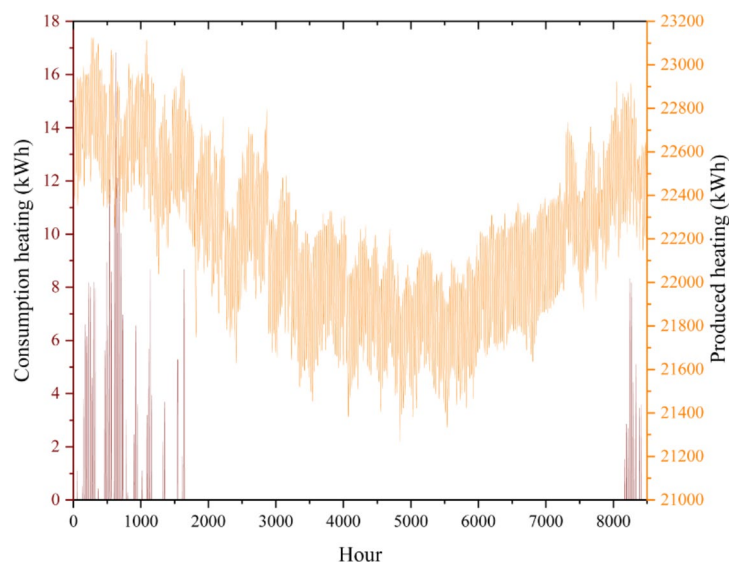


Fig. 29. Comparison of heating bar.

- Adding the Kalina cycle to the current work system can help increase the output power of the system in addition to creating innovation for the work of future researchers.
- In this system, adding solar energy and combining it with biomass energy can help increase CGS - efficiency and also the system's production power, and on the other hand, it can help stabilize the system.
- Using a RO (reverse osmosis desalination) unit to produce fresh water can also be a good idea for providing drinking water to the school building.

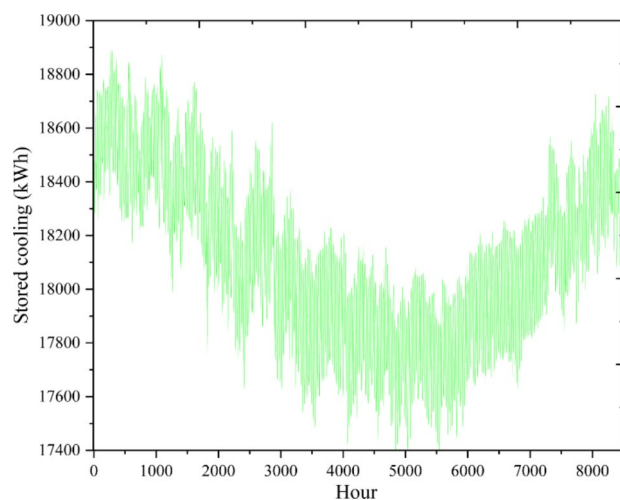


Fig. 30. Stored cooling bar.

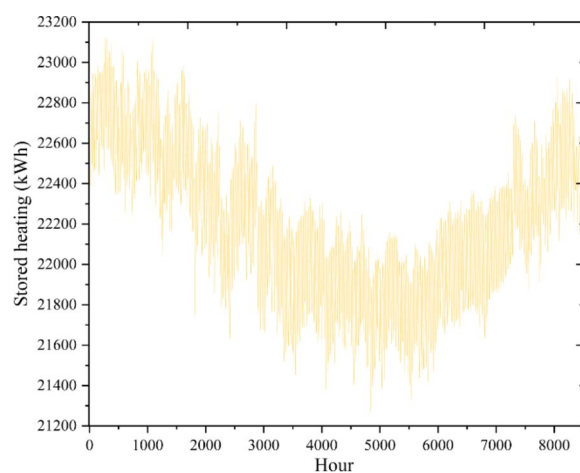


Fig. 31. Stored heating bar.

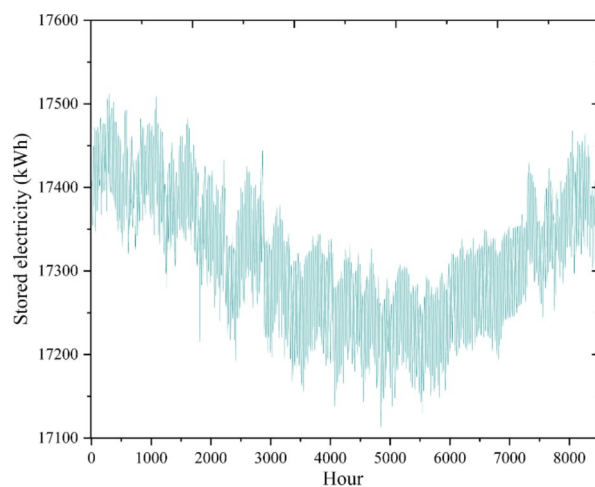


Fig. 32. Stored clean electricity.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

Ali Ghanbari Birgani: Conceived the initial research idea, conducted the literature review, and performed the numerical analysis. Ehsanolah Assareh: Served as the supervising professor, edited the initial draft, created the charts, and contributed to the optimization of the study. Ashkan Ghafouri: Reviewed and revised the content, analyzed the obtained data, and acted as the guiding professor. Ali Falavand Jozaei: Conducted software analysis and served as the consulting professor.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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