SIMULACIJA ENERGETSKIH PERFORMANSI POTENCIJALNIH SISTEMA ZA KGH I PRIMENA OBNOVLJIVIH IZVORA ENERGIJE ZA POSTIZANJE NISKE POTROŠNJE ENERGIJE NA PRIMERU POSLOVNE ZGRADE U NIŠU

SIMULATION OF THE ENERGY PERFORMANCE OF POTENTIAL HVAC SYSTEMS AND IMPLEMENTATION OF RENEWABLE ENERGY SOURCES TO ACHIEVE NZEB ON THE EXAMPLE OF AN OFFICE BUILDING IN NIS

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Jedan od ključnih pristupa postizanju optimalnog balansa između potrošnje energije i ukupnog komfora u postojećim zgradama leži u korišćenju sofisticiranih simulacija za efikasno upravljanje HVAC sistemima. Modeliranje i simuliranje energetske performanse zgrada predstavljaju visoko naprednu tehniku koja omogućava predviđanje kompleksnih ponašanja sistema na osnovu fizičkih zakona i principa. Ove simulacije omogućavaju precizno rešavanje termalnih ravnotežnih jednačina, uzimajući u obzir sve bitne fizičke karakteristike zgrade, kompleksnost mehaničkih sistema koji je opslužuju, kao i širok spektar dinamičkih ulaznih promenljivih tokom celog kalendarskog ciklusa.

Ključni faktori koji značajno utiču na potrošnju energije u zgradama su klimatski uslovi specifični za region, kao i individualna očekivanja korisnika u vezi sa unutrašnjom temperaturom, vlažnošću i kvalitetom vazduha.

Metodologija ovog naprednog istraživanja bazira se na upotrebi najsavremenijeg alata za simulaciju pod nazivom EnergyPlus, što omogućava detaljnu analizu energetske performanse zgrade.

Ovaj holistički pristup omogućava unapređenje energetske efikasnosti postojećih zgrada i optimizaciju rada HVAC sistema, što rezultira značajnom uštedom energije i poboljšanim ukupnim korisničkim komforom. Takođe, ovom studijom se cilja na demonstraciju poboljšanja sistema zgrada kako bi se postigle zgrade skoro bez potrošnje energije (nZEB) i iskoristila obnovljiva izvora energije.

Očekuje se da će rad koristiti simulacije modela, zajedno sa dodatnim sistemima, kako bi se minimizirala neto potrošnja energije na mestu upotrebe putem PV panel-integrisanih sistema u poređenju sa modelom bez takvih sistema. Rezultati dobijeni iz osnovnog modela već pokazuju nisku potrebu za energijom, dok se očekuje da će korišćenje PV panela rezultirati još nižom potrošnjom. Ukupna energija potrebna za zadovoljenje energetskih potreba zgrade iznosi 41.109,67 kWh, što se prevodi u 36,41 kWh/m² ukupne površine zgrade.

Rad će takođe pokazati smanjenje emisija CO_2 u poređenju sa modelom bez PV panel-integrisanih sistema.

Ključne reči: *energetska simulacija zgrade; EnergyPlus; sistemi za KGH; nZEB; energetska efikasnost*

One of the key approaches to achieving an optimal balance between energy consumption and overall comfort in existing buildings lies in the use of sophisticated simulations for efficient management of HVAC systems. Modeling and simulating the energy performance of buildings represent a highly advanced technique that enables the prediction of complex system behaviors based on physical laws and principles. These simulations allow for precise solving of thermal equilibrium equations, taking into account all essential physical characteristics of the building, the complexity of the mechanical systems serving it, as well as a wide range of dynamic input variables throughout the entire calendar cycle.

Critical factors significantly influencing energy consumption in buildings are region-specific climatic conditions, as well as individual user expectations regarding indoor temperature, humidity, and air quality.

The methodology of this advanced research is based on the use of the state-of-the-art simulation tool EnergyPlus, which enables a detailed analysis of the building's energy performance.

This holistic approach enables the enhancement of energy efficiency in existing buildings and optimization of HVAC system operation, resulting in significant energy savings and improved overall user comfort. Furthermore, this study aims to demonstrate the improvement of building systems themselves to achieve nZEB buildings and the utilization of renewable energy sources.

The work is expected to use simulations of the model, along with additional systems, to minimize the net site energy through PV panel-integrated systems compared to the model without such systems. The results obtained from the baseline model already demonstrate low energy requirements, while the use of PV panels is expected to result in even

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lower consumption. The total energy required to meet the building's energy needs is 41,109.67 kWh, which translates to 36.41 kWh/m² of the total building area.

The paper will also demonstrate a reduction in CO_2 emissions compared to the model without PV panel-integrated systems.

Key words: *building energy simulation; EnergyPlus; HVAC systems; nZEB; energy efficiency*

1. Introduction

The model of this building has already been presented in a previous work. The study focused on assessing CO_2 emissions through the use of heat pumps and district heating/cooling. The study reveals a significant inconsistency: the difference in CO_2 emissions between these two sources is very small. This is precisely because coal (lignite) is used in Serbia for electricity production. In this research, using an analytical method and simulations within EnergyPlus, the minimal CO_2 emissions were estimated at 26.65 kg CO_2/m² per year for the building. Therefore, further reductions require the implementation of additional construction measures and the introduction of low-energy consumption systems [1].

The Intergovernmental Panel on Climate Change (IPCC) released its Special Report in October 2018, focusing on the impacts of global warming at 1.5°C above pre-industrial levels and corresponding greenhouse gas emission pathways worldwide. This report, based on scientific evidence, illustrates that human-induced global warming has already reached 1°C above pre-industrial levels and is increasing by about 0.2°C per decade. Without intensified international efforts to combat climate change, global average temperatures could approach a 2°C increase shortly after 2060, with continued rise thereafter. Such uncontrolled climate changes have the potential to turn Earth into a "greenhouse," increasing the likelihood of irreversible and widespread climate effects. The IPCC report confirms that approximately 4% of the global land area is expected to transition from one ecosystem type to another with a 1°C temperature increase, and this number increases to 13% with a 2°C temperature shift [2].

In Rosa Francesca De Masi's work, the question is raised: Is the most energy-efficient solution also the best in terms of ecological sustainability? This study attempts to answer this question through a holistic approach for a combined energy and ecological assessment, also considering a new impact analysis method with different assigned weights. This approach is applied to a case study of a real nZEB building. To assist designers and researchers in choosing the right technologies for clean and sustainable buildings, this paper proposes a holistic approach to evaluate the energy and ecological performance of nearly zero-energy projects. It also describes a new impact analysis method useful for understanding how different design choices contribute to each impact category. This approach is applied to a real-case study simulated in three different climatic conditions: Naples, Munich, and Paris. During the design process of nearly zero-energy buildings, aiming to maximize energy performance, super insulation and high integration of renewable energy are the most common solutions. By varying these characteristics, different design configurations are compared from both an energy and ecological perspective.

The main overall conclusion is that designers should find a balance between reducing fossil fuel consumption during building use and the ecological impacts throughout the building's life cycle. Numerical analysis cannot provide the same guidance for both fields. With the integration of a photovoltaic system, the energy analysis shows that it is not favorable to exceed the installed maximum power, as this could negatively affect the national grid with excess energy coming from many buildings. It is also recommended to integrate storage systems to maximize self-use of renewable energy. On the other hand, in terms of emissions balance, the minimum Global Warming Potential of Building Materials (GPBT) is achieved with the maximum possible installed power for the PV system [3].

In Tünde Kalmár's work, a low-temperature radiant heating system is used for simulation purposes, widely used in nearly zero-energy buildings. The conclusion is that increasing the number of building surfaces used for radiant heating leads to increased energy consumption. The worst results are obtained in the case of nearly zero-energy buildings, where heating energy consumption increases by 23.2% to 24.8% compared to "traditional" radiator heating. For nearly zero-energy buildings, heat loss can exceed the heat delivered. The least increase in heating energy consumption is achieved when only floor heating is considered. In all analyzed cases, floor temperature can be maintained below the maximum allowable value specified in building comfort standards. From an energy perspective, the use of radiant heating systems is more efficient when mostly indoor building surfaces are used for heating. Therefore, for individual houses, it is more cost-effective if the building has at least two floors and indoor walls and slabs are used for radiant heating. The indoor slab can be used simultaneously for ceiling and floor heating, providing adequate thermal comfort without increasing heating system heat losses [4].

Rodrigo Fiorotti's work explores a new approach to planning the energy needs for nearly zero-energy buildings (nZEB) supplied with solar panels (PV/grid) and highlights the main contribution and novelty of the study in considering user comfort as input data. This approach takes into account factors such as user comfort, the available price of electricity, the technical specifications of household appliances, and the times when these appliances can be used. Constructive heuristics and an improved Multi-Start algorithm are used to regulate energy consumption. The proposed approach has been successfully applied to two specific cases with different comfort indexes required by users, and then with three different sizes of installed PV systems to assess the economic viability of using photovoltaic panels to power a smart home. Key conclusions of the study are that energy procurement can be reduced by 48.07% without compromising user comfort, and energy costs can be reduced by 85.04% while reducing user comfort by 65%. The study also provides an overview of the advantages of using PV systems [5].

Małgorzata Fedorczak-Cisak's article proposes an innovative approach to the design, implementation, and use of buildings that make up the "smart residential community" model. The entire process of implementing the "smart residential community" is divided into verifiable stages. Specific objectives and predefined targets must be achieved to move on to the next phase. In the first phase, the focus is on the buildings, which must be designed to minimize energy consumption for utility purposes and provide sufficient comfort to residents. The presented study verified the technical feasibility of constructing energy self-sustainable residential communities. This was achieved by combining demonstration objects within an existing community and additional design calculations. For a real house with an annual electricity consumption of 8118 kWh/year, it was shown that the autonomous electrical system is technically feasible and capable of providing the required services, resulting in the potential for a 96% reduction in greenhouse gas emissions compared to complete reliance on the electrical grid [6].

In Dominik Maierhofer's work, a life cycle analysis of the innovative "2226" building concept is conducted on the original application, the office building "be 2226" in Lustenau, Austria. The building employs an innovative passive construction concept that achieves thermal comfort in the building without the use of heating and cooling systems. The results show that, compared to conventional buildings, a significant reduction in greenhouse gas emissions throughout the entire life cycle can be achieved with the "Existing Standard." However, in comparison to concepts with similar ambitions (i.e., nZEB), further reduction in greenhouse gas emissions throughout the entire life cycle is not feasible. Regarding emissions from construction materials, it appears that the main causes of emissions are in the production phase, especially the bricks used in exterior walls. This is not surprising, as the "2226" concept relies on large building masses to ensure thermal comfort. Total operational emissions were considered based on measured three-year averages of the building's energy standard. By using various literature sources, total operational emissions were "reverse-engineered" into individual modules for operational energy requirements. It was shown that in the building concept, approximately 30% of energy consumption and thus operational emissions can be attributed to systems that are not integrated into the building (e.g., plug-in devices) in Module B6.3. Since this type of operational emissions is often not included in common system boundary definitions in building life cycle analyses, especially in highly energy-efficient building concepts, the inclusion and assessment of these emissions are of great importance to obtain an accurate picture of operational emissions [7].

Progress in energy efficiency through digitalization, household automation, labeling, and standardization has long-term effects that go beyond the boundaries of the European Union. Since appliances and electronics are both imported into the EU and exported to international markets, foreign manufacturers comply with EU standards [2].

2. Model

2.1. Model description

The goal of this work is to reduce energy consumption and increase energy efficiency. A mechanical project of thermotechnical installations that includes HVAC systems on a real object includes two systems. The first system is a Fan coil system that works during the cooling mode, and the second system is a Low temperature radiant system and works in heating mode. The model in the program was made based on the same systems to check consumption.

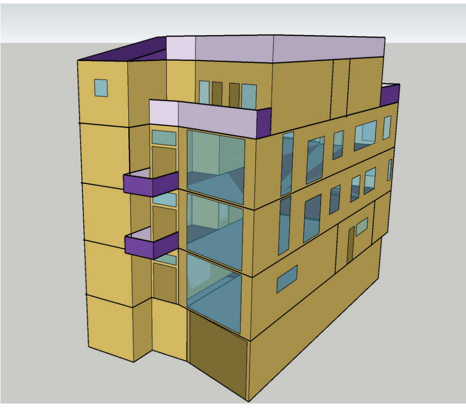

Figure 1. View of the building in SketcUp

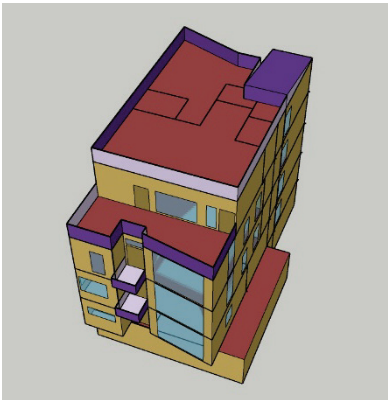

Figure 2. View of the building on roof

The geometry of the building contains 305 partitions (walls, mezzanine structure, floor and roof) and 44 windows of different dimensions. In EnergyPlus, the location of the investigated object is entered as initial data, the geographical latitude of the object is 43.34° and the geographic longitude is 21.85°. Total building area is 1129.22 m². The maximum temperature of the dry thermometer for the first month is -10.3°C, and for the seventh month 32.9°C. The simulation is performed for one year with a step of 6 iterations per hour.

In the following table, the number of people in certain zones is given, according to which the load from people is calculated, which is also given according to the mechanical design of the HVAC installation, for other zones, the load is adopted to the area of the zone.

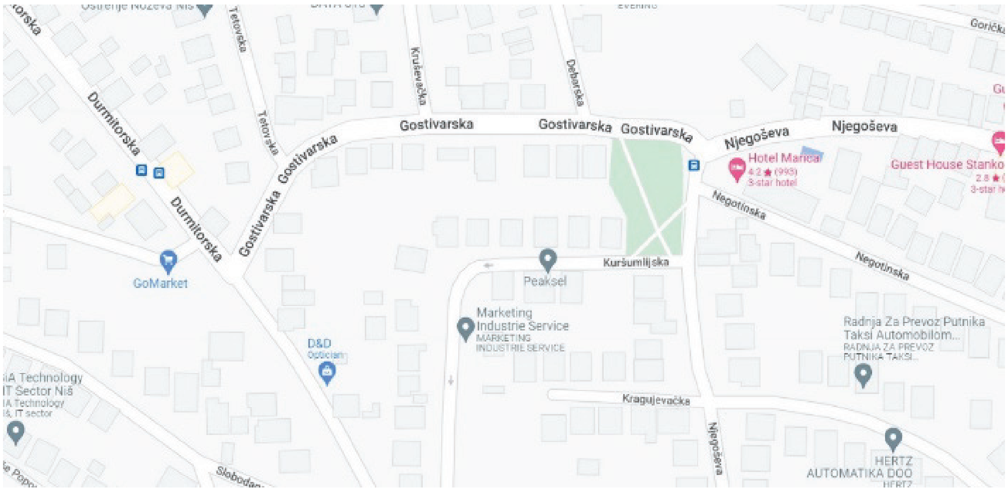

Figure 3. Location of building

2.2. Characteristic of model in EnergyPlus

In order to initiate a simulation on this model, the necessary characteristics are provided. This includes the number of thermal zones, which is 34, with 21 of them served by HVAC systems. It is specified that in all zones, the total number of people in the model is 53, 13 thermal zones are illuminated with 4 W/m², and 11 zones have electric equipment with a load of 10 W/m².

The temperature of the feed water in the heating mode is 55°C, and in the cooling mode 17°C, while the thermostats in the heat zones have a set value of 23°C in both the heating and cooling modes.

For system operation in heating/cooling mode, the system is switched on at 06.00 and switched off at 20.00 for five working days per week (Monday-Friday).

The equipment operation schedule is divided into several groups due to the simultaneity factor of the equipment, i.e. the degree of equipment operation.

Table 1. Equipment operation period

Equipment operation period	Coefficient of simultaneity
08.00-16.00	0.8
16.00-22.00	0.3
22.00-08.00	0
Weekend	0.05

Table 2. Lighting operation period

Lighting operation period	Coefficient of simultaneity
08.00-16.00	0.5
16.00-22.00	0.9
22.00-08.00	0.1
Weekend	0.2

The lighting work schedule is also divided into several groups, with lighting simultaneity factors:

The presence of people was done with a concentration of 100% of the expected number of people in the period from 08.00 to 16.00.

Before the simulation itself, it is necessary to enter the heating/cooling parameters. This field allows to determine the global heating/cooling parameters. These relationships apply at the zone level to all zone heating/cooling loads and airflow rates. The heating dimensioning factor and the cooling dimensioning factor are entered in the field. The heating/cooling sizing factor represents the global heating/cooling sizing ratio applied to all heat loads in the heating/cooling mode and airflow within the zones. A value of 1.15 was adopted for both factors.

2.3. Cases

As previously mentioned, the model uses fan coil and low-temperature radiant systems. Therefore, the primary focus is on two scenarios: with and without the use of PV (photovoltaic) panels. The characteristics of the PV panels are as follows: the panels are installed on the roof of the building at a 35° angle, as shown in Figure 4, which displays the panel layout.

The value for cell efficiency is fixed at 0.225, and the type is crystalline silicon. The total surface area of one panel is 3.12 m², with a maximum power output of 700 W on that surface. On the roof, there are 30 PV panels with these characteristics, installed at an angle of 32° facing south. Spacing requirements have been adopted between the panels for system maintenance. These conditions create opportunities for further space utilization.

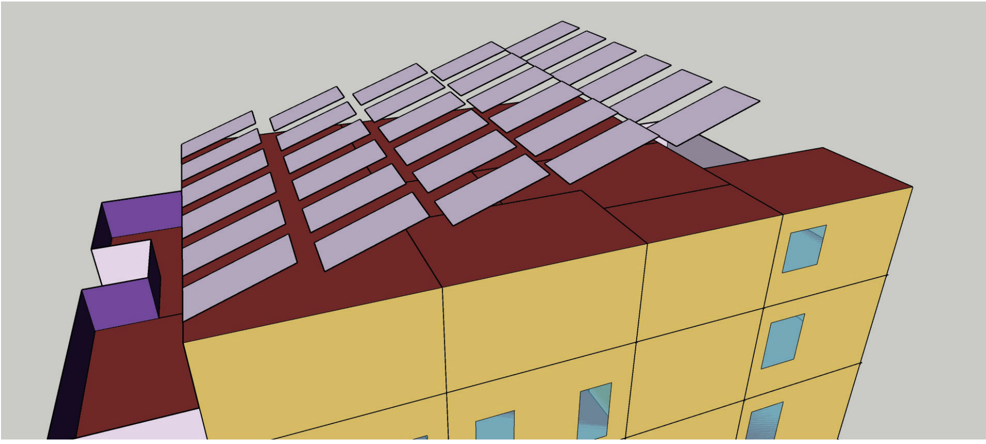

Figure 4. The arrangement of PV panels on the model

3. Results

After the simulation, the most important result obtained is that the total energy demand of the building is 36.49 kWh/m^2, or 41,200.88 kWh, for the model without PV panels.

Table 3 Essential characteristics of the building

Exterior wall (U-value W/m²K)	0.205
Window (U-value W/m²K)	0.8
Required energy per building area (kWh/m²)	36.49
Annual heating energy consumption (kWh)	5046.73
Annual cooling energy consumption (kWh)	11886.42
Energy for lighting (kWh)	6516.29
Energy for ventilation (kWh)	240.89
Energy for pumps (kWh)	618.93
TOTAL (kWh)	24309.26

Table 4 Energy consumer

(%)	
Interior lighting	15.82
Space heating	12.25
Space cooling	28.85
Fans	0.58
Receptacle equipment	41
Miscellaneous	1.5

The time of peak for district cooling is on July 21st at 15.22 kW, while for district heating, it occurs on January 15th at 12.43 kW. The peak electricity demand is on August 28th, with a requirement of 5.83 kW.

For the model with PV panels, the simulation results are as follows: The total energy consumption of the building remains the same at 36.49 kWh/m²; however, the building's demand decreases to 13.03 kWh/m².

Photovoltaic panels generate 26,391.32 kWh of electrical energy annually, with 24,262.6 kWh being utilized, and the remaining 2,128.7 kWh can be fed back into the electrical distribution grid.

The required annual capacity for electrical energy is 24,267.7 kWh, which means that on an annual basis, there is a difference of 5 kWh that needs to be sourced from the electrical distribution grid, with the remaining portion being supplied by the PV panels.

Regarding CO_2 emissions and the data on 0.626 gCO_2 per kWh of electrical energy [8], we have the following.

Table 5 PV production of electricity

Month	kW
January	890.4099007
February	1231.321798
March	1908.306285
April	2651.947186
May	3255.421445
June	3529.376852
July	3801.347526
August	3416.284754
September	2451.131526
October	1652.822102
November	914.5930302
December	688.3527302

Table 6 Annual CO_2 emission from used electrical energy (kg CO_2)

Month	Emission without PV panels	Emission with PV panels
Januar	1257.832026	700.44
Februar	1141.188121	370.4
Mart	1294.670982	100.07
April	1172.736586	-487.4
Maj	1358.17655	-679.72
Jun	1318.775947	-890.62
Jul	1283.538891	-1096.1
Avgust	1380.520705	-758.07
Septembar	1268.897753	-265.5
Oktobar	1266.908302	232.24
Novembar	1237.29754	664.76
Decembar	1211.052864	780.14

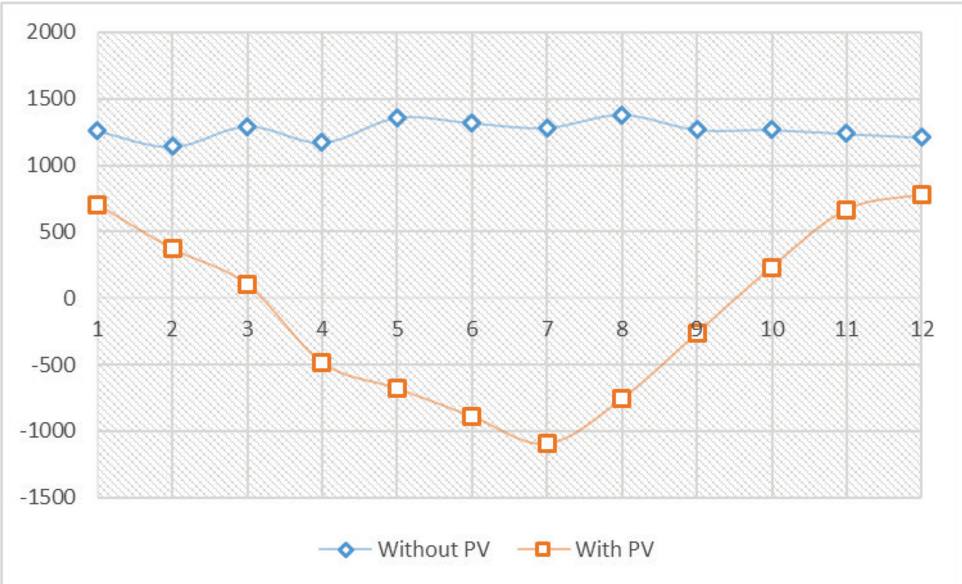

Figure 5 Annual CO_2 emission of electricity (kg CO_2)

4. Conclusion

The results obtained through simulation on this model provide a clear overview that this building belongs to the category of low energy consumption, almost nZEB (nearly Zero Energy Building). By implementing PV panels, energy consumption is reduced from 36.49 kWh/m² to 13.03 kWh, representing a 64.3% reduction in consumption, which is a significant step towards achieving nZEB.

The challenge we face with this theory is whether energy consumption can be reduced using PV panels in this manner. Specifically, in reaching the balance point between consumption and electricity generation, where in several months we have more electricity generation than consumption, while simulations provide results on a monthly basis, and are used regardless of having lower production than consumed energy on a particular day.

From the perspective of CO_2 emissions, without PV panels, the annual emissions amount to 15.192 tCO_2, whereas with PV panels, emissions are reduced to 0.863 tCO_2 per year, assuming that all electrical energy from the PV panels is utilized. This represents a 94.3% reduction in emissions, which can be a significant environmental achievement.In the previously written paper, an overview of CO_2 emissions was provided using a heat pump and district heating/cooling, showing a small difference in emissions between these sources due to high CO_2 emissions per produced kWh [1].

However, it is emphasized in this paper that even under ideal simulation conditions and when considering a monthly overview of electricity production, this may not be feasible as not all the generated electrical energy will be utilized.In the end, the net energy has been reduced from 36.49 kWh/m² to 13.03 kWh/m², which was the goal of this study. In future work, it remains to observe the model and PV electricity production on an hourly basis, considering real-time consumption and production, as this approach would reduce the error in CO_2 emissions.

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