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Impact of the COVID-19 on electricity consumption of open university campus buildings – The case of Twente University in the Netherlands

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ABSTRACT

Since the COVID-19 outbreak, the restrictive policies enacted by countries in response to the epidemic have led to changes in the movement of people in public places, which has had a direct impact on the use and energy consumption of various public buildings. This study was based on electricity consumption data for 25 on-campus public buildings at 1-hour intervals between January 2020 and June 2022 at Tewnte University in the Netherlands, and after the data were climate-corrected by multiple regression analysis, the changes in EU and EUI for various types of buildings were compared for different restriction periods using ANOVA, LSD and t-tests. And additionally, further analyzed the changes and reasons for the electricity consumption of various public buildings on campus and customers' electricity consumption behavior in a period of time after the lifting of the epidemic restriction policy. The results of ANOVA analysis show that the restriction policy has a significant effect on teaching, sports, and cultural buildings, and the electricity intensity of the three types of buildings is reduced by 0.28, 0.09, and 0.07 kwh/m^2/day respectively under the strict restriction policy; The *t*-test results show that during the restriction period, all building types, except for living and academic buildings, show a significant decreasing trend, with the teaching buildings having the greatest energy saving potential, with an average daily EU reduction of 1088kwh/day and an EUI reduction of 0.075kwh/ m^2/day. The above findings provide a case study of a complete cycle of energy consumption changes in university buildings under similar epidemic restriction policies before and after the epidemic restriction, and inform the electricity allocation policies of university and government energy management authorities.

1. Introduction

On January 5, 2020, the World Health Organization (WHO) announced that it had received news of a case of pneumonia of unknown origin from Wuhan, China [1], and officially released the COVIN-19 Joint Operations Investigation Report on February 28, 2020 [2]. Each country then developed a series of restrictions based on the reporting guidelines and its own situation to help contain the spread of the epidemic [3–6]. These restrictions directly affect the normal functioning of various industries, including but not limited to healthcare [7], education [8], tourism [9,10], industry [11,12], economy [13], energy [14], environment [15,16], etc. At the same time, a series of changes in the behavior of people's daily activities, such as work and study, have occurred due to restrictive policies. The daily behavior of occupants, in turn, has a significant impact on building energy consumption [17,18]. Therefore, the restrictive policies during the epidemic will certainly cause changes in building energy consumption.

Energy consumption in buildings has a strategic importance in world energy consumption [19], and for this reason, a series of studies have been carried out in the academic community on the changes in energy consumption in different types of buildings during the epidemic. Among them, Hyuna Kang et al. evaluated the energy consumption of different types of buildings in Korea based on big data and found that the overall electricity and natural gas were 4.46 % and 10.35 % lower compared to the year before the epidemic, and the rate of change in building energy consumption depended on the correlation between building function and neo crown pneumonia [20]. Ahmed Abdeen et al. used statistical meth-

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ods to analyze electricity data from more than 500 households in Canada and found a 12.8 % increase in daily household electricity demand compared to the pre-epidemic period [21]. Usep Surahman et al. studied the use of natural gas and appliances in 311 residential houses in Indonesia through interviews and field surveys, which showed that the average annual energy consumption during the epidemic was elevated by 3.0 GJ compared to the previous period [22]. Energy consumption changed not only in residential buildings, but also in public buildings during the epidemic with significant fluctuations, Matheus Soares Geraldi et al. analyzed and investigated the electricity consumption of municipal buildings during the Floriańopolis epidemic restriction policy and found that the average electricity consumption of health centers, administrative buildings, elementary school and kindergartens decreased by 11.1 %, 38.6 %, 50.3 % and 50.4 %, respectively, compared to the pre-epidemic period [23]. ZF Huang and ZH G's statistical analysis of half-hourly electricity consumption and intensity of electricity use in municipal public buildings in Scotland, UK, yielded the same findings as Floriańopolis et al. The intensity of electricity use was significantly reduced in all public buildings except for office buildings, with the lowest reduction in building energy consumption in secondary schools [24].

Based on the current study of building energy consumption during the aforementioned epidemic, it was shown that the most significant reduction in energy consumption was seen in primary and secondary school buildings [25]. Perhaps because the education industry is generally a congregation of students and teachers, the impact during the New Coronavirus was more pronounced. However, university campuses are generally larger and have a greater variety of building types and therefore higher energy demand compared to primary and secondary schools. The restrictions during the epidemic have also had a knock-on effect on university campuses, such as a drop in the mobility of international students [26], Some teachers are unable to teach normally due to city restrictions, and the teaching mode is changed to online teaching mode with the help of modern communication tools such as computers and cell phones [27–30], A safe distance needs to be maintained even when attending classes on campus during the restriction period [31], and the academic and psychological stress that COVID-19 causes to students, etc [32–34]. The changes brought about by these shocks also have a direct impact on the energy consumption and carbon emissions of university campus buildings [35–37]. The energy consumption of university campus buildings occupies an important position in the energy consumption of urban buildings, so it is necessary to conduct a detailed study of the changes in energy consumption of university campus buildings during the epidemic.

At present, a few scholars have begun to pay attention to the changes in energy consumption of university campuses during the epidemic. For example, Paula Brumer Franceschini evaluated the existing research methods of campus building performance, and looked forward to the future research topics based on the impact of the new crown epidemic on campus personnel living behavior models [38]. Sharifah Nurain Syed Nasir et al compared the building electricity consumption of a research complex at the National University of Malaysia in 2019–2020 and found that the building's energy consumption decreased by 11 % during the covid-19 period [39]. In contrast, Reza Mokhtari et al. used a simulation optimization algorithm to evaluate the effects of the presence of people, air exchange rate, class time and work time on HVAC system energy consumption and the number of people infected with New Crown Pneumonia in a building at Tehran University during the New Crown Pneumonia epidemic, concluding that increasing the ventilation rate of the building during the New Crown Pneumonia epidemic was effective in reducing the number of infections, but the corresponding building energy consumption would also increase [40]. In addition, K. Gaspar et al. investigated the energy consumption of 83 teaching buildings of the Polytechnic University of Catalonia-Barcelona during the covid-19 blockade, The results show that the weather-corrected energy consumption of the entire university campus buildings decreased by 19.3 % during the year during the epidemic, and the occupancy rate of academic buildings did not significantly affect the changes in building energy consumption [36]. XC Gui, ZH Gou and others compared the energy consumption of Griffith University in a normal academic year and an epidemic academic year, and concluded that during the new coronary pneumonia period, by shutting down the air conditioners in academic, administrative, teaching, retail and other buildings, the average energy consumption per Weekly energy can save at least 860kwh of energy consumption [41].

However, most of the existing studies on building energy consumption on university campuses during the epidemic period focus on the comparison between the period before the epidemic and the period during the epidemic restriction, and lack a trend analysis on the change of building energy consumption after the lifting of the epidemic restriction policy. In addition, due to the epidemic situation and policies of different countries and the influence of climatic conditions, the energy consumption changes of different university campus buildings during the epidemic also vary greatly. In short, there is still a paucity of research cases exploring the potential for building energy efficiency using changes in building energy consumption data on university campuses during the New Crown Pneumonia outbreak as a case study. As an important part of urban educational resources, university campuses have various public buildings inside the campus for a large number of students. The teaching activities with aggregation type are more sensitive to the restrictive policy of epidemic, and with the intervention of online education, the usage of some public buildings (teaching buildings or cultural centers, etc.) inside university campuses is significantly reduced. If we can understand the impact of the epidemic restriction policy on the energy consumption of different types of public buildings on campus by studying the changes in energy consumption of university campus buildings during the epidemic, we can develop subsequent response plans according to the degree of impact on each type of building, which will make a great contribution to reducing carbon emissions in cities.

This paper uses the latest real-time data on the hourly electricity consumption of 25 different types of public buildings on campus in the database of the University of Twente in the Netherlands from 2020 to June 2022 to explore the impact of the new crown epidemic restriction policy on the energy consumption of different types of public buildings on university campuses. It provides a more detailed and complete campus case for building energy consumption research under the covid-19 epidemic, and provides a reference for the government and university energy management departments to formulate policies under similar conditions. The main content of the article is structured as follows: Section 2 introduces the research methods and cases, Section 3 compares and analyzes the corrected data in different periods and stages, and Section 4 discusses the results. Section 5 presents the main conclusions drawn from this study.

2. Methodology

2.1. Definition of space-time boundaries for study cases

The research subject, Twente University, is located in Enschede, a municipality in the eastern part of the Netherlands, in the interior of the country, with a typical temperate maritime climate. The climate features a relatively mild performance with adequate rainfall. The highest average temperature month of the year is July, with an average temperature of 17.2 °C, and the lowest average temperature month is January, with an average temperature of 1.7 °C. The maximum average temperature difference between winter and summer is about 15.5 °C, so there is a degree of demand for heating and cooling in winter and summer.

On February 27, 2020, the Dutch government announced the first coronavirus person [42], Since then, COVID-19 has been spreading widely in the Netherlands, and according to Dutch government statistics, as of August 18, 2022, the number of people infected with COVID-19 in the Netherlands has reached 8.37 million, with 22,565 deaths [43]. In the interest of citizen health and safety, the government began developing measures to curb the spread of the virus on March 12, 2020, and officially issued strict restrictions on March 23, 2020.

Twente University immediately announced a series of response measures in accordance with the restrictions issued by the Dutch government. Due to the uncertainty of the epidemic, these measures have also changed with the new restrictions announced by the government, but they are basically based on government rules [44]. Important responses on campus as of now are divided into the following time periods:From March 27 to June 1, 2020, all teaching and examinations will be conducted online, students will study at home, and all university teaching services will be closed until the government announces the relaxation policy. Some services and facilities on the university campus and public transportation will be restored one after another under the specified number of restrictions from June 1, 2020 to August 31, 2020 before the start of the academic year, but the university's teaching is still required to be conducted online (strict restriction period 2020.3.27 ~ 2020.8.31). With COVID-19 effectively controlled under the restrictive policy August 31, 2020, Twente University decided to open the school normally under the government's relaxed restrictive policy, but on-campus personnel must wear masks and maintain a safety distance of more than 1.5 m, adopting a hybrid online and offline teaching model. During this period, the university closed some public buildings due to the resurgence of the epidemic but the rest of the academic activities were carried out normally. (Relaxed restriction period 2020.9.1 ~ 2020.12.14). With the rebound of the New Crown epidemic, the university campus began another period of strict control on December 15, 2020, with a change in the educational model to online closure of indoor gymnasiums, libraries, and other similar public facilities, and a curfew policy (strict restriction period 2020.12.15 ~ 2021.4.25). With the introduction of the vaccine, the situation of COVID-19 improved, the Dutch government lifted the curfew and other restrictive policies on April 26, 2021, and opened various public places one after another, and universities opened some face-to-face education again, but with time and number regulations. The University officially opens on September 1, 2021, during which there are partial restrictions on the hours of operation of some public buildings, and on-campus personnel conduct teaching and learning activities under protective regulations (relaxed restriction period – 2021.4.26 ~ 2022.2.16). On February 17, 2022, the government officially lifted all restrictions and resumed normal activities as the New Crown vaccine became widespread and the epidemic stabilized. For a more intuitive understanding of the research cycle, this study divided the cycle of response measures during the epidemic into restricted and unrestricted periods based on the campus response strategies and time points described above. Among them, the restriction period mainly includes strict restriction and easy restriction period, and the non-restriction period includes pre-epidemic and post-epidemic. (Table 1).

Since school vacation dates and public holidays can also have an impact on the use of public buildings on campus, this issue needs to be considered in the analysis. In Fig. 1 we have drawn a detailed timeline based on the campus calendar with different phases of restriction levels, schools and public holidays. As can be seen from the chart, the number of vacation days during 2020 ~ 2022 is basically the same, but the specific vacation time varies. This study analyzed the electricity consumption of 25 different types of public buildings in Twente University based on the above timeline framework.

Table 1
Search process time point.

Year	Period	Time
2020 ~ 2021	Unrestricted Period (Before the COVID-19)	2020/01/01 ~ 2020/03/26
	Strictly Restricted	2020/03/27 ~ 2020/08/31
	Easting Restricted	2020/09/01 ~ 2020/12/14
	Strictly Restricted	2020/12/15 ~ 2021/04/25
2021 ~ 2022/06	Easting Restricted	2021/04/26 ~ 2022/02/16
	Unrestricted Period (After the COVID-19)	2022/02/17 ~ 2022/06/30

2.2. Data collection

Twente University's public building energy consumption data is published in real time on its official website, which includes the hourly electricity consumption of many types of buildings and campus facilities within the University, covering the real-time electricity consumption of 45 public places on campus [45]. These include public lighting, parking lots, cultural centers, teaching buildings, laboratories, facility management rooms, and commercial buildings on campus, among others. CSV format can be exported for analysis at any time as needed. The building electricity consumption (EU) is recorded hourly by the smart meter, which can effectively ensure the accuracy of the data.

Due to the lack of electricity consumption data for some time periods in the public data and some sites are not suitable for this research scope, after a series of screening, 25 buildings were finally selected for this analysis. In addition, based on the campus building information and campus map [46],this paper used QGIS software combined with the high-resolution sentinel-12 images provided by ESA (European space Agency), extracted the building base vector area data using random forest deep learning method, and imported into Google Earth (google earth) for correction, finally estimated the building area and determined the building type. Table 2 shows the basic classification of buildings and floor area statistics (Estimated floor area = base area * number of building floors). Although the estimated floor area cannot reach full accuracy, it is sufficient for calculating the building electricity intensity (EUI) based on the same comparison conditions in this paper.

2.3. Climate adjustment data

Climate characteristics are an important factor affecting building energy consumption that cannot be ignored [47]. The outdoor temperature in different years is not the same for building energy consumption, and it is not reasonable to use raw data to directly evaluate and compare energy consumption in different years under this objective factor. It is therefore necessary to make climate corrections to the raw data in order to compare building energy consumption over time under the same base conditions [48]. Currently, climate correction has been widely used to evaluate

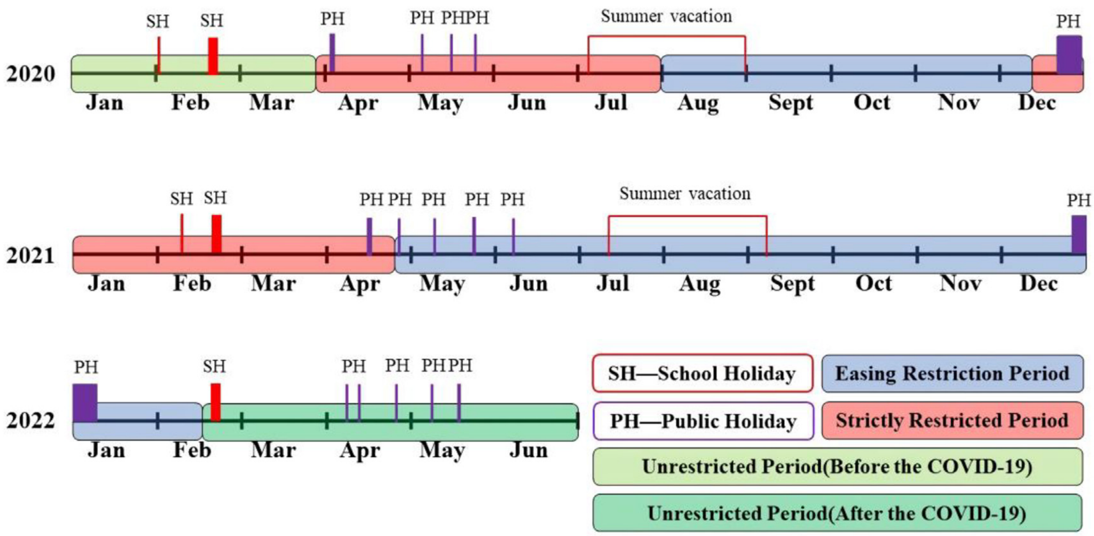

Fig. 1. Twente University Calendar Arrangement and Different Restriction Periods.

Table 2
Final selection of buildings and classification.

Building type	Numbers of case	Estimated floor area (m^2)		
		Average Value	Maximum Value	Minimum Value
Service building	9	2718	6810	1600
Teaching building	6	14,501	38,830	3980
Research building	4	2777	7350	600
Sports building	3	3817	6180	1600
Office building	2	5495	9580	1410
Culture building	1	12,536	12,536	12,536

building energy assessment studies during the New Crown Pneumonia outbreak [20,36], The principle is to perform a multiple regression of building energy consumption against the climate proxies HDD (heating degree days) and CDD (cooling degree days) of the study area. There are two main steps: firstly, the HDD and CDD are calculated based on the local climate data, and secondly, the correction coefficients are derived from the multiple regression analysis.

The first climate data used for the calculation were obtained from the website of the local weather station in the Netherlands [49]. Then a reference temperature is set for the calculation of HDD and CDD. The reference temperature varies from country to country due to the different regions and climatic conditions around the world, and in this study the reference temperature is set to 18.3 °C according to the international standard recommended by ASHRAE, the American Society of Heating Refrigeration and Air Conditioning Engineers. The simplest way to calculate the average daily temperature is to compare it with the reference temperature, and when the average temperature is lower than the reference temperature, it is classified as HDD, and vice versa, it is classified as CDD. The calculation formula is as follows:

$$HDD = \sum_{i=1}^{n} (18.3 - T_{meani}) \quad (1)$$

$$CDD = \sum_{i=1}^{n} (T_{meani} - 18.3) \quad (2)$$

In the above equation, where T_{meani}=(T_{maxi} + T_{mini})/2,That is, the average of the daily maximum temperature and the daily minimum temperature. 18.3 is the set reference temperature. After the HDD and CDD are calculated, formula (3–5) is used to calculate the building energy consumption after climate adjustment. Eq. (3) shows the regression analysis between the independent variable (monthly HDD and CDD) and the dependent variable (amount of energy consumed in the building), Eq. (4) then represents the use of the regression coefficients (B_{1j} and B_{2j}) derived from the above multiple regression analysis to calculate the correction coefficients ($CORR_{jk}$). Eq. (5) then represents the climate-adjusted energy consumption data obtained by subtracting the correction factor ($CORR_{jk}$) from the raw monthly consumption data (Y_{jk}) of the different buildings mentioned above.

$$Y_{jk} = b_{0j} + b_{1j} \cdot HDD_{ij} + b_{2j} \cdot CDD_{ij} \quad (3)$$

$$CORR_{jk} = \widehat{b}_{1j} \cdot (HDD_{jk} - NHDD_j) + \widehat{b}_{2j} \cdot (CDD_{jk} - NCDD_j) \quad (4)$$

$$Y_{jka} = Y_{jk} - CORR_{jk} \quad (5)$$

where Y_{jk} represents the electric energy consumption of class j building in month k,b_{0j} represents normal time and day rather than seasonal energy consumption; HDD_{jk} and CDD_{jk} then represent the HDD and CDD of building type j in month k, respectively. b_{1j} represents the regression coefficient of HDD_{jk}; b_{2j} represents the regression coefficient of CDD_{jk}; $CORR_{jk}$ represents the correction coefficient of building category j in month k. $NHDD_j$ represents the average HDD_j in month k of recent years; $NCDD_j$ represents the average CDD_j in month k of recent years, and the last 5 years of climate data are used for the calculation in this paper. Y_{jka} then represents the climate-corrected standardized building electrical energy consumption data.

2.4. Analytical method

In this study, ANOVA, LSD method and independent sample *t*-test were used to compare and analyze various types of buildings under different restriction policies during the study period. IBM SPSS Statistics 22 software was used in this analysis process. The variance model is used to determine whether the control variables have a significant effect on the observed variables and has been used to analyze the effect of different surface materials on the surrounding thermal environment [50]. In this paper is used to determine whether there is a significant effect of COVID-19 limit intensity on building electricity consumption and intensity of electricity use. LSD is further used to determine the value of the difference between groups of the same type over different restriction periods, while the independent samples *t*-test is used to determine whether there is a significant difference in two overall means using the overall sample, and has long been established in similar studies [51]. It was mainly used in this study to supplement the analysis of the changes and differences in EUI occurring in various types of buildings before and after the restriction period and epidemic in different years.

Since there is a certain lag effect between the time of restriction policy release and the response of electricity consumption behavior, in order to ensure the real situation of electricity consumption fluctuation under different restriction intensity in the ANOVA process, we screened the electricity consumption data of one stable natural month in each restriction period for ANOVA analysis From T0 before the implementation of the restriction policy until T5 after the lifting of the restriction, for a total of 6 natural months.

- T0(2020.2.25 ~ 3.25)
- T1(2020.5.15 ~ 6.15)
- T2(2020.10.15 ~ 11.15)
- T3(2021.2.15 ~ 3.15)
- T4(2021.6.15 ~ 7.15)
- T5(2022.3.15 ~ 4.15)

And before the analysis, it is necessary to conduct normal distribution and homogeneity test of variance on the data to determine whether the variance of power consumption of various buildings under different restriction periods is equal. The analysis results only have statistical significance when they conform to the normal distribution and the Sig value in the variance test is ≥ 0.05. The comparative analysis of LSD further compares the difference values of the same type of building in different restriction periods based on the results of ANOVA analysis. In the final step of the independent samples *t*-test, the main output parameters in the model include the test statistical observation, the p-value to test the likelihood of difference, and the mean difference value. A significant difference between the two clusters is considered to exist when the p-value is<0.05; and vice versa. The flow of the comparative analysis is depicted in detail in Fig. 2.

Since there is a sample of single buildings in this building classification group, such as cultural buildings. Therefore, it is necessary to verify whether the existing sample size (Table 3) can meet the requirements of the *t*-test. In this study, G power 3.1 was used to carry out a software validation of the existing sample size for the effect size, first selecting in the execution command *t* test- difference between two independent means, The mode was set to and post hoc analysis, and since this study belongs to the sample size under objective conditions, the effect size d was set to 0.5 is acceptable under the current conditions. The α err prob is generally preset to 0.05, and the output efficacy value Power (1 - β err prob) can be derived after inputting the current sample size. Usually, an output efficacy value greater than 0.8 represents acceptable, and the minimum sample output efficacy value in this study was 0.89, which indicates that the current sample size is valid and sufficient for this study.

3. Analysis

3.1. Basic overview of data

After climate-correcting all the data, this paper initially compares the electricity consumption of different types of campus buildings at various stages of the study cycle. Table 4 shows the daily average EU of the six types of campus buildings in this study at six stages. As can be seen from the table, teaching buildings, as the main part of the university campus complex, have the highest EU, with a daily average EU of 21,407.88kwh even during the strict restriction period, followed by research buildings and living buildings, with a total daily average EU of 13,883.25kwh and 9,559.87kwh, respectively. The average daily EU of the three types of buildings, sports, office and culture, is very close, at 1489.54 kwh, 1490.99 kwh and 1491.31 kwh, respectively. As can be seen from the overview of electricity consumption data, teaching and research activities are the main activities on university campuses, and most of the students' or teachers' activities and time are concentrated in the educational buildings, so the EU of teaching buildings is much higher than that of other buildings. In addition, the EU of research buildings is also relatively high, second only to teaching buildings, because research buildings contain many high-powered instruments and equipment, and some equipment may need to run non-stop due to experimental reasons, consuming a lot of electricity in the process of continuous operation. The living buildings are involved in the daily needs of students and faculty such as eating and shopping, and therefore also account for an important part of the energy consumption of campus buildings. Office buildings provide office functions but are not the main functions of the university, while sports and cultural buildings are more often used by students after school, so these three types of buildings account for a relatively low share of the overall electricity consumption of the university campus.

And after further comparing the average daily electricity consumption during different restriction periods, it can be found that all other types of the university were affected to some extent during the restriction period, except for research buildings. During the strict restriction period, the EU of teaching, sports, office and cultural buildings decreased significantly, while the EU of living buildings increased, and the academic buildings were not affected much.

Due to the large sample size of the daily average EUI, this paper calculates the weekly average of the sample data in order to better show the changes of EU and EUI of buildings in different stages. Fig. 3 shows the changes of EUI in different restricted stages of various types of buildings. The red and blue areas represent periods of restriction of different intensities, respectively, and the cyan and gray areas represent non-restricted periods before and after the outbreak. As can be seen from the figure, the EUI of academic buildings is originally higher than that of other types of buildings, and the EUI performance is very smooth in different restriction periods. Life building EUI is second only to academic building, but it is more influenced by the restriction measures, and the EUI change goes to show a more substantial change in different restriction periods, the stronger the restriction period, especially the first strict restriction phase, the overall EUI is inversely proportional to the intensity of the epidemic restriction, while the teaching building EUI is lower than the life building, but it is also influenced by the restriction policy and is proportional to the intensity of the

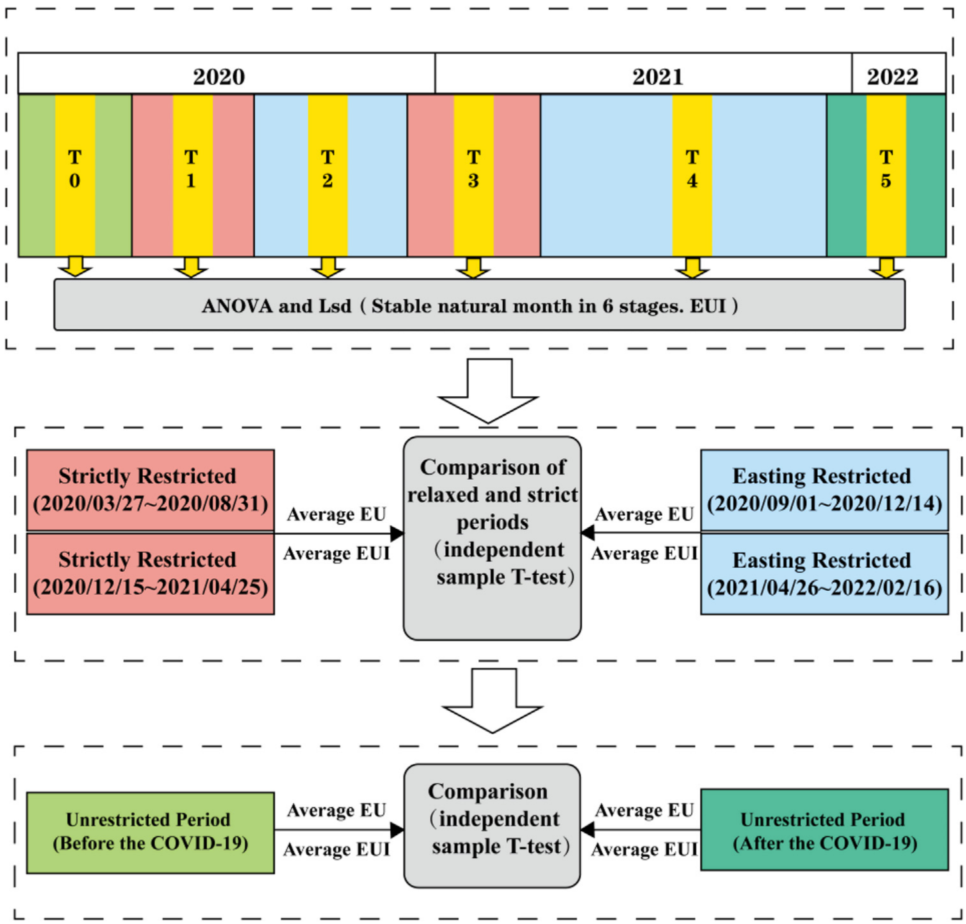

Fig. 2. Analysis and comparison framework.

Table 3
Sample size of different types of public buildings on campus.

Building Type	Unrestricted Period (Before the COVID-19)	Strictly Restricted (2020/03/27∼2020/08/31)	Easting Restricted (2020/09/01∼2020/12/14)	Strictly Restricted (2020/12/15∼2021/04/25)	Easting Restricted (2021/04/26∼2022/02/16)	Unrestricted Period (After the COVID-19)
Service	765	1413	945	1188	2673	1206
Teaching	510	942	630	792	1782	804
Research	340	628	450	528	1188	536
Sports	255	471	315	396	891	402
Office	170	314	210	264	594	268
Culture	85	157	105	132	297	134

Table 4
The average daily electricity consumption of different types of campus buildings after climate correction.

Building Type	Unrestricted Period/EU (Before the COVID-19)	Strictly Restricted/EU (2020/03/27∼2020/08/31)	Easting Restricted/EU (2020/09/01∼2020/12/14)	Strictly Restricted/EU (2020/12/15∼2021/04/25)	Easting Restricted/EU (2021/04/26∼2022/02/16)	Unrestricted Period/EU (After the COVID-19)	Mean/EU
Service	6632.48	12156.4	8785	9486.8	9531.2	10767.39	9559.87
Teaching	24091.88	21407.88	25,560	23544.53	25185.17	26259.53	24341.49
Research	13691.03	13750.58	14317.32	13737.5	13963.4	13839.67	13883.25
Sports	1433.51	1080.87	1643.04	1226.65	1573.6	1979.58	1489.54
Office	1612.27	1403.09	1429.59	1379.57	1501.1	1620.35	1490.99
Culture	1635.28	1147.35	1500.12	1277.28	1523.65	1864.15	1491.31

restriction. The EUI performance of sports, office and cultural buildings is low, and the change in EUI picks up somewhat during the unrestricted and loosely restricted periods and improves significantly after the epidemic of exposure to restrictions.

3.2. ANOVA and LSD results for EUI of buildings in different periods

Because of the large amount of electricity used in various types of buildings, electricity intensity is derived from the constant of

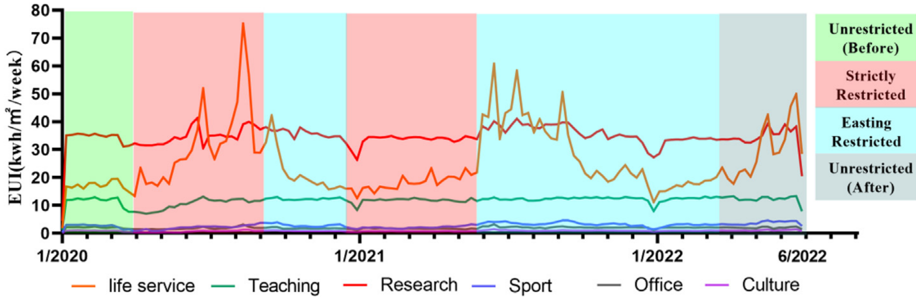

Fig. 3. Weekly EUI changes at different stages.

electricity consumption divided by floor area, and the results and significance are the same in ANOVA analysis, so this section starts ANOVA analysis with EUI as the base data. Before the analysis of variance, the data has passed the K-S normal distribution test in SPSS. In addition, in order to test the effectiveness of the ANOVA analysis model, the homogeneity test of variance must be carried out to determine which types of buildings have statistical significance in different periods. The test parameters of the dependent variable include, Service, Teaching, Research, Sports, Office, Culture EUI of six types of buildings, and the impact factors are set to a total of six periods from T0 to T5. The results show that the EUI in different periods conforms to the homogeneity of variance test, and only three types of buildings are significant, namely, Teaching (F = 10.106, Sig. = 0.055), Sports (F = 10.106, Sig. = 0.055), and Culture (F = 58.274, Sig. = 0.062). Sig. values of service, research and office of the other three types of buildings are less than 0.05, which does not conform to the homogeneity test of variance, so the statistical results are meaningless.

The results of the ANOVA analysis kind show that the sig. values of EUI for all types of buildings in different periods are less than 0.05, indicating that the epidemic restrictions have a limiting effect on the electricity consumption of all types of buildings. Among them, the values of teaching, sports, culture and P of the three types of buildings that conform to the homogeneity of variance are equal to 0.000, which indicates that the power consumption of these three types of buildings in different periods has changed significantly. Further LSD analysis is needed to further explore the most significant differences between these three types of buildings during the restriction period and before the restriction. Table 5 lists the LSD comparison results of three types of buildings in different periods before the epidemic and after the restrictive measures are taken.

From the table, it can be seen that the electricity intensity in the restriction period of teaching buildings in T1 phase decreases by 0.28 kwh/ m^2/day compared to the EUI in T0 period, and also decreases by 0.09 kwh/ m^2/day and 0.07 kwh/ m^2/day for sports and cultural buildings, respectively, indicating that the restriction measures have significant effects on the electricity intensity of all three types of buildings. The intensity of sports buildings changed most significantly with the restrictions, decreasing by 0.12kwh/ m^2/day in T3 phase, increasing by 0.20kwh/ m^2/day in T4 phase during the second period of relaxed restrictions, and improving by 0.08kwh/ m^2/day after the restrictions were lifted after the epidemic compared to the period before the restrictions were taken. Cultural buildings received the most intuitive impact under the epidemic restriction intensity, with electricity intensity decreasing by 0.07kwh/ m^2/day and 0.03kwh/ m^2/day during the two mandatory restriction measures T1 and T3, respectively, until the restriction measures were lifted after the epidemic to return to normal.

3.3. Comparison of strict restrictions and easting restrictions

In order to further compare the impact of different restraint intensities on various types of public buildings on campus, this paper uses T-test to further compare the daily average EU and EUI of various types of buildings in different restraint intensity periods during the research period. The results in Table 6 show that the p-values of EU and EUI for different restriction intensities are <0.001 for all building types except living buildings, which are statistically significant and show significant differences. The largest

Table 5
Multiple comparison results of the impact of restriction policies on EUI of Teaching, Sports and Culture buildings in different periods.

EUI	Each period(I)	Each period(J)	Mean difference (I-J)	Standard error	Sig.	95 % confidence interval	
						Lower limit	Upper limit
Teaching	T0	T1	0.28417*	0.06073	0.000	0.1643	0.4040
		T2	0.02600	0.06073	0.669	−0.0938	0.1458
		T3	−0.01057	0.06223	0.865	−0.1334	0.1122
		T4	−0.01449	0.06120	0.813	−0.1353	0.1063
		T5	−0.11600	0.06073	0.058	−0.2358	0.0038
Sports	T0	T1	0.09066*	0.02035	0.000	0.0505	−0.1308
		T2	0.03451	0.02035	0.092	−0.0056	0.0747
		T3	0.12058*	0.02085	0.000	0.0794	0.1617
		T4	−0.20202*	0.02051	0.000	−0.2425	−0.1615
		T5	−0.08462*	0.02035	0.000	−0.1248	−0.0445
Culture	T0	T1	0.06943*	0.00671	0.000	0.0562	0.0827
		T2	0.02754*	0.00671	0.000	0.0143	0.0408
		T3	0.03322*	0.00688	0.000	0.0197	0.0468
		T4	−0.3244*	0.00676	0.000	−0.0458	−0.0191
		T5	−0.00820	0.00671	0.223	−0.0214	0.0050

* Significance level < 0.05.

Table 6
T-test results for EU and EUI in strictly restricted and loosely restricted periods.

Building Type	EU			EUI		
	t-test	P-value	Mean of differences (kwh/day)	*t*-test	P-value	Mean of differences (kwh/day)
Service	1.869	0.62	755.3	1.869	0.62	0.278
Teaching	8.131	< 0.001	2599	8.131	< 0.001	0.179
Research	6.188	< 0.001	669.6	6.188	< 0.001	0.241
Sports	20.3	< 0.001	665.4	20.3	< 0.001	0.174
Office	4.905	< 0.001	202.8	4.905	< 0.001	0.037
Culture	12.59	< 0.001	416.3	12.59	< 0.001	0.033

EU daily mean difference is for teaching buildings (2599kwh/day), followed by research (669.6kwh/day), sports buildings (665.4kwh/day), and cultural buildings (416.3), and the smallest EU mean difference is for office buildings (202.8kwh/day), and the mean difference for living buildings is also relatively high, but does not have statistically significant. The above results show that the intensity of the restriction policy is inversely proportional to the EU of other types of public buildings on campus except for living, that is, the higher the intensity of the COVID-19 restrictive policy, the lower the electricity consumption of other types of public buildings on campus except for living. And in the comparison of EUI, it can be found that the largest difference in mean value is for research buildings (0.241kwh/ m^2/day), followed by teaching (0.179kwh/ m^2/day) and sports buildings (0.174kwh/ m^2/day), and the smallest is for office buildings (0.033kwh/ m^2/day) and cultural buildings (0.033kwh/ m^2/ day). This indicates that the research, teaching, and sports categories have the highest energy saving potential under different intensity of epidemic restriction policies.

3.4. Comparison before and after the COVID-19 unrestricted period

Finally, to understand whether the EU and EUI of each type of public building on campus changed before and after the restriction policy of the New Hall epidemic, this paper further compared the EU and EUI data before and after the unrestricted period using t-tests. The results of the data in Table 7 show that, except for the research and office buildings, the rest of the building types changed significantly before and after the epidemic, with p-values < 0.05 and statistically significant. The most significant changes in EU are in living buildings (4135kwh/day) and teaching buildings (2168kwh/day), followed by sports buildings (546kwh/-day) and cultural buildings (228.9kwh/day). This indicates that the restriction policy during the New Crown epidemic suppressed people's out-of-home activities and electricity consumption habits to a certain extent. Due to the long-term suppression, people's electricity consumption habits became more frequent than before for a period of time after the lifting of the restriction, resulting in an increase in electricity consumption in the category of living services and buildings. And this is reflected in the mean difference of EUI. The highest mean difference of EUI before and after the epidemic is for living buildings (1.522kwh/ m^2/day), followed by teaching (0.149kwh/ m^2/day) and sports buildings (0.143kwh/ m^2/day). This suggests that the potential for electricity use in living and educational buildings can be considered first in future electricity management decisions.

4. Discussion

4.1. Impact of government restrictions on electricity consumption in public buildings on campus

To demonstrate that the introduction of restrictions at Twente University's campus is not an isolated reference, and to discuss in more detail the impact of restrictions on electricity consumption in campus public buildings, the campus shutdown index from the Oxford Coronavirus Tracking Project is cited to indicate the intensity of campus restrictions over time [52],The index reflects the different levels of the government's policy on school closures in the region, mainly including no measures (0), recommended closures (1), conditional closures (2), and full closures (3). The higher the value, the more restrictive the greater the strength. The government policy for schools provides a more comprehensive understanding of the impact of the intensity of restrictions from different dimensions on the electricity consumption of public buildings on university campuses.

Fig. 4 shows the intensity of restrictions on schools in the Dutch region during the New Crown epidemic, and Fig. 5 shows the change in weekly average EU for Twente universities. By comparing Fig. 4 and Fig. 5, it can be found that from mid-February 2022, with the Dutch government's restrictive policy of total school closures, there was a significant downward trend in EU for all types of buildings on campus, except for research buildings, until June when it began to gradually rebound. This strict restriction occurred three times, in February 2020, December 2020, and December 2021, during which all types of buildings on campus showed a downward trend, but as the number of times increased, the second and third strict restrictions gradually shortened the recovery time of electricity consumption compared to the first. It indicates that the combined online + offline education model

Table 7
T-test results for EU and EUI before the COVID-19 restriction policy was issued and after the restriction was lifted.

Building Type	EU			EUI		
	t-test	P-value	Mean of differences (kwh/day)	*t*-test	P-value	Mean of differences (kwh/day)
Service	7.965	<0.001	4135	7.965	<0.001	1.522
Teaching	3.558	0.0005	2168	3.558	0.0005	0.149
Research	1.002	0.317	148	1.002	0.317	0.053
Sports	9.118	<0.001	546.1	9.118	<0.001	0.143
Office	0.1001	0.9204	8.088	0.1001	0.9204	0.001
Library	3.582	0.0004	228.9	3.582	0.0004	0.018

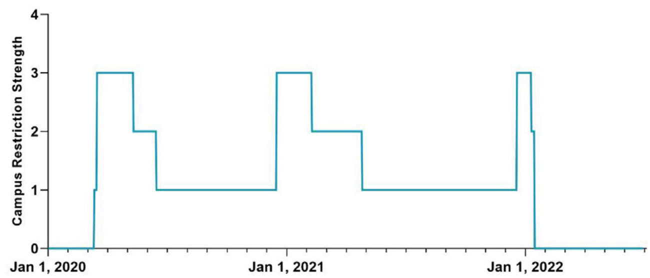

Fig. 4. Netherlands Regional school policy restricts intensity amid COVID-19.

developed by the campus has led to the beginning of a gradual reduction in the impact of the epidemic on various public buildings on campus.

4.2. Changes in campus electricity consumption before and after covid-19

COVID-19 has left people living under restrictive policies for the past two years. The prolonged restriction policy has potentially affected people's life and electricity consumption behavior while affecting energy consumption in various buildings. In the case of this study, the EU changes of residential buildings before and after the epidemic were the most obvious. In the T-test results of 3.4, the electricity consumption of residential buildings increased by 4135kwh/day compared with that before the epidemic, which indicates that the use of residential buildings The duration and utilization rate have increased, and this change has a certain relationship with the utilization rate of public buildings for living. Although detailed data on the usage rates of public buildings containing campus amenity categories are not available in detail, this paper uses the data on the usage rates of various amenity services in the Dutch region from Google's Community Mobility Report on New Coronary Pneumonia as an indirect evidence reference for the usage rates of amenity buildings in this study [53]. Fig. 6 shows the relative change in the number of visitors in various types of restaurants, shopping centers, cafes, and other public places in the Netherlands region from January 2020 to the present with respect to the date.

It can be seen that from February 26, 2022, when the restriction policy was fully lifted in the Netherlands, the number of visitors to living public places began to rise rapidly and by June 30, 2022, had fully surpassed the pre-epidemic period. On the one hand, this is due to the fact that although personal protection habits were developed, many students' awareness of protection began to decrease after the lifting of restrictions [54], and on the other hand, the curfew policy implemented in the Netherlands during the epidemic had a direct impact on the hours of use of such living buildings, which led to a surge in the number of visitors as the hours of operation increased after the lifting of the ban, and as people broke out after being suppressed by the long-term restriction policy. This reason led to an increase in building occupancy limits and an increase in electricity consumption in such living buildings, which explains the spike in EU in campus living buildings before and after the outbreak in Fig. 5.

4.3. Implication and limitations

The restrictions imposed by the government during COVID-19 have led to changes in the movement of people in public places and the frequency of use of various buildings, and the frequency of use of buildings and the number of visitors has a direct impact on the energy consumption of buildings [41]. And this paper analyzes the EU and EUI changes of different types of campus public buildings at different stages during the epidemic in real time by interpreting the restriction policies of the government and schools, especially analyzing the link of joining the analysis before and after the epidemic, and studying the impact of electricity consumption of various types of campus public buildings before and after the epidemic in a more comprehensive way, which has important reference significance for the government in formulating campus restriction measures and energy saving policies under similar climatic conditions. Although it is partly indicated that the popularity of vaccines has eased the epidemic situation in schools and other institutions [55], the virus is still mutating, and people may be restricted by other activities in the future. Therefore, the opening hours or energy restrictions of buildings should be appropriately adjusted according to the changing patterns of energy consumption of different building types during the epidemic to ensure that more energy-efficient policy measures are developed in the face of similar situations.

In addition, with the restriction of the new crown epidemic, online education became one of the main tools of the campus response policy, but according to the available research results, although the energy consumption performance of the teaching buildings decreased somewhat during the epidemic, the overall decrease was small corresponding to their large floor area. But on the other hand, it also shows that online education is still limited to reduce the electricity consumption of education type buildings, and the energy saving potential of education buildings can still be improved. If the energy consumption of student course types can be combined to develop online + offline teaching models to accommodate the relaxed restrictions, it may be possible to improve the energy utilization of campus buildings [37,40]. The results of the current study show that campus buildings have great potential for energy savings [36,41], The data cut-off date of this study is June 30, 2022, and the study period includes all the time periods before the outbreak, during the restriction and after the lifting of the restriction, and the actual electricity consumption data of various public buildings on campus are analyzed with the

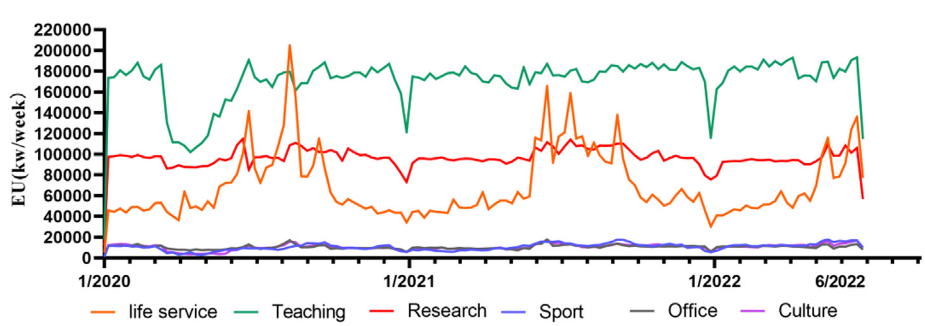

Fig. 5. Weekly average EU for public buildings on the University of Twente campus.

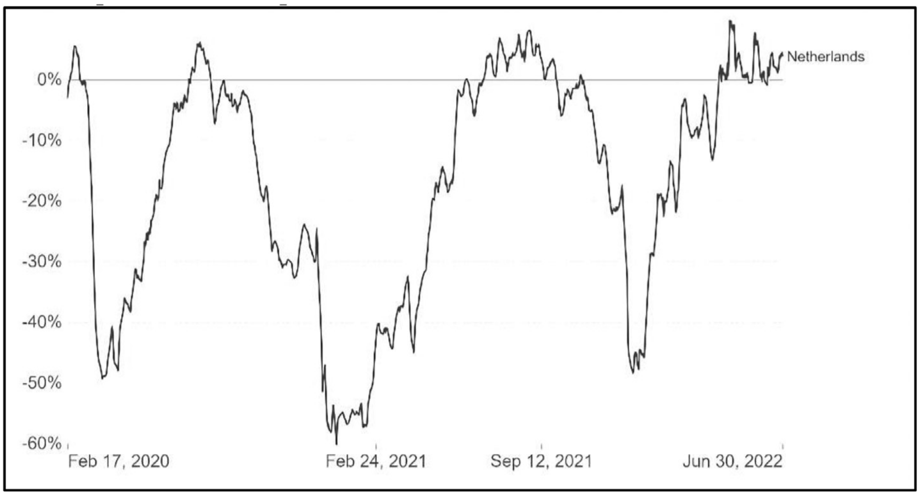

Fig. 6. Relative change in visitor numbers to retail and entertainment venues.

real-time restriction policy and intensity, which provides an exhaustive and complete case study of the energy consumption transformation of campus-type buildings during the outbreak with important practical significance. In addition, by comparing the EU and EUI changes of various campus buildings under different restrictions at the government and school levels, the reasons for the changes in people's electricity consumption behavior in different periods are revealed, which will provide evidence and support for energy managers to deal with electricity domination during the epidemic period.

Of course, there are certain limitations in this study, such as the floor area data measured and calculated using QGIS and Google satellite maps may not be accurate enough, and also the study only includes the public type buildings inside the campus, if the analysis can be done in conjunction with the dormitory type buildings, such as Zhou et al.'s assessment of the change in electricity consumption in campus dormitories during the COVID-19 [56], the change in building energy consumption of a complete campus living system can be better assessed. In addition, this study only analyzed the impact of the epidemic restriction policy on the electricity consumption of campus buildings between January 1, 2020 and June 30, 2022, which has certain timeliness and limitations. Moreover, since the climatic conditions in different regions also have an impact on the use of different types of buildings, it is necessary to investigate and analyze campus buildings in other climatic regions in the future to improve the study.

5. Conclusion

Based on the building energy consumption database of Twente University in the Netherlands, this study compared and analyzed the EU and EUI of different types of buildings at the university at various stages throughout the epidemic period. the impact of restricting policy intensity on various types of buildings on campus was revealed through analysis of variance, LSD, and *t*-test, and the energy saving potential and energy consumption change patterns of different types of buildings were explored. the main conclusions are as follows.

1. In the results of ANOVA analysis shows that the epidemic restriction intensity has a significant effect on three types of buildings, namely teaching, culture and sports, especially under the first restriction policy intensity, the electricity intensity of the three types of buildings decreased by 0.28, 0.09 and 0.07kwh/ m^2/day respectively. LSD results show that cultural and sports buildings fluctuate with the intensity of restrictive policies indicating that these two types of buildings are more sensitive to restrictive policies.
2. In the supplemental *t*-test analysis results, except for living buildings, EU and EUI of teaching, academic, sports, office, and cultural buildings are inversely proportional to the epidemic restriction intensity, i.e., the higher the restriction intensity, the lower the EU and EUI.
3. After the epidemic restriction policy was lifted compared to before the restriction policy was implemented, people's electricity consumption behavior habits changed under the influence of the long-term restriction policy, and the EU and EUI of living, teaching, sports and cultural buildings on campus improved significantly. Especially, the average daily EU of living class buildings improved by 4135kwh/day and EUI improved by 1.522kwh/ m^2/day.

Although the government has now lifted all restrictions, wearing masks and maintaining social distance has become a habit for many people. After experiencing COVID-19, the surge in electricity consumption of various buildings on campus may only last for a period of time, and people will return to normal after they release their suppressed emotions, or people have completely changed their electricity consumption habits due to the epidemic restriction policy. This state of affairs will continue, but confirming this speculation will take longer and follow-up research to complete. Therefore, the main objective is to adjust the electricity distribution policy according to the existing findings in order to optimize the city's electrical energy load and to improve the efficiency of building energy consumption.

Data availability

Source data source address has been provided in the article

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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