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KEYWORDS

Energy consumption | building stock | data analysis | energy efficiency | key performance indicators (KPIs)

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Discussion paper n. 53/2025

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Developing a Python code for the automated analysis of thermal and electric energy sub-hourly data: a case study for academic and public buildings

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Abstract. Nowadays, the building sector accounts for a significant share of the overall energy consumption, up to 40% in the EU. Within this context, academic and public buildings are particularly important. Unfortunately, analysing these types of buildings can be challenging due to multiple factors, such as the coexistence of multiple uses within the same structure (i.e., offices, labs, classrooms), and sometimes the dimensions of the building stock managed by the same public institution. This study highlights in which way a systematic analysis of the real consumption data can drive the efficient energy management of the building stock. In this paper, a methodology of data analysis tested with real data obtained from buildings of the University of Bologna is presented and discussed. A building complex was used as a demonstrator by installing a series of electrical and heat meters to assess the effective energy consumption within the building during the whole year. A Python script was used to automate the analysis of the sub-hourly energy consumption data available from the energy supply companies and the installed meters; it is demonstrated that the extrapolation of a series of key performance indicators useful for optimal energy management of the site is possible. The methodology was further applied to additional buildings of the University of Bologna to examine its applicability in identifying discrepancies between actual and expected consumption, highlighting all the singular behaviours which have to be corrected for the optimal energy management of each specific site of a building stock.

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1. INTRODUCTION

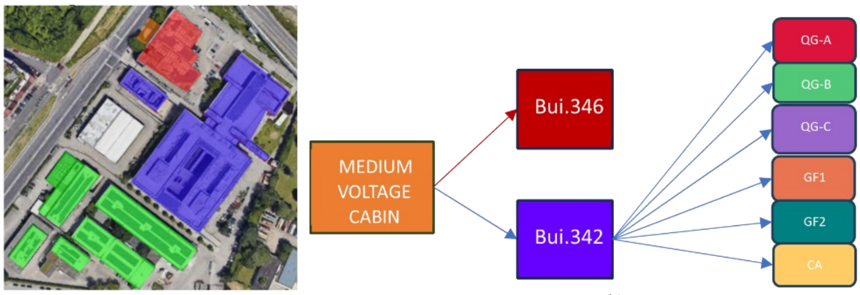
As reported in the World Energy Outlook 2023 by the International Energy Agency (IEA), global energy consumption continues to increase annually, with the building sector accounting for approximately 30% of global final energy consumption and 26% of energy-related greenhouse gas emissions [1]. To address this challenge, the European Directive 2024/1275 sets ambitious targets for reducing energy consumption in non-residential buildings, mandating a 16% reduction by 2030 and a 26% reduction by 2033. Within this framework, public universities, as educational and research institutions, are expected to take a leading role in adopting sustainable practices [2]. According to Laporte et al. [3], energy efficiency strategies implemented by universities are often limited, primarily focusing on upgrading energy systems and reducing building energy consumption, with minimal reliance on renewable energy sources. Barelli et al. [4] proposed a methodology for energy auditing in university facilities. The analysis highlighted the importance of evaluating electrical and thermal energy consumption in relation to external variables, such as outdoor temperature and space utilisation. The findings revealed that inefficiencies in heating and cooling systems significantly increase energy consumption, suggesting improvements such as optimising thermal insulation and modernising HVAC systems. In this context, Speca [5] explored the application of dynamic methods for energy audits in buildings, demonstrating how advanced modelling techniques enhance the accuracy of energy performance assessments. This approach enables more informed decision-making regarding interventions, aligning with the guidelines established by ENEA for energy audits in public buildings [6], which emphasise the importance of detailed consumption analysis to identify effective improvement measures. On a broader scale, the review Benchmarking Energy Consumption in Universities [7] provides an overview of the challenges and opportunities in energy management across university campuses. It highlights how the integration of advanced energy audits and targeted interventions can significantly improve the overall energy efficiency of academic facilities. In academic campuses, the complexity is further heightened by the presence of diverse buildings serving various functions, such as classrooms, laboratories, libraries, and student residences. These variations result in differing energy needs and consumption patterns for both thermal and electrical energy. Effective energy management in such contexts requires an integrated and flexible approach that accommodates uncertainties related to space occupancy. The primary aim of this study is to develop an automated tool capable of deeply analysing annual hourly energy consumption profiles.

2. METHODOLOGY

The University of Bologna (UniBO) is divided into a series of campuses throughout the Emilia-Romagna region. It is composed of 287 different buildings, 43% of which are scholastic and light laboratories, 29% of which are offices, 10% of which are heavy laboratories, and 8% of which are hospitals, residential, and sports activities. The large number of buildings and their dispersion across the territory make the energy management of the whole campus extremely difficult. This situation is very common for other entities, such as municipalities, regional governments, banks, or other universities. Moreover, the energy consumption of these infrastructures is exceptionally high. For instance, in the period from 2015 to 2022, UniBO consumed around 43 GWh of electricity and 4 million Sm^3 of gas per year, corresponding to approximately 6000 toe (tonnes of oil equivalent) annually. The proportion between thermal and electrical energy consumption is nearly equal, accounting for 44% and 56%, respectively. It is clear from this analysis that a correct management of the buildings is necessary to reduce energy consumption, and, therefore, limit CO_2 emissions and energy bills. A survey of UniBo buildings assessed electrical and thermal consumption. Electrical data includes external and courtyard areas, while thermal refers to indoor conditioned spaces. Areas are classified by use, but mixed functions within buildings complicate accurate energy analysis. Another aspect to consider when performing this type of analysis is that multiple buildings can be connected to the same medium-voltage substation. As a result, the electricity meters will only provide total consumption, making it impossible to directly allocate the energy usage of individual buildings connected to the same substation. A similar situation can occur when more buildings are connected to the same centralised HVAC system. Last but not least, compliance is influenced by the fact that more than one service can be powered by the same energy source. This is particularly common during the cooling season when both the cooling unit and other electrically powered devices (such as computers, lighting, and equipment) absorb electric energy from the grid. To address these issues and validate the methodology, a reference building cluster was selected and thoroughly studied, also through the installation of a series of electrical submeters. The analysis was performed using the Python programming language. More specifically, the developed code processes consumption data from a designated folder and correlates the electric energy consumption associated with the Point of Delivery (POD) and the natural gas consumption related to the Point of Redelivery (PDR) to their respective buildings. This allows for a clear analysis of the energy behaviour of each examined building. Additionally, the code generates a report for each building, summarising key information and trends. These reports assist energy managers in identifying potential inefficiencies or improper energy management. The Python code can be executed automatically, enabling periodic analysis of one or more buildings.

2.1. Description of the case study

The demonstrator was chosen for its complexity. Three different clusters of buildings are connected to the same medium voltage cabin (Fig. 1). All buildings have very different intent of use: the one represented in red (Bui. 346) is composed of heavy laboratories and offices, the one depicted in blue (Bui. 342) is composed of offices, scholastic rooms and light laboratories, and the one reported in green (Bui. 341) presents only light laboratories.



a) b)

Fig. 1: Aerial view of the Bertalia district (a) and schematic representation of the installed electrical sub-meters (b).

To decouple the electric energy consumption of each building from the overall use of the cluster and characterise each complex, a series of electrical submeters were installed. The sub-meters are: Gossen Metrawatt U2389-V027 ensure high-precision measurement of three-phase electrical quantities, including energy, power, and harmonic distortion, with ±1% accuracy. QG-A, QG-B, and QG-C are distribution networks supplying substations in Building 342 for laboratories, offices, classrooms, and shared spaces, managing heating, cooling, and air handling systems, with 3 air handling units in Substation A, 3 in Substation B, and 8 in Substation C. At the same time, CA is a compressed air section with extremely low consumption. Moreover, analysing thermal energy consumption linked to space heating can help reduce energy waste. Each building has its own gas boiler: two Rhoss KX 775 (1630 kW) on Bui. 341, two Unicall Ellprex 1570 (3140 kW) on Bui.342, and two Ici Tra (489 kW) on Bui. 346. And the chillers for space cooling are: Rhoss TCAEB 4155 (148.2 kW, A35/W7) on Bui.341, two McQuay ALS E279.3XN (1890 kW, A35/W7) on Bui.342, and Climaveneta NX/LN-CA 0352P (93.8 kW, A35/W7) on Bui.346. To analyse the energy consumption trends, an in-house Python script was developed. This script processes electric energy consumption data. The script is also designed to analyse the thermal energy consumption data, available on a daily basis.

3. RESULTS

In this Section, the analysis of electrical and thermal energy consumption data that can be performed with the Python tool is shown.

3.1. Electric energy analysis

The Python code described previously was used to analyse the sub-hourly electric energy consumption taken from the sub-meters. Figure 2 reports the daily overall electric energy consumption of the district measured at the medium-voltage cabin in the period from July 2023 to June 2024. In that figure, the orange dots refer to the cooling season, when the chillers are turned on, while the blue dots refer to periods with no cooling energy demand. It is clear that the electric energy consumption during the summer is approximately double that of the other parts of the year due to the energy consumption of the chillers. In addition, the consumption data of the cooling period are more scattered because the chiller's electric energy demand depends significantly on the external temperature. The reduction in consumption observed in August can be explained by the holiday period and the inactivity of the district.

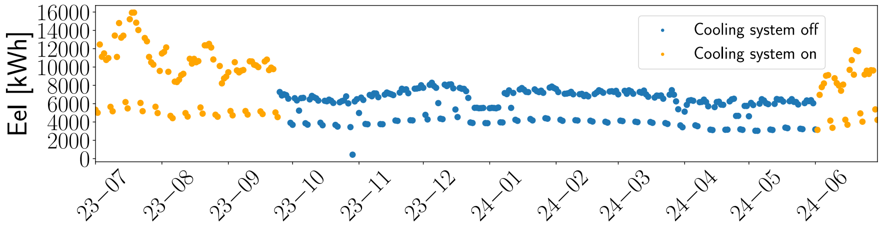


Fig. 2: Overall electric energy consumption of the district obtained from the medium-voltage cabin on a daily resolution.

The analysis of reported data for the winter period points out that the electric energy consumption follows a certain periodicity over the weeks, with a reduction of the energy consumption during the weekends, except for the Christmas holiday period. Another interesting aspect is that the two different trends can be defined, with an average value of 5000 and 8000 kWh/day, respectively. The data on the lower part of the graph refers to all the devices always active, representing the baseline of energy consumption. Conversely, the data arranged in the upper part of the graph are influenced by occupant activities within the buildings and vary depending on the time of day. Thanks to the submeters installed in Bui. 342, the electric energy required by the chillers can be decoupled from the consumption related to other uses. Figure 3 shows the different contributions of the subsystems to the overall electrical energy consumption. The teal and orange bars refer to the energy demand of the chillers; these terms are not null only during the summer. The other trends are almost constant over the year, except in the months of August and during the Christmas break, when the number of occupants decreases drastically.

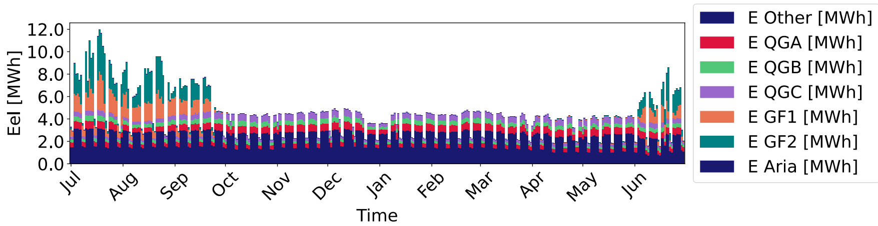


Fig. 3: Daily energy consumption of Bui. 342 over the year, divided for all the submeters.

It is interesting to notice that the energy related to QG-A, QGB, QG-C and CA is almost constant over the year, except for the reduction during the weekend, August and Christmas break. By post-processing the data obtained from the electric submeters, it is possible to define the energy consumption related to each use and, consequently, investigate potential inefficiencies. Figure 4 presents the sub-hourly consumption of the cooling period and the other part of the year. Each point is a sample of the yearly measured data and is reported coloured as a function of the consumption bands F1, F2 and F3 [8].

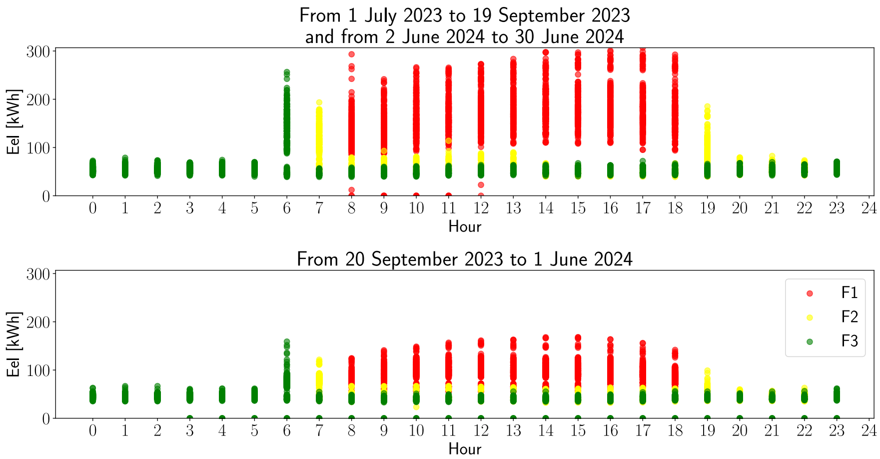


Fig. 4: Sub-hourly energy consumption, colour-coded according to the electricity consumption bands (F1, F2, and F3). Each point represents a 15-minute energy measurement taken throughout the year. The analysis is divided into two periods: the summer period, when the cooling units are active (top), and the winter period (bottom).

These bands are defined by ARERA, and they divide the week into three different parts: Band F1 applies on weekdays from 8:00 to 17:00. Band F2 covers weekdays at 7:00 and 19:00–22:00, and Saturdays from 7:00 to 22:00. Band F3 includes weekdays from 23:00 to 6:00 and all day Sunday. The analysis of data reported in Figure 4 allows to define different trends in the district's electric energy consumption. The nighttime electric consumption is very low, with the points closely clustered together for the whole year, with an average value of 46 kWh. Consequently, the cooling systems are turned off during the night. The analysis of the electric energy consumption during band F3 (green points) gives a representation of the baseline consumption of the considered building. During the cooling period, a peak in electric energy demand occurs at 6, related to the startup additional power of the cooling system, necessary to restore the internal set-point temperature after the nighttime shutdown. In correspondence with band F2, a similar behaviour is observed, except for a higher consumption between 7 and 13. Therefore, some activities are present in the district on Saturdays until 13, which causes some deviations from the baseline. Finally, the electric demand in band F1 is associated with the typical activities performed within the buildings and the energy demand of the chillers. Focusing on the period from 20 September 2023 to 1 June 2024, it is possible to see that the baseline is closer to the one in the summer period. The electric energy demand in band F1 has the same trend (but with a lower value of the energy request due to the absence of contribution of the cooling units) as the summer period, except for the absence of the morning peak related to the cooling system activation. Conversely, a higher electricity consumption is observed for band F2 between 13 and 19.

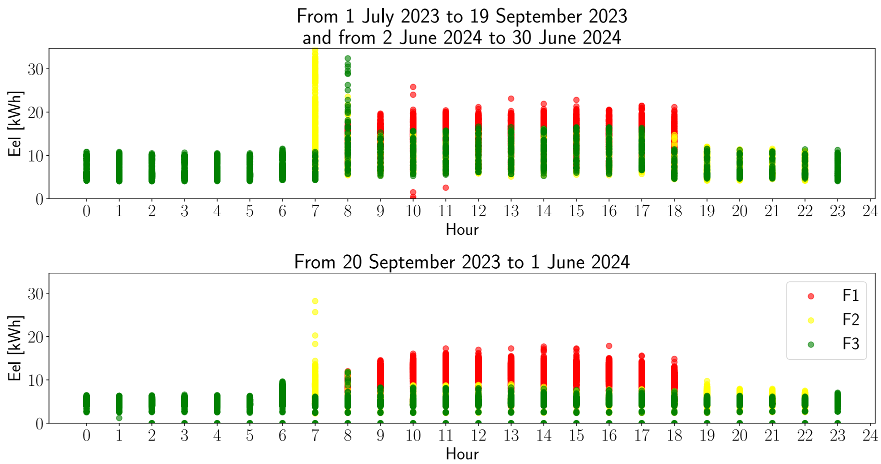


Fig. 5: Sub-hourly energy consumption for a building that shows an increase of electrical energy demand during the weekend of the summer period, highlighting that the cooling system is always working; this can be correlated with a waste of electricity.

Therefore, additional activities are performed in the district on Saturday afternoons during the winter season. The analysis reported before allows for a detailed investigation of the electric energy consumption in a building or a district, identifying the control logic of the HVAC system and analysing consumption trends related to the installed equipment and occupants. Additionally, the detection of deviations from expected trends is possible. For example, if a building presents activities only from Monday to Friday (e.g., an office or a school), no electric energy consumption above the baseline should be present between 8 and 18 (as highlighted in this case). This analysis would immediately reveal such discrepancies, allowing energy managers to take action to mitigate inefficiencies, a clear example is reported in Fig. 5, where is possible to appreciate that during the summer period, a large amount of energy is required also during the week-end (green dots from 8:00 to 18:00). From this analysis is possible to suppose that the cooling systems is kept on also when the building is suppose to be empty (Saturday and Sunday). This information can be useful for an energy manager to conduct a target analysis on the origin on the origin of this potential energy waste.

3.2. Thermal energy analysis

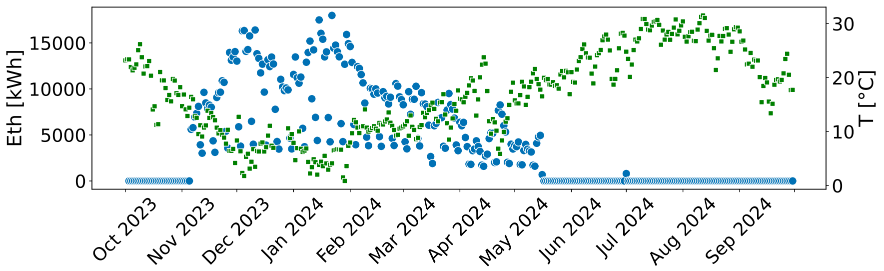


Fig. 6: Thermal energy consumption for Bui. 342 (blue dots) and daily external air temperature (green dots) from October 2023 to October 2024.

The analysis of thermal energy demand for space heating is also crucial to reducing energy waste. Unlike electric consumption data, which are available at sub-hourly intervals, gas consumption data are available only on a daily basis. The thermal energy consumption can be plotted on an annual basis, as reported in Fig. 6 for Bui. 342. The daily external temperature values are also reported to analyse the correct behaviour of the HVAC system control logic. As expected, the blue and the green dots have an opposite trend; this means that when the outdoor temperature is low, more energy is required to meet the building space heating energy demand. Data depicted in Fig. 6 shows that the daily thermal energy demand presents two different trends. The lower trend is characterised by an almost constant value equal to 2700 kWh/day and refers to the attenuation mode set on Sunday. The second trend has a large dispersion in the daily consumption values, ranging from 4000 kWh/day and 17650 kWh/day, and refers to the rest of the week. It is also interesting to notice that the thermal energy demand is prolonged until the middle of May, about one month after the end of the heating season set by the current regulation. The effectiveness of the control logic (i.e., whether the energy demand is linked to the external temperature with a climatic control strategy) and the presence of an attenuation regime for different days per week can be easily evaluated by manipulating these data. In Fig. 7, the Building Energy Signature (BES) [9] of Bui. 342 is reported. It is obtained by correlating the daily heating capacity of the HVAC system with the external temperature. The black dots refer to the working days (from Monday to Friday), while the grey points are related to the weekend (Saturday and Sunday). This analysis highlights the attenuation regime imposed on Sundays, in correspondence with which, for the same external temperature, the HVAC system heating capacity is noticeably lower compared to other days of the week. Furthermore, the control logic appears to be effective, as the data points align well with a linear trend, indicating a clear linear relationship between the external air temperature and the thermal load. The BES presented in Fig. 7 allows for estimating the thermal load, evaluated in correspondence with the design external air temperature (-5°C for Bologna), and the heating limit external temperature, i.e., the ambient temperature which nullifies the building thermal load.

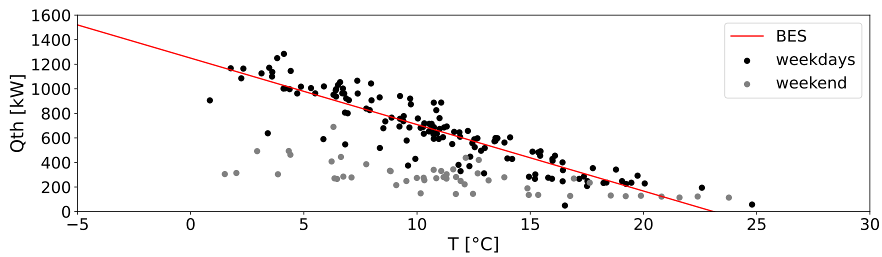


Fig. 7: Building energy signature (BES) for Bui. 342. Each point is the thermal power required in a day. The red line is the linear interpolation of only the black points.

The power evaluated at the design temperature of 1.5 MW is in line with the nameplate data of the installed generator. As for the plant's shutdown temperature (i.e. the temperature at which the power demand went to zero), it is 22 °C, which indicates that a temperature higher than the design temperature of 20 °C is maintained inside the rooms. This points to possible energy wastage. Another way to clearly analyse if the HVAC system is managed efficiently is to evaluate the cumulative building thermal energy demand over the season as a function of the Heating Degree Days (HDD). The trend reported in Figure 8 shows that the HVAC system is managed properly since a linear correlation between the cumulative thermal energy demand and the HDD is present. It is also evident that during the Christmas period (i.e., from 23rd December to 7th January), the HVAC system was not switched off. This is highlighted by the continued accumulation of energy.

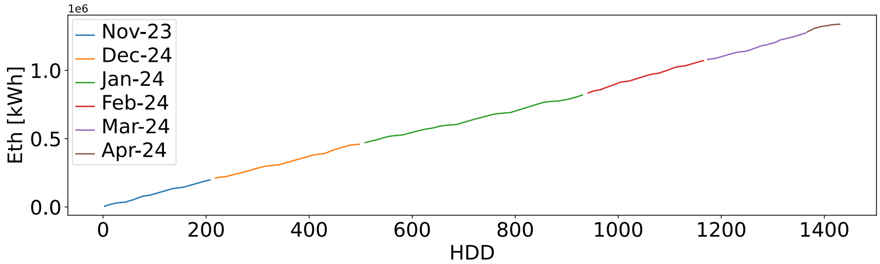


Fig. 8: Cumulative thermal energy demand as a function of the heating degree days; the different colour refers to the months of the heating season.

4. CONCLUSIONS

The presented research addresses the increasing demand for optimising energy management in buildings, particularly in academic and public complexes. These clusters of buildings pose significant challenges for effective consumption monitoring and management since they often host a mix of activities, such as offices, laboratories, and classrooms, characterised by different profiles and needs. To address these challenges, a Python-based script was developed to automate the analysis of daily or sub-hourly electric and thermal energy data, enabling a rapid and detailed assessment and generating reports useful for energy managers. In this paper, a cluster of buildings owned by the University of Bologna was considered as an application case study. The research was focused on the analysis of the electrical and thermal energy consumption of the site. The data available for a year were manipulated to obtain a series of easy-to-read plots that can describe several aspects of the energy management in a build, such as the analysis of the electrical consumption bands, which are useful to estimate the behaviour in different periods of the day and seasons, highlighting where energy consumption is most concentrated. The building energy signature was also evaluated, giving a correlation between the external temperature and the building heating load. In addition, the behaviour of the control system of the heating unit is analysed by plotting the energy as a function of the HDD. This study highlighted that an automated energy analysis allows for comprehensive consumption profiling, identifying seasonal patterns, peaks, and baseline trends. This approach facilitates the identification of operational inefficiencies, such as unnecessary system activations during periods of inactivity, and provides critical insights for optimising energy management. Additionally, the study can be used to identify zero-cost energy-saving measures, such as adjustments on the HVAC system operating hours or the introduction of setback modes or shutdowns during periods of low usage. The research demonstrates that an integrated approach, combining advanced technologies, data-driven methodologies, and community engagement, is essential for improving energy efficiency in academic campuses and public buildings.

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