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ORIGINAL ARTICLE

Enhancing the accountability and comparability of different campuses' energy profiles through an energy cluster approach

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Abstract International sustainability ranking systems generally set criteria in order to monitor global achievement of universities in terms of sustainability. However, current sustainability ranking systems do not provide specific consumption thresholds according to the different buildings' function or characteristic and the comparison among universities lacks of precise criteria. Thus, this paper proposes different energy clusters enabling a meaningful comparison among campuses within the international rankings. Energy profiles of two university campuses—Politecnico di Torino (Italy) and Hokkaido University (Japan)—similar for climate, surface, and population have been collected for 4 years as a relevant case study. Five different clusters of homogeneous consumption have been identified: cluster 1 (around 1 GJ/m^2/year) includes the Art departments, cluster 2 (2 GJ/m^2/year) includes the Science faculties, cluster 3 (3 GJ/m^2/year) includes the hospital and the medicine departments, cluster 4 includes the Data Centre (9 GJ/m^2/year), and cluster 5 includes special research facilities with consumption over 10 GJ/m^2/year. Findings show how comparisons between different buildings should also take into account the electrification rate (dependence on electricity) and the leveling rate (variation of consumption during a year), which variations are directly related to the main building function (e.g., hospitals/data centers have high values, while arts or humanities departments have low values for both rates). The proposed energy cluster approach and the introduction of proper weights for energy performances based on the proposed clusters can significantly enhance the accountability and comparability of different campuses' energy profiles, contributing to a better evaluation of universities' energy performances.

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Introduction

Reduction of energy consumption and the shift toward a more sustainable use of resources are increasingly becoming a challenge for any sector and activity related to the built environment (Wilkinson et al., 2007). The buildings' sector is indeed the highest

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energy-consumer, accounting for over one-third of the final energy consumption globally, and an equally important source of carbon dioxide (CO_2) emissions (Newman, 2006). Since energy demand is expected to rise by 50% by 2050 if no action is urgently taken (International Energy Agency, 2013), university's campuses have a significant role to play respect to local energetic and socioeconomic impacts, going far beyond the university scale itself (Ferrer-Balas et al., 2009). Universities are increasingly conceived as hubs within cities and regions, since their activities involve a range of very different users and facilities and can serve as test bed for new energy reduction innovative strategies (Agdas et al., 2015; Chung & Rhee, 2014; Escobedo et al., 2014). For this purpose, energy performance improvement and its monitoring are nowadays recognized as the first step for assessing and managing campus energy transitions (Faghihi et al., 2015).

However, it is difficult to track an effective reduction in energy consumption in the high-ranked universities (Lauder et al., 2015), since current rankings for university campus sustainability do not provide reliable mechanisms for national or international cases inter-comparison (Lozano, 2010), or internal follow-up and sustainability culture permanence (Disterheft et al., 2014). The challenges in designing a sounding comparison among campuses are also linked to the diversity of material utilization, CO_2 emissions, energy sources, and regulatory compliance, which vary from country to country, and from city to city (Cottafava et al., 2018; Shriberg, 2002). In the past years, several researches focused on clustering approaches (Wei et al, 2018) in order to classify buildings according to various aspects such as the main space use or the household behavior (Ben and Steemers, 2018), just to name a few, by using different clustering algorithms (Gao and Malkawi, 2014), as the k-shape algorithm (Yang, et al., 2017), energy simulations (Cipriano et al., 2017), or smart meter data collection (Klingler and Schuhmacher, 2018) both at dwelling (Cipriano et al., 2017) and at neighborhood/city level (Jaeger et al., 2020; Chen, et al., 2019). These studies proved how meaningful comparisons among different buildings need a robust classification with respect to several specific aspects that can affect the energy pattern such as the presence of children (Klingler Anna-Lena and Schuhmacher, 2018). However, the majority of these studies targeted mainly residential buildings (Cipriano et al., 2017; Chen, et al., 2019) and only a few public school buildings (da Silva Jota et al., 2017). Indeed, current sustainability assessment framework does not categorize the energy consumptions in relation to different university functions. This aspect makes difficult any energy performance comparison among university campuses, since the international ranking position is influenced by many other factors (presence of green areas or km of bike paths) not directly attributable to the university. In turn, hosted functions, climate conditions, or building typologies (heritage buildings, for instance) require appropriate energy policies and relative assessment. In light of this paradox, greener university results do not assure any better performance in terms of energy efficiency, as stated in the article of Agdas et al. (2015) and they are not related at all to the presence of hospitals or high energy-consuming laboratories nested in a city system (although in Greenmetric ranking, the difference between campus-like and campus nested in a city has been recently introduced).

To face this challenge in current international sustainability ranking practices, an energy cluster approach may enable comparison of university campuses' energy use according to their morphology, hosted functions, and weather conditions, thus advancing toward a more consistent assessment method for sustainable universities (Sonetti et al., 2016). The goal of this study is to present the energy profile collection methods and analysis in two large scale university campuses, used as relevant case studies, in order to pick up best practices in similar universities and to suggest more effective criteria in university sustainability assessment frameworks. In particular, this paper deepens the research on the need of cluster analyses on the complex building environments of university campuses by presenting the results of energy data collection held at the Politecnico di Torino (POLITO), Italy, and at the Hokkaido University (HOKUDAI), Japan. To highlight the need of a precise methodology which takes into account factors as the buildings' functions, or working hours, into international sustainability rankings, a cluster analysis, based on the primary energy (PE) consumption for the Hokkaido University, and an analysis based on two energy indicators, i.e., the electrification and the leveling rate, has been conducted for both campuses. Findings have then been discussed in terms of the university position in the Greenmetric ranking. Five clusters based on the building functions, i.e., arts, science, medicine, data centers, and research centers, have been proposed in order to further improve the current Greenmetric data collection process and the comparison among university campuses with a different composition in terms of departments and hosted activities.

The rest of the paper is structured as follows. In the "Methods" and "Case studies' structures and energy profiles" sections, the two case studies are discussed into detail, as well as the two adopted energy indicators. In the "Results and discussion" section, findings related to discrepancies between the energy profiles of the two universities and the relative position in the Greenmetric ranking are presented and discussed. Finally, in the "Conclusions" section, the main results are wrapped up and future studies pointed out.

Methods

This research is based on a concurrent mixed-method, using both qualitative and quantitative data, and it analyzes two relevant and purposefully (Stake, 1995) case studies (Yin, 2018) to provide an analytical generalization of the findings (Johnson and Onwuegbuzie, 2004). The two analyzed campuses have been the Politecnico di Torino (POLITO), in Italy, and the Hokkaido University (HOKUDAI), in Japan. Primary data, i.e., all energy-related information for the two universities, have been collected from official documents, and data mining from Living Lab offices both in POLITO and HOKUDAI, while secondary data derive from interviews (the complete list of interviewed people can be found in the Appendix) among sustainability relevant stakeholders in each university which gave access to the requested reports and dataset available from 2008 to 2012. They were selected mainly based on their level of involvement with energy-related initiatives. The energy consumption profiles per individual department were determined, as well as the leveling rate and electrification rate (as described in the next subsection) in addition to multiple linear regression analysis.

Then, the position of the two campuses in the Greenmetric international ranking, related to the energy consumption and climate change impact category, has been analyzed. Data from the Greenmetric ranking website[1] have been collected to situate POLITO and HOKUDAI in the trend of energy consumption of all the world universities joining to the Greenmetric ranking, while data from the Ministry of Education (METU) in Japan were used to compare the HOKUDAI energy performance in relation to the other Japanese Universities. The energy conversion factor used to normalize the energy unit in Joule is displayed in Table 4 in the Appendix. The advantage of choosing the POLITO campus relies in the availability of a wide historical dataset and the precise match of energy-related information and the locus of its consumption, thanks to a wide net of smart meters, periodical human-based control on data trends, and an open access website prompting all data from 1998 to current time. The HOKUDAI case, in turn, represents a perfect test bed to analyze the energy performance of a large-scale campus thanks to the exact match between the building floor areas and the department's functions hosted. Such spatial and functional symmetry is embedded in the design of the campus itself that has been respected and integrated in continuity with the original concept, assigning a different function to each building.

Energy data collection at POLITO

POLITO energy data collection relies on a web-based and open infrastructure (managed via the ARCHIBUS software) and a dedicated officer for energy data analysis. The facility management office collaborates with the Living Lab manager to match energy data and related square meters, energy source, and number of occupants, gathering info both from smart metering disseminated around the campus and from bills by the energy providers and the facility intervention log. In 2008, a research project co-funded by the local regional authority started the Living Lab monitoring activity. The on-site acquisition system is mainly based on 485 network segments on MODBUS, a widely accepted protocol widely used within Building Management Systems (BMS) and Industrial Automation Systems (IAS), for a total length of more than 7 km. This wiring is used to monitor water consumption, photovoltaic (PV) panels, thermal

[1] http://greenmetric.ui.ac.id/overall-ranking-2015/

energy production, and consumption. The system for the acquisition of electricity consumption's data is measuring both active energy and reactive energy at the distributor outlet of 22 kV and of transformation cabins at internal 400 V. Dedicated smart meters are located in the office blocks or specific laboratories with high consumption. In total, there are about 150 measurement stations in the entire Cittadella Politecnica site. In 2012, the Living Lab opened an open-access website as the result of the close cooperation between different entities and divisions at POLITO (energy manager office, energy department, information technology area, construction and logistics, and all energy-related entities). In the Living Lab, all data streams are collected from on-site sensors and then processed and analyzed. The main aim is to provide a decision support system for the energy management, but there are also regular requests for research support and various educational initiatives. Every 15 min, all the devices send their data to a central repository. An automatic check-scanning in the acquisition chain runs all the time to trigger alert in case of anomalies, both in terms of acquisition failures or outliers. This function (shown in Fig. 12 in the Appendix as ETL—Extract, Transform, Load) is written in Perl, an open source code. The detail is, then, enriched with all possible categorizations that may be useful in following reporting, analytics, and data mining activities. For example, timestamp is accompanied by tags related to date of measurement, date (year, month, day, hour, minute), day of week, weekday or holiday, energy band (F1, F2, F3), late evening or special working time, etc. Capabilities of ETL and data processing feed the Data Warehouse (DW) in Microsoft SqlServer 2012. The DW layer can be easily migrated to open source applications such as MySQL or Postgres. Another important set of tags comes from mapping the electricity meter location. The ARCHIBUS software enables the collection of data on rooms according to area, volume, intended use, number of occupants, closest cost center, and other features. This information allows calculating a room-specific consumption either per m^2 or per person in a certain range, allowing performance comparisons, benchmarking, summary report, or detail query. Consumption related to a certain block is used to calculate the average consumption (kWh/m^2), and then it is multiplied to the surface of a single room. It is therefore a mixed model (on-site plus analytical measures), but since functions are the same inside all offices, errors may be negligible. Of course, laboratories with high consumption appliances (e.g., the wind tunnel) represent the exception. At current stage, thermal energy monitoring is less refined than the electricity one, although there are several dedicated gas meters for special plants and single buildings, and the thermal energy provider collaborates with POLITO in a number of research projects, thus sharing consumers' database and campus building thermal profiles.

Energy data collection at HOKUDAI

HOKUDAI data access is available just for research purposes. Only few documents related to data consumption historical trends have been provided for this study. Aspiring an international recognition, HOKUDAI launched Hokkaido University Initiative for Sustainable Development (HUISD) project in 2005. The previous actions combined with the strengthening of law enforcement in Japan on the rationalization of energy consumption, governmental instructions (Sunikka-Blank & Iwafune, 2011), and the occurrence of the great east Japan earthquake (MacAskill & Guthrie, 2014) provided the background for the establishment of the Office for Sustainable Campus (OSC) in November 2010. In March 2012, Hokkaido University through the OSC developed a Sustainable Campus Action Plan. The process included both a top-down approach with the support from the university administration in combination with a bottom-up approach through engaging students. The Office for Sustainable Campus is considered the institution's core organization tasked with promoting campus sustainability and the establishment of a campus-wide environmental management system and encompasses a variety of educational and research programs working closely with departments, schools, and institutes. Overall, the OSC is promoting mostly sustainability weeks' event (since 2007), and stakeholders meeting (since 2006) to support assessment of its environmental performance, power saving initiative, voluntary student activities, and so forth. A survey held at Hokkaido university in 2012 (Dantsiou, 2012) outlined that HOKUDAI campus users did presented self-motivation drivers, but the effect of existing energy reduction campaigns as causes of behavioral change is very limited. However, the limited participation in energy-savings activities is outweighed by a great interest in future participation indicating the future potential of sustainability initiatives as long as the right communication tools and strategies are implemented. Another valuable source for hard data on energy consumption was found in the sustainability reports submitted to the ISCN (International Sustainable Campus Network). In that 2012 report, the section related to "Energy and Climate Change" stated that HOKUDAI is partially replacing its energy appliances with more efficient ones, favoring the use of clean biomass and solar power as alternative energy source within the campus, implementing policies for climate change adaptation and mitigation and so forth. However, the nationwide positioning of Hokkaido University based on environmental reports in 2012 confirmed that primary energy consumption per floor area at Hokkaido University was relatively large, with about 2.2 GJ/m^2/year, among large-scale university campuses. Data on energy trends are therefore analyzed with attention on possible features influencing this anomalous high consumption among similar institutions.

Energy analysis at HOKUDAI

A multiple linear regression analysis according to the electricity consumption per floor area and per capita was performed in four HOKUDAI departments (Engineering, Science, Medicine, and Agriculture). The explanatory variables were the outside air temperature, number of lecture days, and proportion of students. In order to understand the effects of the explanatory variables, the standardized partial regression coefficient, taking multicollinearity into account, was verified. In addition, to understand the proportion of electricity consumption against the total energy consumption, the electrification rate with Eq. (1) was calculated. When the electrification rate is low, the dependence on electricity is low; when the rate approaches 1, the dependence on electricity is high.

$$\text{Electrification rate} = \frac{\text{Annual electricity consumption}}{\text{Annual final energy consumption}} \tag{1}$$

Moreover, to understand the electricity load variation along the average, the leveling rate with Eq. (2) was calculated. When the leveling rate is low, the fluctuation in electricity consumption is large, and when the rate approaches 1, the fluctuation is small. The leveling rate for electricity consumption in all departments was calculated multiplying by 12 the minimum electricity consumption per month and dividing the result by the annual electricity consumption.

$$\text{Leveling rate} = \frac{\text{Monthly minimum electricity consumption} \times 12}{\text{Annual electricity consumption}} \tag{2}$$

Case studies' structures and energy profiles

In this section, the paper explores the bases for distinguishing two campus models and their related energy profiles. The Politecnico di Torino (POLITO) and the Hokkaido University (HOKUDAI) are indeed analyzed in their urban settings (Sects. 3.1 and 3.3) and energy consumption trends (Sects. 3.2 and 3.4). Comparative results from which emerge the energy cluster hypothesis are deduced and discussed in the fourth section.

The POLITO campus setting

The POLITO campus is organized in distinct geographical locations with very different features from the architectural, urban, and functional points of view. Figure 1 shows the two main buildings of POLITO. The POLITO setting counts five campuses scattered throughout the city, with buildings dated from the seventeenth century (the *Castello del Valentino*, with an area of about 40,000 m^2) to late 1950s (the main extended complex is *Corso Duca degli Abruzzi*, 187,000 m^2) and to 2000 (*Cittadella Politecnica*, 89,000 m^2 of student residences, research activities, technological transfers, and service buildings). Some kilometers away from the city center, two former industrial sites were refurbished and currently are used for teaching activities (*Mirafiori* and *Lingotto*, former automotive factory sites).

The POLITO energy use profile

In total, in 2012, the whole campus accounted for 33,600 users (students and staff), and a yearly primary energy (PE) consumption of 225,475 kWh/m^2. All data related to energy consumption are collected by the Living Lab and revised by the Energy Manager, an internal professor of POLITO, who is in charge to communicate the annual energy consumption to the Italian Federation for Energy Efficiency (FIRE).

Fig. 1 The Politecnico di Torino main sites located in the city of Turin. The Castello del Valentino and Cittadella Politecnica are represented respectively in the left and right side of this figure

Figure 2 exhibits the monthly electricity consumption in MWh of the main building site of POLITO from 2008 to 2012. Data were obtained from the Living Lab dataset for the fiscal years (FY) 2008–2012. The variation in the consumption profile of the *Corso Duca* site is strongly tied to the higher external temperature in summer due to a lack of thermal insulation in the concrete walls and single-glazed windows in most of the buildings. Furthermore, peaks of electric energy consumption may follow the occupational path of student lectures in the winter and spring terms, plus the laboratory experiments that are running all over the year. During the interviews with POLITO energy managers, the re-design of the entire site plan was claimed as necessary by every of them. Most of the interventions are focused on the improvement of the external building envelope efficiency, by integrating the most energy-leaking walls with thermal insulation coatings and double-glazed windows. The peaks in summer periods remained the same (about 1600 MWh), slightly decreasing in 2008 and 2011. In 2012, the curve of electric energy consumption rarely went behind the others, meaning that a higher consumption trend could be considered for the energy planning of forthcoming years.

As for the thermal energy quality, the *Cittadella Politecnica* building is connected to the district-heating network, while the historic offices in the *Castello del Valentino* (Architecture Department) and the new headquarters of *Mirafiori* (Industrial Design, Visual Communication and Automotive Engineering departments) are served by natural gas boilers. Thermal energy consumption in 2012 weighted per floor area ranked the *Valentino* site the most consuming (76 kWht/m^2) and *Corso Duca* (67 kWht/m^2) and *Cittadella* (32 kWht/m^2) sites the less consuming. The possibility to individually control the fan coil units, the high percentage of glass surface (east and north exposed, thus dispersing the heat accumulated during the day at night-time), coupled with the use of natural gas supply, made the consumption of *Valentino* site higher than the two newer sites, where the district heating provides centralized and strictly controlled thermal energy flows following the occupational path of the buildings. The heterogeneity of energy source and delivery systems must therefore be regarded as a design constraint that cannot be removed. The connection to the city district heating lets the gas consumption to be zero for several years but increased the energy bill, as confirmed by interviews with the Living Lab and contract manager at POLITO. The

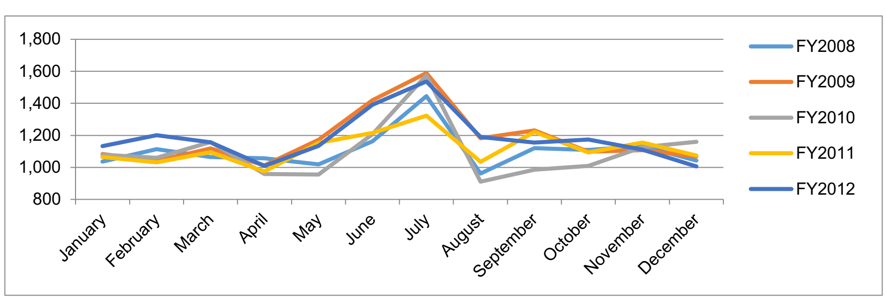


Fig. 2 Monthly electricity consumption (MWh) in the POLITO site of Corso Duca against the 12 months from 2008 to 2012. Source: POLITO Living Lab

annual TEP consumption of the other Politecnico di Torino's sites (Mirafiori, Lingotto and Valentino) has been disregarded, since their contributions (5%, 5%, 8%, respectively) are very low compared to the total TEP consumption of POLITO main site of *Corso Duca* (79%), that therefore became the object of the analysis.

In Fig. 3, thermal energy consumption trends are shown for the POLITO *Corso Duca* main site over the years 2008/2012. The shape of load curves for the all 5 years is almost similar, being zero from May to September: it starts increasing when the outside temperature starts decreasing, reaching its peak in January and February. Generally, there is a slight increase of thermal energy consumption although the minimum external temperature is slightly increasing. The year 2012 presents a drop of consumption in January, October, and November. An anomalous electrical equipment use, probably due to exceptional experiments in the material science labs during wintertime, may have produced the peak observed in the "February 2012" column in Fig. 3.

The HOKUDAI campus setting

The Hokkaido University (HOKUDAI) was founded in 1876 and it is located in the center of the city of Sapporo and almost concentrated in a single campus area. At the time of the survey (2012), it counted over 18,000 students. The campus is situated in downtown Sapporo and covers an area of 707,969 m^2 and 1,776,249 m^2 including the entire park in which buildings are located. Hokkaido University follows a series of sustainability initiatives in order to reduce its environmental impact and acts as a "showcase" for sustainable campuses. The university runs periodical stakeholder meetings in order to bring expertise from outside the university regarding the implemented programs and feedback on areas requiring improvement. To this end, Hokkaido University established the "Office for a Sustainable Campus" as the institution's core organization tasked with promoting campus sustainability actions and that provided the data at the base of this study.

The HOKUDAI energy use profile

Figure 4 shows the scatter plot of the annual PE consumption per floor area against the floor area for 60 Japanese universities in 2012, while Fig. 5, the scatter plot of the electrification rate (Eq. 1) versus the outside air temperature (in Celsius degree). Primary energy consumption per floor area at Hokkaido University was relatively large (Fig. 4), with about 2.2 GJ/m^2/year among large-scale university campuses, although the dependence on electricity was one of the lowest (Fig. 5). In the total primary energy consumption in the entire campus, electricity and gas combined accounted for over 95% of the total energy source use. The seasonal correlation of gas consumption was particularly high, as well as the energy consumption per floor area in peak winter months, when heating demand was more than double that than peaks in summer months.

In Fig. 6, monthly primary energy consumption per floor area for the 38 department at the Hokkaido University was plotted. A total of 15 departments out of 38 presented a higher PE consumption than the entire campus, on average. Furthermore, monthly fluctuation characteristic trends lead to group similar function into homogeneous profile of consumption. According to such reclassification, primary energy consumption per floor area, leveling rate, and electrification rate were studied. Electricity

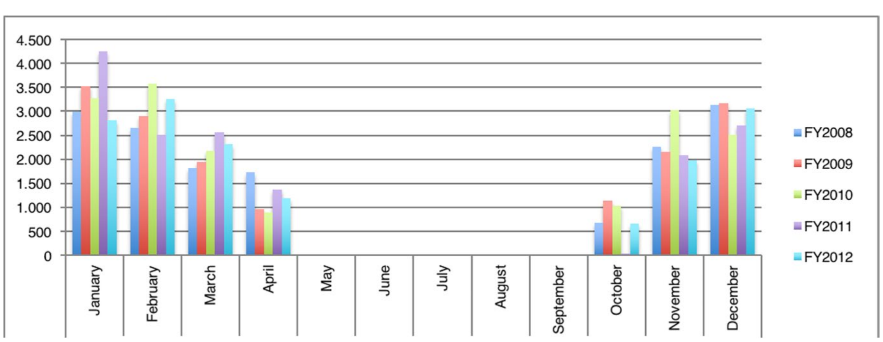


Fig. 3 Thermal energy consumption (MWht) at POLITO's Corso Duca against 12 months site from 2008 to 2012. Source: POLITO Living Lab

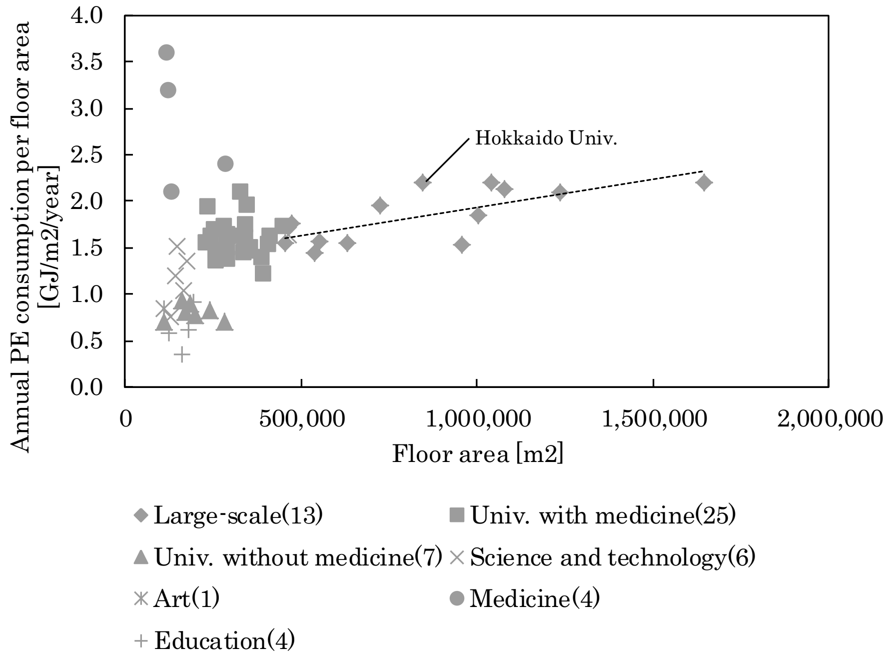


Fig. 4 Relationship between floor area and annual PE consumption per floor area in 60 Japanese Universities in 2012. Source: (Kikuta & Hayama, 2015)

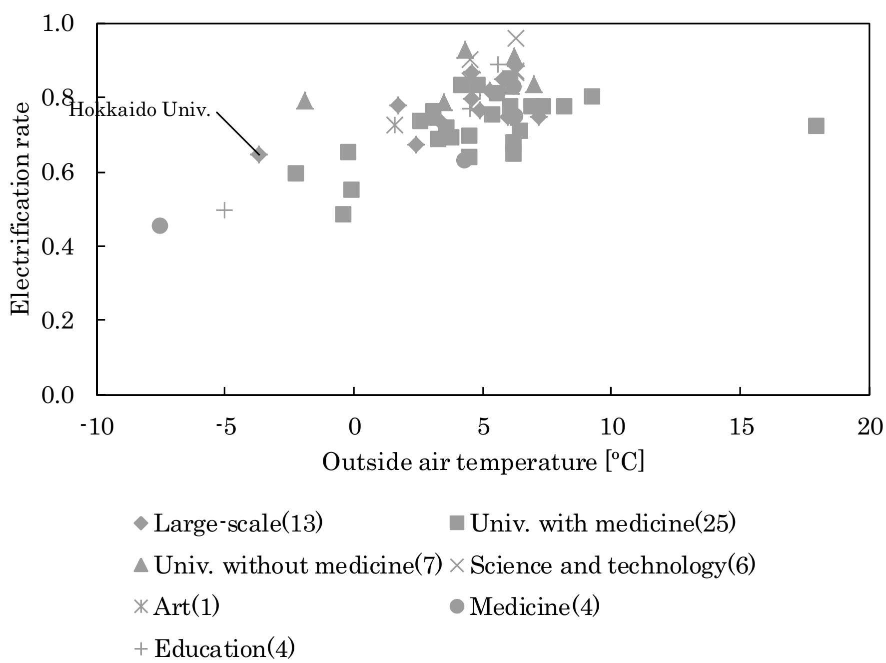


Fig. 5 Relationship between outside air temperature and electrification rate in 60 Japanese Universities in 2012. Source: (Kikuta & Hayama, 2015)

consumption for all 38 departments was about 3000 MWh/year on average. Because University Hospital is operating 24 h a day and 365 days a year, this consumption ranged from 2 to 4 GJ/m^2/year, while gas consumption also accounted for almost a quarter of the entire campus energy consumption.

Fig. 6 Index of monthly primary energy consumption in 38 departments at the Hokkaido University Campus

Results and discussion

HOKUDAI's university campus area (516,509 m^2) is 40% smaller than the Turin's University. However, 16,418 users (51% less than POLITO) consume 1,731,798 GJ of PE (668% more than POLITO, in 2012), as summarized in Tables 2 and 3. University of Turin (UNITO) data were added aside the POLITO's one in order to be able to compare the sum of the two Turin's major universities (POLITO as the technical one and UNITO as the wider one, with medicine) as a whole university campus, including all the departments already present in the HOKUDAI campus.

Indeed, while the POLITO campus hosts just the departments of Engineers and Architecture, the University of Turin (UNITO), with about 70,000 students; 4000 academics, administrative, and technical staff; and with 120 buildings in more than 500 km^2, carries out scientific research and organizes courses in all disciplines, except for Engineering and Architecture. As shown in Tables 2 and 3, the sum of UNITO and POLITO annual electrical consumption from all kinds of departments and functions, including hospitals and data centers, is 88.82 kWh/m^2, 1.83 times more than the HOKUDAI's electrical consumption per square meter. The variance becomes higher when the units are weighted per campus users: 778 kWh/capita (POLITO + UNITO) vs 7044 kWh/capita (HOKUDAI only). The same proportions are revealed by the charts displaying thermal energy consumption: UNITO and POLITO sum up for 0.31 GJ/m^2, while HOKUDAI's total consumption of GJ/m^2 is 0.64. When the GJ is weighted per person, the 27.67 GJ/capita in HOKUDAI appears to be almost ten times more than the UNITO plus POLITO 2.82 GJ/capita for thermal energy consumption, revealing a higher need of energy for heating purposes in the Japanese campus.

Although weather data in Fig. 13 in the Appendix shows that the minima in Sapporo are far below zero than the Turin's, the gap remains striking. Moreover, while PE consumption per capita in Turin is 6.71 GJ, in Sapporo it is 105 GJ (1471% more); the cost of it has been 117 € per capita in Turin and 2779 € per capita in Sapporo (2275% more) in 2012. Strangely enough, in the global ranking chart for the Energy and Climate Change category in 2015, POLITO (1.025 points) and HOKUDAI (946 points) are situated in the same density area of values (Fig. 7). This evident discrepancy led the study to deepen the analysis on data on the external variables affecting the consumption of the HOKUDAI case.

A cross comparison among the PE per floor area for the three universities has been not possible due to the lack of conciliated data between thermal energy consumption counter and building site. The only information available from the Greenmetric website was the total PE consumption for the whole campus of UNITO. Therefore, an analysis is carried out on the POLITO and HOKUDAI cases in order to understand the contribution of the thermal and electric energy consumption out of the total. A comparison among

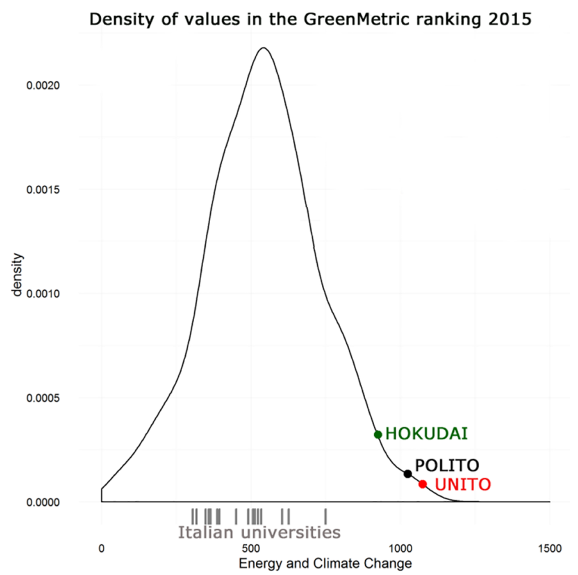


Fig. 7 Density of values in the Greenmetric ranking for 2015 in the Energy and Climate Change category. In green, black, and red, the position of HOKUDAI, POLITO, and UNITO. In gray bars on the X axis, the position of the other Italian Universities. Source: Greenmetric, 2015 data elaborated by authors

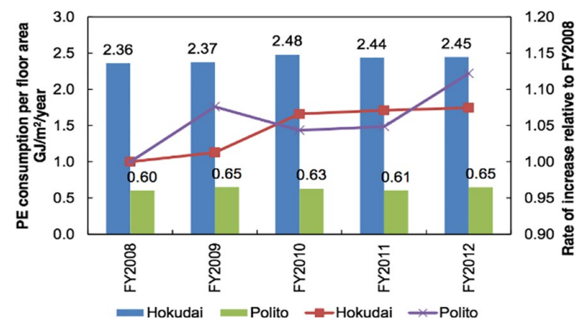


Fig. 8 PE consumption per floor area from 2008 to 2012 for POLITO and HOKUDAI campuses

the weather data of Torino and Sapporo has been carried out (Fig. 13). Comparing the two cities over the previous 3 years, the average outside air temperature was 9.4° C for Sapporo and 14.7 °C for Torino, when the yearly span for Sapporo was wider than for Torino. The average global solar radiation was 3377 Wh/m^2/day (1234 kWh/m^2/year) for Sapporo and 3473 Wh/m^2/day (1271 kWh/m^2/year) for Torino. During summer time, the solar radiation for Torino tended to be much higher than for Sapporo, where the outside temperature tends to not follow the increase rate of global solar radiation. It can mean that Turin gives a faster response to the incident radiation thanks to other elements (relative humidity, heat island effects, wind speed, pressure, ozone concentration).

Figure 8 shows that the annual PE consumption per floor area of POLITO was four times lower than HOKUDAI. Figure 9, instead, shows the PE versus the outside air temperature for different fuel and energy types. Analyzing the relation of outside air temperature and consumption of different energy type, the seasonal correlations for gas in HOKUDAI ($R^2 = 0.96$) and district heating at POLITO ($R^2 = 0.89$) were obviously high; in addition, due to the effect of summer vacation, the electricity path in August for POLITO was below the trend line. For the two campuses, the seasonal correlation was quite low for electricity consumption. A multiple linear regression analysis with electricity consumption per floor area and capita for four departments (Engineering, Science, Medicine, and Agriculture) was performed. The explanatory variables were the outside air temperature, number of lecture days, and proportion of students. The results on multiple linear regression analysis are presented in Tables 2 and 3 in Appendix. In order to understand the effects of the explanatory variables, the standardized partial regression coefficient, taking multicollinearity into account, was verified. Larger absolute values of the standardized partial regression coefficient are associated with a stronger relation of the explained variable and explanatory variables. The adjusted R^2 was 0.5, and as a result, the outside air temperature results to be the strongest factor for agriculture, while the proportion of students is the strongest factor for the other departments. In particular, from November to April, the influence of the outside air temperature was largely different for individual departments. We can infer that the thermal performance of buildings and how to operate the heating are both significant factors. In addition, the number of lecture days for Engineering was a more important factor than for the other departments.

The cluster approach

Due to the cluster shape of the campus, and the perfect correspondence between building and department, the HOKUDAI buildings have been analyzed according to their primary energy consumption per square meter per

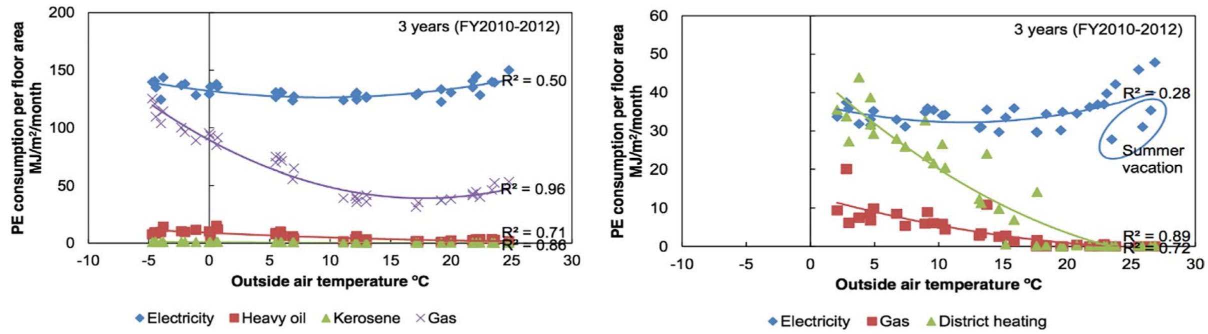


Fig. 9 Relationship between outside air temperature and PE consumption per floor area over 3 years (2010–2012) for HOKUDAI (left) and POLITO (right)

year (namely 2012), the leveling rate, and the electrification rate. In Table 5 in the Appendix, all the 38 departments have been grouped according to the typology of studies and functions hosted. The electrification rate with Eq. (1) was calculated. When the electrification rate is low, the dependence on electricity is low; when the rate approaches 1, the dependence on electricity is high. The electrification rate is shown in the last column of Fig. 10. Data Center had a very high dependence on electricity. Because of the effect of electricity consumption on IT equipment and air conditioning system, etc., the electrification rate consequently reached 0.93. The rates for Medicines Group, Sciences Group, and Research Center were close to 0.5, which was relatively high. Hospital, where gas consumption (heating in particular) is high, had the lowest rate, 0.27. This consumption characteristic differed from the electricity consumption per floor area and the leveling rate. On the other hand, the proportion of electricity and district heating relative to final energy for Corso Duca at POLITO was the same level (0.48), and the electrification rate was about the same as for Sciences Group at HOKUDAI (0.51). Moreover, to understand the electricity load variation along the average, the leveling rate with Eq. (2) was calculated. When the leveling rate is low, the fluctuation in electricity consumption is large, and when the rate approaches 1, the fluctuation is small. The high consumption-low fluctuation region includes Sciences, Medicines, and Research Centre groups. A major improvement in the efficiency of large experimental equipment used during the whole year may reduce this amount of costs. The low consumption-high fluctuation region includes mostly Arts and Humanities groups of faculties. The Data Centre electricity consumption per floor area was far higher than the others, followed by the Research Centre and Hospital groups (beyond 200 kWh/m^2/year). Comparing the leveling rate of each group, the rate was very high for Sciences Group and Medicines Group (about 0.9) and low for Arts Group and Others Group (about 0.7). Figure 10 shows the identified clusters and the related values of PE consumption per square meters per year, the electrification, and the leveling rate, while Fig. 11 exhibits the identified clusters on a scatter plot with PE consumption versus the building area. A hierarchical cluster analysis by agglomerative method with PE consumption per floor area produced the clusters in Fig. 11, grouped in different colors in Fig. 10. The first column in Fig. 10 shows the relationship between floor area and PE consumption per floor area. An increase of floor area is normally accompanied by an increase of PE consumption per floor area, leveling off at a certain point. In contrast to the huge energy consumption by Data Center and a part of the Research Center, the consumption of the Sciences Group, Medicines

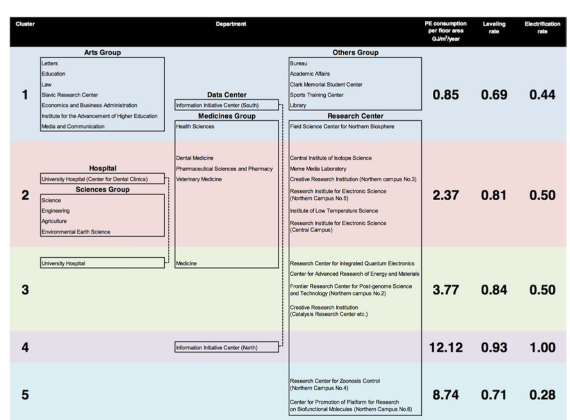


Fig. 10 Electrification rate per clusters of department at the Hokkaido University

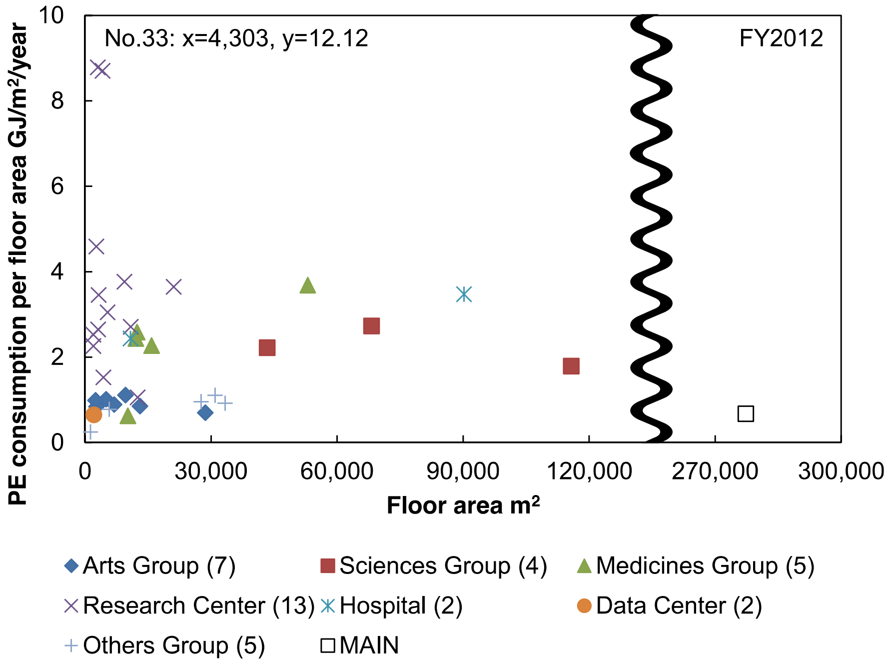


Fig. 11 Relationship between floor area and PE consumption per floor area in different cluster of buildings at HOKUDAI in 2012. POLITO is represented with the Corso Duca main site as "MAIN"

Group, and Hospital was mostly confined to the range of 2 to 4 GJ/m^2/year. In addition to Arts Group and Others Group and in line with the engineering department, Corso Duca site at POLITO entered this clusters in the range of 2 GJ/m^2/year. The mean fluctuation characteristics for each cluster vary from Cluster 1 (a total of 15 departments, around 1 GJ/m^2/month) including the Art group, Cluster 2 (a total of 14 departments, around 2 GJ/m^2/month) including the Science group, to Cluster 3 (a total of 6 departments, around 3 GJ/m^2/month) including hospital and Medicine group. Cluster 4 included the Data Centre, and Cluster 5, the biology research center.

To overcome the limitation of this study that takes into account only two case studies and therefore cannot infer the applicability of these clusters, i.e., range of consumption, for a large number of Universities, further research is recommended for collecting energy use profiles from many different university buildings belonging to these clusters around the world. The present work highlights the kind of relationships existing between energy use intensity and urban local parameters (building surface, weather data and big energy-demanding functions. Including these features in the data collection for sustainability assessment can set internal thresholds and warning values to improve the accuracy of university campus frameworks. An open dataset of energy data may also put the bases of interoperability among different sources. Although the authors are aware that if the sustainability transition is framed only around energy consume monitoring, this could lead to a "neo-functionalist paradigm" (Morgan, 1980; Shepherd & Challenger, 2013; Giulia Sonetti et al., 2019); the need of Living Lab tools to follow up progresses on energy reduction and of a human supervision on trends, target setting, and failure energy performance appears crucial in any university to avoid the risk of a tick-the-box philosophy (Babones, 2015; Ryan & Golden, 2006). Moreover, simplified information dashboards and alert and control panels that can be accessed via web or smartphones, tablets, monitors, and information kiosks settled in the campus set interesting doors for bottom up collaboration and stakeholder engagement in campus sustainability initiatives, proven to be crucial for any long-term sustainability implementation. Final contents can be defined according to the target (public, students, employees, technicians, professors, and energy managers) and can be used to compare university's own data management with similar institutions and to grow together toward a truly sustainable university campus.

Conclusions

Current sustainability international rankings, as the Greenmetric ranking, have no clear methodology to evaluate and compare university campuses with respect to energy consumption and climate change criteria. To fill the gap of current energy indicators and to enable a meaningful comparison among similar universities, this paper proposes an energy cluster approach that looks at homogenous range of energy consumption according to the building hosted function. The energy profiles, and the relative position in the Greenmetric ranking, of two university campuses—Politecnico di Torino (POLITO), Italy, and in Hokkaido University (HOKUDAI), Japan—have been analyzed as purposefully case studies, splitting electrical and thermal energy consumption per each department. Findings highlight how Energy and Climate Change category of Greenmetric ranking is not an accurate indicator for energy performances. Indeed, HOKUDAI university campus consumes 1,731,798 GJ of PE (668% more than POLITO) although its campus area is 40% less with respect to Turin and its users are 16,418 (51% less than POLITO), while POLITO (1.025 points) and HOKUDAI (946 points) in 2015 were situated in the same density area of values for the Energy and Climate Change category. This evident anomaly led the study to deepen the analysis on the external variables affecting the consumption of the HOKUDAI case. A multiple linear regression analysis according to the electricity consumption per floor area and per capita was performed in four HOKUDAI departments (Engineering, Science, Medicine, and Agriculture). The explanatory variables were the outside air temperature, number of lecture days, and proportion of students. According to the obtained results, five clusters are proposed according to the academic functions hosted in the analyzed buildings, and relative range of consumption: cluster 1 (around 1 GJ/m2/year) includes the Art group, cluster 2 (around 2 GJ/m2/year) represents the Science group, and cluster 3 (around 3 GJ/m2/year) consists of hospital and Medicine group. Furthermore, cluster 4 includes the Data Centre, and cluster 5, the biology research center, which may be assigned to special research facilities. Moreover, each cluster has been analyzed in terms of the electrification and the leveling rate, two indicators which take into account the dependence on electricity and the average monthly variation of consumption, revealing how buildings' functions deeply affect the consumption pattern (e.g., data centers and hospitals have a high electrification rate and a constant consumption during the whole year, while traditional university buildings, e.g., arts department, show a low electrification and leveling rate). Thus, comparisons between buildings with different features, functions, and occupancy patterns should be addressed with different criteria by international ranking. This study suggests new criteria to assess the University energy performances, not disregarding the functions hosted by each campus, since we showed that high energy demand buildings, such as data centers or hospitals, strongly affect the total energy performance of University campuses.

Although further studies are needed in order to propose concrete weighting factors per each of the presented clustering options, the aim of the present work is to introduce the possibility of novel approaches for energy performance comparison, addressing each University's special and local and unique features. Concluding, a first result of this paper is suggesting to collect energy consumption data according to our proposed five clusters (i.e., arts, science, medicine, data centers, and research centers) to overcome the risk of the tick-the-box philosophy hidden in current campus sustainability assessment frameworks. This could be a first level of approximation to perform a comparison between similar clusters, rather than between the total energy consumption of university campuses. Such pre-clustered data collection, if performed directly by the Greenmetric ranking, could allow future studies with statistically significant dataset for universities able to deliver concrete weighting factors within each of the cluster.

Abbreviations *BMS*: **Building Management System;** CO_2: **Carbon dioxide;** *DW*: **Data warehouse;** *ETL*: **Extract, transform, load;** *FIRE*: **Italian Federation for Energy Efficiency;** *FY*: **Fiscal year;** *GJ*: **Giga joule;** *HOKUDAI*: **Hokkaido University;** *HUISD*: **Hokkaido University Initiative for Sustainable Development;** *IAS*: **Industrial Automation Systems;** *ISCN*: **International Sustainable Campus Network;** *km*: **Kilometer;** *kWh*: **Kilowatt-hour;** *kWht*: **Kilowatt-hour thermal;** *kV*: **Kilovolt;** *METU*: **Ministry of Education in Japan;** *OSC*: **Office for Sustainable Campus;** *PE*: **Primary Energy;** *POLITO*: **Politecnico di Torino;** *PV*:

Photovoltaic; R^2: R squared; *UNITO*: University of Torino

Declarations

Conflict of interest The authors declare no competing interests.

Appendix

Figures 12, 13 and14

Tables 1, 2, 3, 4, 5 and 6.

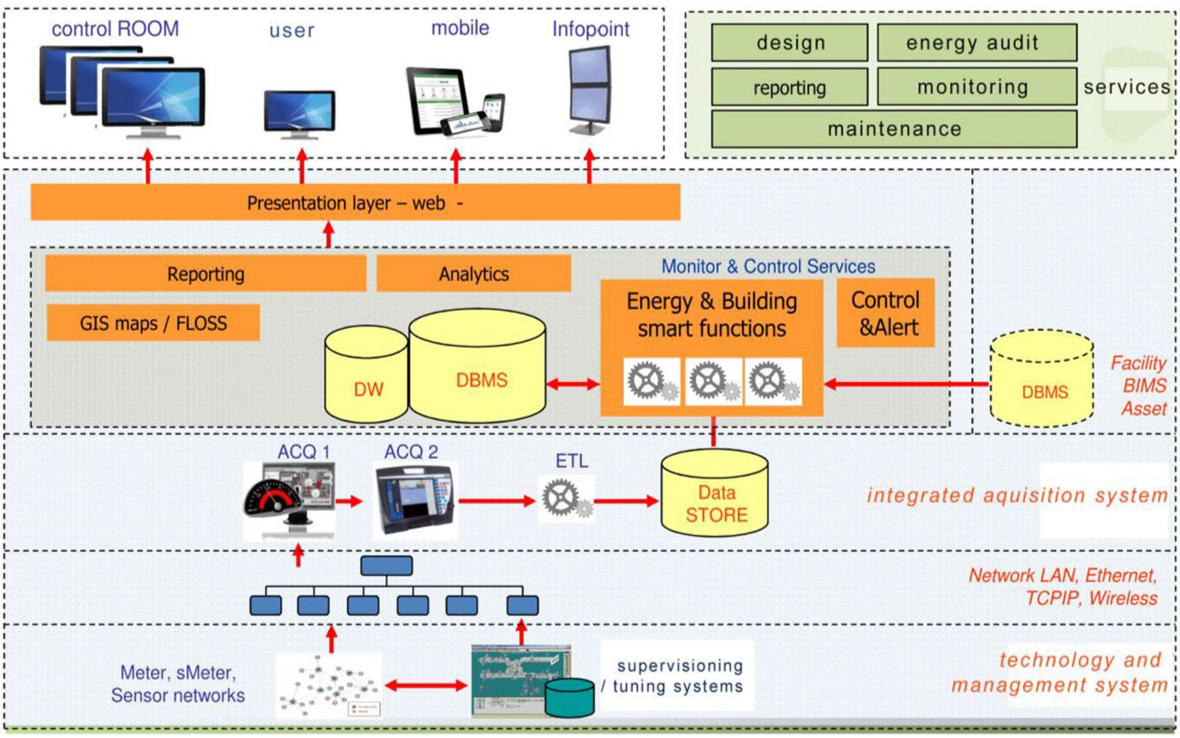
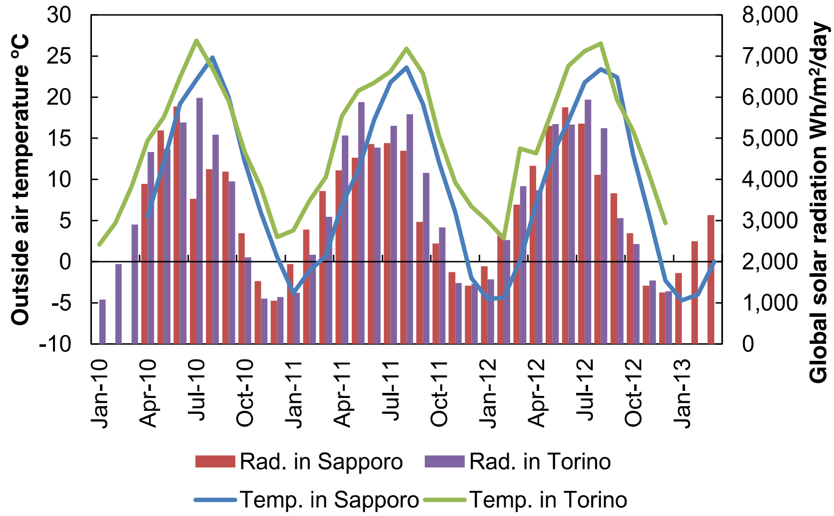


Fig. 12 The Living Lab IT architecture. Source: author elaboration on a scheme found at http://www.fierabolzano.it/klimaenergy/mod_moduli_files/Bozza%20new.pdf



	Outside air temperature ºC		Global solar radiation Wh/m^2/day	
	Sapporo	Torino	Sapporo	Torino
Average	9.4	14.7	3,377	3,473
Maximum	24.8	26.9	5,778	5,985
Minimum	-4.7	2.1	1,056	1,082
Standard deviation	9.9	7.9	1,397	1,702

Fig. 13 Meteorological data for Sapporo and Torino

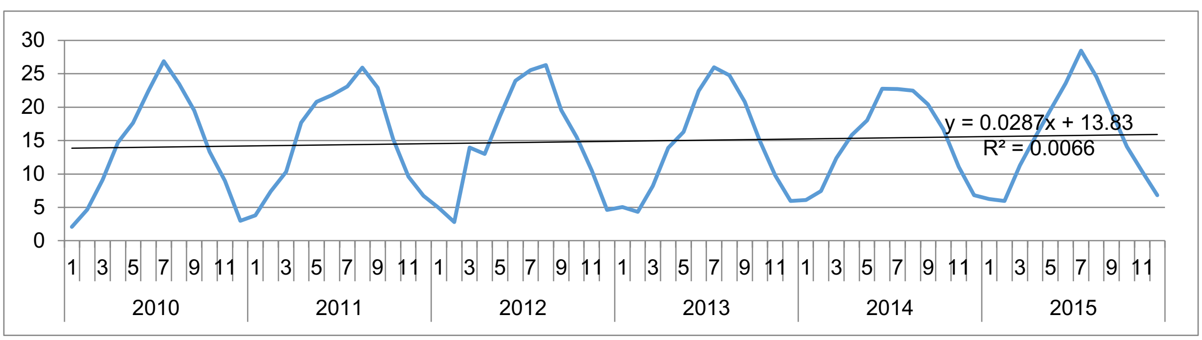


Fig. 14 External temperature average (°C) trend in Turin from 2010 to 2015. Source: POLITO weather station

Table 1 List of interviewed stakeholders for energy-related queries at POLITO and HOKUDAI

Sustainability management team at POLITO	Prof. R. Borchiellini (Vice Rector, Facility Manager)
	Prof. G.V. Fracastoro (Energy Manager)
	Eng. Gianni Carioni (Living Lab Manager)
	Arch. Valeria Giovanardi (EDILOG Office for Construction and Logistics)
Sustainability management team at HOKUDAI	Prof. Takao Ozasa (Director of the Office for Sustainable Campus)
	Dr. Maki Komatsu (Coordinator a t theOffice for a Sustainable Campus)
	Mr. Tomohiro Morimoto (Unit chief, Facilities Department, Sustainable Campus Promotion Division, Office for Sustainable Campus)
	Mr. Takashi Yokoyama (Project Manager, Office for a Sustainable Campus)

Table 2 Dataset used for the two case studies related to 2012. *DH*, district heating. Source: ARCHIBUS software and HOKUDAI Sustainability Office

Name	Target area	Fiscal year	Floor area m^2
Hokudai*	Sapporo campus	FY2008	682,585
		FY2009	687,915
		FY2010	693,308
		FY2011	707,969
		FY2012	
Polito**	Corso Duca	FY2008–2012	187,446
	Cittadella Politecnica		89,910
	Castello Valentino		39,676
	Politecnico Lingotto		15,780
	Mirafiori	FY2011–2012	14,945
	Unified campus	FY2012	347,756
Unito***	Unified Campus	FY2012	514,387

Table 3 Multiple linear regression analysis

Name	Target area	Floor area m^2	Capita	Electricity—MWh	Gas -m^3	DH -MWht	Tot GJ	kWh/m^2	GJ/m^2	kWh/p	GJ/p
HOKUDAI*	Sapporo campus	707,969	16,418	115,656	12,278,786	0	454,315	163.36	0.64	7,044	27.67
POLITO**	Unified campus	347,756	33,600	16,354	381,834	15,383	69,507	47.03	0.20	487	2.07
UNITO***	Unified campus	514,387	74,000	21,497	1,494,286	0	55,289	41.79	0.11	291	0.75

* Hakodate campus is not listed in the target since it is outside the city of Sapporo

** Corso Duca, Cittadella Politecnica, Castello Valentino, Politecnico, Lingotto, Mirafiori

*** All the 120 sites

Table 4 Energy conversion factors for the energy consumption values in POLITO and HOKUDAI

Name	Target energy	Value	Unit
Hokudai	Electricity (daytime)	9.97	GJ/MWh
	Electricity (nighttime)	9.28	GJ/MWh
	Heavy oil	39.10	GJ/kL
	Kerosene	36.70	GJ/kL
	Gas	46.05	GJ/1000 m^3
Polito	Electricity	9.21	GJ/MWh
	Gas	51.00	GJ/1000 m^3
	District heating	3.60	GJ/MWht

Table 5 List of HOKUDAI departments and their classification in groups

No	Department (38)	Group (7)
1	Letters	Arts Group
2	Education	
3	Law	
4	Slavic Research Center	
5	Economics and Business Administration	
6	Institute for the Advancement of Higher Education	
7	Media and Communication	
8	Science	Sciences Group
9	Engineering	
10	Agriculture	
11	Environmental Earth Science	
12	Medicine	Medicines Group
13	Dental Medicine	
14	Pharmaceutical Sciences and Pharmacy	
15	Veterinary Medicine	
16	Health Sciences	
17	Central Institute of Isotope Science	Research Center
18	Field Science Center for Northern Biosphere	
19	Research Center for Integrated Quantum Electronics	
20	Meme Media Laboratory	
21	Center for Advanced Research of Energy and Materials	
22	Creative Research Institution (Northern campus No.3)	
23	Frontier Research Center for Post-genome Science and Technology (Northern campus No.2)	
24	Research Center for Zoonosis Control (Northern Campus No.4)	
25	Research Institute for Electronic Science (Northern Campus No.5)	
26	Institute of Low Temperature Science	
27	Research Institute for Electronic Science (Central Campus)	
28	Creative Research Institution (Catalysis Research Center etc.)	
29	Center for Promotion of Platform for Research on Biofunctional Molecules (Northern Campus No.6)	
30	University Hospital	Hospital
31	University Hospital (Center for Dental Clinics)	
32	Information Initiative Center (South)	Data Center
33	Information Initiative Center (North)	
34	Bureau	Others Group
35	Academic Affairs	
36	Clark Memorial Student Center	
37	Sports Training Center	
38	Library	

Table 6 Results of the standardized partial regression coefficient in HOKUDAI for three main explanatory variables, namely, outside air temperature, number of lecture days, and proportion of students out of the total department users. Data referred to 2012

Electricity consumption per floor area and capita		Standardized partial regression coefficient						Adjusted R^2
		Outside air temperature		Number of lecture days		Proportion of students***		
Wh/m^2/person/month		ºC		days/month		person/person		
Engineering	Nov-Apr	-0.56	**	0.44	**	-0.67	**	0.91
	May-Oct	0.53	**	0.46	**	-0.73	**	0.79
Science	Nov-Apr	-0.23	**	0.14	*	-0.92	**	0.94
	May-Oct	0.39	**	0.15	*	-0.87	**	0.91
Medicine	Nov-Apr	-0.12				-0.88	**	0.81
	May-Oct	0.58	**	0.24	**	-0.79	**	0.89
Agriculture	Nov-Apr	-0.90	**	0.48	**	-0.38	**	0.88
	May-Oct	0.67	**	0.29		-0.55	**	0.59
*		Statistical significance: P < 0.05						
**		Statistical significance: P < 0.01						
***		=B/(A+B) A=Teachers+Staffs B=Undergraduate students+Graduate students						

References

Agdas, D., Srinivasan, R. S., Frost, K., & Masters, F. J. (2015). Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy. *Sustainable Cities and Society, 17*, 15–21. https://doi.org/10.1016/j.scs.2015.03.001

Babones, S. (2015). Interpretive quantitative methods for the social sciences. *Sociology*, 0038038515583637.

Ben, H., & Steemers, K. (2018). Household archetypes and behavioural patterns in UK domestic energy use. *Energy Efficiency, 11*(3), 761–771.

Chen, S., et al. (2019). A study of citywide urban residential energy information system for the building energy efficiency management: A cluster model of seven typical cities in China. *Energy efficiency, 12*(6), 1509–1528.

Chung, M. H., & Rhee, E. K. (2014). Potential opportunities for energy conservation in existing buildings on university campus: A field survey in Korea. *Energy and Buildings, 78*, 176–182. https://doi.org/10.1016/j.enbuild.2014.04.018

Cipriano, X., Vellido, A., Cipriano, J., Martí-Herrero, J., & Danov, S. (2017). Influencing factors in energy use of housing blocks: A new methodology, based on clustering and energy simulations, for decision making in energy refurbishment projects. *Energy Efficiency, 10*(2), 359–382.

Cottafava, D., Sonetti, G., Gambino, P., & Tartaglino, A. (2018). Explorative multidimensional analysis for energy efficiency: Dataviz versus clustering algorithms. *Energies, 11*(5), 1312.

Dantsiou, D. (2012). *Energy use behaviour and sustainability actions in Japanese universities* (No. REPORT WP3 DRAFT/DD/V1).

da Silva Jota, P. R., de Souza, A. P. A., & da Silva, V. R. B. (2017). Energy performance indexes: Analysis in public schools in Brazil. *Energy Efficiency, 10*(6), 1433–1451.

De Jaeger, I., Reynders, G., Callebaut, C., & Saelens, D. (2020). A building clustering approach for urban energy simulations. *Energy and buildings, 208*, 109671.

Disterheft, A., Caeiro, S., Azeiteiro, U. M., & Filho, W. L. (2014). Sustainable universities – A study of critical success factors for participatory approaches. *Journal of Cleaner Production, 106*, 11–21. https://doi.org/10.1016/j.jclepro.2014.01.030

Escobedo, A., Briceño, S., Juárez, H., Castillo, D., Imaz, M., & Sheinbaum, C. (2014). Energy consumption and GHG emission scenarios of a university campus in Mexico. *Energy for Sustainable Development, 18*(1), 49–57. https://doi.org/10.1016/j.esd.2013.10.005

Faghihi, V., Hessami, A. R., & Ford, D. N. (2015). Sustainable campus improvement program design using energy efficiency and conservation. *Journal of Cleaner Production, 107*, 400–409. https://doi.org/10.1016/j.jclepro.2014.12.040

Ferrer-Balas, D., Buckland, H., & de Mingo, M. (2009). Explorations on the university's role in society for sustainable development through a systems transition approach. Case-study of the Technical University of Catalonia (UPC). *Journal of Cleaner Production, 17*(12), 1075–1085.

Gao, X., & Malkawi, A. (2014). A new methodology for building energy performance benchmarking: An approach based on intelligent clustering algorithm. *Energy and Buildings, 84*, 607–616.

International Energy Agency. (2013). Transition to sustainable buildings - Strategies and opportunities to 2050. https://doi.org/10.1787/9789264202955-en

Johnson, R. Burke, and Anthony J. Onwuegbuzie. “Mixed methods research: A research paradigm whose time has come.” *Educational researcher* 33.7 (2004): 14–26

Kikuta, K., & Hayama, H. (2015). Analysis on energy consumption structure on large scale university campuses - A study at Sapporo campus in Hokkaido University. *Journal of Environmental Engineering (transactions of AIJ), 80*(711), 461–469. https://doi.org/10.3130/aije.80.461

Klingler, A. L., & Schuhmacher, F. (2018). Residential photovoltaic self-consumption: Identifying representative household groups based on a cluster analysis of hourly smart-meter data. *Energy Efficiency, 11*(7), 1689–1701.

Lauder, A., Sari, R. F., Suwartha, N., & Tjahjono, G. (2015). Critical review of a global campus sustainability ranking: GreenMetric. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2015.02.080

Lozano, R. (2010). Diffusion of sustainable development in universities' curricula: An empirical example from Cardiff University. *Journal of Cleaner Production, 18*(7), 637–644. https://doi.org/10.1016/j.jclepro.2009.07.005

MacAskill, K., & Guthrie, P. (2014). Application of sustainability principles in post-disaster reconstruction. In *Proceedings 30th Annual Association of Researchers in Construction Management Conference*, ARCOM 2014 (pp. 43–52).

Morgan, G. (1980). Paradigms, metaphors, and puzzle solving in organization theory. *Administrative science quarterly*, 605–622.

Newman, P. (2006). The environmental impact of cities. *Environment and Urbanization, 18*(2), 275–295. https://doi.org/10.1177/0956247806069599

Ryan, L., & Golden, A. (2006). 'Tick the box please': A reflexive approach to doing quantitative social research. *Sociology, 40*(6), 1191–1200.

Shepherd, C., & Challenger, R. (2013). Revisiting paradigm (s) in management research: A rhetorical analysis of the paradigm wars. *International Journal of Management Reviews, 15*(2), 225–244.

Shriberg, M. (2002). Institutional assessment tools for sustainability in higher education: Strengths, weaknesses, and implications for practice and theory. *International Journal of Sustainability in Higher Education, 3*(3), 254–270. https://doi.org/10.1108/14676370210434714

Sonetti, G., Brown, M., & Naboni, E. (2019). About the triggering of UN sustainable development goals and regenerative sustainability in higher education. *Sustainability (switzerland), 11*(1), 254. https://doi.org/10.3390/su11010254

Sonetti, G., Lombardi, P., & Chelleri, L. (2016). True green and sustainable university campuses? Toward a clusters approach. *Sustainability* (Switzerland), 8(1). https://doi.org/10.3390/su8010083

Stake, Robert E. *The art of case study research*. sage, 1995.

Sunikka-Blank, M., & Iwafune, Y. (2011). Sustainable building in Japan - Observations on a market transformation policy. *Environmental Policy and Governance, 21*, 351–363. https://doi.org/10.1002/eet.580

Wei, Y., Zhang, X., Shi, Y., Xia, L., Pan, S., Wu, J., & Zhao, X. (2018). A review of data-driven approaches for prediction and classification of building energy consumption. *Renewable and Sustainable Energy Reviews, 82*, 1027–1047.

Wilkinson, P., Smith, K. R., Beevers, S., Tonne, C., & Oreszczyn, T. (2007). Energy, energy efficiency, and the built environment. *The Lancet, 370*(9593), 1175–1187.

Yang, J., Ning, C., Deb, C., Zhang, F., Cheong, D., Lee, S. E., & Tham, K. W. (2017). k-shape clustering algorithm for building energy usage patterns analysis and forecasting model accuracy improvement. *Energy and Buildings, 146*, 27–37.

Yin, Robert K. (2018). *Case study research and applications*. Sage.