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Lessons from unsuccessful energy and buildings sustainability actions in university campus operations

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ABSTRACT

Higher Education Institutions (HEIs) are increasingly striving to deploy actions that promote the efficient use of energy and other resources on university campuses. Successful sustainability initiatives are vastly described in literature, especially for the *operations* phase. In turn, reports on unsuccessful cases are small in number, or are overlooked and undiscussed, possibly providing a biased view of reality, thus hiding eventual failures. The main objective of this article is to highlight those latter cases and discuss the causes of such results. Through a systematic review of empirical-based scientific literature on ineffective or less successful sustainability actions in the areas of 'Energy' and 'Buildings' on campus operations, it was possible to identify common potential triggering factors for the unsuccess. These were classified into four groups according to the number of occurrences in literature: technical, economic, climatic and behavioral. Within these groups, the main causes include: inadequate planning, the inappropriate design of systems, the lack of proper maintenance, the low return on investment, mismatch between the actions and the local climate, or the uncertainty of long-term commitment to a sustainable behavior. Based on these findings, a set of lessons were disclosed for each group, which may be helpful for all those who are involved in decision-making, planning or monitoring of sustainability actions on campus, as a means to help anticipate and overcome difficulties in early phases. Lastly, more empirically based literature is encouraged, as the disproportion between information on the description of actions and on their impacts is notorious.

Keywords: Sustainable campus, sustainability, campus operations, energy actions, buildings actions

1 Introduction

Assuming the commitment to tackle climate change and address the goals of the United Nations' Sustainable Development 2030 Agenda, Higher Education Institutions (HEIs) are increasingly striving to bring forward the results of initiatives aimed at reducing the environmental impact of their activities.

The incorporation of sustainability by HEIs has been largely argued in literature. Alshuwaikhat and Abubakar (2008), Cortese (2003) and Velazquez et al. (2006) have contributed to the debate, by bringing forward conceptions for a *sustainable university*. Although each with its own nuances, these authors propose integrated approaches to sustainability in HEIs as a way to mitigate negative environmental, economic and social impacts, by acting on such aspects as education, research, operations, outreach and community relations as critical features of a system. Alongside, and based on the most varied approaches, several examples have been putting forward means of embodying those conceptions, such as the commitment between institutions (Lozano et al., 2013; Wright, 2002), the assessment (Yarime and Tanaka, 2012) or the reporting (Ceulemans et al., 2015) of sustainability actions. Despite these, literature has recognized that HEIs have not been able to accelerate the process of immersing sustainability at the expected pace (Mohammadalizadehkorde and Weaver, 2018), and the identification of some critical barriers is an example (Leal Filho et al., 2017).

University campuses commonly embrace a mixed and intensive use of diverse building typologies and outdoor spaces, which may be understood as notable examples of small communities (Ávila et al., 2017) or, where applicable, urban districts, sharing similar morphological characteristics and problems (Kwan and Hoffmann, 2010). Due to their large consumption of energy and other resources with resulting greenhouse gases (GHG) emissions, the *operations* phase is responsible for the largest share of expenditures (Xue et al., 2020) and has the greatest environmental impacts during their life cycle (Huang et al., 2018). On the other hand, financial and energy savings on a short to medium term may be achieved. In addition, the fact that all assets may be under the umbrella of a single administration can be seen as an opportunity to explore more interrelated, sustainable and innovative solutions on a district scale, to monitor conditions and manage services (Gu et al., 2019). Simultaneously, the instructive role of the institutions may be enhanced, offering students communities a unique scenario of living laboratories (Baletic et al., 2017) or even supporting scientific careers related to sustainability, as a means of narrowing the path between research and operations (Hernandez-Aguilera et al., 2021).

Launched internally or in accordance with national or local policies, economic incentives have been among the major drivers for HEIs to implement concrete actions on campuses (Aleixo et al., 2018; Wright and Horst, 2013). Nevertheless, since these incentives are usually directed to standardized measures, which have been theoretically encouraged (Leal Filho et al., 2019), some questions are raised on how to ensure their success given the specificity of each campus context.

In a previous study highlighting a set of major actions which were put into effect in HEIs, it became clear that these were predominantly related to the areas of 'Energy' and 'Buildings' on campus operations (Amaral et al., 2020). Nonetheless, it was also concluded that there was no evidence that the chosen measures produce the expected results. It was apparent that the idea of a basic measurement and verification procedure, essential in any energy efficiency strategy implementation, is missing. And in fact, various publications report the unfeasibility or inappropriateness of certain measures in relation to their context, as many of these unsuccessful actions have usually been underestimated and undiscussed. This limited information on failures may lead to a less clear view of reality especially since the number of successful cases in literature is notoriously high.

Therefore, this article investigates a set of examples reported in scientific literature, in order to identify the causes for the undesired and less positive contribution of actions chosen for leveraging campuses sustainability in its environmental dimension. Actions covering the areas of 'Energy' and 'Buildings' are emphasized, as those where HEIs invest the most and where the impacts are higher on a short and medium term. For the purpose, an analysis of published empirical data was carried out focusing on the environmental and energy performance. From this analysis, the potential triggering factors for the unsuccess are gathered and lessons are drawn. The aim is to raise awareness and provide information to all those involved in the process of planning, implementing and/or monitoring the actions on campus. The achievements of this work help to anticipate and surpass common perceived shortcomings for HEIs that intend to adopt actions already reported in similar circumstances on campus and, thus, to increase the probability of successfully achieving the goals for a sustainable campus.

2 Material and Methods

The undertaken work follows a systematic literature review (Bryman, 2012). The overall methodology is depicted in Figure 1. Knowing that the literature has been reporting the implementation of a common set of actions on campuses, the adopted procedure aims to address the question of the effectiveness of these reported measures. The study comprises a three-phase process:

I. Literature survey: a search was carried out on peer reviewed scientific publications indexed on Science Direct and Google Scholar websites – a broad search platform covering relevant databases such as Scopus and Web of Knowledge –, and retrieved through the use of “sustainab*”, “university”, “campus” and “energy” or “buildings” keywords. A time filter was applied, considering that a timeframe of about a decade provides a balance between what has been done in the near past with repercussions in the present, and the latest developments in new emerging technologies that have been implemented. Therefore, articles published between 2010 until October 2020 were filtered. As a systematic review, only publications with an empirical basis and which provide some type of results from sustainability actions on campus operations were considered. Publications were bounded and categorized according to the STARS tool definition for ‘Energy’ and ‘Buildings’ in the Operations category (AASHE, 2019). Thus, a total of 213 publications were retrieved – 150 journal articles, 32 book chapters and 31 conference proceedings. From the sample of collected publications, a total of 51 which report initiatives that have residual or no environmental benefits and/or economic savings were selected to be discussed in this work.

II. Analysis and data curation: A preliminary evaluation identified two types of studies: a) publications which report actions already implemented on campuses; and b) theoretical studies that evaluate the potential for implementing actions, using real data obtained from campuses or presenting them as case studies. From the selected articles, the description of the actions, all the information available for their framework, and the conclusions were extracted and analyzed. These were clustered by type of action (*e.g.*, sustainable energy systems, envelope energetic retrofit, *etc.*) and compiled into tables (Tables S1 and S2 presented in Supplementary Material).

III. Classification and synthesis of lessons: from the curation of the extracted material, the potential triggering factors for the unsuccess were identified and classified. These motivated a critical reflection that is synthesized in lessons that may help to prevent future unsuccess in implementing sustainability actions on university campuses.

The present work assumes a technical approach, focusing on the impacts of actions promoting energy conservation, generation and savings. Notwithstanding, it acknowledges the three strands of sustainability, concluding that the analyzed actions may provide another understanding from a social or educational point of view. The more interpretative aspects of the studies have been left out even though this may be seen by experts in research methodologies as a drawback (Bryman and Bell, 2011), since they could eventually relate the societal impacts of these same actions. Nonetheless, the objectivity of the empirical data sought in the articles allows comparing and prioritizing sustainability actions, which cannot be dismissed by sustainability planners and decision-makers.

On the other hand, the restriction of only using peer-reviewed publications establishes the validity of the collected information as it has been reviewed; however, other paths of information that may also report unsuccessful cases may have been omitted but their sources may not be reliable.

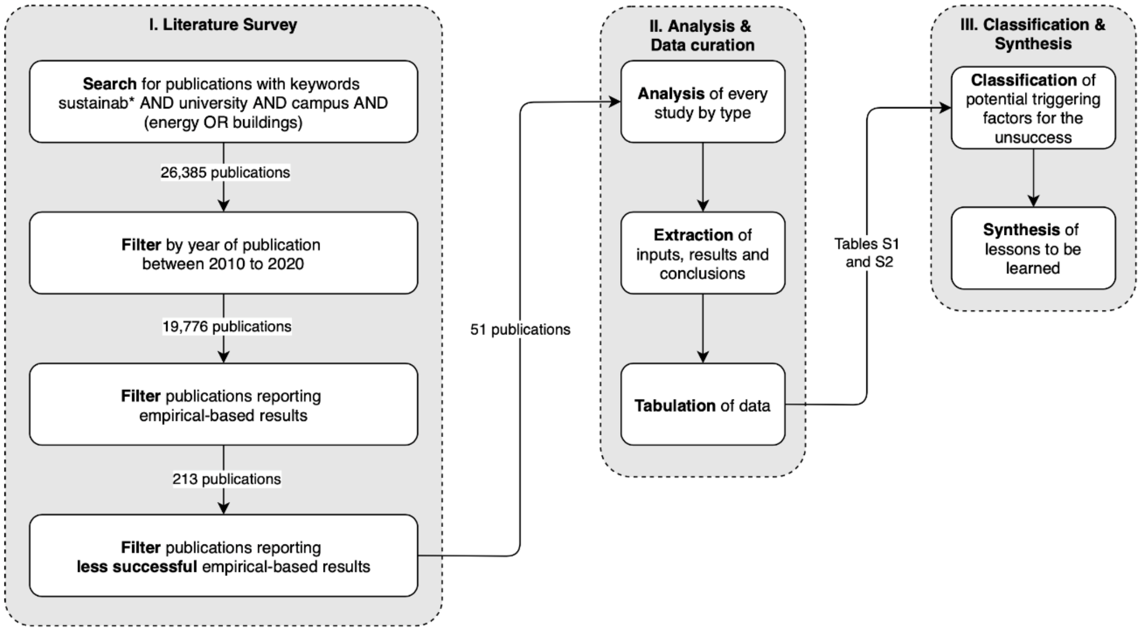

Figure 1. Study concept framework.

3 Results and Discussion

The overall sustainability initiatives found in literature in the areas of ‘Energy’ and ‘Buildings’ for campus operations are depicted in Figure 2 and Figure 3, where the proportion of reported cases with zero or negative environmental contribution is evident. From all the collected studies on the areas of ‘Energy’ and ‘Buildings’, 24 % describe some type of unsuccessful aspect on actions. In the case of ‘Energy’ area, the percentage of these actions is 18 %, while in ‘Buildings’ area, the percentage is 16 %.

The description of the actions found in the abovementioned publications are detailed in the Supplementary Material. Input from the studies and methods used were also added, in order to understand the magnitude and depth of information available to frame the assumptions, and to understand in detail the reasons that led to a result being considered as negligible.

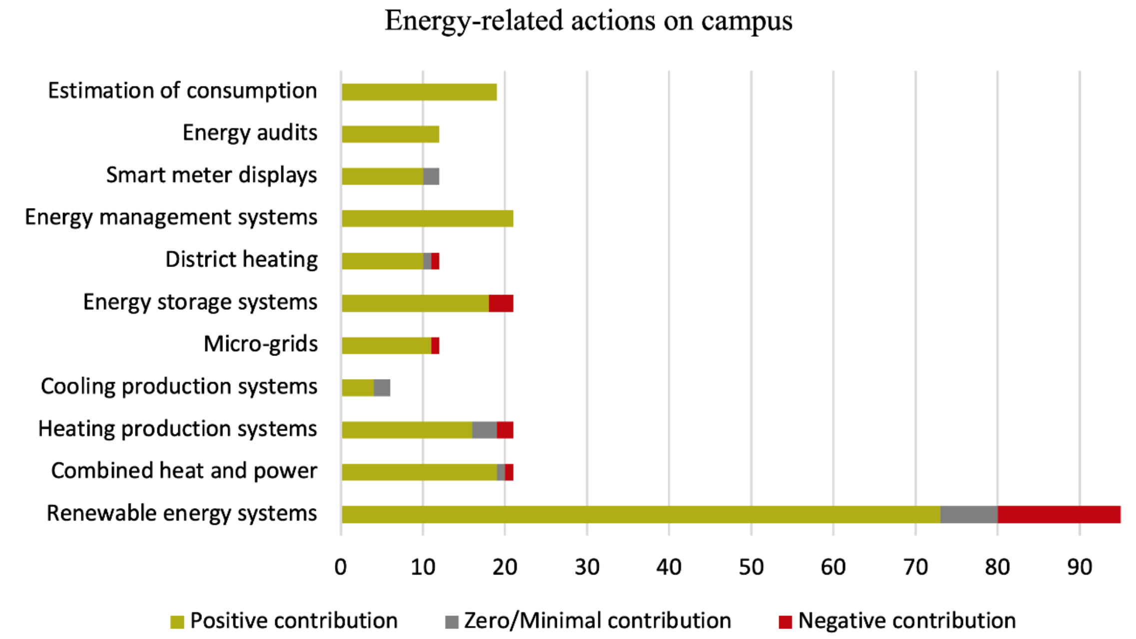

Figure 2. Number of energy-related actions on university campuses found on literature and their contribution to the HEIs environmental performance.

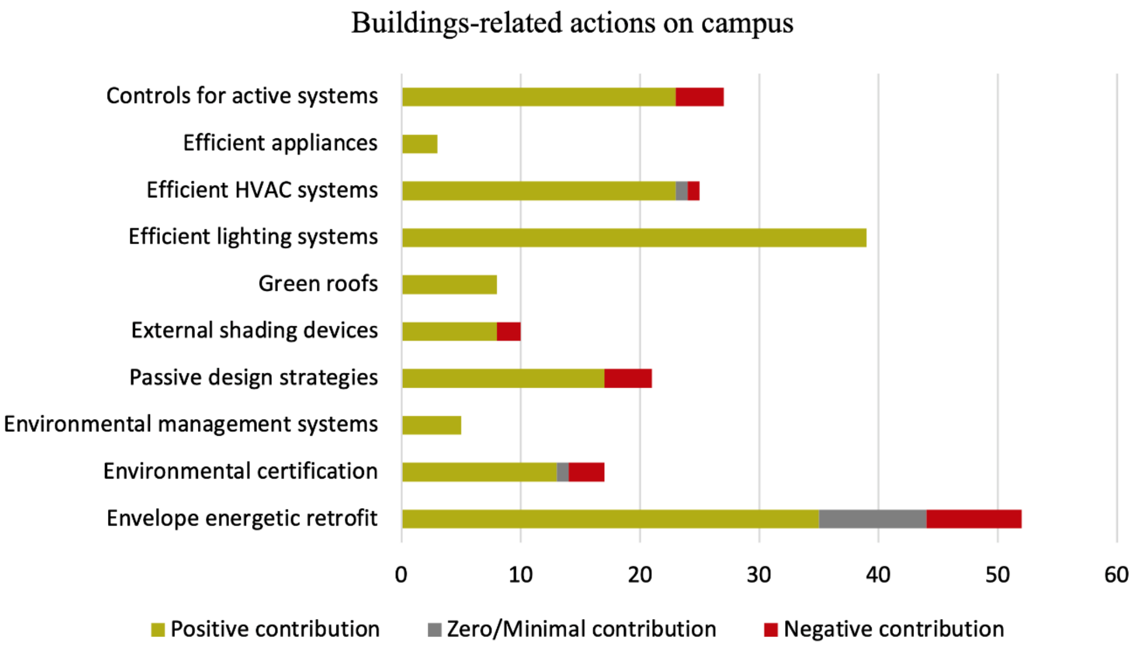

Figure 3. Number of buildings-related actions on university campuses found on literature and their contribution to the HEIs environmental performance.

3.1 Energy-related actions

From the 18 % of studies that report unsuccessful initiatives, the majority is related to the penetration of renewable energy systems (RES) on campuses, namely to solar photovoltaic (PV) systems. The success of these systems and the variability in the energy supply indicators is dependent on local conditions but also on technical parameters, such as the amount and efficiency of the installed panels, their power capacity, the campus or buildings' energy demand, among others. As a way of making PV systems cost-effective, studies show that these need to be combined with other sources such as wind (Bonanno et al., 2012; Park and Kwon, 2016), fuel cell (Kurland, 2011; Washom et al., 2013) or geothermal (Bauer, 2018), with storage systems (Esfandyari et al., 2019; Opel et al., 2017), or integrated in microgrids (Ruviaro et al., 2018; Zhu et al., 2018).

Other actions with a significant expression of implementation were found. Contrary to the RES, these do not depend on neither the location nor the size of the campus but rather on the equipment, and the impacts are modest but undisputed, as expected. As an example, energy management systems seem to help all the participating HEIs in decreasing energy consumption (Cypriano et al., 2019; Kolokotsa et al., 2016; Podoprigora et al., 2020) and provide support in the management of PV systems (Angelim and Affonso, 2018; Mizuno et al., 2013). Irrespective of the campus' location or dimension, energy audits or estimates of energy consumption are unanimously reported as a successful starting point for leveraging further initiatives. They provide insights to draw adequate action plans (Allab et al., 2017; Chihib et al., 2020; Guan et al., 2016), to better design the energy supply systems and justify investments (Jovanović et al., 2015), or even to recognize that the chosen strategies are not the most adequate (Karuchit et al., 2020).

Focusing on less impactful actions, the information provided by literature is summarized in Figure 4 with further details provided in Table S1 in the Supplementary Material.

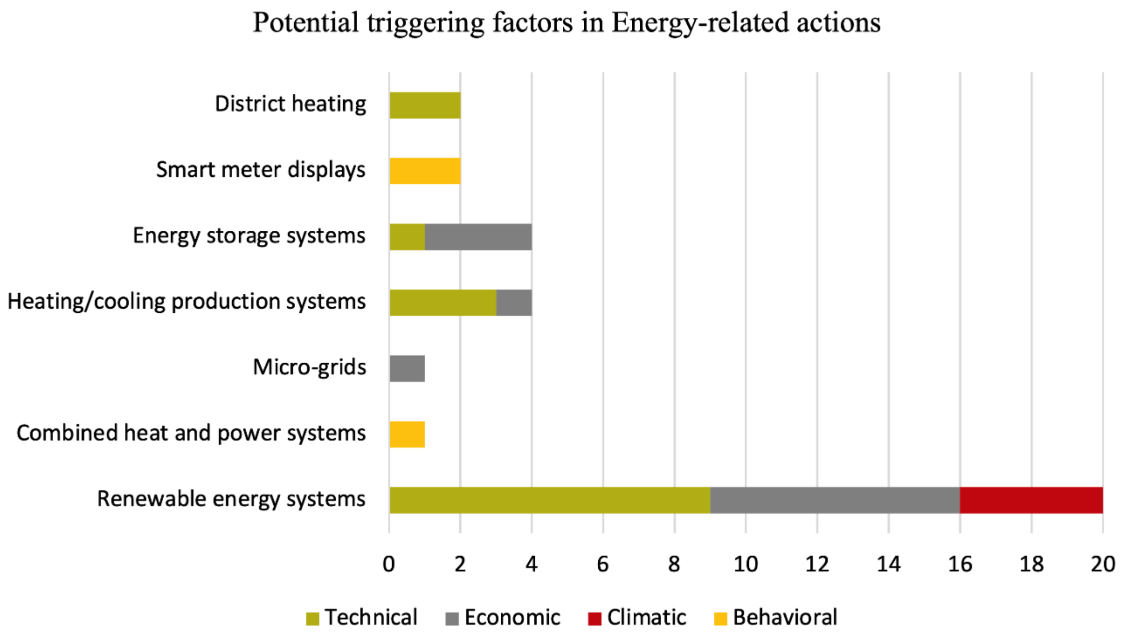

Figure 4. Share of potential triggering factors for the unsuccess of Energy actions on campus operations.

From the results and the framework derived from each study, common explanations for some cases are perceived, representative of certain types of actions, irrespective of the HEI nature and location. They may be clustered into four major factors for the unsuccess, and ranked according to the number of appearances:

i) *Technical.* Distinct technical problems that may prevent the effective operation of the energy strategies are raised – the inefficiency of the systems (Dvorak et al., 2020; Fonseca et al., 2018; Kalkan et al., 2011; Pusat and Akkoyunlu, 2018; Ruth et al., 2019); the difficult, poor or inexistent maintenance (Forman et al., 2017; Koch, 2018) that may lead to the undesired deterioration of the equipment (Medrano et al., 2018); the mismatch between demand and supply in the case of RES (Kwan and Kwan, 2011; Wiryadinata et al., 2019); the low contribution of the action to the baseline improvement (Al Doury et al., 2020; Leon et al., 2020, 2018); the potential conflicts of adapting new technologies to historical buildings (Cho et al., 2020); or even the morphology of a campus that is not suitable for implementing a RES (Kwan and Hoffmann, 2010). Forman et al. (2017) suggest some relevant factors which may cause the installed RES to only provide slight reductions in energy and emissions: the lack of post-occupancy evaluations by designers, due to the fact that projects are often commissioned externally and, therefore, there may be a gap between the estimated goals and the real performance in the use phase; and the organizational structures of institutions and the inappropriate attribution of competences and lack of skills among facility managers and maintenance staff. Even so, the framework for maintenance teams, schemes or budget is not explored in literature.

ii) *Economic*. Even in different contexts, several cases are unanimous in discouraging the implementation of certain energy actions given the high implementation or maintenance costs of the systems in light of the savings they provide (Bellido et al., 2018; Fernando et al., 2018; Fonseca et al., 2018; Kwan and Kwan, 2011; Mohammadalizadehkorde and Weaver, 2020; Ruth et al., 2019; Wiryadinata et al., 2019). The economic contexts of HEIs and their capacity to invest in costly actions, such as technology-based ones usually related to energy generation and storage systems, are extremely diverse. In this respect, the existence of financing programs and policies or the lack thereof can make a difference in the economic viability of an action (Husein and Chung, 2018), and may justify why an initiative results in a minimal contribution in terms of energy savings and yet is presented in the literature as a positive achievement. This is the case of the examples referred by Wanke (2017) – where investors have signed long-term use contracts or even a student initiative that financed a PV unit – and by Mukherji et al. (2019) – which recognized that the feasibility of the PV array was determined by the 30 % subsidy for the installation. Accordingly, Husein and Chung (2018) suggest that taxes and incentives should be considered in energy planning due to their influence on the attractiveness of the investment and on the technology mix to be chosen. Few examples in literature provide this type of information, even in studies based on techno-economic analyzes. Generally, the cost of the system is calculated and the savings are compared, and the evaluation of the economic interest of the action is made by the authors. Among those few is Drahein et al. (2019) who clearly state that the lack of governmental incentives is recognized by Brazilian HEIs as a barrier to a substantial implementation of sustainability on campus, which may justify the deviation to low-cost actions.

iii) *Climatic*. In the particular case of RES, the lack of local climatic conditions to make the most of the sources is recognized, such as low levels of irradiation in the case of PV systems (Escobedo et al., 2014; Kalkan et al., 2011; Mewes et al., 2017) or low wind velocity in the case of wind turbines (Kwan and Hoffmann, 2010). In order to assess the potential of implementing and increasing the probability of success, simulation tools play a very important role. Some of the studies that revealed the unfeasibility of RES resulted from the simulation of the potential based on current campus data (Angelim and Affonso, 2018; Kwan and Kwan, 2011; Mewes et al., 2017). HOMER, PVSyst, PV Watts or even DesignBuilder tools have been found for RES assessment and/or dimensioning (Cho et al., 2020; Fernando et al., 2018; Fonseca et al., 2018; Mohammadalizadehkorde and Weaver, 2020).

iv) *Behavioral*. A typical outcome in a campaign's actions of installing smart meters and energy dashboards in student residences on campus is uncovering occupants' behavioral responses and their willingness to save energy. Although the majority of studies show a positive impact with a contribution to the decrease in energy consumption during the campaigns, some acknowledge the inexistence of a follow-up in the post-campaigns period (Chiang et al., 2014; Wisecup et al., 2017). The pedagogical character of the user-oriented initiatives is unarguable, however, the positive results may merely correspond to the period of the campaign, with a later reversal of the obtained savings (Opel et al., 2017) as it is known that sustaining a more conservative behavior from building users in the long term is more difficult (Timm and Deal, 2016). Ng et al. (2017) noticed that almost half of the participants in a campaign did not cooperate, although they were aware of it, and Sanguinetti et al. (2017) verified a decline in the number of participants over time.

Although some authors deliver an optimistic vision of the potential implementation of actions as PV systems (Gu et al., 2018; Kumar et al., 2019; Zhu et al., 2018) or combined heat and power (Bonanno et al., 2012), the results express small percentages to cover the electricity demand, thus corresponding to a minor contribution. However, due to the absence of a context analysis, the reasons why slight contributions are seen as great solutions by the authors are difficult to comprehend.

3.2 *Buildings-related actions*

Regarding the initiatives focusing on the area of ‘Buildings’, the evaluation or implementation of retrofitting measures is predominant in two main aspects: a) through passive strategies, and b) through active systems.

The passive strategies are dominated by the introduction of bioclimatic design such as natural lighting, ventilation, orientation or green roofs (Battisti et al., 2018; Jain and Pant, 2010), but especially by the upgrade of the thermal performance of the building envelope, through the addition of thermal insulation to façades and/or the replacement of windows by low emissivity, double or triple glazing (Cho et al., 2020; Opel et al., 2017). Since these strategies are dependent on local climatic conditions, differences were observed in their effectiveness. Among an optimistic majority, and despite some recognition of the benefits of improving indoor environmental quality and thermal comfort (Mancini et al., 2017; Manni et al., 2017), several studies concluded that their contribution is minimal to the overall reduction of energy consumption in buildings, as illustrated in Table S2 in the Supplementary Material.

As an alternative, efficient active systems may represent a feasible solution for starting the pathway towards more efficient buildings. As they are not dependent on climatic conditions but rather on the efficiency of the systems itself, they are unanimously reported as having positive effects in reducing the energy consumption of buildings. The adoption of efficient equipment such as LED lighting (Fonseca et al., 2018; Hu, 2018; Udas et al., 2018), heating, ventilation and air-conditioning (HVAC) (Erhart et al., 2016; Escobedo et al., 2014; Nagpal and Reinhart, 2018), or control sensors for those systems (Granderson et al., 2011; Omar et al., 2018; Petratos and Damaskou, 2015), results in significant energy savings in all campus dimensions and locations.

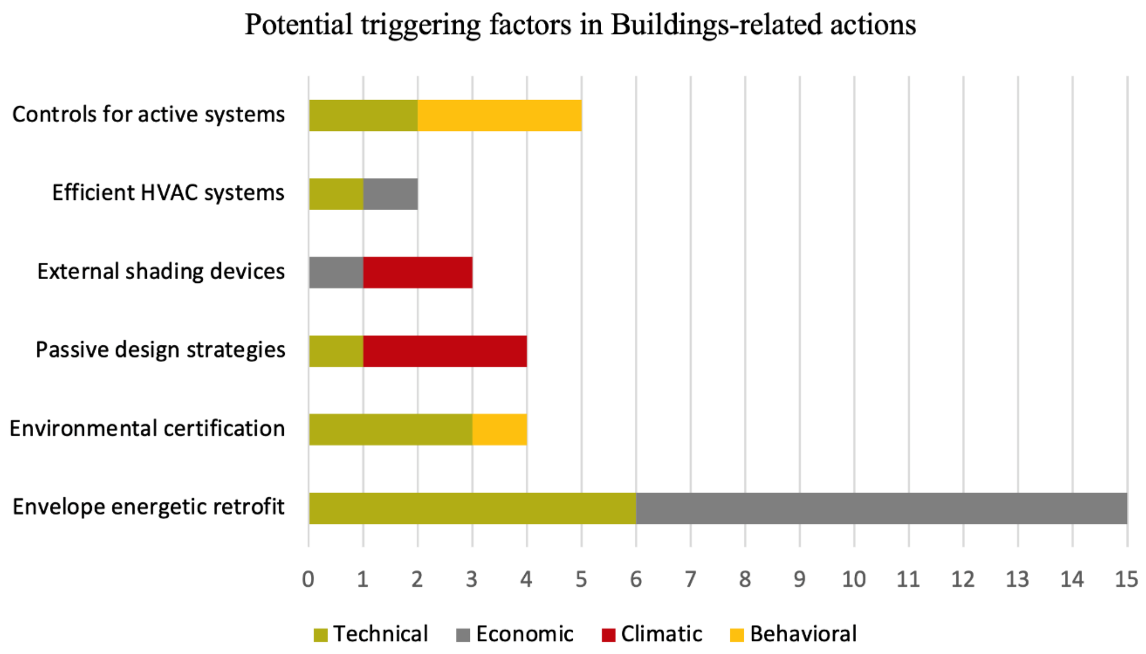

Figure 5. Share of potential triggering factors for the unsuccess of Buildings actions on campus operations.

The reasons responsible for a less positive contribution to building actions, as displayed in Figure 5, consist of the same four major subjects similar to the actions found in the area of 'Energy' even though they encompass a more diverse nature. They are presented in order of occurrence in literature:

i) *Technical*. Different operating problems are identified in this area – the inefficiency of the systems chosen (Karuchit et al., 2020), and the poor, or lack of, maintenance (Costa et al., 2019; Gupta and Gregg, 2016). Again, sparse information on the existing or planned maintenance scheme for the campuses in the studies was manifest. However, from the evidence available, the effects of the inappropriate management of facility operations is very clear, especially in buildings expected to achieve high performance levels. The external commissioning of the project followed by a lack of training of the technical staff to deal with the building management system and the existence of several organizational difficulties, namely the lack of knowledge and time and costs cuts, may result in a lower than expected performance of a certified building (Gupta and Gregg, 2016). Also, Forman et al. (2017) draw attention to identical issues for the areas of 'Energy' and 'Buildings' – the mismatch between projected and monitored actions due to disparate teams that do not work together. In this case, in a BREEAM Excellent rated building, the incorrect estimation of electricity and gas demands led to misadjusted consumptions and occupants' dissatisfaction.

ii) *Economic*. Several studies conclude that, when both an economic and technical analysis is carried out, the high investment or maintenance costs of the systems against the savings they provide, may render the actions to be cost-ineffective (Ascione et al., 2019, 2017; Bellia et al., 2018; Huang et al., 2012; Patiño-Cambeiro et al., 2019; Pini et al., 2019). This is especially evident in the passive strategies of retrofitting buildings' envelope, namely through the addition of thermal insulation and/or the upgrade of windows to low emissivity, double or triple glazing. It was also noted that these conclusions were generally obtained from studies for smaller campuses, often just based on a single building. As campuses increase in size (or, in this case, the considered number of buildings increases), investing in improving a building's envelope appears to compensate, as there is an increase in the energy savings for heating and/or cooling (Chung and Rhee, 2014; Geng et al., 2013).

iii) *Climatic*. Regarding mostly the buildings passive design, climatic location is crucial to the effectiveness of the strategies' performance, as their principle is precisely the adequacy to local environment and conditions. Some authors pointed out that, for the location of the studied HEIs, the passive strategies have limitations (Dai et al., 2019; Hua et al., 2014; Liu and Ren, 2020; Zhou et al., 2019) and, in one case, it was noted that implementing overhangs in the external façades did not present a satisfactory performance considering its lifetime (Huang et al., 2012). Also, the thermal insulation of façades and windows reveals to be more appropriate for colder climates, especially windows with triple glazing. This may justify why these actions are considered as having a minimal contribution in warm temperate and hot summer climates (Ascione et al., 2019; Bellia et al., 2018). Building simulation tools may produce supportive results in terms of evaluating several retrofitting strategies. Real campus buildings and climatic data were used as input in tools such as EnergyPlus, DesignBuilder, CitySim or Green Building Studio, to demonstrate that it is possible to optimize the choice of the most appropriate measures for each case, among sets of equated alternatives (Coccolo et al., 2015; Dai et al., 2019; Mytafides et al., 2017; Samaan et al., 2018). Simulation analyses also allow the recurrent perception that intervening in buildings façades may not imply a significant reduction in energy demand (Ascione et al., 2019), or is not enough to meet the energy targets set for HEIs (De Angelis et al., 2015; Nagpal and Reinhart, 2018; Sesana et al., 2016).

iv) *Behavioral*. In post-occupancy evaluations (POE) and surveys, some considerations were raised regarding the reverse effects of centralized controls for active systems, namely for HVAC setpoints. Rigid controls without taking into account occupancy and activities patterns may lead to higher electricity consumption in periods of non-occupation (Gul and Patidar, 2015), since the occupancy has a strong influence on HVAC use (Li et al., 2020). Additionally, building occupants reported their desire for greater control over temperature, as one of the greatest contributors to discomfort and lower productivity (Lawrence and Keime, 2016). Although literature has highlighted the benefits of using centralized controls to avoid wasting energy (Chung and Rhee, 2014; Granderson et al., 2011; Shea et al., 2019), including the waste caused by users, the lack of awareness by occupants when leaving lights, HVAC and/or other equipment always on during unoccupied periods can amount to more than half of the total energy consumption of a university building (Masoso and Grobler, 2010). These plug loads that are not usually accounted for in the design phase may trigger the difference between the estimated and the verified energy consumption in the use phase (Forman et al., 2017), documented in literature as 'energy performance gap' (De Wilde, 2014). The inappropriate use of buildings, either for operational or usage issues, can even compromise the performance of a building designed to be energy efficient, demonstrating in the use phase that it is not (Kim et al., 2019). In this case study, two factors contributed to the performance gap: operational problems related to misadjusted lighting controls, and behavioral problems, due to the exterior doors widely open that impact negatively the HVAC functioning. These aspects, while seemingly contradictory, show how critical the role of automated systems is, when adequately designed and correctly parameterized according to occupancy information. For this, the Internet of Things may provide support in real time (Azizi et al., 2020).

4 Lessons learned

The debate over the impact of an action has necessarily become much broader than that unveiled by literature. More information would be helpful to frame and justify some options that appear not to be the best ones, but more importantly to have a clearer perception of the real proportion between the more or less successful contributions of the diverse documented actions. Although the scarcity of studies and the absence of information could overshadow the lessons to be learned, the results reported in the literature would not change in any way.

As such, the results of this work allow to outline a set of lessons on certain potential factors prone to failure. These also involve a critical analysis of some conclusions stated by the authors when analyzing the results of their studies. In this sense, lessons were outlined according to each one of the four groups – technical, economic, climatic, and behavioral –, which may help all those who, in some way, are involved in moments of feasibility analyses, decision-making and planning for sustainability actions on campus.

4.1 Lessons from technical factors

Understanding the scope of technical analyses. Operation initiatives, such as 'Energy' and 'Buildings', require a context analyses of their choice. Strategies that have an impact in reducing in energy consumption such as interventions in buildings, or those related to energy supply, for example RES, require the identification of parameters that must be analyzed which go beyond the availability of local resources. Variables raised by some studies, such as political wills, nationally designed strategies/policies, external investment for example through patronage, or even the specific needs of the HEI, are usually mentioned but not substantiated. Therefore, they could have helped to better frame the choice of measures that proved to be of minimal or no contribution.

Extending the scope of the technical analyses, in order to include those variables, requires additional information and time; however, more accurate and realistic analyses may be produced.

Paving the way for disruptive/novel approaches in technical analyses. On the other hand, if the technical analyses to evaluate the potential of actions demonstrate limited expressive contributions, considering new approaches may demonstrate different results. As literature has referred, university campuses are notable examples of small communities or urban districts; however, the approaches used when analyzing the feasibility of interventions in buildings to increase the supply from RES or energy conservation, consider the campus as a sum of isolated buildings, dismissing typical urban morphological factors which may influence their performance. Additionally, the opportunity to intervene on a multi-building level, as suggested by the only study found with such an approach (Legorburu and Smith, 2020), seems to have been disregarded even though it identified significant savings. Extending the energy analysis to a broader scale allows for a compensation between buildings with better and worse performances, in addition to the sharing of costs and resources that mitigate the mismatch between demand and supply (Amaral et al., 2018). Thus, even if a solution may seem to be unfeasible for a single building, it should be analyzed at the community level that a campus is, prior to being disregarded, as the impacts will certainly be different and, possibly, surprising.

To guarantee the legitimacy of this approach, a legal framework for community energy planning is needed; also, the existence of financing focused on the improvement of buildings as isolated objects may discourage a broader analysis.

Uphold the follow-up and monitoring of systems. One of the most pronounced but least cited questions in the literature is related to the maintenance and monitoring of the systems implemented during sustainability actions. Technical analyses should consider the HEI's ability to respond to the proper maintenance of systems, so that their effectiveness is preserved throughout the considered lifetime. Likewise, the contributions of the systems must be checked over time beyond the immediate period in which they are implemented. Moreover, measurement and verification procedures, where POE are included, are essential, since the collection, analysis and comparison of data before and after the implementation of energy conservation strategies, is the most accurate means of providing information on their real impacts and savings. They are as well the needed procedure to reduce the energy performance gap verified in some cases. This is particularly critical in buildings with environmental certifications, such as LEED or BREEAM, given the high costs of the certification. Forman et al. (2017) are among the few who provide a clear sense of the impacts of the lack of technical capacity or skills and communication between the technicians involved. Otherwise, as suggested by Carlson (2012), it would be preferable to consider spending the corresponding cost of certification on non-labeled sustainability actions of equal importance and impact.

Although the monitoring of the adopted actions may reveal the HEIs needs for trained staff, it is also an opportunity to improve technical capacities and to develop adequate M&V plans.

4.2 Lessons from economic factors

Maintenance and cost-benefit analyses. A large number of studies use a methodology based on a techno-economic analysis, providing a broader perspective on the implications of implementing an initiative beyond energy savings. However, with regard to the economic aspect, the equation is often balanced only with the initial costs of the systems and of the energy, as Tables S1 and S2 in Supplementary Material show. This is particularly critical when most of the works in the "Buildings" area recommend active systems such as HVAC as the most economically viable alternatives, without considering the maintenance that these systems naturally require over time. This demonstrates that in fact maintenance is still not a widespread concern. The inclusion of maintenance costs and the consideration of the degradation of performance along the lifespan of the systems may provide more accurate and realistic economic (and also technical) analysis and the perception of long-term expenses against energy savings. On the other hand, well planned maintenance – which implies extra costs disclosure – provides less degradation over time and helps to maintain the performance of the systems, contributing to greater energy savings during their lifespan.

Flexibility in financing policies for sustainability actions. Findings show different results in different campuses for the same sustainability action. Some studies point to the financing of some measures, but few are clear on whether the proposed or implemented ones are framed by the existence of financing programs and none describe what they consist of. It is already known that the main execution driver may be the financial support for certain initiatives (Leal Filho et al., 2019; Maiorano and Savan, 2015; Wright and Horst, 2013). In this sense, the adequacy of policies and, especially, of financing programs to the characteristics of university campuses based on their specific contexts and needs is a doubt that will remain unclear. The existence of financing programs for the implementation of standardized measures, such as the installation of PV panels or the replacement of windows, leads HEIs to the inevitability of competing for actions that, in some cases, may not be the most appropriate nor the most urgent. Thus, more care should be taken when generalizing these policies, even within a single country, which may have climatic, physical, economic, cultural or organizational characteristics sufficiently distinct to support distinct measures in accordance with regions. HEIs should be able to apply for financing for the most appropriate measures, through an integrated analysis of those with the greatest savings and impacts, eventually in a hierarchical prioritization scheme. Despite the need for a multidisciplinary team, the development of holistic or global sustainability plans is an opportunity to avoid the adoption of isolated actions, the results of which may fall short of expectations.

4.3 Lessons from climatic factors

Estimation of the potential of implementation in accordance with local conditions. Studies based on cost-benefit analyses have provided valuable insights into the unfeasibility of some actions against local conditions, namely solar, wind or geothermal availability, or even environment settings for passive strategies. These analyses play a crucial role in the planning phase, so the use of simulation tools such as those listed for both operation areas, which generally include updated climatic data for different locations (or others considered more appropriate), may provide analyses, the results of which are closer to reality the more input is available.

The impacts of climate change in future scenarios. A common approach and transversal to most actions is related to the estimation of campuses energy supply and buildings energy demand either based on measured data or on climatic data from simulation software. However, climatic variations are increasingly worrying and less static. From the collected publications, only one work considered a future prediction, through a model for the thermal performance of the campus in 2050 (Coccolo et al., 2015), while another one framed the influence of extreme events on the choice of the initiative (Huang et al., 2012). The Intergovernmental Panel on Climate Change (IPCC) long-term projections for climate change foresees that air temperature will increase every 10 years (IPCC, 2014), which means within the lifetime of the energy systems. Thus, it is increasingly significant to model energy demand and supply based on different scenarios of temperature change, so that the dimensioning of the systems can anticipate more realistic future conditions. An example is provided by Nik et al. (2017) that performed a comparison between different datasets available for energy simulation. As expected, all resulted in projections of decreasing heating needs and increasing cooling needs at long term. Likewise, the escalation in the frequency of extreme events, especially in more prone areas, should encourage the need of rethinking the process of implementing and monitoring 'Energy' and 'Buildings' actions, but especially the capacity of resilience of the campuses.

4.4 Lessons from behavioral factors

The importance of academic community engagement. It was noticed that many of the studies originated from the initiative of researchers who voluntarily provided their contribution to the HEI sustainability, namely those related to the assessment of the potential for implementing actions. This justifies a certain disregard for the HEI's organizational structure, in particular the facilities management. Although planning and implementing sustainability actions on campus may seem hard work and costly tasks, it has the unparalleled power of being a catalyst for life in the community that defines a HEI. Participatory approaches, by the involvement, empowerment and accountability of all users may help to overcome the resulting limited effects from some reported campaigns. With respect to these actions, authors recommend that they should be extended over time (Timm and Deal, 2016) or associated to additional efforts (Ng et al., 2017). A technical shift on campus is more prone to success when a cultural change happens simultaneously at the institution. For that, a wider approach should be embedded across all aspects of institutional activities, such as the Education for Sustainable Development, a persuasive instrument able to provide students and teachers the skills and sensitivity needed for the success of participatory initiatives, but especially for the rational use of energy on campus buildings.

Organizational culture for campus sustainability. Difficulties in communication and in assigning competences between teams are reported as contributors for the ineffectiveness in systems maintenance. On the other hand, other studies show that some isolated actions may have an insignificant contribution to the overall energy performance of the campus, but in combination with other measures – usually various renewable sources to supply energy generation (Park and Kwon, 2016), or passive and active strategies for buildings retrofitting (Ascione et al., 2019; Sesana et al., 2016) –, their contribution becomes valuable. This suggests that, for an effective sustainable campus, long-term goals and integrated plans should be established; and each action, either on operational, educational or organizational aspects of sustainability in HEIs, should be part of. In this respect (as in others), sustainability offices can play a crucial mediating role between all the involved actors and the academic community.

Although an informed and involved academic community is needed, it is a unique opportunity to contribute to achieving a sustainable HEI in all its dimensions.

5 Conclusions

The implementation of sustainability actions in the field of operations of campuses lifespan may be one of the most powerful strategies of HEIs against climate change effects. In addition to the tangible and measurable impacts in terms of decreasing energy consumption and GHG emissions, these actions may allow students and researchers to learn and explore groundbreaking solutions in living laboratories, and help the academic community to get involved in incorporating sustainability in all the dimensions of a HEI, creating models for other communities or districts.

However, if the chosen actions prove to be unfeasible or of insignificant contribution, it is unlikely that technical staff and decision makers will encourage the adoption of succeeding sustainability activities. In this sense, this article brought to the debate some less successful but realistic cases found in literature among the most sought initiatives worldwide, by discussing the motives for less positive impacts of such common actions. The most frequent are related with the inadequate planning design and monitoring of actions, the lack of economic and/or human resources required to ensure an effective maintenance, the low return on investment, the discrepancy between design actions and local climate conditions, and the difficulty in sustaining long-term behavior changes in the users.

These events, common to the areas of ‘Energy’ and ‘Buildings’, allowed the identification of four categories of problems of significant importance, grouped into technical, economic, climatic and behavioral aspects, which may prevent campuses achieving expected performance levels. From the discussion of those events, conclusions were drawn, of which are highlighted:

- The need for a clearer understanding of the context of the technical options for the chosen implemented actions;
- The advantage of considering the campus as a whole community with shared needs and resources, as opposed to a sum of isolated buildings approach;
- The importance of monitoring the implemented actions and of including maintenance in both the economic and technical analyses as a means to prevent unexpected costs or malfunctioning during the systems operation phase;
- The constricting impact of external financing programs which are conceived for specific type of measures, leaving out more appropriate or urgent ones;
- The robustness of solutions which consider local current and future climate data in their technical analyzes;
- The need to promote long-standing sustainable behaviors by fostering an integrated culture of sustainability within an HEI.

Limitations were noted in the number and content of publications found. Knowing what was behind the studies could have made a difference and put the context of an action in perspective, however it would not modify the results. Therefore, findings allowed the documentation of the potential restrictors to the success that should be considered in the decision-making process in any context.

In this sense, a significant number of the articles found are essentially descriptive, and do not have the character of confronting an initiative with its real contribution – either more or less feasible – to the overall sustainability performance of a campus. It is true that a more optimistic view may be more encouraging, however the mere listing of initiatives may provide a less clear view of reality due to the little information on possible failures. Conversely, scientific research has proven to play a crucial role on the progress of sustainable campus operations. The valuable contribution of the presented techno-economic analyses and the exploration and development of tools that can support the decision-making process is unquestionable. Not rarely, technical staff does neither dominate nor has the time to dedicate to multicriteria analyses or the use of new tools. In this sense, authors must feel encouraged to deepen these topics and to provide more information, even when the results are not the expected. As this work has evidenced, there are factors that should be addressed in early phases, increasing the likelihood that an HEI will successfully achieve its sustainability goals.

CRediT author statement

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References

AASHE, 2019. STARS Technical Manual Version 2.2.

Al Doury, R.R.J., Ozkan, S., Mengüç, M.P., 2020. Cascaded Thermodynamic and Environmental Analyses of Energy Generation Modalities of a High-Performance Building Based on Real-Time Measurements. Entropy 22, 445. https://doi.org/10.3390/e22040445

Aleixo, A.M., Leal, S., Azeiteiro, U.M., 2018. Conceptualization of sustainable higher education institutions, roles, barriers, and challenges for sustainability: An exploratory study in Portugal. J. Clean. Prod. 172, 1664–1673. https://doi.org/10.1016/j.jclepro.2016.11.010

Allab, Y., Pellegrino, M., Guo, X., Nefzaoui, E., Kindinis, A., 2017. Energy and comfort assessment in educational building: Case study in a French university campus. Energy Build. 143, 202–219. https://doi.org/10.1016/j.enbuild.2016.11.028

Alshuwaikhat, H.M., Abubakar, I., 2008. An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices. J. Clean. Prod. 16, 1777–1785. https://doi.org/10.1016/j.jclepro.2007.12.002

Amaral, A.R., Rodrigues, E., Gaspar, A.R., Gomes, Á., 2020. A review of empirical data of sustainability initiatives in university campus operations. J. Clean. Prod. 250. https://doi.org/10.1016/j.jclepro.2019.119558

Amaral, A.R., Rodrigues, E., Rodrigues Gaspar, A., Gomes, Á., 2018. Review on performance aspects of nearly zero-energy districts. Sustain. Cities Soc. 43, 406–420. https://doi.org/10.1016/j.scs.2018.08.039

Angelim, J.H., Affonso, C.M., 2018. Energy Management on University Campus with Photovoltaic Generation and BESS using Simulated Annealing, in: 2018 IEEE Texas Power and Energy Conference (TPEC). pp. 1–6. https://doi.org/10.1109/TPEC.2018.8312112

Ascione, F., Borrelli, M., De Masi, R.F., Rossi, F. De, Vanoli, G.P., 2019. Energy refurbishment of a University building in cold Italian backcountry. Part 2: Sensitivity studies and optimization. Energy Procedia 159, 2–9. https://doi.org/10.1016/j.egypro.2018.12.010

Ascione, F., De Masi, R.F., De Rossi, F., Ruggiero, S., Vanoli, G.P., 2017. NZEB target for existing buildings: Case study of historical educational building in Mediterranean climate. Energy Procedia 140, 194–206. https://doi.org/10.1016/j.egypro.2017.11.135

Ávila, L.V., Leal Filho, W., Brandli, L., Macgregor, C.J., Molthan-Hill, P., Özuyar, P.G., Moreira, R.M., 2017. Barriers to innovation and sustainability at universities around the world. J. Clean. Prod. 164, 1268–1278. https://doi.org/10.1016/j.jclepro.2017.07.025

Azizi, S., Rabiee, R., Nair, G., Olofsson, T., 2020. Application of occupancy and booking information to optimize space and energy use in higher education institutions, in: E3S Web of Conferences. EDP Sciences, p. 25010. https://doi.org/10.1051/e3sconf/202017225010

Baletic, B., Lisac, R., Vdovic, R., 2017. Campus Living Lab Knowledgebase: A Tool for Designing the Future, in: Filho, W.L., Azeiteiro, U.M., Alves, F., Molthan-Hill, P. (Eds.), Handbook of Theory and Practice of Sustainable Development in Higher Education Volume 4. Springer International Publishing, pp. 441–456. https://doi.org/10.1007/978-3-319-47895-1

Battisti, A., Laureti, F., Zinzi, M., Volpicelli, G., 2018. Climate Mitigation and Adaptation Strategies for Roofs and Pavements: A Case Study at Sapienza University Campus. Sustainability 10. https://doi.org/10.3390/su10103788

Bauer, W., 2018. Turning Waste into Power: Michigan State University' s Anaerobic Digester, in: Leal Filho, W., Frankenberger, F., Iglecias, P., Mülfarth, R.C.K. (Eds.), Towards Green Campus Operations. World Sustainability Series. Springer, Cham, pp. 385–391. https://doi.org/10.1007/978-3-319-76885-4_25

Bellia, L., Borrelli, M., De Masi, R.F., Ruggiero, S., Vanoli, G.P., 2018. University building: Energy diagnosis and refurbishment design with cost-optimal approach. Discussion about the effect of numerical modelling assumptions. J. Build. Eng. 18, 1–18. https://doi.org/10.1016/j.jobe.2018.02.017

Bellido, M.H., Rosa, L.P., Pereira, A.O., Falcão, D.M., Ribeiro, S.K., 2018. Barriers, challenges and opportunities for microgrid implementation: The case of Federal University of Rio de Janeiro. J. Clean. Prod. 188, 203–216. https://doi.org/10.1016/J.JCLEPRO.2018.03.012

Bonanno, F., Capizzi, G., Gagliano, A., Napoli, C., 2012. Optimal management of various renewable energy sources by a new forecasting method, in: International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM). IEEE, pp. 934–940.

Bryman, A., 2012. Social Research Methods, 4th Editio. ed. Oxford University Press, Oxford.

Bryman, A., Bell, E., 2011. Business Research Methods, 3rd Editio. ed. Oxford University Press.

Carlson, S., 2012. Sustainability and Higher Education Architecture : Best Practices for Institutional Leaders, in: Martin, J., Samels, J.E. (Eds.), The Sustainable University : Green Goals and New Challenges for Higher Education Leaders. The Johns Hopkins University Press, Baltimore, pp. 180–199.

Ceulemans, K., Molderez, I., Van Liedekerke, L., 2015. Sustainability reporting in higher education: A comprehensive review of the recent literature and paths for further research. J. Clean. Prod. 106, 127–143. https://doi.org/10.1016/j.jclepro.2014.09.052

Chiang, T., Mevlevioglu, G., Natarajan, S., Padget, J., Walker, I., 2014. Inducing [sub]conscious energy behaviour through visually displayed energy information: A case study in university accommodation. Energy Build. 70, 507–515. https://doi.org/10.1016/J.ENBUILD.2013.10.035

Chihib, M., Salmerón-Manzano, E., Manzano-Agugliaro, F., 2020. Benchmarking energy use at university of Almeria (Spain). Sustainability 12, 1–16. https://doi.org/10.3390/su12041336

Cho, H.M., Yun, B.Y., Yang, S., Wi, S., Chang, S.J., Kim, S., 2020. Optimal energy retrofit plan for conservation and sustainable use of historic campus building : Case of cultural property building. Appl. Energy 275, 115313. https://doi.org/10.1016/j.apenergy.2020.115313
Chung, M.H., Rhee, E.K., 2014. Potential opportunities for energy conservation in existing buildings on university campus: A field survey in Korea. Energy Build. 78, 176–182. https://doi.org/10.1016/j.enbuild.2014.04.018
Coccolo, S., Kaempf, J., Scartezzini, J.L., 2015. The EPFL campus in Lausanne: New energy strategies for 2050. Energy Procedia 78, 3174–3179. https://doi.org/10.1016/j.egypro.2015.11.776
Cortese, A.D., 2003. The Critical Role of Higher Education in Creating a Sustainable Future. Plan. High. Educ. 15–22.
Costa, M.L., Freire, M.R., Kiperstok, A., 2019. Strategies for thermal comfort in university buildings - The case of the faculty of architecture at the Federal University of Bahia, Brazil. J. Environ. Manage. 239, 114–123. https://doi.org/10.1016/j.jenvman.2019.03.004
Cypriano, J.G.I., Pinto, L.F., Machado, L.C., da Silva, L.C.P., Ferreira, L.S., 2019. Energy management methodology for energy sustainable actions in University of Campinas - Brazil, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012034. https://doi.org/10.1088/1755-1315/257/1/012034
Dai, J., Jiang, S., Li, J., Xu, X., Wu, M., 2019. The Influence of Layout on Energy Performance of University Building, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, pp. 1–6. https://doi.org/10.1088/1755-1315/371/2/022069
De Angelis, E., Ciribini, A.L.C., Tagliabue, L.C., Paneroni, M., 2015. The Brescia Smart Campus Demonstrator. Renovation toward a zero energy classroom building. Procedia Eng. 118, 735–743. https://doi.org/10.1016/j.proeng.2015.08.508
De Wilde, P., 2014. The gap between predicted and measured energy performance of buildings: A framework for investigation. Autom. Constr. 41, 40–49. https://doi.org/10.1016/j.autcon.2014.02.009
Drahein, A.D., De Lima, E.P., Da Costa, S.E.G., 2019. Sustainability assessment of the service operations at seven higher education institutions in Brazil. J. Clean. Prod. 212, 527–536. https://doi.org/10.1016/j.jclepro.2018.11.293
Dvorak, V., Zavrel, V., Torrens Galdiz, J.I., Hensen, J.L.M., 2020. Simulation-based assessment of data center waste heat utilization using aquifer thermal energy storage of a university campus. Build. Simul. https://doi.org/10.1007/s12273-020-0629-y
Erhart, D.K., Haag, M., Schmitt, A., Guerlich, D., Bonomolo, M., Eicker, U., 2016. Retrofitting Existing University Campus Buildings to Improve Sustainability and Energy performance, in: PLEA2016 Los Angeles - Cities, Buildings, People: Towards Regenerative Environments. pp. 1–8.
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 Sustain. Dev. 18, 49–57. https://doi.org/10.1016/j.esd.2013.10.005
Esfandyari, A., Norton, B., Conlon, M., McCormack, S.J., 2019. Design and performance of a campus photovoltaic electric vehicle charging station in a temperate climate. Sol. Energy 177, 762–771. https://doi.org/10.1016/j.solener.2018.12.005
Fernando, W., Gupta, N., Linn, H.H., Ozveren, C.S., 2018. Design of Optimum Configuration of a Hybrid Power System for Abertay University Campus, in: 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 2018. IEEE, pp. 1795–1800. https://doi.org/10.1109/EIConRus.2018.8317454
Fonseca, P., Moura, P., Jorge, H., de Almeida, A., 2018. Sustainability in university campus: options for achieving nearly zero energy goals. Int. J. Sustain. High. Educ. 19, 790–816. https://doi.org/10.1108/IJSHE-09-2017-0145
Forman, T., Mutschler, R., Guthrie, P., Soulti, E., Pickering, B., Byström, V., Lee, S.M., 2017. Improving Building Energy Performance in Universities: The Case Study of the University of Cambridge, in: Filho, W.L., Brandli, L., Castro, P., Newman, J. (Eds.), Handbook of Theory and Practice of Sustainable Development in Higher Education Volume 1. Springer International Publishing, pp. 245–266. https://doi.org/10.1007/978-3-319-47868-5_16
Geng, Y., Liu, K., Xue, B., Fujita, T., 2013. Creating a "green university" in China: a case of Shenyang University. J. Clean. Prod. 61, 13–19. https://doi.org/10.1016/J.JCLEPRO.2012.07.013
Granderson, J., Piette, M.A., Ghatikar, G., 2011. Building energy information systems: user case studies. Energy Effic. 4, 17–30. https://doi.org/10.1007/s12053-010-9084-4
Gu, Y., Wang, H., Robinson, Z.P., Wang, X., Wu, J., Li, X., Xu, J., Li, F., 2018. Environmental footprint assessment of green campus from a food-water-energy nexus perspective. Energy Procedia 152, 240–246. https://doi.org/10.1016/j.egypro.2018.09.109
Gu, Y., Wang, H., Xu, J., Wang, Y., Wang, X., Robinson, Z.P., Li, F., Wu, J., Tan, J., Zhi, X., 2019. Quantification of interlinked environmental footprints on a sustainable university campus: A nexus analysis perspective. Appl. Energy 246, 65–76. https://doi.org/10.1016/j.apenergy.2019.04.015
Guan, J., Nord, N., Chen, S., 2016. Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study. Energy Build. 124, 99–111. https://doi.org/10.1016/j.enbuild.2016.04.051
Gul, M.S., Patidar, S., 2015. Understanding the energy consumption and occupancy of a multi-purpose academic building. Energy Build. 87, 155–165. https://doi.org/10.1016/j.enbuild.2014.11.027
Gupta, R., Gregg, M., 2016. Empirical evaluation of the energy and environmental performance of a sustainably-designed but under-utilised institutional building in the UK. Energy Build. 128, 68–80. https://doi.org/10.1016/j.enbuild.2016.06.081
Hernandez-Aguilera, J.N., Anderson, W., Bridges, A.L., Fernandez, M.P., Hansen, W.D., Maurer, M.L., Nébié, E.K.I.,

Stock, A., 2021. Supporting interdisciplinary careers for sustainability. Nat. Sustain. https://doi.org/10.1038/s41893-020-00679-y
Hu, M., 2018. Optimal Renovation Strategies for Education Buildings - A novel BIM-BPM-BEM framework. Sustainability 10, 1–22. https://doi.org/10.3390/su10093287
Hua, Y., Göçer, Ö., Göçer, K., 2014. Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building. Build. Environ. 79, 124–137. https://doi.org/10.1016/j.buildenv.2014.04.029
Huang, L., Liu, Y., Krigsvoll, G., Johansen, F., 2018. Life cycle assessment and life cycle cost of university dormitories in the southeast China: Case study of the university town of Fuzhou. J. Clean. Prod. 173, 151–159. https://doi.org/10.1016/j.jclepro.2017.06.021
Huang, Y., Niu, J., Chung, T., 2012. Energy and carbon emission payback analysis for energy-efficient retrofitting in buildings—Overhang shading option. Energy Build. 44, 94–103. https://doi.org/10.1016/J.ENBUILD.2011.10.027
Husein, M., Chung, I.Y., 2018. Optimal design and financial feasibility of a university campus microgrid considering renewable energy incentives. Appl. Energy 225, 273–289. https://doi.org/10.1016/j.apenergy.2018.05.036
IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC. Geneva, Switzerland.
Jain, S., Pant, P., 2010. Environmental management systems for educational institutions: A case study of TERI University, New Delhi. Int. J. Sustain. High. Educ. 11, 236–249. https://doi.org/10.1108/14676371011058532
Jovanović, R., Sretenović, A.A., Živković, B.D., 2015. Ensemble of various neural networks for prediction of heating energy consumption. Energy Build. 94, 189–199. https://doi.org/10.1016/j.enbuild.2015.02.052
Kalkan, N., Bercin, K., Cangul, O., Morales, M.G., Saleem, M.M.K.M., Marji, I., Metaxa, A., Tsigkogianni, E., 2011. A renewable energy solution for Highfield Campus of University of Southampton. Renew. Sustain. Energy Rev. 15, 2940–2959. https://doi.org/10.1016/j.rser.2011.02.040
Karuchit, S., Puttipiriyangkul, W., Karuchit, T., 2020. Carbon Footprint Reduction from Energy-Saving Measure and Green Area of Suranaree University of Technology, Thailand. Int. J. Environ. Sci. Dev. 11, 170–174. https://doi.org/10.18178/ijesd.2020.11.4.1246
Kim, Y.K., Bande, L., Aoul, K.A.T., Altan, H., 2019. Using Energy Audit with POE Study to Reduce Energy Performance Gap in an Office Building in UAE, in: Kim, J., Noguchi, M., Altan, H. (Eds.), ZEMCH 2019 Zero Energy Mass Custom House 2019 International Conference. ZEMCH Network, Seoul, Korea, pp. 97–104. https://doi.org/ISBN: 979- 11- 961166- 1- 3
Koch, N., 2018. Green Laboratories: University Campuses as Sustainability "Exemplars" in the Arabian Peninsula. Soc. Nat. Resour. 31, 525–540. https://doi.org/10.1080/08941920.2017.1383546
Kolokotsa, D., Gobakis, K., Papantoniou, S., Georgatou, C., Kampelis, N., Kalaitzakis, K., Vasilakopoulou, K., Santamouris, M., 2016. Development of a web based energy management system for University Campuses: The CAMP-IT platform. Energy Build. 123, 119–135. https://doi.org/10.1016/j.enbuild.2016.04.038
Kumar, N.M., Sudhakar, K., Samykano, M., 2019. Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia. Int. J. Ambient Energy 40, 434–443. https://doi.org/10.1080/01430750.2017.1410226
Kurland, N.B., 2011. Evolution of a campus sustainability network: A case study in organizational change. Int. J. Sustain. High. Educ. 12, 395–429. https://doi.org/10.1108/14676371111168304
Kwan, C.L., Hoffmann, A., 2010. The Los Angeles Community College District: Establishing a net-zero energy campus, in: Sustainable Communities Design Handbook. Elsevier Inc., pp. 181–215. https://doi.org/10.1016/B978-1-85617-804-4.00011-2
Kwan, C.L., Kwan, T.J., 2011. The financials of constructing a solar PV for net-zero energy operations on college campuses. Util. Policy 19, 226–234. https://doi.org/10.1016/j.jup.2011.07.003
Lawrence, R., Keime, C., 2016. Bridging the gap between energy and comfort: Post-occupancy evaluation of two higher-education buildings in Sheffield. Energy Build. 130, 651–666. https://doi.org/10.1016/j.enbuild.2016.09.001
Leal Filho, W., Salvia, A.L., Paço, A. do, Anholon, R., Gonçalves Quelhas, O.L., Rampasso, I.S., Ng, A., Balogun, A.-L., Kondev, B., Brandli, L.L., 2019. A comparative study of approaches towards energy efficiency and renewable energy use at higher education institutions. J. Clean. Prod. 237, 117728. https://doi.org/10.1016/j.jclepro.2019.117728
Leal Filho, W., Wu, Y.C.J., Brandli, L.L., Avila, L.V., Azeiteiro, U.M., Caeiro, S., Madruga, L.R. da R.G., 2017. Identifying and overcoming obstacles to the implementation of sustainable development at universities. J. Integr. Environ. Sci. 14, 93–108. https://doi.org/10.1080/1943815X.2017.1362007
Legorburu, G., Smith, A.D., 2020. Incorporating Observed Data into Early Design Energy Models for Life Cycle Cost and Emissions Analysis of Campus Buildings. Energy Build. 110279. https://doi.org/10.1016/j.enbuild.2020.110279
Leon, I., Oregi, X., Marieta, C., 2020. Contribution of University to Environmental Energy Sustainability in the City. Sustainability 12, 1–21. https://doi.org/10.3390/su12030774
Leon, I., Oregi, X., Marieta, C., 2018. Environmental assessment of four Basque University campuses using the NEST tool. Sustain. Cities Soc. 42, 396–406. https://doi.org/10.1016/j.scs.2018.08.007
Li, X., Chen, S., Li, H., Lou, Y., Li, J., 2020. Multi-dimensional analysis of air-conditioning energy use for energy-saving management in university teaching buildings. Build. Environ. 185, 107246. https://doi.org/10.1016/j.buildenv.2020.107246
Liu, Q., Ren, J., 2020. Research on the Building Energy Efficiency Design Strategy of Chinese Universities Based on Green Performance Analysis. Energy Build. 110242. https://doi.org/10.1016/j.enbuild.2020.110242
Lozano, R., Lukman, R., Lozano, F.J., Huisingh, D., Lambrechts, W., 2013. Declarations for sustainability in higher

education: Becoming better leaders, through addressing the university system. J. Clean. Prod. 48, 10–19. https://doi.org/10.1016/j.jclepro.2011.10.006
Maiorano, J., Savan, B., 2015. Barriers to energy efficiency and the uptake of green revolving funds in Canadian universities. Int. J. Sustain. High. Educ. 16, 200–216. https://doi.org/10.1108/IJSHE-07-2012-0062
Mancini, F., Clemente, C., Carbonara, E., Fraioli, S., 2017. Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria. Energy Procedia 126, 195–202. https://doi.org/https://doi.org/10.1016/j.egypro.2017.08.140
Manni, M., Tecce, R., Cavalaglio, G., Coccia, V., Nicolini, A., Petrozzi, A., 2017. Architectural and energy refurbishment of the headquarter of the University of Teramo. Energy Procedia 126, 565–572. https://doi.org/https://doi.org/10.1016/j.egypro.2017.08.290
Masoso, O.T., Grobler, L.J., 2010. The dark side of occupants' behaviour on building energy use. Energy Build. 42, 173–177. https://doi.org/10.1016/J.ENBUILD.2009.08.009
Medrano, M., Martí, J.M., Rincón, L., Mor, G., Cipriano, J., Farid, M., 2018. Assessing the nearly zero-energy building gap in university campuses with a feature extraction methodology applied to a case study in Spain. Int. J. Energy Environ. Eng. 9, 227–247. https://doi.org/10.1007/s40095-018-0264-x
Mewes, D., Monsalve, P., Gustafsson, I., Hasan, B., Palén, J., Nakakido, R., Capobianchi, E., Österlund, B., 2017. Evaluation Methods for Photovoltaic Installations on Existing Buildings at the KTH Campus in Stockholm, Sweden. Energy Procedia 115, 409–422. https://doi.org/10.1016/j.egypro.2017.05.038
Mizuno, Y., Kida, K., Kiyoyama, K., Kishikawa, T., Ikeda, M., Kamohara, S., Tanaka, R., Shimojima, M., Hinata, H., Tanaka, Y., 2013. System with Modelling of Green Energy Devices by Constructing a Micro-Grid System in University Campus (report II), in: ICRERA 2013 - International Conference on Renewable Energy Research and Applications. IEEE, pp. 321–325.
Mohammadalizadehkorde, M., Weaver, R., 2020. Quantifying potential savings from sustainable energy projects at a large public university: An energy efficiency assessment for texas state university. Sustain. Energy Technol. Assessments 37, 100570. https://doi.org/10.1016/j.seta.2019.100570
Mohammadalizadehkorde, M., Weaver, R., 2018. Universities as Models of Sustainable Energy-Consuming Communities? Review of Selected Literature. Sustainability 10, 3250. https://doi.org/10.3390/su10093250
Mukherji, R., Mathur, V., Bhati, A., Mukherji, M., 2019. Assessment of 50 kWp rooftop solar photovoltaic plant at The ICFAI University, Jaipur: A case study. Environ. Prog. Sustain. Energy 39, 1–14. https://doi.org/10.1002/ep.13353
Mytafides, C.K., Dimoudi, A., Zoras, S., 2017. Transformation of a university building into a zero energy building in Mediterranean climate. Energy Build. 155, 98–114. https://doi.org/10.1016/j.enbuild.2017.07.083
Nagpal, S., Reinhart, C.F., 2018. A comparison of two modeling approaches for establishing and implementing energy use reduction targets for a university campus. Energy Build. 173, 103–116. https://doi.org/10.1016/j.enbuild.2018.05.035
Ng, T.F., Firdaus, A., Shabudin, A., Hassan, M.S., Muslim, M., Ibrahim, K., 2017. Energy Consumption in Student Hostels of Universiti Sains Malaysia: Energy Audit and Energy Efficiency Awareness, in: Filho, W.L., Mifsud, M., Shiel, C., Pretorius, R. (Eds.), Handbook of Theory and Practice of Sustainable Development in Higher Education Volume 3. Springer International Publishing, pp. 191–207. https://doi.org/10.1007/978-3-319-47895-1_!2
Nik, V.M., Coccolo, S., Kämpf, J., Scartezzini, J.L., 2017. Investigating the importance of future climate typology on estimating the energy performance of buildings in the EPFL campus. Energy Procedia 122, 1087–1092. https://doi.org/10.1016/j.egypro.2017.07.434
Omar, W., Abdul Rahman, A., Fadhil Md Din, M., Mat Taib, S., Krishnan, S., Safitri Zen, I., Hanafi, N., 2018. Greening campus experience: moving towards living laboratory action plan, in: E3S Web of Conferences. EDP Sciences. https://doi.org/10.1051/e3sconf/20184802006
Opel, O., Strodel, N., Werner, K.F., Geffken, J., Tribel, A., Ruck, W.K.L., 2017. Climate-neutral and sustainable campus Leuphana University of Lueneburg. Energy 141, 2628–2639. https://doi.org/10.1016/j.energy.2017.08.039
Park, E., Kwon, S.J., 2016. Solutions for optimizing renewable power generation systems at Kyung-Hee University's Global Campus, South Korea. Renew. Sustain. Energy Rev. 58, 439–449. https://doi.org/10.1016/j.rser.2015.12.245
Patiño-Cambeiro, F., Armesto, J., Bastos, G., Prieto-López, J.I., Patiño-Barbeito, F., 2019. Economic appraisal of energy efficiency renovations in tertiary buildings. Sustain. Cities Soc. 47, 101503. https://doi.org/10.1016/j.scs.2019.101503
Petratos, P., Damaskou, E., 2015. Management strategies for sustainability education, planning, design, energy conservation in California higher education. Int. J. Sustain. High. Educ. 16, 576–603. https://doi.org/10.1108/IJSHE-03-2014-0038
Pini, F., Verzari, S., D'Angelo, A., 2019. Energy Savings in an University Educational Building - the Case of Chemistry Building of Sapienza, in: Proceedings of the 5th World Congress on New Technologies (NewTech'19). pp. 1–7. https://doi.org/10.11159/icert19.123
Podoprigora, Y., Zaharova, T., Eliseev, A., Crozat, D., 2020. Energy Efficiency and Environmental Friendliness of University Campuses, in: International Scientific Conference "Far East Con" (ISCFEC 2020). Atlantis Press, pp. 2429–2434. https://doi.org/10.2991/aebmr.k.200312.337
Pusat, S., Akkoyunlu, M.T., 2018. Evaluation of wind energy potential in a university Campus. Int. J. Glob. Warm. 14, 118–130. https://doi.org/10.1504/IJGW.2018.10002423
Ruth, C.E., Byrne, R., Hewitt, N.J., MacArtain, P., 2019. Electricity autoproduction, storage and billing: A case study

at Dundalk Institute of Technology, Ireland. Sustain. Energy Technol. Assessments 35, 257–264. https://doi.org/10.1016/j.seta.2019.07.008
Ruviaro, A., Sperandio, M., Ebert, P., Boaski, M.A.F., Mallmann, J.F., 2018. Energy Efficiency Studies in a Brazilian University Campus, in: Proceedings of the 2018 IEEE PES Transmission and Distribution Conference and Exhibition - Latin America, T and D-LA 2018. IEEE. https://doi.org/10.1109/TDC-LA.2018.8511781
Samaan, M.M., Farag, O., Khalil, M., 2018. Using simulation tools for optimizing cooling loads and daylighting levels in Egyptian campus buildings. HBRC J. 14, 79–92. https://doi.org/10.1016/j.hbrcj.2016.01.001
Sanguinetti, A., Pritoni, M., Salmon, K., Meier, A., Morejohn, J., 2017. Upscaling participatory thermal sensing: Lessons from an interdisciplinary case study at University of California for improving campus efficiency and comfort. Energy Res. Soc. Sci. 32, 44–54. https://doi.org/10.1016/J.ERSS.2017.05.026
Sesana, M.M., Grecchi, M., Salvalai, G., Rasica, C., 2016. Methodology of energy efficient building refurbishment: Application on two university campus-building case studies in Italy with engineering students. J. Build. Eng. 6, 54–64. https://doi.org/10.1016/j.jobe.2016.02.006
Shea, R.P., Kissock, K., Selvacanabady, A., 2019. Reducing university air handling unit energy usage through controls-based energy efficiency measures. Energy Build. 194, 105–112. https://doi.org/10.1016/j.enbuild.2019.04.020
Timm, S.N., Deal, B.M., 2016. Effective or ephemeral? the role of energy information dashboards in changing occupant energy behaviors. Energy Res. Soc. Sci. 19, 11–20. https://doi.org/10.1016/j.erss.2016.04.020
Udas, E., Wölk, M., Wilmking, M., 2018. The “carbon-neutral university” – a study from Germany. Int. J. Sustain. High. Educ. 19, 130–145. https://doi.org/10.1108/IJSHE-05-2016-0089
Velazquez, L., Munguia, N., Platt, A., Taddei, J., 2006. Sustainable university: what can be the matter? J. Clean. Prod. 14, 810–819. https://doi.org/10.1016/j.jclepro.2005.12.008
Wanke, A., 2017. Sustainable Campus Management at Freie Universitat Berlin - Governance and Participation Matter, in: Filho, W.L., Mifsud, M., Shiel, C., Pretorius, R. (Eds.), Handbook of Theory and Practice of Sustainable Development in Higher Education Volume 3. Springer International Publishing, pp. 27–45. https://doi.org/10.1007/978-3-319-47895-1_2
Washom, B., Dilliot, J., Weil, D., Kleissl, J., Balac, N., Torre, W., Richter, C., 2013. Ivory tower of power: Microgrid implementation at the University of California, San Diego. IEEE Power Energy Mag. 11, 28–32. https://doi.org/10.1109/MPE.2013.2258278
Wiryadinata, S., Morejohn, J., Kornbluth, K., 2019. Pathways to carbon neutral energy systems at the University of California, Davis. Renew. Energy 130, 853–866. https://doi.org/10.1016/j.renene.2018.06.100
Wisecup, A.K., Grady, D., Roth, R.A., Stephens, J., 2017. A comparative study of the efficacy of intervention strategies on student electricity use in campus residence halls. Int. J. Sustain. High. Educ. 18, 503–519. https://doi.org/10.1108/IJSHE-08-2015-0136
Wright, T., Horst, N., 2013. Exploring the ambiguity: What faculty leaders really think of sustainability in higher education. Int. J. Sustain. High. Educ. 14, 209–227. https://doi.org/10.1108/14676371311312905
Wright, T.S.A., 2002. Definitions and frameworks for environmental sustainability in higher education. Int. J. Sustain. High. Educ. 3, 203–220. https://doi.org/10.1108/14676370210434679
Xue, Z., Liu, H., Zhang, Q., Wang, J., Fan, J., Zhou, X., 2020. The Impact Assessment of Campus Buildings based on a Life Cycle Assessment-Life Cycle Cost Integrated Model. Sustainability 12, 1–24. https://doi.org/10.3390/su12010294
Yarime, M., Tanaka, Y., 2012. The Issues and Methodologies in Sustainability Assessment Tools for Higher Education Institutions: A Review of Recent Trends and Future Challenges. J. Educ. Sustain. Dev. 6, 63–77. https://doi.org/10.1177/097340821100600113
Zhou, X., Zhu, Y., Peng, H., Zeng, Z., Huang, Y., Li, L., 2019. Energy efficiency optimization for building envelopes on a green campus in Guangzhou, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012072. https://doi.org/10.1088/1755-1315/238/1/012072
Zhu, Y., Wang, F., Yan, J., 2018. The Potential of Distributed Energy Resources in Building Sustainable Campus: The Case of Sichuan University. Energy Procedia 145, 582–585. https://doi.org/10.1016/j.egypro.2018.04.085