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Procedia Computer Science 198 (2022) 608–613

Procedia Computer Science

www.elsevier.com/locate/procedia

International Workshop of Innovation and Technologies (IWIT 2021)
November 1-4, 2021, Leuven, Belgium

Modeling Energy-Efficient Policies in Educational Buildings – A Literature Review

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Abstract

This work focuses on a literature review that characterizes the most prominent lines of research on energy efficiency in educational buildings, including energy use intensity (EUI); the implementation of energy efficiency measurement; the results obtained by decreasing the EUI, energy consumption, and CO_2 emission; and the main relationships between energy consumption incidence variables. For these purposes, a systematic literature review is structured based on specialized databases, wherein the information is assessed using spreadsheets and visualization tools such as VOSviewer®. From the review, the authors were able to determine that the integration of energy efficiency with educational institutions is a growing line of research that offers opportunities for building an environmentally sustainable educational culture with high social impact. This paper discusses different modeling systems and policy assessment options that identifies complexity and dynamics constraints to explore new simulation methodologies, such as systems dynamics providing sustainable approaches within industry 4.0 based on the assessment of national energy efficiency policies through dynamic simulation models that allow significant savings in energy-consuming sectors.

Keywords: energy efficiency; buildings; educational buildings; modeling; system dynamics.

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10.1016/j.procs.2021.12.294

1. Introduction

As it may provide a solution to increasing energy consumption by means of fostering energy security, climate change mitigation, and a transition to new energy sources, as well as reducing environmental impacts, energy efficiency has become an important component in national policies [1]–[4]. In fact, the European Commission estimates that the implementation of energy efficiency policies may potentially lead to 25% savings in energy demand [5]. In addition, energy efficiency also encompasses affordability, energy security, and environmental sustainability variables [6]. In sectors with high energy demands, such as energy, industrial, and transportation sectors, studies typically consider energy efficiency within the sectors’ policies and measures for reducing energy consumption and related emissions [7]–[9]. The residential sector can also be included in this category as it has also started maintaining focus on energy demand and good consumption habits to secure energy conservation [10]–[12].

For large-population systems, such as hospitals, universities, high schools, and educational institutions, this line of research is recent (2010). Nonetheless, it has exhibited sustained growth in annual publications. The importance of assessing the impact of energy efficiency policies and measures in these institutions is since these policies and measures constitute a critical component of the society as well as for the economic development of nations against the challenging task of stimulating education, scientific research, and social impact. [13].

This work proposes a literature review that characterizes the most prominent lines of research on energy efficiency in schools and other academic institutions, including energy use intensity (EUI); the implementation of energy efficiency measurement; the results obtained by decreasing the EUI, energy consumption, and CO2 emissions; and main relationships between energy consumption incidence variables.

2. Materials and Methods

This study aims to identify the opportunities for modelling energy efficiency policies in schools and academic institutions. For these purposes, a systematic literature review is structured around specialized databases, including Scopus, Science Direct, Web of Knowledge, and Google Scholar. The search equation is centred on scientific papers published from 2010 to 2019 using the following criteria: “energy efficiency” AND “school” and “energy efficiency” AND “educational building.” In addition, the following keywords are included in the equation: “energy,” “energy efficiency,” “school,” “educational buildings,” and “modelling.” Fig. 1. summarizes the corresponding search results. In academic research, the implementation and assessment of energy efficiency policies in educational buildings is considered a relatively new branch. However, this line of research has experienced rapid growth as it encompasses other critical lines of research, such as energy efficiency, environmental sustainability, economic sustainability, and nonconventional sources of renewable energy, in addition to raising awareness and education on climate change and mitigation options. In fact, current research trends focus on modernizing buildings and designing academic campuses with energy saving and self-generation features based on renewable sources, such as wind and solar power systems. Furthermore, energy efficiency measures are considered as possible replacements for lighting fixtures and air conditioning equipment, according to the needs of each institution. These measures are included in government energy efficiency policies and are framed in different climate change mitigation agreements, such as Intended Nationally Determined Contributions (INDCs) [2]; these research papers address energy sector characterization, energy planning, and the assessment of energy saving measures and policies using optimization and simulation models [14].

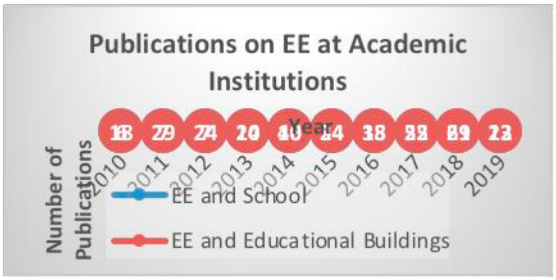

Fig. 1. Annual publications on EE at higher-education institutions. Source: Adapted from Scopus, 2019.

Regarding the distribution of research studies by country, United States and China are the prevailing countries; this may be due to the high correlation they exhibit with population growth, population, migration effects, industrialization, economic development, pollution, and research capabilities [15]. Other countries, such as the United Kingdom, although not as polluting, are highly developed economic powers that gear public policies toward reducing CO2 emissions and fostering sustainable energy self-sufficiency [16].

3. Results and Discussions

3.1. Energy Efficiency in Educational Buildings

From an industrial standpoint, energy efficiency is commonly defined as the set of actions aimed at optimizing the relationship between energy consumption and productivity; the latter being understood as the number of products and/or services obtained from a given amount of energy [4]. At the national level, energy efficiency is considered as a mechanism for streamlining the energy resources available and guaranteeing proper power supply through new technologies and the adoption of good consumption habits. Based on the database searches performed, the VOSviewer® software [17] is used to visualize the results obtained, shown in Fig. 2.

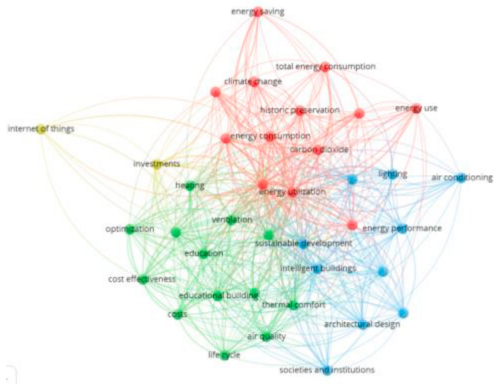

Fig. 2. Keyword visualization.

As it may be observed in Fig. 2, four large groups or clusters are clearly defined. For example, the red cluster includes academic works characterizing energy consumption in academic buildings through audits, their relationship with climate change, and other aspects, such as the role heating insulation plays in building efficiency. Herein, the works by [18], are prominent. The blue cluster includes the papers that assess power consumption from different devices at these buildings. In addition, the works included in this cluster discuss intelligent buildings and matters related to energy performance, using their relationship with sustainable development as a common thread [18].

The green cluster encompasses articles on cost analysis, life cycle, air quality, and heating in educational buildings. One of the common elements in these works is the focus on reconditioning equipment for improving efficiency and decreasing energy consumption [4], [10], [6]. Finally, the yellow cluster only contains two of the most recent terms identified in the literature review: the Internet of Things and investments. Both terms are widely related to improvements in equipment efficiency and reducing electricity consumption in educational buildings.

In fact, studies focusing on universities and colleges report average EUI values of approximately 79–251 kWh/m2/yr [19]. For example, [21] reported EUI values of approximately 223 kWh/m2/yr at 11 South Korean universities, with a possible 6%–30% energy savings achieved by changing the room temperature and occupant behaviour. Most energy consumption characterizations at academic buildings denote that over 66% is associated with air conditioning systems (heating, air conditioning, and ventilation), followed by 14% in lighting, 7% in water heating systems, 5% in computers and office equipment, and 3% in kitchen and refrigeration appliances [18]. In addition, the energy consumption structure is composed of electricity (93%) and natural gas (7%), thus implying that electricity usage is the key factor for the implementation of energy conservation and efficiency measures.

The assessed energy efficiency measures are mostly associated with changing lighting fixtures, the overall replacement of heating, cooling, and air conditioning systems, and good conservation and saving practices regarding energy consumption. Along these lines, [19] discussed key energy consumption characterization variables at 23

Chinese schools and found lighting fixtures and air conditioners to be the largest consumption areas. With the implementation of HVAC systems with variable air volume and refrigerant and heat recovery systems, energy usage becomes more efficient, reporting up to a 33% reduction in energy consumption when compared to conventional systems. In addition, the shift to LED lights can result in potential energy savings of 40% and their market price is 75% lower than conventional lights.

Despite the importance of implementing energy management systems and energy efficiency measures for achieving environmental sustainability, there are hurdles that hinder their dissemination and application at certain institutions. According to [23], these barriers can be aggregated into five blocks: 1) Economic: market and non-market failures; 2) Structural: infrastructure, energy trading capacity, and interconnection networks; 3) Organizational: environmental culture and learning capabilities; 4) Institutional: laws, policies, regulations, and policy instruments; and 5) Behavioural: sources of information. However, statistical and optimization methods are still more frequently used than modelling and simulation tools [14]. In this line of research, the most prominent models concentrate on finding correlations between variables and evaluating different alternative solutions to specific resource allocation and cost reduction problems associated with energy consumption and greenhouse gas emissions; some even include econometric analyses [24]. Nevertheless, current research trends are focused on assessing climate change mitigation policies and measures aimed at reducing carbon and fossil fuel-based energy, with high exploration potential into economic sectors other than the energy, transportation, industrial, and residential sectors [3], [10], [24], which have already been widely researched. The next section unveils research opportunities for modelling energy efficiency policies and measures for other critical sectors, such as the education sector.

3.2. Modeling Energy Efficiency Policies in Educational Buildings

Problem modelling facilitates understanding systems in terms of their structure, complexity, variable relationships, and proposing solution alternatives through different methodologies [14]. Each model differs in its object of study, scope, methodology, and time horizon. According to their modelling methodology, models can be classified as econometric models, optimization models, and simulation models [22].

Econometric models assess the effects from these policies in terms of macroeconomic variables, considering a perfect balance and a high level of aggregation (nation, region, and global) [24]. Optimization models use different techniques to find the best option based on the objectives and constraints established [25]. Finally, Simulation models, rather than focusing on finding an optimal decision rule, assess system behaviour in different scenarios. These models facilitate system learning in terms of reviewing its structure and the behavioural equations governing relationships between variables to support policy assessments [22].

System dynamics has also gained increasing interest for examining highly complex dynamic systems, exerting high impact on assessing and implementing climate change mitigation and energy efficiency policies, especially in the energy, industrial, and residential sectors. For the industrial sector, the work focuses on characterizing power consumption in energy-intensive production processes and on assessing energy efficiency policies and measures aimed at reducing power consumption and CO2 emissions. In this context, [27] studied the production and export scenarios for the Iranian cement industry using a simulation model encompassing demand, production, energy consumption, and CO2 emission blocks; the simulation results revealed that the repeal of all current energy subsidies and the implementation of corrective policies in this industry could potentially lead to 29% and 21% reductions in the consumption of natural gas and electricity, respectively, as well as a 22% reduction in CO2 emissions. Similar studies exploring other energy-intensive industries can be found at [7], [8].

Similarly, [6] proposed other modelling exercises. For example, the authors developed a platform for assessing greenhouse gas mitigation policies in the residential electricity sector in Colombia, wherein policies such as the micro-generation of solar and wind power, and the implementation of feed-in tariffs were examined. [30] also generated a simulation model for replacing old refrigerators in Colombian households based on VAT exemption policies and government subsidies. Other studies focusing on this sector were proposed by [24].

The results obtained from the literature searches on system dynamics and energy efficiency at academic institutions reveal that the number of publications is low, which unveils multiple opportunities for generating research on policy modelling. Fig. 3 lists the number of works published in 2010–2019.

Fig. 3. Annual publications on system dynamics and energy efficiency at higher-education institutions. Source: Adapted from Scopus, 2019.

In their paper, [31] discussed the impact exerted by different project prioritization strategies on the success of the revolving fund sustainability program, developing a novel modelling approach for assessing sustainability decisions using the system dynamics approach at a major university and considering three program performance measures (net present value, program length, and carbon dioxide reduction per unit). This model evaluated the effects from five common project prioritization strategies on three program performance measures across a wide range of initial investment levels. For the industrial sector, [32] proposed a system dynamics model for appraising energy model scenarios in Ecuador. The analysis describes the existing relationship among dynamic factors such as policies, energy dependence and energy demands, forecasting future scenarios and trends in energy supply and demand, and CO2 emissions up until 2030. As per the results from the system dynamics model, if Ecuador can expand its energy efficiency projects and increase funding for renewable energy sources, a 13% reduction in energy demands is feasible. According to research conducted by [33] smart universities, it is strongly anchored to IT, with particular emphasis on the concept of the Internet of Things, which interconnect systems and people, stimulating innovation to facilitate a set of objectives for the benefit of all, helping to minimise problems related to administration. Physical and financial resources, implementation of controls for the consumption of natural resources, security systems and emergency responses. The implementation of the IoT through the IT allows the development of models of system dynamics methodology, used to evaluate national energy efficiency policies that contribute to the reduction of energy consumption.

4. Conclusions

The literature review process performed in this study identified that integrating energy efficiency at academic institutions is a growing line of research aimed at leveraging high population density levels to develop an educational culture on energy consumption and climate change to foster good consumption habits, environmental sustainability, and social development coupled with high economic impact. The main studies in this line focus on the implementation of energy efficiency measures for reducing electricity consumption by replacing electronic air conditioning equipment, using LED-based lighting systems, leveraging solar power, and retrofitting infrastructure toward intelligent buildings. These models have achieved their purposes as they proposed feasible solutions for reducing energy consumption, costs, and CO2 emissions throughout the entire energy generation process while exploring different options for self-generating clean energy, such as using wind and solar power. However, system dynamics and complexity modeling constraints have been identified in some discrete simulation and optimization models. As these models fail to consider nonlinear relationships, causal relationships, decision-making delays, and side effects and co-benefits associated with policy assessment and integration, these constraints compromise the reliability of model results and their supporting role in the decision-making process. In addition, the need for developing tools that can steer decision-making processes toward the development of government policies for climate change mitigation, considering the specific conditions of each system under study, still prevails.

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