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A comprehensive review of obstacles and drivers to building energy-saving technologies and their association with research themes, types of building, and geographic regions

Cristino, T.M.¹, Lotufo, F.A.¹, Delinchant, B.², Wurtz, F.², Faria Neto, A.^{1*}
talitamaryane@hotmail.com – francisco.lotufo@unesp.br – benoit.delinchant@g2elab.grenoble-inp.fr –
frederic.wurtz@g2elab.grenoble-inp.fr – antfarianeto@gmail.com

1 = São Paulo State University (UNESP), School of Engineering, Guaratinguetá, Brazil

2 = University of Grenoble Alpes, CNRS, Grenoble INP, G2Elab, Grenoble, France

* Corresponding author:

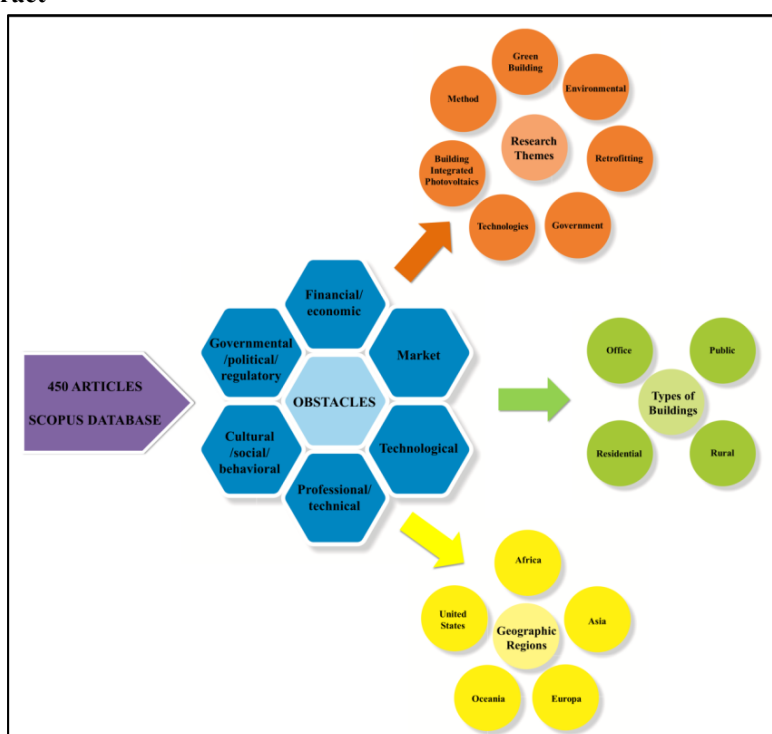
Antonio Faria Neto

E-mail address: antfarianeto@gmail.com

São Paulo State University (UNESP), School of Engineering, Guaratinguetá, Electrical Department

Av. Dr Ariberto Pereira da Cunha, 333, Portal das Colinas, Guaratinguetá CEP 12516-640 – São Paulo, Brazil. Tel +55(12) 3123-2147

Graphical abstract



Abstract

The building sector has played an important role in energy consumption over the last few decades, demanding actions to decrease it. A way to reach this goal, without affecting the occupants' welfare, is the adoption of building energy-efficient (BEE) technologies. There are several of these technologies available, bringing lots of benefits. However, there are barriers that hinder their adoption. Before overcoming such barriers, it is necessary to know them. Thus, after examining 450 publications, from 2000 to 2018, only eight presented some kind of taxonomy to the barriers, ranging from three to five categories, showing that some barriers were perhaps not considered. The dependence relationship of the barriers and the types of buildings and geographical region as well as their evolution has not yet been evaluated. The recommendations to overcome such barriers are spread throughout the literature and have not yet been compiled. This review gathered 105 barriers that were grouped into six categories (Financial, Market, Technological, Professional, Political and Behavioural), followed by their respective timelines, as well as the dependence relationship of them and the types of buildings and geographical regions. A compilation of the strategies to overcome such barriers is also presented. These results, besides supporting the formulation of policies for the adoption of BEE technologies, clarify the structure of each group of barriers and allow

researchers to identify the most relevant ones for their realities followed by the starting point to overcome them, focusing their attention on neuralgic points.

Highlights

- Twenty-seven obstacles to the adoption of building energy-efficient technologies were identified.
- The obstacles were grouped into six categories.
- The temporal distribution of the obstacles was constructed.
- Strategies to overcome the obstacles were compiled.
- The dependence of the obstacles on types of buildings and geographical regions was assessed.

Keywords

Barriers; Energy efficiency; Energy-efficient technologies; Energy saving; Building energy efficiency; Buildings

Word Count: 9,986

1. Introduction

Energy has been considered one of the most important factors for the growth of the world economy, which is why the demand for electricity has been increasing over the last few decades [1-6]. The increase in energy consumption brings with it several concerns, such as the shortage of primary energy resources, the consequent search for new sources of energy, and the environmental impacts, mainly the increase in greenhouse gas emissions [6-8].

For many years, the industrial sector had been the target of energy conservation measures, since it had been seen as the sector that was responsible for most of the energy consumption. However, as time went by, energy consumption shifted towards the building sector, i.e. residential, commercial, and public buildings [6,9].

According to the International Energy Agency [10], buildings are responsible for almost 36% of total energy consumption. It is estimated that, beyond the impact on electricity consumption, buildings account for 40% of total greenhouse gas emissions.

Thus, it is necessary to identify a way to reduce the demand for energy without affecting the economic growth of nations [9,11]. The best approach to reach such a goal without affecting the occupants' welfare is the adoption of Building Energy-Efficient (BEE) technologies [8,12,13].

There are several BEE technologies concerned with the building envelope, such as heating, ventilation, and air-conditioning (HVAC) systems, lighting, renewable energy, etc., which are capable of improving the energy efficiency of the building [8,14-23].

According to Yeatts et al. [23] and Mihic et al. [24], buildings that adopt energy-efficient technologies, as well as increasing energy performance, accumulate several benefits for the occupants, such as reduced energy bills, increased thermal comfort, moderated indoor temperatures, low humidity, better air quality, and low greenhouse gas emissions [12,13,19,24-27]. The potential for energy saving and the reduction in environmental impacts depends on the extent to which BEE technologies are being applied [9,15,28-30]. Furthermore, the construction costs of efficient buildings are slightly higher (5–15%) when compared to regular buildings [13,23,31,32].

Despite all of the benefits brought by BEE technologies, they have not been widely adopted, so the theoretical potential for reducing electricity consumption has not been reached [33,34]. This phenomenon is known as the energy-efficiency gap [35,36].

The energy-efficiency gap has been studied for decades [35-41]. There are several definitions of this phenomenon. The seminal paper by Jaffe and Stavins [36] defined the “energy-efficiency gap” as a difference between the optimal and observed level of energy saving; i.e., there is an unrealised potential consumption reduction due to barriers to the adoption of energy-saving technologies.

The energy-efficiency gap is also defined as the hypothetical level of energy efficiency that can be achieved by overcoming all obstacles to the adoption of energy-efficient technologies [39]. In brief, the “energy-efficiency gap” is due to the existence of barriers to the adoption of energy-efficient technologies [40].

The cause of the “energy-efficiency gap” is determined by the existence of obstacles, or barriers, that act as mechanisms to inhibit the adoption of energy-efficient technologies even though they are

economically viable and bring numerous benefits [13,33,42-45]. Therefore, to fill this gap, it is first necessary to identify the obstacles that hinder the adoption of BEE technologies.

After examining 450 publications concerned with BEE technologies, from 2000 to 2018, only 58 dealt with barriers; of these, only eight [6,34,40,42,43,46-48] presented some kind of classification, or taxonomy, to the barriers, ranging from three to five categories. This means that it is quite possible that none of the articles presented all of the barriers, making it necessary to search the literature to identify all of the barriers. Still no article evaluates the dependence relationship of the barriers and types of buildings (residential, commercial, etc.) and the geographical region (North America, Asia, etc.). The recommendations to overcome the barriers are spread throughout the literature, making it necessary to compile them. It would be valuable to see the evolution of these barriers over time. However, the literature has not provided such information.

Therefore, this article aims to identify and classify the obstacles to BEE technologies, along with their respective timelines, through a comprehensive literature review, and to compile the recommendations to overcome them, as well as the dependence between them and the types of buildings and geographical regions. As a plus, this article will investigate the dependence relationship of the barriers and some research themes formerly defined by Cristino et al. [49] within the field of knowledge of building energy efficiency.

This manuscript is organised into five sections. Section 2 presents a detailed discussion of the methodological approach employed to carry out the research. Section 3 presents the obstacles and their classification into groups, as well as the strategies, pointed out by the authors, to overcome them. Finally, a temporal distribution of the barriers is also included in this section. In section 4, the titles of the articles from which the barriers were sourced were scanned for relevant information, resulting in a set of significant words that were classified into three categories: research themes, geographical region and type of building in which the research was carried out. The conclusions will be summarised in Section 5.

2. Method for analysis

The literature review consists of five steps, which are described below. Fig. 1 illustrates the procedure flow employed to carry out this study.

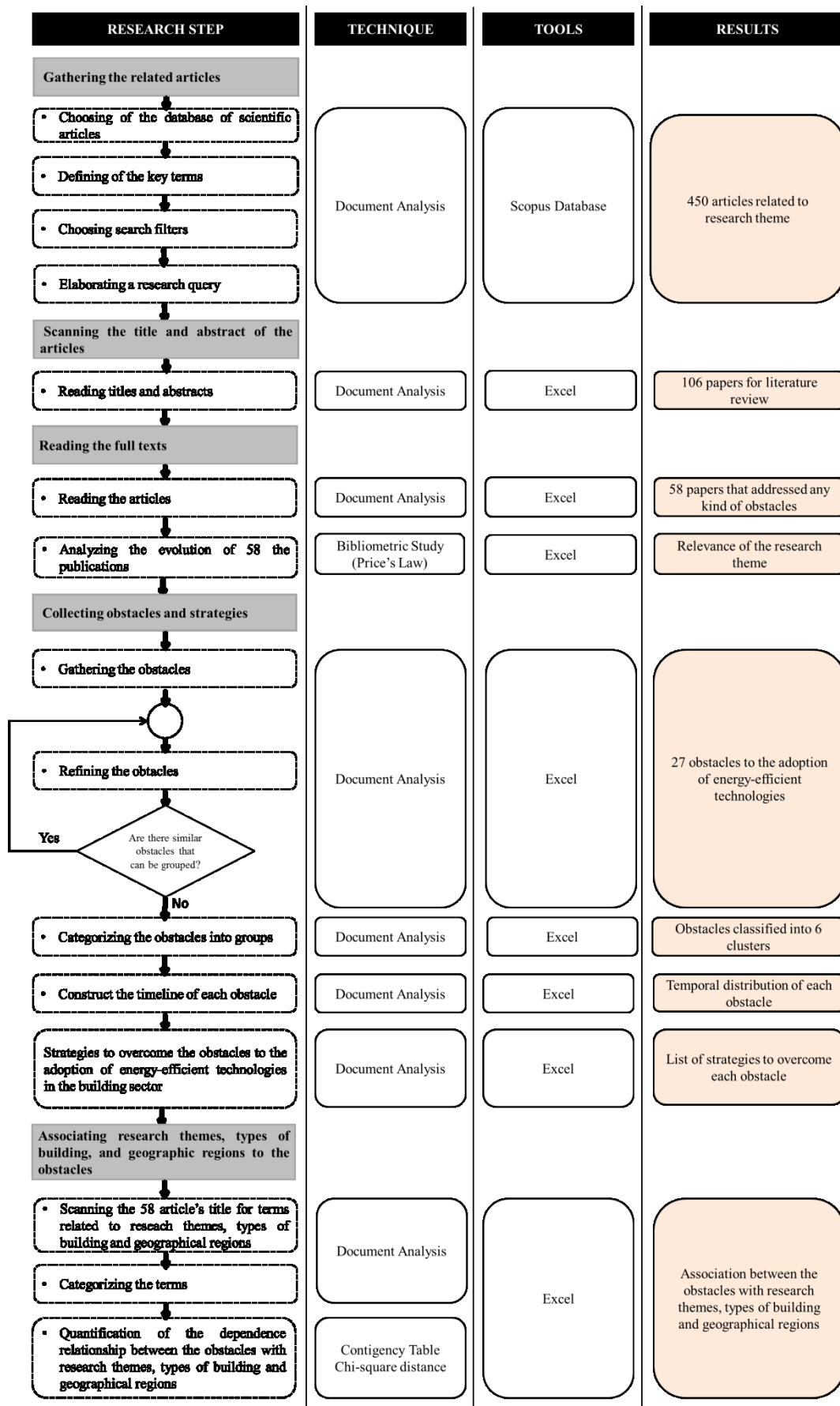


Fig. 1 Research methodological flow.

2.1 Gathering the related articles

In the first step, before properly formulating the problem, it was necessary to carry out a preliminary literature review; however, before this, it was necessary to gather the papers dealing with the main subject.

SCOPUS was the database chosen for this research, since it has wide coverage of high impact journals and "is the largest database of abstracts and citations in the literature with peer review: scientific journals, books, congress processes and publications of the sector, presented intelligent tools to track, analyse and view research" [50].

The main interest of this step relied on identifying a query with which it was possible to gather a significant sample of publications dealing with obstacles to the adoption of BEE technologies.

Therefore, a preliminary examination of some papers [2,5,7,9,22,29] related to "building energy efficiency" was first done to determine the starting point. The research was carried out on the title, abstract, and keywords. Only articles from journals were considered, and the period covered by this search extended until 2018. In total, 893 publications were retrieved, leading to more than 3000 keywords (Fig. 2).

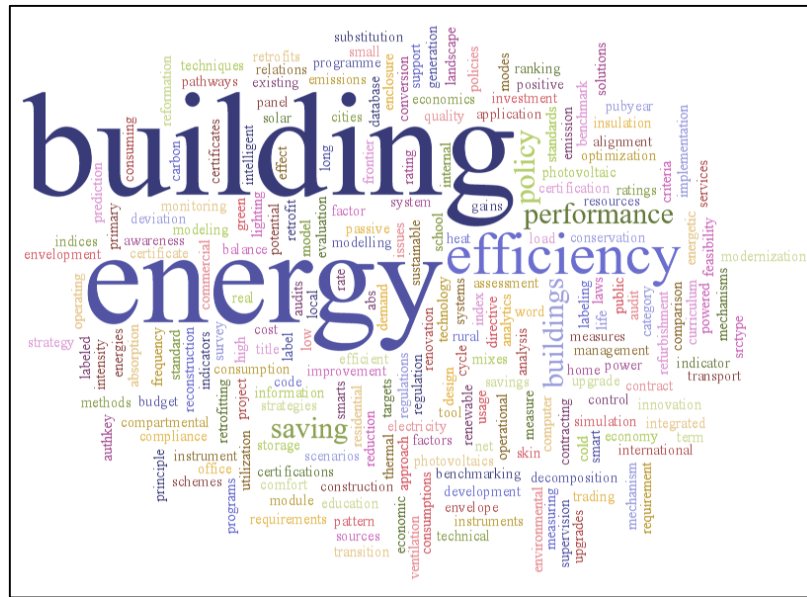


Fig. 2 Cloud of words used to build the search terms.

From these keywords, 103 were identified as key terms and used in the formulation of a new query. Since only a few articles were published in this field of knowledge before 2000, the period covered by this search extended from 2000 to 2018. A total of 14,451 publications were identified, but not all of them were concerned with barriers and obstacles. Therefore, the previous query was modified to include more restrictive terms like "obstacle" and "barrier". This final query returned 450 articles and is shown in Fig. A.1.

2.2 Scanning the titles and abstracts of the articles

This step covers the scanning of titles and abstracts of each of the 450 articles gathered at the end of the previous step, to isolate those articles that deal with any obstacle to the adoption of energy-saving technologies in buildings from those in which the terms "barrier" and "obstacle" are incidental. At the end of this step, the number of papers eligible for further analysis decreased to 106.

2.3 Reading the full texts

Next, the full text of each of the 106 articles was scanned. This ensured that no relevant information was missed. Therefore, all publications that addressed any kind of obstacle to the adoption of energy-efficient technologies in buildings were set aside for further analysis. As a result, 58 full texts were selected to trace the barriers and their respective overcome strategies. Fig. 3 shows the temporal distribution of these articles.

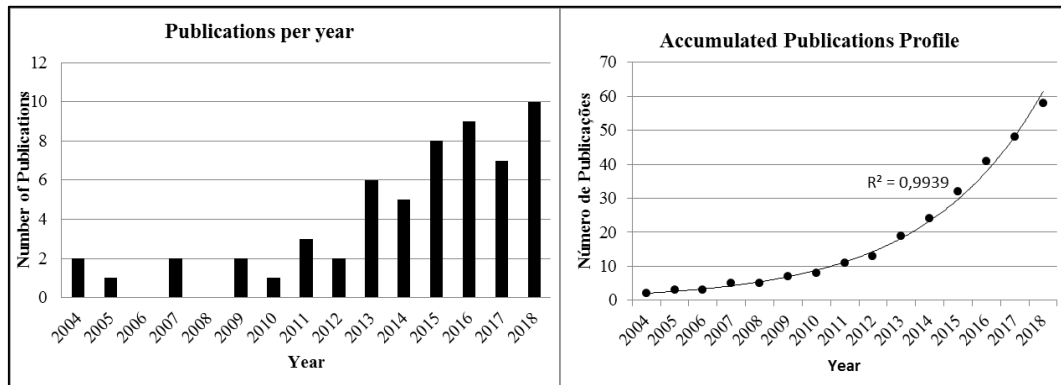


Fig. 3. The temporal distribution of the 58 documents that traced the obstacles.

The first publications dealing with obstacles were from 2004 [51;52]. Few articles covering this topic were published prior to 2012, while the number of publications since then has increased exponentially.

According to Price's Law [53], every field of knowledge grows exponentially until it reaches a point of inflection and reaches a threshold value around which scientific production stabilises. When scientific production reaches this point, it is said that this field of knowledge has reached its maturity and the aspect of the curve that represents the evolution of publications goes from exponential to logistics, signalling that the scientific community interest in this field has cooled down.

From observing Fig. 3, it is clear that the evolution of publications has been growing exponentially and has not yet reached the inflection point; therefore, the maturity of the theme has not yet been reached, with several aspects yet to be explored.

2.4 Collecting obstacles and strategies

The next step was to gather the obstacles from the articles. The 58 publications were read in depth, and 105 barriers were gathered. However, many barriers presented a similar meaning, for example "lack of technical experts" and "lack of knowledge"; "lack of financial support" and "lack of economic incentives"; "lack of market for BEE technologies" and "lack of market demand"; "lack of government support" and "lack of government incentives"; and "resistance to change" and "uncertainties on behavioural changes". As a result, the 105 obstacles were reduced to 65.

In many cases, the similarity between the barriers was not as obvious, so further reading, taking into account the context from which the barriers were picked, was necessary. After this new round of reading, the number of barriers fell to 27. Fig. 4 illustrates the entire process.

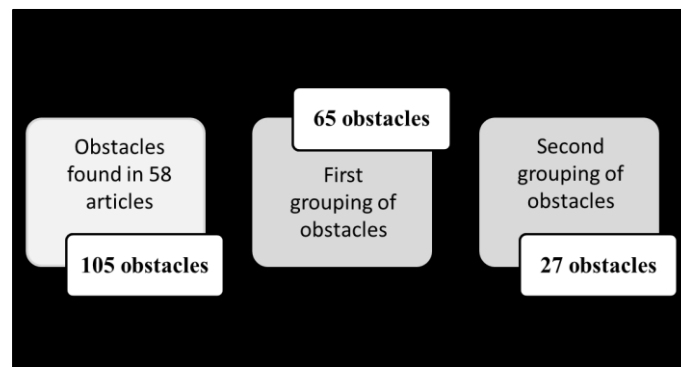


Fig. 4. The process of collecting obstacles.

Although the number of barriers collected within this research is 27, the number of barriers highlighted in the literature is increasing continuously as new publications emerge [15].

It is worth mentioning that these barriers increase in light of several considerations. For example, when this subject is studied from an economic point of view, several barriers rise toward this issue. In the same way, these barriers should be examined from others aspects like the government, markets, and so on. Such categorisation is known as taxonomy, and it is valuable since it allows a broad comprehension of the research area. Such an understanding is an important step for the formulation of strategies to overcome the barriers [44].

Therefore, the 27 barriers retrieved from the reading of the 58 full texts were classified into six groups: Financial/Economic obstacles, Market obstacles, Technological obstacles, Professional/Technical obstacles, Governmental/Political/Regulatory obstacles and Cultural/Social/Behavioural obstacles.

Afterward, still in this step, a timeline of the appearance of each barrier within each cluster was built in order to visualise the chronological track, leading to a better understanding of the field of knowledge over the years in the literature.

Eventually, the strategies to overcome the barriers were proposed according to the literature.

2.5 The barriers and associated themes, types of building and geographical regions

The titles of the 58 articles from which the six groups of barriers were gathered bring additional information like the country in which the paper was written, types of building focused on in the research presented by the article, whether or not environmental issues are present, whether or not public power is involved, and so on. Therefore, in this step, the title of these articles was scanned looking for terms referring to research themes, types of buildings and geographical regions. The terms collected were categorised in order to quantify the dependence relationship between the terms and the obstacles.

3. Obstacles to the adoption of energy-saving technologies in buildings

The comprehensive literature review has examined obstacles which hinder the adoption of energy-saving technologies in the building sector. A summary of the groups of barriers (categorised as Financial/Economic, Market, Technological, Professional/Technical, Governmental/Political/Regulatory, and Cultural/Social/Behavioural) is presented.

3.1 Financial/Economic obstacles

This group brings together barriers related to economic and financial issues that inhibit the adoption of energy-efficient technologies in buildings. Table 1 shows the obstacles named according to their appearance frequency within the literature followed by a brief description and the references in which they were found.

Table 1
Financial/Economic obstacles.

Obstacles	Definition	References
High investment	High investment inhibits the use of technologies in BEE projects.	[6,15,34,37,40,41,43,46,47,48,54,55,56,57,58,59,60,62,63,64,65,66,74,75,76,77,78,79,80,81,82]
Lack of economic incentives	Lack of economic incentives for the development of BEE projects.	[12,15,23,34,42,43,47,51,58,61,65,66,67,70,79]
Long payback periods	Investments in BEE technologies have long periods of financial return.	[7,9,11,13,34,40,46,47,48,56,57,58,68,69,70,71]
Difficult access to financing	Inaccessibility to financing lines for BEE actions.	[12,33,34,42]
Financial limitations of owners	Owners do not have the capital to invest in BEE technologies.	[29,55]
Investment risks	Investments in BEE technologies may not yield the expected financial results.	[43,65]

Financial/Economic obstacles are related to the high investment required for the adoption of energy-saving technologies in buildings [41,47,54]. Investments in the adoption of such technologies are higher than in conventional technologies, thus affecting the rate of adoption of technologies to reduce energy consumption in buildings [46,55-58]. The use of technologies and renewable energies, such as HVAC systems, more efficient lighting systems, photovoltaic devices, and geothermal heat pumps increases the cost of investments [6,13,40,59,60]. The high salaries of professionals specialised in BEE projects is another reason for the increased investment capital [62]. Therefore, the diffusion of energy-efficient technologies is affected by these aspects, which make investors reluctant to apply their capital for BEE projects [15,41,37,63,64].

According to Wang et al. [47], economic incentives are essential for the adoption of BEE technologies. However, several studies show that the lack of economic incentives to implement energy-efficient technologies is recurrent [23,58,61,65]. This barrier arises when local governments do not provide financial support, economic incentives, and special funding support for the building owners to adopt such technologies rather than conventional ones [7,12,42,51,66,67].

BEE projects tend to have a longer payback period than conventional projects, which has been seen as a barrier by several authors [7,9,45,58]. This obstacle arises because the return of investments is not immediate, but happens in a medium- to long-term period [13,68-70]. Therefore, investors tend to forego energy-efficient investments, making BEE projects unattractive [46,47,56,57,71].

The difficulty in accessing financing lines to adopt energy-saving measures are also recognised as an obstacle affecting the development of BEE programmes [12,33,34]. It is difficult for investors to access sufficient resources to invest in technologies for the development of BEE projects [33,42].

Another barrier that affects the development of BEE projects is the financial constraints of building owners; in many situations, the owners do not have sufficient capital to invest in BEE technologies or to make necessary reforms [29]. In addition, the owners may have the capital to invest but are unwilling to pay for these technologies, because they believe that there are no justifiable benefits to invest in energy-efficient technologies that are often more expensive than conventional technologies [55].

Many investors and owners are averse to the risks of investing in BEE technologies [43]. There is uncertainty about long-term savings in operating costs. They do not believe that the adoption of such technologies will generate the expected financial results. Thus, they prefer to adopt conventional alternatives for the use of energy [65].

3.1.1 Strategies to overcome the Financial/Economic obstacles

Table 2 presents recommendations to overcome the Financial/Economic obstacles. According to [70], the best strategy to overcome the high investment required to develop BEE projects is the development of educational projects around financial analysis, with the aim of highlighting the relationship between high cost and long-term financial returns. Thereby, investors and owners will have clear knowledge that the high investments made will bring some future payback [56].

Developing a pattern of economic incentives that result in tax reductions and financial rewards is an alternative to overcome the lack of economic incentives [47,55]. However, it is important that this pattern is clear, rather than general or ambiguous [7], and also available to both the investors involved in the BEE projects and the owners [34].

Table 2
Strategies to overcome the Financial/Economic obstacles.

Obstacles	Overcome Strategy	References
High investment	Educational projects around financial analysis.	[56,70]
Lack of economic incentives	Developing a pattern of economic incentives.	[7,33,47,55]
Long payback periods	Reducing costs.	[48,72,73]
Difficult access to financing	Easy access to financing provided by the government.	[74]
Financial limitations of owners	Financial rewards to owners.	[41,47]
Investment risks	Financial risk analysis.	[12,43]

The reduction in the costs of energy-saving technologies decreases the payback time on invested capital [72]. One way to mitigate the "long payback periods" barrier is to use a combination of financing mechanisms according to different values of investment capital, which would result in different periods of financial return [48]. As a result, investors can choose the type of financing appropriate to their project, in order to reduce the cost to fit their investment capital and the financial payback period expected [73].

It is important for the government to develop a financing model to provide easy access to the financing needed for clients to use energy-efficient technologies, as an effective way to help to overcome the “difficult access to financing” barrier [74].

Despite the financial limitations of some owners, it is recommended that the government applies financial rewards to the investments made [47]. This economic incentive is a way to encourage clients to invest their capital in BEE projects [41].

In addition, it is suggested that financial risk analysis be made mandatory before adopting any energy-efficient technology [43]. It is important that risk analysis involves payback time studies, return on investment analysis, property depreciation analysis, and the development of global standards for tried and tested technologies by risk assessment [12].

3.1.2 Temporal distribution of Financial/Economic obstacles

Fig. 5 presents the spread of financial/economic barriers in the literature during the period from 2004 to 2018 by means of a timeline, above which the references published in the corresponding year (in a box) are presented, followed by the current number of citations of the corresponding reference (in a circle), giving the idea of a bar graph that shows the time distribution of the number of publications dealing with a given barrier. The citations provide additional information, allowing the researchers to assess the quality of the publications.

It can be seen that the “high investment” barrier was the most frequent in the publications (it appears in 32 articles). After 2013, there was an increase in the number of articles that cited this obstacle. In 2018, nine articles addressed the impact that the high investment brings to the BEE projects, showing in this way that this obstacle has had a great impact on the use of technologies in buildings in recent years. Among the articles that highlighted this barrier, the most cited was “Greening project management practices for sustainable construction” [59], published in 2011 and cited 194 times.

The obstacles “lack of economic incentives” and “long payback periods” appeared in 16 articles each, and were cited for the first time in 2004 and 2009, respectively. Such barriers have had a stable occurrence profile along the timeline. The “lack of economic incentives” obstacle was more frequently addressed by articles published in 2017/2018, while the “long payback periods” obstacle in 2015/2016, demonstrating that these barriers have existed for years, and have not yet been overcome. Among the articles dealing with these obstacles, the most cited was “Barriers and drivers for sustainable building” [7], cited 196 times in both cases.

The barriers “difficult access to financing”, “financial limitations of owners”, and “investment risk” appeared sparsely throughout the timeline, showing that these barriers can arise in the development of BEE projects, but these are not the obstacles with the greatest impact.

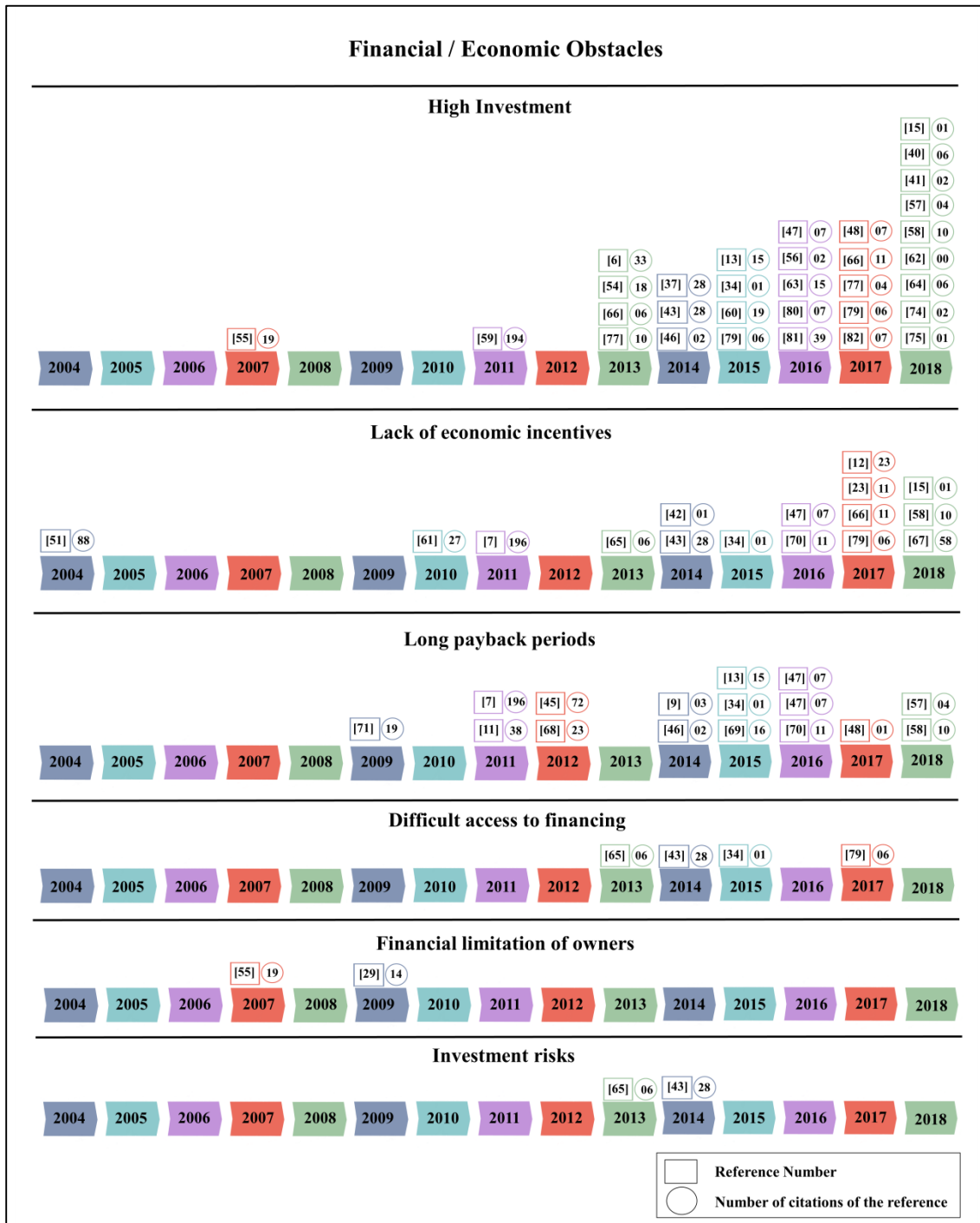


Fig. 5. Temporal distribution of Financial/Economic obstacles.

3.2 Market obstacles

Market aspects play an important role in the adoption of energy-saving technologies. Market barriers are listed in Table 3 along with their definitions and references.

Market barriers are more commonly associated with low customer demand [42,43,75]. This arises because many buyers do not care about the sustainable performance of a building, which makes the market unfavourable to the adoption of such technologies [34,37,76].

Another obstacle is the lack of investors in BEE projects. This type of barrier is related to the investors' sensitivity to the price of buildings, since energy-efficient buildings require high investments, which makes the investors feel that investing in BEE projects is not attractive [42].

Many investors and owners are not attracted to BEE technologies because of the lack of knowledge and awareness of the market potential of BEE projects [57]. In general, limited knowledge of the benefits of BEE reduces the demand for the BEE projects, affecting the market progress of BEE [37].

One factor that has an impact on the level of awareness about the importance of these technologies, making them less attractive, is the lack of marketing strategies [15]. A lack of good strategies to promote BEE technologies makes owners and investors unaware of the economic and social benefits of adopting such technologies [43].

Table 3
Market obstacles.

Obstacles	Definition	References
Lack of a market for BEE technologies	The market is unfavourable, with low investors demand.	[37,42,43,75,76]
Lack of investors in the BEE projects	Investors do not see attractiveness in the BEE projects.	[42]
Limited knowledge of market potential	Lack of knowledge about how to increase the market potential of BEE technologies.	[57]
Lack of good marketing strategies	Good marketing strategies are not adopted to promote the BEE actions.	[15]

3.2.1 Strategies to overcome the Market obstacle

The recommendations to overcome the Market barriers are presented in Table 4.

Table 4
Strategies to overcome the Market obstacles.

Obstacles	Overcome Strategy	References
Lack of a market for BEE technologies	Government actions to the promoting of BEE projects.	[37,75]
Lack of investors in the BEE projects	Incentivise the potential investors.	[23]
Limited knowledge of the market potential	Develop technical/practical guidelines.	[55]
Lack of good marketing strategies	Investing in marketing strategies.	[8,23,34]

According to [37], the lack of market for the implementation of BEE projects can be overcome by government actions. It is important to offer incentives to potential investors regarding the adoption of technologies in their projects [23].

One way to increase knowledge about market potential is to develop guidelines with technical and practical guidance that will be ideal for investors and owners as a quick guide to meeting market requirements [55].

Investing in marketing strategies that disseminate the advantages and needs of BEE projects is an important suggestion for the improvement of BEE projects [34]. It is important to have good communication channels by means of which reliable information can flow, such as workshops, project demonstrations and the use of the media to divulge the benefits of the use of energy-saving technologies [8]. These channels are educational training tools that increase specific knowledge about technologies and their advantages [23].

3.2.2 Temporal distribution of the Market obstacles

Fig. 6 presents the spread of Market barriers in the literature in the period from 2004 to 2018. It is possible to infer that the four barriers within this group impact little on the adoption of BEE technologies. The "lack of market for BEE technologies" barrier was studied in five articles, with the highest occurrence in 2014 (three publications). The most frequently cited article was "Barriers to the adoption of energy-

saving technologies in the building sector: A survey of Jing-jin-tang, China" [37] which was published in 2014.

The other obstacles "lack of investors in BEE projects", "limited knowledge of market potential" and "lack of good marketing strategies" appeared in only one article each, demonstrating that such barriers do exist, but do not impact on the adoption of BEE.

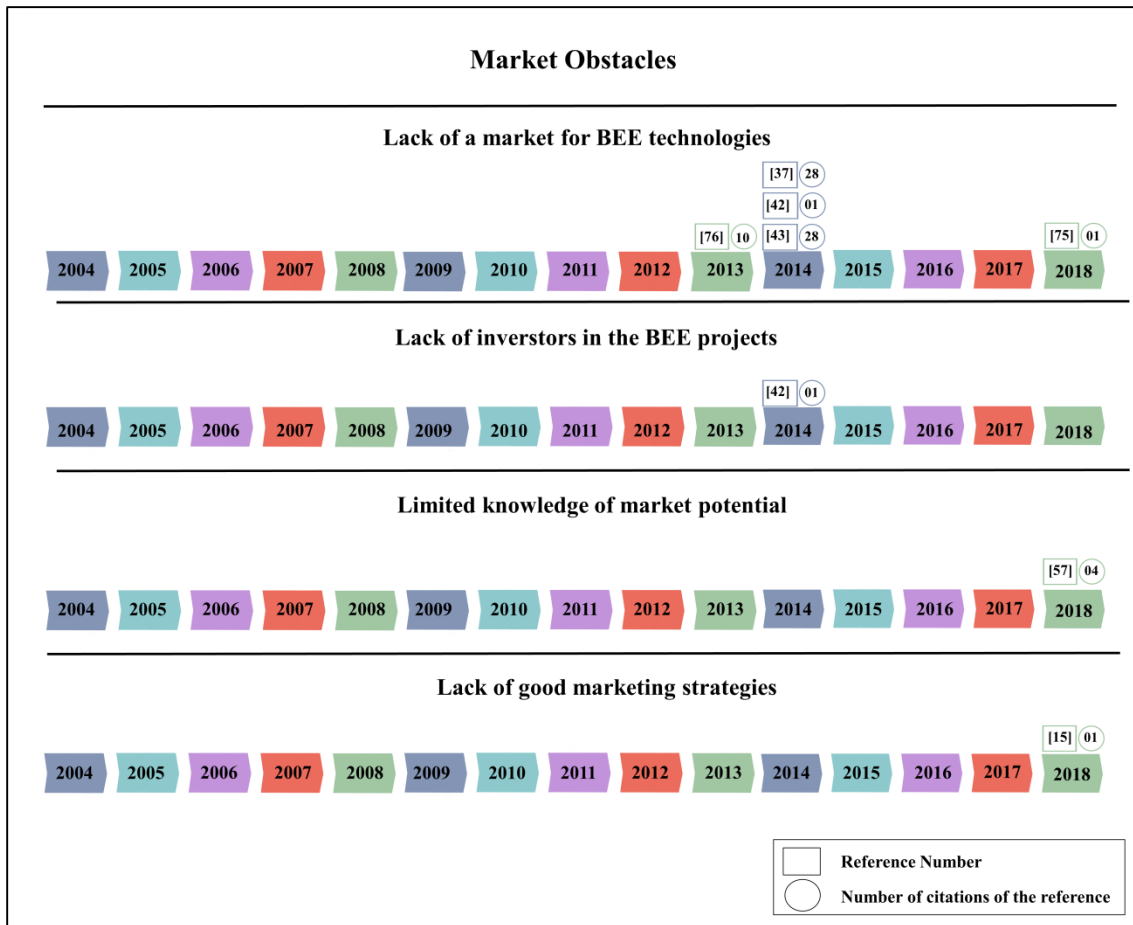


Fig. 6. Temporal distribution of Market obstacles.

3.3 Technological obstacles

Technological barriers group problems with technologies and innovative solutions that are fundamental to the rational use of energy in buildings. The obstacles and their respective definitions and references are presented in Table 5.

Table 5
Technological obstacles.

Obstacles	Definition	References
Inadequate BEE technologies	Inadequate, incompatible and/or inaccessible BEE technologies.	[12,34,42,43,74,83,84]
Lack of information	There is not enough information on the available technology options.	[8,45,67,85,86]
Lack of technology demonstration	There is a lack of projects to demonstrate innovative BEE technologies.	[68]

Some studies suggest that there may be a technology-related barrier to BEE projects. This obstacle arises due to the belief in the non-existence of proper technologies for the efficient use of energy in buildings [12,43,74]. Thus, the investors prefer to invest in conventional technologies since they are afraid

that BEE technologies will not reach the desirable performance, resulting in lower energy savings with higher costs [42,34,83,84].

The availability of information about the potential of appropriate technologies is crucial for their adoption, thus increasing their rate of use [45,86]. However, the lack of clear and reliable information on the performance of technologies, and also on the ways to integrate such technologies in BEE projects, is often a barrier that inhibits the adoption of such technologies [8,67,85].

In addition to the lack of information, there has been a lack of pilot projects presenting a technological assessment that demonstrates innovative and energy-efficient actions to investors and owners [68]. One can conclude that the latter two obstacles are underlying causes for the existence of the former [12,45,68].

3.3.1 Strategies to overcome the Technological obstacles

Table 6 shows the strategies to overcome the Technological barriers. It is important to develop measures to overcome such technological barriers. One way is to develop technological solutions and improve existing ones [52]. For this, the government should support research aimed at the development of energy-saving technologies, since efficient technology is an effective channel for solving energy efficiency issues [1,67]. It is interesting that the government encourages universities and local institutions to develop research centres as a platform for production, learning, and research with the goal of developing low-cost technological alternatives for energy efficiency [41].

Table 6
Strategies to overcome the Technological obstacles.

Obstacles	Overcome Strategy	References
Inadequate BEE technologies	Research centres as platforms for production, learning, and research on BEE technologies.	[23,41,52,67]
Lack of information	More information provided by the government and research centres.	[47,84,86]
Lack of technology demonstration	Develop projects to demonstrate BEE technologies.	[34,69]

Furthermore, it is interesting that the government provides information to the public on reliable technologies and procedures to maximise the use of energy-efficient technologies [86]. Research centres can provide a full set of recommendations on available technologies, which will increase the choice for BEE projects [47].

Another good way to improve the use of BEE technologies is the development of technology demonstration projects [34]. These projects teach how to successfully use technologies and are an effective alternative to gaining practical experience for the development and dissemination of BEE projects [23]. Thus, investors and owners may feel more confident about the benefits and development of BEE projects [34,84].

3.3.2 Temporal distribution of Technological obstacles

Fig. 7 shows the timeline for the Technological barriers in the literature in the period from 2004 to 2018.

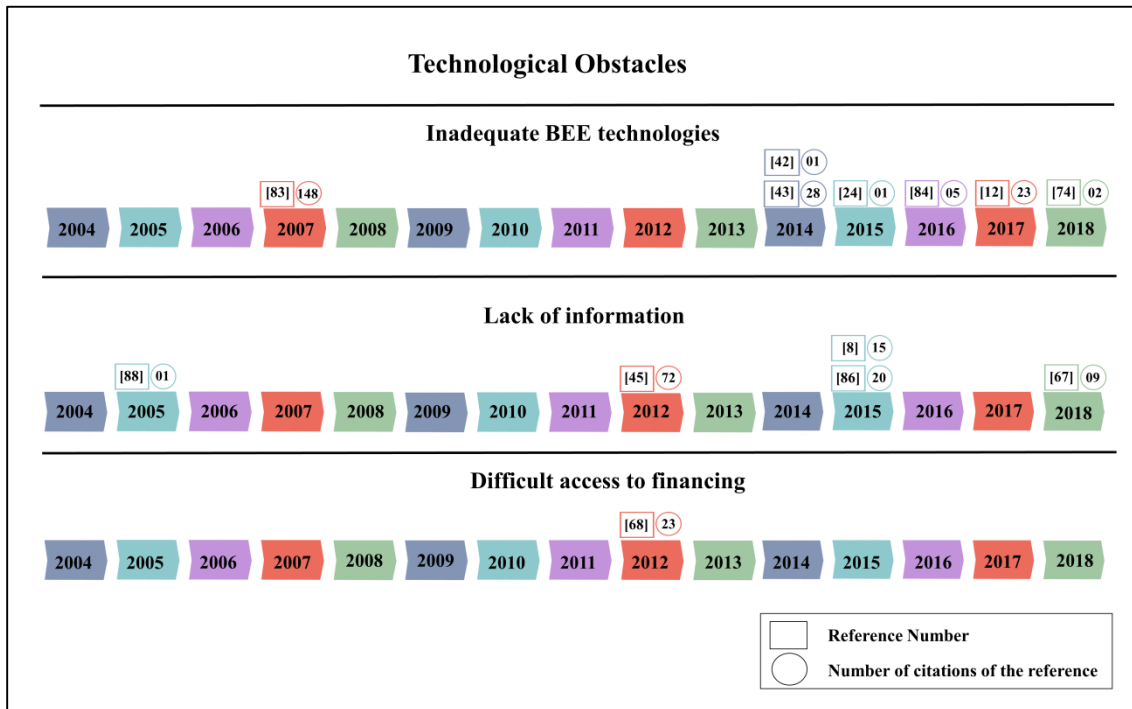


Fig. 7. Temporal distribution of Technological obstacles.

According to Fig. 7, the "inadequate BEE technologies" barrier was the most addressed in this group, appearing in seven documents. Among these articles, this obstacle was first mentioned in 2007 and was only addressed again in 2014, keeping a stable number of articles that dealt with this barrier; this shows that there is a perception that energy-saving technologies are not entirely appropriate. The most cited paper was entitled "What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments" [83], which was published in 2007 and cited 148 times.

The "lack of information" obstacle was reported in five articles, with few appearances over the entire period; the most frequently cited article was "Energy savings potential in buildings and overcoming market barriers in member states of the European Union" [45], with 72 citations. The "lack of technology demonstration" barrier appeared only once "A roadmap for navigating voluntary and mandated programmes for building energy efficiency" [68], which was cited 23 times in other studies.

3.4 Professional/Technical obstacles

The adoption of BEE technologies faces some Professional/Technical barriers, which may arise in different forms, as shown in Table 7, with their descriptions and references.

Table 7
Professional/Technical obstacles.

Obstacles	Definition	References
Lack of technical competence	Difficult to find professionals specialised in the development of BEE projects.	[7,34,37,41,42,43,45,47,54,55,57,58,62,63,64,65,66,72,73,75,77,83,85,87]
Lack of professional involvement	There is no professional engagement in the planning of BEE projects.	[37,40,45,61,65,67,78,88]
Incredulity on the part of the designers	There is a reluctance of designers to use energy efficiency measures in building projects.	[37,88]

The main Professional/Technical barrier is the lack of professionals specialised in the development of BEE projects [7,42,57,75,85]. This obstacle arises from the lack of institutions that offer specialist courses for professional training [58,37,64]. Most practitioners are not qualified in energy-saving technologies and are therefore not familiar with the principles needed to implement energy efficiency measures [7,34,43,77]. Unskilled professionals may not have adequate skills to develop projects that adopt these technologies,

which may delay the project schedule and also undermine the energy efficiency of the buildings [41,47,58,66,45,83].

Many professionals do not have sufficient knowledge of energy-saving technologies, especially those that are complex, seldom-used, or state-of-the-art [37,43,54]. This lack of competence means that professionals do not have a technical perception of inefficiencies and opportunities to implement energy efficiency measures [45,63,66,75].

Due to a lack of knowledge, professionals are not involved in the design of BEE projects [9, 45,55,63,66,78]. A lack of engagement often leads to professionals not being active users of energy-saving technologies, which hampers the adoption of energy efficiency requirements during BEE projects [35,80].

Many designers are reluctant to adopt energy efficiency measures in their building projects [73], because they do not believe that such measures will bring the desired return to both the company and the investors and owners, preferring instead to focus their efforts mostly on conventional projects [63,73].

3.4.1 Strategies to overcome the Professional/Technical obstacles

Table 8 shows strategies for overcoming the Professional/Technical barriers.

Table 8
Strategies to overcome Professional/Technical obstacles.

Obstacles	Overcome Strategy	References
Lack of technical competence	Specialised training of professional provided by government.	[9,12,23,37,41,69]
Lack of professional involvement	Excellence awards to professionals involved in BEE projects.	[9,55,63]
Incredulity on the part of the designers	Improve the communication between designers.	[47,37,76]

The main hint to overcoming this set of barriers is to improve the awareness and knowledge of professionals by means of specialised training [9,12,37,41,69] supported by organisations that promote the requirements and benefits of energy-saving measures. If professionals are fully aware of the benefits of energy-efficient technologies and available government subsidies, they can serve as pioneers in promoting technologies for rational energy use [67].

It is also important to increase the level of professional involvement in BEE projects [2]. For this, it is suggested that professionals be evaluated and receive energy efficiency awards according to the projects developed [9,55,63]. This is a way to encourage more professionals to adopt energy-saving technologies [37,47,76].

3.4.2. Temporal distribution of Professional/Technical obstacles

Fig. 8 presents a timeline for Professional/Technical barriers in the literature over the period from 2004 to 2018.

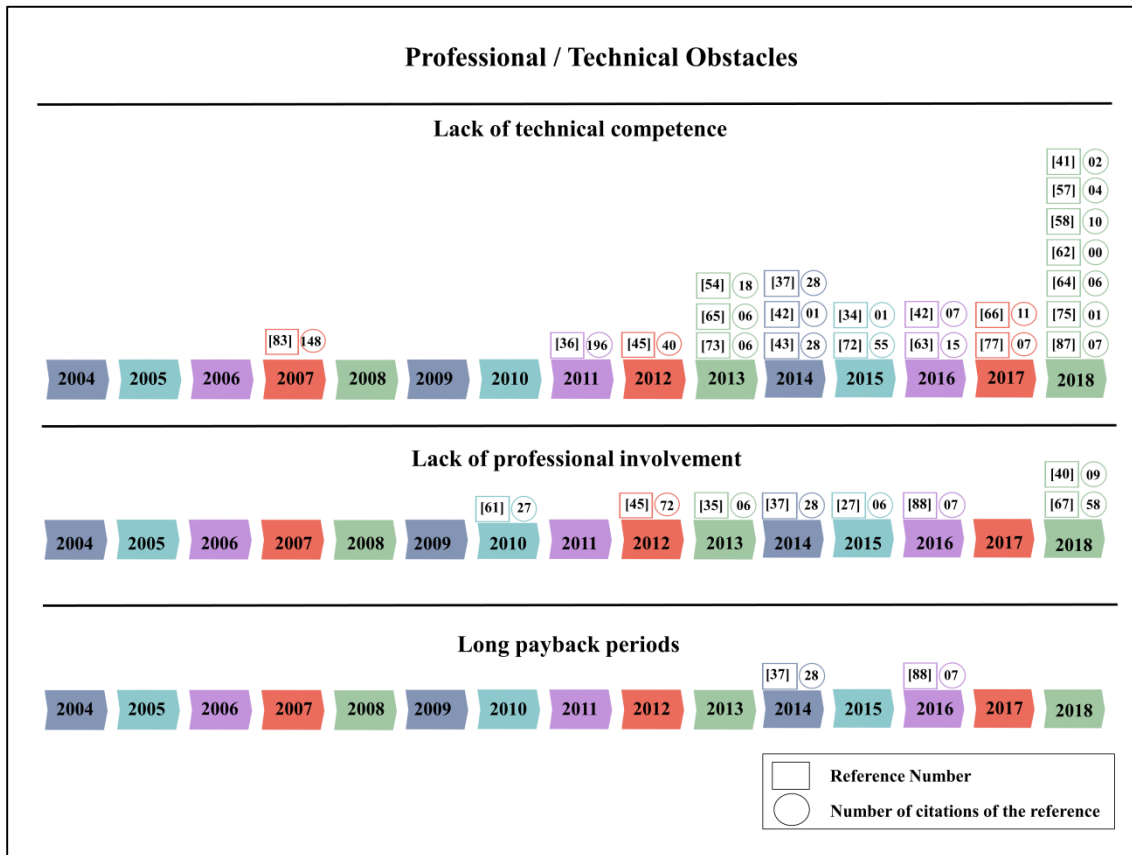


Fig. 8. Temporal distribution of Professional/Technical obstacles.

It can be seen that the “lack of technical competence” barrier was the most cited in the publications (24 times). Most of the articles dealing with this obstacle were published in 2018, showing that the lack of technical competence has increasingly impacted the adoption of BEE technologies. Within the articles dealing with these important barriers, the most cited were "What is stopping the sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments" (148 citations) [83].

The "lack of professional involvement" obstacle appeared in 8 articles, being cited for the first time in 2010, and presented a stable occurrence profile in the following years. Among these articles, the most cited was "Energy savings potential in buildings and overcoming market barriers in member states of the European Union" [45], which was cited 72 times.

The "incredulity on the part of the designers" barrier appeared sparse over the period depicted in the timeline. This obstacle was addressed in only two articles, which shows that such a barrier has only a small impact on the adoption of the BEE measures.

3.5 Governmental/Political/Regulatory obstacles

This group of barriers has been defined as obstacles due to political institutions. Table 9 shows the barriers found in the literature, followed by a brief description and the references in which they were found.

The group of Governmental/Political/Regulatory barriers brings together obstacles that inhibit the progress and development of energy-efficient technologies. The main barrier found is related to inconsistent policies and poor governance standards that delay the adoption of energy-saving technologies [42,45,67,69,70]. The inconsistency of government energy efficiency policies is an obstacle that affects the choice of the proper technology for buildings [34,46,55,74,75,88]. An inadequate policy system can lead to inconsistency in the application of laws and regulations, thereby reducing market enthusiasm for energy efficiency [8,12,47,58]. In addition, the lack of consistency in government standards represents an obstacle preventing better guidance on energy saving in buildings, effective energy management and the motivation to select more energy-efficient technologies [43,46,55,65,79,87].

The lack of incentive and the lack of government commitment to the development of BEE projects is another prominent barrier in the literature [43,63,70,71]. Often, the government does not understand the urgency and importance of developing government projects aimed at increasing energy efficiency in

buildings [6,48,62,67]. There is no government involvement in creating laws and regulations that help investors and owners make more rational decisions, thereby influencing the diffusion rate of technologies employed in BEE projects [41,40,47,51,61,64].

There are government issues related to distorted fiscal policies that inhibit investments in energy efficiency [3,76]. These distortions are related to taxes, subsidies or other fiscal policy interventions that influence the costs of the energy resources consumed by the occupants of the buildings [13,42,46,52].

Table 9
Governmental/Political/Regulatory obstacles.

Obstacles	Definition	References
Inefficient BEE codes/regulations/standards	Inconsistent policies and poor governance standards on BEE technologies.	[8,12,34,37,42,43,45,46,47,55,58,65,67,69,70,74,75,79,87,88]
Lack of government support	Absence of incentive and governmental commitment to the development of BEE projects in the country.	[6,40,41,43,47,48,49,51,62,63,65,70,71,64]
Distorted fiscal policies	Taxes, subsidies or other policy interventions that make energy consumption more expensive for occupants.	[13,29,46,52,58,76]
Complex certification procedures	The procedures for obtaining BEE certification are complicated and require a lot of enforcement.	[7,37,48]
Policies do not address the financial implications	A weak approach to the financial implications of BEE projects in government policies.	[55,64]
Lack of knowledge on energy efficiency by legislator and regulator	Developers of policies and regulations are not aware of BEE technologies benefits.	[60,65]
Lack of efficient dissemination of codes/regulations	The government needs to improve the mechanisms of dissemination of regulations/standards on BEE technologies.	[46]

In some cases, the procedures for obtaining BEE certification are complicated and require a lot of effort from the stakeholders, so are therefore considered an obstacle [7,48]. When certification systems are complex, they may make it difficult to provide information on good solutions for the use of technologies, and can effectively discourage investors from adopting energy-saving technologies in their projects [37].

Another obstacle that affects the development of BEE projects is the financial implications that are poorly addressed by public policies [55,64].

In other cases, policy and regulatory developers are unaware of energy-efficient technologies [60]. The lack of knowledge of the legislators and the regulator is an obstacle that reflects the development of inappropriate legislation and regulations [65].

Furthermore, government institutions and mechanisms do not clearly expose their codes and regulations. This obstacle arises from the lack of interest or existing ability in institutions to disseminate government information on energy efficiency programmes for buildings [46].

3.5.1 Strategies to overcome the Governmental/Political/Regulatory obstacles

Table 10 presents the strategies to overcome the Governmental/Political/Regulatory barriers.

The development of efficient norms, regulations, and laws is important to boost the use of technologies, clearly providing energy saving goals to be achieved [9,19]. Laws, regulations, and standards should signal a future perspective of government policy, showing what measures can be taken to ensure that the government goals are met [6,31,49].

Table 10

Strategies to overcome the Governmental/Political/Regulatory obstacles.

Obstacles	Overcome Strategy	References
Inefficient BEE codes/regulations/standards	Developing more efficient codes/regulations/standards.	[12,23,43,52,73]
Lack of government support	Governmental commitment with BEE projects.	[41,55]
Distorted fiscal policies	Effective policies on government subsidies and tax credits.	[41,34,61]
Complex certification procedures	Simplify the certification procedures.	[29,55]
Policies do not address the financial implications	Policy guidance on the financial implications.	[76,80]
Lack of knowledge on energy efficiency by legislator and regulator	Training on BEE technologies for regulators and legislators.	[8,12,81]
Lack of efficient dissemination of codes/regulations	Rigorous policy framework to disseminate information on the benefits of BEE technologies.	[12,23,34,69,73]

In addition, it is important to create a government support mechanism to provide guidance and assistance to both designers and occupants [41]. Government support should provide a culture of energy efficiency to ensure the adoption of technological measures [55].

It is recommended that the government formulates different economic incentive packages according to the characteristics of BEE technologies implemented, in order to increase the financial return of building projects [34,61]. Such packages should increase subsidies and create interest-free policies [41].

The government should provide tools to make energy efficiency certification procedures clearer and more accessible for designers [55]. It is also important for the government to submit a specific general plan for building inspections in order to achieve the level of energy efficiency in the certification process [61]. Furthermore, the government should provide support by means of economic incentives so that investors can find alternative options to deal with the financial implications of BEE projects [76,80].

It is important to provide training for regulators and legislators [81] involved in the BEE regulations/laws. The more information they have, the more rational the decisions will be about the legislation that is most appropriate for increasing the rate of diffusion of energy-efficient technologies [8,12].

The government needs to have a rigorous policy framework to disseminate information on the benefits of adopting BEE technologies, as the awareness of occupants is still weak [12,34,73]. Regulations and standards should be developed with a clearer definition of the importance of energy efficiency actions in buildings, which can be disseminated by means of public hearings and workshops for financial institutions, professionals and potential occupants [23,69].

3.5.2. Temporal distribution of Governmental/Political/Regulatory obstacles

The timeline of the publications that addressed the Governmental/Political/Regulatory barriers is presented in Fig. 9.

According to Fig. 9, the obstacle "inefficient BEE codes/regulations/standards" was addressed in 20 articles. This barrier was first mentioned in an article published in 2007 and was only addressed again from 2012 onwards. The period with the greatest number of publications was from 2014 to 2018; therefore, it is possible to realise that these issues still hinder the use of technologies for rationalising energy consumption. The most cited article was "Energy savings potential in buildings and overcoming market barriers in member states of the European Union" [45], with 72 citations.

The "lack of support government" barrier appeared in 14 publications. Although this obstacle appeared sparsely over the period presented in the timeline, it was most frequently cited in 2016 (three articles) and 2018 (four articles). The most commonly cited publication was "Progress in energy-efficiency standards for residential buildings in China" [51], cited 88 times.

The other obstacles, "distorted fiscal policies" (six papers), "complex certification procedures" (three papers), "policies of the financial implications" (two papers), "lack of knowledge of legislator and regulator" (two papers), and "lack of disclosure about codes/regulations" (one paper), have appeared in a few articles, thus demonstrating that such barriers exist, but have little impact on the adoption of BEE project technologies.

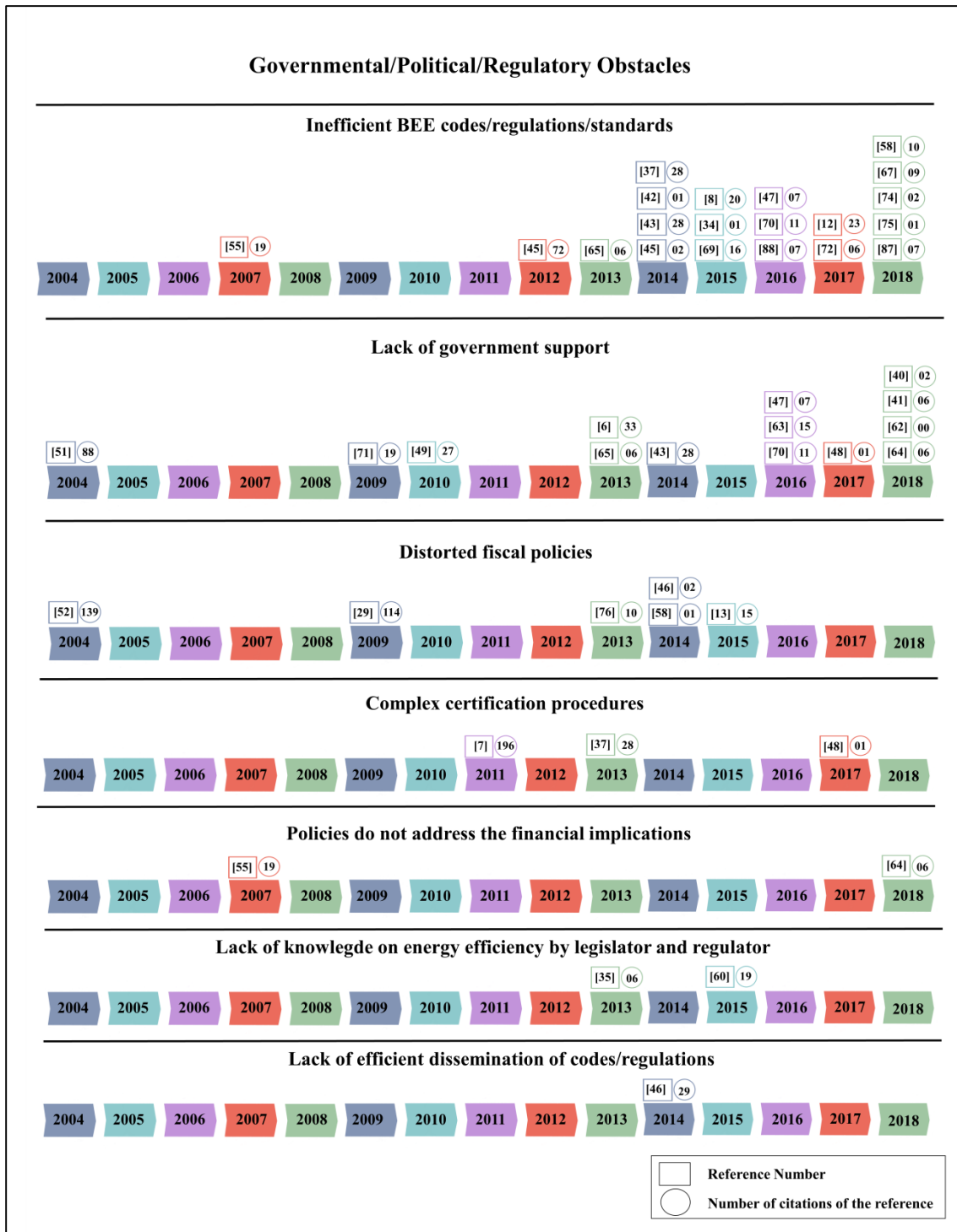


Fig. 9. Temporal distribution of Governmental/Political/Regulatory obstacles.

3.6. Cultural/Social/Behavioural obstacles

The main barriers within this group are related to cultural, social and behavioural aspects that are important determinants to delay the successful implementation of BEE technologies. Cultural/Social/Behavioural barriers are listed in Table 11 along with their definitions and references.

Cultural/Social/Behavioural barriers are issues that characterise the behaviour of the occupants and their relationship with the consumption of energy [11,12,34,42,55,58,65]. These obstacles can arise from the lack of information and education on energy efficiency that prevents occupants from adopting energy-efficient measures [33,43,52,78,82,88]. Lack of information leads to uncertainty about the costs and benefits of energy efficiency [48,54,63,64,70]. In many situations, occupants find it difficult to obtain sufficient information about relevant energy efficiency options, and even if this information is available, it is often difficult to analyse it [9,15,54,60,62]. Therefore, the lack of information on specific ways to improve the energy efficiency and reduce energy waste is highlighted as an important reason why the occupants of buildings do not make apparently cost-effective improvements in their buildings, so the owners do not change their behaviour and continue to use conventional measures [45,74,81,85].

The lack of information about BEE leads occupants to be less susceptible to adopting energy-efficient practices, making them resistant to the behavioural changes needed to save energy [41,62,63,87,88]. The occupants show a certain aversion to the adoption of energy-saving technologies, since there is a need for maintenance throughout the useful life of the building. Although the maintenance procedures are not difficult to be carried out by the occupants, they are highlighted as one of the reasons for not making the necessary improvements [69,77,85]. This fear of change slows energy efficiency improvements and lowers customer demand for BEE projects [46,82].

Table 11
Cultural/Social/Behavioural obstacles.

Obstacles	Definition	References
Lack of information/education about BEE technologies	Lack of education programmes to inform and educate building occupants about policies, costs and benefits associated with BEE technologies.	[9,11,12,15,33,42,43,45,47,48,52,54,55,58,60,62,63,64,65,68,70,74,75,77,81,82,85,88]
Fear/Resistance to change	High resistance to occupant behavioural changes to the BEE actions.	[41,46,62,63,69,85,77,87,82,88]
Lack of motivation	Occupants are not motivated to develop the BEE actions.	[23,70,85]
Lack of confidence	Occupants do not trust on information disseminated by the government or the BEE market.	[65,87]

In many situations, occupants are afraid to use available energy efficiency technologies because of another barrier known as lack of motivation [23,85]. Some occupants, while fully aware of the potential of energy-efficient technologies, are not motivated to improve the efficiency of their buildings, resulting in the non-use of such technologies [76].

Another factor that implies the adoption of the technologies is the lack of confidence that the occupants have in relation to the information disseminated by the government and the market [87].

3.6.1 Strategies to overcome the Cultural/Social/Behavioural obstacles

Table 12
Strategies to overcome the Cultural/Social/Behavioural obstacles.

Obstacles	Overcome Strategy	References
Lack of information/education about BEE technologies	Education and training programmes for building occupants.	[7,52,63]
Fear/Resistance to change	Improve occupant awareness about BEE programmes.	[8,43,81]
Lack of motivation	Make use of the proper channels of communication to incentive the occupants to adopt BEE technologies.	[23,80]
Lack of confidence	Provide clear and reliable instructions on the benefits of BEE technologies.	[8,23,52]

Developing measures to overcome such barriers is fundamental to increasing the use of energy-saving technologies. This means improving the information available, which will increase the level of knowledge and awareness of building occupants of the benefits of BEE technologies [52]. This information should be included in educational and training programmes by means of interactive tools and games that help occupants to better understand the life implications for inefficient energy use [7].

Public awareness of the use of energy-efficient technologies is an important suggestion to overcome the "fear/resistance to change" barrier [43]. Implementing public participation programmes improves occupant awareness, making them less resistant to the adoption of such technologies [81]. An effective public awareness that addresses the relevant concepts about the benefits of adopting BEE technologies in projects increases the possibility of acceptance, thus increasing the demand for customers interested in adopting BEE technologies [8,43].

Another recommended measure is the education and training of occupants by means of training projects that include the use of open channels of communication, regular workshops, internet dissemination and TV advertisements; these are all alternatives that help with the construction of a dynamic platform for the introduction of new technologies, thus motivating occupants to improve the efficiency of their buildings with the use of such technologies [23,81].

Furthermore, in order for the occupants to feel more confident about the information provided by the government and the market, it is important to create opportunities for the government laws and information about the benefits of BEE to be well-disseminated among the occupiers [8,52]. Therefore, providing clear and easy-to-understand instructions will increase communication among stakeholders, thereby increasing the confidence of occupants in relation to seemingly cost-effective improvements to their buildings [23,63].

3.6.2 Temporal distribution of Cultural/Social/Behavioural barriers

The timeline for the publications that addressed the Cultural/Social/Behavioural barriers and their respective number of citations is presented in Fig. 10.

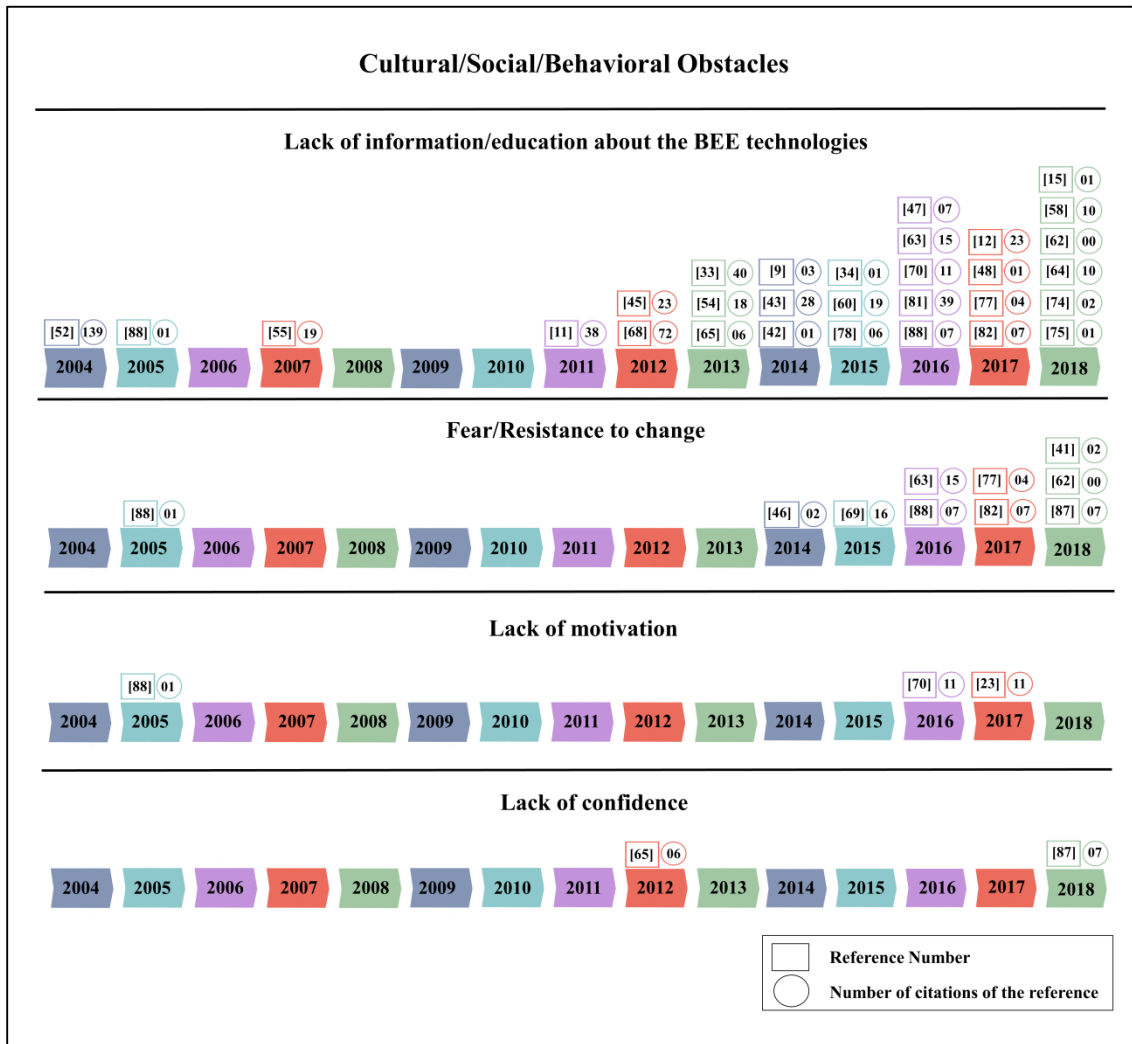


Fig. 10. Temporal distribution of Cultural/Social/Behavioural obstacles

It can be seen that a “lack of information/education about BEE technologies” barrier was the most cited in the publications (30 times), followed by the “fear/resistance to change” barrier that appeared in 10 publications.

The lack of information/education about BEE technologies has greatly impacted the adoption of energy-efficient measures, mainly since 2011. In the articles dealing with these important obstacles, the most cited were “Energy savings potential in buildings and overcoming market barriers in member states of the European Union” [45], with 72 citations.

The “fear/resistance to change” obstacle was first mentioned in 2005, and was only addressed again from 2014 onwards, presenting a stable occurrence profile in the following years. Among the articles that highlighted fear/resistance to change as an important barrier, the most frequently cited was “Factors influencing the retrofitting of existing office buildings using Adelaide, South Australia as a case study” [69], which was cited 16 times.

The other barriers “lack of motivation” and “lack of confidence” have been addressed in a few publications, showing that such barriers are relevant but there is no major interference with BEE projects.

The Fig. 11 presents the temporal distribution of the six groups of barriers, as well as the h-index of each group over the period covered by this research.

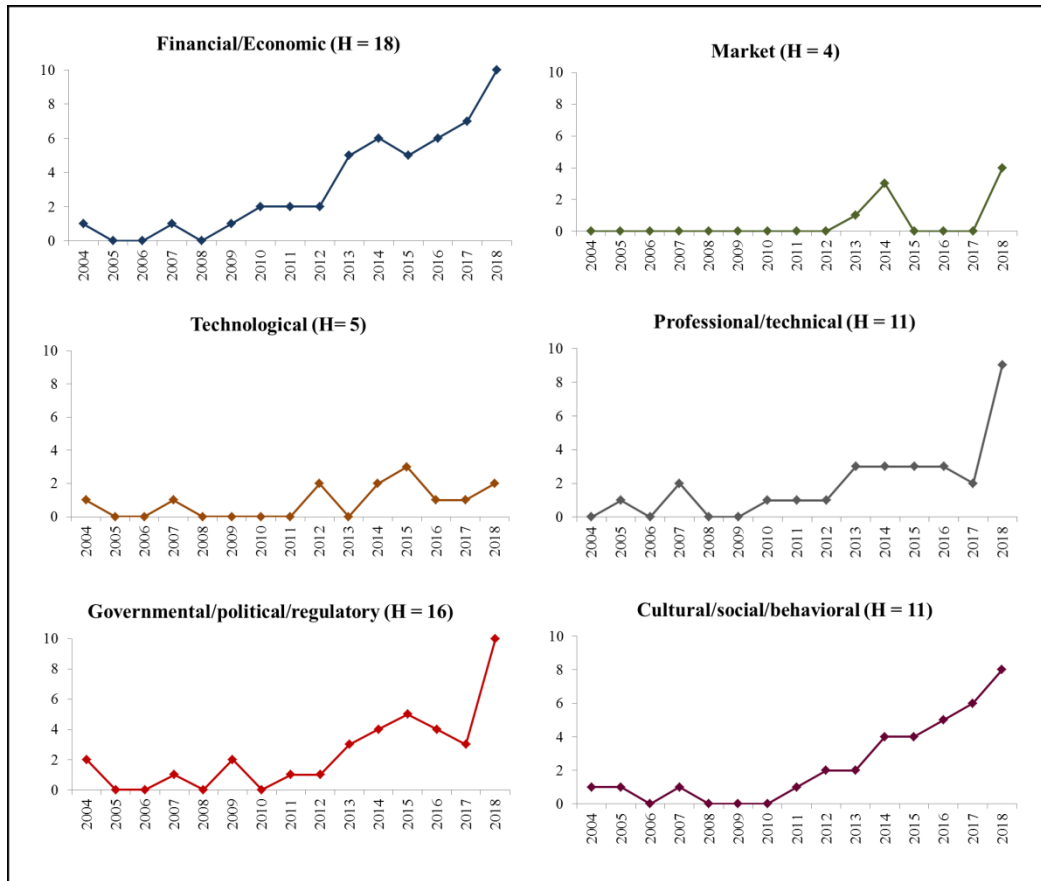


Fig. 11. Temporal distribution of the six groups of barriers gathered from the literature.

It is evident that Financial/Economic barriers have a major impact on the adoption of energy-efficient construction technologies, as these have the greatest h-index. The number of articles dealing with this barrier category has been growing over the years. Therefore, the development of actions to overcome such barriers is fundamental.

The second most impacting group of barriers is the Governmental/Political/Regulatory, since this group has the second greatest h-index. This group of barriers experienced a highlighted period from 2012 to 2017, reaching the maximum of publications in 2015. Although the number of publications concerned with this group of barriers in 2018 is the largest one over the covered period, it is still soon to say that there is a recent interest in such barriers.

The Professional/Technical and Cultural/Social/Behavioural groups share the third highest rank of importance. This group has been growing over the years while the former one, after being stable for many years, experienced a growth and decline from 2012 to 2017. Here, it is impossible to determine whether the large number of publications in 2018 signals an upward trend or is just incidental.

The Technological and Market groups are the ones with the least influence, since they have the lowest h-index. Publications dealing with Market obstacles only appeared in three years during the period covered by this study. Publications concerned with technological barriers have been roughly constant over time.

4. The barriers and associated themes, types of building and geographical regions

This study is interested in knowing as much as possible about the barriers to BEE technologies and their dynamics. This article compiles knowledge that can be further explored by the scientific community. Besides, the more that is known about the barriers, the easier it will be to overcome them. Therefore, by studying several types of dependent relationships, important insights can be highlighted. For instance, knowing which category of barriers is more common to which type of building will allow the formulation of strategies that are most suitable to that segment. In the same way, identifying how the barriers spread themselves over the globe opens up the possibility to find countries that can be used as a benchmark.

A research carried out by [49] identified several research themes within the field of knowledge building energy-efficiency. The 58 articles used to gather the barriers were scanned in order to identify the themes that were treated concomitantly with the barriers. Thus, this paper also presents the dependence relation of

the barriers on such themes. This is useful to contextualise the scenario in which a given barrier is raised. This knowledge can also be useful to understand the two previous dependence relationships.

By scanning the titles of the 58 articles that sourced the obstacles, it was possible to gather further information beyond the barriers. For example, the title “Barriers to the adoption of energy-saving technologies in the building sector: A survey study of Jing-jin-tang, China” [37], also mentions “energy-saving technologies” which can be put into the category technologies applied to energy efficiency in buildings, for example; the term “survey” is more concerned with a category which groups research methods, while the words “Jing-jin-tang, China” refer to where the study was carried out. Proceeding in the same way for all 58 titles, it was possible to pick up 61 terms which were clustered into 23 sub-categories, which were eventually summarised into 9 categories, as shown in Table 13. The sub-categories are the middle point between the raw terms gathered from the titles, and the category itself. This was only an artifice to make the categorisation process easier.

Table 13
Sub-categories and categories extracted from the title.

TITLE WORDS	SUB-CATEGORIES	CATEGORIES	
Ghana; Ghanaian	Africa		
Japan; Cambodia; China	Asia		
Sweden; Berlin; UK; European Union; Italy; England	Europe	GEO (Geographic Region)	
United States	North America		
Australia; South Australia; New Zealand	Oceania		
Office Buildings	Office Building		
Public Buildings; Public Hospitals; Public Schools; Hellenic Buildings; Healthcare	Public Building	TOB (Types of building)	
Residential Buildings; Residential Built; Home; Home Energy	Residential Building		
Rural Buildings	Rural Building		
Green Building	Green Building		
Sustainable building; Sustainable Construction	Sustainable Building		
Sustainability; Sustainable Technology; Clean Development; Sustainable; Sustainable Materials	Sustainability	GRB (Green buildings)	
Low-Energy Buildings	Zero Energy Building		
Low-Carbon Buildings; Carbon Emissions	Carbon Emissions	ENV (Environmental)	
Environmental	Environment		
Retrofitting; Renovation; Renovate; Retrofit; Building Renovation; Green Retrofitting	Retrofitting	RTF (Retrofitting)	
Economic	Economic		
Policy; Mandated Programmes; Policies; Environmental Legislation; Standards; Regulation; Certification	Policy	GOV (Government)	
Social	Social		
Energy-Saving Technologies; Energy-Efficient Technologies	Technologies	TEC (Technologies)	
BIM	Building Information Modelling		
BIPV; Building-Integrated Photovoltaics	Building Integrated Photovoltaics	BIP (Building integrated photovoltaics)	
Semi-Structured Interviews; Case Study; SWOT Analysis; Survey	Method	MET (Research method)	

The category GEO groups every reference to a country, city, and continent. Office buildings, rural buildings, etc. were clustered into types of building. Many other terms found among the titles' words were classified according to Cristino et al. [49] into seven other categories named research themes: GRB, ENV, RTF, GOV, TEC, BIP, and MET.

The category GRB is a particular case. This term appears clearly in some titles, but according to Cristino et al. [49] it should be grouped together with terms like sustainable buildings, sustainability and zero energy buildings. Thus, the term Green Building (GRB) from now on will be used to refer to a category, rather than an isolated term.

Table 13 is graphically represented in Fig. 12. In the centre of the figure, six arrows representing the six groups of obstacles can be seen. The thickness of each arrow is directly related to the number of barriers (or items) classified into the respective category. Each arrow points to a bar graph which shows three different pieces of numerical information: the number of research themes associated with the groups of barriers; the number of times a given geographical region is mentioned in association with a group of barrier; and the number of times a type of building and a specific group of barriers appeared together.

From Fig. 12, it can be seen that the most frequent research theme associated with the obstacles is GRB; the most frequent region is Europe (EUR), followed closely by Asia (ASI) and Africa (AFR); public buildings (PUB) and residential buildings (RBD), respectively, are the most cited types of building, together with the groups of barriers.

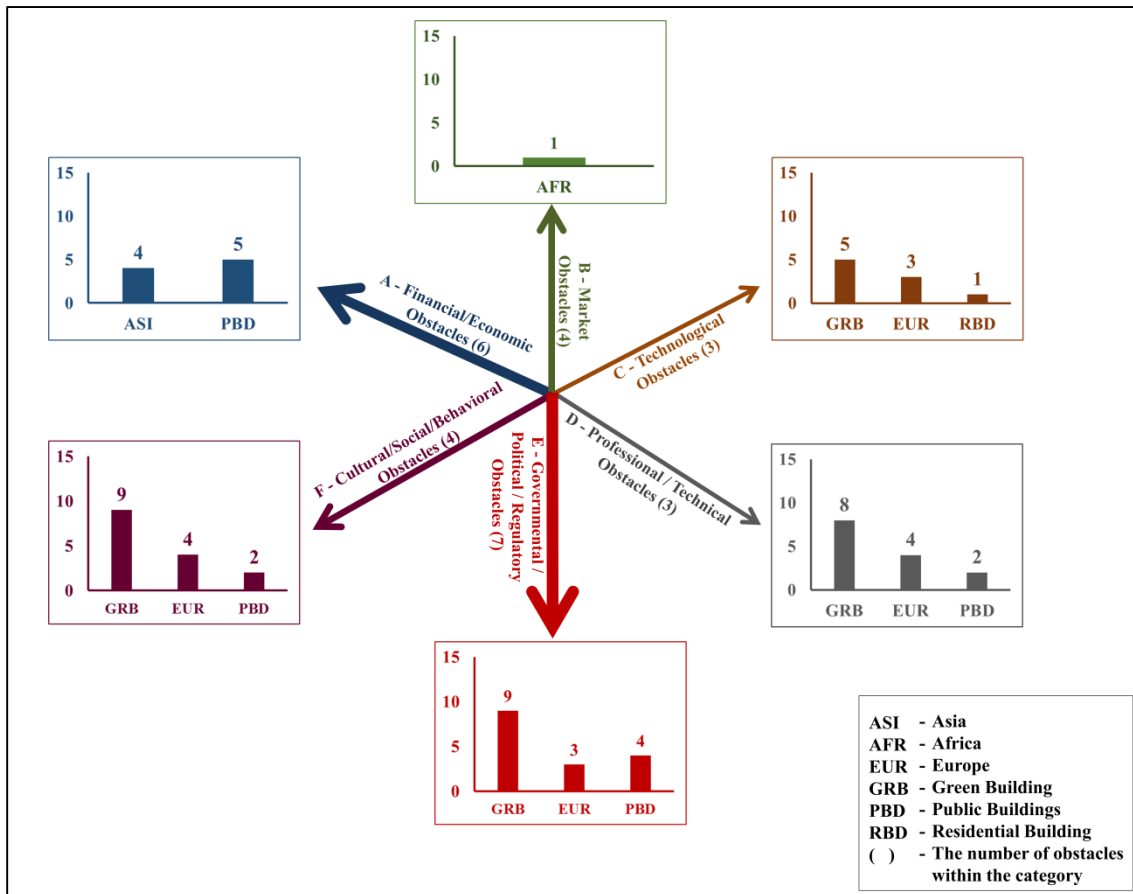


Fig. 12. Groups of barriers and their association with research themes, geographical regions, and types of building.

In order to perform more detailed analyses, the next step was to count the number of times that each category and each barrier appeared, simultaneously, in the 58 titles. In other words, three contingency tables were built: counting the number of times each group of obstacles appeared associated with each theme; the number of times each group of barriers appeared associated to each geographical region; and the number of times each group of obstacles appeared associated with each type of building. Table 14 synthesises these three tables.

Table 14 is useful to understand how strongly a research theme, geographical region, or type of building is associated with each of group of barriers. For instance, the research theme GRB is strongly associated with all groups of barriers, while the theme RTF (Retrofitting) is not associated with the groups of obstacles

B and C. It is possible to see that, of all of the articles related to the group of barriers A, only one is not associated with any of the seven research themes, while 22% of all documents dealing with the group of barriers E is related to none (N) of the seven themes.

Table 14 also presents the column average profile, as the profile of each group of barrier should be compared to it. For instance, the association of the theme GRB with the group of barrier B is greater than the average; that is, 38% of the articles dealing with the group of barriers B is due to the theme GRB, while the average is only of 28%. On the other hand, the contribution of the theme POL for the group of barriers C, 15%, is lower than the average (20%).

Table 14
Contingency Table.

CATEGORIES		GROUPS OF BARRIERS						AVERAGE PROFILE
		A	B	C	D	E	F	
RESEARCH THEMES	BIP	2 (0.04)	1 (0.13)	0 (0.00)	2 (0.07)	1 (0.03)	1 (0.03)	7 (0.04)
	ENV	4 (0.08)	1 (0.13)	1 (0.08)	2 (0.07)	2 (0.06)	2 (0.06)	12 (0.07)
	GRB	14 (0.29)	3 (0.38)	5 (0.38)	8 (0.28)	9 (0.25)	9 (0.26)	48 (0.28)
	POL	12 (0.25)	0 (0.00)	2 (0.15)	5 (0.17)	7 (0.19)	8 (0.23)	34 (0.20)
	MET	4 (0.08)	1 (0.13)	0 (0.00)	1 (0.03)	2 (0.06)	4 (0.11)	12 (0.07)
	RTF	5 (0.10)	0 (0.00)	0 (0.00)	3 (0.10)	3 (0.08)	4 (0.11)	15 (0.09)
	TEC	6 (0.13)	1 (0.13)	0 (0.00)	4 (0.14)	4 (0.11)	6 (0.17)	21 (0.12)
	N	1 (0.02)	1 (0.13)	5 (0.38)	4 (0.14)	8 (0.22)	1 (0.03)	20 (0.12)
GEOGRAPHICAL REGIONS	AFR	2 (0.04)	1 (0.13)	2 (0.15)	2 (0.07)	2 (0.06)	2 (0.06)	11 (0.07)
	ASI	4 (0.08)	0 (0.00)	0 (0.00)	1 (0.03)	3 (0.08)	3 (0.09)	11 (0.07)
	EUR	3 (0.06)	0 (0.00)	3 (0.23)	4 (0.14)	3 (0.08)	4 (0.11)	17 (0.10)
	OCE	2 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	2 (0.06)	5 (0.03)
	AME	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)	2 (0.01)
	N	37 (0.77)	7 (0.88)	8 (0.62)	22 (0.76)	26 (0.72)	23 (0.66)	123 (0.73)
TYPES OF BUILDING	OBD	1 (0.02)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)	3 (0.02)
	PBD	5 (0.10)	0 (0.00)	0 (0.00)	2 (0.07)	4 (0.11)	2 (0.06)	13 (0.08)
	RBD	4 (0.08)	0 (0.00)	1 (0.08)	0 (0.00)	3 (0.08)	2 (0.06)	10 (0.06)
	RuBD	1 (0.02)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)	1 (0.03)	4 (0.02)
	N	37 (0.77)	8 (1.00)	12 (0.92)	26 (0.90)	27 (0.75)	29 (0.83)	139 (0.82)

Fig. 13 makes such analysis immediate. It presents six slightly modified versions of the radar type chart, one for each group of barriers. Each axis corresponds to a research theme and there is one (N) in case there is no theme attached to an obstacle. Another particularity is that in all axes there is a mark signalling the average profile, which allows us to immediately compare the contribution (the association) of a theme to a barrier with the average contribution. At the bottom of the Fig. 13, a scale showing the chi-square distance between groups of barriers can be seen. The first point of such a scale is the average profile. Thus, one can evaluate those barriers that are similar to the average profile, and barriers that are more similar to one another.

One realises that each theme is associated with different groups of obstacles in different ways; that is, each theme associates more strongly with one type of barrier than others. However, in spite of this particularity, it can be seen that the theme GRB is the most commonly associated with all obstacles. The second theme that is most associated with all barriers (except for barrier B) is the POL.

The group of barriers A is the most strongly associated with all themes, since the association of all themes with this obstacle is above average. It is also remarkable that only one article out of those addressing the group of barriers A does not refer to any of the research themes. The group of obstacles C is the least associated with research themes. It is also possible to realise, considering the chi-square distance, that the groups of obstacles A, E, and F are the most similar to each other, which means that the association of these barriers with the research themes is similar. The group of obstacles C is the most different to the others. The group of barrier D is pretty close to the average profile.

Fig. 14 shows the relationship between the groups of barriers and the geographical region in which the research was carried out. A remarkable point is that most of the papers addressing any kind of obstacle do not mention the region in which the research was carried out. It is worth mentioning that only barriers E and F are related to the five continents highlighted by the papers considered for this study; the others mention three regions at most. It can be seen that the geographic region AFR (Africa) is mentioned by all groups of obstacles, while Europe (EUR) is the most frequently mentioned continent. The relationship between the barriers C, D, and F and Europe is higher than the average. The second most frequently mentioned continent is Asia (ASI), but obstacles B and C do not have any relationship with Asia. As in the previous analysis, the groups B and C are the most distant from the average profile and from the other groups.

Fig. 15 shows the strength of the relationships between the barriers and the types of building mentioned in the documents; that is, the context, from the point of view of the types of building, in which the barriers were studied. Most of the articles do not mention the type of building. None of the articles dealing with the group of obstacles B show any relation with any kind of building. The group of barriers C is related to residential buildings only, while barriers A, E, and F relate to all kinds of buildings. The group of obstacles D is related to two types of building. Office buildings (OBD) and Rural buildings (RuBD) are the least frequently mentioned types of building in publications. Public buildings are the type of building with the most impact on relationships, with more of an impact on Barriers C and A, respectively.

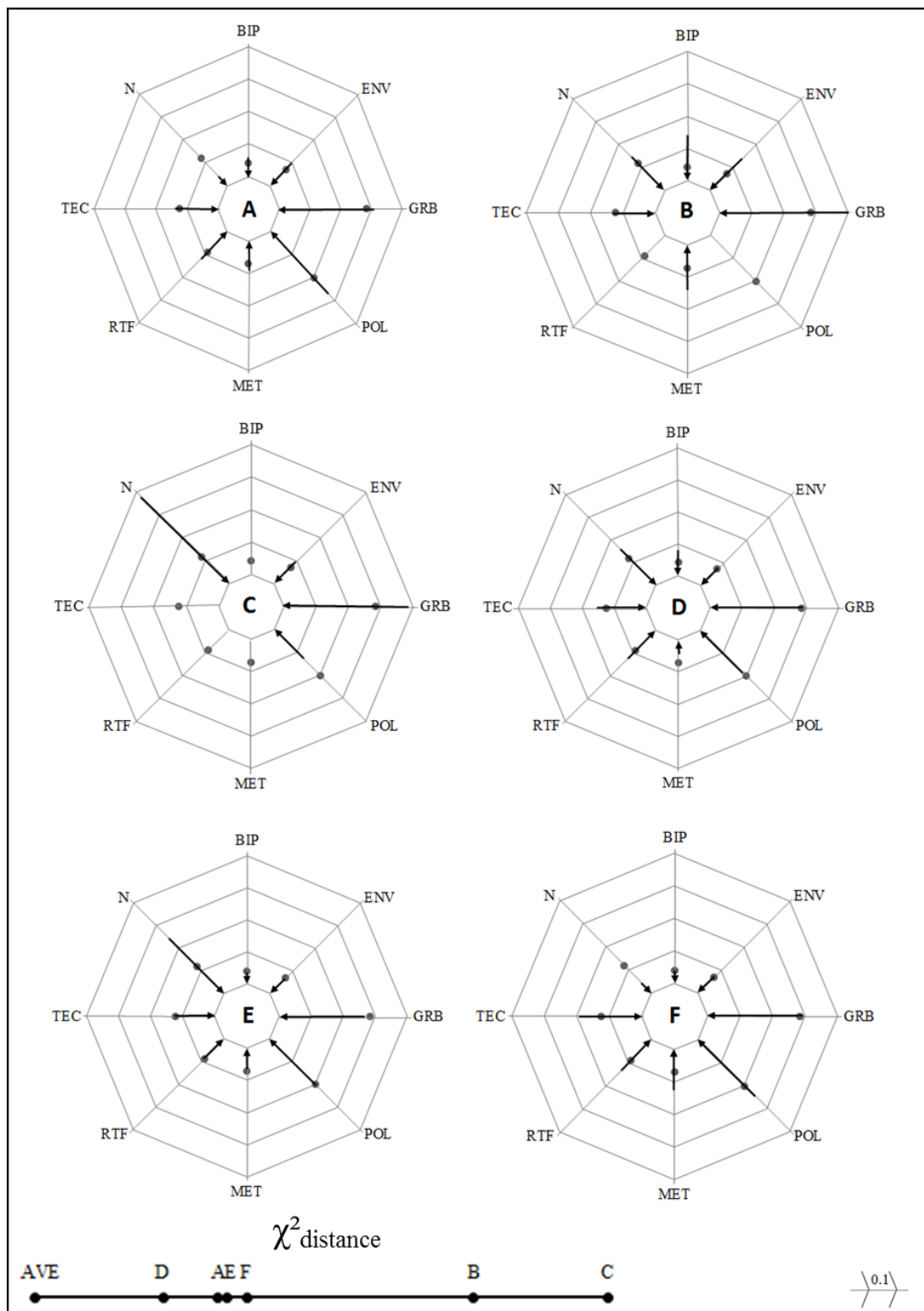


Fig. 13. Association between groups of obstacles and research themes.

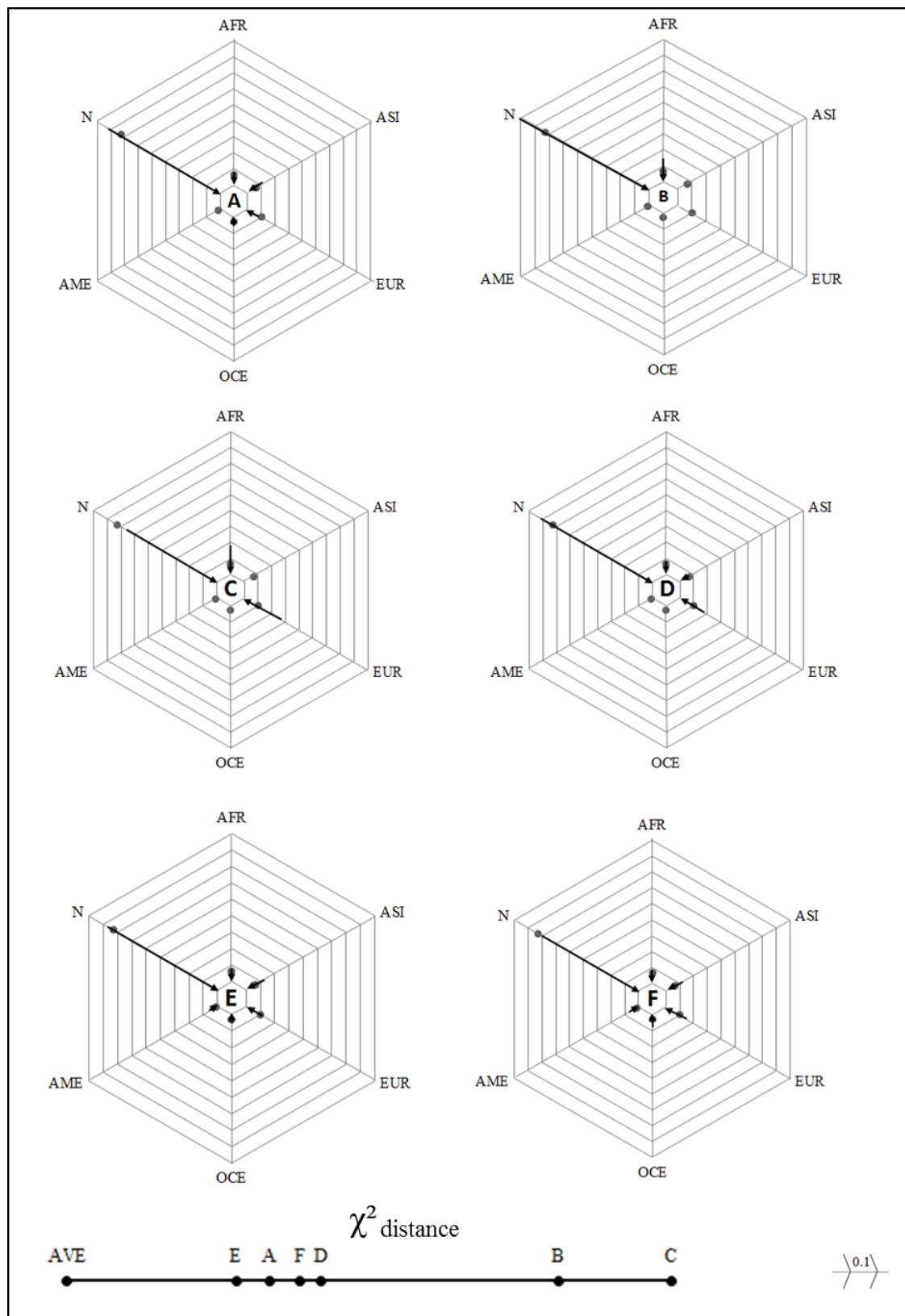


Fig. 14. Association between groups of obstacles and geographical regions.

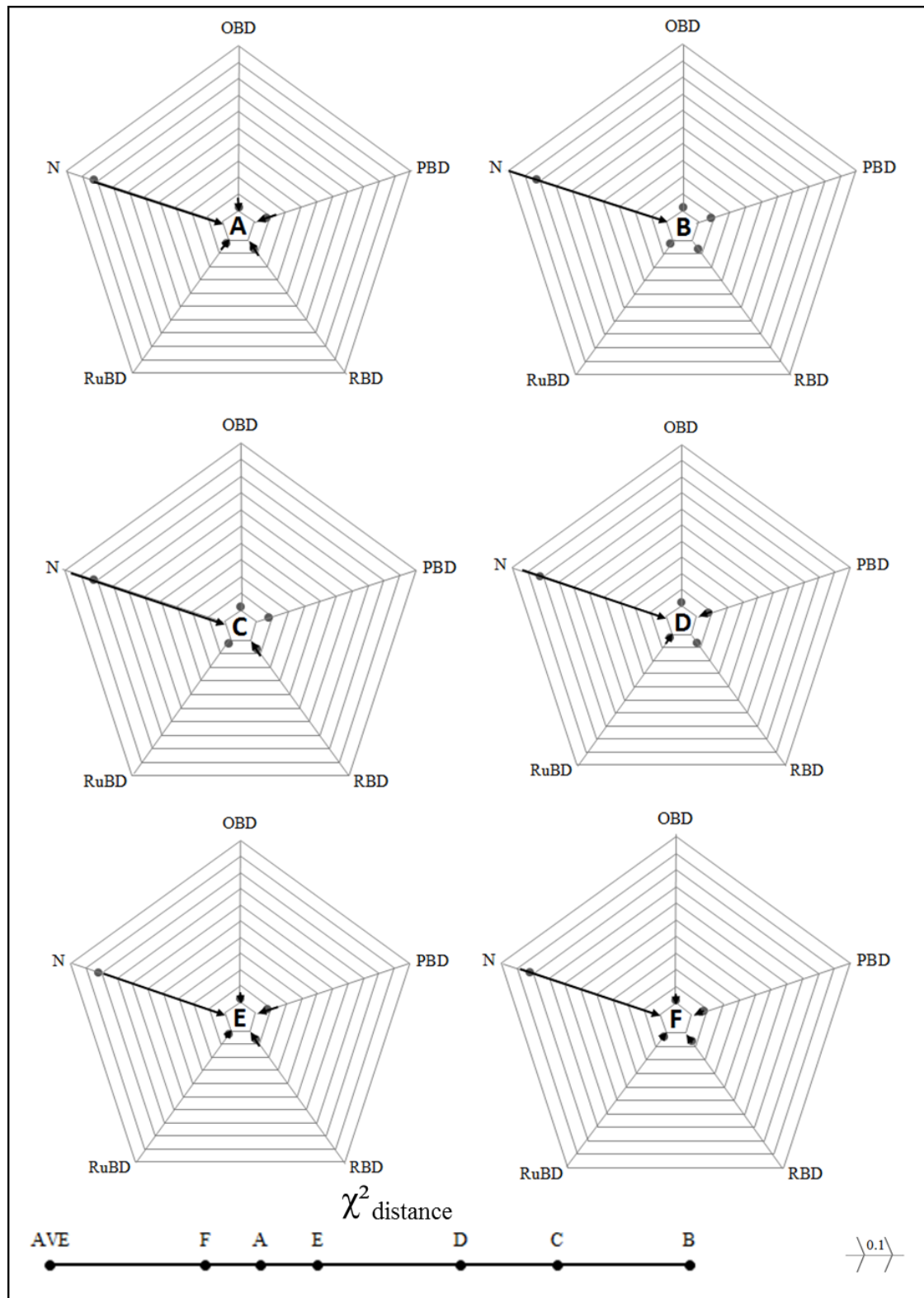


Fig. 15. Association between groups of obstacles and types of building.

Conclusions

This article is the first to identify 27 barriers to the adoption of BEE technologies and propose a new taxonomy, classifying such barriers into six categories, as well as establishing the h-index as a measure of the importance of a given barrier or group of barriers, as it takes into account the number of publications dealing with such barriers or groups and the number of citations.

The barriers were classified into six categories ranked from the most important to the least important as follows: Financial/Economic, Governmental/Political/Regulatory, Cultural/Social/Behavioural, Professional/Technical, Technological, and Market. These categories rely on three levels of importance. The highest level of importance is occupied by the Financial/Economic and Governmental/Political/Regulatory categories; the second level brings the groups Professional/Technical and Cultural/Social/Behavioural barriers; and, far below, are the Technological and Market categories. Therefore, capital availability and public policies have a great impact on the adoption of BEE technologies, closely followed by the cultural aspects of the stakeholders and the availability of skilled labour. It seems that technological barriers call the attention of a small part of the scientific community and market approaches to improve BEE is out of reach to the greatest part of the stakeholders. That is why these two categories have the lowest impact on the adoption of BEE technologies.

Another contribution of these article is the temporal distribution of the barriers and their categories. A timeline for each of the six groups of barriers is presented, as well as the barriers themselves within each group. By means of such graphics, it is possible to see that this field has shown great development during this decade. The evolution of the Financial/Economic and Cultural/Social/Groups seems to follow exponential growth, showing, according to Price's general law, that there are several aspects to be studied and which still require the attention of the scientific community. Thus, these are fertile themes for research and publications. The Market and Technological groups shows no growth patterns. Thus, it is not a good idea to invest time and money in research involving such groups of barriers. The other two categories, Governmental/Political/Regulatory and Professional/Technical, have been growing over time but do not present a clear pattern of growth; despite that, the Governmental/Political/Regulatory category still includes many aspects to be explored due to its intrinsic characteristics.

This study is the only one to bring together all of the barriers to BEE technologies found out in the literature and the strategies used to overcome them. In order to improve the adoption of BEE technologies, it is necessary to increase the credits for BEE projects, and the government should also embrace the idea of building energy efficiency and provide incentives for the building's owners and technologies manufacturers as well as working towards clear and steady regulations for the sector. Government, manufacturers, universities, research centres, and utility companies should come together to educate the society in some aspects of energy efficiency in order to make efficiency a mandatory requirement for any project.

This article showed that Barriers and types of buildings are variables, along with barriers and geographical locations. The most frequent region that appears in the papers dealing with barriers to BEE technologies is Europe, followed by Asia and Africa (with only one article). The legislative instrument created in the Europe Union, Directive on Energy Performance in Buildings, determines that new buildings should consume nearly zero energy from the power grid in 2020. The first targets of such legislation were probably public buildings. Thus, it is natural that the scientific community turned their attention toward the barriers to this goal, and much research was carried out in Europe to gather data from public buildings. However, this legislation drives a lot of research on green buildings, which is why most of the articles dealing with barriers were produced in Europe and are concerned with green buildings.

Although this article presents a large amount of data on barriers to the adoption of BEE technologies, there is room for further studies in this area. It is important to assess the feasibility and effectiveness of the measures to overcome such barriers. It would be valuable to study the economic impact of the energy-efficiency measures, so this study can be used to persuade governments to support pro-energy-efficiency programmes. All of the available BEE technologies should also be compiled, and the level of education of society regarding energy-efficiency should be investigated. Based on that, programmes toward energy-efficiency focused on segments of the society should be developed.

Finally, the results of this article may be useful for the formulation of public policies, since it identified all barriers to the adoption of BEE technologies. As these barriers are ranked in importance, it will be easy to start developing actions and programmes focused on the most important categories of barriers. Many of these actions are listed in this paper.

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Appendix

Fig. A.1 Research query used to gather the related articles

TITLE-ABS ("Building energy conservation" OR "Building energy analysis" OR "Building energy consumption" OR "Building energy demand" OR "Building energy efficiency" OR "Building energy management" OR "Building energy model" OR "Building energy modeling" OR "Building energy modelling" OR "Building energy performance" OR "Building energy policy" OR "Building energy regulation" OR "Building energy simulation" OR "Building energy standard" OR "building envelope retrofit" OR "Building information modelling" OR "Building integrated photovoltaics" OR "Building Management System" OR "Building operational performance" OR "Building Performance Criteria" OR "building performance simulation" OR "Building renovation of energy- saving" OR "Building retrofit" OR "Building retrofitting" OR "energy demand in buildings" OR "Energy rating of buildings" OR "Energy refurbishment of buildings" OR "Energy use in buildings" OR "Energy-efficiency building" OR "energy-efficient building" OR "Energy-saving construction" OR "Green Building Energy" OR "Green building compliance" OR "Green building evaluation" OR "Green buildings Energy" OR "Green energy efficiency" OR "Green Building programme" OR "High performance building skin" OR "High performance buildings" OR "Home energy efficiency" OR "Intelligent Building" OR "intelligent building design" OR "Low carbon buildings" OR "Low Consumption Building" OR "Low energy building" OR "Low-energy building" OR "Nearly zero energy buildings" OR "Net-Zero Energy building" OR "Building Operating energy" OR "building operational energy efficiency" OR "building Passive energy design" OR "Passive solar building" OR "Positive Energy Building" OR "building Potential energy saving" OR "building Real energy savings" OR "building Reconstruction for energy efficiency" OR "Smart buildings" OR "Solar-powered residential buildings" OR "Sustainable building" OR "Sustainable building management" OR "sustainable buildings" OR "Sustainable development and green building" OR "Sustainable energy building" OR "Zero emission building" OR "Zero Emissions Buildings" OR "Zero energy building" OR "Zero-energy building" OR "building energy assessment" OR "Building Energy audit" OR "building Energy audits" OR "Building energy awareness" OR "Building Energy balance" OR "Building Energy benchmark" OR "building Energy certification" OR "building Energy conversion" OR "building Energy cost" OR "building Energy demand" OR "building Energy economics" OR "building Energy economy" OR "building energy education" OR "building Energy efficiency" OR "energy efficiency building" OR "Energy efficiency in buildings" OR "Energy efficiency of buildings" OR "Building Energy efficient" OR "Energy efficient building" OR "Building Energy improvement" OR "Building Energy label" OR "Building Energy laws and regulations" OR "Building Energy load" OR "Building energy performance" OR "Energy performance in buildings" OR "Energy performance of buildings" OR "Building Energy regulations" OR "Building Energy renovation" OR "Building Energy requirement" OR "Building Energy retrofit" OR "Building Energy saving" OR "Building Energy storage" OR "Building Energy use" OR "Building Energy utilization efficiency" OR "Building Energy-efficiency" OR "Building Energy-saving") OR AUTHKEY ("Building energy conservation" OR "Building energy analysis" OR "Building energy consumption" OR "Building energy demand" OR "Building energy efficiency" OR "Building energy management" OR "Building energy model" OR "Building energy modeling" OR "Building energy modelling" OR "Building energy performance" OR "Building energy policy" OR "Building energy regulation" OR "Building energy simulation" OR "Building energy standard" OR "building envelope retrofit" OR "Building information modelling" OR "Building integrated photovoltaics" OR "Building Management System" OR "Building operational performance" OR "Building Performance Criteria" OR "building performance simulation" OR "Building renovation of energy- saving" OR "Building retrofit" OR "Building retrofitting" OR "energy demand in buildings" OR "Energy rating of buildings" OR "Energy refurbishment of buildings" OR "Energy use in buildings" OR "Energy-efficiency building" OR "energy-efficient building" OR "Energy-saving construction" OR "Green Building Energy" OR "Green building compliance" OR "Green building evaluation" OR "Green buildings Energy" OR "Green energy efficiency" OR "Green Building programme" OR "High performance building skin" OR "High performance buildings" OR "Home energy efficiency" OR "Intelligent Building" OR "intelligent building design" OR "Low carbon buildings" OR "Low Consumption Building" OR "Low energy building" OR "Low-energy building" OR "Nearly zero energy buildings" OR "Net-Zero Energy building" OR "Building Operating energy" OR "building operational energy efficiency" OR "building Passive energy design" OR "Passive solar building" OR "Positive Energy Building" OR "building Potential energy saving" OR "building Real energy savings" OR "building Reconstruction for energy efficiency" OR "Smart buildings" OR "Solar-powered residential buildings" OR "Sustainable building" OR "Sustainable building management" OR "sustainable buildings" OR "Sustainable development and green building" OR "Sustainable energy building" OR "Zero emission building" OR "Zero Emissions Buildings" OR "Zero energy building" OR "Zero-energy building" OR "building energy assessment" OR "Building Energy audit" OR "building Energy audits" OR "Building energy awareness" OR "Building Energy balance" OR "Building Energy benchmark" OR "building Energy certification" OR "building Energy conversion" OR "building Energy cost" OR "building Energy demand" OR "building Energy economics" OR "building Energy economy" OR "building energy education" OR "building Energy efficiency" OR "energy efficiency building" OR "Energy efficiency in buildings" OR "Energy efficiency of buildings" OR "Building Energy efficient" OR "Energy efficient building" OR "Building Energy improvement" OR "Building Energy label" OR "Building Energy laws and regulations" OR "Building Energy load" OR "Building energy performance" OR "Energy performance in buildings" OR "Energy performance of buildings" OR "Building Energy regulations" OR "Building Energy renovation" OR "Building Energy requirement" OR "Building Energy retrofit" OR "Building Energy saving" OR "Building Energy storage" OR "Building Energy use" OR "Building Energy utilization efficiency" OR "Building Energy-efficiency" OR "Building Energy-saving") AND TITLE-ABS ("barrier" OR "obstacle") OR AUTHKEY ("barrier" OR "obstacle") AND SRCTYPE (j) AND PUBYEAR > 1999 AND PUBYEAR < 2019