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Barriers and drivers to the adoption of energy-efficient technologies in the building sector: a survey in Brazil

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I dedicate this research, in a special, to my family.

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ABSTRACT

Energy is one of the most important factors for the growth of the world economy, thus the demand for it has increased over the years. Such a growing brings, among several issues, environmental impacts, mainly the increase of greenhouse gas emissions. For decades, the industrial sector was responsible for the greatest part of the energy demand, but as time went by the consumption shifted toward the building sector, which is responsible for 36% of the global final energy consumption and 40% of the total greenhouse gas emissions. Brazil, as well as worldwide, has been facing increasing energy consumption in the building sector. Such a scenario suggests urgency in reducing energy consumption. 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. Thus, before overcoming such barriers, it is necessary to know them. Therefore, the aim of this research is to identify the barriers that hinder the adoption of energy-saving technologies in the Brazilian building sector, and propose strategies to overcome them. To achieve such an objective, this research carried out a literature review over more than 450 articles gathered from the SCOPUS database, and 27 barriers were found to the adoption of energy-efficient technologies, which was classified into 6 groups, named as Financial/Economic; Market; Technological; Professional/Technical; Governmental/Political/Regulatory; and Cultural/Social/Behavioral. Such barriers were submitted to the judgment of Brazilian experts in order to capture their relevance to the national reality, by means of a structured questionnaire. A total of 1000 questionnaires were answered by professionals registered on the LinkedIn social network who had some academic education or professional experience related to building energy efficiency. Then, based on such questionnaires, a cluster analysis and factor analysis was performed in order to confirm the taxonomy proposed by the literature review, classifying at the same time, the categories according to their importance. The results confirmed the taxonomy proposed by the literature review, and the Governmental/Political/Regulatory and Financial/Economic barriers were the groups more important, according to the perception of the Brazilian experts. Furthermore, some strategies to overcome such barriers were proposed based on literature. Therefore, it is worth highlighting the main scientific contribution of this research is the theoretical consolidation on the barriers to the adoption of BEE technologies in the Brazilian building sector, in addition to presenting strategies to overcome them. It is worth noting that these contributions helped to fill scientific gaps related to the theme, which was presented in the research justification. As a practical contribution, the results of this research can be useful for the formulation of public policies, since it identified the barriers that most hinder the adoption of BEE technologies in Brazil. As these barriers are ranked in importance, it will be easy to start developing actions and programs focused on overcome the most important categories of barriers.

KEYWORDS: Energy efficiency. Building energy efficiency. Energy-saving technologies. Energy-efficient technologies. Barriers. Strategies.

RESUMO

A energia é um dos fatores mais importantes para o crescimento da economia mundial, portanto, a demanda por ela vem aumentando ao longo dos anos. Esse crescimento traz, entre várias questões, alguns impactos ambientais, principalmente o aumento das emissões de gases de efeito estufa. Durante décadas, o setor industrial foi responsável por grande parte da demanda de energia, mas com o passar do tempo, o consumo passou para o setor de edificações, que é responsável por 36% do consumo final global de energia e 40% do total de gases de efeito estufa emissões. O Brasil, assim como em todo o mundo, vem enfrentando um aumento no consumo de energia no setor de edificações. Esse cenário sugere urgência na redução do consumo de energia. Uma maneira de atingir esse objetivo, sem afetar o bem-estar dos ocupantes, é a adoção de tecnologias energeticamente eficientes em edificações. Existem várias tecnologias energeticamente eficientes disponíveis que trazem muitos benefícios ao setor de edificações. No entanto, existem barreiras que impedem sua adoção. Assim, antes de superar essas barreiras, é necessário conhecê-las. Portanto, o objetivo desta pesquisa é identificar as barreiras que impedem a adoção de tecnologias energeticamente eficientes no setor de edificações no Brasil, e propor estratégias para superá-las. Para atingir esse objetivo, esta pesquisa realizou uma revisão da literatura em mais de 450 artigos reunidos na base de dados SCOPUS, e foram encontradas 27 barreiras à adoção de tecnologias energeticamente eficientes em edificações, classificadas em 6 grupos, denominados Financeiro/Econômico; Mercado; Tecnológico; Profissional/Técnico; Governamental/Político/Regulatório; e Cultural/Social/Comportamental. Tais barreiras foram submetidas ao julgamento de especialistas brasileiros, a fim de capturar a sua importância para a realidade nacional, por meio de um questionário estruturado. Um total de 1000 questionários foram respondidos por profissionais inscritos na rede social LinkedIn, que possuiam alguma formação acadêmica ou experiência profissional relacionada à eficiência energética em edificações. Em seguida, com base nesses questionários, os dados foram analisados por meio da análise de cluster e análise fatorial, a fim de confirmar a taxonomia proposta pela revisão da literatura, classificando ao mesmo tempo as categorias de acordo com sua importância. Os resultados obtidos confirmaram a taxonomia proposta pela revisão da literatura, e os grupos Governamental/Político/Regulatório e Financeiro/Econômico foram considerados mais importantes, segundo a percepção dos especialistas brasileiros. Além disso, algumas estratégias para superar essas barreiras foram propostas com base na literatura. Destaca-se, portanto, que a principal contribuição científica desta pesquisa é a consolidação teórica das barreiras à adoção de tecnologias BEE no setor de edificações no Brasil, além de apresentar estratégias para superá-las. Cabe ressaltar que essas contribuições ajudaram a preencher lacunas científicas relacionadas ao tema, apresentadas na justificativa da pesquisa. Como contribuição prática, os resultados desta pesquisa podem ser úteis para a formulação de políticas públicas, uma vez que a pesquisa identificou as barreiras que mais impedem à adoção de tecnologias energeticamente eficientes no Brasil. Como essas barreiras são classificadas em importância, será fácil começar a desenvolver ações e programas focados em superar os grupos de barreiras mais importantes.

PALAVRAS-CHAVE: Eficiência energética. Eficiência energética em edificações. Tecnologia de economia de energia. Tecnologias energeticamente eficientes. Barreiras. Estratégias.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFR	Africa
AME	America
ASI	Asia
BEE	Building Energy Efficiency
BEN	Brazilian Energy Balance
BIPV	Building Integrated Photovoltaic Systems
CFLs	Compact Fluorescent Lamps
EES	Embedded Surface Systems
EPDB	National Electricity Conservation Program
EPS	Expanded Polystyrene
EUR	Europe
FA	Factor Analysis
GEO	Geographical Regions
GHP	Geothermal Heat Pump
GHSP	Ground Source Heat Pump
IEA	International Energy Agency
HVAC	Heating, Ventilation, and Air-Conditioning
INMETRO	National Institute of Metrology, Standardization and Quality
KMO	Kaiser-Meyer-Olkin
LED	Light-Emitting Diodes
OBD	Office Buildings
OCE	Oceania
PBE	Brazilian Labeling Program
PCM	Phase Change Material
PROCEL	National Electricity Conservation Program
PBD	Public Buildings
PV	Photovoltaic
RBD	Residential Buildings
RuBD	Rural Buildings
SWH	Solar Water Heating
TABS	Thermally Active Building Systems
TES	Thermal Energy Storage
TOB	Types of Building
VAV	Variable Air Volume
VRV	Variable Refrigerant Volume
XPS	Extruted Polystyrene

SUMMARY

1 INTRODUCTION

Energy is considered one of the most important factors for the growth of the world economy and technological advances, that is why the demand for electricity has been increasing over the last decades (KOJOK *et al.*, 2016; MAHMOUD *et al.*, 2017; MERTCUCE; RIFFAT, 2016; PAN *et al.*, 2018; SEPÚLVEDA, 2016; ZHANG; WANG, 2013). The increase in the energy consumption brings with it several concerns, such as the shortage of primary energy resources and the consequent search for new sources of energy, and the environmental impacts, mainly the increase of the greenhouse gas emissions (HÄKKINEN, 2011; PERSSON; GRÖNKVIST, 2015; ZHANG; WANG, 2013).

For many years, the industrial sector was the target of the energy conservation measures, since it was seen as the sector responsible for most of the energy consumption. However, as time went by, the energy consumption shifted toward the building sector, i.e. residential, commercial, and public buildings (GREENOUGH; TOSORATTI, 2014; ZHANG; WANG, 2013).

According to the International Energy Agency (IEA, 2019), buildings are responsible for almost 36% of the final energy consumption. It is estimated that, beyond the impact on electricity consumption, buildings account for 40% of total greenhouse gas emissions (IEA, 2018). Over the last four decades, residential, commercial, and public sector electricity consumption has been consistently increased in Brazil, having exceeded industrial sector consumption in the last decade, reaching 50% of total energy consumption (BRAZILIAN ENERGY BALANCE, 2017).

Thus, it is necessary to find out a way of reducing the demand for energy without affecting the economic growth of the nations (BOND, 2011; GREENOUGH; TOSORATTI, 2014). The best approach to reach such a goal is to the adoption of energy-saving technologies (PERSSON; GRÖNKVIST, 2015).

There are several technologies capable to improve the building energy efficiency (BEE), such as those related to improvements in building envelope, HVAC (heating, ventilation, and air-conditioning) systems, modern lighting, use of renewable energy, etc (ALAJLAN; SMIAI; ELANI, 1998; DADZIE *et al.*, 2018; GENG *et al.*, 2015; HARKOUSS; FARDOUN; BIWOLE, 2018; KIM; LEE; KIM, 2018; LIU; REN, 2018; LU; FAN; ZHAO, 2018; PERSSON; GRÖNKVIST, 2015; WHIFFEN *et al.*, 2016; WIEL *et al.*, 1998; YEATSS *et al.*, 2017).

The buildings that adopt energy-efficient technologies, besides increasing its energy performance, aggregate several benefits for the owners and occupants, like the reduction of energy bill; increased the thermal comfort; moderate indoor temperatures; low humidity; better air quality; and low greenhouse gas emissions (GUPTA; ANAND; GUPTA, 2017; KORDJAMSHIDI; KING, 2009; LIU; GUO; HU, 2014; LIU; REN, 2018; MIHIC *et al.*, 2012; PRETE *et al.*, 2017; SOARES *et al.*, 2017). The potential of energy saving and the reduction of environmental impacts depends on the extent to which energy-efficient technologies are applied, from the building's design to its construction and operation (DADZIE *et al.*, 2018; GENG *et al.*, 2015; GREENOUGH; TOSORATTI, 2014; LI; COLOMBIER, 2009; YATES; ARONSON, 1983). Furthermore, the construction costs of efficient buildings are a bit higher (5% to 15%) when compared to the regular buildings (CHOW; LI; DARKWA, 2013; GLIEDT; HOICKA, 2015; GOLDEMBERG *et al.*, 1994; YEATTS *et al.*, 2017).

Despite the above benefits, energy-efficient technologies have not been widely used in buildings, so the theoretical potential for reducing electricity consumption is not achieved (PALMER *et al.*, 2013; ZHANG; ZHOU, 2015). This phenomenon is known as the "energy-efficient gap" (HIRST; BROWN, 1990; JAFFE; STAVINS, 1994).

The "energy-efficient gap" has been studied for decades (DU *et al.*, 2014; GERARDEN; NEWELL; STAVINS, 2017; HESSELINK; EMILE; CHAPPIN, 2019; HIRST; BROWN, 1990; JAFFE; STAVINS, 1994; KANGAS; LAZAREVIC; KIVIMAA, 2018; ZHANG *et al.*, 2018). The seminal paper by Jaffe and Stavins (1994) defines the "energy-efficient gap" as a difference between the optimal and observed level of energy efficiency, i.e. there is unrealized energy efficiency potential due to barriers to the adoption of energy-saving technologies.

Nowadays, the "energy-efficient gap" is related to the apparent reality that there are technologies that are not widely adopted, despite the apparent inherent socio-economic and environmental benefits (GERARDEN; NEWELL; STAVINS, 2017; KANGAS; LAZAREVIC; KIVIMAA, 2018). 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 (HESSELINK; EMILE; CHAPPIN, 2019). In brief, the "energy-efficiency gap" is due to the existence of barriers (KANGAS; LAZAREVIC; KIVIMAA, 2018).

According to Addy, Adinyira and Koranteng (2014); Djokoto, Dadzie, and Ohemeng (2014); Gliedt and Hoicka (2015); Jafarzadeh and Utne, (2014); Palmer *et al.* (2013); Tuominen *et al.* (2012), the causality of "energy-efficient gap" is determined by the existence of obstacles, or barriers, that act as mechanisms that inhibit the adoption of energy-efficient technologies even though they are economically viable and bring numerous benefits.

Therefore, to fill this gap, it is necessary to identify the obstacles to the adoption of BEE technologies and to propose strategies to overcome them. Based on this, the research questions that guide the development of this research are: what are the barriers to the adoption of energy-efficient technologies in the Brazilian building sector? And what are the strategies to overcome them?

1.1 OBJECTIVES

The aim of this research is to identify the barriers to the adoption of energy-efficient technologies in the Brazilian building sector, and to propose strategies to overcome them.

1.1.1 Specific Objectives

In order to achieve the main objective, the following specific objectives shall be pursued:

- To find out, in the literature, the main barriers to the adoption of BEE technologies;
- To create a taxonomy encompassing the barriers;
- To carry out a survey to verify the adherence of the barriers to the Brazilian scenario;
- To classify the barriers according to their importance;
- To find out, in the literature, the strategies to overcome them.

1.2 JUSTIFICATION FOR THE RESEARCH

The building sector has been gaining relevance in the energy consumption global as well as in environmental impacts, mainly, related to greenhouse gas emissions (BERARDI, 2017; FAZELI; DAVIDSDOTTIR, 2017; de MELO; JANNUZZI, 2015; MIHIC *et al.*, 2012). Nowadays, the building sector responds for almost 36% of the global final energy consumption, 55% of electricity produced globally, and 40% of the total greenhouse gas emissions (IEA, 2019).

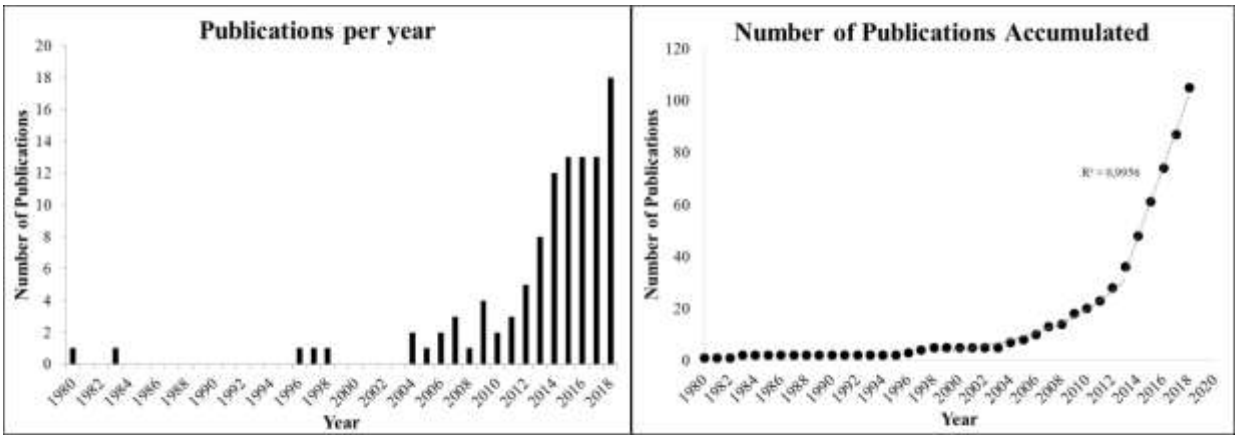
Brazil, along with other developing countries, has been facing increasing energy consumption in the building sector (WONG; KRÜGER, 2017). Therefore, the development of energy-efficient buildings is an important strategy for sustainable development, environmental protection, and saving of energy resources (LIU; GUO; HU, 2014; MIHIC *et al.*, 2012; ZHANG *et al.*, 2014).

According to PROCEL (National Electricity Conservation Program) (2013), new buildings constructed using technologies established by Brazilian Labeling Program (PBE Edifica) can achieve energy savings of up to 50%, while existing buildings can achieve 30%. Therefore, the findings of this research may lead to public policy formulations that stimulate the use of BEE technologies. The results of this research may also suggest improvements in the national energy-efficient labeling policy in the building sector, recalling that the adherence to this program is still low according to INMETRO (National Institute of Metrology, Standardization, and Quality) (2018).

From the academic point of view, this research carried out a brief bibliometric study to analyze the interest of the international scientific community in the theme, and only to identify some scientific gaps present in the articles used to collect barriers to the adoption of BEE technologies.

Therefore, the interest of the international scientific community in the theme has arisen since the 1980s. Figure 1 shows the evolution of publications related to the theme in a temporal distribution from 1980 to 2018.

Figure 1 - Evolution of publications related to barriers to the adoption of BEE technologies



Source: SCOPUS database (2019).

According to the Price's Law (1963), every field of knowledge grows exponentially until it reaches a point of inflection and afterward a threshold value around which scientific production stabilizes. 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, signalizing that the scientific community interest in this field has cooled down.

Observing Figure 1, one notes that the scientific production associated with the central theme has been growing exponentially and has not reached the inflection point yet, so the theme's maturity has not been reached yet, leaving several aspects to be explored, which is to say that there are good research possibilities in this area.

Furthermore, as observed in the scientific literature on the theme, there are some explored research opportunities (scientific gaps) that are still little explored in this research field. According to Nunhes, Motta, and Oliveira (2016), the identification of scientific gaps is a way to explore new relevant themes that have not yet been explored in a given research field. Therefore, the articles published in the last two years (2017-2018) are read in detail, in order to find the current gaps to be filled.

The scientific gaps directly related to the object of this study were identified in the research project phase of this dissertation. Thus, in order to explain the research relevance, Table 1 presents five scientific gaps identified in the recent scientific literature related to the field of knowledge and which still need to be explored.

Table 1 - Scientific gaps related to the research theme

Scientific Gaps	**References**
Development of research aimed at providing more scientific assessments on barriers to the use of BEE technologies and strategies to overcome such barriers.	Yeatts *et al.* (2017)
Identification of the most critical barriers among all identified barriers to BEE, in order to structure strategies to face them.	Gupta; Anand; Gupta (2017)
Explore appropriate strategies for the adoption of BEE technologies, in order to optimize large-scale implementation and accelerate the adoption of such technologies.	Arunkumar; Suveetha; Ramesh (2018); Zhang *et al.* (2018)
Further investigation is recommended, based on a larger sample of professionals.	Durdyev *et al.* (2018)
Future studies can be carried out in other countries to improve the generalization of these research findings.	Mostafa *et al.* (2018)

Source: The author.

Yeatts *et al.* (2017) developed an extensive literature review to identify the barriers that prevent the use of energy-efficient technologies throughout the life cycle of buildings, as well as the specific strategies available to overcome these barriers. Based on the study developed, the authors stressed the need for more research that provides assessments on the barriers to the adoption of BEE technologies, and beyond the strategies to overcome them. Therefore, the present study intended to collaborate to fill this gap, since the main objective of this research is directly focused on this gap.

Gupta, Anand, and Gupta (2019) address in their study the obstacles to the implementation of BEE measures. As a suggestion for future study, the authors emphasize that it is relevant to identify the most critical barriers to BEE, in order to structure strategies to face them. Furthermore, the authors Arunkumar, Suveetha, and Ramesh (2018); Zhang *et al.* (2018) also underscore the importance of studies that focus on exploring appropriate strategies to overcome barriers to the adoption of BEE technologies, in order to optimize large-scale implementation and accelerate the adoption of such measures.

Therefore, to contribute to filling both gaps, this research has developed an extensive literature review to identify the barriers that inhibit the adoption of energy-efficient technologies in the building sector, as well as the strategies to overcome them.

Durdyev *et al.* (2018) identified the relevance of barriers that prevent the adoption of BEE technologies in Cambodia, by submitting a questionnaire to professionals in the construction sector. However, based on the results of the study, the authors stressed the need for further investigation in the studies to be developed in this area, based on a larger sample of professionals. For this, the present study analyzed the relevance of each of the barriers identified in the literature, according to the perception of a larger sample of professionals who have some academic education or professional experience in BEE.

Finally, Mostafa *et al.* (2018) identified the barriers to the adoption of BEE technologies in the building sector in Australia and proposed that studies in this regard should be developed in other countries. Furthermore, among the publications selected for the bibliometric study, studies developed in several countries were found, for example, United Kingdom (GIESEKAM; BARRET; TAYLOR, 2016; STENVENSO; BABORSKA-NAROZNY, 2018), Sweden (PERSSON; GRÖNKVIST, 2015), United States (ZIMMERMAN; HALFACRE-HITCHCOOK, 2006), China (DING *et al.*, 2018; WANG *et al.*, 2016; ZHOU *et al.*, 2016), Russia (PAIHO; AHVENNIEMI, 2017), German (ACHITNICHT; MADLENER, 2014; AMORUSO; DONEVSKA; SKOMEDAL, 2018), Finland (KANGAS; LAZAVERIC; KIVIMAAA, 2018); Norway (AMORUSO; DONEVSKA; SKOMEDAL, 2018), Spain

(TRAVEZAN; HARMZEN; TOLEDO, 2013), among others. However, there are no records of the analysis of this theme in light of the Brazilian reality.

Furthermore, no studies have yet been found that link obstacles to the adoption of energy-efficient technologies with the types of buildings (residential, commercial, etc.), and geographical regions (North America, Asia, etc.).

Therefore, it is clear that there are opportunities that research that still needs to be explored, thus justifying the development of this study.

1.3 RESEARCH DELIMITATION

This research is delimited to Brazilian buildings (residential, commercial, and public buildings). The selected professionals are those with some professional experience or academic education related to BEE in the areas of architecture, civil engineering, electric/electronic engineering, mechanical engineering, certificate programs, etc. The sample size will be, at last, 1000 useful interviews, which is enough according to the number of variables considered for factor analysis.

1.4 RESEARCH STRUCTURE

The research was structured in 8 chapters. Chapter 2 brings the theoretical framework, the concepts concerned with the BEE, and the energy-saving technologies adopted in the building sector.

Chapter 3 covers the methodological approach adopted to carry out this research. This chapter exposes the research classification and steps flowchart for the research development.

Chapter 4 presents the obstacles and their classification into groups, the temporal distribution of the barriers according to the literature, as well as the barriers association with types of building and geographical regions.

Chapter 5 presents the results of quantitative research design to capture the perception of Brazilian experts in the relevance of the barriers to the adoption of BEE technologies pointed out in the literature.

Chapter 6 presents the strategies to overcome the barriers to the adoption of BEE technologies according to the literature

Chapter 7 presents the conclusions, the contributions, and the limitations of this study. And finally, the references and appendix are presented.

2 THEORETICAL FRAMEWORK

This chapter presents the main topics for the theoretical basis of the research. The first section of this chapter introduces the concepts of BEE. Subsequently, in the second section, are presented the main BEE technologies.

2.1 BUILDING ENERGY EFFICIENCY

Energy is important for the development of a world economy (KOJOK *et al.*, 2016; MAHMOUD *et al.*, 2017; MERTCUCE; RIFFAT, 2016; PAN *et al.*, 2018; SEPÚLVEDA, 2016; ZHENXING; JING, 2007). According to the International Energy Agency (IEA, 2017), it is relevant to adopt measures to deal with concerns related to the shortage of primary energy resources, and the environmental impacts, mainly the increase of the greenhouse gas emissions

BEE is a relevant way to save energy and reduce environmental impacts (KAZANASMAS *et al.*, 2014). According to Zhang *et al.* (2015) adopting measures to improve BEE is one of the most economic and immediate ways to reduce energy demand in the residential, commercial, and public sectors. Therefore, this has made the BEE increasingly relevant to energy savings (SILVERO *et al.*, 2019; ZORITA *et al.*, 2016).

The focuses on the BEE is to use measures as a contribution to reduce building energy consumption, to preserve the thermal comfort of the occupants, to reduce energy bill, minimize the environmental impacts, and even promote the growth of the economy (DASCALAKI *et al.*, 2016; LIU *et al.*, 2014; MAHMOUD *et al.*, 2017; PAN *et al.*, 2018; SOARES *et al.*, 2017; TAN *et al.*, 2016).

There are several government laws that require new buildings to be constructed with a high level of energy efficiency. For example, in Europe, the EPDB (The Directive on Energy Performance in Buildings) was developed, since the building sector consumes more than 40% of the electricity produced. Thus, it is expected that new buildings constructed in Europe will consume "nearly zero" of the electricity grid, and that adopt the use of renewable sources. This type of building is named as a “very low energy building” or “nearly zero-energy building” by presents a high energy performance (ECEEE, 2010).

In North America, the energy crisis that arose in California (2000-2001) encouraged the creation of programs that promote the adoption of measures to increase energy efficiency in commercial, residential, and public buildings.

In Brazil, the concern with energy efficiency arose in the 1970s, opening space for the development of actions aimed at conservation and efficient use of energy (BRASIL, 2011). The first procedures related to energy conservation in the building sector emerged during the energy crisis facing the country in 2001. Law No. 10,295, created on October 17, 2001, established the National Policy for the Conservation and Rational Use of Energy (BRASIL, 2001), that presents the specific legislation for the save energy in the building sector (LIU; GUO; HU, 2014; SANGOI; GHISI, 2019; SCALCO *et al.*, 2012).

In 2003, PROCEL EDIFICA (a subprogram of PROCEL) was created to disseminate and stimulate the application of BEE technologies, in order to contribute to the expansion, in an energy-efficient way, the country's building sector (PROCEL, 2013).

According to the Brazilian Energy Balance (BEN), published in 2018, the building sector is responsible for 46% of the electricity consumption in Brazil. The energy consumption continues to rise, driving the adoption of more energy-saving technologies in this sector (BAVARESCO; GHISI, 2018; VELOSO *et al.*, 2018).

This shows a growing concern to improve the BEE in pursuit of sustainable development (CAO; DAI; LIU, 2016). Therefore, it is evident that BEE is one of the sustainable development strategies to reduce building energy consumption and mitigate greenhouse gas emissions (MERTCUCE; RIFFAT, 2016; PAN *et al.*, 2018; WONG; KRÜGER, 2017; ZHANG *et al.*, 2014).

2.2 BUILDING ENERGY EFFICIENCY TECHNOLOGIES

The energy-efficient technologies are an essential part of one strategy for a reduction in building electricity use (DU *et al.*, 2014; IM *et al.*, 2017). Such technologies are adopted to provide the same energy level and thermal comfort with lower energy consumption and natural resource utilization (TAN *et al.*, 2016).

Exist a wide range of options for the energy-efficient technologies for being used in buildings, for example, measures employed for better envelope thermal insulation; the use of renewable energy system; the adoption of HVAC systems more efficient; the use of economic lamps, and others (HARKOUSS; FARDOUN; BIWOLE, 2018; KIM; LEE; KIM, 2018; LU; FAN; ZHAO, 2018; WHIFFEN *et al.*, 2016).

The adoption of BEE technologies brings several benefits for the owners and occupants, like the reduction of energy demand; the decrease of greenhouse gas emissions; the reduction of the operating costs; and the increasing of thermal comfort (GUPTA; ANAND; GUPTA, 2017; LIU; REN, 2018; PRETE *et al.*, 2017). Furthermore, the construction costs of efficient buildings are a bit higher (5% to 15%) when compared to the regular buildings (CHOW; LI; DARKWA, 2013; GLIEDT; HOICKA, 2015; GOLDEMBERG *et al.*, 1994).

However, the potential of energy saving and the reduction of environmental impacts depends on the extent to which energy-efficient technologies are applied (GENG *et al.*, 2015; LI; COLOMBIER, 2009; YATES; ARONSON, 1983). According to Soares *et al.* (2017) and Dascalaki *et al.* (2016), the use of the BEE technologies leads to a saving up to 30% of the total energy consumption for existing buildings, while this number rises to 50% for new buildings. That is why it is important to be aware of the available BEE technologies.

Therefore, the next sections present the main energy-efficient technologies related to building envelope, HVAC systems, renewable energy, lighting, and home appliances.

2.2.1 Building Envelope Technologies

This group brings together, technologies related to the design and architectural planning from the outside of the building to achieve energy consumption reduction. Table 2 shows the technologies named according to their appearance frequency in the literature followed the by references where it was found.

The building envelope should be designed to ensure the best thermal performance of the building (ADEYEYE; OSMANI; BROWN, 2007; BARRET *et al.*, 2008; HARKOUSS; FARDOUN; BIWOLE, 2018; LIU *et al.*, 2018; PAN *et al.*, 2018; PASZTORY; PERALTA; PESZLEN, 2011; TAN *et al.*, 2016; WANG; LIU, 2015). The use of energy-saving technologies in the building envelope is crucial to improve the thermal comfort of the indoor environment (AL-MOFLEH *et al.*, 2016; CAO; DAI; LIU, 2016; GELEGENIS *et al.*, 2014). Such technologies are employed to make the building envelope resistant to air and humidity, thus ensuring the reduction of the cooling and heating loads of the building.

Most of the building envelope is made up of facade and walls (GE *et al.*, 2018; YU; LIANG, 2016). Poor insulation of building walls and facades are responsible for 30% of a building's energy consumption and 35% of heat loss (FOWLER; RAUCH, 2007; HUO; SHAO; HUO, 2017; KIM; LEE; KIM, 2018; MA; SI, 2014; PRETE *et al.*, 2017). One of the measures to improve the building's indoor climate and improve thermal insulation is the adoption of technologies on the envelope of walls and facades of buildings (DAY; JONES; TURTON, 2013; FOWLER; RAUCH, 2007; KISS, 2016; LIU; REN, 2018)

Table 2 - Building envelope technologies

(to be continued)

Technology		References
Envelope thermal insulation	Insulation of external facades	Adeyeye; Osmani; Brown (2007); Alajlan; Smiai; Elani (1998); Barret *et al.* (2008); Begum; Pereira (2010); Cao; Dai; Liu (2016); Quitzau; Hoffmann; Elle (2012); Harkouss; Fardoun; Biwole (2018); Kiss (2016); Liu *et al.* (2014); Liu *et al.* (2018); Liu; Ren (2018); Lu; Fan; Zhao (2018); Pan *et al.*(2018); Pasztory; Peralta; Peszlen (2011); Prete *et al.*, (2017); Tan *et al.* (2016); Wang; Liu (2015); Wiel *et al.* (1998); Xu *et al.* (2016)
	Insulation of internal walls	Chow; Li; Darkwa (2013); Dimoudi (2013); Ge *et al.* (2018); Gelegenis *et al.* (2014); Geng *et al.* (2015); Huo *et al.* (2015); Huo; Shao; Huo (2017); Kim; Lee; Kim (2018); Li; Zhao; Zhu (2013); Liu *et al.* (2014); Luo *et al.* (2018); Ma; Si (2014); Pan *et al.* (2018); Palm (2013); Rashwan; Farag; Moustafa (2013); Yates; Aronson (1983); Yu; Liang (2016)
Materials	Phase change materials	Cao; Dai; Liu (2016); Cui *et al.* (2016); Day; Jones; Turton (2013); Geng *et al.* (2015); Harkouss; Fardoun; Biwole (2018); Huo *et al.* (2015); Liu; Liao; Hsueh (2016); Sleiti; Naimaster (2016); Zhang *et al.* (2017)
	Proper thermal insulation materials	Begum; Pereira (2010); Buonomanoa *et al.* (2016); Kim (2017); Liu; Liao; Hsueh (2016); Xu *et al.* (2016)
Building Façades	Double-skin facade	Ge *et al.* (2018); Huo *et al.* (2015); Liu; Liao; Hsueh (2016); Lu; Fan; Zhao (2018); Rinaldi; Schweiker; Iannone (2018); Wang; Liu (2015)
Wall technologies	Lower U-value and higher R-value wall	Cao; Dai; Liu (2016); Chow; Li; Darkwa (2013); Mahmoud *et al.* (2017); Rashwan; Farag; Moustafa (2013); Xiao; Wei; Wang (2014).
	Transparent/opaque curtain wall	Li; Zhao; Zhu (2013); Luo *et al.* (2018); Thibaudeau (2008).
	Trombe wall	Cao; Dai; Liu (2016); Dimoudi (2013); Huo *et al.* (2015); Tan *et al.* (2016)
Roofing technologies	Thermal insulation of roofs	Dimoudi (2013); Gelegenis *et al.* (2014); Geng *et al.* (2015); Huo; Shao; Huo (2017); Li; Zhao; Zhu (2013); Liu *et al.* (2014); Palm (2013); Rashwan; Farag; Moustafa (2013)
	Green roof technology	Cao; Dai; Liu (2016); Geng *et al.* (2015);Liu *et al.* (2014); Liu; Liao; Hsueh (2016); Luo *et al.* (2018); Mahmoud *et al.* (2017); Wang; Liu (2015)

Table 2 - Building envelope technologies

(conclusion)

Technology		References
Window technologies	Low-E windows/glass	Chow; Li; Darkwa (2013); Geng *et al.* (2015); Hester *et al.* (2012); Im *et al.* (2017); Kim (2017); Kim; Lee; Kim (2018); Liu *et al.* (2014); Liu; Liao; Hsueh (2016); Luo *et al.* (2018); Mahmoud *et al.* (2017); MertCuce; Riffat (2016); Wang; Liu, (2015); Xu *et al.* (2016); Yoshida; Shimoda; Ohashi (2017)
	Double-glazed window	Barret *et al.* (2008); Begum; Pereira (2010); Day; Jones; Turton (2013); Dimoudi (2013); Fowler; Rauch (2007); Gelegenis *et al.* (2014); Geng *et al.* (2015); Huang *et al.* (2012); Im *et al.* (2017); Liu; Liao; Hsueh (2016); Luo *et al.* (2018); Tsagarakisa; Karyotakis; Zografakisc (2012); Yoshida; Shimoda; Ohashi (2017)
	Big/Large windows	Hester *et al.* (2012); Im *et al.* (2017); Li; Zhao; Zhu (2013); Manzano-Agugliaro *et al.* (2015);Palm (2013); Rashwan; Farag; Moustafa (2013); Thibaudeau (2008)
	Use operable window/glass	Cao; Dai; Liu (2016); Ge *et al.* (2018); Hester *et al.* (2012); Liu *et al.* (2014); Manzano-Agugliaro *et al.* (2015); Wiel *et al.* (1998)
	Thermal insulation of windows	Al-Mofleh *et al.* (2016); Fowler; Rauch (2007); Prete *et al.* (2017); Vine (2002); Yates; Aronson (1983).
	Optimizing window/glazing area	Barret *et al.* (2008); Begum; Pereira (2010).
Shading systems	Shading external devices	Begum; Pereira (2010); Buonomanoa *et al.* (2016); Ekwall (1991); Huo; Shao; Huo (2017); Hester *et al.* (2012); Liu; Ren (2018); Mahmoud *et al.* (2017); Wang; Liu (2015); Xu *et al.* (2016); Thibaudeau (2008)
	Building Orientation/Geometry	Begum; Pereira (2010); Buonomanoa *et al.* (2016); Dimoudi (2013); Harkouss; Fardoun; Biwole (2018); Hester *et al.* (2012); Kim; Lee; Kim (2018); Liu *et al.* (2014); Lu; Fan; Zhao (2018); Mahmoud *et al.* (2017);
	Installation of interior blinds	Dimoudi (2013); Ekwall (1991); Hester *et al.* (2012)

Source: The author.

The efficient thermal insulation of walls and facades is made by means of materials that have a lower thermal conductivity that stabilizes the internal temperature of the building

(CHOW; LI; DARKWA, 2013; GELEGENIS *et al.*, 2014; MA; SI, 2014; PAN *et al.*, 2018; RASHWAN; FARAG; MOUSTAFA, 2013).

The use of plasterboard, wood slats, thermal laminate battens, laminated panels, brick strips, coated boards, mineral wool insulation panels, mineral foam insulation panels, and insulation wallpaper are some examples of materials used to increase the thermal resistance of facades and walls (HUO *et al.*, 2015; LI; ZHAO; ZHU, 2013; LIU *et al.*, 2014; LIU *et al.*, 2018; PRETE *et al.*, 2017; YATES; ARONSON, 1983). These materials are used to make the insulating layer of the outer fabric and the inner lining layer of the building (GENG *et al.*, 2015; HUO *et al.*, 2015). These technologies reduce energy consumption and provide occupant well-being inside of the environment (MA; SI; 2014; PRETE *et al.*, 2017; RASHWAN; FARAG; MOUSTAFA, 2013).

It is important to use suitable thermal insulation materials in the construction of walls and facades, such as phase change materials (PCM's) (BEGUM; PEREIRA, 2010; KIM, 2017). PCM's are used in buildings to improve thermal performance and have a direct impact on indoor comfort (BUONOMANOA *et al.*, 2016; CUI *et al.*, 2016; GENG *et al.*, 2015; HUO *et al.*, 2015; LIU; LIAO; HSUEH, 2016; SLEITI; NAIMASTER, 2016; ZHANG *et al.*, 2017). These materials help to increase the thermal capacity of the building envelope and to keep the temperature of the internal environment relatively constant by means of storage and release thermal energy in response to external ambient temperature variations (CAO; DAI; LIU, 2016; DAY; JONES; TURTON, 2013; SLEITI; NAIMASTER, 2016; SONG *et al.*, 2017). Expanded polystyrene (EPS) and extruded polystyrene (XPS) are examples of thermal insulation materials used on the exterior of walls and façades (XU *et al.*, 2016). Adopting PCM's in the building envelope is beneficial in decreasing the electrical load demand required for HVAC system performance and improving occupant thermal comfort (HARKOUSS; FARDOUN; BIWOLE, 2018; HESTER *et al.*, 2012; SLEITI; NAIMASTER, 2016).

Another technology that can be used in building facades is the adoption of double-skin facades (HUO *et al.*, 2015; RINALDI; SCHWEIKER; IANNONE, 2018). Double-skin facades are composed of two layers of facades that are separated by an air cavity (GE *et al.*, 2018; WANG; LIU, 2015). This technology is used to optimize the thermal properties of the building envelope, as well as to improve acoustic and light transmittance (LU; FAN; ZHAO, 2018). Double-skin facades help control solar heat in warmer periods, and it has thermal properties to heat the air in the cavity on colder days, thus benefiting from reduced heating demand, increased building cooling loads, and occupant well-being (LIU; LIAO; HSUEH, 2016; RINALDI; SCHWEIKER; IANNONE, 2018).

Trombe wall is a technology used in building walls to increase the thermal capacity of buildings (HUO *et al.*, 2015; TAN *et al.*, 2016). This technology is a passive heating device adopted for heating space, intercepting and transmitting solar energy efficiently for an indoor environment of the building (CAO; DAI; LIU, 2016; HUO *et al.*, 2015; TAN *et al.*, 2016). Trombe walls reduce the need for space heaters, which reflects in the reduction of energy (TAN *et al.*, 2016).

Another technology used is transparent/opaque curtain walls, which consist of non-structural coating systems used to construct the external walls of the building (LI; ZHAO; ZHU, 2013). The curtain wall is an aluminum frame that contains panels made of transparent or opaque filled glass (LUO *et al.*, 2018; THIBAUDEAU, 2008). The use of this type of technology is beneficial because of its ability to make walls more resistant to humidity and infiltration (THIBAUDEAU, 2008).

Furthermore, it is important that the use of such technologies maximizes the thermal resistance of the building walls (R-value), and minimizes the heat transfer by means of the walls (U-value). This affects in less energy to keep the indoor environment comfortable for occupants (CHOW; LI; DARKWA, 2013; RASHWAN; FARAG; MOUSTAFA, 2013; XIAO; WEI; WANG, 2014).

The improving thermal insulation of roofs and the construction of green roofs are technologies used for the roof of the building (GENG *et al.*, 2015; LUO *et al.*, 2018; WANG; LIU, 2015).

The use of reflective insulation materials, foam boards, insulation blankets are some examples adopted to improve roof insulation (GELEGENIS *et al.*, 2014; HUO; SHAO; HUO, 2017; LI; ZHAO; ZHU, 2013; LIU *et al.*, 2014). Such technologies avoiding heat loss reducing HVAC system requirements (DIMOUDI, 2013; GENG *et al.*, 2015; PALM, 2013; RASHWAN; FARAG; MOUSTAFA, 2013)

The green roofs are built by installing the rooftop vegetation of the building (LIU; LIAO; HSUEH, 2016; MAHMOUD *et al.*, 2017). The use of this technology reduces the incidence of radiation and temperature variations on the roof of the building and improving the architectural design of buildings (CAO; DAI; LIU, 2016; LIU *et al.*, 2014; MAHMOUD *et al.*, 2017).

The high-performance windows are also energy-efficient options to decrease thermal losses and improve the visual comfort of the environment (LUO *et al.*, 2018; PALM, 2013; PRETE *et al.*, 2017; VINE, 2002; WANG; LIU, 2015; WIEL *et al.*, 1998; XU *et al.*, 2016; YATES; ARONSON, 1983). The low-E window/glass, dual pane windows, operable windows, double-glazed windows are some examples of high thermal performance windows used in energy-efficient buildings (AL-MOFLEH *et al.*, 2016; CAO; DAI; LIU, 2016; DIMOUDI, 2013; IM *et al.*, 2017; LI; ZHAO; ZHU, 2013; PALM, 2013; THIBAUDEAU, 2008).

The low-E windows are made by applying a thin film coating in the window glass, known as low-E glass (IM *et al.*, 2017; KIM, 2017; LUO *et al.*, 2018; WANG; LIU, 2015; XU *et al.*, 2016). The low-E glass protects the environment from unwanted ultraviolet rays, reducing radiation on the building surface, controlling radiant heat, and maximizing the use of natural light in the building (CHOW; LI; DARKWA, 2013; GENG *et al.*, 2015; HESTER *et al.*, 2012; KIM; LEE; KIM, 2018; YOSHIDA; SHIMODA; OHASHI, 2017).

Another technology for windows is the installation of double-glazed windows that contribute to the thermal and luminous comfort of the building (GENG *et al.*, 2015; YOSHIDA; SHIMODA; OHASHI, 2017). The double-glazed windows are made up of two panes of glass filled with air, preventing the external temperature from affecting the internal environment temperature of the building (BARRET *et al.* 2008; BEGUM; PEREIRA, 2010; DIMOUDI, 2013; FOWLER; RAUCH, 2007; GELEGENIS *et al.* 2014; IM *et al.* 2017).

It is also important to optimize the number of windows per wall and big windows can be installed, thus increasing the lighting and ventilation area (IM *et al.*, 2017; HESTER *et al.*, 2012; MANZANO-AGUGLIARO *et al.*, 2015; RASHWAN; FARAG; MOUSTAFA, 2013; THIBAUDEAU, 2008). The use of operable window provides the potential for reducing cooling and heating loads, lowering HVAC system costs, and providing the best use of natural ventilation (CAO; DAI; LIU, 2016; GE *et al.*, 2018; HESTER *et al.*, 2012; LIU *et al.*, 2014; MANZANO-AGUGLIARO *et al.*, 2015).

External shading devices use technologies applied to the building envelope and the outside of windows (BEGUM; PEREIRA, 2010; MAHMOUD *et al.*, 2017; THIBAUDEAU, 2008; WANG; LIU, 2015). Such devices can reduce high temperatures and the need for cooling of a building, as well as improve the natural lighting quality of the building's interior environment (EKWALL, 1991; HESTER *et al.*, 2012; LIU; REN, 2018). The use of curtains and interior blinds, for example, well-designed vertical louver blinds, roller blinds, and blackout blinds can reduce sunlight penetration (BUONOMANOA et al, 2016; HUO; SHAO; HUO, 2017; XU *et al.*, 2016).

Furthermore, the optimization of building geometry and orientation is important to improve the shading of the buildings (BEGUM; PEREIRA, 2010; BUONOMANOA *et al.*, 2016; DIMOUDI, 2013; MAHMOUD *et al.*, 2017). Effective planning of building orientation and geometry increases the BEE, reducing the need for auxiliary cooling and heating, and improving the comfort of the indoor environment (HARKOUSS; FARDOUN; BIWOLE, 2018; HESTER *et al.*, 2012; LIU *et al.*, 2014; LU; FAN; ZHAO, 2018).

If the building envelope structure is improved by the adoption of such technologies, an optimal level of energy savings can be achieved, leading to lower costs during building operation as well as substantial reductions in energy consumption and environmental impacts (QUITZAU; HOFFMANN; ELLE, 2012).

2.2.2 HVAC Technologies

The HVAC systems mean Heating, Ventilation, and Air Conditioning systems. Table 3 shows the HVAC technologies found in the literature, followed by their references.

Table 3 - HVAC system technologies

(to be continued)

Technology		References
HVAC systems	Passive ventilation	Adeyeye; Osmani; Brown (2007); Al-Tamimi (2017); Andrews; Krogmann (2009); Cao; Dai; Liu (2016); Dimoudi (2013); Ge *et al.* (2018); Geng *et al.* (2015); Harkouss; Fardoun; Biwole (2018); Huo; Shao; Huo (2017); Jiang; Tovey (2009); Kiss (2016); Liu *et al.* (2014); Liu; Ren (2018); Lu; Fan; Zhao (2018); Wei *et al.* (2018)
	Heat pumps	Alajlan; Smiai; Elani (1998); Chow; Li; Darkwa (2013); Fowler; Rauch (2007); Ge *et al.* (2018); Jiang; Tovey (2009); Kojok *et al.* (2016); Pinkse; Dommisse (2009); Prete *et al.* (2017)
	Radiant heating and cooling systems	Adeyeye; Osmani; Brown (2007); Cao; Dai; Liu (2016); Gelegenis *et al.* (2014); Geng *et al.* (2015); Li; Zhao; Zhu (2013); Liang *et al.* (2007); Lu; Fan; Zhao (2018); Song *et al.* (2017)
	Heat recovery technology	Cao; Dai; Liu (2016); Ge *et al.* (2018); Huang *et al.* (2012); Kim (2017); Kiss (2016); Mardiana-Idayua; Riffat (2012); Xiao; Wei; Wang (2014)
	Evaporative cooling system	Adeyeye; Osmani; Brown (2007); Begum; Pereira (2010); Cao; Dai; Liu (2016); Fowler; Rauch (2007); Gelegenis *et al.* (2014); MertCuce; Riffat (2016); Whiffen *et al.* (2016)
	Chiller and inverter technology	Ahmad; Othman (2014); Lam *et al.* (2014); Liu *et al.* (2018); Rinaldi; Schweiker; Iannone (2018); Xiao; Wei; Wang, (2014)

Table 3 - HVAC system technologies

(conclusion)

Technology		References
HVAC systems	Heat exchangers	Begum; Pereira (2010); Geng *et al.* (2015); Hernandez-Roman;Sheinbaum-Pardo; Calderon-Irazoque (2017); Wiel *et al.* (1998); Xiao; Wei; Wang (2014); Yoshida; Shimoda; Ohashi (2017)
	Automated ventilation Control	Alajlan; Smiai; Elani (1998); Begum; Pereira (2010); Ekwall (1991); Heidarinejad *et al.* (2018); Luo *et al.* (2018); Yoshida; Shimoda; Ohashi (2017)
	Energy recovery ventilation	Buonomanoa *et al.* (2016); Geng *et al.* (2015); Hernandez-Roman; Sheinbaum-Pardo; Calderon-Irazoque (2017); Liu *et al.* (2014); Lu; Fan; Zhao (2018); Xu *et al.* (2016)
	Programmable thermostat	Al-Tamimi (2017); Andrews; Krogmann (2009); Dimoudi (2013); Harrell; Kulkarni (2004); Hernandez-Roman; Sheinbaum-Pardo; Calderon-Irazoque (2017); Tan *et al.* (2016)
	Ceiling fans	Dimoudi (2013); Fowler; Rauch (2007); Liu; Liao; Hsueh (2016); Mardani *et al.* (2016); Yoshida; Shimoda; Ohashi (2017)
	VRV (variable refrigerant volume) system	Geng *et al.* (2015); Hong *et al.* (2014); Huang *et al.* (2012); Liu *et al.* (2014); Mahmoud *et al.* (2017)
	VAV (variable air volume) system	Andrews; Krogmann (2009); Geng *et al.* (2015); Liu *et al.* (2014); Wang; Liu (2015)
	Thermal storage technology	Cao; Dai; Liu (2016); Kojok *et al.* (2016); Li; Zhao; Zhu (2013); Lu; Fan; Zhao (2018)
	Earth tubes for ventilation system	Tsagarakisa; Karyotakis; Zografakisc (2012); Wang; Qi (2011); Yu; Chan (2006)
	Economizer cycles	Andrews; Krogmann (2009); Liang *et al.* (2007); Todesco (2004).

Source: The author.

The HVAC systems account for the greatest electrical load of a building, therefore they have a great potential for energy saving (CAO; DAI; LIU, 2016; GENG *et al.*, 2015; KIM; LEE; KIM, 2018; KOJOK *et al.*, 2016; LU; FAN; ZHAO, 2018). Substantial energy savings can be achieved by using technologies that improve the efficiency of the HVAC system, reducing in such a way the operating costs (BUONOMANOA *et al.*, 2016; GE *et al.*, 2018; HUO; SHAO; HUO, 2017; LIU *et al.*, 2017; XIAO; WEI; WANG, 2014).

Passive ventilation is an energy-efficient system that uses natural forces to improve fresh airflow and heat dissipation, reducing in such a way the thermal load of a building (ADEYEYE; OSMANI; BROWN, 2007; AL-TAMIMI, 2017; CUI *et al.*, 2016; GENG *et al.*, 2015; HARKOUSS; FARDOUN; BIWOLE, 2018; JIANG; TOVEY, 2009; KISS, 2016; LIU *et al.*, 2014; LIU; REN, 2018; LUO *et al.*, 2018). This strategy should be used in combination with HVAC systems, since it reduces its energy consumption (CAO; DAI; LIU, 2016; DIMOUDI, 2013; GE *et al.*, 2018; HESTER *et al.*, 2012; HUO; SHAO; HUO, 2017; LIU *et al.*, 2017; LU; FAN; ZHAO, 2018; WEI *et al.*, 2018).

The automated ventilation control is an automated system that controls the building's ventilation areas. The windows open and close automatically, by means of a system of sensors that detect which areas need ventilation, thus redirecting the air according to the needs of the space (HEIDARINEJAD *et al.*, 2018; LUO *et al.*, 2018; YOSHIDA; SHIMODA; OHASHI, 2017). For example, system sensors detect periods of rain or wind and close room windows when needed (EKWALL, 1991; HEIDARINEJAD *et al.*, 2018). Automated ventilation control besides controlling the use of natural ventilation and air conditioning also decreases the operating costs of HVAC systems (ALAJLAN; SMIAI; ELANI, 1998; BEGUM; PEREIRA, 2010).

The combined use of ceiling fans and air conditioning systems evenly distributes air throughout the space, creating a lower thermal sensation than the actual temperature, so it is possible to keep the air conditioning temperature higher, reducing the load for operation. air conditioner and consequently its energy consumption (DIMOUDI, 2013; FOWLER; RAUCH, 2007; LIU; LIAO; HSUEH, 2016; MARDANI *et al.*, 2016; YOSHIDA; SHIMODA; OHASHI, 2017).

Heat pumps consist of a geothermal cooling system that can be reversed to heat or cool the building indoor environment (ALAJLAN; SMIAI; ELANI, 1998; EKWALL, 1991; GE *et al.*, 2018; KIM; LEE; KIM, 2018; KOJOK *et al.*, 2016; PRETE *et al.*, 2017). It takes advantage of the constant temperature by means of a closed water circuit that exchanges heat with the Earth (CHOW; LI; DARKWA, 2013; FOWLER; RAUCH, 2007; JIANG; TOVEY, 2009; PINKSE; DOMMISSE, 2009; WIEL *et al.*, 1998).

It is important to recover the energy lost due to the HVAC system, this can be done by adopting a heat recovery system such as heat recovery technology and energy recovery ventilation (KIM, 2017; KISS, 2016; LU; FAN; ZHAO, 2018; XU *et al.*, 2016). These recovery systems use a heat exchanger to absorb heat from the inside the building (GE *et al.*, 2018; GELEGENIS *et al.*, 2014; HUANG *et al.*, 2012).

The heat recovery technology has the function of transferring energy from one air source to another, both with different temperatures (CAO; DAI; LIU, 2016; XIAO; WEI; WANG, 2014). The adoption of this technology can impact the reduction in demand for energy used for heating and cooling the buildings (GE *et al.*, 2018; XIAO; WEI; WANG, 2014).

The building's exhaust air is used in HVAC systems to generate or dissipate heat, this depends on climatic conditions and building requirements (QIU, 2014). The system transfers thermal energy to the fresh air received, increasing the temperature and reducing the energy used for heating (KISS, 2016; MARDIANA-IDAYUA; RIFFAT, 2012; XIAO; WEI; WANG, 2014). Furthermore, the air is used as a heat sink for thermal energy present in the air received, which reduces the demand for cooling. Therefore, this system provides a significant reduction in the demand for energy used in building air conditioning systems (KISS, 2016; SINGH; HENRIQUES; MARTINS, 2018).

The energy recovery ventilation is similar to heat recovery technology (BUONOMANOA *et al.*, 2016; LIU *et al.*, 2014). However, this technology used the exhaustion air to treat external air entering the ventilation system (XU *et al.*, 2016). Besides lowering the thermal load of the HVAC system, the energy recovery ventilation technology is ideal for controlling the humidity levels of the environment (HERNANDEZ-ROMAN; SHEINBAUM-PARDO; CALDERON-IRAZOQUE, 2017; LU; FAN; ZHAO, 2018).

“Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating or cooling applications and power generation” (SARBU; SEBARCHIEVICI, 2018). Adopting TES in HVAC systems increase the energy efficiency of the system, reducing the running costs, and improving its reliability (ANDREWS; KROGMANN, 2009; CAO; DAI; LIU, 2016; LIU *et al.*, 2014).

Another technology incorporated by HVAC systems that increase the BEE is the radiant heating and cooling system (GENG *et al.*, 2015; LU; FAN; ZHAO, 2018). This system is used to transfer energy by means of temperature-controlled surfaces that exchange heat with the external environment by means of heated or cooled water pipes (CAO; DAI; LIU, 2016; GELEGENIS *et al.*, 2014; LIANG *et al.*, 2007). There are three types of radiant heating and cooling, namely: thermally active building systems (TABS), embedded surface systems (ESS), and underfloor radiant panels (ADEYEYE; OSMANI; BROWN; 2007; SONG *et al.*, 2017). These radiant systems consume less energy than conventional systems and reduce the energy load demand (GENG *et al.*, 2015; LI; ZHAO; ZHU, 2013; LIANG *et al.*, 2007).

Furthermore, thermal comfort is the main focus on the adoption of radiant heating and cooling systems (ADEYEYE; OSMANI; BROWN, 2007; LI; ZHAO; ZHU, 2013).

Another technology used in HVAC systems is the evaporative cooling system (ADEYEYE; OSMANI; BROWN, 2007; FOWLER; RAUCH, 2007; MERTCUCE; RIFFAT, 2016; WHIFFEN *et al.*, 2016). This technology aims to provide cooling air by means of water evaporation (GELEGENIS *et al.*, 2014; BEGUM; PEREIRA, 2010). The system draws in hot air by means of a cooling unit installed on the roof of the building and distributes the cooled air by means of ducts, providing a constant supply of air to the indoor space and improving the humidity level of the air (ADEYEYE; OSMANI; BROWN, 2007; CAO; DAI; LIU, 2016; GELEGENIS *et al.*, 2014). By increasing air humidity, this technology is attractive in HVAC systems installed in environments with hot and arid climatic conditions, resulting in significant temperature reductions (BEGUM; PEREIRA, 2010; XU *et al.*, 2016). Evaporation systems are an efficient alternative to conventional air conditioners, offering low energy consumption (BEGUM; PEREIRA, 2010; MERTCUCE; RIFFAT, 2016).

The chiller technology is used to provide cooling to the HVAC system air conditioner (LIU *et al.*, 2018; WHIFFEN *et al.*, 2016). The chillers cool the water used to cool and dehumidify the air inside the building, removing heat by means of a cooling cycle, reusing the heat lost in the system, which leads to significant energy savings (AHMAD; OTHMAN, 2014; LAM *et al.*, 2014; WHIFFEN *et al.*, 2016).

The inverter is another technology used in air conditioning systems that consists of a device that turns the alternating current into direct current (AHMAD; OTHMAN, 2014; LIU *et al.*, 2018). This technology allows the air conditioner motor to operate at variable speeds, eliminating wasted system operation (WHIFFEN *et al.*, 2016). Such technologies offer new ways for energy saving in HVAC systems, increased humidity control, and reduced operating costs (LAM *et al.*, 2014; RINALDI; SCHWEIKER; IANNONE, 2018).

Another technology used to increase the energy saving of the building's cooling system is heat exchangers (BEGUM; PEREIRA, 2010; GENG *et al.*, 2015; HERNANDEZ-ROMAN; SHEINBAUM-PARDO; CALDERON-IRAZOQUE, 2017; WIEL *et al.* 1998). Heat exchangers are devices that transfer heat from one environment to another (BEGUM; PEREIRA, 2010; WIEL *et al.* 1998). In HVAC systems, this device puts the indoor air in contact with a refrigerant fluid, so the heat from the indoor environment is removed and transferred outside the building, and thus the cooled air can be returned to the building indoor environment (BEGUM; PEREIRA, 2010; YOSHIDA; SHIMODA; OHASHI, 2017). This technology requires less energy used in the cooling system in the building, providing occupant thermal comfort and reductions in the amount of air pollutants and contaminants (HUANG *et al.* 2012).

The programmable thermostat is well used in HVAC systems (ANDREWS; KROGMANN; 2009; DIMOUDI, 2013; HERNANDEZ-ROMAN; SHEINBAUM-PARDO; CALDERON-IRAZOQUE, 2017). This smart and efficient device is designed to regulate heating and cooling equipment by adjusting the room temperature according to predefined settings (ANDREWS; KROGMANN, 2009; HARRELL; KULKARNI, 2004; TAN *et al.*, 2016). This technology helps reduce electricity costs because it controls the period of time the HVAC system is active in the building (AL-TAMIMI, 2017; HARRELL; KULKARNI, 2004). Furthermore, programmable thermostats help maintain the ideal and consistent temperature throughout the building's interior, meeting occupant thermal needs (DIMOUDI, 2013; HERNANDEZ-ROMAN; SHEINBAUM-PARDO; CALDERON-IRAZOQUE, 2017).

The variable refrigerant volume (VRV) is one refrigerant system used in HVAC systems (HONG *et al.*, 2014; HUANG *et al.*, 2012; MAHMOUD *et al.*, 2017). This technology is capable of modulating the volume of refrigerant according to the needed of the indoor environments of the building, that is, has the ability to control simultaneously heating and cooling to different indoor environments of the building, while the HVAC system continuing to operate efficiently (HONG *et al.*, 2014; HUANG *et al.*, 2012; LIU *et al.*, 2014; MAHMOUD *et al.*, 2017). Thus, the reduction of energy consumption and the individualized thermal comfort control are achieved (GENG *et al.*, 2015).

The variable air volume (VAV) is another type of HVAC system (ANDREWS; KROGMANN, 2009; LIU *et al.*, 2014). This system varies the supply air volume flow rate, meeting different heating or cooling loads of the building (WANG; LIU, 2015). This system has several advantages when compared with conventional HVAC systems, especially the fact that the system can maintain the predetermined temperature and humidity of the air in the indoor environment for the occupants' thermal comfort (GENG *et al.*, 2015).

The energy-efficient buildings can have the alternative of bringing in outside air by means of the earth tubes, which are essential for ensuring both air control and good indoor air quality (TSAGARAKISA; KARYOTAKIS; ZOGRAFAKISC, 2012; YU; CHAN, 2006). The earth tube is a passive technology used in HVAC systems that allows the air temperature, used for cooling or heating of buildings, alters according to the temperature transfer of ground by means of underground ventilation ducts, reducing the energy consumption of the HVAC system (WANG; QI, 2011).

The economizer cycle is a technology that works as a heat exchanger used in HVAC systems (ANDREWS; KROGMANN, 2009; TODESCO, 2004). This technology pulling the cool outside air to be used for cooling of the indoor environment of the building, reducing the cooling energy consumption (LIANG *et al.*, 2007; TODESCO, 2004).

The main characteristics of such energy-efficient technologies adopted in the HVAC system are to provide occupant thermal comfort, improve indoor air quality, as well as increase the building energy performance (MARDIANA-IDAYUA; RIFFAT, 2012).

2.2.3 Renewable Energies

Energy-efficient buildings are often encouraged to use renewable energy sources to reduce the consumption of conventional fuels and electricity. Renewable energies have characteristics of clean and inexhaustible energy sources. Table 4 shows the main renewable energy sources adopted in buildings, according to literature, followed by their references.

Table 4 - Renewable energy

(to be continued)

Technology		References
Solar Thermal Energy	Solar water heating (SWH)	Anglani; Muliere (2011); Begum; Pereira (2010); Cao; Dai; Liu (2016); Chow; Li; Darkwa, (2013); Day; Jones; Turton (2013); Ge *et al.* (2018); Gelegenis *et al.* (2014); Geng *et al.* (2015); Harkouss; Fardoun; Biwole (2018); Hernandez-Roman; Sheinbaum-Pardo; Calderon-Irazoque (2017); Huang *et al.* (2012); Jiang; Tovey (2009); Lam *et al.* (2014); Liu *et al.* (2014); Lu; Fan; Zhao (2018); Manzano-Agugliaro *et al.* (2015); Mardani *et al.* (2016); Pinkse, Dommisse (2009); Prete *et al.* (2017); Tan *et al.* (2016); Wang; Liu (2015); Wei *et al.* (2018); Whiffen *et al.* (2016); Xiao; Wei; Wang (2014)
Geothermal Energy	Ground source heat pump (GSHP)	Cao; Dai; Liu (2016); Ge *et al.* (2018); Gelegenis *et al.* (2014); Geng *et al.* (2015); Kim; Lee; Kim (2018); Liao *et al.* (2016); Liu *et al.* (2014); Lu; Fan; Zhao (2018); Wei *et al.* (2018); Whiffen *et al.* (2016); Xiao; Wei; Wang (2014)
	Geothermal heat pump (GHP)	Day; Jones; Turton (2013); Hao; Zhang; Chen (2007); Huang *et al.* (2012); Vine (2002)

Table 4 - Renewable energy

(conclusion)

Technology		References
Solar Photovoltaic Energy	Building integrated photovoltaic system (BIPV)	Cao; Dai; Liu (2016); Chow; Li; Darkwa (2013); Ge *et al.* (2018); Geng *et al.* (2015); Jiang; Tovey (2009); Kim; Lee; Kim (2018); Prete *et al.* (2017); Thibaudeau (2008); Wang *et al.* (2016); Whiffen *et al.* (2016).
	Photovoltaic (PV) panel/cell	Adeyeye; Osmani; Brown (2007); Cao; Dai; Liu (2016); Day; Jones; Turton (2013); Gelegenis *et al.* (2014); Harkouss; Fardoun; Biwole (2018); Hernandez-Roman; Sheinbaum-Pardo; Calderon-Irazoque (2017); Ishii *et al.* (2010); Liu *et al.* (2014)
Wind Energy	Wind turbines	Cao; Dai; Liu (2016); Chow; Li; Darkwa (2013); Harkouss; Fardoun; Biwole (2018); Jiang; Tovey (2009); Liu *et al.* (2014); Mardani *et al.* (2016); Wang; Liu (2015); Wei *et al.* (2018).
Bioenergy	Biomass boiler	Cao; Dai; Liu (2016); Gelegenis *et al.* (2014); Palm (2013); Prete *et al.* (2017)

Source: The author.

There are several options of renewable energy sources that can be adopted to cover the energy consumption needs of buildings, such as solar thermal energy, geothermal energy, photovoltaic energy, wind energy, and biomass energy (ANDREWS; KROGMANN, 2009; DAY; JONES; TURTON, 2013; KIM; LEE; KIM, 2018; LIU *et al.*, 2014; MARDANI *et al.*, 2016; PRETE *et al.*, 2017; WEI *et al.*, 2018).

The solar thermal energy stores solar energy to be used for different applications (ANGLANI; MULIERE, 2011; BEGUM; PEREIRA, 2010; HONG *et al.*, 2014; MANZANO-AGUGLIARO *et al.*, 2015). In the buildings, this system helps to achieve the highest solar gain to reduce energy demand used for water heating systems (BEGUM; PEREIRA, 2010; GELEGENIS *et al.*, 2014; GENG *et al.*, 2015; HARKOUSS; FARDOUN; BIWOLE, 2018; PINKSE; DOMMISSE, 2009).

The water heating systems capture sunlight by means of solar collectors that are fixed to the roofs of the buildings (DAY; JONES; TURTON, 2013; GE *et al.*, 2018; GELEGENIS *et al.*, 2014; PALM, 2013; WHIFFEN *et al.*, 2016). The absorbed heat is transferred by means of a circulation pump to the boiler, which stores and conserves hot water for use in the building, thus avoiding the need for electricity to heat water (ANDREWS; KROGMANN, 2009; LIU *et al.*, 2014; TAN *et al.*, 2016; XIAO; WEI; WANG, 2014). When there is little sunlight, such as on cloudy days, and solar panels do not absorb enough heat for heating, boilers can still be used as an auxiliary system for water heating (LU; FAN; ZHAO, 2018; MANZANO-AGUGLIARO *et al.*, 2015; WANG; LIU, 2015; WHIFFEN *et al.*, 2016).

The solar photovoltaic energy captures solar energy and converts it into electrical energy (ADEYEYE; OSMANI; BROWN, 2007; CAO; DAI; LIU, 2016; ISHII *et al.*, 2010; LU; FAN; ZHAO, 2018). Photovoltaic solar technology consists of solar panels or solar cell modules made of silicon semiconductors installed on the roof of the buildings (HARKOUSS; FARDOUN; BIWOLE, 2018; HUANG *et al.*, 2012; JIANG; TOVEY, 2009; WANG *et al.*, 2016). This technology provides renewable energy to be used in the buildings, reducing the demand for conventional electric energy (ADEYEYE; OSMANI; BROWN, 2007; DAY; JONES; TURTON, 2013; LIU *et al.*, 2014; LU; FAN; ZHAO, 2018).

Another technology employed is building integrated photovoltaic (BIPV), which does not limit the use of photovoltaic panels to the building roof, but includes the photovoltaic system as an integral part of the building structure, such as façades, skylights, marquees, and others (CAO; DAI; LIU, 2016; KIM; LEE; KIM, 2018; PRETE *et al.*, 2017; WANG *et al.*, 2016; WHIFFEN *et al.*, 2016). BIPV technology provides savings on building materials and electricity costs, improves the architectural design of the building, allowing for a modern approach to building, as well as reducing environmental impacts (CHOW; LI; DARKWA, 2013; GE *et al.*, 2018; GENG *et al.*, 2015; WANG *et al.*, 2016).

Surface geothermal energy, like renewable energy resources, is also commonly used in the HVAC system of the building (KIM; LEE; KIM, 2018; WEI *et al.*, 2018). The utilization of stored thermal energy from the ground is suitable for the cooling/heating of fresh air (GE *et al.*, 2018; LU; FAN; ZHAO, 2018; WEI *et al.*, 2018). The most common geothermal technology used in the HVAC system is the ground source heat pump (GSHP) or geothermal heat pump (GHP) (WANG; QI, 2011; WHIFFEN *et al.*, 2016).

The geothermal heat pump utilizes a piping system to extract heat from underground and transfer it to the building (LIAO *et al.*, 2016; LIU *et al.*, 2014; VINE, 2002). The transferred thermal energy is adopted to provide water heating or indoor heating for buildings (HUANG *et al.*, 2012; LIAO *et al.*, 2016; XIAO; WEI; WANG, 2014). This technology is capable of cooling the building space during warmer periods and warming it on colder days, thus providing better thermal comfort for occupants (GELEGENIS *et al.*, 2014; GENG *et al.*, 2015; HAO; ZHANG; CHEN, 2007).

The energy-efficient buildings also use the wind turbines for generated renewable energy from wind speed, as known as, the building-integrated wind turbines (CHOW; LI; DARKWA, 2013; DAY; JONES; TURTON, 2013; TAN *et al.*, 2016). This system can be adopted to the installation of turbines between two nearby buildings, or inside in a hole in the building structure done specifically for this (CAO; DAI; LIU, 2016; JIANG; TOVEY, 2009; LIU *et al.*, 2014; MARDANI *et al.*, 2016; WANG; LIU, 2015). Another more economical way is the use of micro wind turbines, which can be installed on the building rooftop or in a specific area of the building (CAO; DAI; LIU, 2016; HARKOUSS; FARDOUN; BIWOLE, 2018; WEI *et al.*, 2018).

Another type of renewable energy used in buildings is biomass energy (JIANG; TOVEY, 2009; PRETE *et al.*, 2017). Biomass energy is generated by burning organic matter such as agricultural waste, plants, and wood in a boiler (CAO; DAI; LIU, 2016; GELEGENIS *et al.*, 2014). The most common use of biomass in buildings is for the supply of energy for indoor and water heating (GELEGENIS *et al.*, 2014; PRETE *et al.*, 2017). Besides helping in energy supply, this technology reduces environmental impacts by appropriate treating organic waste (GELEGENIS *et al.*, 2014; JIANG; TOVEY, 2009).

The adoption of some kind of renewable energy is a strategy for sustainable building architecture that used for improving the energetic autonomy of the building (HARKOUSS; FARDOUN; BIWOLE, 2018; WEI *et al.*, 2018). The renewable energy sources decrease the consumption of conventional energy sources and are effective for reducing degradation to the environment, since no pollutants are emitted (ANGLANI; MULIERE, 2011; CAO; DAI; LIU, 2016; JIANG; TOVEY, 2009).

2.2.4 Lighting Technologies

Lighting technologies play an important role in BEE, in particularity, these technologies ensure adequate lighting levels with less energy consumption. Lighting technologies found in the literature are listed in Table 5 along with their references.

Energy consumption for the lighting system is considered the highest when it comes to end-use energy consumption in the building sector (CAO; DAI; LIU, 2016; HARRELL; KULKARNI, 2004; LI; ZHAO; ZHU, 2013; ZOGRAFAKIS; KARYOTAKIS; TSAGARAKIS, 2012). The measures employed in buildings to achieve energy saving gains in the lighting system are related to advanced lighting technologies and strategies employed to collect natural light (ANDREWS; KROGMANN, 2009; CAO; DAI; LIU, 2016;

GOLDEMBERG *et al.*, 1994; KIM, 2017; LIU *et al.*, 2014; TAN *et al.*, 2016). Regarding building lighting systems, the main technologies can be grouped into lighting devices, lamps, and passive lighting (CAO; DAI; LIU, 2016; GE *et al.*, 2018; LAM *et al.*, 2014; LI; ZHAO; ZHU, 2013; THIBAUDEAU, 2008; WHIFFEN *et al.*, 2016; WIEL *et al.*, 1998; XIAO; WEI; WANG, 2014).

Intelligent lighting control is a measure used to reduce unnecessary energy consumption (ANDREWS; KROGMANN, 2009; GE *et al.*, 2018; LIU; REN, 2018; WIEL *et al.*, 1998; ZOGRAFAKIS; KARYOTAKIS; TSAGARAKIS, 2012). This technology is related to solutions and devices smart adopted for ensuring that the lighting system is optimized based on energy saving and better visual quality of the occupants (WHIFFEN *et al.*, 2016). The devices smarts are capable of manager automatically different lighting parameters, program the absence of occupants in the building, regulate the light intensity and control of daylight (HARKOUSS; FARDOUN; BIWOLE, 2018; LI; ZHAO; ZHU, 2013).

Light sensors are used to control ambient lighting by means of identifying occupant presence and ambient light level, ensuring that the light level is appropriate to the indoor space conditions (HARRELL; KULKARNI, 2004; KIM, 2017; LIU *et al.*, 2014; WIEL *et al.*, 1998; YOSHIDA; SHIMODA; OHASHI, 2017; ZOGRAFAKIS; KARYOTAKIS; TSAGARAKIS, 2012). The adoption of lighting sensors allows significant reductions in electricity bills and also is a technology that is affordable for building occupants (DAY; JONES; TURTON, 2013; LEE; SONG; CHO, 2018; YOSHIDA; SHIMODA; OHASHI, 2017).

Table 5 - Lighting technologies

Technology		References
Lighting Devices	Intelligent light control	Andrews; Krogmann (2009); Ge *et al.* (2018); Harkouss; Fardoun; Biwole (2018); Kim; Lee; Kim (2018); Lee; Song; Cho (2018); Li; Zhao; Zhu (2013); Liu *et al.* (2014); Liu; Ren (2018); Whiffen *et al.* (2016); Wiel *et al.* (1998); Zografakis; Karyotakis; Tsagarakis (2012)
	Light Sensors	Day; Jones; Turton (2013); Harrell; Kulkarni, (2004); Kim (2017); Lee; Song; Cho (2018); Liu *et al.* (2014); Whiffen *et al.* (2016); Wiel *et al.* (1998); Yoshida; Shimoda; Ohashi (2017); Zografakis; Karyotakis; Tsagarakis (2012)
	Dimming control technology	Banwella *et al.* (2004); Begum; Pereira (2010); Harrell; Kulkarni (2004); Lee; Song; Cho (2018); Mahmoud *et al.* (2017); Mardani *et al.* (2016); Morgenstern; Al-Jurf (1999); Thibaudeau (2008); Yoshida; Shimoda; Ohashi (2017)
	Bi-level lighting control	Alajlan; Smiai; Elani (1998); Buonomanoa *et al.* (2016); Ekwall (1991); Li; Zhao; Zhu (2013); Liu *et al.* (2014); Xiao; Wei; Wang (2014)
Lamps	Light-emitting diodes (LED)	Ahmad; Othman (2014) Cao; Dai; Liu (2016); Elsarrag (2008); Harrell; Kulkarni (2004); Im *et al.* (2017); Jiang; Tovey (2009); Kim (2017); Lee; Song; Cho (2018); Li; Zhao; Zhu (2013); Vine (2002); Xiao; Wei; Wang (2014); Xu *et al.* (2016)
	Compact fluorescent lamps (CFLs)	Ahmad; Othman (2014); Andrews; Krogmann (2009); Day; Jones; Turton (2013); Goldemberg *et al.* (1994); Im *et al.* (2017); Kim (2017); Kojok *et al.* (2016); Morgenstern; Al-Jurf (1999); Tan *et al.* (2016); Tsagarakisa; Karyotakis; Zografakisc (2012); Wiel *et al.* (1998); Xiao; Wei; Wang (2014); Zografakis; Karyotakis; Tsagarakis (2012).
Passive Lighting	Daylighting Harvesting	Andrews; Krogmann (2009); Cao; Dai; Liu (2016); Ge *et al.* (2018); Harkouss; Fardoun; Biwole (2018); Harrell; Kulkarni (2004); Lee; Song; Cho (2018); Liu *et al.* (2014); Thibaudeau (2008); Wang; Liu (2015); Wiel *et al.* (1998)
	Natural Lighting	Fowler; Rauch (2007); Gelegenis *et al.* (2014); Hester *et al.* (2012); Im *et al.* (2017); Jiang; Tovey (2009); Liu *et al.* (2014); Thibaudeau (2008); Zografakis; Karyotakis; Tsagarakis (2012).
	Tubular daylighting	Estiri (2015); Hester *et al.* (2012); Lu; Fan; Zhao (2018)

Source: The author.

Another important energy-saving technology is dimming control, which can be operated by photocells or occupancy sensors (MAHMOUD *et al.*, 2017; THIBAUDEAU, 2008). The dimming control technology is used to detect the ambient light level, by turning the lights on and off when necessary to compensate for the use of natural light (BEGUM; PEREIRA, 2010; LAM *et al.*, 2014; LEE; SONG; CHO, 2018; MORGENSTERN; AL-JURF, 1999). This technology also allows gradually varies lighting brightness intensity according to the needed of the environment, improving the visual comfort of the occupants (BANWELLA *et al.*, 2004; BEGUM; PEREIRA, 2010; HARRELL; KULKARNI, 2004; MARDANI *et al.*, 2016).

The use of bi-level lighting control is a technology that provides two levels of lighting (LI; ZHAO; ZHU, 2013; XIAO; WEI; WANG, 2014). When this type of lighting control detects motion, the useful ambient light level increased (EKWALL, 1991). And when motion is no longer detected, a minimum light level is offered (BUONOMANOA *et al.*, 2016; WHIFFEN *et al.*, 2016). This technology is combined with light sensors to significantly reduce the energy use of lighting systems, since it only increases the ambient lighting level only when occupant presence is detected (ALAJLAN; SMIAI; ELANI., 1998).

Lighting technologies also include the adoption of energy-saving lamps such as light-emitting diodes (LED) and compact fluorescent lamps (CFLs) to reduce energy consumption and increase the light quality, so increasing occupant comfort (AHMAD; OTHMAN, 2014; IM *et al.*, 2017; KIM, 2017; LEE; SONG; CHO, 2018; TAN *et al.*, 2016; VINE, 2002; XIAO; WEI; WANG, 2014).

LED lamps are energy-efficient light-emitting devices predominantly adopted in buildings due to its quality, long service life and good lighting effectiveness (AHMAD; OTHMAN, 2014; FOWLER; RAUCH, 2007; JIANG; TOVEY, 2009; LEE; SONG; CHO, 2018; LI; ZHAO; ZHU, 2013). The use of LED lamps is an alternative to mitigate environmental impacts since the materials of the LED lamps are less harmful than conventional lamps (CAO; DAI; LIU, 2016; ELSARRAG, 2008; KIM, 2017; XU *et al.*, 2016).

CFLs are also a common type of lighting and were well used to replace incandescent lamps before LED lamps appeared (DAY; JONES; TURTON, 2013; KIM, 2017; MARCUS; SOMMERS; BERK, 1982; TAN *et al.*, 2016). This type of lamp combines the energy efficiency level of conventional fluorescent lamps with the popularity of incandescent lamps (ANDREWS; KROGMANN, 2009; GOLDEMBERG *et al.*, 1994; MORGENSTERN; AL-JURF, 1999). The CFL's are designed to provide the same level of light as an incandescent bulb, but consuming less energy (HERNANDEZ-ROMAN; SHEINBAUM-PARDO; CALDERON-IRAZOQUE, 2017; WIEL *et al.* 1998).

The passive lighting is also an energy-saving option that impacts the reduction of the electricity consumption used for ambient lighting (FOWLER; RAUCH, 2007; HESTER *et al.*, 2012; LI; ZHAO; ZHU, 2013; LIU *et al.*, 2014; THIBAUDEAU, 2008). The passive lighting technologies consider the quality of natural lighting so that occupants have more access to natural light within the building (FOWLER; RAUCH, 2007; IM *et al.*, 2017; WANG; LIU, 2015).

The adoption of natural lighting is done by means of the use of windows and exterior glazes (JIANG; TOVEY, 2009; THIBAUDEAU, 2008). This alternative reduces the artificial lighting requirements (GELEGENIS *et al.*, 2014; ZOGRAFAKIS; KARYOTAKIS; TSAGARAKIS, 2012).

Daylighting harvesting is a strategy that uses automatic lighting control technologies, like photosensors or dimming and control modules, to adjust the electric lighting according to the natural light level of each indoor environment (CAO; DAI; LIU, 2016; GE *et al.*, 2018; HARKOUSS; FARDOUN; BIWOLE, 2018; LIU *et al.*, 2014; THIBAUDEAU, 2008). This technology reduces the energy consumption generated by the use of artificial lighting according to natural lighting availability (HARKOUSS; FARDOUN; BIWOLE, 2018; HESTER *et al.*, 2012; JIANG; TOVEY, 2009; LEE; SONG; CHO, 2018; WANG; LIU, 2015).

There are also tubular daylighting devices that allow the use of natural light in the building's indoor environment by means of mirror tubes that are fixed to the roofs (LU; FAN; ZHAO, 2018). This is an effective measure to be implemented indoors for the use of natural light and energy saving (ESTIRI, 2015; ZOGRAFAKIS; KARYOTAKIS; TSAGARAKIS, 2012).

Good lighting system planning is essential in the architecture design of the building (THIBAUDEAU, 2008). Therefore, the use of such lighting technologies can lead to energy savings and so increasing the thermal comfort of the occupants (PRETE *et al.*, 2017).

2.2.5 Energy-Efficient Appliances

Appliances account for 30% of building energy consumption, thus representing an important group in promoting BEE. Table 6 shows the energy-efficient appliances found in the literature, followed by the references where they were found.

Table 6 - Energy-efficient appliances

Technology		References
Appliances	High-efficient refrigerator and freezers	Alajlan; Smiai; Elani (1998); Huang *et al.* (2012); Im *et al.* (2017); Morgenstern; Al-Jurf (1999); Tan *et al.* (2016); Xiao; Wei; Wang (2014)
	High-efficient washing machine	Alajlan; Smiai; Elani (1998); Huang *et al.* (2012); Vine (2002); Wiel *et al.* (1998); Xiao; Wei; Wang (2014)
	High-efficient cooking appliance	Alajlan; Smiai; Elani (1998); Cano *et al.* (2017); Wiel *et al.* (1998); Xiao, Wei, Wang (2014)
	High-efficient LED televisor	Cao; Dai; Liu (2016); Harkouss; Fardoun; Biwole (2018); Xiao; Wei; Wang (2014)

Source: The author.

Household appliances are products used for improving the life quality of the occupants, such as washing machines, refrigerators, kitchen appliances and televisions (CANO *et al.*, 2017; IM *et al.*, 2017; WIEL *et al.*, 1998; XIAO; WEI; WANG, 2014). Over the years, the adoption of these appliances had increased substantially in the building sector, which encouraged the development of appliances with technologies to reduce energy consumption (ALAJLAN; SMIAI; ELANI, 1998; CANO *et al.*, 2017; HUANG *et al.* 2012; WIEL *et al.*, 1998).

The energy-saving technologies for household appliances are related to the devices that are incorporated in the appliances for reducing the peak load of electricity and waste of energy resources (HUANG *et al.*, 2012; MORGENSTERN; AL-JURF, 1999; XIAO; WEI; WANG, 2014). Such technologies are related to the use of heat pumps in the clothes dryers; the adoption of advanced compressors and evacuated panel insulation for refrigerators; the horizontal axis technologies and higher spin speeds in spinner of the washing machine; the efficient gas stoves; the use of LED technology in the televisors; the adoption of intelligent home appliance control devices, etc (MORGENSTERN; AL-JURF, 1999; TAN *et al.*, 2016; WIEL *et al.*, 1998).

The level of energy saving of energy-efficient household appliances can be recognized by occupants by means of the energy rating labels (ALAJLAN; SMIAI; ELANI, 1998; HARKOUSS; FARDOUN; BIWOLE, 2018; IM *et al.*, 2017; XIAO; WEI; WANG, 2014). The labels encourage occupants to opt for energy-efficient appliances, which is important for reducing the energy demand of the building sector and to reduce the value of the energy bill for the occupants (HUANG *et al.*, 2012; IM *et al.*, 2017; VINE, 2002).

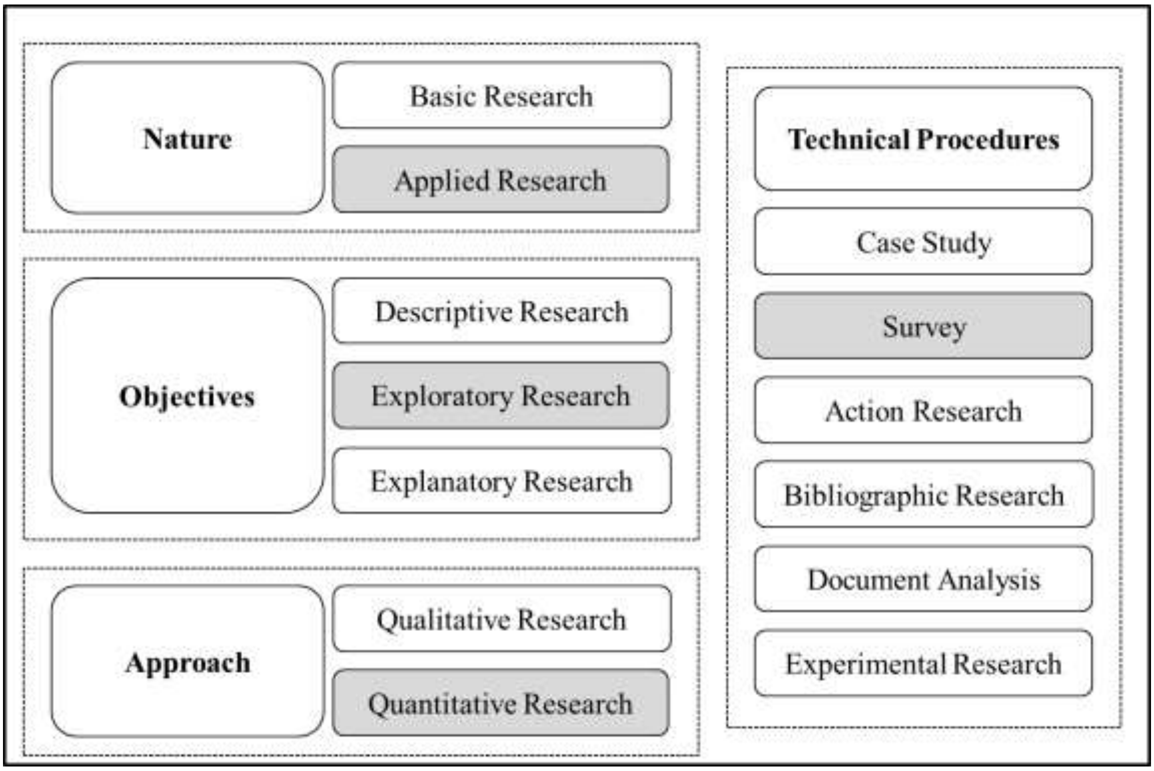
3 METHODOLOGICAL APPROACH

This Chapter presents information on research classification and methodological flow for the research development.

3.1 RESEARCH CLASSIFICATION

The research can be classified according to its nature, approach, objectives, and technical procedures (PROVDANOV; FREITAS, 2013). Figure 2 highlights the different aspects of types of research according to their classification.

Figure 2 – Research classification



Source: Adapted from Provdanov and Freitas (2013).

This research is characterized, as its nature, as applied since it has practical interests, as the research results can be used to solve specific problems (PROVDANOV; FREITAS, 2013). This type of research is more focused on the immediate application of knowledge than on theory development (GIL, 2008).

This research is exploratory, since it enhances ideas and knowledge about the theme, by means of literature review and interviews (GIL, 2002; PROVDANOV; FREITAS, 2013).

The research approach is quantitative, since it uses statistical techniques for describing, analyzing, and interpreting specialist opinions (KOTHARI, 2013). According to Miguel *et al.* (2012), quantitative research can be classified as axiomatic or empirical. This research is classified into the empirical category because it is based on actual observations (MIGUEL *et al.*, 2012).

Regarding the technical procedures used, the research was carried out by means of a survey. The survey consists of requesting information from a significant sample of individuals by means of a questionnaire related to the research theme (GIL, 2002; PONTO, 2015). This procedure has a quantitative characteristic because it allows the use of a variety of methods to analyze and interpret the data (PONTO, 2015; PROVDANOV; FREITAS, 2013; GIL, 2008).

3.2 METHODOLOGICAL FLOWCHART

Figure 3 presents the 7 steps that followed to carry out this research. These steps range from the characterization of the problem to the proposition of the strategies to overcome the barriers to the adoption of the building energy-saving technologies.

3.2.1 Research problem formulation

The key points of the research were established in this step. The choice of the research theme, the formulation of the research questions, the definition of the objectives, the relevance of the theme, and the research delimitation were topics within this step whose results are presented in the Introduction chapter.

3.2.2 Gathering the related articles

The SCOPUS was the database chosen for this research since it has a wide coverage of high impact journals and "it 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, analyze and view research" (ELSEVIER, 2019). The period covered by this research extends until 2018, and only articles and reviews from journals were considered.

Figure 3 - Research methodological flow

(to be continued)

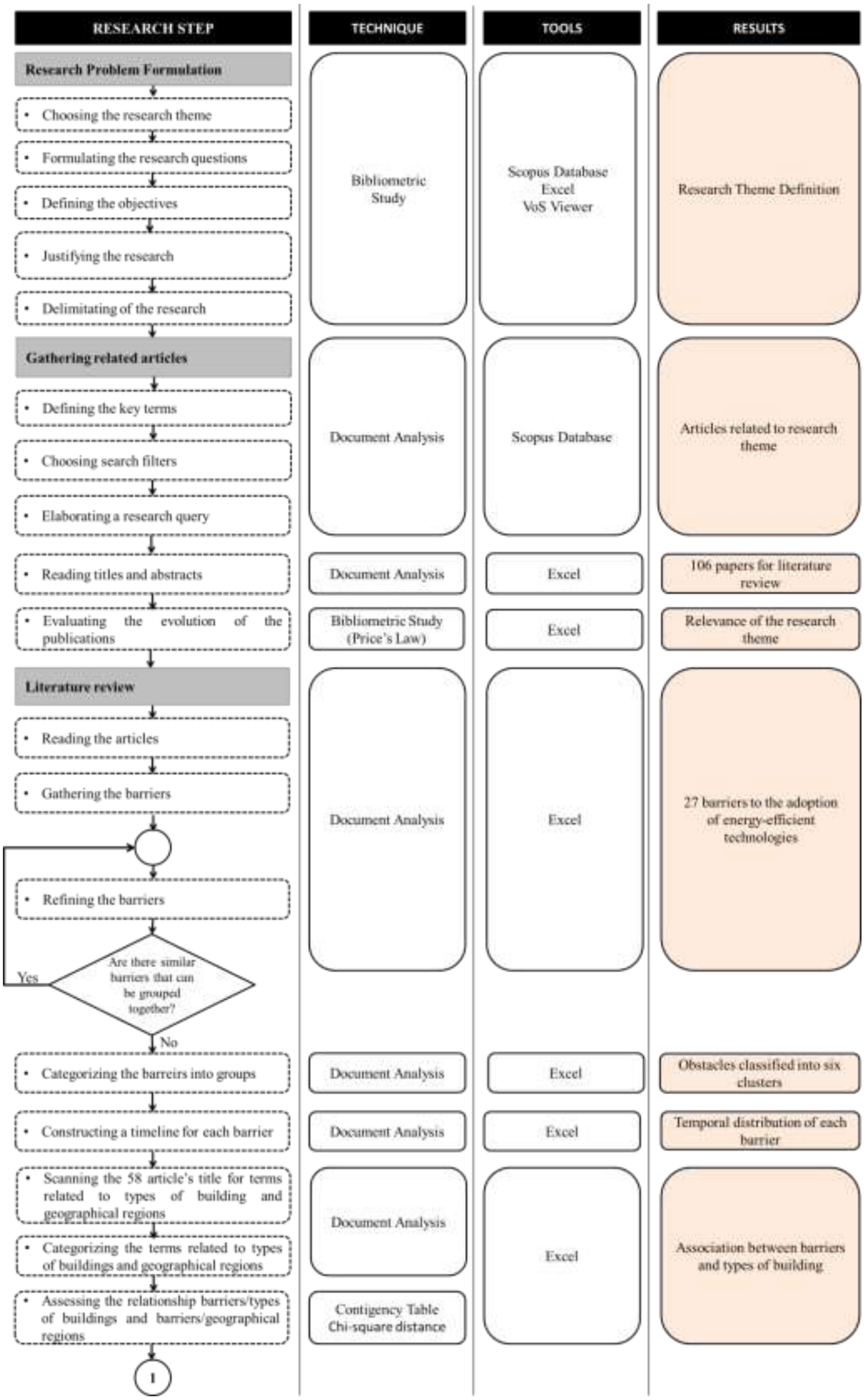
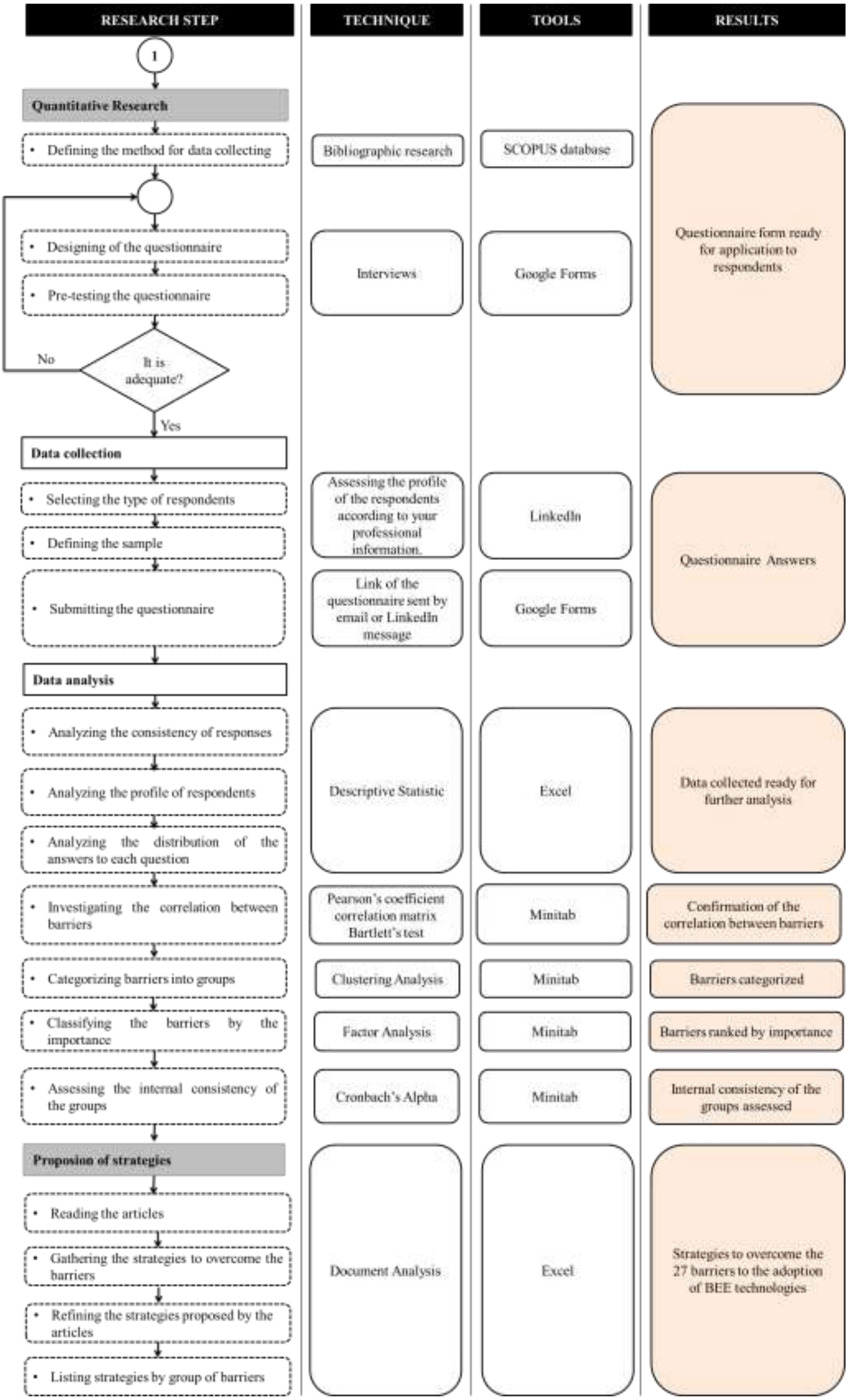


Figure 3 – Research methodological flow

(conclusion)



Source: The author.

The definition of key terms was the first step to collect the articles of interest. It is worth recalling that the target of this step is to identify a query with which it was possible to gather a significant sample of publications dealing with the core theme. Firstly, the examination of known papers lead to the choice of terms like “building energy efficiency”; "building energy conservation"; "building energy performance"; "building energy use"; "building energy consumption"; “zero energy building”; “building energy saving”; and so on. These terms were used as the initial query, for research based on the title, abstract, and the authors’ keywords. It was retrieved 14.451 publications. Afterward, the initial query was modified to include more restrictive terms like "obstacle" and "barrier”. This new query returned 450 articles. Appendix A presents the research query used.

Within this step, the title and abstract of each of the 450 articles were read in order to select the articles that really dealt with any obstacle to the adoption of BEE technologies from the others in which the terms “barrier” and “obstacle” were only incidental. At the end of this step, the number of papers eligible for further analysis dropped to 106.

The evolution of these publications over the years was analyzed in light of the Price’s fundamental law and was presented in the Introduction chapter.

3.2.3 Literature review

The next step was to gather the obstacles from the articles. The 106 publications were fully read (MORETTI, 2013), and 105 barriers were gathered from the 58 articles. After several runs of reading and analysis, the final number of barriers dropped to 27.

The 27 barriers recovered were classified according to their similarities, resulting in six groups, giving a complete overview of the most relevant aspects of this field.

At this stage, a timeline for the appearance of each barrier within each cluster was built, leading to a better comprehension of the theme (TANG *et al.*, 2019).

The titles of the 58 articles were scanned, once more, for terms related to types of building and geographical regions. Afterward, the gathered terms were grouped into categories for further analysis.

3.2.4 Quantitative Research

A structured questionnaire was designed with Google Forms in order to capture the Brazilian experts' perception of the importance of the barriers, pointed out in the literature, to the adoption of BEE technologies.

According to Snook and Harrison (2001), and Gil (2008), the structured questionnaire is based on a predefined set of questions, whose order and wording remain the same for all respondents. This type of questionnaire allows for a broad exploration of the subject, a high level of confidence in the answers, and the possibility to perform statistical analysis of the data collected (GIL, 2008; SNOOK; HARRISON, 2001).

The questionnaire is segmented into 3 parts. Firstly, an introductory text contextualizes the theme. Next, the kernel of the questionnaire, the 27 barriers for which the respondents are invited to assess their importance by means of an 11-point scale. The final wording of the barriers was reached after a pretest. A group of 20 respondents was selected for interviews. After each interview, the questions were modified until they reach their final writing. Afterward, four more questions characterized the respondents. The final version of the questionnaire is shown in Figure 14.

According to DeCastellarnau (2018) and Yang, Moon, and Jeon (2019), the choice of the response scale is generally the most important decision to ensure the reliability of the data collected with the application of a questionnaire. However, this choice depends on some criteria, for example, the applicability of the scale to the meaning of the question, the facility for the respondent to interpret and answer a question, and especially, the adequacy of the scale to the techniques used for data analysis (DARBYSHIRE; MCDONALD, 2004).

Dawes (2007) and Rammstedt and Krebs (2007) state that using a larger scale (10-11 points) provides significantly more space for respondents to express their opinion than a smaller scale (5-7 points). For Yang, Moon, and Jeon (2019), larger scales are more easily understood and interpreted by respondents than smaller scales.

According to Rammstedt and Krebs (2007), an 11-point scale shows increased variability in responses. Furthermore, longer scales are generally better for analyzing data using advanced statistics, such as factor analysis (DARBYSHIRE; MCDONALD, 2004).

Afterward, there was a blank, which could be filled with a new barrier outside the original list. The final part of the questionnaire aims to the respondents, i. e., their academic formation, and their jobs professional segments where they work.

The next step was data collection. The questionnaire respondents were sampled from professionals subscribed to the LinkedIn social network. The selected professionals were those with some professional experience or academic education related to BEE in the areas of architecture, civil engineering, electric/electronic engineering, mechanical engineering, etc. The questionnaire link has been sent by email or by means of the LinkedIn message to the groups of interest.

After the data collection was carried out, the consistency of the answers was analyzed, discarding those questionnaires improperly answered. Afterward, a complete analysis of the profile of the respondents was carried out.

The next step was to present the distribution of the responses for each question. Thus, it was possible to identify the most and less important barriers according to the respondents. Before proceeding with the data analysis, it is worth investigating the correlation between the barriers to see if it is possible to submit the responses to analysis more sophisticated.

Therefore, the Pearson’s coefficient correlation matrix, or simply a correlation matrix, were submitted to the Bartlett’s test for sphericity to see whether the matrix correlations are statistically significant. The Bartlett’s test for sphericity is used to test the hypotheses that the correlation matrix is, or not, statistically different from the identity matrix. (FAN *et al.*, 2019; JAIN; RAI, 2013; OGUNSANYA *et al.*, 2019; PHOGAT; GUPTA, 2019).

Therefore, as the results of both tests were considered statistically significant, it was possible to analyze which were the underlying factors using multivariate statistical techniques.

As the Bartlett’s test for sphericity confirmed that the barriers are really correlated one with another it showed that it is possible to use the responses to build underlying factors models, as the variable clustering using the correlation matrix as a measure of similarity and the factor analysis.

Therefore, the barriers were submitted to a hierarchical clustering algorithm using the correlation matrix as a matrix of similarity. The result was presented under a form of a clustering tree whose numbers of groups and the barriers within each group ratified the theoretical model.

In order to confirm the results of the clustering analysis and to classify the groups of barriers for importance, a Factor Analysis was carried out and the internal consistency of the groups was assessed by the Cronbach’s Alpha.

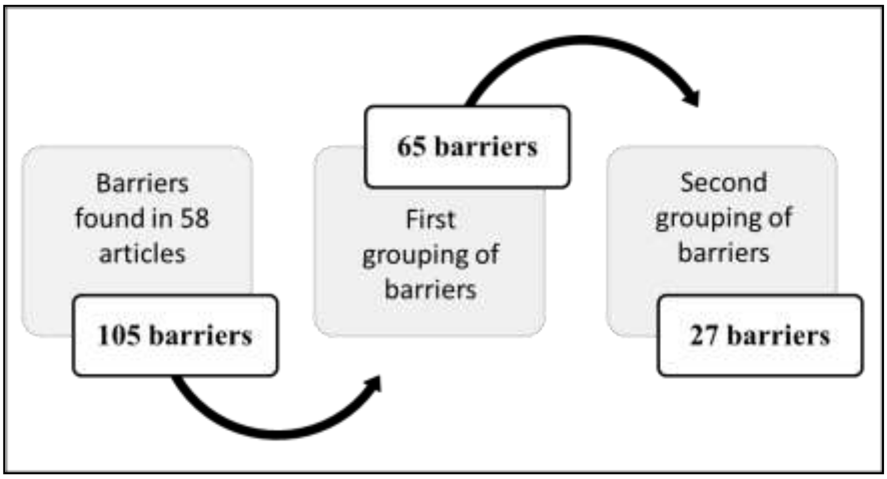
Since the Brazilian’ experts testified that the barriers found in the literature make sense for the Brazilian scenario, the literature was scrutinized to find effective strategies to overcome them. Then, the list of these strategies was the final result of this research.

4 BARRIERS TO THE ADOPTION OF ENERGY-EFFICIENT TECHNOLOGIES IN THE BUILDING SECTOR

This chapter presents a literature review based on existing literature to collect barriers to the adoption of energy-saving technologies. The 106 publications were submitted to a close read (MORETTI, 2013), resulting in 105 barriers gathered from 58 out of the 106 publications. 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" means the same as "lack of market demand"; "lack of government support" and "lack of government incentives" can be understood as the same thing; "resistance to change" and "uncertainties on behavioral changes" is another example. Therefore, after a first reading, the former 105 obstacles were reduced to 65.

In many cases, the similarity between the barriers was not so clear and 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 (Table 7). Figure 4 illustrates the whole process.

Figure 4 - The process of collecting barriers



Source: The author.

Table 7 - Barriers to the adoption of BEE technologies

(to be continued)

Barriers	Definition	References
High investment	Implementation of BEE technologies requires high capital investments.	Adeyeye; Osmani; Brown (2007); Amoruso; Donevska; Skomedal (2018); Caputo; Pasetti (2017); Chmutina; Goodier; Berger (2013); Curtius (2018); Dadzie *et al.* (2018); Djokoto; Dadzie; Ohemeng (2014); Du *et al.* (2014); Durdyev *et al.* (2018); Foong *et al.* (2017); Gliedt; Hoicka (2015); Goodier; Chmutia (2014); Holloway; Parrish (2015); Hosseini *et al.* (2016); Huang; Mauerhofer; Geng, (2016); Jagarajan *et al.* (2017); Kangas; Lazarevic; Kivimaa (2018); Liu *et al.* (2015); Marefat; Toosi; Hasankhanlo (2018); Oduyemi; Okoroh; Fajana (2017); Paiho; Ahvenniemi (2017); Robichaud; Anantatmula (2010); Shukla *et al.* (2018); Stevenso; Baborska-Narozny (2018); Teng *et al.* (2016);Travezan; Harmsen; Toledo (2013); Wang *et al.* (2016); Zadeh; Xuan; Shepley (2016); Zhang *et al.* (2018); Zhang; Wang (2013); Zhang; Zhou (2015); Zhou; Li; Chiang (2013)
Lack of confidence	Occupants and owners do not trust the incentives promised by the government.	Alreshidi; Mourshed; Rezgui (2018); Chmutina; Goodier; Berger (2013)
Lack of a market for BEE technologies	Lack of demand for BEE technologies.	Addy; Adinyira; Koranteng (2014); Djokoto; Dadzie; Ohemeng (2014); Du *et al.*, (2014); Stevenso; Baborska-Narozny (2018); Zhou; Li; Chiang (2013)
Ineffective BEE codes/ regulations /standards	Ineffective government laws, regulations, and standards that encourage the incorporation of BEE technologies.	Addy; Adinyira; Koranteng (2014); Adeyeye; Osmani; Brown (2007); Alreshidi; Mourshed; Rezgui (2018); Amoruso; Donevska; Skomedal (2018); Bertone *et al.* (2016); Bruce *et al.* (2015); Chmutina; Goodier; Berger (2013); Ding *et al.* (2018); Djokoto; Dadzie; Ohemeng (2014); Du *et al.* (2014); Durdyev *et al.* (2018); Foong *et al.* (2017); Goodier; Chmutia (2014); Gupta; Anand; Gupta (2017); Hopkins (2016); Persson; Grönkvist (2015); Stevenso; Baborska-Narozny (2018); Tuominen *et al.* (2012); Wang *et al.* (2016); Zhang; Zhou (2015)
Lack of confidence of the specialized professional	Specialized professionals do not believe in the results promised by BEE technologies.	Chmutina; Goodier; Berger (2013); Ding *et al.* (2018); Du *et al.* (2014); Holloway; Parrish (2015); Hopkins (2016); Kangas; Lazarevic; Kivimaa (2018); Karkanias *et al.* (2010); Tuominen *et al.* (2012)
Lack of fiscal policies	Lack of subsidies or other policy interventions to reduce energy prices.	Alanne; Saari (2004); Durdyev *et al.* (2018); Gliedt; Hoicka (2015); Goodier; Chmutia (2014); Li; Colombier (2009); Zhou; Li; Chiang (2013)

Table 7 - Barriers to the adoption of BEE technologies

(to be continued)

Barriers	Definition	References
Limited knowledge of market potential	The market knows little about the many BEE technology options.	Shukla *et al.* (2018)
Lack of technology demonstration	Lack of demonstration facilities for energy-efficient technologies	Peterman; Kourula; Levitt (2012)
Complex energy efficiency certification procedures	Complex procedures for the certification of energy-efficient buildings.	Du *et al.* (2014); Häkkinen (2011); Paiho; Ahvenniemi (2017)
Inadequate BEE technologies	The available BEE technologies are inadequate, incompatible and/or inaccessible.	Addy; Adinyira; Koranteng (2014); Amoruso; Donevska; Skomedal (2018); Castleberry; Gliedt; Greene (2016); Djokoto; Dadzie; Ohemeng (2014); Gupta; Anand; Gupta (2017); Willians; Dair (2007); Zhang; Zhou (2015)
Long payback periods	Long payback period on capital invested in energy efficient projects.	Bertone *et al.* (2016); Bond (2011); Bruce *et al.* (2015); Durdyev *et al.* (2018); Gliedt; Hoicka (2015); Greenough; Tosoratti (2014); Häkkinen (2011); Jin *et al.* (2009); Paiho; Ahvenniemi (2017); Shukla *et al.* (2018); Tuominen *et al.* (2012); Wang *et al.* (2016); Zadeh; Xuan; Shepley (2016); Zhang; Zhou (2015)
Difficult access to financing	Lack of specific credit lines for BEE projects.	Addy; Adinyira; Koranteng (2014); Gupta; Anand; Gupta (2017); Palmer *et al.* (2013); Zhang; Zhou (2015)
Incredulity on the part of the architects and engineers	The reluctance of architects and engineers to adopt energy-efficient measures in their projects.	Du *et al.* (2014); Hopkins (2016).
Lack of knowledge by policymakers	Lack of knowledge by policymakers about the benefits of using BEE technologies.	Chmutina; Goodier; Berger (2013); Liu *et al.* (2015).

Table 7 - Barriers to the adoption of BEE technologies

(to be continued)

Barriers	Definition	References
Lack of knowledge about the BEE technlogies	Lack of knowledge by occupants and owners of all the benefits of adopting BEE technologies.	Addy; Adinyira; Koranteng (2014); Adeyeye; Osmani; Brown (2007); Alanne; Saari (2004); Amoruso; Donevska; Skomedal (2018); Bertone *et al.* (2016); Bond (2011); Caputo; Pasetti (2017); Chmutina; Goodier; Berger (2013); Curtius (2018); Dadzie *et al.* (2018); Djokoto; Dadzie; Ohemeng (2014); Durdyev *et al.* (2018); Greenough; Tosoratti (2014); Gupta; Anand; Gupta (2017); Holloway; Parrish (2015); Hopkins (2016); Hosseini *et al.* (2016); Huang; Mauerhofer; Geng (2016); Liu *et al.* (2015); Marefat; Toosi; Hasankhanlo (2018); Oduyemi; Okoroh; Fajana (2017); Paiho; Ahvenniemi (2017); Palmer *et al.* (2013); Peterman; Kourula; Levitt (2012); Ruiz (2005); Stevenso; Baborska-Narozny (2018); Travezan; Harmsen; Toledo (2013); Tuominen *et al.* (2012); Wang *et al.* (2016); Zhang; Zhou (2015)
High Investment risks	Investments in BEE technologies are of high financial risk.	Chmutina; Goodier; Berger (2013); Djokoto; Dadzie; Ohemeng (2014)
Lack of technical competence	Difficult in finding skilled professionals to deal with BEE technologies.	Addy; Adinyira; Koranteng (2014); Adeyeye; Osmani; Brown (2007); Alreshidi; Mourshed; Rezgui (2018); Caputo; Pasetti (2017); Cattano *et al.* (2013); Chmutina; Goodier; Berger (2013); Curtius (2018); Djokoto; Dadzie; Ohemeng (2014); Du *et al.* (2014); Durdyev *et al.* (2018); Häkkinen (2011); Hosseini *et al.* (2016); Jagarajan *et al.* (2017); Marefat; Toosi; Hasankhanlo (2018); Ruiz (2005); Stevenso; Baborska-Narozny (2018); Shukla *et al.* (2018); Travezan; Harmsen; Toledo (2013); Tuominen *et al.* (2012); Wang *et al.* (2016); Willians; Dair (2007); Wilson; Crane; Chryssochoidis (2015); Zhang *et al.* (2018); Zhang; Zhou (2015)
Lack of government support	Lack of government incentive to adoption to the BEE technologies.	Bertone *et al.* (2016); Chmutina; Goodier; Berger (2013); Curtius (2018); Djokoto; Dadzie; Ohemeng (2014); Hosseini *et al.* (2016); Jin *et al.* (2009); Kangas; Lazarevic; Kivimaa (2018); Lang (2004); Li; Colombier (2009); Marefat; Toosi; Hasankhanlo (2018); Paiho; Ahvenniemi (2017); Wang *et al.* (2016); Zhang *et al.* (2018); Zhang; Wang (2013)
Lack of investors in the BEE projects	Lack of investors interested in BEE.	Addy; Adinyira; Koranteng (2014)

Table 7 - Barriers to the adoption of BEE technologies

(conclusion)

Barriers	Definition	References
Policies do not address the financial implications	Government policies for the sector underestimate the actual costs of implementing BEE measures.	Adeyeye; Osmani; Brown (2007); Curtius (2018)
Fear/Resistance to change	Fear/resistance to change by owners and occupants of the buildings.	Alreshidi; Mourshed; Rezgui (2018); Bruce *et al.* (2015); Caputo; Pasetti (2017); Goodier; Chmutia (2014); Hopkins (2016); Marefat; Toosi; Hasankhanlo (2018); Oduyemi; Okoroh; Fajana (2017); Ruiz (2005); Zhang *et al.* (2018)
Lack of economic incentives	Lack of economic incentives for the development of BEE projects.	Addy; Adinyira; Koranteng (2014); Bertone *et al.* (2016); Chmutina; Goodier; Berger (2013); Dadzie *et al.* (2018); Ding *et al.* (2018); Djokoto; Dadzie; Ohemeng (2014); Durdyev *et al.* (2018); Foong *et al.* (2017); Gupta; Anand; Gupta (2017); Häkkinen (2011); Jagarajan *et al.* (2017); Karkanias *et al.* (2010); Lang (2004); Wang *et al.* (2016); Yeatts *et al.* (2017); Zhang; Zhou (2015)
Lack of information	Lack of information on BEE technology available on the market.	Akadiri (2015); Ding *et al.* (2018); Persson; Grönkvist (2015); Ruiz (2005); Tuominen *et al.* (2012)
Lack of motivation	Lack of motivation of occupants and owners to promote energy efficiency actions.	Bertone *et al.* (2016); Ruiz (2005); Yeatts *et al.* (2017)
Lack of efficient dissemination of codes/regulations	Precarious dissemination of policies, regulations, and standards that encourage the incorporation of energy-efficient technologies in buildings.	Goodier; Chmutia (2014)
Financial limitations of the owners	Lack of capital for specific investment in energy efficiency.	Adeyeye; Osmani; Brown (2007); Li; Colombier (2009)
Lack of good marketing strategies	Lack of good marketing strategies to promote energy-efficient technologies and their benefits.	Dadzie *et al.* (2018)

Source: The author;

Although the number of barriers collected within this research is 27, the number of barriers pointed out in the literature has been increasing continuously as new publications emerge (HONG *et al.*, 2014).

It is worth mentioning that these barriers rise 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 other aspects like government, market, and so on. Such categorization is known as taxonomy, and it is valuable since it allows a broad comprehension of the research area. Such comprehension is an important step to formulate strategies to overcome the barriers (CAGNO *et al.*, 2012).

The literature review identified eight relevant taxonomies, as shown in Table 8.

Table 8 - Relevant taxonomies presented in the literature

Addy, Adinyira and Koranteng (2014)	**Djokoto, Dadzie and Ohemeng (2014)**
• Social and behavioural barrier • Professional barrier • Policy barrier • Market barrier • Financial barrier	• Cultural barriers • Financial barriers • Capacity/Professional barriers • Government barriers
Goodier and Chmutia (2014)	**Kangas, Lazarevic and Kivimaa (2018)**
• Market • Economic and finance • Institutional • Social	• Economic market barriers • Behavioural barriers • Organisational barriers • Institutional barriers
Paiho and Ahvenniemi (2017)	**Wang *et al.* (2016)**
• Social barriers • Economic barriers • Regulative barriers	• Economic barriers • Technical barriers • Government barriers • Cultural barriers
Zhang and Wang (2013)	**Zhang and Zhou (2015)**
• Legal barriers • Market barriers • Financial barriers • Social barriers • Technological barriers	• Financial • Technical • Technological • Political • Market

Source: The author.

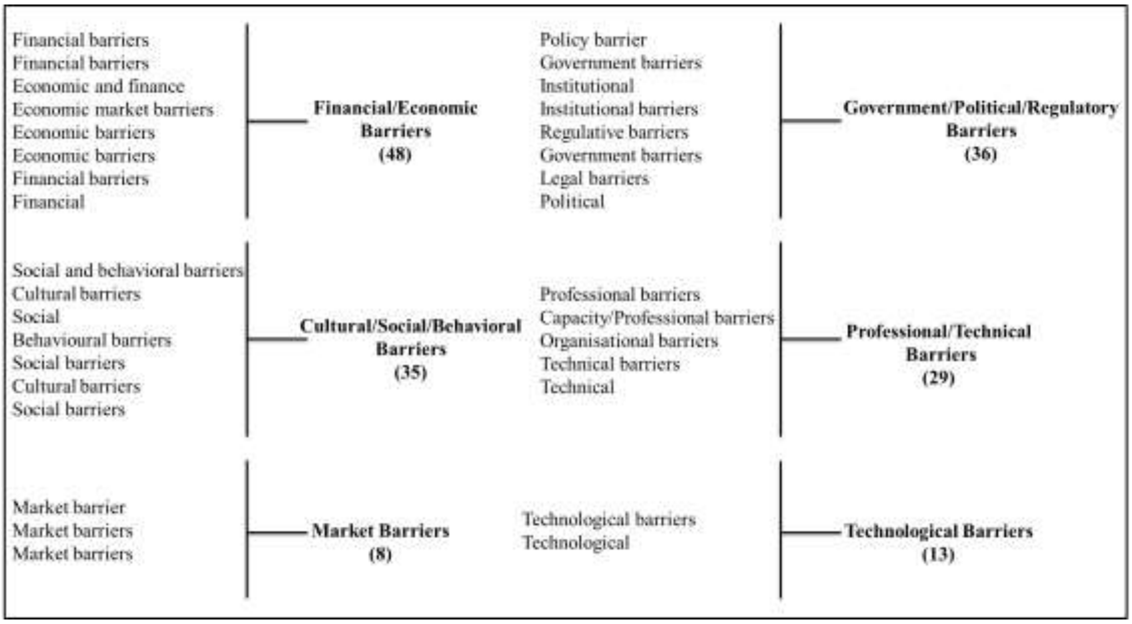
It can be seen from Table 8 that the number of categories ranges from 3 to 5.

4.1 A NEW TAXONOMY

The name of the categories varies from author to author, however, in most cases the differences are slight, making it easy to compare them. In other cases, the differences required an attentive reading of the barriers description to group them.

Figure 5 illustrates the process employed to create a new taxonomy. Each category is followed by the number of articles where one or more barriers within the respective category appear. For example, 48 out of the 58 articles from which barrier was gathered, present, at least, one barrier within the group named Financial/Economic barriers.

Figure 5 - The process employed within this research to create a new taxonomy



Source: The author.

This section presents the six clusters of barriers along with the description of each barrier according to the literature.

4.1.1 Financial/Economic Barriers

This group brings together, barriers related to economic and financial issues that inhibit the adoption of energy-efficient technologies in the building sector. Table 9 shows the barriers found out in the literature, followed by a brief description and the references where they were found.

Table 9 - Financial/Economic barriers

(to be continued)

Barriers	Definition	References
High investment	Implementation of BEE technologies requires high capital investments	[23] Adeyeye; Osmani; Brown (2007); [50] Amoruso; Donevska; Skomedal (2018); [57] Caputo; Pasetti (2017); [35] Chmutina; Goodier; Berger (2013); [65] Curtius (2018); [7] Dadzie *et al.* (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [32] Du *et al.* (2014); [27] Durdyev *et al.* (2018); [59] Foong *et al.* (2017); [10] Gliedt; Hoicka (2015); [24] Goodier; Chmutia (2014); [58] Holloway; Parrish (2015); [34] Hosseini *et al.*, (2016); [62] Huang; Mauerhofer; Geng (2016); [38] Jagarajan *et al.* (2017); [14] Kangas; Lazarevic; Kivimaa (2018); [29] Liu *et al.* (2015); [33] Marefat; Toosi; Hasankhanlo (2018); [64] Oduyemi; Okoroh; Fajana (2017); [48] Paiho; Ahvenniemi (2017); [28] Robichaud; Anantatmula (2010); [26] Shukla *et al.* (2018); [51] Stevenso; Baborska-Narozny (2018); [61] Teng *et al.* (2016); [21] Travezan; Harmsen; Toledo (2013); [22] Wang *et al.* (2016); [25] Zadeh; Xuan; Shepley (2016); [13] Zhang *et al.* (2018); [1] Zhang; Wang (2013); [46] Zhang; Zhou (2015); [52] Zhou; Li; Chiang (2013)
Lack of economic incentives	Lack of economic incentives for the development of BEE projects.	[37] Addy; Adinyira; Koranteng (2014); [43] Bertone *et al.* (2016); [35] Chmutina; Goodier; Berger (2013); [7] Dadzie *et al.* (2018); [39] Ding *et al.* (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [27] Durdyev *et al.* (2018); [59] Foong *et al.* (2017); [9] Gupta; Anand; Gupta (2017); [36] Häkkinen (2011); [38] Jagarajan *et al.* (2017); [30] Karkanias *et al.* (2010); [18] Lang (2004); [22] Wang *et al.* (2016); [6] Yeatts *et al.* (2017); [46] Zhang; Zhou (2015)
Long payback periods	Long payback period on capital invested in BEE projects.	[43] Bertone *et al.* (2016); [63] Bond (2011); [42] Bruce *et al.* (2015); [27] Durdyev *et al.*, (2018); [10] Gliedt; Hoicka (2015); [24] Goodier; Chmutia (2014); [2] Greenough; Tosoratti (2014); [36] Häkkinen (2011); [44] Jin *et al.* (2009); [48] Paiho; Ahvenniemi (2017); [41] Peterman; Kourula; Levitt (2012); [26] Shukla *et al.* (2018); [40] Tuominen *et al.* (2012); [22] Wang *et al.* (2016); [25] Zadeh; Xuan; Shepley (2016); [46] Zhang; Zhou (2015)

Table 9 - Financial/Economic barriers

(conclusion)

Barriers	Definition	References
Difficult access to financing	Lack of specific credit lines for BEE projects.	[37] Addy; Adinyira; Koranteng (2014); [9] Gupta; Anand; Gupta (2017); [45] Palmer *et al.* (2013); [46] Zhang; Zhou (2015)
Financial limitations of owners	Lack of capital for specific investment in energy efficiency.	[23] Adeyeye; Osmani; Brown (2007); [8] Li; Colombier (2009)
High Investment risks	Investments in BEE technologies are of high financial risk.	[35] Chmutina; Goodier; Berger (2013); [31] Djokoto; Dadzie; Ohemeng (2014)

Source: The author.

Financial/Economic obstacles are related to the high investment required for the adoption of energy-saving technologies in buildings (TRAVEZAN; HARMSEN; TOLEDO, 2013; WANG *et al.*, 2016; ZHANG *et al.*, 2017). Investments in the adoption of such technologies are higher than in conventional technologies, thus affecting the rate of adoption of BEE technologies (DURDYEV *et al.*, 2018; GOODIER; CHMUTIA, 2014; SHUKLA *et al.*, 2018; ZADEH; XUAN; SHEPLEY, 2016). The use of technologies, such as HVAC systems, more efficient lighting systems, photovoltaic devices, and geothermal heat pumps increase the cost of investments (GLIEDT; HOICKA, 2015; KANGAS; LAZAREVIC; KIVIMAA, 2018; LIU *et al.*, 2015; ROBICHAUD; ANANTATMULA, 2010; ZHANG; WANG, 2013).

Furthermore, the high salaries of specialized professionals is another reason for the increased investment capital (DJOKOTO; DADZIE; OHEMENG, 2014). Therefore, the diffusion of BEE technologies is affected by these aspects, which make investors reluctant to apply their capital (CURTIUS, 2018; DADZIE *et al.*, 2018; DU *et al.*, 2014; MAREFAT; TOOSI; HASANKHANLO, 2018; ZHANG *et al.*, 2018).

According to Wang *et al.* (2016), 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 (CHMUTINA; GOODIER; BERGER, 2013; DURDYEV *et al.*, 2018; KARKANIAS *et al.*, 2010; YEATTS *et al.*, 2017). This barrier arises when local governments do not provide financial support and economic incentives for the building owners to adopt such technologies rather than conventional ones (ADDY; ADINYIRA; KORANTENG, 2014; DING *et al.*, 2018; GUPTA; ANAND; GUPTA, 2017; HÄKKINEN, 2011; JAGARAJAN *et al.*, 2017; LANG, 2004).

BEE projects tend to have a longer payback period than the conventional projects, which has been seen as a barrier by several authors (DURDYEV *et al.*, 2018; GREENOUGH; TOSORATTI, 2014; HÄKKINEN, 2011; TUOMINEN *et al.*, 2012). This obstacle arises because the return of investments happens in a medium- to long-term period (BERTONE *et al.*, 2016; BRUCE *et al.*, 2015; GLIEDT; HOICKA, 2015; PETERMAN; KOURULA; LEVITT, 2012). Thereby, investors tend to forgo energy-efficient investments (GOODIER; CHMUTIA, 2014; JIN *et al.*, 2009; SHUKLA *et al.*, 2018; WANG *et al.*, 2016; ZADEH; XUAN; SHEPLEY, 2016).

The difficulty in accessing financing lines to adopt energy-saving measures is also recognized as an obstacle affecting the BEE programs (GUPTA; ANAND; GUPTA, 2017; PALMER *et al.*, 2013; ZHANG; ZHOU, 2015). It is difficult for investors to access sufficient resources to invest in technologies for the development of BEE projects (ADDY; ADINYIRA; KORANTENG, 2014; PALMER *et al.*, 2013).

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 (ADEYEYE; OSMANI; BROWN, 2007; LI; COLOMBIER, 2009). Furthermore, 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.

Many investors and owners are averse to the risks of investing in BEE technologies (DJOKOTO; DADZIE; OHEMENG, 2014). There is uncertainty about long-term savings. They do not believe that the adoption of such technologies will generate the expected financial results (CHMUTINA; GOODIER; BERGER, 2013).

4.1.2 Market Barriers

Market aspects play an important role in the adoption of energy-saving technologies. Market barriers are listed in Table 10 along with their definitions and references.

Market barriers are more commonly associated with low customer demand (ADDY; ADINYIRA; KORANTENG, 2014; DJOKOTO; DADZIE; OHEMENG, 2014; STEVENSO; BABORSKA-NAROZNY, 2018). This arises because many buyers do not care about the sustainable performance of a building, which makes the market unfavorable to the adoption of such technologies (DU *et al.*, 2014; ZHANG; ZHOU, 2015; ZHOU; LI; CHIANG, 2013).

Table 10 - Market barriers

Barriers	Definition	References
Lack of a market for BEE technologies	Lack of demand for BEE technologies.	[37] Addy; Adinyira; Koranteng (2014); [31] Djokoto; Dadzie; Ohemeng (2014); [32] Du *et al.* (2014); [51] Stevenso; Baborska-Narozny (2018); [52] Zhou; Li; Chiang (2013)
Lack of investors in the BEE projects	Lack of investors interested in BEE.	[37] Addy; Adinyira; Koranteng (2014)
Limited knowledge of market potential	The market knows little about the many BEE technology options.	[26] Shukla *et al.* (2018)
Lack of good marketing strategies	Lack of good marketing strategies to promote BEE technologies and their benefits.	[7] Dadzie *et al.* (2018)

Source: The author.

Another obstacle is the lack of investors in the BEE projects. This type of barrier is related to the investors' sensitivity to the price of buildings, since energy-efficient buildings require high investments (ADDY; ADINYIRA; KORANTENG, 2014).

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 (DU *et al.*, 2014; SHUKLA *et al.*, 2018). In general, limited knowledge of the benefits of BEE reduces the demand for the BEE projects, affecting the market progress (DADZIE *et al.*, 2018).

Lack of good strategies to promote these technologies makes owners and investors unaware of the economic and social benefits of adopting them (DJOKOTO; DADZIE; OHEMENG, 2014).

4.1.3 Technological Barriers

The Technological barriers group problems with 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 11.

Table 11 - Technological barriers

Barriers	Definition	References
Inadequate BEE technologies	The available energy-efficient technologies are inadequate, incompatible and/or inaccessible.	[37] Addy; Adinyira; Koranteng (2014); [50] Amoruso; Donevska; Skomedal (2018); [54] Castleberry; Gliedt; Greene (2016); [31] Djokoto; Dadzie; Ohemeng (2014); [9] Gupta; Anand; Gupta (2017); [53] Willians; Dair (2007); [46] Zhang; Zhou (2015)
Lack of Information	Lack of information on energy-efficient technology available on the market	[56] Akadiri (2015); [39] Ding *et al.* (2018); [3] Persson; Grönkvist (2015); [55] Ruiz (2005); [40] Tuominen *et al.* (2012)
Lack of technology demonstration	Lack of demonstration facilities for energy-efficient technologies	[41] Peterman; Kourula; Levitt (2012)

Source: The author.

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 (AMORUSO; DONEVSKA; SKOMEDAL, 2018; DJOKOTO; DADZIE; OHEMENG, 2014; GUPTA; ANAND; GUPTA, 2017). Thus, there is a fear that BEE technologies will not reach the desirable performance (ADDY; ADINYIRA; KORANTENG, 2014; CASTLEBERRY; GLIEDT; GREENE, 2016; WILLIANS; DAIR, 2007; ZHANG; ZHOU, 2015).

The availability of information about the potential of appropriate technologies is crucial for their adoption (AKADIRI, 2015; TUOMINEN *et al.*, 2012). However, the lack of reliable information on the ways to integrate such technologies in BEE projects is a barrier to such technologies (DING *et al.*, 2018; PERSSON; GRÖNKVIST, 2015; RUIZ, 2005).

Furthermore, there is a lack of pilot projects that demonstrates innovative and energy-efficient actions to investors and owners (PETERMAN; KOURULA; LEVITT, 2012). One can conclude that the latter two obstacles are underlying causes for the existence of the former (GUPTA; ANAND; GUPTA, 2017; PETERMAN; KOURULA; LEVITT, 2012; TUOMINEN *et al.*, 2012).

4.1.4 Professional/Technical Barriers

The adoption of the BEE technologies faces some Professional/Technical barriers, which may arise in different forms as shown in Table 12.

Table 12 - Professional/Technical barriers

Barriers	Definition	References
Lack of technical competence	Difficult in finding skilled professionals to deal with energy-efficient technologies.	[37] Addy; Adinyira; Koranteng (2014); [23] Adeyeye; Osmani; Brown (2007); [60] Alreshidi; Mourshed; Rezgui (2018); [57] Caputo; Pasetti (2017); [49] Cattano *et al.* (2013); [35] Chmutina; Goodier; Berger (2013); [65] Curtius (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [32] Du *et al.* (2014); [27] Durdyev *et al.* (2018); [36] Häkkinen (2011); [34] Hosseini *et al.* (2016); [38] Jagarajan *et al.* (2017); [33] Marefat; Toosi; Hasankhanlo (2018); [55] Ruiz (2005); [26] Shukla *et al.* (2018); [51] Stevenso; Baborska-Narozny (2018); [21] Travezan; Harmsen; Toledo (2013); [40] Tuominen *et al.* (2012); [22] Wang *et al.* (2016); [53] Willians; Dair (2007); [47] Wilson; Crane; Chryssochoidis (2015); [13] Zhang *et al.* (2018); [46] Zhang; Zhou (2015)
Lack of confidence of the specialized professional	Specialized professionals do not believe in the results promised by energy-efficient technologies	[35] Chmutina; Goodier; Berger (2013); [39] Ding *et al.* (2018); [32] Du *et al.* (2014); [58] Holloway; Parrish (2015); [66] Hopkins (2016); [14] Kangas; Lazarevic; Kivimaa (2018); [30] Karkanias *et al.* (2010); [40] Tuominen *et al.* (2012)
Incredulity on the part of the architects and engineers	The reluctance of architects and engineers to adopt energy-efficient measures in their projects.	[32] Du *et al.* (2014); [66] Hopkins (2016)

Source: The author

The main Professional/Technical barrier is the lack of professionals specialized in the development of BEE projects (ADDY; ADINYIRA; KORANTENG, 2014; HÄKKINEN, 2011; RUIZ, 2005; SHUKLA *et al.*, 2018; STEVENSO; BABORSKA-NAROZNY, 2018). This obstacle arises from the lack of institutions that offer courses for professional training (CURTIUS, 2018; DU *et al.*, 2014; DURDYEV *et al.*, 2018). Most practitioners are not qualified in energy-saving technologies and are therefore not familiar with the principles needed to implement energy efficiency measures (CAPUTO; PASETTI, 2017; DJOKOTO; DADZIE; OHEMENG, 2014; HÄKKINEN, 2011; ZHANG; ZHOU, 2015).

Unskilled professionals do not have a technical perception of inefficiencies and opportunities to implement energy efficiency measures, which may delay the project schedule and also undermine the energy efficiency of the buildings (DURDYEV *et al.*, 2018; JAGARAJAN *et al.*, 2017; TUOMINEN *et al.*, 2012; WANG *et al.*, 2016; WILLIANS; DAIR, 2007; ZHANG *et al.*, 2018).

Many professionals do not believe in the supposed benefits bought by the use of energy-efficient technologies, mainly those more complex (DJOKOTO; DADZIE; OHEMENG, 2014; DU *et al.*, 2014; STEVENSO; BABORSKA-NAROZNY, 2018; TRAVEZAN; HARMSEN; TOLEDO, 2013). This leads professionals not to be active users of energy-saving technologies, that hampers the adoption of energy efficiency requirements during the energy-efficient projects (ADEYEYE; OSMANI; BROWN, 2007; GOODIER; CHMUTIA, 2014; GREENOUGH; TOSORATTI, 2014; HOLLOWAY; PARRISH, 2015; HOSSEINI *et al.*, 2016; JAGARAJAN *et al.*, 2017; TENG *et al.*, 2016; TUOMINEN *et al.*, 2012).

Many architects and engineers are reluctant to use energy-efficient measures in their projects (CATTANO *et al.*, 2013), since they are not confident that such measures will bring the desired return to both the company and the investors/owners, preferring to focus their efforts mostly on conventional projects (CATTANO *et al.*, 2013; HOSSEINI *et al.*, 2016).

4.1.5 Government/Political/Regulatory Barriers

This group of barriers has been defined as obstacles due to political institutions. Table 13 shows the barriers found in the literature, followed by a brief description and the references where they were found.

The group of Government/Political/Regulatory barriers brings together obstacles that inhibit the progress and development of energy-efficient technologies. The main barrier is concerned with inconsistent policies and poor governance standards that delay the adoption of energy-saving technologies (ADDY; ADINYIRA; KORANTENG, 2014; BERTONE *et al.*, 2016; BRUCE *et al.*, 2015; DING *et al.*, 2018; TUOMINEN *et al.*, 2012).

The inconsistency of government energy efficiency policies affects the choice of the proper technology for buildings (ADEYEYE; OSMANI; BROWN, 2007; AMORUSO; DONEVSKA; SKOMEDAL, 2018; GOODIER; CHMUTIA, 2014; HOPKINS, 2016; STEVENSO; BABORSKA-NAROZNY, 2018; ZHANG; ZHOU, 2015). An inadequate policy system can lead to inconsistency in the application of laws and regulations, thereby reducing market enthusiasm for energy efficiency (DURDYEV *et al.*, 2018; GUPTA; ANAND; GUPTA, 2017; PERSSON; GRÖNKVIST, 2015; WANG *et al.*, 2016).

Table 13 - Governmental/Political/Regulatory barriers

(to be continued)

Barriers	Definition	References
Inefficient BEE codes/ regulations /standards	Inefficient government laws, regulations, and standards that encourage the incorporation of energy-efficiency technologies in buildings.	[37] Addy; Adinyira; Koranteng (2014); [23] Adeyeye; Osmani; Brown (2007); [60] Alreshidi; Mourshed; Rezgui (2018); [50] Amoruso; Donevska; Skomedal (2018); [43] Bertone *et al.* (2016); [42] Bruce *et al.* (2015); [35] Chmutina; Goodier; Berger (2013); [39] Ding *et al.* (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [32] Du *et al.* (2014); [27] Durdyev *et al.* (2018); [59] Foong *et al.* (2017); [24] Goodier; Chmutia (2014); [9] Gupta; Anand; Gupta (2017); [66] Hopkins (2016); [3] Persson; Grönkvist (2015); [51] Stevenso; Baborska-Narozny (2018); [40] Tuominen *et al.* (2012); [22] Wang *et al.* (2016); [46] Zhang; Zhou (2015).
Lack of government support	Lack of government incentive to adoption to the energy-efficient technologies.	[43] Bertone *et al.* (2016); [35] Chmutina; Goodier; Berger (2013); [65] Curtius (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [34] Hosseini *et al.* (2016); [44] Jin *et al.* (2009); [14] Kangas; Lazarevic; Kivimaa (2018); [18] Lang (2004); [8] Li; Colombier (2009); [33] Marefat; Toosi; Hasankhanlo (2018); [48] Paiho; Ahvenniemi (2017); [22] Wang *et al.* (2016); [13] Zhang *et al.* (2018); [1] Zhang; Wang (2013)
Lack of fiscal policies	Lack of subsidies or other policy interventions that reduces energy prices.	[19] Alanne; Saari (2004); [27] Durdyev *et al.* (2018); [10] Gliedt; Hoicka (2015); [24] Goodier; Chmutia (2014); [8] Li; Colombier (2009); [52] Zhou; Li; Chiang (2013)
Complex energy efficiency certification procedures	Complex procedures for the certification of energy-efficient buildings.	[32] Du *et al.* (2014); [36] Häkkinen (2011); [48] Paiho; Ahvenniemi (2017)
Policies do not address financial implications	Government policies for the sector underestimate the actual costs of implementing energy efficiency measures.	[23] Adeyeye; Osmani; Brown (2007); [65] Curtius (2018)

Table 13 - Governmental/Political/Regulatory barriers

(conclusion)

Barriers	Definition	References
Lack of knowledge by policymakers	Lack of knowledge by policymakers about the benefits of using energy-efficient technologies.	[35] Chmutina; Goodier; Berger (2013); [29] Liu *et al.* (2015)
Lack of efficient dissemination of codes/regulations	Precarious dissemination of policies, regulations, and standards that encourage the incorporation of energy-efficient technologies in buildings.	[24] Goodier; Chmutia (2014)

Source: The author.

Furthermore, the lack of consistency in government standards prevents a better guidance on energy saving in buildings, effective energy management and the motivation to select more energy-efficient technologies (ADEYEYE; OSMANI; BROWN, 2007; ALRESHIDI; MOURSHED; REZGUI, 2018; CHMUTINA; GOODIER; BERGER, 2013; DJOKOTO; DADZIE; OHEMENG, 2014; FOONG *et al.*, 2017; GOODIER; CHMUTIA, 2014).

The lack of incentive and the lack of government commitment to the development of BEE projects is another prominent barrier in the literature (BERTONE *et al.*, 2016; DJOKOTO; DADZIE; OHEMENG, 2014; HOSSEINI *et al.*, 2016; JIN *et al.*, 2009). Often, the government does not understand the urgency of developing government projects aimed at increasing energy efficiency in buildings (DING *et al.*, 2018; MAREFAT; TOOSI; HASANKHANLO, 2018; PAIHO; AHVENNIEMI, 2017; ZHANG; WANG, 2013). 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 BEE technologies (CURTIUS, 2018; KANGAS; LAZAREVIC; KIVIMAA, 2018; KARKANIAS *et al.*, 2010; LANG, 2004; WANG *et al.*, 2016; ZHANG *et al.*, 2018).

There are government issues related to distorted fiscal policies that inhibit investments in energy efficiency (LI; COLOMBIER, 2009; ZHOU; LI; CHIANG, 2013). These distortions are related to 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 (ADDY;

ADINYIRA; KORANTENG, 2014; ALANNE; SAARI, 2004; GOODIER; CHMUTIA, 2014).

In some cases, the procedures for obtaining the BEE certification are complicated and require a lot of effort from the stakeholders, so are therefore considered an obstacle (HÄKKINEN, 2011; PAIHO; AHVENNIEMI, 2017). 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 (DU *et al.*, 2014).

Another obstacle that affects the development of BEE projects are the government policies for the sector the underestimate the actual costs of implementing energy efficiency measures, making investors unattractive in this type of building project (ADEYEYE; OSMANI; BROWN, 2007; CURTIUS, 2018).

In other cases, policy and regulatory developers are unaware of energy-efficient technologies (LIU *et al.*, 2015). The lack of knowledge of policymakers is an obstacle that reflects the development of inappropriate legislation and regulations (CHMUTINA; GOODIER; BERGER, 2013).

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 BEE programs (GOODIER; CHMUTIA, 2014).

4.1.6 Cultural/Social/Behavioral Barriers

The main barriers within this group are related to cultural, social and behavioral aspects that are important determinants to delay the successful implementation of BEE technologies. Cultural/Social/Behavioral barriers are listed in Table 14 along with their definitions and references.

Cultural/Social/Behavioral barriers are issues that characterize the behavior of the occupants and their relationship with the consumption of energy (ADDY; ADINYIRA; KORANTENG, 2014; ADEYEYE; OSMANI; BROWN, 2007; BOND, 2011; CHMUTINA; GOODIER; BERGER, 2013; DURDYEV *et al.*, 2018; GUPTA; ANAND; GUPTA, 2017; ZHANG; ZHOU, 2015). These obstacles can arise from the lack of information and education on energy efficiency that prevents occupants from adopting energy-efficient measures (ALANNE; SAARI, 2004; DJOKOTO; DADZIE; OHEMENG, 2014; HOLLOWAY; PARRISH, 2015; HOPKINS, 2016; ODUYEMI; OKOROH; FAJANA, 2017; PALMER *et al.*, 2013). Lack of information leads to uncertainty about the costs and benefits of energy efficiency (BERTONE *et al.*, 2016; CURTIUS, 2018; HOSSEINI *et al.*, 2016; PAIHO; AHVENNIEMI, 2017; TRAVEZAN; HARMSEN; TOLEDO, 2013).

Table 14 - Cultural/Social/Behavioral barriers

Barriers	Definition	References
Lack of knowledge about the BEE technologies	Lack of knowledge by occupants and owners of all the benefits of adopting energy efficient technologies.	[37] Addy; Adinyira; Koranteng (2014); [23] Adeyeye; Osmani; Brown (2007); [19] Alanne; Saari (2004); [50] Amoruso; Donevska; Skomedal (2018); [43] Bertone *et al.* (2016); [63] Bond (2011); [57] Caputo; Pasetti (2017); [35] Chmutina; Goodier; Berger (2013); [65] Curtius (2018); [7] Dadzie *et al.* (2018); [31] Djokoto; Dadzie; Ohemeng (2014); [27] Durdyev *et al.* (2018); [2] Greenough; Tosoratti (2014); [9] Gupta; Anand; Gupta (2017); [58] Holloway; Parrish (2015); [66] Hopkins (2016); [34] Hosseini *et al.* (2016); [62] Huang; Mauerhofer; Geng (2016); [29] Liu *et al.* (2015); [33] Marefat; Toosi; Hasankhanlo (2018); [64] Oduyemi; Okoroh; Fajana (2017); [48] Paiho; Ahvenniemi (2017); [45] Palmer *et al.* (2013); [41] Peterman; Kourula; Levitt (2012); [55] Ruiz (2005); [51] Stevenso; Baborska-Narozny (2018); [21] Travezan; Harmsen; Toledo (2013); [40] Tuominen *et al.* (2012); [22] Wang *et al.* (2016); [46] Zhang; Zhou (2015).
Fear/Resistance to change	Fear/resistance to change by owners and occupants of the buildings.	[60] Alreshidi; Mourshed; Rezgui (2018); [42] Bruce *et al.* (2015); [57] Caputo; Pasetti (2017); [24] Goodier; Chmutia (2014); [66] Hopkins (2016); [34] Hosseini *et al.* (2016); [33] Marefat; Toosi; Hasankhanlo (2018); [64] Oduyemi; Okoroh; Fajana (2017); [55] Ruiz (2005); [13] Zhang *et al.* (2018)
Lack of motivation	Lack of motivation of occupants and owners to promote energy efficiency actions.	[43] Bertone *et al.* (2016); [55] Ruiz (2005); [6] Yeatts *et al.* (2017)
Lack of confidence	Occupants and owners do not trust the incentives promised by the government.	[60] Alreshidi; Mourshed; Rezgui (2018); [35] Chmutina; Goodier; Berger (2013)

Source: The author.

In many situations, occupants find it difficult to obtain sufficient information about relevant energy efficiency options, and even if the information is available, it is often difficult to analyze it (DADZIE *et al.*, 2018; GREENOUGH; TOSORATTI, 2014; LIU *et al.*, 2015; MAREFAT; TOOSI; HASANKHANLO, 2018; TRAVEZAN; HARMSEN; TOLEDO, 2013). Therefore, the lack of information on specific ways to improve the energy efficiency and reduce energy waste is highlighted 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 behavior and continue to use conventional measures (AMORUSO; DONEVSKA; SKOMEDAL, 2018; HUANG; MAUERHOFER; GENG, 2016; RUIZ, 2005; TUOMINEN *et al.*, 2012).

The lack of information about BEE leads occupants to be less susceptible to adopting energy-efficient practices, making them resistant to the behavioral changes needed to save energy (ALRESHIDI; MOURSHED; REZGUI, 2018; HOPKINS, 2016; HOSSEINI *et al.*, 2016; MAREFAT; TOOSI; HASANKHANLO, 2018; ZHANG *et al.*, 2018). 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 pointed out as one of the reasons for not making the necessary improvements (BRUCE *et al.*, 2015; CAPUTO; PASETTI, 2017; RUIZ, 2005). This fear of change slows energy efficiency improvements and lowers customer demand for the BEE projects (GOODIER; CHMUTIA, 2014; ODUYEMI; OKOROH; FAJANA, 2017).

In many situations, occupants are afraid to use available energy efficiency technologies because of another barrier known as a lack of motivation (RUIZ, 2005; YEATTS *et al.*, 2017). Some occupants, while fully aware of the potential of energy-saving technologies, are not motivated to improve the efficiency of their buildings, resulting in the non-used of such technologies (ZHOU; LI; CHIANG, 2013).

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 (ALRESHIDI; MOURSHED; REZGUI, 2018).

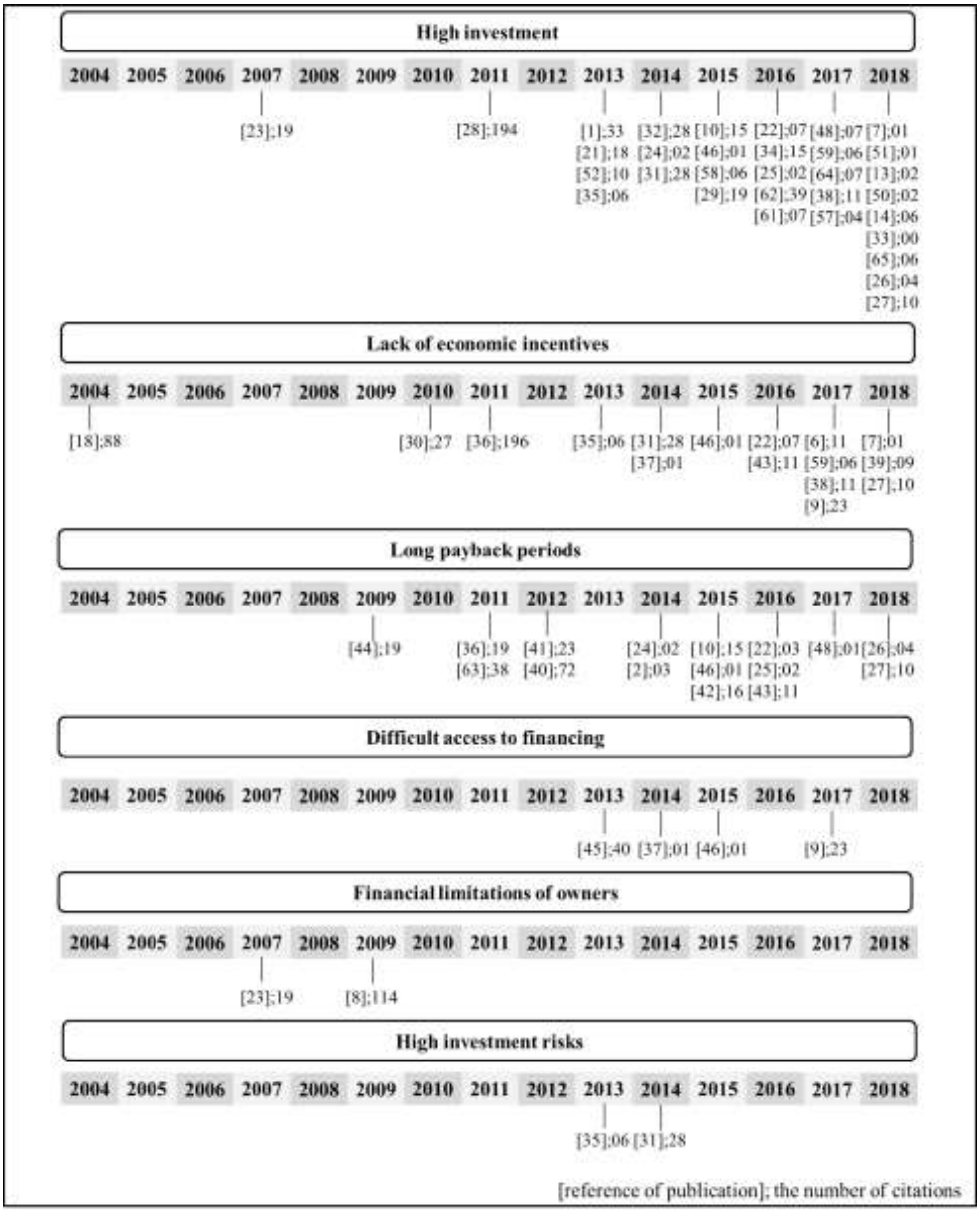
4.2 TEMPORAL DISTRIBUTION OF THE BARRIERS

This section presents a timeline of the appearance of each barrier within each group in order to visualize its chronological track. The publications, as well as its citation, in which each barrier was found are represented along the timeline as follows: [reference of publication]; the number of citations.

4.2.1 Temporal Distribution of the Financial/Economic Barriers

Figure 6 presents the spread of the Financial/Economic barriers in the literature during the period from 2004 to 2018.

Figure 6 - Temporal distribution of Financial/Economic barriers



Source: The author.

It can be seen that “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 that this obstacle has had a great impact on the adoption of BEE technologies in recent years.

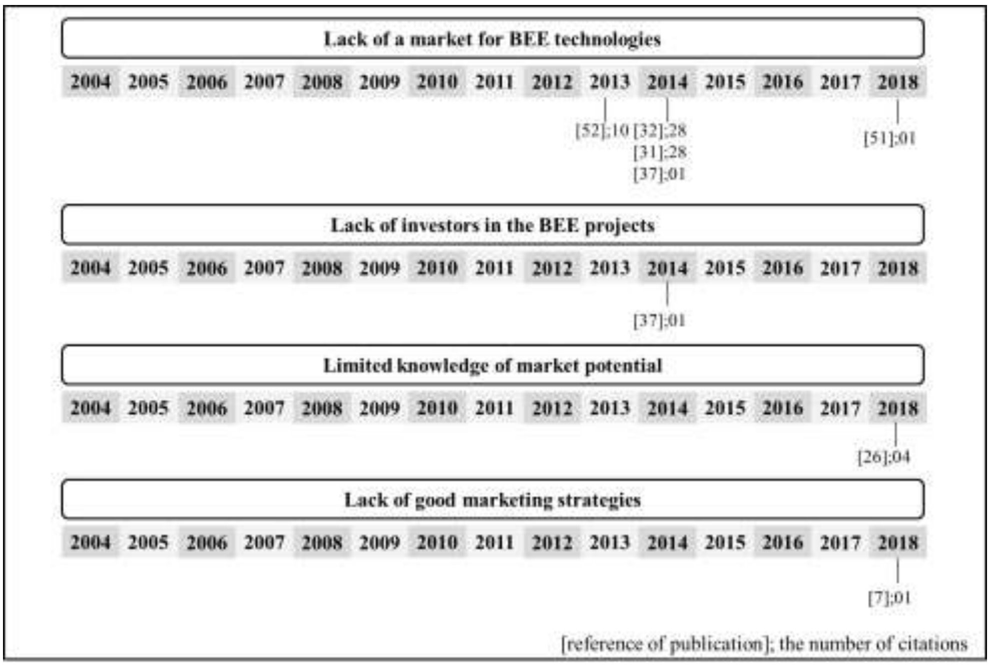
The obstacles "lack of economic incentives" and "long payback periods" appeared in 16 articles each, and were cited for the first time in 2004 and 2009, respectively. Such barriers have had a stable occurrence profile along the time line. The "lack of economic incentives" obstacle was more addressed by articles published in 2017/2018, while the "long payback periods" obstacle in 2015/2016, demonstrating that these barriers have existed for years, but have not yet been overcome.

The barriers "difficult access to financing", "financial limitations of owners", and "high investment risks" appeared sparsely throughout the time line, showing that these barriers can arise in the development of BEE projects, but these are not the obstacles with the greatest impact.

4.2.2 Temporal Distribution of the Market Barriers

Figure 7 presents the spread of the Market barriers in the literature in the period from 2004-2018.

Figure 7 - Temporal distribution of Market barriers



Source: The author.

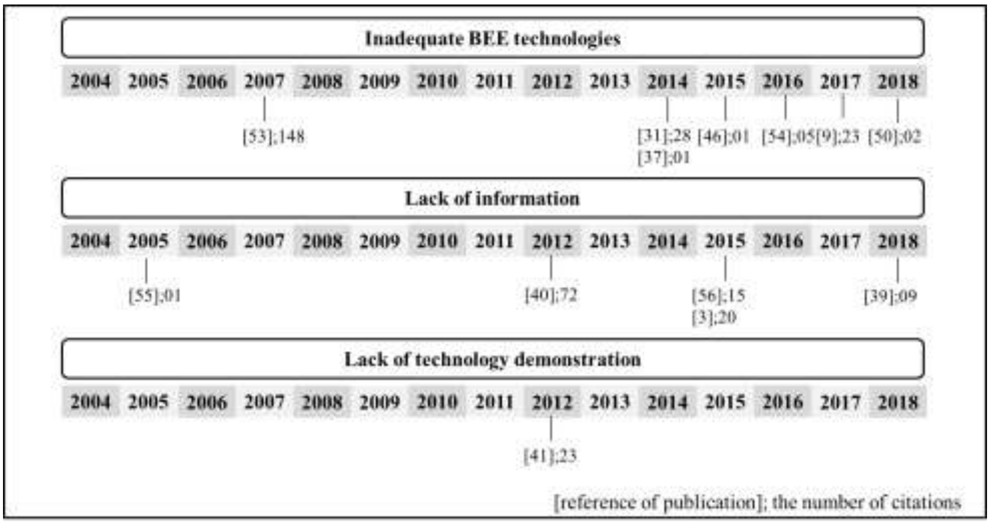
It is possible to infer that the four barriers within this group impact little on the adoption of BEE technologies. The "lack of market for BEE technologies" barrier was studied in five articles, with the highest occurrence in 2014 (three publications).

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

4.2.3 Temporal Distribution of the Technological Barriers

Figure 8 shows the time line for the Technological barriers in the literature over the period from 2004 to 2018.

Figure 8 - Temporal distribution of Technological barriers



Source: The author.

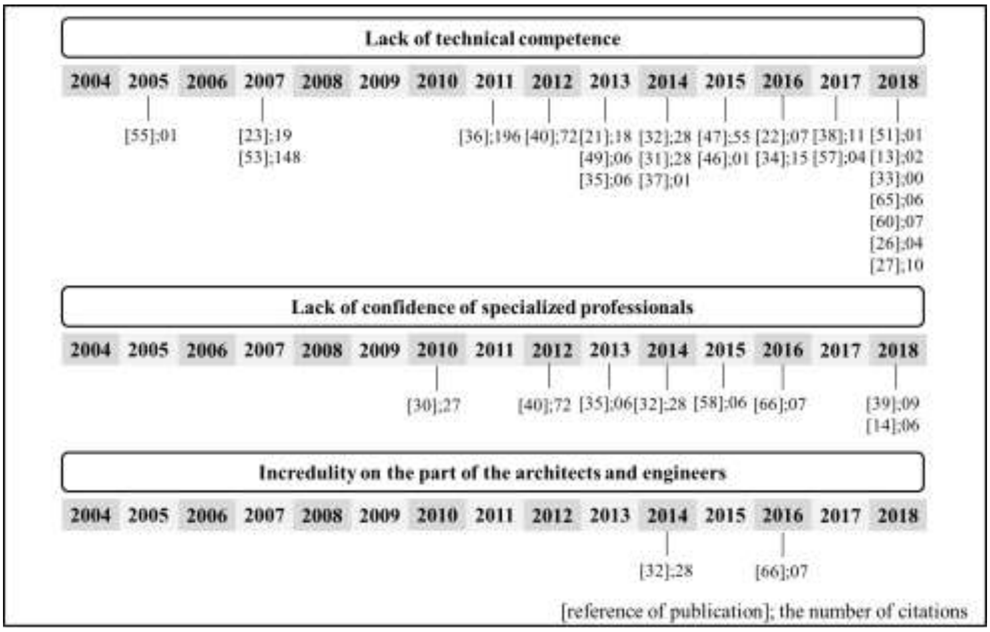
According to Figure 8, the "inadequate BEE technologies" barrier was the most addressed in this group, appearing in seven documents. This obstacle was first mentioned in one article published in 2007. After 2014 the number of publications dealing with this barrier kept stable; this shows that there is a perception that the energy-saving technologies are not entirely appropriate.

The "lack of information" obstacle was reported in five articles with sparse appearances over the period. The "lack of technology demonstration" barrier appeared only once.

4.2.4 Temporal Distribution of the Professional/Technical Barriers

Figure 9 presents a time line for the Professional/Technical barriers in the literature over the period from 2004 to 2018.

Figure 9 - Temporal distribution of Professional/Technical barriers



Source: The author

It can be seen that “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.

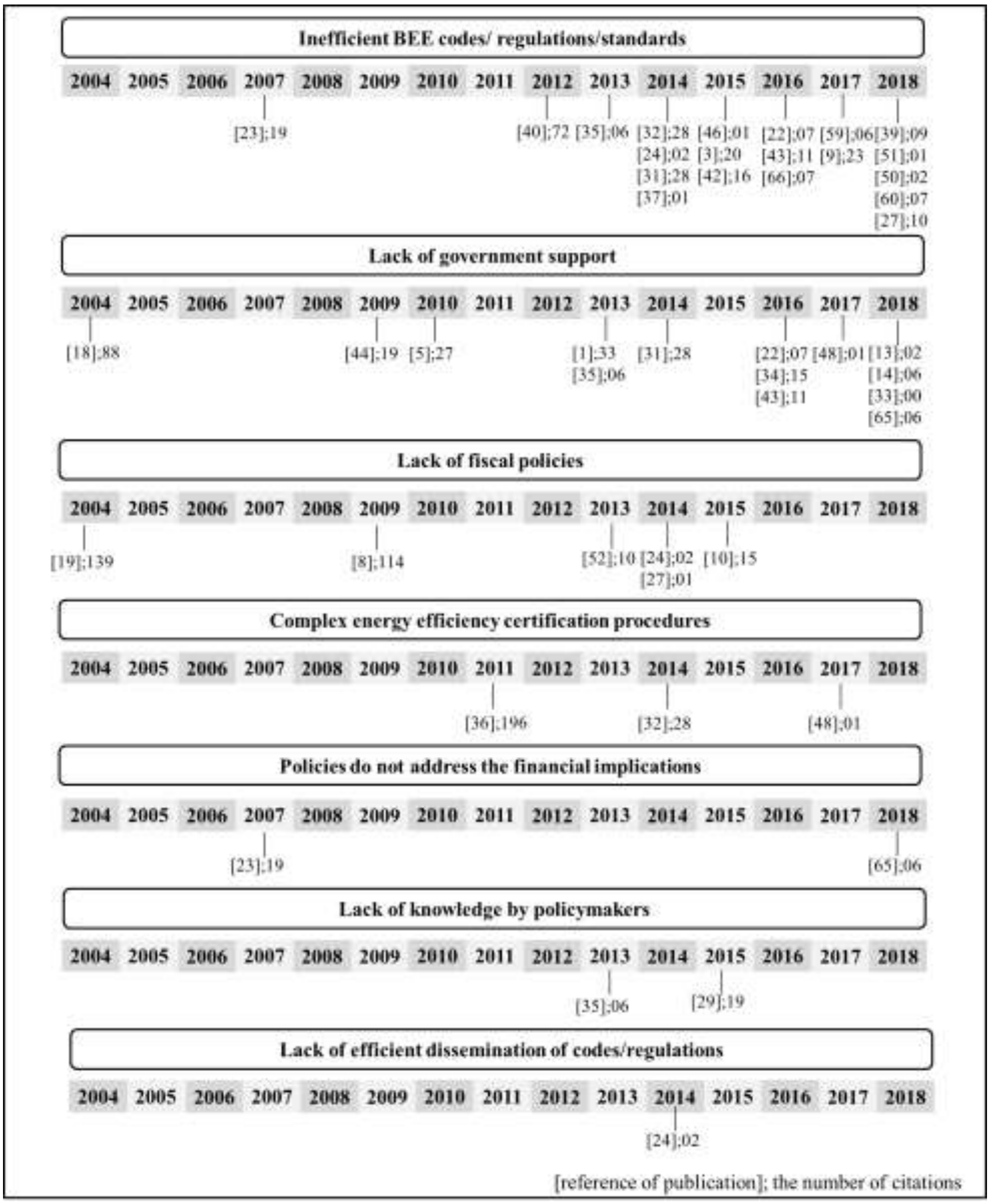
The "lack of confidence of specialized professional" obstacle appeared in 8 articles, being cited for the first time in 2010 and presented a stable occurrence profile in the following years.

The "incredulity on the part of the architects and engineers" barrier appeared sparse over the period depicted in the time line. This obstacle was addressed in only two articles, which shows that such a barrier is a few impacting on the adoption of the BEE measures.

4.2.5 Temporal Distribution of the Governmental/Political/Regulatory Barriers

The time line of the publications that addressed the Government/Political/Regulatory barriers are presented in Figure 10.

Figure 10 - Temporal distribution of Government/Political/Regulatory barriers



Source: The author

According to Figure 10, 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 realize that these issues still hinder the use of technologies for rationalizing energy consumption.

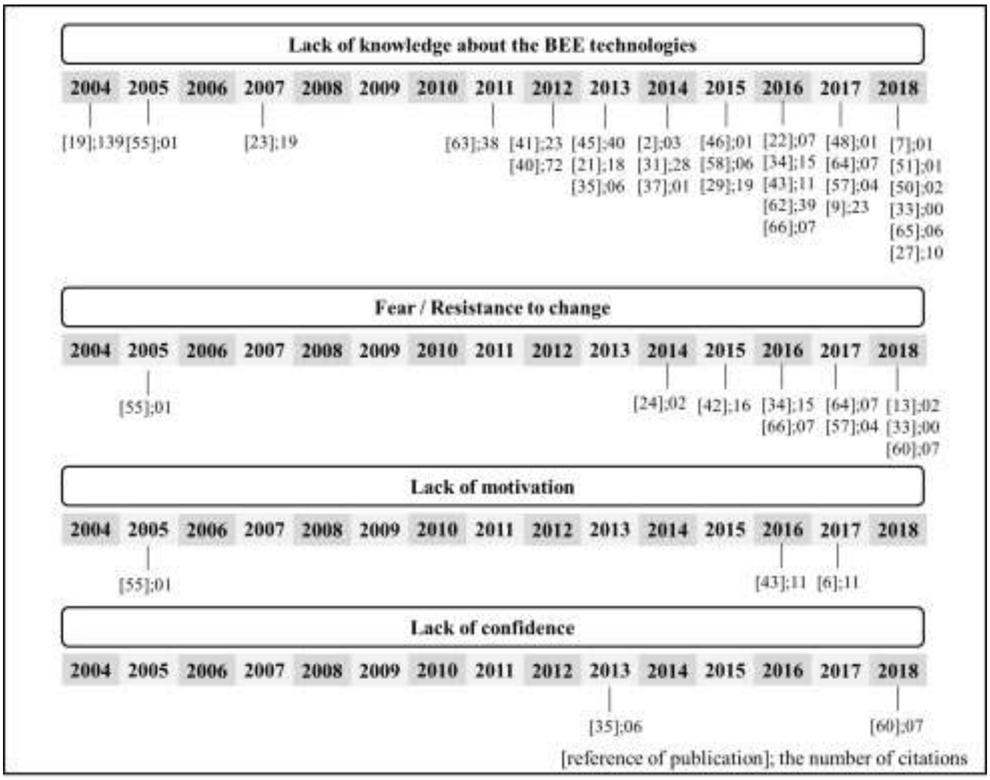
The "lack of government support" barrier appeared in 14 publications. Although this obstacle appeared sparsely over the period presented in the time line, it was most frequently cited in 2016 (three articles) and in 2018 (four articles).

The other obstacles, "lack of fiscal policies" (six papers), "complex energy efficiency certification procedures" (three papers), "policies do not address the financial implications" (two papers), "lack of knowledge by policymakers" (two papers), and "lack of efficient 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 the BEE project technologies.

4.2.6 Temporal Distribution of the Cultural/Social/Behavioral Barriers

The time line for the publications that addressed the Cultural/Social/Behavioral barriers and their respective number of citations is presented in Figure 11.

Figure 11 - Temporal distribution of Cultural/Social/Behavioral barriers



Source: The author

It can be seen that a “lack of awareness about the 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 awareness about the BEE technologies has greatly impacted the adoption of energy-efficient measures mainly from the year 2011. 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.

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 the BEE projects.

4.3 THE BARRIERS ASSOCIATION WITH TYPES OF BUILDING AND GEOGRAPHICAL REGIONS

By scanning the titles of the 58 articles that sourced the obstacles previously presented, it was possible to gather further information beyond the barriers. For example, the title “Assessing drivers and barriers of energy-saving measures in Oklahoma’s public schools” (CASTLEBERRY; GLIEDT; GREENE, 2016), beyond the term barriers, it mentions “public schools” which can put into the category, let us say, type of building focused on; and the term “Oklahoma” refer to the geographical region where the study was carried out. Proceeding in the same way for all the 58 titles it was possible to pick up 26 terms which were clustered into 9 sub-categories, which were eventually summarized into 2 categories as shown in Table 15.

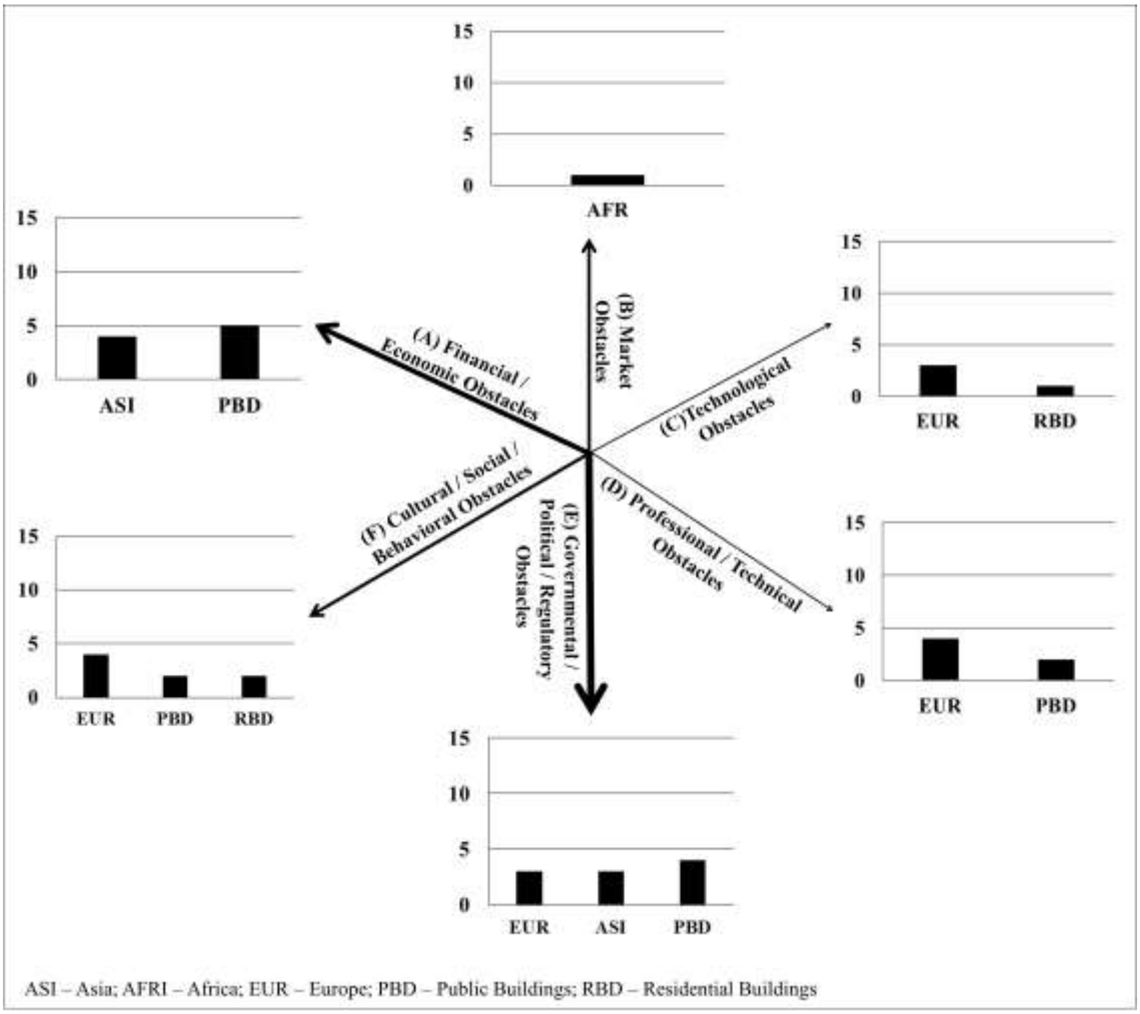
Table 15 - Sub-categories and categories extracted from the title

TITLE WORDS	SUB-CATEGORIES	CATEGORIES
Ghana; Ghanaian	Africa	GEO (Geographical Region)
Japan; Cambodia; China	Asia	
Sweden; Berlin; UK; European Union; Italy; England	Europe	
United States	North America	
Australia; South Australia; New Zealand	Oceania	
Office Buildings	Office Building	TOB (Types of building)
Public Buildings; Public Hospitals; Public Schools; Hellenic Buildings; Healthcare	Public Building	
Residential Buildings; Residential Built; Home; Home Energy	Residential Building	
Rural Buildings	Rural Building	

Source: The author.

The category GEO groups every reference to a country, a city, and a continent. Office buildings, rural buildings, etc. were clustered into types of building. Figure 12 summarizes Table 15.

Figure 12 - Groups of barriers and their association with geographical regions, and types of building



Source: The author

In the center of Figure 12, one sees six arrows representing the six groups of obstacles. 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 two different numerical information: 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 Figure 12 one sees that the most frequent region is Europe (EUR), followed closely by Asia (ASI) and Africa (AFR); public buildings (PBD) and residential buildings (RBD), respectively, are the most cited types of building together with the groups of barriers.

In order to make more detailed analyses, the next step was to count the number of times that each of the two categories (GEO, TOB) and each group of barriers appeared simultaneously, see Table 16.

Table 16 - Count of the number of times each of the two categories (GEO, TOB) and each group of barriers appeared simultaneously

CATEGORIES		GROUPS OF BARRIERS					
		A	B	C	D	E	F
GEOGRAPHICAL REGIONS	AFR	2 (0.04)	1 (0.13)	2 (0.15)	2 (0.07)	2 (0.06)	2 (0.06)
	ASI	4 (0.08)	0 (0.00)	0 (0.00)	1 (0.03)	3 (0.08)	3 (0.09)
	EUR	3 (0.06)	0 (0.00)	3 (0.23)	4 (0.14)	3 (0.08)	4 (0.11)
	OCE	2 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	2 (0.06)
	AME	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)
	N	37 (0.77)	7 (0.88)	8 (0.62)	22 (0.76)	26 (0.72)	23 (0.66)
	TOTAL	48	8	13	29	36	35
TYPES OF BUILDING	OBD	1 (0.02)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)
	PBD	5 (0.10)	0 (0.00)	0 (0.00)	2 (0.07)	4 (0.11)	2 (0.06)
	RBD	4 (0.08)	0 (0.00)	1 (0.08)	0 (0.00)	3 (0.08)	2 (0.06)
	RuBD	1 (0.02)	0 (0.00)	0 (0.00)	1 (0.03)	1 (0.03)	1 (0.03)
	N	37 (0.77)	8 (1.00)	12 (0.92)	26 (0.90)	27 (0.75)	29 (0.83)
	TOTAL	48	8	13	29	36	35

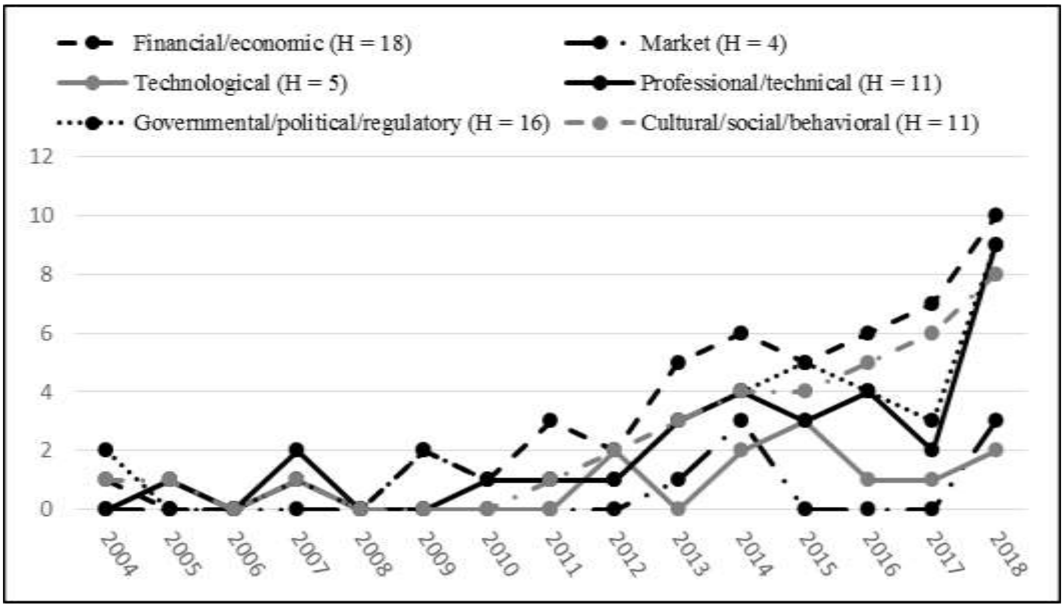
Source: The author

The rows of Table 16 share the groups GEO and TOB, while the columns are the groups of barriers, described in Figure 12. The total lines present the number of articles out of the 58 from which the barriers were gathered. For example, the group of barriers D (Professional/Technical barriers) appeared in 29 articles. Out of these articles, two mention AFR, one ASI, and EUR. None of them mentions neither OCE nor AME; and 22 do not mention any geographical region. In the same way, considering the group of barriers D, one can see that 26 articles do not mention any TOB, two are related to PBD and just one to RuBD. The numbers in brackets are the percentages taking into account the totals.

Table 16 is useful to evaluate the association between and the groups of barriers. The geographical regions are associated with each of the groups of barriers as well as between types of building and the groups of barriers. It can be seen that the association between the barriers and geographical regions, and between the barriers and types of buildings are weak, which shows that the outgrowth of barriers to the adoption of energy-saving technologies is independent of region and types of building.

The Figure 13 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.

Figure 13 - Count of the number of times each of the two categories (GEO, TOB) and each group of barriers appeared simultaneously



Source: The author

It is evident that Financial/Economic barriers have a major impact on the adoption of energy-efficient construction technologies, as it has 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 it has the second greatest h-index. This group of barriers experienced a highlight 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/Behavioral groups share the third rank of importance. The further 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, yet it is impossible to know whether the large number of publications in 2018 signalize an upward trend or it is just incidental.

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

5 QUANTITATIVE RESEARCH

A structured questionnaire (Figure 14) was designed to capture Brazilian experts' perceptions of the relevance of the barriers to the adoption of BEE technologies, found in the literature, for Brazil.

Figure 14 – Questionnaire (Google Forms)

(to be continued)

Energy-Efficient Technologies

Electricity consumption has been steadily increasing over the years, worrying the government about the scarcity of primary energy resources, leading to the search for alternative sources of energy. Nowadays, the public, commercial and residential buildings are responsible for 36% of total energy consumption and 40% of total greenhouse gas emissions. Therefore, it is necessary to reduce the consumption of electricity. However, such a reduction must be made without decreasing the building occupant's welfare. This aim can be achieved by the adoption of energy-efficient technologies in the building sector. Although there are consolidated technology options in the market, their adoption is still timid. Recent research listed the following items as the main obstacles to the adoption of energy-efficient technologies in buildings.

Indicate, according to your perception, the relevance to the Brazilian reality, of each of the barriers below, on the scales from 0 (not important) to 10 (very important).

Implementation of energy-efficient technologies requires high capital investiments

0 1 2 3 4 5 6 7 8 9 10

Lack of confidence, by owners and occupants, on the information disseminated by the government and/or market concerned with the building energy-efficient technologies

0 1 2 3 4 5 6 7 8 9 10

Lack of a market for building energy-efficient technologies

0 1 2 3 4 5 6 7 8 9 10

Ineffective building energy efficiency codes/regulations/standards

0 1 2 3 4 5 6 7 8 9 10

Lack of confidence of the specialized professionals, in the results claimed by energy-efficient technologies

0 1 2 3 4 5 6 7 8 9 10

Lack of subsidies or other policy interventions that reduces energy prices

0 1 2 3 4 5 6 7 8 9 10

Limited knowledge of market potential

0 1 2 3 4 5 6 7 8 9 10

Figure 14 – Questionnaire (Google Forms)

(to be continued)

Lack of technology demonstration

0 1 2 3 4 5 6 7 8 9 10

Complex energy efficiency certification procedures

0 1 2 3 4 5 6 7 8 9 10

Inadequate building energy-efficient technologies for Brazilian reality

0 1 2 3 4 5 6 7 8 9 10

Long payback periods

0 1 2 3 4 5 6 7 8 9 10

Difficult access to financing building energy-efficient projects

0 1 2 3 4 5 6 7 8 9 10

Lack of knowlegde on the benefits associated with building energy efficiency by owners and occupants

0 1 2 3 4 5 6 7 8 9 10

High investment risks

0 1 2 3 4 5 6 7 8 9 10

Lack of technical competence

0 1 2 3 4 5 6 7 8 9 10

Lack of government support

0 1 2 3 4 5 6 7 8 9 10

Lack of investors in building energy-efficient projects

0 1 2 3 4 5 6 7 8 9 10

Policies do not address the financial implications

0 1 2 3 4 5 6 7 8 9 10

Fear/Resistance to change by the owners and occupants

0 1 2 3 4 5 6 7 8 9 10

Lack of economic incentives

0 1 2 3 4 5 6 7 8 9 10

Lack of information on technologies available in the Brazilian market

0 1 2 3 4 5 6 7 8 9 10

Figure 14 – Questionnaire (Google Forms)

(conclusion)

Lack of motivation of owners and occupants to develop building energy-efficient actions

0 1 2 3 4 5 6 7 8 9 10

Lack of efficient dissemination of codes/regulations/policies, by the government, concerned with building energy efficient

0 1 2 3 4 5 6 7 8 9 10

Financial limitation of the owners

0 1 2 3 4 5 6 7 8 9 10

Lack of good marketing strategies to promote the building energy-efficient technologies

0 1 2 3 4 5 6 7 8 9 10

Incredulity on the part of the architects and engineers

0 1 2 3 4 5 6 7 8 9 10

Lack of knowledge on energy efficiency by legislators and regulators

0 1 2 3 4 5 6 7 8 9 10

Is there another barrier that you would like to add to the above list?

What is your academic education?

- ☐ Architecture
- ☐ Civil Engineering
- ☐ Electrical/ Electronics Engineering
- ☐ Mechanical Engineering
- ☐ Certificate Programs
- ☐ Other:__________

What type of company do you work for?

- ☐ Architecture/Engineering Office
- ☐ Construction Company
- ☐ Engineering Department
- ☐ Government
- ☐ Research Center
- ☐ University
- ☐ INMETRO Accredited Organization
- ☐ Other:__________

When was the last time you read or studied about building energy efficiency?

- ☐ Less than 6 months
- ☐ From 6 months to 1 year
- ☐ From 1 year to 5 years
- ☐ Greater than 5 yerars

You have gained your knowledge of building energy efficiency by means of:

- ☐ Conferences
- ☐ Trainning Programs
- ☐ Technical Journals
- ☐ Magazines
- ☐ Books
- ☐ Internet
- ☐ During the school
- ☐ Other:__________

Source: The author,

The questionnaire designed for this research is firstly composed of an introductory text that contextualizes the theme to the respondents. Followed by 27 questions that were intended to assess the importance of each of the 27 barriers, found out in the literature, in the Brazilian situation. Afterward, there are four more questions designed to characterize the respondents. It is worth mentioning that the final wording of the questions was reached after a pretest. A group of 20 respondents was selected for interviews. After each interview, the questions were modified until they reach their final writing as presented in Figure 14.

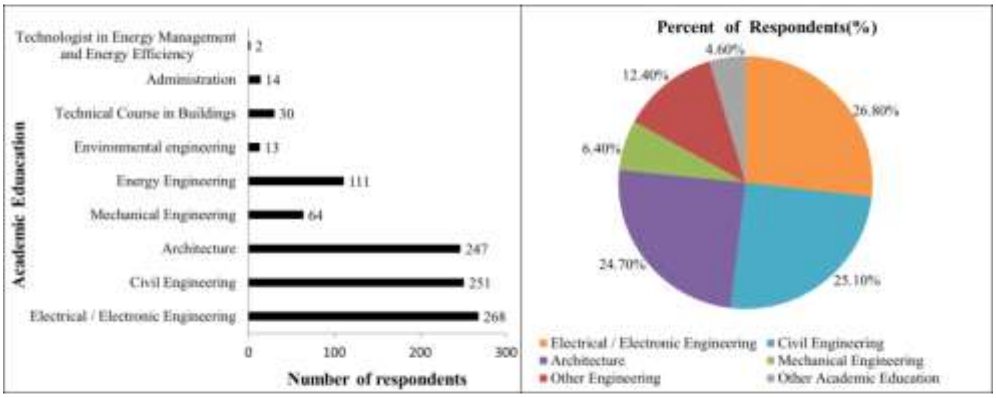
5.1 DATA COLLECTION

The sample of the respondents was selected from a population of professionals with academic education in architecture, civil engineering, electric/electronic engineering, and mechanical engineering subscribed to the LinkedIn social network.

The questionnaire was available on Google Forms from December 2019 to May 2020. During this period, the questionnaire link was sent to 3,506 professionals by means of the LinkedIn message tool, 1,236 were returned, and 1,000 were considered valid, leading to a net response rate of 28.5%.

Figure 15 shows the education profile of the respondents. More than 75% of the respondents have a degree in Electrical/Electronic or Civil Engineering, or Architecture.

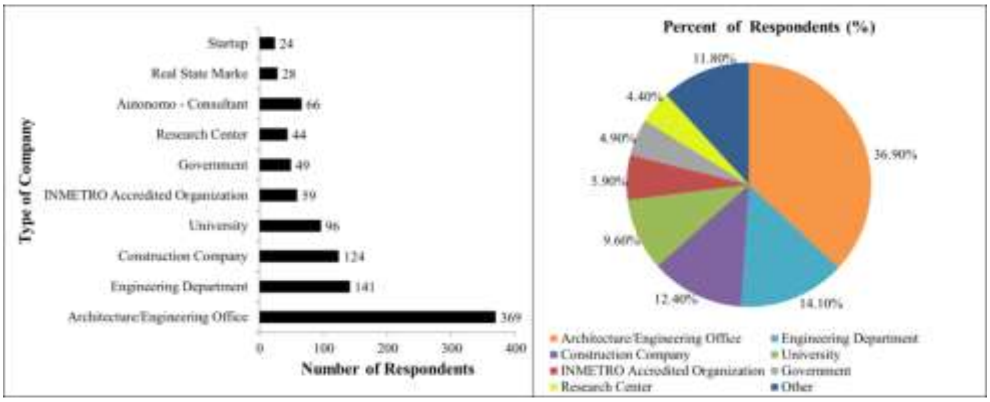
Figure 15 - Academic education of the survey respondents



Source: The author.

About 63.5% of respondents work in companies that deal, directly or indirectly, with BEE, as illustrated in Figure 16.

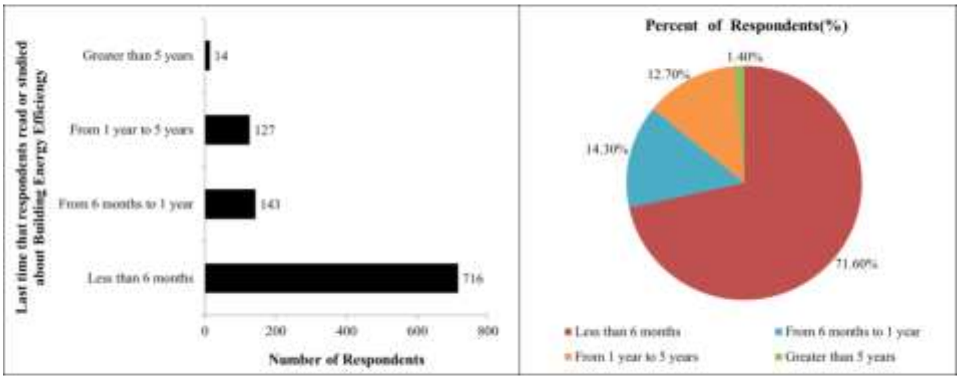
Figure 16 – Occupation profile of the survey respondents



Source: The author

According to Figure 17, the respondents are updated with the subject, since 71.6% of the respondents were involved in knowledge acquisition activities within the last six months.

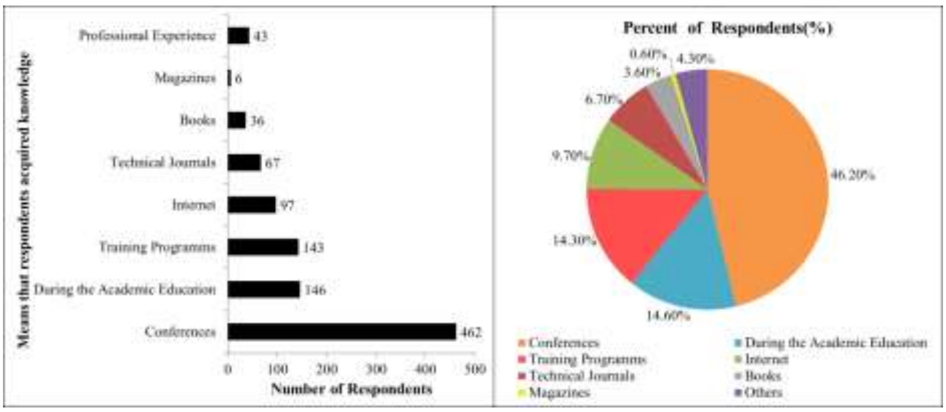
Figure 17 - Distribution of the survey respondents according to the last time they were involved information acquirement on BEE.



Source: The author

Conferences are the main source of acquiring knowledge in BEE, followed by formal academic education and training programs as can be seen in Figure 18.

Figure 18 – Knowledge source used by the respondents



Source: The author

5.2 THE PERCEPTION OF THE IMPORTANCE OF THE 27 BARRIERS ACCORDING TO THE BRAZILIAN EXPERTS

The respondents, by means of an eleven-point scale, assessed the importance of the 27 barriers, found out in the literature, Table 17. The respondents indicated the relevance of each barrier, from 0 to 10, (not important – very important).

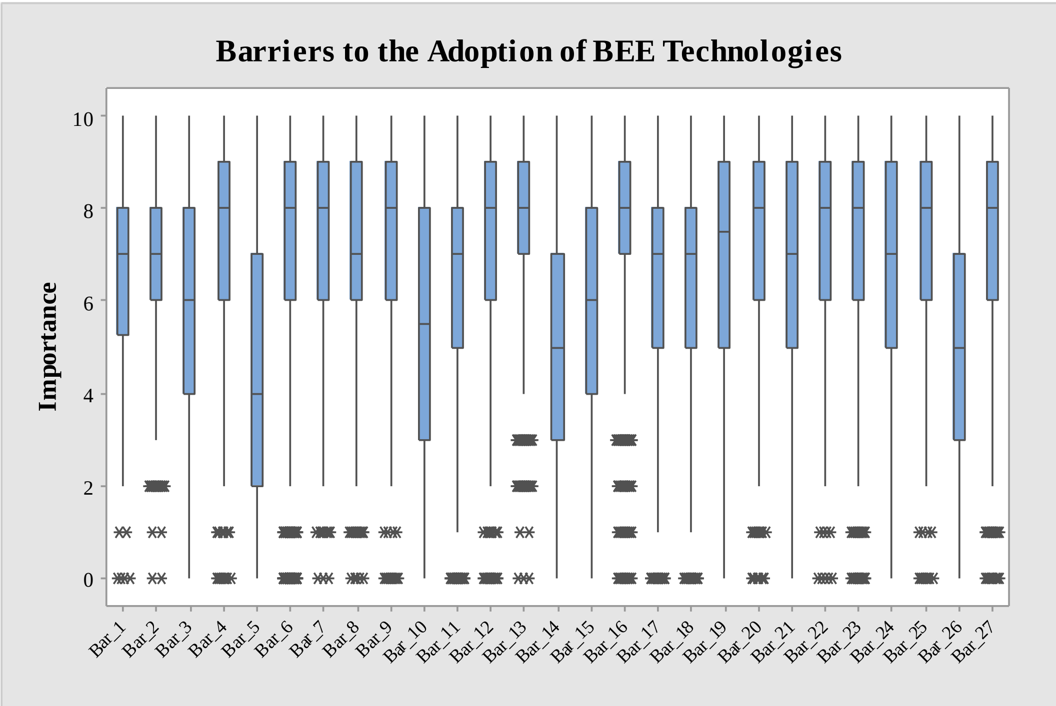
Table 17 – Variables

Variable's code	Barrier's name represented by the variable
Bar_01	High investment
Bar_02	Lack of confidence
Bar_03	Lack of a market for BEE technologies
Bar_04	Ineffective BEE codes/ regulations /standards
Bar_05	Lack of confidence of the specialized professional
Bar_06	Lack of fiscal policies
Bar_07	Limited knowledge of market potential
Bar_08	Lack of technology demonstration
Bar_09	Complex energy efficiency certification procedures
Bar_10	Inadequate BEE technologies
Bar_11	Long payback periods
Bar_12	Difficult access to financing
Bar_13	Lack of knowledge about the BEE technologies
Bar_14	High investment risks
Bar_15	Lack of technical competence
Bar_16	Lack of government support
Bar_17	Lack of investors in the BEE projects
Bar_18	Policies do not address the financial implications
Bar_19	Fear/Resistance to change
Bar_20	Lack of economic incentives
Bar_21	Lack of information
Bar_22	Lack of motivation
Bar_23	Lack of efficient dissemination of codes/regulations
Bar_24	Financial limitations of the owners
Bar_25	Lack of good marketing strategies
Bar_26	Incredulity on the part of the architects and engineers
Bar_27	Lack of knowledge by policymakers

Source: The author.

Figure 19 shows the distributions of the responses for each barrier.

Figure 19 – Distribution of the responses for each barrier



Source: The author.

The following points are remarkable:

- Some of the barriers have an importance profile quite similar Bar_4, Bar_6, Bar_7, Bar_9, Bar_12, Bar_20, Bar_22, Bar_23, Bar_25, and Bar_27);
- The vast majority of the barriers were considered relevant according to the experts, since most of the distributions (14 out of the 27 barriers) showed that 75% of the grades assigned by the respondents are higher than six;
- The barriers whose distributions showed more than 50% of the grades assigned lower than six were considered less importance barriers: Bar_5, Bar_10, Bar_14, Bar_15, and Bar_26. It is worth noticing the large variability in the assessment of such barriers.
- Three of the barriers present the lowest interquartile range (Bar_2, Bar_13, and Bar_16) higher than six meaning that there were few doubts about the degree of relevance of such barriers.

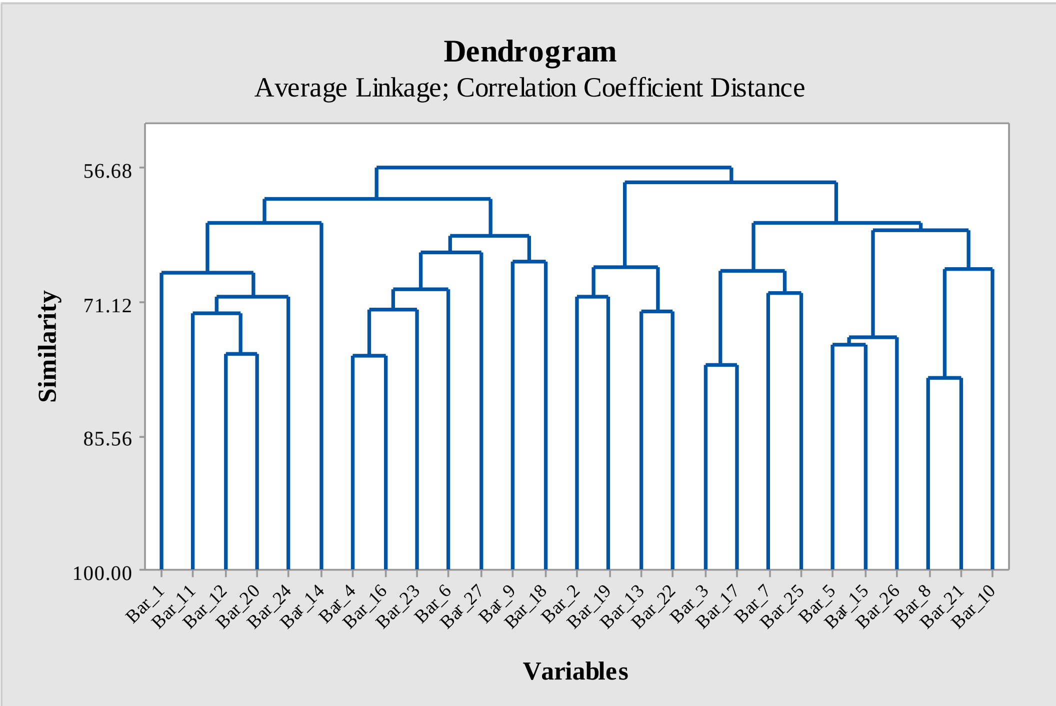
Before proceeding with the analysis it is interesting to investigate the correlation between the barriers. If the barriers are not correlated with one another, the analysis cannot go beyond the descriptive statistics presented; otherwise, a wide range of possibilities is open.

The Pearson's coefficient correlation matrix, or simply correlation matrix, is presented in Appendix B and the Bartlett's test for sphericity is shown in Appendix C, which shows whether the correlation matrix is statistically different from the identity matrix. In other words, whether the correlations in the matrix are statistically significant. Thus, the correlation matrix concerned with the scores assigned to each barrier by the respondents is significantly different from the identity matrix. Roughly speaking, that means that the variables can be summarized in underlying factors, by two methods: variable clustering analysis and factor analysis.

5.3 VARIABLE CLUSTERING ANALYSIS

Since the importance assigned to each barrier by the respondents are significantly correlated (see Appendix C), the correlation matrix can be used as a similarity measure and submitted to a hierarchical clustering algorithm. Doing that, the resultant clustering tree is shown in Figure 20.

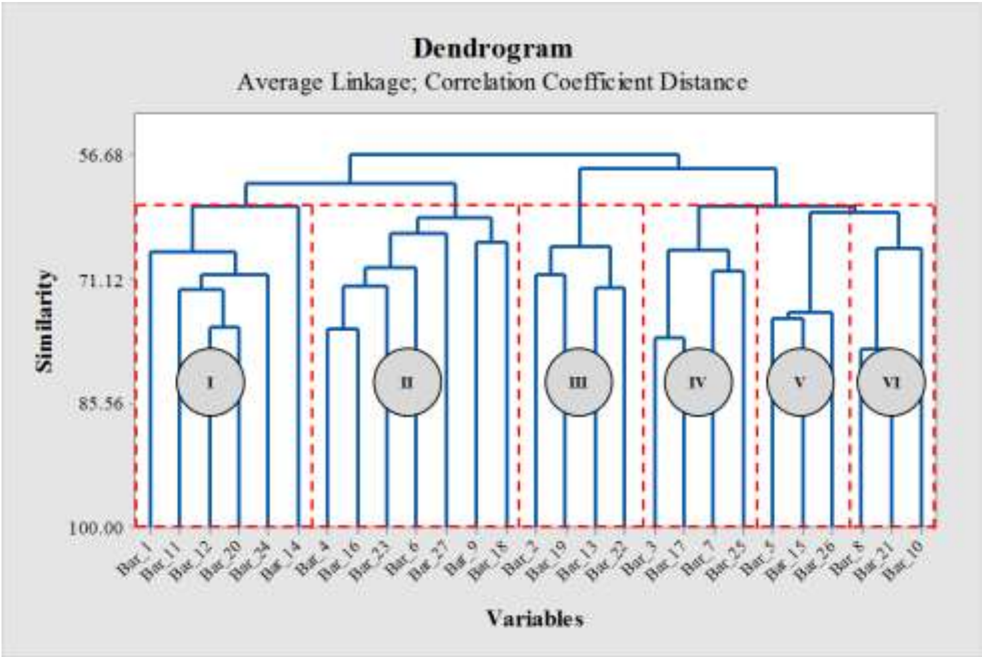
Figure 20 – Clustering tree



Source: The author.

Figure 20 shows a clustering tree of the 27 barriers that hinder the adoption of BEE technologies, where it is easy to identify six groups of barriers, as can be seen in Figure 21.

Figure 21 - Groups formed in clustering analysis



Source: The author

It is important to notice that the clusters seen in Figure 21 are the same as those defined in the proposed taxonomy (Chapter 4) shown in Table 18.

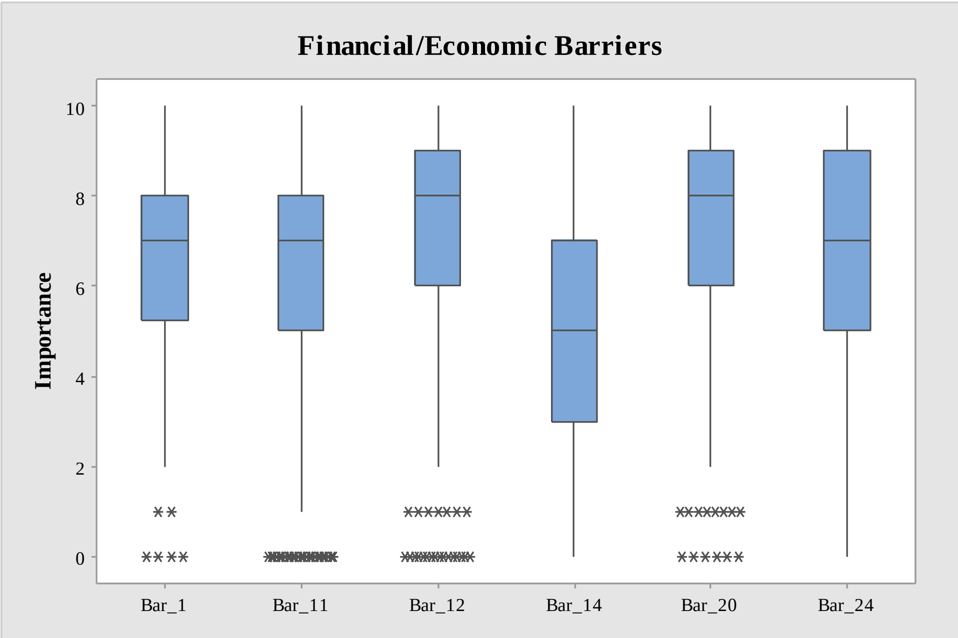
Table 18 – Categorization of the barriers according to their importance

Cluster number	Cluster Name	Variable code	Name of barriers represented by the variable
I	Financial/ economic barriers	Bar_11	Long payback periods
		Bar_01	High investment
		Bar_12	Difficult access to financing
		Bar_24	Financial limitations of the owners
		Bar_14	High Investment risks
		Bar_20	Lack of economic incentives
II	Government/ political/ regulatory barriers	Bar_04	Ineffective BEE codes/regulations/standards
		Bar_16	Lack of government support
		Bar_23	Lack of efficient dissemination of codes/regulations
		Bar_06	Lack of fiscal policies
		Bar_27	Lack of knowledge by policymakers
		Bar_09	Complex energy efficiency certification procedures
		Bar_18	Policies do not address the financial implications
III	Cultural/social/ behavioral barriers	Bar_02	Lack of confidence
		Bar_19	Fear/Resistance to change
		Bar_13	Lack of knowledge about the BEE technlogies
		Bar_22	Lack of motivation
IV	Market barriers	Bar_03	Lack of a market for BEE technologies
		Bar_17	Lack of investors in the BEE projects
		Bar_07	Limited knowledge of market potential
		Bar_25	Lack of good marketing strategies
V	Professional/ technical barriers	Bar_05	Lack of confidence of the specialized professional
		Bar_15	Lack of technical competence
		Bar_26	Incredulity on the part of the architects and engineers
VI	Technological barriers	Bar_08	Lack of technology demonstration
		Bar_21	Lack of information
		Bar_10	Inadequate BEE technologies

Source: The author

The barriers concerned with Financial and Economic affairs form the Cluster I. It is possible to infer from the distributions that the most important barriers in this group are Bar_12 (“difficult access to financing BEE projects”) and Bar_20 (“lack of economic incentives”), since 75% of the grades assigned to them by the experts is higher than six. In the opposite way is Bar_14 (“high investment risks”) as can be seen in Figure 22.

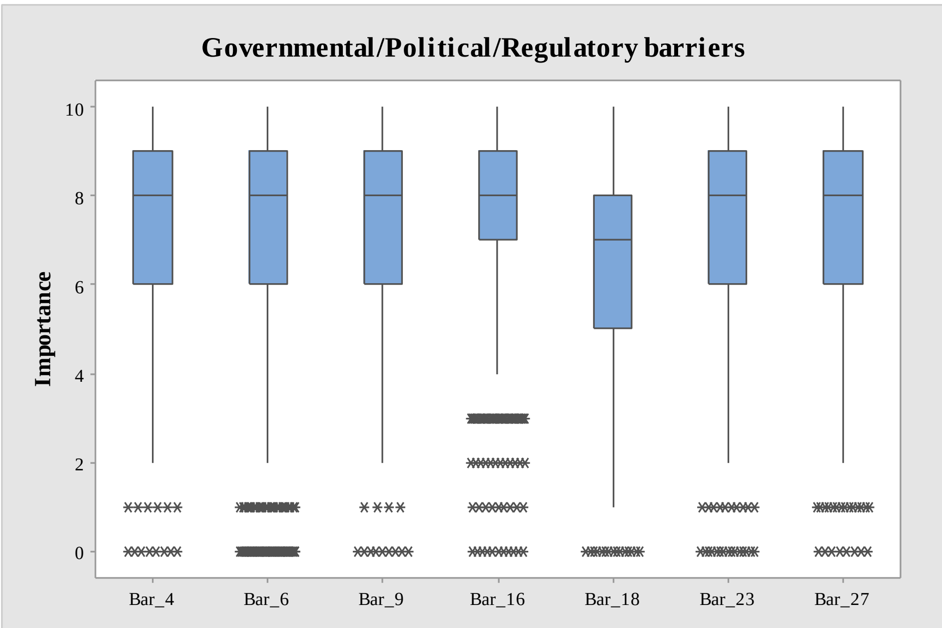
Figure 22 – Cluster I



Source: The author

The Cluster II gather the barriers related to the category named Governmental/Political/Regulatory (Figure 23). It can be considered that the respondents attach to this group great importance assessing nearly equally all the barriers, notice that the five out of the seven barriers have nearly the same distribution. While Bar_16 (“lack of government support”) seems to be the most important, Bar_18 (“policies do not address the financial implications”) is slightly less important than the others.

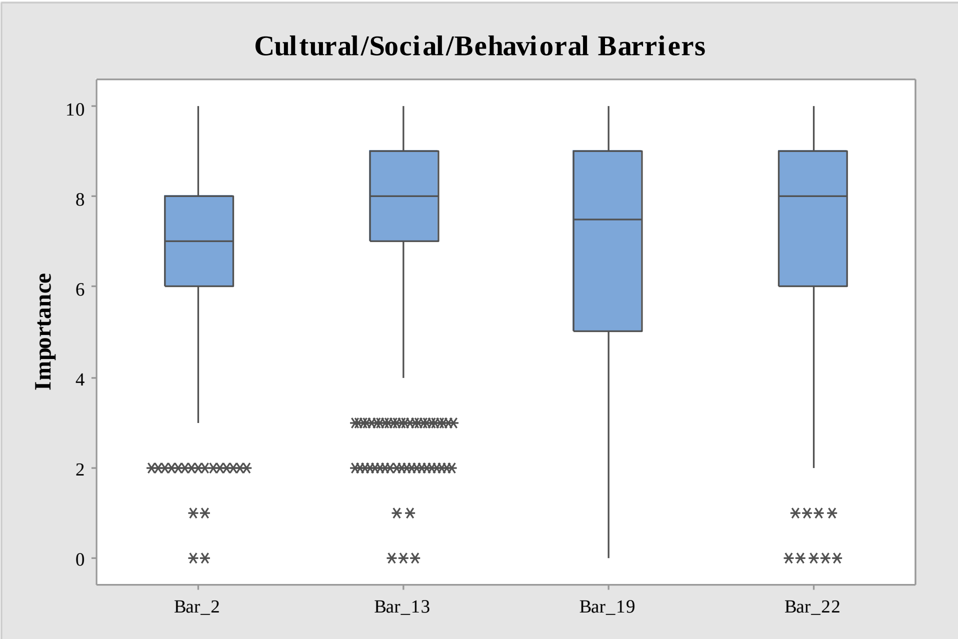
Figure 23 – Cluster II



Source: The author

Cluster III groups the barriers concerned with Cultural, Social, and Behavioral aspects. The respondents attached great importance to this group since nearly 75% of them assigned a score greater than six to the importance of such barriers. Bar_13 (“lack of knowledge about the BEE technlogies”), seems to be the most important within this group since 75% of the respondents assigned seven to their relevance (Figure 24).

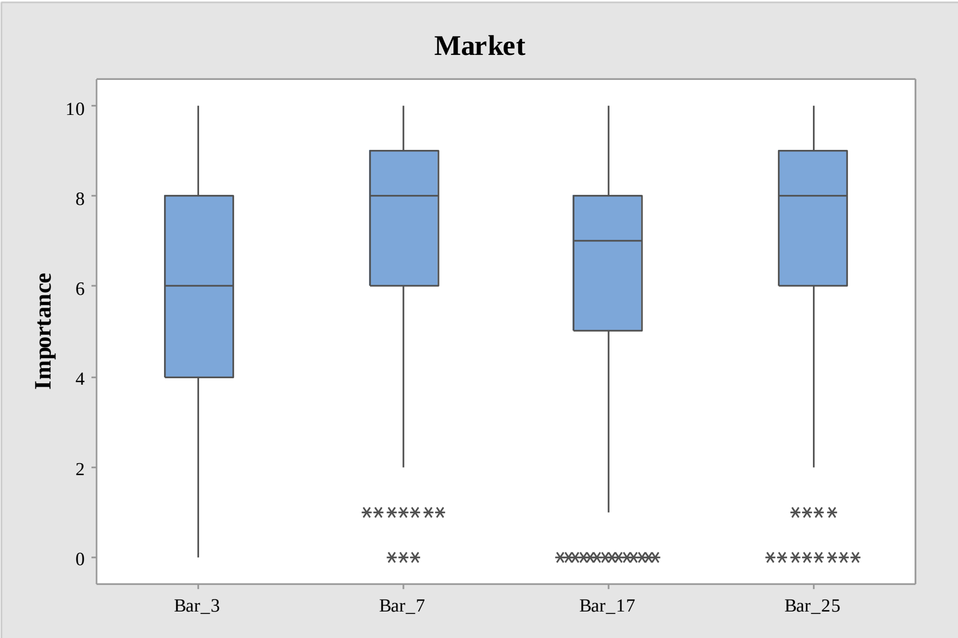
Figure 24 – Cluster III



Source: The author

Figure 25 shows the Cluster IV, that get together the barriers associated with Market issues. The most important barriers within this group are Bar_7 (“limited knowledge of market potential”) and Bar_25 (“lack of good marketing strategies”).

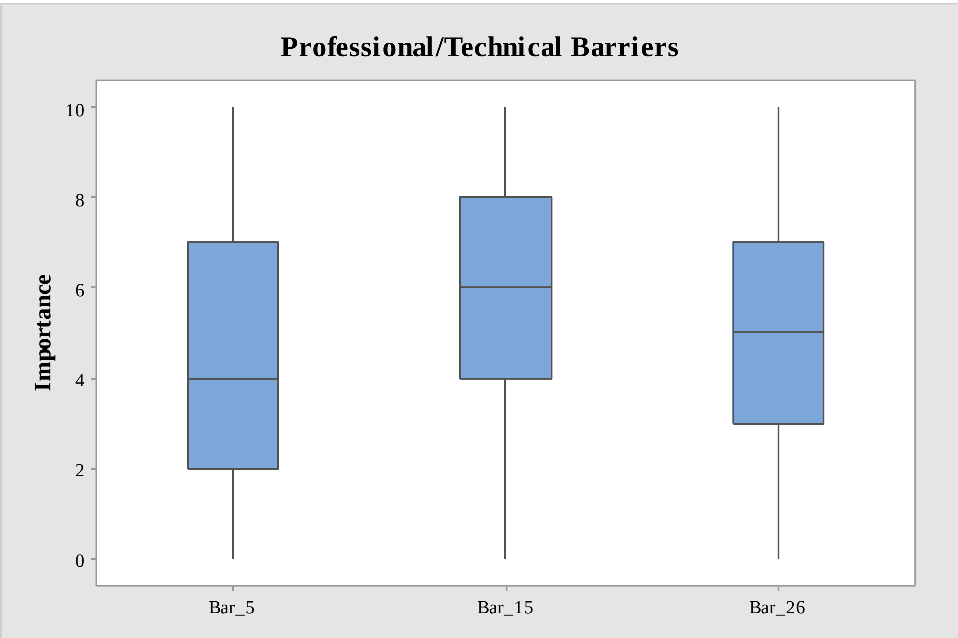
Figure 25 – Cluster IV



Source: The author

The Cluster V gather the three barriers related to Professional and Technical aspects (Figure 26). Such group was considered the less important according to the perception of the experts based on the same criterion used above.

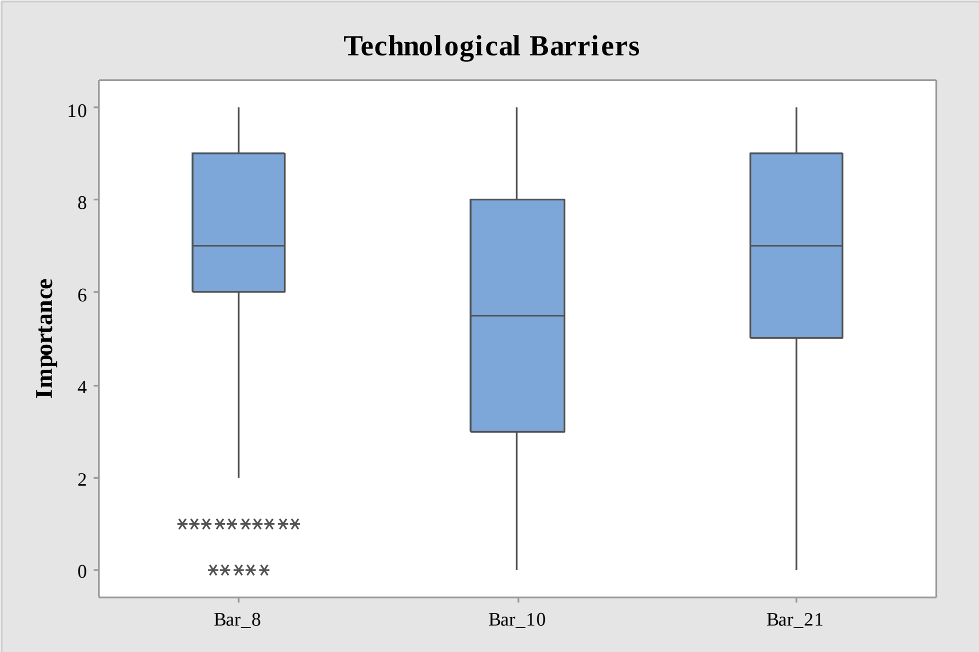
Figure 26 – Cluster V



Source: The author

Three barriers concerned with Technology (Figure 27) form the Cluster VI. According to the respondents, Bar-10 (“inadequate BEE technologies for the Brazilian scenario”) is the less relevant barrier within the group and one of the less important considering all barriers.

Figure 27 – Cluster VI



Source: The author

Although the results from the clustering analysis ratified the taxonomy proposed in Chapter 4, it was not possible to sort these groups by importance, since this is not one the characteristics of the clustering algorithms. However, once the correlation between the barriers is statistically significant, the correlation matrix is suitable to factor analysis.

5.4 FACTOR ANALYSIS (FA)

The essential motivation of Factor Analysis is to describe the correlation relationships among several variables in terms of a few underlying, but not observable, quantities called factors, underlying variables, or constructs. An underlying factor model is based on the possibility that the variables can be grouped by their correlations, i.e., all variables within a particular group are highly correlated among themselves, but weakly correlated with the variables in other groups. Therefore, it is plausible that each group of variables represents a single underlying factor (or construct), that is responsible for the observed correlations.

Recall that this research, has identified 27 barriers, in the literature, that hinder the adoption of the BEE technologies and has proposed a taxonomy in which such barriers were grouped into six categories. Such a structure suggests a model in which each category represents a construct and the barriers within each group are possibly highly correlated, and weakly correlated with the others.

Thus, the factor analysis, in the scope of this research, aims to verify whether the underlying factor model, obtained from the perception of the Brazilian experts, confirms the previous clustering analysis, ultimately whether it is consistent with the proposed taxonomy. Additionally, the factor analysis classify such groups by the importance assigned to them by the experts.

The starting point of the Factor Analysis is the correlation matrix of the variables. Although the Bartlett's test for sphericity assured that the correlation matrix is suitable to Factor Analysis, it is usual double check such adequacy by means of the computation of the Kaiser-Meyer-Olkin measure of sampling adequacy, which value, in this case, is 0.851, which is very good according to (FÁVERO et al, 2009; JAIN; RAJ,2013; PHOGAT; GUPTA, 2019). See Appendix C.

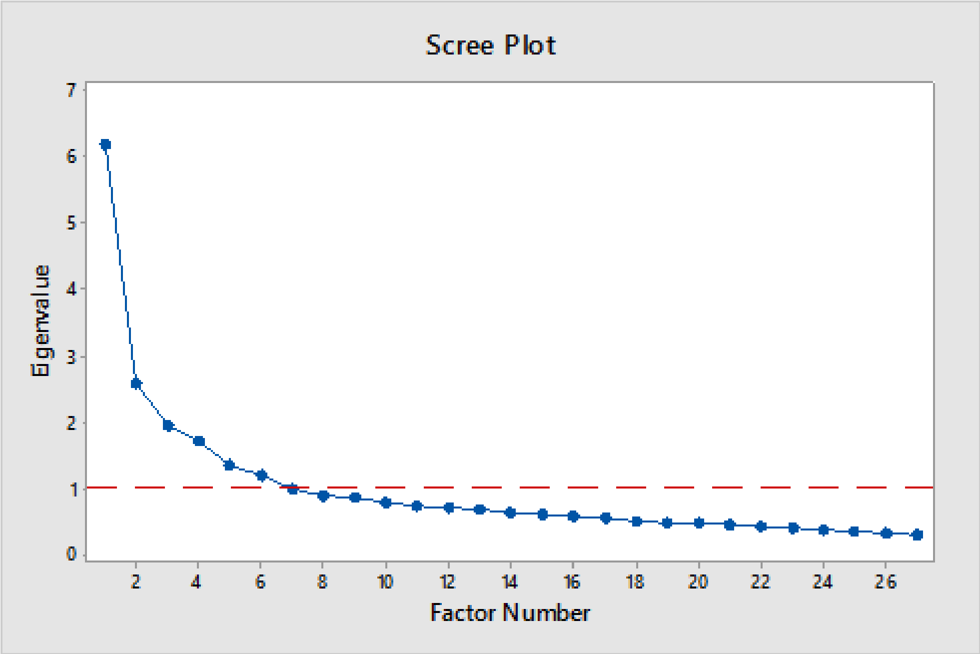
Since the factors (or constructs) extracted from the correlation matrix are a linear combination of the variables, there are as many factors as variables. Each factor is capable to explain a portion of the variance of the raw data, in such a way that all of them together are capable to explain almost 100% of the data variability.

Using all the factors to represent the data is not a great deal. Instead, the underlying factor model intends to use a minimal number of factors to summarize the whole variables into latent factors. The number of factors must be such, that they are capable to explain a significant amount of the variability in the data.

There are several criteria to determine the minimal number of factors (or the most important) to be extracted from the correlation matrix. The most important factors are those with a high variance, i.e., with a variance higher than a certain value, for example, higher than 1. Since the eigenvalues of the correlation matrix equal the variance of each factor, a common criterion is to include the factors with an eigenvalue above 1.

A common way to assess factors eigenvalues is by mean of the scree plot (Fig. 28), which displays the number of factors against its corresponding eigenvalue.

Figure 28 – Scree Plot



Source: The author

According to Fig. 28, the six firsts eigenvalues are greater than 1, thus the minimal number of Factors to be extracted from the correlation matrix should be six as well. It is interesting to notice that six also is the number of categories into which the barriers were formerly grouped during the clustering analysis and is the number of categories of the proposed taxonomy as well.

The next step is to determine which of the six factors have the greatest influence on each variable. This can be reached by examining the correlation between observed variables and latent common factors (constructs). Such a correlation can be directly observed through a parameter known as factor loading. The examination of the loading pattern determines the factor that has the greatest influence on each variable. Obviously, the loadings range from -1 to 1. Thus, loadings close to ±1 indicate that the factor strongly influences the variable. Loadings close to zero indicate that the factor has a weak influence on the variable.

It is worth mentioning that the statistical significance of the loading is related to the size of the sample, thus according to Fávero *et al.* (2009) for a sample size larger than 350, factor loadings higher than 0.3 are considered significant.

Table 19 presents the loadings for the six factors extracted from the correlation matrix.

Table 19 – Loading for the six factors extracted from the correlation matrix

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Communality
Bar_16	**0.789**	0.104	-0.128	0.033	0.025	-0.077	0.657
Bar_4	**0.695**	0.145	-0.074	-0.061	0.099	0.033	0.525
Bar_6	**0.684**	0.136	0.026	0.101	-0.028	0.042	0.500
Bar_23	**0.680**	0.014	-0.206	0.125	0.009	-0.190	0.557
Bar_18	**0.520**	0.230	0.187	-0.010	0.213	-0.243	0.463
Bar_27	**0.484**	0.050	-0.251	0.151	0.234	0.008	0.378
Bar_9	**0.400**	0.161	0.015	0.079	0.119	-0.398	0.365
Bar_11	0.071	**0.742**	-0.063	0.143	-0.039	-0.137	0.600
Bar_1	0.072	**0.696**	-0.050	-0.040	-0.020	0.026	0.495
Bar_24	0.175	**0.653**	-0.209	0.087	0.056	0.025	0.513
Bar_12	0.293	**0.626**	-0.168	-0.017	0.064	-0.048	0.513
Bar_14	-0.022	**0.583**	0.310	-0.015	0.310	-0.101	0.543
Bar_20	0.478	**0.541**	-0.177	0.130	-0.023	-0.120	0.584
Bar_7	-0.004	0.065	**-0.690**	-0.058	0.294	-0.161	0.596
Bar_25	0.184	0.065	**-0.612**	0.208	0.163	-0.066	0.487
Bar_3	0.133	0.265	**-0.566**	0.330	0.002	-0.075	0.523
Bar_17	0.160	0.232	**-0.531**	0.321	0.087	-0.153	0.496
Bar_5	0.061	0.108	0.003	**0.803**	0.087	-0.135	0.687
Bar_26	0.033	-0.021	-0.208	**0.740**	0.224	-0.030	0.643
Bar_15	0.154	0.027	-0.239	**0.720**	-0.032	-0.188	0.636
Bar_19	0.076	0.028	-0.009	0.181	**0.714**	-0.019	0.550
Bar_2	0.145	0.109	-0.009	0.009	**0.683**	-0.053	0.502
Bar_22	0.049	0.031	-0.252	0.129	**0.665**	-0.050	0.528
Bar_13	0.025	-0.060	-0.386	-0.077	**0.646**	-0.073	0.581
Bar_21	0.142	0.009	-0.386	0.174	0.081	**-0.717**	0.720
Bar_10	0.010	0.133	0.115	0.402	-0.052	**-0.694**	0.677
Bar_8	0.084	0.016	-0.422	-0.025	0.159	**-0.667**	0.656
Variance	3.220	2.798	2.476	2.324	2.281	1.875	14.974
%Var	0.119	0.104	0.092	0.086	0.084	0.069	0.555

Source: The author

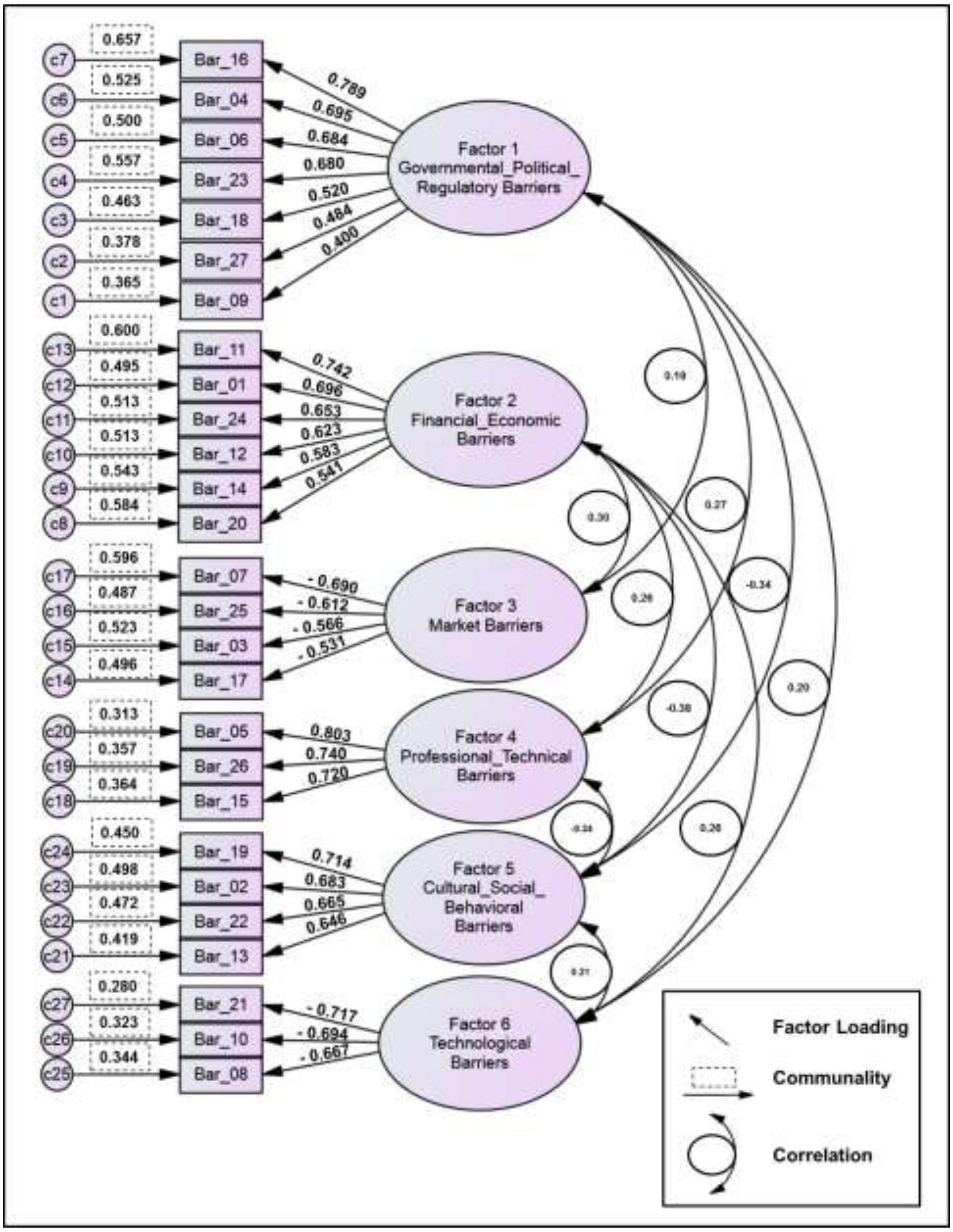
Table 19 showed the variables sorted based on their factor loadings. Thus, those variables more correlated with the Factor 1 come first, followed by the ones more correlated with the second factor, and so on.

The last column of Table 19 presents the communality for each variable, which is the proportion of variability that is explained by the factors. The closer the communality is to 1, the better the variable is explained by the factors (FAN *et al.*, 2019; OGUNSANYA *et al.*, 2019). Thus, Bar_21 is the variable whose variability is the best explained by this set of factors while Bar_9 is just the opposite.

At the bottom of Table 19, it can be seen the percentage of the variance in the data explained by each factor. Recall that the higher is the %Var, the more important is the factor. Thus, Factor 1, explains by itself almost 12% of the total variability, and all the factors together explain more than 55% of the whole variability.

Figure 29 presents the Underlying Factor Analysis model. The Fig. shows which barriers are affected by which factors as well as the loadings. The picture also allows the reader identify the most important factors. The bidirectional edges connecting the factors represent the weak correlation between them, as expected. It is worth mentioning that correlations bellow to 0.1 were not represented.

Figure 29 – Categorization of the barriers according their importance



Source: The author

Before relying on these results it is important to verify the internal consistency of each group by means of the Crombach' Alpha. In ordinary questionnaires, the Cronbach's Alpha measures how well a set of variables measure an underlying factor (or construct). In this case, the Cronbach's Alpha measures how well the set of barriers are correlated one to another within the same group, how well each of them fit the category. Table 20 shows the Cronbach's Alpha for each Factor and their respective 95% confident interval.

Table 20 - Internal consistency (Factor Cronbach's alpha coefficient)

Factors	**Items**	**Number of Respondents**	**Cronbach's α coefficient (95% CI)**	$\begin{cases} H_0: \alpha \geq 0.700 \\ H_1: \alpha < 0.700 \end{cases}$	**P-value**
1	7	1000	0.756 ≤ 0.774 ≤ 0.792	> 0.700	< 0.001
2	6	1000	0.746 ≤ 0.765 ≤ 0.783	> 0.700	< 0.001
3	4	1000	0.703 ≤ 0.727 ≤ 0.750	> 0.700	0.032
4	3	1000	0.729 ≤ 0.752 ≤ 0.774	> 0.700	< 0.001
5	4	1000	0.675 ≤ 0.701 ≤ 0.726	< 0.700	
6	3	1000	0.644 ≤ 0.674 ≤ 0.702	< 0.700	

Source: The author

According to Phogat and Gupta (2019), it is desirable that the Alpha coefficient is greater than 0.7. Then, Alpha's value can be considered greater than 0.700 for Factors 1-4, with the respective P-values showed in the last column of Table 15. The Alpha's value for Factors 5 and 6 are slightly lower than 0.700. It is not seems to be a great deal, since a growing number of authors consider 0.6 acceptable.

Comparing Figure 30 with Table 18 (clustering) and Tables 9-14 (proposed taxonomy) it can be seen that the Brazilian experts' perception led to the same classification as the Taxonomy proposed by this research.

Although the respondents considered the Government/Political/Regulatory and Financial/Economic barriers the most important barriers, at end of the Questionnaire they pointed out several barriers that they considered important and were not present. It is worth analyzing them searching for signs of new barriers.

5.5 NEW BARRIERS ADDED BY THE RESPONDENTS

After assessing the importance of the 27 barriers, the respondents were able to fill a blank with another barrier they considered important and were not listed and submitted to their assessment. The participants suggested around 40 barriers. Although, this is a small number of suggestions, devoid of statistical significance, considering that more than 1000 questionnaires were processed, it is worth analyzing them in order to see whether valuable insights come from them, justifying deeper research.

According to a few numbers of respondents (Table 21) the Brazilian industries are not capable to develop high quality BEE technologies, thus it is necessary to import them. However, some of the imported products are poor quality as well as many of them do not take into account the strong regionalities in Brazil. Comparing such statements with the

Techological Barriers, from the proposed taxonomy, they can be summarized into the barrier "***Inadequate BEE technologies"***.

Table 21 – New barriers, added by the respondents, related to "Inadequate BEE technologies"

STATEMENT	#RESPONDENT
"Lack of national technologies"	360
"Low development of new national technologies"	923
"Lack of development of national technologies to compete with imported technologies"	668
"Few national manufacturers of energy-efficient technologies"	327
"Restricted national technologies"	415
"Most of the technologies used to improve BEE are imported"	200
"Poor quality of many imported technologies"	418
"Difficulty importing efficient technologies"	904
"Lack of technologies aimed at different regions of the country"	216

Source: The author

A small number of other respondents (Table 22) were concerned with the purchasing power of lower classes. A careful analysis of such statements shows that they can be included into the barrier ***"Financial limitations of the owners"***.

Table 22 – New barriers, added by the respondents, related to "Financial limitations of the owners"

STATEMENT	#RESPONDENT
"The middle and lower classes do not have access to BEE technologies"	81
"Lack of cost-effective efficiency solutions for the most vulnerable class"	20
"Available technologies do not include differences in social and regional classes"	21
"Little disclosure about energy-efficient technologies for different social classes in the country"	863
"There are no technologies available for the different popular strata, especially for the middle and lower classes of the country"	761
"The low purchasing power of the middle and lower classes"	710
"The low incentive for popular devices for the middle and lower classes"	278

Source: The author

Other respondents make statements related to the certification procedures (Table 23) that recall the barrier entitled ***Complex energy efficiency certification procedures***.

Table 23 – New barriers, added by the respondents, related to “Complex energy efficiency certification procedures”

STATEMENT	#RESPONDENT
"Bureaucratic processes with the concessionaire and the government are longer. Even with the technology already ready to be used, the time required for its adoption to be released can take months or even almost 1 year"	226
"Bureaucratic processes for adopting new technologies are time-consuming, which makes the market unstable"	20

Source: The author

Some respondents believe that the energy utilities should have an important role in supporting the adoption of BEE Technologies (Table 24), which is a point of controversy that deserves to be debated. These few statements can be considered included into the barrier “***Lack of economic incentives”***.

Table 24 – New barriers, added by the respondents, related to “lack of economic incentives”

STATEMENT	#RESPONDENT
"There is no participation of energy concessionaires for the dissemination and encouragement of the adoption of energy-efficient technologies"	76
"Energy utilities’ reluctance to encourage the adoption of energy-efficient technologies "	175
"Energy utilities are afraid of losing their market share"	223
" Energy utilities do not want to lose market share "	272

Source: The author

Great part of the respondents suggested that the main barriers to the adoption of BEE technologies are concerned with academic education in Building energy-Efficiency (Table 25). It is expected that the technical competence is related to the academic or technical education. Thus, the suggestions given by the respondents must be included into the barrier ***“Lack of technical competence”***.

Table 25 – New barriers, added by the respondents, related to “Lack of technical competence”

STATEMENT	#RESPONDENT
"Lack of incentives from universities and a research centers to train specialists in the field of energy efficiency"	10
"Lack of academic guidance on BEE for undergraduate students"	16
"Lack of education on energy efficiency technologies at universities"	32
"Lack of undergraduate student training"	47
"There are no specific disciplines that address the energy-efficiency issues, or even within disciplines courses, there is no emphasis on the benefits of adopting BEE technologies"	72
"Little dissemination on the theme in the academic area"	141
"Lack of education on the theme in universities"	145
"Lack of disciplines on the theme in universities" *"The subject in question should be compulsory in undergraduate courses"*	288
"There is no incentive for academic institutions to teach (educate) students about the importance of the use of energy-efficient technologies"	317
"Inadequate, outdated and/or low quality higher education"	332
"I believe that the barrier starts in education. Many still see energy efficiency as a "plus" and not as a building need, and this is due to the fact that many universities still treat energy efficiency that way"	338
"Low quality of technical education and undergraduate courses"	502
"Lack of specialization courses focused on energy efficiency"	609
"Academia treats the theme less importantly"	702
"Undergraduate courses do not address energy efficiency technologies "	712
"Lack of courses at universities turned to prepare students to design and work with energy-efficient technologies"	744
"Lack of technical information for training purposes"	781

Source: The author

It was valuable to listen to the respondents opinions on potential new barriers, although, a short analysis demonstrated that no new barriers at all arise from their comments, they raised insights for new researches. For instance, it should be interesting to look for answers for questions like this: Why Brazilian industries are not capable to develop BEE technologies? What is the impact of the BEE technologies imports on the Brazilian energy-efficiency sector? Should Energy utility companies support R&D of BEE technologies? Should energy utility companies promote the adoption of BEE technologies? Are universities providing a high quality education on energy-efficiency? What is the real role of the universities on the adoption of energy-efficiency technologies? Undoubtedly these are important questions. However, they are out of the scope of this research. Now, that the barriers to the adoption of BEE technologies pointed out in the literature were recognized valid to the Brazilian scenario it is important to see what the literature proposes to overcome them.

6 STRATEGIES TO OVERCOME THE BARRIERS TO THE ADOPTION OF ENERGY-EFFICIENT TECHNOLOGIES IN THE BUILDING SECTOR

The strategies to overcome the barriers are presented below to encourage the adoption of the BEE technologies.

6.1 STRATEGIES TO OVERCOME THE FINANCIAL/ECONOMIC BARRIERS

Table 26 presents recommendations to overcome the Financial/Economic barriers.

Table 26 - Strategies to overcome the Financial/Economic barriers

Obstacles	Overcome Strategy	References
High investment	To create educational projects around financial analysis so that owners understand that high investment treats a financial return.	Bertone *et al.* (2016); Zadeh; Xuan; Shepley (2016)
Lack of economic incentives	To develop a pattern of economic incentives that results in tax reductions and financial rewards of the owners.	Adeyeye;Osmani; Brown (2007); Häkkinen (2011); Palmer *et al.* (2013); Wang *et al.* (2016)
Long payback periods	To create BEE projects that present different periods of financial return, so that the owners can choose the most suitable project for their building.	Cattano *et al.* (2013); Paiho; Ahvenniemi (2017); Wilson; Crane; Chryssochoidis (2015)
Difficult to access financing	To develop a financial model to provide easy access to the financing needed for BEE projects.	Amoruso; Donevska; Skomedal (2018)
Financial limitations of owners	To create financial rewards to owners according to investment done.	Wang *et al.* (2016); Zhang *et al.* (2018)
Investment risks	To do financial risk analysis toward to BEE adoption.	Djokoto; Dadzie; Ohemeng (2014); Gupta; Anand; Gupta (2017)

Source: The author

According to Bertone *et al.* (2016), the best strategy to overcome the 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 a clear knowledge that the high investments made will bring some future payback (ZADEH; XUAN; SHEPLEY, 2016).

Developing a pattern of economic incentives that result in tax reductions and financial rewards is an alternative to overcome the lack of economic incentives (ADEYEYE;

OSMANI; BROWN, 2007; WANG *et al.*, 2016). However, it is important that this pattern is clear, rather than general or ambiguous (HÄKKINEN, 2011), and also available to the investors involved in the BEE projects (PALMER *et al.*, 2013).

The reduction in the costs of energy-saving technologies decreases the payback time on invested capital (WILSON; CRANE; CHRYSSOCHOIDIS, 2015). 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 (PAIHO; AHVENNIEMI, 2017). As a result, investors can choose the type of financing appropriate to their projects (CATTANO *et al.*, 2013).

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 to access financing” barrier (AMORUSO; DONEVSKA; SKOMEDAL, 2018).

Despite the financial limitations of some owners, it is recommended that the government applies financial rewards to the investments made (WANG *et al.*, 2016). This economic incentive encourages clients to invest their capital in BEE projects (ZHANG *et al.*, 2018).

Furthermore, it is suggested that financial risk analysis be made before adopting any energy-efficient technology (DJOKOTO; DADZIE; OHEMENG, 2014).

6.2 STRATEGIES TO OVERCOME THE MARKET BARRIERS

The recommendations to overcome the Market barriers are presented in Table 27.

Table 27 - Strategies to overcome the Market barriers

Obstacles	Overcome Strategy	References
Lack of a market for BEE technologies	To invest in government actions to the promotion of BEE projects and expand the market of BEE technologies.	Du *et al.* (2014); Stevenso; Baborska-Narozny (2018)
Lack of investors in the BEE projects	To create actions to encourage potential investors to invest in BEE projects aimed at adopting BEE technologies.	Yeatts *et al.* (2017)
Limited knowledge of the market potential	To develop technical guidelines that will be used by investors as a quick guide to meeting market requirements.	Adeyeye; Osmani; Brown (2007)
Lack of good marketing strategies	To invest in marketing strategies that disseminate the advantages of BEE technologies.	Persson; Grönkvist (2015); Yeatts *et al.* (2017); Zhang; Zhou (2015)

Source: The author

According to Du *et al.* (2014), the lack of market for the implementation of BEE projects can be overcome by incentives to potential investors regarding the adoption of technologies in their projects (YEATTS *et al.*, 2017).

One way to increase knowledge about market potential is to develop guidelines with technical guidance that will be ideal for investors and owners as a quick guide to meeting market requirements (ADEYEYE; OSMANI; BROWN, 2007).

Investing in marketing strategies that disseminate the advantages of BEE projects is important for the improvement of BEE projects (ZHANG; ZHOU, 2015). It is important to have good communication channels by means of which 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 (PERSSON; GRÖNKVIST, 2015).

6.3 STRATEGIES TO OVERCOME THE TECHNOLOGICAL BARRIERS

Table 28 shows the strategies to overcome the Technological barriers.

Table 28 - Strategies to overcome the Technological barriers

Obstacles	Overcome Strategy	References
Inadequate BEE technologies	To create research centers that can be used as platforms for production, learning, and research on BEE technologies.	Alanne; Saari (2004); Ding *et al.* (2018); Yeatts *et al.* (2017); Zhang *et al.* (2018)
Lack of information	To provide the society with more information on available technologies in the country.	Akadiri (2015); Castleberry; Gliedt; Greene (2016); Wang *et al.* (2016)
Lack of technology demonstration	To develop projects to demonstrate BEE technologies for investors and owners to show the benefits of BEE technologies.	Bruce *et al.* (2015); Zhang; Zhou (2015)

Source: The author

One way to overcome this barrier is the support to research aimed at the development of energy-saving technologies (ALANNE; SAARI, 2004; DING *et al.*, 2018). It is interesting that the government encourages universities and local institutions to develop research centers as a platform for production, learning, and research with the goal of developing low-cost technological alternatives for energy efficiency (ZHANG *et al.*, 2018).

Furthermore, the government and research centers should provide the society with information on reliable technologies and procedures to maximize the use of energy-efficient technologies (AKADIRI, 2015; WANG *et al.*, 2016).

Demonstration projects are another way to improve the use of BEE technologies (ZHANG; ZHOU, 2015). These projects teach how to successfully use technologies and are an effective alternative to disseminate BEE projects (YEATTS *et al.*, 2017). Thus, investors and owners may feel more confident about the benefits and development of BEE projects (CASTLEBERRY; GLIEDT; GREENE, 2016; ZHANG; ZHOU, 2015).

6.4 STRATEGIES TO OVERCOME THE PROFESSIONAL/TECHNICAL BARRIERS

Table 29 shows strategies for overcoming the Professional/Technical barriers.

Table 29 - Strategies to overcome Professional/Technical barriers

Obstacles	Overcome Strategy	References
Lack of technical competence	To develop training programs, support by government or research centers, of professionals that develop BEE projects.	Bruce *et al.* (2015); Du *et al.* (2014); Greenough; Tosoratti (2014); Gupta; Anand; Gupta (2017); Yeatts *et al.* (2017); Zhang *et al.* (2018)
Lack of confindence of specialized professional	To create an excellence awards to professionals involved in BEE projects.	Adeyeye; Osmani; Brown (2007); Greenough; Tosoratti (2014); Hosseini *et al.* (2016)
Incredulity on the part of the designers	To carry out more workshops, conferences, training related to BEE project.	Du *et al.* (2014); Wang *et al.* (2016)

Source: The author

The main hint to overcoming these barriers is to improve the awareness and knowledge of professionals by means of specialized training supported by government or research centers that promote the requirements and benefits of energy-saving measures (GUPTA; ANAND; GUPTA, 2017; BRUCE *et al.*, 2015; DING *et al.*, 2018; DU *et al.*, 2014; GREENOUGH; TOSORATTI, 2014; ZHANG *et al.*, 2018).

It is also important to increase the level of professional involvement in BEE projects (MAHMOUD *et al.*, 2017) by means of awards according to the projects developed (ADEYEYE; OSMANI; BROWN, 2007; GREENOUGH; TOSORATTI, 2014; HOSSEINI *et* *al.*, 2016). This is a way to encourage professionals to adopt energy-saving technologies (DU *et al.*, 2014; WANG *et al.*, 2016; ZHOU; LI; CHIANG, 2013).

6.5 STRATEGIES TO OVERCOME THE GOVERNMENTAL/POLITICAL/ REGULATORY BARRIERS

Table 30 presents the strategies to overcome the Governmental/Political/Regulatory barriers.

Table 30 - Strategies to overcome the Governmental/Political/Regulatory barriers

Obstacles	Overcome Strategy	References
Inefficient BEE codes/ regulations/ Standards	To develop more efficient codes/regulations/standards	Alanne; Saari (2004); Cattano *et al.* (2013); Djokoto; Dadzie; Ohemeng (2014); Gupta; Anand; Gupta (2017); Yeatts *et al.* (2017)
Lack of government support	To create a governmental commitment to BEE projects.	Adeyeye; Osmani; Brown (2007); Zhang *et al.* (2018)
Lack of fiscal policies	To develop effective policies on government subsidies and tax credits.	Karkanias *et al.* (2010); Zhang *et al.* (2018); Zhang; Zhou (2015)
Complex certification procedures	To make BEE certification procedures clearer.	Adeyeye; Osmani; Brown (2007); Li; Colombier (2009)
Policies do not address the financial implications	To create policy guidance on the possible financial implications of BEE projects.	Teng *et al.* (2016); Zhou; Li; Chiang (2013)
Lack of knowledge on energy efficiency by legislator and regulator	To create training programs on BEE technologies for regulators and legislators.	Gupta; Anand; Gupta (2017); Huang; Mauerhofer; Geng (2016); Persson; Grönkvist (2015)
Lack of efficient dissemination of codes/regulations	To create a rigorous policy framework to disseminate information on the codes and regulations of BEE technologies.	Gupta; Anand; Gupta (2017); Bruce *et al.* (2015); Cattano *et al.* (2013); Yeatts *et al.* (2017); Zhang; Zhou (2015)

Source: The author

The development of efficient norms, regulations, and laws is important to boost the use of technologies, clearly providing energy-saving goals to be achieved (GREENOUGH; TOSORATTI, 2014). 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 (CHOW; LI; DARKWA, 2013; ZHANG; WANG, 2013).

Furthermore, it is important to create a government support mechanism to provide guidance and assistance to both designers and occupants (ZHANG *et al.*, 2018). Government support should provide a culture of energy efficiency to ensure the adoption of technological measures (ADEYEYE; OSMANI; BROWN, 2007).

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 (KARKANIAS *et al.*, 2010; ZHANG; ZHOU, 2015). Such packages should increase subsidies and create interest-free policies (ZHANG *et al.*, 2018).

The government should provide tools to make energy efficiency certification procedures clearer and more accessible for designers (ADEYEYE; OSMANI; BROWN, 2007). 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 (KARKANIAS *et al.*, 2010). 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 (TENG *et al.*, 2016; ZHOU; LI; CHIANG, 2013).

It is important to provide training for regulators and legislators involved in the BEE regulations/laws (HUANG; MAUERHOFER; GENG, 2016). 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 (GUPTA; ANAND; GUPTA, 2017; PERSSON; GRÖNKVIST, 2015).

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 (CATTANO *et al.*, 2013; GUPTA; ANAND; GUPTA, 2017; ZHANG; ZHOU, 2015). 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 (BRUCE *et al.*, 2015; YEATTS *et al.*, 2017).

6.6 STRATEGIES TO OVERCOME THE CULTURAL/SOCIAL/BEHAVIORAL BARRIERS

Table 31 shows strategies for overcoming the Cultural/Social/Behavioral barriers.

Table 31 - Strategies to overcome the Cultural/Social/Behavioral obstacles

Obstacles	Overcome Strategy	References
Lack of knowledge about the BEE technologies	To create education and training programs that use interactive tools and games to help the building occupants to better understand the implications of inefficient energy use.	Alanne; Saari (2004); Häkkinen (2011); Hosseini *et al.* (2016)
Fear/Resistance to change	To improve public awareness about BEE technologies and their benefits.	Djokoto; Dadzie; Ohemeng (2014); Huang; Mauerhofer; Geng (2016); Persson; Grönkvist (2015)
Lack of motivation	To use the channels of communication to present the benefits in the adoption of BEE technologies.	Teng *et al.*, 2016; Yeatts *et al.*, 2017
Lack of confidence	To provide clear and reliable instructions on the benefits of BEE technologies.	Alanne; Saari (2004); Persson; Grönkvist (2015); Yeatts *et al.* (2017)

Source: The author

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 (ALANNE; SAARI, 2004). This information should be included in educational and training programs by means of interactive tools and games that help occupants to better understand the life implications for inefficient energy use (HÄKKINEN, 2011).

Public awareness of the use of energy-efficient technologies is an important suggestion to overcome the "fear/resistance to change" barrier (DJOKOTO; DADZIE; OHEMENG, 2014). Implementing public participation programs improves occupant awareness, making them less resistant to the adoption of such technologies (HUANG; MAUERHOFER; GENG, 2016). 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 (DJOKOTO; DADZIE; OHEMENG, 2014; PERSSON; GRÖNKVIST, 2015).

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 (HUANG; MAUERHOFER; GENG, 2016; YEATTS *et al.*, 2017).

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 (ALANNE; SAARI, 2004; PERSSON; GRÖNKVIST, 2015). 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 (HOSSEINI *et al.*, 2016; YEATTS *et al.*, 2017).

7 CONCLUSION

As already highlighted in this research, the best way of reducing the demand for energy without affecting the economic growth of the nations is the adoption of BEE technologies. There are several of these technologies available, bringing a lot of benefits. However, there are barriers that hinder their adoption.

Therefore, this research was developed to answer the following questions: What are the barriers to the adoption of energy-efficient technologies in the Brazilian building sector? And what are the strategies to overcome them?

Thus, in order to answer such questions, it was important, firstly, to structure the theoretical framework that sought to privilege the inclusion of themes directly linked to the object of study and pointed out by the literature as relevant, as the BEE technologies adopted in the building sector to reduce energy consumption.

Subsequently, an extensive literature review was developed to identify barriers to the adoption of BEE technologies. From that it was possible to create a new taxonomy that grouped 27 barriers found in the literature into 6 groups, named according to financial, market, technological, professional, governmental, and cultural aspects. Furthermore, it was possible to study the temporal distribution of each barrier which showed that the groups of barriers Financial/Economic, Governmental/Political/Regulatory, and Cultural/Social/Behavioral are the most important groups in the literature. And still, it was possible to see that the outgrowth of barriers to the adoption of BEE technologies independent of geographical regions or types of building.

The results obtained in this step were relevant to show the importance of the theme, and also to support the elaboration of the following research stages, since from these results it was possible to study the degree of importance attributed to each of the 27 barriers for the Brazilian scenario, by means of the application of the structured questionnaire.

Regarding the research method used, the survey, was shown to be relevant to the development of this research, which was classified as applied, exploratory, and quantitative. The decision to carry out a quantitative research based on the survey method made it possible to identify the importance of the barriers found in the literature according to the perception of Brazilian experts'.

Furthermore, the sample of respondents proved to be consistent, and very representative, as the results achieved were comprehensive to understand the impact of the investigated barriers. The methods for analysis used (clustering analysis and factor analysis) confirmed the respondents' perception with the proposed taxonomy in the literature review, which led to the conclusion that the perception of the Brazilian experts' regarding the barriers the adoption of BEE technologies is in line with what has been studied in the literature over the years. And still, it was possible to identify that the Governmental/Political/Regulatory and Financial/Economic groups are the most important groups of barriers for the Brazilian scenario, based on their ranking by importance, a result obtained in factor analysis.

The classifying of groups by importance suggested that society expects more from the government than from the technologies themselves, since the Technological group was considered the least important, according to the perception of Brazilian experts'.

Furthermore, the strategies were proposed based on the articles used in the literature review, and proved to be relevant to encourage the adoption of BEE technologies.

Therefore, the main scientific contribution of this research is the theoretical consolidation on the barriers to the adoption of BEE technologies in the Brazilian building sector, in addition to presenting strategies to overcome them. It is worth noting that these contributions helped to fill scientific gaps related to the theme, which was presented in the research justification.

As a practical contribution, the results of this research can be useful for the formulation of public policies, since it identified the barriers that most hinder the adoption of BEE technologies in Brazil. As these barriers were ranked in importance, it will be easy to start developing actions and programs focused on the most important groups of barriers.

However, this research has some limitations that deserve to be considered, such as the impossibility of studying which of the strategies found in the literature that could be implemented more easily in the Brazilian scenario, and still to present examples and directives of how they could be implemented. Furthermore, it was not possible to study the perception of respondents based on their academic education and occupation profile. From this stage it would be possible to analyze what are the most impacting barriers by a group of the respondent (according to the academic formation or the occupation profile), that is, it would be possible to analyze whether there are statistically significant differences between the perception of these different groups of respondents regarding the importance of the 27 barriers. However, such limitations did not interfere with the execution of the main research objective and can be used as suggestions for future research.

Furthermore, another recommendation for future research is to replicate this study in other sectors of the country, such as the industrial sector, which is also responsible for a large part of energy consumption in Brazil.

Finally, it should be noted that this research resulted in the publication of the following scientific articles:

- CRISTINO, T.M. LOTUFO, F.A. DELINCHANT, B. WURTZ, F. FARIA NETO, A. *A comprehensive review on obstacles and drivers to building energy-saving technologies and their association with research themes, types of building, and geographic regions.* ***Renewable & Sustainable Energy Reviews***, 2020. Available in: https://doi.org/10.1016/j.rser.2020.110191.
- CRISTINO, T.M. FARIA NETO, A. COSTA, A.F.B. *Energy efficiency in buildings: analysis of scientific literature and identification of data analysis techniques from a bibliometric study.* ***Scientometrics***, v. 114, p. 1275-1326, 2018. Available in: https://doi.org/10.1007/s11192-017-2615-4

Such publications can contribute to the construction of knowledge about BEE and provide a theoretical basis for conducting new research in this area.

Therefore, according to the above, it can be concluded that the research achieved its objectives, showing not only the barriers that most impact the adoption of the BEE technologies in Brazil, but also the strategies to overcome them, through a rich literature review and use of sophisticated methods for data analysis.

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APPENDIX A- Research query

(to be continued)

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

APPENDIX A- Research query

(conclusion)

"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

APPENDIX B - Pearson's coefficient correlation matrix

Pearson's coefficient correlation matrix																											
	Bar_01	**Bar_02**	**Bar_03**	**Bar_04**	**Bar_05**	**Bar_06**	**Bar_07**	**Bar_08**	**Bar_09**	**Bar_10**	**Bar_11**	**Bar_12**	**Bar_13**	**Bar_14**	**Bar_15**	**Bar_16**	**Bar_17**	**Bar_18**	**Bar_19**	**Bar_20**	**Bar_21**	**Bar_22**	**Bar_23**	**Bar_24**	**Bar_25**	**Bar_26**	**Bar_27**
Bar_01	1	0.11	0.20	0.18	0.01	0.15	0.02	0.05	0.12	0.05	0.40	0.27	-0.02	0.29	0.05	0.12	0.13	0.14	0.04	0.38	0.07	0.01	0.11	0.39	0.06	0.01	0.10
Bar_02	0.11	1	0.15	0.17	0.10	0.11	0.17	0.17	0.16	0.00	0.09	0.14	0.33	0.12	0.07	0.17	0.12	0.16	0.41	0.15	0.17	0.36	0.11	0.14	0.13	0.11	0.14
Bar_03	0.20	0.15	1	0.15	0.28	0.17	0.35	0.25	0.20	0.21	0.23	0.22	0.13	0.03	0.34	0.23	0.56	0.12	0.15	0.28	0.30	0.16	0.23	0.25	0.39	0.26	0.21
Bar_04	0.18	0.17	0.15	1	0.07	0.31	0.11	0.12	0.24	0.01	0.15	0.28	0.08	0.14	0.07	0.54	0.18	0.29	0.07	0.32	0.12	0.12	0.42	0.22	0.13	0.05	0.35
Bar_05	0.01	0.10	0.28	0.07	1	0.12	0.12	0.14	0.18	0.37	0.21	0.10	0.02	0.10	0.51	0.11	0.26	0.08	0.13	0.19	0.23	0.17	0.16	0.16	0.19	0.50	0.17
Bar_06	0.15	0.11	0.17	0.31	0.12	1	0,00	0.09	0.18	0.06	0.17	0.26	0.01	0.10	0.15	0.49	0.13	0.33	0.07	0.36	0.10	0.01	0.38	0.18	0.16	0.06	0.27
Bar_07	0.02	0.17	0.35	0.11	0.12	0,00	1	0.39	0.16	0.03	0.08	0.16	0.38	0.02	0.13	0.10	0.39	0.09	0.19	0.09	0.29	0.29	0.14	0.18	0.41	0.17	0.25
Bar_08	0.05	0.17	0.25	0.12	0.14	0.09	0.39	1	0.2	0.27	0.13	0.15	0.27	0.03	0.24	0.18	0.27	0.10	0.15	0.21	0.59	0.20	0.22	0.11	0.29	0.21	0.23
Bar_09	0.12	0.16	0.20	0.24	0.18	0.18	0.16	0.20	1	0.22	0.23	0.16	0.05	0.11	0.14	0.30	0.20	0.34	0.13	0.28	0.24	0.11	0.33	0.21	0.21	0.13	0.23
Bar_10	0.05	0.00	0.21	0.01	0.37	0.06	0.03	0.27	0.22	1	0.20	0.08	-0.02	0.12	0.31	0.10	0.25	0.17	0.08	0.17	0.43	0.06	0.17	0.13	0.09	0.22	0.07
Bar_11	0.40	0.09	0.23	0.15	0.21	0.17	0.08	0.13	0.23	0.20	1	0.45	-0.01	0.31	0.16	0.17	0.21	0.15	0.03	0.45	0.16	0.08	0.16	0.42	0.15	0.11	0.12
Bar_12	0.27	0.14	0.22	0.28	0.1	0.26	0.16	0.15	0.16	0.08	0.45	1	0.13	0.30	0.13	0.36	0.25	0.26	0.08	0.53	0.19	0.11	0.21	0.40	0.17	0.09	0.17
Bar_13	-0.02	0.33	0.13	0.08	0.02	0.01	0.38	0.27	0.05	-0.02	-0.01	0.13	1	0.04	0.10	0.12	0.21	0.07	0.36	0.06	0.24	0.44	0.12	0.07	0.27	0.18	0.19
Bar_14	0.29	0.12	0.03	0.14	0.1	0.10	0.02	0.03	0.11	0.12	0.31	0.30	0.04	1	-0.05	0.03	0.06	0.26	0.13	0.14	-0.05	0.12	-0.02	0.22	-0.02	0.00	0.07
Bar_15	0.05	0.07	0.34	0.07	0.51	0.15	0.13	0.24	0.14	0.31	0.16	0.13	0.10	-0.05	1	0.20	0.35	0.09	0.12	0.27	0.40	0.13	0.28	0.15	0.30	0.49	0.17
Bar_16	0.12	0.17	0.23	0.54	0.11	0.49	0.10	0.18	0.30	0.10	0.17	0.36	0.12	0.03	0.20	1	0.27	0.35	0.10	0.47	0.23	0.11	0.46	0.19	0.20	0.09	0.30
Bar_17	0.13	0.12	0.56	0.18	0.26	0.13	0.39	0.27	0.20	0.25	0.21	0.25	0.21	0.06	0.35	0.27	1	0.19	0.17	0.32	0.35	0.25	0.24	0.25	0.29	0.32	0.26
Bar_18	0.14	0.16	0.12	0.29	0.08	0.33	0.09	0.10	0.34	0.17	0.15	0.26	0.07	0.26	0.09	0.35	0.19	1	0.15	0.29	0.13	0.10	0.29	0.24	0.10	0.04	0.25
Bar_19	0.04	0.41	0.15	0.07	0.13	0.07	0.19	0.15	0.13	0.08	0.03	0.08	0.36	0.13	0.12	0.10	0.17	0.15	1	0.15	0.12	0.34	0.10	0.07	0.19	0.24	0.18
Bar_20	0.38	0.15	0.28	0.32	0.19	0.36	0.09	0.21	0.28	0.17	0.45	0.53	0.06	0.14	0.27	0.47	0.32	0.29	0.15	1	0.28	0.11	0.38	0.41	0.24	0.12	0.27
Bar_21	0.07	0.17	0.30	0.12	0.23	0.10	0.29	0.59	0.24	0.43	0.16	0.19	0.24	-0.05	0.40	0.23	0.35	0.13	0.12	0.28	1	0.25	0.32	0.11	0.34	0.28	0.20
Bar_22	0.01	0.36	0.16	0.12	0.17	0.01	0.29	0.20	0.11	0.06	0.08	0.11	0.44	0.12	0.13	0.11	0.25	0.10	0.34	0.11	0.25	1	0.18	0.15	0.29	0.25	0.24
Bar_23	0.11	0.11	0.23	0.42	0.16	0.38	0.14	0.22	0.33	0.17	0.16	0.21	0.12	-0.02	0.28	0.46	0.24	0.29	0.10	0.38	0.32	0.18	1	0.22	0.31	0.14	0.34
Bar_24	0.39	0.14	0.25	0.22	0.16	0.18	0.18	0.11	0.21	0.13	0.42	0.40	0.07	0.22	0.15	0.19	0.25	0.24	0.07	0.41	0.11	0.15	0.22	1	0.23	0.10	0.23
Bar_25	0.06	0.13	0.39	0.13	0.19	0.16	0.41	0.29	0.21	0.09	0.15	0.17	0.27	-0.02	0.30	0.20	0.29	0.10	0.19	0.24	0.34	0.29	0.31	0.23	1	0.31	0.25
Bar_26	0.01	0.11	0.26	0.05	0.50	0.06	0.17	0.21	0.13	0.22	0.11	0.09	0.18	0.00	0.49	0.09	0.32	0.04	0.24	0.12	0.28	0.25	0.14	0.10	0.31	1	0.25
Bar_27	0.10	0.14	0.21	0.35	0.17	0.27	0.25	0.23	0.23	0.07	0.12	0.17	0.19	0.07	0.17	0.30	0.26	0.25	0.18	0.27	0.20	0.24	0.34	0.23	0.25	0.25	1

APPENDIX C – Results of the KMO test and the Bartlett's test for sphericity

KMO and Bartlett's test		
Kaiser-Meyer-Olkin measure of sampling adequacy		0,851
	Approx. Chi square	8361.885
Bartlett's test of sphericity	Df	351
	Sig.	0.000

Source: SPSS