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# Energy consumption and efficiency in buildings: current status and future trends

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ABSTRACT

The building sector is considered as the biggest single contributor to world energy consumption and greenhouse gas emissions. Therefore, a good understanding of the nature and structure of energy use in buildings is crucial for establishing the adequate future energy and climate change policies. Availability of the updated data is becoming increasingly important in order to allow a rigorous analysis. In this paper, recent data on the world energy consumption in both residential and commercial buildings are reported. Past situation, current status and future trends are discussed and analyzed for selected countries. A breakdown of buildings energy consumption is realized in order to determine the influencing key parameters. A whole section of this paper is dedicated to give an overview of measures and policies adopted by different countries, allowing the monitoring, management and reduction of the energy consumption in buildings. Critical aspects of these policies are discussed based on the feedback of the early adopters.



## 1. Introduction

The sustainability challenges concerning energy saving and environment protection are enormous (Dovì et al., 2009; Diedrich et al., 2011; Van Vuuren et al., 2012; Allouhi et al., 2015) and will require major changes, not only in the way that energy is supplied but in the way that it is consumed. On the other hand, the close relationship between energy and economic development gives rise to the necessity of a good understanding and a continuous monitoring of energy consumption (Asafu-Adjaye, 2000; Lee, 2005; Shahbaz et al., 2013), something that cannot be achieved without its quantification and categorization by sector and end-use. Even if great efforts are undertaken by many organizations to supply sufficient information of energy consumption worldwide, the clear screen related to this target cannot be drawn without a global cooperation between nations, international organizations and agencies. A special focus should be given to the characteristics of the building sector due to its significant amount of the energy consumption and the associated $CO_2$ emissions (Lukas and Ugursal, 2009; Santoyo-Castelazo and Azapagic, 2014; Mattinen et al., 2014).

In a previous interesting work, Lombard et al. (2008) presented an analysis, based on available information relative to 2004 period, about energy use in residential and commercial buildings with a detailed breakdown and special focus on HVAC systems. In the regard of obtaining more recent data on this topic, the present study aims at surrounding energy consumption in the building sector by giving updated information of energy indicators. Many countries are considered as references according to the illegibility of official data. Furthermore, resulting strategies and measures adopted by the reviewed countries along with their successful achievements are discussed. The remainder of this paper is organized as follows: After presenting briefly the methodology adopted in the current study in Section 2, we describe the world evolution of energy use in Section 3. Zooms in on the energy consumption relative to the building sector via a multi-angle analysis covering the general impacting factors are discussed in Section 4. Founded on the feedback of the early adopters, Sections 5 discusses the critical aspects of energy efficiency policies as a powerful method to reduce energy consumption in buildings and the resulting $CO_2$ emissions.

## 2. Methodology

An extensive literature review is presented in this paper to gather detailed information about the status of energy

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consumption in the building sector. Several international reports and recent academic publications were regrouped. The second stage of this approach is data selection through examining the relevant documents and official reports. As a consequence, some countries were selected as references throughout the different sections of this paper.

The reporting of the updated information related to energy consumption in the building has allowed the description and the analysis of the key factors impacting energy use in the building sector. Then, the topic of energy efficiency was treated by discussing the most important options and solutions and the prospective barriers encountered.

Fig. 1 shows the followed approach conducted for the current investigation.

## 3. World energy use: past orientations, recent status and future trends

Energy is indispensable for socioeconomic development and life-quality improvement in all nations (ASHRAE, 1990; Kousksou et al., 2014). Ensuring the energy supply and minimizing the resulting environmental impacts (Global warming and ozone layer depletion) are certainly the greatest challenges related to the twenty first century's energy advances. The need to analyze past data and forecast future trends of energy consumption is one of the important measures to take in order to draw next strategies for energy production and supply concerns. For that, the International Energy Agency (IEA) publishes periodically new statistics on the world energy status. In its last report, the IEA presented a figure of world final energy consumption and world $CO_2$ emissions from 1971 to 2011 (Figs. 2–3 (IEA, 2013)). It is clear that the global energy consumption and $CO_2$ emissions approximately doubled during the concerned period.

Between 2005 and 2011 an average annual energy consumption growth of about 3.15% is observed. In 2011, the global energy consumption rate was 8.92 Gtoe/year and it is predicted that this rate would amount to 14 Gtoe/year by 2020. These data indicate that the global energy consumption and $CO_2$ emission rates are on the rise in the next years.

The analysis of many preponderant socioeconomic and energy parameters are fundamental to draw a clear picture about the world energy consumption evolution; a legitimate reflection should be taken in order to link these socioeconomic parameters with energy use evolution in time. Table 1 illustrates the 2001's and 2011's values of the main indicators. Interesting conclusions can be deduced after analyzing these indicators:

- The total energy consumption is growing faster than population (2.75% vs 1.4%); it can be explained by the increasing need for individual energy; in fact, the Per Capita Energy Consumption has increased by 11.18% in 10 years as a result of the improvement of comfort level and the extension of human activities.

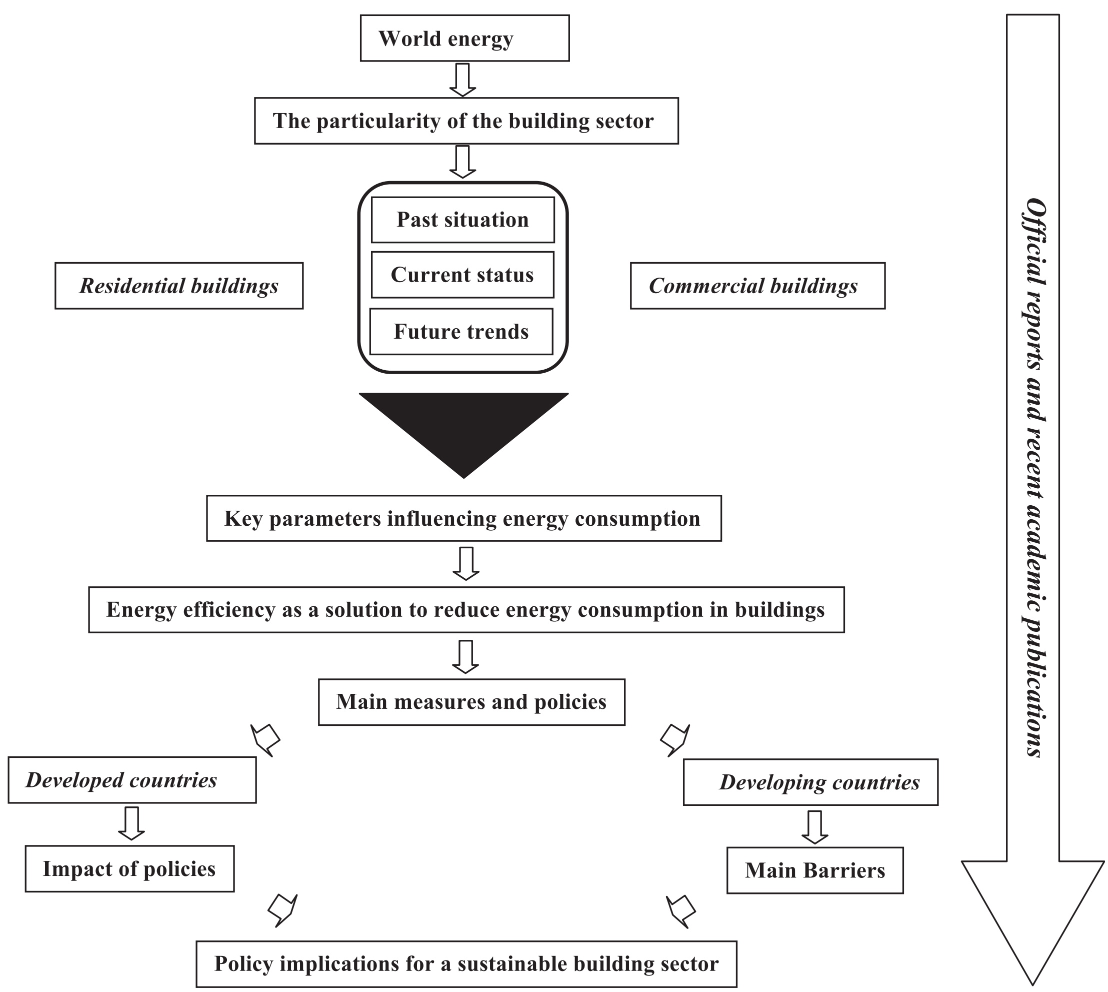


**Fig. 1.** Adopted approach in the study.

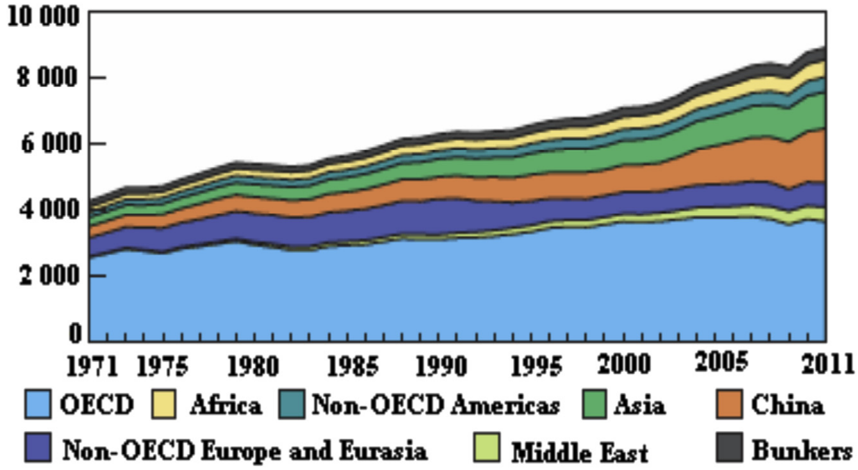


**Fig. 2.** World total final consumption from 1971 to 2011 by regions (Mtoe) (IEA, 2013).

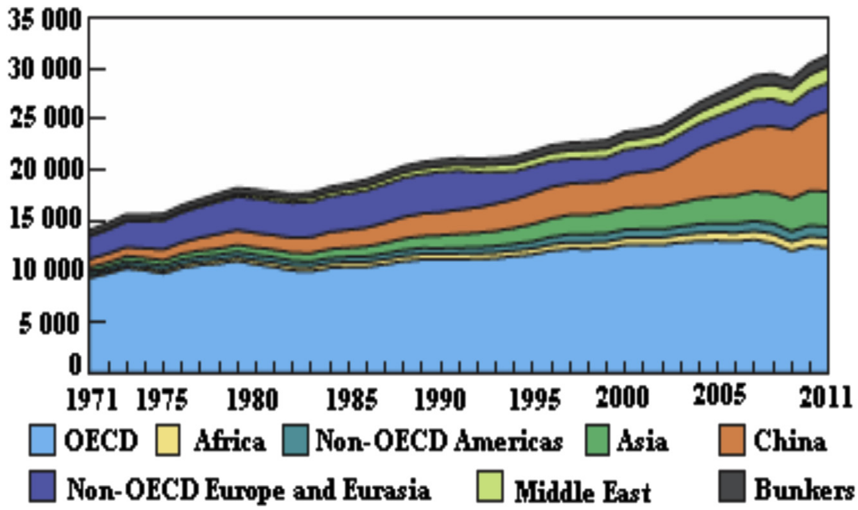


**Fig. 3.** World total $CO_2$ emissions from 1971 to 2011 by regions (Mt) (IEA, 2013).

**Table 1**
Global energy indicators evolution in periods 2001–2011.

| Indicators | 2001 | 2011 | Rate of growth during 2001–2011 (%) | Mean annual rate of growth (%) |
|---|---|---|---|---|
| Population (Million) | 6102 | 6958 | 14.03 | 1.40 |
| GDP (G$ year 2005) | 34 399 | 52 486 | 52.58 | 5.26 |
| Energy production (Mtoe) | 10 209 | 13 202 | 29.32 | 2.93 |
| Total primary energy supply (Mtoe) | 10 029 | 13 113 | 30.75 | 3.08 |
| Total final consumption (Mtoe) | 6994 | 8917 | 27.49 | 2.75 |
| Electric consumption (MToe) | 1220 | 1754 | 43.77 | 4.38 |
| $CO_2$ emissions (Mt of $CO_2$) | 23 683 | 31 342 | 32.34 | 3.23 |
| Per capita income ($ year 2005) | 5.64 | 7.54 | 33.81 | 3.38 |
| Transformation rate (%) | 98.24 | 99.33 | 1.11 | 0.11 |
| Supplying rate (%) | 69.74 | 68.00 | −2.49 | −0.25 |
| Global energy usage rate (%) | 68.51 | 67.54 | −1.41 | −0.14 |
| Electrical consumption part (%) | 17.44 | 19.67 | 12.77 | 1.28 |
| Per capita energy consumption (toe) | 1.15 | 1.28 | 11.81 | 1.18 |
| Per capita $CO_2$ emissions (ton) | 3.88 | 4.50 | 16.06 | 1.61 |
| Primary energy intensity (toe/G$ year 2005) | 291.55 | 249.84 | −14.31 | −1.43 |
| Final energy intensity (toe/G$ year 2005) | 203.32 | 169.89 | −16.44 | −1.64 |

- The economic factor is also a definitive parameter in energy consumption increase; the GDP is growing about 5.26% per year influencing directly the total final consumption.
- Electricity consumption has increased by 43.77%, with such rate the future situation is certainly stressful, having in mind that about one-third of the world's population still does not have access to electricity, and that underdeveloped and developing countries mostly use fossil fuels as the major source of energy (Vujić et al., 2012)
- The improvement of energy transformation methods is attractive (more than 99% of transformation rate), unlike supplying activity which decreases by about 2.5% during the fixed period.

Improving energy supplying means remains a great challenge for the world community.

- $CO_2$ emissions presented a relative higher growth rate than the total energy consumption, showing a 33% increase during this period. According to the Intergovernmental Panel of Climate Change (**IPCC**), several dangerous consequences are predicted if the current rate does not diminish.

Concerning future trends, the last report "*International Energy Outlook 2013*" of the Energy Information Administration (EIA, 2013) projects that world energy consumption will grow by 56% between 2010 and 2040. A profile of the trend of the world energy use is given in the next figure (Fig. 4). Total world energy use may rise from 13.2 Gtoe in 2010 to 15.9 Gtoe in 2020 and to 20.7 Gtoe in 2040. Attractive increase (90%) in energy consumption can be observed in the non-OECD countries (not belonging to the Organization for Economic Cooperation and Development), where demand is governed by strong, long-term economic growth. In the OECD countries, the increase is estimated at 17%. Proportionally, a serious environmental impact is expected (Köne and Büke, 2010).

Facing this situation, amplified efforts should be put to find realistic and permanent solutions. One of these solutions having major concern is the renewable energy development; however, despite all the achieved success, worldwide share of renewable energy is not very important (18% of global energy consumption) as demonstrated in Fig. 5 (Kumar et al., 2010). Another development field is improving energy efficiency in all sectors via implementing adequate strategies and measures. Certainly the combination of these two points while involving socioeconomic aspects will positively change the current status.

In what follows, particular attention will be addressed on reviewing the updated information of energy consumption in the building sector in countries with official data.

## 4. Energy in buildings

Usually, the building sector does not exist as a unique slice when categorizing the final energy consumption. In fact, a lot of energy agencies and organizations divide the final energy consumption into three main parts: industry, transport and 'other'. The term 'other' is vague and incorporates various sub-sectors. It regroups, according to the IAE, residential, commercial, public services, agriculture/forestry, fishing and non-specified consumption. Accordingly, the quantification of the energy consumption in buildings has often not been well estimated. However, buildings with their numerous types are surely responsible for a major part of

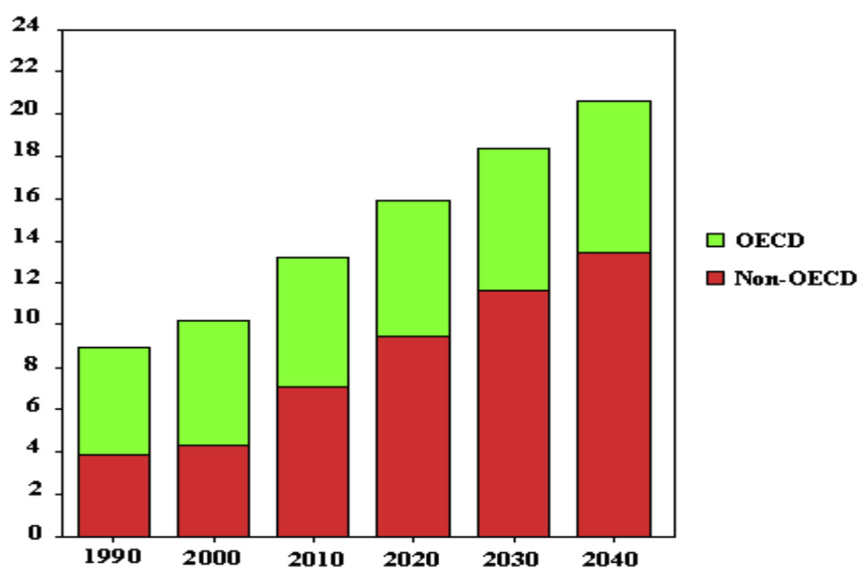


**Fig. 4.** World energy consumption past data and future estimations (Gtoe) (EIA, 2013).

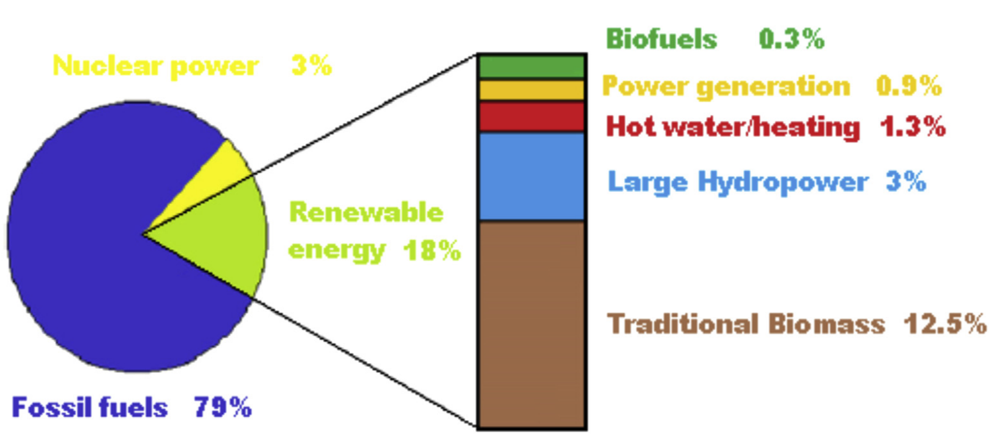


**Fig. 5.** Global energy consumption (Kumar et al., 2010).

**Table 2**
Evolution World final energy consumption by sector.

| Sector | 1973 (Reference) | 2001 | 2004 | 2011 | Mean variation ratio |
|---|---|---|---|---|---|
| Industry | 35.20% | 31.10% | 29.6% | 31.60% | −0.125 |
| Transport | 24.60% | 34.60% | 28.30% | 30.20% | 0.261 |
| Other | 40.20% | 34.40% | 42.10% | 38.20% | −0.0489 |

**Table 3**
Evolution of the world electricity consumption by consumption.

| Sector | 1973 (Ref) | 2001 | 2004 | 2011 | Mean variation ratio |
|---|---|---|---|---|---|
| Industry | 51.30% | 41.70% | 41.40% | 42.60% | −0.183 |
| Transport | 2.40% | 1.80% | 1.80% | 1.60% | −0.277 |
| Other | 46.30% | 56.50% | 56.80% | 55.80% | 0.217 |

the consumed energy by the 'other' sector (Tables 2 and 3). In Europe, commercial and residential buildings account for 38.7% of the total energy consumption. As a result, a variety of initiatives for energy consumption reduction were granted (Directorate General for Energy, 2009) like the Energy Performance Building Directive (EPBD) 2002/91/EC and its recast 36/EC/2010, launched in 2002 by the European Parliament and the council (Caldera et al., 2008; Boyano et al., 2013).

As mentioned before, the final energy consumption is time dependent. For instance, in the EU, energy consumption of the building sector has increased by around 1%/year since 1990, mainly in non-residential buildings (1.5%/year for non residential buildings compared to 0.6%/year for households (see Fig. 6 (Environment and Energy Management Agency, 2012))). From an environmental perspective, buildings are responsible for one third of global greenhouse gas emissions, both in developed and developing countries. Indeed, the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) estimated building-generated greenhouse gas emissions to be around 8.6 million metric tons $CO_2$ equivalent in 2004 (IPCC, 2007).

As well as the complexity encountered when analyzing historical data, the uncontrollable aspect of influencing factors such as: expansion of human activities, improving building services with high comfort level and geographical dispersion associated with population growth and so on, makes the prediction of this consumption so complex. Consequently, many recent mathematical models are developed, including elaborate and simplified engineering methods, statistical methods and artificial intelligence methods (Zhao and Magoulès, 2012; Pedersen, 2007; Foucquier et al., 2013). However, the uncertainty of the impacting parameters in energy use in the building does not generally lead to satisfying results.

### 4.1. Residential buildings

The residential sector includes all detached houses and attached dwellings (such as apartment complexes and town houses). In the recent decades, many factors have spurred **a** demand for larger homes and more energy services, increasing energy consumption in this sector, which averages approximately 30% worldwide (Saidur et al., 2007).

Socioeconomic development (amelioration of human comfort levels and entertainment activities), architectural design, geography and climate data are the main factors underpinning the energy consumption trend in residential buildings. Theoretically, a lot of developed models are applied to analyze these affecting parameters, Xu and Ang (2014) reported 20 analyzing residential energy consumption and energy-related carbon emissions studies using Index Decomposition Analysis (IDA). However, the non-controllability and the time-dependence aspect of these factors do not allow the identification of the causal character between the already mentioned factors and the energy consumption behavior. Thereafter, the main factors are discussed from a more realistic point of view, taking comparison between some countries via official energy reports with main results reviewed from the literature.

- Fig. 7 (EIA, 2011) presents a comparison between energy consumption in residential buildings in the US between 1973 and 2009. During this period, demographic (population growth and urbanization index) and socioeconomic (lifestyle and personal income) changes have influenced the evolution and categorization of the residential energy consumption.
- Other underlying forces driving the energy consumption in residential building are weather and geography. For example, Fig. 8 (Buildings Data Book; The Centre for International Economics, 2007) shows the consumed energy by end-use in separate locations: USA and Australia; referring to the same year (2007). It can be seen that, due the climate difference between Australia and USA, the heating applications consume a great part of the total energy consumption in Australia (62%) compared to the USA (43%).

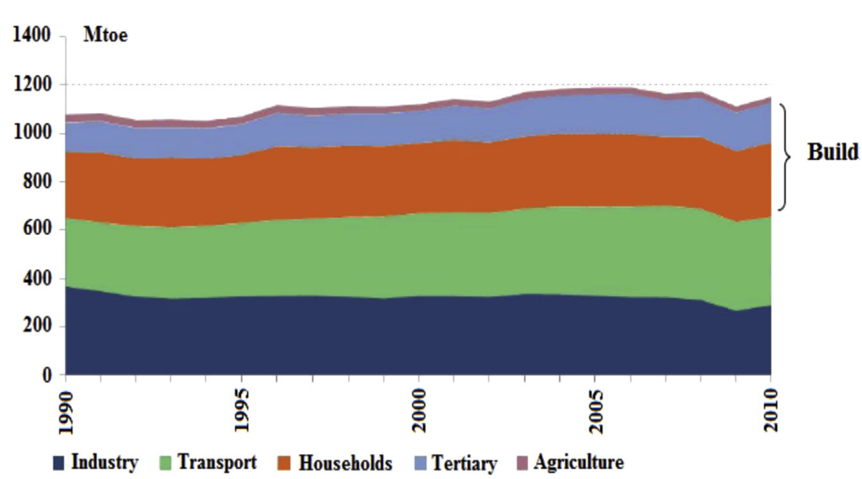


**Fig. 6.** EU energy consumption evolution (1990–2010) (Environment and Energy Management Agency , 2012).

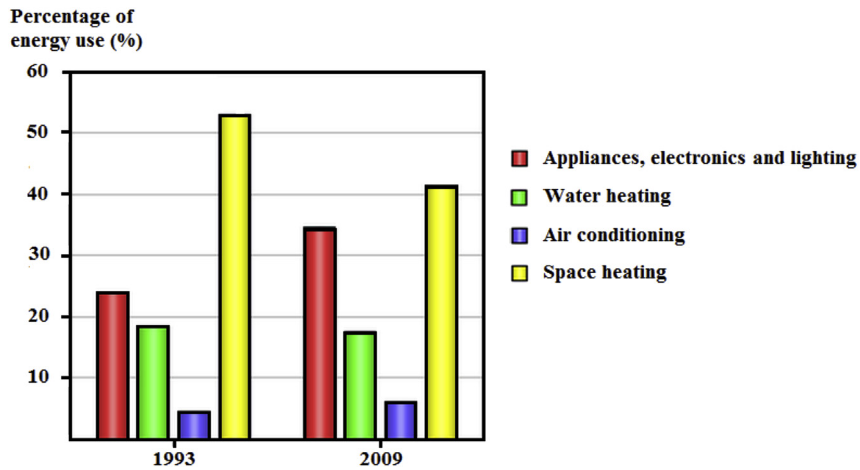


**Fig. 7.** US percentage of energy by end use: Comparison 1993/2009 (EIA, 2011).

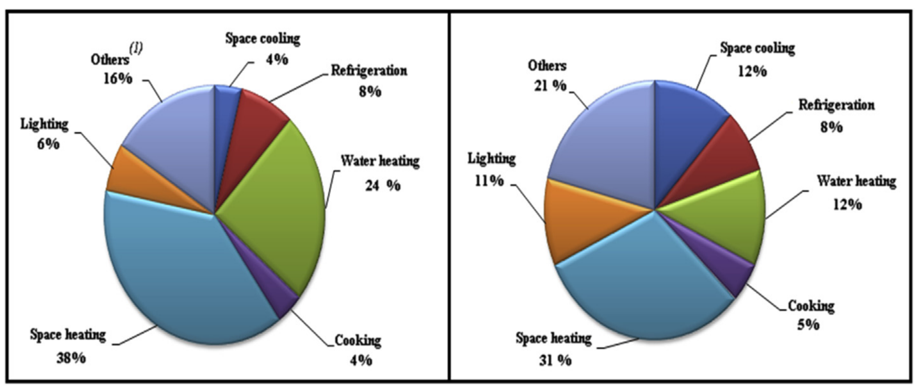


**Fig. 8.** Energy consumption by end-use in Australia (left) and US (right) (Buildings Data Book; Centre for International Economics, 2007).

- The demand for lighting is indirectly related to the daylight length (Hviid et al., 2008) which depends on the location. Fig. 8 shows also that lighting application covers 11% in the USA compared to 6% in Australia.
- The occupant behavior must not be neglected; it has a substantial impact on the amount of the consumed energy (Yu et al., 2011; Azar and Menassa, 2011; Sweeney et al., 2013). In fact, Dietz et al. (2009) reported that occupant energy savings have the potential to reduce US emissions by 7.4% with little or no impact on household well-being.
- Advances in energy efficiency measures are also determinants; according to the most recent Residential Energy Consumption Survey (RECS) (EIA, 2010) estimations, 48% of energy consumption in U.S. houses in 2009 was for heating and cooling, down from 58% in 1993. This change can be interpreted by adoption of more efficient equipment, better insulation and application of federal efficiency standards.
- Technological development impacts the society mentality conducing to new trends in the manner and the quantity of the consumed energy. Many studies (Sadorsky, 2012; Hilty et al., 2006; Røpke and Christensen, 2012) had argued the significant relationship between the development of Information and Communication Technologies (ICT) and electricity consumption.

Evaluating the evolution and the importance of residential energy building consumption from several sources, the followings were highlighted:

- In the USA, primary energy consumption in the residential sector totaled 54% of consumption in the building sector and 22% of total primary energy consumption in the U.S. Appliances and electronics energy consumption continues to rise. Actually, non-weather related energy utilization for appliances, water heating, lighting and electronics, accounts for 52% of the total residential consumption, compared to 42% in 1993 (EIA, 2010)
- In Australia, the energy consumption of the residential sector in 1990 was about 7.14 Mtoe and that by 2008 this had grown to about 9.60 Mtoe and is projected to reach 11.15 Mtoe by 2020 under the present trends. This depicts a 56% augmentation in residential sector energy consumption (Department of the Environment, Water, Heritage and the Arts, 2008)
- In China, the residential building sector consumed about 135 Mtoe in 2007 and is considered as the second energy consumer after the industrial one, representing 11% of national energy end-use (Chen et al., 2008; Zhao et al., 2012)
- In Europe, the residential sector is the second larger energy consumer sector (after the transport sector). For example, in the UK, it accounted for 29% of the overall energy consumption in

2009 (Office of National Statistics (2009)). According to the (**ODYSSEE)** database (energy efficiency data and indicators for the EU members); during the period of (1997–2010), a remarkable progression of the EU household energy use (0.5%/year) is observed, mainly due to a higher consumption for electrical appliances and lighting (+2.6%). However, it should be noted that energy consumption trends for the residential sector started to decrease in the last years due to the implementation of energy efficiency policies (European Commission, 2012)

- Electricity as a major source of energy in residential building; for instance, it will contribute to 53% of residential energy consumption by 2020 in Australia up, from 46% in 1990 (Department of the Environment, Water, Heritage and the Arts, 2008)
- The energy consumed by electronics and appliances becomes more and more significant; the wide development of ICT associated with the large propagation of entertainment activities may be the main cause for this tendency.

### 4.2. Commercial buildings

According to the U.S. Department of Commerce's (Bureau of Economic Analysis (2002)), commercial buildings cover office buildings, including financial buildings, special care buildings, medical buildings, multi-merchandise shopping, food and beverage establishments, warehouses, and other commercial structures. This categorization is not universal, associated to wide climatic and construction type variations, varying building/space types and floor area, which makes the comparison and the analysis very difficult (Hinge et al., 2004).

Therefore, after revising several sources, specific characteristics of the energy consumption in commercial buildings of some countries were concluded:

- The tendency of growth toward more specialized services and enterprise management in national economies leads to an increase of the share of national energy use held by the commercial sector relative to other sectors (Michael MacDonald, 2004).
- In the USA, commercial buildings consumed about 46% of the building energy consumption, with a grow rate exceeding 6% (see Fig. 9 **(Buildings Data Book))** and 55% of this consumption use electricity resource. Predictions show that this rate will reach 0.71% in future years.
- In the UK, the rate of growth in commercial energy consumption in the last 25 years has been approximately three times greater than in the domestic sector, and is projected to exceed the growth in all other sectors except transport (Scrase, 2000). Actually, it accounts for around 7.5% of the UK's energy consumption and about 10% of the total $CO_2$ emissions.
- During the last 30 years (1978–2008), the commercial building stock in China has grown by twelve times, from 0.53 to 7.05 billion $m^2$ (Xiao et al., 2012). Current statistics suggest that commercial energy consumption in China's is underestimated by about 44% (Zhou and Lin, 2008)
- Retail and office are the most energy intensive typologies in many regions (see Table 4 (Buildings Data Book; Council of Australian Governments (2012); Building Research Establishment, 2000)); in Australia (60% of the consumed energy in commercial buildings result from offices and retails).
- Generally, the predominance of HVAC systems as a high energy consumption application in commercial buildings is conspicuous (Lombard et al., 2008; Vakiloroaya et al., 2014; Zhao et al., 2013)
- The tendency in energy end use in commercial building differs according to the region, For example, in China, the largest growth occurs in the demand for lighting and other applications, such as office equipment, elevators, and other electric-powered equipment (Fridley et al., 2008). In the USA, the growth is more noticeable for HVAC applications, indeed, space heating/cooling consumed 37% of site energy in the commercial sector in 2010 (Department Of Energy, 2011).

**Table 4**
Energy consumption in commercial sector by building type (Buildings Data Book; Council of Australian Governments (2012); Building Research Establishment, 2000).

| Building type | USA | Australia | UK |
|---|---|---|---|
| Offices | 19% | 25% | 22% |
| Retail | 23% | 35% | 17% |
| Hotels | 7% | 11% | 16% |
| Education | 11% | 13% | 10% |
| Hospitals | 8% | 14% | 6% |
| Other | 32.00% | 2% | 29% |

## 5. Energy efficiency in buildings

### 5.1. Measures and policies to reduce energy consumption in buildings

As a response to the increasing trend of energy use in buildings, decision makers and public authorities around the world adopted policies and measures aiming to reduce energy consumption and promote energy efficiency in buildings (Painuly et al., 2003; Bull

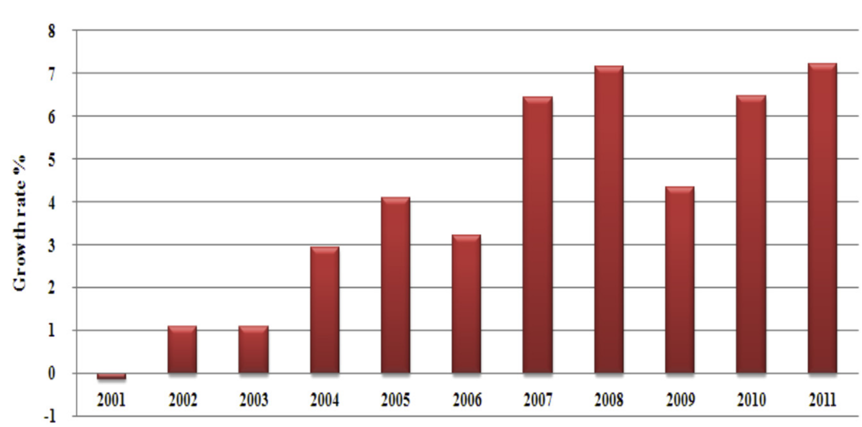


**Fig. 9.** Grow rate of energy consumption in the US commercial buildings (2000 as reference year) (Buildings Data Book).

et al., 2012; Mardookhy et al., 2014). These policies are widely different and can be generally split into three categories (Goeders, 2010; Atanasiu et al., 2012; Annunziata et al., 2013):

- Regulatory measures such as building regulations, which has mandatory aspects and include minimum requirements.
- Soft instruments which consist mainly of voluntary standards such as certifications go beyond the regulation requirements.
- Economic incentive which is deployed forward to motivate building owners and occupants to undertake refurbishment or renovation works in order to improve the energy efficiency of their buildings such as: Energy savings performance contracting, Tax exemptions/reductions, Capital subsidies, grants and subsidized loans (Goeders, 2010).

Understanding building energy policies requires specific technical knowledge which makes monitoring and evaluating the evolution of legal framework from a political viewpoint difficult. Therefore, the main goal of this section is limited to provide an overview of some established standards and measures, illustrating some examples and presenting their energy and economic impacts in some selected countries. Several barriers that were faced while implementing these policies are reported.

#### 5.1.1. *Building regulations*

Buildings thermal regulation, called also thermal codes (Pérez-Lombard et al., 2011; Bartlett et al., 2003), are a set of legal and mandatory requirements for building design and their compliance provisions during the construction period aiming at promoting energy performance of buildings (Bartlett et al., 2003; Laustsen, 2008). Building regulations usually include specifications for thermal properties of building envelope as the use of thermal insulation or double glazed windows. They can include also cover heating, ventilation, air conditioning (HVAC), lighting, electrical power, renewable integration and building maintenance. These legal frameworks are the most frequently adopted strategy to promote energy efficiency in buildings and are described as a proven and a cost effective measure (Pérez-Lombard et al., 2011; Laustsen, 2008). Casals (2006) reported that two main factors decide the success of a building energy regulation in effectively controlling the energy consumption: First, the adopted energy performance indicator on which is based energy consumption calculations and energy efficiency evaluation. Accordingly, Santos et al. (2013) showed that an evaluation of building energy performance based only on final energy calculation can cause a distortion in the identification of options that truly preserve natural resources and minimize environmental impacts. The second factor is the promoted energy assessment tools which is a main key factor that defines the relevance of any building energy performance evaluation. Below is a resumed overview of different building regulations and technical framework adopted in different countries.

In Europe, the Scandinavian countries were the first to introduce thermal building requirements to improve energy efficiency and comfort in buildings. For other European countries, reducing energy dependence after the oil crisis in the 1970s was the main motivation to set building thermal regulation (Pérez-Lombard et al., 2011). Since the Energy Performance of Buildings Directive (EPBD) in 2002, all Member States of the EU were required to introduce a general framework and to set a building energy code requirements based on the global building approach (Laustsen, 2008; Annunziata et al., 2013). After the EPBD in 2002, regulation requirements have progressively shifted to a performance-based approach instead of the prescriptive approach. This shift is regarded as a major change in the EU building code trends. With the recent recast of EPBD in 2010, important changes are also expected through the incorporation of the new cost optimality concept in technical and legal framework for energy in buildings (Laustsen, 2008; Andaloro et al., 2010; Atanasiu et al., 2012; Annunziata et al., 2013). These requirements cover building energy performance, harmonized calculation methodology, energy certification and HVAC systems inspection. One of the strengthened requirements introduced by the last EPBD recast is the obligation for all new buildings to be nearly zero-energy by the end **of 2020**.

Despite considerable efforts to harmonize thermal codes between EU Members States, some studies highlighted the large differences among results achieved in improving energy efficiency in the building sector (Ekins and Lees, 2008). Annunziata et al. (2013) reported four key factors which are the **sources** of this heterogeneity:

- Authorities involved in energy regulations
- Existing building regulations and execution models
- Difference in contextual characteristics
- The country's maturity in the application of energy efficiency measures.

Therefore, the European Commission has adopted a range of programs with the aim of supporting Member States during the implementation of their national building regulation (Ekins and Lees, 2008). The USA energy strategy was, from the first adopted framework in 1975 (ASHRAE 90-1975), remarkably different than EU policy. This difference is due to the fact that it heavily focused on energy conservation issues from their early conception (Pérez-Lombard et al., 2011).

Generally, the USA state building codes are based on two model codes which are developed in collaboration between the US Department of Energy (DOE) and by private organizations: the ASHRAE standard developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers and International Energy Conservation Code (IECC) developed by the International Code Council. These two standard codes are based on prescriptive efficiency requirements for each part of the building and installations. As the implementation of building energy codes are the responsibility individual states, in most states the ASHRAE is usually adopted for large and complex buildings and for trade and service buildings while the IECC is used for small residential and simple buildings (Laustsen, 2008; Liu et al., 2010). One of the important key to the success of USA energy efficiency policy is the cooperative contribution of public and private organizations, professional societies and manufacturer associations (Pérez-Lombard et al., 2011).

In Asia, rapidly developing economies, essentially India and China, look to reduce the dramatic increase of energy consumption in buildings due to the fast urbanization rate. In China alone, more than 2 billion $m^2$; are constructed every year (Laustsen, 2008), and this rate accounts for more than 40% of all new constructions in the world. China was a pioneer to introduce the building standards in the region. In 1980, the Chinese national government decided to set the first building regulation for the northern residential sector, which spread to all regions by 2000 (Ye et al., 2013). Chinese building standards for commercial buildings were mainly aligned with the ASHRAE 90.1 Standard. The recent building code for all of China consists of different requirements for five different climatic regions and for residential and commercial buildings. Liu et al. (2010) presented five influencing factors that helped the national Chinese Government to set and implement these standards. Many studies discussed buildings energy consumption situation in China, as well as national government policy in promoting energy efficiency and encouraging sustainable buildings (Kong et al., 2012; Ye et al., 2013).

In India, the first stand-alone thermal code for new buildings was adopted in 2007 which targeted exclusively large commercial buildings that have, at least, a connected load of 500 kW or a contract demand of 600 kVA (Tulsyana et al., 2013). The Indian thermal code is called Energy Conservation Building Code (ECBC), and it consists of a prescriptive and energy performance methods and sets requirements for different building components such as air conditioning, artificial lighting, envelope, water heating, etc. The ECBC was based on the ASHRAE code and the Californian building code and was updated in 2010 by the Energy Conservation Act (Government of India, 2010). The indian residential electricity consumption in has known an increasing growth, so more effort should be put to promote energy efficiency by extending the ECBC standards for residential buildings (Liu et al., 2010).

The Australian building code is set by the national government as a voluntary standard. To be a mandatory regulation, it has to be adopted by the federal states. The current thermal code adopted for residential and commercial buildings consists of a 6-star rating system to assess the building energy performance. This stars system is reported to have a successful effect on driving the national market to a higher efficiency than minimum requirements (Kordjamshidi, 2011). Moore (2012) reported that the weak point of the Australian housing policy is the lack of innovation and communication between stakeholders in addressing sustainability challenges.

### 5.1.2. Building labels and certifications

Since building codes set minimum requirements for energy efficiency in buildings, several countries have developed voluntary standards, encouraging sustainability and higher energy efficiency buildings (Carlo and Lamberts, 2008; Andaloro et al., 2010; Franzitta et al., 2011; Díaz et al., 2013; Ye et al., 2013). These standards, also called Labels or Certifications, have, generally, more forward-looking requirements and could include also some environmental specifications.

In general, all these certifications and labels, even if they have different methodologies. Energy assessment tools and calculation methods tend to target one of the following buildings energy concepts: Low Energy Buildings (Abel, 1994; Hui, 2001; Mahdavi and Doppelbauer, 2010), Passive Houses (Schnieders and Hermelink, 2006; Sadineni et al., 2011; Zhang et al., 2013; Ye et al., 2014), Zero Energy Buildings (Lund et al., 2011; Bourrelle et al., 2013; Li et al., 2013; Mohamed et al., 2014), Zero Carbon Buildings (Webb, 2001; Xing et al., 2011; Marszal et al., 2011) and Positive Energy Buildings (Bojić et al., 2011; Kolokotsa et al., 2011; Miller and Buys, 2012).

There are many green building assessment tools such as: Leadership in Energy and Environmental Design (LEED, United States), BRE Environmental Assessment Method (BREEAM, United Kingdom), Green Building Council of Australia Green Star (GBCA, Australia) (Zuo and Zhao, 2014).

- BREEAM was the first green building assessment tool to be launched in 1990. It sets the standard for best practice in sustainable building design, construction and operation (**BAREEAM**).
- The BREEAM's strategy aims to minimize the life cycle's environmental impacts, allow recognizing buildings based on their environmental performance, stimulate the search for sustainable buildings and provide a credible building certification (Ferreira et al., 2014).
- The BREEAM assessment of a project is carried out by a licensed independent assessor who ultimately gives the building a final BREEAM score and rating (Lowe and Watts, 2011).
- The main disadvantage of BREEAM's rating system is the complicated calculation process. This calculation is performed based on various calculators and is followed by different weighting scores for each category involved in the assessment. This makes the calculation less transparent.
- LEED (Leadership in Energy and Environmental Design) is an internationally recognized green building certification system that was introduced in 2000 by the US Green Building Council (**USGBC**). LEED is a rating system based on an integrated design approach combining energy use reduction, indoor environmental quality improvement and sustainability. The process of certification starts by gathering information about the building by design team members or by LEED Accredited Professionals or LEED Green Associates. After the verification of project compliance with LEED requirements, the certification is decided exclusively by the GBC Institute. Evaluation of energy savings for LEED certificate buildings is a subject of scientific debate. For example, in 2008, after the New Buildings Institute (NBI) published their study, in which it concluded that LEED certification reduces energy use by a 25–30% (Turner and Frankel, 2008), many researchers criticized these results and the methodology adopted. Since then many studies investigated the energy savings of LEED certified buildings and calculation methodology (Scofield, 2013; Newsham et al., 2009; Stoppel and Leite, 2013).
- The Green Star rating tool was introduced by the Green Building Council of Australia in 2003. Green Star evaluates and rates buildings, fitouts and communities against a range of environmental impact categories (GBCA, 2013). These categories include management, energy, indoor environment quality, water, materials, transport, land use, site selection and ecology and emissions (Seo et al., 2006). Buildings are assessed using a 1 (minimum practice) to 6 (world leadership) star rating system. However, this tool concerns only commercial buildings (Ding, 2008).

## 5.2. Impact of energy policies

It is difficult to evaluate with accuracy the real economic, social or environmental impact of an energy policy, especially when there is a number of limitations and uncertainties as the free rider effect, the rebound effect, hidden costs and hidden impacts (Boza-Kiss et al., 2013; Santos et al., 2013). Accordingly, a quantitative evaluation of an energy policy and its cost-effectiveness is a complicated exercise (Boza-Kiss et al., 2013). Moreover, many authors showed that energy efficiency measures can lead to contrasting results by increasing energy consumption in buildings (Brookes, 2004; Jevons, 2009; Khademvatani and Gordon, 2013; Saunders, 2013).

In a micro-level analysis, there are two main arguments to consider: first, the net energy benefit taking in consideration the cost of energy savings and the increase of building value due the application of energy efficiency solutions (Kok and Jennen, 2012). Boza-Kiss et al. (2013) investigated the results of **numerous policy evaluations** to allow actual quantitative comparison of the economic cost-effectiveness on the societal level and the environmental effectiveness. They concluded that all reviewed policy instruments have the potential to cost-effectively increase energy efficiency in buildings.

Several benefits of setting buildings energy efficiency policies for governments can be retained. Beside reducing energy consumption, energy dependence and $CO_2$ emissions, it contributes also to create new jobs, improve occupants' comfort and increases asset values (Ryan and Campbell, 2012). In what follows, some general tendencies of the impact of adopting energy efficiency measures in the building sector are briefly reported based on the succesfull experiences of developed countries such as USA and EU.

According to the Analysis of EIA's Residential Energy Consumption Survey (RECS) conducted since 1980, it was put in evidence how improvements in energy efficiency in the residential sector reduced energy intensity considerably to offset about 70% of the growth in both the number of households and the size of dwellings.

An interesting example to cite, related with the economical benefit of implementating energy efficiency measures in buildings is that of The Warm Front home energy efficiency scheme introduced in the United Kingdom that has a budget of USD 573 million and delivered a potential USD 952 reduction in energy bills for each of the 127 930 targeted households (DECC, 2011). Furthermore, this scheme has ameliored building energy performance ratings by an average of 27 points.

Very recently, Broin et al. (2015) analyzed the correlation between European energy efficiency policies and the demand in space heating in the residential sector for the period 1990–2010 using a fixed effects static panel data model. The results showed that the reduction in energy consumption due to regulatory policies is estimated at 5.8%, 5% for the financial policies and 0.5% for informative polices. One of the main findings of the authors is that regulatory policies reduce demand in the year in which they are introduced and for at least 7 years thereafter.

### 5.3. *Barriers to energy efficiency implementation*

Regardless of the sector nature, energy efficiency barriers are derived from the apparent contrast between the possibilities of reduction in the energy consumption and the real investments allocated by the concerned parties. These barriers are the main cause of "the efficiency gap"or "efficiency paradox" (Jaffe and Stavins, 1994; Kounetas and Tsekouras, 2008; Chai and Yeo, 2012). It is difficult to detect energy efficiency barriers independently **from** the characteristics of the country. The existing barriers may be common worldwide, nevertheless, some points are more prounced in the case of developing countries (Sarkar and Singh, 2010; Suzuki, 2015). In the building sector, these barriers are primarily political, but also technical, financial and related to a lack of information and awareness of key actors and stakeholders. The main barriers are classified and summarized below:

#### 5.3.1. *Economical barriers*

According to a recent survey (2013) conducted by the Rexel Foundation and Opinion Way concerning USA, UK, France and Germany, 63% of residents express that cost and other financial considerations are deterring them to the application of energy efficiency measures. High equipment costs, limited access to investments and the non-adequacy of the current financial models of micro-credit institutes with energy services and products can be described as the main financial obstacles. It is also important to notice that energy efficiency policies can generate some invisible extra-costs such as maintenance and transport. These barriers are certainly more pronounced in the case of developing countries.

#### 5.3.2. *Political and institutional barriers*

While some states have made significant strides on energy efficiency in the building sector, a great part of the world is becoming more conscious about the topic and is developing initial programs and policies to diminish their energy bills. But also, in several parts of the world, governments are preoccupied with short term concerns, especially in the case of economic or political instability. Moreover, the energy-efficient buildings implementation is a long process and requires the involvement of several institutional operators in the country. The non-rigorous administrative planning and the little synergy between public and private authorities associated with the lack or absence of subsidies to building owners keep these policies far from the real application. As a result, almost all of the new buildings in southern and eastern Mediterranean countries does not include thermal insulation (Sénit, 2008).

#### 5.3.3. *Social barriers*

In the building sector, as we highlighted previously, the social parameter (behaviors, lifestyle and culture) is one the most influencing factor in energy consumption, equally, it can be considered as a real obstacle of energy efficiency: Energy waste comportments and unconsciousness of the current energy and environmental issues are the most important manifestations of the social barrier. Sometimes, small actions can contribute significantly to the energy consumption reduction; however, these accessible opportunities are often ignored by consumers (Chappell's and Shove, 2005). The behavioral aspect draws its features from the human mentality which is nowadays very impressed by the media. Unfortunately, in such topic, the media does not play its expected role which is the wide dispatching of knowledge and positive practices relative to energy efficiency issues to the general public.

#### 5.3.4. *Other barriers*

If the energy consumption is not well quantified or the future gains of energy-efficient standards are not well valued, the shareholders do not see the interest of investing in energy efficiency. Accordingly, imperfect data and information is a serious obstacle encountered by several countries in the implementation process. Likewise, the technological aspect is also significant. In fact, there is a lack of appropriate production technologies (LAPT) generally, in developing countries and the manufacturing of sustainable energy products is insufficient. Furthermore, the continuous change in professional practices is often added to the technical complications of energy regulations at the construction stage.

The climate conditions (if we talk about renewable energies) and the time constraint can be also listed among the energy efficiency barriers.

### 5.4. *Suggestions to remove the barriers*

The removal of barriers and barriers interaction facing the implementation of energy efficiency in the building sector is necessary and must be taken seriously. Possible suggestions are listed below:

- The co-implication of all actors (institutions and individuals) to the implementation of energy efficiency policies.
- Reaserch for finanicial support via establishing paterships with international bodies and institutions in order to overcome the economic barriers.
- Reducing transaction costs by using market-based regulatory instruments like Energy Performance Contracting (EPC). EPC allows the payement of energy efficiency instruments from the estimated economic benefits.
- Research for complementarity between the state and private sector in order to fill the technological gap and ensure the effectiveness of energy efficiency measures
- A global sharing of new technologies using renewable resources.
- Local energy audit programmes in public buildings.
- Media involvement in the energy and environmental issues for more awareness of the customers.

At the reaserch level, in our sence, systematic methods for analyzing shortcomings in energy efficiency policy in the building sector must be proposed.

## 6. Conclusion

The continuation of the greenhouse gas emission at the same pace will certainly lead to a catastrophic situation, which makes the world now living a historic turning point in the field of energy and environment. The building sector with its high energy consumption needs more attention and effective actions. Therefore, the continuous monitoring and the complete comprehension of the key factors impacting the buildings energy use are required.

Fortunately, this sector holds a highly concentrated potential for diminishing energy consumption: boosted by a global increasing concern, energy efficiency must be the ideal solution for the 21st century world's energy challenge. Consequently, several countries adopted different policies and measures to promote energy efficiency in buildings and some have already reaped the resulting benefits. However, such issue is not yet seriously undertaken in a large part of the world first because of the lack of awareness about the present energy and environment challenges, then because of preoccupations such as political and economic stability. Surely, the salvation from the current situation requires the involvement of all nations in the frame of a unified vision: preserving the earth for the future generations.

Through this work, the topic of energy consumption in the building sector was treated from several aspects:

- Actual situation: by reporting up-to date information of energy consumption in the building sector via gathering maximal official data from several resources.
- Future trends: The revision of the future estimation concerning the energy consumption in the building sector for both residential and commercial activities allows to conceive the next needed efforts to be undertaken by policymakers in different parts of the world. This information is also useful to evaluate beforehand the impact of energy policies adopted.
- Analysis of the main factors influencing the energy consumption in buildings: In order to understand how energy consumption is varying according to time and space, it is necessary to regroup and conduct a multi-aspect analysis of the historical data and the future estimations. This analysis give the possibility to detect the key factors impacting the energy use in this sector.
- Energy efficiency policies: Actualy, policymakers are completely aware that one of the main ways of reducing energy consumption and $CO_2$ emissions is to increase energy efficiency in the building sector. In this paper, buildings thermal regulations and labels and certifications were reported and discussed in detail.
- Barriers to energy efficiency in buildings: Regrettably, the implementation of energy efficiency measures comes across different obstacles. They are classified as economic, social, political/institutional and others.
- Possible suggestions to remove the barriers of energy efficiency in buildings

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