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The historical evolution of the energy efficient buildings

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ABSTRACT

The today energy efficient buildings are mainly related only to the available standards when their performances are described. This approach is correct just in terms of formal qualification to meet the requirements of the statutory rules and give people confidence. Beyond these facts, todays energy efficient buildings have to be known not only in the context of the existing technology, but also in the evolution of the equipment and the design concept used in synchronization with the contemporaneity of the science. In this paper, a historical laborious presentation of the techniques and concepts evolution that lead to energy efficient buildings as we know them today, is presented. An overview of the modern approach for the design of the main elements of such type of buildings is also presented. The paper realizes a review of the current state of the energy efficient buildings, in terms of definitions and characteristics.

Contents

1. Introduction

Nowadays in Europe, the building sector is responsible for about 40% of the total primary energy consumption [1] and there is a significant potential in the energy consumption reduction. In this respect, highly topical analyses and interventions are related to energy savings while ensuring adequate comfort conditions. This is called energy efficiency of building. It accomplishes two important goals of sustainable development while reducing energy demand, namely, primary resources economy and reducing emissions to the environment.

In order to develop new technologies and strategies for improving energy efficiency in buildings, their evolution throughout history is important to be known. Only based on previous experiences and knowing the barriers encountered by predecessors, the progress can be fulfilled. Without understanding the evolution of the energy efficient buildings, new concepts and new solutions to reduce energy consumption in building sector will be hard to imagine.

A study of the historical evolution of the energy efficient buildings is necessary for a better understanding of changes made through time with the aim of improving comfort and optimizing the energy consumption. Generally speaking, people are aware of the need to apply new concepts, standards and laws when they are presented in contrast with old ones. Scientists accept new concepts rapidly if they are based on the results of specific equations or experiments. On the contrary, regular people accept them because “the present standard/law imposes the solution” or just because they are “topical” and promoted by mass-media. An intellectual, regardless its specialization will always desire to understand the stream of thinking and will not accept a concept as an axiom. He will explore the evolution of technology in time, to get to the roots.

On the other hand, this kind of studies induce a demystification of some arbitrary practices, called “rules of good practices”, that

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sometimes are controversial. Sciences like philosophy, arts, mathematics, physics, engineering have dedicated studies of their historical evolution and this fact encourage related studies for the domain of energy and energy efficient buildings.

This paper presents, beyond the chronological aspects, an exposure that facilitates the awareness of the historical evolution of the energy concept applied to the buildings. Indoor comfort is not achieved unilaterally to fulfill certain ergonomic demands but it is inherently followed by economical optimization and increasing of energy efficiency.

Undoubtedly, the evolution of the concern in the energy efficiency of buildings over time has many dimensions and ramifications, but the purpose of this study is only to emphasize the key moments in the evolution of energy efficient buildings. It covers issues that have had an important impact, durability of use and mass adoption. There are many techniques to improve the energy efficiency of the buildings and this study does not aim to present them all, because the evolution of the concepts is intended to be observed globally. This paper tries to identify the degree of impact and of innovation at their time, related to the energy consumption reduction. It also presents the degree of preservation and classicization and how much are found in the exigencies of the present, aiming to find some invariants of design.

The requirements defined for buildings are not recent findings. They are the outcome of science and mentality evolution throughout human history in the broadest sense, with an acceleration of change and innovation on buildings beginning with the 19th century.

The concern for energy efficiency always exists in a latent form but awareness of this issue has occurred in the 19th century, when the main sciences underwent a sensitive differentiation and took the form known today. The 20th century helped to insert into the collective mentality through media, standardization and regulation, the importance of energy efficiency. The 21st century is found in the conjuncture of widespread energy concerns in most areas of science and technology.

After passing through the oldest time of building technologies, from thermal point of view, up to the contemporaneity, this paper will insist especially on the period that began in 1990s with the design of passive houses, exposing the technics, requirements and exigencies of the new designs and concepts.

This paper is elaborated by authors mainly in the context of the experiences accumulated during the designing and building of the passive house constructed in the campus of University Politehnica of Bucharest.

The energy efficiency of a building is mainly related to two components: passive properties – given by thermal insulation, captured solar radiation, natural ventilation, shading; and active properties given by equipment of capture, conversion and use of energy (renewable energy). In this regard, the trends of used design and its usefulness as comfort and cost for the people that benefit from it must be explained.

2. Historical evolution of the technics and concepts of the energy efficient buildings

The purpose of this section is to make a historic journey in order to highlight various ingenious solutions in building houses used over time with benefits in terms of comfort and energy. The main text will reveal the most important aspects of the evolution and the information will be presented in a smooth way to keep the continuity between distinct events. More events about the history of energy efficiency of the buildings are shown in Table 1 where the information is chronologically summarized.

Since ancient times, man has found ways of using and converting natural mechanisms to improve the living conditions and among them are the houses and their construction techniques.

Even if the "energy efficiency" was not a common term as it is nowadays, before the 20th century, people have created and transferred from one generation to another the good practice codes. Therefore the method used to build a house was based on previous experiments. At that moment, this was a satisfactory method to improve and to preserve certain construction techniques.

Each age brought something new or improved the existing techniques, but a remarkable fact is that systems based on renewable sources of energy used nowadays have ancient forerunners.

It is found that in 5500 BC in the region of Carpathians [2] people used the solution of the houses built partially buried, obtaining in this way a more stable indoor temperature. Benefits of the ground thermal properties were also used later in the houses of the Cappadocians, Essenian communities from Middle East and Native Americans. An evolution of those designs has to be remarked in the Persians' "badghir" (wind tower) [3], where in dedicated routings the wind and ground energy were employed to assure indoor comfort. A similar technique, but only using wind energy can be found in the Egyptian's "malqaf" (wind catchers) [4]. An improvement in the thermal comfort by the wall's structure design was materialized by Egyptians using thick brick walls or tiles [5] (that have also special acoustic properties) and later by Greeks and Romans who used cavity walls [6]. Romans also used the heating with burning gases that flows through cavities in the floor or the walls [7]. These elements with high thermal mass actively keep the indoor temperature at a comfortable level for a longer period of time. Windows covered with mica were also an active way to preserve a pleasant temperature of the inside air by trapping the solar radiation. This solution conducted to special design of rooms in Roman Empire, namely "Heliocaminus" [8].

The Ancient times had brought real gains to the buildings sector. They were considered traditional, a form to express aspects of the national identity and they were preserved through centuries, including Middle Ages. Renaissance brought to the fore and accentuated the values of the Ancient times and marked various fields from culture to science, architecture and technologies.

The 19th century marked the maturity of classicism in science and progress also occurred in the domain of buildings. This was one of the most important ages of the scientific discoveries by classic meaning. Scientists not only materialized the technical innovation but also formed a fundamental scientific base by various treatises, books, dissertations, etc.

In the last decade of the 19th century, the scientific works in the building field implied studies of the thermal insulation effect in the heat transfer domain, formation and transport of the moisture in the walls, multilayer configurations of windows, etc. At this time, the preheating of the air at the service room located in the basement became a common method. In this way the ventilation process was being initialized by convective circulation of the air towards the top floors.

At the beginning of the 20th century, the researchers already had the theoretical and technological foundations to achieve naturally the desire of a future energy efficient house. Carrier invented the electric equipment of air conditioning and later issued a psychometric diagram.

"House of Tomorrow" of George F. Keck and "MIT Solar House 1" of Hoyt C. Hottel built in 1930s demonstrated the important heat gains from the Sun [9,10]. The two buildings started the stream concept of energy efficiency in buildings based on scientific methodologies of calculation, strategies of design and construction. Thermal design of the components and the equipment such as solar collectors were the keys of these buildings. Later on, the number of technical solutions had been increased. The enhancement of the

Table 1
History of the thermal strategies evolution in buildings

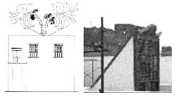
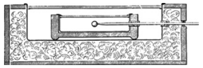
Period	Location	Project/concept/equipment description
≈ 5500 B.C.	Dacia (Romania)	In the Carpathian region (≈ 5500 B.C.), people used to build “bordei” or “coliba” houses [2]. This type of house was partially or totally built in the ground. The technique was very useful in keeping a constant indoor temperature during the year. 
≈ 4000 B.C.	Persia (Iran)	Wind Towers (Badqhir) – used wind effect in order to introduce the outside fresh air inside the building through an underground water canal (qanat) where the evaporative cooling occurred [3,35,36]. 
≈ 3100 B.C.	Egypt	Construction of the walls by thick brick as thermal insulation to keep cool the indoor air [5].
≈ 3100 B.C.	Egypt	Thermal insulation of the walls through an air cavity that separates two masonry walls [6].
≈ 2650 B.C.	Egypt	Ceramic “Tile” (Latin origin of the word “to cover”) used in passages of Pyramids due to their properties of thermal and sound insulation.
≈ 2500 B.C.	Egypt	Cooling of the rooms by evaporating water [37]. 
≈ 1300 B.C.	Egypt	Houses with wind-catchers (“Malqaf”) [4,38]. 
≈ 500 B.C.	Greece	Houses oriented to the South as usual rule – “Socratic Houses” [8]
≈ 500 B.C.	Greece	Cavity Walls often used by Greeks, a solution that Egyptians discovered earlier.
≈ 400 B.C.	Roman empire	Heliocaminus – South oriented room with windows covered with mica to trap indoor the solar thermal radiation [8]; “Greenhouse Effect” usually created in buildings by applying “mica” on the windows surface. “Hypocaust” heating system – an under floor heating system with burnt gases circulating through floors with big thermal mass [7]. 
≈ 400 B.C	Roman empire, middle east, Persia	Solar chimneys used for natural ventilation of the house. Chimney compartment is placed on the southern side of the house. The sun energy is passively captured by the ventilation air. The stack effect generates the air circulation through an underground pipe where it is cooled.
≈ 100 B.C.	Palestine	Communities of Essenes were living in upgraded caves – benefiting from the cooling effect of the ground in summer.
≈ 50 A. D.	Roman empire	Romans used the hot springs for baths and also to heat their homes.
≈ 400 A.D.	France	Systems of water distribution from geothermal springs [39].
≈ 600 A.D.	USA	Native Americans build houses in rocks oriented to the South (the practice was much older than the time of colonialism) [40]. 
≈ 900 A.D.	Iceland	Turf houses were built for the first time in Iceland between 800 and 900. Natural elements such as strips of turf, stones, mud were used to build the houses [41]. Wood crisis of 1700s constraints Iceland people to return to the traditional turf houses. 
≈ 1200s	China	Traditional houses Toulu in Southern China [42]. This type of buildings has properties encountered in passive houses. The heating and cooling systems were not necessary. 

Table 1 (*continued*)

Period	Location	Project/concept/equipment description
≈ 1500s	Italy	Leonardo da Vinci built the first mechanical air cooler, containing a partially submerged wheel moved by a stream of water. The air cooled by evaporating process of the water was introduced in the house [37]. He constructed also the first hygrometer (containing a ball of wool) to determine the level of humidity [37].
1760	Swiss	Horace de Saussure built first solar collectors; its design prototype is used also in present [9]. 
1800	Germany	William Herschel discovered infrared radiation.
1855	Russia	Franz San Galli inspired from the designs of thermal radiators available at that time, invents the cast iron radiator based on hot water. The radiator is the forerunner for present designs of hydronic radiators.
1865	USA	Thomas Stetson patents double layer windows that assure a more stable temperature in the room [43].
1882	USA	Nikola Tesla invented the electric fan and later it was found the ingeniously solution to cool the indoor air by putting ice in front of the air current, thus increasing comfort during summer [44].
1883	Norway	Polar ship “Fram” of Fridtjof Nansen by its construction design (air tightness, thickness of the walls, triple panel windows, and ventilation) makes possible the absence of a heating system. The thermal design principles of “Fram” are considered very closed to those of a present “passive house” [45].
1890s	Europe, North America	Scientists started to investigate the thermal insulation of different type of systems and made evaluations of the humidity transport in walls. Use of double panes windows began to be widespread.
1891	USA	Clarence Kemp invents first commercial solar water heater consisted of several 25-gallon cylindrical water tanks painted black inside a hot box (Climax Solar Water Heater) [46]. The house of Walter Rosen uses it in 1896. 
1902	USA	Willis Haviland Carrier invents the electric equipment for air conditioning, controlling the temperature and humidity by passing the air through a network of cold or warm pipes [47].
1904	USA	Willis Haviland Carrier designed a psychrometric diagram of the moist air at constant pressure [47].
1904	Italy	Piero Ginori Conti builds the first electric plant having geothermal energy source.
1907	UK	Hydronic radiant floor heating with iron pipes.
1920s	USA	Heating by electric resistance becomes very popular.
1923	France	Richard Mollier proposes the diagram h–x (enthalpy–humidity ratio) used for the representation of the comfort zones.
1930	Germany	Vacuum insulation panel (VIP) is patented in Germany and later, in 1970s with some design modifications it is used for buildings due to its high insulation properties and compactness [48].
1933	USA	George F. Keck builds the “House of Tomorrow” at “1933 Century of Progress Exposition” from Chicago, demonstrating that the indoor air is kept warm in clear sky days of winter by using walls of glass.
1935	USA	It is commercialized first room cooler in a compact shape looking like a piece of furniture [44].
1937	Switzerland	It is proposed “Crittall” system of radiant heating and cooling by embedded pipes in the floor.
1939	USA	At MIT University, H. C. Hottel builds Solar House #1 based on solar collectors and water accumulator, demonstrating the heating of the house in winter [13]. The series of MIT houses continues until 2007 when at “Solar Decathlon” from USA was built MIT Solar House #7 that is able to produce more energy than it is consumed. 
1946	USA	First ground-source geothermal heat pump, installed at geothermal source of energy at commonwealth building of Portland, Oregon [49,50,51].
1946	USA	Russel Ohl discovers P–N Junction and in the same year, based on his discovery, it was developed and patented the first silicon solar cell able to produce electricity when it is exposed to the light.
1949	USA	Telkes and Raymond, in Dover (Massachusetts), demonstrate the thermal storage in a phase changing material (Glauber Salt NaSO4.10H2O) that will become usual in 1973 for the design of the walls passively heated by the Sun [10].
1950	USA	Giese and Downing used an air to air heat exchanger with heat recovery for an animal shelter. The result was a drastic reduction of the heat loss by ventilation in the winter [52,53].
1950	USA	First radiant ceiling panel heating system.
1953	Canada	Hutcheon considered the air tightness of the buildings from the preoccupation to reduce the condensation in the walls [26,54]. Two decades later the air tightness is associated further with the reduction of the heat loss.
1955	USA	Bliss builds in Arizona dessert a house on a rock bed with thermal storage of the energy from the sun [10].
1960s	USA	There are issued methods for estimation of the energy consumption in buildings based on weather data with increasing use of computer to process them. Later are developed advanced methods like Degree-Day, Bin, Modified Bin, etc.
1967	USA	Fanger proposes a comfort model that is the most widely used today. There are taken into consideration several types of heat transfer body-environment and the subjective perception of the comfort by statistical algorithms.
1970s	USA	The term “sustainability” appears in economy. Edward Barbier (1987) uses for the first time the notion of “sustainable development”. The United Nation's “Brundtland Report” gives a definition that takes into account the present needs without compromising the needs and preoccupations of future generations. In 1992 publication “Environmental Building News” presents a guide of “sustainable construction”.
1972	France	Felix Trombe builds a wall with external surface covered by a glass layer delimitating an air space – the effect is the trapping of thermal radiation of the sun. Earlier, in 1881, American Edward Morse describes and patents a similar type of wall [55].
1973	World	Oil crisis caused by Arab states members of OPEC with big increase in oil price. This event caused the amplification of interest in buildings energy efficiency.
1975	UK	Brenda and Robert Vale publish “The Autonomous House”, a technical guide for developing housing solutions that are energy-self-sufficient, environmentally friendly, relatively easy to maintain, and have a traditional appearance. They also define the “Green House” concept [14].
1975	Germany	Horster and Steinmuller build in Aachen “Phillips Experimental House” [19], a super-insulated experimental house equipped with ground heat exchangers, controlled ventilation, solar and heat pump technology. 
1975	Denmark	Esbensen and Korsgaard build at Technical University of Denmark “DTH zero-energy house” and launch the term “Zero Energy House” [20,21]. Specifics: super-insulated (12… 16 mm thickness), air to air heat exchanger (80% efficiency), Double Panel Windows, solar collectors with water storage tank. Air infiltration in the envelope was considered, but at sub-evaluated values of 0.03…0.15 h^{-1} than the reality. 

1976	USA	Wayne Schick builds "Lo-Cal House" (Low Calorie House) at University of Illinois [22,23,24]. Specifics: super-insulation, double walls, triple panel windows, air tightness, air barrier. It is promoted the concept of "super insulation" that is developed further by the published papers of William Shurcliff in 1980.	
1977	Sweeden	Researchers from Sweeden use "Blower Window Test" for measurements of air tightness of the buildings. In USA the test method is improved by using more practical "Blower Door Test". Gautam Dutt affirms that buildings's heat losses are 3…7 times greater than the estimations provided by the calculation and the main cause is air leakage.	
1977	Canada	Robert Besant, Rob Dumont, David Eyre and Harold Orr build "The Saskatchewan Conservation House" [25–27]. Specifics: super-insulated, triple panale windows, ventilation with heat recovery, air tightness (0.8 h^{-1} at 50 Pa), solar collectors. Rob Dumont uses the term "low-energy house" and recommends the passive design up against active design.	
1977	USA	Eugene Leger builds "Leger House" in Pepperell, Massachusetts [18]. Specifics: super-insulated, air tightness, air to air heat exchanger.	
1979	USA	Southwall Technologies from Palo Alto (California) commercializes first Low-E glass that also was named "heat mirror" or "transparent insulation" resulted from researches of MIT [56].	
1980	USA	Began to be contoured the concept of intelligent building [34].	
1985	Sweeden	Hans Aek builds a "Super-Low-Energy House" at Ingolstadt-Halmstadt with heating load of 30 kW h/m^2/y. Specifics: highly insulated, air tightness, mechanical ventilation with air to air heat exchanger.	
1987	Germany	It is built "Schrecksbach House" – the first German low-energy building – designed by Manfred Such in 1987.	
1988	Germany, Sweeden	Wolfgang Feist promotes the concept of "Low Energy House" based on performances of "Schrecksbach House" [27,28]. Inspired by the designs of the energy efficient houses from North America, Bo Adamson (Sweden) and Wolfgang Feist (Germany) sketch the concept of "Passive House".	
1990	Germany	Concepts of Wolfgang Feist are materialized by the architects Bott, Ridder and Westermeyer that built "Kranichstein Passive House" in Darmstadt. Specifics: highly insulated walls (lateral walls 275 mm, roof 450 mm, intermediary roof 250 mm), solar collectors, air tightness (0.3 h^{-1}@50 Pa), mechanical ventilation with heat recovery by air to air heat exchanger with pre-circulation of the air through an embedded tube in the ground, (efficiency 80%) [23].	
1993	UK	Brenda and Robert Vale build a green house called "Autonomous house" that in significant proportion is able to produce the needed energy. Specifics: recycled materials of the walls, PV panels, etc.	
1994	Germany	Fraunhoffer Institut of Solar Energy Systems builds an "auto-sufficient" or "autarchic" house. The house is not connected to the public electrical grid. The electric energy is produced by PV panels and stored in classic batteries based on acid. Specifics: solar collectors, earth to air heat exchanger, equipment of humidification and dehumidification. The house produces 5 times more electrical energy than it consumes and is the forerunner of the "Plus-Energy House" concept that will appears later in 1996.	
1994	Germany	Rolph Disch builds Heliotrope in Freiburg which is capable to produce 4…6 times more energy than the internal need with zero CO_2 emissions. Specifics: walls with phase changing materials and walls insulated by internal vacuum space, sun tracking system of the PV panels [32].	
1995	Germany	Wolfgang Feist defines Passivhaus Standard: Space Heat Demand $\leq$ 15 kW h/m^2/y, Airtightness Pressure Test $n_{50} \leq 0.6\ h^{-1}$, Primary Energy demand (for all energy services) $\leq$ 120 kW h/m^2/y [57].	
1996	Germany	Foundation of PassivHaus Institut by W. Feist in order to promote Passivhaus Standard.	
2000s	USA, Europe	Infrared Plasm Heating Panels are commercialized.	
2004	Germany	The solar city Solarsiedlung am Schlierberg designed by architect Rolph Disch in accordance with Plusenergiehaus® standard [58]. It contains Sonnenschiff (Solar ship), the first positive energy commercial building, which is linked in a network with other proximate buildings that have installed on their roofs solar equipment. It is a self-sustaining city.	

thermal insulation was becoming a basic rule [11]. The next decade was dedicated to the Second World War and postwar reconstruction. During the 1940s the domestic technological progress slowed down and the field of the energy in buildings was not characterized by remarkable preoccupations.

At the end of 50s the seasonal energy storage system was one of the most important topics in the area of buildings. One of these projects was materialized in Germany in 1984 as the first long-term thermal energy storage [12].

60s came with the enthusiasm of processing thermal load data by computer that becomes a very useful method in evaluating the energy performance of the buildings [13]. This is the time when the buildings energy load estimations methods started to be substantiated. Later on, the researchers developed the Degree Day Method, Bin-Method, and Modified Bin-Method. Fanger had a great contribution in the quantification of the thermal comfort that rule the necessary thermal load. In his model, the outdoor conditions have an important role too. In the present days, Fanger's model is still one of the most used comfort models.

Oil crisis from 1973 determined the amplification of the interest in buildings energy efficiency. People become more preoccupied about air tightness of buildings, super-insulation, and heat recovery in ventilation system, use of triple pane windows and passive technologies that mainly were oriented to the use of thermal energy from the sun. In this time, the older concepts are redefined by newer ones described by Brenda and Robert Vale: self-sufficient houses, autonomous house and green house [14].

They revived the sustainability in buildings by later applying their theories of “Green House” and “Autonomous House” on a house in Nottingamshire, England. Local recycled materials such as broken bricks, concrete blocks made of waste ash from a local power station, bricks for the external walls fired with landfill gas from decomposing garbage were used to build the house. The house was considered close to the self-sufficient status from the energy and water supply point of view [15].

After the energy crisis, several scientists progressively completed the definition of the sustainable development concept. The building area adopted the sustainability principles which were very important in defining new design strategies. Later, the buildings that took into account these principles were appreciatively called “sustainable buildings”, where the design contains also the orientation towards integration in the landscape and community acceptance. The “sustainable building” became a branch of the more general term “sustainable development” [16–18].

In 1974 the Center for Energy and Environmental Studies of Princeton University received a federal grant of research. The research team represented by Ken Gadsby, Gautam Dutt, David Harrje andFrank Sinden (Princeton House Doctors) began the studies of the air exchange influence on the heat loss of the buildings [19].

“Phillips Experimental House” (1975) [20], DTH zero-energy house (1975) [21,22], “Lo-Cal House” (1976) [23–25], “The Saskatchewan Conservation House” (1976) [26–28], “Leger House” (1977) [19], are top examples of materialized projects edified with energy efficiency in mind. In the 1970s the term of Zero-Energy House, which is very popular nowadays, goes forth.

As a result of the technological advancements in the early 1980s, it was created the first “intelligent building”. Hans Aek builds a house with the properties of “Ultra-Low-Energy” and Wolfang Feist promotes the concept of “Low Energy House” [28,29].

In the late 80s, inspired by the energy efficient houses of the 1970s, Wolfgang Feist in collaboration with Bo Adamson sketched the concept of “Passive House”.

The Passive House concept outlined at the beginning of the 90s integrated all the valuable theories and algorithms of design. The first “Passive House Kranichstein” was built in 1991 in Darmstadt, Germany.

In 1992, the first energy autonomous house designed by Fraunhofer Institute for Solar Energy from Freiburg, Germany [30] was built. Due to a great insulation and of the solar energy technologies, the house was able to cover its own needs without the help of external energy sources [31].

In 1994, a new standard called Minergie was created. Especially developed for new and refurbished buildings, Minergie is a Swiss quality label for low-energy consumption buildings based on the ideas of Ruedi Kriesi and Heinz Uebersax [32]. In 1994, the first two Minergie houses were built. Minergie became an official standard in 1998. After three years, the Minergie Asociation labelled Minergie-P. More rigorous than the initial standard, Minergie-P represents the correspondent of the Passive House standard.

In 1994, also came into operation the first positive energy house (plusenergiehaus) called Heliotrope. The house built in Freiburg im Breisgau was designed by the architect Rolf Disch. This was the first house in which the amount of energy produced was greater than that consumed. The technologies implemented in the building used energy entirely provided by renewable sources [33].

In 1995 W.Feist developed the Passive House standard based on the experience of construction and operation of the first house built in Darmstadt. The Passive House Institute founded in 1996 and led by F. Feist started to promote the standard and set out clear requirements.

The intelligent building concept has started emerging since 1980 when several buildings gradually integrated the control of various equipment and systems. Initially, the automated systems implemented in buildings were dedicated separately to each machine [34] and later their complexity was capable to control multiple systems. Today, a single system integrates the capability to monitor and control the security, the heating, the air conditioning and the electricity systems. The latest developments led to the implementation of monitoring and control by wireless systems and internet.

Wang (2010) distinguished four stages in the intelligent building age: 1980 to 1985 with integrated single function/dedicated systems; 1985 to 1990 with integrated multifunction systems; 1990 to 1995 by building level integrated systems; 1995 to 2002 with computer integrated building; 2002 present with enterprise network integrated systems [34].

3. Actual concepts of energy efficient buildings design

Recent technological progresses, which are also transmitted in construction techniques, allow energy-saving ideas to be easily integrated into building's design in order to improve comfort, energy efficiency, utility or even esthetics. In the last decades researchers involved in the design of low energy houses came constantly with creative solutions and rules of thermal design.

Whereas specific options and style may vary, energy-efficient houses have some basic elements in common as result of an established pattern of design: super-insulation of the walls, windows and doors, complex configuration and tightness of envelope, ventilation with heat recovery unit, high-efficiency heating and cooling systems, solar equipment and energy-efficient appliances.

This section describes several solutions applied to improve the design efficiency. Most of them are design rules issued in 1970s by North American researchers or in 1990s by the German school of Passive and PlusEnergy Houses. There are also ingenious solutions proposed by several authors. The issue is to integrate the practical and theoretical solutions associated with their main benefit in a synthetic block (Table 2).

The comfort in a building should be delivered from a minimal space dedicated to HVAC system [59] and the essential equipment will be located in this space.

Theoretically, to achieve the energy efficient building requirements, there are several ways to reduce the expensiveness. Thus, many relatively inexpensive insulation materials are available on the market. However, it is important to use proper materials, equipment and solutions for each aspect required to be met by the building.

A problem that seems contradictory for passive houses is linked to their air tightness. High air tightness reduces heat losses but results in a very low natural air exchange between the indoor and the outdoor, causing its slow refresh cycle. To prevent air quality problems it is recommended a minimum air flow rate exchanged by the building of 9… 30 m^3/h/capita or at least 0.35 h^{-1} air changes per hour (ASHRAE) for keeping the air quality (CO_2 concentration ≤ 0.1%). The ventilation is provided by a mechanical ventilation system with high rate of heat recovery (MVHR unit) which works continuously and ensures minimal heat losses. Feist (2006) recommends the installation of a recovery unit if the temperature is often below 8 °C or above 32 °C and use of the ground as a "buffer" for air heating or cooling.

Preheating or precooling of the fresh ventilated air by natural thermal resources is a specific method for energy efficient houses. In this way, the load of dedicated equipment of heating or cooling is reduced.

Ventilation using heat recovery unit is effective in combination with three well known HVAC equipments: classic heating and cooling, ground-sourced heat pump (GSHP) or earth-to-air heat exchanger (EAHX). In a combination with EAHX, the MVHR unit has to be by-passed in the warm season.

The definition of a passive house goes to a more general concept than the one related to a certain standard [23]. While Passive House Institute recommends mechanical ventilation with heat recovery, there is also the alternative of using natural ventilation system (passive ventilation).

Currently, the design of efficient energy houses includes windows with "Low-E" layers on both sides of the glass. In the summer, when the outside air temperature is greater than the inside one, the exterior Low-E layer does not allow passing of thermal radiation and by reflecting it, reduces the solar heat gains. In the winter, the Low-E coating on the opposite side reflects the thermal radiation reducing the heat loss to outside (in this way the inner surface of the glass has a higher temperature than a normal glass). Depending on the building orientation, thus on the angle of radiation incidence, some optical properties can be assigned to the glass layer.

Miller [60] highlights two issues in sequence as optimization principles: the principle of minimizing losses that involves the improving of fundamental elements of building such as walls, windows, mechanical ventilation; the second principle consist in gains maximization.

The experimental house built in compliance with the design criteria presented in Table 2 and located in the University Politehnica of Bucharest campus stands as an example of energy efficient building.

"Politehnica House" is intended to be an energy efficient house prototype suitable for the Romanian climate and a practical reference for the construction of other buildings in this area. The building comprises two twin houses of 2 × 140 m^2 with very high insulation and tight envelope, triple glazing Low-E and a southern orientation. Both houses use a mechanical ventilation system with heat recovery and technologies based on renewable energies [66]. The first house called "House Est" has an open geothermal system (earth to air heat exchanger) used to preheat/cool the ventilation air. The second house named "House West" is heated/cooled by water radiant panels supplied with warm water produced by a geothermal heat pump. Solar collectors and PV panels were considered the best solutions to cover hot water needs and the electricity consumptions. Analysis and simulation of these systems have been carried out within different research projects [67,68,69].

4. Current state of the energy efficient buildings definitions

It is well known that global reduction of CO_2 emissions plays a vital part in diminishing the climate changes. A decrease of the energy consumption in the most important fields is the main solution to reduce directly the greenhouse gas emissions. The European Directive approved in 2007 set three goals taking as a reference year 1990: to lower the emissions with 20%, to raise the energy production from renewables with 20% and to improve the energy efficiency with 20% [70]. Due to the great potential in increasing the energy efficiency, the buildings sector drew the attention to itself. Furthermore, in order to ensure the energy performance of buildings, the European Commission developed the Directive 2010/31/EU in May 19th 2010 [71]. Aspects involving cost-optimal assessment of the design for the buildings are described in the supplementing directive no. 244/2012 [72].

Houses with high energy efficiency have started various debates around their role. There are multi-criteria definitions depending on energy consumptions, greenhouse gas emissions, economic issues and period of evaluation (one year or even a life cycle).

In terms of energy consumption that is directly influenced by the passive properties of the building, the following classification is largely used: standard-energy (E ≤ 65 kW h/m^2/y), low-energy (E ≤ 40…50 kW h/m^2/y), ultra-low energy (E ≤ 20…30 kW h/m^2/y) and Passive (≤ 15 kW h/m^2/y).

The "low energy building" is usually characterized by a high level of insulation, windows with high energy efficiency and a low level of air leakage. A construction of this type has often a mechanical ventilation system. There is no global definition of these buildings unanimously accepted around the world. The most general definition says that a low energy building is a construction with an energy performance higher than the efficiency of a standard building [73].

For the case of an "Ultra Low Energy Building" the addition of renewable energy systems could bring the status of "Nearly-Zero Energy" or even "Net-Zero-Energy"/"Plus-Energy" building.

The "Passive House" standard developed in Darmstadt, Germany, is the fastest growing energy efficiency standard. According to the German Institute [74], "a Passive House is a building, in which thermal comfort [ISO 7730] can be provided solely by post-heating or post-cooling the fresh airflow which is required for good indoor air quality [DIN 1946] – without using additional recirculated air".

Passive House Institute developed three basic criteria for certification of a passive house: Space Heat Demand ≤ 15 kW h/m^2/y, Pressure Test airtightness $n_{50} \leq 0.6\ h^{-1}$ at 50 Pa, Primary Energy Demand (for all energy services) ≤ 120 kW h/m^2/y [57]. To these basic criteria, another criterion for Space Cooling Demand that appends an additional term for dehumidification to the Space Heating Demand is added.

The Passive House reduces the energy consumption for heating/cooling and CO_2 emissions by a factor 10 compared to the usual old building [59]. Compared with the houses built as per current standards, the energy reduction factor is about 2…4.

The Passive House is a very popular standard not only in the residential area but also in the tertiary sector. The standard can be applied to public buildings, commercial and even industrial buildings [75].

The widespread application of the Passive House concept will significantly contribute to the achievement of the objectives set at the European level. The European Union Directive on the Energy Performance of Buildings EPBD2010 [71] proposes the term "Nearly-Zero Energy" for the buildings that use renewable energy sources in a significant proportion.

The "Nearly Zero-Energy Building" represents a real solution in reducing the energy consumption and the CO_2 emissions. According to the European Union Energy Performance of Buildings Directive

Table 2
Modern concepts of energy efficient buildings design

Design element	Features
Design	The design has to be balanced and to consider as much as possible details of thermal phenomena and internal heat gains. For example, the heat produced by the body is an important factor.
	Algorithms of design should take in consideration as many as possible parameters for a greater warranty to achieve the defined conditions.
	If a monitoring system is implemented then it should have a high degree of granularity of the processes in time.
	A net-zero or plus energy house will require a metering system to monitor and manage the energy exchanged between house and grid.
Positioning	Low exposure to winter winds and instead vented as much as possible in summer wind [23].
	A curtain of trees at an acceptable distance (that not produce significant effect of shading) may be useful in limiting wind speed in winter and therefore heat loss.
	Integration of the building in the landscape is an important desire of the sustainable buildings.
Orientation	Solar orientation and shading should maximize solar heat gain in winter and minimize it in the summer [59].
	Feist indicates the orientation of the main facade of the house at an angle in the range of $\pm 30^{\circ}$ from the South [61].
Geometry	The geometry of the house must determine a coefficient of compactness (envelope area per volume) as small as possible and less than 1.
Shading	Balconies, overhangs, venetian blinds, trellises, decks, trees are some examples of passive shading objects. Active shading devices represent also an efficient solution for large buildings having large glazing areas, with benefit of solar thermal radiation and lighting control.
	Use of natural shading (by trees, vegetation) in order to reduce summer's solar radiation at times of peak values.
	Reflective surfaces or green areas (with vegetation) reduce solar gain in summer.
	Trees shading the windows and/or walls in optimal times of the season and of the day [59].
Envelope – walls	For insulation thickness there is a point at which it provides maximum efficiency; exceeding of this threshold causes an overinvestment. In such situation is recommended an evaluation on whether adding PV panels could be more cost effective than increasing further the insulation thickness [25].
	The building's envelope is required to be highly insulated to have a low permeability for air and to have no thermal bridges.
	Thermal insulation reduces the thermal interaction of the building with exterior reducing the amplitude of the indoor air temperature variation.
	In order to check the values of the linear coefficient of heat loss by thermal bridge (should be less than 0.01 W/m/K) a finite element analysis should be carried out during the designing of the building envelope.
	Interior surfaces temperature higher than 12.6 °C should avoid the moisture accumulation on the surface [61].
	A radiant barrier layer of air installed under the roof prevents more than 95% of solar radiation.
	The adoption of an adequate design of the envelope and the connections between its elements should limit thermal bridges in order to avoid condensation and local heat losses.
	Materials should be as natural as possible (with low degree of processing and chemical content).
	Use of thermal storage walls that absorb solar radiation and stabilize the indoor temperature.
	Radiative night cooling by thermal storage system that cools the air and in the night releases the heat accumulated during the day.
Moisture protection	The materials used in building envelope should limit the penetration of water vapor through envelope materials on one side and enable drying of envelope on the other side.
	Use of vapor barrier or vapor diffusion retarder that is a material that reduces the transmission rate of vapors, controlling the moisture of the thermal envelope.
	Natural ventilation of the facade evacuates the moisture from the envelope.
Internal heat sources, ocupancy	In the design process, all the internal heat sources must be considered (electric appliances, lighting, persons, etc.)
	The body heat production is considered 20–50 m^2 per person [61].
Envelope – windows and doors	Maximization of the southern windows surface, minimization of the northern windows area.
	Use of triple pane windows with double-glazed Low-E that block the passage of thermal radiation from warmer side to the cooler side. The space between glass layers must be vacuumed and filed with Argon, Krypton or mixture.
Ventilation and heat recovery comfort	The duct routes of the air ventilation system usually are embedded in ceiling and walls and this gives a benefit from the interaction with their thermal mass. By placing the pipes in the walls, the space is saved and the esthetics of the room is not affected.
	An air flow of 20–30 m^3/h per person or at least 0.3…0.35 h^{-1} air change rate must be considered [62].
	Use of heat recovery unit with thermal efficiency of at least 75% [63].
	When natural ventilation is preferred instead of mechanical one, is important to check if a significant stack effect can be provided in order to overpass a minimum required air change per hour.
	Natural ventilation improves energy efficiency of a house and also brings it closer to the concept of "Green House". On one side, this type of ventilation does not require energy consumption and eliminates the environmental impact but on the other side it is very difficult to control the flow rate and the indoor air temperature.
	The cross ventilation can be used in summer (powered by the wind) by allowing cold outdoor air to enter and the hot indoor air to exit through doors and windows [64]. Ventilation use by solar chimney is a solution of natural ventilation too.
	Passive ventilation by stack effect of a vertical space (tower) where the air flow convectively upward creating vacuum that causes cold air intake through openings at the bottom of this space.
	In the design of ventilation system, the zones of "stagnant air" must be avoided and also air speed not to exceed 0.5 m/s.
	Overheating over 25 °C need to be $\leq$ 10% of a year [65].
	Systems that employ renewable energy must be capable to assure indoor air temperature of at least 16.5 °C even at outdoor temperatures of -10 °C. The remaining energy needed to heat the air to the comfort value, will be assured by other sources.
	The temperature of internal surface of the windows to vary with small amplitude and to be close to that of the surface of the walls to avoid local discomfort.
	Use of Fanger Model or others for more accurate estimation of the thermal comfort to be provided.
	Humidity: recommended range of 40…60% or at most 30%…70%.
Electric appliances	In order to keep the energy consumption under an imposed maximum/standard value and to be in synchronization with the global aims of low energy buildings is recommended to use equipment with at least class A+ energy efficiency.
	In comparison with lighting by incandescent bulbs, the use of the fluorescent or LED lamps lower significantly the energy consumption and increase the lifespan.
Energy load	Up to 8–10 times lower heating/cooling load compared to a regular house.
Economic aspects	The recovery of additional investment is about 16…30 years, function of the chosen solution and equipment.
	In general, the extra-cost for the systems required by a passive house is 5…15% of the house's total cost.

(EPBD), the nearly zero energy building is a building with a very high energy performance and a nearly zero or a very low energy demand, covered by energy generated on site or nearby from renewable sources [68]. This type of building is a reference target for 2018.

In 2006, NREL introduced the term of Net-Zero Energy Building (NZEB) highlighting the achievement of this rigor of energy production based on renewable energy systems [76]. The term “Net” is an abbreviation of the “Electric Network”.

Torcellini et al. (2006) [77] based on various criteria are detailing the notion of “zero-energy building” (ZEB) proposing four definitions: Net Zero Energy Building Site (NetZSEB) – building produces in a year at least as much energy as it is consumed; Net Source Zero Energy Building (NetZSEB) – building produces in a year at least as much energy as it consumes and the balance is based on primary energy conversion factors for energy import or export; Net Zero Energy Cost Building (NZECB) – building obtains payments on energy produced in a year and exported to the grid that equals one year service costs and energy consumption; Net Zero Energy Emissions Building (NetZEEB) – building uses in a year at least as much renewable energy (emission-free energy sources) as emitters. Hernandez also describes the concept of Life Cycle Zero Energy Buildings (LC-ZEB) [78].

The “Positive Energy Building” represents the latest challenge in the building sector. This type of building is able to produce more energy than it consumes and can deliver the excess to the local or public grids. Positive Energy Local Network is a new trend that creates the premise towards energy independent cities.

There is a classification considering the connection to the public power supply “On-Grid Zero/Plus Energy Building” where the excess energy produced and temporary deficit is compensated with the public grid and “Off-Grid Zero Energy Building” where the general system of energy production and storage have redundancy by oversizing in order to compensate for any deficits in energy production [79,80]. Depending on location of energy production there is the definition of “On-Site Zero Energy Building” (energy is produced at the afferent site of the building) or “Off-Site Zero Energy Building” (energy is produced outside the afferent site of the building) [73].

Currently there are preoccupations to regulate the energy projects implying smart-grid such that small and big investors in Net-Zero or Plus Energy Buildings to take concrete advantages from this solution. Most difficulties remain at political level and partially the classic system of electric energy distribution has its own inertia.

Many countries around the world have carried out intensive research work and developed their own standards. Those that are mentioned more often because of significant results from researches and also because of their rigorous standards are: USA (ASHRAE, RESNET – Residential Energy Services Network and Energy Star Certification and HERS Index); Canada (R-2000 Standard); Germany (EneEV – Energy Saving Ordinance, Passivhaus Standard, DIN- Deutsche Industrie Normen); Swiss (Minergie Standard); Denmark (DS – Danish Standard); France (RT2012 – Reglementation Thermique); UK (BS – British Standard); Sweden (SBC – Sweedish Building Code); Finland (NBCF – National Building Code of Finland) and Australia (NatHERS – Nationwide House Energy Rating Scheme). European Normative (EN) constantly issues standards that are intended to be applied in all member countries and some of the requirements find common ground with ISO Standard.

The standards usually offers criteria that should be fulfilled by the buildings, systems, etc. An important complement to them is the certification criteria that introduce classifications, rankings of the buildings based on energy efficiency. Currently, in the most cases, the buildings are not related in the checking process only by the classic result “Passed/Failed”, they are framed with a specific status based on the measured level of performance on energy efficiency. In this way the standards are capable to consider for verification multiple categories of buildings including those “state of the art” and as consequence is driven the use of modern measurement and monitoring equipment.

5. Conclusions

In this study an evolution of the energy efficient buildings over time is presented. Significant moments of introducing several equipment, concepts of energy efficiency, thermal design rules and comfort exigencies are also outlined.

It is necessary to think the energy efficient building concept in the context of its evolution along the history. Even if by the end of 19th century the awareness of the energy efficiency in buildings did not exist, still the usefulness criterion was in practice. In this paper are gathered all important moments that participated to the definition of the energy efficiency that became fully mature as concept by the end of 20th century. Today, the standards and the technology covers all criteria that makes the systems to be safety, energy efficient, with reduced emissions of contaminants in exploitation and tuned to cost-optimal point for the defined life-cycle of utilization. More than these technical aspects, harder to be quantified exigencies are also considered. It involves mainly the human perception associated to the concepts of “environmental friendly”, “sustainability” and “ergonomics”.

As it can be seen, each new innovation that emerged at some point continuously and harmoniously integrated to the existing issues. It is revealed that in ancient times either scientifically or not, man has used ingenious solutions in order to assure comfort inside the house with minimal effort.

Newest theories on energy efficient buildings were inspired by the design and objectives that animated the 1970s when it was a true emulation of the ambition (urged by world's economic circumstances or powered by scientific spirit) to find new solutions based on the current state of the technology. Beginning with 1990s, the designs start to be consistently inspired by the principles promoted by Passive House Institute and also by the stream of thinking determined by Plus Energy House concept.

Currently, the building is considered as an organism in constant evolution, which should be treated, rehabilitated and modernized over time to meet the requirements set by the user to a certain stage.

The significant moments of the thermal design evolution of the buildings are mentioned in this paper, where new ways to diversify the solutions or to improve the existing ones were gradually found in time.

Four key moments are distinguished in the history of 20th century buildings in terms of energy: the construction and design principles of MIT Solar House Solar House I, 1939; the 1970s when oil crisis caused a more intense concern in finding ways in increasing energy efficiency in buildings, promoting the super-insulation, the heat recovery, the air tightness of the building and solar energy use; construction of “Kranichstein” passive house in Darmstadt, Germany in 1990 and founding of the Passivhaus Institut in 1996 to promote the passive house standard and new rules for energy-efficient design; construction in 1992 by the Fraunhofer Institute of a solar house in Freiburg, able to produce more energy than the consumed one.

A selection of the main criteria that streamlines the building design from the energy point of view is realized. This guarantees an exploitation of the buildings in an efficient way with less GHG emission.

Standards come to assist human needs and they are also under change along the time in synchronization with the new discoveries, new expectations and exigencies. In the world are several standards of energy efficient design and certification and the trend is towards cost-optimal aspect that gives effective options to the people that invest in the construction of the house.

The experimental low energy "Politehnica House" is presented as practical example of energy efficient house concept implementation in present days. The house is subject of several experiments and simulations conducted by authors. The researches cover the domain of the systems control and monitoring, thermal simulation in variable conditions, weather models and comfort intelligent assistance. Workshops and seminars to bring the awareness to the masses about the advantage of investing in this type of buildings are periodically organized.

Based on the experience accumulated in thermal systems research and especially on the experimental low energy house project we considered that this kind of study that covers large parts of the problems linked to the energy efficiency in buildings is really necessary. Solving current problems of a project is a sufficient approach but in order to deeply investigate is absolutely necessary to put the issues in a historical circumstance. In this way the future evolution of the design could be seen much clearer and it can become a research subject.

After reading this paper, the question on how the buildings could be conceived remains. First of all, available standards for the buildings will not be seen only as a given thing or as axioms that should only be followed in design. It is prepared the ground to look at them also as a natural evolution in time in terms of requirements, challenges, multi-disciplinary expansion and effect of technological eclecticism. There are also selected methods that are taken into account in the today designs in order to improve the efficiency and the predictability of the designed system. A more balanced design is capable to incorporate more heterogeneous blocks that interact among them under diverse causalities generated by evolution in time or specific functionality.

This is a qualitative and quantitative evolution of the design principle for a system that is considered not only on an average state, but also depending on the characteristics in time of the weather evolution, dynamic response of the systems etc. Also the evolution of the building design in the context of the progress of general science and technology can be seen. It is important to know what was necessary and useful to be imported from the discoveries of a given time. Future standards become easier to define because the trend of the present could be judged easily after the dedication to study the fervency of the scientific world, of the international organizations, of the markets and of the beneficiary.

Through its content this paper has achieved its purpose, namely to present an historical evolution of the main concepts and techniques that have guided the construction of buildings with respect to the energy matters. The key moments in the evolution of buildings, viewed as milestones in energy efficient buildings, were pointed. Theories, standards and basic techniques for sustainable design in buildings construction and operation were also quantified.

Today, even at the small scale systems, the preoccupation to make them to be energy independent or to use renewable energy is growing continuously. Thus, the availability of the technology to be applied at the building level is by far more common and intended to welcome the basic human needs. Evolution of the markets favours the applicability of those trends implying the technology dedicated to the energy and not less important, the legislation is about to be adapted to the present, and also issued and applied.

Energy efficiency in buildings is a high priority on the political agenda as governments seek to reduce wasteful energy consumption, strengthen energy security and cut greenhouse gas emissions. There are only few countries around the world that have not set goals to consume less energy and to decrease their CO_2 emissions. In order to avoid temperature increasing of 5–6 °C by the end of this century, humanity needs to adopt ambitious programmes of energy efficiency in all sectors but particularly in that of buildings.

EU policymakers have long recognized the importance of energy-efficient buildings in mitigating climate change. This concern is reflected in the Energy Performance of Buildings Directive from 2002 (revised in 2010) and most recently in the 2012 Energy Efficiency Directive. While the efficiency of new buildings has improved over time, most of Europe's existing building stock (over 90% of the total) has yet to be affected by energy performance requirements. Therefore, based on the experience gained over time, new technologies and strategies for improving energy efficiency in buildings need to be developed.

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