Innovative Energy Technologies for Powering Buildings

Nicolae Badea[1,*],George Vlad Badea[2] and Andreia Podasca[2]

[1]University of Galati, Domneasca Street, Galati, Romania and [2]BGV Energy Consultancy SRL, Bucharest, Romania

Abstract: This paper makes a technical analysis of the methods that can be used to provide Energy to Residential Buildings. The paper firstly describes the legislative framework for increasing the efficiency in the building sector and building certification. The key for improving the energy efficiency of buildings is 'Nearly Zero-Energy Buildings(nZEB)'. The main research in nZEB is described in section three and the technologies for increasing the energy performance of buildings, in summary, are presented in section four. A case study of the integration of renewable sources in the energy supply of residential buildings describes the calculation methodology of required energy, the specific consumption, and energy performance of building after inclusion of renewable energy for powering the building. The results of this analysis show that the energy uses in nZEB buildings are influenced by the building location, their architecture, energy system design, and level of renewable energy production.

Key Words: Energy efficiency of buildings, Nzeb, Renewable energy, Photovoltaics, Solar thermal panels.

1. LEGISLATIVE FRAMEWORK BETWEEN OPPORTUNITY AND NECESSITY

During the economic period before the1990s, the development of the Romanian economy had been based on the development of the intensive energy branches of the heavy industry. Restructuring the post-revolution economy had led to a major decline in final energy consumption in the industrial sector. These effects had been intensified by the economic crisis so that after 2010, the industrial sector did not occupy its leading position in what concerns its share in final energy consumption, the role being taken over by the domestic sector. The household sector was the main national energy consumer in 2015 [1], covering 34% of the final energy consumption of the country, exceeding the final energy consumption of the industrial sector by 5%.

The Climate-Energy Framework 2020 sets three key targets: to cut 20% in green gas emissions (compared to 1990 levels), to increase the EU renewables share by 20%, and to improve energy efficiency by 20%. One of the ways to improve energy efficiency is to capitalize on the huge potential for increasing the efficiency in the building sector, which is the largest energy consumer in Europe, absorbing 40% of the final energy.

Directive of the European Parliament and of the Council of 19 May 2010 [2] on the energy performance of buildings (EPBD) requires each EU Member State to promote the improvement of energy efficiency of buildings by setting standards, assessing performance on a consistent basis, and by providing Energy Performance Certificates (EPCs) for buildings so that this performance is effectively communicated in all advertisements for sale or rental of buildings.

On 30th of November 2016, the European Commission adopted a "Clean Energy for All European Citizens" Package (also known as the "Electro-mobility requirements of the Winter Energy Package of November 2016") that comprised of eight legislative proposals and other actions to help the EU achieve its 2030 energy and climate objectives. The above package also included the proposal of the European Parliament and of the Council for amending Directive 2010/31 / EU on the energy performance of buildings [3].

The revised framework:

- Included the obligation that all new buildings should be near-zero energy buildings by 2021 ("nZEB").
- Required the Member States to comply with the general requirement that all new buildings meet the minimum energy performance requirements.
- Introduced an obligation to provide documentation on overall energy performance after installation, replacement, or upgrading of construction engineering systems.
- Introduced the requirement to execute the recharge points for electric vehicles in the parking lots of the new buildings with more than ten parking spots for electro-mobility.

*Address correspondence to this author at the University of Galati, Domneasca Street, Galati, Romania; Email: Nicolae.Badea@ugal.ro

E-ISSN: 2409-9821/20

The proposal of the Commission materialized on 30th of May 2018 by EU Directive of the European Parliament and of the Council [4] amending Directive [2] on the energy performance of buildings and Directive [5] on energy efficiency, published in the Official Journal of the EU (L156) on 19th of June 2018, 9th of July 2018 being the date when it entered into force. The EU countries have the obligation to transpose the new elements of the Directive into their national law within 20 months. This is the first of the eight legislative acts adopted in the "Clean Energy for All European Citizens" Package.

Innovation and new technologies also make it possible for buildings to support the general de-carbonization of the economy by using electric vehicles, combined with a higher share of renewable electricity production, producing less carbon dioxide emissions, which has resulted in better air quality.

Art. 2 of the Directive, at Point 3, provided that"<technical building system>means technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity generation, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit".

From a technical point of view, Annex 1 of the Directive provides:

- “The energy performance of a building shall be determined on the basis of calculated or actual energy use and shall reflect typical energy use for space heating, space cooling, domestic hot water, ventilation, built-in lighting, and other technical building systems.
- The energy needs for space heating, space cooling, domestic hot water, ventilation, lighting, and other technical building systems shall be calculated in order to optimize health, indoor air quality, and comfort levels defined by Member States at the national or regional level.
- The calculation of primary energy shall be based on primary energy factors or weighting factors per energy carrier, which may be based on national, regional, or local annual, and possibly also seasonal or monthly, weighted averages or on more specific information made available for individual district system.
- In the calculation of the primary energy factors for the purpose of calculating the energy performance of buildings, Member States may take into account renewable energy sources supplied through the energy carrier and renewable energy sources that are generated and used on-site, provided that it applies on a non-discriminatory basis.
- For the purpose of expressing the energy performance of a building, Member States may define additional numeric indicators of total, non-renewable and renewable primary energy use, and of greenhouse gas emission produced in kg CO_2 eq./(m^2.y) ”;

Thus, result as the main legislative instrument and the key element of this, at the European level, for improving the energy efficiency of buildings is its requirement for ‘Nearly Zero-Energy Buildings’

2. OVERVIEW OF ROMANIAN BUILDINGS CERTIFICATION

In the Romanian legislation, the Energy Performance Certificate was established by Law no. 159/2013 for amending and completing the Law no. 372/2005 on the Energy Performance of Buildings. Order No. 13/2016 for amending and supplementing Law No. 372/2005 on the energy performance of buildings shows that:

- The Energy Performance Certificate of the building [6] - "document issued according to the methodology for calculating the energy performance of buildings, indicating the energy performance of a building or building unit and containing data on primary and final energy consumption, including renewable energy sources, as well as the amount of eq. CO_2 emissions. For the existing buildings, the certificate also includes recommended measures to reduce energy consumption and to increase the share of renewable energy use in total consumption";
- A building whose energy consumption is almost equal to zero [7]- a building with a very high energy performance, where energy consumption is almost equal to zero or very low and is covered at a minimum of 10% with energy from renewable sources, including renewable energy produced on-site or nearby.

As presented, The Energy Performance of Buildings Directive (EPBD) introduced at Article 9“The near-zero energy buildings” (nZEB) as a requirement that by 31st of December 2020, all new buildings will be buildings whose consumption of energy is almost equal to zero, and after 31st of December 2018, the new buildings occupied and held by public authorities are buildings whose energy consumption is almost equal to zero.

The housing stock in Romania consists of approximately 8.2 million dwellings in some 5.1 million buildings [8,9]. In the urban area, the majority of dwellings (72%) are found in blocks of flats, in contrast to rural areas where the majority (94.5%) have individual dwellings. Individual single-family buildings represent around 98% of the Romanian residential buildings stock.

Approx. 53% of residential buildings are built before 1970 and more than 90% before 1989 (in terms of m2), having an energy performance level between 150-400kWh/m2/yr. Heating energy represents around 55% of the overall energy use in apartments and up to 80% in individual houses.

3. STATE OF ART IN NZEB

The issue of the ‘Nearly Zero-Energy Buildings‘is addressed both through scientific papers and through projects funded at the national, European, and international levels. Compared to research projects that lead to practical achievements and detailed analysis of all technologies to increase the energy performance of buildings, scientific papers present specific advantages of a single technology for dedicated applications like new buildings, retrofit, office, residential, etc or to identifying the current practices and future research need. In this sense, we can mention a series of scientific papers that reduce the building energy consumption by buildings retrofitting [10.11], the computer's usage to simulation and optimization to minimize the building life cycle environmental impacts [12,13,14], present the current practices and future research needed in this field and not last row, models for estimating the discounted payback period of investments for reducing energy resources needed in building's development [15]. Other papers analyze the societal barriers of nZEBimplementation [16] because the social aspect has had much influence on the demand and promotion of NZEBs.

The technical barriers across the construction sector is the lack of skills and expertise of some workers or lack of experience in design and execution, or lack of knowledge and/or interest in energy efficiency among residents and building owners in the decision-making process, often due to lack of awareness combined with challenges with architectural and cultural values they are not approached through scientific papers but only through projects funded by institutions at international, European and national levels.

At the international level, the International Energy Agency (IEA), through the "Energy Conservation in Buildings and Community Systems" program (ECBCS), funds high priority research themes such as integrated planning and building design, building energy systems, building envelope, community-scale methods and real building energy use [17].

At the level of the EU (FP7/2007-2013) funded projects in nZEB, we found that the ZEBRA 2020 [18] is a project that aims to evaluate the EU’s buildings stock and the progress towards nZEBs and offers a 'nZEB radar' to compare nZEB standards and ambitions across countries and ZenN [19] which assesses the common barriers and challenges in current nZEB practice in Europe. The European Union’s by Horizon 2020 funded new energy-efficiency projects [20].The new projects aim to facilitate the implementation of nearly-zero energy buildings; enhancing public capacity for sustainable energy, strengthening green procurement; developing innovative construction methods for energy-efficient buildings, and deploying a new generation of intelligent district heating and cooling networks.

The innovations in the energy supply of the nZEB buildings are based on the analysis of the energy balance oriented towards the reduction of the losses, the use of renewable energies, and the complementary heat production in an efficient manner. The trend of action can be systematized as:

- Insulation of walls and reduction of thermal bridges, replacement of uncontrolled ventilation with a system that can control the fresh air flow and recover heat.
- Use of renewable energies, in particular, solar collectors, heat pumps, photovoltaic systems, or the use of firewood.
- The use of high-efficiency cogeneration systems.

At the European level in the last 20 years, energy efficiency has become an increasingly important aspect of building planning and assessment, as well as a subject of legislation within the EU. As a result, the operating energy consumption of new and refurbished buildings has declined considerably during this period. Figure **1** shows the ratio of operating energy (for regulated uses, such as heating, ventilation, cooling, and lighting under EPBD) during the usage phase and the built-in energy due to manufacturing the construction products and their End of Life (EoL).

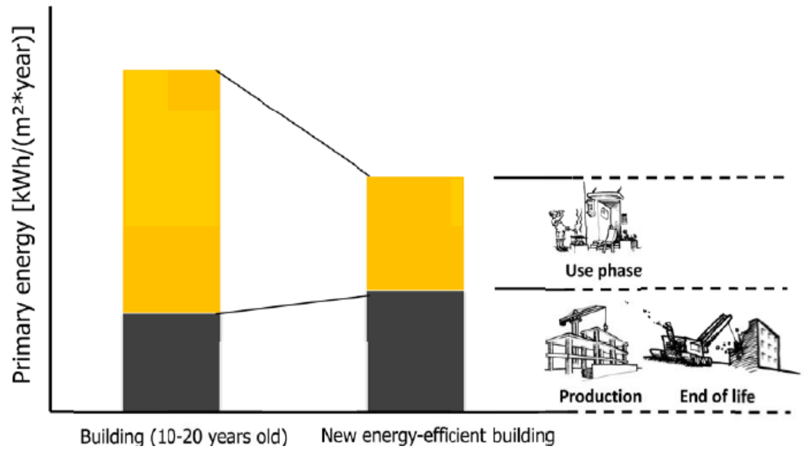


Figure 1: Ratio of usage phase to production /EoL [21].

The usage phase for older buildings dominates all the other stages of the life cycle. Today, new buildings can consume less than 15 kWh of heating energy per m² per year, if it complies with the Passivhaus standard [22]. New "surplus energy" or "positive energy" types of buildings can even be net energy producers. Therefore, the ratio between operational impacts (usage phase) and incorporated impacts (e.g. for production and EoL) is now more or less balanced. The factors that influence the energy consumption of buildings in the usage phase are systematized [23] and shown in Figure **2**.

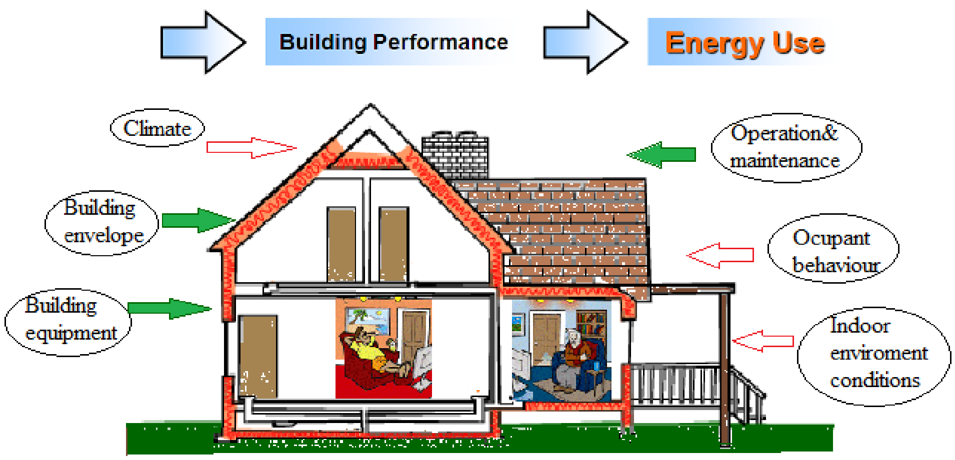


Figure 2: Factors affecting energy consumption [23].

In what concerns the climatic and environmental conditions, the interventions and the innovations cannot intervene. With respect to the operation of the building, the occupant can act by building an energy management system and by building occupant's awareness, but their efficiency does not lead to energy savings if building insulation and equipment have poor performances.

Consequently, the latter two factors are the most important for increasing the energy efficiency of a building, because the interventions can be made through passive measures on the building envelope and through active measures, by equipping the buildings with innovative energy technologies. Energy savings can be achieved through a range of measures, including smart design, improved insulation, low power appliances, high-efficiency ventilation, and heating/cooling systems, and building user's conservation behavior.

4. TECHNOLOGIES FOR INCREASING THE ENERGY PERFORMANCE OF BUILDINGS

In what concerns the necessary measures to ensure that the new buildings meet the minimum energy performance requirements for new buildings, the Directive states [5], "before the construction works are started, the feasibility of the alternative high-efficiency systems of the types listed below, from a technical, economic and environmental point of view, is taken into consideration, if available:

a) decentralized energy supply systems based on renewable energy sources;

b) cogeneration;

c) district or block heating or cooling systems, in particular when they are based, in whole or in part, on energy from renewable sources;

d) heat pumps".

The European buildings receive a renewal of energy efficiency and a number of innovative, eco-friendly technologies are the perfect tools for this job. As Europe advances to reduce both energy consumption and carbon footprint, priority was given to the revision of buildings in the region. Many buildings are developed for renovation purposes in the coming years, and millions of m2 of homes will be built or refurbished after some harsher directions in 2020. In response, the green building sector has begun the deposition of patents [24] related to green buildings which tripled in less than a decade.

The most dynamic areas of patenting in green building construction:

- Heating, ventilation, and air conditioning (HVAC). Approximately half of the total energy of a building is dedicated to heating, ventilation, and air conditioning (HVAC). So it is not surprising that the field has become a focal point for innovation. One of the many promising patent areas for HVAC is air purification, incorporating technologies such as ultraviolet light and photo reactive chemical substances similar to those appearing in the Earth's atmosphere. Such systems allow buildings to reuse large amounts of domestic air and help reduce heating costs. Another innovative field is passive heating with solar and radiant energy, where warm, sunny air is diverted to heat a building or, in the summer months, used to draw in cold air for ventilation.
- Energy-efficient insulation. Energy-efficient heating can only maintain a warm building if there is sufficient thermal insulation to keep the heat inside. These include:
  - Insulating concrete forms (ICFs) that use interconnected polystyrene concrete forms to create a seamless wall through which air cannot penetrate.
  - Structural insulated panels (SIP) are another commonly used insulation option, partly because they can be integrated into a range of materials, including particle and plasterboards, metal plates, plastics, and foams. They work by thermal insulation of the interlaced sheets of construction materials to create a uniform coating.
- The phase-change materials (PCM). This insulation uses a different thermal principle, i.e. it absorbs or eliminates the heat as it changes from a solid-state to a liquid state. In a way, they "melt" and "freeze" in conditions close to room temperature and pull out or release heat in the process.
- "Green" lighting- LED technology (light-emitting diodes) and OLED (organic light-emitting diode) applications require about one-tenth of the incandescent bulb energy and about half that of compact fluorescent lights (CFLs) that are standard in Europe.
- Inclusion of renewable energy.Two large forms of energy can be used to increase the energy performance of buildings, namely solar energy (roof photovoltaic cells, building facades, and even transparent modules used as windows and skylights) and biomass. Various innovations will help integrate these technologies in buildings that can produce enough energy to cover their own energy requirements and even send excessive energy back to the power grid. The innovative Solar Technologies are:
  - Solar thermal systems are plants that capture solar energy and convert it into heat for domestic hot water production and/or heating input. The three main types are flat plate collectors, commonly used for solar water heating systems in heating the home space, solar panels with vacuum tubes that can reach higher temperatures, and an integrated collection-storage system with thermal pipes. Combining an integrated collection and storage system with a thermal compressor can lead to the development of active solar cooling systems.
  - Solar electric systems use photovoltaic cells to absorb solar radiation. The cells are connected to form panels and each panel creates 300 watts. Usually, a building or a house has several panels for apower supply.
  - The hybrid systems are composed of PV panels with integrated phase shift materials to maintain low cell temperatures, thus improving efficiency while storing sufficient heat for space or water heating.
  - Integrated energy systems for buildings. These are renewable technologies that are integrated into the building structure. The construction of integrated renewable energy sources can either be used to produce electricity (solar roof [25] - have a lower efficiency of two percent compared to the traditional solar panels or photovoltaic glass [26] - for building façade) or to produce heating/cooling thermal energy.

5. CASE STUDY OF THE RENEWABLE ENERGY INTEGRATION METHODOLOGY IN THE ENERGY SUPPLY OF RESIDENTIAL BUILDINGS

A case study of the renewable energy integration methodology in the energy supply of residential buildings is applied to a reference building from Romania. The reference building [27] is represented by the individual residential building with ground floor and first floor, shown in Figure **3**. It is considered to be a building with a relatively simple architecture, with a sloping roof, facing south. The conditioned ground floor and first-floor space are heated up to 20° C. The basement (the garage and the central heating room) and the attic are considered to be unheated.

Figure 3: Reference building.

5.1. Methodology for Calculating the Thermal Energy Demand

To calculate the actual amount of thermal energy needed to heat a building throughout the year, we need to know the difference between the average daily exterior temperatures and indoor temperature in the building. The net energy loss is:

$$\Delta Q = \int P \quad dt = \int UA \quad \Delta\theta \cdot dt = UA \quad \int \Delta\theta \cdot dt \qquad (1)$$

The average daily exterior temperatures are useful to calculate the length of the heating season. Also, these are used to determine the average temperature during the heating period ( ) and the number of heating degrees-days (HDD). The length of the heating season dhs expressed in days (Figure **4**) is determined in accordance with relation:

$$d_{hs} = \sum_i d_i \text{ for } \vartheta_{e,i} \le \vartheta_b \qquad (2)$$

Where:

- d_i-is number of days;
- $\vartheta_{e,i}$-temperature of the external environment, average value for the respective day;
- ϑ_b-is the base temperature (=12oC) sometimes called the balance point temperature.

The average temperature during the heating season can be calculated with relation:

$$\vartheta_{e,hs} = \frac{\sum_1^{365} \vartheta_{e,i}}{d_{hs}} \text{ for } \vartheta_{e,i} \le \vartheta_b \qquad (3)$$

ϑ_i -is the interior temperature (setpoint internal temperature for space heating). Its standard value is ϑ_i =20° C

The climate parameter called "Degree-Days" is a measure of the severity and duration of cold weather or warm weather. They are, in essence, a summation over time of the difference between a reference or 'base' temperature and the outside temperature. The basic definition of degree-days is as the difference between the base temperature and the mean daily outdoor temperature. Two values may be calculated for "Degree-Days". The first value namely Heating Degree-Days (HDD) is a measure of the severity and duration of cold weather and the second value, Cooling Degree-Days (CDD), is a measure of the severity and duration of warm weather.

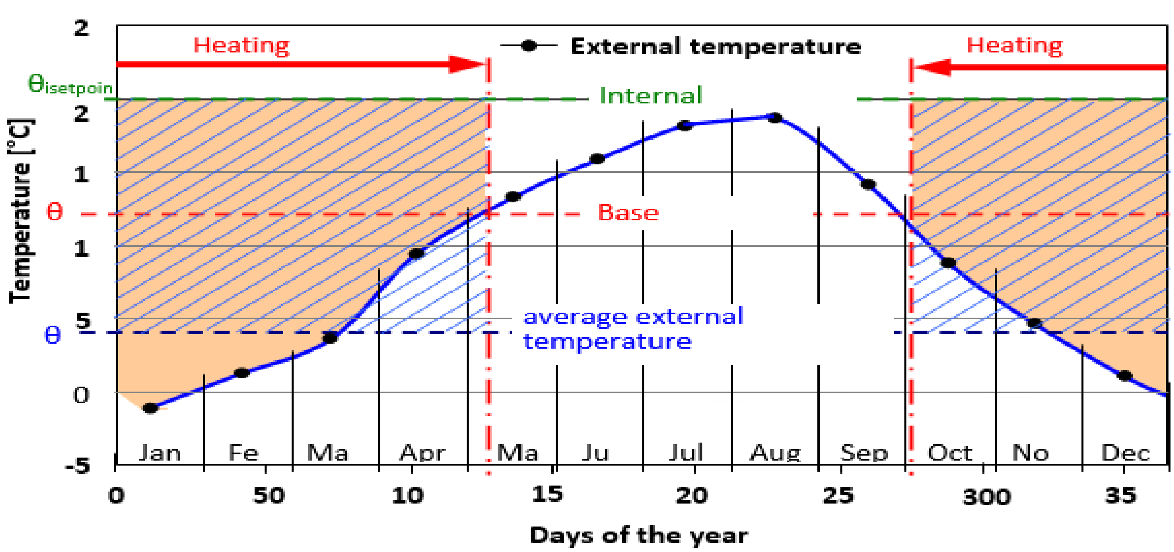


Figure 4: Determination of seasonal climate by use of monthly average data [28].

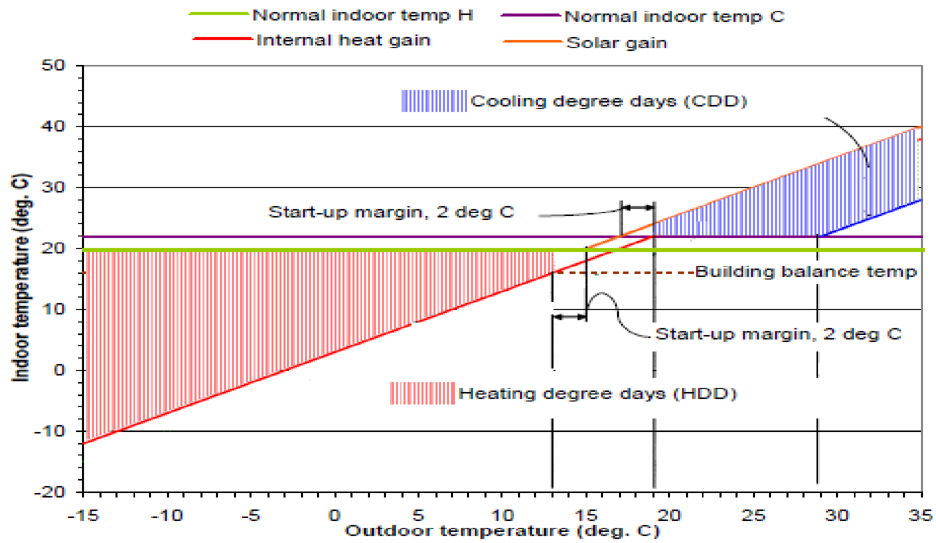


Figure 5: The correlation between temperature and degree-days [28].

The number of degree-days for a heating season is determined from $HDDy = \sum_{day}(\vartheta_b - \vartheta_{e,i}) = \int \Delta\theta \cdot dt$ for $\vartheta_b \geq \vartheta_{e,i}$

Where: is the outdoor temperature (or the base temperature) above which no heating is required is called the balance point temperature; is the average outdoor temperature for each day (without considering temperatures above). A building uses thermal energy to compensate for the heat flowing from the inside to the outside through its walls during the heating season.

The heat loss of building transmitted through a surfaceA_{ref} is $\dot{Q}_{losses} = UA_{ref} \cdot (\vartheta_i - \vartheta_e)$ (5)

The building heat loss coefficient UA_{ref} found by identifying every route of heat loss from a building and adding these together. The routes for heat transfer between the interior and exterior are through the building envelope, air exchange between inside and outside (infiltration). Fuelling the heating space has to compensate for the losses of heat transmitted through walls and the roof, and also the losses given by the heated air from the mechanical or natural ventilation systems. The total building heat loss coefficient is given by the relation:

$$UA_{ref} = UA_{conduction} + UA_{\text{Air Change}} \quad (6)$$

Based on the interior design of the ground floor, respectively of the first floor, (Annex 2), and on the constructive dimensions, surfaces can be determined based on those four cardinal points.

The heat loss for reference building of Figure **3** is achieved by:

- *Thermal conduction of walls and windows*. The thermal power lost through conduction is

$$P_{cond} = A\frac{\Delta\theta}{R_t} = UA_{cond}\Delta\theta \quad (7)$$

Step 1: Coefficient of thermal transfer through conduction (UA conduction).

Building Element		U-value	Aria	U x Area	Description
Orientation	**Element**	**W/ m²°C**	**m²**	**W/°C**	
South	Wall	0.56	30	16.8	**S=37.80**
	Door	1.30	1.8	2.34	
	Window	1.30	6	7.80	
East	Wall	0.56	24.6	13.77	**S=37.80**
	Window	1.30	9	11.7	
	Door	1.30	4.2	5.46	
North	Wall	0.56	37.8	21.17	**S=37.8**
West	Wall	0.56	35.6	19.94	**S=394.8**
	Window	1.3	2.2	2.86	
Roof		0.35	63.11	22	
Plateau		0.52	50	26	
		UA conduction		**149.84**	

- *Infiltration.* The typical infiltration areas are around windows and doors. In any building, the clear air must be brought from the outside and heated (or cooled) at the internal temperature. The infiltration rate is measured in the number of Air Changes per Hour (ACH). For example, a very old house can have its entire air changed every hour, ACH = 1 hr^{-1}. On the contrary, an insulated structure might have the ACH = 0,2 hr^{-1} (i.e. it requires a 5 hours period for completely changing the air from the structure). The air volume which must be heated in the Δt time unit is:

$$\Delta V = ACH x V x \Delta t \quad (8)$$

The thermal power necessary for covering the heat loss due to infiltration is:

$$P_{air} = \frac{\Delta E}{\Delta t} = \frac{c_v \Delta V \Delta\theta}{\Delta t} = \frac{c_v (ACH \cdot V \cdot \Delta t)\Delta\theta}{\Delta t} = c_v (ACH \cdot V \cdot)\Delta\theta = UA_{inf\,ltration}\Delta\theta \quad (9)$$

Relation which can be associated to the infiltration transfer coefficient

$$UA_{inf\,iltration} = c_v \cdot ACH \cdot V \quad (10)$$

The predicted building heat transfer under steady-state conditions is shown in the next tables where c_V=0.718kJ/kg^{o}K volumetric heat capacity (VHC) with density ρ=*1.205 kg/m³* at 20 *°C*. Volumetric heat capacity (VHC), expressed in kWh/m³, has the value of 0.166kWh/m³.

Step 2: Heat loss by infiltration ("UA" infiltration).

Specific Volumetric Heat Capacity (VHC)	**0.166**	**Wh/m³°C**
Volume of the building	250	m3
Number of Exchanges Per Hour (Air Changes Per Hour - ACH)	0.51	ACH
"UA" Infiltrations =VHC x Volume x ACH	21.16	W/°C

5.2. The Annual Requirement of Thermal Energy and Specific Consumption

The annual energy need for heating can be determined by integration (or by summation over daily or hourly averages) as follow:

$$Q_{heating,year} = UA_{ref} \cdot \int(\vartheta_b - \vartheta_i)dt \approx 0.024 \cdot UA_{ref} \cdot HDD \quad \text{[kWh/year]} \quad (11)$$

Similarly, below calculated is the annual cold consumption, Q_C, the difference resides only in that the formula for calculation becomes the following:

$$\boldsymbol{Q_C = 0.024 \cdot UA_{ref} \cdot CDD} \quad \text{[kWh/year]} \quad (12)$$

The statistics daily average values for each month of the year of the solar radiation energy density are given for each locality in the climatic data of the area, so for Bucharest - Baneasa we find the data in Table 2 Annex 3. Based on the above data from Table 2 annex 3, the following global and specific consumptions are obtained:

a) Heat consumption:

The computation ratio of the heat requirement during the heating period of the building is determined with the ratio:

Q_h = 0.024 · UA_{ref} · HDDy = 0.024 ·171 · 2926 = **12088kWh/year**

The specific heat consumption / m² year:

$q_{h\ spec.}$ = Q_h/ A_u= = 12088/100=**120 kWh/m²/ year,**

where: - $Q_h$is the heat requirement per year

- UArefis the thermal transfer coefficient of the residency;

- HDD is the days - degree heating requirement;

- $q_{hspec.}$is the specific yearly heat consumption.

From the heat specific consumption's point of view, the residency is included in the **C energy class (117**kWh/m²/an**<**$q_{h\ spec.}$<**173**kWh/m²/year

b) The energy consumption for space conditioning

The computation ratio of the heating demand for the building's heating time is determined by the ratio:

Q_c = 0.024 · UA_{ref} · CDDan = 0.024 ·171 · 1504 = 6172.4**kWh/year**

The specific energy consumption m2/y is$q_{h\ spec.}$ = Q_c/ A_u = = 6172.4/100**=62kWh/m²/year,**

Where: - Q_c is the requirement for the space conditioning per year

- UArefis the thermal transfer coefficient of the residency;

- CDD is the days - degree cooling requirement;

- $q_{hspec.}$is the specific yearly consumption.

From the point of view of the specific consumption for space conditioning, the residency is included in the **C energy class (50**kWh/m²/an**<**$q_{h\ spec.}$< 87 kWh/m²/year.

For the conditioning of the space, a chiller with mechanic compression was used which had a COP = 4 (Performance Coefficient), consuming a specific electricity of qc/COP=15,5 kWh/m² y.

5.3. Specific Electricity Consumption

From the point of view of the specific electricity consumption of the residence for lighting and household appliances, the building is considered in energy class A with a specific consumption of 40kWh / m2y.The total amount of electricity consumed for conditioning space and facilities is e_t=55.5kWh/m^{2}y.

5.4. Domestic Hot Water (DHW) Consumption

Given that 3 – 4 persons live in the residency and knowing that a person consumes, on average, 50 l/day of domestic hot water, it results in a requirement of l/day, respectively 1 year.

By using a formula: Q_{dhw} = m x c x Δθ, where:

- $Q_{hw}$is the heat necessary for heating the water per day;

- m=50 kg (liters) is the water quantity;

- cis the specific water quantity (4.18 J/g˚C), i.e. 1.16 W/kg°C

- Δθisthe temperature difference between cold water (18˚) and hot water (45˚)

The estimated daily requirement of domestic hot water:

- For 4 persons isQ_{dhw} = 4x50 x 1.163 x 27x10^{-3} = 6.26 kWh/day,
- At year level: Q_{dhw} = 365x 6.26 = 2286.36kWh/day,

The yearly specific consumption is q_{dhw} = Q_{dhw}/A_{net}= 2286.36/100 =**23** kWh/m²/year.

From the point of view of DHW specific consumption, the residency is included in the **B energy class 15**kWh/m²/an**<**$q_{h\ spec.}$<**35**kWh/m²/year.

The annual requirement of thermal energy specific consumption is q_t=$q_{hspec+}q_{dhw}$=**143**kWh/m^{2}y.

5.5. Total Energy Performance of Building without Renewable Energy

*Total energy performance of building E_p*is determined by introducing the final weighting factor, namely primary energy conversion factors (Annex 4) to define the integrated energy performance of buildings, hence:

$$\backslash E_{pt} = \sum E_{del,i} \cdot f_{p,del,i} \quad (13)$$

Where:E_{p_t}- The total primary energy demand, $E_{del,i}$- final energy demand of energy carrier *i*, $f_{p,del,i}$- primary energy factor for demand energy carrier *i*, ,*i* - the current number of the carrier.

The result of the calculation is:

$$E_{pt} = \sum E_{del,i} f_{p,del,i} = 2{,}5 \cdot e_t + 1{,}1 \cdot q_t$$
$$= [55{,}5)]x2{,}5 + [143]x1{,}1$$
$$= 296 kWh/m^2 y$$

5.6. Integration of Renewable Sources into the Energy Supply of Residential Buildings

5.6.1. Aggregation of specific consumptions

The specific annual energy consumption of the residence is expressed in kWh / m^{2}y and the energy production of renewable sources is per m^2 panel. In order to integrate the renewable sources into residential buildings, their production should be expressed in the same unit of measure, i.e. in kWh / m^{2}y, i.e. per m^2 of net area of residence. Also, the specific heat consumption and space conditioning are different from month to month in agreement with HDD and CDD. Their distribution should be in accordance with these parameters. The consumption of hot water and electricity is considered constant at the level of a given month, respectively a day.

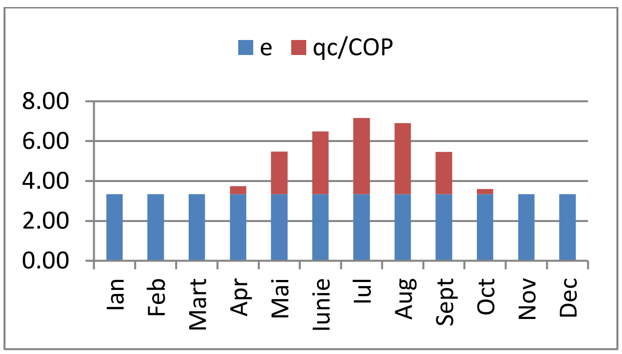
Electricity is used to condition the residential space. The process of converting electricity to cold is characterized by the *COP* performance coefficient, defined as the ratio between the amount of cold produced by the chiller and the amount of consumed electricity. *COP* reference value can be considered as 4. Based on this value, the electrical energy consumed by the chiller is determined. The electrical load of the system is determined as the sum of the residential electricity demand and the electricity consumed by the chiller, plus the internal consumption of the system. As far as the thermal load of the system is concerned, it is equal to the thermal demand of the residence and is determined by adding the heat consumption for heating and the domestic hot water consumption of the residence.

Considering that for the conditioning of the space, it is used for the same chiller with mechanic compression with COP = 4, the aggregation of the consumption in the two energy vectors leads to the following monthly values:

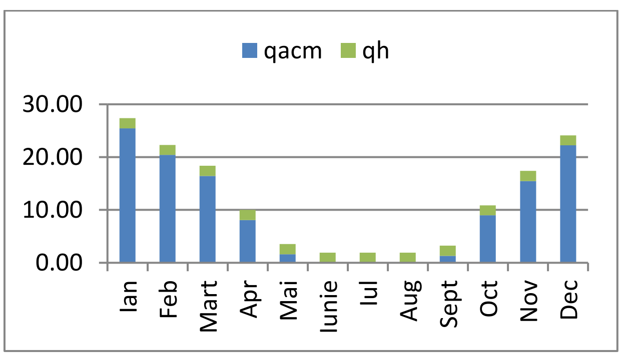
The forms of the load curves for the electricity and thermal energy of the mCCHP system are shown in Figure **6**.

Table 1: The monthly distribution of these specific consumptions in agreement with HDD and CDD.

Month	**Degree Day**		**Specific Consumptions kWh/m²**					**Aggregated Consumptions kWh/m²**	
Month	HDD-°C-d	CDD-°C-d	q_h	q_c	q_{acm}	e	qc/COP	qt	et
Jan	632	0	25.43	0.00	1.92	3.33	0.00	27.35	3.33
Feb	507	0	20.40	0.00	1.92	3.33	0.00	22.32	3.33
Mar	409	0	16.46	0.00	1.92	3.33	0.00	18.38	3.33
Apr	201	39	8.09	1.61	1.92	3.33	0.40	10.01	3.74
May	40	208	1.61	8.57	1.92	3.33	2.14	3.53	5.48
June	0	306	0.00	12.61	1.92	3.33	3.15	1.92	6.49
July	0	372	0.00	15.34	1.92	3.33	3.83	1.92	7.17
Aug	0	347	0.00	14.30	1.92	3.33	3.58	1.92	6.91
Sept	33	207	1.33	8.53	1.92	3.33	2.13	3.24	5.47
Oct	223	25	8.97	1.03	1.92	3.33	0.26	10.89	3.59
Nov	384	0	15.45	0.00	1.92	3.33	0.00	17.37	3.33
Dec	552	0	22.21	0.00	1.92	3.33	0.00	24.13	3.33
Yearly	**2982**	**1504**	**120**	**62**	**23**	**40**	**15.50**	**142.96**	**55.50**



a –The electric load system model



b –The thermal load system model

Figure 6: The load curves model for mCCHPsystem with mechanical compression chiller.

5.6.2. The calculation of solar thermal panel's production

The daily average production of a solar thermal panel is determined based on yearly specific domestic hot water consumption (q_{dhw}) with the relation:

$$Q_z = A_u \cdot q_t / N_d = \frac{100 \cdot 23}{365} = 6.3\text{kWh/d}$$

The thermal power of the panel is determined by dividing the daily average power by the average duration of the solar radiation:

$$P\_u = Q\_z/t\_s = 6.3/3.89 = 1{,}62kW$$

We consider that thermal panels with an efficiency of 50-60% are mounted solar on the Southern surface of the roof so that to cover the specific heat consumption of the summer months. The efficiency formula $\eta\_c = P\_u/(G \cdot A\_p)$ allows us to determine the area A_p of the solar thermal panel of about 2.3-3.2 m², where G=1000W/m²

5.6.3. The calculation of photovoltaic panel's production

If we choose for economic reasons polycrystalline panels with the power of P=250 W, which will be mounted in theon-grid system on the roof of the building, southern façade, on an area of maximum of 30 m². These panels have the following characteristics in Annex 5.

The number of panels in a row is the ratio between the area of the southern façade of the roof and the area of a panel: $n\_PV = 30/1.6 \approx 18$.

Maximum installed power is :$P_i = n_{PV} P_{PV} = 4.5kW$. Assessing average daily energy production requires daily production to be determined monthly with the ratio:$E_z = P_i \cdot t_s = 4.5 \cdot 3{,}89 = 17.5kWh/$

$d$where *ts* is the solar hour number. The monthly energy production$E_l = E_z \cdot N_z$and the yearly energy production is $E\_a = \sum E\_l = 6388 kWh/y$ .This value corresponds to a specific production ofe_{PV}=Ea/A_u=**63.8**kWh/m^{2}y., where Au-is net area of residence.

The average daily production E_{PV} [kWh/day] –the average daily production can be obtained by summing the total annual production divided by the number of days [annual production / 365 = average daily production]. This value will be chosen as the reference value for the photovoltaic system dimensioning in relation to daily average consumption.

The total renewable specific energy production is the sum of PV production and thermal solar production

$$E_{p,ren} = 63.8 + 23 = 86.8 kWh/m^2 y$$

5.6.4. New energy performance of building

The result of this calculationis:

- Consumed energy:

$$E_{del} = \sum E_{del,i} f_{p,del,i} = 1 \cdot e_t + 1.1 \cdot q_h = [55.5]x1 + [23]x1 + [120]x1.1 = 210.5 kWh/m^2 y$$

Where primary energy factors for solar thermal panels and photovoltaic panels have the value.

$$f_{p,del} = 1$$

- Energy exported to the network (electricity) :

$$E_{exp_{pv}} = \sum E_{del,i} f_{p,del,i} = [63.8 - 55.5]x1 = 8.3 kWh/m^2 y$$

New integrated energy performance of buildings:

$$E_p = E_{del} - E_{exp_{pv}} == 210.5 - 8.3 = 202.2 kWh/m^2 y$$

By renewable energy use for buildings, the new standard defines the ratio between renewable and total integrated energy performances, namely share of renewable or Renewable Energy Ratio (RER) by the equation:

$$RER = E\_(p,ren)/E\_p\ .100 \qquad \%$$

The share of renewable or Renewable Energy Ratio (RER) for this building is:

$$RER = \frac{86.8}{202.2}.100 = 42.9\%$$

CONCLUSIONS

The sustainability of European society and economy will be based on renewable energy and resource efficiency. Energy use in buildings depends on a combination of good architecture and energy systems design and on effective operations and maintenance once the buildings are occupied and are influenced by the building location, their architecture, energy system design, and level of renewable energy production.

The current legislative framework promoted by the European Union requires Member States to move to ‘Nearly Zero-Energy Buildings ‘

The effort of researchers through scientific papers or research projects satisfies this goal by proposing new solutions to improve the energy performance of buildings both through passive measures on the building envelope and through active measures, by equipping the buildings with innovative energy technologies.

The most efficient active energy-saving measures in construction are solar thermal systems for domestic hot water and the usage of photovoltaic panels for electricity production.

Methodology for calculating the thermal energy demand allows any engineer, architect, or other specialists to quickly determine the energy demand depending on the location of the building, its orientation, constructive and architectural elements as well as their thermal properties.

The case study of the renewable energy integration methodology in the energy supply of residential buildings was conducted so that the solar thermal panels cover the energy demand for domestic hot water.

The roof surface of the building allowed the installation of photovoltaic panels whose production covers the electricity demand of the building and a small surplus delivered to the network.

The result of the use of renewable energy shows that the integrated energy performance of buildings is 202.5kWh / m2 y compared to the value of 296kWh / m2 y of energy performance of building without renewable energy, which indicates a percentage decrease of 31.5%

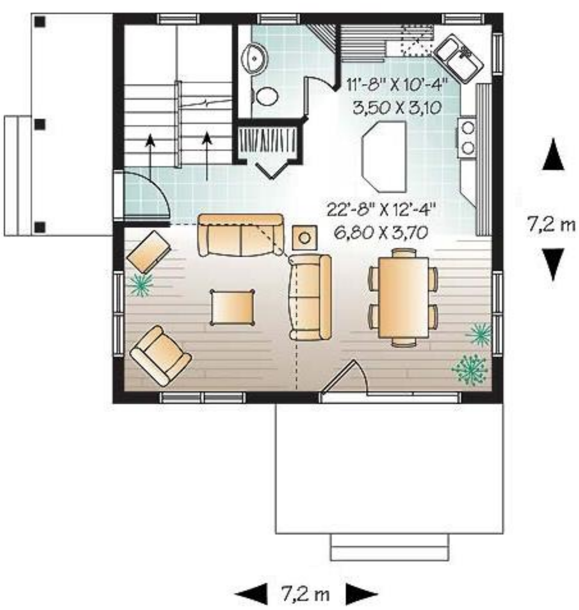
By renewable energy use in this building, the Renewable Energy Ratio (RER) defined as the ratio between renewable and total integrated energy performances is 42.9%.

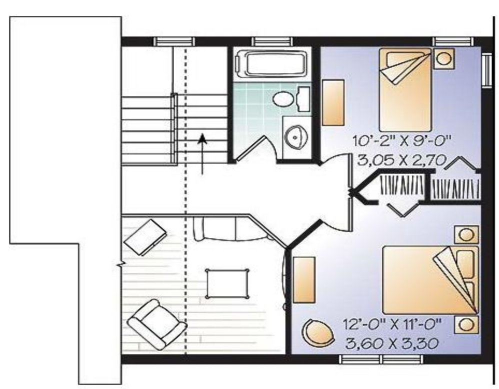
Technologies such as these, which can be used in any location in the world,can reduce the cost of energy generation and consumption, mitigate the resulting pollution emitted to the environment from that energy, and improve the reliability and resilience of our energy system.

Annex 1

Parameter	Value / Description
Number of conditioned floors	2
Net area A_u	99.7 m2
The height of a floor	2.5 m
U - walls	0.56 W/(m2K)
U – roof	0.35 W/(m2K)
U – lower bottom	0.52 W/(m2K)
U – windows, doors	1.30 W/(m2K)
Glazing ratio (window/facade ratio)	12% (without windows on the Northern facade)
Shadowing system	None
Air tightness	Moderate
Thermal bridges	Yes
Heating system	Gas boiler (constant value: 20°C), Energy efficiency: 0.9
DHW installation	Back up -, Gas boiler- DHW efficiency: 0.9 Solar panel
Ventilation system	Natural / through windows ventilation (0.51/h)
Climate control system	Split System , COP 4
Internal contributions	5 W/m²
Installed power of the lighting system	18 W/m²
Automatic regulation of the lighting level	No
Limits regarding the primary energy requirement	It is not required

Annex 2





Ground floor BlueprintFirst floor Blueprint

Annex 3

Location

	Unit	Place of Climate Data	Facility's Location
Name		Romania - Bucharest / Baneasa	Romania - Bucharest - Bucharest
Latitude	°N	44.5	44.4
Longitude	°E	26.1	26.1
Climate area		4A - Mixed - Humid	4A - Mixed – Humid
Altitude	m	91	83

Climate Data

Month	Air Temp. °C	Relative Humidity %	Daily Solar Radiation kWh/m²/day	Wind Speed m/s	Ground Temp °C	HDD_m Heating Days-Degree °C-Day	CDD_m Cooling Days-Degree °C-Day
Jan.	-2.4	88.3%	1.44	2.4	-1.6	632	0
Feb	-0.1	82.3%	2.30	2.7	0.3	507	0
Mar.	4.6	75.0%	3.40	2.8	6.3	409	0
Apr.	11.3	71.70%	4.85	2.6	13.3	201	39
MaY	16.7	69.1%	6.04	2.1	19.6	40	208
June	20.2	71.0%	6.55	1.7	23.6	0	306
July	22.0	69.4%	6.49	1.6	26.5	0	372
Aug.	21.2	69.7%	5.77	1.4	26.3	0	347
Sept.	16.9	74.5%	4.40	1.5	21.1	33	207
Oct.	10.8	81.1%	3.06	1.7	14.1	223	25
Nov.	5.2	86.9%	1.36	2.2	5.7	384	0
Dec.	0.2	88.9%	0.95	2.2	-0.4	552	0
Annual average	**10.6**	**77.3%**	**3.89**	**2.41**	**13.0**	**2982**	**1504**

Annex 4

Type of the Energy Supplier	Primary Energy Factor		
	Renewable fp.ren.	Non-renewable-fp.nren	Total fp.tot
District heat / nearby	0	1.3	1.3
Grid electricity	0.2	2.3	2.5
Solar thermal	1	0	1
Photovoltaics	1	0	1
Bio gas	0.2	0.9	1.1
Natural gas	0	1.1	1.1

Annex 5

PV data

- Electrical:
  - P_p– maximum power of a panel P_{PV}=255 W
  - U_{max}-Tension in the maximum power point Umax=31.62 V
  - I_{max} - current in the maximum power point Imax=8.37A
  - U_{oc}- idle tension U_o=37.98 V
  - Isc - panel's flask current I_{sc}= 8.9A
  - Panel's efficiency 16.4%
- Thermal characteristics of the panel:

- Design operating temperature of NOCT cells (generally equal to 45°C)
- Variation coefficient of tension with temperature β=−0,3166%/ ^{o}C,
- Variation coefficient of tension of current with temperature α = 0,04 73%/ ^{o}C,
- Variation coefficient of power with temperature γ = -0.397%/ ^{o}C,

o Mechanical characteristics:

- panel's geometric dimensions (Lxlxh) 1657mm x 998mm x 38mm
- panel's weight 18.1 kg
- protection degree IP 65
- section and length of the connecting cable 4mm^2
- number of series cells 60(6x10)

REFERNCES

[1] IULIANA LAZĂR - Trends in Energy Efficiency and Policies in ROMANIA - January 2018 – The Romanian Energy Regulatory Authority, Energy Efficiency Department.

[2] EPBD Directive -2010/31 / CE of the European Parliament and of the Council of 19 May 2010. https://doi.org/10.1037/e58801 2011-001

[3] COM / 2016/0765 final - 2016 / 0381 (COD). Available from https://op.europa.eu/en/publication-detail/-/publication/4908dc52-b7e5-11e6-9e3c-01aa75ed71a1/language-en (accessed May 05 2020).

[4] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 of amending Directive 2010/31/UE on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency. https://doi.org/10.5604/ 01.3001.0012.0760

[5] Energy efficiency directive Directive -2012/27 / EC of the European Parliament and of the Council.

[6] Order no. 13/2016, article 3, point 3- Official Gazette of Romania no. 764/20161.

[7] Order no. 13/2016, article 3, point 15- Official Gazette of Romania no. 764/20161.

[8] BogdanAtanasiu – Implementation of near-zero energy buildings (nZEB) in Romania, 2012 ,Buildings Performance Institute Europe (BPIE).

[9] Steven Borncamp – Romania's Greenest Buildings -2014 – The Romanian Green Building Council.

[10] Paglianoa L, Carlucci S, Causonea F, Moazamib A, Cattarina G. Energy retrofit for a climate resilient child care centre. Energy and Buildings. 127;2016:1117–1132. https://doi.org/10.1016/j.enbuild.2016.05.092.

[11] Nik VM, Mata E, Kalagasidis AS, Scartezzini J. Effective and robust energy retrofitting measures for future climatic conditions-Reduced heating demand of Swedish households. Energy and Buildings. 121;2016:176-187. https://doi.org/10.1016/j.enbuild.2016.03.044.

[12] Ferrando M, Causone F, Hong T, Chen Y. Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches. Sustainable Cities and Society. 62;2020:102408. https://doi.org/10.1016/j.scs.2020.102408.

[13] Vincent J.L. Gan, Irene M.C. Lo, Jun Ma, K.T. Tse, Jack C.P. Cheng, C.M. Chan- Simulation optimisation towards energy efficient green buildings: Current status and future trends .Journal of Cleaner Production.254:2020;120012. https://doi.org/10.1016/j.jclepro.2020.120012.

[14] Anna Joanna Marszal, Per Heiselberg. Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark. Energy 2011; 36(9): 5600-5609. https://doi.org/10.1016/j.energy.2011.07.010.

[15] Gorshkov AS, Vatin NI, Rymkevich PP, Kydrevich OO. Payback period of investments in energy saving. Magazine of Civil Engineering 2018; 78(2): 65–75. doi: https://doi.org/10.18720/MCE.78.5.

[16] Pignatta G, Chatzinikola C, Artopoulos G, Papanicolas CN, Serghides DK, Santamouris M. Analysis of the indoor thermal quality in low income Cypriot households during winter. Energy and Buildings 2017; 152:766-775. https://doi.org/10.1016/j.enbuild.2016.11.006.

[17] Energy Conservation in Buildings and Community Systems" Available from https://www.iea-ebc.org/Data/publications/ECBCS_News_2012_12_web.pdf (accessed May 05 2020).

[18] Nearly Zero-Energy Building Strategy 2020 https://zebra2020. eu/ (accessed May 05 2020).

[19] Nearly Zero energy Neighborhoods https://cordis.europa.eu/project/id/314363/es (accessed May 05 2020).

[20] Making net zero-energy real and affordable in EU residential buildings https://wayback.archive-it.org/12090/20210412130329/https://ec.europa.eu/easme/en/news/making-net-zero-energy-real-and-affordable-eu-residential-buildings (accessed May 05 2020).

[21] Laurent PEREZ-EeBGuide- Nov 26, 2012 Available from https://issuu.com/ekopolis/docs/res-1210-eebguide-a-final-pr_2012-1 (accessed May 05 2020).

[22] Passive House Institute- Passive House requirements Available from https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm (accessed May 05 2020).

[23] Badea N, Badea GV. Life cycle analysis in refurbishment of the buildings as intervention practices in energy saving. Energy and Buildings 2015; 86: 74-85. https://doi.org/10.1016/j.enbuild.2014.10.021.

[24] Building the future: Four innovation trends that are shaping green construction. Available from : https://www.epo.org/news-events/in-focus/sustainable-technologies/green-construction.html (accessed May 05 2020).

[25] Solar roof https://www.tesla.com/pl_pl/solarroof (accessed May 05 2020).

[26] Buildings to Generate Their Own Power With Innovative Glass Blocks Available from: https://futurism.com/buildings-to-generate-their-own-power-with-innovative-glass-blocks (accessed May 05 2020).

[27] Case cu amprenta la sol de 50 mp. Constructii mici cu detalii deosebite Available from https://casepractice.ro/case-cu-amprenta-la-sol-de-50-mp/ (accessed May 05 2020).

[28] Badea N. Design for Micro-Combined Cooling, Heating and Power Systems. Springer: London 2015.

[29] High Energy Performance Buildings: Design and Evaluation Methodologies New features in EN 15603, overall energy use and definition of energy ratings Laurent Socal (IT) – Bruxelles 25th of June 2013 Available from https://epbd-ca.eu/wp-content/uploads/2018/04/05-CCT1-Factsheet-PEF.pdf (accessed May 05 2020).

Received on 06-10-2020 Accepted on 15-12-2020 Published on 30-12-2020

DOI: https://doi.org/10.15377/2409-9821.2020.07.8