Environmental Engineering and Management Journal

November 2015, Vol.13, No. 11, 2725-2731
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

ANALYSIS OF PRIMARY ENERGY USE OF TYPICAL BUILDINGS IN HUNGARY

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Abstract

The building stock in Eastern European countries varies greatly in terms of the thermal properties of the materials used. During recent decades, the requirements related to building energy performance have been changed. Nevertheless, the number of newly built buildings has decreased in recent years, so there are few buildings that fulfill the strictest requirements that were recently introduced. Several national programs have been started to help owners improve the energy use of their buildings. In this paper, the various requirements of the past several decades were presented, and the energy analysis of different typical buildings (family house, multi-family house, block of flats, public house) was performed. The possibility of PV cells installation was also analyzed.

Key words: building type, heating, Hungarian standards, requirements

Received: February, 2014; Revised final: October, 2014; Accepted: October, 2014

1. Introduction

The existing building stock in European countries accounts for over 40% of the final energy consumption in the European Union (EU) member states, of which residential use represents 63% of the total energy consumption in the building sector (Poel et al., 2007). Population growth, increasing demand for building services and comfort levels, and the rise in time spent inside buildings assure that the upward trend in energy demand will continue in the future (Pérez-Lombard et al., 2008).

Taking into account the Union's goals to reduce the energy dependency and the greenhouse gas emissions in recent years, different directives were elaborated to enhance the energy efficiency and the use of renewable energy sources in the building sector (EC Directive, 2003, 2010). With an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) and to honor both its long-term commitment to maintain a global temperature rise below 2 °C and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20 % below 1990 levels and by 30 % in the event of an international agreement being reached (EC Directive, 2010).

Built environment includes fuel and electricity use in the residential and public sector. The energy use includes fuel and electricity use in buildings, households and offices for heating, cooling and the use of household and office appliances. Energy savings measures can be categorized into measures that (Wesselink et al., 2010)

- reduce the heating and cooling demand of new and existing buildings,
- improve energy conversion in buildings, and
- reduce the electricity demand in buildings (electric appliances, lighting, sanitary hot water and electric space heating).

To assess the existing building stock, energy certification was required and introduced in European countries. These certificates indicate the primary energy use of buildings, and the quality of a

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building is established based on requirements specific for each country. There are several energy certification programs elaborated in European countries with implemented EPBD requirements (Rey, 2007). In Hungary, the WinWatt software is currently used. Certain scholars claim that these certificates do not consider the embodied energy and that life cycle analysis should be performed (Casals, 2006; Szalay, 2007). The quality of energy used is also omitted by energy labeling methods (Kalmar, 2014). In this paper, we analyzed the primary energy use of typical buildings with different functions depending on the regulation requirement, which was taken into account during their design.

2. Building regulations in Hungary

During recent decades, significant changes were registered in building energy performance standards and regulations. In the case of buildings built before 1960 in Hungary, there were practically no certain thermal requirements related to the building envelope. External building elements had to fulfill only certain static requirements. A building pocketbook edited in 1934 presents different thermal insulation materials, and the overall heat transfer coefficient of external walls had a highest accepted value of 1.68 W/m^{2}K (Möller et al., 1934). Consequently, an external wall built from 38 cm solid brick with inner and outer plastering fulfills the requirement with its 1.56 W/m^{2}K overall heat transfer coefficient. In 1966, the Ministry of Building Industry published a Technical Prescription related to the thermal calculation methods. In this regulation, the physical properties of different building materials are presented, and the correction factors of thermal bridges are given (Technical Prescription ME-30-65, 1966). The required values of the overall heat transfer coefficients were established as a function of the specific mass of the building element:

- external walls
- specific mass <300 kg/m^2 – 1.40 W/m^{2}K
- specific mass 300 – 700 kg/m^2 – 1.55 W/m^{2}K
- specific mass >700 kg/m^2 – 1.64 W/m^{2}K
- slabs
- specific mass <300 kg/m^2 – 1.05 W/m^{2}K
- specific mass 300 – 700 kg/m^2 – 1.16 W/m^{2}K
- specific mass >700 kg/m^2 – 1.22 W/m^{2}K

The first standard related to thermal performance of building elements was elaborated and issued in 1979 (Standard MSZ-04.140/2-79, 1979). This standard stated the thermal requirement values related to external walls and slabs of spaces in which the temperature during the heating season was higher than 16 °C and the relative humidity of indoor air was lower than 75 %. According to this standard, the maximum value of overall heat transfer coefficient was as follows:

- external walls: 0.85 W/m^{2}K
- slabs: 0.40 W/m^{2}K

In 1986, the requirements of Standard MSZ 04140/2 were modified and a requirement related to windows overall heat transfer coefficient was introduced (Standard MSZ 04140/2-85, 1985):

- external walls: 0.70 W/m^{2}K
- slabs: 0.40 W/m^{2}K
- windows: 3.0 W/m^{2}K.

The MSZ 04140/2 Standard was changed in 1992 (Standard MSZ 04140/2-91, 1992). A detailed calculation method was presented, but the requirements related to the thermal properties of external building elements were erased. Instead, a requirement of the specific heat loss of the building and a requirement related to the average heat transfer coefficient of the building envelope were established as a function of the ratio of the envelope area to the heated volume. In the case of continuously used buildings, the requirement of average heat transfer coefficient of the building envelope was 0.6+0.1(V/ΣA). In the case of single-family houses, this value was approximately 0.7 W/m^{2}K. To obtain this average heat transfer value for the whole building envelope, the opaque elements (external walls, slabs) had to be designed with a lower heat transfer coefficient because of the higher heat transfer coefficient of windows and doors. With the introduction of the mean heat transfer coefficient value, the negative effects of thermally poor structures were balanced with well-insulated building elements.

Ministry Regulation 7/2006 TNM issued in 2006 introduced drastic changes to the assessment and requirements related to the energy performance of the buildings (Regulation 7/2006 TNM, 2006).

The building and its elements must satisfy three levels of requirements. The basic requirement is related to the external building elements (opaque and transparent). Practically, the maximal values of overall heat transfer coefficient U [W/m^{2}K] are limited. Several values are presented in Table 1.

Table 1. Admissible values for heat transfer coefficient (Regulation 7/2006 TNM, 2006)

Building element	***Heat transfer coefficient, U [W/m^{2}K]***
External walls	0.45
Flat roofs	0.25
Ceiling on the cellar	0.50
Walls between heated and unheated rooms	0.50
Attic ceiling	0.30
Floor on the soil	0.50
Windows with wood or PVC frames	1.60
Windows with Al frames	2.00
Roof windows	1.70
Entrance doors, or doors between heated and unheated rooms	1.80

The second level of requirements concerns the whole building and is the maximal admitted value of specific heat loss q_m [W/m^{3}K], which depends only on the area of the external elements and the heated volume ratio (ΣA/V). The q_m value may be determined using one of the following relations:

$$\Sigma A/V \le 0.3 \qquad q_m = 0.2\, W/m^3K$$
$$0.3 \le \Sigma A/V \le 1{,}3 \qquad q_m = 0.086 + 0.38(\Sigma A/V)\, W/m^3K$$
$$\Sigma A/V \ge 1.3 \qquad q_m = 0.58\, W/m^3K \qquad (1)$$

The uppermost level of requirements is related to the primary energy consumption of the buildings. Thus, at this level, both the building and its service systems are included. The maximal admitted values of primary energy consumption E_P [kWh/m²a] depend on the building function and the ΣA/V ratio and express the yearly primary energy consumption per net floor area.

Regulation 40/2012 of the Ministry of Interior did not change the requirements; only the indoor environmental parameters in buildings are specified, and the hydraulic balancing of heating, ventilating and air conditioning (HVAC) systems is explicitly required (Regulation 40/2012, 2012).

Regulation 20/2014 of the Ministry of Interior, which goes into effect on 1st January 2015, establishes stricter requirements related to building elements and whole buildings (Table 2) (Regulation 20/2014, 2014).

Table 2. Admissible values for heat transfer coefficient (Regulation 20/2014, 2014)

Building element	***Heat transfer coefficient, U [W/m²K]***
External walls	0.24
Flat roofs	0.17
Ceiling on the cellar	0.26
Walls between heated and unheated rooms	0.26
Attic ceiling	0.17
Floor on the ground	0.30
Windows with wood or PVC frames	1.15
Windows with Al frames	1.40
Roof windows	1.25
Entrance doors, or doors between heated and unheated rooms	1.45

The second level of requirements concerns the whole building and is the maximal value of specific heat loss q_m [W/m³K], which depends only on the area of the external elements and the heated volume ratio (ΣA/V). The q_m value may be determined using one of the following relations:

$$\Sigma A/V \le 0.3 \qquad q_m = 0.16\, W/m^3K$$
$$0.3 \le \Sigma A/V \le 1.3 \qquad q_m = 0.079 + 0.27(\Sigma A/V)\, W/m^3K$$
$$\Sigma A/V \ge 1.3 \qquad q_m = 0.43\, W/m^3K \qquad (2)$$

The recast of EPBD has established several new or strengthened requirements, such as the requirement that all of the new buildings be nearly zero-energy by the end of 2020 (EC Directive, 2010; Annunziata et al., 2013).

3. Hungarian building stock

The majority of the existing residential and public buildings in Hungary were built in the last century. The envelopes of these buildings have various thermal properties, and the HVAC systems are very different. In the last few years, the number of new constructions has decreased drastically. The building stock is aged and the energy performance of buildings lags behind the current requirements. Because the number of newly built buildings is decreasing, the expected energy savings in the building sector cannot be obtained without the thermal refurbishment of the existing building stock. Most existing flats are on private property, which is a disadvantage from the energy refurbishments point of view.

Based on the data of the Hungarian Central Statistical Office, the number of flats, the building type, the year of building and the properties of the flats are presented in Table 3. More than 96% of the flats are on private property. Approximately 64% of the private flats are placed in buildings with a maximum of three flats. In the following, let us analyze the energy use of single-family and multifamily buildings as well as public buildings that can be found in almost every Hungarian settlement.

Table 3. Existing Hungarian building stock

Year of building	***Private property***			***Local government property***	***Property of other organizations***	***Total***
	Number of flats in the building		***Total***			
	1-3	***>3***				
before 1919	151 104	122 180	273 284	26 297	6 629	306 210
1919-1945	310 561	92 636	403 197	16 153	4 739	424 089
1946-1960	347 506	95 975	443 481	10 409	3 739	457 629
1960-1970	365 064	211 161	576 226	10 063	3 920	590 209
1971-1980	423 696	426 029	849 725	22 146	4 994	876 865
1981-1990	376 407	247 231	623 638	10 506	3 709	637 853
1990-2000	211 792	40 462	252 254	2 361	2 373	256 988
2001-2005	126 067	73 466	199 533	7 006	2 878	209 417
2006-2011	89 404	58 020	147 424	1 359	4 386	153 169
Total	2 401 601	1 367 160	3 768 762	106 300	37 367	3 912 429

4. Analysis of typical buildings, case studies

Type 1 – Single-family house

In Hungary the most prevailing family house has a square shape; the floor slab can be placed directly on the ground or on the cellar. This type of house was first constructed in 1960 (Fig. 1). Usually, the walls are built from solid brick (38 cm), gas silicate (30 cm) or, after 1980, brick with vertical cavities (30 cm). No insulation is used for the walls. The floor structure is realized without an insulation layer, the ceiling is realized using timbers, and a porous filling material layer (slag, dross) is usually built in. The windows are double glazed with a wood frame. The energy carrier is usually natural gas; the heat source is a constant temperature boiler or gas convector. The net floor area of the analyzed house is 129.5 m^2.

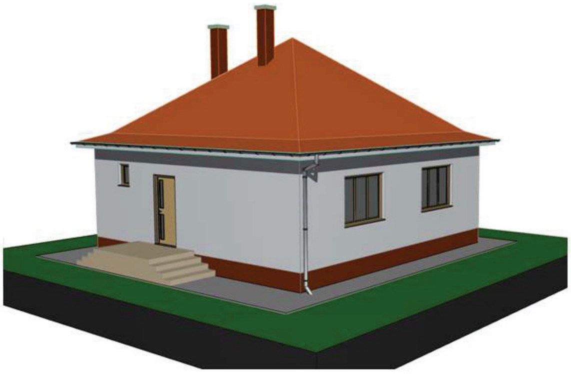

Fig. 1. Single-family house

Type 2 – Multifamily house built with traditional technologies

These buildings usually have four to five levels and are built using solid brick or brick with vertical cavities (Fig. 2). The slabs are realized from steel concrete with a dross layer for thermal insulation. The windows are double glazed with a wood frame. Usually, these buildings have a single boiler or gas convectors as the heat source. The net floor area of the analyzed house is 877.2 m^2.

Fig. 2. Multifamily house built with traditional technologies

Type 3 - Multifamily house built with industrial technologies

These buildings are built from prefabricated multilayered panels using Russian technologies (Fig. 3). The number of levels can be from 4 to 11. The slabs are from steel concrete, and their thickness is approximately 16 cm. The panel structure used for walls is 15 cm of steel concrete, 5 cm of polystyrene, and 7 cm of steel concrete. The polystyrene layer thickness can be, depending on the construction period, up to 8 cm. Heating and hot water supply is usually solved by connection to a district heating system. The analyzed building has five levels, two staircases and 32 flats. The net floor area of the analyzed house is 2040.6 m^2.

Type 4 - Public building

Each settlement has its own local government, kindergarten and schools. There are cases when these institutions are placed in old monument buildings or buildings having a monumental shape. The energy refurbishment of these buildings is difficult because these buildings usually are protected by law (the facades cannot be changed). The main building of a secondary school will be analyzed (Fig. 4). These buildings are built from 50-cm-thick solid brick; the large windows are double glazed.

Fig. 3. Multifamily house built with industrial technologies

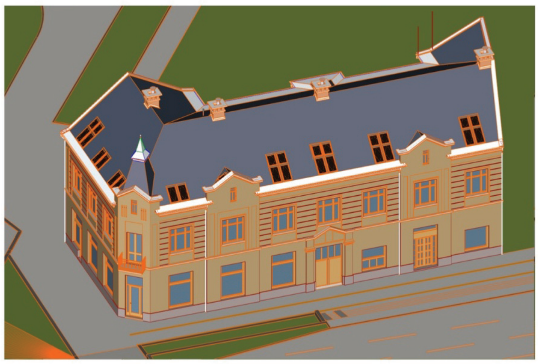

Fig. 4. Public building

Assuming a complex energy refurbishment of these buildings, let us analyze the energy use and CO_2 emission if the refurbishment was performed according to requirements established in 1991, 2006 and 2020.

In the case of a Type 1 building, to fulfill the requirements of Standard 04140/2-1991, each external building element is provided with an additional insulation layer thickness, the heat source is a constant temperature boiler and the heating system has a central thermostat. To comply with the requirements of Regulation 7/2006 TNM, the additional insulation layers are increased considerably, the heat source has to be replaced with a condensation boiler, and the radiators are provided with thermostatic valves. The windows and doors were chosen to fulfill the expected heat transfer coefficient values.

To fulfill the expected requirements in 2020, additional 15- to 20-cm-thick insulation layers are necessary. A geothermal heat pump is installed for heating and cooling, solar collectors are installed to provide the hot water, and PV cells are installed to reduce the electricity consumption. Having low heat demand, after refurbishment, the radiators can be replaced with ceiling heating, and the same panels can be used for cooling.

In the case of a Type 2 building, because the structure of external building elements is similar to that of a Type 1 building, the additional insulation thickness of walls and slabs will be the same. The windows and doors were chosen to fulfill the expected heat transfer coefficient values. In this case, because of the compact shape of the building, the specific heat losses are lower, and because of the higher number of users, the yearly efficiency of the boiler will be higher than in the previous case. The heat source was replaced with geothermal heat pumps because there is enough space around the building to drill the boreholes.

In the case of building Type 3, the 1991 requirements can be fulfilled with the use of a few cm of additional insulation around the envelope and the installation of central and local control elements, which allows the heat supply to be controlled according to an ever-changing heat demand. To comply with the 2006 requirements, the additional insulation layer of the walls will be 10 cm thick, or 15 cm thick for roofs. The expected requirements of a nearly zero energy house can be fulfilled if a 15- to 20-cm insulation layer around the building envelope and triple glazed windows are used and the heat is provided by a cogeneration plant with high efficiency.

The public building practically fulfills the requirements of Standard 04140-1991. To comply with the requirements of Regulation 7/2006 TNM, new central and local control elements have to be installed, and the heat source has to be replaced with a condensation boiler. In the end, the nearly zero-energy building can be obtained with internal wall insulation, window replacement, and ceiling insulation. The condensation boiler has to be replaced with geothermal heat pumps.

The CO_2 emission of the analyzed building is shown in Fig. 5. The primary energy use of the analyzed buildings is shown in Fig. 6.

In the case of building refurbishment the variation in the physical properties of building materials have to be considered (Lakatos and Kalmár, 2013; Lakatos, 2014).

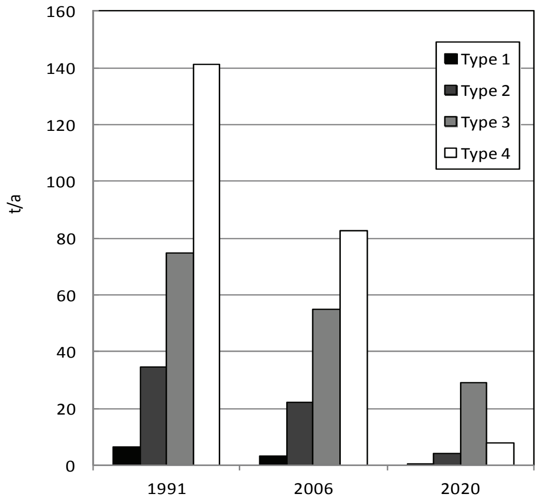

Fig. 5. CO_2 emission of analyzed buildings

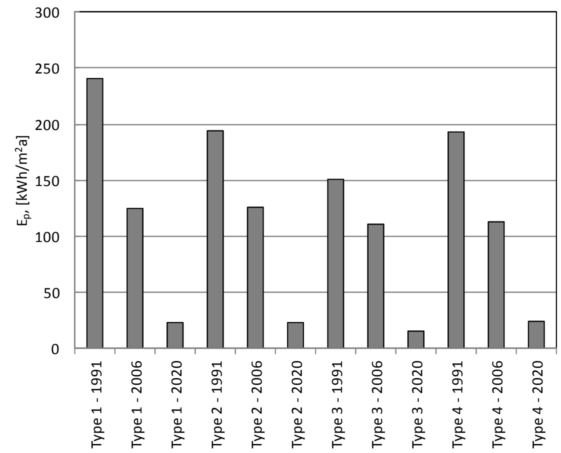

Fig. 6. Primary energy use of analyzed buildings

Without the installation of PV cells, the primary energy use cannot satisfy the expected requirements of a zero-energy building (Fig. 7). In the case of a Type 1 building, 10 1000×1600 mm PV panels can be installed, which means the output is approximately 2 kW_e. Considering the meteorological conditions in Hungary, approximately 2100 kWh/a of electricity will be produced. In the case of a Type 2 building, the installed area of the PV panels is 160 m^2, and the output is 20 kW_e. Thus, 21000 kWh/a of electricity will be produced. In the case of a Type 3 building, because the available roof surface is higher, the installed PV panel area is 450 m^2 (taking into account the shadowing), the output is 55 kW_e. The electricity produced by this system is approximately 59000 kWh/a. According to current building energy regulations, the buildings energy categories are presented in Table 4.

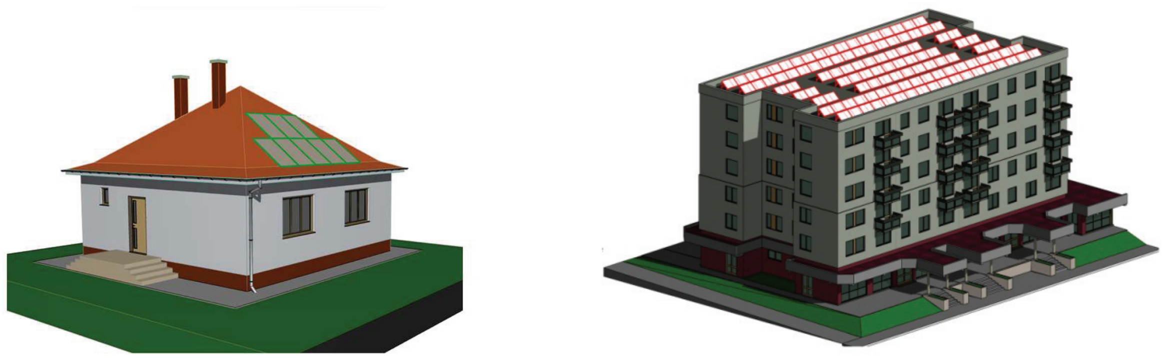

Fig. 7. Installation of PV panels

Table 4. Energy categories of analyzed buildings

Building	***A/V ratio***	***Specific heat loss***	***Energy category***
	[m^2/m^3]	***[W/m^{3}K]***	
Type 1 - 1991		0.544	E
Type 1 - 2006	0.799	0.302	C
Type 1 - 2020		0.134	A+
Type 2 - 1991		0.428	E
Type 2 - 2006	0.478	0.231	C
Type 2 - 2020		0.114	A+
Type 3 - 1991		0.353	E
Type 3 - 2006	0.427	0.209	B
Type 3 - 2020		0.104	A+
Type 4 -1991		0.354	F
Type 4 - 2006	0.503	0.166	B
Type 4 - 2020		0.076	A+

5. Conclusions

The European Union's energy dependency can be considerably reduced by enhancing the energy efficiency in the building sector. Analysis of several typical buildings in Hungary has shown that the primary energy use of these buildings can be reduced even to 15% using modern technologies. In the case of monumental buildings and similar buildings, due to restrictions, the energy consumption can be reduced to 40%.

At present, further decrease is not possible because of monumental building protection laws. Without the integration of renewable energy sources these energy savings are not possible. The minimum energy use is obtained with modern HVAC equipment and optimal integration of local, affordable renewable energy sources.

Acknowledgments

The work is supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0041 project. The project is co-financed by the European Union and the European Social Fund.

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