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Building stock refurbishement in Romania. A case study in Bucharest.

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***Abstract*—The energy consumption of buildings is responsible for 40% of total EU energy consumption and is the main source for greenhouse gas emissions (about 36% of the EU's total CO_2 emissions). In this context, refurbishment of the existing building stock represents one of the main solutions in order to improve the energy efficiency in the building sector. Consequently, the aim of this study is to present data in this field, based on a case study for a block of flats in Bucharest (Romania). Heating energy consumptions are compared, before and after thermal rehabilitation interventions. The computations are performed based on the Romanian calculation methodology concerning Building Energy Performance, using standard and measured climatic data. It is worthwhile to mention that the results are compared to measured heating energy consumptions for several heating seasons.**

***Keywords*—rehabilitation of buildings, heating energy consumption, reduction of CO_2 emissions**

I. Introduction

Recently, on 24 October 2014, the European Council approved the "2030 Framework for Climate and Energy", proposed by the European Commission. Consequently, the main objectives to be met by 2030 are the following: reducing greenhouse gas emissions by at least 40% compared to 1990, increasing the share of renewable energy to at least 27%, and increasing energy efficiency by at least 27% [1]. These impressive energy and climate targets represent the continuation and even the reinforcement of the current European Union (EU) objectives for 2020, known as "20-20-20" targets: 20% greenhouse gas emissions reduction from 1990 levels, raising the share of energy consumption produced from renewable resources to 20%, and improvement energy efficiency by 20% [2].

On the other hand, it is known that buildings are responsible for approximately 40% of EU energy consumption and 36% of EU CO_2 emissions [3]. In addition, buildings have a great potential for using energy generated by renewable sources. As a result, measures to improve energy efficiency in this sector have a strong leverage impact in order to reach EU climate and energy current and future goals.

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In line with this, Romania has adopted specific policies and national strategies regarding the energy efficiency of buildings, even since the negotiations period for EU accession [4]. Furthermore, several national energy strategies were implemented after Romania has joined the EU on the 1st January 2007 (e.g. "Romanian Energy Strategy for 2007-2020" [5], "National Strategy for Sustainable Development of Romania – horizons 2013-2020-2030" [6]). In addition, EU Directives on energy efficiency have been transposed in the Romanian legislation (e.g. Directive 2002/91/EC regarding the Energy performance of buildings – Romanian Law 372/2005).

As the building stock refurbishment represents one of the major action concerning the increase of energy efficiency in buildings and reduction of CO_2 emissions, Romania has implemented numerous measures and instruments to also endorse the objectives of Directive 2010/31/EU [7]. The main legislative acts in this field are the following: the Government Emergency Ordinance (GEO) no. 18/2009 regarding the increasing of energy performance of blocks of flats [8] and the GEO no. 69/2010 concerning thermal rehabilitation of residential buildings with financing through bank loans with governmental guarantee [9]. GEO [8] establishes the intervention works involving the thermal insulation of residential buildings built during the period 1950-1990, the necessary stages of execution, the means to finance them as well as obligations and liabilities of public administration authorities and building owners. The intervention works have to improve the energy efficiency of residential buildings so that the calculated annual specific energy need for heating will decrease below 100 kWh/m^2 usable area, in terms of economic efficiency.

Based on GEO [8], a multiannual programme for financing the buildings refurbishment, approved by the Romanian Government, was launched in 2009 [10]. Accordingly, a number of almost 3.500 buildings (with nearly 150.000 apartments) have been rehabilitated between 2009 and 2011. The amount allocated from the state budget for this programme was 155 million EUR [4].

In this context, the aim of this study is to present data concerning the thermal rehabilitations works for a block of flats in Bucharest, as a representative example for the buildings refurbishment procedure completed in the last years in Romania, through the intermediary of [8]. In addition, it is worthwhile to mention that the results are compared to measured data in order to better assess the precision of the calculation methodology and the influence of the rehabilitation works quality.

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II. Building description

The building taken into consideration is a block of flats carried out in 1972 (Fig. 1). Its shape is rectangular (80.5 x 11.04 m^2). The main geometrical characteristics of the building are given in Table I.

TABLE I. BUILDING CHARACTERISTICS

Built-up area (m^2)	888.72
Usable floor area (m^2)	3790.88
Heated area (m^2)	4443.60
Living area (m^2)	2181.40
Envelope area (m^2)	4405.26
Heated volume (m^3)	11997.72

The block of flats has 4 parts (15 flats on each). The basement is used for parking and stockrooms. The main façade is toward East.

Figure 1. Existing building

The external façade walls are made of special large prefabricated panels (thickness 25 cm), including the following layers: reinforced concrete (8 cm), autoclaved cellular concrete – ACC (7 cm), polystyrene panels (4.8 cm), and reinforced concrete (5.2 cm). The external lateral walls (with loggia) are made of two layers: ACC (20 cm) and concrete (14 cm). The roof structure is also made of concrete and thermal insulation of ACC (thickness 12 cm). Windows are double-glazing (glass thickness: 3 mm) and wood frame. Thermal resistances of the envelope elements taken into account within the computations for the existing building are shown in Table II: R – unidirectional thermal resistance; r – reduction coefficient of the unidirectional thermal resistance, based on the evaluation of thermal bridges; R' – corrected unidirectional thermal resistance, R' = r R).

The corrected thermal resistance of each construction element was calculated according to the Romanian methodology of Building Energy Performance [11].

The heating and the domestic hot water for the block of flats are assured by the district heating system of Bucharest. The existing building heating system is comprised of old cast iron radiators (equipped with partially functional vanes) and black steel pipes for the distribution.

TABLE II. THERMAL RESISTANCES – EXISTING BUILDING

Envelope element	Surface (m^2)	R (m^2°C/W)	r (-)	R' (m^2°C/W)
External wall (East)	822.15	1.576	0.548	0.864
External wall (West)	738.15	1.576	0.446	0.703
External wall (South)	149.04	1.576	0.856	1.349
External wall (North)	149.04	1.576	0.856	1.349
External lateral wall loggia (North)	72.36	0.971	0.829	0.805
External lateral wall loggia (South)	72.36	0.971	0.829	0.805
Double glazing, wood frame (East and West)	564.60	0.310	1.000	0.310
Metallic external frame – staircase (East)	48.60	0.170	1.000	0.170
Metallic external frame, door (East – main access)	11.52	0.170	1.000	0.170
Ceiling structure	888.72	0.903	0.870	0.786
Ground floor structure	888.72	0.360	0.980	0.353

III. Rehabilitation works

The rehabilitation interventions in order to improve the energy performance of the envelope have included (Fig. 2):

- supplementary thermal insulation of external walls: 8 cm of polystyrene applied on the external face of the walls
- supplementary thermal insulation applied on the ceiling: 15 cm of polystyrene
- supplementary thermal insulation applied on the ground floor: 8 cm of polystyrene
- replacing old wood windows frame with high-quality PVC frame (containing ventilation grilles)

Figure 2. Rehabilitated building

Thermal resistances for the new envelope structure are given in Table III. The results confirm the expected increase of the thermal bridges due to the greater wall thickness.

TABLE III. THERMAL RESISTANCES – REHABILITATED BUILDING

Envelope element	Surface (m^2)	R (m^2°C/W)	r (-)	R' (m^2°C/W)
External wall (East)	822.15	3.390	0.623	2.112
External wall (West)	738.15	3.390	0.555	1.881
External wall (South)	149.04	3.390	0.772	2.617
External wall (North)	149.04	3.390	0.772	2.617
External lateral wall loggia (North)	72.36	3.390	0.793	2.688
External lateral wall loggia (South)	72.36	3.390	0.793	2.688
Double glazing, wood frame (East and West)	564.60	0.550	1.000	0.550
Metallic external frame – staircase (East)	48.60	0.170	1.000	0.170
Metallic external frame, door (East – main access)	11.52	0.550	1.000	0.550
Ceiling structure	888.72	4.310	0.802	3.457
Ground floor structure (over unheated basement)	445.97	2.178	0.970	2.113

In addition, there have been special measures for the rehabilitation of the heating system: replacement and thermal insulation of the distribution pipes located in the technical basement. The same intervention has been carried out for the domestic hot water installation.

IV. Heating energy consumptions

Heating energy consumptions were estimated using [11], taken into account standard and measured climatic data (Table IV):

$$Q_{fh} = Q_h + Q_{th} - (Q_{rhh} + Q_{rwh}) \text{ [kWh/an]} \quad (1)$$

where Q_{fh} – total heating energy consumption; Q_h – building energy need for space heating (building thermal properties, indoor and outdoor climate); Q_{th} - total heating energy consumption depending on the efficiency of the heating system; Q_{rhh} – recovered heating system heat losses; Q_{rwh} - recovered domestic hot water system heat losses.

$$Q_h = Q_L - \eta Q_G \text{ [kWh/an]} \quad (2)$$

Q_L - heat losses of the building envelope; η – utilization factor; Q_G – heat gains (metabolic gains from the occupants, power consumption of lighting devices, household appliances, solar gains).

$$Q_{th} = Q_{em} + Q_d + Q_g + Q_S + KW_e \text{ [kWh/an]} \quad (3)$$

Q_{em} – thermal energy required for heat emission (non-uniform internal temperatures distribution in each thermal zone, emitters embedded in the building structure towards the outside or unheated spaces, control of the operative temperature; Q_d - ; Q_g - ; KW_e -.

Furthermore, we present in Table IV variations of the outside air temperature considered in our calculations for the existing building and rehabilitated building.

TABLE IV. OUTSIDE AIR TEMPERATURE VALUES

Outside air temperature during the heating season (°C)	Standard climatic data [12]	Measured climatic data		
		2007-2008	2008-2009	2009-2010
Average	5.10* / 5.85**	7.11	5.84	5.60
Low of average monthly	-2.40	-2.48	-2.56	-0.54
High of average monthly	11.30	13.59	11.08	11.92

* existing building; ** rehabilitated building

The achieved results before/after the all rehabilitation process, detailed above, are presented in Table V and Table VI, respectively.

TABLE V. RESULTS – EXISTING BUILDING

Result	Standard climatic data [12]	Measured climatic data (2007-2008)
Heating season (days)	242	238
Specific heating energy (kWh/m^2,year)	178.64	156.69

TABLE VI. RESULTS – REHABILITATED BUILDING

Result	Standard climatic data [12]	Measured climatic data	
		2008-2009	2009-2010
Heating season (days)	222	202	207
Specific heating energy (kWh/m^2,year)	91.36	83.04	86.34

Furthermore, in order to have a better data interpretation, we corrected the measured heating energy consumptions by the heating degree-days (HDD) method [12]. The attained results are presented in Table VII.

TABLE VII. MEASURED HEATING ENERGY CONSUMPTIONS

Heating season	Measured* (kWh/m^2,year)	Measured normalized based on HDD method (kWh/m^2,year)
2007-2008	98.84	110.33
2008-2009	62.72	69.60
2009-2010	66.40	76.79

*values reported by Bucharest District Heating Company

Finally, calculated and measured specific heating energy consumptions are compared in Table VIII for different heating seasons (existing and rehabilitated building).

TABLE VIII. HEATING ENERGY CONSUMPTIONS

Heating season	Measured (kWh/m^2,year)	Calculated [11] (kWh/m^2,year)
2007-2008	98.84	156.69

2008-2009	62.72	83.04
2009-2010	66.40	86.34

We note that there are substantial differences between estimated and measured heating energy consumptions (approximately 60% for the existing building and 30% for the new envelope structure). On the other hand, the differences between the calculated values based on standard climatic data and measured values normalized based on HDD method (Table VII) are between 62% for the existing building and 20% for the rehabilitated block of flats.

v. Conclusion

The set of measures concerning the thermal rehabilitation of the building presented in this study has led to improving the building energy performance by 32-36%, based on measured data for two heating seasons.

Nevertheless, there are important discrepancies between recorded and estimated heating energy consumptions based on the Romanian methodology of Building Energy Performance [11]. More precisely, the calculated values overestimate the billed heating energy consumptions. It is interesting to note that the differences are reduced in the case of the rehabilitated building (30%) compared to the case of the old envelope structure (60%). There are some objective explanations for these gaps, excepting the accuracy of the numerical model (any calculation method has its limits). The most important reasons would be the following: long periods of time in which users do not provide comfort internal temperatures in all apartments or in some thermal zones inside the apartments (the occupants prefer to maintain lower temperatures or even to close the thermostatic valves sometimes); the quality of the works carried out in situ, that does not meet the requirements of technical projects, developed according to proposed rehabilitation measures and solutions.

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