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A NEW TYPE OF STRUCTURE MADE OF PRECAST CONCRETE FRAMES FOR CIVIL BUILDINGS

BY

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Abstract. The paper aims to synthetically explain the embedded energy term, its quantity variation according to different types of structures for civil buildings, the amount of energy embedded in different building materials and the amount of energy required in operating a civil building. To highlight the quantity variation of embedded energy and of operational energy, depending on the type of structure, in this paper is analysed a multi-storey house, with B+GFl+1Fl system of height, having in the first case the load bearing structure made of reinforced concrete frames and in the second case a new type of structure made of precast concrete frames. All calculations in this study lead to the conclusion that choosing the type of load bearing structure for civil buildings is a complex process that can influence energy consumption.

Key words: energy efficiency; energy consumption; load bearing structure; building materials.

1. Introduction

The art of building aims to an optimal use of space and materials. For a building with a given destination, the problem consists in choosing, from a wide variety of possible solutions the one which verifies at the same time a set of

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required data (characteristics of available materials, climatic conditions and the nature of the soil, exterior actions, established safety factors) and of criteria for price and comfort, which is done through conception and execution. Taking into account the need of building optimization different types of structures are chosen, having a sufficient safety and reasonable through cost and minimum energy consumption, manual labor and materials. The option chosen must embody an optimal balance between service, safety, economy and the adopted structure (Negoiţă, 1976).

Construction or civil buildings, which host various functional processes, are designed to create optimal conditions for housing and carrying out multiple processes of social life and are influenced by a number of factors that must be considered in their design and implementation, which is a complex process and which should be based on the system concept. Among the main factors that determine and influence the building design and the overall composition of the building, respectively building elements and construction subassemblies, can be mentioned the following: human beeing, human activity and nature and environment factors (interior and exterior).

In general, a building as a system, consists of several subsystems and subassemblies and building elements performing roles and clearly defined functions as folows:

a) subassemblies or elements that make up the load bearing structure and which ensure the building's strength and stability under the action of vertical and horizontal loads;

b) subassemblies or partitioning elements or for padding and thermal and acoustic insulation materials;

c) elements or finishing work, with aesthetic and protection role of structural and non-structural elements.

Load bearing structure type is chosen according to a number of factors, the most important of them, which should be considered, are: building's destination and organization of space, system of height, site conditions, construction materials that are used, execution technology and technical-economic indices (Marusciac, 1998).

Civil buildings can be built using one of the following main types of load bearing structures:

a) structures consisting of load-bearing walls of solid brick masonry;

b) structures made of reinforced monolithic or precast concrete frames;

c) mixed structures composed of frames and load-bearing walls of masonry.

Embedded energy is the energy needed for manufacturing building materials and putting them into practice. Operating energy is the energy required in maintaining the inside environment through processes such as heating, lighting, air conditioning and ventilation. Operational energy is influenced by the building users, while embedded energy depends on the constructive design and the materials used. Embedded energy of a building enters the calculations only once, while the energy required in use accumulates over time. In establishing the two types of energy consumptions an important role has the life of the building, because throughout it, from time to time, maintenance and rehabilitation works can be done.

2. Comparative Analysis of Embedded Energy and Operating Energy of a Civil Building

The present study highlights the importance of choosing the proper type of load-bearing structure comparing two types of structures in terms of embodied energy in building materials needed and of building's operating energy. Calculations were performed for a multi-storey house, with B+GF+1F system of height, having in the first case the load-bearing structure made of reinforced concrete frames and in the second case a new type of structure made of precast concrete frames. The recommendations of "Methodology for calculating the energy performance of buildings", Mc 001/1, 2, 3, 4, 5-2006 and MDRT Order no. *2513*/22.11.2010 on the energy performance of the building have been taken into account. The functional composition and size of the housing unit, located in Cluj-Napoca, depending on the type of load-bearing structure are shown in Figs. 1,...,4. The house has a single stair case and is equipped with central heating and internal network-wide automated thermostat. All rooms are heated up to +20°C. The stair case is heated. The basement is not heated.

2.1. Reinforced Concrete Frame Structure

Frames are structural systems of vertical bars (columns) and horizontal (beams), rigidly joined in nodes, which keep a spatial balance through layout the beams on two directions in plane (transverse and longitudinal). Sectional efforts that occur in bars depend largely on the size and on the rigidities of the beams and columns. The distribution of moments between the bars of the frame is influenced by the ratio between the stiffness of the beams and the rigidity of the columns. Thus, with increasing the rigidity of the columns, positive moments in beams increase and the negative ones in the frame nodes, respectively in colums, decrease and *vice-versa*. Given the fact that beams (requested to bending) have a good ductility and the columns (requested to excentric compression) have a lower dutility, to ensure a good earthquake conformation, it is necessary that higher deformations to be oriented towards the beams. In this case the first plastic hinges occur at the end of the high requested beams from the lower levels of the frame, which then extend in the beams from the upper levels and in columns.

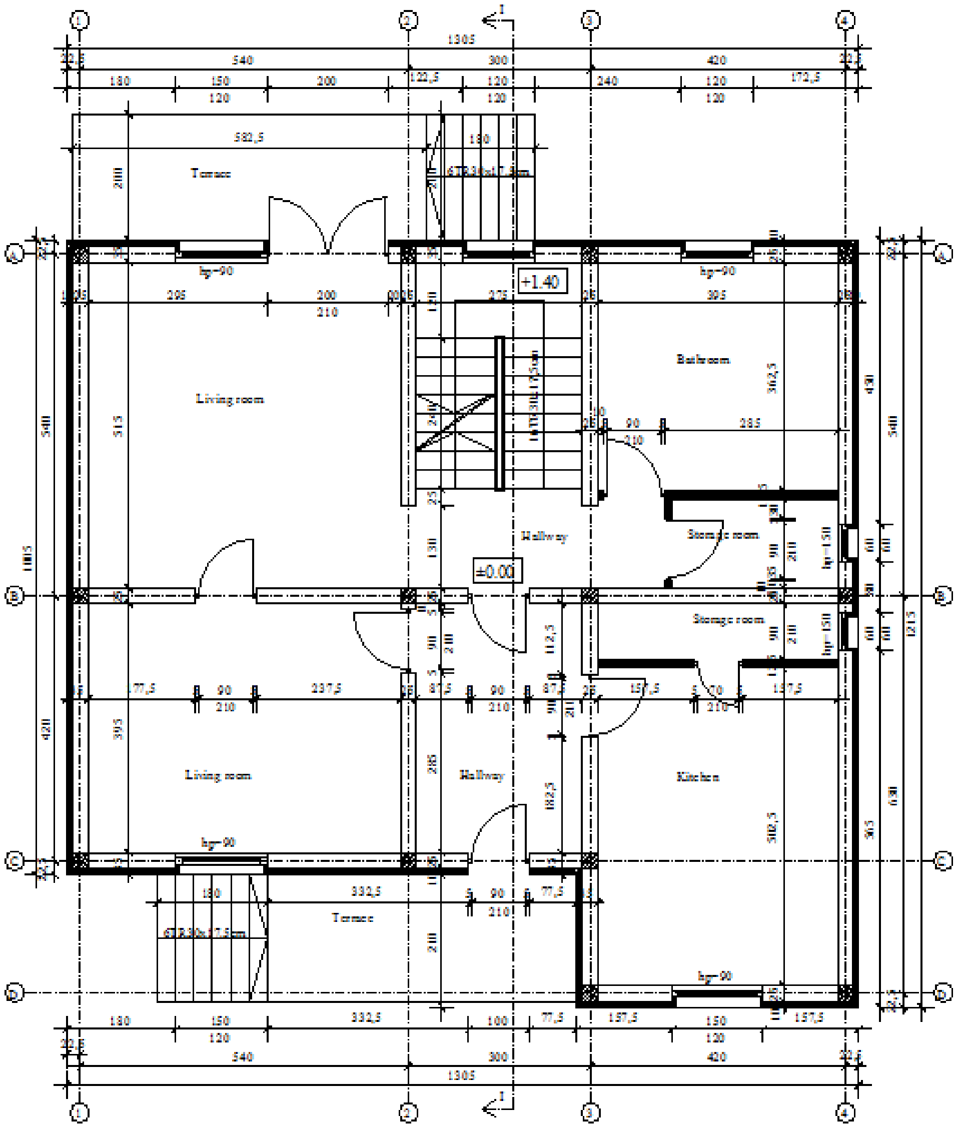


Fig. 1 – Ground floor plan of the building with reinforced concrete frame structure.

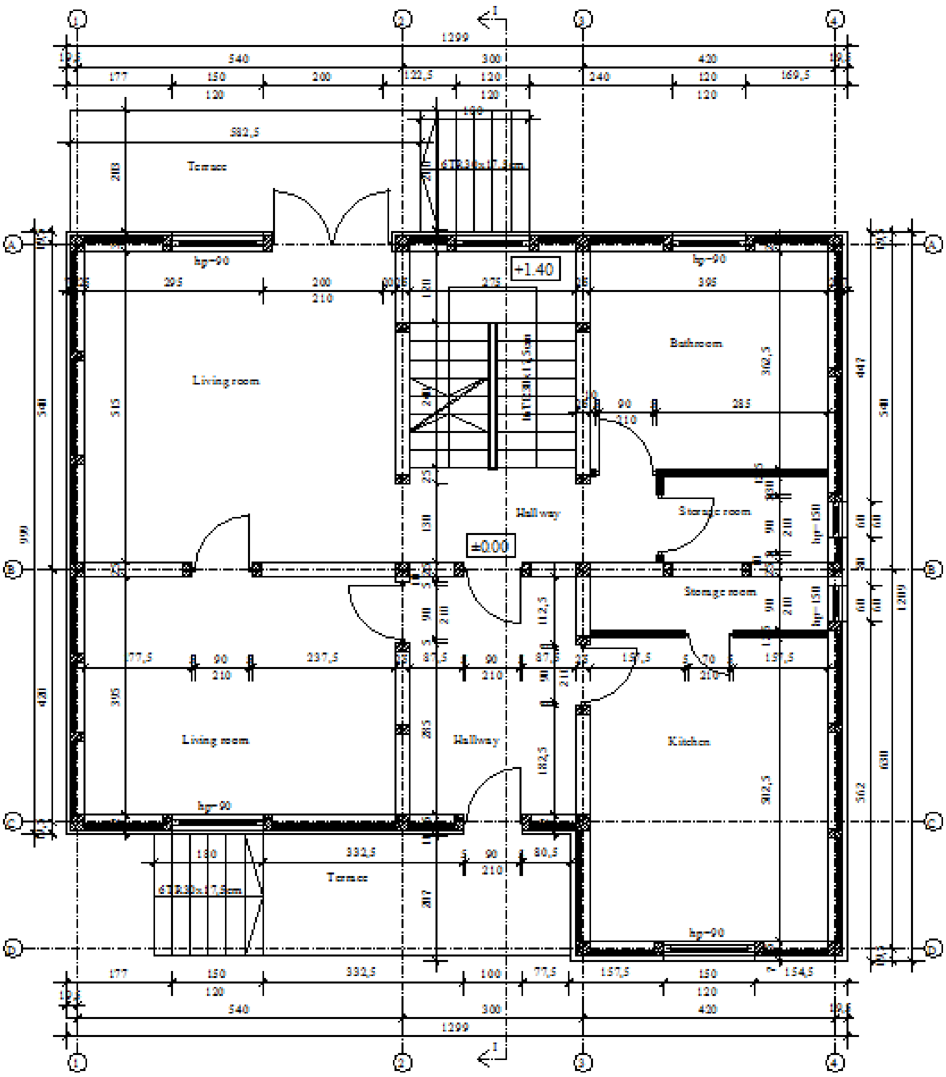


Fig. 2 – Ground floor plan of the building with the new type of structure made of precast concrete frames (Marusciac, 1998).

LEGEND:
1. interior wall coating
2. vapor barrier
3. precast concrete column 25x25cm
4. autoclaved aerated concrete
5. mineral wool layer d=20cm
6. air layer
7. precast elements, modular type

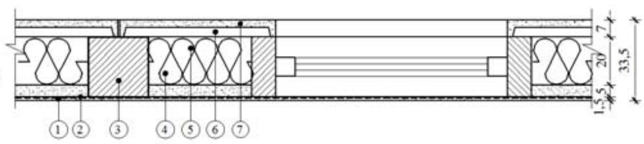
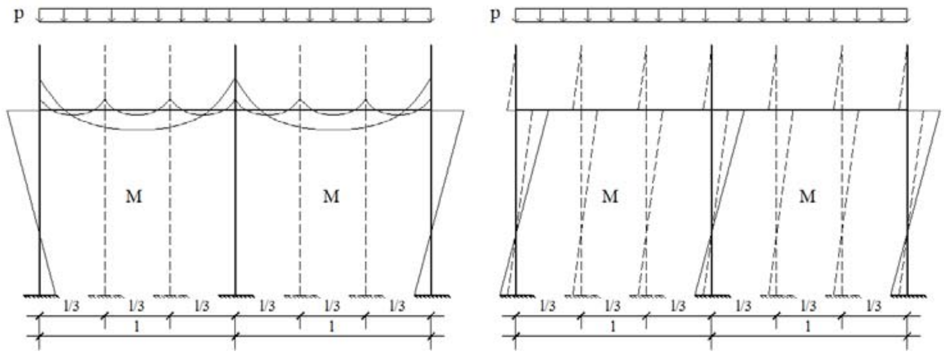


Fig. 3 – Horizontal plane detail to achieve exterior walls (Marusciac, 1998).



a *b*

Fig. 4 – Comparative static schemes of the bending moment diagrams:
a – reinforced concrete frame structure, *b* – structure made of precast concrete frames according to the Invention Patent no. *113071* C (Marusciac, 1998).

2.2. A New Type of Structure Made of Precast Concrete Frames

The new type of structure made of precast concrete frames used to achieve storied houses, is made up of columns that are disposed at the intersection of the main axis and “stair type” plane elements that are disposed between the columns, forming a rigid spatial frame, able to take over and to transmit all the loads to the infrastructure. Columns can be done with their height on two levels, depending on the height of the building and on the adopted execution technology. The “stair type” elements consist of

a) upper flange, which acts as a beam for propping floor panels, two or three vertical uprights, which are intermediate bearings for the upper flange, being at the same time uprights for demarcation of the openings for doors or windows;

b) lower flange, which is used to stiffen the uprights and possibly for fixing interior dry finishes;

c) horizontal ribs that occur only at the hollow elements, acting as a lintel or as a window railing, respectively at the elements from the staircase area for propping stairheads or flights (Marusciac, 1998).

Therefore, the new structure allows a better load distribution and a substantial reduction of sectional efforts (*N*, *M* and *T*).

Fig. 4 shows the comparative static schemes of the bending moment diagrams corresponding to the reinforced concrete frame structure (*a*) and to the new type of structure made of precast concrete frames according to Invention Patent no. *113071* C (Marusciac, 1998).

3. Study on Embedded Energy and Operating Energy for the Studied Structures

Each building is a complex combination of materials processed, each of which contributes to the amount of embedded energy. Renovation and maintenance of a building, during its life cycle increases the amount of embodied energy. Choosing building materials and execution technology wisely can also significantly change the embodied energy value in the structure of a building. The embedded energy can vary from country to country, from region to region, the materials used can have different amounts of energy from one manufacturer to another depending on the technology of production (Baran, 1998). Generally as a material passes through several stages of processing, from raw product to the finished product, the embedded energy is higher.

The calculations, performed initially, establish the quantities of materials used for the construction of the building according to the two chosen types of resistance structures, dividing the building into four major subsystems: infrastructure, superstructure, envelope and interior finishes.

In Table 1 (*a* and *b*) are presented: the final values of the quantities of materials needed to build the two buildings taking into account the four major subsystems, the final amount of embedded energy for each building, in MJ, the final value of embedded energy for each building, in GJ, and the embedded energy for each building, in GJ/m^2.

Energy consumed in operation for the two types of the studied structures is divided into: energy consumption and energy efficiency of heating systems (Q_h^{year} annual energy demand for heating, in kWh/m^{3}year, reported to directly and indirectly heated volume and q_h^{year} annual energy requirement in relation to heated directly and indirectly useful area, in kWh/m^2 year), energy consumption and energy efficiency of ventilation and air conditioning installations, energy consumption and energy efficiency of domestic hot water installations (q_{dhw}, in kWh/year) and energy consumption and energy efficiency of lighting installations (q_{light}, in kWh/year). The calculations were made according to the relations given by the ”Methodology for calculating the energy performance of buildings” Mc 001/1, 2-2006 and are presented in the Table 2, where: A_{EW} is the opaque areas of the exterior wall area of the building;

Table 1

Embedded Energy in Building Materials for: a - Reinforced Concrete Frames and b – the New Type of Structure Made of Precast Concrete Frames

Reinforced concrete frames				
Material	Value	Unit.	Total energy MJ	
Wood	1060.85	sq m	43919.19	
Concrete (30MPa)	167.18	cm	531632.4	
Concrete	209.07	cm	491314.5	
Steel	17219.6	kg	551027.2	
Steel (Steel props)	52	pcs	40768	
Brick (for walls)	70.92	cm	366656.4	
Gypsum wallboard (interior walls)	40	sq m	32300	
Glass (doors, windows)	56.64	sq m	85073.28	
Mineral wool insulation	193.48	sq m	5378.744	
Moisture barrier	125	sq m	9637.5	
Waterproofing	199.94	sq m	90812.748	
Aggregate	123.76	sq m	742.56	
Basement slab insulation	102	sq m	23868	
Polystyrene insulation	315	sq m	88452	
Steel (for attic)	50	m	9545.6	
PVC (doors, windows)	56.64	sq m	530263.68	
Wall coating	320	sq m	5241.6	
			2906633.4	MJ
			2906.6334	GJ
			5.15653101	GJ/sq m

a

The new type of structure made of precast concrete frames				
Material	Value	Unit.	Total energy MJ MJ	
Wood	620.52	sq m	25689.528	
Precast concrete	42.96	cm	119428.8	
Concrete (30MPa)	119.98	cm	381536.4	
Concrete	219.82	cm	516577	
Mortar	2.5	cm	8000	
Steel	17386.85	kg	556379.2	
Steel (Steel props)	26	buc	20384	
Metal work	336	kg	10752	
Brick (for attic)	7.2	cm	37224	
Gypsum wallboard (interior walls)	40	sq m	32300	
Glass (doors, windows)	56.64	sq m	85073.28	
Mineral wool insulation	247.62	sq m	6883.836	
Basement slab insulation	102	sq m	23868	
Moisture barrier	280.45	sq m	21622.695	
Waterproofing	280.45	sq m	127380.39	
Aggregate	247.62	sq m	1485.72	
Autoclaved aerated concrete	92.96	cm	218456	
Steel (for attic)	50	m	9545.6	
PVC (doors, windows)	56.64	sq m	530263.68	
Wall coating	320	sq m	5241.6	
			2738091.73	MJ
			2738.09173	GJ
			4.81518544	GJ/sq m

b

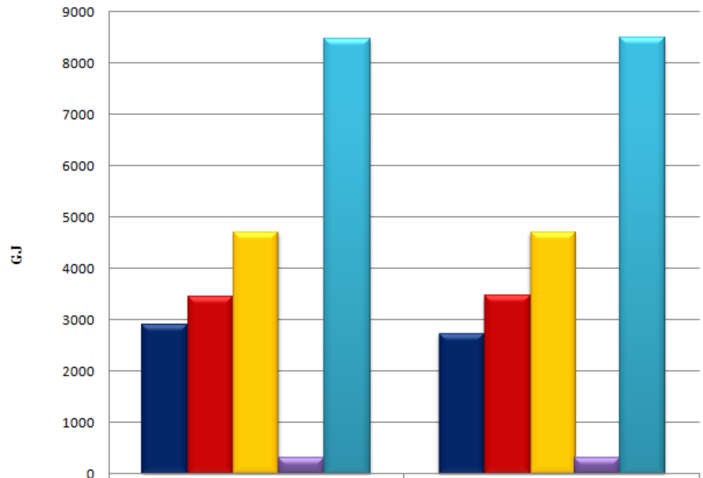
Table 2

Values of The Energy Consumed in the Operation of the Two Studied Structures

Building type/Geometric characteristics	Corrected thermal resist. m^2K/W	Coeff G W/m^3K	Q_h^{year} kWh/ m^3year	q_h^{year} kWh/ m^2year	q_{dhw} kWh/ m^2 year	q_{light} kWh/ m^2 year
Reinforced concrete structure B+Gf+1F $A_{EW} = 253.32$ m^2; $A_G = 30.18$ m^2 $A_{TF} = 123.76$ m^2; $A_{BF} = 123.76$ m^2 $A_{env} = 531.02$ m^2; $V_h = 638.602$ m^3; $A_{u,h} = 247.52$ m^2	$R_{EW} = 2.00$ $R_G = 0.82$ $R_{TF} = 4.777$ $R_{BF} = 3.10$	0.498	30.002	**77.405**	**105.85**	**7.10**
Structure made of precast concrete frames according to the Invention Patent B+Gf+1F $A_{EW} = 252.194$ m^2; $A_G = 30.18$ m^2 $A_{TF} = 123.76$ m^2; $A_{BF} = 123.76$ m^2 $A_{env} = 529.894$ m^2; $V_h = 638.602$ m^2 $A_{u,h} = 247.52$ m^2	$R_{EW} = 2.107$ $R_G = 0.82$ $R_{TF} = 4.777$ $R_{BF} = 2.183$	0.50	30.18	**77.865**	**105.85**	**7.10**

A_G – glazed area of the building; A_{TF} – terrace floor area; A_{BF} – area of the floor above the basement; A_{env} – area of the building's envelope; V_h – heated volume of the building; $A_{u,h}$ – heated useful area of the building; R_{EW} – corrected thermal resistance of the exterior walls; R_G – corrected thermal resistance of the glazed area of the building; R_{TF} – corrected thermal resistance of the terrace floor; R_{BF} – corrected thermal resistance of the floor above the basement; G – overall heat loss coefficient, in W/m^{3}K.

The values from the explicative table accompanying graph from Fig. 5 show that a building having a structure made of precast concrete frames has the total embedded energy value lower than the structure made of reinforced concrete frames. The amount of energy consumed in operation for the new type of precast concrete structure made according to the invention patent has a close value to that for the reinforced concrete structure.



	Case I Reinforced concrete frames	Case II The new type of structure made of precast concrete frames
Initial embedded energy	2906.63	2738.09
Energy consumed for heating/50 years	3448.365	3468.858
Energy consumption of domestic hot water installations/50 years	4715.58	4715.58
Energy consumption of lighting installations/50 years	316.3	316.3
Total energy consumed in operation/50 years	8480.245	8500.738

Fig. 5 – Graph comparing the energy consumption values for the two analysed structures.

By adopting the new type of structure the following major advantages are obtained:

a) increasing the degree of prefabrication and typification of the structural elements;

b) considerable increase of productivity and reduced period of execution by simplifying the work of handling, transport and installation;

c) precast sections and weight reduction, respectively of consumption of energy-intensive materials (steel and cement), by adopting new types of structural elements, having a static scheme which allows a better load distribution and a substantial reduction of efforts in bars and nodes, compared to conventional solutions (traditional);

d) the new type of structure made of precast concrete frames, can be designed for different floor plans, with two or more floors and any type of filling material for closing elements and for subdivision elements (Marusciac, 1998).

4. Conclusions

Calculations have shown the need for the conformation of the construction elements that influence the amount of embedded energy. We noticed the need to develop a standardized approach of data collection, in terms of embodied energy. When industry has a standard for collecting and analysing information, achieving energy savings of embedded energy in a building would be useful to compare products and buildings in terms of energy efficiency (Dixit *et al*., 2010).

The concept of *embedded energy* in a structure should be reconsidered and building materials industry should give it a greater importance. It can be observed, for both types of structures, that although the amount of energy consumed in operation for the new type of precast concrete structure built according to the invention patent has a value close to that for the reinforced concrete structure, the value of embedded energy for the structure built according to the cited invention is lower than that for the reinforced concrete frames. Therefore the manner of approaching the concept of embedded energy in a structure should change.

Operating costs of a building can be greatly reduced by planning and using materials appropriate to the climate zone in which the building will be located. Low temperature areas will benefit of construction materials with high thermal inertia (such as concrete, brick or stone) and areas with moderate temperatures will benefit of materials for light-weight buildings (steel or wood). Creating a thermal comfort will be less determined on heating and ventilation systems.

Using materials with similar durability throughout the building will reduce the need for renovation and repair. Renewable energy use in the production of materials becomes problematically when taking into account the actual cost of different technologies.

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UN NOU TIP DE STRUCTURĂ DIN CADRE PREFABRICATE DIN BETON ARMAT PENTRU CLĂDIRI CIVILE

(Rezumat)

Se explică sintetic termenul de *energie înglobată*, variaţia cantităţii acesteia în funcţie de diferite tipuri de structuri pentru clădiri civile, cantitatea de energie înglobată în diferite materiale de construcţie şi cantitatea de energie necesară în exploatarea unei construcţii civile. Pentru a se evidenţia variaţia cantităţii de energie înglobată şi de energie necesară în exploatare, în funcţie de tipul structurii, s-a considerat o casă etajată de tip vilă, cu regimul de înălţime S+P+E, având în primul caz structura de rezistenţă din cadre de beton armat monolit şi în al doilea caz un nou tip de structură din cadre prefabricate din beton armat. Toate calculele efectuate în acest studiu duc la concluzia că alegerea tipului de structură portantă pentru clădirile civile este un proces complex ce poate influenţa consumul de energie.