SUSTAINABLE RETROFITTING OF LARGE PANEL PREFABRICATED CONCRETE RESIDENTIAL BUILDINGS

Alexandru A. BOTICI
"Politehnica" University of Timisoara, Romania, alex.botici@ct.upt.ro

Viorel UNGUREANU
"Politehnica" University of Timisoara, Romania, viorel.ungureanu@ct.upt.ro

Adrian CIUTINA
"Politehnica" University of Timisoara, Romania, adrian.ciutina@ct.upt.ro

Alexandru BOTICI
"Politehnica" University of Timisoara, Romania, alexandru.botici@ct.upt.ro

Dan DUBINA
"Politehnica" University of Timisoara, Romania, dan.dubina@ct.upt.ro

Summary

In the present context, large part of the Romanian urban population lives in collective multi-storey residential buildings made out of large prefabricated reinforced concrete panels. Most of these buildings are over 30 years old, and the materials used for thermal insulation are already out-dated. Because most residential buildings do not meet the modern internal ambient regulations, it is necessary to improve their energy efficiency by sustainable renovation solutions, which besides the economic and social benefits will lead to reductions in greenhouse gas emissions. The study evaluates different types of retrofitting solutions starting from basic thermal retrofit and moisture control solutions, which ensure the compliance with quality requirements, up to more developed systems, integrating new materials and technologies and including the use of green energy. In order to apply a global renovation strategy, the paper also presents the representative typologies of executed buildings, the context when they appeared, their evolution in time and their current and actual problems. There are presented approaches for retrofitting the existing residential building stock. In the second part, the paper presents a comparative study, related to the environmental impact analysis, for the rehabilitation stage only, considering three solutions for cladding.

Keywords: retrofit strategies, multi-storey residential buildings, large prefabricated concrete panels, primary energy reduction

1 Romanian building stock – statistics

According to the Census of Population and Housing of 2011, Romania had about 19 million inhabitants. They were living in 8.5 million dwellings with 22.7 million rooms. 52.8 % of the population lives in urban areas, most of them in collective residential buildings. The total number of apartment buildings is around 84000 units, containing 2.5 million apartments.

According to the same census, over 71 % of the existing urban housings were multi-dwelling type, covering an about 66 % from the total inhabitable area. From a total of 57431 large panel prefabricated concrete buildings, most of them built during 1965–1989, 41540 buildings have 5 storeys.

This large number of precast collective dwellings, built in Romania, was achieved during the heavy industrialization period between 1958 and 1978, when a large wave of population migrated towards the cities, the urban population doubled, and the number of cities grew from 187 to 237. In order to accommodate the large number of urban habitants, new homes had to be erected, in a short period of time and the solution was by using highly industrialised building technologies with simple assembling on site.

This phenomenon was a common feature of Eastern Bloc cities in the 1970s and 1980s. In order to achieve large cost advantages in the construction of these apartment blocks, the national design institutes delivered standardized projects that were to be built in the cities. In Romania the prefabricated housing development used a series of these standardized projects. The most popular ones were the low rise 5 storey (project type 770, project type 774, project type 994, project type 1013-1168; project type 1340; project type 1586; project type 2926; project type 1399) and the 9 storey project type 772.

Even by the late 1980s, sanitary conditions in most Eastern Bloc countries were generally far from adequate. For all countries with monitored data, 60 % of dwellings had a density of greater than one person per room between 1966 and 1975 (see Figure 1). The average in western countries was about 0.5 persons per room.

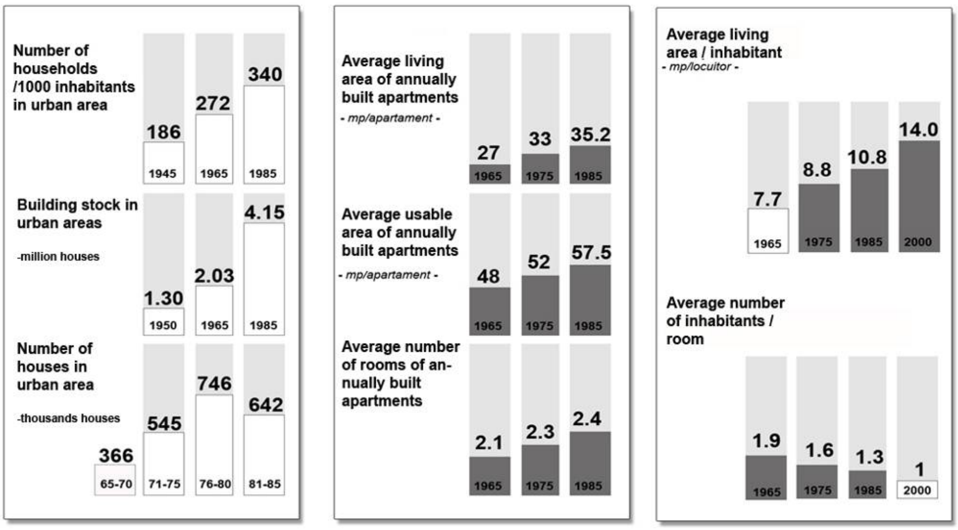
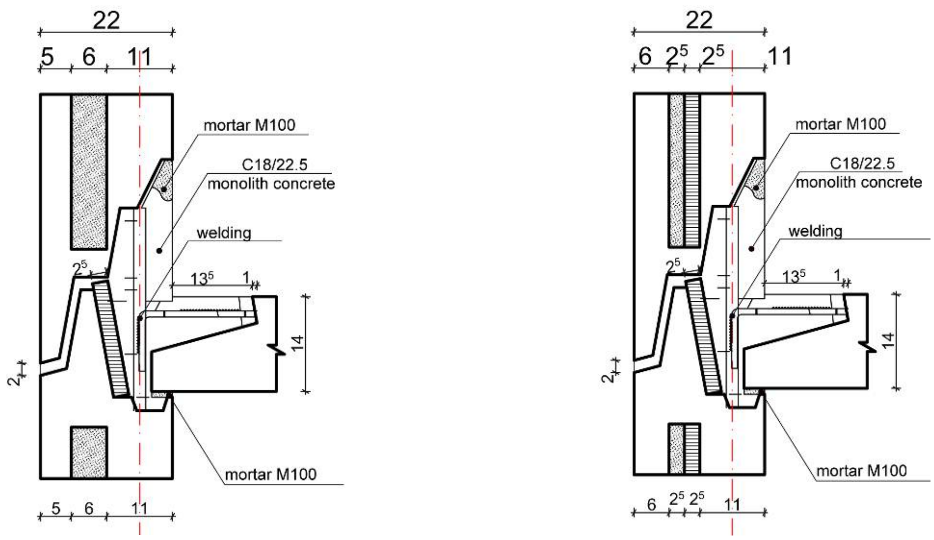


Fig. 1 *Statistical data regarding housing numbers and used areas*

As shown in previous studies [1], the collective buildings were erected in 3 main stages using different typologies of standard projects, due to design improvements, cost efficiency and new state decrees regarding usable area of flats. The studies conducted on the existing building stock for the city of Timisoara, confirmed the fact that in the period 1962–1990, three different types of projects were mainly used. In the first period of this urban development, between 1962 and 1975, the most used standard project was “T744R-IPCT”. In the second period, 1975–1982, frequently used was the project type “770-IPCT”, while between 1982 to 1989, the project type “1340-IPCT” had the largest application. In present conditions, the apartments of such buildings are privately owned, the buildings being in condominium type ownership. The buildings are in most of cases administrated by Home Owner Association (HOA).

2 Case study buildings

The most used prefabricated building typologies i.e. T744R, 770 and 1340 (5-storey structures) are used as case studies. The structure of these units is entirely made of precast panels fixed and mounted on site. These panels were executed on specialized construction companies and transported to the site. The buildings have different urban configuration regarding density, distance between units and even different facilities. The facade was integrated in the prefabricated concrete panels (composed of layers with different functions), i.e. the load bearing layer, the thermal insulating layer and the protection layer. The structural layer on reinforced concrete had the thickness of 11 cm for the case of projects T744R and 1340, while for project 770 a thickness of 9.5–12 cm, all of them made on C16/20 equivalent concrete class. The protection layer had 5–6 cm for all project types and was also made on C16/20 concrete class.

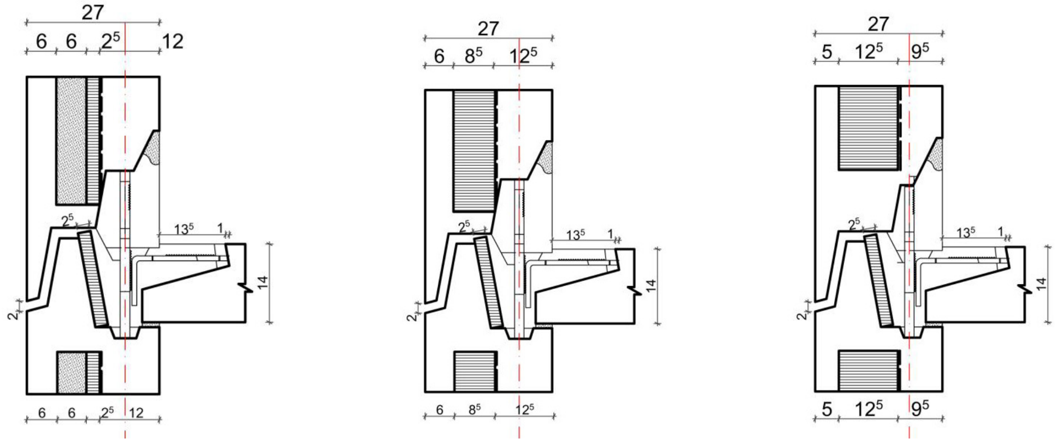


a. exterior wall: 22 cm thickness (var. I)
1) structural layer: 11 cm thickness (C16/20)
2) thermal insulation: 6 cm thickness (mineral wool)
3) protection layer: 5 cm thickness (C16/20)

a. exterior wall: 22 cm thickness (var. II)
1. structural layer: 11 cm thickness (C16/20)
2. thermal insulation: 2.5 cm (BCA) + 2.5 cm (polystyrene) thickness
3. protection layer: 6 cm thickness (C16/20)

Fig. 2 *Prefabricated concrete panels for T744R-IPCT project: exterior wall – details for connections and insulation*

The major differences between typologies included the thermal insulation layer. For T744R type project, initially was used one layer of mineral wool of 6 cm thickness and later changed to a thermal insulation composed of one layer of 2.5 cm of autoclaved aerated concrete (BCA) and another one of 2.5 cm polystyrene (see Figure 2). In case of the 770 type project, in a first stage, the thermal layer consisted of 2.5 cm polystyrene and 6 cm mineral wool changed later to an 8.5 cm polystyrene layer, while in the last period for this project a thermal insulation of 12.5 cm autoclaved aerated concrete (BCA) was used (see Figure 3). For project type 1340, in all the periods, the thermal layer was composed of 8 cm thick of mineral wool (see Figure 4).

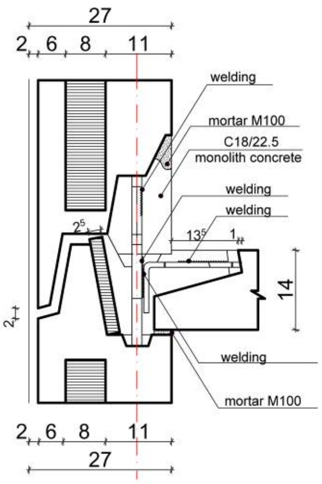


a. exterior wall: 27 cm thickness (var. Ia)
1. structural layer: 12 cm thickness (C16/20)
2. vapour barrier: 0.15 cm
3. thermal insulation: 6 cm (mineral wool) + 2.5 (polystyrene)
4. protection layer: 6 cm (C16/20)

a. exterior wall: 27cm thickness (var. Ib)
1. structural layer: 12 cm thickness (C16/20)
2. vapour barrier: 0.15 cm
3. thermal insulation: 8.4 cm (polystyrene)
4. protection layer: 6 cm (C16/20)

a. exterior wall: 27 cm thickness (var. II)
1. structural layer: 9.5 cm thickness (C16/20)
2. vapour barrier: 0.15 cm
3. thermal insulation: 12.5 cm (BCA)
4. protection layer: 5 cm (C16/20)

Fig. 3 *Prefabricated concrete panels for façade (770-IPCT project): details for connections and insulation*



a. exterior wall: 27 cm thickness
1. structural layer: 11 cm thickness (C16/20)
2. thermal insulation: 8 cm (mineral wool)
3. protection layer: 6 cm (C16/20)
4. finishing: 2 cm

Fig. 4 *Prefabricated concrete panels for façade (1340-IPCT project): details for connections and insulation*

Regardless the deficiencies in structural installation and the high operational energy required for these buildings, major dysfunctions in present days exist due their lack of retrofitting, degradation of the urban aesthetics, and the poor interior space partitioning.

3 Sustainable retrofitting by interior space partitioning

Two possible interventions are presented in Figure 5 and Figure 6, for the typology T744R-IPCT, by reconfiguration of horizontal spaces.

Fig. 5 *Horizontal reconfiguration and optimization of usable area in apartments*

Fig. 6 *Horizontal reconfiguration by coupling two apartments*

In Figure 5 is presented, the possibility of redefining interior space and creating new possible open areas inside old apartments. This solution improves the actual partition of the apartment. In Figure 6 the previous example is extended and, by creating the same enlargements into the structural diaphragms, two apartments are coupled. This operation comes in order to achieve multiple ways of interior repartition for old apartments and also can double the reduced usable areas of these apartments. This particular example of coupling two or more apartments into a single one, in order to define new space configuration, can also be used for creating commercial spaces and small offices, especially at the ground floor level of the prefabricated building.

The necessity of making large openings in walls is highlighted from the architectural point of view that allows the redesign of the interior rigid partitions and also provides multiple options for interior furnishing arrangement. Figure 5 and Figure 6 also present different solutions for optimization of the interior usable area of the flats [1, 2]. Reconfiguring the apartments by practicing large openings in the load bearing elements, must be done in a coherent way for the whole building, not to affect the structural bearing capacity [2]. Finally, the purpose of the study is to analyse different types of apartment repartitioning, in order to obtain cost-effective, structural and functional solutions that could be integrated into a reliable 3D structural building matrix (see Figure 7).

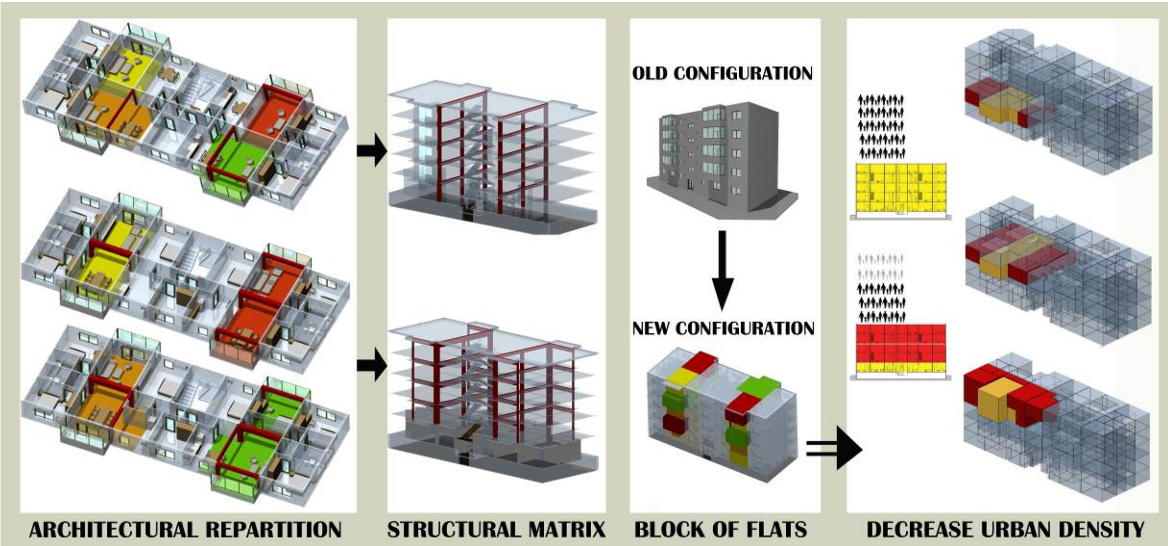


Fig. 7 *Example of interior partition reconfiguration*

Besides providing more attractive living spaces in apartments, this type of intervention can rebalance urban areas in terms of density, green zones for residents and can help to decongest traffic routes.

4 Energy performance of the T744R, 770 and 1340 blocks of flats

For each typology of residential building (T744R, 770 and 1340), three levels of energy performance (EP) have been studied:

- EP I – analysis of the existing building as designed, located in Timisoara and having the most disadvantageous orientation considering natural lighting;
- EP II – analysis of the existing building as designed, located in Timisoara and having advantageous orientation considering natural lighting;
- EP III – analysis of the existing building, located in Timisoara, using thermal rehabilitation as used currently in Romania, in accordance to minimal requirements of the design code C107-2005 (revised in 2010) [3].

All typologies (T744R, 770 and 1340) have been checked for the case of Timisoara city. Table 1 presents the heat transfer coefficients, studied for the building envelope elements and the minimum accepted values required by C107/2005 [3] code (updated in 2010).

Tab. 1 *Overall heat transfer coefficient (U) for building envelope elements*

Types of envelope	***U*** **[W/m²K] 744R**	***U*** **[W/m²K] 770**	***U*** **[W/m²K] 1340**	***U*** **[W/m²K] C107 [3]**
Exterior wall	0.657	0.848	0.685	0.56
Basement slab	2.512	2.512	2.512	0.35
Roof terrace	1.677	1.677	1.677	0.20
Windows	5.263	5.263	5.263	1.30

It could be observed that the *U*-coefficients for basement slab, roof terrace and windows are far low than the required values in the C107/2005 code [3] and must be improved.

The total energy consumption, expressed in kWh/m²year, and heating consumption [kWh/m²year] of the studied buildings were computed by using the *Doset-PEC* building energy rating tool [4], for all three levels of energy performance (EP). For project T744R--IPCT the results are presented in Table 2.

Tab. 2 *Annual energy consumption for the three EP levels, for T744R-IPCT project*

Project type	**Annual energy consumption [kWh/m²year]**	**EP I**	**EP II**	**EP III**
T744R-IPCT	Total energy consumption [kWh/m²year]	339.4	331.7	165.6
	Heat consumption [kWh/m²year]	247.2	239.5	73.4

Table 2 shows that the energy consumption does not depend greatly on favourable or unfavourable orientation of the building, the difference being of only 8 kWh/m²year. In both cases (EP I and EP II) the energy class is the same, the buildings being rated in class *D*, according to the well known energy efficiency classes from *A* to *G*, where *A* being the most energy efficient, while *G* the least efficient.

To check the worst scenario encountered in practice (considering errors from execution, local damage of panels, damage of the coating panel etc., of the built projects), the energy consumption of the analysed buildings was evaluated without considering the initial thermal layer, being considered affected by condensation process. The results computed with *Doset-PEC* building energy rating tool [4] are shown in Table 3.

Tab. 3 *Annual energy consumption values for the studied buildings (worst scenarios)*

Types of annual energy consumption	**T744R-IPCT**	**770-IPCT**	**1340-IPCT**
Total energy consumption [kWh/m²year]	431.9	417.6	387.2
Heating [kWh/m²year]	334.2	311.6	294.0
Hot utility water [kWh/m²year]	81.3	90.1	75.8
Domestic energy [kWh/m²year]	16.4	15.9	17.4

Under these conditions the thermal resistances (R) and overall heat transfer coefficients (U) for the exterior panels are:

R = 0.735 [m²K/W]; U = 1.360 [W/m²K] for the building type T744R;
R = 1.044 [m²K/W]; U = 0.957 [W/m²K] for the building type 770 (var. 1b);
R = 1.121 [m²K/W]; U = 0.899 [W/m²K] for the building type 1340.

For the EP III case, considering the thermal rehabilitation of the envelope, five different solutions were proposed, with different thermal transfer resistances. The Government Emergency Ordinance no. 18/2009 (*Increasing the Energy Performance of Apartment Buildings*) [5] establishes the intervention works for thermal insulation of residential buildings designed and built in the period 1950–1990, the steps needed for the work, the mode of financing, the obligations and responsibilities of public authorities and of owners associations, specifying that the enhancement of energy performance for residential buildings must be done so that the specific annual energy consumption for heating to fall below 100 kWh/m^{2}year, in terms of economic efficiency. In order to see under what circumstances the thermal rehabilitation of these buildings can achieve the energy requirement for heating (i.e. below 100 kWh/m^{2}year), several technical solutions for rehabilitation have been proposed, according to codes currently in force.

Table 4 presents the overall heat transfer coefficients (U) for the five solutions chosen for rehabilitating the envelopes. Solutions I and II are similar and they have minimum U-values prescribed by C107/2005 (see column 5 in Table 5). Solutions III and IV present higher values for the heat transfer, while solution V uses materials that present higher values for the heat transfer and also improve the aesthetic quality of the existing facades (see column 5 in Table 5).

Tab. 4 *Heat transfer resistance values(U) for the thermal rehabilitation solutions(I-V)*

U-coefficient [W/m^{2}K] / Solution	**I**	**II**	**III**	**IV**	**V**
U for walls insulating layer [W/m^{2}K]	0.513	0.473	0.384	0.270	0.266
U for basement slab [W/m^{2}K]	0.336	0.336	0.322	0.322	0.237
U for roof terrace [W/m^{2}K]	0.199	0.199	0.166	0.132	0.108

In order to have a comparison for the efficiency of presented solutions and to determine the ability to reduce the energy consumption, the same thermal rehabilitation solutions have been considered for all three building typologies. The results obtained for energy consumption, compared with the one for initial solutions, are presented in Table 5.

Tab. 5 *Annual heating energy consumption, the type and the thickness (d) of insulation used for thermal rehabilitation solutions*

Heating	**T744R** [kWh/m^{2}year]	**770** [kWh/m^{2}year]	**1340** [kWh/m^{2}year]	**Insulating material**	**Wall *d*** [mm]	**Slab *d*** [mm]	**Terrace *d*** [mm]
Initial proj.	334.2	311.6	294.0	-	-	-	-
Solution I	95.4	93.2	90.9	polystyrene	100	120	200
Solution II	100.0	95.7	93.2	rock wool	100	120	200
Solution III	88.5	89.4	77.3	fibreboard	120	80	140
Solution IV	83.6	83.9	67.8	cellular glass	200	140	300
Solution V	81.3	84.6	68.8	polyisocyanurate	120	100	250

It results that all the retrofitting solutions led to substantial energy savings for building heating category. Additionally, the energy consumption for hot water preparation and domestic electricity is considered as in the original use. However, an energy reduction for these categories requires retrofitting interventions on global electric installations and use of green energy systems.

Table 6 presents globally the energy savings achieved for the five proposed rehabilitation solutions. The results are quantified for 1/5/10 and 20 years respectively. The results show that the energy saving is high and, comparable values are obtained for the three building typologies under study.

Tab. 6 *Heating energy savings from proposed variants of thermal rehabilitation*

Heating energy savings	Time [years]	Var. I [kWh/m^2]	Var. II [kWh/m^2]	Var. III [kWh/m^2]	Var. IV [kWh/m^2]	Var. V [kWh/m^2]
T744R-IPCT [kWh/m^2]	1 year	238.8	234.0	245.7	250.6	251.0
	5 years	1194.0	1170.0	1228.5	1253.0	1255.0
	10 years	2388.0	2340.0	2457.0	2506.0	2510.0
	15 years	3582.0	3510.0	3685.5	3759.0	3765.0
	20 years	4776.0	4680.0	4914.0	5012.0	5020.0
770-IPCT [kWh/m^2]	1 year	218.4	215.9	222.2	227.7	227.0
	5 years	1092.0	1079.5	1111.0	1138.5	1135.0
	10 years	2184.0	2159.0	2222.0	2277.0	2270.0
	15 years	3276.0	3238.5	3333.0	3415.5	3405.0
	20 years	4368.0	4318.0	4444.0	4554.0	4540.0
1340-IPCT [kWh/m^2]	1 year	203.1	200.8	216.7	226.2	225.2
	5 years	1015.5	1004.0	1083.5	1131.0	1126.0
	10 years	2031.0	2008.0	2167.0	2262.0	2252.0
	15 years	3046.5	3012.0	3250.5	3393.0	3378.0
	20 years	4062.0	4016.0	4334.0	4524.0	4504.0

5 Conclusions

The results of this study show the fact that the refurbishment of existing building stock made on large prefabricated concrete elements is strictly necessary in order to ensure the comfortable living in the considered residential buildings. This process is currently carried out by the owners of the flats (after 1990) in almost all the Romanian cities, in most of the cases without specific documentation or adequate analysis of the problem. The study presented above lead to the following conclusions:

- the interior repartitioning of building walls may improve the comfort of inhabitants;
- new flats with different configuration can be emerged while new interior space perspectives can be achieved within the existing buildings through horizontal apartment coupling;
- energy efficiency can be achieved by using appropriate solutions of envelope thermal retrofitting systems;
- the rehabilitation and retrofitting of these buildings in decay, and revival of community spirit, have to be the main goal of local authorities.

Acknowledgement

This work was supported by grant no. 3-002/2011, INSPIRE – Integrated Strategies and Policy Instruments for Retrofitting buildings to reduce primary energy use and GHG emissions, Project type PN II ERA NET, financed by the Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI), Romania and partially by the strategic grant POSDRU 107/1.5/S/77265, within POSDRU Romania 2007-2013 co-financed by the European Social Fund – Investing in People.

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