ENVELOPE ENERGY PERFORMANCE OF A SINGLE FAMILY HOUSE WITH REINFORCED CONCRETE STRUCTURE

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Abstract. Sustainability criteria impose a rethinking of building envelopes, in order to ensure better indoor comfort and limit the consumption of resources over constructions lifetime cycle. In the case of reinforced concrete structures in colder climates, it is necessary to consider special measures concerning to compensate the thermal conductivity of the material and consider the effect of thermal bridges in the design stage. The case-study presented in this paper analyses a single-family modern house under construction in Suceava, with reinforced concrete post and beam structure, for which special measures were provided regarding the envelope, in order to achieve a complex architectural design and meet the highest standards of thermal comfort. In this article, the authors comment on the constructive challenges, present specific solutions, and a thermal modeling of the house in case, with specific analysis of thermal bridges.
Keywords: reinforced concrete structure, energy performance of building envelope, thermal comfort, heat and mass transfer, thermal bridges.
Rezumat. Criteriile dezvoltării durabile impun o regândire a anvelopei clădirilor, cu scopul de a asigura un confort interior mai bun şi pentru a limita consumul de resurse pe durata de viaţă a construcţiilor. În cazul structurilor din beton armat în climate reci, este necesar să fie luate în considerare măsuri speciale pentru a compensa nivelul redus de protecţie termică specific betonului şi a considera efectul punţilor termice din faza de proiectare. Studiul de caz prezentat în această lucrare analizează o locuinţă unifamilială în construcţie din Suceava, cu structură din cadre de beton armat, pentru care au fost prevăzute măsuri speciale în ceea ce priveşte anvelopa, în vederea obţinerii unei conformări arhitecturale complexe, şi atingerii celor mai ridicate standarde de confort termic. În acest articol, autorii prezintă provocările constructive, soluţiile specifice prevăzute, şi rezultatele modelărilor numerice ale transferului termic şi de masă pentru clădirea evaluată, cu analize specifice punţilor termice şi performanţei energetice globale.
Cuvinte cheie: structură din beton armat, performanţă energetică a anvelopei clădirii, confort termic, transfer de căldură şi de masă, punţi termice.

1. INTRODUCTION

Energy[3] conservation and an intelligent use of resources are among primary objectives in the contemporary society. Reducing energy consumption contributes along with the optimization of operating costs to the preservation of the environment. The energy impact of buildings during use, in winter through heating and in summer through ventilation, is higher in their life-cycle than in the construction phase, prompting for passive measures from the design stage (Kirk-Barkauskas *et al.*, 2004).

Reinforced concrete structures are vital components in contemporary construction today, with many environmental advantages, including durability, longevity, heat storage capability, and chemical inertia, for which is superior to other materials such as wood and steel (Babor *et al.*, 2009). In addition to being one of the most energy-intensive materials used in the construction industry, the structural elements made of reinforced concrete determine significant thermal bridges in buildings envelope that lead to higher energy losses from the building in service. The amount to which thermal bridges intervene in the overall energy performance of a building depends on the structural conformation (dimensions, span, disposal of posts and beams) and the position and dimension of enclosing elements in relation with the structural ones. To minimize energy consumption, thermal bridges should be considered in the design stage, so that conformation and dimensioning of the envelope would compensate the thermal disadvantages of the reinforced concrete structure.

In a dense urban context, the architectural proposal for the house analyzed in this paper resorted to a contemporary volume and flexible spaces in

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order to better integrate in a mixed-styled neighborhood and satisfy complex customer demands regarding functionality. The architects involved with the design, came up with a reinforced post and beam structural solution, conducive to a minimalist volume (Fig. 1), allowing for large spans, and also respecting fire regulations and norms, restrictive due to the proximity of buildings surrounding the site.

Fig. 1. Architectural proposal renderings.

Concerning the thermal comfort required for a zone IV microclimate, with a reference temperature of –21ºC in winter (C 107/3-2005), special attention had to be given to the envelope of the house. The complexity of the solutions meant taking into account the integrated non-heated garage, the large terrace at the 2nd floor, the upper terraced roof over the 2nd floor, cantilevered elements of architectural decoration (Fig. 2).

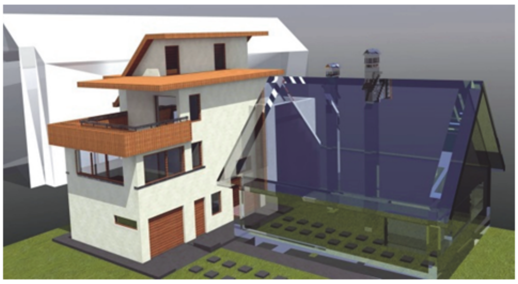


Fig. 2. Architectural proposal renderings.

2. THERMAL BRIDGING

In the context of extensive steps towards optimizing the energy efficiency of buildings, taken in latter years for a sustainable development, the passed down measure of improving building's envelope insulation remains a prerequisite towards the decrease of energy consumption in dwellings. Although the requirements for thermal protection level specified by national regulations have constantly raised the comfort standards, thermal bridges remain weak areas in constructions thermo-hygro-energetic behaviour. As a result, thermal losses are often greater in use than those anticipated during the design stage (Theodosiou & Papadopoulos, 2008). Thermal bridges determining increased heat losses to the outdoor environment in the cold season, are to be found in vulnerable areas (protruding balcony slabs, foundation boundary, windows perimeter), can be geometrical or constructive, their presence leading not only to increased heat loss but also to higher risk of condensation (Hegger *et al.*, 2008).

2.1. Architectural considerations regarding the building's envelope

The volumetric composition of the assessed house was influenced mainly by the urban context, characterized by dense edification and vicinity with an old neoclassical house, to which the new building relates. As such, the volume and the ratio of windows on the facades is to a lesser extent related to the cardinal orientation constraints, and it is not depending on prevailing winds.

The volume is not a compact one, and includes instead consoles, juts, upright and horizontal volumetric ruptures. These features of the architectural solution, imposed by the urban context, set out the premises for thermal losses, as opposed to a more compact volumetric solution (Fig. 3). In the same manner, the ratio of window/opaque surfaces on the facades was imposed by the functional and urban relations rather than cardinal orientation considerations. As such, on the western facade, the window area is 4.92 m^2, from a total area of 83.75 m^2, with a window/opaque ratio of 5.87%, on the eastern facade, the window area is 13.99 m^2, from a total area of 78.47 m^2, with a window/opaque ratio of 17.82%, on the northern facade, the window area is 21.41 m^2, from a total area of 145.81 m^2, with a window/opaque ratio of 14.69%, on the southern facade, the window area is 17.08 m^2, from a total area of 145.81 m^2, with a window/opaque ratio of 11.71%.

2.2. Specific technical solutions. Thermal protection

In order to compensate for the aforementioned flaws in the volumetric conformation of the house, predisposing to thermal losses, a few measures were considered for the envelope. On exterior walls, build-up of hollow 30 cm thick bricks, there were applied insulation layers of 20 cm thick mineral wool (Fig. 4), with special considerations taken in the design stage in order to limit thermal bridges. For the inclined and terraced roofs, a specific stratification was designed, to include sandwich panels, with 8 cm isoprene core insulation, a solution intended to exceed the minimum required values for thermal protection (Fig. 5, 6).

Fig. 3. House photos in construction phase.

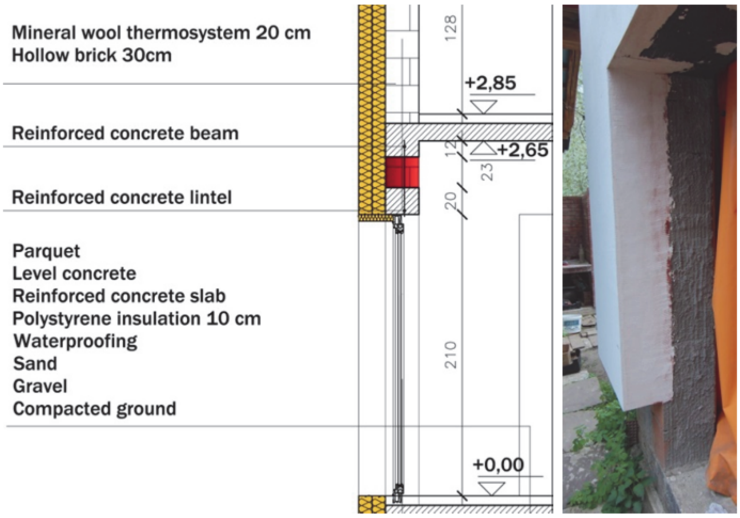


Fig. 4. Wall technical detail and photo in construction phase.

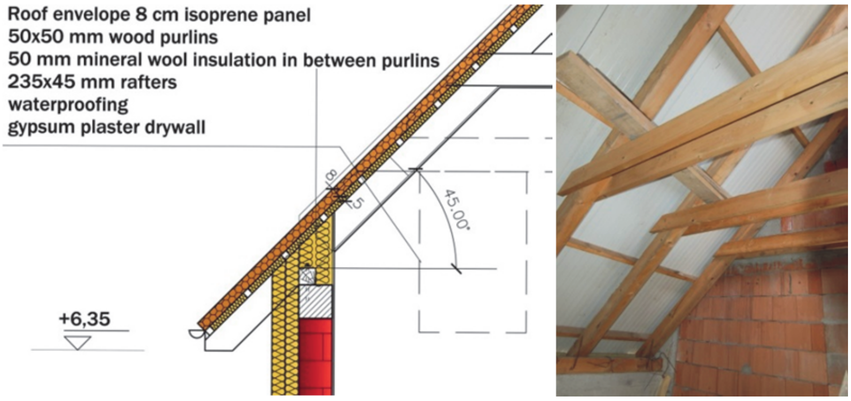


Fig. 5. Inclined roof detail and photo in construction phase.

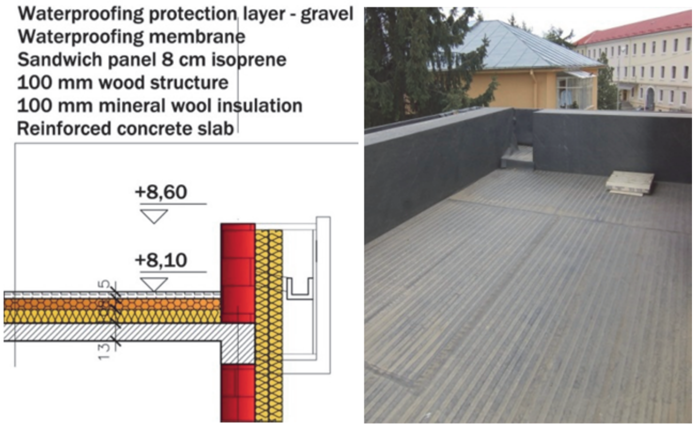


Fig. 6. Terrace detail.

3. ASSESSMENT OF ENERGY PERFORMANCE

3.1. Envelope energy performance

For obtaining an accurate evaluation of building envelope, there is necessary to determine the specific parameters of thermal bridges (Georgescu *et al.*, 2010; Ge *et al.*, 2013), and the most significant thermal bridges in current case are identified and assessed through steady-state heat transfer (Table 1).

Farther, corrected values of thermal resistances are obtained by using the linear transmittances (C 107/3-2005), which are required in order to determine the overall thermal insulation coefficient. The envelope review, as the national regulations indicate, is attained by complying with the exigencies presented in Table 2. Two envelope elements, as observed, are below criteria, and thus, while for the ground slab it will not be possible to intervene at the build-up house, there will be given recommendations to improve thermal protection at roof truss. The result for the ground floor is determined by the calculation methodology, in the conditions of a small footprint in relation to the perimeter. The measures of insulation provided are constructively rational and the result will be further corrected by a thin layer of cork insulation on top of the concrete slab.

Table 1

Specific thermal bridges evaluation

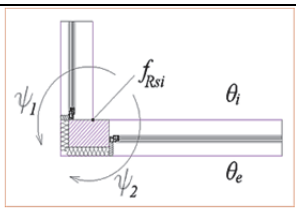
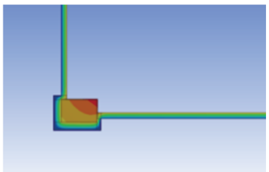
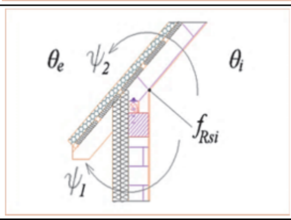
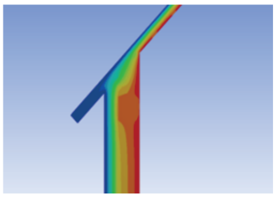
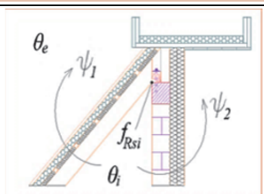
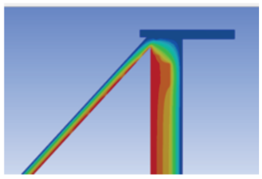
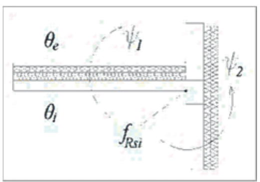
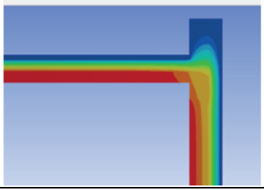
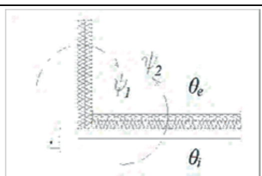
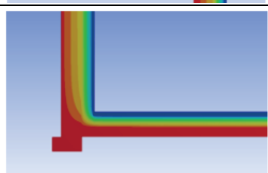
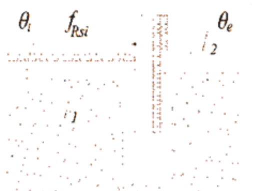
Detail		Thermal field	ψ_1 [W/m·K]	ψ_2 [W/m·K]	f_{Rsi} [-]
Column detail at corner with windows			0.149	0.051	0.741
Overhang detail			0.017	0.036	0.893
Ridge detail			0.186	0.050	0.785
Parapet detail			0.093	0.100	0.841
Exterior wall and terrace junction			-0.045	-0.054	0.952
Foundation detail			0.354	0.056	0.823

Table 2

Envelope assessment. Global thermal insulation coefficient

Envelope component		***A*** [m²]	***R*** [m²·K/W]	***R'$_m$*** [m²·K/W]	***R$_{min}$*** [m²·K/W]
Ground slab		73.62	5.75	2.77	4.50
Slab over exterior		3.91	5.97	6.57	
Terrace over first floor		23.92	6.99	5.37	5.00
Terrace over second floor		29.93	6.99	5.32	
Roof truss		34.04	5.22	4.09	
NV façade	Under roof truss	25.14	7.31	4.58	1.80
	Under terrace	34.23	7.31	6.15	
	At screened entrance	4.85	7.31	7.67	
SE façade	Under roof truss	23.02	7.31	6.56	
	Under terrace (ground floor and first floor)	25.05	4.53	2.93	
	Under terrace (second floor)	7.26	7.31	3.41	
SV façade	Under roof truss	47.63	7.31	5.28	
	Under terrace (ground floor and first floor)	17.61	4.53	2.70	
	Under terrace (second floor)	4.22	7.31	4.86	
	At screened entrance	4.67	7.31	13.48	
NE façade	Under roof truss	11.82	7.31	3.90	
	Under terrace	78.19	7.31	4.75	
NV windows		4.56		0.83	0.77
SE windows		12.70			
SV windows		15.86			
NE windows		24.02			
***G* = 0.46 W/(m³·K) < *GN* = 0.49 W/(m³·K)**					

3.2. Annual energy consumption for heating and cooling

The methodology for building energy efficiency assessment is thoroughly presented in national regulations (Mc 001/1, 2, 3-2007), and although there are taken into consideration the variable climatic conditions, for this study another approach has been proceeded. Using Wufi Plus software, unsteady-state heat an mass transfer has been simulated for the entire building. As results, there are presented hourly variations of temperature, relative humidity and energy consumption for heating and cooling (Fig. 7-12). For a more relevant display of results, comparisons are made with the data obtained for a less efficient insulation solution. Though differences for indoor comfort are not highly significant, there are grounding the high insulated design.

For closure, annual energy consumption for heating and cooling is detailed in Table 3. Although the house is not brought under the passive house criteria by designing a high insulation level, there are considerable differences justifying the investment.

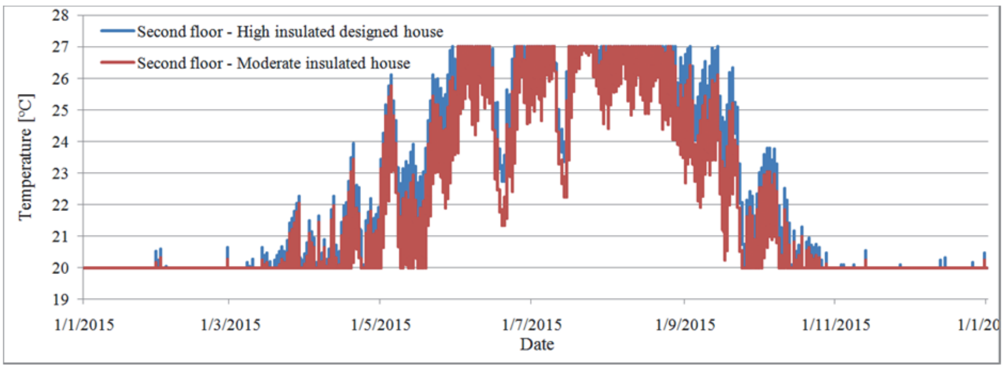


Fig. 7. Temperature variations for second floor.

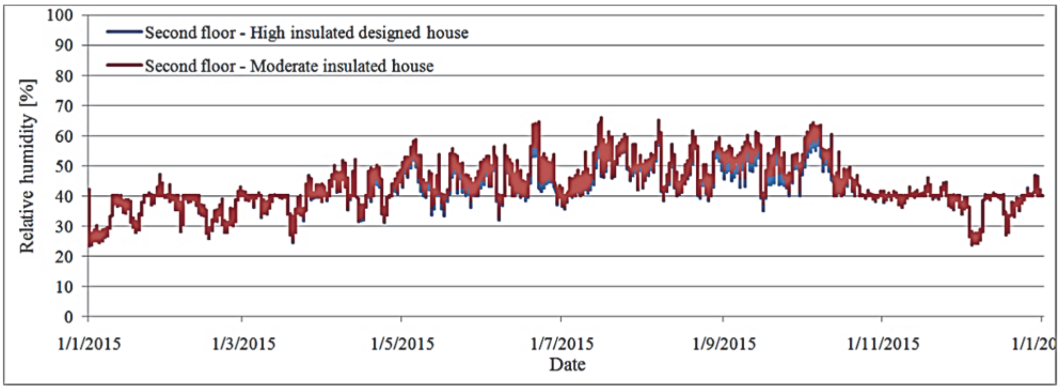


Fig. 8. Relative humidity variations for second floor.

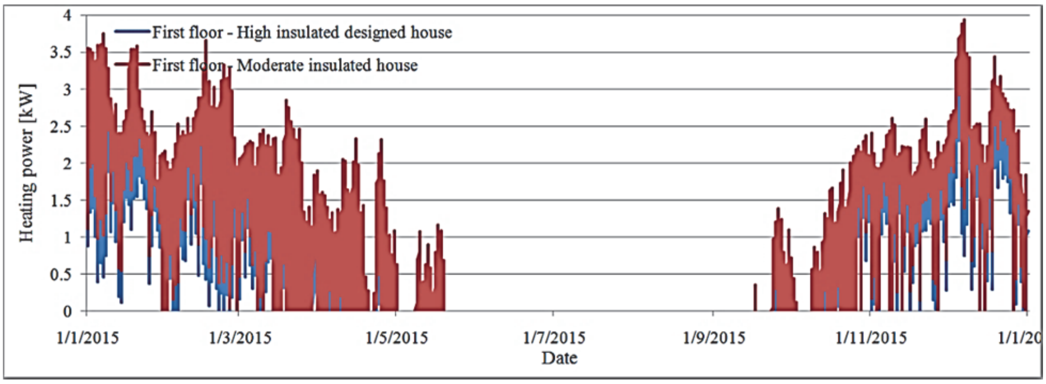


Fig. 9. Heating power for first floor.

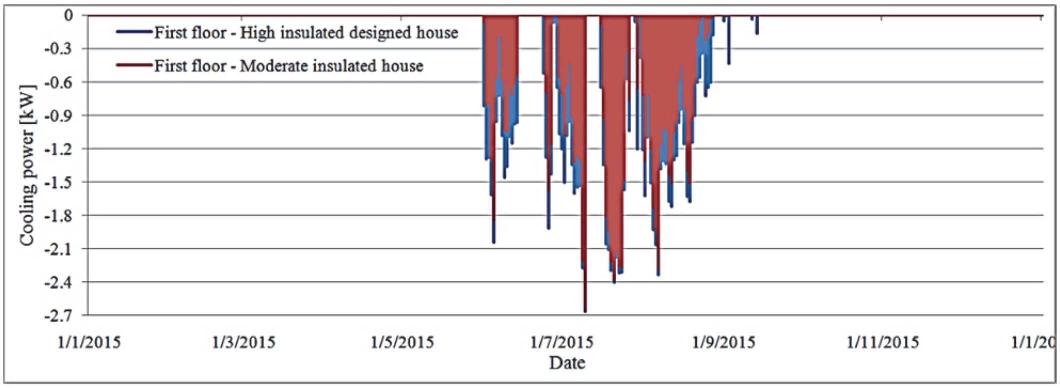


Fig. 10. Cooling power for first floor.

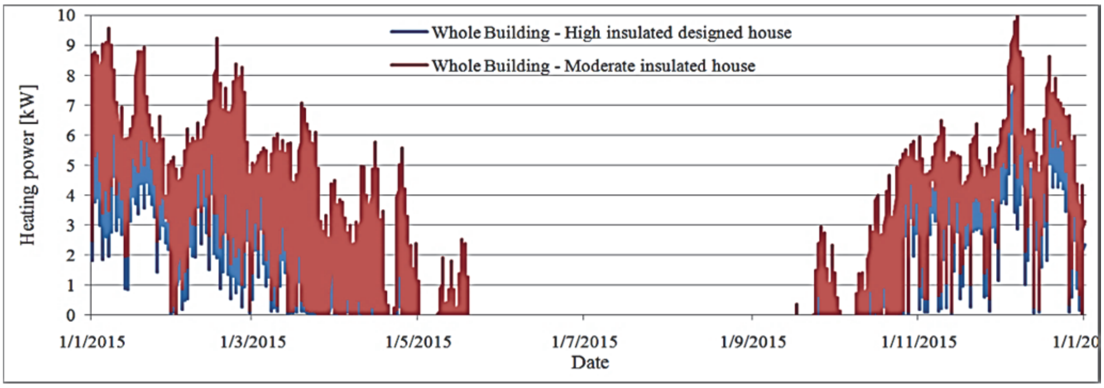


Fig. 11. Heating power for entire building.

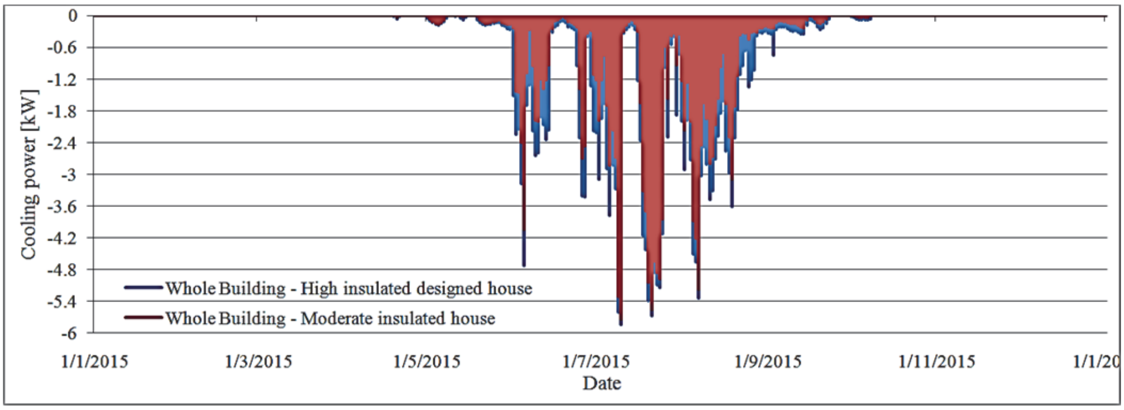


Fig. 12. Cooling power for entire building.

Table 3

Annual heating and cooling power

High insulated designed house					
Moderate insulated house					
Heated zone	Area	Heating power		Cooling power	
	[m²]	[kW·h/year]	[kW·h/year·m²]	[kW·h/year]	[kW·h/year·m²]
Ground floor	51.02	3109	60.9	-216	-4.2
		4204	82.4	-102	-2.0
Bathroom	3.79	103	27.4	-69	-18.1
		166	43.9	-46	-12.0
First floor	62.82	6338	100.9	-554	-8.8
		8359	133.1	-369	-5.9
Kitchen	14.71	1053	71.6	-14	-1.0
		1354	92.1	-9	-0.6
Second floor	48.75	4133	84.8	-471	-9.7
		5892	120.9	-328	-6.7
Bathroom	4.86	62	12.8	-177	-36.3
		89	18.3	-146	-30.1
Whole building	**185.95**	**14801**	**79.6**	**-1500**	**-8.1**
		20068	**98.0**	**-1000**	**-4.9**

4. CONCLUSIONS

The architectural design (volume, window/opaque ratio, the structural solution) has generated several thermo-hygro-energetic deficiencies, which had to be ameliorated through measures taken at building envelope level. Thermal bridges analysis has highlighted different responses for constructive elements: a good behaviour for walls, a satisfactory behaviour for terraces, and an unsatisfactory response for the roof truss and for the ground slab. Heating and cooling power usage indicate different energy specific consumptions corresponding to each function, but also influenced by space configuration and orientation.

Overall, although the dwelling has a high embedded energy in the construction phase (due to reinforced concrete structure with high CO_2 emissions), is energy efficient during operation, notably through measures for effective heat insulation.

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