FROM THEORY TO PRACTICE WHEN ASSESSING BUILDING ENERGY PERFORMANCE

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Abstract. *The study is focused on a multi-family building block of flats type and includes an energy analysis on its construction and installations elements. Simulation results based on design are compared with metered energy consumptions to infer losses associated with an incorrect execution of works during building construction. Results conclude with energy performance indicators and recommendations for additional energy efficiency measures. Different packages of measures are analyzed for economical efficiency and appropriate conclusions are drawn. It is thus shown how a building can approach conditions compatible with "nearly zero" energy consumption from classical sources, with reasonable costs for owners.*
Keywords: building energy performance.

1. INTRODUCTION

The European documents and the national ones transposing them consistently promote for the near future a new concept, NZEB – nearly zero energy building, for much influencing the current standards for building design and technologies. The objectives rose from the necessity to diminish the energy consumption from fossil fuels on well known reasons: national energy independency, limited fossil resources, and environment protection. But the emerging technology based on renewable energy resources (RES) is still expensive and thus prohibitive on a large scale. One way to generate economical efficiency for investments in RES solutions is clearly a significant reduction in the building energy demand while ensuring the thermal comfort for the occupants. Once this demand is very small, corresponding to near zero primary energy, the required investment in heating/cooling/ lightning installations is not that important relative to the size of the building. The present study represents an example of this approach and starts from the energy analysis of a building performed at the time of construction. This was fortunate for the developer, as results from the analysis could still be applied before the building commissioning.

2. DESCRIPTION OF THE BUILDING

The building, block type, is placed in a climate zone characterized by a statistical minimum temperature of $T_e = -15^{o}$C and an average wind speed of 5 m/s. The long facades are oriented towards NW and SE, the whole building having open exposure all around.

The block, with a ground level, one more storey and a technical attic, was built in 2011. The building execution stages are illustrated in Figure 1. The foundation is made of reinforced concrete and is continuous under portent walls. The structural walls are made of two O.S.B. (oriented strand board) panels with foam in between, in S.I.P. (structural insulated panels) system. The roof, constructed with Posi Joists beams, wooden structure, and special S.I.P. panels, is covered by metal tiles. The windows have thermally insulated frames of white PVC and low-emissivity double glazing.

The electrical wiring and the sanitary and sewing piping are the usual ones. The building design includes electrical radiant panels for heating and water tanks with electrical resistances. The ventilation rate is achieved with special devices mounted on the upper windows frames, with air vents in bathrooms and cooker hoods in kitchens.

The building block includes 12 apartments of 2 and 3 rooms, summing a total surface area (apartments, entrances and staircases) and of 835 m^2 and a useful surface area (apartments) of 621 m^2.

3. ENERGY PERFORMANCE ESTIMATION

One-dimensional thermal resistances, R, for the building envelope elements are computed based on their structure and of estimated convective heat transfer coefficients at indoor and outdoor surfaces. The *R*-values are then corrected as *R*'-values, to account for the 2-D and structural thermal bridges in the envelope. The influences from the thermal bridges were quantified with the aid of a computational 2-D program [Kalibat]. The average corrected resistance for the entire building envelope resulted as *R*' = 3,032 m2K/W. In Table 1, corrected thermal resistances of different envelope elements are compared with the minimal values specified in the Romanian norms. The criterion for compliance is *R*' ≥ *R*'min [1, 2, 3, 4]. The table 1 shows that all the building elements meet the standard heat transfer requirements.

Fig. 1. Building execution stages.

Table 1

Compliance with the thermal insulation requirement

Element	*R*' [m^2K/W]		*R*'$_{min}$ [m^2K/W]
Exterior wall	3.169	>	1.80
Slab under the roof	5.161	>	5.00
Slab on grade	5.427	>	4.50
Windows	0.780	>	0.77
Total envelope	**3.032**		

All energy consumptions for heating/cooling, domestic hot water, ventilation and lighting are based on electricity. Table 2 summarizes the energy indicators, as annual final energy consumptions relative to the block useful surface area, as well as the associated equivalent CO_2 emissions.

Table 2

Energy and environment indicators based on design

Heating	DHW	Lighting	Venti-lation	Cooling	U.M.
14723	42359	9286	38	7022	kWh/year
23.72	68.25	14.96	0.06	11.31	kWh/m^2year
7140	20544	4504	18	3406	kgCO_2/year
A	**D**	**A**	**A**	**A**	**Energy Class**

Noteworthy, the heating season is estimated to last 132 days (November 9th – March 20th), which is with about 80 days less than the heating duration for similar in size buildings placed in the same climate zone.

The energy certification of buildings represents a classification of buildings according to their specific energy consumptions, such as to include the building in one energy class out of 7 (A-best to G-worst). The Romanian methodology includes also an energy mark that can range from 20-minimum to 100-maximum [5].

The preliminary analysis based on the design led to an energy mark of 100 and an energy class of A for the entire building, corresponding to a total specific energy consumption of 118.3 kWh/m^2year. Energy class is also specified on the last row of Table 2 for each type of use, as corresponding to the energy grills of Romanian methodology for energy certification of buildings. Noteworthy, a building of identical architecture but with the standard requirements for thermal insulation, called „reference building" [2], would have a total final energy demand of 133,6 kWh/m^2year. Otherwise said, the analyzed building is more performant than required by standards, although these were recently modified at a pretty high level in December 2010.

However, after a winter season passed, the building users complained about the indoor discomfort they were having during the cold season. Thermographical images were then taken fro the inside and outside of the building to identify causes for heat losses. Some of them are displayed in Figures 2 and 3, as indoor and outdoor images, respectively.

The temperature differences greater than 2^{o}C indicate significant losses at all the panel joints and the entrance door vicinity. These are translated as increased thermal bridges at all joints and enhanced air exchange between outdoor and indoor of the building. It seemed that a low-quality execution of the design led to a lower energy quality of the building than initially anticipated based on the design.

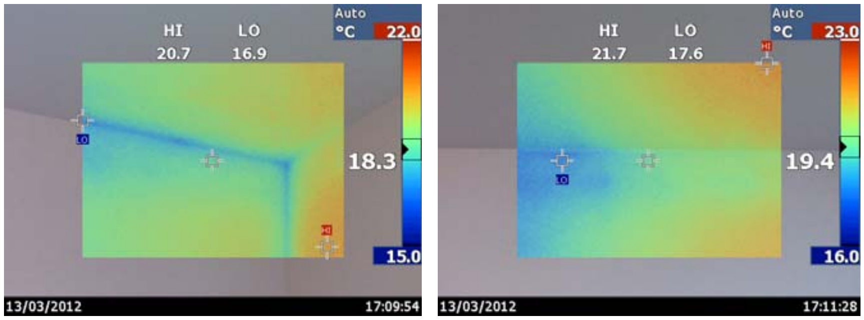

Fig. 2. Indoor thermographical images for the corner and the edge close to the entrance door.

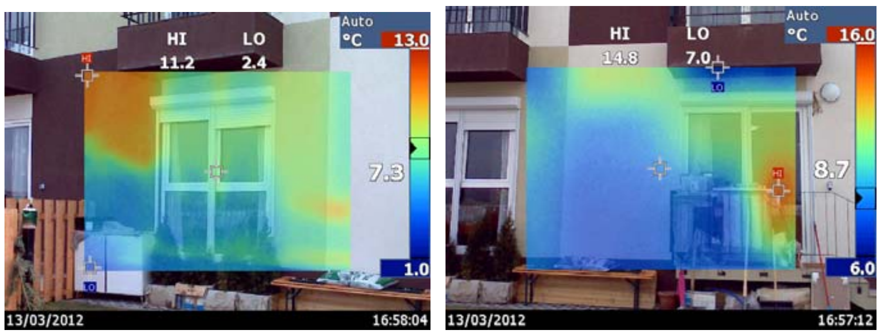

Fig. 3. Outdoor thermographical images for the South facade.

The real electricity consumption was available from the bills over ten months (November 2011-August 2012). Since no other energy type has been used for heating, the energy data could be analyzed to separate the component that correlated with the actual outdoor temperature and thus corresponded to use for space heating. It must be emphasized here that air conditioning was not used and enhanced night ventilation was sufficient for summer cooling. The available data was analyzed using the inverse modeling technique of Krarti [6]. Although this techniques is recommended as a statistical tool for multiple year data, it was applied here for the only data available since the building commissioning and start of normal use.

The base load (appliances, hot water, and lighting) resulted as 5.12 kWh/m^{2}month. While heating led to a seasonal average of 10.45 kWh/m^{2}month, or approximately 62.75 kWh/m^{2}year. Although the results are not statistically determined, they give a clear hint on the fact that the theoretical estimation (23.72 kWh/m^{2}year in Table 2) is far from reality. An estimation of the building equilibrium outdoor temperature (below which heating installation must be put in operation) indicated the value of 16 ^{o}C.

A new evaluation was then performed on the building, using corrected values for the wall and terrace thermal bridges to account for the bad sealing of the joints and resulting increased humidity near the edges. The mathematical model produced a heating consumption close to the measured one when the air-exchange factor was equal to about unity (n = 1 h^{-1}). The correction was performed this way, as the measurement techniques to determine the real air-exchange of the building are intrusive, complicated and costly. The new energy performance results for the adapted simulation are summarized in Tables 3 and 4 below.

Noteworthy, the slab under the roof and the slab on grade do not comply anymore with the Romanian regulation C107 and have lower thermal resistances than the standards.

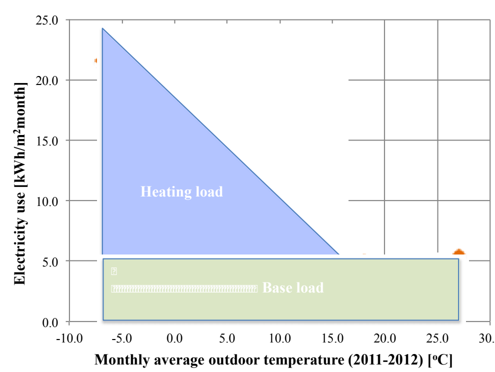

Fig. 4. Separation of base load and heating load from metered electricity data.

Table 3

Compliance with the thermal insulation requirement of the adapted model

Element	R' $[m^2K/W]$		R'_{min} $[m^2K/W]$
Exterior wall	2.702	>	1.80
Slab under the roof	4.135	<	5.00
Slab on grade	4.458	<	4.50
Windows	0.780	>	0.77
Total envelope	**2.032**		

Table 4

Energy and environment indicators based on adapted design data

Heating	DHW	Lighting	Ventilation	Cooling	U.M.
38610 (162%)	42359	9286	83 (118%)	10326 (47%)	kWh/year
62.21	68.25	14.96	0.13	16.64	kWh/m^2year
18726	20544	4504	40	5008	$kgCO_2/year$
A	**D**	**A**	**A**	**A**	**Energy Class**

As expected, energy for hot water and lighting were not affected by the corrected thermal resistances and air exchange. By contrast, energy consumption for heating is with 162% higher, for ventilation is with 118% higher and for cooling is estimated a need with 47% more than in the previous calculation (Table2). Since the envelope thermal resistance in Table 3 is only 11% less than the initially calculated one (Table 1), it is concluded that the doubled air exchange (from normal value of 0.5 to 1 h^{-1}) is the major cause for the diminished thermal performance of the building. Even it is noticed in Tables 2 and 4 that the energy classes remained the same, the differences in the absolute energy needs cannot be neglected.

When recommending additional measures for better energy performance, such differences also affect the economical efficiencies of the interventions and even the decision to act in a direction or another.

4. MEASURES FOR INCREASED BUILDING ENERGY PERFORMANCE

Energy analysis of the building block in Figure 1 indicated an excellent performance if compared to the standards used for regular new and retrofitted buildings. However, additional energy efficiency measures may be applied with acceptable economical efficiency to reduce even further the energy consumption and associated bills, approaching the NZEB promoted by the medium and long term strategies and action plans of the European Union.

The analyzed building is thermally insulated at an appropriate level relative to the current requirements (see Table 1). An additional thermal insulation would not be economically justified.

The simulation of the building energy performance put into evidence the need for summer cooling both by increased night-ventilation and air-conditioning by indoor air cooling and dehumidifying equipment. This intervention does not attract energy savings, but a significant improvement of the indoor thermal comfort during the summer. And it must not be forgotten that a non-consumption of energy that creates discomfort is not « energy saving », neither « energy efficiency ».

A real energy saving can be achieved on a long term by using thermal solar panels for the preparation of the DHW in the tank, having electricity only as a corrective energy source. This measure is technically feasible as it was foreseen in the building design as a possible future intervention. Available space exists on the roof towards SE.

The building has private land around it, now used as yards for the ground level apartments and for a common swimming pool. A piece of this land, as well as the little river running at 20 m away from the building may be used to install a water-water heat pump that can supply the thermal energy needed for both space heating and DHW preparation. Combinations of thermal solar panels - heat pump - grid electricity may be also used to cover heating and DHW energy needs.

The field landscape (i.e., open space) around the building facilitates the installation of a small wind turbine to produce electricity. On the vertical supporting pillar, small PV panels may be mounted as well, to complement the wind RES. These systems can feed with electricity the outdoor lighting system, and also provide some electricity for indoor use (lightning, appliances). A cheaper alternative would be to have only PV panels mounted on vertical pillars to cover only the street lightning needs. Batteries for electricity storage or connection of RES equipment to the local electrical grid are also needed to ensure energy availability at the time of consumption.

Three packages of measures are proposed and then analyzed from the point of view of economics. Associated costs, energy savings and emission reductions are summarized in Table 3.

Package #1: Installment on the SE roof of 9 thermal solar panels with 24 vacuum tubes each. DHW is prepared in two bivalent 500 l tanks, each having one coil for solar heated fluid and a 2.5 kW electrical resistance.

Package #2: This package includes all package #1, plus the measures described further here. Treatment of indoor air with ventilo-convectors mounted in bedrooms, living rooms and kitchens. Halls and bathrooms are indirectly heated/cooled by moving air inside the apartment. These ventilo-convectors provide heating during winter and cooling during summer by using water treated in a heat pump that uses the water of the nearby river as heat source. The heat pump can provide 19 kW thermal energy with COP=5, being able to cover heating load and also the secondary energy load for DHW (in addition to the solar). The cooling load is provided by the same heat pump, with EER=4.6, in addition to the night ventilation during the summer.

Package #3: Installation of a wind turbine of 3 kW, with storage devices or connected to the grid, capable of supplying energy for outdoor and indoor lighting, for heat pump electricity consumption, and for the electrical resistances in the two water tanks. The electricity production over a year is estimated at about 17520 kWh.

Package #4: This package is the sum of packages #2 and #3. Under these conditions, the building becomes practically "nearly zero energy". Thus, 10 lighting devices of 55 W (outdoor and with motion sensors at at least half of them) and the entire indoor lighting need about 9700 kWh/year. The heat pump needs electricity of about 7524 kWh/year, for both heating and cooling. These two demands together are below the energy produced by the wind turbine.

In this analysis, electricity consumption for appliances is not considered.

5. ECONOMICAL ANALYSIS OF RECOMMENDED MEASURES

Economical analysis of recommended measures is based on the following assumptions:

– Calculation is made in Euros with an exchange rate of 4,20 RON/Euro (NBR, July 2011).

– The specific cost of electricity is c = 0,3247 RON/kWh (without VAT) or 0,0959 Euro/kWh (with VAT 24%) (Enel, 2011).

– The annual increase in energy price, 10%.

– The annual depreciation rate of Euro, 3%.

The economical indicators used to compare and analyze the packages are:

- The net present value (NPV) of the income resulted from the investment at the moment "0" in energy performance and environment protection along the lifetime of the implemented measures. This value should be positive (if initial investment costs are negative and savings are positive) along the measures lifetime.
- The payback period of time (PBP), which is the time when the NPV=0, i.e. all the investment costs are paid back by the value of savings. The PBP should be less than half of the measures lifetime.
- Specific investment (e) for the unit of energy savings along the measures lifetime. This value should be inferior to the energy tariff at moment "0" to make the investment attractive.

It is mentioned that this simplified analysis does not include maintenance costs for the purchased equipment. The results of the economical analysis are included in Table 4.

Noteworthy, all packages are economical efficient in long-term; payback is less than half of the estimated lifetime, NPV is positive, and the specific investment per saved kWh is much below the electrical energy tariff. However, it is concluded that the most beneficial package of measures is package #4, where less than 5% of the building electricity demand is taken from the national grid (Table 5), investment payback is very attractive and over the remaining years the value of savings rises to values which are 8 to11 times the initial investment. Even considering maintenance costs, this package is certainly extremely economical efficient. When comparing the base case with the adaptive case, the motivation for interventions is even higher for the latter, as all economical indicators are better.

It is recommended to implement the measures during Spring time, in order to benefit over the summer as much as possible. Financing of the technical assistance, materials, equipment and execution work is needed from legal sources: owners resources, bank loans, subsidies from national programmes, sponsorships, performance contracting etc. In case of measure #3, about 34 green certificates may be issued at a cost of 55 Euros (Romanian Operator of Electrical Energy Market, 2011), which totals 1870 Euros/year. If subsidies and green certificated are taken into account in the economical analysis, results are even more optimistic. Moreover, there are countries (i.e., Poland), where every tone of emissions that are reduced over the year has associated a cost.

Table 5

The analysis of the energy and environment performances associated with the recommended packages: base care / adapted case

Package	Costs (equip.+ work)	Solution lifetime	Energy savings	Energy bill reduction	CO_2 emission reduction
-	Euro	years	kWh/year	%	t/year
1	9787	20	23038 / 23038	31.39 / 22.90	11.17 / 11.17
2	22000	20	52715 / 72975	71.83 / 72.55	25.57 / 35.39
3	9548*	20	17224 / 24156	23.47 / 24.02	8.35 / 11.71
4	31548	20	69940 / 97131	95.30 / 96.57	33.92 / 47.11

* Invesment without outdoor lightning fixtures, evaluated at 1452 Euro.

Table 6

Economical analysis of measures for increased building energy performance: base case / adapted case

Packages	Cost of saved energy	NPV	PBP	Specific investment, e*
	Euro/year	Euro	years	Euro/saved kWh
1	2208 / 2208	84779 / 84779	3,8 / 3.8	0,021 / 0.021
2	5053 / 6996	194387 / 277547	3,7 / 2.8	0,021 / 0.015
3	1651 / 2316	61154 / 89609	4,8 / 3.5	0,028 / 0.020
4	6704 / 9311	255540 / 367157	4,0 / 3.0	0.023 / 0.016

* It is compared with the cost of electricity of 0.0959 Euro/kWh.

6. CONCLUSION

An existing building can become "nearly zero energy", which is the new European standard for buildings in the medium to long term, with reasonable costs. First, the energy demand must be diminished with a high-level thermal insulation for all envelope elements. Then, the real conditions must be examined to search for appropriate renewable energy sources to be deployed with minimal costs. Special attention must be given to the numerical simulations for estimation of the energy performance of the building. Thermal bridges and air exchange are difficult and costly to measure on commercial bases, but critical in the correct estimation of energy needs and economical efficiency of additional improvements. The economical analysis must be performed including all possible benefits generated by the low energy consumption and over a sufficient period of time. The present study shows results for a block of flats, a type of building very common for social or private housing. Energy efficiency measures involving a heat pump, solar thermal panels and a wind generator of electricity may bring the energy consumption from classical sources to a very low value, while the investment payback period is only about 4 years under the prognosis assumptions considered here.

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