Retrofitting of a Heritage Building–Technical and Legal Constraints, Possible to Achieve Economic Effect

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***Abstract*— Retrofitting of existing buildings can result in energy savings, although it is difficult to predict real benefits. As showed on the example of the Polish school theoretical effect of improvements (59-71%) could differ significantly from the achieved reduction in energy consumption (33%). Situation is much more complicated if we consider ancient buildings. They are often high energy consuming structures, however some technical and legal constraints could hinder a process of modernization. This paper discusses issues connected with retrofitting of an old factory building that has been adopted for a school, apartments and offices several years ago. Possible to apply improvements regarding the structure, HVAC systems were discusses, with emphasizing main technical problems as well as legal ones resulting from a heritage conservator's recommendations. Part of requirements leads to a significant increase of investment costs, whereas others make few improvements not possible, for example isolation of external walls. Ecological effect of retrofitting was estimated as 51% of CO2 emission reduction..**

***Index Terms*—retrofitting, energy consumption, energy savings, SPBT**

I. Introduction

Lately, we can observe that a special emphasis is put on development of new low-energy buildings. However, it is necessary to mark that a relevant number of existing buildings needs improvements that led to reduction in the energy consumption. Possible to achieve savings in a sector of Polish residential and public buildings were described in [1][2], whereas as shown in [3] the theoretical effect of improvement (59-71%) could differ significantly from the achieved reduction in energy consumption (33%).

Much more problematic could be retrofitting of ancient buildings, where law requirements, heritage conservationists recommendations etc. often preclude isolation of external walls or replacement of windows.

This paper discusses improvements possible for deployment, technical and law constraints as well as economic effect of refinements.

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II. Description of an Ancient Building

The post-factory building constructed in 1892, located in the north-east part of Poland was analysed (Fig. 1). In 20th century it was changed to a school, a community centre to be used by about 130 people, 9 flats and public offices. Total heated area was estimated as 2100 m^2, while the building's volume was 8776 m^3.

Figure 1. Front elevation of the analysed building.

A. *Characteristic of the Building before Modernization*

External walls were made of solid bricks with 0.60 m thickness, with lime-sand mortar. Internal walls were also made of full ceramic bricks with a thickness from 0.25 to 0.60 m. A floor on the ground was made of boards on wooden balls, whereas the floor above the ground floor consisted of a wooden floorboard and beams. The spaces between the beams were filled with 0.10 m layer of clay on the thatch. The ceiling over the first floor was made of wooden beams with insulation (0.10 mm layer of sawdust mixed with lime). The technical condition of the ceiling was very bad and the roof required reinforcement or repair of damaged elements, as far as it was necessary to replace a leaking roofing and a damaged thermal insulation. Values of heat transfer coefficients for main parts of the building are presented in table 1. They are

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compared with maximum U values according to Polish law [4] for new buildings.

TABLE I. HEAT TRANSFER COEFFICIENTS

No	Part of the building	Heat transfer coefficient U [W/m2K)]	Max U [W/m2K)]
1	External wall	1.08	0.23
2	Roof	1.10	0.18
3	Window	3.30	1.1
4	Door	3.00	1.5
5	Floor	1.t09	0.30

The heating system was working like a two-pipe, pumping open system. All pipes were made of steel. Horizontal pipes were located partly in underfloor pits and partly above the floor. Vertical pipes were located in rooms, while distributors were set in an inspection chamber in the stairwell. The technical condition of the system was very bad. Due to numerous leaks, the floor and construction parts of the building were damaged, what was especially well-seen an outcrop of the floor school part. The insulation of pipes was almost completely destroyed. The old, long-time operating iron and ribbed steel radiators were also in a bad condition, without thermostatic valves to maintain a proper microclimate.

Domestic hot water was supplied by a low-parameter heat network with polyethylene pipes. This system was modernized 4 years before this analyses, so no changes is required. Ventilation was working like a natural one with high air change rates (ACHs) stemming from low leak-proofness

B. Range of Improvements Regarding Walls, Roofs and Windows

It should not be noted that in case of this building, by virtue of its ancient style, that is protected by a heritage conservationist, it was not possible to make any external isolation of walls. This fact hindered the building retrofitting significantly. After a deep analysis of indoor conditions, the decision to isolate only small parts of external walls inside flats was taken. The thickness of expanded polystyrene used was estimated for 0.06 m. The thicker isolation would case a water vapour existence and unwanted reduction of flats area, however this improvement would not allow to achieve U value at the recommended level [4]. The rest of external walls had to stay in a preliminary conditions, with very high U (1.08W/m2K), nearly five times more than recommended, so this fact influenced a final efficiency of the retrofitting significantly. Regarding the roof, there were no contraindications for its modernization, because works did not influence the overall building view. I analysed different thicknesses of mineral wool to apply in the air bareness above the second floor. Finally, to meet law expectations and receive U value as 0.18 W/m2K and decrease energy consumption, 0.18 m of isolation (mineral wool) was proposed. Moreover the heritage conservationist agreed to replace old, untighten windows and external doors by modern, well-insulated new ones, provided always that the old division of glasses into pieces would be preserved as well as external side would imitate antique wood. Without doubts these conditions made the price of modernization significantly higher comparing to typical windows. Finally, after analysis of different kinds of windows, 3-glasses 6-chambers windows with PVC profiles with U=1.1 W/m2K were selected.

C. Range of Improvements in the HVAC

The proposed solutions that can improve the efficiency of the heating system are:

- replacing old pipes by new ones with a good isolation,
- replacing old radiators by new ones with low thermal inertia, that allow for fast and efficient control of indoor parameters and maintaining temperature on the required level,
- installation of thermostatic valves,
- installation of a closed expansion vessel to protect the system.

In the case of DHW system a modernization is not expected, because this installation meets all current requirements. In a range of ventilation, no improvements are anticipated either, however, new windows are expected to be leak-proof to reduce heat load for ventilation. It should be noted that reduction of ACH cannot be too high to ensure the minimum required ventilation air flow.

III. REDUCTION OF ENERGY CONSUMPTION, GREENHOUSE GASSES EMISSION AND THE SIMPLE PAYBACK TIME

Heat load and energy consumption for the building in the actual conditions and after the proposed improvements were estimated according to standards and regulations [4][5], using Audytor Edu Sankom software. Results of calculations are shown in table 2.

Theoretical energy savings were estimated as 48%, whereas in case of possibility to isolate also external walls they would increase by next 20%. Moreover a reduction of carbon dioxide emission resulting from this building retrofitting would be about 481 MgCO2, so 51% of actual value. Significantly higher ecological effect could be reached by increasing of the share of biomass in cogeneration heat source.

TABLE II. MAIN PARAMETERS OF THE ENERGY CHARACTERISTIC BEFORE AND AFTER RETROFITTING

No	Parameter	Before retrofitting	After retrofitting
1	Heat load for heating and ventilation [kW]	277	181
2	Heat load for hot water [kW]	52	52
3	Efficiency of heating system [-]	0.65	0.90
4	Annual energy consumption for heating [GJ/year]	4191	2037
5	Factor of annual energy consumption for heating [kWh/(m3year)]	132.7	65.1

For each of the proposed improvements concerning the building's envelope and technical system the SPBT (Simple Payback Time) was estimated and the results are shown in Fig. 2. The shortest SPBT can be obtained in case of insulation of external walls and the roof, while the longest one for works connected with windows replacement. This fact is connected with a high price of untypical windows stylized for old ancient ones.

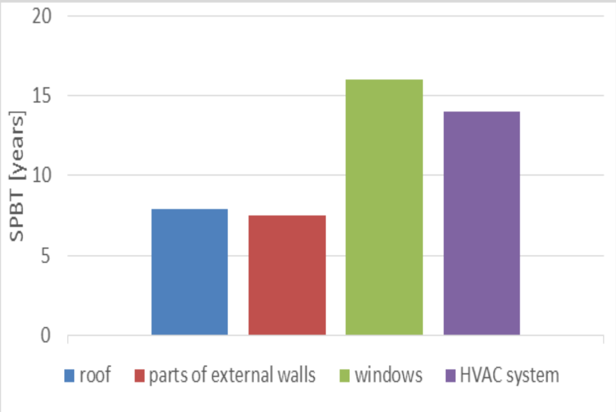

Figure 2. SPBT for selected improvements.

IV. Conclusions.

The analyses of possible to develop improvements, from both technical and legal point of view, showed significant constraints connected with isolation of external walls. The fact that it was not possible to isolate them in main parts reduced the efficiency of retrofitting by about 20%. Moreover from financial aspect, replacing windows in ancient buildings is more big-budget work than in normal buildings. Hoverer a total energy reduction in the ancient building was estimated for 48%, whereas Simple Payback Time for the whole investment relevant to envelope's isolation and improvements in the HVAC system came to 14.5 years. The reduction of carbon dioxide emission resulting from proposed changes was estimated as about 51% of actual CO2 emission, whereas further decreasing could be reached by increasing of the share of biomass in cogeneration heat source system.

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