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Energetic analysis of complex modernizations of educational buildings

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Abstract

In this paper, the complex modernizations of existing educational buildings are examined from energetic aspect. A case study based research was conducted between 2010 and 2017 with the involvement of architect student groups. The selected buildings are architecturally valuable secondary schools in Győr (Hungary) built in 1950-70. Firstly, the present conditions of the buildings were recorded in plans and in experts' reports. Secondly, 18 complex modernization designs were developed on the 6 buildings in order to offer complex solutions to the existing problems. The analyzing and planning processes were done with a holistic approach. The main motive of building modernization is usually to improve energy efficiency, therefore energy performance of buildings were examined on scientific level according to the Hungarian regulations in the second part of the research. Detailed energy calculations were made in the present and modernized conditions of the school buildings based on design proposals. In this way, the effect and efficiency of each modernizing measure could be analyzed revealing the omitted possibilities of the plans. Main conclusion of the evaluation was that the existing buildings could not fulfil the new, stricter energetic requirements if they had been renovated with usual methods. Based on the lessons, a general action plan was formulated with 12 measures in logical order, which can be applicable on any buildings having similar characteristics to the examined ones. In this way, these can be renovated according to the expectations of cost-optimal or nearly-zero-energy buildings, as well. Suitability of the general action plan was tested with energetic calculations on the studied school buildings. The energetic analysis revealed that the suggested general action plan could be effectively applicable to the modernization of existing educational buildings.

Keywords: building renovation; complex modernization; educational buildings; energetic analysis; energy performance of buildings

1. Introduction

During the past two decades, our building construction practice has significantly changed. One of the most important modifying effects is our new approach to the energy performance of buildings, especially in the European Union. The EU is already addressing energy efficiency as a priority issue, not only because it is aware of the seriousness of the global situation, but also because its territory is relatively poor in energy sources, so the dependence of countries on energy imports is high. "Energy policy for Europe" has been steadily developing since the years 2000. Energy strategies were established with concrete targets for 2020, 2030, and 2050 [1-3]. The 2010/31/EU Energy Performance of Buildings Directive [4] and some background studies [5, 6] introduced the notions of cost-optimized and nearly-zero-energy buildings. These studies investigated the construction and operation costs of new buildings in a 30-year long period searching for the cost optimal situation. According to the directive, EU states constituted the national regulations with quantitative requirements in the past few years. In Hungary, this actual regulation is the several times modified 7/2006. TNM Decree [7]. The more serious energetic requirements written in the decree must be implemented from 2018 in the case of cost-optimized, and from 2021 in the case of nearly-zero-energy buildings.

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In Hungary, 40% of the total energy consumption is used in our buildings. This rate has practically remained unchanged over the past ten years and corresponds to the rate observed in EU countries with similar geographic conditions [8]. The absolute amount of building related energy use can be decreased when new buildings are built in an energy-efficient way, and when existing buildings are renovated energetically. Energy strategies and the background studies generally focus on the new buildings, particularly on the new residential ones, though energetic modernization of existing buildings has also great potential, especially in case of public buildings. The replacement of public buildings with newly built, energy-efficient ones is even smaller than the renewal of the residential building stock, so here almost the only energy consumption reduction can be expected through building renovations. Public buildings are the 12% of the whole building stock in the EU, and 17% of GDP is spent for public building related expenditures. Among the public buildings, the educational buildings are represented in the largest number, in Hungary this rate is 42% [9]. Based on these, it would be reasonable to place significant emphasis on government-initiated renovation of the existing public buildings, starting with the largest stock, on educational buildings.

The energetic modernization of existing educational buildings raises a number of issues in the light of the new cost-optimized and nearly-zero-energy requirements. For example:

- Can educational buildings be modernized according to cost-optimized or nearly-zero-energy expectations?
- What kinds of energy savings are available in an educational building?
- Is the 25% renewable energy ratio available for a renovated school building?
- Is it possible to improve the energy quality of schools better with the right choice of modernization measures?
- How could educational buildings demonstrate the energy awareness for students, teachers, and society?

2. Methods

The research into the complex modernization of educational buildings described in this article was conducted in the Széchenyi István University 2010-2017 with the involvement of architect students. The initial goal was that students gain experiences in the multi-criteria status analysis and complex modernization of existing buildings from the second half of 20th century in teamwork. Educational buildings of Győr were obviously suitable for the investigation. During that period, 6 different secondary schools were examined by different student groups with the same methodology as case studies. Students could practice the on-site inspection, documentation from archives, making expert opinions, complex modernization design from program creation to detail processing. To the 6 buildings, 18 different modernization plans were developed. From the surveys and modernization plans, technical reports were edited, which are now online accessible documents, referencing to the all utilized sources and their authors [10-15].

Meanwhile, it became clear that the students' works are worth for further consideration and the detailed analysis. Therefore, the university project was converted into a personal research project in which the energetic performances of the school buildings were investigated as case studies. Firstly, characteristics of the buildings were described in order to answer the question: Do the selected buildings belong to one characteristic group? After that, their energetic feature data were determined according to the Hungarian regulations and calculation methods [7], which are harmonized with the EU standards. Calculations were made with the Auricon Energetic software in the legal and software environment in July 2017. Buildings were examined in several conditions (in current state, according to modernizations or action plans), but the boundary conditions and the applied simple or detailed methods were the same in each calculation, so the comparability of the results was assured.

3. Designing complex modernizations of educational buildings in Győr

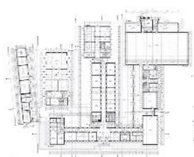
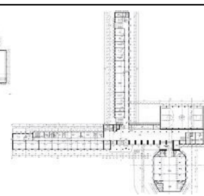
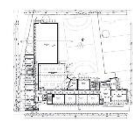
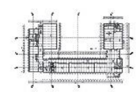
3.1. Selection of buildings

We intend to issue university semester assignments in which the systematic status analysis of existing buildings and the development of renovation and expansion plans can be practiced by students. For this, we have been looking for local buildings, which offer a sufficiently complex task, and whose future renewal is a task ahead. Thus, the opinions and suggestions developed can even contribute to the real modernizations of buildings, what motivates students to work properly on the one hand and institutions to support our work on the other hand. The above mentioned aspects are particularly true for schools, most of them have problems in each topics to be studied.

In Győr there are about 45 kindergartens, 30 primary and 30 secondary schools with often changing institutional and building backgrounds. The age of the buildings has naturally a large variance, there are hundreds of years old and quite new buildings, and we have to mention the partially or completely renovated, possibly enlarged buildings as well

[16]. The buildings of the 1950s and 1960s were chosen because these were interesting and valuable ones from architectural aspects, and from constructional point of view they were born in a particularly exciting era when industrialized technologies replaced the traditional ones. The six chosen educational buildings are presented in Table 1, where some identifying data, typical images, and ground floor plans are also visible.

Table 1. Parallel presentation of the studied buildings.

Assignment year	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
School name shortly	Hild József Secondary School of Construction	Bercsényi Miklós Secondary School of Transport and Sport	Lukács Sándor Secondary School of Mechatronics and Mechanics	Baross Gábor Secondary School of Economics and Management	Dance & Fine Arts Primary and Secondary School of Győr	Szabóky Adolf Vocational School
A typical image						
Ground floor plan, same scale						
Architects	Fátay T, Eördögh É, Sebők T.	Cserhalmy J, Winkler G, Mikóczi T; Czeglédi	Rimanóczy Gy.	Hegedűs E, Mikóczi T, Lados P, Németh Gy	Harmati J. Papp L, Ambrus Z, Wyberál L.	Vidra A. Németh Gy.
Designing and construction	1956-58; 1958-62.	1950; 1955-56.	1950; 1951-53.	1961-62; 1962-64.	1962; 1963.	1967; 1969.
Expansion and/or restructuring	1973: new wing; 1991: gym	1969: workshop; 1975: gym; 1984: classrooms; 1994: garages	1961: gym, by original plans	1986: new block; 1997: great hall; 1999: new storey	1988: ballet halls	2004, 2006: small internal transformations
Total floor area	3 324 m^2	8 810 m^2	11 668 m^2	4 226 m^2	3 615 m^2	3 001 m^2
Volume	11 469 m^3	32 978 m^3	42 119 m^3	16 828 m^3	12 882 m^3	10 003 m^3

3.2. Multi-criteria status analysis

For complex status analysis of existing school buildings, the assessment and recording of the current state of buildings are indispensable. Students made 1:200 scale recording plans compiled the original designs from the city and school archives and actualized with the modifications noticed during the on-site inspections. Information was collected on the operating experiences drawing our attention to architectural, functional, constructional and service deficiencies of buildings. The student groups reviewed the buildings, expert opinions were made, presented and discussed together. The method of multi-criteria status analysis has progressively refined over the period, covering the following areas, according to the specific literature:

- exploring architectural values, making value inventories;
- functional compliance according to the regulations and standards of secondary education buildings;
- accessible and universal use based on existing regulations and design aids;
- identification of building structures, condition survey using visual inspection and thermal images;
- energy performance based on current regulations, with detailed energy calculations helped with software and on the general literature of the subject;
- building acoustics: soundproofing and noise protection, room acoustics;
- fire protection of buildings based on existing regulations and educational materials.

In the status analysis, 50-60 year old buildings were examined according to the current expectations. Therefore, it is almost natural that buildings do not conform in all respects to the recent technical requirements. These, for example in the building energetics and fire protection, have changed considerably in the past few years, but there are many changes in functionality as well, considering the necessity of accessibility or reviewing existing standards for schools.

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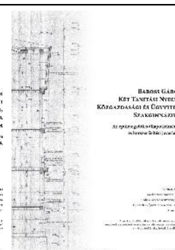
3.3. Modernization designs

Comparison of recent requirements and the features of existing educational buildings helped the student groups with the definition of their own design programs for complex modernizations. In the programs, the different problems were represented with different emphases, in this way groups could develop different complex solutions. The stressed problems in the design processes have changed from year to year according to the particular requirements of the buildings and to the students' preliminary qualifications. Therefore, other and other aspects were in the focus of interest in the certain groups' work, such as the education as function, accessibility, preservation of architectural values, increased energy awareness, or implementation of passive house components. Each design proposal contains valuable ideas, which can draw the attention to existing problems and give some ideas to solve them.

Altogether 18 different complex modernization designs were developed to the 6 schools over the period. This means on average three plans per building. Within the framework of this article, only a small part of the voluminous materials of the design proposals may be presented (Table 2), therefore detailed research reports [10-15] were prepared to each school building, in which the status survey, the main results of multi-criteria analysis, and the different complex modernization proposals were also published with several useful and interesting data.

Table 2. Research reports and an overview of alternative modernization proposals

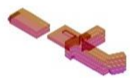
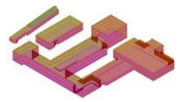
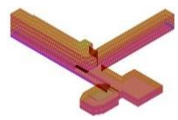
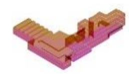
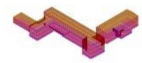
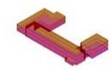
School name	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Front-page of research report						
Reference, pages	[10] 50 pages	[11] 50 pages	[12] 80 pages	[13] 62 pages	[14] 60 pages	[15] 50 pages
Content	3 record, 3 proposal	1 record, 2 proposal	1 record, 3 proposal	1 record, 4 proposal	1 record, 3 proposal	1 record, 3 proposal
A typical image of "A" proposal						
A typical image of "B" proposal						
A typical image of "C" proposal						

4. Energetic analysis of designed complex modernizations

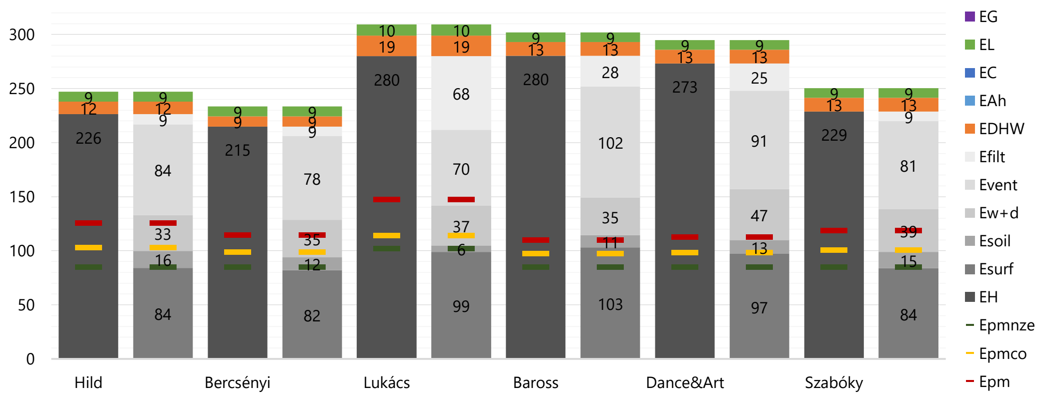
4.1. Energetic analysis in the present conditions

Although the student groups were motivated to design complex modernizations taking into account almost all aspects, we were aware that, unfortunately, modernizations are often incomplete in real life. "It is difficult and meaningless to separate purely technical, energetic or sustainability-based interventions, however in most cases this happens." [17] It is possible to examine each modernization objectives, to what extent it contributes to improving the sustainability of the building that is to what extent they are beneficial from the environmental, social, and economic aspect. In general, it can be stated that those modernization goals have a greater chance of realization, which are proven economical. Experience shows that the main motivation of building renovations is at present the desire for energy saving [18]. Investigating the energy consumption of buildings is usually a priority in preparing decisions on modernization, therefore energy indicators of the six building complexes were examined with detailed energetic calculations, at first in the current state. Main results of the calculations are presented in Table 3.

Table 3. The energy indicators of the six educational buildings in current state

School name	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Spatial relations, heated spaces and cooling surfaces of buildings, axonometries, in scale						

Energy demand of:
E_H: heating, in this:
E_{surf}: cooling surf.
E_{soil}: soil contact
E_{w+d}: windows
E_{vent}: ventilation
E_{filt}: filtration
E_{DHW}: hot water
E_{Ah}: air handling
E_C: cooling
E_L: lighting
E_G: energy gain
Requirements:
E_{pmnze}: nearly zero
E_{pmco}: cost-optimal
E_{pm}: general, old



	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Heat loss factor [q]	0.446 W/m^{3}K	0.456 W/m^{3}K	0.497 W/m^{3}K	0.406 W/m^{3}K	0.481 W/m^{3}K	0.459 W/m^{3}K
Energy perf. [E_p]	246.917 kWh/m^{2}a	233.308 kWh/m^{2}a	309.304 kWh/m^{2}a	301.858 kWh/m^{2}a	294.791 kWh/m^{2}a	250.407 kWh/m^{2}a
Renewable energy	5.779%	6.355%	3.624%	5.107%	5.397%	7.374%
Energy class	290%; GG	274%; GG	305%; GG	355%; HH	347%; HH	295%; GG

In Table 3, the energy indicators of the six educational buildings are visible with the dimensions of the buildings. Red color signs that the indicator could not fulfil the concerning requirements. In the graph, each building has two columns. In the first one, the main components of the overall primary energy performance are included: heating, air handling, cooling, domestic hot water, lighting and energy gains. In the second one energy needs of heating are shared in proportion of heat losses: building boundary structures apart from doors, windows and soil contact structures, ventilation and filtration. Overall, it can be stated that the average of the energy performance of the currently partially renovated buildings is 272.76 kWh/m^{2}a (standard deviation: 29.98) which represents 311% of the reference value (standard deviation: 30), so their average energy class is HH or "weak".

4.2. Energetic analysis according to the designed modernizations

In the next step, the energy indicators of the modernized buildings had to be determined according to the 18 proposals. In this process, it was only partially possible to rely on the students' energy calculations because they were not prepared with a uniform methodology. Therefore, new calculations had to be made for all plans in accordance with current rules, with a consistent approach. The students' task was not only to renovate existing structures, but they had to develop complex proposals based on the results of multi-criteria analysis, therefore the buildings had been substantially modified or enlarged in several versions, or just the alignment of the thermal envelope were adjusted. The modifications are illustrated in the figures of Table 4, where the main results of calculations are also presented.

Summarizing the results, we can see that, although all 18 modernization plans significantly reduced the specific primary energy use of the schools, none of them could be fully met with the complex requirements of nearly-zero-energy buildings. The same can be said for the cost-optimized requirements, which should be applied for the renovation of an existing building under the current regulation. Overall, it can be concluded that the average of the energy performance of the complex modernized buildings is 127.40 kWh/m^{2}a (stand. dev: 18.84) which represents 146% of the reference value (stand. dev: 27), so their average energy class is DD or "approaching up-to-date".

The result of the energy calculations of the complex modernized buildings showed that buildings could not have been renovated according to the new cost-optimized or nearly-zero-energy building requirements with the usual design methods and solutions of the current technical practice. For the preparation of renovations careful architectural, constructional and building service engineering design is needed with the application of effective new technologies.

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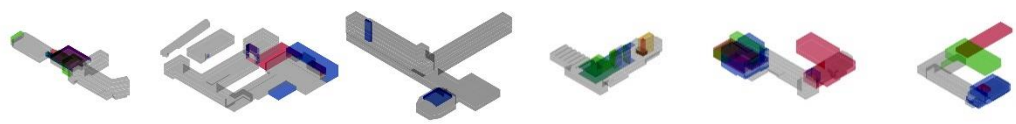
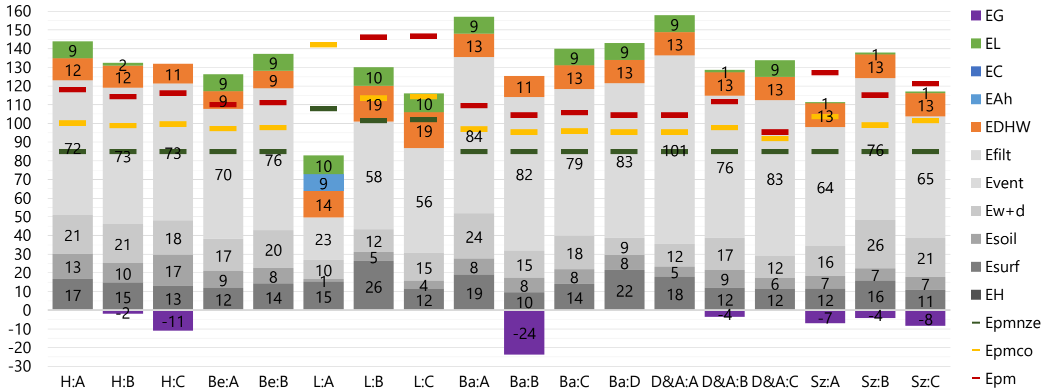
Table 4. The energy indicators of the buildings according to the complex modernization proposals

School name	Hild			Bercsényi		Lukács			Baross				Dance&Art			Szabóky		
Changes in spatial relations, heated spaces and cooling surfaces of buildings in plans, axonometries																		
Versions	H:A	H:B	H:C	Be:A	Be:B	L:A	L:B	L:C	Ba:A	Ba:B	Ba:C	Ba:D	T:A	T:B	T:C	Sz:A	Sz:B	Sz:C

Energy demand of:
E_H: heating, in this:
E_{surf}: cooling surf.
E_{soil}: soil contact
E_{w+d}: windows
E_{vent}: ventilation
E_{filt}: filtration
E_{DHW}: hot water
E_{Ah}: air handling
E_C: cooling
E_L: lighting
E_G: energy gain
Requirements:
E_{pmnze}: nearly zero
E_{pmco}: cost-optimal
E_{pm}: general, old



	H:A	H:B	H:C	Be:A	Be:B	L:A	L:B	L:C	Ba:A	Ba:B	Ba:C	Ba:D	T:A	T:B	T:C	Sz:A	Sz:B	Sz:C
H. l. f. [q] W/m^{3}K	0.176	0.145	0.167	0.129	0.130	0.114	0.162	0.110	0.141	0.083	0.109	0.108	0.077	0.118	0.078	0.111	0.131	0.113
E. p. [E_p] kWh/m^{2}a	144	131	121	126	137	83	130	116	157	102	140	143	158	125	134	104	134	109
Renewable energy	8.2%	12.7%	10.9%	9.3%	10.0%	16.5%	7.4%	8.7%	10.0%	14.0%	10.0%	8.0%	7.1%	10.9%	6.9%	15.8%	15.7%	18.7%
Energy class	169% EE	154% DD	142% DD	148% DD	161% EE	77% AA	128% CC	114% CC	185% EE	120% CC	165% EE	168% EE	186% EE	147% DD	157% DD	123% CC	157% DD	128% CC

5. Action plan to make energy modernization of educational buildings more efficient

5.1. Action plan: modernization steps in logical order

A revision were prepared in which the partial results of the energy calculations were compared in the existing and the modernized state of the buildings. Following the sequence of calculation lessons were collected from the energy aspects of the design process. Based on the lessons, general proposals were formulated for the efficient design of energy modernization of school buildings. After that, concrete proposals were elaborated for the renovations of the six building complexes in consideration of the architectural and environmental characteristics of them, so the applicability of the general proposals or the action plan was tested on all six buildings.

The elements of the general building modernization action plan in the logical order of the application: (1) Definition and rationalization of the position of the thermal envelope. (2) Subsequent heat insulation of the heated volume boundary structures, preferably in accordance with the cost-optimized requirements, taking into account the technical state of the structures and the architectural values. (3) Revision of the thermal bridges in the heated volume boundary structures. (4) Heat insulation of the soil-contact structures in a rational manner, taking into account the technical state of the structures and the architectural values. (5) Replacement of doors and windows no longer meeting the requirements for heat insulation and/or airtightness. (6) Elimination of leaks, ensuring general air tightness. (7) Modernization of ventilation according to functional demands to reduce the heat loss of air exchange by the installation of decentralized ventilation systems with heat recovery, preferably in the whole building with intermittent operation. (8) Optimization of direct radiation heat gains with the tools of appropriate glazing, window division and shielding, taking into account the risk of overheating in the summer. (9) Modernization of the heating system, supporting with renewable energies. Exploration of the possibilities of geothermal heat production according to the characteristics of the building and its surroundings. (10) Modernization of the domestic hot water system, supporting with renewable energies. Connection to the heating system if possible and reasonable. (11) Modernization of the lighting, supporting with renewable energies. (12) Installing solar photovoltaic panels on roofs to supply the building service systems and other electrical consumers, according to the characteristics of the building and its surroundings.

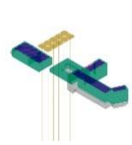
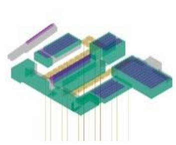
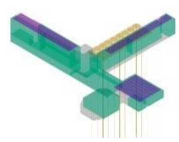
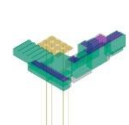
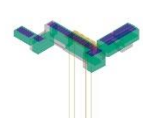
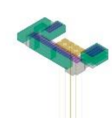
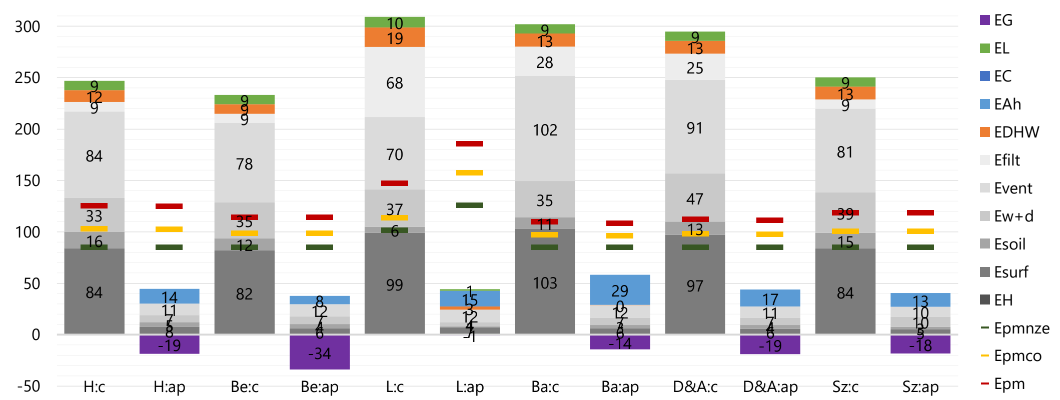
5.2. Evaluation of the general action plan with energetic analysis

In order to evaluate the general action plan, detailed energy calculations were made for the six educational building complexes. The individual measures of the action plans were applied on the buildings in the current status, so the other aspects of the obviously necessary complex modernizations could not be counted in these models.

In Table 5, illustrations explain the applied innovative building service solutions in the case of each building. The graph shows the primary energy use of service systems of the building complexes in the current and upgraded state. The energy needs of heating system are shared in proportion of the different types of heat losses. The heating energy need was decreased significantly, partially because of the thermal insulation of the building boundary structures, but mainly due to the elimination of heat loss in the air exchange, however this generates new energy needs for the artificial air handling. Renewable energies can be presented only partially in graph, because significant parts of them are already counted in the energy use of building services.

All of the overall energy performances calculated on the basis of the energy modernization proposals of action plans fulfilled the requirements for the cost-optimized and the nearly-zero-energy buildings in the cases of the six educational buildings. The amounts of renewable energy use also fulfill the 25% requirement of nearly-zero-energy buildings in all cases. Based on the above, it can be stated that using the general action plan each of the six educational complexes can be renovated not only as a cost-optimized but also as a nearly-zero-energy building as well.

Table 5. The energy indicators of the buildings in current status and after a renovation according to the action plan

School name	Hild		Bercsényi		Lukács		Baross		Dance&Art		Szabóky	
Spatial relations of buildings, axonometries, Green: ventilation Purple: PV panels Yellow: soil probes												
Status	Current	Planed	Current	Planed	Current	Planed	Current	Planed	Current	Planed	Current	Planed
Energy demand of: E_H: heating, in this: E_{surf}: cooling surf. E_{soil}: soil contact E_{w+d}: windows E_{vent}: ventilation E_{filt}: filtration E_{DHW}: hot water E_{Ah}: air handling E_C: cooling E_L: lighting E_G: energy gain Requirements: E_{pmnze}: nearly zero E_{pmco}: cost-optimal E_{pm}: general, old												
H. l. f. [q] W/m³K	0.446	0.161	0.456	0.137	0.497	0.099	0.406	0.114	0.481	0.135	0.459	0.150
E. p. [E_p] kWh/m²a	246.917	25.844	233.308	4.064	309.304	43.417	301.858	43.958	294.791	24.938	250.407	22.019
Renewable energy	5.779%	47.589%	6.355%	82.879%	3.624%	32.573%	5.107%	38.913%	5.397%	50.854%	7.374%	65.618%
Energy class	290% GG	30% AA++	274% GG	5% AA++	305% GG	34% AA++	355% HH	52% AA+	347% HH	29% AA++	295% GG	26% AA++

6. Conclusions

A common desire with our students is to make our research utilized. This can happen if our alternative modernization plans could have an impact on the design process of renovations and extensions, or before that, in the tender phase of them. As the modernization of public buildings is a public interest and because the institutions were also interested in our results, it was necessary to publish an overview research report for each building [10-15], which were disseminated after the research with my PhD thesis [19].

The energetic examinations on the complex modernizations of the secondary schools in Győr presented that the educational buildings of 1950s and 1960s could be modernized according to cost-optimized or nearly-zero-energy expectations in general. To be scientifically correct, it should be declare that the results of the examinations can be extended only for the buildings having the same characteristics with the analyzed ones. The six school buildings have similar energetic characteristics due to their urban situation, function, age, size, geometric, architectural, and structural features, moreover they were renovated on the almost same level, so they can be examined as a group.

Our case study based research shows similar results as other surveys on the energetic characteristics of the Hungarian building stock. The National Building Energy Strategy states that the cost-optimized modernization of educational buildings can result in 61.2% reduction, and the nearly-zero-energy aimed modernizations can result in 65.5% reduction of the overall energy performance in contrast with the existing status of the buildings [8]. Other research projects like NEGAJOULE and RePublic_ZEB also emphasize the need for the energetic modernization of public buildings with similar calculations and international examples [20, 21].

The results showed that these modernizations could not be performed with the usual methods, but they can be done with careful architectural, constructional, and building service engineering design, and with the application of effective new technologies. Important recognition of this study is that educational buildings usually have exceptionally good conditions to place soil probes under schoolyards and photovoltaic panels on roofs, and there is a mandatory need for artificial ventilation with heat recovery. This triple, mutually cooperative system is extremely efficient energetically. In this way the requirement for the 25% renewable energy use of the nearly-zero-energy buildings is also feasible.

The defined general action plan with its 12 steps can help the future modernizations of educational buildings. The wording of proposals in general action plan intentionally refers to the necessity of the consideration of the possibilities, which is an important duty and responsibility of the designers. In the field of building energetics, especially in the modernizations of existing buildings, several disciplines meet, so it is particularly important to apply the holistic approach. The interactions of simultaneously existing, often conflicting factors should be placed and ranked in the triple system of stress, requirement and performance, so the right decisions could be achieved from architectural and technical aspects as well [22]. With this kind of attitude, the complex modernizations of educational buildings can give positive examples of energy and environmental awareness for the next generations and the whole society.

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