PASSIVE SYSTEMS IN RAISING ENERGY EFFICIENCY OF PUBLIC UTILITY BUILDINGS – ACTION SIMULATIONS

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Abstract

Public utility buildings are formally, structurally and functionally complex entities. Frequently the process of their design involves retroactive reconsideration of energy engineering issues, once a building concept has already been completed. At that stage minor formal corrections are made along with the design of the external layer of the building, satisfying or even exceeding applicable standards. Architecture students do the same when designing assigned public utility buildings. It can be demonstrated on a few examples that transforming the form, structure and function of a building can significantly affect its energy efficiency. In order to prove such a thesis the following assumption was made: both prior to and following the incorporation of changes, the analysed building features external layers of the same thermal insulating. Thus, the building is fitted with external envelopes of the same coefficients of thermal transmittance – U. The following aspects needed to be examined in the analysed buildings: the location in relation to the directions of the world, in order to open it to the insolation from the south and to maximally close it from the north, to improve the function layout in order to enable room temperate zoning, to use passive systems of solar energy gain (direct, indirect and compilation gain systems) from the southern side and to design the control of warm and cool air masses in the building.

Streszczenie

Budynki użyteczności publicznej są złożonymi formalnie, strukturalnie i funkcjonalnie jednostkami. Często przy ich projektowaniu zagadnienia energetyczne są przemyśliwane wtórnie, po ukończeniu koncepcji obiektu. Wówczas dokonuje się niewielkich korekt formalnych i projektuje się powłokę zewnętrzną obiektu, zgodną z obowiązującymi normami lub nawet je przewyższającą. Podobnie czynią studenci architektury projektując zadane obiekty użyteczności publicznej. Na kilku wybranych przykładach można dowieść, że przekształcenie formy, struktury i funkcji obiektu w istotny sposób wpłynie na sprawność energetyczną obiektu. By udowodnić tą tezę dokonano takiego założenia: zarówno przed jak i po zmianach analizowany obiekt posiada powłoki zewnętrzne o takiej samej izolacyjności cieplnej. Więc obiekty zarówno przed jak i po zmianach mają przegrody zewnętrzne o takich samych współczynnikach przenikalności cieplnej – U. W rozpatrywanych obiektach należało przeanalizować: położenie obiektu w stosunku do stron świata, uczynić go otwartym na insolację od południa, maksymalnie zamknąć od północy, poprawić układ funkcji by umożliwił strefowanie temperaturowe pomieszczeń, zastosować od południa systemy bierne pozyskiwania energii słonecznej (system zysków bezpośrednich, pośrednich i kompilacyjny) zaprojektować kontrolę ciepłych i zimnych mas powietrza w obiekcie.

Keywords: **Architecture of public buildings; Passive solar energy solutions; Energy efficient building.**

1. INTRODUCTION

Energy efficient building engineering is becoming a standard in the 21st century, when everyone declares and follows the rules of sustainable development. This paradigm has been adopted as the norm in the entire progressive world and one of the conditions is conservation of non-renewable energy raw materials. Therefore, building engineering needs to create buildings whose operation is energy efficient. The aim is to ensure that buildings use the least possible amounts of

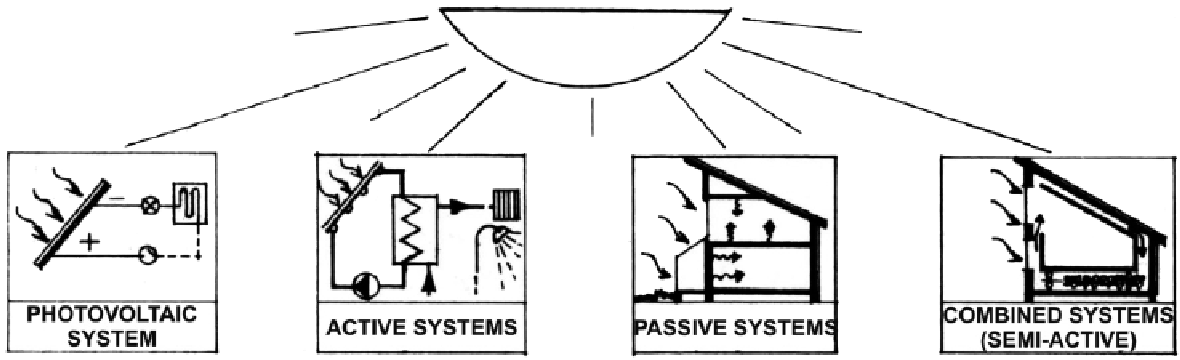

Figure 1.
Diagrams of solar energy conversion used in building engineering [5]

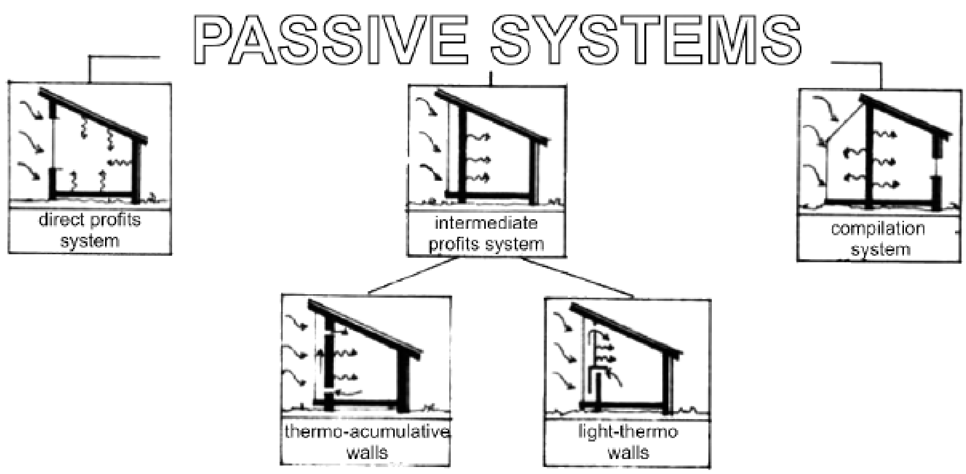

Figure 2.
Diagrams of passive systems of solar energy conversion used in building engineering [5]

energy generated from conventional sources, and to ensure that they use energy from non-conventional energy sources (renewable energy) as much as possible. Among all the various renewable energy sources, solar energy is the most accessible and providing extensive opportunities of using it in building engineering. There are various methods of converting solar energy used in building:

1/converting solar energy into electrical energy – photovoltaic systems,
2/converting solar energy into thermal energy transported through heated liquid or air in solar energy collectors, and then in complex installation systems – active systems,
3/converting solar energy into thermal energy through heating adequately shaped building elements with solar rays with the use of the phenomena known from physics: transfer, conductivity, convection – passive systems,
4/converting solar energy into thermal energy through heating adequately shaped building elements with solar rays but the rays of that energy are controlled – semi-active systems.

Passive systems are the systems that change building architecture the most. The systems are inexpensive and efficient, but they require predicting and providing solutions at an initial stage of a project. They are systems whose efficiency is affected by building architecture. It is a direct gain system ("opening" of a building from the southern side – large window openings, glazed surfaces), or an indirect gain system (in which suitably designed building elements are found behind southern glass envelopes, indirectly participating in the heating of adjacent rooms by being heated with sun rays), or finally a compilation system (combining the characteristics of the two above-mentioned systems, e.g. greenhouses/conservatory/glazed courtyards that heat the adjacent cubature).

For years they have been successfully used in energy-efficient single-family houses. The experience of residential housing needs to be transferred in a different scale and with more sophisticated solution to public utility buildings. The benefits of applying those systems are evident and can be computed with the use of software simulating a building energy operation. Such simulations can be made with the following programmes: Ecotect, Vasari, Grasshopper.

2. COMPARATIVE ANALYSES OF PUBLIC UTILITY BUILDING DESIGNS

2.1. Public utility building designs – standard design procedure

Public utility building designs entail a whole range of highly complex functional configurations, and therefore complex spatial configurations, such as: health care, educational, cultural, multifunctional buildings (e.g. commercial-service-gastronomy), etc. Both experienced designers as well as architecture students focus on this complex function of a building and its aesthetics when designing that type of buildings. Despite the fact that energy efficiency is presently treated as a necessity, the issues related to it are solved retroactively. The first concept of a building is developed with the issues of its function, form and construction in mind. In designers' view, energy efficiency is a task to be solved at the stage of developing a technical design of a building. It is then that thermal properties of its external layers are solved through the use of high thermal isolation envelopes, larger openings are designed from the south side and smaller ones from the north (although that is rare), some gadgets might be added, such as liquid or photovoltaic solar energy collectors and, in the best case scenario, a recuperator or a heat pump. Buildings so designed are said to be highly energy efficient, using the state-of-the art pro-ecological building solutions. Such description of those buildings is a misuse of the term, since the architecture of such buildings was not designed as energy efficient.

2.1.a. Energy analyses of public utility buildings

Several public utility building designs were analysed. The completed designs of public utility buildings were examined with regard to energy efficiency of the solutions they feature through the application of the following programs: Ecotect, Vasari, and in case of simpler analyses (shading, insolation of building planes) Archicad program extensions were sufficient. The following aspects needed to be examined:

- location: Is a building properly positioned relative to the direction of the world? Does the southern façade receive sufficient amount of insolation? Isn't the building shaded with other structures – mainly at the time of equinox – 21.03 and 23.09?
- shape of the building body: Is it shaped in such a way that its own shadow interferes with room light? Which building body surfaces receive the most solar energy?
- amount of daylight and of solar radiation in particular rooms: How much light do the provided window openings allow into the rooms? How do they function in intense insolation?
- annual thermal balance, itemized into individual months: What is the demand for heat at specific, constant coefficient value of external envelopes insulating power for all analysed buildings (solid walls $U = 0.15\ W/m^2K$, roofs and flat roofs $U = 0.1\ W/m^2K$, ground slab $U = 0.1\ W/m^2K$, windows $U = 0.7\ W/m^2K$, conservatory, glass curtain walls, doors $U = 1.2\ W/m^2K$). It was calculated what proportion of thermal energy demand is covered by solar radiation gains, what proportion is obtained from gains generated by people and devices, and how much needs to be supplied from conventional sources of heating. For the summertime, the question is how much energy will be consumed by air conditioning that cools the buildings.

Note – To ensure the comparability of results, all the designed buildings featured the same coefficient of insulating power properties of external envelopes as specified above.

As a result of the conducted analyses, the authors themselves recognized significant defects of their own solutions. The most frequent defects included:

- inappropriate location of rooms in the building relative to the directions of the world,
- inappropriately shaped form of the building - breaks causing high shading, excessively shaded patios,
- inappropriately designed window openings and curtain walls,
- lack of solutions related to operation of the building in the cold and hot seasons.

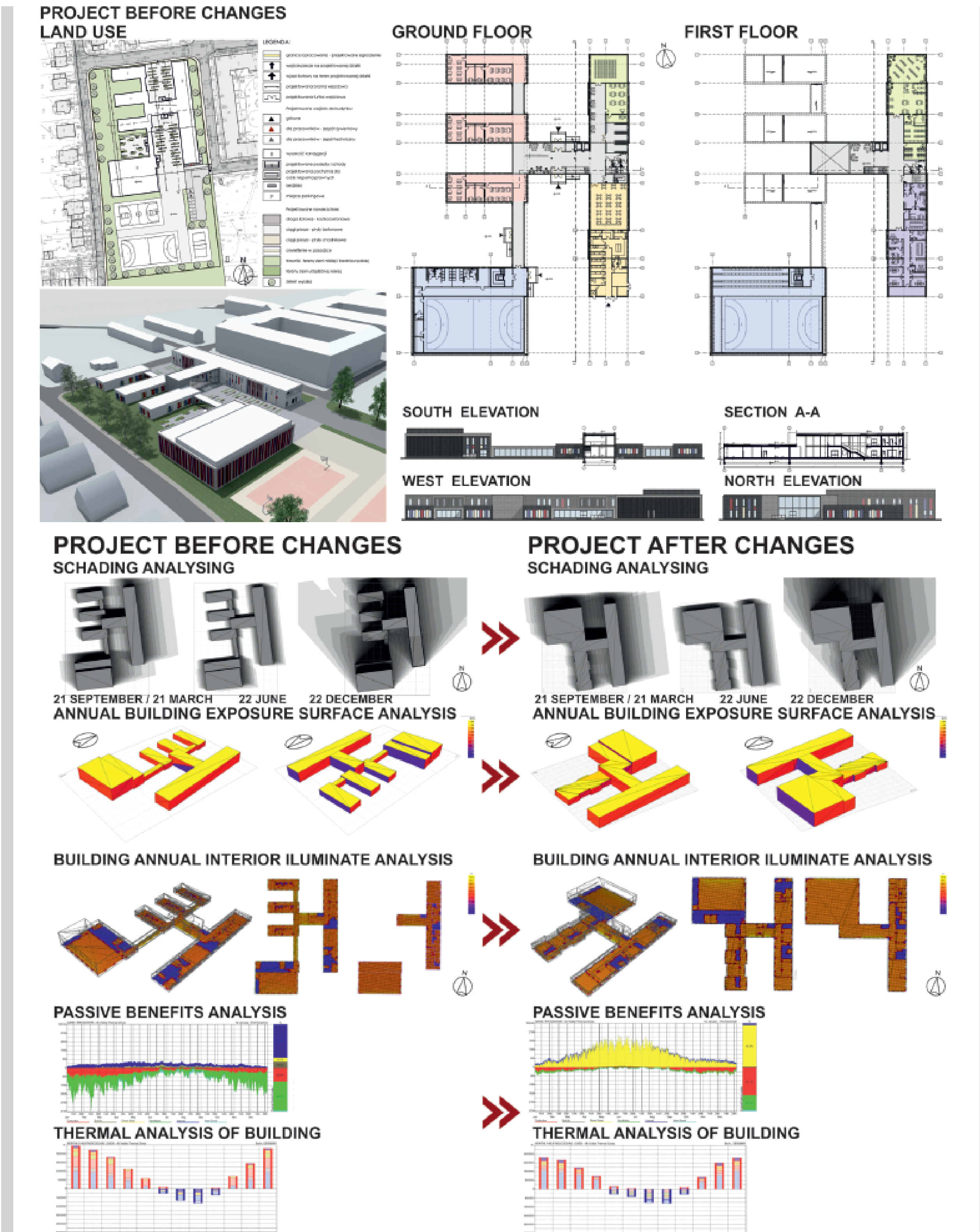

Figure 3.
Design and analysis of Junior High School building – Summary analysis of the object before the change and after the changes (shading, lighting sunlight envelope planes of the building, interior lighting by daylight, the annual heat balance); author – student A. Pichulska, under the direction of prof. M. Wołoszyn

2.2. An energy efficient public utility building featuring passive and active systems of solar energy use – corrections or complete changes of original design solutions

The defects found in the analysed designs had to be corrected. Additionally, designers obtained extensive information on simple and efficient passive systems of solar energy use. Design corrections eventually became substantial redesigns. Knowing the functional diagrams of previously designed buildings, designers found it easy to incorporate changes and supplementations of new solutions increasing energy efficiency.

The changes involved:

– remodelling the body of a building, in order to decrease building's own shadow, e.g. softening breaks or reforming them in such a way so as to prevent them from shading adjacent parts of the building;

– shaping the form of the building in such a way that a longer façade has been created on the southern side;

– designing a room layout that enables temperature zoning of building rooms (warm from the south or the centre of the layout, cold from the north or as an external buffer from the windward side);

– addition of a greenhouse / conservatory as an integral structure element that co-operates with the body of the building in terms of its energy efficiency;

– incorporation of other passive systems of acquiring thermal energy from solar radiation (systems of direct and indirect gains);

– conceptual solution of air circulation in winter and summer time;

– proposal of a system of heat recuperation from ventilated air and a way of preliminary heating of air introduced into the ventilation system;

After the completion of so many analyses and necessary changes, the building designs became new, different designs of the same functional program but solved in a new form, re-examined in terms of energy. A conservatory (greenhouse) is now one of the fundamental elements integrally connected with the building. It constitutes a supplementation of entrance, recreation, gastronomy and other types of space, but it is also an element improving the building's energy balance. The functioning of the space during winter and summer time also needs to be considered. Aspects that have to be solved include: cooling, heating, air circulation and the use of air from the greenhouse, etc.

2.2.a. Energy analysis of a redesigned building

New building designs were subjected to similar examinations as the original designs, whose focus was on: – location, – shape of the form of the building, – daylight amount and amount of insolation in individual rooms, – annual thermal balance including an itemization of individual months. According to the assumption, all external construction envelopes in a new and in the original design feature the same thermal insulating power. This enables a comparison of thermal balances devised for original and post-conversion designs. The differences in thermal balance result exclusively from different architecture of both forms of the building and not from any mechanical increase or decrease of thermal insulating power of external envelopes in the designed form of a building. As demonstrated through calculations and simulations, energy efficiency of such a building is significantly greater than that of the original building, while the participation of passive systems in the thermal balance is very substantial. Such systems enable significant savings in the consumption of conventional energy carriers. Both in the autumn and in the spring, those gains eliminate the use of conventional heating, which is clearly visible in the diagrams simulating heating in particular months. The conducted calculations of thermal balance for the original and redesigned buildings energy savings are up to 50%. It should be emphasized that the savings result from a change in space solutions and new function layouts, and not from increasing insulation power of external envelopes in newly designed buildings. Insulating power of the envelopes remains unchanged, in order to demonstrate to designers/architects how significant is the role that architectural solutions of a building play in energy efficiency (form, function, construction).

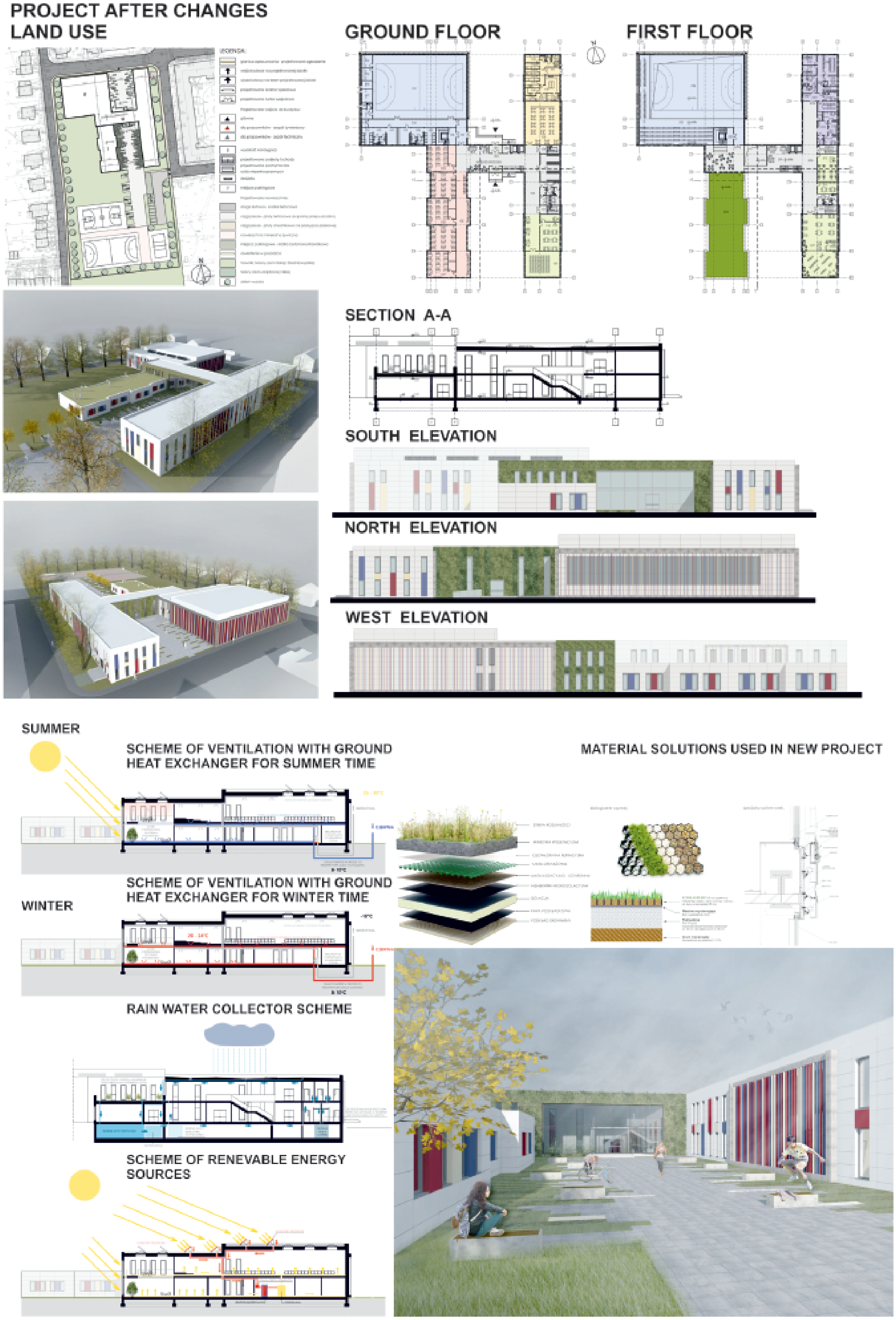

Figure 4.
Designs and scheme of work of a redesigned building of a Junior High School in Szczecin; author – student A. Pichulska, subject conducted by prof. M. Wołoszyn

3. CONCLUSIONS

The 21st century designs of public utility buildings should always be energy efficient and feature other pro-environmental solutions. Energy efficiency must not be an element supplemented in a technical design through an increase of thermal insulation layers and the application of glazed surfaces of higher thermal transmittance. Addition of liquid or photovoltaic collector to a building becomes a newsworthy event. The analyses conducted with the use of Ecotect and Vasari programs revealed energy efficiency related defects in the building designs. The analyses demonstrated that the form and internal space layout have a significant impact on the energy efficiency of a building. Buildings of the same functional program and similar cubature, but changed architecture are twice as energy efficient. It must be concluded that an energy efficient building using simple architectural passive application of solar energy must be developed from the start in keeping with such assumptions. Consequently, its energy efficiency is substantially higher than the one obtained through an increase in thermal insulation of external envelopes. Therefore, the role of an architect is a crucial one, since an architect ought to consider energy efficiency from preliminary design concept.

Energy efficiency further entails the right form and space layout of a building, and even function solutions, not merely insulation elements of external envelopes and some technical gadgets.

An ideal solution would involve the existence of advanced Building Information Menagements – type computer software that would provide remarks on an ongoing basis in the course of concept formulation, informing of the energy efficiency of a developed body of a building. Each change incorporated by a designer would be assessed and presented as a commentary on energy efficiency results. Such helpful operation of BIM programs would provide a significant assistance in making the right design decisions. It is sure that the use of such software is a question of not so distant future.

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