Classification of historical buildings based on energy efficiency tests and comfort tests

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Abstract. The article presents a proposal for the classification of historic buildings in terms of improving energy efficiency, ensuring the comfort of users and their impact on the environment. In the case of historic buildings, Polish law does not require energy efficiency improvement. The proposed classification also takes into account the function of the object and is largely based on "in situ" research. The presented model of classification will help users of historic buildings to undertake appropriate thermo-modernization measures to improve energy efficiency and comfort of use. In situ tests in historic buildings are of particular importance also for the correct diagnostics of this type of buildings.

1. Introduction
Buildings are responsible for around 1/3 of total energy consumption worldwide. For this reason, the construction sector contributes significantly to global CO2 emissions [1]. Buildings consume around 50% of energy for space heating and cooling, and for producing domestic hot water. Both in Poland and other countries, regulations are introduced to improve energy efficiency in sectors with the highest energy consumption rates. Construction is one of these sectors of the economy. In European countries, very restrictive thermal protection requirements for new buildings were introduced from January 2021. These regulations in Poland do not apply to historic buildings. The tightening of regulations is the result of the implementation of Directive 2010/31/EU on the energy performance of buildings [2]. Directive 2010/31/UE points out that the low primary energy demand should as far as possible come from renewable energy sources, produced on site or in the vicinity of the building. A building that meets these requirements is called a "nZEB building with almost zero energy demand". All Member States undertook to implement the nZEB standard for new buildings from December 31, 2020. With regard to historic buildings and under conservator's care, the requirements to improve energy efficiency have not been formulated in Polish regulations. However, the analysis of energy consumption levels according to the age of the building leads to the conclusion that the older the building, the more energy-consuming it is, while at the same time having greater potential for improving energy efficiency. This is evident, for example, in the case of buildings in European countries, built before the decade 1960-1970 [3]. Pre-1960 buildings often have no thermal insulation at all in their external partitions and consequently have very high U-values and very high energy consumption. This is a consequence of the very lenient energy efficiency legislation at the time. The total share of old buildings (pre-1960) in European countries varies depending on the region, ranging from 35% to 42% [3]. It is these old buildings that are the main reason that the construction sector consumes much more energy than other sectors of the economy. Among old
buildings, historic monumental buildings are a particularly important group, and for these there are no requirements to improve energy efficiency in Poland.

However, the amendment to the Directive on the energy performance of buildings of 2018 - Directive of the European Parliament and of the Council (EU) 2018/844 of May 30, 2018 for the first time introduced a provision on improving the energy efficiency of historic buildings, as well as testing such solutions and at the same time ensuring the protection and preservation of cultural heritage " [4] [5].

2. Protection of historic buildings in Europe and Poland

Historical buildings, defined as built before 1945, by definition are usually buildings with low energy efficiency (as e.g. for the Netherlands, van Krugten et al. [6] have shown and account for about 30-40% of the total resources of the construction sector in European countries. Budyinki historyczne zaliczane do zabytków mogą są chronione prawem przed zmianami związanymi z zachowaniem ich wyglądu wizualnego, ale także dotyczącymi materiałów i elementów które powinny stanowić integralną część dziedzictwa kulturowego. Według Fabbriego i Pretelliego [7], A historic object is one that, due to its historical value, is subject to legal protection. And so, for example, in Italy, buildings defined as historic, built before 1919 account for about 19%, and buildings built in the years 1919-1945 about 12% of all existing buildings [8].

The resources of historic buildings in Poland are shown in Figure 3. Data are available according to the most recent National Population and Housing Census of 2011 in Poland [9]. It shows that historic buildings (built before 1945) account for over 20% of the building stock in Poland.

The first Polish law protecting art and cultural monuments [10] was the decree on the protection of art and cultural monuments. The decree introduced a division into immovable and movable monuments as well as excavations and finds. Pursuant to the Decree, all immovable monuments are protected by law, regardless of the title of their ownership. Thanks to the legislative provisions, the order to inventory monuments located within the borders of the Polish State was introduced. The immovable monuments include, among others, both brick and wooden buildings with their surroundings. In Polish law, the provisions of art. 5 of the Construction Law Act [11] states that objects subject to protection under the provisions on the protection and care of monuments are exempt from the obligation to determine energy performance for buildings;
However, due to the provisions of Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018, monuments should be given the greatest respect as objects of national interest and, if possible, improve their energy characteristics and comfort of use. Often, when changing the function of historic buildings in relation to their original function, it is worth carrying out possible thermal modernization works in addition to other technical and construction works. Examples of assigning new functions to historic buildings are given in publications [12][13]. Changing the function of buildings and adapting to new needs usually involves reconstruction, thermal modernization and improvement of energy efficiency, if possible. However, the design and implementation decisions made, not supported by any requirements, research or analyzes, are often incorrect and lead to deterioration of the monument instead of improving its condition. It seems indispensable to create a methodology for selecting conservation works that would involve much more than a simple vision of the facility.

3. Possibilities of improving the energy efficiency of historic buildings depending on the performed or planned function.

There are several methods to improve the energy performance of historical buildings. Each of them must be considered individually, depending on the technical, financial and social capabilities of the building, and finally the most important - conservation consents. The most important activities are the improvement of the thermal insulation of the building envelope. However, this is not traditionally possible from the outside. Improving the insulation of partitions from the inside, if not skilfully done, leads to thermal and humidity problems and deterioration of the technical condition of the building, as shown in diagram 1. A wooden wall insulated from the inside causes thermal and humidity problems, as shown in Figure 2a. With thermal insulation from the outside, such problems do not occur, as shown in Figure 2b.

Figure 2. a) Warming from the inside (thermal and humidity problems). b) Warming from the outside (no thermal and humidity problems).

Another problem is the provision of highly efficient heating / cooling and ventilation systems. Historic buildings are equipped with outdated heat sources and gravity ventilation. Often, without major renovation work, it is impossible to change HVAC systems [14][15]. The lack of reliable knowledge about the possibilities of improving the technical condition and energy efficiency usually leads to the deterioration of the technical condition of a historic building. Therefore, it is necessary, before making a decision on thermal modernization measures in historic buildings, to perform appropriate "in situ" tests to check the actual technical condition of the building. Standard actions of designers and contractors carrying out thermo-modernization works based solely on a local vision will not allow to assess the actual condition of the monument and may lead to technical problems and deterioration of the microclimate. In the methods of assessing the condition of a historic object, it is worth including "in
"situ" examinations of both the technical condition (thermovision, air-tightness test) and microclimate tests (thermal, vibro-acoustic and lighting comfort). In the works [16][17][13] Case studies of research conducted on historic buildings are described in detail.

Monuments are our national property, it is important to keep them in good technical condition. Those that are not used or not improved, their technical condition deteriorate and fall into disrepair. In historic buildings, especially those not in use, it is worth considering the selection of functions and transforming decaying disused monuments into used objects, while maintaining many aspects of respecting both the old and the present generation.

Correctly performed work with the preceding energy efficiency analyzes, in the case of adapting a historic building to its new function, has a positive effect on its technical condition. Historical buildings in use also require thermal modernization measures in order to reduce operating costs and improve the comfort of users. Depending on the planned new function or the restoration of an unused facility, it is necessary to consider the scope of conservation works.

3.1. An original proposal for assessing the condition of a monument and the possibility of improving its energy efficiency, comfort of use and environmental impact, prepared in the publication [12].

Istnieje wiele systemów certyfikacji budynków. Są to wielokryterialne systemy oceny prowadzące budowę budynków od procesów decyzyjnych w projektowaniu, przez cały proces budowy i późniejsze użytkowanie. Przeznaczone są głównie do nowych, energooszczędnych budynków [18][19]. An interesting proposal is the first Polish certificate of energy-efficient buildings developed by experts from the Krakow University of Technology [20].

Due to many limitations, it is not a simple matter to establish criteria that can be the basis for the certification of historic buildings in terms of energy efficiency. In this article [21] The authors presented an innovative proposal of a hybrid decision model for selecting the utility function for a historic building, taking into account the criteria of energy efficiency, room use comfort and the building's impact on the environment. In this article [22] the authors conducted an analysis of the choice of the building function under conservator's protection on the example of the Willa "Stara Polana" facility in Zakopane, taking into account the improvement of the building's efficiency and the improvement of the comfort of use. As the Technical Conditions do not provide requirements for historic buildings, the adopted criteria are the criteria developed by the authors. This article will present an amendment to the multi-criteria method of assessing historic objects, after analyzing specific cases and attempting to classify them in accordance with the method indicated in the article [12]. The figure 3 shows all the criteria developed in the previous article. In this article, only the criteria of energy efficiency, quality of workmanship, which has a direct impact on heat losses, room comfort excluding vibration and acoustic comfort, environmental impact, taking into account the financial, social and cultural heritage context, will be analyzed.
3.2. An amendment to the energy assessment system based on research and analyzes carried out on historic buildings.

The criteria marked in green were changed to amend the previously developed methodology. The changes result from the in-depth knowledge of the authors about the possibilities of improving the energy efficiency of buildings after examining specific examples of historic buildings [17][23][24]. In the criterion “energy efficiency”, the sub-criterion “thermal insulation of the casing” has been removed. The authors’ experience shows that it is not always possible to improve the thermal insulation of walls, windows, roofs and floors. Therefore, it seems pointless to disqualify buildings in which the conservator does not allow the improvement of the insulation of external partitions or there is a conservation consent for the use of specific solutions that do not significantly improve thermal insulation. The sub-criterion “useful energy index” has been left in this criterion due to the fact that it is the main measure of the energy demand of a building. Often, when it is not possible to insulate the walls, other activities can be performed to improve the final demand for usable energy, for example, insulating the floor on the ground or placing thermal insulation material in an unused attic. Such an example of improving thermal insulation was analyzed in a historic sacred building located in southern Poland. If there is no possibility of thermal insulation of the external walls, a variant of laying the thermal insulation material above the wooden ceiling under the unused attic was proposed. An additional change is the introduction of an “in situ” study of the real heat transfer coefficient U in order to obtain the actual value for further analysis, this study was described and tested in the article [25]. It is also recommended to test ‘in situ’ the actual interior climate in cases where the hygrothermal analysis will be performed. This study was tested in the article [26]. After substituting the actual measurements of the indoor climate, completely different results of the hygrothermal diagnostics were obtained.

The criterion of “workmanship” was left on the assumption that in most cases of historic buildings it is possible to seal places with various materials, eg PIR / pur foam, airgel, etc., reducing heat loss. Historic buildings are usually characterized by a large leakage of the housing, which significantly affects energy losses. An example of a leak test is described in the article [13]. It is important that the sealing material harmonizes with the historic tissue. Thus, the criterion of “quality of workmanship” is based on the “in situ” test of the air tightness of the housing. It can be mad“ with the ”Blower door” system, as described in the case of the “Stara Polana” building in the article [13].
The criterion of comfort of use includes thermal and lighting comfort. The comfort of vibration and acoustics is being analyzed by other teams of scientists. The thermal comfort can be improved by often minor non-invasive treatments, such as the introduction of sun screens or curtains. The lighting comfort can be improved by introducing modern light sources such as LED bulbs, which additionally contribute to saving electricity. Determination of these parameters should be based on “in situ” tests. Additionally, “in situ” tests of comfort constitute a proprietary approach consisting in introducing the results of actual “in situ” tests of the microclimate in historic buildings to thermal and humidity diagnostics.

In the criterion “impact on the environment”, the parameter “carbon footprint” has been replaced by the index of non-renewable primary energy EP [kWh / m2year]. This parameter is very important due to the energy efficiency requirements in force in Poland and other European countries. It is directly related to the impact of the building on the environment through sources of heat and electricity. In the case of the aforementioned sacred building, in order to replace the outdated, ineffective heating from a gas boiler room, which strongly affects the EP index, a conservation consent was obtained for the use of effective underfloor heating based on an air-to-water heat pump.

In addition, in the event of a change in the function of the building, financial, social and historical aspects should also be taken into account. In the article [], the authors proposed a survey system taking into account these criteria. An example may be the fact what are the social expectations when it comes to the new function of the facility or the financial capacity of, for example, local government authorities. These parameters should be determined on the basis of questionnaire surveys. The F5 and F6 criteria will be analyzed in other articles by the authors who are the originators of these criteria.

The figure 4 shows the revised, proposed energy assessment system for historic buildings, taking into account the comfort conditions and the building's impact on the environment. The chart also shows how to measure the following criteria. The criteria F1 and F4 are based on the result of the calculation of the building's energy performance. The F2, F3 criteria are based on "in situ" tests before and after thermomodernization measures, the F5 and F6 criteria are based on the questionnaire method. Figure 4 shown an improved version of the criteria for assessing historic buildings

![Figure 4. An improved version of the criteria for assessing historic buildings](image-url)
3.3 Classes of new criteria

Classes for improving the energy efficiency of historic buildings have been set at three levels below 10%; from 10% to 20% and above 20%. This principle was adopted in the criteria F1 / P1, F2 / P1, F3 / P1, F3 / P2 and F4 / P1. Depending on the proposed function of the historic building, the level of improvement of these criteria will be selected individually. If a historic building has a future function, for example, a residential building, such as a hotel, the levels of improvement in energy efficiency and comfort must be at the highest level, if the new function of the building is, for example, a gallery or a facility not permanently inhabited by people, these criteria may be at a lower level. An example of the selection of improvement classes for the discussed criteria has been discussed in the article [12]. In the new approach, the level of improvement in energy efficiency and comfort will be considered individually on a case-by-case basis and will be based on an analysis of technical and financial possibilities. In the article presenting the earlier version of the methodology, specific values were taken as the reference level. It was a wrong approach because each historic object should be considered individually and only on a percentage scale it is possible to determine the real and necessary values.

4. Conclusions

Amendment of the Directive on the energy performance of buildings of 2018 - Directive of the European Parliament and of the Council (EU) 2018/844 of May 30, 2018 amending Directive 2010/31 / EU on the energy performance of buildings and Directive 2012/27 / EU on energy efficiency for the first time introduced a provision on the legitimacy of improving the energy efficiency of historic buildings, which reads: "Scientific research on new solutions to improve the energy performance of buildings and historic buildings should be supported, as well as testing such solutions, and at the same time ensuring the protection and preservation of cultural heritage." The authors proposed to update the previously developed system for assessing the energy efficiency of historic buildings, in particular buildings in which the selection and change of use functions is to take place. The amendment to the system is based on the results of specific research and analyzes contained in the articles cited in the text. The amendment captures the experience from research carried out on real historic buildings and adjusts the assessment to the possibilities of improving the energy efficiency of historic buildings and buildings undergoing thermal modernization. In the course of further research, the authors will collect a database of historic buildings subjected to an innovative evaluation system.

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