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Adaptation of Reinforced-Concrete, Postindustrial Buildings in Terms of Thermal Retrofitting on the Example of a Historical Water Tower

Adaptacja żelbetowych obiektów postindustrialnych w zakresie termomodernizacji na przykładzie zabytkowej wieży ciśnień

Keywords: historical construction, reinforced concrete, diagnostics, thermal retrofitting, adaptive reuse

Słowa kluczowe: budownictwo historyczne, żelbet, diagnostyka, termomodernizacja, adaptacja

Introduction

Historical postindustrial buildings such as former production plants, warehouses, silos, gasometers, or water towers are an important element of the cultural landscape of Polish cities and towns. They remind us of important historical events and processes, such as the development of industry in the second half of the nineteenth century and the first half of the twentieth century. This industry, regardless of its branch, in turn contributed to the development of the country and the enrichment of its inhabitants, providing jobs for the population and improving living standards.

Many historical factory complexes or their elements from this period, namely the second half of the nineteenth century and the first half of the twentieth century, have survived into the present. Most of them have significant cultural values, which means that selected complexes (or structures) are protected either

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Fig. 1. View of the Petersheim Factory Complex in Cracow – a historical factory complex from the turn of the nineteenth and twentieth centuries, after adaptation and revalorization, 2021; photo by D. Kuśnierz-Krupa
Ryc. 1. Widok zespołu fabrycznego Petersheim w Krakowie – historycznego zespołu fabrycznego z przełomu XIX i XX w., po adaptacji i rewaloryzacji, 2021; fot. D. Kuśnierz-Krupa

by being listed in the historical monuments register of a given voivodeship or by appropriate provisions in a local spatial development plan. Many of them are also included in the voivodeship monument registers and municipal monument records (Fig. 1).

It should also be noted that many of these valuable monuments have fallen into disuse, which in turn necessitates a search for a way to adapt them to new, contemporary functions. In principle, this is the only solution for a historical but now disused postindustrial complex to have a chance of surviving [Kobylarczyk et al. 2020, pp. 97–103; Kuśnierz-Krupa 2014, pp. 123–131; Kulikov et al. 2019, pp. 140–146].

The adaptive reuse of historical buildings requires adapting them to modern technical and construction regulations. Industrial buildings erected at the turn of the twentieth century were not designed in accordance with modern utility and technical standards, including thermal and humidity requirements. Today, they must meet applicable regulations and standards with regard to, among other things, heating and ventilation, which is not always feasible due to obvious boundary conditions. Therefore, the extent of interventions in the area of building physics can have a significant impact on the use of a building, the preservation of its durability, and retaining the authenticity of its historical substance.

This paper presents the problem of the thermal retrofitting of postindustrial buildings on the example of the adaptation of a historical building – a former water tower in the fortress complex in Nysa, Poland – which included its thermal retrofitting. The building, a pioneering project in this part of Europe, innovatively combined new materials, technologies, and structural solutions. The adaptation of the concrete tower, including a scope of work that had not previously been carried out to such an extensive extent in this type of building, and the subsequent ex-post evaluation, provided a range of new information. In particular, the new findings related to the building's thermal retrofitting proved valuable.

Fig. 2. Water tower in Nysa; source: postcard, 1940s
Ryc. 2. Wieża ciśnień w Nysie; źródło: pocztówka, lata 40. XX w.

It must be added here that water towers, as tall structures equipped with a water tank, served primarily to ensure stable pressure in the water supply system and to cover water shortages. These structures are still an important element, and sometimes even a dominant feature in the landscape. It is worth noting that they often have original forms and rich architectural details, and deserve to be protected [Podwojewska 2009, pp. 85–94; Supernak, Ziółko 1998; Supernak, Ziółko 2002; Jarzynka 1989].

State of research

To explore the revalorization, adaptative reuse and adjustment of postindustrial sites and historical complexes to current regulations, a review of research arrangements in this area was carried out. Research on historical buildings located in Poland was reviewed. The focus was on issues related to the renovation of old factories and technical facilities, such as water towers.

Postindustrial monument revalorization and adaptive reuse were investigated by, among others, B. Szmygin, who analyzed the methodology of world heritage in adaptive reuse [Szmygin, 2009, pp. 129–136]; M. Żychowska discussed the revitalization of postin-

Fig. 3. Water tower in Nysa, pre-adaptation, a) entrance area, b) damaged concrete balustrade, 2007; photos by P. Opałka
Ryc. 3. Wieża ciśnień w Nysie, stan przed adaptacją, a) strefa wejściowa, b) uszkodzona betonowa balustrada, 2007; fot. P. Opałka

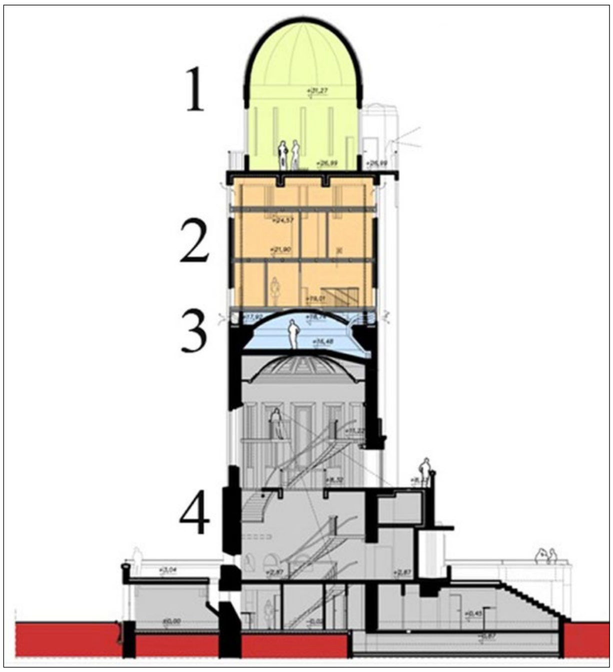

Fig. 4. Vertical cross section, 1) view terrace, 2) rooms for rent, 3) technical space, 4) catering and exhibition area; design: P. Opałka, 2008
Ryc. 4. Przekrój pionowy, 1) taras widokowy, 2) pomieszczenia do wynajęcia, 3) przestrzeń techniczna, 4) część gastronomiczno-wystawiennicza; proj. P. Opałka, 2008

dustrial sites and spaces as a vehicle for the identity of metropolitan areas [Żychowska, 2007]; E. Wojtoń wrote on the heritage of industrial buildings and spaces as a vehicle of the identity of metropolitan areas [Wojtoń, 2007]. Wojtoń discussed the industrial heritage of Sosonowiec [Wojtoń, 2010]; Ł. Kadela explored the directions of revitalization of nineteenth-century postindustrial historical buildings from the Łódź area [Kadela, 2014, pp. 54–65]; W. Szygendowski and B.M. Walczak also investigated the adaptation of postindustrial monuments in Łódź [Szygendowski, Walczak 2009, pp. 137–157]; E. Kowalówka wrote about the adaptation of historical buildings of the former coal mine "Katowice" [Kowalówka, 2020]; A. Mastelarz presented the results of his research and the transformation of industrial facilities in the context of the revitalization and protection of cultural heritage [Mastelarz, 2017, pp. 27–45]; and J. Kobylarczyk and D. Kuśnierz-Krupa et al. investigated adaptations of historical postindustrial buildings from the late nineteenth and early twentieth centuries [Kobylarczyk, Kuśnierz-Krupa et al., 2020].

Historical background of the building

The tower was erected in 1907 in the vicinity of Fort Prussia in honor of Otto von Bismarck, as one of

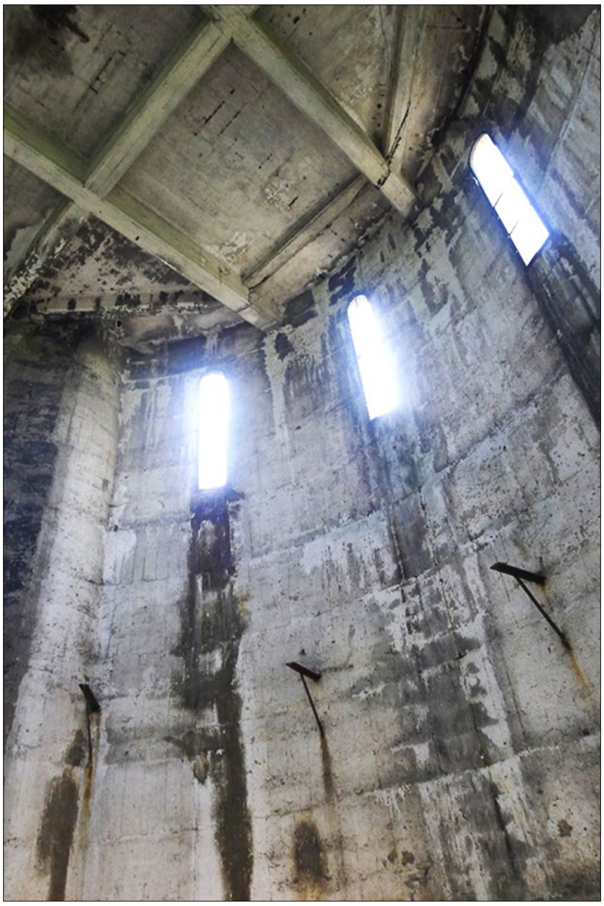

Fig. 5. Interior of the water tower before renovation, 2007; photo by P. Opałka
Ryc. 5. Wnętrze wieży ciśnień przed remontem, 2007; fot. P. Opałka

Fig. 6. The former "Hall of the Fallen" with its original architectural detail and color scheme restored, 2012; photo by I. Solisz
Ryc. 6. Dawna Sala Poległych z przywróconym oryginalnym detalem architektonicznym i kolorystyką, 2012; fot. I. Solisz

many grand monuments erected in Germany between 1869 and 1934 to celebrate the Chancellor (German: Bismarckturm) and at the same time foster a sense of national pride (Fig. 2). Therefore, the tower initially had formal functions (design of the surroundings and massing, facade decoration) and viewing functions (terrace on top), but it was later adapted for use as a water tower by building a reinforced concrete tank in 1924 in the upper part of the building and a pumping station in the basement rooms of the second section. A year later, plaques with the names of almost 800 Nysa citizens killed in the First World War were placed in the hall for patriotic ceremonies, thus establishing the Hall of the Fallen (Kriegergedächtnishalle).

The water tower is one of the first buildings built using monolithic reinforced concrete technology in Lower Silesia and, at the same time, one of the better preserved in Europe. After the Second World War, the building was used by the Nysa military garrison, but it no longer served as a water tower. After the army left the city in 1989, the disused structure rapidly deteriorated (Fig. 3a, b). Fortunately, the tower was entered into the Opole Voivodeship register of monuments. The building was adapted to its new function in 2012, for tourist and cultural purposes (Fig. 4) [Opałka 2008].

The entire facility was adapted to the needs of people with impaired mobility. On the first floor, there is a complex of rooms for rent, with extensive sanitary facilities. On levels I–IV, a catering facility and a tourist information center were designed. Level V was intended to house technical uses, and levels VI and VII, like the first floor, contained rooms that could be rented out. A climbing wall was built at the north facade.

Numerous exemptions from the regulation concerning the technical conditions to be met by buildings and their placement had to be obtained in order to maintain hygiene and sanitary safety, as well as fire safety. A staircase that did not meet current requirements required the use of non-standard fire protection systems. The installation of all the utilities required custom solutions. Due to the geometry of the shaft (height h= 30.5 m, irregular diameter Ø 220 ± 10 cm, and shaft inclination of approximately 1.5°, it was not possible to use a hydraulic drive and install a shaft top and bottom), a special cylindrical lift with a "backpack" design and electric drive controlled by an inverter was designed, as well as a custom opening system for the semicircular shaft and cabin doors.

To make use of the building comfortable year-round, electric heating and mechanical ventilation

Fig. 7. Insulation on the interior of the exterior walls and the terrace above the basement, 2012; photo by P. Opałka
Ryc. 7. Ocieplenie po wewnętrznej stronie ścian zewnętrznych i tarasu nad piwnicą, 2012; fot. P. Opałka

Fig. 8. Part of the ground floor after thermal retrofitting and interior finishing, 2013; photo by P. Opałka
Ryc. 8. Część parteru po termomodernizacji i wykończeniu wnętrz, 2013; fot. P. Opałka

with heat recovery were designed. In the rooms that are the most exposed to the cold and that could not have insulation applied to them from the outside (e.g., the space under the entrance stairs), building partitions were insulated from the inside. Due to its historical nature, the building did not fully meet applicable energy efficiency requirements [Regulation of the Minister of Infrastructure of April 12, 2002].

Structural condition assessment

The tower is a monolithic concrete structure on a dodecagonal plan with eight columns around the perimeter, with a height of approximately 33 m. Adjoining the main section at the front are two circular circulation shafts. One of these contains an historical staircase and the other (formerly a technical staircase) was fitted with an elevator during the 2012 renovation of the building.

The foundations were identified on the basis of local excavations. They were found to be concrete. The subsoil was found to carry the loads from the building. Subsoil testing did not show evidence of groundwater. Sclerometric tests were carried out to assess the strength of the concrete. The compressive strength of concrete was found to be similar in all structural elements (walls, stairs, ceilings) and was around 30 MPa. The lower terrace walls had lower strength. As recommended, the locally weathered material was removed and replaced with PCC mortars for concrete restoration.

The external walls of the tower (Fig. 5) have a cross-section that varies along the height of the structure. The highest wall thickness was recorded on the lowest floor at about 1.4 m and the smallest at about 0.2 m at the support of the reinforced concrete tank, where it provides support for a slab that is the observation deck, and the reinforced concrete dome. The walls were made of monolithic concrete reinforced only locally within the window openings. The condition of the wall structure was described as very good. Repairs consisting of filling local cavities were carried out during the renovation.

The floor of the lower terrace, made of reinforced concrete, as well as the slab and rib system required repairs consisting of filling lagging and cavities and removing corrosion on exposed rebar, together with the application of corrosion proofing agents. It was recommended to replace the finish layers of the terrace and apply effective waterproofing. The condition of the next floor (at level +7.87 m), with the same structural layout as the previous one, was described as sufficient. Repairs were required similar to those on the lower floor. The next ceiling, in the form of a vaulted ribbed reinforced concrete dome, did not show structural defects. Only minor repairs to the concrete structure were carried out. The vault, which served as the bottom of the water tank, was shaped as an arch. It was recommended to demolish it or leave it as self-supporting, following the recommended repairs to the cavities. The ceiling, which forms the structure of the observation deck, is directly connected to the main structure of the tower walls. It consists of two intersecting pairs of reinforced concrete ribs bonded by a reinforced concrete slab. The ribs are supported directly on the tower walls and carry their own weight and the loads from the walls that form the top of the tower, including the roof dome. Additional ribs tangential to the circle of the tower wall appear in the support line. The ceiling was exposed to an aggressive environment as it was located above an open water tank. The increase in humidity caused accelerated corrosion of the alloy structure. Repair was required. The structure was cleaned and the areas where concrete was missing were filled with suitable PCC-type mortars for the renovation and repair of concrete structures. The tower is topped by a reinforced concrete roof dome. No cracks or damage indicative of its poor technical condition were found. Only minor cavity repairs and restoration of the roofing were performed.

Fig. 9. View of the front facade of the water tower after renovation, 2013; photo by P. Opałka
Ryc. 9. Widok elewacji frontowej wieży ciśnień po remoncie, 2013; fot. P. Opałka

Fig. 10. View of the water tower from an unmanned aerial vehicle, 2019; photo by Ł. Bednarz
Ryc. 10. Widok na wieżę ciśnień z drona, 2019; fot. Ł. Bednarz

Essentially, interference with the structure of the building during the refurbishment works was limited to the demolition of the secondary built-in water tank and the connection of the lower floors inside the main body of the tower cylinder by making two openings in the ceilings for stairs and the introduction of two mezzanine floors. The demolition of the reinforced concrete water tank (with a diameter of approximately 7.3 m and a height of approximately 8.3 m) allowed the introduction of an additional story. The first floor's level was lowered by 0.5 m. In the former "Hall of the Fallen," equipped with the richest visual decoration, the original color scheme and architectural details were restored on the basis of stratigraphic surveys (Fig. 6).

Local graffiti stains were removed by laser ablation. The cleaning was preceded by a substrate survey during which the parameters of the laser beam (pulse duration, peak power density, and pulse frequency) were selected. In a multistage manner, layers were removed from the surface so as not to damage the substrate.

Proposal for adaptation and thermal retrofitting

In the context of conservation considerations, the identification and assessment of the existing technical condition of the building proved to be a key issue, which determined potential interventions in the building. The scope of the predesign work included, among other things, a detailed building survey, geological and technical condition surveys, and historical and conservation investigation. Interventions in the structure of the building were limited to the demolition of the second-built water tank and the connection of the lower floors inside the main body of the tower cylinder through the construction of two ceiling penetrations and the introduction of two mezzanine floors.

One of the most important problems in the building's adaptive reuse project was its thermal retrofitting (Fig. 7), as it carried certain limitations.

First, all interventions had to be reversible, including not only those resulting from the execution of the thermal insulation itself, but also the effects of potential damage during use under new hygrothermal conditions. Secondly, preserving the authenticity of the historical substance ruled out the installation of insulation on the outside of the building. The lower part of the tower features reinforced concrete masks, emblems, laurel wreaths, and the town's coat of arms, so any attempt to insulate the building from the outside would have changed the perception of the architectural detail.

Additionally, insulating the core of the tower would not only distort the form of the building, but would also change the texture of the facade and, consequently, the authenticity of the entire building. Third, the thermal insulation of the base of the tower, with its extensive terraces on three levels and the stairs connecting them, required bespoke solutions.

Taking into account the boundary conditions into account, the exterior walls, dome, and external stairs were finally insulated inside with an active system of mineral climate panels, while the ceilings of the terraces on the ground floor were insulated on the outside with extruded polystyrene. Insulation was eliminated in the representative room, where the original colors and architectural details were restored on the basis of stratigraphic research. The effect of the restoration work can be seen in Figures 8–10.

The execution of the insulation inside required ensuring standard air and temperature exchange rates and maintaining a low diffusion resistance to infiltration of the internal finishing material. The design featured the installation of mechanical ventilation with heat recovery in the building.

The thickness of the insulation layers adopted in most cases was determined by limitations on the height of the rooms and the width of the escape routes. Due to the building's entry in the provincial register of monuments, it was possible to dispense with thermal retrofitting, but the use of electric heating as the least invasive solution required the search for solutions allowing for the most economically rational operation of the building.

However, to meet modern guidelines, especially with regard to thermal insulation of walls in historical buildings, one of the best technical solutions appears to be the use of internal insulation systems using capillary-active mineral plaster, board, or block systems. These systems achieve high thermal insulation parameters due to their highly porous structure and very low density ($\rho < 115$ kg/m^3). A thermal conductivity coefficient of $\lambda \leq 0.0043$–0.045 W/m·K and a water vapor diffusion resistance coefficient $\mu \approx 5$ are very low.

The use of thermal insulation on the inner sides of building partitions, especially in historical buildings, is an innovative solution. Only a properly conducted analysis of thermal characteristics, moisture content and the layout of the insulation on the partitions guarantees the correct operation of the partition. The problem is clearly presented here because it concerns the adaptation of a postindustrial building to modern requirements and operating conditions through, among other measures, non-standard thermal retrofitting.

A detailed analysis of the problem of internal insulation is presented, for example, in the publication *Monitoring of thermal and moisture processes in various types of historical external walls* [Bajno et al. 2020, pp. 1–16]. The wall of the historical building was insulated from the inside with a 10 cm thick capillary active mineral layer. Moisture conditions were monitored using 2 FP type probes of the FOM2 system, which were placed in the mortar layer between the original wall and the internal insulation layer. The FOM2 system is a time-domain reflectometry and electrical conductivity system consisting of an FOM2/mts measuring device and FP/mts probes. Measurement results can be transmitted to mobile devices using a Bluetooth connection. It is also possible to use the probes of an IoT (Internet of Things) system. This technology is capable of providing continuous, wireless monitoring of a structure's state, including, for example, temperature, humidity, displacement, deviation, vibration, and other parameters necessary for structural diagnostics.

Hygrothermal parameter monitoring was done by analyzing the data from humidity and temperature measurements and material parameters using WUFI 2D v.3.4 software [WUFI 2D v.3.4 2014].

WUFI is not designed to estimate the drying time of lightweight partitions from initial to operational moisture, as popularly believed. It simulates the behavior of partitions under varying indoor and outdoor climate conditions and is not designed to calculate the drying time of partitions.

Analyzing the state and distribution of temperature isotherms and adiabatic heat fluxes for a corner of a wall that is insufficiently insulated, with the insulation applied from the inside with a 10 cm thick capillary-active mineral layer, a significant decrease in the cooling of the corner was found. A significant decrease in the moisture content of the insulated wall was also recorded. The results obtained, in addition to confirming the suitability of the internal insulation performed with mineral systems, point to a very important problem. When insulating walls from the inside, it is important to remember to adequately protect the surfaces of the external wall. As demonstrated by Finken [2016, pp. 202–214], it is clear that additional insulation of historical walls from the inside cannot be carried out on exposed walls without additional protection of their external surfaces against precipitation. Otherwise, despite the internal insulation, mold can develop on the surfaces behind the internal insulation. The measurements and observations made by the authors confirmed this.

The internal insulation of a building's envelope requires detailed hygrothermal analyses to be carried out on a case-by-case basis, as this method should not be considered universal. Incorrect application may lead to faster technical wear of the envelope or even to its complete deterioration. This is exactly what was observed in this building. After the water tower was put into use, one of the building's tenants repainted the four-story restaurant space at their own discretion in 2014. The coating used did not have low diffusion resistance, leading to a accumulation and condensation process beginning inside the partition, leading to the formation and growth of mold.

Conclusions

In view of the boundary conditions resulting from statutory conservation, it should be noted that the scope of works should be limited to those that do not compromise the authenticity of historical tissue. This, in turn, is related to the scope and type of planned interventions, including thermal retrofitting. The limited scope of interventions requires modeling via hygrothermal calculations for the entire building, not just selected parts of a building's envelope. The experience of adapting the Nysa water tower shows that the facility must be operated and monitored permanently.

The thermal retrofitting of buildings from the inside has not been fully explored. There are no technical guidelines supported by standards or technical instructions on how to do this correctly. It is still in the research phase, and can be considered in a pioneering stage. It should be clarified that a proper assessment of the technical condition had been carried out, and allowed the application of thermal insulation from the inside.

In conclusion, it should be stated that the adaptation of a historical building, including postindustrial complexes and facilities, is currently a frequently faced and at the same time a major challenge for designers, both architects and structural engineers, in cooperation with conservators. They face the daunting task of adapting buildings and bringing them up to modern standards without compromising their historical value. The example presented shows that it is possible, and at the same time sometimes unavoidable, for disused historical postindustrial buildings to survive by being adapted to a new use, so that they may continue to be a part of the cultural landscape of cities in Lower and Upper Silesia, Pomerania, Lesser Poland and other regions of the country, as has been the case for over a century [Barełkowski 2021, pp. 283–332; Brzeziński 2013, pp. 81–94; Gryglewska 1992, pp. 48–58].

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Abstract

Today, the only way to save an unused historical building is to subject it to adaptive reuse. This adaptation, on the one hand, allows the historical structure to "live" and on the other it often makes it possible to raise funds for its maintenance.

In the case of postindustrial historical buildings subjected to adaptive reuse, one of the important design issues is their thermal retrofitting. Industrial buildings erected at the turn of the nineteenth and the twentieth centuries were not designed in accordance with contemporary functional and technical requirements, including those concerning thermal and humidity requirements. The extent of the interventions carried out in the area of building physics can have a significant impact on the use of the building, on maintaining its durability, and on preserving the authenticity of the historical substance. The paper presents the problem of thermal retrofitting in postindustrial facilities using the example of the adaptation of a historical concrete water tower. Additionally, on the basis of adaptation experience and ex-post evaluation, the risks associated with the adaptation of this type of structure are highlighted.

Streszczenie

Współcześnie jedynym sposobem na uratowanie nieużytkowanego obiektu zabytkowego jest poddanie go adaptacyjnemu ponownemu wykorzystaniu. Adaptacja ta z jednej strony pozwala „żyć" zabytkowej budowli, z drugiej często umożliwia pozyskanie środków na jej utrzymanie. W przypadku poprzemysłowych obiektów zabytkowych poddawanych adaptacyjnemu ponownemu wykorzystaniu jednym z ważniejszych zagadnień projektowych jest ich termomodernizacja. Obiekty przemysłowe wznoszone na przełomie XIX i XX wieku nie były projektowane zgodnie ze współczesnymi wymogami użytkowymi i technicznymi, w tym z wymaganiami cieplno-wilgotnościowymi. Zakres prowadzonych ingerencji w obszarze fizyki budowli może mieć istotny wpływ na użytkowanie obiektu, zachowanie jego trwałości i autentyczności substancji zabytkowej. W artykule przedstawiono problematykę termomodernizacji w obiektach postindustrialnych na przykładzie adaptacji zabytkowej żelbetowej wieży ciśnień. Ponadto na podstawie doświadczeń związanych adaptacją oraz ewaluacją *ex post*, wskazano na zagrożenia związane z adaptacją tego typu obiektu.