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THE IMPACT OF CONSTRUCTION MODIFICATIONS TO A 1930S APARTMENT ON THE LIFE CYCLE

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Abstract

This study examines the life cycle and energy performance of a 1930s apartment building in Brno, Czech Republic, utilizing detailed historical and technical documentation. The analysis focuses on the effects of building modifications and heating system updates on energy consumption and structural wear over time. The findings indicate that high-quality construction materials and thoughtful modernization, including insulation and heating system upgrades, significantly enhance energy efficiency and extend the building's service life. Gas consumption for heating decreased by 62% over three decades, underscoring the importance of strategic retrofitting in older buildings. The study further highlights the role of predictive maintenance and Building Information Modeling (BIM) in optimizing long-term asset management. These insights contribute to sustainable building practices and the reduction of environmental impacts.

Keywords:

Building life cycle;
Energy performance;
Predictive maintenance;
Price influences;
BIM.

1 Introduction

When dealing with the value and function of buildings, the commonly used term Building Life Cycle (BLC) cannot be ignored. In general terms, BLC can be defined as the various stages that a building goes through, from its inception, through its use, repair and retrofit cycles, to its disposal and the now required recycling of the building as a whole and its parts. Lifetime can also be extended by an appropriately chosen maintenance strategy, preferably predictive maintenance that responds promptly to the current observed structural condition of the structures.

1.1 Functionalist apartment buildings

Although the basic principles of functionalism were given, each of the architects conceived of them slightly differently, and so there was no uniformity in the functionalist apartment buildings. Some buildings were characterised by nautical symbolism, reminiscent of the architecture of ocean liners. Typical motifs are circular windows, ramped staircases, tubular railings or balconies reminiscent of a captain's bridge. The architects' aim was therefore to create the perfect living space. This entire phase lasted approximately 10 years, from 1931 to 1941, when it was cancelled by the building closure due to the wartime events of World War II. New materials and technologies began to be used for construction. Architects began to place emphasis on residential culture, by which was meant the illumination of living rooms and the introduction of bathrooms and toilets in all apartments.

The installation of lifts has contributed to the increased comfort of living, which has also changed the hierarchy of use of the apartments. Previously, the owner or builder had an apartment on the first floor, with the introduction of the elevator, he moved to the top floor, where there was more peace and the possibility of a terrace. Machine laundries were set up in the apartment buildings, most often making use of spaces previously used for fuel storage. Nevertheless, some houses still used local heating in individual living rooms. In these houses it was necessary to maintain large cellars for fuel storage. The central heating was heated by district heating, while electricity powered the technology and provided lighting. These houses, which were mostly built in Prague, were called Electric Houses. They were a glamorous type of housing - for middle- and upper-class city dwellers.

The most common source of hot water for radiators was coke-fired boilers, which were a further product of the production of lamp gas. Coke boilers were almost smokeless and thus met the requirements for heating in cities. An alternative source of heat was heating plants, which were often combined with thermal power stations. The hot water from the boilers was piped to the radiators. This greatly increased the thermal comfort in residential buildings. While coke-fired boilers had a design life of 25 years, the life of cast iron radiators and connecting pipes is much longer. Therefore, after the coke boilers had reached the end of their service life, boilers using other types of fuel were connected to the heating system. The introduction of gas-fired boilers, which have low maintenance requirements, are easy to regulate and, with good adjustment and balancing of the heating system, are economical, has so far proved to be very advantageous.

1.2 Research gap and questions

The life cycle assessment of residential buildings has been a widely studied topic, particularly in the context of energy efficiency, maintenance strategies, and modernization techniques. However, several gaps remain in the existing body of research [1]:

1) Long-term Impact of Building Modernization; While studies have examined energy-efficient retrofitting in residential buildings, fewer have analyzed the long-term effects of modernization efforts over several decades, this paper fills that gap by evaluating nearly 90 years of operational data from a selected apartment building.

2) Comparative Analysis of Heating System Evolution; Previous research has examined energy consumption trends in residential buildings, but detailed historical records of heating system upgrades and their energy-saving effects are scarce. This paper systematically documents heating system transformations from coke-fired boilers to modern gas heating, offering a unique longitudinal perspective on energy efficiency improvements.

3) Economic and Environmental Trade-offs in Building Renovations; Modernization efforts, such as insulation and new heating systems, reduce operational energy consumption. However, the study questions whether shorter lifespans of modern heating appliances counterbalance these gains due to increased material and energy demands for production and replacement.

To address these gaps, this study formulates the following research questions:

1) How do modernization interventions influence the long-term wear and service life of structural elements in a 1930s apartment building?

2) What are the measurable effects of different heating system upgrades on energy efficiency over successive decades?

3) How does predictive maintenance compare to reactive and preventive maintenance in extending the service life of key building components?

4) What are the economic and environmental trade-offs associated with frequent heating system replacements versus long-term operational energy savings?

By addressing these questions, the study aims to provide insights into the sustainable management of older residential buildings, balancing energy performance, cost-effectiveness, and environmental impact.

2 Research background

2.1 Model building

Functionalist apartment buildings seemed to be the most suitable for this life cycle research because they met several requirements. These were houses that are not at the beginning of their life cycle, and they allow for building modifications (e.g. insulation), which excluded buildings with listed facades. The most important requirement for the selection of the model house was the existence of complete drawing documentation including records of the operation of the house over a long period.

After an inspection of several apartment houses from the 1930s that did not meet the required criteria, the apartment house at Street of the Čapek Brothers No. 12 in Brno was selected, which was built according to the principles of residential culture, all building documentation and records of the operation of the house in the period 1932 to 1947 were preserved.

Favourable conditions and incentives for the construction of apartment buildings in the 1930s, especially the tax breaks given by law, led the builder to the idea of building a six-storey house with 12 small flats. These small flats were, according to the legislation in force, flats with a floor area of living rooms of up to 80 m^2. The total usable area of all the flats in the house was 1,100 m^2.

According to the available documentation, the cost of the construction of the house was CZK 1.5 million CZK. The house was equipped with the most modern technical equipment of the time. There was a machine laundry for 21,500 CZK, a lift for 60,000 CZK, but the biggest item was the central heating, designed and implemented by CKD Company for 99,500 CZK. This amount included two, then state-of-the-art STREBEL-II coke boilers and 70 radiators. This amount also included the installation of Thermona heat meters for each apartment, which allowed each tenant to set the temperature in the apartment according to their requirements and for this they also paid.

The expected lifetime of the heating system was estimated at the time of construction to be 25 years. The construction of the house was started on 3 August 1931 and the building permit for the use of the house was issued on 1 July 1932, i.e. the conditions set by the state for obtaining the subsidy were fulfilled, the apartment house was exempted from paying the rent tax for 25 years.

2.2 Construction life cycle

Usually, based on the literature and other general sources [2], the construction life cycle can be broadly divided and described as follows:

1) Pre-investment phase,
2) Investment phase,
3) Operational phase,
4) End-of-life phase.

The pre-investment phase [2] usually includes a preliminary conceptual analysis of possible market opportunities, a feasibility study, an architectural study, etc.

The investment phase is usually divided and includes the planning phase (land purchase, geological, building history, zoning or other decision-making, basic documentation), the pre-implementation phase (tender documentation, contractor selection, documentation for construction execution) and the implementation phase (construction implementation, documentation of the actual construction execution, handover of the construction to the investor) [2].

The operational phase usually includes the actual use of the building and related activities. One of the main activities is periodic repairs to the structure or other activities associated with the maintenance and operation of the structure [2].

The operational phase is the longest phase of the construction life cycle and is the main focus of this article. As already mentioned, one of the main activities in this phase is the maintenance and periodic repair of the structure. It should be noted here that maintenance and repairs are also fundamentally related to the service life of the individual elements of the building or their wear and tear, where in a causal relationship with the wear value, as the wear rate approaches 100%, this part of the building becomes non-functional [2].

End-of-life phase (structure removal phase or demolition phase), which includes the disposal and reuse of materials, or the definition of a new building function, can be defined as a separated phase of the building life cycle and should be considered in life-cycle-cost analysis (LCCA).

Doseva and Chakyrova [3] reported that approximately 60% of residential buildings in Bulgaria were constructed before the 1990s, meaning they have been in use for over 30 years. Additionally, the final energy consumption of Bulgarian residential buildings is the highest in Europe, highlighting the critical need to improve the energy performance of existing residential structures. This study aims to evaluate the impact of the heat transmittance coefficient of external building envelope elements on the annual energy consumption for heating and cooling, with the goal of identifying its optimal value. Life-cycle cost is employed as the optimization criterion. The optimization process is tailored to Bulgaria's climatic and economic conditions while considering the existing legal framework. A genetic algorithm is utilized to determine the minimum life-cycle cost of the building.

LCCA is a part of asset management of a structure. The analysis becomes key when deciding on the structural design of a building and thus comes to the forefront when making investment decisions. It is real issue in case of infrastructure and military issues [4, 5].

2.3 Basic types of maintenance

Basic maintenance methods as outlined by Evans [6]. These are reactive maintenance, preventive maintenance and predictive maintenance [6]. Reactive maintenance is a leave it alone and run it until it breaks. There is generally no or very little effort made to ensure the long-term design life and performance of the structure in operation. The building is operated with the assumption of a very long service life for all components, usually with respect to the existing contractor's warranty. Only the most routine service and maintenance tasks are performed. The occurrence of failures is not predicted or operationally treated in any way. The faults that occur may be low-risk operational faults, but there are also faults that require immediate intervention and remediation as they pose a high risk.

Planned maintenance may be defined as an activity carried out on the basis of a schedule based on operating characteristics, planned lifetimes or the actual condition of the structure or technology. This type of maintenance aims to inspect, detect and slow down the degradation or obsolescence of components, structures and equipment with the objective of – at least achieving, but rather extending the design operational life, while maintaining the design parameters of the building for as long as possible. Simply put, by performing preventive maintenance as intended and recommended by the designer and manufacturer of the equipment, the operational life and reliability of the equipment can be achieved or extended. This, of course, has an economic impact. Surveys report an average cost saving of 12-18% for preventive maintenance, compared to purely reactive maintenance [6].

The principle of predictive maintenance beyond planned maintenance involves performing measurements and analyses to alert the owner in advance of incipient degradation and to slow or eliminate the causes of physical degradation and wear of the building and its parts in sufficient time. The advantage of this maintenance is to enable the functioning of low-wear components without the need to replace them when their theoretical lifetime expires, but on the other hand to detect in time the shortening of the lifetime of other components, usually due to their increased load, lower quality, etc. [6].

Maintenance issues provide inputs to the asset management systems which became important especially for operation of larger owners of real estates. It can be expected that the asset management systems will be reinforced by Building Information Modeling (BIM) [7, 8]. Asset management requires valid data concerning the actual condition of the structures and their elements often taken automatically from non-destructive testing as known from infrastructure structures [9-14]. As in case of infrastructure it requires the creation of unique databases for each structure [15].

2.4 Historical buildings

Although this paper does not specifically address historical buildings, many of the topics related to them are applicable to contemporary buildings and vice versa. One of the topics is obtaining data on the layout of the building [16-19], including surrounding paved roads [12, 20].

3 Material and Methods

Building modifications and replacement of structures can positively affect the life cycle of a building. This will result in an increase in the real lifetime and a reduction in the overall wear and tear of the building.

3.1 Lifetime of constructions and wear and tear

Determining the service life of individual parts of the building and technological equipment is a rather complicated area. The reason for this is the inconsistency and diversity of the documentation, as well as differences in construction, technical and technological equipment. Classification of structures is generally a discipline that is determined both by technical documents, standards, manufacturers' instructions, but also by progressive experience and practice.

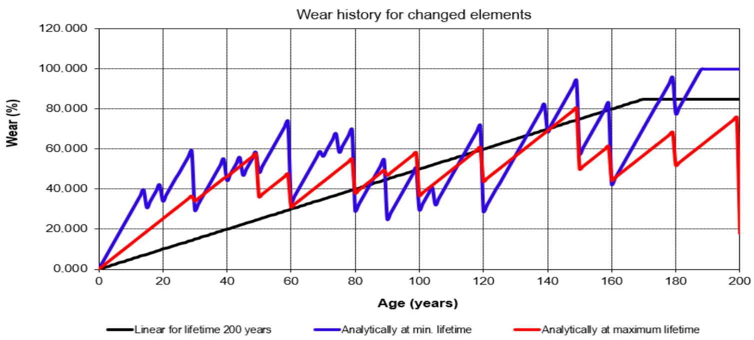

Fig. 1: Wear progression (maximum × minimuim).

By wear and tear we express the fact that the building is degrading. The most common method for estimating the amount of wear and tear is the linear method, which assumes that wear and tear increases in direct proportion to time, from zero for a new building to 100% for a completely dilapidated building. Other approaches can be used, for example, where wear increases along a quadratic curve or in other ways. If we consider that each element of the building wears out at a different rate, we need to use the so-called analytical approach, where the wear of the building is as a whole determined on the basis of a weighted average of the wear of the individual parts, where the weight is the price share of the building. The latter expresses the proportion of the value of the building element to the total value of the building. Using the lifetime values and price shares for the dwelling house from the Decree, the wear and tear of the building will always vary depending on the replacement of the element that has reached the end of its lifetime. This is illustrated in the graph at Fig 1.

3.2 Model example of structure replacement

As mentioned in the section 2.1 of the paper for the purpose of the described research an apartment of 1930s building is taken as a model. In the Tab. 1 there is a comparison between the assumed designing service life given by valuation code of the Czech Ministry of Finance [21], the actual (real or current) service time of existing or some replaced building elements and expected time of operation.

Table 1: Comparison of design-service-life, real and expected service-life.

Item No.	Name	Designed service-life [years]	Real (current) service-life [years]	Expected service-life [years]
1	Foundations including earthworks	150-200	92	200
2	Vertical structures	80-200	92	200
3	Ceilings	80-200	92	200
4	Roofing outside the covering	70-150	92	150
5	Covering, roof 1932	40-80	92	90
5	Covering, roof 2016	40-80	8	90
6	Plumbing const. 1932	30-80	92	90
6	Plumbing const. 2016	30-80	8	90
7	Adjustments to internal surfaces	50-80	92	90
8	Adjustments to external surfaces 1932	30-60	92	85
8	Adjustments to external surfaces 2016	30-60	8	85
9	Interior ceramic tiles unchanged (60%)	30-50	92	100
9	Interior ceramic tiles 2008 (20%)	30-50	76	100
9	Interior ceramic tiles 2023 (20%)	30-50	1	100
10	Stairs	80-200	92	200
11	Doors unchanged	50-80	92	120
12	Gates	-	-	-
13	Windows 1932	50-80	92	85
13	Windows 2016	50-80	8	80
14	Floor surfaces unchanged (90%)	15-80	92	120
14	Floor surfaces 2008 (5%)	15-80	16	80
14	Floor surfaces 2023 (5%)	15-80	1	80
15	Heating (17%) unchanged (radiators and piping)	20-50	92	120
15	Boilers for coal 1932 (83%)	20-50	92	60
15	Boilers 1983 (83%)	20-50	51	30
15	Boilers 2007 (83%)	20-50	24	20
15	Boilers 2021 (83%)	20-50	14	20
16	Electrical installation 1932	25-50	92	80
16	Electrical installation 2015	25-50	9	25
17	Lightning rod 1932	30-50	92	90
17	Lightning rod 2016	30-50	8	90
18	Internal water supply 1932	20-50	31	40
18	Internal water supply 1963	20-50	61	70
19	Internal sewerage unchanged	30-60	92	120
20	Internal gas pipeline unchanged	20-50	92	120
21	Hot water heating 1932	20-40	51	50
21	Hot water heating 1983	20-40	25	30
21	Hot water heating 2008	20-40	13	20
21	Hot water heating 2021	20-40	3	20
22	Equipment of kitchens 1932	15-30	30	30
22	Equipment of kitchens 1962	15-30	30	30
22	Equipment of kitchens 1992	15-30	30	30
22	Equipment of kitchens 2022	15-30	30	30
23	Indoor sanitary facilities including toilet 1932	30-60	78	80
23	Indoor sanitary facilities including toilet 2010	30-60	14	20
24	Elevators 1932	30-50	54	60
24	Elevators 1986	30-50	30	30
24	Elevators 2016	30-50	30	30

On the basis of the values from Tab. 1, a graph of the wear progression was drawn by the analytical method. Graph at Fig. 2 shows the dependence of wear on the maximum expected lifetime of the table and on the actual lifetime, i.e. the time during which the element was part of the apartment building. In buildings built before World War II some elements significantly exceed the maximum design service life.

Some structures see elevator were replaced earlier, although they were still functional, but were replaced with newer technology. The actual service life of some of the replaced elements has been significantly reduced from the original and is close to the lowest tabulated values. This is particularly evident in the case of boilers for heating, which are the subject of a separate section in this paper. The difference in service life and wear is shown in graph at Fig. 2.

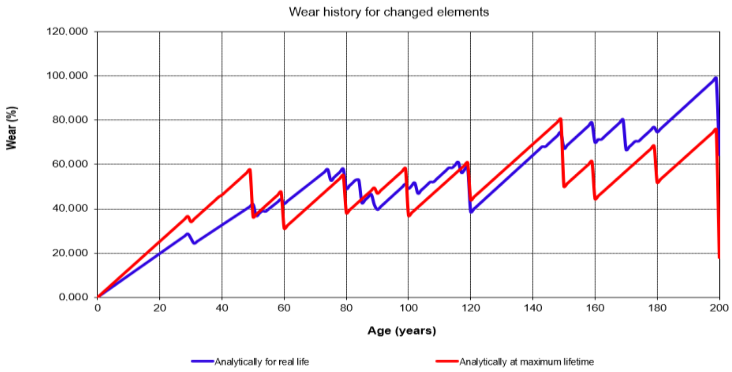

Fig. 2: Wear progression (maximum = by design × real).

From the above tables and graphs it is quite clear that the building owner should responsibly plan for the repair and maintenance of the building. For some items, these are significant capital items that need to be planned for in the future.

Tab. 2 shows the amount of money needed to replace parts of the building assuming the cost of the whole building as CZK 50 million. (1 € is approx. 25 CZK). These amounts are calculated on the basis of the price shares also used for the calculation of wear and tear by the analytical method. This is shown in Fig. 2.

Table 2: Price shares of constructions.

Item No.	Name	Price share [-]	Price of construction [CZK]
1	Foundations including earthworks	0.060	3,006,864
2	Vertical structures	0.188	9,421,507
3	Ceilings	0.082	4,109,381
4	Roofing outside the covering	0.053	2,656,063
5	Covering, roof	0.024	1,202,746
6	Plumbing constructions	0.007	350,801
7	Adjustments to internal surfaces	0.069	3,457,894
8	Adjustments to external surfaces	0.031	1,553,546
9	Interior ceramic tiles	0.021	1,052,402
10	Stairs	0.030	1,503,432
11	Doors	0.032	1,603,661
12	Gates	0,000	0
13	Windows	0.054	2,706,178
14	Floor surfaces	0.031	1,553,546
15	Heating	0.047	2,355,377
16	Electrical installation	0.052	2,605,949
17	Lightning rod	0.004	200,458
18	Internal water supply	0.033	1,653,775
19	Internal sewerage	0.032	1,603,661
20	Internal gas pipeline	0.004	200,458
21	Hot water heating	0.021	1,052,402
22	Equipment of kitchens	0.018	902,059
23	Indoor sanitary facilities including toilet	0.038	1,904,347
24	Elevators	0.013	651,487
25	Others	0.056	2,806,406

3.3 History of the heating system in the model apartment building from 1932 to 2021

The heating season of the model house started in October 1932. The boiler room with two coke boilers was in the basement of the house and was connected to the apartment of the caretaker, who was also the heating engineer of the house. During the first heating season (October 1932 to May 1933), 19.64 tons of coke was heated.

In the following heating seasons, coke consumption fluctuated according to the temperature conditions in a given year. For example, in the heating season 1943/44 the annual consumption was 29.00 tons of coke, but the average annual consumption for the period 1932/33 to 1946/47 (15 years) was 21.00 tons. The average length of the heating season was 223 days, i.e. the daily consumption of coke was approximately 94 kg.

For the heating season 1937/38, the house was equipped with a new coke boiler for central hot water. The increased consumption of coke led to the enlargement of the coal room at the expense of the cellar space. Over the next 10 years the average annual consumption of coke for hot water was 7.5 tons.

In the late 1940s, the records of coke consumption end as the building was nationalized as it housed offices as well. The house came under the management of the Housing Authority, a state-owned company that managed the housing stock.

In 1982 the boiler room was reconstructed and two Hungarian gas boilers were installed. The Körös 25 ES boiler (25 kW) was used for domestic hot water production and the second boiler ETÏ-60E (70 kW) was used for heating. A circulation pump was added to the system and power control was provided by an electronic Komextherm. The thermal comfort of the house was significantly improved. The old boilers, originally serving 50 years instead of the planned 25, were scrapped. In 1991, after restitution, the building passed back into the hands of heirs of original owners.

In 1992, the annual gas consumption was 31,000 m³. Thanks to the tuning of the boilers and the optimization of the heating, consumption was reduced in the 1990s - in 2003 it reached 23,600 m³. The regulation on the installation of thermovalves in 2004 brought further savings, and the house's consumption dropped to 20,000 m³ in 2005. However, in 2007 it became clear that both Hungarian boilers had reached the end of their service life. After consulting with experts, it was decided to install two stationary Viadrus boilers with outputs of 25 kW and 49 kW.

The preparation of domestic hot water was ensured by two boilers with a capacity of 250 l. The boilers were connected in parallel so that they could work separately or simultaneously, which allowed for better optimization of the heating, especially in transitional periods [22].

In 2008, heat meters were installed on radiators and the annual consumption dropped to 16,000 m3. The boilers worked relatively well, but occasionally had electronic faults (Siemens). In 2015 and 2016, a comprehensive insulation of the house was carried out, including the replacement of windows with triple-glazed windows. The annual consumption of the house dropped to 12,000 m^3 [22].

The increasing price of energy led to the insulation of the facade, which still reduces energy costs and increases thermal comfort. Therefore, in 2015, work was started on the overall insulation of the house and completed in 2016. The old, inadequate castle windows were replaced with plastic windows with triple glazing. The windows were equipped with external blinds and the facades were equipped with 140 mm of graphite expanded polystyrene insulation, supplemented with 30 mm of mineral wool.

In the fall of 2020, the service life of both Viadrus boilers ended after 13 years of operation, repair was not possible, spare parts were not available and heating was provided provisionally. In 2021, Thermona installed a system of three THERM 24 KDN boilers connected in a cascade with modern electronics and computer control as the optimal solution. The reconstruction of the boiler room was carried out so efficiently in June that the interruption of the hot water supply lasted only one day. The new boilers allow remote control using data cables or wi-fi, which transformed the boiler room into a heating plant control room. Thanks to this modernization, annual gas consumption dropped to less than 10,000 m³. To evaluate the effects of individual interventions in the heating system and the structure of the house, this thirty-year period was divided into 3 decades, see Tab 3 and Fig. 3.

Table 3: Gas consumption in an Apartment Building 1992 – 2021 [22].

Year	**1992 – 2001**		**Year**	**2002 – 2011**		**Year**	**2012 – 2021**	
	Heating [m³]	**Water heating [m³]**		**Heating [m³]**	**Water heating [m³]**		**Heating [m³]**	**Water heating [m³]**
1992	21,847	9,060	**2002**	19,238	4,701	**2012**	9,380	5,120
1993	20,056	9,146	**2003**	19,006	4,616	**2013**	9,533	5,550
1994	19,237	7,697	**2004**	17,589	4,424	**2014**	7,495	4,624
1995	20,066	6,336	**2005**	17,073	4,748	**2015**	8,901	4,610
1996	21,501	6,753	**2006**	15,730	4,532	**2016**	7,806	4,415
1997	18,973	7,574	**2007**	13,246	4,490	**2017**	6,366	4,896
1998	20,386	6,399	**2008**	11,289	4,790	**2018**	6,354	4,784
1999	18,573	6,994	**2009**	10,495	5,400	**2019**	6,166	4,450
2000	17,741	6,162	**2010**	12,023	5,500	**2020**	6,379	4,423
2001	20,336	5,310	**2011**	9,900	4,930	**2021**	6,802	5,412
Total	198,72	71,43		145 60	48,13		75,18	48,28
Avar.	19,872	7,143		14,559	4,813		7,518	4,828

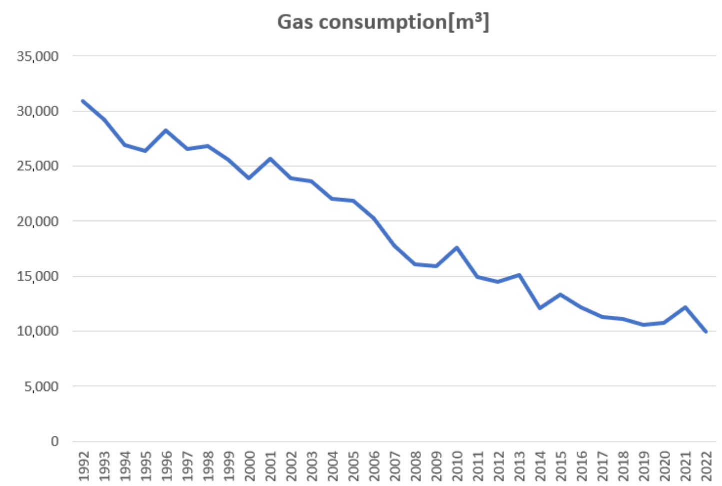

Fig. 3: Gas consumption in individual years.

4 Results

In the first part of the article, we discussed the expected service life and wear of apartment buildings and the wear of the actual building based on the service life determined from the actual repairs of the house. This was evaluated for a house from the 1930s, when the most modern high-quality structures were used. From the above data, it is clear that the course of actual wear and tear over a large part of the evaluated period of 200 years almost copies the course of maximum expected wear and tear. However, towards the end of the service life of the building, actual wear and tear shows significantly lower values due to the replacement of building elements. The owner of a similar apartment building can plan the repair time and costs that will need to be incurred in the years around the maximum expected service life of the elements and will be ready to make these investments in good time.

Table 4: Comparison of Apartment Building energy performance.

Fuel type	**Cokes**	**Quantity G [ton]**	**Energy W [GJ]**	**Comparison S [%]**
Period 1932/33–1946/47	Heating	21	630	100
	Water heating (37-46)	75	225	100
Period 1948 – 1991	No record			
Fuel type	**Gas**	**Quantity V [m³]**	**Energy W [GJ]**	**Comparison S [%]**
1. decade 1992–2001	Heating	19,872	656	104
	Water heating	7,143	236	105
2. decade 2002–2011	Heating	14,559	480	76
	Water heating	4,813	159	71
3. decade 2012–2021	Heating	7,518	249	40
	Water heating	4,828	159	71

Another area of investigation was the evaluation of the energy performance of the building following the repairs and modernization of some building elements. If we were to designate the average annual consumption of gas as fuel in the first decade as 100%, then in the second decade it is 73% and in the third decade 38%. In the same period, the average gas consumption for the hot water preparation by decades is 100%, 67% and 67%. It is obvious that in the second and third decades the gas consumption for the hot water preparation does not change, while the gas consumption for heating in the third decade is only 38% of the gas consumption in the first decade. The data shown show that both the technical evaluation of the old heating system and the structural modernization of an older house have a fundamental impact on reducing the energy performance of the building, especially for heating.

If we compare the calorific value of fuels in GJ, we can analyze fuel consumption in the 1930s and over the last three decades. We assume that 1 ton of coke has a calorific value of 0.3 GJ and 1,000 m³ of natural gas has 33 GJ. The results are presented in Tab. 4 and Fig. 4.

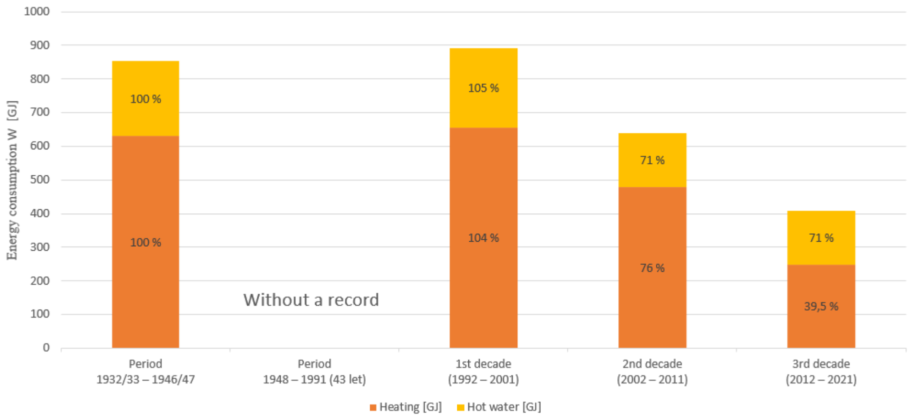

Fig. 4: Comparison of Apartment Building energy performance (1932-47, then by decade 1992-2021).

5 Discussion

Life cycle cost analysis (LCCA) plays a crucial role in evaluating the economic efficiency of a building's structural design. Effective maintenance and modernization strategies can enhance building performance, extending its lifespan and improving overall efficiency. Although this study focuses on a single 1930s apartment building, its findings are applicable to similar structures. A key objective was to compare theoretical service life expectations with real-world data. The results confirm that high-quality construction materials and proactive maintenance significantly extend building longevity beyond initial design assumptions, reinforcing the effectiveness of predictive maintenance in optimizing service life.

A critical finding of this study is the long-term impact of modernization interventions on both structural wear and energy efficiency. While previous research has focused on short-term benefits of insulation and heating upgrades [1], this study provides a rare longitudinal assessment spanning nearly 90 years. The data shows that well-planned interventions can extend the useful life of key building components while significantly reducing operational energy consumption. For instance, gas consumption for heating decreased from 100% in the 1992–2001 period to just 38% in 2012–2021, demonstrating the cumulative benefits of insulation and heating system upgrades.

However, modernization strategies also present economic and environmental trade-offs. Although newer heating systems improve energy efficiency, they often have shorter lifespans than older systems, leading to increased material waste and replacement costs. This raises concerns about whether long-term energy savings offset the environmental burden of frequent system replacements. Future research should assess the full life-cycle impact of these interventions, integrating operational efficiency with embodied energy costs.

Additionally, this study underscores the importance of predictive maintenance in ensuring building longevity. Compared to reactive maintenance, predictive strategies allow for better planning of repairs and replacements, reducing both costs and unexpected failures. Empirical data suggests that predictive maintenance extends the service life of structural components and heating systems, contributing to more sustainable asset management.

Economic considerations further highlight that financial motivations for modernization may be secondary to ecological concerns. The return on investment for some energy efficiency improvements is realized over decades rather than years, meaning that property owners often prioritize sustainability over immediate financial gains. Rough calculations suggest that the payback period of modernization measures depends on energy price fluctuations and the real service life of newly installed materials, which remains uncertain due to their potential early obsolescence.

The study also indicates that some building elements are replaced due to trends or technological advancements rather than actual deterioration. While modern insulation materials and efficient heating systems reduce energy consumption and environmental impact, the shorter service life of newer heating appliances may counteract these benefits. This paradox highlights an important direction for future research—assessing whether the environmental and financial costs of frequent replacements outweigh the energy savings achieved through modernization.

From an investment perspective, modernization efforts significantly affect property value. The rental price of a modernized apartment can be up to 70% higher than a non-modernized one with the same amenities [23]. However, determining the precise impact of modernization on property value is challenging due to multiple influencing factors, including market trends and buyer preferences. New owners often modify properties to suit their needs, sometimes undoing prior modernization efforts, making economic valuation highly variable. The uncertainty in assessing structural renovations further complicates investment decision-making [24].

By addressing these challenges, this study contributes to the ongoing discussion on sustainable management of older residential buildings, balancing energy performance, cost-effectiveness, and long-term structural viability.

6 Conclusion

The archive of Street of the Čapek Brothers No. 12 apartment building in Brno provides valuable information from its inception in the 1930s to the present. It contains data on repairs, heating, fuel consumption for heating and hot water. This data allows us to accurately monitor the structural and technical condition of individual building elements and, given the requirements for reducing CO_2 in the atmosphere, to document the energy efficiency of the building. Specifically, it is possible to evaluate the effects of modernization interventions not only in the heating system, but also in the building structure. Based on this information, it is then possible to better predict the future condition of houses in practice and appropriately supplement or adjust the properties of elements in BIM.

The topic for follow-up research is to determine the economic benefit function of individual investments in real estate in the context of various scenarios of the development of housing requirements, the development of energy prices, discount rates, rental prices, prices of building materials, etc.

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