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OUR-CEE

(Overcoming Underperforming Renovation in Central and Eastern Europe)

National baseline assessment on underperforming renovations

Croatia

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1. EXECUTIVE SUMMARY

In Croatia, as well as in the entire European Union, almost 50 % of final energy consumption is used for heating and cooling, out of which 80 % in buildings. Croatia is striving to reduce GHG emissions to slow down the pace of climate change, and to achieve this, the buildings sector is of essential importance. However, the very start of those efforts back in 2012 was not so bright since a **Study for the EC based on 2012-2016 data**[1] estimates that only 1,5 % of residential sector renovations were medium depth and 0,1 % deep renovations, based on floor area. Energy renovations in non-residential buildings were estimated to comprise only 1,1 % medium, and 0,2 % deep energy savings. These shares will have changed since, as renovation programmes across the 2016-2020 period targeted at least 50 % energy savings for most projects, with the exception of single measures improvements in single family houses.

Despite this first renovation wave on public buildings in Croatia, by 2020 less than 10 % of public buildings had been renovated. Due to low ambition, already-renovated public buildings fall short of expected energy savings and they are dismissed from further action because they are labelled as “already renovated”. The reasons behind this underperformance are unknown, and public sector employees lack a general understanding of building life-cycle costs, leading to the abandonment of renovation projects with higher initial investment costs.

Project OUR-CEE addresses the issue of underperforming renovations in public buildings and how to overcome it. It focuses on four CEE countries traditionally challenged by low renovation ambitions and poor quality of the building stock. Starting with this study, the project will support the acceleration of deep renovation in CEE. National baseline assessment on underperforming renovations in Croatia aims to improve institutional knowledge of the current state regarding the underperforming energy renovations in Croatia. Assessment starts with the introduction where the problem is addressed. Further elaboration presents the overview of the national (public) building stock and related policies, showing the buildings energy performance, number of renovated buildings and buildings to be renovated, building categories by purposes and by year of construction etc. Chapter “Assessment of energy performance of renovated public buildings” has been broken down into assessment performed on a national and local level. To analyse energy renovations at the national level, publicly available documents have been used (desk research) which contain all the necessary information to obtain a comprehensive view of energy renovations at the national level. At the local level, the national energy management system (ISGE) was used, from which it is possible to extract the energy consumption data for each individual building. Detailed analysis on a local level has been performed for three pre-selected buildings which went through the renovation process but are showing signs of underperformance. Results of this chapter will serve to better understand and identify the possible reasons behind underperforming renovations in public buildings which have been presented in the next chapter “Identification of possible reasons behind underperforming renovations in public buildings”. And finally based on these identified possible reasons behind underperforming renovations in public buildings, policy measures have been proposed in the

[1] Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU

last chapter, which, if implemented, can significantly improve the performance and impact of future public building renovations in Croatia.

2. INTRODUCTION

Renovating both public and private buildings was singled out in the European Green Deal as a key initiative to drive energy efficiency in the sector and deliver on objectives. To pursue the dual ambition of energy gains and economic growth following the COVID-19 pandemic, the Commission published in 2020 the strategy "A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives" along with an action plan and a document presenting available EU funding. The Renovation Wave initiative builds on the national long-term building renovation strategies of Member States, other aspects of the Directive on Energy Performance of Buildings, and building-related aspects of each EU country's national energy and climate plans (NECPs). The Renovation Wave aims to at least double the EU's annual energy renovation rate by 2030.

Despite several good attempts to increase the energy performance of Europe's building stock, according to the BPIE's 2023 publication[2] "Buildings climate tracker – 2nd edition", the actions taken since 2015 have not been effective enough to decarbonize the EU building stock at the rate and depth required. In particular, countries in the Central and Eastern Europe (CEE) region are far from being on track; the region has gone backwards and requires a "better implementation of legislative requirements and more ambitious and inclusive strategies" (especially in view of the high share of people experiencing energy poverty) to decarbonize the building stock.

In order to meet 2050 decarbonization goal in the buildings sector and to catch the full speed of the renovation wave, the CEE region should learn from its previous experiences and mistakes. In particular, it is of utmost importance to manage underperforming energy renovations (i.e., renovations which have not resulted in their projected energy savings) and to identify the possible reasons behind them. The OUR-CEE project addresses the issue of underperforming renovations in public buildings and how to overcome it, focusing on four CEE countries traditionally challenged by low renovation ambitions and poor quality of the building stock. Public buildings, which are expected to lead the way in deep renovation, have been undergoing renovation for many years in CEE – but a significant proportion of this renovation is not achieving appropriate energy savings. The findings of the project will support the acceleration of deep renovation in CEE and achievement of the EU's energy efficiency targets.

This study is the first step of this project, aiming to provide insights into the magnitude of the problem of underperforming renovations in the OUR-CEE project countries, though national baseline studies as well as a regional study of CEE. At the same time, these studies will present the possible reasons that might be behind underperforming energy renovations. Finally, the baseline studies will offer a series of policy recommendations which, if implemented, can significantly improve the performance and impact of future public building renovations in CEE region. The main goal of baseline studies is thus to improve the understanding of underperforming renovations among decision-makers.

[2] BPIE, EU buildings climate tracker 2nd edition, 2023

3. OVERVIEW OF THE NATIONAL BUILDING STOCK AND RELATED POLICIES

In Croatia, as well as in the entire European Union, almost 50 % of final energy consumption is used for heating and cooling, out of which 80 % in buildings. Croatia is striving to reduce GHG emissions to slow down the pace of climate change, and to achieve this, the buildings sector is of essential importance. However, the very start of those efforts in 2012 was not so bright since a Study for the European Commission based on 2012-2016 data estimates that only 1,5 % of residential sector renovations were medium depth and 0,1 % deep renovations, based on floor area. Energy renovations in non-residential buildings was estimated to comprise only 1,1 % medium, and 0,2 % deep energy savings. These shares will have changed since, as renovation programmes across the 2016-2020 period targeted at least 50 % energy savings for most projects, with the exception of single-measure improvements in single family houses. Additionally, it is expected that current energy renovation rate of 0,7 % per year will gradually rise to 3 % over the 2021-2030 period, with a 10-year average rate of 1,6 %.

Energy and climate related legislation are aligned with the EU acquis. At the implementation level, energy and climate fall within the competence of two ministries - the Ministry of Environmental Protection and Energy and the Ministry of Physical Planning, Construction and State Assets.

The overview of the building stock in the following chapters is based on existing data from available strategic documents, plans and programmes.

3.1. Overview of the national building stock

All data, including images, tables and textual descriptions are taken from the **Long-term Strategy for National Building Stock Renovation by 2050**[3], **Integrated National Energy and Climate Plan for the Republic of Croatia for the period 2021-2030 (NECP)**[4], **Public Sector Building Energy Renovation Program for the period until 2030**[5] and from the national annual publication titled **Energy in Croatia 2022**[6] (Ministry of Economy and Sustainable Development). Based on these documents, the following information are provided.

3.1.1. Total gross floor area

The latest comprehensive data research carried out in the Long-term strategy for mobilising investment in the renovation of Croatia's national building stock is based on data in the Long-term strategy for mobilising investment in the renovation of Croatia's national building stock of June 2014, the National Plan for increasing the number of nearly zero-energy buildings, the National energy efficiency programme for the 2008–2016 period, the Energy renovation programme for family houses for 2014– 2020 with a detailed plan for 2014–2016, the Energy renovation programme for multi-apartment buildings for 2014–2020 with a detailed plan for 2014–2016, the Energy renovation programme for commercial non-residential buildings for 2014–2020 with a detailed plan of energy renovation of commercial non-residential buildings for 2014–2016, the Energy renovation programme for public buildings for 2016–2020, and

[3] Long term strategy for national building stock renovation by 2050
[4] Integrated National Energy and Climate Plan for the Republic of Croatia for the period 2021-2030
[5] Public Sector Building Energy Renovation Program for the period until 2030
[6] Energy in Croatia

statistics on the census of households and population. Additional inputs and assumptions have been harmonised with data contained in the Integrated national energy and climate plan for the Republic of Croatia for 2021–2030and Croatia's Energy development strategy until 2030 with an outlook to 2050.

Available data indicate that Croatia's building stock covered a total gross floor area of 198.133.193 m² in 2011. Annual changes in the building stock between 2011 and 2018 were determined from building stock trends, derived from data on issued building permits, as well as completed and demolished buildings. The Figure 1 below shows the movement of the total area of buildings from 2011 to 2018.

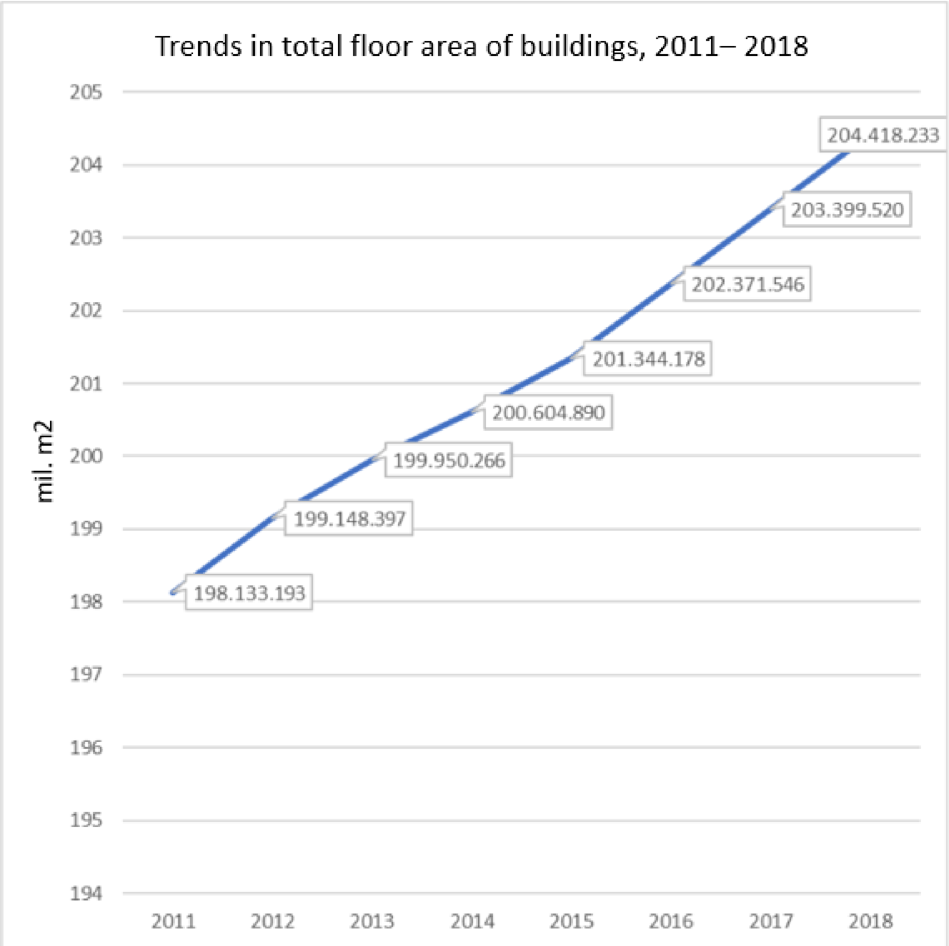

Figure 1 Trends in total floor area of buildings, 2011 – 2018

In 2020, the national building stock of Croatia covered a total useful floor area of 237.315.397 m², of which 178.592.460 m² in residential buildings and 58.722.937 m² in non-residential buildings. The floor area of permanently occupied residential structures in 2020 was calculated using data from the 2011 census, adjusted to reflect changes based on statistics regarding building completions and demolitions from 2011 to 2018, and projected for 2019 and 2020.

The document Energy in Croatia in 2021 states the total fund includes 76.92 % residential buildings and 23.08 % non-residential buildings, and the building stock increased compared to the previous year by a total of 2.881.707 m^2 of usable area, of which 1.551.977 m^2 were residential buildings and 1.329.730 m^2 of non-residential buildings.

The document Energy in Croatia in 2022 states the total fund includes 76.54 % residential buildings and 23.46 % non-residential buildings, and the building stock increased compared to the previous year by a total of 3.450.808 m^2 of usable area, of which 1.984.811 m^2 (family houses and multi-apartment buildings) were residential buildings and 1.153.673 m^2 of non-residential buildings.

3.1.2. Building stock categories by purpose

The total fund of buildings in Croatia can be divided according to the purpose as follows:

- multi-apartment buildings
- family houses
- public buildings
- commercial buildings

Public buildings are buildings predominantly owned by public sector entities in which socially-oriented activities (education, training, science, culture, sport, healthcare and social welfare) and the activities of national and state administration, as well as those of local and regional self-government bodies and organisations and legal persons with public authority are performed; community housing buildings, including barracks, penitentiaries, prisons, correctional centers and other buildings intended for the use by armed forces, police or fire departments; buildings of citizens' associations and those of religious communities.

A family house is any building in which more than 50 % of the gross floor area is intended for housing, and which meets one of the following two conditions: it has a maximum of three residential units and/or a gross construction area of less than or equal to 600 m^2.

Multi-apartment buildings are all buildings in which the entire gross floor area or more than 50 % of the gross floor area is intended for housing, which have three or more residential units and are managed by a building manager, who is either a legal or a natural person.

Commercial buildings are all predominantly privately-owned buildings in which more than 50 % of the gross floor area is intended for commercial and/or service activities.

Buildings with the status of cultural property may be found in all four building categories. Buildings with the status of immovable cultural heritage are included in the **Register of Cultural Property** of the Republic of Croatia (https://registar.kulturnadobra.hr), according to which 102.615 buildings within cultural and historical units have the status of cultural property, or 1.950 buildings have the status of individually protected cultural heritage.

The Table 1 below shows the area of buildings of individual categories. An increase in the area of buildings can be observed in all categories.

Table 1 Total gross floor area of buildings in Croatia by purpose in m² per year

	2011	2012	2013	2014	2015	2016	2017	2018
residential	**146.561.449**	**146.638.808**	**146.694.469**	**146.740.186**	**146.782.378**	**146.821.550**	**146.875.125**	**146.924.679**
multi-apartment	56.566.680	56.596.537	56.618.031	56.635.665	56.651.950	56.667.068	56.687.746	56.553.324
family	89.994.769	90.042.271	90.076.466	90.104.521	90.130.429	90.154.482	90.187.379	90.371.355
non-residential	**51.571.744**	**52.342.025**	**53.542.879**	**53.542.879**	**54.244.761**	**55.414.108**	**56.440.826**	**57.493.554**
office	8.641.609	8.690.577	8.700.234	8.786.495	8.841.865	8.871.938	8.992.494	9.310.763
education	5.614.153	5.682.727	5.720.018	5.751.638	5.793.588	5.827.083	5.888.671	5.912.968
hotels and restaurants	3.318.095	3.357.532	3.414.540	3.472120	3.548.686	3.689.688	3.890.329	4.083.148
hospitals	2.952.511	2.988.574	3.008.186	3.024.815	3.046.877	3.064.492	3.096.881	3.109.659
sports halls	416.633	421.722	424.489	426.836	429.949	432.435	437.005	438.808
trade services	11.397.783	11.582.614	11.731.774	11.857.714	11.949.236	12.010.125	12.089.527	12.167.833
other	19.230.960	19.618.277	20.005.159	20.223.261	20.634.561	21.518.348	22.045.919	22.470.375

3.1.3. Building stock categories by year of construction

The starting point for the analysis was the 2011 population census, in which data on all apartments and occupied apartments in the following periods: prior to 1919, 1919–1945, 1946–1960, 1961–1970, 1971–1980, 1981–1990, 1991–2000, 2001–2005, 2006 and later, were processed; then they were supplemented with data on building permits issued and apartments and buildings demolished between 2011 and 2018, and finally adjusted for the demolition level included in the model. In 2018, the total building stock was 204.418.233 m², of which 146.924.679 m² in residential and 57.493.554 m² in non-residential buildings. The Table 2 below shows Croatia residential building stock by construction year for all buildings.

Table 2 Croatia residential building stock by construction year (all buildings)

	multi-apartment		family	
	No of buildings	floor area	No of buildings	Floor area
	-	m^2	-	m^2
prior to 1941	37.201	5.773.897	64.391	10.155.639
1941-1970	85.959	13.341.431	151.507	23.895.416
1971-1980	59.882	10.296.314	93.109	16.268.543
1981-1987	44.434	9.309.485	68.348	14.551.505
1988-2005	38.358	8.097.343	75.615	16.220.608
2006-2009	18.256	6.138.560	13.762	4.702.172
2010-2011	6.600	1.938.285	4.976	1.484.737
2012-2018	5.646	1.658.009	10.365	3.092.734
Total in 2018	**290.690**	**56.553.324**	**471.708**	**90.371.355**

The non-residential building stock increased by 7.151.193 m² between 2011 and 2018 (Table 3); however, given that no data is available on the public/commercial status of those buildings, in the model they were included in public and commercial sectors according to their current ratio.

Table 3 Non-residential stock of Croatia by construction year

	commercial		public	
	No of buildings	floor area	No of buildings	Floor area
	-	m^2	-	m^2
prior to 1941	2.338	1.498.159	12.365	1.545.813
1941-1970	12.587	8.064.602	22.525	2.815.845
1971-1980	6.733	5.251.934	19.021	1.882.000
1981-1987	4.323	5.108.279	10.158	2.152.000
1988-2005	10.596	8.107.287	11.059	2.722.497
2006-2009	6.199	6.352.000	3.673	2.073.747
2010-2011	1.952	2.158.198	1.395	610.000
2012-2018	6.354	5.190.616	11.392	1.960.577
Total in 2018	**51.082**	**41.731.075**	**91.588**	**15.762.479**

3.1.4. Buildings to be renovated by 2050

The share of renovated buildings in 2050 depends on the approach applied to building renovation and the overall size of the building stock – not renovated, renovated and newly built. Even if an expected increase in space standard from the current 30 m² of living area per person to 48 m² in 2050 is taken into account, population changes indicate that Croatia's permanently occupied residential floor area will be 158 mil. m² in 2050 which is increase of 22,5 % compared to the value of 129 mil. m² reached in the 2020.

In the period up to 2050, there will be no major territorial redistribution of the building stock at county level, primarily due to the small share of new builds compared to the size of the existing building stock. However, renovation will change the buildings' energy performance. The registered energy renovation rate of Croatia's building stock was 0.7 % of the building stock, or 1.35 mil. m² per year, between 2014 and 2020. Any further increase in the renovation rate between 2021 and 2050 depends largely on two critical factors – the first being the financial capacity of building owners and society as a whole to support a high rate of investment in buildings at a time of limited economic growth and depopulation, as well as the capacity of the construction sector to perform the appropriate scope of works.

The baseline value for monitoring the progress of renovation was determined based on the total building stock in 2020. For residential buildings, the floor area of newly built buildings and those renovated between 2011 and 2020 was deducted from the floor area of residential buildings permanently occupied in 2020 (128 960 894 m²) to obtain the useful floor area of 110 143 965 m² to be renovated in residential buildings by 2050, of which 42 395 923 m² in multi-apartment buildings and 67 748 042 m² in family houses. For non-residential buildings, the 2020 total useful floor area was 58 722 937 m², comprising 42 623 410 m² in commercial buildings and 16 099 527 m² in public buildings. The 2020 heated useful floor area of non-residential buildings amounted to 41 944 955 m2, of which 30 445 293 m² is accounted for by commercial buildings and 11 499 662 m2 by public buildings. That is the floor area size to be renovated by 2050.

Table 4 Total 2020 useful floor area of buildings for renovation

Permanently occupied residential buildings	128.960.894 m²
Residential buildings for renovation	**110.143.965 m²**
Family houses for renovation	67.748.042 m²
Multi-apartment buildings for renovation	42.395.923 m²
Non-residential buildings for renovation	**58.722.937 m²**
Commercial non-residential buildings	42.623.410 m²
Public non-residential buildings	16.099.527 m²
Total buildings for renovation	**168.866.902 m²**

Without policies to channel investment into renovation and preservation of the existing building stock, the pace of building renovation is generally slow. With the initial reason for construction being to meet the immediate and expected needs for space, investment is directed at the construction of new buildings. Only by actively channelling investment into increasing the rate of building renovation is it possible to affect the intensity of building renovation and the ratio of new construction to building renovation. Building renovation formally encompasses buildings being rebuilt and/or undergoing energy renovation, as well as those being built at the site of existing buildings, which are therefore removed (replacement construction). When monitoring the renovation rate, replacement buildings are difficult to identify because, as a rule, their purpose and size change and they are formally not linked to energy renovation.

3.1.5. Energy consumption and energy performance

The energy performance of buildings is determined using data available in the Information system of energy certificates (IEC), according to energy performance certificates collected and entered in the database between 30 September 2017 and 19 October 2019.

Energy ratings established according to the energy required for heating ($Q_{H,nd}$) by building type, based on the share in the total floor area of buildings (Figure 2), are evenly distributed in multi-apartment buildings and somewhat evenly distributed in office buildings (residential and office buildings are the most common building types), while all other building types show a shift towards lower (hospitals, family houses) and higher (shops, hotels and restaurants) energy ratings.

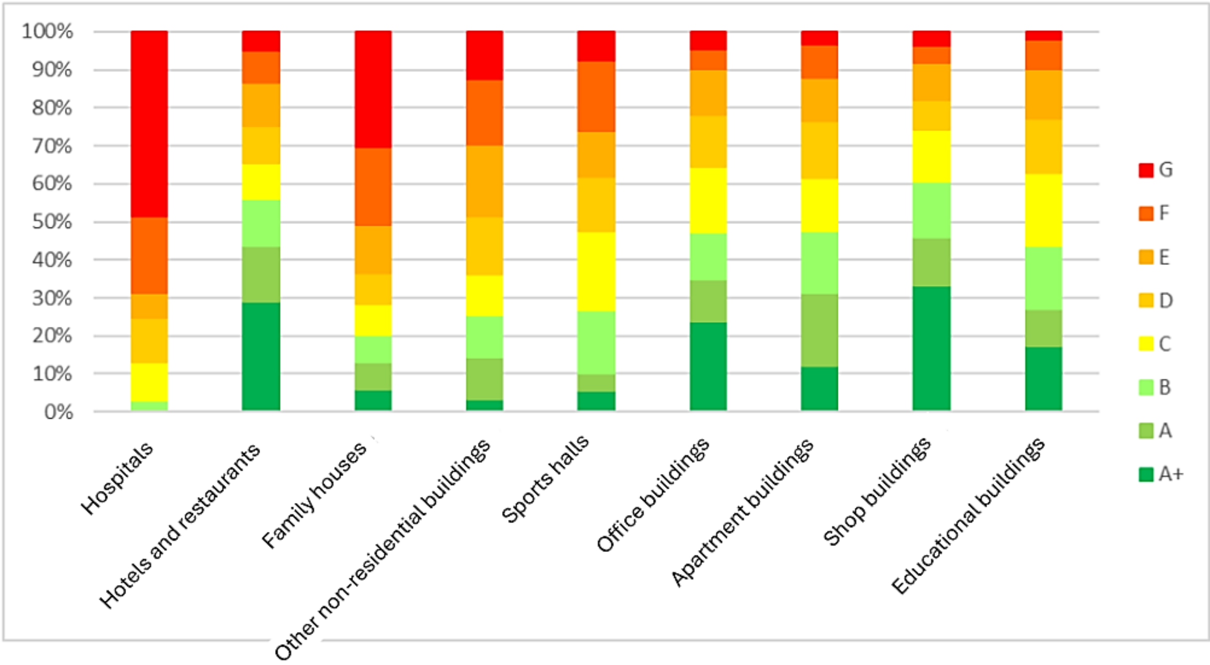

Figure 2 Distribution of energy ratings by $Q_{H,nd}$ by building type

An overview of energy ratings by primary energy (Figure 3) shows a greater share of energy performance certificates with lower energy ratings, probably as a consequence of the relatively recent introduction of primary energy as the main indicator of building energy performance. There is a significant discrepancy in the energy class of hotels and restaurants as well as office buildings by thermal energy required for heating and their primary energy rating. The main reason for this lies in the inclusion in primary energy of the energy required for cooling and lighting, which has a major share [in the energy consumption] in these types of buildings. The rating of energy performance certificates is determined based on the minimum requirements for new buildings and the average characteristics of existing buildings. The bounds of primary energy ratings for existing buildings are such that, based on the calculations made in accordance with the Methodology of energy audits of buildings and their purpose, the buildings which do not use quality technical solutions, such as hospital cooling systems (which have to be taken into account when assessing their energy ratings) are penalized for the systems they do not have installed and promptly downgraded to a lower energy class.

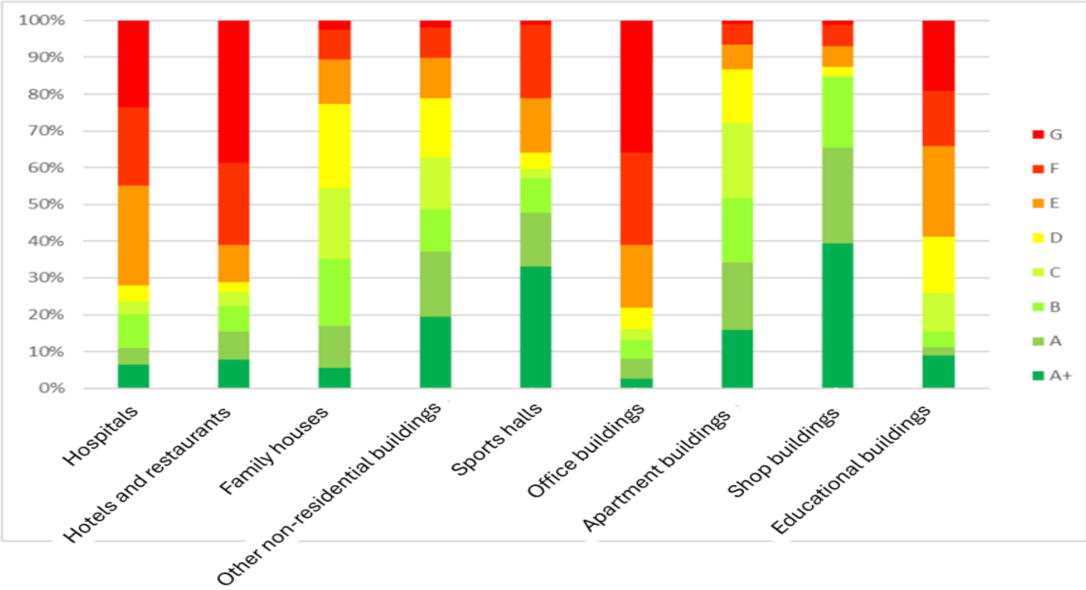

Figure 3 Distribution of energy ratings according to E_{prim} by building type

The **thermal transmittance** coefficients (U-values)[7] of typical external envelope structures fall progressively as the construction year of the building is further in the past (Figure 4). The thermal transmittance coefficient decreases most noticeably in glazed structures, where the average Uw equals 1.3 W/m²K. Having deteriorated in the 1970s, the thermal transmittance coefficient of the external wall structures, as well as flat and slanted roofs, subsequently reached 0.30 W/m²K and 0.25 W/m²K, respectively, while averaging 0.45 W/m²K for ground walls and floors on ground level. The average thermal transmittance coefficients of all buildings, indicating the average condition of the building stock, equal 1.02 W/m²K for external walls, walls bordering garage or ventilated attic, 0.63 W/m²K for flat and slanted roofs and ceilings bordering unheated attic, 0.97 W/m²K for grounds walls, and 2.21 W/m²K for windows and glazed structures. Changes in the average thermal transmittance coefficients of structures may be used as a direct indicator of increased energy efficiency of the building stock. It shows how stricter energy related regulations have influenced reduction of U-value for building envelope elements over the years.

[7] The "U" thermal transmittance coefficient is the measurement unit for determining the loss of heat in a building element. It expresses the quantity of heat which crosses a square meter of a building element per second for a temperature difference of 1°C between internal and external air.

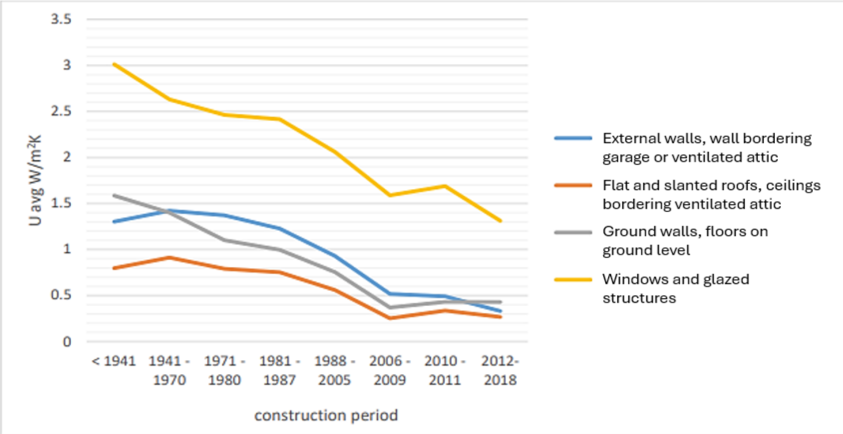

Figure 4 Change in typical thermal transmittance coefficients by construction period

3.1.6. Share/number of nZEB

According to data collected by the Ministry of Physical Planning, Construction and State Assets from administrative departments in charge of physical planning and construction, a total of 145 nZEBs with a total floor area of 176.981m² were built between 1 April 2014 and 31 December 2019 (Table 5). In the database of energy performance certificates of buildings (for the certificates entered into the IEC up to 29 October 2019), there were entries for a total of 616 buildings meeting nZEB requirements even before these became mandatory for public buildings in 2019. However, before the 2019 obligation came into force, check for compliance was not recorded. Therefore, 1,6 % of buildings with an energy performance certificate issued in 2018 and 2019 are classified as nearly Zero Energy Buildings.

Table 5 Number of nZEBs based on reports of administrative department in change of physical planning and construction

Total nZEBs for the period	Total gross floor area (m²)	Total net floor area (m²)	period
22	47.790	42.879	1 January 2014 – 30 June 2017
18	14.220	8.171	1 July 2017 – 31 December 2017
17	9.007	8.360	1 January 2018 – 30 June 2018
38	73.931	59.632	1 July 2018 – 31 December 2018
49	31.668	28.494	1 January 2019 – 30 June 2019
1	365	307	1 July 2019 – 31 December 2019
145	**176.981**	**147.843**	

3.2. Overview of the national public building stock

The Technical Regulation on the Rational Use of Energy and Thermal Insulation in Buildings[8] includes definitions of buildings based on their purpose, and public purpose buildings may be classified into any of the nine purposes stipulated according to the manner of use of the building:

[8] The Technical Regulation on the Rational Use of Energy and Thermal Insulation in Buildings

- family house, hotel and restaurant, store - as rarely present purposes in the public sector,
- multi-residential (for community housing), office, educational, hospital, sports hall, and other non-residential buildings - as mostly present purposes in the public sector.

All data, including images, tables and textual descriptions are taken from Long term strategy for national building stock renovation by 2050 (Ministry of Physical Planning, Construction and State Assets), Energy in Croatia (Ministry of Economy and Sustainable Development), Program for energy refurbishment of public sector buildings 2016-2020 and Integrated National Energy and Climate Plan for the Republic of Croatia (for the period 2021-2030).

3.2.1. Total gross floor area

The total area of public sector buildings determined in the Public Sector Building Energy Renovation Program for the period 2016-2020 amounts to 13.801.902 m^2. In 2020 this number increased by 2.297.625 m^2 and the final value was 16.099.527 m^2.

3.2.2. Public buildings to be renovated by 2050

It is a fact that the energy renovation in the public sector is not taking place at a fast enough pace. When it comes to types of energy renovations of buildings, there are deep energy renovations (DER) and partial renovations. Most of the public sector buildings have not even been renovated, as shown below (Table 6). Data on the state of energy renovation is modeled according to the total area of public sector buildings, as well as according to the purposes and area of completely and partially renovated buildings in ISGE.

Table 6 Current state of the renovation process in the public sector (useful area of the heated part of the building A_k in m^2)

	Energy renovation		
	DER (m^2)	Partial (m^2)	not renovated (m^2)
Single-family homes	0	0	4.863
Multi-apartment buildings	50.983	130.194	825.018
Office buildings	7.793	156.921	3.306.792
Educational buildings	16.747	979.084	4.186.382
Hospital buildings	150.958	276.854	1.357.913
Restaurants and hotels	2.052	29.434	60.127
Museums and libraries	0	27.147	577.050
Sports halls	13.162	89.456	508.465
Trade services	0	138	30.880
Other non-residential buildings	231	1.574	34.244
TOTAL	**241.925**	**1.690.801**	**10.891.735**

It is evident that hospital buildings are the front-runners in terms of deep energy renovation, which is not so strange due to the fact that energy renovation is not expressed by the number of renovated buildings but by the building useful area which has been renovated. Knowing the size of those buildings, it is not surprise that 62 % out of total renovated useful area (DER) refers to hospitals. On the other hand, in category of partial renovation, educational buildings clearly stand out with 58 % of renovated useful area out of the total number of 1.690.801 m^2. This is also expected due to the fact that numerous calls for national subsidies were aiming this type of buildings.

3.2.3. Public building stock categories by purpose and by year of construction

The buildings of the public sector are divided according to purpose into a total of nine categories:

1. Single-family homes
2. Residential buildings - multi-apartment buildings
3. Office buildings
4. Educational buildings
5. Hospital buildings
6. Restaurants and hotels
7. Other non-residential buildings
8. Sports halls
9. Shops
10. Other

The distribution of the share of individual categories in the total fund was determined according to the available data of the Information System for Energy Management (ISGE), whereby the types of buildings according to the Ordinance on energy inspection of the building and energy certification.

The following Table 7 shows the usable area of the heated part of public buildings sector according to purpose and period of construction.

Table 7 Area of the usable area of the heated part of the building (A_k) according to purpose and period of construction in m²

	construction period									
purpose	all construction period	≤ 1945	1946-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020	no data
Single-family homes	6.105	1.167	0	188	251	0	53	44	94	4.308
Residential buildings - multi-apartment buildings	1.263.152	214.957	62.582	144.306	161.629	207.193	50.606	54.182	26.272	341.426
Office buildings	4.358.047	977.266	267.518	253.651	358.989	255.999	157.236	174.780	42.142	1.870.466
Educational buildings	6.505.629	1.275.959	630.027	875.762	1.028.385	658.072	295.187	379.063	116.896	1.246.279
Hospital buildings	2.241.757	531.136	158.031	208.975	333.889	323.327	41.895	105.790	5.976	532.738
Restaurants and hotels	115.009	1.141	5.859	0	0	46.556	0	0	679	60.756
Museums and libraries	758.495	181.807	25.714	28.102	51.438	33.414	63.334	53.449	54.955	263.283
Sports halls	767.140	21.262	16.926	10.876	101.049	58.718	35.288	248.926	34.863	239.231
Trade services	38.939	3.828	1.658	1.290	2.241	1.856	87	3.430	0	24.549
Other	45.254	1.300	0	267	9.228	4.940	637	19.27	0	9.605
In total	**16.099.527**	**3.212.823**	**1.168.314**	**1.523.417**	**2.047.099**	**1.590.074**	**644.323**	**1.038.940**	**281.895**	**4.592.642**

3.2.4. Public buildings energy consumption

Specific annual required thermal energy for heating for residential buildings in the public sector due to the small number of buildings belonging to this group was determined according to the data on the characteristic reference residential buildings according to the construction period up to 1970, 1971 to 2005 and after 2005, while for non-residential buildings it is determined according to data from the database of issued energy certificates, separately according to climatic area and period of construction. Following two tables (Table 8, Table 9) show Specific annual required thermal energy for heating (kWh/m²year) according to the purpose and construction period of the building for Continental and Coastal Croatia.

Table 8 Specific annual required thermal energy for heating (kWh/m²year) according to the purpose and construction period of the building for Continental Croatia

	<1945 (kWh/m²a)	1945-1960 (kWh/m²a)	1961-1970 (kWh/m²a)	1971-1980 (kWh/m²a)	1981-1990 (kWh/m²a)	1991-2000 (kWh/m²a)	2001-2010 (kWh/m²a)	2011-2020 (kWh/m²a)
Single-family homes	220	220	220	160	160	160	80	80
Residential buildings - multi-apartment buildings	150	150	150	110	110	110	80	80
Office buildings	158	170	171	189	173	108	78	65
Educational buildings	171	163	158	142	128	118	82	64
Hospital buildings	191	173	196	157	157	137	97	80
Restaurants and hotels	201	178	214	217	171	135	100	74
Museums and libraries	259	225	246	231	218	160	125	133
Sports halls	202	225	151	209	207	134	148	80
Trade services	173	201	200	227	168	107	101	65
Other	-	-	-	-	-	-	-	-

Table 9 Specific annual required thermal energy for heating (kWh/m²year) according to the purpose and construction period of the building for Coastal Croatia

	<1945 (kWh/m²a)	1945-1960 (kWh/m²a)	1961-1970 (kWh/m²a)	1971-1980 (kWh/m²a)	1981-1990 (kWh/m²a)	1991-2000 (kWh/m²a)	2001-2010 (kWh/m²a)	2011-2020 (kWh/m²a)
Single-family homes	130	130	130	90	90	90	60	60
Residential buildings - multi-apartment buildings	100	100	100	90	90	90	50	50
Office buildings	182	103	96	104	88	65	52	61
Educational buildings	100	93	86	161	80	80	60	35
Hospital buildings	115	107	110	91	91	69	49	40
Restaurants and hotels	119	135	122	106	91	101	63	45
Museums and libraries	130	143	134	128	119	133	70	49
Sports halls	83	105	132	183	182	64	78	66
Trade services	100	115	112	113	94	83	54	42
Other	-	-	-	-	-	-	-	-

Another way of analysing energy consumption in public sector buildings is the assessment of annual delivered and primary energy by type of building. It is determined based on a model data on the building stock and the average required thermal energy for heating, and data on the delivered and primary energy for buildings in ISGE.

If we summarize Table 8 and Table 9, we get Table 10 which shows specific annual required thermal energy for heating, cooling and domestic hot water, as well as delivered and specific annual primary energy for heating, cooling, hot water consumption and lighting kWh/m²year by type of building and climate for all types of public building sector.

Total consumption of primary energy for thermal needs (heating, cooling, ventilation, preparation of domestic hot water and lighting) for 16.099.527 m² of public sector buildings before renovation amounts to 3.593 GWh per year, with the generated emission of 602.804 tons of CO_2. The delivered energy for the energy needs of buildings amounts to 2.621 GWh per year

Table 10 Specific annual required thermal energy for heating, cooling and domestic hot water, as well as delivered and specific annual primary energy for heating, cooling, hot water consumption and lighting kWh/m²year by type of building and climate

	Continental Croatia			Coastal Croatia		
	specific required thermal energy for heating, cooling and domestic hot water kWh/m²a	E_{del} for heating, cooling, domestic hot water and lighting kWh/m²a	E_{prim} kWh/m²a	specific required thermal energy for heating, cooling and domestic hot water kWh/m²a	Edel for heating, cooling, domestic hot water and lighting kWh/m²a	E_{prim} kWh/m²a
Single-family homes	185	**242**	**318**	135	**185**	**254**
Residential buildings - multi-apartment buildings	145	**196**	**251**	145	**205**	**275**
Office buildings	192	**170**	**234**	209	**142**	**204**
Educational buildings	183	**148**	**201**	180	**117**	**166**
Hospital buildings	335	**239**	**322**	329	**189**	**270**
Restaurants and hotels	287	**228**	**310**	296	**185**	**263**
Museums and libraries	203	**171**	**226**	234	**142**	**196**
Sports halls	205	**216**	**280**	219	**168**	**226**
Trade services	287	**168**	**232**	321	**142**	**210**

3.3. Overview of the current state of related policies

3.3.1. EU legislation in the field of energy efficiency

Energy efficiency is one of the five dimensions of the European Energy Union. Through the principle "Energy efficiency first", the European Union has recognized and confirmed that energy efficiency is Europe's most important source of energy. The main determinants of EU energy efficiency policy, with a focus on buildings sector, are given in the following directives and regulations:

- **Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast)**

- **Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)**

- **Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652**

In addition to directives, the EU has recognized the importance of energy efficiency and energy renovation of buildings through new initiatives, such as:

- Green Deal
- Renovation wave
- Fit for 55
- Just transition mechanism
- REPower EU

3.3.2. National legislation in the field of energy efficiency

Energy efficiency in the Republic of Croatia is regulated by:

• Energy Efficiency Act (OG Nos. 127/14, 116/18, 25/20, 32/21, 41/21),

• Building Act (OG Nos. 153/13, 20/17, 39/19, 125/19),

• Act on Protection against Light Pollution (OG No. 14/19),

• by-laws that follow from these Acts.

An overview of the regulatory measures defined in the aforementioned laws and relevant by laws is shown in Table 11. The aforementioned laws and regulations in Croatia meet the requirements of the following EU directives:

- Directive 2012/27/EU of the European Parliament and of the Council of 25th October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (Text with EEA relevance (OJ L 315, 14th Nov 2012);

- Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency (Text with EEA relevance) (OJ L 328, 21st Dec 2018) - (hereinafter: the Energy Efficiency Directive);

- Directive 2010/31/EU of the European Parliament and of the Council of 19th May 2010 on the energy performance of buildings (recast) (OJ L 153, 18th Jun 2010.);

- Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance) (OJ L 156, 19th Jun 2018) (hereinafter: the Directive on Energy Performance of Buildings);

- Directive 2010/30/EU on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products, and Regulation 2017/1369 setting a framework for energy labelling and repealing Directive 2010/30/EU (Text with EEA relevance.) (OJ L 198, 28th Jul 2017);

- Directive 2009/125/EC of the European Parliament and of the Council of 21st October 2009 establishing a framework for setting eco-design requirements for energy-related products (recast) (Text with EEA relevance) (OJ L 285, 31st Oct 2009).

Table 11 Overview of existing regulatory measures for energy efficiency

ENERGY EFFICIENCY ACT
The obligation of the Government of the Republic of Croatia to adopt the National Energy Efficiency Action Plan for three years with measures to be implemented on the entire territory of the Republic of Croatia under the Integrated National Energy and Climate Plan (NECP), which defines alternative policy measures including measures to ensure the annual renovation of 3 % of the total floor area of heated and/or cooled buildings owned and used by the central government.
The obligation of counties and large cities (> 35,000 inhabitants) to adopt (three-year) Action Plans and annual energy efficiency plans.
Energy efficiency obligation scheme for energy suppliers – encourages the implementation of energy efficiency measures in households affected by energy poverty or in social housing spaces.
Supplier's obligations to measure and account for consumption and to inform customers about past consumption, including comparison with the average normal or reference final customer from the same category of final customers.
The obligations of energy distributors are to enter data on metering and consumption of energy in the public sector monthly in the national Energy Management Information System (ISGE) and to provide individual meters to final customers.

The obligations of the Energy Regulatory Authority are to promote energy efficiency through tariffs and provide incentives to improve efficiency in the planning and operation of natural gas and electricity infrastructure.
The obligations of transmission and distribution system operators are to provide network access, transmission and distribution of electricity produced from high-efficiency cogeneration.
The obligations of large enterprises on implementing energy audits every four years introducing an energy management system - Ordinance on energy audit for large enterprises (OG 123/15, 5/20, 97/21).
The public sector must conduct energy audits of public lighting systems every five years and maintain and reconstruct public lighting in such a way as to reduce electricity consumption and meet other requirements prescribed by the Act on Protection against Light Pollution (OG 14/19) and the regulations arising from it.
The public sector must systematically manage energy, which implies the appointment of a responsible person for energy management, regular monitoring of energy consumption and the entry of data on energy consumption into the national information system for energy management (ISGE) - Ordinance on systematic energy management in the public sector (OG 18/15 and 06/16).
The obligation is to report all energy efficiency activities and realized savings in the national system for monitoring, measuring and verification of savings (SMiV) for the public sector, energy service providers and subsidy providers - Ordinance on the system for monitoring, measuring and verification of energy savings (OG 98/21, 30/22).
The competent ministries and the National Coordinating Body (NKT) are obligated to establish and run an energy efficiency platform - National Energy Efficiency Portal: https://www.enu.hr/.
Energy-related device labelling obligation - relevant EU regulations for individual groups of devices.
Regulation of energy services (energy performance contracts) in the public sector - Regulation on contracting and implementation of energy services in the public sector (OG 11/15).
It regulates the contracting of multi-apartment building energy services, and energy renovation works. It determines the adoption of a decision on energy renovation based on a simple majority of votes of co-owners, which is calculated by co-ownership parts.
The obligation is to use energy efficiency criteria in public procurement procedures for energy-related products - Ordinance on energy efficiency requirements in public procurement procedures (OG 70/15).
The obligation is to meet the requirements for eco-design of energy-related products when placed on the market - Ordinance establishing conditions for eco-design of energy-related products (OG 50/15)

Ordinances on conditions and criteria for determining the quality-of-service systems and works for certification of installers of renewable energy sources - photovoltaic systems (OG 56/15); solar thermal systems (OG 33/15, 56/15 and 12/17); smaller biomass boilers and stoves (OG 39/15, 56/15 and 12/17); shallow geothermal systems and heat pumps (OG 56/15 and 12/17).
CONSTRUCTION ACT
Energy management and heat conservation are essential requirements for buildings - Technical regulation on rational energy use and thermal protection in buildings (OG 128/15, 70/18, 73/18, 86/18 and 102/20). Minimum energy performance of buildings, method of determining the energy performance of buildings, presentation of the technical, environmental, and economic feasibility of available high-efficiency alternative energy supply systems, equipping buildings with automation systems, and requirements for nearly zero energy buildings.
The Government should adopt the Long-Term Strategy for the Renovation of the National Building Stock of the Republic of Croatia at the proposal of the Ministry responsible for the construction and update it every five years.
The Government should adopt energy renovation programs for buildings from 2021 to 2030 at the proposal of the ministry responsible for construction affairs.
The Government should adopt the Green Infrastructure Development Program from 2021 to 2030 at the proposal of the Ministry responsible for construction affairs
The Government should adopt the Circular Management programme for spatial buildings from 2021 to 2030 at the proposal of the ministry responsible for construction affairs.
Promoting electromobility and establishing charging infrastructure in new buildings and buildings undergoing significant renovation for residential and non-residential buildings.
The obligation is to regularly inspect heating and cooling or air conditioning systems in buildings and energy certification of buildings. Ordinance on energy audit of buildings and energy certification (OG 88/17, 90/20, 1/21 and 45/21). Ordinance on the control of the energy certificate of the building and the report on regular inspection of heating systems and cooling systems or air conditioning in the building (OG 73/15 and 54/20). Ordinance on persons authorized for energy certification, an energy audit of buildings and regular inspection of heating systems and cooling or air conditioning systems in buildings (OG 73/15, 133/15, 60/20 and 78/21).
ACT ON PROTECTION AGAINST LIGHT POLLUTION
When planning, designing, constructing, maintaining, and reconstructing outdoor lighting, which is approved under the law governing construction, such technical solutions must be selected by the lighting project to ensure energy efficiency; local self-government units are obliged to adopt a lighting plan as well as an action plan for the construction/reconstruction of lighting; the Ordinance prescribes energy efficiency criteria for lighting. Ordinance on the content, format, and manner of drafting a lighting plan and action plan for the construction and / or reconstruction of outdoor lighting (OG 22/23).

4. ASSESSMENT OF ENERGY PERFORMANCE OF RENOVATED PUBLIC BUILDINGS

To analyse energy renovations at the national level, publicly available documents have been used (desk research) which contain all the necessary information to obtain a comprehensive view of energy renovations at the national level. At the local level, the Croatian ISGE information system was used, from which is possible to extract data on energy consumption for each individual building. ISGE is a computer application for monitoring and analysing energy consumption in public sector buildings in which general building data and energy performance data, as well as data on immediate energy and water consumption for each public building, are entered through an internet portal. Likewise, in the ISGE system, it is possible to obtain different types of data related to the characteristics of the building, such as: Gross floor area of the building [m²], Effective area of the gross floor area of the building [m²], Area of the heated part of building A [m²], Volume of the heated part of the building V_e [m³], Area of the cooled surface of the building, A_{kh} [m²], Area of the cooled part of the building A_h [m²], Volume of the cooled part of the building V_{eh} [m³], Number of floors and other relevant data for analysis.

4.1. Assessment of energy performance of renovated public buildings at national level

On October 31, 2013, the Government of the Republic of Croatia adopted the Program for energy renovation of public sector buildings for period 2014-2015. The goal of the Program was to meet the requirements of the Energy Efficiency Directive, i.e. to renovate each year at least 3 % of the total floor area of buildings owned by public bodies. The goal of the Program was the contracting and implementation of a complete energy renovation of public buildings sector with a total area of about 400.000 m², which would achieve a reduction in energy consumption of 30-60 % (about 150 kWh/m² per year) and reduction of carbon dioxide emissions by 20.500 tons, initiated investments of approx. EUR 55 million and initiated the development of the ESCO (energy service company) market. The fundamental characteristic of this Program was that is based on the energy service model[9] in accordance with the Regulation on contracting and implementation of energy services into the public sector, which made it possible to spend without additional budget funds owner's/user's means to implement energy efficiency improvement measures in public buildings sector.

The results of the Program are as follows:

- 69 buildings have been renovated at 12 locations,
- The renovated usable area of the heated part of the building is 248.661,82 m², which represents 62 % of the set goal,
- The average achieved savings in direct energy consumption (delivered energy) are 51,69 %, or a total of about 60 GWh/year, which means a reduction of up to 240 kWh/m²/year,
- Financial savings of over 4 million EUR/year have been achieved,
- The share of RES in the supply of renovated buildings is almost 20 % of the buildings' total energy requirement

[9] Energy service (performance-based) model is a business model used to finance and implement energy efficiency and sustainable energy projects where the ESCO company undertakes the financing of the project and is responsible for achieving savings. The end user pays the ESCO company depending on the amount of energy saved (long term contract).

The problems in the implementation of this Program were related to the lengthy process of preparing the project tasks as a basis for announcing public procurement, but this part of the process is absolutely necessary.

Namely, data on the existing state of the building, legal status of the building, projects defining the existing conditions of the building are often lacking in practice, and the original documentation is rarely available in archives or in the possession of the user or owner buildings. In addition to this, interventions are often carried out on public sector buildings without appropriate documentation, which also affects the location permit and the legal status of the building. Therefore, good preparation of input data is necessary, which should be the responsibility of the owner of the building.
Perception of high riskiness of ESCO projects by financial institutions and the impossibility of insurance of the ESCO company's own funds for project implementation is also one of the significant barriers in implementation of this model. Determining energy savings is a key element of any ESCO project. It is necessary to enable determination savings and by measuring energy consumption before and after renovation and usage regime with the creation of dynamic building simulations.

All problems are also recognized in the Program for energy renovation of public sector buildings for the period 2016–2020 adopted by the Government of the Republic of Croatia. The goal of this Program was a complete renovation that will achieve a reduction in energy consumption in buildings public sector up to 70% and annual energy savings of around 50 GWh. This Program foresees a continued implementation of the renovation according to the ESCO model as well as according to the contracting model, and it was foreseen for both models use of grants from the European Regional Development Fund (ERDF) based on the Operational program "Competitiveness and cohesion 2014-2020" (OPCC).

However, in the past period, an appropriate model of using European Structural and Investment (ESIF) funds was not adopted in addition to the ESCO model, so the aforementioned renovation Program was implemented solely on the basis of the allocation of grants through public calls, which is announced by Ministry of Physical Planning, Construction and State Assets as intermediary body of level 1, and implemented by Fund for Environmental Protection and Energy Efficiency as intermediary body of level 2. With this Program, 4 calls were announced. Three invitations referred exclusively to public institutions engaged in education, while one, and the last invitation, was open to all public sector buildings.

In total, over EUR 253.4 million has been allocated for projects under these four calls. It should be noted that the originally planned allocation according to OPCC for this specific goal was EUR 211 million, so these data clearly show the needs and interest of the public sector in energy renovation of buildings. €53 million from the OPCC programme was allocated to a financial instrument, i.e. to the lending program managed by Croatian Bank for Reconstruction and Development. These funds were intended to cover the financing gap of projects that were previously granted subsidies based on the decision on financing within the specific call “Reduction of energy consumption in public sector buildings” SC 4c1. Interest rates on the loan were in the range between 0,1 % and 0,5 %, depending on the level of development of the area in which the investment is carried out. So far with this loan program 66 users were supported. In November 2021, the allocation was reduced to around EUR 30 million and the program closed.

According to data from the System for monitoring, measuring and verifying energy savings, the energy savings achieved are shown in Table 12 below:

Table 12 Effects of the energy renovation program of public sector buildings for the period 2014. - 2020.

Year of implementation	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**
New annual savings - Program 2014-15 [PJ]	0	0,0342	0,0293	0,0715	0,0946	0	0
New annual savings – Program 2016-20 [PJ]	0	0	0	0,0225	0,0301	0,2499	0,1796
New annual savings – Fund for Environmental protection and Energy Efficiency [PJ]	0	0,0879	0,0406	0,0406	0	0,0001	0,0009
Total annual savings in 2020 [PJ]	**0,8646**						
Cumulative savings 2014-2020 [PJ]	**2,5895**						

According to National Energy Efficiency Action Plan the projected cumulative savings in 2020 was 2.7700 PJ, and from the table above it is evident that about 93 % of this goal has been achieved. At the same time, 36 % of the achieved cumulative savings comes from projects implemented using the ESCO model, 30 % from projects co-financed by OPCC, and 34 % from projects co-financed by Environmental protection and Energy Efficiency Fund. This distribution is understandable, given that the projects using the ESCO model and projects co-financed by Environmental protection and Energy Efficiency Fund have been implemented earlier, therefore their cumulative effect is greater comparing to the projects co-financed by OPCC which started 2 years later. Looking at the achieved annual savings, projects have the greatest effect or share in savings co-financed from OPCC with 56 %, then ESCO projects with 26 %, and then projects co-financed by Fund for Environmental protection and Energy Efficiency with 18 %. These data tell us much more:

- from OPCC, large funds were invested in around 800 projects energy renovations, most of which had to meet the requirement of 50 % savings in $Q_{H,nd}$ after implementation energy renovation compared to the state before the renovation, and significant new annual savings were achieved
- according to the ESCO model, 69 buildings were renovated in 12 locations, and the savings from that are relatively small number of projects comparable to others
- the least new annual savings were expected to be achieved from implementation of projects which introduced single renovation measures.

As shown in chapter 3.2.2., in energy renovation projects of public buildings which are conducted so far, there is significant number of partial renovations done and a very low number of deep energy renovations. Most of the public sector buildings have not even been renovated, as shown below (

Table *13*). Moreover, for those public buildings which have been partially renovated, it can be concluded they do not meet the minimum requirements in terms of energy performance according to the national legislation, meaning they have been renovated (partially) but they did not fulfill the full potential of energy savings – **they are underperforming**.

The fact is that during the program period from 2014 to 2020, numerous legal amendments happened, especially with regard to meeting the energy performance requirements, and therefore the energy renovation projects that were realized during that period did not have to meet the current requirements in terms of minimum energy performance. Additionally, despite the fact that maximum permitted values for existing buildings during reconstruction have been set according to the technical regulation, there are some exceptions which allow the project designer to not meet the maximum permitted values if it can be proved that EE measures needed to meet these values are technically, functionally and economically unjustified, thus limiting the building to reach its full potential of energy savings.

Table 13 Not renovated and partially renovated public sector buildings (useful area of the heated part of the building in m2)

	Energy renovation	
	Partial (m^2)	Not renovated (m^2)
Single-family homes	0	4.863
Multi-apartment buildings	130.194	825.018
Office buildings	156.921	3.306.792
Educational buildings	979.084	4.186.382
Hospital buildings	276.854	1.357.913
Restaurants and hotels	29.434	60.127
Museums and libraries	27.147	577.050
Sports halls	89.456	508.465
Trade services	138	30.880
Other non-residential buildings	1.574	34.244
TOTAL	**1.690.801**	**10.891.735**

4.2. Deeper analysis of energy renovated public buildings on a local level to address the underperforming energy renovations issue

Four buildings in different counties in Croatia have been selected for performing deeper energy performance analysis. All selected buildings went through the renovation process but are showing signs of underperformance. Results of this chapter will serve to better understand and identify the possible reasons behind underperforming renovations in public buildings.

In order to perform analysis of energy renovated public buildings on a local level the following methodology was used. Based on an extensive research of energy renovated public buildings on a municipal level in three different counties in Croatia, four buildings, showing the signs of underperformance, have been selected for further detail analysis. The first step was to compare the energy savings calculation from their respective master project documentation with the building code requirements for specific type of the building (educational – mostly schools and kindergartens). Primary energy was used as the main indicator for comparison. If the calculated primary energy of the renovated building is lower than the maximum allowed primary energy defined by the building code, it will be concluded this building is underperforming, i.e. it has not achieved its full potential of energy savings. The following table (Table 14) shows the maximum permitted values for existing buildings heated and/or cooled to temperature 18 °C or higher during reconstruction according to the Technical regulation on energy economy and heat retention in buildings (Official Gazette 128/15 - Provisional Translation, 70/18 - Provisional Translation, 73/18, 86/18, 102/20). Calculated values of primary energy consumption after the renovation have been obtained by using the master project documentation which has been developed specifically for the purpose of energy renovation of analysed buildings.

Table 14 Maximum permitted values for existing buildings heated and/or cooled to temperature 18 °C or higher during reconstruction according to Technical regulation

Renovation requirements	$Q''_{H,nd}$ [kWh/(m²·a)]						E_{prim} [kWh/(m²·a)]	
	Continental $\theta_{mm} \leq 3$ °C			Coastal $\theta_{mm} > 3$ °C			Continental	Coastal
Building type	$f_0 \leq 0{,}20$	$0{,}20 < f_0 < 1{,}05$	$f_0 \geq 1{,}05$	$f_0 \leq 0{,}20$	$0{,}20 < f_0 < 1{,}05$	$f_0 \geq 1{,}05$	$\theta_{mm} \leq 3$ °C	$\theta_{mm} > 3$ °C
Multiapartment	50,63	$40{,}49 + 50{,}73 \cdot f_0$	93,75	27,00	$21{,}59 + 27{,}06 \cdot f_0$	50,00	180	130
Family house	50,63	$40{,}49 + 50{,}73 \cdot f_0$	93,75	27,00	$19{,}24 + 38{,}82 \cdot f_0$	60,00	135	80
Office building	21,18	$11{,}03 + 50{,}73 \cdot f_0$	64,29	17,60	$12{,}19 + 27{,}06 \cdot f_0$	40,60	75	75
Educational	14,98	$4{,}84 + 50{,}73 \cdot f_0$	58,10	10,81	$5{,}40 + 27{,}06 \cdot f_0$	33,83	90	75
Hospital	23,40	$13{,}26 + 50{,}73 \cdot f_0$	66,51	50,48	$45{,}06 + 27{,}06 \cdot f_0$	73,48	340	330
Hotel/restaurant	44,35	$34{,}21 + 50{,}73 \cdot f_0$	87,48	12,50	$7{,}09 + 27{,}06 \cdot f_0$	35,50	145	115
Sports hall	120,49	$110{,}35 + 50{,}73 \cdot f_0$	163,61	40,91	$35{,}50 + 27{,}06 \cdot f_0$	63,93	420	215
Trade services	61,14	$50{,}99 + 50{,}73 \cdot f_0$	104,25	15,11	$9{,}71 + 27{,}06 \cdot f_0$	38,13	475	300
Other	50,63	$40{,}49 + 50{,}73 \cdot f_0$	93,75	27,00	$21{,}59 + 27{,}06 \cdot f_0$	50,00	180	130

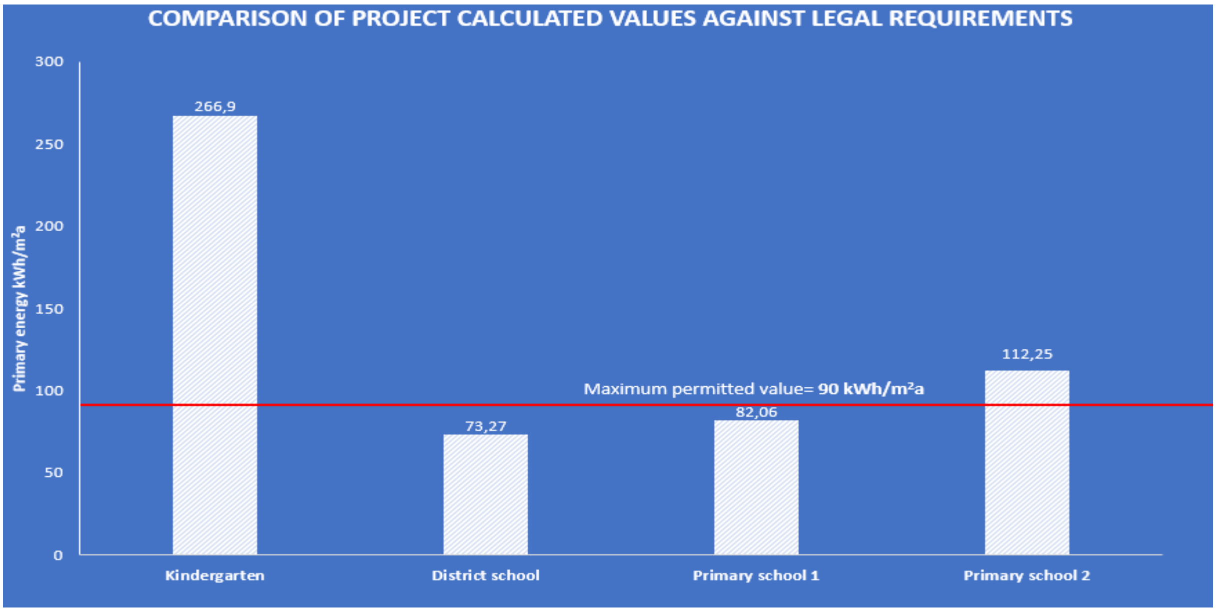

Figure 5 Comparison of project calculated values (primary energy) against legal requirements for analysed renovated educational buildings in ***Croatia (continental part)***

It is clear that two out of four analysed buildings are showing the signs of underperformance because they do not meet the legal requirements in terms of maximum permitted values of primary energy for existing buildings heated and/or cooled to temperature 18 °C or higher during reconstruction. However, it should be noted that exceptions during design phase do exist, and they are defined in the legislation, but this does not change the fact these buildings did not achieve the full potential of energy savings.

Moreover, to elaborate underperforming issue in detail, analysis was made on three specific buildings to compare their calculated energy savings with the real consumption data in years after the renovation. In order to avoid the climate impact (difference in number of heating degree days in reference year prior the renovation and in years after the renovation), linear regression function was used in order to get comparable consumption values without climatic influences.

The following figures (Figure 6, Figure 7, Figure 8) show comparison graphs - for the reference year before the renovation (delivered/final energy consumption (Edel), measured real consumption) and for the year after the renovation (measured real consumption, calculated energy consumption Edel and adjusted real consumption to the heating degree days in the reference year).

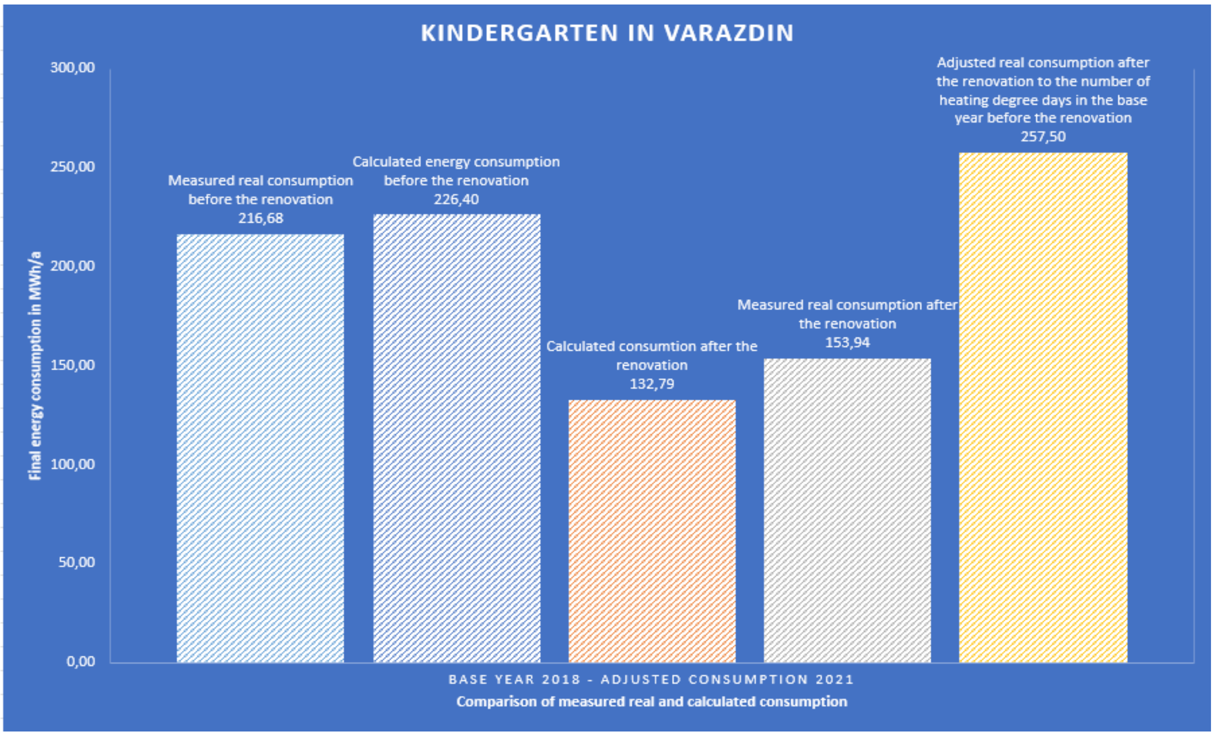

Figure 6 Comparison of project calculated delivered energy for heating against measured real consumption and adjusted real consumption (using heating degree days) for analysed kindergarten in ***Croatia (continental part)***

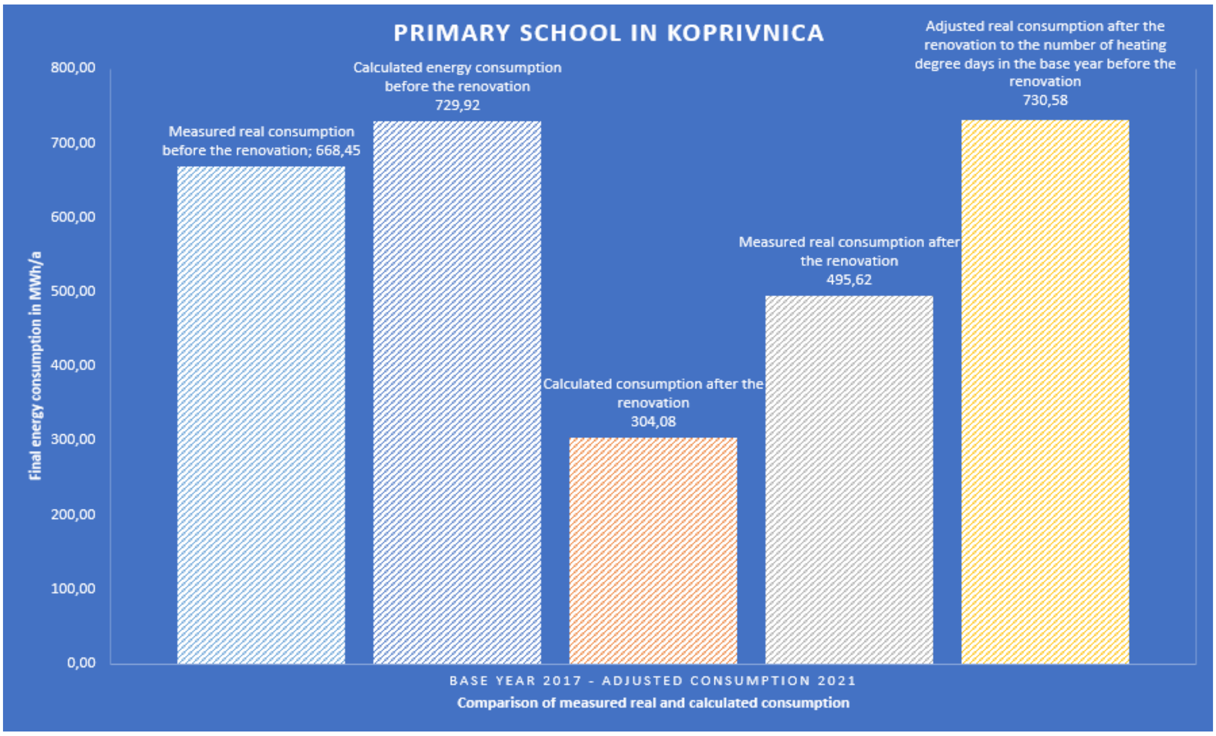

Figure 7 Comparison of project calculated delivered energy for heating against measured real consumption and adjusted real consumption (using heating degree days) for analysed school in ***Croatia (continental part)***

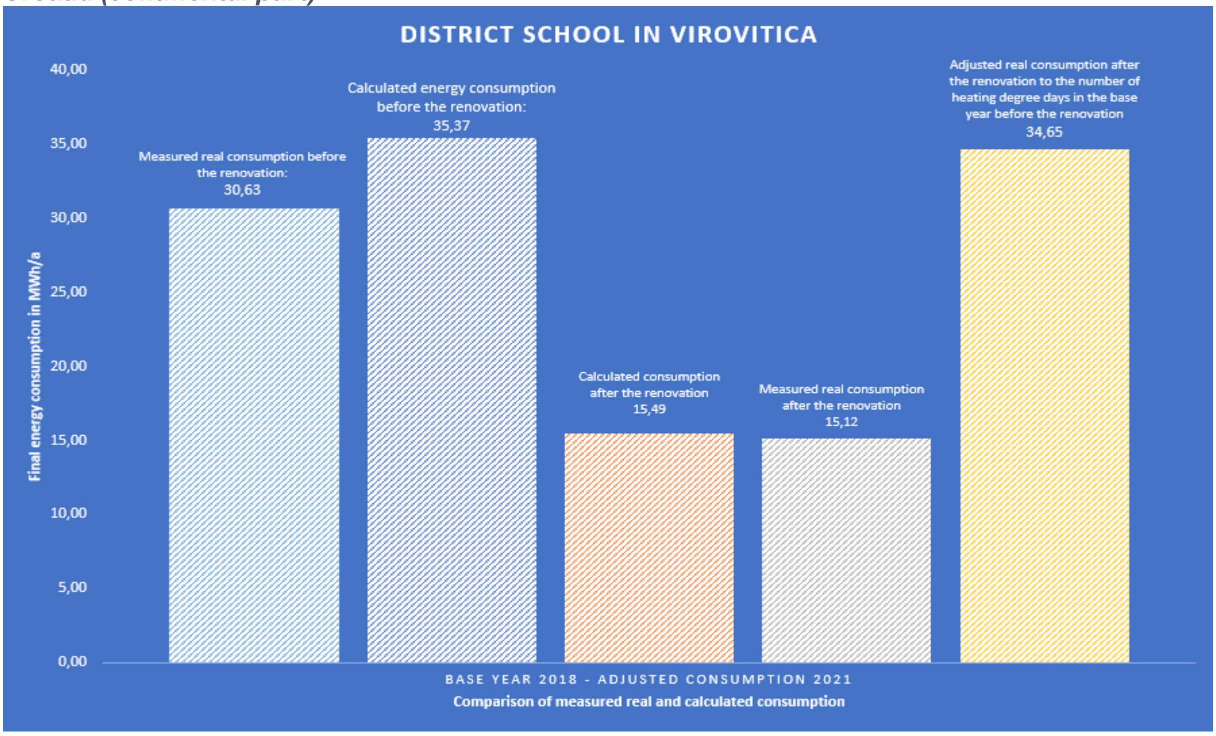

Figure 8 Comparison of project calculated delivered energy for heating against measured real consumption and adjusted real consumption (using heating degree days) for analysed school in ***Croatia (continental part)***

All three graphs show the differences between the consumption of the calculated values and the measured real consumption after the renovation. After adjustment of the real consumption after the renovation to the same climatic conditions as in the base year before the renovation (linear regression function), there is a clearly visible higher energy consumption (adjusted) in the year after the renovation compared to the calculated consumption after the renovation.

First of all, the difference between the project calculated energy consumption before the renovation and measured real consumption before the renovation will be analysed. There is a minor difference (5-13 %) in calculated energy consumption and measured real energy consumption before the renovation. A potential reason for that could be the applied national methodology for calculation of energy consumption which defines the internal project temperature for different types of buildings. For this particular case the temperature of 20°C is applied for school buildings and 22°C for kindergarten. Based on the conversations with end users and based on the results of numerous energy audits which have been conducted for these types of buildings, it is confirmed that the real set temperature in these buildings during the heating season is higher than the internal project temperature.

Regarding the differences between the project calculated energy consumption and measured real consumption after the renovation, it is clear there is a difference between those two, especially if we compare the project calculated consumption after the renovation with the adjusted real consumption after the renovation (taking into account the number of HDDs in the base year before the renovation). There are potentially many reasons that can cause this difference, starting from the design phase, also the execution phase and finally in the operational phase – user behaviour. All these potential reasons will be elaborated and analysed in detail in the next chapter - 5. Identification of possible reasons behind underperforming renovations in public buildings.

5. IDENTIFICATION OF POSSIBLE REASONS BEHIND UNDERPERFORMING RENOVATIONS IN PUBLIC BUILDINGS

As already mentioned in the previous chapter, there are potentially many reasons behind underperforming renovations in public buildings and for the purpose of this analysis, they will be divided into three stages of the renovation process:

1. Design stage (planning and project designing)
2. Execution stage (execution of works, including supervision of works)
3. Operational stage (user behaviour)

Design stage

- **The legislation framework in Croatia is insufficiently strict** when it comes to meeting the requirements in terms of energy performance for renovation of existing buildings. Despite the fact that maximum permitted values for existing buildings during reconstruction have been set according to the Technical regulation, there are some exceptions which allow the project designer to not meet the maximum permitted values if it can be proved that energy efficiency measures needed to meet this values are technically, functionally and economically unjustified. In practice, this is usually not elaborated and justified enough by the project designers but they simply use this exception because it exists in the regulation, thus limiting the building to reach its full potential of energy savings.
- **Limited financial capacity of investors to perform deep energy renovation** is sometimes a possible reason behind underperforming renovations in public buildings. Considering the fact that investor's decision is the final one in terms of realization of renovation project, they influence the project designer, i.e. they demand that energy efficiency measures have to be planned to fit into the available budget, which usually ends up with performing partial renovation, thus limiting the building to reach its full potential of energy savings.
- **Limited knowledge and data about the existing conditions of the buildings to be renovated**. This is usually the main reason why there are differences in project calculated energy consumption and measured real consumption before the renovation. Project designers are led by the national methodology which defines the indoor project temperatures for different types of buildings, the input which significantly determines the value of the building energy consumption. Based on the results of numerous energy audits which have been conducted, it is confirmed that the real set temperature in existing buildings during the heating season is higher than the indoor project temperature defined by the methodology. Some project designers do not take into account the use pattern of the building during design stage, i.e. they do not talk to the end-users while defining the existing conditions of the building and do not take into consideration the real energy consumption which is noticeable in the master project documentations because there are no explanations of possible deviations between calculated and measured real energy consumption. Moreover, sometimes the calculated energy consumption before the renovation is deliberately calculated as very high only so that later with the planned measures the bigger possible savings could be shown. This is very often for the projects which are applying for the subsidies where usually energy savings have to be more than 50 % compared to the existing conditions in order for the project to be eligible for possible subsidies.

Execution stage

- The first prerequisites for bad execution quality are **poor-quality energy audits and master project documentation**, which do not describe in detail the planned energy-saving measures. In Croatia, this is particularly noticeable in energy renovation of family houses which applied for national subsidies. Master project documentation is not required for energy renovation of these buildings but only energy certificate and respective energy audit report which does not describe in detail the planned energy-saving measures nor elaboration of important details which are crucial for quality of performed works.
- **Tender procedures for the selection of contractors** where the leading criterion for selection is still the "lowest price", often result in the output of cheaper and lower quality because these contractors usually have cheaper and less skilled workers.
- **Limited knowledge and low skills of workers** about the new requirements in construction (nZEB, ZEB, airtightness, paying attention to details). In Croatia, this is especially noticeable among foreign workers which are not familiar with this type of standards in construction. This usually results with poor-quality of performed works.
- **Absence of responsibility for not achieving the calculated energy savings**. This can be applied in both stages, design and execution. Who is to blame if the energy savings are not achieved after the renovation. If there is no defined responsibility for underperformance prior the renovation, it often ends up with having the renovated building which doesn't achieve its full potential of energy savings.
- **Lack of quality construction supervision** during the energy renovation of existing buildings. Construction supervisor is often present only on paper, especially during the renovation works of family houses.

Operational stage

- **User behaviour after the renovation** is usually the most common reason for building underperformance in the operational stage. End-users are not educated on how to use the building and new systems after the renovation. It has already been mentioned in the design stage, if the users are not informed about the indoor temperature that has to be set during the heating season in order to achieve the calculated energy savings, or that they do not have to open their windows to get fresh air inside because they have the mechanical ventilation with heat recovery, it is inevitable that there will be a differences between the calculated and real energy consumption, i.e. real energy consumption will be higher.

- **Lack of quality monitoring and verification of energy savings**. In Croatia, the verification is usually done only through the energy audit and energy certificate after the renovation works. This document only confirms the values from the master project documentation or from the previous certificate without taking into account the real energy consumption after the renovation what would be in the interest of the investor/end user.

6. POLICY RECOMMENDATIONS TO OVERCOME THE ISSUE OF UNDERPERFORMING RENOVATIONS IN PUBLIC BUILDINGS

To address underperforming renovations in public buildings in Croatia, the following policy recommendations are proposed:

6.1. Improve Design and Execution process

It is necessary to analyse the needs of the building's users in order for the energy renovation process to result in a better performance – calculated energy savings aligned with the real measured savings. In addition, it is certainly important to establish guidelines for achieving a high standard such as (n)ZEB in the execution phase in order to ensure good functionality of the building.

6.2. Improved Project Management

In order to avoid mistakes in the implementation process of energy renovation projects, it is necessary that the project managers and other involved stakeholders have some experience in such renovation projects. In addition to the experience, constant training and knowledge increase through various forms of education and certification is necessary. Considering that EU directives are regularly subject to changes and amendments, it is important to be updated with all the changes and adjust projects to the new requirements so that performance of the energy renovation is always in line with the new standard.

6.3. Quality Assurance

Implement strict quality control measures to ensure high standards of workmanship. Introduce responsibility clauses in case anticipated energy savings have not been met. Avoid using the "lowest price" as the main criterion for the selection of contractors in tender procedures.

6.4. Maintenance and Evaluation

Develop and enforce comprehensive maintenance plans to prolong the lifespan of renovations. Implement systems for ongoing monitoring and evaluation of renovated buildings to ensure they meet performance expectations.

Additional recommendations which apply to all buildings

6.5. Dedicated Funding and Budget Management

Ensure sufficient funds from the budget intended for energy renovation projects, meaning ensuring coverage for all planned measures. Likewise, provide funds to cover unexpected costs that may arise in the process of energy renovation if they are relevant for increasing energy efficiency of the building.

6.6. Stakeholder Engagement

Involve building users and community members in the planning process to ensure renovations meet their needs. Also, it is necessary to encourage better communication and coordination among all stakeholders involved in the energy renovation process.

6.7. Sustainability and Energy Efficiency

Promote the use of sustainable materials and energy-efficient technologies in all public building renovations and provide financial incentives for projects that meet or exceed sustainability criteria.

6.8. Technological Integration

Encourage the integration of modern technologies to enhance building functionality and adaptability. Here, it is very important to emphasize the readiness of the market for new technologies in terms of the necessary knowledge of contractors and designers. Considering this fact, it is necessary to constantly conduct education for all of them and familiarize them with new standards and technologies.

6.9. Economic and Political Stability

Secure stable funding sources to ensure the continuity of renovation projects regardless of economic or political changes. Maintain consistent policy support for public building renovations across different government administrations.

6.10. Long-term renovation planning

Introduce Building Renovation Roadmaps (BRPs) which will serve as a tool that recommends measures for the implementation of long-term, stepwise building renovation strategies aimed at achieving a final long-term goal – buildings sector decarbonization by 2050.

Implementing these policy recommendations can significantly improve the performance and impact of public building renovations in Croatia, ensuring they meet current and future needs effectively.

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