Rehabilitation of partially damaged during the war school and kindergarten buildings with accordance of energy efficiency requirements

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Background and Relevance

Russia came with a war to the territory of Ukraine **10 years ago**.

For the **last 900 days**, we have been in a particularly hot phase of the war and are experiencing it in conditions of daily horrors, deaths of children and destruction.

The ongoing war in Ukraine has resulted in widespread destruction of critical infrastructure, including schools and kindergartens.

The destruction of the educational infrastructure leads to a violation of children's and youth's access to education, affects the quality of education, socialization, integration into society.

The results of the calculations of the Kyiv School of Economics showed that as a result of the destruction caused to schools, kindergartens, universities and other educational institutions, **Ukraine suffered losses in the amount of at least 6.8 billion dollars**.

Destroyed school in Chernihiv / Photo: Oleksandr Gulich
https://24tv.ua/education/skilki-zakladiv-osviti-ponishhili-rosiyani-ukrayini_n2626819

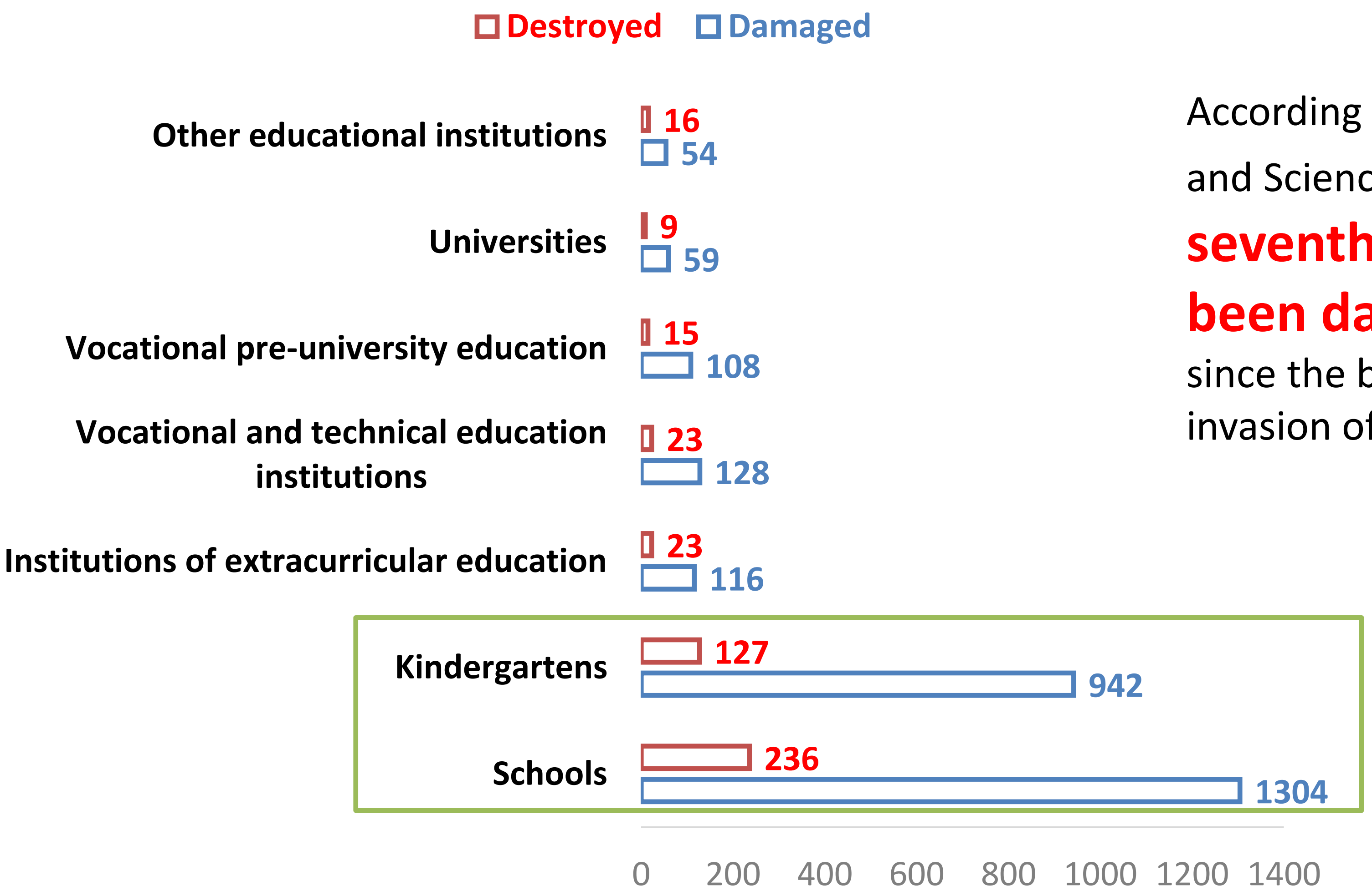
Destroyed kindergarten
https://static.nv.ua/

Geography of damaged or destroyed schools and kindergartens in Ukraine

According to Forbes, educational institutions were most destroyed or damaged in frontline areas:

- Donetsk - 67.27%;
- Kharkiv - 37.79%;
- Luhansk - 35.14%;
- Mykolaiv – 25.53%;
- Kherson - 20.95%;
- Zaporizhzhia - 16.8%;
- Kyiv – 13,5%;
- Chernihiv – 12,7%.

The number of schools and kindergartens destroyed or damaged due to the war in Ukraine



According to the Ministry of Education and Science of Ukraine, **every seventh school** in Ukraine **has been damaged** or **destroyed** since the beginning of the full-scale invasion of Russia.

During the 900 days of war in Ukraine, **2,600 schools and kindergartens were destroyed or damaged**.

We have a lot of damaged schools an kindergartens in Ukraine, but we do not have enough experience of rehabilitation of these buildings.

Our vision to solve this problem:

- ✓ Identification of the main Damages of Schools and Kindergartens infrastructure due to the war
- ✓ Determination of the Main Challenges in Rehabilitating Partially Damaged Buildings
- ✓ Development of the procedure of Rehabilitation of Partially Damaged Buildings
- ✓ Calculation of the heat losses in building envelops
- ✓ Determination of the value of Energy Efficiency Potential of real schools
- ✓ Identification of the Key Energy-Efficient Improvements

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Brief Description of War-Damaged Infrastructure of Schools and Kindergartens

The extent of damage can vary from minor structural issues to complete destruction, depending on the intensity and duration of the hostilities. Below is a summary of the typical impact on school and kindergarten infrastructure in war zones:

1. Structural Damage

- Partial or Complete Collapse of walls, roofs, and supporting structures due to direct hits from bombs, artillery fire, or missile strikes
- Weakening of the foundation of the building
- Damaged Windows and Doors

2. Interior and Classroom Destruction

- Destroyed Classrooms due to collapsed ceilings, damaged furniture, and broken floors
- Loss of Learning Spaces (libraries, laboratories, and other specialized learning spaces) impacting the school’s ability to provide comprehensive education

3. Damage to Utilities and Essential Systems

- Power lines, transformers, and internal wiring are frequently damaged or destroyed
- Water pipes may be broken or contaminated, and sewage systems can be damaged
- HVAC systems are often severely damaged, which is crucial for a healthy learning environment

4. Loss of Playgrounds and Outdoor Facilities

- Outdoor playgrounds, sports fields, and recreational facilities are often destroyed or heavily damaged
- Schoolyards and playgrounds may become contaminated with unexploded ordnance (UXO), making them hazardous for children to use without proper clearance efforts

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Overview of the Challenges in Rehabilitating Partially Damaged Buildings

The process of restoring these buildings requires a careful balance of maintaining structural integrity, preserving historical value (when relevant), and upgrading to meet modern standards, including energy efficiency and resilience.

Below is an in-depth overview of the major challenges encountered when rehabilitating partially damaged buildings:

1. Structural Damage and Safety Concerns	2. Retrofitting for Modern Building Codes	3. Limited Financial Resources, Legal and Administrative Barriers
• Assessment of Structural Integrity • Stability During Restoration • Hidden Damages	• Adapting to New Building Standards • Energy Efficiency Upgrades	• High Costs of Restoration • Conflicting Priorities • Permitting Delays

4. Skilled Labor Shortages	5. Logistical and Environmental Challenges	6. Preserving Historical and Cultural Integrity
• Loss of Workforce • Training and Capacity Building	• Accessibility of the Site • Weather and Environmental Conditions • Contamination and Debris	• Balancing Restoration with Preservation • Regulatory Constraints

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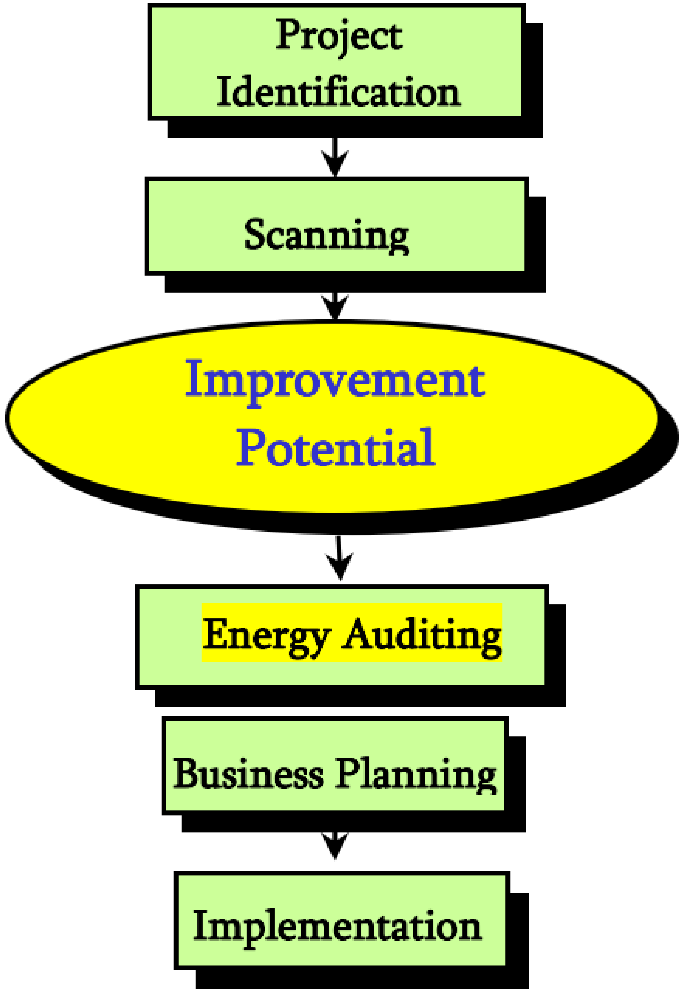
The main steps in Rehabilitation of Partially Damaged Buildings



3. Description of the condition of the building

3.1 General condition

Building Type	Public School #24			
Construction Date	1934	Currently in operation		
	Workdays	*Saturday*	*Sunday*	
Operation Schedule	12	-	-	*(hour/day)*
Heating Schedule	24	-	-	*(hour/day)*
Number of staff and teachers / students				
Staff	275	*Adult*		
Student	800	*Child*		
Average indoor temperature: *20 °C*				

Building Data

Total Heating Area	4 789	m^2	First Floor Area	1 400	m^2
Total Heating Volume	76 442	m^3	Second Floor Area	1 184	m^2
Roof Area	1 626	m^2	Third Floor Area	1 115	m^2
Number of Storeys	4	*storey*	Fourth Floor Area	1 089	m^2

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Example of Rehabilitation of Partially Damaged Buildings

Exterior walls						
General assessment of the condition of the walls			Unsatisfactory			
Total area of exterior walls (excluding windows/doors area)	**3 748**		m^2	Heat transfer Coefficient $U_{average}$	**1.63**	W/m^2 K
Type of wall	Material Type	Insulation Type	Insulation Thickness	Slab Thickness, *m*	Area, m^2	
Solid wall	Silicate Brick	-	-	0.4	**4 641**	
Orientation	**North-East**	**South-East**		**South-West**	**North-West**	
Wall NET area	1 128	936		914	770	
Description	The wall is built of silicate brick with a coefficient of thermal conductivity λ=0.95 W/m*K. Thickness is δ=0.4 m, Inner plaster is Gypsum δ=0.01 m, λ=0.5 w/m*K. External plaster is Sand-Cement plaster δ=0.02 m, λ=1.6 w/m*K. The existing thermal resistance of the wall is calculated as follows: R_0=1/8.7+0.4/0.95+0.01/0.5+0.02/1.6+1/23 = 0.61 m²* K/W The heat transfer coefficient is: **U= 1/0.61= 1.63 W/m²* K**						

Table:11- External Walls Data

External Walls								
General evaluation of the condition of the walls		Poor						
Total area external walls		2363		m²	U value (average)	1,88		W/m²K
Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Wall area	623.87		593.32		538.69		607.12	
Material type	precast block	-	precast block	-	precast block	-	precast block	
U_{value}, W/m²K	1,88	-	1,88	-	1,88	-	1,88	
Insulation type	No		No		No		No	
Material type	• Precast block thermal conductivity coefficient λ = 1.51 W/mK. Wall thickness δ = 0.45 m. Internal gypsum plaster thickness δ = 0.025 m, internal plaster thermal conductivity coefficient λ = 0.56 W/mK, external plaster sand-cement mortar thickness δ = 0.025 m, and thermal conductivity coefficient λ = 0.76 W/mK. R_{req} = 1/8.7 +0,025/0,76+0,45/1,51+0,025/0,56+1/23,3 = 0,53 W/m²K U_{value} = 1,88 W/m²K								
Insulation	No							

Picture:2- School External Walls

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Table:12- Windows Data

Windows								
General evaluation of the condition of windows					**Damaged**			
Total area windows			966		**m²**	**U value (average)**	**2,9**	**W/m²K**
Orientation	**Material[1]**	**Type[2]**	**Area**	**Quantity**	**Solar energy absorption coefficient**	**U value**		
			m2	**unit**	**g**	**W/m²K**		
Building								
N	P	2G	206,15	69	0,5	2,9		
E	P	2G	274,75	94	0,5	2,9		
S	P	2G	291,35	100	0,5	2,9		
W	P	2G	193,75	64	0,5	2,9		
Total both wings			**966**	**327**				
Material [1]	Wood (W), Aluminium (Al), **Plastic (P),** Steel (St)							
Type [2]	Single-frame (S), Double-frame (D), Bonded frame (B), Single glazed (1G), **Double glazed (2G),** Triple glazed (3G)							

Picture:3- School Windows

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Table:13- Doors Data

Doors						
General evaluation of the condition of doors:	**Poor**					
Steel doors		**37,41**	**m^2**	**U_{value} St**	**6**	**W/m^2K**
Material [1]	Wood (W), Aluminium (Al), **Plastic (P), Steel (St)**					
Type [2]	Single-frame (S), Double-frame (D), Bonded frame (B), Single glazed (1G), Double glazed (2G), Triple glazed (3G)					

Picture:4- School Doors

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Distribution of heat losses of the building

Part of the building	Percentage
Windows and doors	27%
Walls	23%
Roof	17%
Ventilation and Infiltration	16%
Thermal bridges	9%
Floor	8%
TOTAL	**100%**

Heat balance of the school building, simulated during heating season with normalised climate data was obtained.

Comprehensive Heat Transfer Coefficient of the Envelope

The comprehensive heat transfer coefficient represents the comprehensive thermal performance of the building envelope, and it can be seen from Equation that it is only related to the heat transfer coefficient and area of the exterior wall, exterior window, and roof.

$$U_{Co} = \frac{U_{wall} A_{wall} + U_{roof} A_{roof} + U_{win} A_{win}}{A_{wall} + A_{roof} + A_{win}},$$

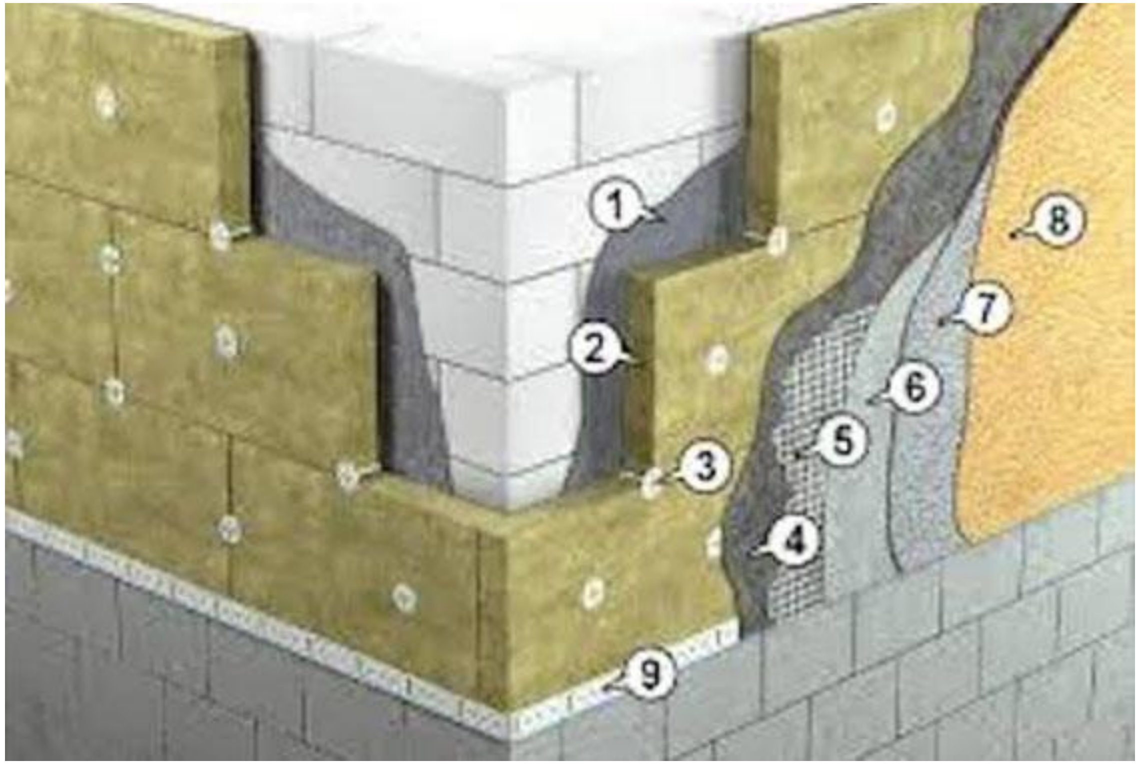
where U_{Co} is the comprehensive heat transfer coefficient, W/(m²·K); U_{wall} is the heat transfer coefficient of the external wall, W/(m²·K); U_{win} is the heat transfer coefficient of the external window, W/(m²·K); U_{roof} is the heat transfer coefficient of the roof, W/(m²·K); A_{wall} is the area of the external wall, m²; and A_{win} is the area of the external window, m².

Energy Efficiency Potential

EE MEASURES		Investment [GEL]	Net Saving [kWh/yr]	Net Saving [GEL/year]	Payback YEAR	NPV [GEL]
1	INSULATION OF WALLS	782,153.00 ₾	728,570.63	108,994.17 ₾	7.2	1,356,984.84 ₾
2	ROOF INSULATION	466,180.00 ₾	1,204,140.30	180,139.39 ₾	2.6	3,069,265.95 ₾
3	IT IS RECOMMENDED TO REPLACE ALL EXISTING DOUBLE-GLAZED WINDOWS AND UNINSULATED DOORS WITH ONES THAT HAVE A U VALUE OF 1.8 Wm^2/K. BY DOING SO, SIGNIFICANT REDUCTIONS IN HEAT LOSS DUE TO THERMAL TRANSFER CAN BE ACHIEVED IN THE BUILDING'S EXTERNAL COMPONENTS.	891,000.00 ₾	366,002.13	54,753.92 ₾	16.3	183,609.62 ₾
4	REPLACEMENT OF BULBS	93,038.11 ₾	51,163.17	15,502.44 ₾	6.0	211,215.40 ₾
5	REHABILITATION OF HEATING SYSTEM AND DHW	41,250.00 ₾	14,611.00	2,185.8 ₾	18.9	-21,902.41 ₾
TOTAL		**2,273,621.11 ₾**	**2,364,487.23**	**361,575.72 ₾**	**6.29**	**4,799,173.39 ₾**

Energy Efficiency Potential: Thermal Insulation of Walls

Based on the investigation of the enclosure structure of more than 50 school buildings in different climate zones of Georgia and Ukraine among the exterior wall construction materials, rock wool is the main choice of insulation layer, accounting for approximately 50 % of all thermal insulation materials.



(1) Brick Wall Base
(2) Building Adhesive
(3) Rockwool board
(4) Protective Cement
(5) Fiber glass mesh
(6) Insulation pin
(7) Protective coating

Energy Efficiency Potential: Thermal Insulation of Walls

Level of thermal performance improvement for different insulation exterior walls

Thickness (mm)	Thermal Performance Improvement			
	Rock wool		EPS	XPS
10	24.61%		26.89%	28.01%
20	33.21%		36.71%	38.36%
40	45.61%		50.11%	52.13%
60	54.13%		58.82%	60.87%
80	60.34%		64.95%	66.91%
100	65.07%		69.48%	71.34%
120	68.79%		72.98%	74.72%
140	71.80%		75.76%	77.39%
160	74.28%		78.02%	79.55%
180	76.35%		79.90%	81.33%
200	78.12%		81.48%	82.83%

Quantification of the heat transfer coefficient of a rock wool insulation exterior wall

Material	Thickness mm	Thermal Conductivity W/m·K	U-Value W/m²·K
Rock wool	10	0.041	0.528
	20	0.041	0.468
	40	0.041	0.381
	60	0.041	0.321
	80	0.041	0.278
	100	0.041	0.244
	120	0.041	0.218
	140	0.041	0.197
	160	0.041	0.180
	180	0.041	0.166
	200	0.041	0.153
Cement mortar	20	0.93	N/A
Aerated concrete block	200	0.14	N/A

Source: Lu, S.; Wang, Z.; Zhang, T. Quantitative Analysis and Multi-Index Evaluation of the Green Building Envelope Performance in the Cold Area of China. Sustainability 2020, 12, 437. https://doi.org/10.3390/su12010437

Energy Efficiency Potential: Thermal performance improvements for rockwool insulation of exterior wall and roof

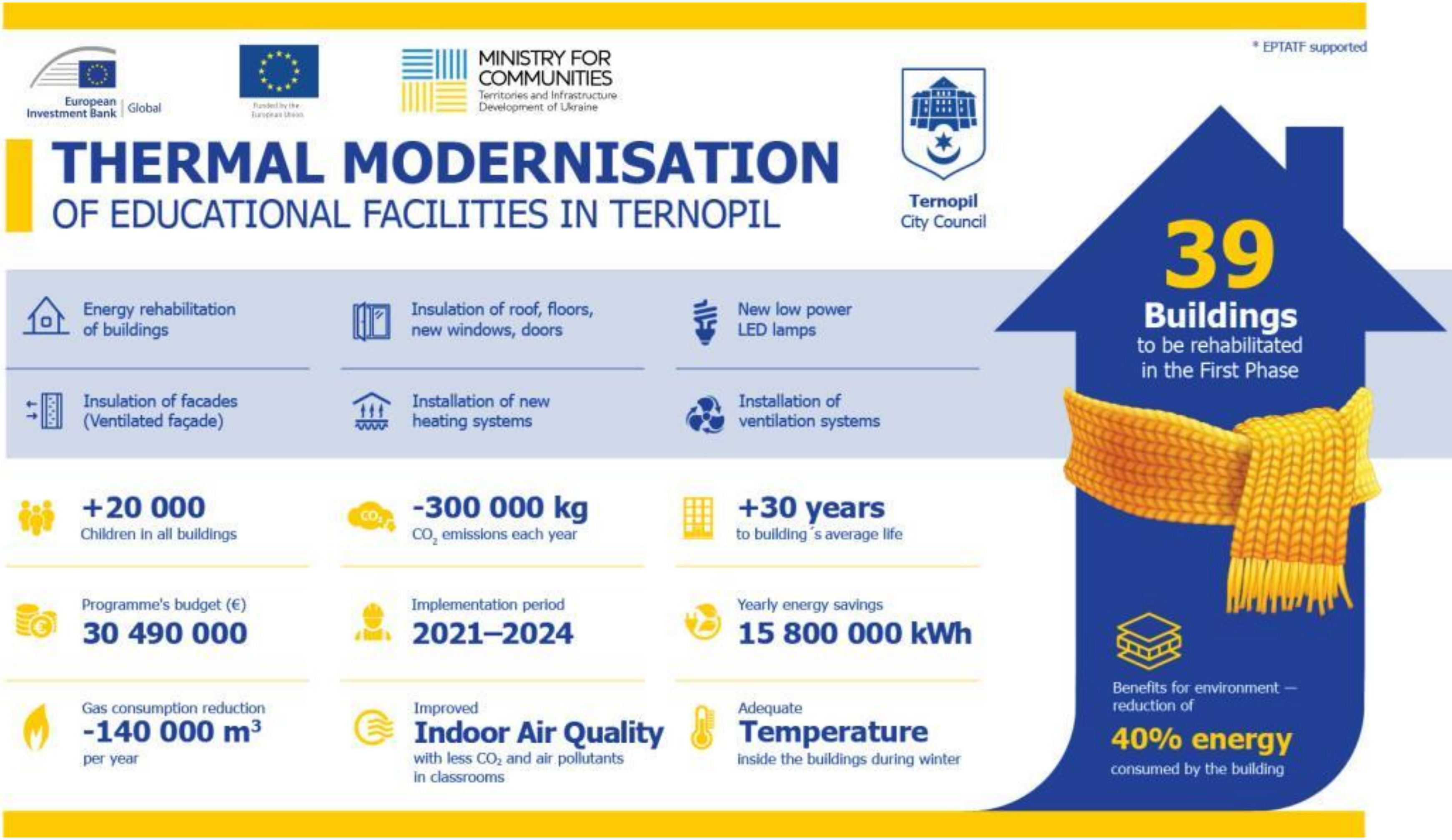
Thickness mm	Exterior Wall		Roof	
	U-Value W/(m²·k)	Improvement	U-Value W/(m²·k)	Improvement
10	0.53	24.61%	1.91	N/A
20	0.47	33.21%	1.30	N/A
40	0.38	45.61%	0.80	N/A
60	0.32	54.13%	0.57	N/A
80	0.28	60.34%	0.45	0.40%
100	0.24	65.07%	0.37	18.27%
120	0.22	68.79%	0.31	30.70%
140	0.20	71.80%	0.27	39.85%
160	0.18	74.28%	0.24	46.87%
180	0.17	76.35%	0.21	52.42%
200	0.15	78.12%	0.19	56.92%

Lu, S.; Wang, Z.; Zhang, T. Quantitative Analysis and Multi-Index Evaluation of the Green Building Envelope Performance in the Cold Area of China. Sustainability 2020, 12, 437. https://doi.org/10.3390/su12010437

Energy Efficiency Potential: Example of thermal modernisation of educational facilities with the EIB funds In Ternopil city

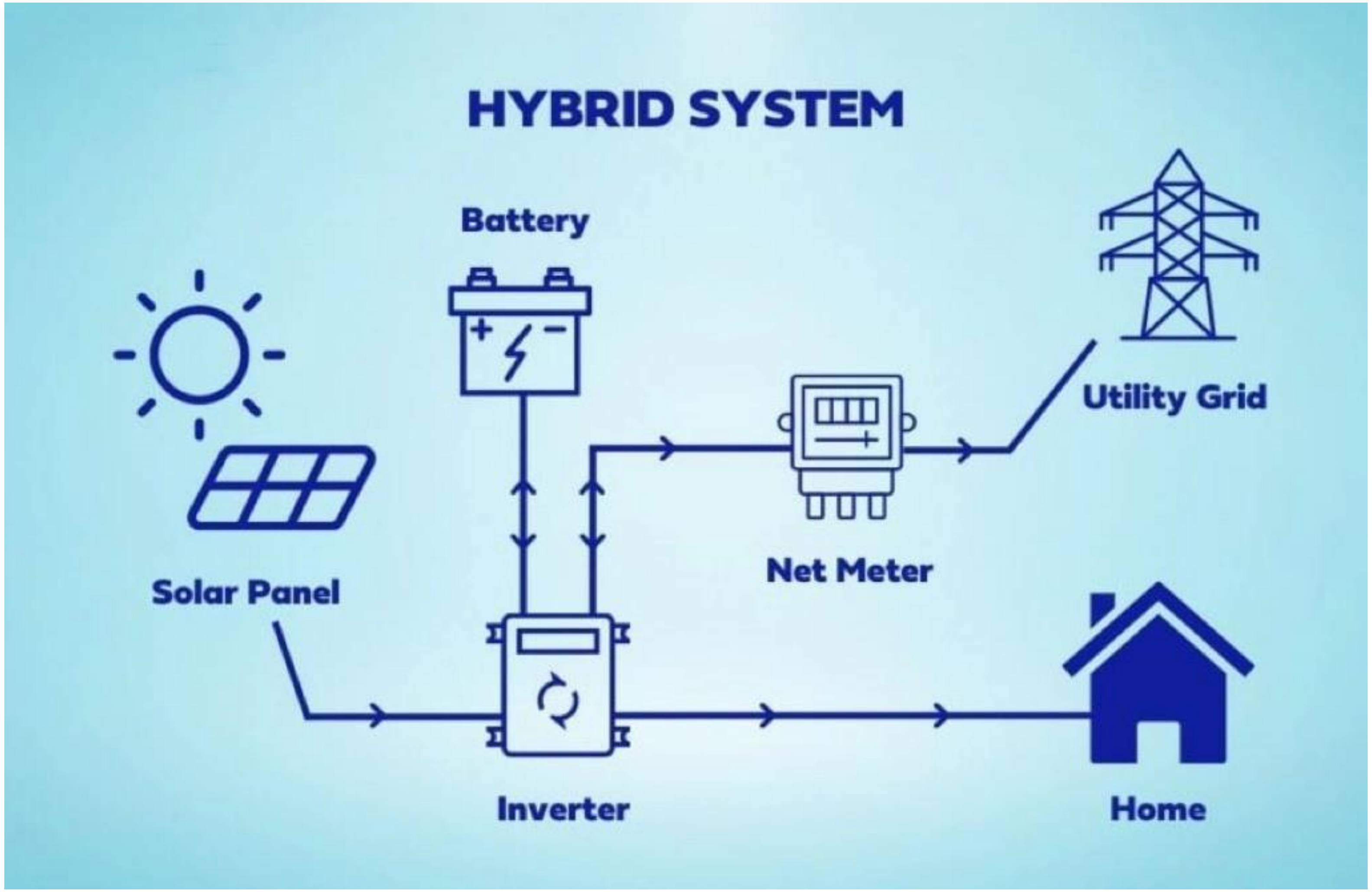
April 7, 2023 – In Ternopil cit was launched the project to improve the energy efficiency of educational institutions under the Ukraine Municipal Infrastructure programme (UMIP) from the European Investment Bank (EIB).

Preschool educational institution №32 is the first kindergarten in the city modernised and insulated under UMIP.



Source: *https://www.eeas.europa.eu/delegations/ukraine/ternopil-launches-thermal-modernisation-educational-facilities-eib-funds_en?s=232*

Energy Efficiency Potential: Using of Hybrid Solar power



Energy Efficiency Potential: Example of installation of Hybrid Solar power plant in Chernihiv

The power of the solar station is 35 kW, and the capacity of the installed energy storage system is 96 kWh.

Source: https://ua-energy.org/uk/posts/avtonomni-ses-dlia-shkil-ta-likaren-iak-potrapyty-u-proiekt

SUMMARY: Key Energy-Efficient Improvements

Below are some of the most important energy-efficient Improvements used today:

1. Insulation Upgrades	2. Window and Door Upgrades	3. Improving the Building Envelope
• Wall Insulation • Roof/Ceiling Insulation • Floor Insulation	• Double or Triple-Glazed Windows • Low-Emissivity (Low-E) Coatings • Weatherstripping and Sealing	• Air Sealing • Thermal Bridging Solutions
4. HVAC System Upgrades	**5. Lighting Upgrades**	**6. Water Heating Improvements**
• High-Efficiency HVAC Systems • Smart Thermostats • Duct Sealing and Insulation	• Switching to LED Lighting • Daylighting Strategies • Smart Lighting Controls	• Tankless Water Heaters • Heat Pump Water Heaters
7. Renewable Energy Integration	**8. Water Conservation Retrofits**	**9. Building Automation and Smart Energy Management Systems**
• Solar Photovoltaic (PV) Systems • Solar Water Heaters • Geothermal Heating and Cooling • Battery Storage	• Low-Flow Fixtures • Greywater Recycling Systems	• Building Management Systems • Demand Response Systems

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Conclusion

1. The rehabilitation of partially damaged schools and kindergartens in post-war regions presents an opportunity to incorporate energy efficiency into the rebuilding process. By adopting energy-efficient improvements, such as solar power, high-performance insulation, and smart energy management technologies, educational facilities can be transformed into sustainable, cost-effective, and resilient structures.

2. The integration of energy efficiency not only reduces long-term operational costs but also contributes to environmental sustainability and improves the learning environment for students.

3. To achieve successful energy-efficient rehabilitation, it is essential to leverage a combination of international energy standards, local building codes, and available financial mechanisms such as government incentives, public-private partnerships, and international aid. Stakeholder engagement, including collaboration with local communities, governments, and private sector partners, plays a critical role in ensuring the feasibility and sustainability of these projects.

4. Rebuilding war-damaged educational facilities with a focus on energy efficiency is not only necessary for immediate recovery but also vital for long-term resilience and sustainability.

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