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Assessment of the Energy - Efficient Modernization of Residential Historical Buildings in Kiev

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Abstract. Most of residential historical buildings in Kyiv, Ukraine are in need of energy efficiency modernization. The present research exposes the assessment of warming effectiveness for the certain enclosing structures in historical residential buildings, considering the overall thermal balance of building. Heat losses through certain enclosing structures considering actual thermal resistance were estimated, also in compliance with standard requirements for thermal resistance of enclosing structures according to the standard DBN B.2.6-31:2006. It turned out that the warming of the whole building envelope and the replacement of transparent enclosing structures allows to reduce the heat flux of the heating system for compensation of thermal losses through the building envelope in 3 times.

1 Introduction

Improved energy efficiency of historic buildings is one of the most urgent problems of construction science of Ukraine. The following researches [1-9] expose the problem of energy efficiency in residential historical buildings.

In this article the possibility of energy-efficient modernization of residential historical buildings in Kiev was considered in accordance with modern standards [10].

Residential building built in 1909 on the Malaya Zhitomirskaya street, 12-A, Kiev was taken as an example for the assessment (historical and architectural monument of local importance [2].

It should be noticed that the design of walling (external walls, attic slabs and basement ceiling) in residential historical buildings of St. Petersburg and Kiev have the common features [2-7, 11-13].

For example, exterior walls have a variable thickness and become thinner with height: the wall thickness varies in the range from 2 to 5 bricks. Therefore, the methodology of energy efficiency modernization can be quite similar for such buildings.

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2 Thermo-technical calculation of building envelope

Design conditions for Kiev and numerical values used for further calculations presented in Tables 1, 2

Table 1. Design conditions for Kiev

Object: Malaya Zhitomirskaya street, 12-A, Kiev	Requirements DBN B.2.6-31:2006	Was in 80-s
Design ambient air temperature t_{ext} °C	-22	-22
The average outdoor temperature during the heating season, $t_{h..s.}$, °C	-0.1	-0.1
Duration of the heating season, z_{ht} , day	176	176
Design interior temperature, t_{int}, °C	20	18
Degree-day heating season	3538	3186

Table 2. Numerical values used for further calculations

Enclosing structure	External wall		Attic slabs		Basement ceiling		Windows and doors	
	DBN B.2.6-31:2006	Was in 80-s	DBN B.2.6-31:2006	Was in 80-s	DBN B.2.6-31:2006	Was in 80-s	DBN B.2.6-31:2006	Was in 80-s
Coefficient taking into account the dependence of the enclosing structure position in relation to ambient air, n	1	1	0.9	0.9	0.4	0.4	-	-
Normalized temperature difference between the interior temperature and the temperature of enclosing structure inner surface, $\Delta t_н$, °C	4	6	3	4	2	2	-	-
Heat transfer coefficient of the enclosing structure inner surface, α_{int}, W/m^2*°C	8.7	8.7	8.7	8.7	8.7	8.7	-	-
Required thermal resistance of enclosing structure according to hygiene requirements R= n (t_{int} - t_{ext})/ α_{int} Δt_n (m^2 •^{0}C)/W	**1.2069**	**0.7663**	**1.4483**	**1.0345**	**0.9655**	**0.9195**	**0.7500**	**0.42**
Normalized heat transfer resistance of enclosing structure, (m^2 •^{0}C)/W	3.3	-	**4.9500**	**-**	**1.5**	**-**	**-**	**-**
Heat transfer coefficient of the enclosing structure outer surface, α_{ext}, W /(m ^{2}*°C)	23	23						

The facade and section of the building on Malaya Zhitomirskaya st., 12A is illustrated in Figure 1.

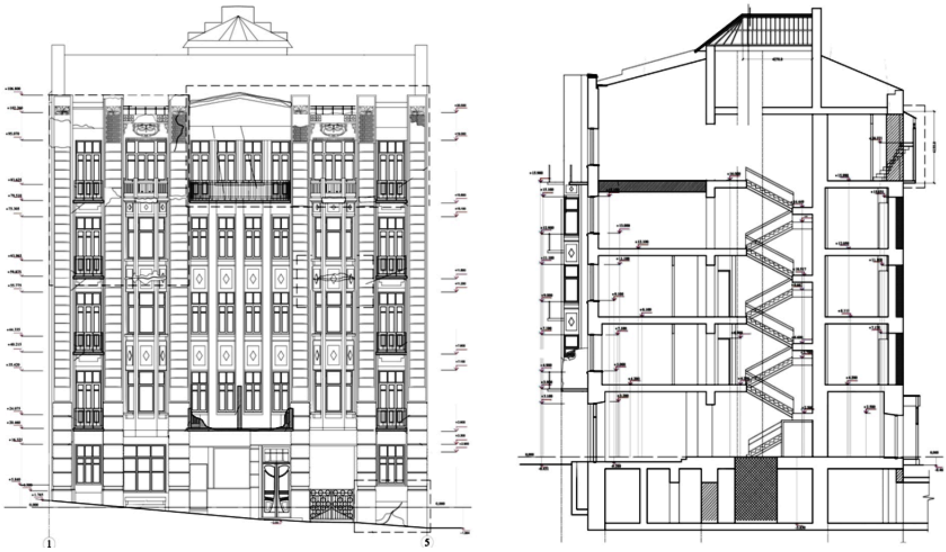

Fig. 1. The façade and section of the building on Malaya Zhitomirskaya st., 12A, Kyiv

As already mentioned above, the design of walling (external walls, attic slabs and basement ceiling) in residential historical buildings of St. Petersburg and Kiev have the common features. Exterior walls have a variable thickness and become thinner with height: the wall thickness varies in the range from 2 to 5 bricks.

The results of calculation for the bricks wall thickness presented Table. 3.

Table 3. The results of calculation for the bricks wall thickness.

Material	Layer thicknes s δ_i, m	Coefficient of heat conductivity, λ_i, [W / (m·°C)]	R_i, [(m^2•°C)/W]
External wall of the 3rd floor			
Brickwork of ordinary loam bricks. (Sand-cement mortar), 1800 kg/m^3	0.62	0.81	**0.76543**
$1/\alpha_в$			0.1149
$1/\alpha_н$			0.0435
r (heat transfer performance uniformity factor)			0.698676
Thermal resistance of enclosing structure R (m^2*°C)/ W			**0.6455**
External wall of the 2nd floor			
Brickwork of ordinary loam bricks. (Sand-cement mortar), 1800 kg/m^3	0.86	0.81	**1.06173**
$1/\alpha_в$			0.1149

$1/\alpha_н$			0.0435
r (heat transfer performance uniformity factor)			0.698676
Thermal resistance of enclosing structure *R* (m^2*°C)/ W			**0.7441**
External wall of the 1^{st} floor			
Brickwork of ordinary loam bricks. (Sand-cement mortar), 1800 kg/m^3	1.06	0.81	**0.76543**
$1/\alpha_в$			0.1149
$1/\alpha_н$			0.0435
r (heat transfer performance uniformity factor)			0.698676
Thermal resistance of enclosing structure *R* (m^2*°C)/ W			**0.7860**

Dependence diagram of heat transfer performance uniformity factor to the thickness of brick wall presented Figure 2.

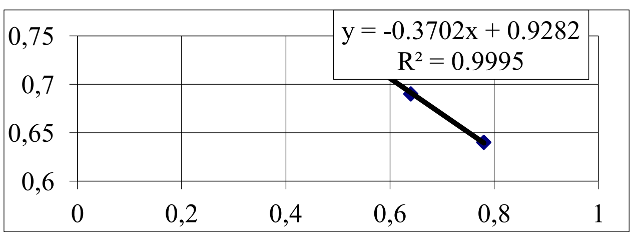

Fig. 2. Dependence diagram of r (heat transfer performance uniformity factor) to the thickness of brick wall.

The calculation results of design and standard values of structural thermal resistance for a residential building are shown in Table 4.

Table 4. Showings of the thermal resistance of enclosing structures in residential buildings

Type of enclosing structures	Thermal resistance, [(m^2·°C)/W]		
	Design	The minimum required for the sanitary and hygiene standards	Standard
External walls: - 1st floor; - 2nd floor; - 3rd, 4th and 5th floors	1.467 / 0.786 1.22 / 0.744 0.924 / 0.646	1.207	3.3
Attic slab	1.035	1.448	4.95
Overlap above the unheated basement	2.3/0.92	2.415/0.966	3.75/1.5
Transparent façade systems	0.42		0.75

Notes: 1. The actual thermal resistance for the exterior walls which is specified in the denominator was determined taking into account the coefficient of thermotechnical homogeneity (r - heat transfer performance uniformity factor);
2. The values of thermal resistance for the overlap above the unheated basement were specified in the denominator with coefficient n=0.4, which was taken for the overlap above the unheated basement below the level.
3. The minimum required thermal resistance for the sanitary and hygiene standards was defined by the standard temperature differential between the inside air temperature and temperature of the inner surface of the building envelope [1];
4. Specified indicators were adopted for the 1st temperature zone of Ukraine [1].

2.1 Heat losses calculation. Variant 1

Considering the first type according to actual terms of thermal resistance of enclosing structure (Table 5).

Table 5. Thermal resistance of enclosing structure:

External walls 1st floor	0.7860	$(m^2 \cdot {}^0C)/W$	Basement ceiling	0.9195	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	0.7441	$(m^2 \cdot {}^0C)/W$	Attic slabs	1.0344828	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	0.6455	$(m^2 \cdot {}^0C)/W$	Windows (double glazing in wooden separate bindings)	0.420	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

The results of calculation of thermal losses are presented in Table 6.
Conventions are as follows:
Ff – Front façade facing the Zhitomirskaya st.
Fy – Yard facade.
Fg – gable facade (adjoins with the Murashko)
EW – External walls
BC – Basement ceiling
AS – Attic slabs
WD – windows and doors

Design interior temperature: t_{int} = 20 [ºC]
Design ambient air temperature: t_{ext} = -22 [ºC]

Table 6. The results of calculation of thermal losses

Room number and its purpose	Characteristic of walling: Title	Characteristic of walling: Orientation	Characteristic of walling: Geometry, [m] a	Characteristic of walling: Geometry, [m] b	Characteristic of walling: Area size, F, [m^2]	n	Walling heat transfer coefficient, k, [W / (m·°C)]	General heat losses, Qo=k·F· (t_{int} - t_{ext}) · n , [W]	Quantity of additional heat losses due to orientation, β	Heat losses including extra losses, Q=Qo·(1+β), [W]	Total losses, [W]
1st floor Ff	EW1	SW	21.58	4.60	99.27	1	1.2722	3921	-	3921	3921
	WD	SW			25.88	1	2.3810	2588	-	2588	2588
1st floor Fy	EW1	NE	21.58	4.60	99.27	1	1.2722	4144	0.1	4558	4558
	WD	NE			21.72	1	2.3810	2172	0.1	2389	2389
	BC		21.58	21.41	462.03	0.4	1.0875	8441	-	8441	8441
											21898
2nd floor Ff	EW1	SW	21.58	3.90	84.16	1	1.3439	3138		3138	3138
	WD	SW			28.56	1	2.3810	2856		2856	2856
2nd floor Fy	EW	NE	21.58	3.90	84.16	1	1.3439	3932	0.1	4325	4325
	WD	NE			14.50	1	2.3810	1450	0.1	1595	1595
											11915
3rd floor Ff	HC1	SW	21.58	4.00	86.32	1	1.5492	5617		5617	5617
	WD	SW			28.56	1	0.8317	998		998	998
3rd floor Fy	EW	NE	21,58	4.00	86.32	1	1.5492	5617	0.1	6178	6178
	WD	NE			14.50	1	0.8317	507	0.1	557	557
											13350
4th floor Ff	EW	SW	21.58	3.90	84.16	1	1.5492	3618		3618	3618
	WD	SW			28.56	1	2.3810	2856		2856	2856
4th floor Fy	EW	NE	21.58	3.90	84.16	1	1.5492	4533	0.1	4986	4986
	WD	NE			14.50	1	2.3810	1450	0.1	1595	1595
4th floor Fg	EW	NE	21.41	3.90	83.50	1	1.5492	5433	0.1	5976	5976
											19031
5th floor Ff	EW	SW	21.58	4.26	91.93	1	1.5492	4298		4298	4298
	WD	SW			25.88	1	2.3810	2588		2588	2588
5th floor Fy	EW	NE	21.58	4.26	91.93	1	1.5492	4569	0.1	5025	5025
	WD	NE			21.72	1	2.3810	2172	0.1	2389	2389
5th floor Fg	EW	NE	21.41	4.26	91.21	1	1.5492	5935	0.1	6528	6528
	AS		21.58	21.41	462.03	0.9	0.9667	16882		16882	16882
											37711

Total heat losses – 103 905 W

As a result,
Overall heat losses through the whole walling – 103905 W
Heat losses through all basement ceilings – 8441 W
Heat losses through all attic slabs – 16882 W
Heat losses through all glazed surfaces and doors – 20411 W
Heat losses through all external walls – 58170 W

Total building heat losses before warming of building envelope is illustrated in Figure 3

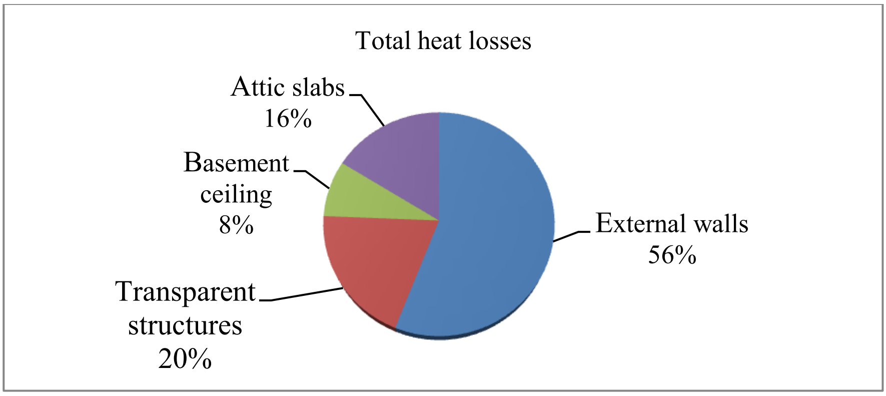

Fig. 3. Total building heat losses before warming of building envelope

2.2 Heat losses calculation. Variant 2

We consider the option of insulating the whole walling to normalized values, according to DBN B.2.6-31:2006 (Table 7)

Table 7. Thermal resistance of enclosing structure:

External walls 1st floor	3.3	$(m^2 \cdot {}^0C)/W$	Basement ceiling	1.50	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	3.3	$(m^2 \cdot {}^0C)/W$	Attic slabs	4.95	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	3.3	$(m^2 \cdot {}^0C)/W$	Double window glazing	0.750	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

Calculation results:
Overall heat losses through the whole walling – **33151 W**
Heat losses through all basement ceilings – 5175 W
Heat losses through all attic slabs – 3528 W
Heat losses through all glazed surfaces and doors – 12486 W
Heat losses through all external walls – 11962 W

Total building heat losses after warming of building envelope according to DBN B.2.6-31:2006 requirements is illustrated in Figure 4.

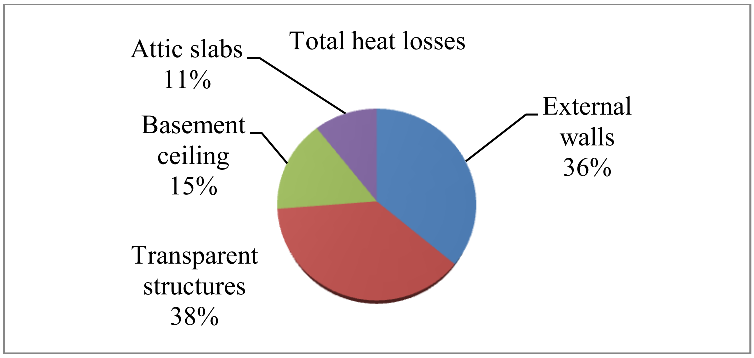

Fig. 4. Total building heat losses after warming of building envelope according to DBN B.2.6-31:2006 requirements

2.3 Heat losses calculation. Variant 3

We consider the option of insulating external walls only (Table 8)

Table 8. Thermal resistance of enclosing structure.

External walls 1st floor	3.3	$(m^2 \cdot {}^0C)/W$	Basement ceilings	0.9195	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	3.3	$(m^2 \cdot {}^0C)/W$	Attic slabs	1.0344828	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	3.3	$(m^2 \cdot {}^0C)/W$	Double window glazing	0.420	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

Calculation results:
Overall heat losses through the whole walling – **60027 W**
Heat losses through all basement ceilings – 8441 W
Heat losses through all attic slabs – 16882 W
Heat losses through all glazed surfaces and doors – 22741 W
Heat losses through all external walls – 11962 W

2.4 Heat losses calculation. Variant 4

We consider the option of replacing old windows with the glass units (Table 9)

Table 9. Thermal resistance of enclosing structure.

External walls 1st floor	0.7860	$(m^2 \cdot {}^0C)/W$	Basement ceilings	0.9195	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	0.7441	$(m^2 \cdot {}^0C)/W$	Attic slabs	1.0344828	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	0.6455	$(m^2 \cdot {}^0C)/W$	Windows	0.750	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

Calculation results:
Overall heat losses through the whole walling – **93650 W**
Heat losses through all basement ceilings – 8441 W
Heat losses through all attic slabs – 16882 W
Heat losses through all glazed surfaces and doors – 10156 W
Heat losses through all external walls – 58170 W

2.5 Heat losses calculation. Variant 5

We consider the option of warming the attic slabs only (Table 10)

Table 10. Thermal resistance of enclosing structure.

External walls 1st floor	0.7860	$(m^2 \cdot {}^0C)/W$	Basement ceilings	0.9195	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	0.7441	$(m^2 \cdot {}^0C)/W$	Attic slabs	4.95	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	0.6455	$(m^2 \cdot {}^0C)/W$	Double window glazing	0.420	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

Calculation results:
Overall heat losses through the whole walling – **90551 W**
Heat losses through all basement ceilings – 8441 W
Heat losses through all attic slabs – 3528 W
Heat losses through all glazed surfaces and doors – 20411 W
Heat losses through all external walls – 58170 W

2.6 Heat losses calculation. Variant 6

We consider the option of warming the basement ceilings only (Table 11)

Table 11. Thermal resistance of enclosing structure.

External walls 1st floor	0.7860	$(m^2 \cdot {}^0C)/W$	Basement ceilings	1.50	$(m^2 \cdot {}^0C)/W$
External walls 2nd floor	0.7441	$(m^2 \cdot {}^0C)/W$	Attic slabs	1.0344828	$(m^2 \cdot {}^0C)/W$
External walls 3rd floor	0.6455	$(m^2 \cdot {}^0C)/W$	Double window glazing	0.420	$(m^2 \cdot {}^0C)/W$
Doors	0.290	$(m^2 \cdot {}^0C)/W$			
t_{int}	20	ºC			

Calculation results:
Overall heat losses through the whole walling – **100638 W**
Heat losses through all basement ceilings – 5175 W
Heat losses through all attic slabs – 16882 W
Heat losses through all glazed surfaces and doors – 20411 W
Heat losses through all external walls – 58170 W

General and additional heat losses through the building envelope at the design outdoor temperature minus 22°C are as follows:
- considering actual terms of thermal resistance - 103910 W;
- considering the observance of regulatory requirements [10] for whole walling - 33950 W;
- considering the observance of regulatory requirements only for external walls - 60030 W;
- considering the observance of regulatory requirements only for transparent structures – 93650 Вт;
- considering the observance of regulatory requirements only for the attic slabs – 90550 Вт;
- considering the observance of regulatory requirements only for the basement ceiling – 100640 Вт.

Conclusion

Thus, implementation of energy saving measures such as insulating for whole walling and replacing transparent walling allows to reduce heat flux of the heating system which compensates the heat loss through the building envelope in 3.1 times. At the same time the external walls facing Malaya Zhitomirskaya st. have to be insulated from the inside, and in other cases the external warming is possible.

During the carrying-out of the regulatory requirements [1] for the thermal resistance of the individual walling structures, the reduction of heat losses will be as follows:

- for external walls - ΔQ=103910 - 60030 = 43880 W (42.2%);
- for transparent structures - ΔQ=103910 - 93650 =10260 W (9.9%);
- for attic floor slab - ΔQ=103910 - 90550 =13360 W (12.9%);
- for the basement ceiling - ΔQ=103910 - 100640 =3270 W (3.1%).

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