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## **THE PROSPECTS OF THE LEVEL INCREASE OF RURAL HOUSING ENERGY EFFICIENCY**

*The proposals to increase the energy efficiency level of housing have been further developed. For the first time, comprehensive research of the volume of the rural building in relation with the energy-saving potential in this sphere has been conducted, based on foreign experience and the proposals regarding alternative energy development. Trends and proportions of urban and rural development have been identified. Diagnostics of energy consumption indicators in rural houses in by Ukrainian regions have been made. Volumes and cost of energy consumption indicators in the city and in the countryside have been calculated. The mechanism of energy audit has been proposed. The role of energy consumptions actors at the state and local levels has been justified. Directions for level energy efficiency increase in rural houses have been suggested.*

**Key words:** energy efficiency, energy consumption, rural houses, energy audit, energy-efficient renovation

**Introduction.** One of the world's major problems is the issue of energy efficiency and energy saving. The level of energy consumption in Ukraine is three times higher than in EU countries. According to government estimates, the energy consumption in the Ukraine could be reduced by almost half through the introduction of energy efficient technologies in industry and the residential sector. Therefore, the potential for the development of efficient energy use, particularly in the field of real estate exploitation, is very high.

Ukraine has been an outdated housing fund with a high degree construction period of 1950s and 1970s. The building lose third of the heat, because the walls and windows are not hermetic, the buildings have significant disadvantages in the roof's waterproofing; long-term operation has been led to the demolition of utility networks. Energy consumption of housing and communal services is 31 %. This requires defining the directions of housing reconstruction on the basis of improving its energy efficiency and energy saving. The building, which consumes less energy to provide greater comfort conditions, is more energy efficient. Therefore, under the current conditions of rising energy costs, the using of alternative energy and energy-efficient technologies for home heating has been very relevant.

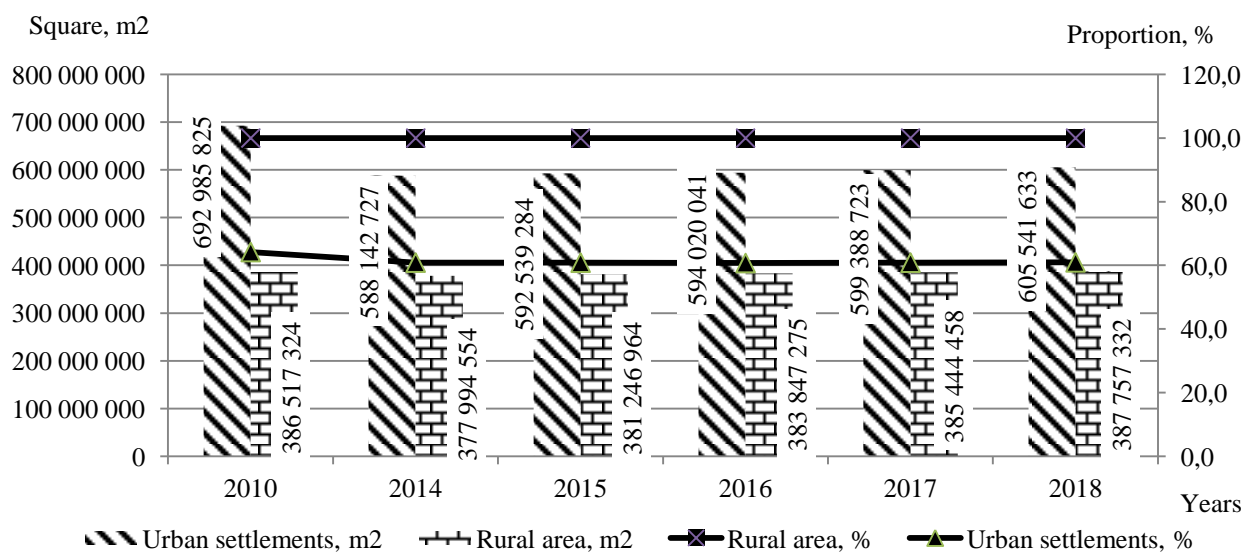
**Literature review.** Research of energy efficiency and energy saving in the economy has been covered in the works of such scholars as: V. Barannik, V. Geyets, S. Yermilov, O. Sukhodolia, O. Ovsienko, V. Mykytenko, S. Denysyuk [1-5] and other Ukrainian and foreign scientists. The

authors explore the rational and conscious use of available energy resources for their careful preservation. Mykytenko V. and O. Sukhodolia [3, 4] study tools and spheres of energy efficiency state regulation. Success factors for energy saving policy have been considered in the works by S. Denysyuk [5]. The problems of energy efficiency and energy saving in the housing sector have been engaged by such economists: M. Villca-Pozo, H. Elsharkawy and P. Rutherford, B. Serrano-Lanzarote, I.G. Hamilton, B.Coyne, R.Lawrence and C.Keime, B.Lin, V.Brigilevich, V.Volkov, T. Zavora, G. Kopets [6-14]. In particular, the studies of Spanish scientists regarding the quantitative determination of the energy saving potential in the Spanish housing fund, the formation of a strategy for its energy renewal and the introduction of tax benefits for the modernization of energy efficiency in housing in Spain are interest [11, 12]. H. Elsharkawy and P. Rutherford present the results from an extensive pre- and post-retrofit home energy use and performance survey of 150 properties located in Nottingham's Aspley. Their research seeks to inform and improve the uptake and delivery of future housing retrofit initiatives [10].

The reasons for the high level of energy consumption in Ukrainian housing have been covered in the work by T. Zavora, L. Svystun, Y. Khudolii [13]. Many Ukrainian scientists study foreign experience of improving the energy efficiency in housing and technologies of rehabilitation and construction of energy efficient buildings. The authors also have been analyzed the financial mechanisms of energy-efficient housing reconstruction [14]. The issue of construction efficiency has been little explored in rural areas. This issue has been partially explored in our work [15], but needs further investigation taking into account current trends in the energy and construction spheres.

**The purpose of the article** has been proposals justification to increase the rural houses energy efficiency level, identify the potential of energy efficiency in rural areas, identify differences in energy consumption in the countryside and in the city.

**Results and discussion.** At the beginning of 2019, the housing of Ukraine has been amounted to 993.2 million m<sup>2</sup> of total area. The housing fund of rural settlements has been accounted for 39.1 % of the total. Estimation of the statistics in the dynamics by years shows a decrease in the total living space of the housing from 1079.5 million m<sup>2</sup> in 2010 to 993.3 million m<sup>2</sup> in 2018. This has been due to subjective reasons, namely: military actions in eastern Ukraine, and consequently, destruction of the housing and failure to include in the statistical information the full amount of this data. However, since 2014, there has been an increase in the housing, namely by 27.2 million m<sup>2</sup> or by 2.8 % (Fig. 1).



**Fig. 1. Housing allocation by urban and rural areas**

Source: summarized by the authors on based [16-22].

The share of rural housing has been increase from 386.5 million m<sup>2</sup> in 2010, or 35.8 % of the total housing to 387.8 million m<sup>2</sup> in 2018, or 39 %; compared to 2014, the rural housing have been increased by 9.76 million m<sup>2</sup>, or 2.6 %, which has been a positive trend. Rural displacement has been uneven in Ukraine. The share of rural housing has been higher in the western regions and ranges from 14.06 % in Donetsk and 19.48 % in Dnipropetrovsk regions to 63.08 % in Zakarpattia. According to the State Statistics Committee, almost all housing (98.2 %) has housed in apartment buildings; the square of dormitories and residential premises in non-residential buildings has been totaled 1.8 % (Table 1).

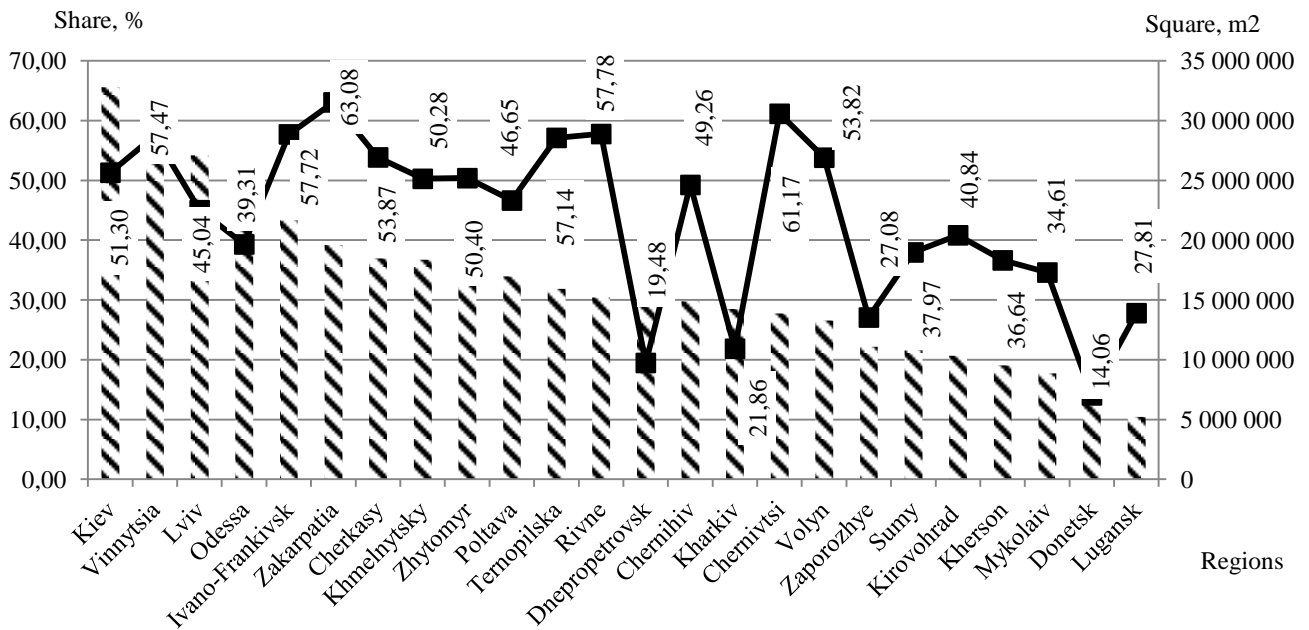
Table 1

**The total area of residential premises, sq.m**

Regions of Ukraine	2010	2011	2015	2016	2017	2018	2018 to 2010, +,-	2018 to 2010, %
Ukraine	372895,1	390490,0	381247,0	383847,3	385444,5	387757,3	14862	4,0
Vinnitsia	27602,5	27493,7	27585,3	27553,1	27566,9	27589,1	-13	0,0
Volyn	12044,8	12235,5	12759,6	12937,0	13123,3	13299,2	1 254	10,4
Dnepropetrovsk	14963,2	14956,9	14993,3	14999,6	15005,1	14988,2	25	0,2
Donetsk	10493,8	10552,3	6885,1	7229,8	7244,9	7247,4	-3246	-30,9
Zhytomyr	16751,2	16828,6	16987,6	17021,4	17052,7	17102,2	351	2,1
Zakarpattia	18282,8	18653,4	19271,6	19376,4	19471,4	19617,6	1335	7,3
Zaporozhye	10992,8	11005,0	11054,7	11059,6	11085,3	11081,5	89	0,8
Ivano-Frankivsk	19316,8	19599,1	20990,3	21056,6	21462,7	21666,6	2350	12,2
Kiev	27160,2	27640,4	30916,1	31760,3	32228,7	32806,8	5647	20,8
Kirovohrad	10452,4	10422,4	10361,5	10366,0	10350,9	10338,9	-113	-1,1
Lugansk	7753,9	7779,1	5219,8	5222,4	5222,5	5231,0	-2523	-32,5
Lviv	24396,5	24857,7	26307,2	26626,9	26838,4	27113,2	2717	11,1
Mykolaiv	8906,8	8856,9	8846,7	8855,0	8861,8	8865,2	-42	-0,5
Odessa	20493,8	21243,8	21710,2	22010,3	22121,9	22436,4	1943	9,5
Poltava	16909,6	16902,9	16976,3	16986,1	16987,3	16988,1	78	0,5
Rivne	14046,0	14192,6	14770,3	14920,8	15072,0	15228,9	1183	8,4
Sumy	10645,9	10669,4	10818,7	10826,4	10818,9	10794,7	149	1,4
Ternopil'ska	15050,7	15192,2	15703,5	15770,9	15851,5	15929,7	879	5,8
Kharkiv	13849,3	14123,3	14261,9	14279,5	14233,0	14248,0	399	2,9
Kherson	9444,5	9474,8	9548,1	9556,1	9300,5	9529,5	85	0,9
Khmelnitsky	18015,5	18127,9	18327,5	18347,3	18365,1	18385,5	370	2,1
Cherkasy	17992,2	18178,0	18438,1	18454,3	18457,4	18479,6	487	2,7
Chernivtsi	12685,7	12908,6	13643,1	13745,5	13826,0	13881,6	1196	9,4
Chernihiv	14644,4	14767,2	14870,6	14885,9	14896,2	14908,4	264	1,8

Source: summarized by the authors on based [16-22].

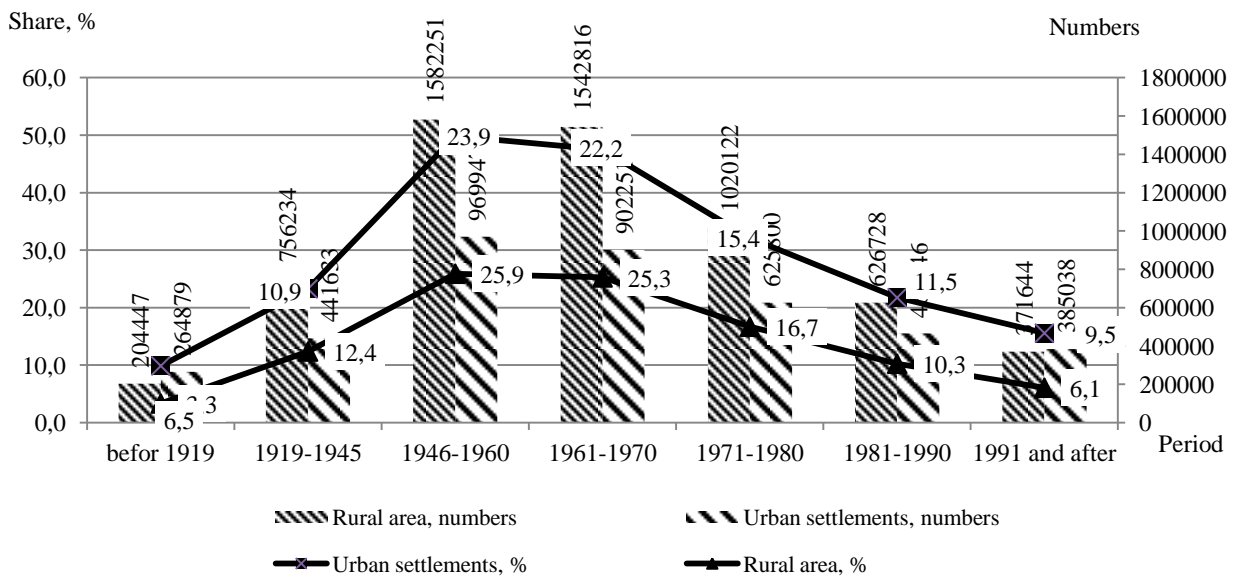
The rural housing dynamics analysis has been shown that rural housing the most significant increase during 2010-2018 in the Kyiv region – from 27.16 million m<sup>2</sup> in 2010 to 32.8 million m<sup>2</sup>, or 20.8 %; in the Volyn region – from 12 million m<sup>2</sup> in 2010 to 13.3 million m<sup>2</sup>, or 10.4 %; Ivano-Frankivsk – by 2.35 million m<sup>2</sup>, or 12.2%; Lviv – by 2.7 million m<sup>2</sup>, or 11.1 %; Odessa – by 1.9 million m<sup>2</sup>, or 9.5%; Chernivtsi – by 1.2 million m<sup>2</sup>, or by 9.4 %. The increase in rural development in Western Ukraine has been primarily due to the region geographical features. Most of these regions buildings have been belonged to the rural area. Large parts of the population of these areas work in other countries and invest their money in the construction of private homes. Similar trends have been also observed in the Odessa region. The region has considerable territorial and economic potential to increase the rural housing. The Kiev region is the capital city and therefore has a higher investment potential comparatively with other regions of Ukraine. As a consequence, the volume of rural housing development has been increased in accordance with the region's socio-economic growth (Fig. 2). Therefore, the leader in housing square in rural settlements has been the Kyiv region – 32.8 million m<sup>2</sup>, and also the leaders in housing square have been Vinnytsia, Lviv, Odesa and Ivano-Frankivsk regions with a housing square of more than 20 million m<sup>2</sup> in each region. These regions have an average share of this housing square kind in total housing square (approximately 50 %). The smallest living area in rural areas is Kherson, Mykolaiv, Donetsk, Luhansk regions with an area of less than 10 million m<sup>2</sup>.



**Fig. 2. Rating of the Ukraine regions by the rural housing square (m<sup>2</sup>) and its share in the total housing square of Ukraine (%)**

Source: summarized by the authors on based [16, 23].

The housing classification by years of development (Fig. 3) has been shown in, that about half of the housing has been put into operation in the postwar years and in the first period of industrial buildings (until 1970). A significant proportion of the country's housing, home to about 50 % of the population, has been in a state of disrepair or outdated and needs major overhaul.



**Fig. 3. The quantity and structure of the Ukrainian housing by years of construction**

Source: summarized by the authors on based [22, 23].

According to experts of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine, more than 70 % of the housing has been need thermo-modernization. In Ukraine, first of all, a 1971s-1980s building has been needed thermomodernization, which is about 18140 buildings (105.1 million m<sup>2</sup>) [24]. This need has been driven by the high level of buildings energy losses that were inherent in the construction technology used in the 1950s-1980s. Most of the heat is lost through the walls and the roof.

Such buildings and structures consume between 160 and 240 kW / m<sup>2</sup> per year. The housing built between the mid-1980s and the early 2000s consumes more than 140 kW / m<sup>2</sup> annually. And only homes built later consume about 100 kW / m<sup>2</sup> per year, which meets current standards to date. These data has been indicated that the energy saving potential of the Ukrainian housing has been quite significant, which indicates the need for energy-saving reconstruction. The innovations developed in the construction sphere have been got the opportunity to build housing from 50 kW / m<sup>2</sup> per year up to the so-called zero energy consumption in current conditions. The experience of buildings renovation in Germany over the last 20 years has been shown that in consequence of the complex rehabilitation of buildings with the thermal modernization measures implementation up to 50 % of energy for heating and hot water can be saved. At the same time, the demand for primary energy has been on average reduced by 0.5-0.7 tonnes of conditional fuel per household per year. This means that greenhouse gas emissions will be less on average of 1.0-1.4 tonnes per household per year.

Estimation of urban and rural development periods has been shown that construction has been carried out almost simultaneously. During the years 1946-1960, over 1.5 million houses (23.9 %) have been erected in the countryside, approximately as many houses have been built in the countryside during the years 1961-1970. At that time, in the city settlements, it has been built 9 million homes, which is 51.2% of all city buildings. The share of new buildings in the countryside has been 9.5 %, in the city this indicator has been 6.1 % (Table 2).

Table 2

**Quantity and proportion of Ukrainian rural housing by years of building by region**

Regions of Ukraine	Total homes quantity	including built in the period:								
		before 1919 p.	1919-1945	1946-1960	1961-1970	1971-1980	1981-1990		1991 and after	
							quantity	share, %	quantity	share, %
Ukraine	6104242	204447	756234	1582251	1542816	1020122	626728	100,0	371644	100,0
AR Crimia	207140	3670	16060	47687	64478	39592	22707	3,6	12946	3,5
Vinnytsia	439186	22422	63134	121266	111745	64660	33557	5,4	22402	6,0
Volyn	177504	1647	15890	48614	43940	3940	2822	0,5	936	0,3
Dnepropetrovsk	250082	13651	39145	67106	58687	34836	22343	3,6	14314	3,9
Donetsk	189101	5078	18817	52955	50498	34810	18803	3,0	8140	2,2
Zhytomyr	268898	7747	37237	74173	69155	41998	23811	3,8	14777	4,0
Zakarpattia	231182	3521	22112	47790	50339	44978	35395	5,6	27047	7,3
Zaporozhye	182936	10267	29187	44997	43129	29015	18825	3,0	7516	2,0
Ivano-Frankivsk	272584	8503	35234	56842	59208	52412	36953	5,9	23432	6,3
Kiev	377025	8168	40016	93991	90393	57927	46261	7,4	40269	10,8
Kirovohrad	188004	10741	31606	51349	44130	27304	15316	2,4	7558	2,0
Lugansk	140091	4856	14500	40009	38742	23098	13193	2,1	5693	1,5
Lviv	343298	12331	53124	77443	78871	58959	37821	6,0	24749	6,7
Mykolaiv	153556	7031	20534	46512	36167	23149	14755	2,4	5408	1,5
Odessa	313557	22730	51022	80590	69440	46177	25756	4,1	17842	4,8
Poltava	291265	9283	37860	82053	70891	42426	32120	5,1	16632	4,5
Rivne	204185	2705	22677	49150	46504	38501	25707	4,1	18941	5,1
Sumy	192961	4467	23177	52488	56399	30623	18214	2,9	7593	2,0
Ternopil'ska	228773	6910	32328	49851	63371	43732	22006	3,5	10575	2,8
Kharkiv	233787	4330	18895	64101	64738	43438	25480	4,1	12805	3,4
Kherson	152088	4331	12292	34736	38803	35665	18481	2,9	7780	2,1
Khmelnitsky	294113	9383	35609	81351	86113	48003	22320	3,6	11334	3,0
Cherkasy	305214	6820	29718	89936	82038	51749	30419	4,9	14534	3,9
Chernihiv	195834	9600	27107	38823	41725	34452	26196	4,2	17931	4,8
Chernivtsi	266225	4198	28625	86829	81501	38890	18635	3,0	7547	2,0

Source: summarized by the authors on based [22, 24].

Analysis of indicators by Ukrainian regions has been shown that in the postwar period (1946-1960), 121266 houses have been built in rural areas in Vinnytsia region, in the following period (1961-1970), 111745 houses have been built in this region. It has been amounted total 53 %. The Chernihiv region also has been undergone large-scale reconstruction in the postwar period. It has been built more than 80,000 homes in each of these periods, accounting for 63.2% of the total



buildings quantity of all periods. Khmelnytsky and Cherkasy regions has been shown similar trends, with the building quantity over 80,000 houses in each period and a total share of more than 56 %. The lowest quantity of rural houses have been built during the years 1945-1960 in Volyn region, which as a whole has the smallest quantity of houses built in all time.

Regarding new buildings in rural areas, ie houses built after 1991, so most of them have been built in Kyiv region (40269 houses, or 10.8 % of the total quantity of new buildings in Ukraine), Zakarpattia region (27047 houses, or 7.3 %) and Vinnytsia region (22402 homes, or 6 %). The lowest quantity of new rural houses has been built in Lugansk (5693 houses, or 1.5 %), Sumy and Chernihiv regions, it is about 7.5 thousand houses (2 % each region). In the 80-90s, the largest quantity of rural houses has been built in Lviv region; it is 37821 houses (6 % of the total quantity of houses in this period in Ukraine).

In the context of the justification of the National Energy Efficiency Action Plan for the period up to 2020, the energy saving potential in the housing has been identified at the state level. The document [25] states that Ukraine has not been collected official statistics on the energy consumption of different types of buildings in different climatic zones. Therefore, the energy efficiency potential has been determined on the basis of computer simulation of energy consumption according to the methodology. The computer models have been based on the real thermal characteristics of the buildings, their age, type and features of the four climatic zones of Ukraine, which as a result has been extrapolated to the total housing. The following standard homes have been accepted as calculating agents:

- house of cottage type for one family with a total area of 60 m<sup>2</sup>;
- 2-storey house with 2 entrances;
- 5-storey building with 4 entrances;
- 10-storey building on one entrance;
- 5-storey single-storey dormitory building [25].

These types of buildings have been the most typical for modern Ukraine. By rural areas, single family cottage-type houses have been occupied the highest proportion, 2-storey house with 2 entrances (or two- or four-owner houses) and dormitory have been also typical, multistoreyed houses have been not typical for rural areas.

The results of calculations of energy consumption characterize the data in Table. 3.

*Table 3*

**Energy consumption of existing houses, determined by the results of modeling in terms of climatic zones of Ukraine, tonnes of oil equivalent (toe)**

Necessary energy, toe	Zone I		Zone II		Zone III		Zone IV	
	volume of consumption, toe	share, %	volume of consumption, toe	share, %	volume of consumption, toe	share, %	volume of consumption, toe	share, %
Zone's characteristics	above 3501 degrees-day		3001-3500 degrees-day		2501-3000 degrees-day		less than 2500 degrees-day	
Regions belonging to the zone	Ternopil, Rivne, Zhytomyr, Khmelnytsky, Vinnytsia, Kyiv, Cherkasy, Chernihiv, Poltava, Sumy, Kharkiv, Lugansk, Donetsk, Kirovograd		Dnepropetrovsk, Zaporizhia, Volyn, Lviv, Ivano-Frankivsk, Chernivtsi		Odessa, Mykolaiv, Kherson, Zakarpattia		AR Crimea	
Houses up to 6 floors in height	1660022	10.1	561611	10.1	239408	7.7	40723	9.6
Houses with 5 storey	2154469	13.1	766560	13.7	397414	12.8	136109	32.2
Houses with a 2 to 4 storey	1431042	8.7	404753	7.3	237487	7.6	29731	7.0
Dormitories	221404	1.3	81205	1.5	41762	1.3	7177	1.7
Cottages	11016089	66.8	3766048	67.5	2197323	70.6	209072	49.4
Annual houses energy consumption	16483026	100.0	5580177	100.0	3113394	100.0	422812	100.0
Total	25599408							

Source: summarized by the authors on based [25].

For calculating the energy consumption indicators in typical houses, the Ukrainian climate zones have been also taken into account. The basis of zoning has been the degree-day index of the heating period (GDOP). It is calculated as the multiplication of the difference between the indoor air temperature and the average outside air temperature and the duration of the heating period. That is, if this indicator is lower, the less energy will be consumed in the houses.

Experimental data has been shown that the received energy consumption of the houses sector has been 25 million tonnes. Specific energy consumption, that is, the average energy productivity in Ukraine is 276 kWh / m<sup>2</sup> of energy consumed and varies from 145 to 327 kWh / m<sup>2</sup> depending on the type of building and the climate zone in which the building is located. An important factor in the houses energy efficiency is the equipment of houses with sources of heating, water supply, cooking. The peculiarities of the rural houses have been the absence of central heat and water supply, as well as the predominance of natural gas as a heating source (Table 4).

Table 4

**The proportion of the equipped total living space in rural areas, 2014, 2018, %**

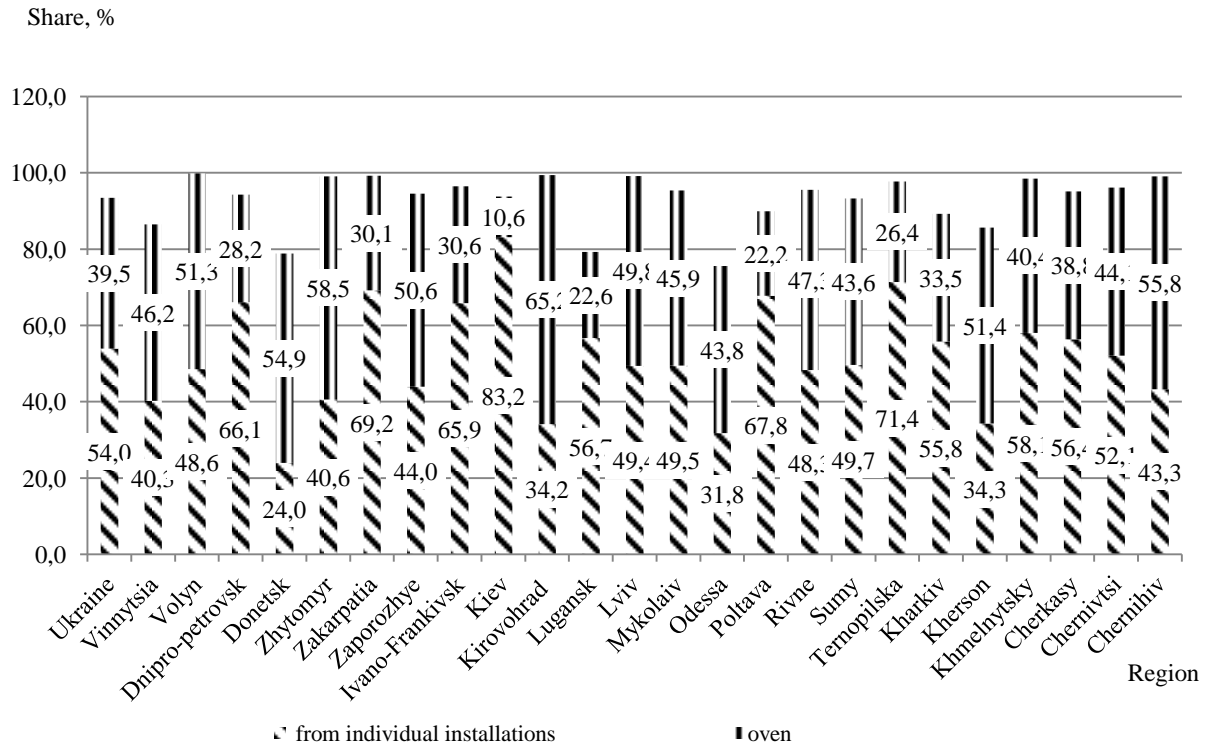
Regions of Ukraine	water supply		hot water supply		sewage system		heating						gas			
							the central one		from individual installations		oven		natural		liquefied	
	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018
Ukraine	28,9	37,4	16,9	24,4	25,2	33,8	1,0	1,4	48,1	54,0	44,2	39,5	53,2	57,5	31,0	26,8
Vinnitsia	17,1	23,2	9,3	12,4	14,8	20,0	0,6	2,0	37,0	40,3	49,8	46,2	41,6	45,0	39,6	37,2
Volyn	33,1	44,5	23,4	35,6	30,2	41,7	0,0	0,1	39,9	48,6	60,1	51,3	43,5	50,2	32,3	26,7
Dnipro-petrovsk	35,5	39,2	11,7	13,5	25,0	28,8	0,9	2,0	59,6	66,1	28,7	28,2	63,5	66,5	24,0	21,9
Donetsk	37,7	39,6	5,8	6,8	24,6	28,1	2,1	1,8	19,5	24,0	59,7	54,9	24,8	26,7	26,7	23,7
Zhytomyr	11,8	15,8	8,2	11,5	11,6	15,7	0,1	0,5	36,0	40,6	63,6	58,5	39,1	42,9	44,1	40,2
Zakarpattia	68,3	73,6	60,9	65,7	67,3	73,6	0,1	-	65,0	69,2	34,5	30,1	62,4	66,1	19,4	17,8
Zaporozhye	29,7	33,9	20,8	24,9	27,0	31,3	1,1	1,4	40,3	44,0	54,3	50,6	42,1	45,1	47,5	44,8
Ivano-Frankivsk	23,3	39,6	18,2	35,3	22,8	39,2	1,5	0,4	56,4	65,9	38,7	30,6	74,1	74,5	9,8	8,5
Kiev	36,6	50,2	26,5	36,7	34,7	48,5	1,9	4,1	82,0	83,2	15,3	10,6	83,5	86,9	13,6	9,9
Kirovohrad	12,6	17,1	5,4	8,4	10,8	15,0	0,1	-	28,4	34,2	65,8	65,2	22,6	25,8	58,3	55,3
Lugansk	28,2	32,6	9,4	12,0	25,6	31,0	0,2	0,6	40,2	56,7	18,2	22,6	64,6	68,4	10,0	8,3
Lviv	32,4	47,8	24,0	39,7	30,6	47,0	0,6	0,8	38,4	49,4	54,7	49,8	71,1	76,3	12,1	9,5
Mykolaiv	34,3	40,4	20,1	24,9	25,6	31,5	0,7	-	43,6	49,5	51,1	45,9	42,0	45,4	47,2	43,5
Odessa	45,8	49,7	16,4	19,7	31,8	35,5	2,1	2,6	26,6	31,8	43,4	43,8	30,5	33,4	55,8	48,5
Poltava	27	31,4	11,6	15,0	24,2	27,8	1,7	3,4	67,1	67,8	26,1	22,2	71,9	73,3	18,7	16,0
Rivne	28,3	35,0	18,8	23,4	26,4	32,8	0,3	2,3	45,1	48,3	54,1	47,3	47,3	50,2	26,3	22,2
Sumy	18,6	24,5	8,8	11,6	15,7	20,9	0,4	1,6	46,4	49,7	46,9	43,6	43,2	46,9	32,3	30,1
Ternopil'ska	30,7	39,1	18,0	25,2	24,3	32,2	0,7	0,1	66,0	71,4	31,1	26,4	75,1	77,3	16,3	13,0
Kharkiv	26,9	31,8	11,5	13,3	24,4	29,2	5,3	4,0	51,2	55,8	38,6	33,5	56,2	60,3	29,7	25,4
Kherson	45,3	48,9	12,5	15,5	32,7	34,9	0,8	0,2	31,6	34,3	52,2	51,4	28,6	31,5	66,3	61,7
Khmelnitsky	12,6	19,3	7,4	13,6	12,1	18,1	0,1	0,1	53,4	58,1	44,0	40,4	57,6	59,8	31,8	29,0
Cherkasy	25,8	31,6	14,6	19,6	24,4	30,0	0,5	0,3	50,8	56,4	43,2	38,8	48,6	52,9	34,9	31,5
Chernivtsi	29,4	39,8	26,6	37,2	28,9	39,5	-	0,0	46,6	52,1	52,2	44,1	54,4	56,9	33,0	29,9
Chernihiv	16,7	22,2	8,9	12,1	14,5	19,6	0,4	0,9	39,0	43,3	60,5	55,8	36,1	39,6	37,4	33,9

Source: summarized by the authors on based [16, 20].

A positive tendency for the provision of rural houses with the main types of communal systems has been observed during 2014-2018. Thus, in Ukraine as a whole, the proportion of homes with water supply has been increased from 28.9 % to 37.4 %, with hot water supply has been increased from 16.9 % to 24.4 %, and sewage has been increased from 25.2 % to 33, 8 %. Despite the tendency to increase the availability of these types of communal systems, a lot of homes do not have water, sewage and hot water. Regarding heating, the share of houses equipped with centralized heating remains insignificant (1.4 %). The rural houses share with gas boilers have been increased

from 48.1 % to 54 %, and the rural houses share with furnace heating has been decreased accordingly from 44.2 % to 39.5 % in 2018 compared to 2014.

Speaking about gas for cooking, share of homes using natural gas has been increased from 53.2 % to 57.5 % in 2018 compared to 2014. Most rural houses with district heating have been located in Kyiv (4,1 %), Poltava (3.4 %) and Kharkiv (4 %) regions, gas boilers have been in Kyiv (83.2 %), Ternopil (71.4 %), Zakarpattia (69.2 %), Poltava (67.8 %), Dnipropetrovsk (66.1 %), Ivano-Frankivsk (65.9 %). The most significant increase in the share of houses equipped with gas boilers in 2018 compared to 2014 has been observed in these regions. Furnace heating has been most popular in Kirovograd (65.2 % of houses have a furnace), Zhytomyr (58.5 %) and Chernihiv regions (55.8 %) (Fig. 2).



**Fig. 2. The structure of rural houses, depending on their equipment with the appropriate type of heating, %**

Source: summarized by the authors on based [16].

The acute crisis of the entire economic system of Ukraine in 2014-2018 has been caused the construction industry. Housing building by new energy efficiency standards has not been carried out. The cost of such housing is too expensive, which makes it impossible to meet the needs of most Ukrainians in modern, high-quality, economical housing.

Studies have been shown that energy costs for heating homes in the city and rural areas have been significantly different. Thus, on average in the city in an apartment building for heating per 1 m<sup>2</sup> of living space for the heating season (6 months) 0.1 Gcal has been spent. The average tariff per 1 Gcal in Ukraine has been 1400 UAH (however, there are significant differences in the regions of Ukraine). The highest prices for heating have been in Kyiv and Rivne regions, the lowest prices have been in Odessa, Chernivtsi, Lviv, and Zaporozhye.

So, the average cost of heating 1 m<sup>2</sup> of living space for the heating season in the city with centralized heating has been 140 UAH. If the heating in the city has been carried out with the help of individual gas boilers, the cost has been about 100 UAH / m<sup>2</sup>. In rural areas, the cost of heating has been significantly higher than in the city. Most rural homes use individual gas boilers. Some households have been combined gas heating with furnace, solid fuel or other (alternative) type of

heating. In the case of gas heating, the average cost of gas per 1 m<sup>2</sup> of living space in rural areas for the heating season has been 320 UAH. Thus, the average cost of heating for the whole period of an average rural house has been 20000 UAH (Table 5).

Table 5

**The houses heating costs during the heating season in the city and rural areas of Ukraine, 2018**

Indicators	Types of heating			
	the central one	from individual installations (gas boilers)	oven	total
<b>Rural areas</b>				
Cost of heating per season (6 months) per 1 m <sup>2</sup>	140	320	130	-
Total rural housing, m <sup>2</sup>	387757332			387757332
The coefficient of equipment with the appropriate type of heating	1.4	54	39.5	94.9
Total rural housing, with appropriate heating type, m <sup>2</sup>	5428603	209388959	153164146	367981708,1
Heating costs for the heating season, UAH million	760.0	67004.5	19911.3	87675.8
Average cost of heating for the season (6 months) per 1 m <sup>2</sup> , UAH	-	-	-	238.26
Probable heating costs provided only furnace heating, UAH million	-	-	-	47837.6
Savings due to substitution of heating type, UAH million	-	-	-	39838.2
Savings due to substitution of heating type, %	-	-	-	45.4
<b>Urban settlement</b>				
Cost of heating per season (6 months) per 1 m <sup>2</sup>	140	100	130	-
Total rural housing, m <sup>2</sup>	590044799	-	-	387757332
The coefficient of equipment with the appropriate type of heating	72,8	5,6	0,7	79,1
Total rural housing, with appropriate heating type, m <sup>2</sup>	429552614	33042509	4130314	466725436
Heating costs for the heating season, UAH million	60137.4	3304.3	536.9	63978.6
Average cost of heating for the season (6 months) per 1 m <sup>2</sup> , UAH	-	-	-	137.08

Source: calculated by the authors .

In total, 87675.8 million UAH has been spent in the Ukrainian rural territories during the season for heating, and UAH 63978.6 million has been spent in the city. On average, considering the share of each type of heating in the city and in the countryside, it has been estimated that the cost of heating 1 m<sup>2</sup> in the rural areas has been 238.26 UAH, in the city has been 137.08 UAH. Assuming that all heating in the rural housing would be stove, which mainly works based on firewood, then savings of UAH 39838.2 million, or 45.4 % would be achieved. Of course, this is not a strategic proposal for energy conservation; because furnace heating is not modern and has several disadvantages. However, this calculation has been shown the efficiency of alternative fuel use. Currently, a mechanism to encourage the installation of solid fuel boilers has been developed in Ukrainian houses, in particular by offsetting their cost when issuing appropriate loans. Solid fuel boilers can be targeted at a wide range of consumption, from domestic to industrial use. Solid fuel boilers have several advantages over other types of boilers: affordability, autonomy and cheap fuel, as well as the fact that the choice of fuel depends on the owner. The assortment of solid fuel boilers is very high, and the fuel for them (such as coal) at relatively low cost has a huge thermal effect [26]. Solid fuel boilers have been conditionally classified according to the following characteristics (Table 6).

Approximately 54 % of the rural population has been used natural gas for heating, so its rise in price since 2014 has been very negative for Ukrainians. A household with square 65m<sup>2</sup>, using automatic boilers, have been needed about 300-350m<sup>3</sup> of gas per month per the heating season. At the current price it has been more than 2.5 thousand UAH per month. This has been more than 30 % of the average salary in rural areas and sometimes more than the monthly pension. Thus, combining gas heating with an alternative, such as equipping the premises with a heat-fuel boiler, has been economically feasible and energy-efficient.

Table 6

**Classification feature of solid fuel boilers**

Classification feature	Characteristic
Depending on the type of fuel used	<ul style="list-style-type: none"> <li>- firewood boilers: dry wood is the main fuel for these boilers;</li> <li>- coal boilers: they are still called “omnivorous”. In such boilers large pieces of solid fuel have been burned, such as coal and lignite, peat and coal braces, anthracite, as well as wood and some sort of construction debris;</li> <li>- pellet boilers: fuel pellets have been used as fuel for these boilers;</li> <li>- mixed fuel boilers - several types of fuel: coal, wood, pellets, eco-peas, oats, etc. could be burned here.</li> </ul>
Depending on the method of combustion of the fuel	<ul style="list-style-type: none"> <li>- naturally aspirated boilers - in these models, the combustion process has been controlled by a thermostatic traction regulator without additional forced air supply;</li> <li>- boilers with additional forced draft – unlike boilers with natural draft, equipped with an additional fan, which additionally adds air to the furnace, and the fan power has been regulated depending on the combusted fuel and smoke draft;</li> <li>- pyrolysis boilers: it is boilers with a more complex combustion mechanism, which consists in the fact that the firewood in the primary chamber has been burned in a low oxygen environment and thus the combustible gas is released, which is ignited in the secondary chamber;</li> <li>- long-burning boilers: in these boilers the combustion process takes place from top to bottom, whereby a longer and even heating of the coolant has been achieved on one tab of the fuel.</li> </ul>

Source: developed by the authors .

In addition, the State Agency for Energy Efficiency and Energy Conservation of Ukraine has been calculated the economic effect of the housing modernization (Table 7). The results of the calculations has been shown that the implementation of these energy-efficient measures in the existing Ukrainian houses and improvement of their energy efficiency will provide to a reduction of total energy consumption by 15.3 million tonnes, or 60 %.

Table 7

**Energy saving potential in the housing sector**

Measures	Potential, thousand toe		
	Apartment buildings	Cottages	Total
Additional wall insulation	1699	3313	5012
Installation of energy efficient windows	975	1901	2876
Additional roof insulation	928	1809	2736
Installation of energy efficient engineering equipment	1439	2806	4245
Replacement of interior lighting	149	291	440
Total	5190	10120	15310

Source: [25].

Therefore, the energy savings potential in the housing sector, particularly in rural areas, has been significant. The rural houses have been needed to implement measures to reduce heat consumption. Housing and utility companies have been consumed about 10 billion kWh each year of electricity and 8.5 billion m<sup>3</sup> of natural gas. With a steady decline in population, energy consumption per Ukrainian citizen in the household sector have been not decreased, and in some regions even increases. This condition has been explained by the following reasons:

1. Energy consumption of household appliances, machines and mechanisms has been increased.

2. Energy savings in the housing sector have not yet gained a critical mass, which would have a significant impact on reducing their consumption.

3. Today, about 40 % of the state's energy resources have been used for houses heating, 2/3 of them have been simply lost during transportation and due to the high energy intensity of buildings

4. Energy, gas and water production and distribution companies have not been very active in introducing resource-saving innovations. Quantity of low-waste and resource-saving technologies has been ranged from 6 to 50 per year, with total innovations over the 10 to 163 year [13].

The level of energy consumption for housing heating has been remained at the level of 1980s design decisions (an average of 210-240 kWh / m<sup>2</sup> per year). This is at times worse than in European countries (around 100) [27].

Developed countries, first and foremost, EU countries that have already made significant strides in addressing the buildings energy efficiency, have been minimized their heat and electricity needs, continue to look for new sources of energy and develop energy-saving measures. For example, by 2020, European countries plan to completely switch to the construction of passive (zero energy) and energy-autonomous (which provide more energy than they consume) homes. Such homes have an independent grid that does not require the cost of maintaining a comfortable temperature. The house has been heated by alternative renewable energy sources (solar collectors, heat pumps, wind turbines, etc.), as well as taking into account the heat generated by people living in it, household appliances, etc. At the same time, heat losses are prevented due to the design features of the building, which uses modern energy-saving technologies and high-efficiency thermal insulation materials for construction [28, 29] (Table 8).

Table 8

**Heat losing depending on the type of buildings in the example of Germany**

The house has an area of 140 m <sup>2</sup>	Annual energy consumption, kWg / (m <sup>2</sup> year)	Specific heat loss, Wg / m <sup>2</sup>
Old building	300	136
The typical house of the 70's	200	91
The typical house of the 80's	150	68
House of low energy consumption of the 90's	to 70	14-32
House of ultra-low power consumption	15-30	7-14
Modern passive house	less 15	less 7

Source: summarized by the authors on based [28].

Energy management procedures, automatic adjustment, hydraulic balancing of the heating system, thermostatic radiator valves all have been contributed to energy efficiency. Reducing energy consumption also have been helped reduce environmental pollution from non-renewable energy sources (natural gas, fuel oil, coal), which has a positive effect on the environment both locally and globally.

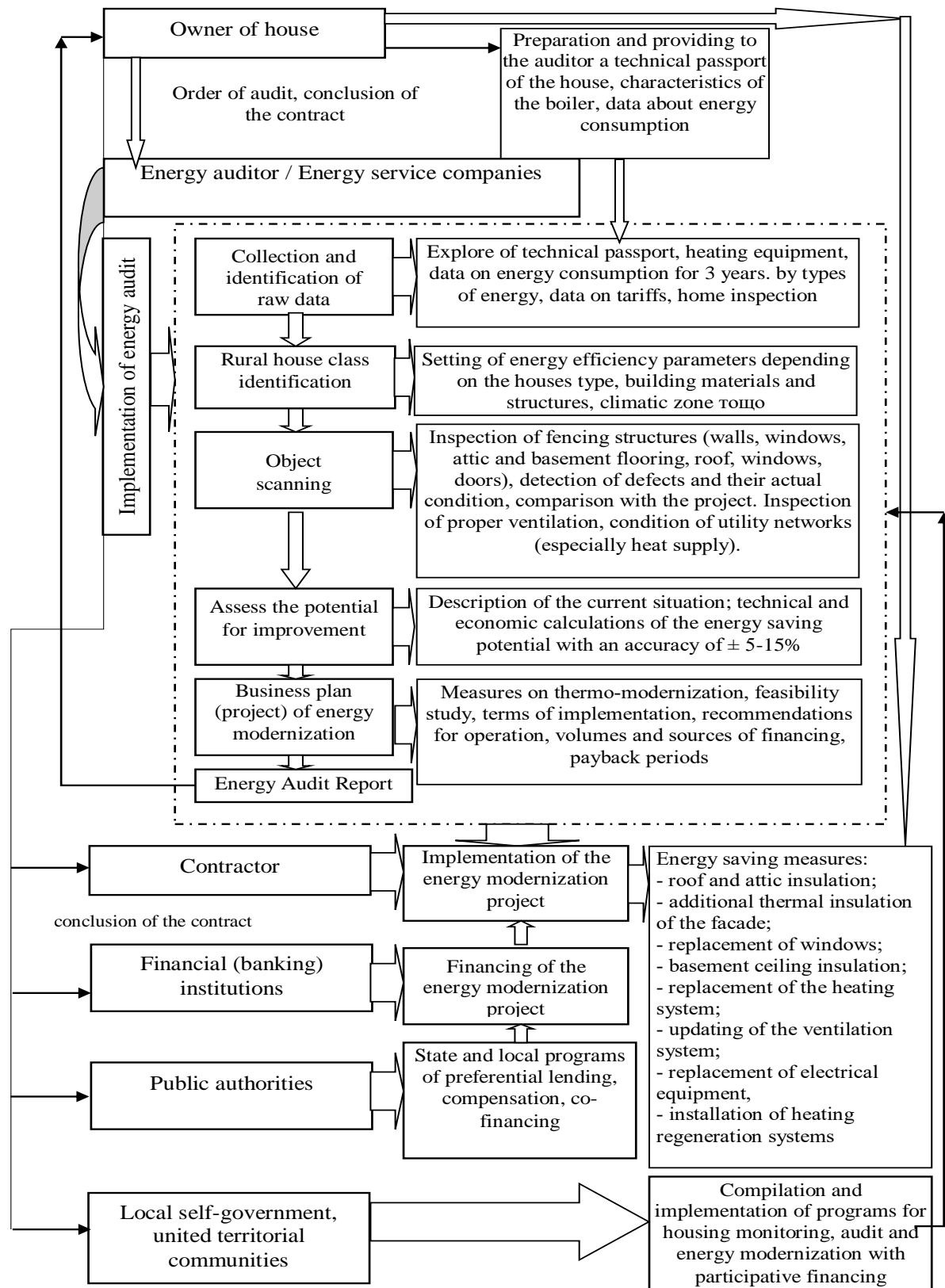
The Directive on the Energy Performance of Buildings (EPBD) [29] has been established the energy efficiency class of a building from A, for energy consumption less than or equal to (25 kWh / (m<sup>2</sup> year), to G, for consumption, exceeding (450 kWh / m<sup>2</sup> year). The following energy conservation goals have been declared in Germany:

- to reduce heat demand over 20 % by 2020;
- increase the share of renewable energy sources in total consumption over 35 % by 2020 (over 80 % by 2050);
- to achieve a reduction of primary energy demand over 80 % by 2050 and to fully transition to the construction of passive buildings [29, 30, 31].

The heating system modernization with the installation of solar thermal plants, heat pumps, biomass heating systems, wood (wood chips, pellets) have been allowed significantly increase energy efficiency. A significant reduction in heat loss could be achieved only by taking a comprehensive approach to the task at hand. In addition, a number of factors should be taken into account, such as overheating of the premises during the transitional period of the year, excessive heat losses due to the low efficiency of external pipelines insulation, excessive actual air exchange in the premises, losses of operational and organizational nature, as well as heat losses caused by unforeseen factors.

The diagnostics of the structure and condition of the housing sphere indicates the necessity of carrying out its complex energy efficient remediation. Renovation of a house is a complex carrying out of actions taking into account technical, economic, and social factors of a dwelling house in order to restore its original technical condition; achieving modern standards for its individual components and maximizing energy savings. Carrying out complex energy-saving renovation (or energy modernization) of the building allows: extend the life of the house; significantly reduce energy consumption; to reduce the owner's money for heating and electricity; significantly reduce greenhouse gas emissions; increase the market value of the housing; to provide comfortable and safe accommodation. The owners should take care to identify the causes of their occurrence and

justify the most effective energy-efficient measures to overcome them, that is, to conduct a comprehensive energy audit. Energy audits should be performed by specially trained and experienced energy auditors. In general, the process of implementing energy-efficient renovation and energy audit of the house is shown in Fig. 3.



**Fig. 3. Mechanism of rural housing energy-saving reconstruction**

Source: developed by the authors .

Energy audits include a survey of buildings, an assessment and analysis of the current situation and the various measures that can be taken to reduce energy consumption and improve the climate in the building. The results of the energy audit are provided in an appropriate report describing the recommended measures with the appropriate volumes and sources of investment, savings and profit of the owner.

In order to comprehensively address the energy losses issue in the housing sector, public authorities and local self-government should, in various ways, stimulate the citizens to conduct energy audits and implement energy-saving remedial measures in their own premises. For example, the introduction of a state-of-the-art program for energy-efficient renovation of buildings in Germany has been allowed the successful reconstruction of about 3/4 of the total houses over 20 years. About 60 % of energy has been saved in renovated homes. Complex renovation of old buildings has been 1/3 of the cost of construction of new ones.

For the effective transformation of rural and urban houses with the creation of investment-attractive climate and the availability of affordable modern comfortable housing at the national and regional level, it has been necessary to provide the following measures:

- creation of a viable state program for investing in the construction and modernization of housing sector, in particular, in rural area;
- implementation of energy saving motivational measures;
- ensuring compliance with the requirements of modern building and energy standards;
- creation favorable financing conditions achieved through price stabilization policies and effective private and public lending instruments;
- ensuring social guarantees for the poor;
- ensuring training for personnel in the sphere of construction and reconstruction, planning, management and financing.

**Conclusions.** The current state of the Ukrainian housing, in particular in rural area, as well as the energy and economic situation in the country, have been required a solution to the problem of improving energy efficiency in the housing sector. In general, the experience of developed countries has been pointed to the need for state regulation of energy saving processes in the housing sector and providing a purposeful policy to increase the energy efficiency of houses.

Effective activity of the specialized energy efficiency fund to ensure stable financing of housing renovation projects should be the basis of the Ukrainian government's efforts to improve the energy efficiency of the housing sector, which will allow for a comprehensive renovation of buildings and will result in annual energy savings. Provided energy-efficient measures and thermal modernization of houses built before the 1990s, Ukraine will be able to reduce gas consumption in the residential sector to 12 billion cubic meters in a few years.

The perspectives of further exploration in this area are to justify the cost-effectiveness of using different types of alternative fuel in rural houses.

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