Evaluation of potential possibility of energy efficiency in residential buildings

B. Petrov*, I. Puikevica-Puikevska, N. Zeltinsh

Energy Efficiency Centre, Institute of Physical Energetics, Latvian Academy of Science, Latvia

ABSTRACT
The programme 'Energy Audit' has been worked out at the Energy Efficiency Centre of the Institute of Physical Energetics, LAS, and may be used for evaluation of heat losses from buildings and the economic efficiency of measures to be taken for their thermal modernization. The programme is based on the thermal energy balance of a building and allows calculating technical and economic characteristics of a building's envelope components to be modernized. By request of the Ministry of Environmental Protection and Regional Development of Latvia, in the framework of this programme the parameters of thermal insulation were determined for more than 1200 public buildings owned by local municipalities. The programme is intended for designing business plans related to the thermal modernization and the energy audit of buildings in Latvia.

INDEX TERMS
Heat losses; Energy saving; Residential building; Envelope; Economic effects

INTRODUCTION

Most residential and public buildings in Latvia are built from bricks or prefabricated concrete panels as multifamily houses. Many of them are in a poor condition because of their design failures and the low quality of building structures. The losses of thermal energy from these buildings are very high and they affect the comfort of the living environment. Therefore, the application of a thermal insulation envelope to the buildings and improvement of their heating and ventilation systems may produce great saving of energy. The costs and the payback period of such measures may be considerably decreased if they are taken during the thorough overhaul of the building.

METHODS—THE THERMAL BALANCE OF THE BUILDING

In order to maintain normal heat conditions and compensate the heat losses through construction elements of the envelope (exterior walls, windows, the roof, etc.), as well as energy consumption for the local hot water system, the ventilation system and various installations of the building, a certain amount of energy is required. In agreement with the thermal energy development concept it is necessary to optimize energy consumption in the residential buildings of Latvia.

For the calculations, the programme 'Energy Audit' was applied. The programme was developed at the Energy Efficiency Centre of the IPE based on the energy balance concept of the building. The heat losses from a building can be estimated as the difference in energy consumption before and after the formation of an insulating envelope around this building. The heat flow out of a building usually proceeds in two ways: through the envelope owing to the heat transfer process if there is a difference between the temperatures inside and outside

*Corresponding author. E-mail: leen@edi.lv

the building, as well as through its gaps due to air convection. The programme allows estimating the technical and economic parameters of the measures taken to modernize public and residential buildings so that the thermal properties of envelopes can be improved.

ESTIMATION OF THE TECHNICAL AND ECONOMIC CHARACTERISTICS OF THERMAL MODERNIZATION OF THE HIGH SCHOOL 1 BUILDING IN THE TOWN OF LUDZA

As an example of applying the programme 'Energy Audit', we present the results of theoretical research into the technical and economic efficiency of measures for thermal modernization of buildings. The research was conducted at the EEC and was intended for thermal modernization of High School N 1 in the town of Ludza (Latvia). It was envisaged to replace the old windows that were in a poor condition in the school building by modern ones having glass packages. The research was carried out in co-operation with the Dutch company 'TEBODIN'. Particular attention was paid to studying the influence of the design parameters of glass packages (such as using glass with improved thermal resistance or filling the packages with inert gases of greater specific weight and lower heat conductivity than air) on the economic characteristics of thermal insulation measures. We also estimated the use of stone wool produced by the 'PAROC' Company as an alternative insulating material for other envelope elements of the school building.

The school was built in 1961 according to a standard design, which allows the obtained results to be used for the improvement of thermal properties of similar buildings. The walls of the school are built from lime-and-sand brick, the attic and cellar ceilings being made of concrete with standard haydite and haydite-concrete thermal insulation. The window frames were in poor condition; their wear and tear, which resulted in increased air infiltration, was accounted for by a coefficient of 1.2 introduced into our calculations (see Table 1).

Table 1 Thermal parameters of the envelope of the school building

Number of storeys	4	
Heated area	2873	m^2
Gross volume	11,205	m^3
Exterior walls		
Material	Lime brick—thickness 64 cm	
Insulated area	1829	m^2
U-value before insulation	1.23	W/m^2 °C
Heat insulation material	Stone wool—thickness 15 cm	
U-value after insulation	<0.25	W/m^2 °C
Windows		
Type before insulation	Two sheet glasses, wooden frame	
Type after insulation I	Plastic frame with a glass package (66.4 LVL/m^2)	
Type after insulation II	Plastic frame with a glass package-selective glass (VEGLA PLANITHERM-FUTUR glass) with argon filling (71.6 LVL/m^2)	
Type after insulation III	Plastic frame with a glass package-selective glass (EKOPLUS glass) with argon (72.6 LVL/m^2)	
Type after insulation IV	Plastic frame with selective-selective glass (EKOPLUS glass) (72 LVL/m^2)	
Insulated area	747	m^2
U-value before insulation	2.9×1.2 = 3.5	W/m^2 °C
U-value after insulation I	2.9	W/m^2 °C
U-value after insulation II	1.3	W/m^2 °C

U-value after insulation III	1.6	W/m^2 °C
U-value after insulation IV	1.9	W/m^2 °C
Attic and cellar		
Construction	Concrete	
Type of standard heat insulation	Haydite + haydite concrete	
Insulated area	718	m^2
U-value before insulation	1.2	W/m2 °C
Heat insulation material of the attic	bat stone wool—thickness 25 cm	
U-value after insulation	<0.2	W/m^2 °C
Heat insulation material of the cellar	stone wool—thickness 15 cm	
U-value after insulation	< 0.25	W/m^2 °C

As follows from Table 1, the replacement of windows decreases the heat conductivity factor depending on the type of glass package within the range from $U = 2.9$ (the common glasses and air filling) to $U = 1.3$ (one selective glass and an argon-filled glass package). Besides, the heat conductivity factor for the windows of type II, which is the best from the viewpoint of thermal resistance, approaches this factor for the exterior annulated walls and, consequently, in this case the specific losses through the window openings and annulated walls become approximately equal. Optimization of the thermal resistance of windows should attract primary attention since the losses of heat through the envelope of the building are determined, to a certain degree, by the losses through the window openings, particularly after the thermal insulation work is completed. As follows from the results of the calculations presented in Table 2, approximately 32% of the heat losses before the renovation work are those through the window openings, 28% through the walls and 40% through the attic and cellar ceilings.

Table 2 Thermal parameters of the envelope of the school building

	Window type					
	I			IV		
	kWh/year	%	%	kWh/year	%	%
Losses before heat insulation	82,6034	100		82,6034	100	
Windows	262,036	31.7	100	262,036	31.7	100
Exterior walls	227,573	27.6	100	227,573	27.6	100
Attic	190,944	23.1	100	190,944	23.1	100
Cellar	145,481	17.6	100	145,481	17.6	100
Total losses after heat insulation	287,363	34.8		212,066	25.7	
Windows	218,363	76.0	83.3	143,065	67.5	54.6
Exterior walls	43,696	15.2	19.2	43,696	20.6	19.2
Attic	11,945	4.2	6.3	11,945	5.6	6.3
Cellar	13,359	4.6	9.2	13,359	6.3	9.2
Total heat saving	53,8671	65.2		613,968	74.3	
Windows	43,673	8.1	16.7	118,970	19.4	45.4
Exterior walls	183,877	34.2	80.8	183,877	29.9	80.8
Attic	178,999	33.2	93.7	178,999	29.2	93.7
Cellar	132,122	24.5	90.8	132,122	21.5	90.8
Losses before heat insulation	826,034	100		826,034	100	
Windows	262,036	31.7	100	262,036	31.7	100

Exterior walls	227,573	27.6	100	227,573	27.6	100
Attic	190,944	23.1	100	190,944	23.1	100
Cellar	145,481	17.6	100	145,481	17.6	100
Total losses after heat insulation	189,476	22.9		166,887	20.2	
Windows	120,476	63.6	46	97,887	58.7	37.4
Exterior walls	43,696	23.1	19.2	43,696	26.2	19.2
Attic	11,945	6.3	6.3	11,945	7.2	6.3
Cellar	13,359	7.1	9.2	13,359	8.0	9.2
Total heat saving	636,558	77.1		659,147	79.8	
Windows	141,559	22.2	54	164,149	24.9	62.6
Exterior walls	183,877	28.9	80.8	183,877	27.9	80.8
Attic	178,999	28.1	93.7	178,999	27.2	93.7
Cellar	132,122	20.8	90.8	132,122	20.0	90.8

After renovation the economy of thermal energy otherwise lost through the walls, attic and cellar ceilings is to become approximately 81–91%. The economy of thermal energy owing to modernization of the windows is estimated to be from 16.7% to 62.6% of the previous heat losses depending on the structure of the glass package Thus, the total economy of thermal energy in the school building after the renovation work should reach 65.2–79.8% depending on the structure of glass packages. Since the total cost of these structural elements varies to a comparatively small extent, it is recommended for the renovation to use more expensive structures of glass packages in order to raise the economy of thermal energy—for example, packages fitted with selective glass and argon filling.

Table 3 presents the calculated data of the heat losses before and after the thermal insulation of the school building envelope and the heat saving for different types of glass packages. Besides, we present the annual emissions of combustible waste into the atmosphere associated with heat losses before the thermal insulation work and, after the completion of this work, the annual decrease in the emissions owing to the heat energy saving. As follows from Table 3, waste emissions of all types decrease with the same rate as the heat losses and are from 65.2% to 79.8% depending on the structure of the glass package. For instance, if we use natural gas for heating, emissions of CO_2 decrease from 185.0 kg/year to 120.7–147.6 kg/year, so the difference makes up 64.5–37.4 kg/year.

Table 3 The decrease in emissions of combustible waste associated with reduced heat losses and the resultant saving of thermal energy

	Window type			
	I	IV	III	II
Losses before heat insulation, kWh/year	826,034	826,034	826,034	826,034
Combusted fuel—coal, kg				
CO_2	421.3			
CO	0.91			
NO_x	0.99			
SO_2	0.26			
Combusted fuel—oil or oil products, kg				
CO_2	256.1			
CO	0.83			
NO_x	0.50			
SO_2	1.65			
Combusted fuel—natural gas, kg				
CO_2	185.0			

CO	0.18			
NO_x	0.22			
Total losses after heat insulation, kWh/year	287363	212066	189476	166887
Total heat saving, kWh/year	538671	613968	636558	659147
Combusted fuel—coal, kg				
CO_2	274.7	313.1	324.6	336.2
CO	0.59	0.68	0.70	0.73
NO_x	0.65	0.74	0.76	0.79
SO_2	0.17	020	0.205	0.21
Combusted fuel—oil or oil products, kg				
CO_2	167.0	190.3	197.3	204.3
CO	0.54	0.61	0.64	0.66
NO_x	0.32	0.37	0.38	0.40
SO_2	1.08	1.23	1.27	1.32
Combusted fuel—natural gas, kg				
CO_2	120.7	137.5	142.6	147.6
CO	0.12	0.14	0.145	0.15
NO_x	0.15	0.17	0.175	0.18

VENTILATION AND IAQ

In order to ensure comfort, there are IAQ standards in Latvia included into the calculation model. On the average, the air supply, for example, to a dwelling or public room is designed as 7 l/s (2.5 m^3/h) per person but the air temperature 20–210ºC.

Let us comment on this problem that arises due to the replacement of the old glass windows in wooden frames, which have served their time, by new glass package windows in plastic frames or some other quality material. The new windows can be practically sealed but the room ventilation in the windows of the former design was ensured by air supply through the gaps in the frames of the old windows. To solve this problem, the structure of the new window frames is such that hinges of a special design can adjust the air inlet through them. Therefore, windows are installed in each room the degree of opening of which can be set at least at five positions:

- completely closed,
- half-open,
- completely open,
- in the summer ventilation mode,
- the winter ventilation mode.

This means that the residents of the room can regulate the air inlet according to the instruction or guided by their own concept of comfort. The economy of energy is achieved due to the circumstance that the air supply may be reduced in the absence of people, which was not possible with the old windows. However, in the rooms where their residents do not pay attention to this manual regulation, mould begins to multiply and the IAQ becomes worse. At the same time, one should stress that the outlet (exhaust) ventilation operates as before the replacement of the windows.

To gain maximum saving of energy, it is necessary to install heat utilization implements. This is costly, and therefore they are mainly installed in newly built houses. At present their installation in houses poses problems because flats are being privatized and their new owners lack finance. However, the results of our calculations include recommendations for the improvement of ventilation systems in all cases.

CONCLUSION

1. The thermal insulation work of the school building envelope permits decreasing the emissions of the waste into the environment at the same rate as the heat losses depending on the structure of the glass package.
2. After the replacement of the old windows by modern ones the economy of thermal energy, which was previously lost due to the poorly insulated windows, varies from 16.7% to 62.6% of the heat losses depending on the structure of the glass package.
3. The application of selective glass in the glass packages having higher thermal resistance and the filling of the glass packages with argon raises the cost of the window units. However, the increased costs of the window units are far outweighed by the economy of thermal energy.
4. The replacement of windows does not impair the IAQ since their structure allows adjusting the air inlet by a certain amount, which ensures comfortable conditions, prevents mould multiplication and, on the whole, improves the IAQ.