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Research Paper

Combined Building-Energy Systems/Calculation and Assessment of the Experimental House EB2020 in Terms of Energy Efficiency of Buildings

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ABSTRACT: *A combined building and energy system comprising the use of solar energy through an energy roof, long-term heat accumulation in ground storage, and active thermal protection was comprehensively evaluated on the basis of calculations and experimental measurements in the dissertation of Ing. Peter Janík, PhD. titled: "Optimization of energy systems with long-term heat accumulation." [13], (supervisor: Kalús), and at the same time in the research project HZ PG 73/2011 titled: "Experimental measurements, analysis, and determination of the optimal rate of use of renewable energy sources on a prototype of a family house EB2020 with nearly zero energy demand "[10], (responsible researcher: Kalús). This is probably the first building in Slovakia with such a system, where long-term measurements took place. To date, no independent (non-commercial) research is known from domestic or foreign sources with published output, based on long-term measurements of all components of this system from heat recovery, through accumulation to supplying ATO. This paper focuses on calculation and assessment of the experimental house EB2020 in terms of energy efficiency of buildings, where experimental measurements took place in 2011 - 2013. Therefore, applicable standards in force at that time are used in the calculations.*

KEYWORDS: *Building structures with an internal energy source, thermal barrier, large-area radiant low-temperature heating/high-temperature cooling, heat/cold accumulation in building structures, solar energy roof, large-capacity ground heat storage, solar energy, geothermal energy*

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I. INTRODUCTION

Combined building energy systems with active thermal protection (ATP) represent an optimal and most comprehensive technical solution for buildings within the meaning of Directive 2018/844/EU [1] amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, which introduced a new concept of "nearly Zero Energy Building (nZEB)" into our legal system. The concept of a technical solution of the experimental house EB2020 with applied active thermal protection (ATP) using solar energy with long-term heat accumulation can be more effective than a concept with an ordinary solution with a conventional heating system only with correct design and appropriate operation. Theoretical calculations, experimental measurements, and analyses revealed facts that are necessary for the calculation, design, selection, and assessment of nearly zero energy buildings. There is no template according to which it would be possible to design an optimal combined building-energy system, and therefore it is necessary to assess each building separately. In the given subject matter there is a possibility of various applications of building materials and technical solutions of energy systems, especially those using RES. For these reasons, it is necessary to continue further research and optimize technical solutions from the energy, economic, and environmental points of view.

II. DESCRIPTION OF THE EXPERIMENTAL HOUSE EB2020

The experimental family house is located 17 km from Bratislava, at an altitude of 128 m above sea level, in the village of Tomášov with a number of houses of about 700. It has a ground floor and the first floor, specific area of 187.4 m2, built-up volume of 590 m3, average construction height of 3.15 m Figure 1. Heat transfer coefficients (U) of individual structures:

- window 0.8 W/m^{2}K,
- wall 0.15 W/m^{2}K,
- floor 0.15 W/m^{2}K,
- roof 0.13 W/m^{2}K.

The perimeter structure consists of internal plaster, aerated concrete block (375 mm, λ = 0.104 W/m.K), adhesive mortar, facade polystyrene (100 mm, λ = 0.035 W/m.K) and external plaster. The ATP is formed by a plastic pipe between the aerated concrete masonry and the facade polystyrene and in the roof structure, Figure 2.

Figure 1: View of the experimental house EB2020 (Photo archive: Kalús) [10, 13]

In Figure 2 shows the temperature distribution in the perimeter structure without the use of ATP and with an average heat transfer medium temperature in the layer of 14°C and 20°C (at an outdoor temperature of -11°C). In the construction without ATP, the surface temperature will be 18.7°C and the temperature between the aerated concrete block and the thermal insulation will be 2.5°C. When installing an ATP with a temperature in its location layer of 14°C, the surface temperature will be 19.6°C.

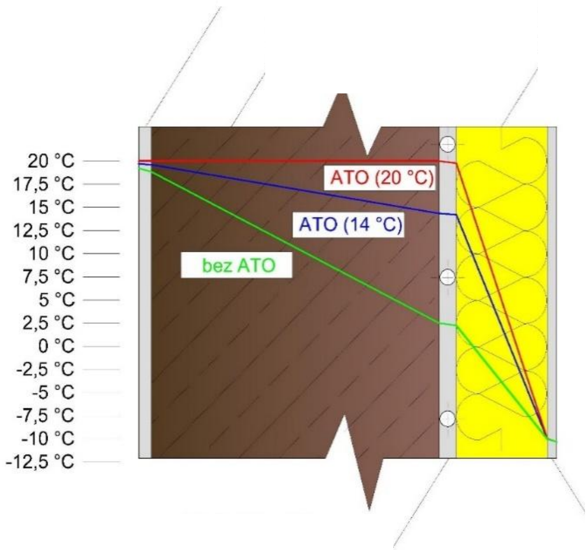

Figure 2: Sectional representation of a perimeter structure with temperature distribution without the use of ATP and with an average heat transfer medium temperature in the ATP layer of 14°C and 20°C [10, 13]

Figure 3 shows the ground floor plan view, Figure 4 1st floor floor plan. Figure 5 shows views of the family house.

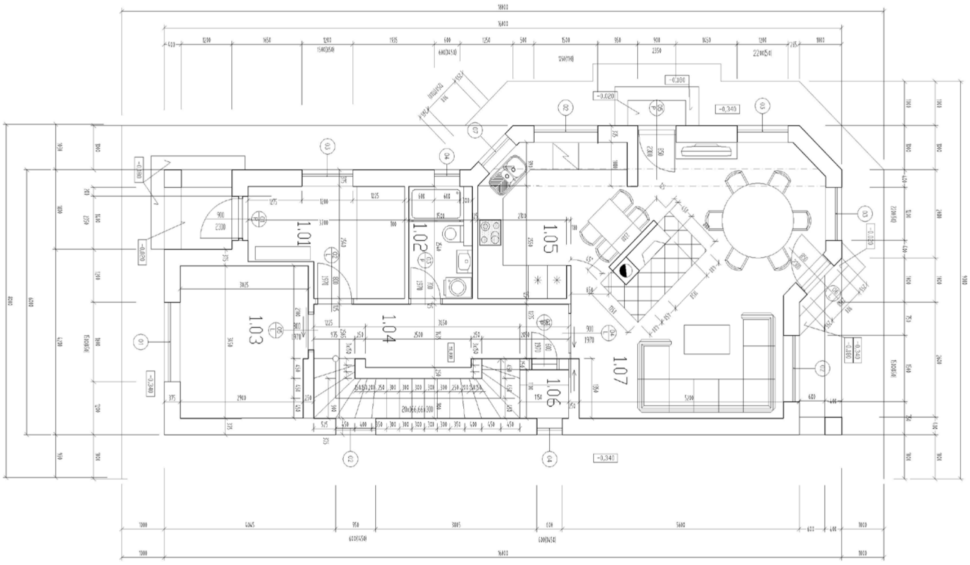

Figure 3: Floor plan of the ground floor of the family house [10, 13]

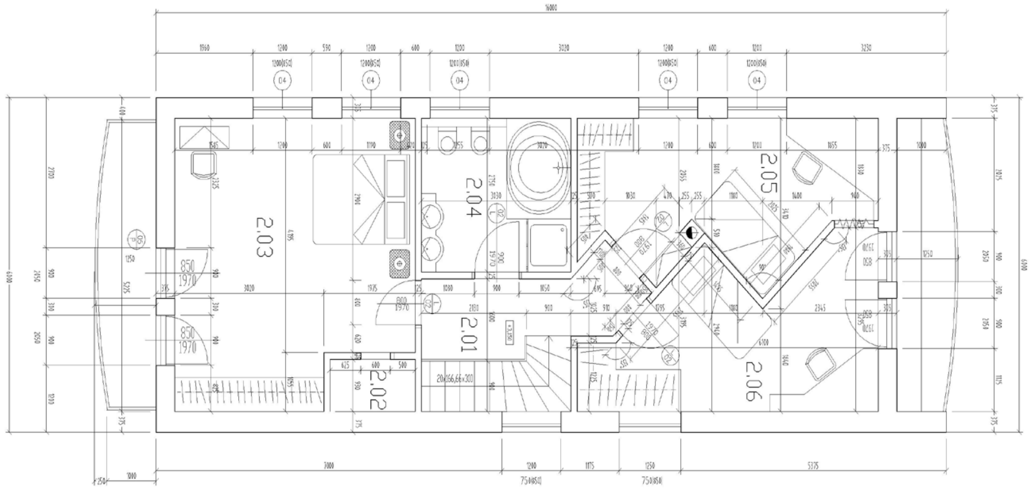

Figure 4: Floor plan of the 1st floor of the family house [10, 13]

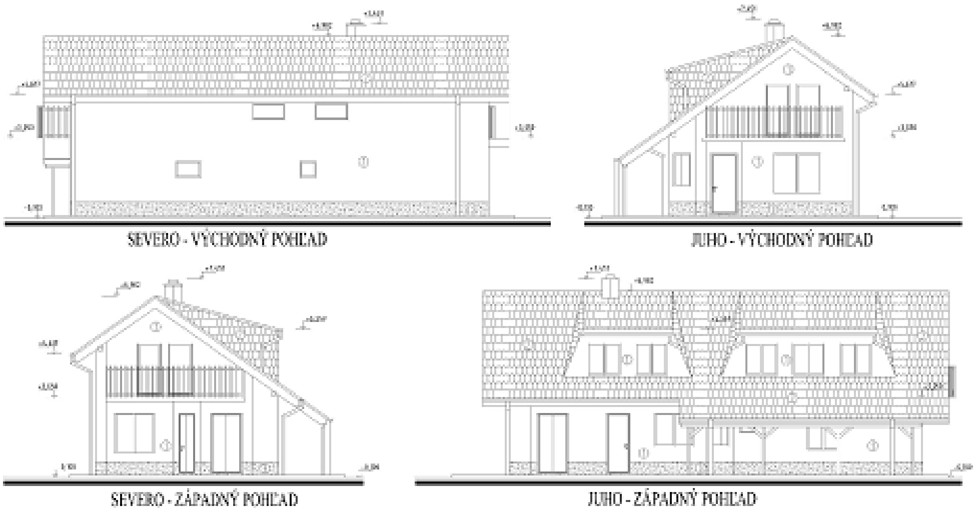

Figure 5: Views of the family house [10, 13]

III. CALCULATION AND ASSESSMENT OF HEATING NEEDS EXPERIMENTAL HOUSE EB2020

The calculation and assessment of heat demand for heating was performed in the TERMO'09 program. Heat recovery was considered in the calculation.

Specified boundary conditions:

Built-up volume of the building	V_b:	587.60 m^3
Total floor area of the building	A_b:	187.40 m^2
Average construction height of individual floors	h_k:	3.14 m
Included effect of thermal bridges	ΔU:	0.05 $W/m^2.K$
Desired/adjusted temperature	θ_I:	20.00 °C
Average outdoor temperature	θ_E:	3.86 °C
Duration of the calculation period	t:	212.00 days
Number of climatic daily degrees	Dt:	3422.00 K.day
Average intensity of air exchange	n:	0.15 1/h
Heat output of internal heat sources	q_i:	4.00 W/m^2
Climate conditions:	Normalized	
Basic time period:	one month	
Building category:	Family house	

Table 1: Thermal technical properties of structures and reduction factors [10, 13]

STRUCTURE	A_i	U_i	bxi	$A_i.U_i.b_{xi}$	Share
	[m^2]	[W/m^2K]	[-]	[W/K]	[%]
Perimeter wall	198.23	0.16	1.00	31.72	31.92
Filling structures	40.23	0.80	1.00	32.18	32.39
Roof 1	3.00	0.25	1.00	0.75	0.75
Roof 2	37.52	0.13	1.00	4.88	4.91
Roof 3	73.83	0.08	1.00	5.91	5.94
Ceiling above exterior space	2.88	0.19	1.00	0.55	0.55
Floor on the terrain	97.39	0.24	1.00	23.37	23.53

$\sum (A_i) = 453.08\ m^2$ $\qquad$ $\sum (A_i.U_i.b_{xi}) = 99.36\ W/K$

Calculation results:

Included effect of thermal bridges	ΔH_{tm}:	22.65 W/K
Specific heat loss by heat transfer	H_t:	122.01 W/K
Average heat transfer coefficient	U_m:	0.27 $W/m^2.K$
Intended air exchange	n:	0.15 1/h
Specific heat loss through aeration	H_v:	23.27 W/K
Specific heat loss of the building	$H=H_t+H_v$:	145.28 W/K

Table 2: Normalized climate conditions and total heat loss [10, 13]

QUANTITY	MONTH						
	I	II	III	IV	X	XI	XII
t [day]	31	28	31	30	31	30	31
θ_E [°C]	-1.8	0.4	4.6	9.9	9.8	4.3	-0.3
θ_I [°C]	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Q_L [kWh]	2356.3	1913.5	1664.5	1056.5	1102.5	1642.2	2194.2

Table 3: Internal, solar, and total heat gains [10, 13]

QUANTITY	MONTH						
	I	II	III	IV	X	XI	XII
Q_i [kWh]	557.7	503.7	557.7	539.7	557.7	539.7	557.7
Q_s [kWh]	169.1	253.9	387.3	493.8	326.8	180.7	149.4
$Q_g=Q_i+Q_s$ [kWh]	726.8	757.6	945.0	1033.5	884.5	720.4	707.1

Table 4: Heat demand for heating [10, 13]

QUANTITY	MONTH						
	I	II	III	IV	X	XI	XII
Q_h [kWh]	1631.0	1160.6	745.3	187.6	298.7	928.8	1488.8
$\sum Q_h$ [kWh]	6440.8						

Note: The value of the annual heat demand for heating SUM (Q_h) is used to calculate the energy demand for heating.

Specific heat demand for heating according to STN 730540/2002 (Values considered according to validity in 2011 - 2013):

Specific heat demand for heating	E_1:	11.07 kWh/m^3.a
Specific heat demand for heating	E_2:	34.70 kWh/m^2.a
Normalized specific heat demand	E_{1n}:	29.87 kWh/m^3.a
Normalized specific heat demand	E_{2n}:	83.65 kWh/m^2.a
Building shape factor	A_E/V_b:	0.77 1/m

Assessment of the energy criterion of the building:

E_2 = 34.7 kWh/m2.year < E_{2n} = 83.6 kWh/m^2.year → the building complies (currently according to STN 73 0540-2 + Z1 + Z2: 2019, [24], according to the building category "Family houses" maximum target value is 40.7 kWh/m^2.year, recommended is 20.4 kWh/m^2.year).

Balance of specific heat demand for heating:

Heat demand to cover heat losses by transfer:	53.45 kWh/m^2.a
- Perimeter wall	13.90 kWh/m^2.a
- Roof	5.29 kWh/m^2.a
- The floor	10.24 kWh/m^2.a
- Filling structures	14.10 kWh/m^2.a
- Thermal bridges	9.92 kWh/m^2.a
Heat demand to cover heat losses by aeration:	10.19 kWh/m^2.a
Heat gains from internal sources	19.00 kWh/m^2.a
Heat gains from solar radiation	9.94 kWh/m^2.a

IV. CALCULATION OF ENERGY NEED FOR HEATING, DHW PREPARATION, PRIMARY ENERGY, AND CO_2 EMISSIONS OF EXPERIMENTAL HOUSE EB2020

The calculation of energy demand for heating, hot water preparation, primary energy, and CO_2 emissions for different combinations of operation of heat sources installed in the experimental house EB2020 are given in Table 5. The energy assessment was performed in accordance with Decree no. 35/2020 Coll., which implements Act no. 555/2005 Coll. on energy efficiency of buildings in the Slovak Republic. [26]

Table 5: Recapitulation of energy efficiency calculations of experimental house EB2020

Heat source	Heat requirement for heating	Heat requirement for hot water	Energy requirement for heating	Energy class for heating	Energy requirement for hot water preparation	Energy class for hot water preparation	Total supplied energy	Energy class of total energy requirement	Primary energy	Energeclass of primary energy	CO_2 emissions
	kWh/(m^2.a)	kWh/(m^2.a)	kWh/(m^2.a)	(-)	kWh/(m^2.a)	(-)	kWh/(m^2.a)	(-)	kWh/(m^2.a)	(-)	kg/(m^2.a)
Low-temperature gas boiler	34.70	10.00	38.56	A	14.29	B	52.84	A	63.94	A1	11.35
Fireplace with a warm water heat exchanger	34.70	10.00	43.38	A	15.38	B	58.76	B	18.22	A0	2.4
Low-temperature gas boiler (70%) +Fireplace with a warm water heat exchanger boiler(30%)	34.70	10.00	40.00	A	14.62	B	54.62	A	51.34	A0	8.78
Low-temperature gas boiler(50%) + Fireplace with a warm water heat exchanger m (50%)	34.70	10.00	40.97	A	14.84	B	55.80	B	41.51	A0	6.81
Low-temperature gas boiler(30%) +Fireplace with a warm water heat exchanger boiler(70%)	34.70	10.00	41.93	A	15.5	B	56.98	B	30.69	A0	4.65
Low-temperature gas boiler+ 30% RES	34.70	10.00	26.99	A	10.00	A	36.99	A	31.33	A0	5.56
Low-temperature gas boiler+ 50% RES	34.70	10.00	19.28	A	7.14	A	26.42	A	22.38	A0	3.97
Low-temperature gas boiler+ 70% RES	34.70	10.00	11.57	A	4.29	A	15.85	A	13.43	A0	2.29
Fireplace with a warm water heat exchanger + 30% RES	34.70	10.00	30.36	A	10.77	A	41.13	A	8.3	A0	0.90
Fireplace with a warm water heat exchanger + 50% RES	34.70	10.00	21.69	A	7.69	A	29.38	A	5.73	A0	0.64
Fireplace with a warm water heat exchanger + 70% RES	34.70	10.00	13.1	A	4.62	A	17.63	A	3.44	A0	0.39

V. CONCLUSION

Based on the results of energy efficiency evaluation of the experimental house EB2020, it can be stated that apart from the variant where the heat source for heating and DHW preparation is only a low-temperature gas boiler, other variants meet the requirements of a nearly zero energy building, they are classified in the primary energy class A0. In terms of primary energy and CO2 emissions, the most advantageous combinations are heat sources for wood using RES. The higher the share of wood and RES, the more energy efficient and environmentally friendly is the experimental house EB2020 (generally all buildings). Combined building-energy systems with active thermal protection (ATO) represent an optimal and most complex technical solution for buildings as they actively influence the thermal-technical properties of building envelope structures and also represent the end elements of energy systems, especially heating and cooling.

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