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Energy Balance of a Low Energy House with Building Structures with Active Heat Transfer Control

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Abstract

A qualitatively new dimension has been introduced to the issue of building structures for energy-efficient buildings by the system of Active Thermal Insulation (ATI), which is already applied in the construction of such buildings. ATI are embedded pipe systems in the envelope structures of buildings, into which we supply a heat-carrying medium with adjusted temperature, so this constitutes a combined building-energy system. This introduces the concept of an internal energy source understood as an energy system integrated into the zone between the static part and the thermal insulation part of the building structure envelope. Under certain conditions, the ATI can serve as a heat recuperator or as an energy collector for a heat pump application. ATI consists of pipe systems embedded in building structures, in which the medium circulates heated by energy from any heat source. The function of the system is to reduce or eliminate heat losses through non-transparent structures in the winter and at the same time to reduce or eliminate heat gains in the summer. It is especially recommended to apply heat sources using renewable energy sources due to the required low temperatures of the heating medium and thus shorten the heating period in the building. Also recommended is to apply ATI for the use of waste heat. Buildings with a given system show low energy consumption and therefore meet the requirements of Directive no. 2018/844/EU, according to which, from 01.01.2021, all new buildings for housing and civic amenities should have energy needs close to zero.

Keywords

building structures with internal energy source, active thermal protection, low energy house, Active Thermal Insulation (ATI)

1 Introduction

Each building is unique in its own way, so in order to find all the possibilities of energy savings, it is necessary to solve each one separately. Building owners (investors) may also have different plans for construction of new buildings, or renovation of a building, respectively, associated with various requirements for gains from implementation of energy saving measures (return on investment time). Therefore, it is necessary not only to find options, but also to consider the economic consequences of the project before we spend more time solving the details. The economic efficiency of building operation is closely related to the choice of heat source/fuel base and the heating system. The environmental load is assessed using primary energy and CO_2 emissions [1–3]. This paper focuses on the energy analysis of a detached family house.

The energy balance of a family house we present on the project of a demonstration low-energy house in the vicinity of Bratislava on an alternative with and without Active Thermal Insulation. The house has two floors with a flat roof.

The building is designed with natural ventilation.

2 Architectural – disposition solution of a low energy family house

The model house is detached two-storey building with external dimensions of 12.0 × 8.17 m (Figs. 1–4 [4]).

The ground floor consists of an entrance hall, toilet, utility room, study, pantry, kitchen directly connected to the dining area and living room, from which there is access to the terrace. Further, there is a hall with a staircase with access to the 1st floor, there are two rooms, bedroom with a wardrobe, bathroom and a toilet combined with a shower.

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Fig. 1 Visualization of a model house (Source: architects of the building: Peter Beňuška and Peter Topinka) [4]

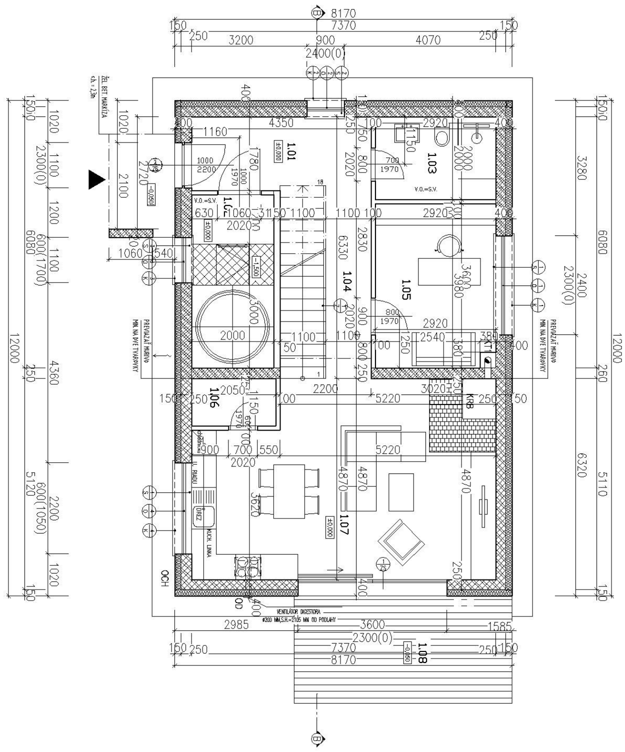

Fig. 2 Ground floor plan of a model house (Source: architects of the building: Peter Beňuška and Peter Topinka) [4]

3 Thermal – technical properties of building structures and energy balance of a low energy family house

The heat transfer coefficients of individual building structures are in Table 1.

The designed heat input in accordance with STN EN 12831-1 is 7.84 kW. The energy demand for heating determined by the degree days method is Q_{UK} = 58.7 GJ/year. The specific heat loss of the enclosed space is q_{OP} = 13.61 W/m³. Specific heat demand for heating E_2 = 48.6 kWh/(m² year), i.e. the building is classified as a low energy building.

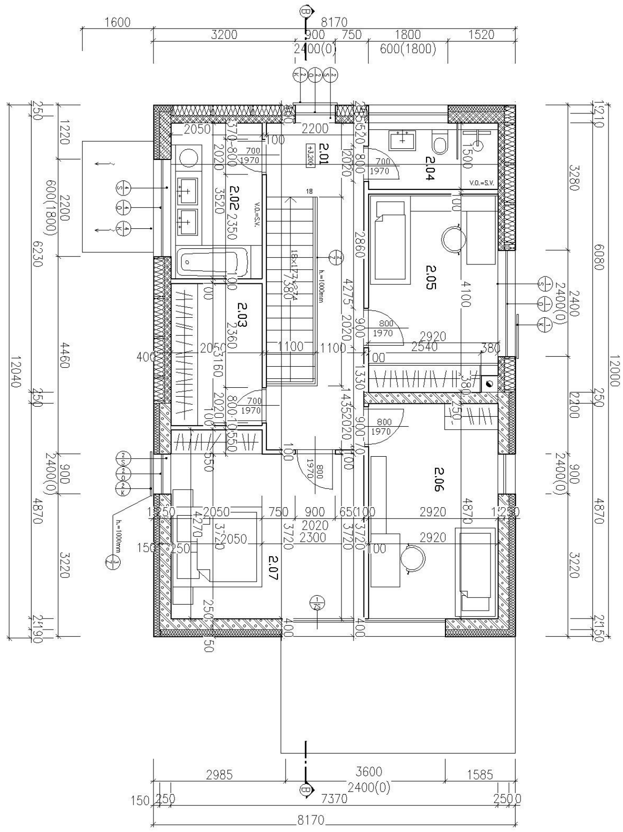

Fig. 3 The 1st floor plan of a model house (Source: architects of the building: Peter Beňuška and Peter Topinka) [4]

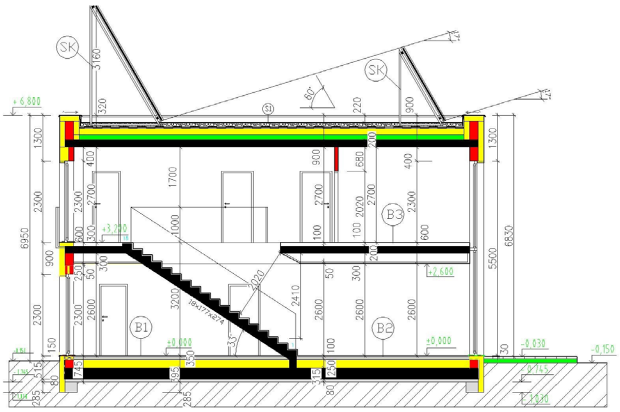

Fig. 4 Cross-section plan of a model house (Source: architects of the building: Peter Beňuška and Peter Topinka) [4]

Table 1 Heat transfer coefficient U (W/(m² K))

No.	Name of building structure	U (W/(m² K))
1	Perimeter wall	0.2
2	Roof	0.2
3	Floor	0.2
4	Window	0.8
5	Entrance door	1.7

Influence of ATI on the course of isotherms in building structures (perimeter wall of brick masonry 250 mm thick, insulated by 150 mm EPS) depending on the mean temperature of the heating medium under the assumption of a steady state is shown in Fig. 5.

Based on the thermal-technical assessment it is clear that the mean temperature in the ATI area has a minimal effect on the increase of the surface temperature on the exterior side of the building structure by only +0.3 °C, from −10.74 °C in the case of a building structure without ATI to −10.44 °C; at building structure with ATI at medium temperature up to +50 °C.

We design objects with ATI so that the whole envelope, i.e. the floor, the perimeter walls and the roof form an "energy barrier" of the building, which is also a large-capacity heat/cold storage tank. Due to the higher temperature of the ATI between the static (interior) and insulating (exterior) part of the envelope building structure, the heat losses are also higher by conduction depending on the mean temperature in the ATI. This increase in heat losses by individual building structures is evident from Table 2, columns 6, 7, 8. Heat losses by transparent structures and heat losses by ventilation remain unchanged [5–7].

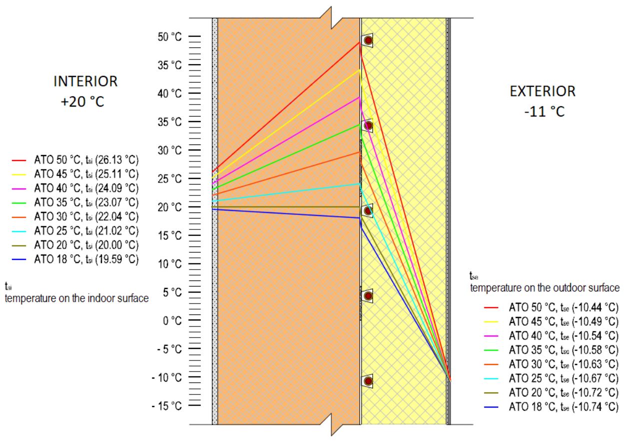

Fig. 5 Course of temperatures (isotherms) in the perimeter wall (Source: Own work of the author, Daniel Kalús)

In terms of the calculation procedure of the designed heat input, there is also the determination of the heat input for heating-up capacity, which takes into account the reduction of the internal temperature of the interior during night or day reduced demand and the subsequent increase of the heat source to achieve the required internal temperature (Table 2, column 10).

For buildings with ATI, due to the long-term accumulation of heat/cold in envelope structures (floor, walls and roof), where the heat source and the entire heating/cooling system is off for several days during the intermittent period, we do not consider determination of projected heat input with heat input for heating-up capacity (Table 2, column 10).

All results of calculation of projected heat input in accordance with STN EN 12831-1 depending on the mean temperature in the ATO in the range from +22 °C to +50 °C are given in Table 2.

A very important aspect of building structures with an internal energy source (ATI) is the fact that envelope building structures also become the end-point elements of the heating/cooling energy system - large-area low-temperature heating, respectively, large-area high-temperature cooling (floor, wall, ceiling). Specific heat losses of individual building structures (floor, wall, ceiling) towards the exterior are in Table 3, columns 3, 4, 5. Specific heat outputs for heating of

Table 2 Calculation results of projected heat input

House type	Mean temperature between the static part and the insulation part of the building construction (°C)			Transmission heat loss through … (W)				Ventilation heat loss (W)	Heating-up capacity (W)	Design heat load* (W)
	Wall	Floor	Roof	Window	Ground	Roof	Walls	Roof	-	-
Column No.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
House without ATI	17.34	19.25	18.57	1222.00	288.00	595.20	1264.30	2357.00	2112.00	**7838.50**
House with ATI	22.00	22.00	22.00	1,222.00	336.00	595.20	1,631.36	2,357.00	0.00	**6,141.56**
	25.00	25.00	25.00	1,222.00	384.00	672.00	1,835.28	2,357.00	0.00	**6,470.28**
	26.00	26.00	26.00	1,222.00	432.00	720.00	1,937.24	2,357.00	0.00	**6,668.24**
	30.00	30.00	30.00	1,222.00	480.00	768.00	2,039.20	2,357.00	0.00	**6,866.20**
	35.00	35.00	35.00	1,222.00	576.00	864.00	2,243.12	2,357.00	0.00	**7,262.12**
	40.00	40.00	40.00	1,222.00	672.00	960.00	2,447.04	2,357.00	0.00	**7,658.04**
	45.00	45.00	45.00	1,222.00	768.00	1,056.00	2,752.92	2,357.00	0.00	**8,155.92**
	50.00	50.00	50.00	1,222.00	960.00	1,152.00	3,058.80	2,357.00	0.00	**8,749.80**

* for the internal design temperature +20 °C and the external design temperature −11 °C

individual building structures (floor, wall, ceiling) towards the interior are in Table 3, columns 6, 7, 8. In Table 3, columns 9, 10, 11 the heating outputs of the individual building structures (floor, wall, ceiling) and the total heat input for heating by means of ATI are in Table 3, column 12.

Based on the analysis of the calculated data, it can be stated that the given object with ATI at the average temperature of the heating medium in ATI of +26 °C will cover the total heat losses of the object of 6.7 kW**,** respectively, will produce heat input for heating of 6.8 kW (outdoor temperature −11 °C, indoor temperature +20 °C). The assessed LEH (low-energy house) without ATI has a projected heat input of 7.8 kW and the same building with application of ATI has a projected heat input of 6.8 kW. *This reduction in heat input by 13 % is due to the accumulation of heat in envelope building structures.* In addition to lower projected heat input for heating, other factors influence the overall energy intensity [8–11].

One of the most important factors is the operating time of the heat source and the heating/cooling system. Based on measurements taking place since October 2011 at the experimental house in Tomášov city, we assume that the operating time of the heat source and heating system is at least 20 % shorter in applications with ATI than the operating time in applications without ATI. Then the energy need according to the degree day method will be 58.70 GJ/year for the application without ATI and 40.30 GJ/year for the application with ATI [12].

This difference indicates a lower energy intensity of the building with ATI as much as 31.35 % [13–15].

Table 4 (columns 4, 5, 6) [16] shows the percentage efficiency of building structures with ATI (floor, walls and roof). It expresses the ratio of the specific heating power to the total power of ATI, i.e. specific heating output + specific heat loss of the building structure with ATI. Building structures without ATI have this value equal to zero.

4 Conclusion

The current state of development of technologies for the use of RES does not allow to the full extent the use of all renewable energy sources. Most of the modern technologies are at a stage introduction to the market, when their investment intensity is still very high. High investment intensity is also related to the fact that these technologies are imported.

For the time being, Active Thermal Insulation is applied either to a building where for the purpose of distributing a low-temperature heat transfer medium obtained from solar and geothermal energy a pipe or hose system is attached to the perimeter wall of a built building and covered with plaster, thermal insulation, and covering plaster. This applies both to new buildings and to thermal insulation of already existing buildings. However, such method of implementing ATI is financially demanding, time consuming, and complicated.

These shortcomings of the existing method of implementing ATI led to the possibility of solving this problem by appropriate technical means. The result of this effort

Table 3 Recapitulation of specific heat losses and specific heat heating outputs and heat inputs for heating of individual building structures (floor, wall, ceiling)

House type	Mean temperature* (°C)	Specific heat loss through the wall to exterior (W/m²)	Specific heat loss through the roof to the exterior (W/m²)	Specific heat loss through the floor to the ground (W/m²)	Specific heat load through the wall to the interior (W/m²)	Specific heat load through the floor to the interior (W/m²)	Specific heat load through the roof to the interior (W/m²)	Heat load through the wall to the interior (W)	Heat load through the floor to the interior (W)	Heat load through the roof to the interior (W)	Total heat load to the interior (W)
Column No.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
House without ATI	17.43	6.20	6.20	3.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
House with ATI	22.00	8.00	6.20	3.50	2.00	6.00	9.00	407.84	576.00	864.00	**1,847**
	25.00	9.00	7.00	4.00	6.00	16.00	24.00	1,223	1,536	2,304	**5,063**
	26.00	9.50	7.50	4.50	9.00	24.00	28.00	1,835	2,304	2,688	**6,827**
	30.00	10.00	8.00	5.00	12.00	32.00	47.00	2,447	3,072	4,512	**10,031**
	35.00	11.00	9.00	6.00	18.00	48.00	71.00	3,670	4,608	6,816	**15,094**
	40.00	12.00	10.00	7.00	24.00	64.00	95.00	4,894	6,144	9,120	**20,158**
	45.00	13.50	11.00	8.00	30.00	80.00	119.00	6,117	7,680	11,424	**25,221**
	50.00	15.00	12.00	10.00	36.00	96.00	142.00	7,341	9,216	13,632	**30,189**

* between the static part and the insulation part of the building construction – wall

Table 4 Efficiency of building structures with ATI

House type	Mean temperature between the static part and the insulation part of the building construction	Specific heat loss of the conditioned space	Efficiency of the wall with ATI	Efficiency of the floor with ATI	Efficiency of the roof with ATI	Energy demand for heating calculated by the degree-day method
Column No.	2.	3.	4.	5.	6.	7.
Unit of measure	(°C)	(W/m³)	(%)	(%)	(%)	(GJ/year)
House without ATI	17.43	13.61	0.00	0.00	0.00	**58.70**
House with ATI	22.00	10.66	20.00	63.16	59.21	**40.30**
	25.00	11.23	40.00	80.00	77.42	
	26.00	11.58	48.65	84.21	78.87	
	30.00	11.92	54.55	86.49	85.45	
	35.00	12.61	62.07	88.89	88.75	
	40.00	13.30	66.67	90.14	90.48	
	45.00	14.16	68.97	90.91	91.54	
	50.00	15.19	70.59	90.57	92.21	

* in accordance with STN EN 17248 [16]

are variants of structures of thermal insulation panels with active heat transfer control (Active Thermal Insulation - ATI) according to the invention described in the European patent document EP 2 572 057 B1 [17].

Thermal insulation panels with active heat transfer control (Active Thermal Insulation) have a wide field of application. These are not only new constructions, but also reconstructions of buildings. Unification of production is also supported by the fact that a large part of residential buildings in Slovakia, Central and Eastern Europe are not yet thermally insulated. By elaborating sample - type documents with laying drawings for individual types, especially panel residential buildings, could significantly contribute to mass production of thermal insulation panels with controlled heat transfer [18–22].

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