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Research Paper

Combined Building-Energy Systems/Energy Roof/Calculation of Energy Efficiency

Assoc. Prof. Ing. Daniel Kalús, PhD.[1] , Ing. Peter Janík, PhD.,[2]
Ing. Matej Kubica[1]

[1]*(Department of Building Services Faculty of Civil Engineering, Slovak University of Technology in Bratislava)*
[2]*(Engineer in the Field of Energy Efficiency of Buildings, Topolčianska 5,851 05 Bratislava)*
Corresponding Author: Daniel Kalús

ABSTRACT: *The use of combined building and energy systems is closely related to the use of renewable heat sources or waste heat. An energy roof is an alternative solution to solar thermal collectors. Research aimed at evaluating the energy efficiency of an energy roof was the subject of the dissertation of Ing. Peter Janík, PhD. entitled: "Optimization of energy systems with long-term heat accumulation." (supervisor: Kalús), and at the same time the subject of 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 "(responsible researcher: Kalús). Due to the fact that determining the efficiency of an energy roof is a relatively difficult matter, as it has differing geometry in enclosed space between the roofing and thermal insulation, this paper focuses on one of the possible calculation methods.*
KEYWORDS: *combined building-energy systems, active thermal protection (ATP), thermal barrier, low-temperature radiant heating/high-temperature cooling, climate factors, energy roof, solar absorbers, solar thermic collectors, energy efficiency*

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I. INTRODUCTION

A combined building and energy system with active thermal protection (ATP), an energy roof, and ground heat storage is based on the principle of active use of solar energy, long-term heat accumulation, and subsequent heat supply for ATP. Solar energy can be used by means of an energy roof, which is formed by an absorber located between the top layer of the roof structure and thermal insulation. The heat transfer medium is then conveyed to the heat storage. During the heating period, heat from the heat storage is supplied to the ATP formed by pipes in the peripheral structures. [2, 7, 8, 9, 10, 13, 20, 24]

Depending on the temperature of the working medium in the ATP, building structures with an internal energy source have different functions, namely large-area wall (ceiling) heating (working medium temperature is higher than indoor air temperature), thermal barrier (working medium temperature is lower or equal the air temperature indoors) or are used for heat accumulation. In summer, they can be used for large-area wall (ceiling) cooling using a cooling circuit.

II. PRINCIPLE OF COMBINED BUILDING-ENERGY SYSTEM WITH AN ENERGY ROOF

An example of a schematic diagram of an energy system is shown in Fig. 1. **Description of summer operation**: A solar energy absorber, which is formed by a circulating liquid in a plastic pipe, is heated by solar radiation. The heated liquid then supplies heat to the ground heat storage. This part of the storage is formed by a plastic pipe in the foundation slab or under the foundation slab. With suitable solar radiation, the heat flux from the solar roof is also fed into an accumulation tank. Heat can be taken from the lower part of the storage to the accumulation tank, while in summer operation the inlet is closed of this heated liquid to the ATP distributor. During the warm period, liquid from the cooling circuit flows into the ATP distributor. The cooling circuit consists of a plastic pipe located at a non-freezing depth away from the heat storage. The temperature there should be approximately constant throughout the year. Using a cooling circuit, we cool building structures. Low temperature heating (floor, wall or ceiling) is not in operation.

Description of winter operation: The solar energy absorber is heated by solar radiation during favorable conditions. The heated liquid then transfers heat to the ground heat storage. This part of the storage transfers heat to the soil under the foundations. Heat is taken from the bottom of the storage for the ATP distributor. The accumulation tank provides heat required for low-temperature heating and preheats the hot water. Due to the overall low heat loss of the building, it is not recommended to design convection heating, but low temperature heating with the lowest possible temperature gradient. A fireplace with a heat exchanger, a heat pump, or another source can be used as a peak source for heating water in the accumulation tank. The accumulation tank can thus always be heated either directly by the energy roof or the peak heat source.

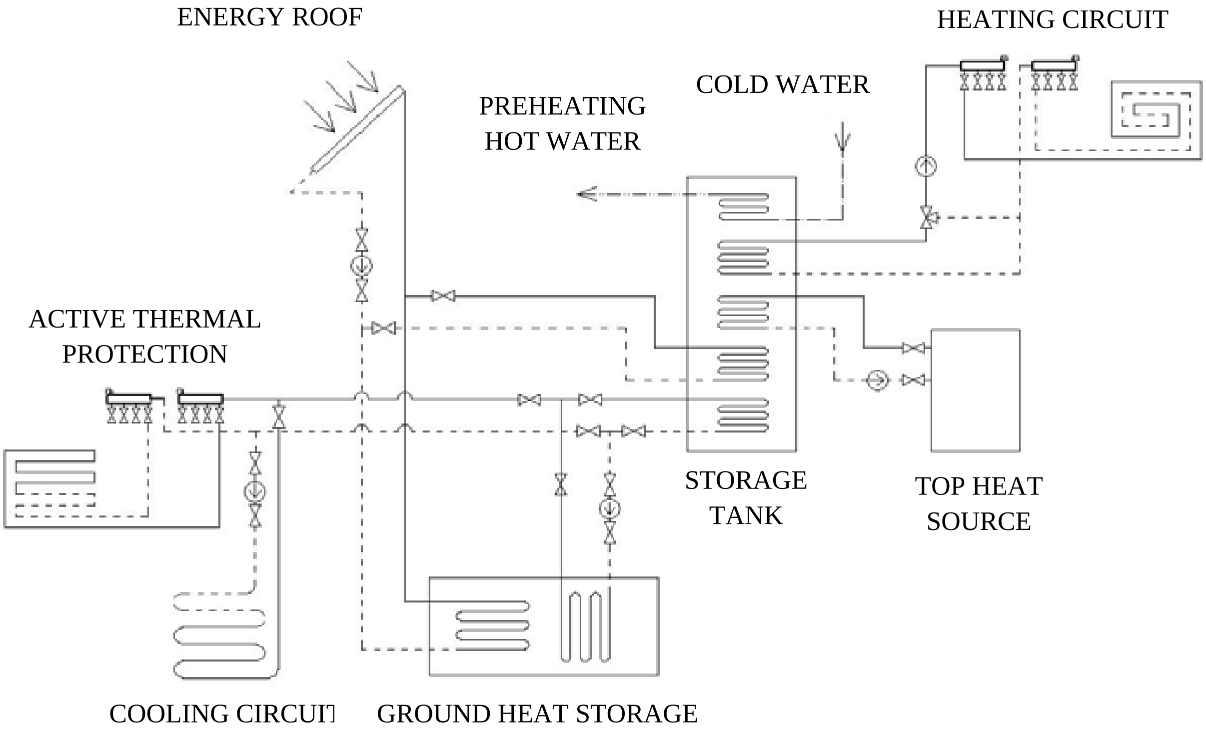

Figure 1: Schematic diagram of the energy system [13]

The basic scheme described above is one of the connection options. In fact, there are many alternatives to choose from. Solar energy can be used by conventional solar thermic collectors, instead of ground storage a large-volume water storage tank can be installed, and hot water can be prepared separately. With regard to the fact that the construction of buildings with ATP is not widespread and, in addition, most buildings are built with patented technology, only a simplified construction manual has been provided. We can only rely on basic physical relationships and experience from builders and designers.

A functional connection of the control system is composed of a regulator and sensors of outdoor air temperature, indoor air temperature, temperature in the pipe at the inlet to the ATP, heating water temperature, working medium temperature in the solar absorber, and temperature in the heat storage tank (or tanks). Actuators are the valves. Pumps are connected in the ATP circuit, low-temperature heating, solar system and heat source circuits. Power supply, the supply from the circulation pumps, the supply from the temperature sensors and the supply from the valve controller are thus connected to the regulator. Under favorable conditions, it is suitable if the working medium from the solar absorber flows directly into the ATP, or into the heating system without a time delay, without heat accumulation. If the external conditions change, the regulator switches the valve and the ATP system and the heating system is supplied from the accumulation storage tank. A view of the technical room in the system with ATP when using the energy roof and ground heat storage is shown in Fig. 2. Visible is a distributor and a collector from the energy roof system, the distributor and collector of the ground heat storage, the distributor and collector of the ATP, circulating pumps, pressure and temperature meters and control valves [2, 20, 41].

Figure 2: View of the technical room with the installed energy system with ATP, energy roof, and ground heat storage [2, 20, 41]

III. ENERGY ROOF AS A SOURCE OF HEAT

A heat source for an active thermal protection system in the function of a thermal barrier and low-temperature heating can be solar energy, ambient energy used by a heat pump, waste heat, or a peak heat source. In addition to conventional collectors, solar energy can be used by plastic absorbers without a cover layer or by an energy roof. Particular attention will be paid to an energy roof and its comparison with flat solar collectors. An energy roof consists of a solar absorber integrated in the roof structure. For this reason, the roof becomes a solar collector and the entire area is used to generate heat. An absorber is usually a plastic pipe placed under the upper waterproofing layer of the roof, either under a roof tile (see Fig. 3) or under the upper insulation board (see Fig. 4).

Figure 3: Plastic placed on the roof structure, the top layer will be roof tiles. Left: Slovakia, right: Luxembourg [20], [21]

Figure 4: Absorber from a plastic pipe placed on the roof structure, the top layer of the structure will be a board with waterproofing, Spain [22]

Detail of mounting a plastic absorber under the roof covering and application also under a light roof cladding made of thin-walled steel profiles in Fig. 5.

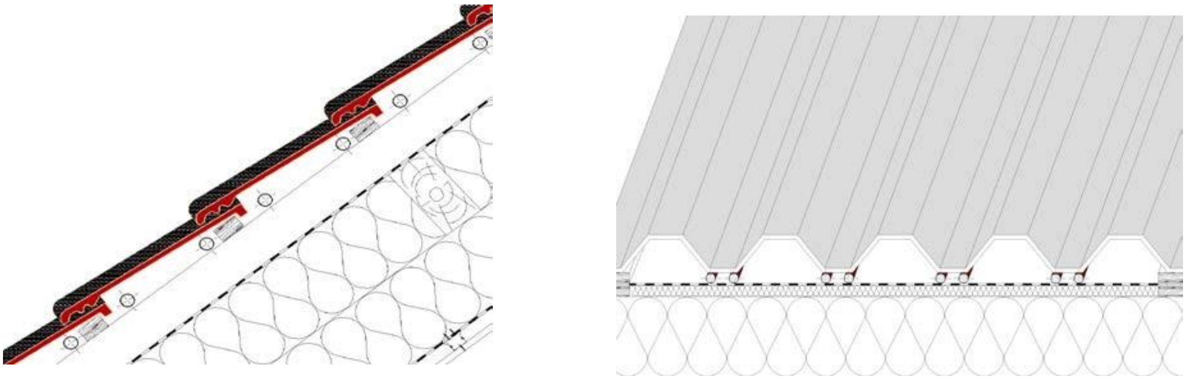

Figure 5: Absorber located under roof tiles (left), Absorber under thin-walled steel profile (right) [20, 21, 22]

The advantage of plastic pipes is light and relatively simple installation, because they are light and flexible. Limited pressure losses are achieved by smooth surface. There is no corrosion and limescale buildup. They are affordable. As they form part of the roof structure, it is suitable if the joints are formed outside the structure. The service life of a pipe depends mainly on the temperature of the working medium and on pressure conditions. In general, polypropylene piping [20], [21], [22], [23] is recommended for the given energy system, which is relatively cheap, but a disadvantage is lower flexibility of the material, due to which it is not recommended to bend the pipes. For this reason, a more suitable pipe is made e.g. of polyethylene. Another disadvantage of polypropylene piping is its lower thermal conductivity. High thermal conductivity and small pipe wall thickness are important parameters for suitable heat absorption. When selecting a pipe, it is also necessary to look at the temperature range of the pipe, as the working medium in the pipe can be heated according to [24] to a temperature of 80°C.

In order to maximize the energy gain from the energy roof, it is recommended that:

- the upper part of the roof structure has high thermal conductivity, is as thin as possible, and has a high absorption of heat from solar radiation, whereby the color also has significant influence,
- the distance between the upper part of the roof structure and the plastic absorber is as small as possible, it is suitable if they are in contact,
- the plastic absorber had small pipe wall thickness and an overall small dimension,
- the thermal insulation under the plastic absorber is of sufficient thickness,
- the regulation is suitably resolved and the circulation pump is switched on if the difference between the temperature in the absorber and the temperature in the heat storage is appropriate,
- the flow rate of the working medium in the plastic absorber is not high,
- the absorber is divided into zones according to the orientation of the roof with regard to cardinal directions,
- several circuits are created in case of a pipe failure.

IV. CLIMATE FACTORS FOR THE DESIGN OF A SOLAR ENERGY SYSTEM

With its latitude, Slovakia is suitable for the use of solar energy. The average annual amounts of global radiation are the highest in the lowlands, 1200 to 1300 kWh/m^2, in the highest parts of the eastern part of the Tatra Mountains it is 1100 to 1200 kWh/m^2, in the middle altitude mountain locations and in the far northwest of Slovakia 1050 to 1100 kWh/m^2, which is influenced mainly by increased cloud cover. [28]

The decisive climate factors in the design of active elements and solar devices are:

- the theoretical amount of solar energy falling per day on differently inclined and oriented surface to the south,
- the mean intensity of solar radiation falling on variously inclined planes oriented to the south,
- average monthly relative irradiation,
- average monthly temperature in time of sunshine, degree of atmospheric pollution.

Theoretically possible amount of solar energy $Q_{s\ day,\ theor.}$ (kWh/m^2) per day falling on variously inclined surfaces oriented to the south are shown in TAB. 1.

TAB. 1 Theoretically possible amount of solar energy $Q_{s\ den,teor}$ (kWh/m^2) per day falling on variously inclined surfaces facing south [28]

Month		January	February	|March	April	May	
	December	November	October	September	August	July	June
0°	1.09	1.48	2.90	5.20	6.52	8.42	9.16
15°	1.78	2.20	4.01	6.21	7.28	9.36	9.76
30°	2.35	2.83	4.90	6.76	7.92	9.72	9.98
45°	2.69	3.26	5.44	7.10	8.19	9.52	9.64
60°	3.00	3.56	5.38	7.06	7.26	8.22	8.48
90°	3.11	3.81	5.30	5.85	5.18	4.56	4.31

On clear days, the total intensity of solar radiation IC acts continuously, but with a cloudy sky, only intensity act of diffuse radiation ID. The time alternation of a clear and cloudy sky over a certain period is usually unknown and in terms of climate data is expressed by the average monthly relative sunshine s_m. The average monthly relative irradiation for Bratislava is shown in TAB. 2. The actual amount of solar energy $Q_{s\ day,\ act}$ (Wh/m^2) falling on an illuminated area on an average day can be calculated from (1):

$$Q_{s,\ day,act} = s_m \cdot Q_{s,\ day,\ theor} \quad (Wh/m^2) \qquad [28]\ (1)$$

Where:

s_m average monthly relative irradiation (-)

$Q_{s\ den,teor}$ theoretically possible amount of solar energy *(kWh/m²)*

TAB. 2 Average monthly relative irradiation s_m (-) for Bratislava [28]

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0.25	0.31	0.42	0.53	0.57	0.60	0.63	0.63	0.58	0.44	0.24	0.20

Average temperatures in the time of sunshine are shown in TAB. 3.

TAB. 3 Average temperatures during sunshine time (°C) for Bratislava [28]

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1.0	3.6	8.5	13.4	18.5	21.6	23.5	23.6	20.5	14.7	8.5	4.2

V. ENERGY EFFICIENCY OF SOLAR COLLECTORS

The energy efficiency of a collector η_k (-) is defined as the ratio of the captured heat flux q_k (W/m^2) of the collector and the falling heat flux q_s (W/m^2) on the collector or as the ratio of the energy captured by the collector Q_k (Wh/m^2) and the energy falling on collector Q_s (Wh/m^2). It is expressed by the formula (2):

$$\eta_k = \frac{q_k}{q_s} = \frac{Q_k}{Q_s}\ (-) \qquad [28]\ (2)$$

Where:

q_k captured heat flux of the collector (W/m^2)

q_s impacting heat flux (W/m^2)

Q_k energy captured by the collector (Wh/m^2)

Q_s energy impacting on the collector (Wh/m^2).

5.1 Energy efficiency of a flat solar collector with a glass cover

The energy efficiency of a flat solar collector with a glass cover η_k (-) is expressed as follows (3):

$$\eta_k = \frac{q_k}{q_s} = \frac{Q_k}{Q_s} = (1-r) - \frac{(U_1+U_2).(\theta_k+\theta_a)}{q_s}\ (-) \qquad [28]\ (3)$$

Where:

r is reflective ability of cover glass (-),
U_1 is the coefficient of heat transfer through the layer on the glass side of the collector (W/(m^2.K)),
U_2 is the heat transfer coefficient through the layer on thermal insulation side (W/(m^2.K)),
θ_k is the mean temperature of the absorption surface of the collector (°C),
θ_a is the average air temperature during sunshine (°C).

Heat losses of a collector with a glass cover depend on optical and thermal losses of the collector. Optical losses are defined by reflectivity and transmittance of the glass cover, which partially reflects the incident solar energy to the surroundings, but for the most part transmits it to the absorption surface. Optical losses of a collector are expressed by reflectivity of the glass r (-), which varies from 0.1 to 0.20, depending on the type and thickness of the glass. Thermal losses of a collector depend on the overall heat transfer coefficient of the individual layers above and below the absorber. The heat transfer coefficient for a collector with one glass cover represents a value around U = 6.0 W/(m^2.K).

5.2 Energy efficiency of an energy roof

Determining the efficiency of an energy roof is a relatively difficult matter, as it has diverse geometry in enclosed space between the roof covering and thermal insulation. The absorber is placed in an unventilated air layer, which is considered to be enclosed to the environment, or with small openings that do not exceed 500 mm^2 for each meter of length of a vertical air layer or 500 mm^2 for each m^2 of a horizontal air layer. [30] In an enclosed air layer, heat spreads by conduction, convection, and radiation. Efficiency using (4) can only be expressed by adopting the following simplifications:

- efficiency is considered without heat losses from the pipe upwards through the top of the roof and downwards through the thermal insulation,
- the area of the absorber in contact with the roof is estimated, as is the area of the absorber in contact with the thermal insulation of the roof.

$$\eta_k = \frac{q_k}{q_s} = \frac{R_{se}}{R_{se} - R_i} \ (-)$$ [29] (4)

Where:
R_{se} is resistance to heat transfer on the outside (m^2.K/W),
R_i is resistance to heat transfer, which includes spreading of heat through the top of the roof, an unventilated air layer, a plastic absorber, and working medium (m^2.K/W).

Thermal resistance of an air cavity with a length and width greater than 10 times the thickness is determined according to (5):

$$R_g = \frac{1}{h_a - h_r} \ (m^2.K/W)$$ [31] (5)

Where:

h_a is the heat transfer coefficient by conduction and flow (W/(m^2.K)),
h_r is heat transfer coefficient by radiation (W/(m^2.K)).

Combined heat dissipation by conduction and convection h_a is determined as follows:

- for horizontal heat fluxes: the greater of 1.25 and 0.025/d W/(m^2.K),
- for upward heat fluxes: the greater of 1.95 and 0.025/d W/(m^2.K),
- for heat fluxes downwards: the greater of 0.12.d$^{-0,44}$ a 0.025/d W/(m^2.K).

[28], [29], [31], [32]

The radiant heat transfer coefficient is determined from (6):

$$h_r = 4.C_{č}.E.\theta_m^3 = E.h_{ro} \ (m^2.K/W)$$ [31] (6)

Where:
$C_č$ black body radiation factor is 5.67.10^{-8} W/(m^2.K^4),
Θ_m is the average thermodynamic temperature of the surface and its surroundings (K),
h_{ro} is the heat transfer coefficient by radiation of a black body (W/(m^2.K)).

Radiant heat transfer coefficient of a black body at 0 °C = 4.6 W/(m^2.K), at 10 °C = 5.1 W/(m^2.K), at 20 °C = 5.7 W/(m^2.K), at 30 °C = 6.3 W/(m^2.K). [165]

Mutual radiation coefficient E is expressed as (7):

$$E = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}\ (-)$$ [31], [29], [32] (7)

Where:
$\varepsilon_{1,2}$ emissivity of given surfaces (-),

The thermal resistance of a small air cavity with a width of less than 10 times its thickness is determined from the formula (8):

$$R_g = \frac{1}{h_a+0{,}5.E.h_{ro}.(1+\sqrt{1+\frac{d^2}{b^2}}-\frac{d}{b}}\ (m^2.K/W)$$ [31], [29], [32] (8)

Where:
d is the air cavity thickness (m),
b is the air cavity width (m).

With regard to the fact that the calculation is relatively extensive and although substantial simplifications are adopted, the whole calculation will not be further broken down here, but just the basic physical relationships.

Thermal resistance of the upper part of the roof (roof covering) is expressed according to (9):

$$R_{str} = \frac{d_{sk}}{\lambda_{sk}}\ (m^2.K/W)$$ (9)

Where:
d_{sk} roofing thickness (m),
$\lambda_{\sigma\kappa}$ thermal conductivity of the roof covering (m).

Thermal resistance of a plastic absorber to the propagation of heat by conduction is expressed according to (10):

$$R_{sr,condtr} = \frac{\ln\left(\frac{r_{ext}}{r_i}\right)}{2.\pi.\lambda}\ (m^2.K/W)$$ (10)

The heat transfer coefficient for flow in a pipe (plastic absorber) is expressed according to (11), where the transfer resistance is expressed as inverse value:

$$h_{conv,i} = \frac{1057.(1{,}352+0{,}019.\theta_i).v^{0,8}}{D_i^{0,2}}\ (m^2.K/W)$$ [31], [29] (11)

Where:
v flow rate of the working medium in the pipe (m/s),
D_i pipe diameter (m),
Θ_i temperature of the working medium in the pipe (°C).

In the calculation according to the given methodology, in [107] the efficiency of the collector in the form of an energy roof was calculated at 17%, while in further calculations it was reduced to 15% (estimate of the effect of heat losses). Boundary conditions of the calculation: roof covering dark-gray: Ɛ = 0.82 (emissivity),

α = 0.90 (absorption), λ = 2.00 W/(mK), d = 3 mm, plastic pipe made of polypropylene: D = 25 mm, r_i (wall thickness) 1 mm, non-ventilated air gap: d = 25 mm (air cavity thickness), b = 17.5 mm (air cavity width), outside air temperature = 30°C, roof surface temperature 70°C, v = 1 m/s (velocity of the working medium in the pipe). However, the calculation is considerably simplified, it does not take into account the actual length of the pipeline and the number of circuits.

5.3 Evaluation of the efficiency of the collector circuit in evaluating the energy performance of buildings according to EN 15136-4-3

The efficiency of a collector circuit η_{loop} can be calculated according to EN 15136-4-3 [33] using the equation (12), (13). Note: η_{loop} takes into account the influence of the heat exchanger. Typical efficiency of a flat solar thermal collector is η_{loop} = 0.9.

$$\eta_{loop} = 1 - \Delta\eta \, (-) \qquad [33]\ (12)$$

$$\Delta\eta = \frac{\eta_0 . A . a_1}{(UA)_{hx}} \, (-) \qquad [33]\ (13)$$

Where:

η_0 collector efficiency at zero loss in accordance with EN 12975-2 (-),
A collector aperture area (m^2),
a_1 primary coefficient of heat loss of a solar collector determined in accordance with EN 12975-2,
$(UA)_{hx}$ value of heat transfer in the heat exchanger (UA - value) (W/K).

It is possible to calculate the efficiency of a collector circuit e.g. with flat solar collector according to EN 15136-4-3 [33]. An energy roof cannot be evaluated according to this standard.

5.4 Comparison of heat gain of an energy roof with a solar collector

A plastic pipe under roof covering is a solar absorber and the roof covering is the covering element. We can compare an energy roof with a classic solar collector with one covering layer - with one glass cover. The heat gain of a solar roof will then be compared with the gain of a conventional solar collector by a simplified balance method according to TNI 73 0302 [67]. The theoretically usable gain of a solar system is determined in individual months as:

$$Q_{k,u} = 0{,}9.\left[\eta_0 - a_1.\frac{t_{k,m} - t_{e,s}}{G_{T,m}} - a_2.\frac{(t_{k,m} - t_{e,s})^2}{G_{T,m}}\right].H_{T,deň}.n.A_k.(1-p)\ (kWh) \qquad [34]\ (14)$$

Where:

η_0, a_1 a a_2 solar collector curve constants,
$t_{k,m}$ mean daily temperature of heat transfer medium in solar collectors °C,
$t_{e,s}$ mean temperature of the air outside during sunshine °C,
$G_{T,m}$ mean daily solar irradiation in the time of sunshine for a given slope and orientation of collectors W/m^2,
$H_{T,day}$ actual daily dose of solar radiation kWh/(m^{2}day),
n - number of days in the month,,
A_k aperture area of a solar collectors m^2,
p value of the deduction from gains due to heat losses.

The calculation considers a common solar collector, whose parameters are as follows: optical efficiency of the solar collector η_0 = 0.8, linear coefficient of heat loss of the collector a_1 = 3.1 W/ m^2.K, quadratic coefficient of heat loss of the solar collector a_2 = 0.005 W/m^2.K. The inclination of the solar collector is considered to be 30 ° and the azimuth deflection is considered to be 45 °, which is the same deflection as the substantial area of the solar roof. A deduction of heat gains is not considered due to distribution or heat storage. The considered period will be the time when the solar roof was in operation at the EB2020 experimental house in Tomášov: 10 July to 6 October. In the calculation according to TNI 73 0302, the $H_{T,Day}$ value is considered for the given slope and orientation: July = 5.19 kWh/(m^{2}day), August = 4.54 kWh/(m^{2}day), September = 3.56 kWh/(m^{2}day)) and October = 2.03 kWh/(m^{2}day). Average outdoor air temperatures during sunshine: July = 22.5°C, August = 22.6°C, September = 19.4°C and October = 13.8°C.

VI. EXPERIMENTAL MEASUREMENTS

The measurement of the energy roof was performed on 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 Slovak Republic (see Fig. 6).

Figure 6: A view at implementation of the energy roof at the experimental house in Tomášov (Photo archive: Kalús) [10, 13]

The energy roof was put into operation on July 4, 2012. Measured were the obtained heat (GJ), flow volume (m^3), flow rate (m^3/h), output (kW), and temperature on the supply and return pipes (°C) - in Fig. 7 denoted as θ_2 and θ_3. These values were measured behind a plate heat exchanger. The temperature of the working medium in front of the heat exchanger at the outlet of the energy roof, marked as θ_1, was also measured. At that time, the temperature at the inlet to the energy roof, flow rate, flow volume, and heat on the primary side had not yet been measured. The individual measuring points are not installed immediately in front of and behind the heat exchanger. Temperatures on the secondary side of the exchanger θ_2 and θ_3 were recorded at one hour intervals, temperatures on the primary side of the plate heat exchanger θ_1 at 5 minute intervals.

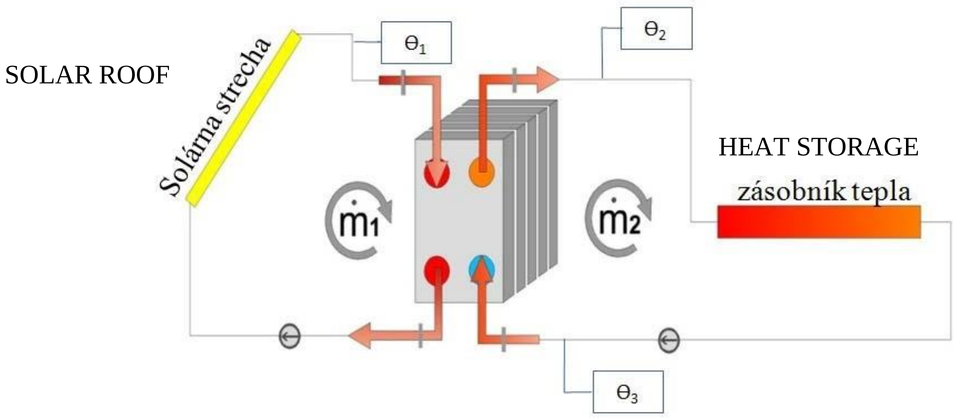

Figure 7: Scheme of measuring points of an energy roof in a family house [10, 13]

The circulation pumps are switched on in favorable conditions (with a suitable temperature difference in the solar roof and in the heat storage). If the temperature in the combined water heat storage is lower than the temperature at the inlet from the solar roof, the heat is accumulated in this vessel. Otherwise, the heat is accumulated in the ground storage. During the whole operation, the heat was accumulated in the ground storage. The first days of operation of the solar roof were not evaluated in the overall balance, as during this period a pressure test was performed and the operation of the system was tested. Values from 10 July 2012 were taken into the overall balance. Suitable conditions for the use of the energy roof were until 6 October 2012. In the periods from 8 to 15 August and from 7 to 14 September, maintenance work was carried out on the energy system, or there was a fault on the server, when inlet and return temperatures, flows and outputs were temporarily not recorded. In view of these facts, the system was analyzed in more detail by month:

- July (considered from 10th to 31st),

- August (8th to 15th individual values were not temporarily recorded),
- September and October (individual values were not recorded from 7 to 14 September. After 19 September, the conditions for the use of the roof were no longer favorable in the given month, in October conditions were only favorable on the 5th and 6th day of the month).

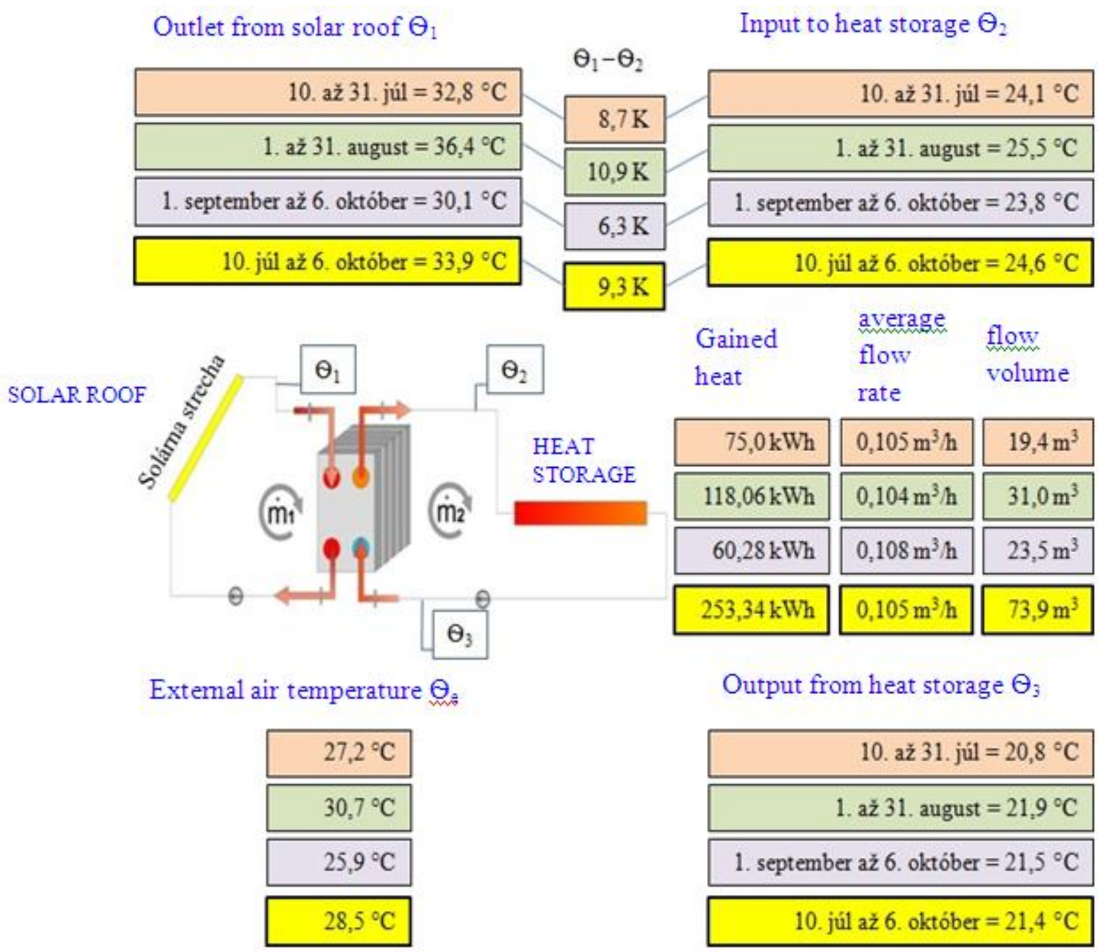

Figure 8: Summary of measured values from the operation of the energy roof - from 10 June to 6 October 2012: average temperatures of the working medium: Θ_1, Θ_2, Θ_3,, average temperature of the outside air Θ_e (from the time periods when the circulating pumps were in operation), total heat obtained, average flow rate and flow volume on the secondary side [10, 13]

Fig. 8 shows the average temperatures of the working medium: θ_1, θ_2, θ_3 and the average temperature of the outside air θ_e from the period when the circulation pumps were in operation. These values were not recorded between 8 and 15 August and 7 and 14 September. The total heat obtained and delivered to ground storage, the average flow rate and the flow volume on the secondary side are also displayed. The values of supplied heat and total flow volume are included from the whole period. The values are displayed for individual months as well as for the entire period of operation for 2012.

On the primary side of the heat exchanger, only the temperature at the outlet from the energy roof θ_1 was measured, the average value of which for the entire operation of 2012 was 33.9°C. On the secondary side behind the heat exchanger, the average temperature was θ_2 = 24.6°C. The temperature difference is 9.3 K. The total heat obtained and stored in the ground storage is 0.912 GJ = 253.34 kWh. With the correct design or use of the heat exchanger, this amount of heat could have been higher. The average flow rate on the secondary side was 0.105 m^3/h = 1.75 l/min. Average outside air temperature during energy roof operation θ_e = 28.5°C.

The measured heat gain of the solar roof in the experimental family house in the village of Tomášov for the given period from 10 July to 6 October was 253.34 kWh. We would get the same heat gain with a classic solar collector with one cover glass and the above parameters with an aperture area of 1.05 m^2. The calculation does not take into account the actual values of solar radiation intensity and other values for the given period, because these values were not measured and are not provided free of charge by the Slovak Hydrometeorological Institute.

Heat gain from the energy roof with circuits of 3x 100 m plastic pipes under the roof covering with an area of 109 m^2 oriented to the south - west with an inclination of 35 ° (above dormers 15 °) and an area of 55 m^2 oriented to the north - east with an inclination of 30 ° is equal to the heat gain of the solar collector with an area of 1.05 m^2 with a south - west orientation with an inclination of 30 ° under the given conditions and in the given months. In addition, a solar collector would probably be able to use solar energy for a longer period of time. Measurements at the experimental house EB2020 revealed that a plate heat exchanger was not properly designed or operated in the family house in Tomášov. The heat obtained could be significantly higher. [10, 13]

Of course, it is not possible to compare only heat gains. It is also necessary to compare temperatures. The average temperature at the outlet from the solar roof for the whole operation was 33.9°C, the temperature at the entrance to the heat storage 24.6°C.

When using the energy roof for the preparation of hot water, it can only be used for preheating and cannot be used as the only heat source in any period. Even in the warmest month of the year - in July, it was not possible to heat water to the required 55°C with the help of the energy roof.

VII. CONLUSION

The heat gain of a solar roof in the experimental family house for the given period of time was 253.34 kWh. If, in theory, the full use of the heat obtained was considered (whether for hot water preparation, ATP supply, or underfloor heating), the savings would be 253.34 kWh of natural gas. The family house is connected by a natural gas connection to the public gas pipeline from SPP with tariff D2, where the price of 1 kWh = 0.0482 Euro. A natural gas saving of 253.34 kWh would thus represent a saving of 12.21 Euros.

The operation of two Grundfos Alpha2 15-60 130 circulation pumps (on the primary and secondary side of the heat exchanger) must also be included in the balance. The pumps have stepless speed control, with an electrical input of 5 to 45 W. A power input of 30 W per pump will be considered, with a total of 487 hours in operation between 10 July and 6 October. This represents 2.30.487 = 29220 Wh = 29.22 kWh. The building is connected to the public electricity network from ZSE with a price per 1 kWh = 0.057 Euro. Cost of operation of circulating pumps is 1.67 Euros. The total savings with full use of the heat obtained from the energy roof would thus represent savings: 12.21 - 1.67 = 10.54 Euros.

When operating the energy roof from April, the savings could be about double. The investment costs of an energy roof consist of the purchase of plastic pipes and installation. A total of 300 m of plastic piping is installed, which at a unit price of 1 Euro per meter represents 300 Euros. The current price of a solar collector is around 600 Euros.

From the ecological point of view, savings of 1 kWh of natural gas represents a saving of 0.220 kg of CO2 emissions into the atmosphere [17]. 253.34 kWh of natural gas represents 55.73 kg of CO_2 emissions. Electricity has a CO_2 emission factor = 0.167 kg/kWh. Operation of the circulation pumps represents a pollution of 29.22. 0.167 = 8.6 kg of CO_2 emissions. The total saving of CO_2 emissions released into the air thus represents 55.7 - 4.9 = 50.8 kg.

REFERENCES

[1] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[2] KRECKÉ E. D .: PATENT SK 284 751: *Energetické zariadenie budov.* [Energy equipment of buildings.] Date of effectiveness of the patent: 3.11.2005. In: Vestník ÚPV SR č .: 11/2005, 10 p.

[3] KALÚS, D .: EUROPEAN PATENT EP 2 572 057 B1: *Heat insulating panel with active regulation of heat transition.* Date of publication and mention of the grant of the patent: 15.10.2014 In: Bulletin 2014/42 European Patent Office, international application number: PCT/SK2011/000004, international publication number: WO 2011/146025 (24.11.2011 Gazette 2011/47), 67 p.

[4] KALÚS, D .: UTILITY MODEL SK 5725 Y1 (UTILITY MODEL): *Tepelnoizolačný panel pre systémy s aktívnym riadením prechodu tepla.* [Thermal insulation panel for systems with active heat transfer control.] Date of entry into force of the utility model: 25.2.2011 In: Vestník ÚPV SR No .: 4/2011, 63 p.

[5] KALÚS, D .: UTILITY MODEL SK 5729 Y1 (UTILITY MODEL): *Samonosný tepelnoizolačný panel pre systémy s aktívnym riadením prechodu tepla.* [Self-supporting thermal insulation panel for systems with active heat transfer control.] Date of entry into force of the utility model: 28.2.2011 In: Vestník ÚPV SR No .: 4/2011, 32 p.

[6] KALÚS, D .: UTILITY MODEL SK 5749 Y1 (UTILITY MODEL): *Spôsob prevádzky kombinovaného stavebno-energetického systému budov a zariadenie.* [Method of operation of a combined construction-energy system of buildings and equipment.] Date of entry into force of the utility model: 1.4.2011 In: Vestník ÚPV SR No .: 5/2011, 23 p.

[7] KALÚS, D. et al .: Research Project HZ 04-309-05 - Design of a passive house using solar and geothermic energy. K-TZB SvF STU Bratislava, 2006.

[8] KALÚS, D. et al .: Research Project HZ 04-310-05 - Assessment of thermal comfort state in an experimental house. K-TZB SvF STU Bratislava, 2006.

[9] KALÚS, D. et al .: Research Project HZ 04-142-07 - Assessment of thermal comfort state in an experimental house. K-TZB SvF STU Bratislava, 2007.

[10] KALÚS, D. et al .: Research Project HZ PG73/2011 - 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. K-TZB SvF STU Bratislava, 2011-2013.

[11] KALÚS, D. et al .: Research Project HZ PR10/2015 - Analysis of energy, economic, environmental aspects and experimental measurements of compact equipment of energy systems for the application of renewable energy sources. K-TZB SvF STU Bratislava, 2015.

[12] CVÍČELA, M .: Analysis of wall energy systems. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2011, 119 pp., SVF-13422-17675.

[13] JANÍK, P .: Optimization of energy systems with long-term heat accumulation. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2013, 185 pp., SvF-13422-16657.

[14] ŠIMKO, M .: Energy efficiency in buildings with systems with active thermal protection. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2017, 152 pp., SvF-13422-49350.

[15] KUBICA, M .: Measurement and optimization of a compact heat station using renewable heat sources. Written part of the dissertation exam. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2019.

[16] ŠIMKO, M. - KRAJČÍK, M. - ŠIKULA, O. - ŠIMKO, P. - KALÚS, D .: Insulation panels for active control of heat transfer in walls operated as space heating or as a thermal barrier: Numerical simulations and experiments. In: Energy and buildings. Vol. 158, (2018), p. 135-146. ISSN 0378-7788 (2018: 4.495 - IF, Q1 - JCR Best Q, 1.934 - SJR, Q1 - SJR Best Q).

[17] KALÚS, D. - ŠIMKO, M. - GALVÁNEKOVÁ, M .: *Intelligent facade system with active thermal protection.* In: Stuttgart: Scholars' Press (October 24, 2014), 56 p., ISBN-10: 9783639665246, ISBN-13: 978-3639665246, ASIN: 3639665244.

[18] Q Zhu, X Xu, J Gao, F Xiao: A semi - Dynamic simplified therm model of active pipe embedded building envelope based on frequency finite difference method. In: International Journal of Thermal Sciences, 2015 - Elsevier, Vol. 88, pg. 170-179, 2015.

[19] KUHNOVA, E.: Bývanie za tepelnou bariérou, www.mojdom.zoznam.sk

[20] ISOMAX. http://www.isomax.sk

[21] GONZÁLES, A. C.: Diseño de una instalación solar térmica multipropósito para un edificio de viviendas en Granada – Proyecto de fin de carrera, Universidad Carlos III de Madrid, 2009

[22] Energía solar – geotérmica, laboratorio de ensayo de energía solar – geotérmica,

[23] Amascmasi, Logroño, La Rioja

[24] www.isomax-terrasol.eu

[25] GUINEA, D.: Gestión integral de la energía en un etorno habitacional, Propuesta Programa Cenit, presentación Sistema geotérmico solar y laboratorio de ensayo, Promociones Sadaba e Hijos, Logroño, La Rioja

[26] SCHULZ, H. V.: Teplo zo slnka a zeme, Staufen bei Freiburg, Verlag GmbH, 1999

[27] http://www.shmu.sk

[28] PETRÁŠ, D. a kol.: Nízkoteplotné vykurovanie a obnoviteľné zdroje energie, Jaga, Bratislava 2001

[29] CHRISTLIEB, X. W.: Gestión térmica de una vivienda con mínimo consumo de energía – Proyecto de fin de carrera, Universidad Pontificia Comillas, 2007

[30] CHMÚRNY, I.: Tepelné mosty, In: Môj dom – Všetko o úsporách energií, roč. 6, 1/2006, s. 48 – 49

[31] CHMÚRNY, I. *Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.* [Thermal protection of buildings.] Bratislava: Jaga, 2003. ISBN 80-889-0527-3.

[32] Guía técnica: Ahorro y eficiencia energética en climatización – Diseño y cálculo del aislamiento térmico de construcciones, aparatos y equipos, Ministerio de industria, Turismo y Comercio de España

[33] EN 15316-4-3 Vykurovacie systémy v budovách. Metóda výpočtu energetických požiadaviek systému a účinností systému. Časť 4-3: Systémy výroby tepla, tepelné slnečné systémy.

[34] TNI 73 0302 Energetické hodnocení solárních tepelných soustav - Zjednodušený výpočtový postup

[35] KRZACZEKA, M., KOWALCZUK, Z .: *Thermal Barrier as a technique of indirect heating and cooling for residential buildings.* In: An international journal devoted to investigations of energy use and efficiency in buildings - Energy and Buildings, 2011 - Elsevier, Vol. 43, pg. 823-837, 2011.

[36] BABIAK, J. - OLESEN, B.W. - PETRÁŠ, D .: *Low temperature heating and high temperature cooling.* REHVA, Guidebook no 7, 2007, ISBN (s): 2960046862, p. 115.

[37] STN 730540-2 + Z1 + Z2: 2019 *Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.* [Thermal protection of buildings. Thermal technical properties of building structures and buildings.] Part 2: Functional requirements. Consolidated text

[38] STN EN 12831: 2019 *Energetická hospodárnosť budov. Metóda výpočtu projektovaného tepelného príkonu.* [Energy performance of buildings. Method of calculation of projected heat input.] Part 1: Heat input, Module M3-3

[39] STN 06 0892 - *Ústredné sálavé vykurovanie so zabetónovanými rúrkami.* [Central radiant heating with concreted pipes.]

[40] www.po.opole.pl. TU in Opole (2013)

[41] http://www.eng.pw.edu.pl TU in Warsaw (2013)