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RESEARCH ARTICLE **(Open Access)**

Determination of the Economically Expedient Thickness of a Reed Roof of Building for Laying Hens

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Abstract

The purpose of the study is to determine the economically expedient roof thickness of a building for laying hens in use heat insulation from reeds and different fuel for heating (pellets and coal "Donbaski"). To achieve the purpose, 6 variants of a roof of 10, 15, 20, 25, 30 and 35 cm thick reeds plates are developed. The price of one reeds plate is calculated by including only the construction works for its preparation. The construction value of the ready roof (with VAT and transport) is obtained by adding to the value of the construction works for the preparation the value of the construction and assembly works of the site, the payment of the labor, the execution of the plank sheathing, the waterproofing and the laths. The annual energy losses through a 1 m^2 of the roof structure are determined through the submitted methodology. The annual heat insulation costs are calculated as a sum of annual energy cost and the depreciation allowances. Verification of condensation of water vapor on the inner surface of the reed roof was carried out. These results show that by using fuel pellets, most appropriate thickness of the thermal insulation is 25 cm, and by using Donbas coal - 30 cm. All investigated variants of the reed roof meet hygienic requirements to prevent condensation of water vapor on its inner surface.

Keywords: Reeds roofs of buildings, laying hens, pellets, coals, energy losses, annual costs

1. Introduction

Construction and operation of buildings have a materially impact on the environment by drawing a significant amount of resources (materials and energy) and generating waste and emissions that are harmful to the atmosphere. Buildings account for 40% of total final energy consumption in the Europian Union [3] which results in 25% of atmospheric emissions of CO_2 [6] .To achieve a sustainable development of humanity in harmony with nature, one of the main universally accepted means is energy efficiency.

For Bulgaria, the energy consumption in the building stock is over 30% of the total in the country. In order to realize energy saving for heating, the thermal insulation of the buildings has been increased in recent years. Tasks of modern construction are to reduce the cost of maintenance during the life cycle of the buildings and to apply innovative engineering solutions to drastically reduce the massively used energy-intensive materials (concrete, steel, aluminum, copper, gypsum, cement, ceramics, glass etc.). In this respect, biomaterials (wood, reed, hemp, straw, etc.) are a good alternative, especially for the buildings in the agrarian sector [4].

Requirements are being made for the heated livestock buildings (for poultry, pig, rabbit, etc.) - increased heat insulation capacity, to consume less heat energy and at the same time to provide the normative microclimatic parameters in the premises, and to meet the veterinary medicinal requirements [2, 5, 9, 10, 11, 12, 13]. Countries such as the Netherlands, Denmark, the United States, Japan, Russia conduct research on environmentally friendly materials. Technologies using straw and reed for roofing have been developed instead of traditional building materials so far [4].

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The reed is a perennial herbaceous plant with a unique structure, which can be made in the form of slabs of different sizes and thicknesses according to the specific needs. It is considered an efficient and economical heat insulator, a 15 cm thick reed slab is characterized by the same energy-saving features as a 35 cm thick brick masonry.

Nowadays in Bulgaria, studies to optimize the thickness of the enclosing structures of heated poultry buildings made of biomaterials are completely missing, depending on the chosen type of fuel for heating. Developments in this area mainly concern residential and public buildings.

The purpose of the study is to determine the economically expedient roof thickness of a building for laying hens by using heat insulation from reeds and different fuel for heating (pellets and coal "Donbaski").

2. Material and methods

For the modern conditions in Bulgaria different types of reed roofs (suitable for heatable livestock buildings) with different degrees of thermal resistance have been studied and their thermo technical properties have been established.

A.

B.

Figure 1. Reed bladed slabs from longitudinally located sheaves (stems thickness 0.2 - 0.5 cm).

For buildings for laying hens, 6 variants of reeds roof slabs (pressed to accomplishing density 200 kg/m^3) of dimensions 220/100 cm and thicknesses of 10, 15, 20, 25, 30 and 35 cm are developed and dimensioned, located longitudinally in the direction of the roof slope (figure 1). When developing, the same conditions are adopted:

- The finished reed slabs are mounted manually over a laths in the following implementation of the roof: wooden supporting structure, underboarding (2,5 cm thick), waterproofing out of two layers of black tar paper, laths and reed coating.
- A heat conductivity coefficient is accept:

\- for pressed reed - λ=0.067 W/mK at density ρ = 200 kg/m^3;

\- for planks - λ=0.15 W/mK at density ρ = 500 kg/m^3;

- An angle of the roof slope of 35 °C (required for reed roofs) is accept;
- Two types of fuel are used to heat the room: pellets and coal "Donbaski", which prices for October (VAT included) are:

\- for pellets - 189 EUR/t;

\- for coal "Donbaski" - 174 EUR/t).

The calculations in the conducted researches are assigned to the 1 m^2 of the roof area.

The annual heat losses through the enclosing building element bordering outside air, are determined by a quasi-static (simplified) method [8,14] due to negligible thermo accumulation.

For each of the accepted thickness of the thermal insulation, the heat transfer coefficient *U* is calculated:

$$U = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{iz}}{\lambda_{iz}} + \frac{1}{\alpha_2}} \quad , W/m^2K$$

where:

α_1 and α_2 are respectively the heat transfer coefficients for the internal and external side of the roof; α_1 = 10 W/m^{2}K and α_2 = 25 W/m^{2}K (Stamov et al., 1990);

λ_{iz} is the heat conductivity coefficient of the thermal insulating layer, W/mK;

δ_{iz} is the thickness of the thermal insulating layer, m (it is set in steps).

There are determined the monthly and the annual heat losses through the roof, refered to a unit area from it - 1 m^2. The monthly heat losses are determined according to the formula:

$$Q_{m,i} = UF(t_r - t_{m,i})\frac{\tau_i}{1000}\ , kWh$$

where:

F is the area of the roof, m^2;

t_r is the air temperature in the room for the heating period, °C (object of study is a building for laying hens with maintained room air temperature during the heating season t_r = +20 ºC);

$t_{m,i}$ is the mean monthly temperature for the ith month out of the heating season,°C [14];

τ_i is the duration of the month in hours, h.

Annual heat losses through the roof are determined as a sum of the monthly losses:

$$Q_a = \sum_{i=1}^{r} Q_{m,i}\ , kWh$$

Only monthly heat losses complying with the following condition should be considered:

$$t_{m,i} < t_r - \Delta t,\ °C$$

where:

$\Delta t \approx 5$ ºC (heat release from the birds compensates thermal losses of buildings by raising t_r with Δt) [7].

The amount of fuel compensating heat losses through the building element is determined:

$$Ba = \frac{Q_a}{r.\eta}\ , kg$$

where:

r is the lower heat transfer capability of the fuel, KJ/kg (kWh/kg);

η are the efficiency systems, converting fuel into heat, and carrying it into the room, (η = 0,6 – 0,9).

For the used fuels we accept:

- for pellets - r = 4.8 kWh/kg; η = 0.9;
- for coal "Donbaski" - r = 4.3 kWh/kg; η = 0.8 [8].

The amount of the necessary fuel Ba is determined for a thickness variation of the thermal insulation in the range from 10 cm to 35 cm.

The annual discounted costs are determined (DC):

$$DC = C + E_s K$$

where:

DC is the amount of discounted costs for 1 year, EUR/am^2;

C is the amount of annual energy costs, corresponding to the heat losses of the roof ($C = Ba.\ P_f$), EUR/am^2;

E_s - standard coefficient of depreciation costs, 1/a (corresponding to the period of thermal insulation depreciation);

P_f is the fuel price, EUR/m^2;

K is the amount of investment costs (the construction value) for thermal insulation, EUR/am^2

A period is assumed for depreciation of thermal insulation - 20 years.

For determination of the investment costs, ie the construction value (the price) per 1 m² of roof cover for each variant, a quantitative and value account are prepared using the country price lists. The price of one reeds plate is calculated by including only the construction works for its preparation. The construction value of the ready roof (with VAT and transport) is obtained by adding to the value of the construction works for the preparation, the value of the construction and assembly works of the site, the payment of the labor, the execution of the plank sheathing, the waterproofing and the laths.

A check for the condensation of water vapor on the inner surface of the reeds roof must be done:

$$\Theta_{in} = t_r - (t_r - t_o)/\alpha_1 R_o,$$

where:

t_r is the air temperature in the room for the heating period, °C;

t_o *is* the temperature of the outer surface of the roof to the outside air, °C;

α_1 is the heat transfer coefficient for the inner surface of the roof to the air in the room, W/m^2K;

$R_o = 1/U,\ m^2 K/W$

For Θ_{in} should be fulfilled the condition that guarantees the absence of condensation:

$$\Theta_{in} > t_{ir}+1$$

where:

t_{ir} is the dew point (the temperature to which the air must be cooled to saturate with water vapor). For laying hens, t_{ir} = 10 ºC (determined by the technological conditions of the microclimate in the building of the H-x diagram for humid air, under the adopted room temperature 20 ºC).

The check is carried out for the coating with the smallest insulation thickness - δ = 10 cm. It is accept that if the check is fulfilled, this iwill also apply to the other variants. During the study the average outdoor temperature in the cold months is taken (t_o = -2 ºC) and the lowest outside temperature during the year (t_o = -15 ºC).

3. Results and discussion

In Table 1 are reflected for the studied thicknesses of reed insulation, the heat transfer coefficient (*U*), the energy costs for 1 m^2 roof, corresponding to the heat losses through the roof for the heating season *(Q_a)* and the amount of the fuel (B_a^p - pellets or B_a^c coal "Donbaski") for their compensation. The results show that as the insulation thickness increases, the annual heat losses and the amount of fuel for their compensate decrease in a direct proportionality depending on the heat transfer coefficient. The values of the indicators for the variant with the insulation thickness of 35 cm are 3.13 times lower, compared to these in thickness of 10 cm. It is seen from the table too, that a more economical solution is the choice of pellets for fuel, compared to the coal.

Table 1. Energy costs and fuels for 1 m^2 reed roof for 1 year

Insulation thickness δ, cm	U, W/m^{2}K	Q_a, kWh	*B_a, kg	
			B_a^p	B_a^c
10	0,569	45.33	10.49	13.18
15	0,399	31.79	7.36	9.24
20	0,308	24.54	5.68	7.13
25	0,268	20.22	4.68	5.90
30	0,211	16.81	3.89	4.82
35	0,182	14.50	3.36	4.22

* It is determined in low thermal conductivity of the fuel

Table 2. Relative construction value (for 1 m^2) of reed slabs and of reed roof

Insulation thickness δ, cm	Value per 1 m^2 of reed slab	Value* per 1 m^2 of reed roof
	EUR/m^2	EUR/m^2
10	6.95	18.51
15	10.43	22.04
20	13.91	25.58
25	17.38	29.12
30	20.86	32.67
35	24.34	36.23

*The value (with VAT and transport) is determined by prices valid for September 2019 and exchange rate of BNB on 20.09.2019 → 1 BGN = 0,511 EUR

Table 3. Discounted costs for 1 m2 reed roof for 1 year in using different fuels, *EUR/am2

Insulation thickness, δ, cm	Pellets			Coal "Donbaski		
	C	*Es**K*	*DC*	*C*	E_s***K*	*DC*
	EUR /am^2	EUR /am^2	EUR /am^2	EUR /am^2	EUR /am^2	EUR /am^2
10	1.98	0.93	2.91	2.29	0.93	3.22
15	1.39	1.10	2.49	1.61	1.10	2.71
20	1.07	1.28	2.35	1.24	1.28	2.52
25	0.88	1.46	2.34	1.03	1.46	2.49
30	0.74	1.64	2.38	0.84	1.64	2.48
35	0.63	1.81	2.44	0.73	1.81	2.54

*EUR/am2 - EUR /annual . m2

**The value (with VAT and transport) is determined by prices valid for September 2019 and exchange rate of BNB on 20.09.2019 → 1 BGN = 0,511 EUR.

Table 2 shows the construction value of one reed slab and the value of the ready roof of a laying hen building in EUR/m2, refered to 1 m2 of the roof area. The data shows the great influence of the thickness of the thermal insulation layer on the value of the entire roof. For example, for reed slabs with thickness 10 cm (value - 18.51 EUR/m2), the roof construction is 2 times cheaper than at a thickness of 35 cm (36.23 EUR/m2). This is due to the fact, that in our country there is still no developed production of reed slabs with a thickness of more than 5 cm in which their calculated value is obtained by accumulation of layers of 5 cm one above the other.

From the results reflected in Table 3 it is seen, that if pellets for fuel are selected, the discounted costs during the year are smallest at an insulation thickness of 25 cm (2.34 EUR/am^2), and at a thickness of 10 cm they are the highest (2.91 EUR/am^2) - 24.4% difference. A good solution is with thickness of 20 cm (2.35 EUR/am^2), with a slight difference in the value of the research indicator compared to this at the thickness of 25 cm - 0.43%. Based on the discounted costs we can say, that the optimum thicknesses of the insulation when using pellets for fuel, is 25 and 20 cm. Regarding the use of heating fuel - “Donbaski” coal, the results show that the discounted costs are smallest (2.48 EUR/am^2) at a thickness of the reed of 30 cm. It is seen also from the table, that the discounted costs at the least studied thickness - 10 cm (3.22 EUR/am^2) are 29.8% higher than the optimum thickness. At a thickness of 25 cm for the research indicator, has been marked a close value (2.49 EUR/am^2) up to that at a thickness of 30 cm.

From the results in Table 3 it becomes clear, that the price of fuel has a more substantial influence on the discounted costs, than the construction value of the roof. For example, at a thickness of the insulation from reed of 30 cm, the value of fuel - pellets is 0.74 EUR/am^2, and of “Donbaski” coal is 0.84 EUR/am^2 (a difference of 13.5%). At the same time, the difference in the discounted costs is 4.2% (values for: pellets - 2.38 EUR/am^2; ”Donbaski” coal - 2.48 EUR/am^2).

The results are presented graphically in Figure 2 and Figure 3.

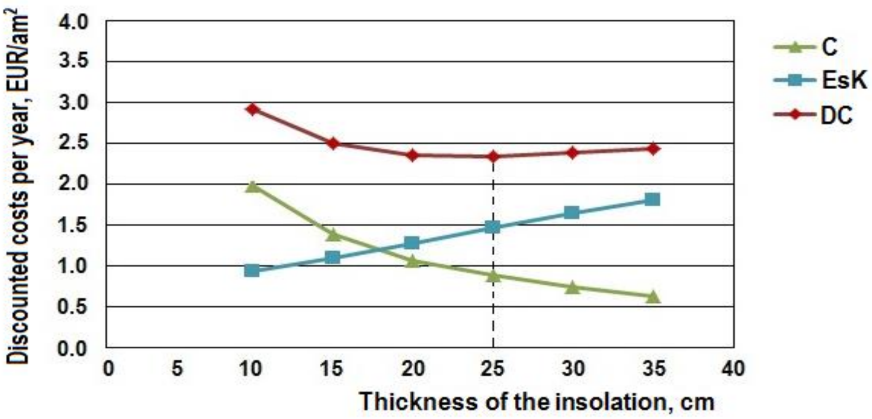

Figure 2. Dependence between the thickness of the reed roof and the relative costs in using pellets for fuel.

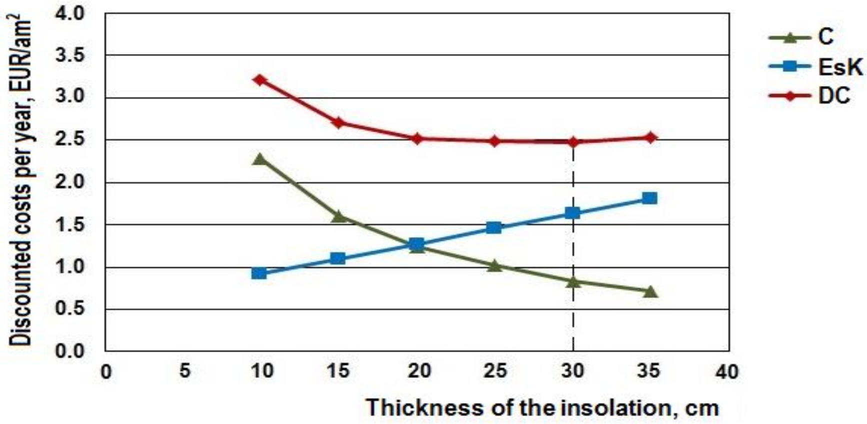

Figure 3. Dependence between the thickness of the reed roof and the relative costs in using “Donbaski” coal for fuel.

From the graphs it is seen, that at a fuel pellets, the discounted costs decrease with increasing the thickness of the thermal insulation up to 25 cm, then increase to a thickness of 35 cm. At the coal they are lowest at a thickness of the reed slabs of 30 cm and are significantly higher at a thickness of 10 cm.

The results of the verification for condensation of water vapor on the inner surface of the reed roof in the variant with the smallest insulation thickness (δ = 10 cm) are given in Table 4. It is seen that for the month of January (with the lowest temperature t_o = -2 ° C) and for the average monthly temperature during the cold months of the year - t_o = -15 ºC, the condition for prevent condensation of water vapor $\Theta_{in} > t_{ir}+1$, is fulfilled.

Table 4. A Verification of condensation of water vapor on the inner surface of the reed roof

Type of thermal insulation	t_r, ºC	t_o, ºC	δ, cm	$\alpha_1 R_0$	$\Theta_{in} = t_r - (t_r - t_o)/\alpha_1 R_o$ $t_{ir} = +10\ ºC$
Reed	+20	-2	10	37,31	+18,75 > +11,0
Reed	+20	-15	10	37,31	+18,01 > +11,0

4. Conclusions

At the 20-year period of depreciation of a wooden roof of a building for laying hens, the economically most advantageous thicknesses of heat insulating layer of reed slabs are: for fuel pellets - 25 cm; for fuel coal "Donbaski" - 30 cm. When using more expensive fuels for compensating heat losses through the roof the optimum thickness of the reed slabs increase. All investigated variants of the reed roof meet hygienic requirements to prevent condensation of water vapor on its inner surface. The developed variants of reed roof are of good heattechnical characteristics and are applicable in the design of environmentally friendly and energy efficient buildings for laying hens.

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