RESEARCH ARTICLE **(Open Access)**

# Optimizing the thickness of the thermal insulation of buildings roofs in facility for gilts

RASKA GEORGIEV[1], VANIA DIMOVA[1], KRASIMIRA UZUNOVA[2*], PLAMENA ATANASOVA[1], ANNA KARKELOVA[1], MARINA TOSHESKA[2]

[1]Department "Agricultural Engineering", Faculty of Agriculture, University of Thrace, 6000 Stara Zagora, Bulgaria

[2]Department "Animal Husbandry" Faculty of Veterinary Medicine, Trakia University, 6000 Stara Zagora, Bulgaria

[3]DVM, Faculty of Veterinary Medicine, Lazar Pop Trajkov 5-7, 1000 Skopje

[*]Corresponding author E-mail: mira60bg@yahoo.com

## Abstract

The study aims to determine the optimum thickness of the roof construction of a facility for gilts when different fuel for heating are used and various kinds of insulation. The presented methodology helps to determine the annual energy losses through a 1 m2 of roof construction. In analyses are taken into consideration various types of heat insulation as insulating sandwich - panels of plasticized LT-layered tin of thermal insulation with EPS, XPS and mineral wool. Annual cost for heat insulation is calculated as the sum of annual energy costs and depreciation for insulation. The obtained results show that the use of fuel - a dry timber at - appropriate thickness of the thermal insulation are: for EPS and mineral wool - 100 mm; for XPS - 80 mm, and when Bobovdol coal is using appropriate thickness of the thermal insulation are: for EPS - 140 mm; for XPS and mineral wool - 100 mm respectively.

**Keywords**: facility’s roofs, sows, energy losses, annual costs

## Introduction

According to veterinary requirement of the EU [4,5,6] with which are and Bulgarian regulations concerted [13,14,15], for design of new construction and reconstruction of existing buildings for pig-breeding an important factor for ensuring the necessary comfort of the animals is strict compliance with the zoo-hygienic requirements to the conditions of the living environment and parameters of the microclimate in the premises.

In recent years, the heating of livestock buildings during the winter season has become a serious problem from economic point of view. On one side are the increasing energy prices, and the other - inefficient thermo insulation of surrounding structures of the buildings,as a result of which no small part of the thermal energy the surrounding air is transmitted. This problem affects the preservation of the environment, as the energy conservation helps to reduce emissions of carbon oxides, sulfur oxides and other atmosphere polluting. According to several authors **[2,3,8,9,10,17,19,23]** the alternative pathway which allowing to find away out of this situation is the achievement of so-called "energy-saving buildings", that have high thermal insulation capability of the surrounding structures and are designed that less amount of thermal energy to provides the normative parameters for the microclimate in the premises.

In the EU-countries there is a trend towards increasing the thermal protection of surrounding structures of the buildings in order to realize energy savings unto their heating [**24,29**]. Optimization of thermal insulation of buildings is often based on cost-effective thickness, i.e. such a thickness that provides minimal investment and energy costs for a given period of time [**21,22,25, 27, 28**].

In recent years the requirements to the energy performance of buildings in Bulgaria repeatedly increased and the current rules and regulations for design and construction [11,12,16] correspond to the European directives and practices.

Depending on the type of the materials and products for the implementation of the thermal insulating layer, the external thermal insulation combined systems of the surrounding structures of the buildings can be: based on foams (expanded polystyrene, polyurethane foam, phenolic resins,etc.) and based on solid slabs of mineral wool (rockorglass). According to **Nazarski** [**10**] most used foams are those based on expanded polystyrene (EPS) which have asubstantially smaller coefficient of diffusion resistance to water vapor(m) in comparison with the products made of extruded polystyrene(XPS) or those based on polyurethane. With this favorable conditions are create for effective evaporation of condensed water vapor in the surrounding structure of the buildings in winter.

The data mentioned in the literature concern mainly the area of housing construction and the new buildings for corporate offices or public services. Not looking for the relationship between the thermo technical properties and the cost price of modern roofing constructions enclosing heated livestock buildings.

The **objective of the study** is to determine the optimum thickness of the surrounding roof structure of a building for gilts sat different fuel used for heating and thermal insulation of different nature.

## Materials and methods

For thermal insulation were using roof panels from XPS, EPS and Mineral (marl) wool. There are two types of fuel, used for heating: dry wood with a moisture content 20% and Bobovdol coal, whose data are:

- for dry wood - 56€/t;
- for Bobovdol coal - 104€/t.

To determine the annual heat loss through the building enclosing element bordering outside air, we use quasi - static method [**16, 26**] due to negligible thermo accumulation.

The issued object is a building for gilts. The air temperature maintained in livestock buildings in heating season ($t_n$) is 20º C [**15,20**]. The building construction of the enclosing element is shown in Figure 1.

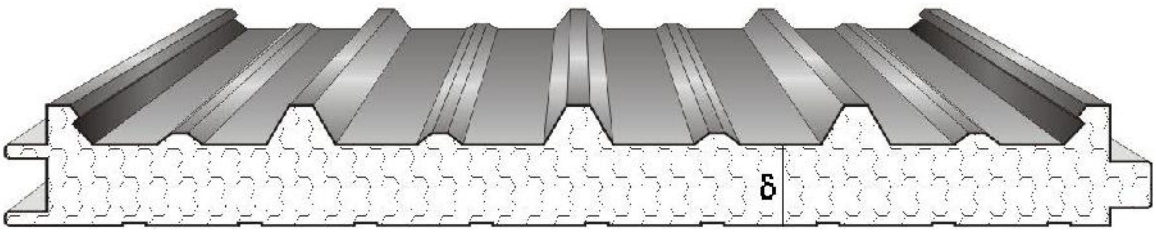


**Figure 1.**Roof thermal insulation panel

Initially, it is necessary to determine the heat transfer coefficient *K*of the enclosing building element for different thickness of thermal insulation, by the formula given below. Used different thicknesses of the insulation (4, 6, 8, 10, 12, 14 cm) and for each of them the coefficient *K* is calculated:

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

where:

$\alpha_1$and $\alpha_2$are respectively the heat transfer coefficients for the internal and external side of the roof; $\alpha_1$= 10 W/m$^2$K and $\alpha_2$= 25 W/m$^2$K [**18**];

$\lambda_{iz}$ is the heat conductivity coefficient of the thermal insulation, W/m.K;

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

Determine the monthly and the annual heat losses through the enclosing element.

The monthly heat losses through the roof are determined according to the formula:

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

where:

*F*is the area of the enclosing element, m$^2$;

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

$t_{m,i}$is the mean monthly temperature for the i$^{th}$month, °C (**16**);

$\tau_i$is the duration for the i$^{th}$month in hours,h.

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

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

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

$$t_{m,i} < t_r - \Delta t, \text{ °C}$$

$\Delta t \approx 5$ ºC (**1**)

Heat release from the animals compensate thermal losses of buildings by raising $t_r$ with $\Delta t$.

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

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

where:

$r$ is calorific value (the lower heat transfer capability) of the fuel, kJ/kg (kWh/kg);

$\eta$ is the efficiency systems, converting fuel into heat and carrying it into the room, ($\eta$ = 0,6 - 0,9).It is accepted $\eta$ = 0,8.

The amount of the necessary fuel $Ba$ was determined for a thickness variation of the relevant thermal insulation in the range from 4 cm to 14 cm.

The annual discounted costs are determined ($DC$) using the general formula:

$$DC = C + E_s K, \text{ €/am}^2$$

where:

$DC$ is the amount of discounted costs per year, €/a.m$^2$;

$C$ - amount of annual energy costs, corresponding to the heat losses of the roof, €/a.m$^2$ ($C = Ba$. Fuel price);

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

$K$ - amount of capital investment for thermal insulation, €/a.m$^2$.

A period is assumed for depreciation of insulation - 25 years.

A check for the condensation of water vapor on the inner surface of the roof panels must be done.

The temperature of the inner surface of the roof panels is determined according to the formula:

$$\Theta_{in} = t_r - (t_r - t_o)/\alpha_1 R_0$$

where:

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

$t_o$–temperature of the outer surface of the roof panel to the outside air, °C;

$\alpha_1$ - heat transfer coefficient for the theinner surface of the panel to the air in the room, W/m$^2$.K;

$R_0 = 1/K$, m$^2$.ºC/K.

For $\Theta_{in}$ should be fulfilled the condition that guarantees the absence of condensation:

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

$t_{ir}$ is irrigation temperature for sows, $t_{ir}$= 13,5 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).

Using the developed method are calculated the heat transfer characteristics of the considered heated livestock buildings, in order to reduce energy costs for compliance with technological standards. Calculations are done for 1 m$^2$ area of the enclosing element of building construction.

## Results and Discussion

In Table 1 are shown the energy costs per 1m$^2$ roof, corresponding to the heat losses of the heating season, ($\sum Q_a$) for different thermal panels, and the amount of fuels used for the season ($B_a^w$ -drywood and $B_a^c$ -Bobovdol coal). It is seen that in choosing an XPS thermal insulation, the amount of the fuels used to compensate for the heat loss is less than that of mineral wool. The annual heat loss in XPS is also relatively smaller than in the wool.

**Table 1.** Energy costs and fuels per 1 m$^2$ roof panel per 1 year

| Insulation thickness,$\delta$ | Roof panel with Polyurethane foam, XPS | | | Roof panel with Rockwool | | |
|---|---|---|---|---|---|---|
| | $\sum Q_a$ | $B_a^w$ | $B_a^c$ | $\sum Q_a$ | $B_a^w$ | $B_a^c$ |
| cm | kWh | kg | kg | kWh | kg | kg |
| 4 | 52,46 | 15,43 | 15,64 | 52,29 | 17,44 | 15,59 |
| 6 | 36,11 | 10,62 | 10,76 | 41,55 | 12,22 | 12,38 |
| 8 | 27,23 | 8,00 | 8,11 | 32,02 | 9,42 | 9,54 |
| 10 | 21,73 | 6,39 | 6,47 | 25,86 | 7,60 | 7,71 |
| 12 | 18,38 | 5,40 | 5,48 | 21,79 | 6,40 | 6,49 |
| 14 | 15,64 | 4,60 | 4,66 | 18,38 | 5,40 | 5,48 |

Table 2 shows comparation of the results of the discounted costs (*DC*) during the year per 1 $m^2$ roof panel of different types. There are referred to and the values of their components, *C* and $E_s K$. It is seen that the optimum thickness of the insulation by XPS using fuel - dry wood is 8 cm, and when is using coal - 10 cm. For mineral wool the optimum thickness, which we can recommend the use of both types of fuel is 10 cm. The results for the dependencies between the thickness of the panels and the discounted costs per year using fuel for heating, respectively dry wood and Bobovdol coal are presented illustrated in Figure 2 and Figure 3.

**Table 2.** Discounted costs per 1 $m^2$ roof panel per 1 year in using different fuels

| Insulation thickness, $\delta$ | Roof panel with Polyurethane foam, XPS | | | | | | Roof panel with Rockwool | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | dry wood | | | coal | | | dry wood | | | coal | | |
| | *C* | $E_s$**K* | *DC* | *C* | $E_s$**K* | *DC* | *C* | $E_s$**K* | *DC* | *C* | $E_s$**K* | *DC* |
| cm | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ | €/a.$m^2$ |
| 4 | 0,87 | 0,65 | 1,52 | 1,63 | 0,65 | 2,28 | 0,98 | 0,73 | 1,71 | 1,62 | 0,73 | 2,35 |
| 6 | 0,60 | 0,74 | 1,34 | 1,12 | 0,75 | 1,87 | 0,68 | 0,79 | 1,47 | 1,29 | 0,79 | 2,08 |
| 8 | 0,45 | 0,84 | **1,29** | 0,84 | 0,84 | 1,68 | 0,54 | 0,85 | 1,39 | 1,00 | 0,85 | 1,85 |
| 10 | 0,36 | 0,94 | 1,30 | 0,67 | 0,93 | **1,60** | 0,43 | 0,95 | **1,38** | 0,80 | 0,95 | **1,75** |
| 12 | 0,30 | 1,05 | 1,35 | 0,57 | 1,04 | 1,61 | 0,36 | 1,08 | 1,44 | 0,68 | 1,08 | 1,76 |
| 14 | 0,26 | 1,19 | 1,45 | 0,48 | 1,19 | 1,67 | | | | | | |

* The value is determined by prices valid for November 2015 and exchange rate of BNB on 27.11.2015 → 1 BGN = 0,511 EUR

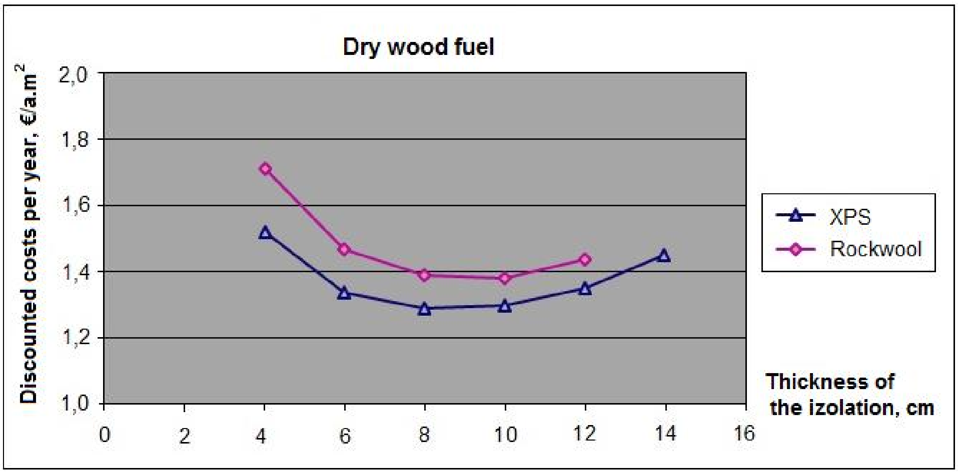


**Figure 2:** Rate of discounted costs in dry wood fuel depending on the thickness of thermal insulation.

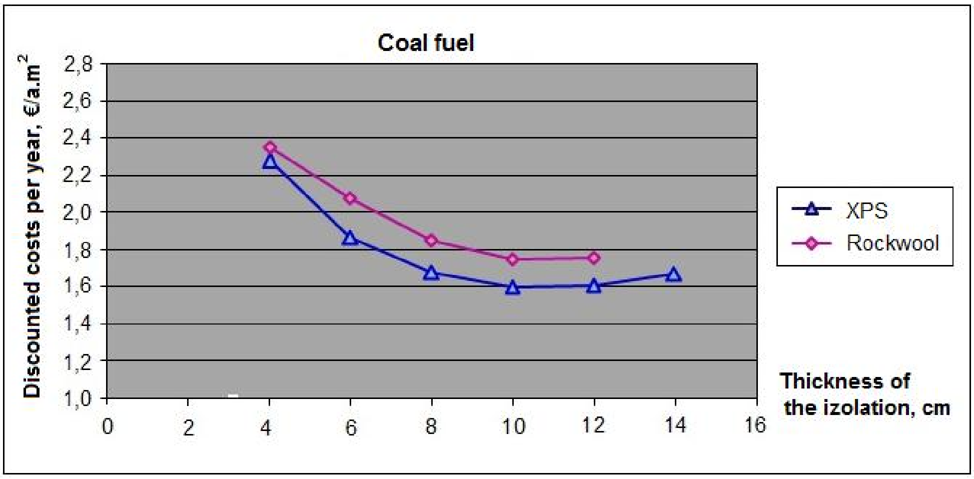


**Figure 3.**Rate of discounted costs in coal fuel depending on the thickness of thermal insulation

From the results it is apparent that in fuel dry wood and in both types of roof panels the relative proportion of the energy component (C) in the minimum discounted costs is in the range of 32-35%, while in coal fuel the ratio is in the range of 42-45%. This is due to the relatively higher price of the coal and the adopted lower coefficient of efficiency of the boilers compared with pyrolysis burning dry wood.

Upon verification for condensation of water vapor on the inner surface of the roof panels for each thermal panel we choose a coefficient $K$ for the optimum thickness, using a different type of fuel. In both cases, we get that$\Theta_{in} > t_{ir}+1$,i.e.can ensure that there will be no condensation of water vapor (Table 3).

**Table 3.**A check for the condensation of water vapor on the inner surface of the roof panel must be done

| Type of thermal insulation | $t_r$ | $t_o$ | $\delta$ | $\alpha_1 R_0$ | $\Theta_{in} = t_r - ( t_r - t_o )/\alpha_1 R_0$ $t_{ir}=13,5$ |
|---|---|---|---|---|---|
| | ºC | ºC | cm | | ºC |
| Rockwool | 20 | 13 | 12 | 31,25 | 18,94 >14,5 |
| XPS | 20 | 13 | 14 | 43,47 | 19,01 > 14,5 |

**Conclusions:**

Based on our investigations and results mentioned above, we underlining these conclusions:

1. Thicknesses up to 8 cm of the applied thermal panels are insufficient to achieve an effective balance between fuel used for heating and the placed thermal insulation.
2. The most economically advantageous thicknesses of the insulating layer of the roof thermal insulation panels of buildings for gilts are:
3. for *dry wood-fuel* - 8 cm (in thermal panel with Polyurethane foam, XPS) and 10 cm (in thermal panel with Rockwool);
4. for *Bobovdol coal-fuel*- 10 cm (in thermal panel with Polyurethane foam, XPS or with Rockwool).
5. When more expensive fuels are use, the optimal thickness of the panel will increase.
6. Economically justified thicknesses of the thermal insulations perform the hygiene requirements to prevent condensation on their inner surfaces too**.**

**References:**


1. Georgiev R: **Energy saving from heating and ventilation of poultry houses**. Thesis for PhD, Technical University, Sofia (Bg). 1985.
2. .Georgiev R and Dinev D: **Economically expedient Degree of thermal Insulation of the Roofs of Buildings for growing Pigs,** Agricultural Machinery 4, 1998:11-13
3. Dinev D and KolevaK: **Interdependences between the technical characteristics of thermal insulation materials and their value for roofs in agrarian buildings**. Journal of Animal Science, 2003(2):143-148.
4. Directive 98/58/EC of 20July1998 on the protection of animals kept for farming purposes (OJ L 221, 08August1998, p.23 with amendments).
5. Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs (Official Journal of the European Union, 18February2009, BG, L 47/5)
6. European convention for the protection of animals kept for farming purposes. Strasbourg, 03October 1992.
7. Law on Energy Efficiency/14 November 2008 (Publ. SG. No. 98 dated 13 March 2009 with amendments).
8. Iliev A, Georgiev R and Dinev D: **Thermal engineering characteristic of Buildings for nursing pigs.**Scientific Session of the Faculty zooengineering, 4.V, StaraZagora. 1990: 8-9.
9. Katsarov V, Dinev D and Delchev N: **Modular green pig farm**. Agricultural Machinery 3, 2002: 35-40.

**10.** Nazarski D: **Effects of new building materials and technologies on modern architecture. International Symposium "Modern architecture - aluminum and glass".** Construction Town, Number 23; 13 June 2005.

11. Regulation No.18, for Energy characteristics of objects, effective from 12 November 2004 (Publ. SG.No. 108 dated 10December 2004), Ministry of Energy and Energy Resources, Sofia (Bg) 2005.

12. Regulation No.7, for energy efficiency, heat and energy saving in buildings, effective from 15 December 2004 (Publ. SG.No. 5 dated 14 January 2005with amendments), Ministry of Regional Development and Public Works, Sofia (Bg). 2005.

13. Regulation No.21, for minimum requirements for the protection and welfare when growing pigs, effective from 14 December 2005 (Publ. SG. No. 5 dated 17January2006),Ministry of Agriculture and Forestry, Sofia (Bg) 2006.

14. Regulation No.16, for the protection and welfare when growing and use of farm animals, effective from 03February 2006 (Publ. SG.No. 18 dated 28February2006),Ministry of Agriculture and Forestry, Sofia (Bg) 2006.

15. Regulation No. 44 concerning the veterinary medical requirements for animal breeding facilities (Published in State Gazette, No. 41 dated 19 June 2006, in effect as of 20 May 2006). Ministry of Agriculture and Forestry, Sofia (Bg); 20.04.2006.

16. Regulation No. RD-16-1058 on parameters for consumption of energy and energy performance of buildings,effective from 10 December 2009 (Publ. SG. No. 103 dated 29December2009), Ministry of Economy and Energy and Ministry of Regional Development and Public Works, Sofia (Bg). 10 December 2009.

17. Savov R: **Handbook for the development of part thermal technical efficiency of technical and design work,** Union of Architects in Bulgaria (UAB – SPSDA), Sofia(Bg). 2002.

18. Stamov S, Sendov S, Nachev N, Markov A, Stoichkov N, Kirov D and Karison V: **A guide to heating, ventilation and air conditioning,** Part I, Technics,Sofia (Bg) 1990.

19. Stamov S: **A guide to heating, air conditioningand cooling**.Technics,Sofia (Bg). 2001.

20. Technological standards for designing animal and poultry complexes and farms. Subsidiary document approved by the Executive Committee of the National Agroindustrial Union, Sofia (Bg), 01 July 1982.

21. Anastaselos D, Giama F, Papadopoulos A: **An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions,** Energy and Buildings 41, 2009: 1165–1171

22. Axaopoulos P, Panagakis P, Axaopoulos I: **Effect of wall orientation on the optimum insulation thickness of a growing-finishing piggery building,** Energy and Buildings 84. 2014: 403–411

**23.** BPIE. Cost **Optimality. Discussing methodology and challenges within the Recast Energy Performance of Buildings Directive.Cost - optimal requirements for buildings.** The BuildingsPerformance Institute Europe (BPIE), 2010: 40pp.

**24.** Claudy M.: **Beyond Economics: A behavioural approach to energy efficiency in domestic buildings.** Euro-Asian Journal of Sustainable Energy Development Policy 1; 2008: 27-40.

25. Comakli K, Yüksel B: **Optimum insulation thickness of external walls for energy saving,** Applied Thermal Engineering 23, 2003: 473–479

26. Georgiev R,Dimova V, Peichev K, Georgiev P: **Optimization of thickness of thermal insulation for roofs of turkey's houses.Agricultural science and technology.** An International Journal, published by Faculty of Agriculture,

Trakia University, Stara Zagora,(Bg) . 6-1, 2014: 40 - 43

27. Yu J, Yang C, Tian L, Liao D: **A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China,** Applied Energy 86,2009: 2520–2529.

28. Kaynakli O: **A review of the economical and optimum thermal insulation thickness for building applications,**Renewable and Sustainable Energy Reviews 16, (1) 2012: 415–425

29. Wittchen, KB, Thomsen KE: **European national strategies to move towards very low energy buildings. EuroACE(The European Alliance of Companies for Energy Efficiency in Buildings),** Study presented by S. Dyrbøl, PassivhusNorden,Trondheim, 2-3.04.2008,14 pp.