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# Optimization of Thermal Insulation of Underfloor Heating in Weaning Pigs

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**Abstract - A pig-shed with under floor heating is considered. Heating was implemented by a heating coil embedded in the floor. Polyurethane foam (XPS) was place under the heating coil to reduce heat losses. The method of heat balance was used to study annual operating costs for heating of the building at different thickness of the thermal insulation under the coil. Data have been obtained for annual consumption of different types of fuel – wood pellets, coal and natural gas needed for heating. Thermal insulation of thickness 8-10 cm was found as suitable and cost effective for an operating period of 20 years. Smaller thickness would result in higher and non cost effective energy costs.**

**Key words – thermal insulation, underfloor heating, pig-shed, optimization, energy consumption**

## 1. Introduction

Thermal resistance of the floor $R_f$ of livestock buildings is one of its most important characteristics. It determines the heat losses of the floor, respectively of the room and surface temperature of the floor affecting the health of animals [2],[5], [6],[11], [12].

The thermal insulation placed under the heating coil is the main layer which creates the thermal resistance of the floor and thus prevents heat losses to the floor/ground. Recommendations and requirements for this layer are high. In addition to its high thermal resistance, it must also have sufficient strength and thickness to carry the load from the upper layers, animals and any motor vehicles. It is recommended to use highly efficient thermal insulation of thermal conductivity coefficient in the range of $\lambda$ = 0.025 – 0.040 W/m.K and thickness of thermal insulation layer $\boldsymbol{\delta}$=20– 60 mm [2], [5] [6], [10] - [12].

Part of the heat losses of the pigs are dependent on the floor on which they rest. This occurs by conduction when pigs are lying and by radiation from floor when in standing position. A well insulated bed (bedding) for the pig can provide comfort equivalent to an increase of air temperature by 3.5 - 8.0 $^{\circ}$C (7-15 $^{\circ}$F). Feed intake of mature animals is 0.45 kg more per day, if floor temperature is lower by 5 $^{\circ}$C [8].

Optimization of thermal insulation of buildings is often based on cost-effective thickness, i.e. suchthicknessthat providesa minimuminvestmentandenergy costsfor a given periodof time [1], [3], [4], [9],[14].

Thepurpose of thisstudyis to determine such thermal insulation thickness offloorheatingin weaning pigs,where discounted costsare lowest for the period of 20 years.

## 2. MaterialsandMethods

A pig-shed with group pens on solid floor for weaning pigs was used for this study. Pens are adjoined in pairs to use a common channel. The building has three access pathways inside, arranged along its length. The building is of floor area 480 m$^2$, of which 148 m$^2$ is with underfloor heating divided in four sections. The area of the windows is 72 m$^2$, surrounding walls 248 m$^2$, and roof area 497 m$^2$. Heat transfer coefficients of walls, roof and windows are 1.92; 2.25 and 3.38 W/m$^2$K, respectively. The building has a forced ventilation system which provides 4.4 m$^3$/h fresh air per pig. Each section of the underfloor heating has a heating coil (Figure 1). The coil is 0.30 m pitch, installed under the lye-in pens which are of length 37 m and width 1.0 m.

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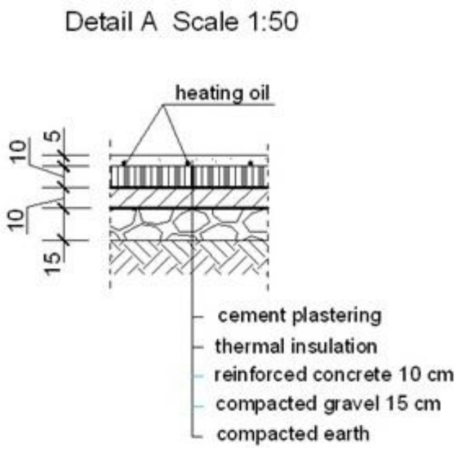

Fig. 1.Structure of floor covering.

The floor with underfloor heating has thermal insulation under the heating coil (Fig. 1). Thermal insulation is of the XPS type and in this study its thickness $\delta_{va}$ every other 2 cm; that is,$\delta_{va}$= 2, 4, 6, 8 and 10 cm. This creates conditions for different heating losses to the ground. The heating coil has cement plastering 4-5 cm over it, that is, there is a small and constant thermal resistance over the heating coil. The thermal insulation of the coil rests on reinforced concrete 10 cm, compacted gravel 15 cm and compacted earth. The portion of floor without heating has no thermal insulation. It was assumed that the building was inhabited by 360 weaning pigs each of weight 15 kg and apparent heat transfer of 65 W from pig [9].
The annual required heat $Q_a$is defined by the amount of the annual energy losses:

$Q_a = Q_{aw} + Q_{af} + Q_{av} + Q_{aa}$, kWh…(2.1)
where index "a" is the amount of the respective value (w- for walls; f – for floor; v – for ventilation; a – for animals) for the heating months.
For determination of the monthly heat losses the average monthly temperature of the heating months for the region of Southern Central Bulgaria was used (November 7.4 ºC, December 1.9 ºC, January 0.2 ºC, February 1.8 ºC, March 6.9 ºC). The amount of fuel needed to heat the building during the year was determined by the formula:

$$Ba = \frac{Qa}{r.\eta}, kg \qquad \ldots(2.2)$$

where **r** is the caloric value of fuel, kWh/kg (4.88 kWh/kg for wood pellets, 9.5 kWh/m$^3$ for natural gas, 2.77 kWh/kg for moulded coal), η - the efficiency of the heat generating device, -(0.92 for pellets; 0.95 for natural gas; 0.82 for moulded coal).
Discounted costs per year (DC) were determined by the classical formula: $DC = C + Es.K$, BGN…(2.3)
where: DC – discounted costs, BGN/a; C – energy costs per annum (fuel costs), BGN/a; $E_s$ - standard coefficient of depreciation costs, BGN/a; K – amount of capital investment for thermal insulation, BGN.
A depreciation period of 20 years was assumed for the thermal insulation. Prices of thermal insulation (XPS) as at March 2014: 2 cm – 3.50 BGN/m$^2$; 4 cm – 7.00 BGN/m$^2$; 6 cm – 10.50 BGN/m$^2$; 8 cm – 14.00 BGN/m$^2$; 10 cm – 17.50 BGN/m$^2$. Fuel prices: wood pellets - 350 BGN/t; natural gas –0.0872 BGN/kWh; coal – 180 BGN/t (1 EUR =1.95583 BGN).

## 3. RESULTSANDDISCUSSION

The results obtained for the annual heat required, corresponding quantity of fuel and its

Table 1. Energy consumed $Q_a$ and quantities of fuel Ba at different thickness of thermal insulation.

| | | Wood pellets | | Natural gas | | Moulded coal | |
|---|---|---|---|---|---|---|---|
| δ | Qa | Ba | Price | Ba | Price | Ba | Price |
| cm | kWh | kg/a | BGN/a | m$^3$/a | BGN/a | kg/a | BGN/a |
| 2 | 46377.2 | 10329 | 3615.1 | 5138.7 | 4044.0 | 20430.5 | 3677.5 |
| 4 | 43352.6 | 9655.4 | 3379.4 | 4803.6 | 3780.3 | 19098.1 | 3437.7 |
| 6 | 41983.6 | 9350.5 | 3272.7 | 4651.9 | 3660.9 | 18495.0 | 3329.1 |
| 8 | 41546.3 | 9253.1 | 3238.6 | 4603.5 | 3622.8 | 18302.3 | 3294.4 |
| 10 | 41117.9 | 9157.7 | 3205.2 | 4556.0 | 3685.4 | 18113.6 | 3260.5 |

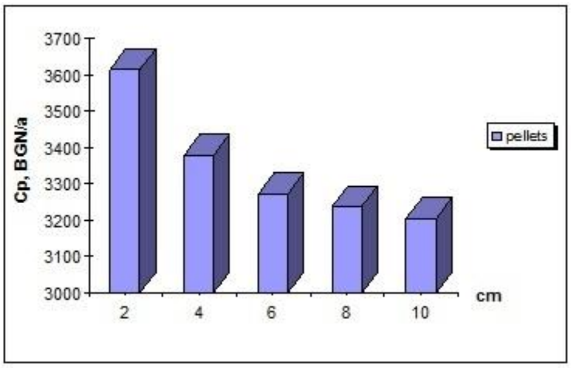

Fig. 2.Price of pellets per heating season.

The amount of discounted costs (DC) for various thickness of thermal insulation is shown in Table 2 and illustrated (for pallets) in Fig. 3.

Table 2.Amount of discounted costs (DC) at different $\delta_{va}$.

| $\delta_{va}$ | Es.K | DC , BGN/a | | |
|---|---|---|---|---|
| cm | BGN/a | Pellets | Natural gas | Moulded coal |
| 2 | 25.9 | 3806.8 | 4066.9 | 3703.4 |
| 4 | 51.8 | 3431.2 | 3821.1 | 3489.5 |
| 6 | 77.7 | 3350.4 | 3738.6 | 3406.8 |
| 8 | 103.6 | 3342.2 | 3726.4 | 3398 |
| 10 | 129.6 | 3334.7 | 3714.9 | 3390 |

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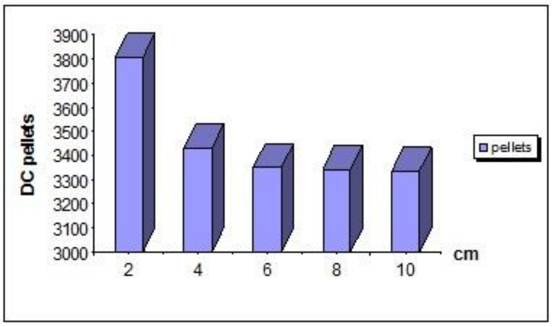


Fig. 3. Amount of DC for various thickness of thermal insulation in pellets as fuel.

Some important analyses can be drawn from the results obtained. The released annual energy by the heating coil decreases with the increase of the thickness of the thermal insulation under it from 46377.2 kWh at δ=2 cm to 41117.9 kWh at δ=10 cm, i.e. by 11%. The highest reduction in the released annual energy was found in the transition from thickness of thermal insulation 2 cm to thickness 4 cm, because the thermal insulation layer increases its thermal resistance two times. Absolute reduction of annual energy consumed was not high (11%), because the main portion of this energy was released from the upper surface of the floor, and with the increase of thermal insulation only heat losses to the ground were decreased. Quantities and prices of fuels decrease following a parabolic relation with the increase of the thickness of thermal insulation, because thermal resistance of the other layers remained constant. Discounted costs (DC), as an integral indicator of the economic evaluation, decreased slightly with the increase of thermal insulation from 6 cm to 10 cm, which was noted also by other researchers [4]. This is due to the increasing costs of thermal insulation against insignificant decrease of the consumed energy.

## 4. CONCLUSIONS

1. It is advisable to use thermal insulation of thickness 8-10 cm beneath the underfloor heating in pig-sheds for weaning pigs. Then, discounted costs will be minimal.
2. Fuel costs are lowest at thermal insulation of recommended thickness 10 cm.
3. Fuel price increase leads to an increase in the thickness of the thermal insulation used.

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