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Influence of thermal insulation from PUR foam to improve thermo-technical parameters of building envelope for broiler housing

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Abstract. The article deals with the thermo-technical assessment of a hall building for broiler breeding. There was a large heat losses in the examined object before the thermal insulation. For this reason, the cladding was from internal side insulated with sprayed PUR foam. In the building was assessed the hygiene criterion, thermo-technical properties of perimeter walls and the life of the structure before and after the insulation. It has been shown that the thermal insulation of the walls had a significant impact on improving the conditions in the hall. Due to the fact that from hygienic assessment and thermovision measurements have been proven heat losses and unsatisfactory condition of uninsulated parts of the hall envelope, it will be necessary to additionally insulate also the soffit part of the ceiling-roof construction and the plinth part.

1. Introduction

In the past, emphasis wasn't placed to energy performance of buildings, which we feel currently mainly in old large area buildings with high energy costs [1]. Modern poultry housing is designed and constructed to reduce a heat loss and to improve energy efficiency [2]. Older hall buildings have large heat leaks, which we are currently trying to reduce through various measures. One of them is insulation of the envelope. It is necessary to solve the envelope of the hall building in relation to the fulfillment of the "hygienic criterion" in all details of building structures [3]. In the case of occurrence of thermal bridges caused by failures during the operation of the building, it has proven successful the additional thermal insulation of the external cladding with the sprayed PUR foam, resistant to the aggressive environment [3]. The aim of this work is therefore to assess the hygiene criterion, the thermal properties of the walls and the service life of the hall building used for the fattening of broilers in the original state (before thermal insulation) and subsequently after thermal insulation with sprayed polyurethane foam from the inside.

2. Material and methods

The subject of the research was a hall building used for broiler breeding situated in the first temperature area with an altitude of 137 meters above sea level. The ground plan dimensions of the hall were 94 m x 15.2 m. The clear height of the hall was 3.1 m. The total area for chickens was 1428.8 m². The supporting structure of the hall object was made of a frame steel supporting structure. Longitudinal peripheral walls of the hall 100 mm thick were made with galvanized sheet on both sides



with thermal insulation of mineral wool. The hall was measured by thermovision in the winter season (before its insulation). To reduce heat loss were subsequently walls of the building partially insulated from the inside by spraying thermal insulation foam and in the following year were made thermovision measurements after their thermal insulation. The roof structure wasn't additionally insulated. The surface temperatures of individual building structures (walls, ceiling and floor) were also measured by a thermal camera before and after thermal insulation of the hall. The heat loss from the hall was also significantly influenced by the rear steel gates, which were also insulated with sprayed thermal insulation foam. After their insulation, the leakage of heat from the hall through the openings was significantly reduced. The thermal bridges in the plinth part were caused by higher temperatures in the bedding and inappropriate wall solution. Since only the sheet-metal part of the wall construction was insulated in the lower part, there were still significant heat loss after the thermal insulation, which are evident from the thermovision pictures.

The hall building was considered in three ways. First of all, compliance with the hygiene criterion was assessed. Subsequently, the walls were assessed of thermo-technical point of view before and after insulation. In the end, the life of the hall building was determined before and after the insulation. The thermo-technical characteristics of the building materials of the wall structure before and after insulation are given in Tables 1 and 2.

Table 1. Thermo-technical characteristics of building materials for wall construction before insulation.

Layer	Material	t (m)	λ (W·m ⁻¹ ·K ⁻¹)	ρ_o (kg·m ⁻³)	c (J·kg ⁻¹ ·K ⁻¹)
1	Corrugated sheet	0.002	204	2700	880
2	Mineral wool	0.100	0.04	15	940
3	Corrugated sheet	0.002	204	2700	880

Table 2. Thermo-technical characteristics of building materials for wall construction after insulation.

Layer	Material	t (m)	λ (W·m ⁻¹ ·K ⁻¹)	ρ_o (kg·m ⁻³)	c (J·kg ⁻¹ ·K ⁻¹)
1	Polyurethane foam*	0.015	0.025	35	1500
2	Corrugated sheet	0.002	204	2700	880
3	Mineral wool	0.100	0.04	15	940
4	Corrugated sheet	0.002	204	2700	880

*Note: inner part of the walls

3. Results and discussion

3.1. Assessment of compliance with the hygiene criterion

The internal wall structure of the monitored hall was assessed from the hygienic point of view before and after her insulation. For the determination of the hygienic criterion of the wall structure of the hall building, it was necessary to proceed in accordance with [6].

3.1.1. Assessment of the wall structure in the place of the thermal bridge before insulation

Input parameters:

- internal air temperature at time of measurement $\theta_i = 17^\circ \text{C}$
- external air temperature at time of measurement $\theta_e = -3.5^\circ \text{C}$
- difference of internal and external temperatures $\Delta\theta_{ie} = 20.5^\circ \text{C}$
- internal air humidity $\varphi_i = 50\%$
- external air humidity $\varphi_e = 38.5\%$

- critical surface temperature for mold formation [4] $\theta_{si,80} = 9.79^\circ\text{C}$
- dew point temperature [4] $\theta_{dp} = 6.51^\circ\text{C}$
- safety surcharge for intermittent heating of stables with a drop in the internal air temperature θ_i up to 5 K [5]: $\Delta\theta_{dp} = 0.2\text{ K}$
- safety surcharge for intermittent heating with a drop in the internal air temperature θ_i up to 5 K [6]: $\Delta\theta_{si} = 0.5\text{ K}$
- surface temperature of uninsulated wall (Figure 1) $\theta_{si} = 6.5^\circ\text{C}$

Requirement for critical surface temperature for mold formation $\theta_{si,80}$ [6]

$$\theta_{si} \geq \theta_{si,N} = \theta_{si,80} + \Delta\theta_{si} \quad (1)$$

$$6.5^\circ\text{C} < 10.29^\circ\text{C} \rightarrow \text{The wall doesn't meet the standard requirement}$$

Requirement for dew point temperature θ_{dp} [5]

$$\theta_{si} \geq \theta_{dp} + \Delta\theta_{dp} \quad (2)$$

$$6.5^\circ\text{C} < 6.71^\circ\text{C} \rightarrow \text{The wall doesn't meet the standard requirement}$$

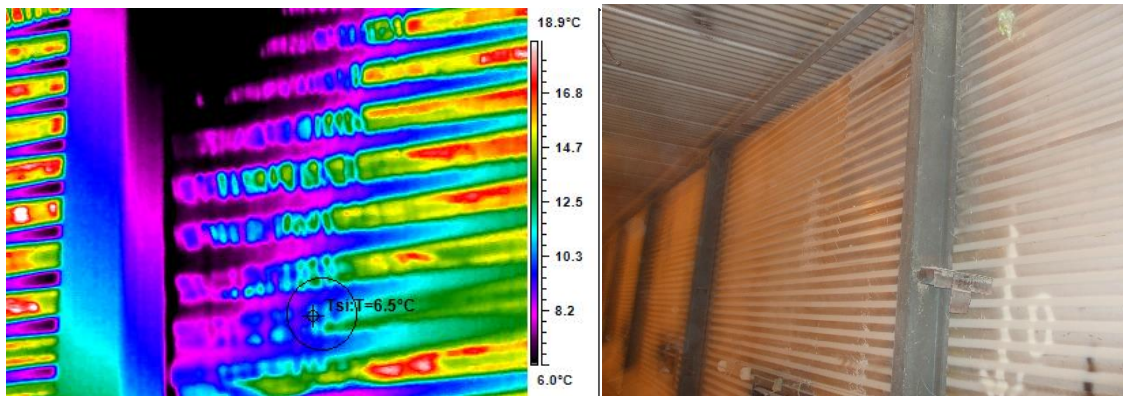


Figure 1. Thermogram of non-insulated internal wall.

3.1.2. Wall construction in the assessed place after thermal insulation

Input parameters were:

$\theta_i = 18^\circ\text{C}$, $\theta_e = -3.5^\circ\text{C}$, $\Delta\theta_{ie} = 21.5^\circ\text{C}$, $\phi_i = 54\%$, $\phi_e = 39\%$, $\theta_{si,80} = 12^\circ\text{C}$, $\theta_{dp} = 9^\circ\text{C}$, $\Delta\theta_{dp} = 0.2\text{ K}$, $\Delta\theta_{si} = 0.5\text{ K}$, $\theta_{si} = 17.4^\circ\text{C}$ (the surface temperature of the insulated wall of Figure 2).

Requirement for critical surface temperature for mold formation $\theta_{si,80}$ [6]

$$17.4^\circ\text{C} \geq 12.5^\circ\text{C} \rightarrow \text{The wall meets the standard requirement}$$

Requirement for dew point temperature θ_{dp} [5]

$$17.4^\circ\text{C} \geq 9.2^\circ\text{C} \rightarrow \text{The wall meets the standard requirement}$$

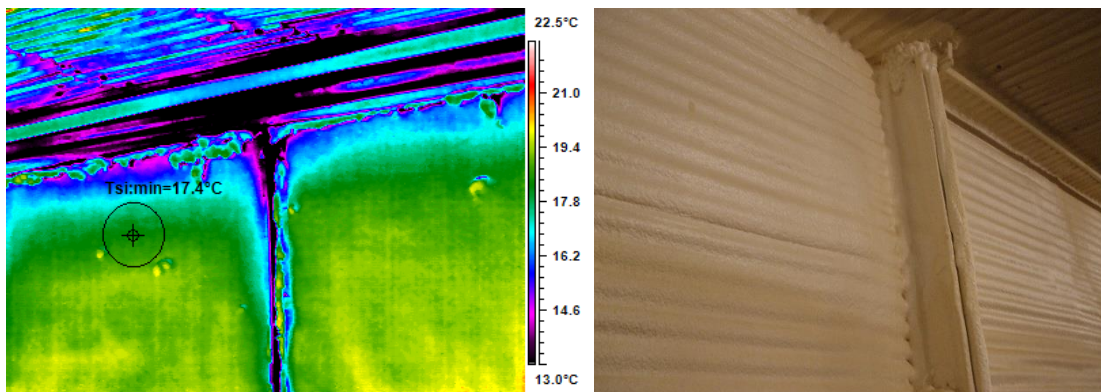


Figure 2. Thermogram of insulated wall from inside.

The surface temperature of the non-insulated peripheral wall of the hall building θ_{si} was only 6.5°C (Figure 1). Assessing the wall from the hygienic point of view, it was found that the monitored wall doesn't meet the standard requirements.

After insulation of the examined wall with thermal insulation foam the inside her surface temperature increased to 17.4°C (Figure 2), at nearly the same indoor air temperature. Subsequently, the wall was assessed from a hygienic point of view, and it was found that after wall insulation it meets the hygienic criterion as its surface temperature was higher than the critical surface temperature for mold formation $\theta_{si,80} = 12^{\circ}\text{C}$ and dew point temperature $\theta_{dp} = 9^{\circ}\text{C}$.

3.1.3. Assessment of the plinth part of the wall

Input parameters:

$\theta_i = 17^{\circ}\text{C}$, $\theta_e = -3.5^{\circ}\text{C}$, $\Delta\theta_{ie} = 20.5^{\circ}\text{C}$, $\varphi_i = 50\%$, $\varphi_e = 38.5\%$, $\theta_{si,80} = 9.79^{\circ}\text{C}$, $\theta_{dp} = 6.51^{\circ}\text{C}$, $\theta_{dp} = 0.2\text{ K}$ (for thermal bridges $\Delta\theta_{dp} = 0\text{ K}$), $\Delta\theta_{si} = 0.5\text{ K}$, the surface temperature of the wall at the thermal bridge TM (Figure 3) $\theta_{si,TM} = 3^{\circ}\text{C}$, the surface temperature of the wall outside of the thermal bridge MTM (Figure 3) $\theta_{si,MTM} = 10.5^{\circ}\text{C}$.

Requirement for critical surface temperature for mold formation $\theta_{si,80}$ [6]

TM: $3^{\circ}\text{C} < 9.79^{\circ}\text{C} \rightarrow$ The wall doesn't meet the standard requirement

MTM: $10.5^{\circ}\text{C} \geq 10.29^{\circ}\text{C} \rightarrow$ The wall meets the standard requirement

Requirement for dew point temperature θ_{dp} [5]

TM: $3^{\circ}\text{C} < 6.51^{\circ}\text{C} \rightarrow$ The wall doesn't meet the standard requirement

MTM: $10.5^{\circ}\text{C} \geq 6.71^{\circ}\text{C} \rightarrow$ The wall meets the standard requirement

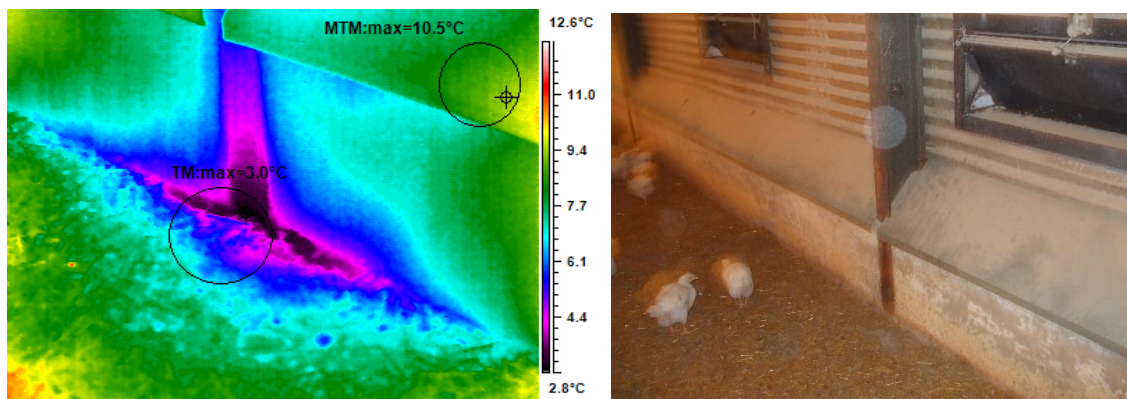


Figure 3. Detail of a thermal bridge of non-insulated plinth.

TM – measurement made at the point of thermal bridge, MTM – measurement taken outside the thermal bridge

A thermal bridge was detected by thermovision in the plinth part of the wall construction in contact wall with bedding, which was subsequently assessed from a hygienic point of view. The results show that the wall in question at the location of the thermal bridge doesn't meet the hygiene criterion. At this place there was a significant leakage of heat resulting in a low surface temperature $\theta_{si,TM} = 3^{\circ}\text{C}$, which was lower than the critical surface temperature for mold formation $\theta_{si,80} = 9.79^{\circ}\text{C}$ and also as dew point temperature $\theta_{dp} = 6.51^{\circ}\text{C}$. Condensation of water vapor and the formation of molds is a prerequisite in the given location. Outside the thermal bridge, the wall met the hygiene criterion as its surface temperature was higher than the norm value of $\theta_{si,MTM} = 10.5^{\circ}\text{C}$.

3.1.4. Contact between insulated wall and uninsulated ceiling from corrugated sheet

Input parameters:

$\theta_i = 16.7^{\circ}\text{C}$, $\theta_e = -3.5^{\circ}\text{C}$, $\Delta\theta_{ie} = 20.2^{\circ}\text{C}$, $\varphi_i = 54\%$, $\varphi_e = 39\%$, $\theta_{si,80} = 10.7^{\circ}\text{C}$, $\theta_{dp} = 7.4^{\circ}\text{C}$, $\theta_{si} = 0.5\text{ K}$, $\Delta\theta_{dp} = 0.2\text{ K}$, surface temperature of the ceiling at the place of the thermal bridge TM (Figure 4)

$\theta_{si, TM} = 5.8\text{ }^{\circ}\text{C}$, surface temperature of insulated wall outside of the thermal bridge MTM (Figure 4),
 $\theta_{si, MTM} = 11.7\text{ }^{\circ}\text{C}$.

Requirement for critical surface temperature for mold formation $\theta_{si, 80}$ [6]

TM: $5.8\text{ }^{\circ}\text{C} < 11.2\text{ }^{\circ}\text{C} \rightarrow$ The wall doesn't meet the standard requirement

MTM: $11.7\text{ }^{\circ}\text{C} \geq 11.2\text{ }^{\circ}\text{C} \rightarrow$ The wall meets the standard requirement

Requirement for dew point temperature θ_{dp} [5]

TM: $5.8\text{ }^{\circ}\text{C} < 7.4\text{ }^{\circ}\text{C} \rightarrow$ The wall doesn't meet the standard requirement

MTM: $11.7\text{ }^{\circ}\text{C} \geq 7.6\text{ }^{\circ}\text{C} \rightarrow$ The wall meets the standard requirement

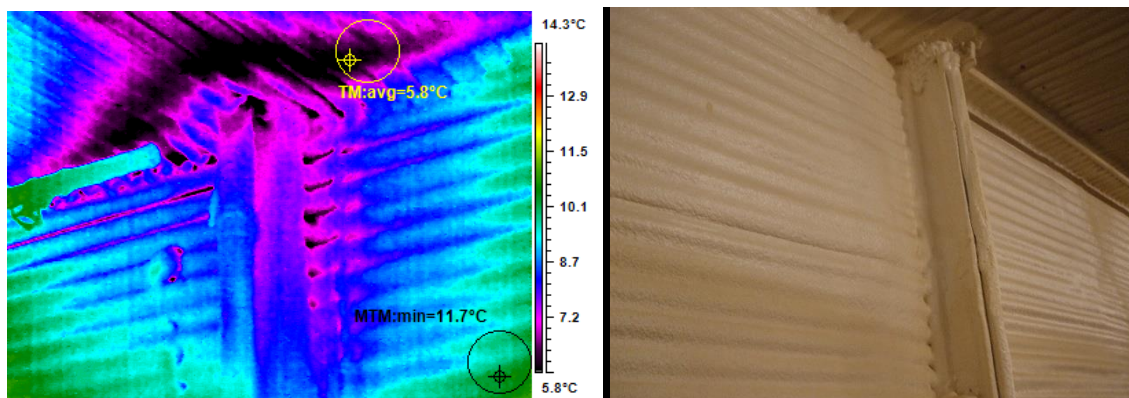


Figure 4. The contact of the uninsulated ceiling and insulated internal wall.

TM – measurement made at the point of thermal bridge, MTM – measurement taken outside the thermal bridge

Wall construction made from corrugated sheet was insulated with sprayed PUR foam, while the ceiling wasn't insulated. There was heat leakage at the point of contact between the ceiling and the wall (Figure 4). Place of the thermal bridge was considered hygienic, while from the point of view of mold formation it didn't meet the standard requirements, because the surface temperature at this critical point was only $\theta_{si, TM} = 5.8\text{ }^{\circ}\text{C}$. In terms of dew point temperature $\theta_{dp} = 7.4\text{ }^{\circ}\text{C}$ and critical surface temperature for mold formation $\theta_{si, 80} = 10.7\text{ }^{\circ}\text{C}$, the wall construction didn't fit. Insulated wall construction outside the thermal bridge meet hygienic criteria. Almost double value of the surface temperature of the thermally insulated part of wall $\theta_{si, MTM} = 11.7\text{ }^{\circ}\text{C}$ above the surface temperature at the site of thermal bridge indicates a need for additional thermal insulation of the ceiling construction. For agricultural buildings with relative humidity over 75 % is recommended to double-shell roof construction system with ventilated air gap [7], to reduce the heat loss through the roof construction during the winter season, thereby reducing the cost of heating the building with gas [8].

3.2. Assessment of thermal performance of the hall building walls

The software „Teplo 2017 EDU“ was used to assess the thermal performance of the hall building walls [9]. Due to the fact that the requirement to the temperature environment in the hall is different with respect to the age of the broilers, we used the calculation of the required insulation from temperature and humidity conditions for broilers in the 5th week of fattening. The desired ambient temperature in the hall for broiler at week 5th is $\theta_i = 20\text{ }^{\circ}\text{C}$ and the optimum advised value of relative air humidity for the broilers is 70 % [10]. In the outdoor environment we considered exterior temperatures $\theta_e = -3.5\text{ }^{\circ}\text{C}$ and air humidity 38.5 %. The marginal conditions for the Nitra region for winter are $\theta_e = -11\text{ }^{\circ}\text{C}$. First of all, we assessed the wall of hall, which was not yet insulated from the inside. Due to the fact that there were significant heat leaks through the structure, the walls of the building were partially insulated from the inside with sprayed PUR foam of 15 mm thickness. Subsequently we assessed the wall after thermal insulation according to [11]. Although this standard is mainly used for residential buildings, we also used it for a hall building because we currently do not have an alternative for hall poultry buildings. Building insulation is important in terms of energy savings for heating in the winter.

At present, according to valid criteria, this thickness of insulation is not sufficient. After designing a larger insulation thickness of PUR foam to 50 mm, this thickness already suited. The recommended heat transfer coefficient of the external wall structure (U_{r1}) according to [11] is $0.22 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$. This value is valid from 2016 to 2020. In order for the condition to be met, $U \leq U_{r1}$ must apply. In the event that this condition cannot be met, at least the condition that the maximum value of the heat transfer coefficient $U_{\max} = 0.46 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$ must be met. The recommended value of the thermal resistance of the external wall structure (R_{r1}) according to [11] is $4.4 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$ (valid from 2016 to 2020) where the condition $R \geq R_{r1}$ must be met. The minimum thermal resistance value of $R_{\min}$ shall be at least $2.0 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$. The calculated and recommended heat transfer coefficient and thermal resistance values of the structure are shown in Table 3.

Table 3. Calculated and recommended heat transfer coefficient and thermal resistance values of the structure.

	U^a ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$)	U_{r1} ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$)	R^b ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$)	R_{r1} ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$)
Wall before insulation	0.375	0.22	2.50	4.4
Wall after insulation	0.306	0.22	3.10	4.4
Wall after insulation, design	0.214	0.22	4.5	4.4

^a U – Heat transfer coefficient of the structure, $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$

^b R – Thermal resistance of the structure, $\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$

Figures 5 – 7 show the temperature course in a typical structure site under steady-state design conditions before thermal insulation, after thermal insulation and after thermal insulation design with greater thickness.

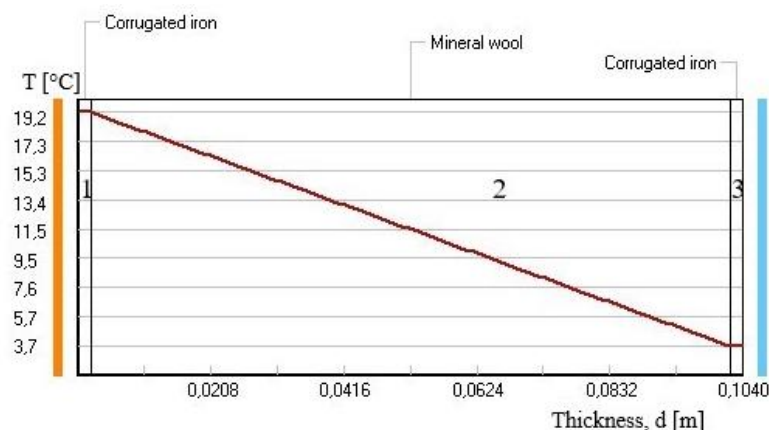


Figure 5. Temperatures in a typical structure site under steady-state design conditions before thermal insulation.

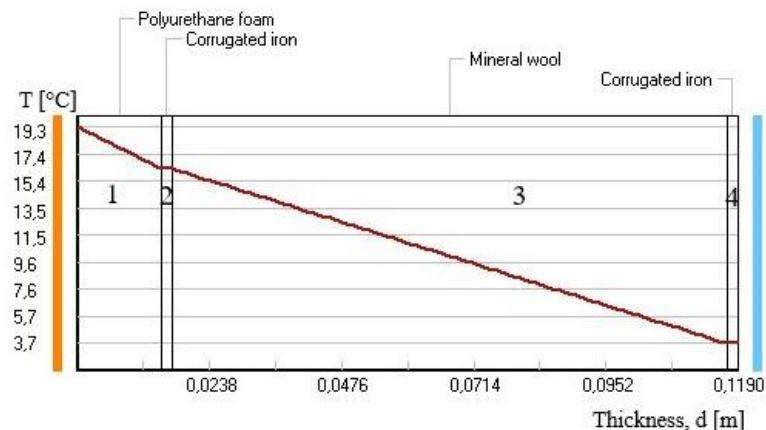


Figure 6. Temperatures in a typical structure site under steady-state design conditions after thermal insulation.

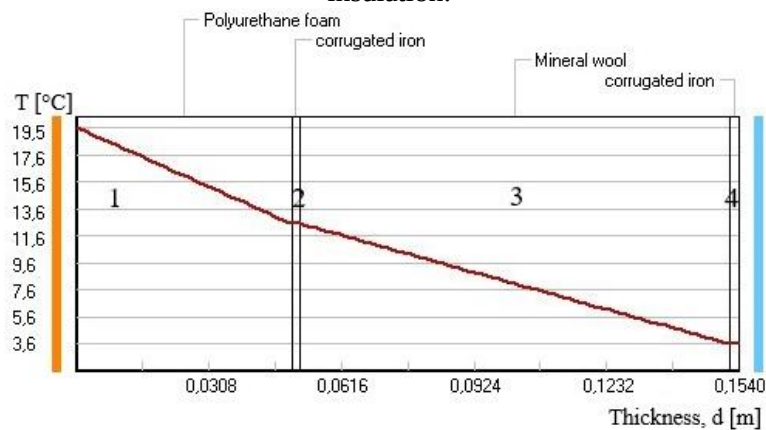


Figure 7. Temperatures in a typical structure site under steady-state design conditions after thermal insulation with greater thickness.

3.3. Determining the lifetime of the hall building before and after thermal insulation

We also assessed the investigated hall building in terms of the service lifetime of the building. The original object had several shortcomings. Some shortcomings have been eliminated by the thermal insulation of the perimeter walls. Due to the fact that the building was partially insulated, the lifetime of the building also increased. The wear of the building is determined by the Bradáč cubic method. The input data for determining the service life of the building are as follows for the building before thermal insulation:

Year of valuation of building : 2013, Year of final inspection: 1990.

The age of the building (V) is 23 years.

Basic life of the building (ZZ) [12]: 100 years.

Basic time of another duration of the building (TT) [12]: 78 years.

State of the components of the long-term lifetime (Q) is 73 %.

Time of another duration of the building: $T = TT \times Q / 100$.

$T = 78 \times 73 / 100 = 57$ years

Total estimated lifetime $Z = V + T$

$Z = 23 + 57 = 80$ years

The estimated lifetime of the original building is 80 years.

The input data for determining the service life of the building are as follows for the building after thermal insulation:

Year of valuation of building : 2014, Year of final inspection: 1990.

The age of the building (V) is 24 years.

Basic life of the building (ZZ) [12]: 100 years.

Basic time of another duration of the building (TT) [12]: 77 years.

State of the components of the long-term lifetime (Q) is 90 %.

Time of another duration of the building: $T = 77 \times 90/100 = 69$ years.

Total estimated lifetime $Z = 24 + 69,3 = 93$ years.

The estimated lifetime of the building was increased to 93 years after thermal insulation.

4. Conclusion

From thermovision measurements and subsequent assessment of the uninsulated wall construction of a hall building used for poultry breeding from the hygienic point of view, we found out that in the wall construction there was heat leakage through thermal bridges, while the hygienic criterion wasn't met in these places. After spraying the wall construction with foam thermal insulation from the inside of the cladding, thermal bridges were eliminated. This improved the thermo-technical properties of the wall construction and the wall meets all requirements. Since from the point of view of the financial intensity of insulation was insulated only the wall construction of the hall, it is necessary to additionally insulate also the soffit part of the ceiling-roof construction and plinth. From the hygienic assessment and from the thermovision measurements, were proved heat losses and unsatisfactory condition of the uninsulated parts of the envelope. The hall building was also assessed in terms of the life of the building. The estimated lifetime of the original building was 80 years. After thermal insulation of the perimeter walls, the lifetime of the building was increased to 93 years. In case that the other construction deficiencies would be removed, it means that would be also insulated the ceiling-roof construction and the plinth part of the construction, the life of the building would be even higher.

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