IMPACT OF THERMAL BRIDGES ON THERMAL PROPERTIES OF THE OLD POULTRY HOUSES STRUCTURES

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The paper is focused on qualitative and quantitative evaluation of the thermal properties and thermal bridges of the old poultry structures. Results of the paper claim poor thermal properties most of the constructions. Qualitative detection of thermal defects with utilization of infrared thermography claimed the most significant thermal bridges on uninsulated socle and flooring, straining band of the wall, gable wall brickwork and window and door frame. Box-and-whisker diagrams were utilized for presentation of outliers or extreme values of individual datasets.

KEYWORDS

Farm building, energy performance, construction, infrared thermography, thermal defect

1 INTRODUCTION

Poultry production is highly dependent on the ambient conditions inside environment of the poultry houses. Buildings for poultry production have high energy consumption (especially ventilation and heating) that is why the energy efficiency of building is necessary. For regulation of inside environment conditions it is used thermal insulation of external envelope elements and technical equipment for heating and ventilation. That is the one of the reasons of high energy consumption of poultry production. Energy is one of the largest controllable costs in most organizations and there is a considerable scope for reducing energy consumption and hence cost. The benefits are reflected directly in an organization's profitability while also making a contribution to global environmental improvement in terms of energy conservation [AlQdah 2010]. Hot and dry summers, cold winters with precipitation, difference between daytime and nighttime temperatures and sudden changes in temperature are the most pronounced characteristics of continental type of climate. Farm animals are usually kept in isolated structures constructed by people. Animals lack almost any skill to adapt to this given environment in line with their needs and their survival thus depends on their own adaptability to these environments. Environmental conditions and animal genotype are two basic factors influencing this adaptability [Olgun 2007]. The studies of the energy saving in poultry industry are solved by [Chan 2007], [Khan 1996]. These authors conducted the energy requirement for poultry processing. [Drewry 2008] studied the poultry farm energy audits and alternative energy sources.

Minimising the adverse effects of buildings on the environment is a key objective in achieving more sustainable development [Omer 2008] and [Zimmermann 2005]. [Theodosiou 2008] stated that the European Directive 2002/91/EC on the Energy Performance of buildings (EPBD) is probably the most important single action towards the improvement of energy efficiency in the building sector throughout Europe since 1970s when, in the aftermath of the energy crisis, most national building regulations introduced mandatory thermal insulation requirements. The implementation of the European Directive 2002/91/EC (revised 2010/31/EU) in the form of national laws by each member state, gradually leads to the need to adopt advanced standards, techniques and technologies while designing and constructing new buildings, but also in applying energy renovation measures in existing ones, in order to comply with the updated energy efficiency requirements. [Herbut 2018] performed study which analyses the efficiency of a Solar Water Heating (SWH) system, potential financial savings and investment profitability of this renewable energy source. A thermal bridge is defined as a zone of the building envelope where it is not possible to consider the heat transfer as monodimensional. This phenomenon is due to mechanical and structural reasons: difference of thermal resistance; local variation in material thickness; difference between indoor and outdoor area. Heat loss due to thermal bridges can reach 30 % [Capozzoli 2013]. [Déqué 2001] state that insulating walls represent one of the simplest solutions for decreasing the building´s heat losses. However, although quite obvious on the energy balance, the ever improving insulation implies that the relative proportion of the heat losses by the cold bridges in the wall became much more important over the years. Consequently, several studies followed to determine the relative influence of thermal bridges in the overall heat losses. The other major improvement in the study of thermal bridges is this recent possibility for engineers to use performing infrared thermography instruments. This technique allows the visualization of heat losses in situ, at a distance (without contact) at the scale of the building and without intrusion in the building walls as non-destructive technique [Zalewski 2010]. Infrared thermography technique has wide utilization in agriculture sector. We can present other examples as a valuation of drying operation [Vitázek 2008] or valuation interior conditions and surface temperature in the heated milking house [Gálik 2004] etc.

The objective of this paper is qualitative and quantitative characterization of thermal bridges on the walls of old poultry houses. In a first step, the proposed methodology involves an infrared camera employed to locate the thermal bridges on the walls. Experimental part of paper consists of thermograms of the envelope with their interpretation. Next step is calculation of the structure thermal characteristics, heat fluxes and heat losses caused by thermal bridges. Subsequently, values of heat fluxes calculated by selected equations were subjected to statistical analysis.

2 MATERIAL AND METHODS

The The analysed poultry houses are located at (latitude 48° 87´ 86´´N, long 16° 54´ 22´´E) Znojmo region, Czech Republic. Two measured old poultry houses have the same technical solution and were built in the 1965. These poultry houses are a part of farm for poultry production. Production capacity of measured poultry houses are designed for 2 × 5000 hens. Poultry houses have forced ventilation with electronic system of measurement and regulation, warm-air heating system. Heating consist of two CNG aggregates (discharge 2 × 70 kW). A continuous winter duct pit ventilation centrifugal fan is integrated with variable speed axial fan to cover the summer ventilation rates. The poultry house consists of two integrated parts (preparation room and breed room). The floor is from concrete and the litter is mechanically removed after every production cycle. Interior air temperature is depending on age category and it is maintained between 20 to 26 °C (mostly 22 °C). The building is overall 15,0 m wide, 77,0 m long and 6,50 m high (exterior sizes). The external walls of the poultry houses are 40 cm in thickness (including plasters) and are made of light clay brick block (old type CD 36 by ČSN 72 2611) plastered on both sides. The roof construction is made of prefabricated steel concrete beams, with ceiling panels without thermal insulation. The roofing consists of bitumen sheets. The inner rooms are divided by brick block walls (0,30m in thickness including plasters) plastered on both sides. There are several old original windows (steel frame and protecting sheet-metal jalousie) and doors (steel frame and sheet-metal sheating). Most of doors and windows are modernized (year 2012). These modernized components are made from plastic (PVC) four cellular profiles with thermal double glazing. The parameters of the doors and gates used in measured buildings are – type D1 (2 pieces) width 1,10 m, height 2,10 m and type D2 (2 pieces) width 2,10 m, height 2,50 m respectively type D3 (4 pieces) width 5,00 m, height 2,50 m. The parameters of the windows are – type W1 (4 pieces) width 0,90 m, height 0,60 m, type W2 (2 pieces) width 0,90 m, height 0,90 m, type W3 (4 pieces) width 0,90 m, height 1,20 m, type W4 with jalousie for regulation of ventilation (12 pieces) width 0,90 m, height 0,90 m, type W5 (30 pieces) width 1,20 m, height 0,60 m.

Infrared thermography of constructions is performed according to EN 13187:1999 and ISO 18434-1. Thermal analyses were performed by FLUKE Ti32 thermal camera. For thermal imaging measurement purposes was measured the air temperature, air humidity, distance from the measured object and material emissivity. Determination of material emissivity was executed by creation of measuring points on the materials, where was executed thermal analyses. At these points was measured temperature with using OMEGA HH11 contact thermometer (accuracy of temperature measurement: ±0,1 °C). The most significant prerequisite was to prevent fluctuation of temperature in the course of time. The aforementioned point was also monitored using FLUKE Ti32 thermal camera. In case that the temperature values proved to differ, the temperature in the thermal camera was calibrated by the means of setting up the emissivity value in the user interface of this device. The final emissivity value was determined at the time when the temperature values on both the devices were balanced. Infrared thermography for the evaluation of heat dispersions in buildings perform at their best if a minimum temperature difference of 10 to 15 °C between the external and internal environment is guaranteed.

The air temperature and relative humidity were measured using KIMO AMI 300 multifunction equipment. The air velocity and temperature were measured with using a telescopic vane probe type HET 14 (in the range of 0,8 to 25,0 $m \cdot s^{-1}$ and -20 to 80 °C) featuring the temperature measurement accuracy of ± 1 °C. The relative humidity was measured with using a telescopic hygrometry probe SVTH (in the range of 5,0 to 95,0 % relative humidity) featuring the measurement accuracy of ± 4 %. The temperature and humidity were measured in the close vicinity of the thermal camera and measured object and the arithmetic mean was subsequently calculated on the basis of these values. Conditions of thermography measurement: cloudy conditions, air temperature 0,9 °C, air velocity 0,40 $m \cdot s^{-1}$, relative humidity 70%.

The distance of the camera from measured object was determined using Leica DISTOtm A5 laser EDM device (measurement accuracy: ± 1,5 mm at a distance between 0,2 and 200 m). The thermal imaging measurement as such was conducted using Fluke Ti32 thermal camera (FOV 45°). The average temperature of the surface was calculated using Fluke SmartView 3.2 software.

The Standard EN ISO 10211:2007 describes the calculation method for linear thermal bridges and superficial temperatures. If we consider a multi layered construction with simplified index to represent the total heat-transfer processes, the total thermal transmittance UT is given by (EN ISO 6946) according to equation:

$$U_T = \frac{1}{R_T} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{1}$$

R_T = the total thermal resistance

The total thermal resistance is given by (EN ISO 6946) according to equation:

$$R_T = R_{si} + R_1 + R_2 + \ldots + R_n + R_{se} \quad \left(m^2 \cdot K \cdot W^{-1}\right) \tag{2}$$

where,

R_{si} = the internal surface resistance

R_1, $R_2 \ldots R_n$ = the thermal resistance of each layer

R_{se} = the external surface resistance

Thermal resistance R for multilayer homogenous building elements is calculated according to equation (EN ISO 6946:2008)

$$R = \frac{d}{\lambda} \quad \left(m^2 \cdot K \cdot W^{-1}\right) \tag{3}$$

where,

d = the thickness of layer

λ = the thermal conductivity

Total heat losses of object Q were calculated according to equation

$$Q = S \cdot \left(I + q_t\right) \quad (W) \tag{4}$$

where,

I = the intensity of grey-body radiation

q_t = the heat losses due to convection

S = the outer surface of construction

Heat losses due to convection were calculated with use of the convective heat transfer coefficient along the vertical wall. This coefficient was determined according of following equations [Bašta 2000]:

Cihelka

$$\alpha_k = 0.48\left(t_1 - t_2\right)^{0.33} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{5}$$

McAdams-Griffiths-Davis

$$\alpha_k = 1.78 \cdot \Delta t^{0.12} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{6}$$

Hencky-Hottinger

$$\alpha_k = 1.67 \cdot \Delta t^{0.27} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{7}$$

King

$$\alpha_k = 1.51 \cdot \Delta t^{0.33} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{8}$$

Michejev

$$\alpha_k = 1.55 \cdot \Delta t^{0.33} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{9}$$

Wilkes - Peterson

$$\alpha_k = 3.04 \cdot \Delta t^{0.12} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{10}$$

Nusselt

$$\alpha_k = 2.56 \cdot \Delta t^{0.25} \quad \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{11}$$

Jakob

$$\alpha_k = 9.7 \cdot \sqrt[3]{\frac{\Delta t}{T_1}} \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{12}$$

Schmidt-Beckmann, Schack

$$\alpha_k = 5{,}6 \cdot \sqrt[4]{\frac{\Delta t}{T_2 \cdot h}} \left(W \cdot m^{-2} \cdot K^{-1}\right) \tag{13}$$

where,

t_1 = the temperature of atmosphere out of thermokinetic layer

Δ_t = the difference of air temperature and surface temperature

Then specific heat fluxes were calculated according to the equation:

$$q_t = \alpha_k (t_1 - t_2) \quad \left(W \cdot m^{-2}\right) \tag{14}$$

where,

α_k = the convective heat transfer coefficient [$W \cdot m^{-2} \cdot K^{-1}$]

t_1 = the temperature of air [°C, K]

t_2 = the temperature of surface [°C, K]

Heat losses due to radiation are calculated in accordance with of Stefan–Boltzmann law. At first total intensity of a grey body radiation is calculated. Then total intensity of an environment radiation was subtracted from total intensity of a grey body radiation.

The equation for calculation of specific heat fluxes due to radiation is following:

$$I = \left(\sigma \cdot \varepsilon_s \cdot T_s^4\right) - \left(\sigma \cdot \varepsilon_t \cdot T_t^4\right) \quad \left(W \cdot m^{-2}\right) \tag{15}$$

where,

ε_s = the emissivity of grey-body

ε_t = the emissivity of environment

T_s = the thermodynamic temperature of grey-body [K]

T_t = the thermodynamic temperature of environment [K]

σ = the Stefan-Boltzmann constant [$W \cdot m^{-2} \cdot K^{-4}$]

The boundary conditions for calculation hypotheses are given in Table 1.

Table 1. Boundary conditions used to calculate thermal resistance and thermal transmittance of the construction

Parameter	Symbol	Value	Unit
External surface thermal resistance	R_{se}	0.04	$m^2 \cdot K \cdot W^{-1}$
Internal surface thermal resistance	R_{si}	0.13	$m^2 \cdot K \cdot W^{-1}$
Indoor temperature	Θ_i	+22	°C
Outdoor temperature	Θ_e	-15	°C

Statistical analysis

The software Statistica 12 was used for statistical analysis. Dataset were tested on normality and boxplots were created. Lilliefors test was used for testing of normal distribution of data.

3 RESULTS AND DISCUSSION

This survey is aimed on thermal defect detection of old poultry house constructions with using IR thermography system. Boundary conditions of infrared thermography measurement are presented in Table 2. Next part is calculation of the thermal properties of the envelope construction (presented in Table 3, 4 and 5) and heat losses caused by thermal bridges (presented in Table 6, 7, 8). Measured poultry houses are heated at temperature from 20 to 26 °C (mostly 22 °C). Interior relative air humidity is about 50 %. Temperature depends at category of age group of animals. First thermogram (Fig. 1) represents first part of the east façade of poultry house 1. Surface temperatures of measured construction are – 4,7 °C (min. temperature), +7,5 °C (max. temperature) and – 0,1 °C (average temperature). Construction of the wall is from aged light clay brick (locally with walling from gas concrete blocks) and external and internal plaster (partially degraded). This construction has poor thermal properties (U_T= 1,208 $W \cdot m^{-2} \cdot K^{-1}$) when nowadays directive (ČSN 73 0540-2:2011) requirement is U_T= 0,30 $W \cdot m^{-2} \cdot K^{-1}$.

Table 2. The boundary conditions for evaluation of the infrared thermography measurement

No.	Object	Emissivity	Atm. temperature	Relative humidity	Distance from measuring point	Measured surface	Average temperature of the surface
		[-]	[°C]	[%]	[m]	[m²]	[°C]
1	Steel concrete straining band of the wall (Fig. 1)	0.92	-0.9	71	15.5	3	0.2
2	Gable wall brickwork (Fig. 4)	0.95	-0.9	71	15.5	16	1.6
3	Frame of the window (Fig. 6)	0.88	-0.8	71	13.5	0.4	5
4	Frame of the door (Fig. 7)	0.88	-0.8	71	13.5	0.8	5.8
5	Uninsulated steel concrete socle (Fig. 8)	0.95	-0.9	71	18.8	21	4.1

Table 3. Calculation of characteristic thermal properties of the old poultry house constructions 1

Type of the construction	Material of the construction layer	Thickness (m)	Thermal conductivity λ (W·m-1·K-1)	Density (kg·m-3)	Total thermal resistance RT (m2·K·W-1)	Total thermal transmittance UT (W·m-2·K-1)
Outside wall	Internal cement plaster	0.02	1.16	2000	0.017	58.82
	Light clay brick	0.36	0.58	1250	0.621	1.61
	External cement-lime plaster	0.02	0.99	2000	0.020	50
	Total thermal properties of the construction				0.828	U_T= 1.20
	Required value according to standard CSN 73 0540-2:2011				-	0.30
Flooring	Concrete	0.10	1.36	2300	0.074	13.51
	Bitumen sheet	0.07	0.21	1400	0.033	30.30
	Steel concrete	0.10	1.58	2400	0.063	15.87
	Gravel	0.15	0.58	1650	0.259	3.86
	Total thermal properties of the construction				0.796	U_T= 1.35
	Required value according to standard CSN 73 0540-2:2011				-	0.45

As we can see on Figure 1 there is increased heat flow in socle parts of the construction because socle, foundations and also flooring has no thermal insulation and there are significant heat fluxes. Flooring and ceiling construction has unsatisfactory thermal properties (U_T= 1.356$W \cdot m^{-2} \cdot K^{-1}$) respectively ($U_T$= 0,58 $W \cdot m^{-2} \cdot K^{-1}$) when nowadays directive requirements are U_T= 0,45 $W \cdot m^{-2} \cdot K^{-1}$ respectively (U_T= 0.24 $W \cdot m^{-2} \cdot K^{-1}$).

Comparable problem with heat transfer over uninsulated foundations is presented in [Al-Anzi 2004]. The same problem with uninsulated construction is evident at top part of the gable wall. Significant structure there is steel concrete straining band of the external wall. It is bearing construction without thermal insulation. This layer (height 0.20m) is situated under steel concrete roof frame. Next thermal bridge related with straining band is bearing roof frame with external brickwork with insufficient thermal resistance. This thermal defect of the envelope is similar to results of [Höglund 1998, Fukuyo 2003, Juárez 2012, Al-Sanea 2012].

Table 4. Calculation of characteristic thermal properties of the old poultry house constructions 2

Type of the constr.	Material of the construction layer	Thickness (m)	Thermal conductivity λ(W·m^{-1}·K^{-1})	Density (kg·m^{-3})	Total thermal resistance R_T (m^2·K·W^{-1})	Total thermal transmittance U_T (W·m^{-2}·K^{-1})
Ceiling	Bitumen sheet roofing	0.007	0.21	1400	0.033	30.30
	Gas concrete heat insulation panel	0.050	0.18	580	0.278	3.59
	Steel concrete ceiling panel	0.200	1.74	2500	0.115	8.69
	Internal cement plaster	0.015	1.16	2000	0.017	58.82
	Roof bearing steel truss	0.300	-	-	-	-
	Total thermal properties of the construction				1.715	U_T= 0.58
	Required value according to standard CSN 73 0540-2:2011				-	0.24

Table 5. Calculation of characteristic thermal properties of the old poultry house constructions 3

Type of the constr.	Material of the construction layer	Thickness (m)	Thermal conductivity λ (W·m^{-1}·K^{-1})	Density (kg·m^{-3})	Total thermal resistance R_T (m^2·K·W^{-1})	Total thermal transmittance U_T (W·m^{-2}·K^{-1})
Original old door	Steel frame (+ sheet-metal sheating)	0.075 (0.004)	50	1400	-	-
	Total thermal properties of the construction				-	U_T= 5.65
	Required value according to standard CSN 73 0540-2:2011				-	1.50
Original old window	Steel frame (+ simple glazing)	0.075 (0.004)	50 (0.76)	1400 (2600)	-	-
	Total thermal properties of the construction				-	U_T= 5.65
	Required value according to standard CSN 73 0540-2:2011				-	1.50
Modernized door and window	PVC four cellular frame (+ heat insulating glazing)	0.075 (0.002)	0.16 (0.71)	1400 (2500)	-	-
	Total thermal properties of the construction				-	U_T= 1.70
	Required value according to standard CSN 73 0540-2:2011				-	1.50

Table 6. The calculated values of heat fluxes and heat losses at chosen critical details - 1

No.	Object	McAdams		Hencky-Hottinger		Cihelka	
		Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]
1	Steel concrete straining band of the brickwork	1.98	5.94	1.88	5.65	0.54	1.63
2	External plaster of gable wall brickwork	2.19	34.97	2.35	37.64	1.62	25.98
3	Frame of the window	2.42	0.97	2.95	1.18	4.97	1.99
4	Frame of the door	2.46	1.96	3.06	2.45	5.91	4.72
5	Uninsulated steel concrete socle	5.40	113.36	6.45	135.39	4.08	85.72

Table 7. The calculated values of heat fluxes and heat losses at chosen critical details - 2

No.	Object	King		Michejev		Wilkes-Peterson	
		Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]
1	Steel concrete straining band of the brickwork	1.71	5.14	1.76	5.28	3.38	10.15
2	External plaster of gable wall brickwork	2.25	35.96	2.31	36.91	8.48	135.73
3	Frame of the window	2.97	1.19	3.05	1.22	21.77	8.71
4	Frame of the door	3.10	2.48	3.18	2.54	25.16	20.13
5	Uninsulated steel concrete socle	6.42	134.83	6.59	138.41	18.44	387.20

Table 8. The calculated values of heat fluxes and heat losses at chosen critical details - 3

No.	Object	Nusselt		Jakob		Schmidt	
		Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]	Heat Fluxes [W·m^{-2}]	Heat Losses [W]
1	Steel concrete straining band of the brickwork	2.88	8.65	1.70	5.10	0.98	2.94
2	External plaster of gable wall brickwork	3.54	56.65	5.08	81.25	2.92	46.76
3	Frame of the window	4.37	1.75	15.59	6.24	8.94	3.58
4	Frame of the door	4.51	3.61	18.53	14.82	10.61	8.49
5	Uninsulated steel concrete socle	9.57	200.98	12.80	268.72	7.34	154.20

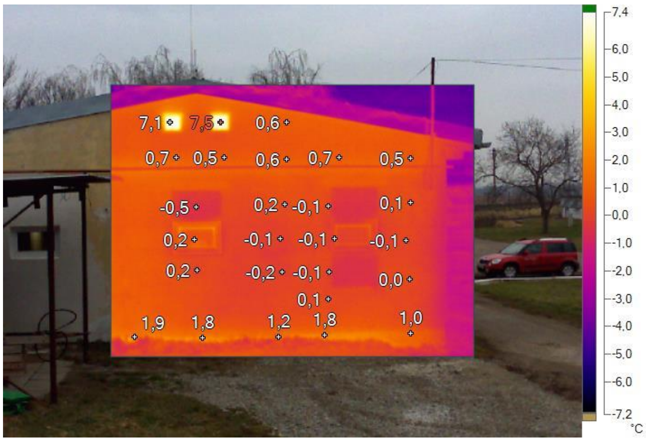

Figure 1. East façade of poultry house 1

Next problematic detail at all figures are doors and windows frames mainly at the pass between frame and brickwork. Probably it is caused by poor thermal parameters of the frames and unsuitable construction design of this detail. Original old as well as modernized doors and windows construction has unsatisfactory thermal properties (U_W= 5.65 W·m^{-2}·K^{-1}) respectively (U_W= 1.70 W·m^{-2}·K^{-1}) when nowadays directive requirements are U_T= 1.50 W·m^{-2}·K^{-1}. Similar case study of thermal bridges by window framework is presented in [Ben-Nakhi 2002. Cappelletti 2011]. Figure 2 and Figure 3 represents two parts of the south façade of poultry house 1.

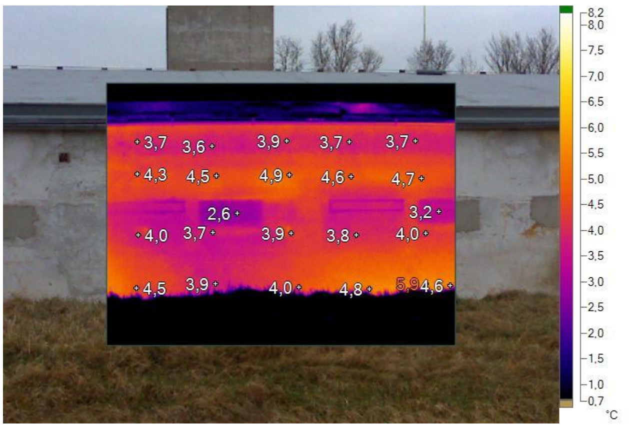

Figure 2. South façade of poultry house 1 – part 1

Surface temperatures of measured construction on Fig. 2 are – 1.2 °C (min.). + 5.9 °C (max.) and + 2.8 °C (avg.). Surface temperatures on Fig. 3 are – 4.7 °C (min.). + 5.2 °C (max.) and + 0.6 °C (avg.). As we can see there is same situation with existence of thermal bridges in critical structure details (mainly uninsulated reinforcement of the wall, foundations and flooring).

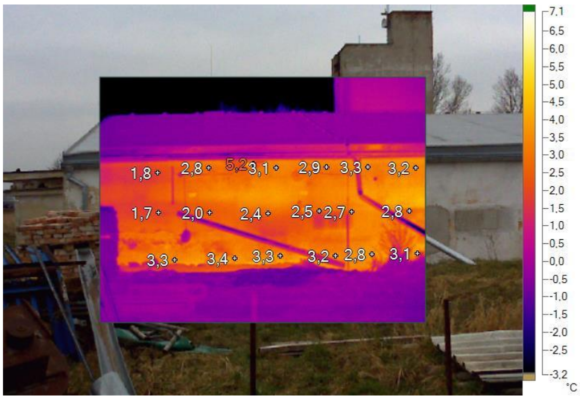

Figure 3. South façade of poultry house 1 – part 2

Figure 4 represent west façade of poultry house 1 (second gable wall).

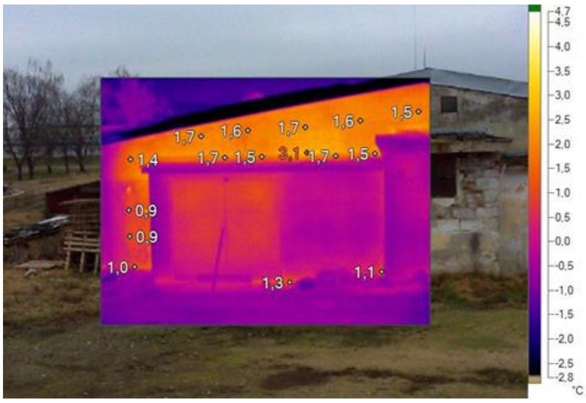

Figure 4. West façade of poultry house 1

Surface temperatures of measured construction on Fig. 4 are – 3.9 °C (min.). + 3.1 °C (max.) and – 0.1°C (avg.). Fig. 5 and Fig. 6 represent north façade of poultry house 1.

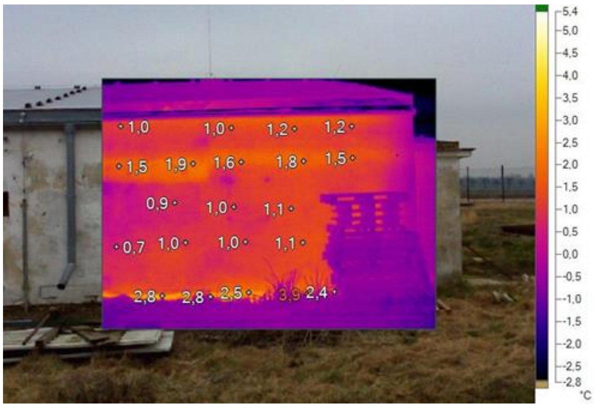

Figure 5. North façade of poultry house 1 - part 1

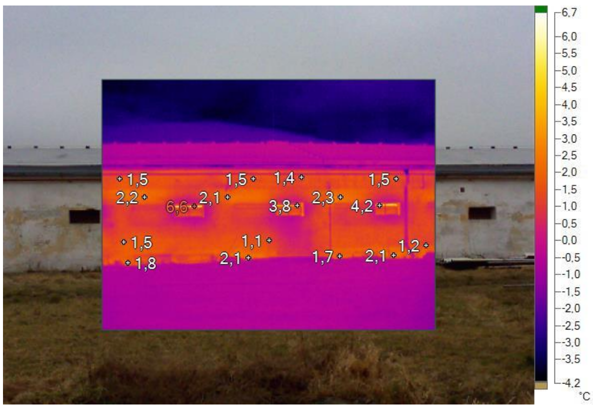

Figure 6. North façade of poultry house 1 - part 2

Surface temperatures of measured construction on Fig. 5 are – 4.1°C (min.). + 3.9°C (max.) and + 0.3°C (avg.). Surface temperatures on Fig. 6 are – 4.1°C (min.). + 6.6°C (max.) and – 0.6°C (avg.). Most problematic there is straining band again. Fig. 7. 8. 9. 10. 11 and 12 represent thermograms of poultry house 2 with similar situation which confirm unsuitable technical solution of structure details. Surface temperatures of measured construction on Fig. 7 are – 4.2°C (min.). + 7.6°C (max.) and + 0.1°C (avg.). Surface temperatures on Fig. 8 are – 4.4°C (min.). + 9.3°C (max.) and + 1.1°C (avg.). Surface temperatures on Fig. 9 are – 4.4°C (min.). + 5.2°C (max.) and + 0.9°C (avg.). Surface temperatures on Fig. 10 are – 4.0°C (min.). + 7.6°C (max.) and + 0.8°C (avg.). Surface temperatures on Fig. 11 are – 5.0°C (min.). + 5.0°C (max.) and – 0.3°C (avg.). Surface temperatures on Fig. 12 are – 5.1°C (min.). + 5.0°C (max.) and + 0.1°C (avg.).

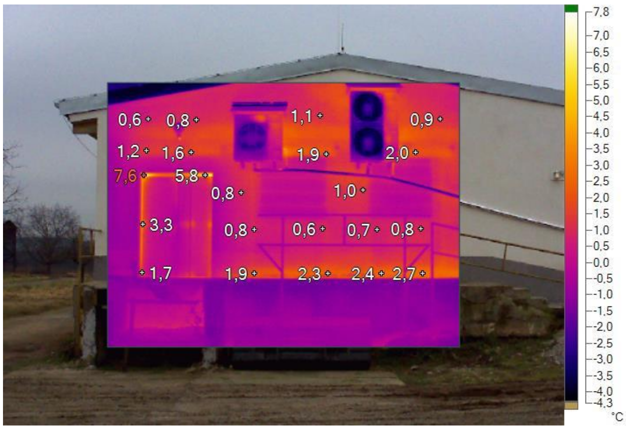

Figure 7. East façade of poultry house 2

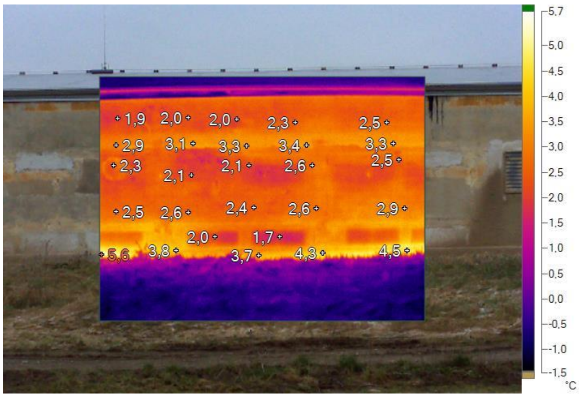

Figure 8. North façade of poultry house 2 - part 1

Figure 9. North façade of poultry house 2 - part 2

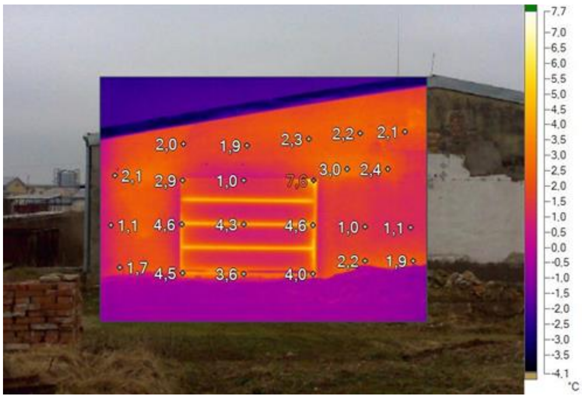

Figure 10. West façade of poultry house 2

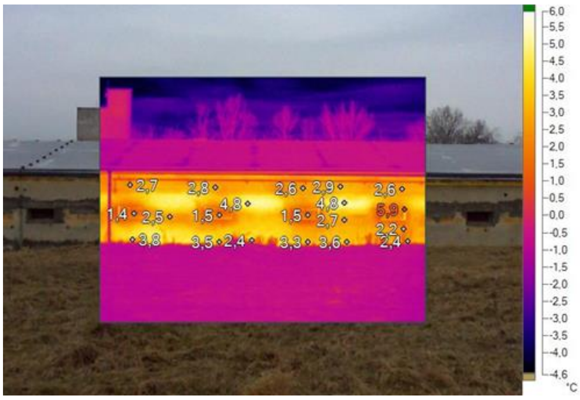

Figure 11. South façade of poultry house 2 - part 1

Figure 12. South façade of poultry house 2 - part 2

Results of statistical analysis are presented at Figs. 13-17.

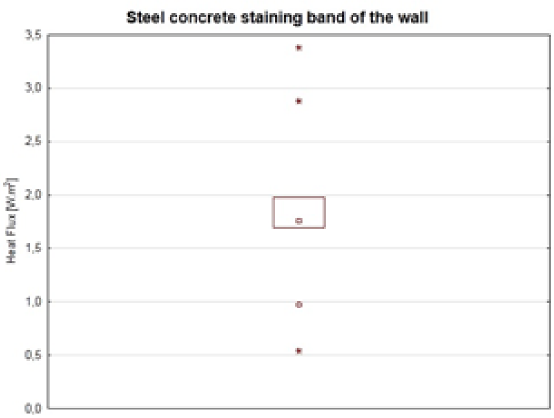

Figure 13. Box-and-whisker diagrams of individual calculated values - 1

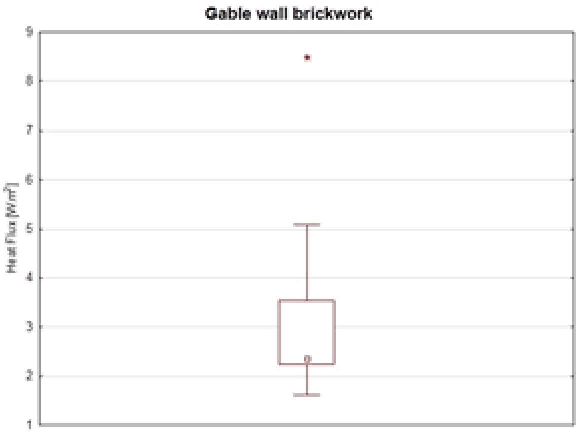

Figure 14. Box-and-whisker diagrams of individual calculated values - 2

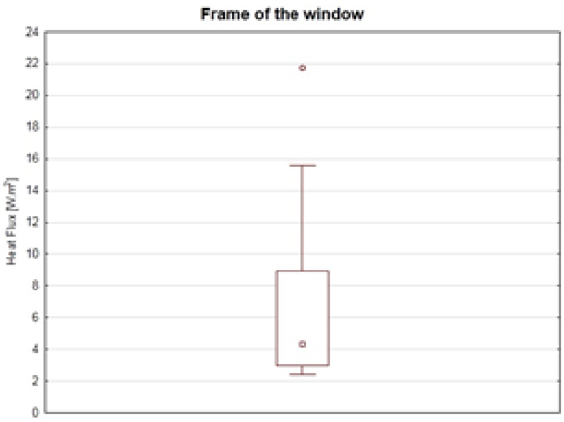

Figure 15. Box-and-whisker diagrams of individual calculated values - 3

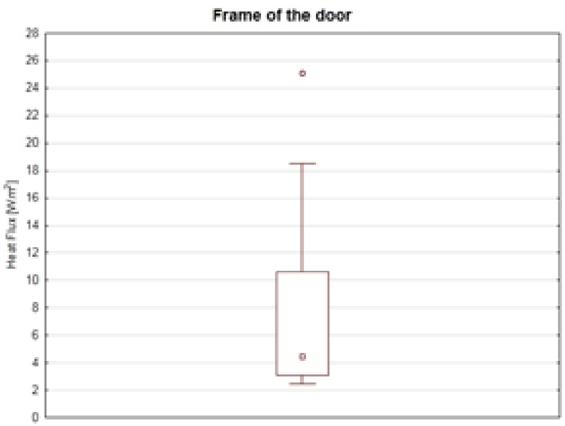

Figure 16. Box-and-whisker diagrams of individual calculated values - 4

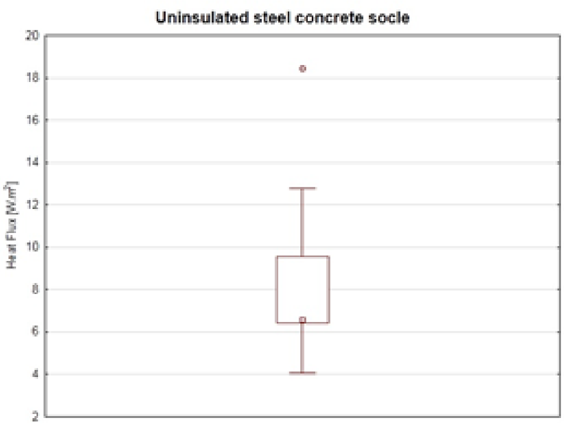

Figure 17. Box-and-whisker diagrams of individual calculated values - 5

Results of this thermographic survey confirm insufficient properties and significant existence of thermal bridges on old farm building structures alike to our previous studies by other farm building [Junga 2014].

4 CONCLUSIONS

Nowadays, the situation in energy consumption and carbon emission has put heavy pressures on the building energy performance, especially on reductions of high energy consumption buildings. As we can see results of IR thermography survey and calculations of heat fluxes and heat losses confirm unsatisfactory technical solutions of critical structure details with thermal bridges existence. Values of heat fluxes range in dependence on temperature difference are from 0.98 to 25.53 $W \cdot m^{-2}$. Calculated values were very variable. Based on this fact statistical analyse was carried out. The following conclusion from statistical analyses can be drawn: Calculated values in accordance with equation 5, 10, 11, 13 were identified as outlying or extreme in the case of object No. 1. Calculation by equation 11 was identified as outlying in other objects. It follows that values calculated by Wilkes-Peterson is possible rejected in the case of approximate calculation of heat losses in object. However, it should be noted that it applies only to boundary conditions at which measurement was carried out.

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