THERMAL ANALYSIS OF OVERGROUND BOUND CONSTRUCTIONS

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ABSTRACT

Thermographic cameras are widely used for inspecting and analyzing surfaces of overground bound constructions. The method demonstrantes a complete image of thermal spots and is suitable for giving limited conclusions about the whole surface temperature of the bound construction. The main problem of infrared analysis is exact temperature layout, because different heat transmission areas can be seen on the screen, but heat radiation levels are not so reliable. Such temperature differences can exceed even 50% of the real surface temperature. To explore more accurate surface point temperatures special thermal sensors and sensor types were applied. By point type infrared and thermo-couple device temperature distribution points on building material surface were gathered,compared and calibrated with the infrared camera output image. With heat flow and attachable temperature sensors,the material surface and surrounding temperatures were analyzed in an extended period. Also mathematical temperature curves were calculated to prove the temperature distribution on the surface. All samples for practical research were made at the Tenax factory, located in Dobele, Latvia. The manufacturer of these samples gave heat properties to compare with the experimental data. By using the above mentioned methods, exact temperature loads can be defined and calculated; these methods are also suitable for analyzing heat transmission of overground bound constructions.

Key words: bound constructions, heat transmission, infrared method.

INTRODUCTION

There is a need for thermographic calculations regarding bound constructions to design energy saving buildings with good indoor climatic conditions, in combination with efficient and highly durable materials, as well as environmentally friendly technologies..
Building bound constructions generally consist of foundations, walls and roofs, but this study analyzes only the above-ground parts of those structures. In every type of construction, intra-thermal processes take place. They depend on the properties of the applied materials and exterior environment. Thermal processes in structures can be identified and quantified in cases where one or more structural surfaces are in different heat and moisture (environmental) conditions. The order of thermal designing of bound constructions is regulated by the Latvian building regulation LBN 002-01 "Heat transfer in building envelopes".
The aim of the research was to combine analytical and experimental methods of thermal analysis and carry out experimental thermal analysis of bound constructions (exterior composite panels).
Using thermal imaging cameras with contact measuring devices, and setting the surface temperature proxies in a wide area, bound construction heat transmission can be calculated by means of a three-temperature method, which includes the point and linear thermal bridges and other places of heat loss in constructions. The method provides an opportunity to expand the experimental use of the thermal image camera for determining heat transfer of bound constructions.

MATERIALS AND METHODS

Technical devices used in the research

1. Electronic measuring system of heat flows and temperatures MBox RF1.

Wireless measuring device of heat flows and temperatures MBox RF1 is designed to measure long term temperatures and heat flows with time step and storing the measured data in a computer.
Technical data:
- Sensors: Thermocouple (K), flow sensors;
- Number of measurement channels: 8 for temperature, 2 for flows;
- Measurement range: temperature -50ºC to +120ºC, flows -150 to +150W/m^2;
- Accuracy: temperature ±0.2 ºC, flows ±0.5W/m^2;
- Resolution: temperature: 0.01 ºC, flows 0.01Wm^2.

2. Testo 845. A thermometer which works in the spectrum of infrared waves in a narrow area (points), equiped with a thermocouple probe for contact measuring surface temperature:
- Measurement range: -35˚C to +950˚C;
- Accuracy of the infrared device and thermocouple at room temperature: ±0.75˚C.

3. ThermoPro TP8. Camera of thermal picture, works in the spectrum of infrared waves (thermographic camera):
   -Measurement range: -20˚C to +800˚C;
   -Resolution: 384 × 288 thermal pixels (sensors);
   -Accuracy: ±1˚C or 1% of the result.
4. Elektrolux ECN 2658/BNI 280. A cooling chamber (Figure 1):
   - Class: SN/T;
   - Volume: 260 L;
   - Cover size: 540 x 845 mm;
   - Temperature: -33 to -38˚C (measured in an experiment).

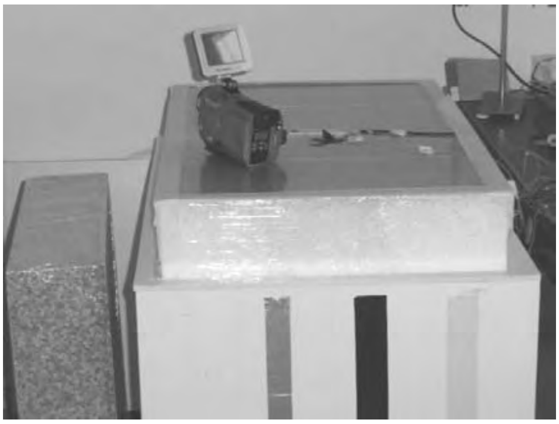

Figure 1. Cooling chamber Elektrolux ECN 2658/BNI 280, laboratory sample, TP8, etc.

Description of the sample

The sample for laboratory measurements was produced at the factory of company Tenax in Dobele, Latvia.
Specifications of the experimental sample:
- Size: width – 540mm, length – 845mm, height – 150mm;
- Type of sample: composite facade panel consisting of two painted metal sheets and thermoinsulation layer;
- Stuffing: expanded polystyrene EPS with graphite foam particles (‘Neopor’, Tenax), type EPS 150;

The book ‘Sendvičpaneļi Tenax. Metodiskie norādījumi projektētājiem un būvniekiem’ (SIA Tenax, 2004) gives a coefficient of permeability of the composite facade panel with EPS stuffing U (W/m^2K): type EPS 150, thickness 150mm, U=0.224 W/m^2K.

Description of laboratory research method

The experimental research methods had several parts.
Setting up samples and connecting sensors. Each wireless transmitters’ thermocouples were divided into groups, two in each. There were eight thermocouples and four groups.

After fixing the thermocouples, heat flow measuring devices q_1 and q_2 were fixed. The scheme of the mounted thermocouples and heat flow measuring devices is shown in Figure 2. Figure 3 shows the fixation of thermocouples.
For about 48 hours the sample was loaded with the *temperature difference* where room temperature was +18..+24ºC, but in the cooling chamber -33..-38ºC, and *ΔT*~56ºC (within Δ=50 to 62 ºC).
Parallel to the period when heat processes were normalized (reaching a balance) and the heat process can be described as homogeneous and heat flows are almost constant, data registation programm *UmeasRF* registered incoming signals with an hour interval (40 measurements were registered, 7 and 8 were chosen for data analysis).

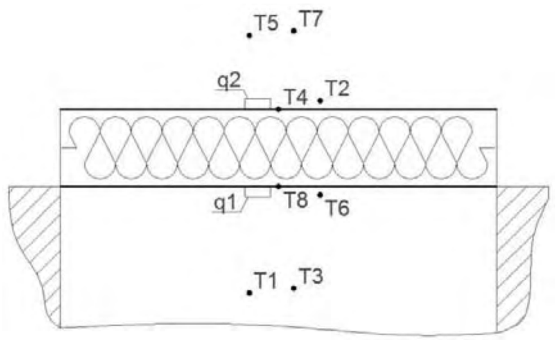

Figure 2. Scheme of the fixation of thermocouples and heat flow measuring devices.

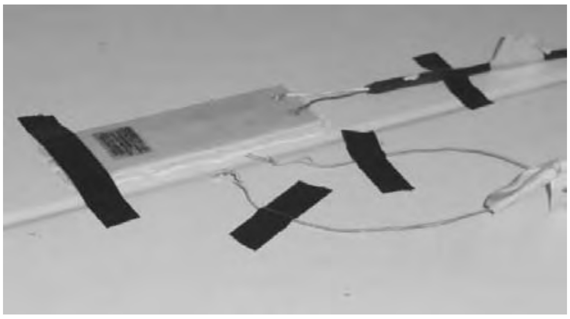

Figure 3. Fixated state of two thermocouples and heat flow measuring device.

When temeperatures were stable, *the sample was turned around* 180º on the condition that the side of the sample which was in the room was placed into the cooling chamber’s cold zone and the cold zone sample surface was turned to the warm zone of the room. Thermal blow of the opposite surfaces in this case was ΔT reaching ~60ºC (from +23ºC to -37ºC).
This conception was presumed because quality and general data were needed for analysis of sensors (T_1 .. T_8, q_1, q_2). That excludes error in case if one of the sensors transmits incorrect information (Figure 4).

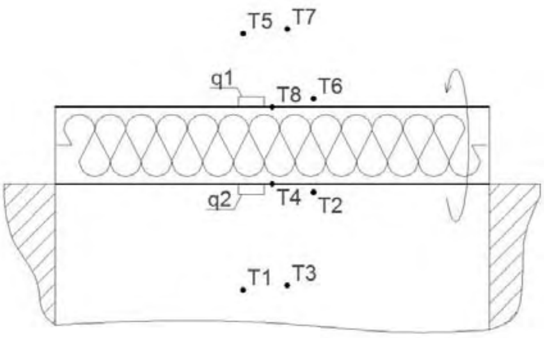

Figure 4. Scheme of mounting of thermocouples and heat flow measuring device in reversed position.

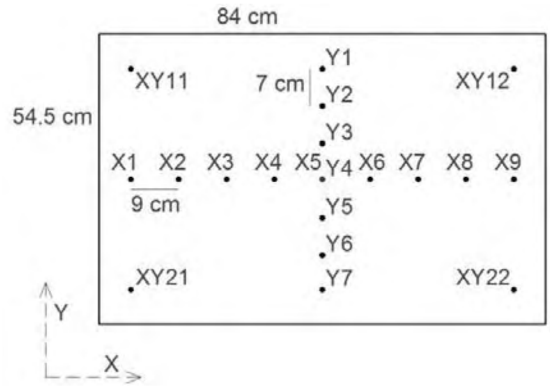

Figure 5. Scheme of measurement points of the sample surface.

Table 1

Measurements of the laboratory sample, ºC

Reading at point	Testo 845, I.R., ε=0.99	Testo 845, T.C.	ThermoPro TP8, ε=0.99	ThermoPro TP8, ε=90
X1	23.4	23.7	25.1	24.6
X2	23.1	23.6	24.3	24.0
X3	23.0	23.6	23.9	23.5
X4	22.9	23.5	23.8	23.4
X5	22.9	23.3	23.6	23.3
X6	23.0	23.4	23.8	23.4
X7	23.0	23.5	24.0	23.6
X8	23.2	23.9	24.3	24.1
X9	23.4	24.2	25.2	24.7
Y1	23.4	23.8	24.6	24.2
Y2	23.2	23.7	24.2	23.9
Y3	23.1	23.6	23.8	23.5
Y4	23.1	23.5	23.6	23.3
Y5	23.4	23.7	23.8	23.5
Y6	23.6	24.1	24.2	23.7
Y7	23.7	24.6	24.7	24.4
XY11	23.3	24.2	25.3	25.3
XY12	23.5	24.4	25.4	25.4
XY21	23.3	24.4	25.3	25.3
XY22	23.5	24.7	25.4	25.4

where
Testo 845 I.R. – temperatures in the infrared spectrum acquired from the Testo 845,
Testo 845, T.C. – temperatures at points read from the Testo 845 thermocouples probe,
ThermoPro TP8, ε=0.99 – results from the programme treating pictures in the infrared spectrum where the coefficient of the surface emission is ε=0.99,
ThermoPro TP8, ε=0.90 – results from the programme treating pictures in the infrared spectrum where the coefficient of the surface emission is calibrated by trial and error method ε=0.90 and corresponds to the result on X-axis at point X_5.

When the second stabilization process was over, the surface of the sample was divided into parts over the midfield in the area of 72 x 42 cm, where the step on X-axis was 9 cm, but the step on Y-axis was 7 cm. Measurement points on X-axis were marked as X_1 .. X_9; on Y-axis: Y_1 .. Y_7. (Figure 5).

According to the matrix principle measurement points XY_{11} (upper left corner), XY_{12}, XY_{21} un XY_{22} (lower right corner) were marked in the corners of the sample.

In the marked points, *surface temperatures were measured using the device Testo 845* with a surface thermometer which works in the spectrum of infrared waves and thermocouple probe. The data gathered are shown in Table 1.
After reading the surface temperature with Testo 845, *thermography of the sample was carried out* with ThermoPro TP8.
Calibrating emission coefficient ε of the picture in the infrared spectrum real temperature division on the sample surface was obtained which corresponded to the measurements of thermocouple in charasteristic points on X-axis and Y-axis.
From the results of the recorder MBox RF1 measurements T_1 .. T_8 were chosen; resistance of surface air layers and coefficient of heat permeability U (W/m^{2}K) were calculated according to civil physics formulas.

RESULTS AND DISCUSSION

Measurements of laboratory samples

Measurements of the surface temperatures show that measurements from the Testo 845 I.R. (infrared spectrum) with emissivity ε=0.99 containt lower temperatures than the Testo 845 T.C. and ThermoPro TP8. Figures show error of the device because the value of surface emissivity *ε* cannot be higher than 1.Electronic measuring device of heat flows and temperatures MBox RF1 fixed temperature on the surface T_4 = 19.55 ºC; couples T_5; T_7 (environmental temperature) = 20.31 ºC; couples T_1; T_3 (temperature in cold area = -36.70 ºC (First case, see Figure 2).After flipping, the temperature on surface T_8 = 20.00 ºC; couples T_5; T_7 (environmnetal temperature) = 20.73 ºC; couples T_1; T_3 (temperature in cold area) = -36.63 ºC (Second case, see Figure 4).

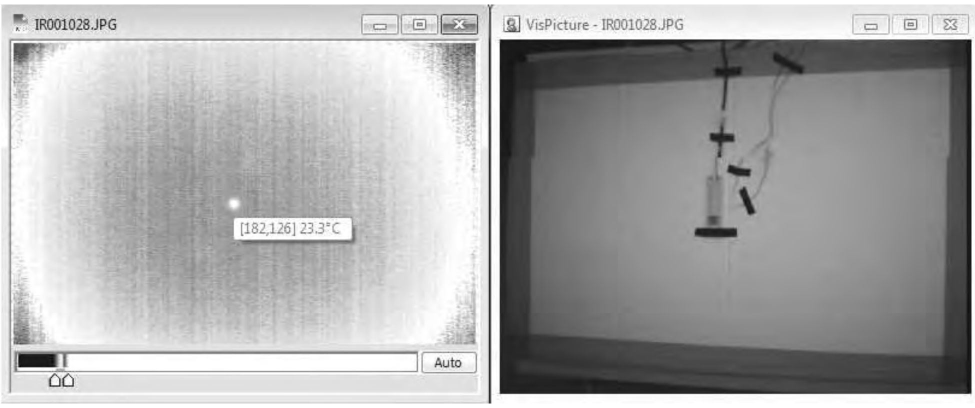

Figure 6. Measurements of the surface temperature with ThermoPro TP8 (ε=0.90).
Analysis made in the programme Guide IrAnalyser.

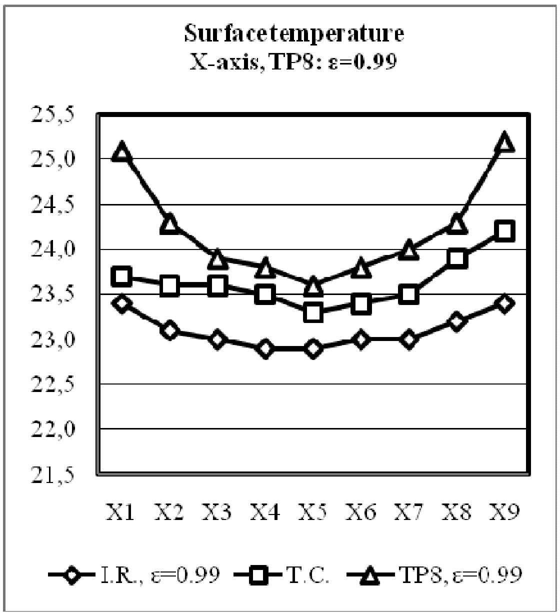

Figure 7. Measurements of the surface temperature on X-axis (ThermoPro TP8: ε=0.99).

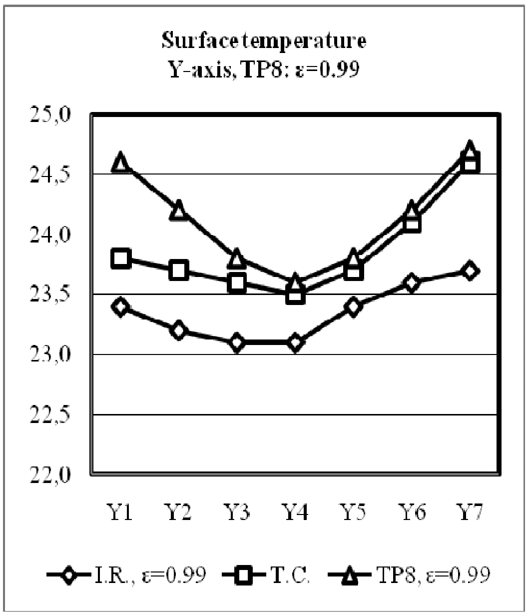

Figure 8. Measurements of the surface temperatures on Y-axis (ThermoPro TP8: ε=0.99).

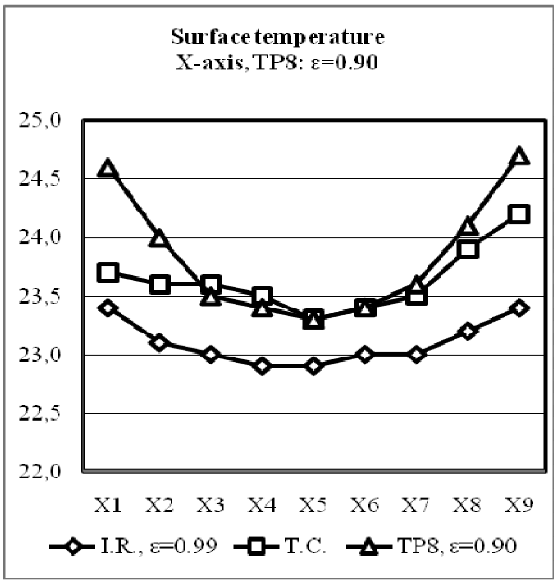

Figure 9. Measurements of the surface temperature on X-axis (ThermoPro TP8: ε=0.90).

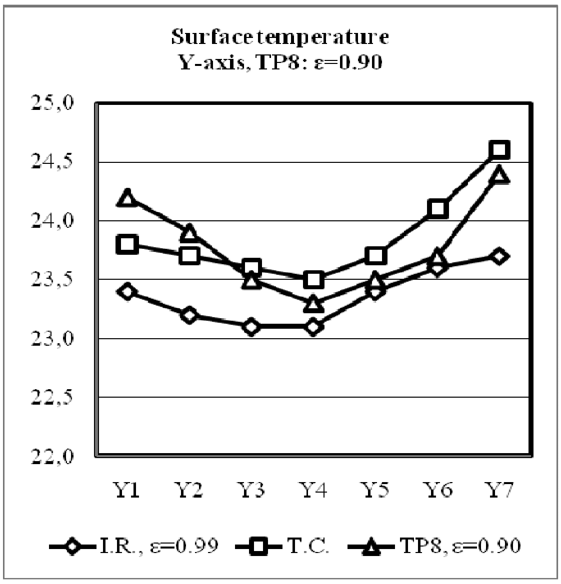

Figure10. Measurements of the surface temperature on Y-axis (ThermoPro TP8: pie ε=0.90).

Heat flows q and heat permeability coefficient U can be defined:

$$q = \propto_i \ (T_i - T_1) = U \ (T_i - T_e) \quad un \qquad (1)$$

$$U = \propto_i \frac{T_i - T_1}{T_i - T_e} \quad , \qquad (2)$$

where
α_i – coeficient of heat transmission on inner surface, W/m^{2}K
T_i – temperature in room, ˚C
T_e – outer temperature in air, ˚C
T_1 – temperature on the first surface of the bound construction, ˚C

Respectively,

$$q = \propto \ \Delta T \quad un \quad \propto = \frac{q}{\Delta T} \qquad (3)$$

Heat transmission coefficients of the border layer $\alpha_{i,1}$; $\alpha_{i,2}$ (for the first and second cases):

$$\propto_{i,1} = \frac{16.11_{(q1,q2)}}{20.31_{(T5,T7)} - 19.55_{(T4)}} = 21.20 \frac{W}{m^2K} \qquad (4)$$

$$\propto_{i,2} = \frac{18.99_{(q1,q2)}}{20.73_{(T5,T7)} - 20.00_{(T8)}} = 26.01 \frac{W}{m^2K} \qquad (5)$$

Knowing heat transmission coefficients of border air layer α , according to equation (2) it is possible to calculate the heat transmission of the bound construction $U_{1-1,\,1-2}$ (W/m^{2}K) In the first case:

$$U_{1-1} = \propto_i \frac{T_i - T_1}{T_i - T_e} = 21.20 \ \frac{20.31_{(T5,T7)} - 19.55_{(T4)}}{20.31_{(T5,T7)} - (-36.70_{(T1,T3)})} = 0.283 \frac{W}{m^2K} \qquad (6)$$

Equation (6) is called ‘equation of heat transmission coeficient by method of three temperatures’.
Verification of the equation (6) by expression (1), marking as U_{1-2} (calculation No 2 for the first case):

$$U_{1-2} = \frac{q}{(T_i - T_e)} = \frac{16.11_{(q1,q2)}}{20.31_{(T5,T7)} - (-36.70_{(T1,T3)})} = 0.283 \frac{W}{m^2K} \qquad (7)$$

Observation (1): Verification of the first calculation is correct.
Heat permeability $U_{2\text{-}1,\,2\text{-}2}$ (W/m^{2}K) of bound construction in the second case:

$$U_{2-1} = \propto_i \frac{T_i - T_1}{T_i - T_e} = 26.01\ \frac{20.73_{(T5,T7)} - 20.00_{(T8)}}{20.73_{(T5,T7)} - (-36.63_{(T1,T3)})} = 0.331\frac{W}{m^2K} \quad (8)$$

Verification of the equation (8):

$$U_{2-2} = \frac{q}{(T_i - T_e)} = \frac{18.99_{(q1,q2)}}{20.73_{(T5,T7)} - (-36.63_{(T1,T3)})} = 0.331\frac{W}{m^2K} \quad (9)$$

Observation (2): Verification of the second calculation is correct.

Standardized coefficient of heat permeability given by the manufacturer to the constrution U=0.224 W/m^{2}K. After calculations, mismatches in both cases: Δ_1 = 20.8 % ; Δ_2 = 32.3 %.
Mismatches (2) Δ_2 =32.3% can be explained by 'thermal blow' what the construction gets after flipping and it is not clear how the insulation layer between heat flow measuring device and surface of the sample behaves. It can be possilble that the attracted air moisture creates ice crystals in the insulator interfering with the reading of accurate data.

CONCLUSIONS

Camera of thermal imaging, which shows surface temperatures in the infrared spectrum alone without other devices indicates only the general temperature of the surface, which can differ from real temperatures >50%, because of an incorrect assumptive coefficient of the surface emission (ε=0.01..0.99);
When using the thermographic camera together with other measuring devices and defining surface temperatures in a wide area, it is possible to calculate the heat permeability of the bound construction, also pointed and linear thermal bridges and other spots of heat loss in the construction. We used the method of three temperatures in the calculations;
A set of serveral precise devices allows us to objectively evaluate the obtained results and avoid serious failures in measurements.

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