

Application of infrared thermography in civil engineering

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Abstract. Infrared thermography is a modern measuring method for the examination of redeveloped and non-renovated buildings. Infrared cameras provide a means for temperature measurement in building constructions from the inside as well as from the outside. Thus heat bridges can be detected. It has been shown that infrared thermography is also applicable for finding the exact position of heating tubes or for discovering the reasons why mold is growing in a particular area. The paper gives a brief description of the theoretical background of infrared thermography. Thermograms of town halls of Rostock, Stralsund, Wismar and Greifswald illustrate the paper.

Key words: infrared thermography, examination of buildings, emissivity.

1. INTRODUCTION

After the discovery of infrared radiation by William Herschel in 1800 and the discovery of the thermoelectric effect by Thomas Johann Seebeck in 1821, scientists have tried to measure this long wave radiation with the help of thermocouples and thermophiles. The military has been particularly interested in this invisible, warm radiation, and after World War II the armed forces invested significant amounts of money into research in this field. Consequently, great progress in the development of infrared detectors took place in the last third of the 20th century and elegant cameras to measure radiation and hence temperature were built. With the help of new systems the spectrum of civil applications grew as well: from construction thermography to its use in electrotechnology, environment engineering, civil engineering and medicine. It can be applied everywhere where processes inside of an object lead to the change of temperature of its surface. Bearing in mind the current discussion on climatic changes, construction

thermography gains importance, because it quickly discovers heat losses of building envelopes. It is in compliance with the Thermal Insulation Ordinance.

Thermography is the determination of surface temperatures of objects and bodies with the help of infrared photography [1-3]. A special-purpose camera captures what the human eye cannot see [4-6]. The camera consists of an infrared-permeable lens, a transmission line and a sensitive detector. The detector converts radiation into electric signals. After processing they are transformed into pixels so that the thermogram appears on the screen.

2. THEORETICAL BASIS

The theory of infrared thermography is based on three well-known radiation laws [2,6]:

- the law about the relation between emission and absorption found by Kirchhoff,
- Planck’s law of radiation,
- the Stefan–Boltzmann law.

Kirchhoff’s law means that a body that absorbs much also emits much. When a “grey” body stands opposite a “black” body, absorption and emission are equal in the thermal balance. Thermography is based on the emission of objects. Therefore it uses the emission coefficient ε as the ratio of emissivity E of a real body to the emissivity E_s of the black body under the same temperature

$$\varepsilon = \frac{E}{E_s}. \quad (1)$$

Thus the emission coefficient ε is nondimensional; it lies between 0 and 1 and depends on the wavelength, on the temperature and the surface texture of the body. The Planck radiation law describes the specific spectral radiation M emanating from the idealized black body:

$$M(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}, \quad (2)$$

where λ is wavelength, T is the absolute temperature, h is the Planck constant and c is the speed of light. If the specific spectral radiation M is plotted over the wavelength λ as a function of temperature, typical Planck curves will result. In them it can be seen that the maximum of the curves shifts with growing temperature towards a smaller wavelength according to the Wien displacement law

$$\lambda_{\max} = \frac{2898}{T}. \quad (3)$$

Stefan and Boltzmann looked at the emission of a surface over all wavelengths, integrated the Planck law and discovered that the radiant power I in W m^{-2} grows with the fourth power of the temperature:

$$I = \sigma T^4, \quad (4)$$

where $\sigma = 5.67 \times 10^{-8}$, $\text{W m}^{-2} \text{K}^{-4}$.

In the thermographic camera the detector determines the traceable range of wavelengths. It is important to stay within the area of atmospheric windows. Only in these windows is the atmosphere's transmissivity high enough for infrared radiation. That is why most cameras operate in the area of 3 to 5 or 8 to 12 μm . Another window exists in the near infrared between 0.78 and 3.0 μm .

The emission coefficient is generally determined experimentally [3,4]. There are two possibilities for that. According to the effect of Seebeck, a thermocouple can be used to measure the temperature of the surface that is to be examined. Then the emission coefficient in the camera is changed until the camera shows the same temperature as the thermocouple does. The second method uses a commercial emission sticker. Its emission coefficient ε is known. The thin paste-on label is stuck to the surface. After the infrared exposure the temperature of the sticker is compared to the surface next to it in the thermogram.

An even easier way is the use of a calibrated black spray. In the meantime many extensive tables and charts with emission coefficients have become available [2-4]. But one has to consider that not every surface texture can be covered with a spray. As for metals, their different oxidation coverage may exclude application of sprays.

3. CONSTRUCTION THERMOGRAPHY

The main application of infrared thermography in the civil sector lies in construction thermography. Fortunately, most materials used in the building industry have emission coefficients between 0.90 and 0.96 (Table 1) [1,4,6]. Therefore good assessment of thermal properties of a building can be made with only one exposure with the same ε .

Post-processing of the thermograms for zinc or copper clad components can then still be done with the computer.

A basic condition for using thermography on buildings is a difference of 20 K between the inside and the outside temperatures. In the literature 10 K are sometimes considered enough. It means that examinations of buildings are reasonable only during the winter when the surrounding temperature lies around the zero-point. Inside exposures are of greater significance because atmospheric conditions such as wind, rain, snow or sun as well as conditions of the building itself like ventilated facades have an effect on the results of the exposure. While heat bridges can be seen from outside, there are cold bridges observable inside. Cold areas clearly stand out on walls, loft conversions, corners on the floor or window

Table 1. Emission coefficients of construction materials

Material	ε
Concrete	0.94
Sand	0.93
Brick	0.93–0.94
Limestone	0.96
Render/plaster	0.90–0.96
Glass	0.93–0.96
Wood	0.96
Roofing felt	0.93
Gypsum	0.90
Paint	0.90–0.95
Clay	0.95
Brickearth	0.93

frames. But heated floors and heaters on walls can also be made visible. Their position and length can be exactly determined. Furthermore, it is possible to find leaking or plugged heating systems, badly done insulation or hidden timbered framework, which has been plastered over. Pictures, taken with thermographic cameras, are admitted in court because they provide unambiguous proof of botched construction works. Construction firms benefit from them as well since they can photograph critical areas in order to design targeted constructional measures before reconstructing old buildings. Infrared exposures can be filed together with regular photographs of the same object and tables with thermographic results for later analysis.

4. SELECTED EXAMPLES

As examples, town halls of the four big Hanseatic cities of Rostock, Stralsund, Wismar and Greifswald were photographed. They all lie on the coast of the Baltic Sea of Mecklenburg-Western Pomerania. Together with every thermographic exposure a regular visual photograph was taken. In addition, data about the surrounding temperature, humidity, distance of the exposure from the object as well as of the emission coefficient were collected. The coefficient was tuned in consistently as 0.95. All city halls had been reconstructed and renovated. The aim of the thermographic pictures was to find out whether there are “climate sinners” among municipal administration buildings. During the reconstruction it had been very difficult to rebuild the premises according to thermal insulation standards as well as to the preservation requirements of historic monuments. This is not always easy, but it was mostly successful thanks to the thick outer walls that were commonly used in former times for reasons of construction engineering rather than because of thermal insulation. Some window installations were to be reduced [5].

Built in the 13th century, the town hall of Rostock (Fig. 1) has had a baroque front since the middle of the 18th century. In 1995 it was completely reconstructed and renovated. The old, thick walls insulate the building excellently. The Thermal Insulation Ordinance [7] was not observed with the windows on the upper floors.

The town hall of Stralsund (Fig. 2) received a gothic facade in 1340. Reconstruction was finished in 2004. In the upper part of the gable there are no windows, but apertures that prevent the facade from collapsing under stormy weather conditions.

The town hall of Wismar (Fig. 3) was constructed between 1817 and 1819 in the classical style. After a fire in the roof it was reopened in 1992. Single red-white windows show that the rooms behind them are heated more than the remaining rooms.

In comparison to the others, the town hall of Greifswald (Fig. 4) is the worst insulated. After the reconstruction of 2000, many heat bridges remained. The building, dating from late gothic times, was erected around in 1400. After two fires in the 18th century it was rebuilt as a baroque edifice.

A different example is localization of cold spots inside a new detached house (Fig. 5). The infrared photograph provides evidence of the deficient insulation and shows that heat bridges lead to inadmissibly low surface temperature. This causes growth of mold as soon as the measured temperature falls below the dew point. With a room temperature of 21 °C and a high relative air humidity of 70%, the dew point lies at approximately 15.3 °C.

An application area of thermography is also detection of the position of heating tubes in floors and walls (Figs. 6 and 7). When, for example, a supplementary chimney is to be built in the living room or a tie is to be placed in an outer wall, it is important to know exact location of the pipes. In the same way any leakage can be detected in heating systems because a leak produces a wide heat spot in the thermogram. Another application of thermography is measurement of moisture in building materials [8].

5. CONCLUSIONS

Infrared construction thermography is a modern contactless measurement procedure for diagnostics and analysis of buildings [2,9]. Pre-conditions are scientific expert knowledge concerning physical fundamentals as well as a minimum of constructional and technical understanding. With the help of construction thermography, compiling evidence for heat losses is possible. One can locate heat and water leakages or make extensive analysis of the actual condition of edifices.

Thermograms and visual photographs are taken from a fixed position and are analysed side by side in the laboratory. On and in the building there must be stationary conditions. Outside exposures must be taken before sunrise, otherwise solar radiation will hit the lens through reflections. Thus the measurement would

(a)



(b)

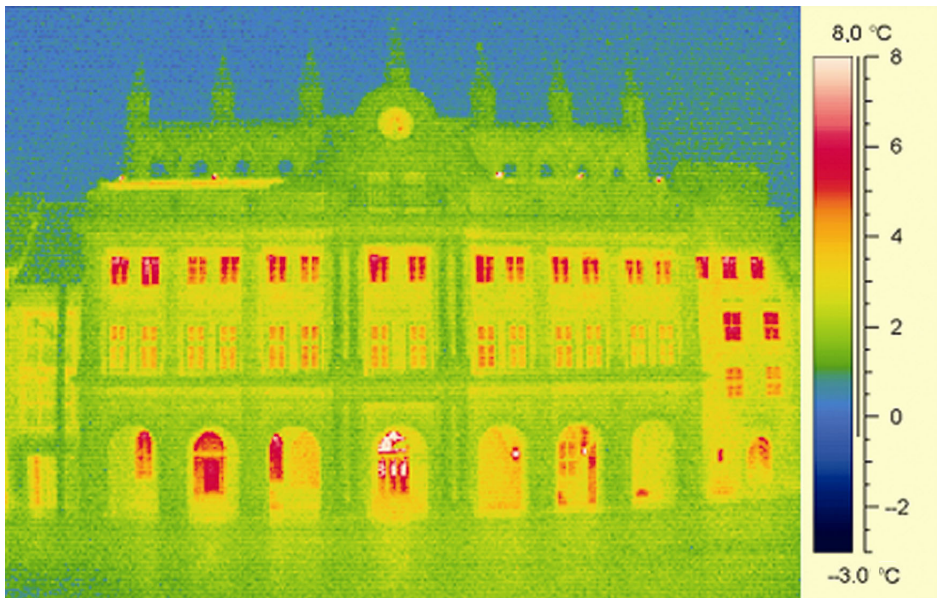


Fig. 1. Real visual photography (a) and infrared exposure (b) of the town hall of the Hanseatic city of Rostock.

(a)



(b)

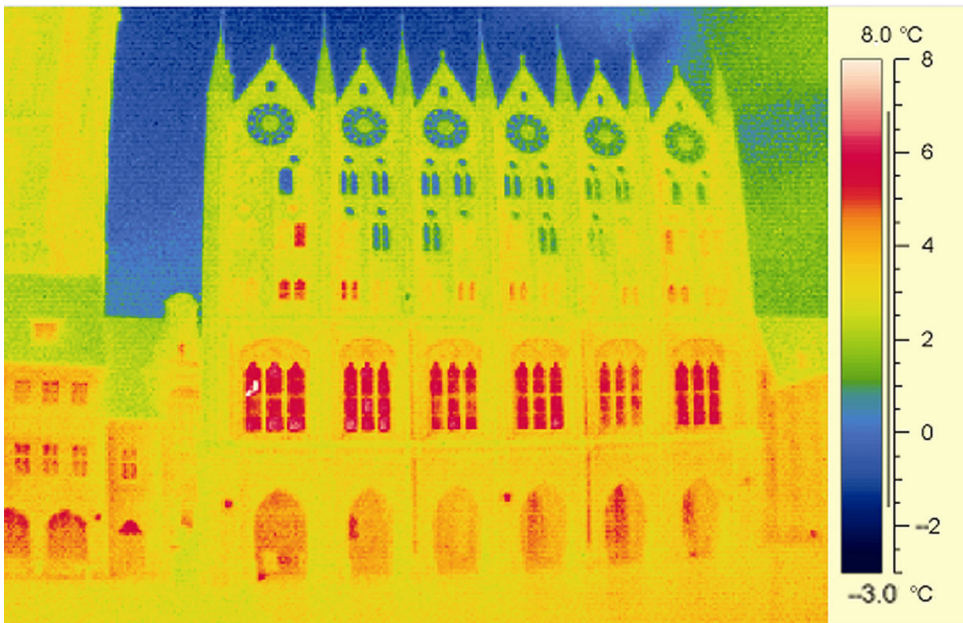


Fig. 2. Real visual photography (a) and infrared exposure (b) of the town hall of the Hanseatic city of Stralsund.

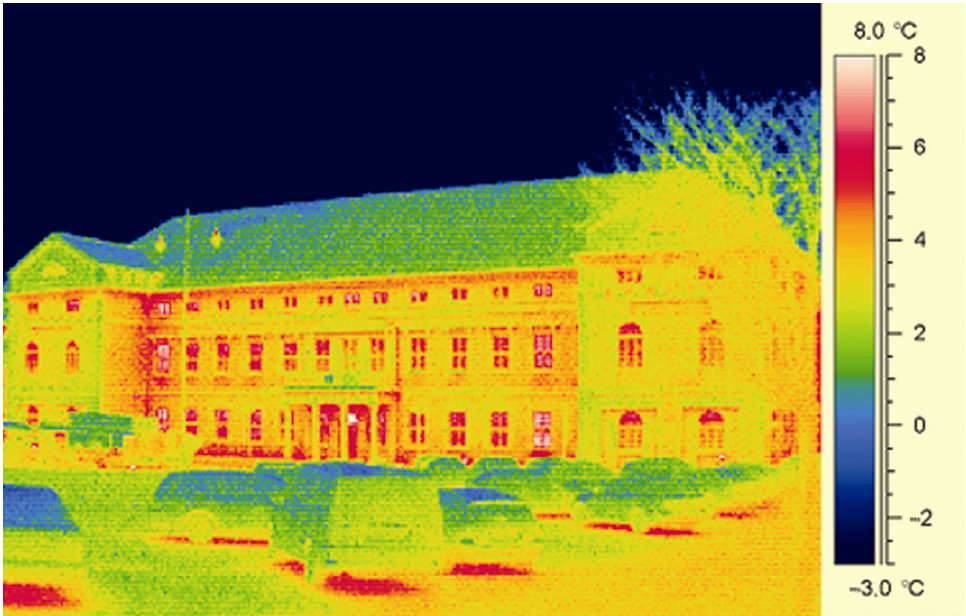


Fig. 3. Thermogram of the town hall of the Hanseatic city of Wismar.

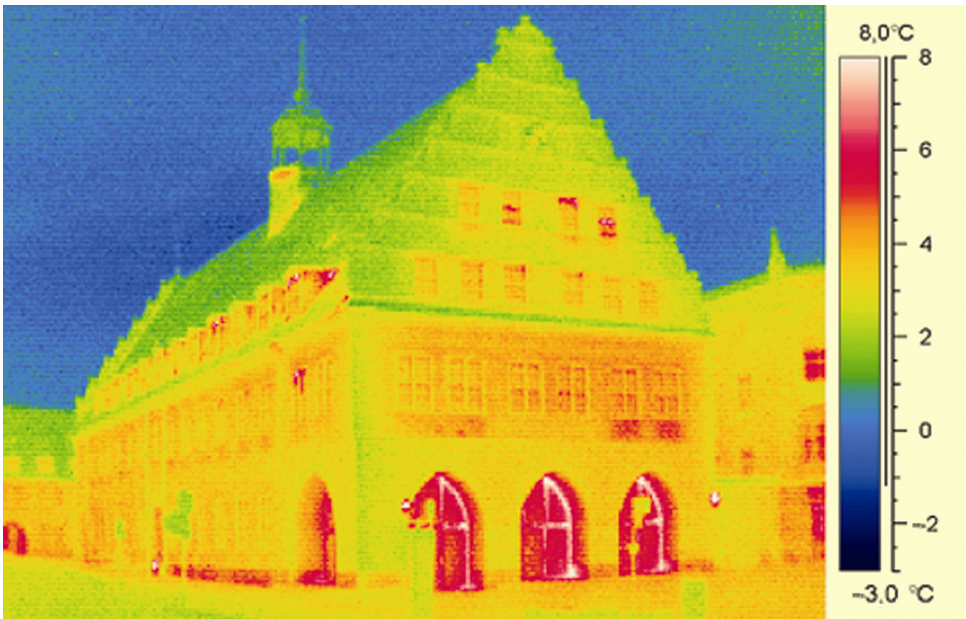
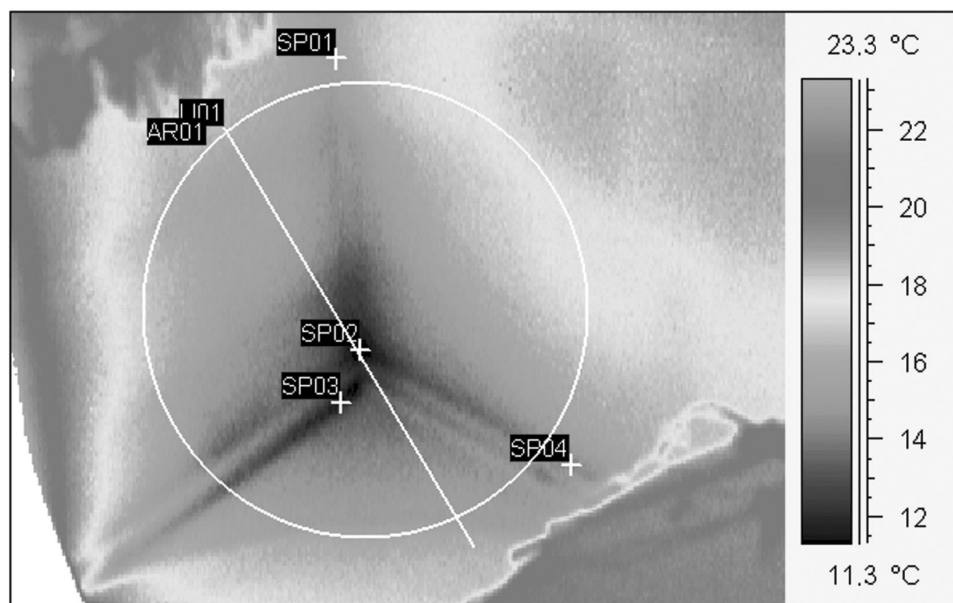


Fig. 4. Thermogram of the town hall of the Hanseatic city of Greifswald.



IR-Daten	Wert
Erstellungsdatum	10.02.2005
Erstellungszeit	08:16:21
Kameratyp	THV 550
Objekt-Parameter	Wert
Emissionsgrad	0.95
Umgebungstemperatur	19.8 °C
Relative Luftfeuchtigkeit	61%
Bezeichnung	Wert
SP01	15.5 °C
SP02	11.2 °C
SP03	11.5 °C
SP04	14.4 °C
LI01: max	16.6 °C
LI01: min	10.9 °C
LI01: max-min	5.7 °C
AR01: max	18.2 °C
AR01: min	10.8 °C
AR01: max-min	7.4 °C

Fig. 5. Complete report of the thermographic investigation a heat bridge with the growth of mold including a thermogram, real visual photograph and measurement parameters.

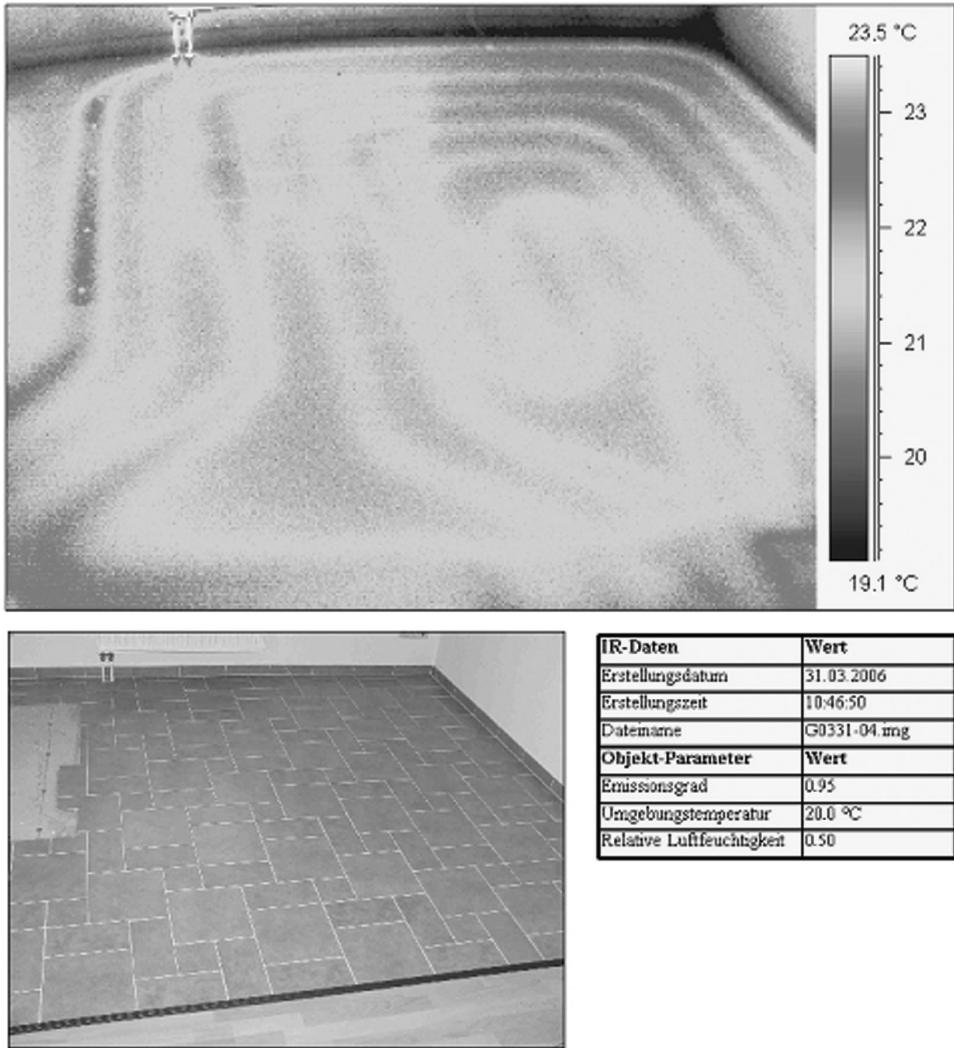


Fig. 6. Localization of the position of floor heating cables in the living room of a detached house.

be adulterated. Ideal conditions for the use of infrared thermography are outside temperatures around 0°C, no wind or rain and inside temperatures around 20°C. Then a temperature resolution up to 0.2 K can be reached. The temperature measurement error is about 2%.

Efficiency of the method is illustrated by thermograms of four town halls and for three particular cases of building inspection.

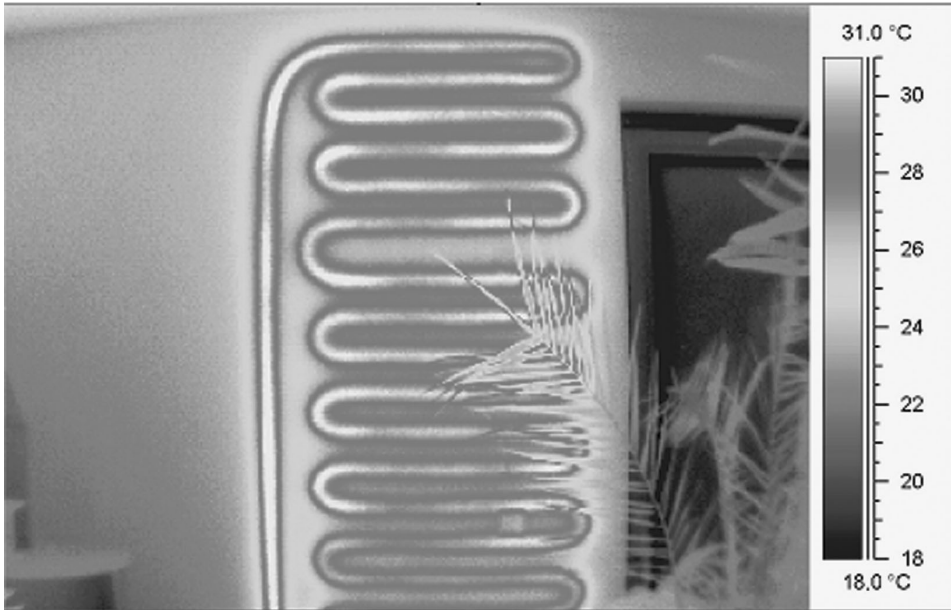


Fig. 7. Position of the pipes of a wall heater, operating with geothermal heat.

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Infrapunatermograafia rakendused ehituses

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Termograafia on omandanud kindla koha ehitiste diagnostikas ja analüüsis, kuid edasised arenguvõimalused on suured. Artiklis on esitatud infrapunatermograafia teoreetilised alused seostatuna ehitusmaterjalide ja -konstruktsioonide termiliste omadustega. Rakendusnäitena on toodud nelja Balti mere ääres asuva hansalinna (Rostock, Stralsund, Wismar ja Greifswald) raekoja termograafilise analüüsi tulemused.