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Influence of geometrical effects on the wall corner temperature in buildings

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Abstract

Thermographic measurements on a wall of a building show clearly a decrease of temperature in the neighborhood of a corner. The same problem has been numerically modelled by taking thermal conduction inside the wall and convection on both sides into account. The modelling confirms the experimental measurements. A simple physical explanation is that a corner provides more "material" for thermal conduction than a flat wall so that the temperature at the inside is lower. The cooling surface outside is larger then inside the corner, which results in higher heat transfer. The opposite phenomenon is observed at the outside of a building. The paper is mainly devoted to camera operators making thermal insulation inspections frequently. In many practical cases the reports contain the wrong interpretation of the effect presented in this paper.

Keywords: thermographic measurements, thermal modeling, heat transfer in buildings.

Wpływ efektów geometrycznych na rozkład temperatury w narożnikach ścian budynków

Streszczenie

Pomiary termowizyjne wewnątrz pomieszczeń budynków zazwyczaj pokazują spadek wartości temperatury w okolicy narożników. Ten problem termiczny został zbadany na drodze modelowania transferu energii przy uwzględnieniu konwekcyjnego przejmowania ciepła po obu stronach przegrody. Wyniki modelowania potwierdziły wyniki eksperymentów. Spadek wartości temperatury w narożach budynków jest zawsze obecny i wynika z większej masy przegrody i innej powierzchni przejmowania ciepła po obu jej stronach, a co za tym idzie zwiększonej wymiany ciepła na zewnątrz przegrody. Jak wykazały symulacje i pomiary wartość temperatury w narożniku może obniżyć się nawet o 20% w porównaniu w temperaturą na ścianie. Należy podkreślić, że przy przepływie ciepła do wewnątrz budynku efekt ten skutkuje wzrostem wartości temperatury w narożniku. Praca została przedstawiona głównie dla praktyków, którzy stosują termowizję do badań stanu izolacji w budownictwie. Często zdarza się, że niektórzy operatorzy kamer termowizyjnych niewłaściwie interpretują spadek wartości temperatury w narożnikach. Ich wnioski sugerują brak izolacji w narożniku, co nie zawsze jest prawdą.

Słowa kluczowe: pomiary termowizyjne, modelowanie termiczne, przenikanie ciepła przez przegrody budowlane.

1. Introduction

If one measures the temperature along the internal side of the wall of a building, one observes generally a uniform temperature. Depending on the wall insulation, this temperature is slightly lower than the inside room temperature. Of course, in the neighborhood of a window or a heat source of the central heating system, the temperature variation can be quite different. Near a corner a temperature decrease is observed. An obvious physical explanation is that at a corner there is more material available for heat transfer by conduction and convection at the outer side of the building.

In this paper we will provide some experimental measurements performed with infrared thermography. Then a theoretical analysis of the problem will be outlined. Finally, a numerical simulation of the problem will be added, too.

2. Experimental measurements

Fig. 1 shows thermographic measurements of a wall in the neighbourhood of a corner [1]. As one can observe clearly, there is a temperature drop going to a minimum in the corner point itself. The temperature drops from roughly 24.2 °C to 21.3 °C.

Near the ground the effect is even more pronounced, which is clearly visible in the first image (Fig. 1). The phenomenon is the same because a corner near the floor can be considered as a spherical three dimensional corner, where the effect is even more pronounced. In the next sections we will limit ourselves to the two dimensional case.

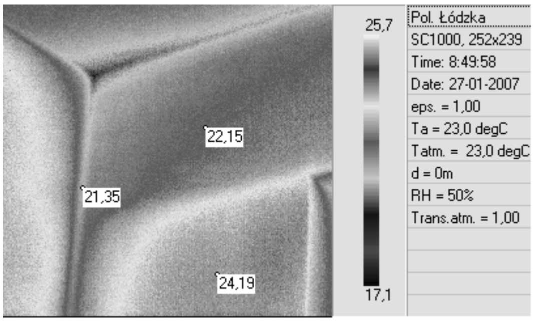

Fig. 1. Thermographic measurement of a wall near a corner
Rys. 1. Obraz termowizyjny narożnika

3. Analytical calculation

To simplify the calculation we assume that the outer side of both parts of the wall is isothermal say T=0. Inside the building we have a constant room temperature say T_0 (e.g. 20 °C). The heat transfer coefficient is h, the thermal conductivity of the wall is k and its thickness is a.

It is also assumed that the wall is made of a homogeneous material, not a mixture of bricks and insulating materials.

Due to symmetry only one half has to be considered as displayed in Fig. 2.

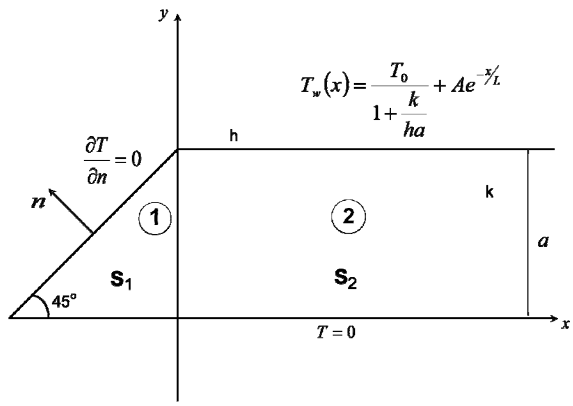

Fig. 2. Cross section of the wall
Rys. 2. Przekrój przez modelowaną strukturę

In the wall we have to solve the Laplace equation

$$\nabla^2 T = 0, \tag{1}$$

together with the boundary conditions:

$$T = 0 \;\; at \;\; y = 0, \tag{2}$$

$$\frac{\partial T}{\partial y} + h(T - T_0) = 0 \;\; at \;\; y = a, \tag{3}$$

$$\frac{\partial T}{\partial n} = 0 \;\; at \;\; y = x + a. \tag{4}$$

An exact analytical solution for this problem is not possible but a good approximation can be found by using variation calculus. It can be proved that the following functional

$$J = \iint_{S_1+S_2} (\nabla T)^2 dxdy + \frac{h}{k}\int_0^\infty (T - T_0)^2 dx, \tag{5}$$

is extreme if the temperature distribution satisfies the equation (1) together on condition we input temperature function T(x,y) in (5) which satisfy all the boundary conditions (2), (3) and (4).

For a one dimensional wall, the inside wall temperature is in steady state given by

$$T_w = T_0 \frac{1}{1 + \frac{k}{ha}}. \tag{6}$$

Hence, we propose for the internal wall temperature in the neighborhood of a corner a relationship

$$T_w(x) = \frac{T_0}{1 + \frac{k}{ha}} + Ae^{-x/L}, \tag{7}$$

where both A and L are still unknown at the moment.

In the half infinite rectangle (2) (Fig. 3) we propose the following trial function

$$T(x, y) = \left(\frac{T_0}{1 + k/ha} + Ae^{-x/L} \right) \frac{y}{a}, \tag{8}$$

and inside the triangle we propose

$$T(x, y) = \frac{(x + a)y}{a^2} \left(T_0 \frac{1}{1 + \frac{k}{ha}} + A \right). \tag{9}$$

From (8) and (9) one can evaluate the temperature gradient and insert the result in (5). Because the value of the function must be extreme, we can then look for the maximum value of (5) as a function of the two parameters A and L. By evaluating

$$\frac{\partial J}{\partial A} = 0 \;\; and \;\; \frac{\partial J}{\partial L} = 0, \tag{10}$$

one obtains:

$$\frac{A}{T_0} = -\frac{ha/k}{1 + ha/k} \frac{1}{1 + \sqrt{3(1 + ha/k)}}, \tag{11}$$

and

$$\frac{L}{a} = \frac{1}{\sqrt{3(1 + ha/k)}}. \tag{12}$$

It turns out that for all possible value of h, k and a the value of L/a is always less than $1/\sqrt{3} \approx 0.577$. Note that A is always less than zero, proving that the temperature must decrease towards the corner. It also turns out that ha/k is the crucial parameter of our problem.

Some graphical representation of the analytical results will be shown in the next section.

4. Numerical calculations

The same problem shown in Fig. 3 was solved numerically using the COMSOL MULTIPHYSICS® finite element software [2]. Fig. 3 shows the values of A/T_0 as a function of the dimensionless parameter h·a/k. The numerical values are compared with the analytical solution (11). The agreement is rather good taking into account the analytical calculation is not an exact one but an approximate method starting from estimated trial functions (8) and (9).

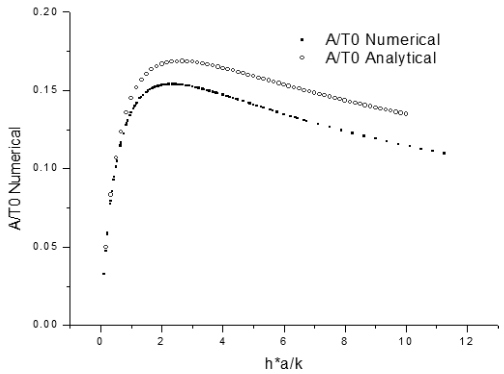

Fig. 3. Quantity A/T_0 as a function of $h{\cdot}a/k$
Rys. 3. Wielkość A/T_0 jako funkcja $h{\cdot}a/k$

Figure 4 displays the normalized characteristic length L/a versus $h{\cdot}a/k$. A good agreement with the analytical (12) is obtained.

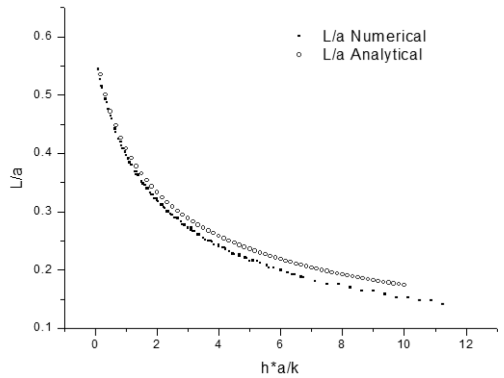

Fig. 4. Quantity L/a as a function of $h{\cdot}a/k$
Rys. 4. Wielkość L/a jako funkcja $h{\cdot}a/k$

For the numerical calculation the thermal conductivity k was chosen in the interval (0.8 – 2.8 W/m·K), the heat transfer coefficient h was varied between 1 W/m^2K and 30 W/m^2K and two wall thicknesses a=0.3 and a=0.4 m were used.

For the special case k=1.8 W/m·K, a=0.3 m, h=10 W/m^2K and T_0=20 °C the inner wall temperature is shown in Fig. 5.

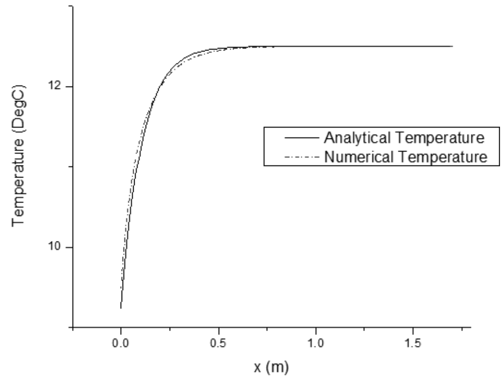

Fig. 5. Temperature distribution on the inner surface (x=0 is the corner)
Rys. 5. Rozkład temperatury w narożniku wewnątrz budynku (x=0 oznacza narożnik)

Then numerical curve almost coincides with the analytical approximation. This result also proves that the inner wall temperature can be very well represented by a simple exponential function, hence the problem can be fully characterized by just two parameters: A and L.

5. Conclusion

From thermographic measurements it was observed that the temperature of inner wall decreased towards a corner. The same problem was also analyzed using an analytical approximation and numerical solution.

It must be pointed out that this corner effect is purely geometrical. Other phenomena, like moisture, can also give rise to similar observations.

More and more thermographic investigations of building are now being performed. The aim of this research was to convict and warn the people doing the inspections how the temperature distribution in the wall corners can be interpreted.

6. References

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