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DETERMINE THE THERMAL EFFECTS OF VACUUM SECLUDE PANEL USING A NON-FIXED LEVELED SOURCE SENSOR

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ABSTRACT

Reducing the energy consumption of buildings is necessary to achieve the goals and regulations of the European Union. One way to reduce energy consumption is to use vacuum insulated panels (VIPs) on the building envelope. Field measurements are required to ensure that the declared thermal properties of the VIP match the installed panels. Using the Transient Plane Source (TPS) method, you can quickly measure the thermal properties of a variety of materials. However, due to the large isotropic nature of the VIP, it is difficult to interpret the temperature rise of the TPS sensor. In this article, we will compare polystyrene and polystyrene and aluminum foil analysis solutions, numerical simulations, and TPS measurements. Instead of VIP, polystyrene and aluminum were used to increase the number of installations. Numerical simulation samples were validated by comparing the simulated temperature rise with a polystyrene sample analysis solution. The simulated temperature rise in the polystyrene sample after 40 seconds was 7.8% higher than the TPS calculation. Loss of TPS sensor wire, inaccuracy in material parameters, and surface resistance can account for the deviation.[12]

KEYWORDS

Thermal properties; Non-fixedlevelled source; Vacuum secluded panel; Analytical solution; Numerical simulation; Measurement;

INTRODUCTION

In Europe, much attention is paid to reducing the energy demand for heating buildings. The European Parliament has set targets to cut energy consumption by 20% in 2020 and 50% in 2050. Achieving these goals will require energy upgrades to existing home inventory. One possible way to reduce heating energy requirements is to use vacuum insulated panels (VIPs) on the building envelope.

VIP consists of a porous core material surrounded by a metallized multilayer polymer film. The film is susceptible to damage and creates thermal bridges around the panel. The initial thermal conductivity of the panel is 4 mW/(m·K), but a thermal conductivity of 7-8·mW/(m·K) should be used in the calculation considering the effect of aging (Simmler et al., 2005)[11]. When the panel is perforated, the thermal conductivity increases to 20 mW/(m K) for VIP with colloidal silica in the core. Therefore, it is important to ensure that the panels installed on the building envelope are intact and have the declared thermal conductivity.

Measurement of the thermal conductivity of a construction site is difficult with modern methods. The measuring method is integrated into the quality assurance process of the VIP production line. The thermal conductivity of a panel can be determined through the heat dissipation built into the core material with a fibrous material whose thermal conductivity is known at various pressures. The thermal sensor is placed on the surface of the panel next to the radiator for a specified amount of time. The decrease in sensor temperature is recorded and the internal pressure of the VIP can be determined using the known relationship between the decrease in temperature and the thermal conductivity of the fiber material (Caps, 2004)[2]. It will be interesting to investigate whether the method described by

Caps (2004)[2] can be improved and can be used to measure VIPs in situ without thermal insulation. Early work by Johansson et al. (2011)[6] compared the temperature rise of a transient planar source (TPS) sensor with a numerical 3D simulation. The results showed that the TPS method can be modified to be applicable to VIP measurement.

The purpose of this study is to investigate the TPS method in more detail to measure the thermal properties of VIP and to investigate the applicability of the TPS method. A numerical counterfeit sample of polar coordinates was used with the analytical solution to calculate the temperature rise of the TPS sensor in two different settings.

A constant power of 0.02 W was applied to the coil and the electrical resistance was recorded and converted into a temperature rise. Measurements are based on 8 consecutive measurements with a 30-minute break in between.[12]

THE NON-FIXED LEVELED SOURCE METHOD

Before you start measuring and simulating the TPS method, we recommend that you familiarize yourself with the measurement method. The TPS method uses a 10 µm thick circular nickel double helix sandwiched between two layers of 25 µm thick Kapton (polyimide film) each in contact with the material sample. The spiral acts as a heat source and resistance thermometer. A probe is held between two samples of the same material and a constant power is applied spirally. As heat is generated, the temperature rises, which increases the resistance of the coil. The rate at which the temperature rises depends on how quickly the heat generated by the coil isdissipated through the surrounding material. Heating continues for a while while the coil voltage is recorded. Since the power remains constant, the voltage changes proportionally to the change in coil resistance. Knowing the change in voltage over time, i.e., the change in temperature over time and the heat flux, we can calculate the thermal conductivity and volumetric heat capacity of a material. Many comparative studies of TPS versus steady-state measurement techniques are described in the literature. Results were compared to steady-state measurements using a heat anemometer. The TPS results appeared to follow the same trend as the normal measurements. Periodic testing of the steady-state method has shown an accuracy of ±2.5%, but the accuracy of the TPS method has not yet been evaluated. See also Almanza et al. (2004)[1] discussed the causes of deviations between steady-state and transient measurements. One of the suggested sources was the initial temperature difference between the heat flux sensor and the sample surface. The deviation was reduced by 7% by removing the first measurement point from the results. Other possible bias factors are the specimen stiffness, the average temperature difference across the specimen, and the specimen size used in both methods. Model (2005)[9] proposed a method to determine the thermal properties of laminated materials by increasing the temperature in the transient state based on the analytical solution using Green's function. The model gave a good agreement with the measures, and the numerical model was used to solve the unresolved problems. The TPS method was evaluated for 5 seconds with 1 W input power. The sensor was a nickel sensor enclosed in a 3.5 mm radius Kapton housing sandwiched between two 63.5 mm diameter composite disk samples. Calculations were performed for the first 5 s with a resolution of 0.025 s. By subtracting the first-time step from the following results, the results agree very well with the numerical calculations.[12]

NUMERICAL COUNTERFEIT SAMPLES

A numerical sample of an isotropic polystyrene enclosure and a polystyrene enclosure covered up with a thin aluminum film are described below. A numerical sample must account for several uncertainties regarding thermal properties and boundary conditions.

The counterfeit sample is based on a 3D case transformed into cylindrical coordinates. The TPS probe was fixed in the center of two identical material samples. If the heat does not reach the sample boundary during a short design period, the device can be viewed as a cylindrical body (see Figure 1).

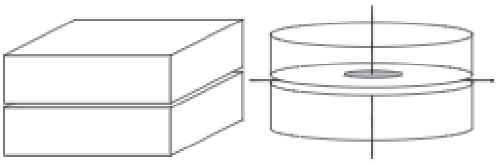

Figure 1 Setup of the TPS measurements with the TPS sensor in the center between two samples of the isotropic material. The three-dimensional case was transformed into cylindrical coordinates.

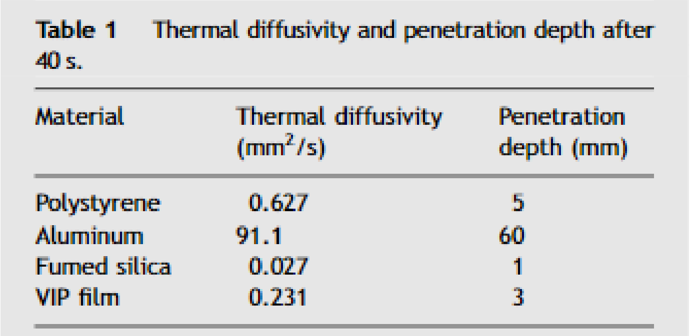

Table 1 Thermal diffusivity and penetration depth after 40 s.

Material	Thermal diffusivity (mm^2/s)	Penetration depth (mm)
Polystyrene	0.627	5
Aluminum	91.1	60
Fumed silica	0.027	1
VIP film	0.231	3

Table 1 shows the thermal diffusivity, a (m^2/s), and penetration depth, d_t (m), where half the possible temperature change has occurred after 40 s. The thermal properties were based on tabulated data.

The geometry of the numerical sample must be greater than the penetration depth after 40 s so that the heat does not reach the boundary of the sample.[12]

NUMERICAL COUNTERFEIT OF ISOTROPIC MATERIAL

One of the uncertain parameters in the calculations was the thermal properties of the material. A sampling of used polystyrene with thermal conductivity 0.032 W / (m K) and volumetric heat capacity 0.051 MJ / (m 3 K) was used in the counterfeit. The initial temperature was 0 °C, the time step was 10-3 s, and the calculation area was 0.02 × 0.02 m2. Cells produced a grid of 200 × 200 cells at 0.1 mm in both radial and vertical directions. Simulations were run for the first 40 seconds with a constant 0.02 W power supply applied to a 6.4 mm radius TPS sensor. Numerical simulations were performed using a numerical finite-difference calculation procedure in Matlab (MathWorks, 2009)[7] using the circular coordinates where the centroid of each computational cell is related to the thermal conductivity (Hagentoft, 2001)[5]. The basic figuring procedure is shown in Figure 2.

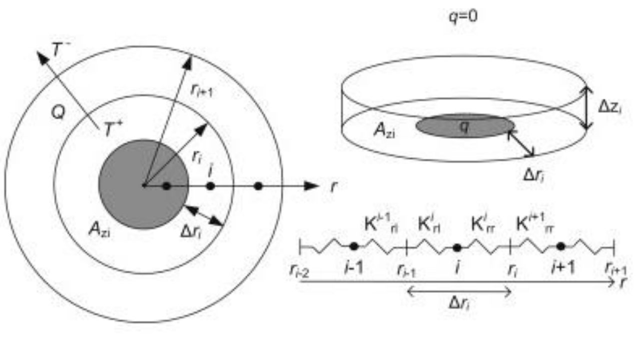

Figure 2 Principle calculation procedure where nodes in the center of each computational cell are connected with a thermal conductance.

Heat is supplied to the TPS sensor located in the center of the facility and all other perimeters are insulated. That is, there is no heat flux across the boundary. The thermal capacity and thickness of the sensor are not taken into account in the model.[12]

NUMERICAL COUNTERFEIT OF ISOTROPIC MATERIAL COVERED BY A HIGH-CONDUCTIVE FILM

The numerical version wished a few changes to be relevant at the case with the isotropic cloth blanketed via way of means of the high-conductive movie. The required length of the computational cells reduced with the skinny movie which results in an extended computational time. In this version, the mobileular length changed into growing with the gap from the skinny movie with a 2.3% boom for every mobileular, beginning with five µm which changed into 1/2 of the movie thickness. The first cells have been placed withinside the movie and the primary mobileular withinside the polystyrene had the equal thickness. The numerical version changed into primarily based totally at the version for the isotropic cloth with an introduced high-conductive movie closest to the sensor as proven in Figure 3.

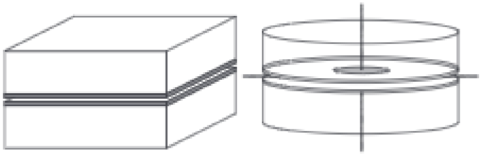

Figure 3 Setup of the TPS measurements with the TPS sensor in the center between two samples of the isotropic material covered by a high-conductive film. The three-dimensional case was transformed into cylindrical coordinates.

The high-conductive movie changed into a natural aluminum movie, 10 µm thick, with a thermal conductivity of 226 W/(m K) and a volumetric warmth capability of 2. five MJ/(m^3 K). The variety of computational cells changed into two hundred×six hundred with an growing length withinside the vertical course and continuously 0.1 mm withinside the radial course. The time step changed into five×ten^{-5} second and the calculations have been finished for the primary forty s with a regular electricity deliver of 0.02 W provided in a TPS sensor of six-point-four mm radius.[12]

DETAILED SOLUTION

The analytical answers for the warmth deliver over part of a rounded area were evolved previously (Carslaw and Jaeger, 1959)[3]. To validate the outcomes of the numerical version in Section (**NUMERICAL COUNTERFEIT OF ISOTROPIC MATERIAL**) the outcomes had been as compared to the analytical answers for the steady-nation and brief temperature for the equal setup. [12]

1. Steady-nation temperature as a result of the warmth deliver over a part of a rounded area.

Consider the steady-nation temperature in an endless or semi-endless medium as a result of a regular warmth deliver in a rounded place of the cloth boundary. The analytical answer for this hassle became derived from (Carslaw and Jaeger, 1959)[3]:

$$T=\frac{qA}{\lambda}\int_0^{\infty}\frac{e^{-sz}J_0(sr/R)J_1(s)}{s}ds \qquad (1)$$

wherein T (°C) is the temperature growth because of a warmth deliver over a round place A (m^2) withinside the area z>zero with regular warmth flux q (W/m^2) over the round place with radius R in a cloth with thermal conductivity λ (W/(m K)). J_1 and J_0 are the Bessel capabilities of the zeroth and primary order of the primary kind.The simplified answer for the common temperature over a rounded area at z=zero became additionally derived from (Carslaw and Jaeger, 1959)[3]:

$$T_{av}=\frac{2q}{\lambda}\int_0^{\infty}\frac{J_1(sR)}{s^2}ds=\frac{8qR}{3\pi\lambda} \qquad (2)$$

wherein Tav (°C) is the common temperature over the circle with radius zero provided warmth flux q over the radius R in a cloth with thermal conductivity λ. [12]

2. Transient temperature growth as a result of the warmth deliver over a part of a round area

When thinking about the brief temperature growth in an isotropic cloth because of a regular warmth deliver, the answer receives extra complicated. Carslaw and Jaeger (1959)[3] derived the answer for the point (r, z) at time t (s):

$$T=\frac{qR}{2\lambda}\int_0^{\infty}\frac{J_0(sr/R)J_1(s)}{s}\{A-B\}ds \qquad (3)$$

$$A=e^{-sz/R}\operatorname{erfc}\left[\frac{z}{2\sqrt{at}}-\frac{s}{R}\sqrt{at}\right] \qquad (4)$$

$$B=e^{sz/R}\operatorname{erfc}\left[\frac{z}{2\sqrt{at}}+\frac{s}{R}\sqrt{at}\right] \qquad (5)$$

wherein q is the provided warmth over the round place with radius R and z=zero withinside the cloth with thermal conductivity λ.

A generalized equation for the temperature at point (zero, zero, z) is (Carslaw and Jaeger, 1959):

$$T_{av}=\frac{2q\sqrt{at}}{\lambda}\left\{ierfc\frac{z}{2\sqrt{at}}-ierfc\frac{z^2+R^2}{2\sqrt{at}}\right\} \qquad (6)$$

$$ierfc(x)=\frac{1}{\sqrt{\pi}}e^{-x^2}-xerfc(x) \qquad (7)$$

wherein q, R and λ are described as above and a is the thermal diffusivity of the cloth. [12]

RESULT

The numerical model was validated by comparing the simulation results with the results of the analysis solution. The simulated temperature rise at the center of the sensor and the average of the sensor surface was compared to the temperature rise calculated by the analysis solution. The simulated temperature rise was then compared to the TPS measurements.

The spread of eight consecutive TPS measurements can be expressed as a coefficient of variation. H. Assuming the standard deviation divided by the average of each measurement. The coefficient of variation for polystyrene was 0.14-40seconds, while the coefficient of variation for aluminum-covered polystyrene was 1.34-40 seconds. Therefore, repeated measurements using the TPS sensor will give less variable results.

Four analytical solutions were used. Two are quiesced and two are conditional. Figure 4 shows how the temporary solution changes over time. H. A few hours to get close to a stationary solution.

The two transient analysis solutions reach the temperature of the stationary solution after a while. Therefore, you can use a transient analysis solution to validate your numerical model until steady state is reached.There was a slight discrepancy between the analytical and numerical simulations of polystyrene accumulation shown in Figure 5. The deviation was greater at the mean temperature in the sensor area than at the central point of the sensor. This can be partially explained by the fineness of the distribution of the computational grid and the boundary conditions of the numerical model.[12]

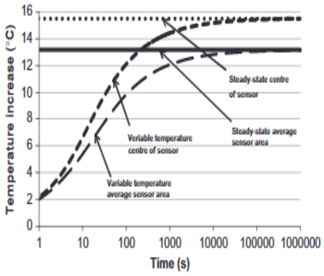

Figure 4 Comparison of the analytical solutions for steady-state and transient conditions in the center of the sensor and in the average of the sensor area.

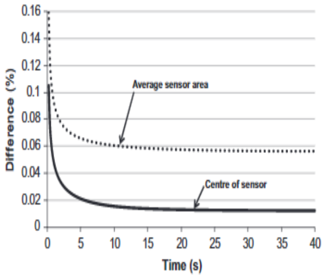

Figure 5 Difference between the analytical solutions and numerical model for the polystyrene setup. The differences have been divided by the temperature increase in the numerical simulation after 40 s.

CONCLUSION

The purpose of this study was to investigate the applicability of using TPS sensors to determine the thermal properties of layered materials in which a less conductive core is covered with a highly conductive thin film. Numerical simulation and analysis solutions were used to model the temperature rise of the TPS sensor in pure polystyrene samples.The temperature rise of the analytical solution and the numerical model of the isotropic polystyrene structure matched very well with a small deviation. Comparing the temperature rise in the numerical simulation of the structure using polystyrene with the TPS measurement, the difference after 40 seconds was very large. For aluminum-coated polystyrene, the deviation in temperature rise after 40 seconds was smaller than that of polystyrene. The temperature was much higher in polystyrene-based structures than in aluminum-covered polystyrene. This demonstrates the importance of heat transfer through the foil.

Thermal properties and other uncertainties B. Surface contact thermal resistance and wire loss between the TPS sensor and the TPS unit may contribute to the difference between the simulated and measured temperature rises.[12]

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