Heat Transfer - 1

A thin, flat heat flux sensor is mounted onto a thick aluminum plate as illustrated. It is a concern that the presence of the sensor will alter the heat flux to the plate. The surface of both the sensor and the plate has a gray body emissivitiy of $\varepsilon = 0.90$. The entire plate is maintained at a constant temperature of $T_p = 27°C$. The sensor has a thickness of $L = 100\ \mu m$ and thermal conductivity of $k = 0.28$ W/m-K. There is an adhesive layer with a contact resistance of $R'' = 0.0005$ m^2-K/W between the plate and the sensor. Assume one-dimensional conduction through the sensor to the plate. The plate and sensor are surrounded by a radiant heater (blackbody) that supplies a uniform incident heat flux to the surfaces of $q''_{inc} = 50{,}000$ W/m^2. Neglect any radiation emitted **from** the plate or sensor. In addition, there is air flow over the surfaces providing convection with a heat transfer coefficient of $h = 500$ W/m^2-K with the $T_o = 200°C$ air. Determine the following for this system at steady state conditions to analyze the effect of the sensor.

a) **(10 points)** Calculate the net radiation heat flux to the plate without the sensor present, q''_{rad}.

b) **(10 points)** Calculate the total convection and radiation heat flux to the plate without the sensor, q''_p.

c) **(40 points)** Now consider what happens with the sensor mounted onto the plate. The temperature of the sensor will be higher than that of the plate because of the added thermal resistance. Using the radiation heat flux from part a), the convection specifications, and the sensor and adhesive parameters, calculate the surface temperature of the sensor, T_s.

d) **(20 points)** Calculate the corresponding heat flux through the sensor, q''_s. How large is the error relative to the heat flux to the plate q''_p without the sensor?

e) **(10 points)** For the specified assumptions find a general expression for the ratio of the sensor heat flux to the plate heat flux without the sensor, q''_s/q''_p. This should be in terms of the thermal resistances in the problem only. The radiation heat flux and all temperatures should be eliminated from the expression. You may combine the sensor and adhesive resistances.

f) **(10 points)** What is the heat flux measurement error in the limiting case if the temperature of the air is the same as the temperature of the plate (27°C)? What is the cause of the error in this case?

Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ W/m^2-K