NISTIR 6242

ANNUAL CONFERENCE ON FIRE RESEARCH
Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

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Monte Carlo Simulations of Radiative Transfer in a House including Specular and Diffuse Reflections for the Evaluation of Two Wavelength Optical Fire Detectors

Y. R. Sivathanu, J. P. Gore and Y. J. Zhu
School of Mechanical Engineering, Purdue University
West Lafayette, IN 47907-1003

Fire detectors based on sensing thermal radiation from a starting fire have the potential to provide early warning and improve fire safety and reduce fire loss. However, these detectors must rely on sensing and discriminating radiation signals of a starting fire from those of common sources such as the sun, room lights and others. The radiation signal incident on a detector may have undergone multiple reflections at the walls with complex properties and configuration factors. Effective radiation temperature based on measurement of intensities at two wavelengths is one of the fire characteristics used in many flame sensors.

We have used Monte Carlo methods to simulate the radiative heat transfer in a simple house to examine the effects of spectral reflectivity of the walls on the radiation signal received by the detector. We also examined the effects of geometric parameters such as the sizes of the room with a fire and that of an adjacent room. The results show that the effective radiation temperature sensed by a two-wavelength fire detector depends on the spectral reflectivity of the walls and also on the number of reflections the photons have undergone. The later quantity depends on the angles of emission, configuration of the room, proportion of the specular and diffuse reflections. Therefore, the radiation temperature measured by a detector depends on all these properties in a non-trivial manner.

Figure 1 shows a sketch of a generic house considered in the present simulations. Only two rooms are considered for simplicity but additional rooms can be added in a modular fashion. We have constructed codes for rectangular and triangular enclosures of arbitrary aspect ratios and with the facility to place fires, detectors and openings at arbitrary locations. These modules can be combined to conform to the architectural plan of a house. In the present example, a fire occurs at the front wall of room 1, which has a triangular roof and a detector is placed on an inclined roof surface as shown in the sketch. The triangular enclosure of the roof is constructed using an imaginary surface separating it from the rectangular enclosure part of room 1. Room 2 is treated as a rectangular enclosure with a flat roof and is connected to room 1 with a full opening (marked as the second imaginary surface). The radiative transfer in the house can now be computed using interconnected program modules involving transfer in simpler enclosures. The fire, designated source in Fig. 1, is assumed to have an effective temperature of 1500 K. We track close to 18 million photons in the enclosure to arrive at converged statistics for radiative transfer between all parts if the enclosure including the detector and the fire. Fewer photons can certainly be used if computational economy is of essence.

Figure 2 shows the temperature measured by the detector as a function of the length of room 1. Longer the room, the larger is the number of reflections that the photons undergo prior to incidence on the detector. The reflectivity of building materials at shorter wavelengths is higher. The results of Fig. 1 are with a reflectivity of 0.66 at 900 nm and 0.6 at 1000 nm and a specular component of 0.4. The estimated temperature can be higher by up to 400 K compared to the fire temperature. Figure 3 shows the effect of reflectivity on the error in the temperature estimate. If the walls are perfectly absorbing, all of the photons incident on the detector are from the source. Therefore, the detector estimates the radiation temperature accurately. As the reflectivity of the wall increases the error in the temperature estimate increases, reaching almost 700 K error for a reflectivity of 0.8. Figure 4 shows the effects of the length and radiative properties of room 2 on the estimated temperature. The top panel shows that independent of the aspect ratio, if the reflective properties of room 2 are identical to those of room 1, the photons incident on the detector are primarily from room 1. Therefore the error in the temperature estimate is rather insensitive to the length of room 2. On the other hand, if room 2 is made more reflective than room 1, the number of photons that have undergone reflections in room 2 and are incident on the detector increases. Therefore, the error in the temperature estimate is sensitive to the length of room 2 as shown in the bottom panel.

Statistical simulations of the type described in this paper can be useful in the design and placement of optical fire detectors. These simulations also provide guidelines for material selection.

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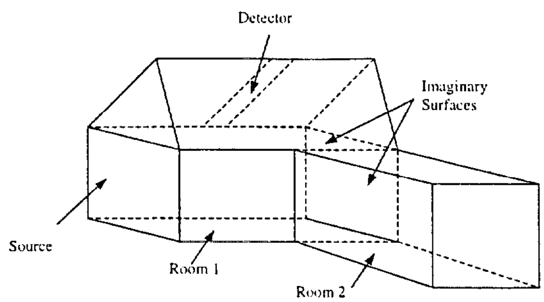

Figure 1: A sketch of a simple house for evaluation of radiative transfer.

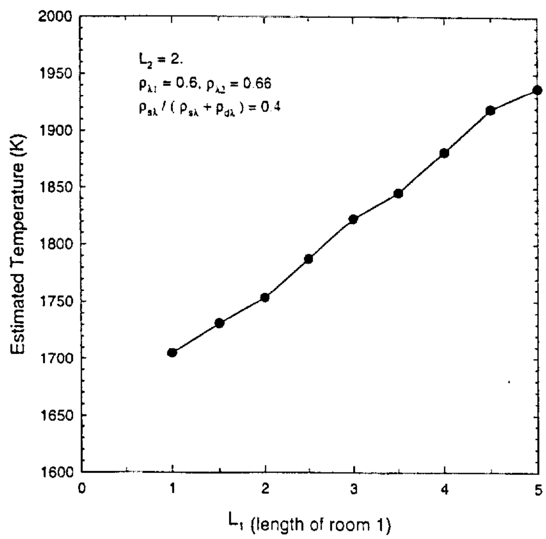

Figure 2: Estimated temperature as a function of length of room 1.

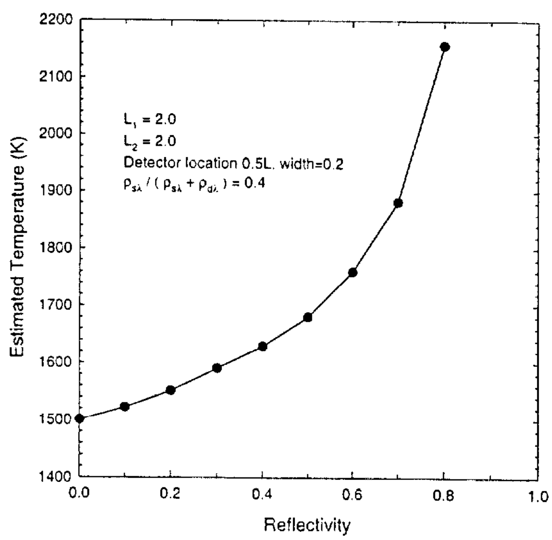

Figure 3: Estimated temperature as a function of reflectivity of the walls.

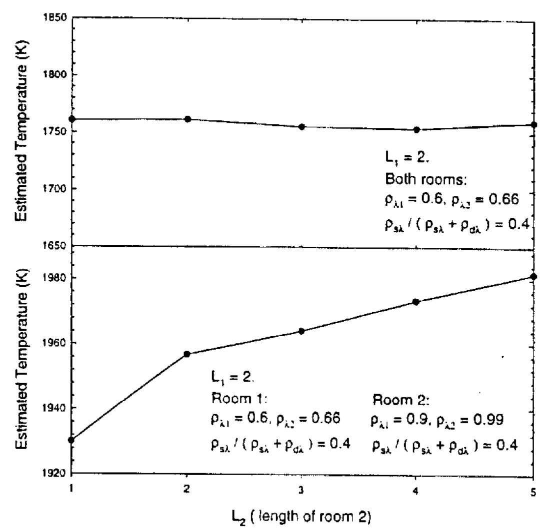

Figure 4: Effect if length and radiative properties of room 2 on the estimated temperature.