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PERFORMANCE ASSESSMENT OF NUMERICAL SIMULATIONS FOR GLAZING TEMPERATURES IN A COMPARTMENT FIRE

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ABSTRACT

The elapsed time before any glazed windows or doors crack and then subsequently fall out is an important criterion in the development and growth of a compartment fire. However before the structural integrity of the glazing panel can be assessed, the temperature distribution both across the panel and through the depth of the panel must be accurately known. Results are presented in this paper from a coupled computational fluid dynamics and heat transfer simulation of a fire in a compartment with a large glazed window, comparisons are made with recently obtained experimental data. The results demonstrate reasonable agreement with the experimental data but highlight a number of concerns regarding the modelling of glazed compartments when using accepted radiative gas property models in field model simulations.

INTRODUCTION

The use of glass in modern buildings, both for natural lighting and for architectural effect, is commonplace. During fire risk assessment it is typically considered that glazing systems will instantaneously fail at some prescribed temperature, for example when the local gas temperature attains 500°C, at which point, provided sufficient flow area exists, the fire is assumed to be over-ventilated. Clearly, with the increasing use of performance based design rules, a more fundamental approach to predicting the temperature and ultimately the time to failure of glazing systems is desirable. Field models, based upon the principles of computational fluid dynamics, offer the potential for describing the detailed behaviour of the whole compartment thermal system, including the interaction between the fire source and any surrounding surfaces, which may include glazed panels. However, the simulation of the coupled convection/radiation problem within both the gaseous combustion products and any semi-transparent media is considerably complicated by their very different radiative properties.

Heat transfer to a glass pane includes both convection from the hot combustion products within the ceiling layer and thermal radiation from the fire source and remote hot surfaces with additional conduction from the surrounding frame or window mount system. Whilst the simulation of convective heat transfer, and the limitations of existing models, is well understood, and no different to an opaque surface, the presence of a (semi-) transparent material introduces a number of complexities when simulating radiative heat transfer. In particular the spectral absorption coefficient can vary considerably from being almost transparent in the wave length range from about 1 to 2.75μm to almost wholly opaque at wavelengths greater than about 4.5 μm [1]. This necessitates models based

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upon spectral bands to describe the radiative properties of the semi-transparent material, such an approach has been reported, specifically for glass in conditions representative of a fire, by Virgone [2].

A typical fire in a compartment generates combustion products comprising CO_2, H_2O and solid particulates (smoke), each of which participates in the overall three dimensional energy balance. Solid particulates may be assumed to have emissivities close to unity and to behave as black bodies with respect to thermal radiation, emitting over all wavelengths. Carbon dioxide and water however display unique distributions of absorption coefficient with clearly differentiated lines, across the infra-red spectrum [3]. Furthermore, the local absorption coefficient in a non-homogenous mixture of gaseous species, resulting from a combustion process, is a complex function of wavelength, temperature, pressure and composition, integrated along a path length. Therefore a hierarchy of approximate models have been developed, ranging from narrow and wide band models which employ a statistical description of the line distributions within a band, to simple grey gas models with assumed mean absorption coefficients.

The concept of a weighted sum of grey gases represents the most widely used model to describe the optical properties of combustion products with a number of different coefficient sets available in the literature. Their popularity stems from the combination of ease of implementation and computational efficiency, indeed the majority of commercial CFD codes utilise variants of the concept. The approach has been shown to be capable of yielding accurate results for non-homogenous mixtures of H_2O/CO_2 with and without the presence of soot [4,5].

However by the very nature of a (multiple) grey approximation it is not possible to readily account for the spectral variation of the absorption coefficient of glass and hence its transmissivity. The principal objective of the work reported in this paper is to evaluate the potential of employing such a model for the gaseous radiative properties whilst approximating the optical properties of the glass by defining a total emissivity, reflectivity and transmissivity, each bounded between zero and unity, and through Kirchoff's rule, summing to unity.

METHODOLOGY

The approach adopted in the present work is based upon a coupled fluid flow / solid conduction calculation for the compartment and enclosing walls. The flow solver (SOFIE, Simulation of Fires in Enclosures) [6,7] obtains a solution for the Favre averaged Navier-Stokes equations, using the standard k-ε two equation turbulence model with buoyancy modifications. Combustion is simulated using either an Eddy-breakup model or a prescribed pdf laminar flamelet based model. Thermal radiation is simulated using a deterministic ray tracing technique with gaseous optical properties described by a weighted sum of grey gases model [8].

When thermal radiation takes place between opaque materials absorption, emission and reflection occurs on their free surfaces. In contrast, for (semi-) transparent materials absorption and emission can take place not just at the surface but through the depth of the material. In the present work the glass panes were assumed to be sufficiently thin for internal absorption to be negligible, therefore the ray tracing procedure was not continued within the glass itself. However three dimensional thermal conduction within the glass pane was accounted for.

RESULTS

During a series of experiments carried out by the University of Ulster [9], gas temperatures (vent, room corner), glass surface temperatures and incident total wall heat fluxes were measured in a test compartment with similar dimensions to a standard ISO compartment. The compartment, constructed from light weight concrete blocks with internal fibre insulation, contained a single open doorway at one end with a single glazed window system in a side wall.

Previous validation of the numerical model for similar compartment fires without windows has demonstrated good agreement with measured vent and room corner gas temperatures, giving confidence in the overall capability of the model [7]. Therefore the results reported in this paper concentrate largely upon glazing temperature prediction, rather than on sub-model validation. Steady state simulations were carried out for a 260kW pool fire fuelled by methanol (HRR determined by mass loss measurements), located in the corner opposite to both window and doorway. A series of predictions were obtained for a discrete set of glass optical properties ranging from almost wholly opaque to 'grey' radiation to wholly transparent with varying degrees of reflectivity.

Figure 1 provides a qualitative illustration of the compartment, the fire plume and the ceiling layer exhausting through the doorway. The baseline simulation specified zero transmissivity and a representative total emissivity equal to 0.85 (following Gardon [10]). Figure 2 depicts the predicted surface temperature distribution on the internal surface of the glazed panels for a total transmissivity equal to 0.9 and a total emissivity equal to 0.1. The presence of the ceiling layer is visible, the maximum temperature difference across the surface of the panel is over 150K, with a maximum predicted temperature of over 400K.

The predicted gas temperature in the vent and at one corner of the compartment shows reasonable agreement with the experimental data, figure 3. The layer height is well defined though the peak temperatures are over-predicted (note though that the experimental data has not been corrected for radiative loss). The choice of radiative property description for the glazed panel is seen to have little effect on the bulk gas temperature, suggesting that only a small fraction of the total energy release is transmitted through the glazing itself. The results are slightly inconsistent with previous simulations and validation of the numerical model for a compartment without glazing [7] which demonstrated good overall accuracy when radiative losses were taken account of. Reduction of the overall heat release rate would improve the predicted peak temperatures though there is no evidence to suggest experimental uncertainty in the methanol mass loss measurements.

Figure 4 presents a comparison between the predictions and experimental data for the internal surface temperature (4a) of the glazed panel and the local gas temperature (4b), for a range of total emissivity and transmissivity. The results clearly demonstrate that as the transmissivity increases the surface temperature decreases corresponding to less energy absorption. However the results do not portray the steep temperature gradient associated with the ceiling layer. The predicted values of local gas temperature demonstrate a similar level of accuracy to the compartment corner and vent locations, with the ceiling layer well defined but the maximum temperature over predicted. The glass surface temperature is a result of a thermal balance between internal conduction and external convective and radiative heat transfer. The experimental data implies that convective heat transfer is dominant, hence the clear transition across the ceiling layer, this is not reflected in the simulations, where radiative heat transfer contributes across the whole glazing panel from floor to ceiling.

CONCLUSIONS

The numerical results have demonstrated the potential capability for coupled CFD / conjugate heat transfer simulations to predict lateral temperature distributions over a glazed panel, a necessary precursor to detailed structural integrity calculations. The experimental data indicated that the internal surface temperature of the glass followed a similar trend, in both distribution and magnitude, to that of the local gas temperature. The simulations, whilst in reasonable agreement with gas temperatures, did not display the rapid transition in temperature across the ceiling layer, even when modelled as almost wholly transparent. One may conclude from this that glass cannot be modelled with a simple, optically 'grey', approximation if accurate surface temperatures are required. However the approximation does allow for reasonable prediction of gas temperatures. This conclusion is of direct importance to the application of many existing (commercial and research) CFD/radiation codes to the performance assessment of glazed compartments. Physically more representative simulations must be obtained, either by accounting for the spectral variation of the combustion products themselves in combination with the glass, or by determining a (multi-) grey approximation for glass itself.

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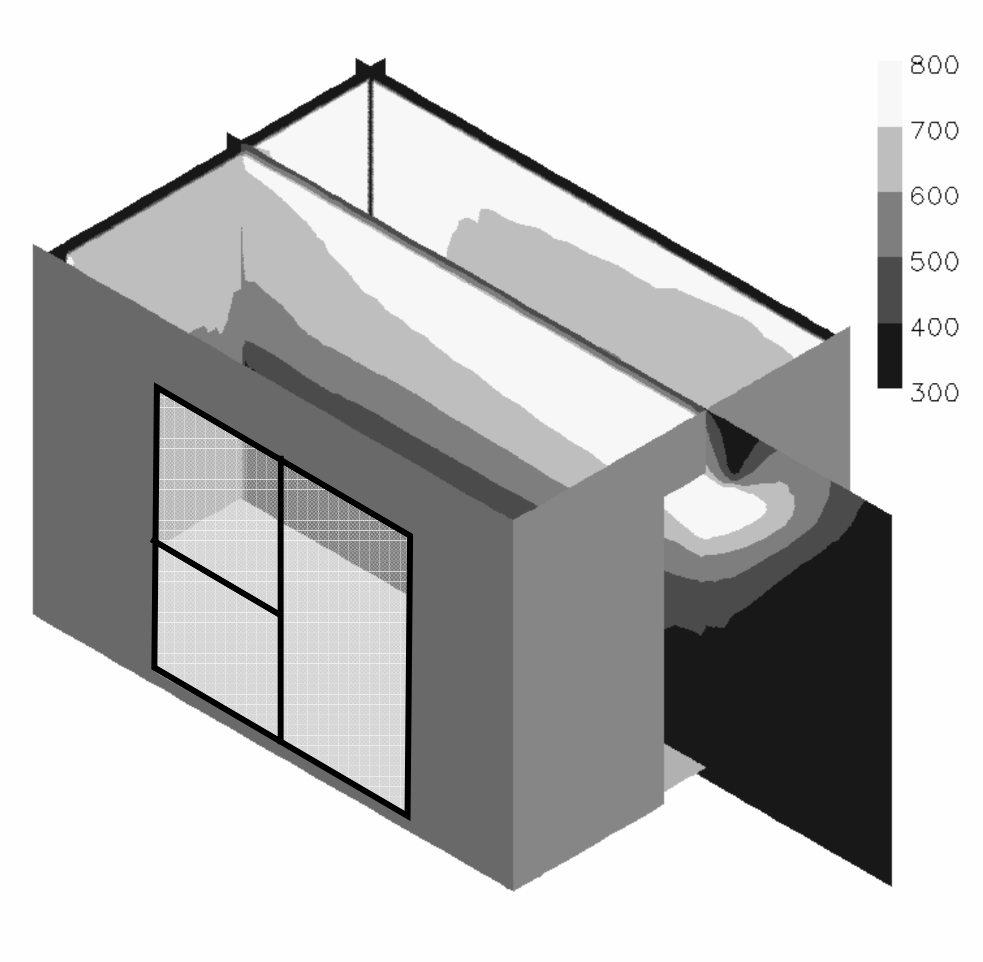

Figure 2: Compartment with corner fire and side window, temperature (K) isotherms illustrated

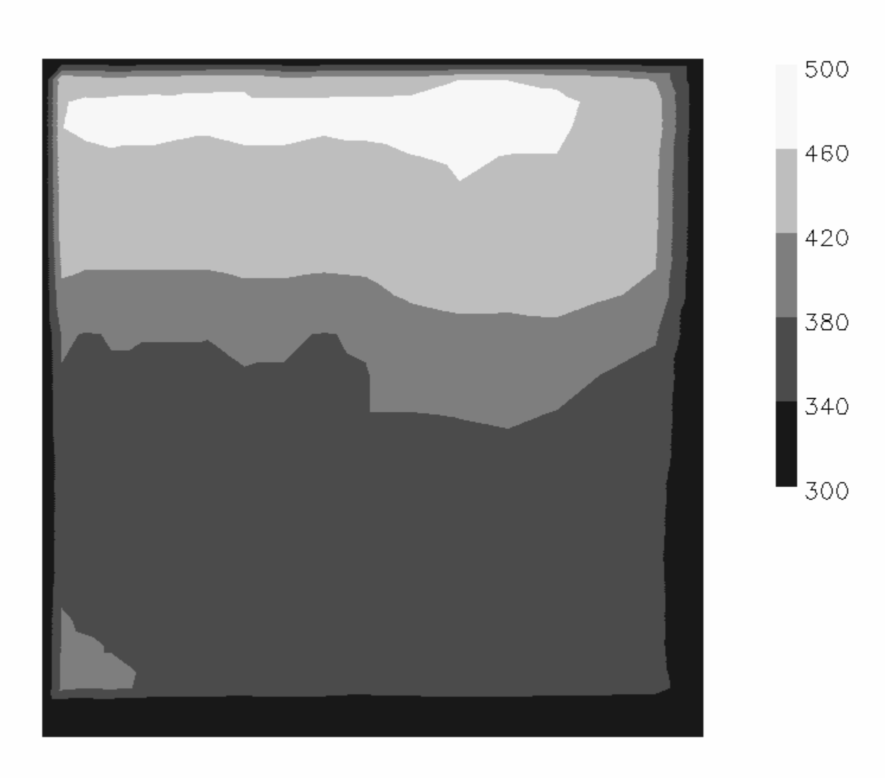

Figure 1: Surface temperature (K) distribution on glazing panel

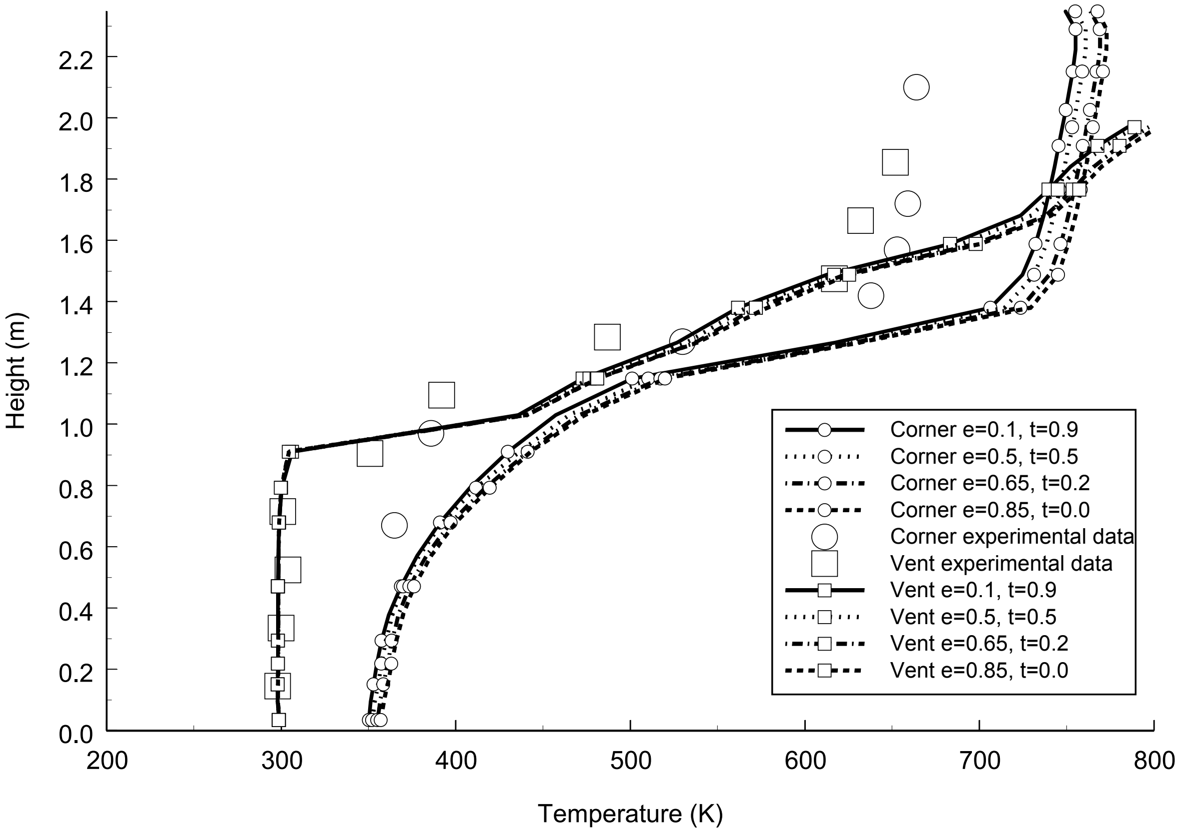

Figure 4: Vertical temperature distribution in room corner and at vent

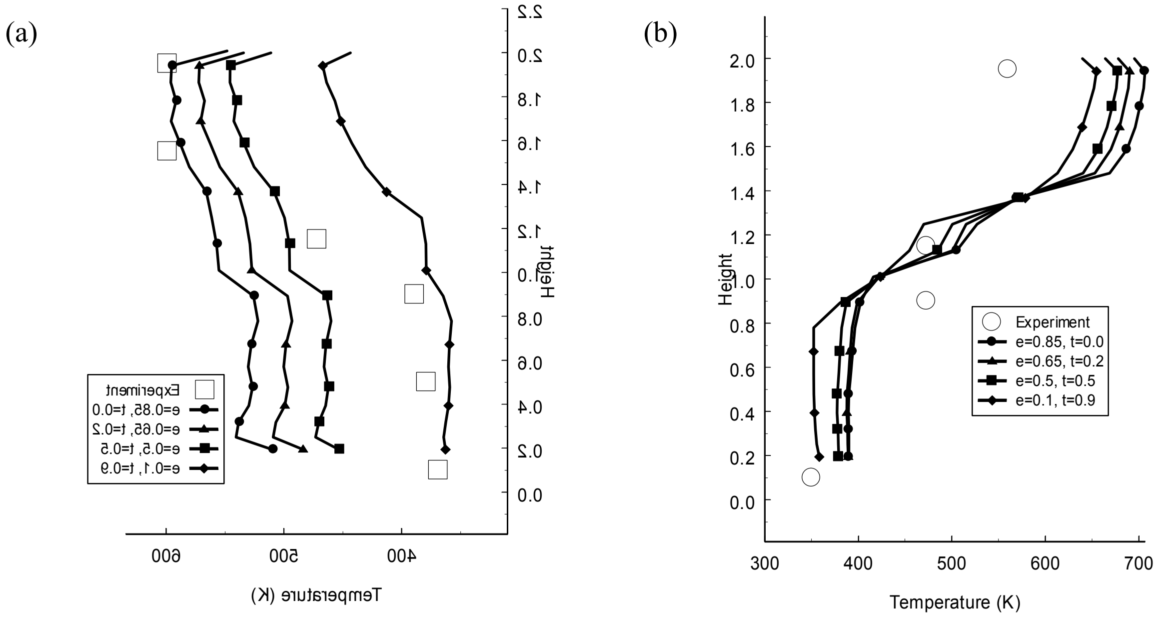

Figure 3: Vertical temperature distribution (a) on surface of glazing (b) local gas temperature