COMPARISON OF MODELED AND MEASURED TRACER GAS CONCENTRATIONS IN A MULTIZONE BUILDING

R.G. Sextro, J.M. Daisey, H.E. Feustel, D.J. Dickerhoff, C.Jump

Indoor Environment Dept., Lawrence Berkeley National Laboratory, Berkeley, CA, USA

ABSTRACT

Few detailed comparisons of modeled and measured pollutant concentrations in multizone buildings have been published. The COMIS air flow and contaminant transport model permits simulation of the effects of building and HVAC operation, as well as the influence of the local meteorology, on air flows within the building. We have recently used this model to simulate the release of a gas-phase tracer in a three-story, multi-room building located at Dugway Proving Ground, Utah, USA. Following detailed leakage and flow-path characterization measurements of the building, experiments were conducted in which tracer gas concentrations were measured as a function of time in each room of the building. Comparison of the simulations with these detailed measurements showed reasonable -- and in some cases, quite good -- agreement. The paper describes some details of the experiments and modeling and discusses the differences between the observed and the predicted concentrations.

INTRODUCTION

In conjunction with a series of field tests to investigate the consequences of a domestic chemical/biological incident, transport of airborne pollutants within buildings has been examined both experimentally and theoretically. Measurements of tracer gas concentrations as a function of time were conducted in a multizone building to provide experimental data against which several interior air flow models could be evaluated. In our case, we have used the COMIS air flow and contaminant transport model to simulate the transport and fate of inert gas-phase species in this multizone building. As there have been very few detailed experiments on the behavior of pollutant or tracer gas species in multizone buildings reported in the literature -- particularly in cases where the buildings have been well characterized [1,2, 3] -- this was an important opportunity for model-measurement comparisons.

COMIS is a modular model for simulating air flows among multiple zones in response to the complex, often interacting effects of building and HVAC operations and the influence of the local meteorology [4]. Among the effects simulated by COMIS are flows through cracks, large vertical openings (e.g. doors and windows), fans and duct systems [5]. Based on the assumption that the pollutant concentration within each zone is instantaneously well-mixed, COMIS also calculates, in response to the interzonal air flow, contaminant transport as a function of time via a series of mass-balance equations.

PHYSICAL CHARACTERISTICS OF THE TEST BUILDING

The tests were conducted in one unit of a multi-unit building located at Dugway Proving Grounds, UT. Each three-story unit contains a set of three-rooms on the first and second floors, topped by a single-room, unfinished attic (see Figure 1). The staircase connecting the floors has landings on each floor through which the open staircase passes. The unit contains an air-handling unit (AHU) that supplies air only to the first and second floor rooms. The

AHU has a single air return - a wall-mounted grille located on the first floor in room 1.2a (Fig. 1). Unducted air return registers mounted in the walls connect the rooms on the first floor only; there is no explicit air return to the AHU from the second floor. The AHU does not provide fresh air; it is only for internal air circulation.

Prior to the tracer gas experiments, LBNL researchers conducted extensive blower door tests on the building to determine interzonal flow parameters, leakage rates, AHU flows and operating conditions. The building characterization measurements suggest that the first floor rooms have relatively low leakage rates to the exterior and to the staircase while the second floor rooms and attic are very leaky. The large leakage rates between the rooms on the first floor are due to the presence of the air return registers, while the large leakage rates between the rooms on the second floor are due to large cracks in the floor and within the walls. The AHU air supply rates were measured with all doors open, including the entrance door into the unit. The pressure drops over the supply and return grilles are on the order of 20 Pa.

TRACER GAS RELEASE EXPERIMENTS

The twelve experiments explored different positions of the internal and stairway doors (open or closed), different release locations on the first floor, and different states of AHU operation (on or off). In nine experiments, tracer gas releases were made at the return plenum of the AHU (which was always on for these tests) in room 1.2a, and in three experiments, the tracer gas was released in the center of room 1.3. The nine experiments were grouped into three sets, each set corresponding to a different position of the interior doors (all doors open, staircase doors closed, all doors closed). For the three releases in room 1.3 -- all of which were done with the staircase doors closed and the remaining interior doors open -- two were done with the AHU in operation and one with the AHU switched off. To capture the influence of the weather conditions on tracer gas transport, the three releases in each set were done at different times of the day (morning, mid-day, or afternoon).. There were no mixing fans to provide tracer gas mixing within each zone, apart from the mixing induced by the air flow from the AHU.

During the experiments, measurements of indoor air temperatures and propylene tracer gas concentrations were performed at 30-second intervals at the center of each room and on each of the three stairwell landings. Two measurement stations were located in room 2.2 - in the center of each half (i.e., at 2.2a and 2.2b in Fig. 1). Weather data were recorded at 15-minute intervals at two fixed sites within 2 - 3 km of the test building. The modeling groups used the weather and interior temperature data, along with the building characterization information, as input to their simulations, and reported the calculated indoor propylene concentrations before gaining knowledge of the measured concentrations.

The tracer gas was released by bursting a propylene-filled balloon containing approximately 20 g of material. However, the exact the mass of tracer gas released in each experiment was not measured, so it was necessary to adjust the predicted concentrations to facilitate model-measurement comparisons. We used the total amount of measured tracer gas within the building between five and ten minutes after tracer release as our normalization period.

Because of space limitations we only discuss in this paper the results of experimental trials 1 and 13 (one experiment had to be repeated), as they yield the best and worst results of the model-measurement comparison.

DISCUSSION OF RESULTS

Trial 1 (all doors open; release at AHU return; AHU on):

Figure 2 shows the measured and predicted tracer gas concentrations as a function of time for room 1.2a (the tracer release room). In this room, both mixing and transport times are fairly rapid with the AHU running and the measured and calculated concentrations differ very little. Comparing the measured and calculated tracer gas concentrations for the attic (room 3.1) provides a somewhat different picture (see Figure 3). COMIS overestimates the time-dependent tracer gas concentration. We believe this may be due to lack of mixing in the attic so that the large air leakage of the attic will exhaust the tracer gas entering through the staircase door before the gas can reach the sensor.

Trial 13 (staircase doors closed; release in room 1.3; AHU off):

In this trial the mixing of tracer gas in the unit and the transport into the upper floors is reduced because the staircase doors are closed and the AHU is off. The predicted and measured concentrations in room 1.2a are shown in Figure 4. The predicted and measured peak concentrations occur at about the same time, though the modeled concentration is lower than the measured for the first thirty minutes. The differences between measured and calculated concentrations for room 3.1 are shown in Figure 5, where the predicted and measured peak concentrations occur at about the same time. However, for almost three hours after tracer gas release there is more total transport of tracer gas into the attic than the model predicts. After that time COMIS over-predicts the concentration. As before, the lack of good mixing within the attic and the possibility that some of the tracer may be exhausted from the attic before reaching the sensor could explain the difference between the observed and predicted concentration decay.

Comparison of 'exposures':

Figure 6 shows the differences in exposure (i.e. the product of concentration and time between the modeled and measured values (as a fraction of the measured value) at various times after the tracer gas release for trial 1. The largest differences are seen for rooms 1.3 and 3.1 within the first five minutes after tracer release. After twenty minutes differences stay below +50 and –15% for all rooms of the unit. After an hour, exposure differences are reduced to less than 20% for all rooms but the attic. The large differences at the beginning of the decay period are again due to the modeling assumption of perfect mixing. In the case of the attic, the tracer gas needs some time to travel within the staircase from the first floor to the third floor landing. COMIS assumes that the tracer gas concentrations equalize immediately within the staircase.

The relative differences in exposure for trial 13 are shown in Figure 7. Because the AHU was off for this experiment, comparisons in exposure for 5, 10 and 20 minutes after tracer release are not very useful due to the lack of mixing. After 40 minutes, the largest differences are between the observed and predicted exposures in the second floor rooms. In contrast, the first floor rooms show differences of less than 25%. The are several possible explanations for the overpredicted exposure values on the second floor, including more rapid actual removal of tracer via ventilation to the outside than the model predicts.

CONCLUSIONS

The COMIS model performed well in the Dugway experiments when the model assumption of rapid mixing within a zone was met. Differences between measured and modeled values were largest in the 10 to 20 minutes immediately after the release, illustrating the lack of

adequate mixing time. Leakage characterization and pressure distribution of the attic and roof may not have been adequate due to the unusual shape of the roof. The assumption of perfect mixing is more difficult to meet when the AHU is not operating. particularly for zones which either have a large vertical dimension (staircase) or have high leakage values to the outside (attic).

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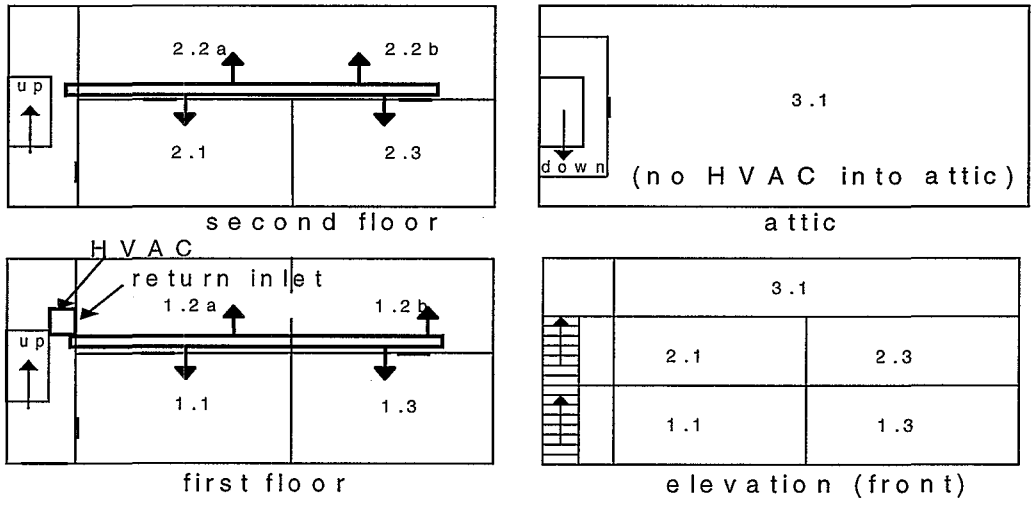

Figure 1: Plan and elevation views of the multizone unit. AHU supply flows are indicated by arrows.

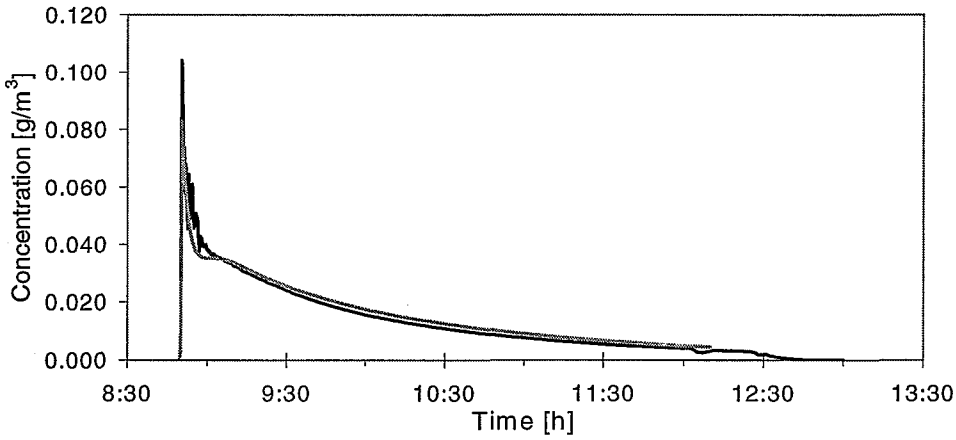

Figure 2: Trial 1 measured (black) and modeled (grey) gas concentrations for room 1.2a.

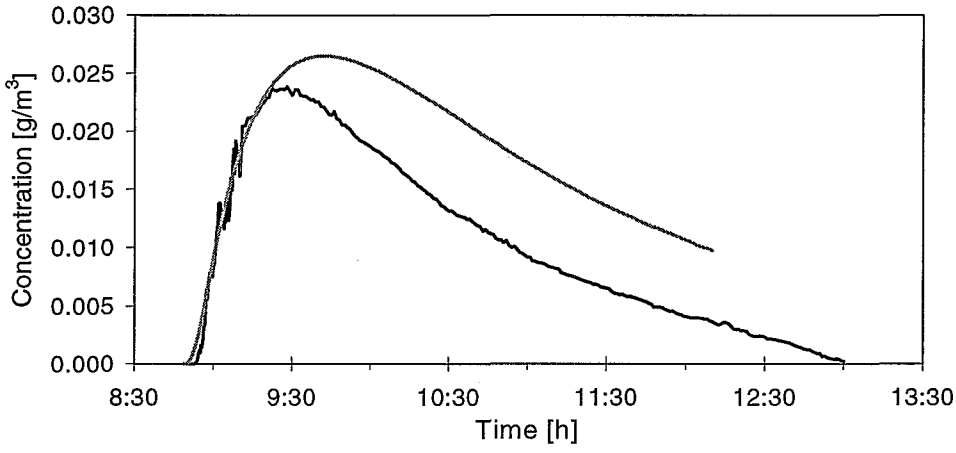

Figure 3: Trial 1 measured (black) and modeled (grey) gas concentrations for room 3.1.

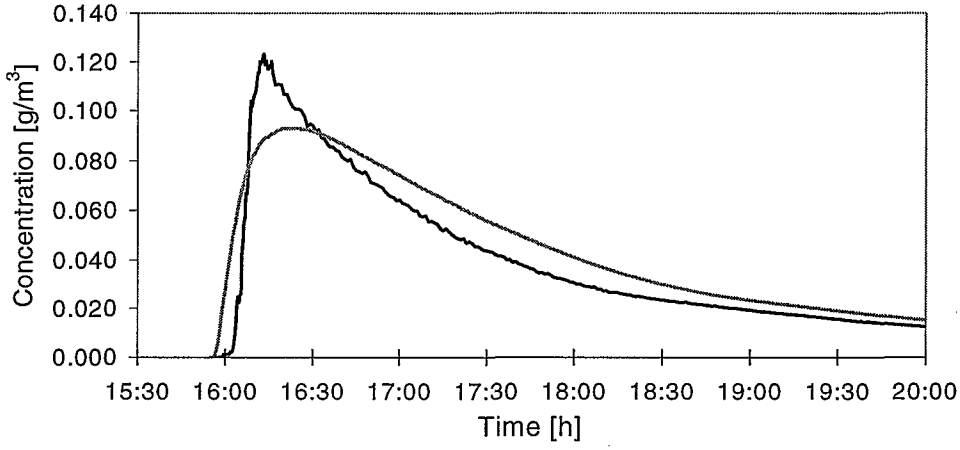

Figure 4: Trial 13 measured (black) and modeled (grey) gas concentrations for room 1.2a.

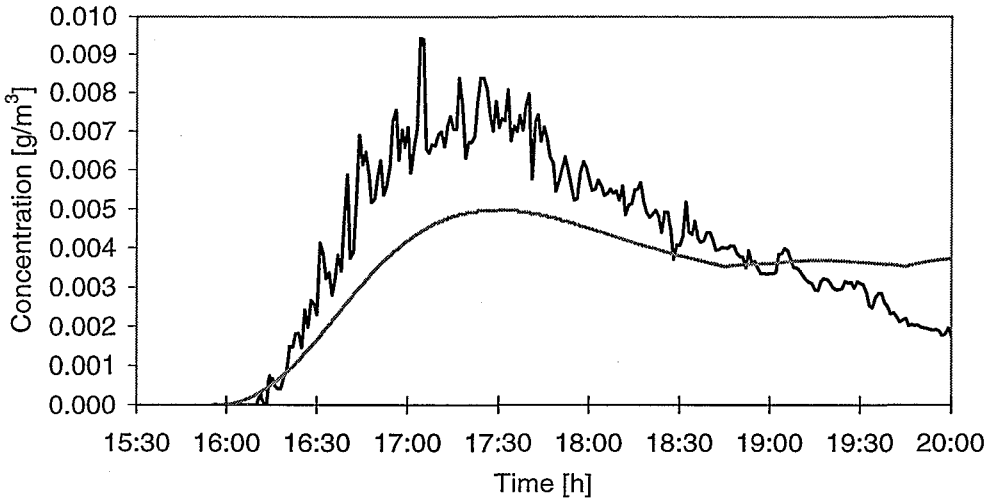

Figure 5: Trial 13 measured (black) and modeled (grey) gas concentrations for room 3.1.

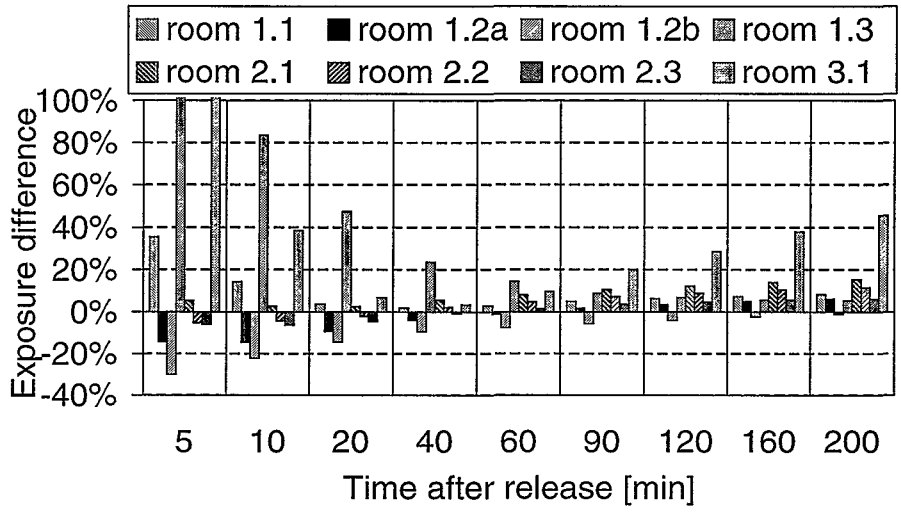

Figure 6: Difference between modeled and measured gas exposures over time for Trial 1.

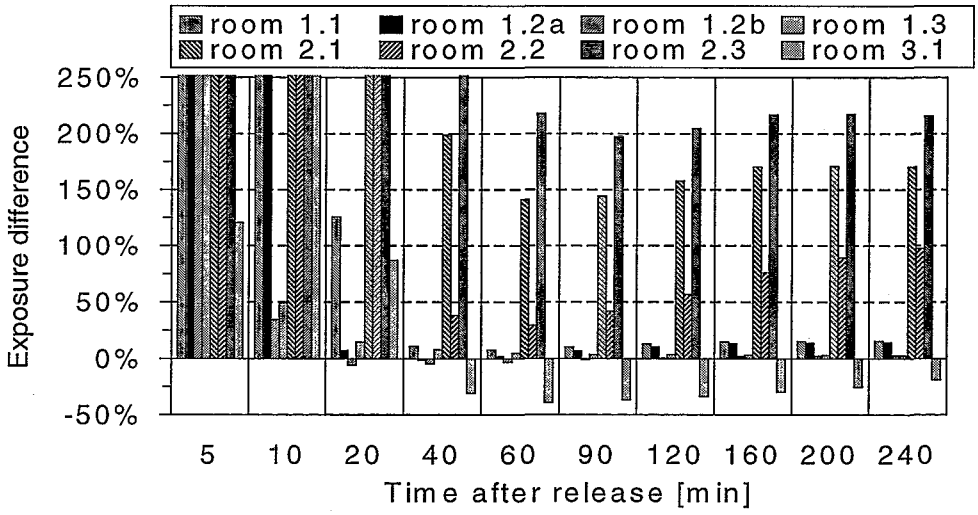

Figure 7: Difference between modeled and measured gas exposures over time for Trial 13.