4792

INDOOR ENVIRONMENT DEPARTMENT

PUBLICATIONS

1995 - 2003

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2003 PUBLICATIONS WITH ABSTRACTS

Alevantis, L.; Wagner, J.; Fisk, W.J.; Sullivan, D.P.; Faulkner, D.. Designing for Smoking Rooms. *ASHRAE Journal* 45(5):26-32. LBNL-53201. No Abstract available.

Apte, M.G.; Hodgson, A.T.; Shendell, D.G.; Dibartolomeo, D.; Hotchi, T.; Lee, S.M.; Liff, S.M.; Rainer, L.I.; Sullivan, D.P.; Fisk, W.J.. Simultaneous Energy Savings and IEQ Improvements in Relocatable Classrooms. To be published in *ASHRAE IAQ Applications*. 2003. LBNL-52690.

ABSTRACT
Relocatable classrooms (RCs) are commonly used by school districts with changing demographics and enrollment sizes. We designed and constructed four energy-efficient RCs for this study to demonstrate technologies with the potential to simultaneously improve energy efficiency and indoor environmental quality (IEQ). Two were installed at each of two school districts, and energy use and IEQ parameters were monitored during occupancy. Two RCs (one per school) were finished with materials selected for reduced emissions of toxic and odorous volatile organic compounds (VOCs). Each had two HVAC systems, operated on alternate weeks, consisting of a standard heat-pump system and an indirect-direct evaporative cooling (IDEC) system with gas-fired hydronic heating. The IDEC system provides continuous outside air ventilation at "15 CFM (7.5 L s-1) person-1, efficient particle filtration while using significantly less energy for cooling. School year long measurements included: carbon dioxide (CO2), particles, VOCs, temperature, humidity, thermal comfort, noise, meteorology, and energy use. IEQ monitoring results indicate that important ventilation-relevant indoor CO2 and health-relevant VOC concentration reductions were achieved while average cooling and heating energy costs were simultaneously reduced by 50% and 30%, respectively.

Black, D.R.; Thatcher, T.L.; Delp, W.W.; Derby, E.A.; Chang, S.C.; Sextro, R.G.. Data summary report of commercial building experiments in Salt Lake City, UT from May 17 to June 10, 2002. LBNL-53801.

ABSTRACT
Under some circumstances, it may be desirable to provide all or part of a building with collective-protection against harmful chemical or biological (CB) agents. Collective-protection, as opposed to individual protection, uses the building-- its architecture, ventilation system, and control components-- to safeguard the health of the building occupants in the event of an indoor or outdoor release of toxic agents.

In this study, we investigate the movement of tracer gases within a six-story building. The building was retrofitted to provide collective-protection on the upper two floors. To achieve this protection, the upper floors were over-pressurized using outside air that had passed through military specification carbon canisters and high-efficiency particulate air (HEPA) filters. The four lower floors were outside the collective-protection area and had a ventilation system that was retrofitted to provide response modes in the event of a CB release. These response modes (e.g. building flush and shelter in place) were designed to reduce the exposure of occupants on the lower floors without compromising the collective-protection zones.

Over the course of four weeks, 16 tracer gas experiments were conducted to evaluate the collective-protection system (CPS) of the building's upper two floors and the ventilation response modes of the lower floors. Tracer gas concentrations were measured at a rate of 50 Hz in up to 30 locations in each experiment, which provided data with very high spatial and temporal resolution. Differential pressure and temperature measurements were also made throughout the building.

Experiments showed that the CPS maintained a positive pressure differential between the upper two floors and the lower floors with various meteorological conditions and within specified settings of the HVAC fans serving the lower floors. However, the tracer experiments did show that a CB agent could enter the first zone of the decontamination areas on each CPS floor. Tracer gas analysis also showed that the shelter in place HVAC mode provided protection of lower floor occupants from an outdoor release by significantly

lowering the air exchange rates on those floors. It was also determined that the efficacy of a flush mode triggered by an agent sensor depends greatly on the location of the sensor.

Chan, W.R.; Price, P.N.; Sohn, M.D.; Gadgil, A.J., Analysis of U.S. Residential Air Leakage Database, LBNL-53367

ABSTRACT
The air leakage of a building envelope can be determined from fan pressurization measurements with a blower door. More than 70,000 air leakage measurements have been compiled into a database. In addition to air leakage, the database includes other important characteristics of the dwellings tested, such as floor area, year built, and location. There are also data for some houses on the presence of heating ducts, and floor/basement construction type. The purpose of this work is to identify house characteristics that can be used to predict air leakage. We found that the distribution of leakage normalized with floor area of the house is roughly lognormal. Year built and floor area are the two most significant factors to consider when predicting air leakage: older and smaller houses tend to have higher normalized leakage areas compared to newer and larger ones. Results from multiple linear regression of normalized leakage with respect to these two factors are presented for three types of houses: low-income, energy-efficient, and conventional. We demonstrate a method of using the regression model in conjunction with housing characteristics published by the US Census Bureau to derive a distribution that describes the air leakage of the single-family detached housing stock. Comparison of our estimates with published datasets of air exchange rates suggests that the regression model generates accurate estimates of air leakage distribution.

Chan, W.R.; Price, P.N.; Gadgil, A.J.; Nazaroff, William W.; Loosmore, G.; Sugiyama, G. Modeling Shelter-in-place including sorption on indoor surfaces. To be submitted to the 84th American Meteorological Society Annual Meeting, Seattle, Washington, January 11-14, 2004. BNL-53987.

ABSTRACT
Intentional or accidental large-scale airborne toxic releases (e.g. terrorist attacks or industrial accidents) can cause severe harm to nearby communities. As part of an emergency response plan, shelter-in-place (SIP) can be an effective response option, especially in situations when evacuation is infeasible. Reasonably tight building envelopes provide protection against exposure to peak concentrations when toxic release passes over an area. However, this protection is temporary because some toxic materials will be carried into buildings by the exchange of air between outdoors and indoors. Prompt termination of shelter-in-place after the outdoor plume has passed is also required to minimize the exposure of the occupants. The purpose of this work is to quantify the level of protection offered by existing houses, and the importance of sorption/desorption to and from surfaces on the effectiveness of SIP. We examined a hypothetical chlorine gas release scenario simulated by the National Atmospheric Release Advisory Center (NARAC). We used a standard infiltration model to calculate the distribution of time dependent infiltration rates within each census tract. Large variation in the air tightness of dwellings means some houses are more protective than others. Considering only the median air tightness, model results showed that if sheltered indoors, the total population intake of non-sorbing toxic gas is only 50% of the outdoor level 4 hours from the start of the release. Based on a sorption/desorption model by Karlsson and Huber (1996), we calculated that the sorption process would further lower the total intake of the population by an additional 50%. The potential benefit of SIP can be considerably higher if the comparison is made in terms of health effects because of the non-linear acute effect dose-response curve of many chemical warfare agents and toxic industrial substances.

Diamond, R.C.; Wray, C.P.; Dickerhoff, D.J.; Matson, N.E.; Wang, D.. Thermal distribution systems in commercial buildings. LBNL-51860.

ABSTRACT
Previous research suggests that HVAC thermal distribution systems in commercial buildings suffer from thermal losses, such as those caused by duct air leakage and poor duct location. Due to a lack of metrics and data showing the potentially large energy savings from reducing these losses, the California building industry has mostly overlooked energy efficiency improvements in this area. The purpose of this project is to obtain the technical knowledge needed to properly measure and understand the energy efficiency of these systems. This project has three specific objectives: to develop metrics and diagnostics for determining system efficiencies, to develop design and retrofit information that the building industry can use to improve these systems, and to determine the energy impacts associated with duct leakage airflows in an existing

large commercial building. The primary outcome of this project is the confirmation that duct leakage airflows can significantly impact energy use in large commercial buildings: our measurements indicate that adding 15% duct leakage at operating conditions leads to an increase in fan power of about 25 to 35%. This finding is consistent with impacts of increased duct leakage airflows on fan power that have been predicted by previous simulations. Other project outcomes include the definition of a new metric for distribution system efficiency, the demonstration of a reliable test for determining duct leakage airflows, and the development of new techniques for duct sealing. We expect that the project outcomes will lead to new requirements for commercial thermal distribution system efficiency in future revisions of California's Title 24.

Diamond, Rick. 2003. "A lifestyle-based scenario for U.S. buildings: Implications for energy use". *Energy Policy*, vol 31 issue 12 pp 1205 -1211. LBNL-50969.

ABSTRACT
Can lifestyle-based scenarios provide insight into the nature of energy use in our future buildings? Participants in a design charrette brainstormed ideas about the future of US homes and workplaces. The teams started from several descriptions of daily lifestyles, and developed specific building characteristics as the place settings for these narratives. In addition to characterizing the physical environment, the teams also identified the forces that would be influential in making these changes. Further reflection was made on the possible unintended consequences of these changes. The energy implications of these changes were characterized with respect to magnitude and direction. While acknowledging the speculative nature of the exercise, the rationale was to broaden the discussion on future energy use by looking at future scenarios in the context of everyday life.

Erdmann CA, Farren G, Baltzell K, Chew T, Clarkson C, Fleshman R, Leary C, Mizroch M, Orenstein F, Russell ML, Souders-Mason V, Wrensch M. Breast Cancer and Personal Environmental Risk Factors in Marin County - Pilot Study. LBNL-52484.

ABSTRACT
The purpose of the Personal Environmental Risk Factor Study (PERFS) pilot project was to develop methodologies and a questionnaire for a future population-based case-control study to investigate the role of selected environmental exposures in breast cancer development. Identification of etiologically relevant exposures during a period of potential vulnerability proximate to disease onset offers the possibility of clinical disease prevention even when disease initiation may have already occurred many years earlier. Certain personal environmental agents or combinations of agents may influence disease promotion. Therefore, this pilot study focused on exposures that occurred during the ten-year period prior to diagnosis for cases and the last ten years for controls, rather than more historic exposures. For this pilot study, we used a community-based research approach. In our collaborative efforts, community members participated with academic researchers in all phases of the research, including research question identification, study design, development of research tools, development of the human subjects protocol, and report writing. Community member inclusion was based upon the concept that community participation could improve the relevance of scientific studies and ultimate success of the research by encouraging an ongoing dialogue between community members and academic representatives. Early activities of this project focused on the collection of input from the community regarding the possible role of environmental factors in the incidence of breast cancer in Marin County. The intent was to inform the scientists of community concerns, enhance the research team's understanding of the community being studied, and provide interested community members with a better understanding of the strengths and weaknesses of traditional research methods through active participation in the research process. This pilot study identified specific testable hypotheses through review of the literature and consultation with relevant experts and the affected community. Initially, the study was to focus on modifiable personal environmental exposures that are associated with breast tumor promotion and higher socioeconomic status (SES). However, little information was available in the scientific literature regarding the putative mechanism by which some of the suspected environmental factors may act (i.e., initiator vs. promoter). Likewise, little is known about the distribution of personal environmental risk factors by socioeconomic status. Therefore, tumor promotion involvement and association with SES were not very useful as selection criteria, and selection of topics was based primarily on published scientific findings of human studies and community input. This study was approved by the Institutional Review Boards at the University of California at San Francisco (Committee on Human Research) and at the University of California at Berkeley (Committee for the Protection of Human Subjects).

Erdmann, C.A.; Satariano, W.A.; Chen, Y.Q.. Traditional risk factor study (TRiFS): Preliminary report on risk factor prevalence and population attributable fraction estimates for breast cancer in Marin County, California. LBNL-51905.

ABSTRACT
The objective of the Traditional Risk Factor Study (TRiFS) was to describe female breast cancer risk factor distributions in Marin County, California by using previously collected, individual-level data. The Marin County breast cancer risk factor distributions were compared with those of the other California counties and the State. Prevalence estimates for traditional breast cancer risk factors (e.g., age at menarche, family history, and age at first birth) were computed using data from the Marin County Breast Cancer Study of Adolescent Risk Factors (ARFS) and the California Health Interview Survey (CHIS). A reference set of relative risk values for the breast cancer risk factors of interest was assembled from published sources. Using the prevalence estimates along with these relative risk values, population attributable fractions were calculated for selected breast cancer risk factors and combinations of these factors. Approximately 84% of Marin County women were exposed to at least one of the following five breast cancer risk factors: earlier age at menarche, later age at 1st birth or nulliparity family history, later age at menopause, and/or higher postmenopausal body mass index (BMI). The results suggest that 50% of Marin County's breast cancer cases would be avoided if the traditional breast cancer risk factors considered in these analyses were eliminated. Later age at first birth and nulliparity after age 30 alone appear to account for about one-third of breast cancer cases in Marin County.

Erdmann, C.A.; Apte, M.G.. Associations of Indoor Carbon Dioxide Concentrations and Environmental Susceptibilities with Mucous Membrane and Lower Respiratory Building Related Symptoms in the BASE Study: Analyses of the 100 Building Dataset. To be submitted to *Indoor Air Special Edition 2003*. LBNL-53842.

ABSTRACT:
Using the U.S. EPA 100 office-building BASE Study dataset, we conducted multivariate logistic regression analyses to quantify the relationship between indoor CO2 concentrations (dCO2) and mucous membrane (MM) and lower respiratory system (LResp) building related symptoms, adjusting for age, sex, smoking status, presence of carpet in workspace, thermal exposure, relative humidity, and a marker for entrained automobile exhaust. In addition, we tested the hypothesis that certain environmentally-mediated health conditions (e.g., allergies and asthma) confer increased susceptibility to building related symptoms within office buildings. Adjusted odds ratios (ORs) for statistically significant, dose-dependant associations ($p < 0.05$) for dry eyes, sore throat, nose/sinus congestion, and wheeze symptoms with 100 ppm increases in dCO2 ranged from 1.1 to 1.2. These results suggest that increases in the ventilation rates per person among typical office buildings will, on average, reduce the prevalence of several building related symptoms by up to 70%, even when these buildings meet the existing ASHRAE ventilation standards for office buildings. Building occupants with certain environmentally-mediated health conditions are more likely to experience building related symptoms than those without these conditions (statistically significant ORs ranged from 2 to 11).

Faulkner, D.; Fisk, W.J.; Sullivan, D.P.; Lee, S.M.. Ventilation Efficiencies And Thermal Comfort Results Of A Desk-Edge-Mounted Task Ventilation System. To be submitted to *Indoor Air 2003*. LBNL-53798.

Abstract:
In chamber experiments, we investigated the ventilation effectiveness and thermal comfort of a task ventilation system with an air supply nozzle located underneath the front edge of a desk and directing air toward a heated mannequin or a human volunteer seated at the desk. The task ventilation system provided outside air, while another ventilation system provided additional space cooling but no outside air. Test variables included the vertical angle of air supply (-15o to 45o from horizontal), and the supply flow rate of (3.5 to 6.5 L s-1). Using the tracer gas step-up and step-down procedures, the measured air change effectiveness (i.e., exhaust air age divided by age of air in the breathing zone) in experiments with the mannequin ranged from 1.4 to 2.7 (median, 1.8), whereas with human subjects the air change effectiveness ranged from 1.3 to 2.3 (median, 1.6). The majority of the air change effectiveness values with the human subjects were less than values with the mannequin at comparable tests. Similarly, the tests run with supply air temperature equal to the room air temperature had lower air change effectiveness values than comparable tests with the supply air temperature lower (~5 o C) than the room air temperature. The change

effectiveness values are higher than typically reported for commercially available task ventilation or displacement ventilation systems. Based on surveys completed by the subjects, operation of the task ventilation system did not cause thermal discomfort.

Finlayson, E.U.; Jayaraman, B.; Kristoffersen, A.R.; Gadgil, A.J.. CFD Analysis of LLNL downdraft table. LBNL-53883. 2003.

ABSTRACT
This study examines the airflow and contaminant transport in an existing room (89"x77"x98") that houses a downdraft table at LLNL. The facility was designed and built in the 1960's and is currently being considered for redesign. One objective of the redesign is to reduce airflow while maintaining or improving user safety. Because this facility has been used for many years to handle radioactive material it is impractical to conduct extensive experimental tests in it. Therefore, we have performed a Computational Fluid Dynamic (CFD) analysis of the facility. The study examines the current operational condition and some other cases with reduced airflow. Reducing airflow will lead to savings in operating costs (lower fan power consumption), and possible improvements in containment from reduced turbulence. In addition, we examine three design (geometry) changes. These are: (1) increasing the area of the HVAC inlet on the ceiling, (2) adding a 15° angled ceiling inlet and (3) increasing the area of the slot in the doorway. Of these three geometry modifications, only the larger doorway slot leads to improved predicted containment.

Finlayson, E.U., Gadgil, A.J., Thatcher, T.L., Sextro, R.G., Pollutant Dispersion in a Large Indoor Space Part 2 – Computational Fluid Dyamics (CF) Predictions and Comparisons with a Model Experiment for Isothermal Flow. Accepted for publication in *Indoor Air*. LBNL-50105.

ABSTRACT
This paper reports on an investigation of the adequacy of Computational fluid dynamics (CFD), using a standard Reynolds Averaged Navier Stokes (RANS) model, for predicting dispersion of neutrally buoyant gas in a large indoor space. We used CFD to predict pollutant (dye) concentration profiles in a water filled scale model of an atrium with a continuous pollutant source. Predictions from the RANS formulation are comparable to an ensemble average of independent identical experiments. Model results were compared to pollutant concentration data in a horizontal plane from experiments in a scale model atrium. Predictions were made for steady-state (fully developed) and transient (developing) pollutant concentrations. Agreement between CFD predictions and ensemble averaged experimental measurements is quantified using the ratios of CFD-predicted and experimentally measured dye concentration at a large number of points in the measurement plane. Agreement is considered good if these ratios fall between 0.5 and 2.0 at all points in the plane. The standard k-epsilon two equation turbulence model obtains this level of agreement and predicts pollutant arrival time to the measurement plane within a few seconds. These results suggest that this modeling approach is adequate for predicting isothermal pollutant transport in a large room with simple geometry.

Fisk, WJ, Seppanen O, Faulkner D, Huang J (2003) Economizer system cost effectiveness: accounting for the influence of ventilation rate on sick leave. *Proceedings of the Healthy Buildings 2003 Conference, December 7-11, 2003*, Singapore, volume 3, pp 361-367. Healthy Buildings 2003, Inc., www.isiaq.org, LBNL-53192

ABSTRACT
This study estimated the health, energy, and economic benefits of an economizer ventilation control system that increases outside air supply during mild weather to save energy. A model of the influence of ventilation rate on airborne transmission of respiratory illnesses was used to extend the limited data relating ventilation rate with illness and sick leave. An energy simulation model calculated ventilation rates and energy use versus time for an office building in Washington, D.C. with fixed minimum outdoor air supply rates, with and without an economiser. Sick leave rates were estimated with the disease transmission model. In the modelled 72-person office building, our analyses indicate that the economizer reduces energy costs by approximately $2000 and, in addition, reduces sick leave. The financial benefit of the decrease in sick leave is estimated to be between $6,000 and $16,000. This modelling suggests that economizers are much more cost effective than currently recognized.

Fisk, W.J.; Faulkner, D.; Sullivan, D.P.; Delp, W.W.. Outdoor airflow into HVAC systems: An evaluation of measurement technologies. LBNL-53834.

ABSTRACT:
During the last few years, new technologies have been introduced for measuring the flow rates of outdoor air (OA) into HVAC systems; however, an evaluation of these measurement technologies has not previously been published. This document describes a test system and protocols developed for controlled evaluation of these measurement technologies. The results of tests of three measurement technologies are also summarized. The test system and protocol were judged practical and very useful. The test results indicate that one measurement technology can measure OA flow rates with errors of 20% or less without a field-based calibration, as long as the OA velocities are sufficient to provide an accurately measurable pressure signal. The test results for a second measurement technology are similar; however, a difficult field-based calibration relating the OA flow rate with the pressure signal would be required to reduce errors below approximately 30%. The errors in OA flow rates measured with the third measurement technology, that uses six electronic airspeed sensors downstream of the OA inlet louver, exceeded 100%; however, these errors could be substantially reduced through a difficult field based calibration. The effects of wind on the accuracy of these measurement technologies still needs to be evaluated.

Fisk, W.J.; Price, P.N.; Faulkner, D.; Sullivan, D.P.; DiBartolomeo, D.L.; Federspiel, C.; Liu, G.; Lahiff, M.. Worker productivity and ventilation rate in a call center: Analyses of time-series data for a group of registered nurses. Submitted to *Indoor Air 2003*. LBNL-53785.

ABSTRACT:
We investigated the relationship of ventilation rates with the performance of advice nurses working in a call center. Ventilation rates were manipulated; temperatures, humidities, and CO2 concentrations were monitored; and worker performance data, with 30-minute resolution, were collected. Multivariate linear regression was used to investigate the association of worker performance with indoor minus outdoor CO2 concentration (which increases with decreasing ventilation rate per worker) and with building ventilation rate. Results suggest that the effect of ventilation rate on worker performance in this call center was very small (probably less than 1%) or nil, over most of the range of ventilation rate (roughly 12 L s-1 to 48 L s-1 per person). However, there is some evidence of worker performance improvements of 2% or more when the indoor CO2 concentration exceeded the outdoor concentration by less than 75 ppm.[1067]

Fisk, W.J.; Faulkner, D.; Palonen, J.; Seppanen, O.. Performance and Costs of Particle Air Filtration in HVAC Supply Airstreams. *HPAC Engineering* 75(7)24-36. LBNL-53212.

ABSTRACT
This paper uses a model, and data on particle size distributions, filter efficiencies, and particle deposition rates to estimate the reductions in the indoor mass concentrations of particles attainable from use of filters in HVAC supply airstreams. Additionally, the energy and total costs of the filtration options are estimated. Predicted reductions in cat and dust-mite allergen concentrations range from 20% to 60%. Increasing filter efficiencies above approximately ASHRAE Dust Spot 65% (MERV 11) does not significantly reduce predicted indoor concentrations of these allergens. For environmental tobacco smoke particles and outdoor fine mode particles, calculations indicate that relatively large, e.g., 80%, decreases in indoor concentrations are attainable with practical filter efficiencies. Increasing the filter efficiency above ASHRAE Dust Spot 85% (MERV 13) results in only modest incremental decreases in concentrations. Energy costs and total costs do not always increase for higher efficiency filters. Total estimated filtration costs of $0.70 to $1.80 per person per month are insignificant relative to salaries, rent, or health insurance costs.

Fisk, W.J.; Faulkner, D.; Sullivan, D.P. Reducing filter bypass. LBNL-54115

ABSTRACT
In a standard air filter bank installed in a HVAC system, significant particle-laden air bypasses the filters by flowing through gaps between adjacent filters and through gaps between filters and the tracks or frames that hold the filters in place. The particles that bypass filters contribute to fouling of the downstream heating and cooling coils, to increases in airstream pressure drops, and to reductions in HVAC system performance. The subsequent deposition of particles on wet cooling coils provides nutrients for microbial growth. Bypass also increases indoor particle concentrations. We developed a new method of measuring the rates at which air bypasses filters and used this method to test a very simple retrofit measure based on the application of plastic seals to the exterior sides of cardboard-filter frames. Before application of the seals, bypass rates were 1% to 3% of the nominal rate of airflow through the filters. The seals reduced bypass flow rates by approximately 85%. This large reduction in bypass rates was obtained using low cost,

off-the shelf materials that can be quickly applied. However, field studies in actual HVAC systems, and studies with other types of filters and filter holding frameworks are needed to evaluate this method of reducing filter bypass more fully.

Gadgil, A.J., Lobscheid, C., Abadie, M.O., Finlayson, E.U., Indoor Pollutant Mixing Time in an Isothermal Closed Room: An investigation using CFD. ***Atmospheric Environment,*** **Vol 37:5577-5586. LBNL-51413.**

ABSTRACT
We report computational fluid dynamics (CFD) predictions of mixing time of a point pulse release of a pollutant in an unventilated mechanically mixed isothermal room. The aims of the study are to determine (1) the adequacy of the standard RANS two-equation (k-ε) turbulence model to predict the mixing times under these conditions, and (2) the extent to which the mixing time is a feature of the room airflow, rather than the source location within the room. CFD simulations modeled the twelve mixing time experiments performed by Drescher et al. (1995) in an isothermal sealed room for a point pulse release. Predictions of mixing time were found in good agreement with experimental measurements, over an order of magnitude variation in blower power. Additional CFD simulations were performed to investigate the relation between pollutant mixing time and pollutant source location. Seventeen source locations were investigated for five different blower power configurations in the room. Results clearly show large dependence of the mixing time on the room airflow, with some dependence on source location. We further explore dependence of mixing time on the local airflow properties (velocity and turbulence intensity) at the source location. Implications for our findings for positioning air-toxic sensors in rooms are also discussed.

Gadgil, A.J., Derby, E., Providing safe drinking water to 1.1 billion unserved people, To be published in ***Proceedings of the 96th Annual AWMA Conference*****, San Diego, CA, June 22-26, 2003. LBNL-52374.**

ABSTRACT
Despite substantial advances in the past 100 years in public health, technology and medicine, 20% of the world population, mostly comprised of the poor population segments in developing countries (DCs), still does not have access to safe drinking water. To reach the United Nations (UN) Millennium Goal of halving the number of people without access to safe water by 2015, the global community will need to provide an additional one billion urban residents and 600 million rural residents with safe water within the next twelve years.

This paper examines current water treatment measures and implementation methods for delivery of safe drinking water, and offers suggestions for making progress towards the goal of providing a timely and equitable solution for safe water provision.

For water treatment, based on the serious limitations of boiling water and chlorination, we suggest an approach based on filtration coupled with ultraviolet (UV) disinfection, combined with public education. Additionally, owing to the capacity limitations for non-governmental organizations (NGOs) to take on this task primarily on their own, we suggest a strategy based on financially sustainable models that include the private sector as well as NGOs.

Hodgson, A.T.; Faulkner, D.; Sullivan, D.P.; Dibartolomeo, D.L.; Russell, M.L.; Fisk, W.J.. Effect of Outside Air Ventilation Rate on Volatile Organic Compound Concentrations in a Call Center. Accepted for publication in ***Atmospheric Environment*** **2003. LBNL-52497.**

ABSTRACT
A study of the relationship between outside air ventilation rate and concentrations of volatile organic compounds (VOCs) generated indoors was conducted in a call center office building. The building, with two floors and a floor area of 4,600 m2, was located in the San Francisco Bay Area, CA. Ventilation rates were manipulated with the building's four air handling units (AHUs). VOC concentrations in the AHU returns were measured on seven days during a 13-week period. VOC emission factors were determined for individual zones on days when they were operating at near steady-state conditions. The emission factor data were subjected to principal component (PC) analysis to identify groups of co-varying compounds. Potential sources of the PC vectors were ascribed based on information from the literature supporting the associations. Two vectors with high loadings of compounds including formaldehyde, 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate, decamethylcyclopentasiloxane (d5 siloxane), and isoprene likely identified occupant-related sources. One vector likely represented emissions from building materials. Another vector

represented emissions of solvents from cleaning products. The relationships between indoor minus outdoor VOC concentrations and ventilation rate were qualitatively examined for eight VOCs. Of these, acetaldehyde and hexanal, which were likely associated with material sources, and d5 siloxane exhibited general trends of higher concentrations at lower ventilation rates. For other compounds, the operation of the building and variations in pollutant generation and removal rates apparently combined to obscure the inverse relationship between VOC concentrations and ventilation. This result emphasizes the importance of utilizing source control measures, in addition to adequate ventilation, to limit concentrations of VOCs of concern in office buildings.

Hodgson, A.T.; Levin, H.. Volatile organic compounds in indoor air: A review of concentrations measured in North America since 1990. To be submitted to *Atmospheric Environment* 2003. LBNL-51715.

ABSTRACT

Central tendency and upper limit concentrations of volatile organic compounds (VOCs) measured in indoor air are summarized and reviewed. Data were obtained from published cross-sectional studies of residential and office buildings conducted in North America from 1990 through the present. VOC concentrations in existing residences reported in 12 studies comprise the majority of the data set. Central tendency and maximum concentrations are compared between new and existing residences and between existing residences and office buildings. Historical changes in indoor VOC concentrations since the Clean Air Act Amendments of 1990 are explored by comparing the current data set with two published reviews of previous data obtained primarily in the 1980s. These historical comparisons suggest average indoor concentrations of some toxic air contaminants, such as 1,1,1-trichloroethane have decreased.

Hodgson, A.T.; Levin, H.. Classification of measured indoor volatile organic compounds based on noncancer health and comfort considerations. to be submitted to *Atmospheric Environment* 2003. LBNL-53308.

ABSTRACT

Building occupants are exposed to complex mixtures of air pollutants including many volatile organic compounds (VOCs). A recent review summarized the central tendency and upper limit indoor VOC concentrations measured in North American residences and office buildings since 1990. Although this database is limited in many respects, it serves as a useful starting point for evaluating the potential health and comfort effects of indoor VOC exposures. Excluding cancer and birth defects, the primary concern is chronic inhalation exposure to toxicants that can cause serious health problems. Additionally, building occupants react to the quality of indoor air through their sensory perceptions and frequently experience unpleasant odors and irritation of the eyes and upper respiratory tract. In this paper, we conduct a simple screening-level assessment of indoor VOC concentrations. We compare measured VOC concentrations to published odor thresholds, sensory irritation levels derived for the general population, and noncancer chronic health guidelines. Hazard quotients are individually calculated for these three effects by dividing maximum or derived 95th percentile VOC concentrations by our selected best estimates of guidance levels for the general population. These results provide a basis for broadly classifying commonly encountered VOCs into groups according to the likelihood that they will produce effects among building occupants. This methodology shows that only a small number of the more than 100 reported VOCs exceed levels that are likely to be of concern with respect to the health and comfort endpoints considered. Although data is lacking for a number of odorous compounds potentially present in buildings, the results indicate that carboxylic acids, higher molecular weight aldehydes and less volatile aromatic hydrocarbons are most likely to be perceived by olfaction and that there is more probability of detection in residences than in offices. Sensory irritation levels were approached or exceed by only a very small number of relatively potent, reactive VOCs. Of these, acrolein was by far the most potent irritant. Although more detailed consideration of the underlying toxicological data is needed, the results suggest that only a small number of commonly measured VOCs, when considered singly, are likely to produce serious irreversible health effects not associated with cancer. These compounds include lower molecular weight aldehydes, and several aromatic hydrocarbons. Again, acrolein stands out as the most potent compound. Based on these results, we recommend that studies to characterize indoor VOC concentrations and exposures focus their resources on compounds that are most likely to impact occupants as determined by the study objectives. For a very few compounds, such as acrolein and formaldehyde, the evidence based on sensory irritation and chronic toxicity appears sufficient to warrant efforts to reduce and control sources of these compounds in buildings.

Hodgson, A.T.; Shendell, D.G.; Fisk, W.J.; Apte, M.G.. Comparison of predicted and derived measures of volatile organic compounds inside four relocatable classrooms die to identified interior finish sources. LBNL-52520.

ABSTRACT

Indoor exposures to toxic and odorous volatile organic compounds (VOCs) are of general concern. Recently, VOCs in portable or relocatable classrooms (RCs) have received particular attention. However, very little was known about indoor environmental quality (IEQ) and the sources, composition, and indoor concentrations of VOCs in RCs. This project task focused on developing and demonstrating a process for selecting interior finish materials for RCs that have relatively low impacts with respect to their emissions of toxic and odorous VOCs. This task was part of a larger project to demonstrate the potential for simultaneous improvements in IEQ and energy efficiency in four new RCs equipped both with a continuously ventilating advanced heating, ventilating, and air conditioning system (HVAC) and a standard HVAC system. These HVACs were operated on alternate weeks. One RC per pair was constructed with standard interior finish materials, and the other included alternate interior materials identified in our prior laboratory study to have low VOC emissions. The RCs were sited in side-by-side pairs at two elementary schools in distinct northern California climate zones. Classroom VOC emission rates (mg hr-1) and concentrations were predicted based on VOC emission factors (µg m-2 hr-1) measured for individual materials in the laboratory, the quantities of installed materials and design ventilation rates. Predicted emission rates were compared to values derived from classroom measurements of VOC concentrations and ventilation rates made at pre-occupancy, eight weeks, and 27 weeks. Predicted concentrations were compared to measured integrated VOC indoor minus outdoor concentrations during school hours in the fall cooling season with the advanced HVAC operated. These measured concentrations also were compared between standard and material-modified RCs. Our combined laboratory and field process proved effective by correctly predicting that IEQ impacts of material VOC emissions would be minor when RCs were ventilated at or above code-minimum requirements. Assuming code-minimum ventilation rates are maintained, the benefits attributable to the use of alternate interior finish materials in RC's
constructed by the manufacturer associated with this study are small, implying that it is not imperative to use such alternative finishing materials. However, it is essential to avoid materials that can degrade IEQ, and the results of this study demonstrate that laboratory-based material testing combined with modeling and field validation can help to achieve that aim.

Hodgson, A.T.. Volatile organic chemical emissions from structural insulated panel (SIP) materials and implications for indoor air quality. LBNL-53768.

ABSTRACT:

The emissions of volatile organic compounds (VOCs) from structural insulated panel (SIP) materials were investigated. Specimens of newly produced SIPs and associated panel adhesives were obtained from two relatively large manufacturers. Additionally, specimens of the oriented strand board (OSB) used as the inner and outer sheathing and the extruded polystyrene ore for the SIP were obtained from one manufacturer. Using small-scale chambers, emissions of formaldehyde, acetaldehyde, acetic acid and other VOCs from SIPs, OSB and polystyrene were measured over a period of four months and from the adhesives over two months. SIP specimens overlaid by gypsum board panels were also tested over four months. The predominant VOCs emitted by the SIPs included acetic acid, pentanal, hexanal and styrene. The emissions of formaldehyde and acetaldehyde were relatively low. Acetic acid and the aldehydes derived from the OSB, while styrene derived from the polystyrene. One of the SIPs emitted toluene and methyl acetate. The adhesives primarily emitted a mixture of hydrocarbons. The emission rates of most VOCs from the SIP/gypsum board assemblies were approximately the same or higher than their respective emission rates from the unfinished SIPs. Modeling using VOC emission factors obtained for the SIP/gypsum board assemblies demonstrated the potential for SIP materials to degrade indoor air quality in houses. A field study to investigate VOC concentrations and emission rates in SIP houses relative to closely matched conventionally constructed houses is necessary to determine the actual impacts of SIPs. If significant impacts are observed, to it may be desirable to develop control measures to reduce the emissions of VOCs from SIPs, such as the substitution of lower emitting materials or the use of vapor diffusion barriers. [1070]

Klepeis, N.E., Apte, M.G., Gundel, L.A., Sextro, R.G., Nazaroff, W.W., Size-specific environmental tobacco smoke particle emissions. To be published in *Aerosol Science & Technology*. LBNL-51049.

ABSTRACT:
Because size is a major controlling factor for indoor airborne particle behavior, human particle exposure assessments will benefit from improved knowledge of size-specific particle emissions. We report a method of inferring size-specific mass emission factors for indoor sources that makes use of an indoor aerosol dynamics model, measured particle concentration time series data, and an optimization routine. This approach provides – in addition to estimates of the emissions size distribution and integrated emission factors – estimates of deposition rate, an enhanced understanding of particle dynamics, and information about model performance. We applied the method to size-specific environmental tobacco smoke (ETS) particle concentrations measured every minute with an 8-channel optical particle counter (PMS-LASAIR; 0.1-2+ micrometer diameters) and every 10 or 30 min with a 34-channel differential mobility particle sizer (TSI-DMPS; 0.01-1+ micrometer diameters) after a single cigarette or cigar was machine-smoked inside a low air-exchange rate 20m^3 chamber. The aerosol dynamics model provided good fits to observed concentrations when using optimized values of mass emission rate and deposition rate for each particle size range as input. Small discrepancies observed in the first 1-2 hours after smoking are likely due to the effect of particle evaporation, a process neglected by the model. Size-specific ETS particle emission factors were fit with log-normal distributions, yielding an average mass median diameter of 0.2 micrometers and an average geometric standard deviation of 2.3 with no systematic differences between cigars and cigarettes. The equivalent total particle emission rate, obtained by integrating each size distribution, was 0.2-0.7 mg/min for cigars and 0.7-0.9 mg/min for cigarettes.

Koomey, J., Craig, P., Gadgil, A.J., Lorenzetti, D., Improving Forecasting: A plea for historical retrospectives, *The Energy Journal,* Vol. 24:4, pp. 75-92. LBNL-52448.

ABSTRACT
One of the most striking things about forecasters is their lack of historical perspective. They rarely do retrospectives, even though looking back at past work can both illuminate the reasons for its success or failure, and improve the methodologies of current and future forecasts. One of the best and most famous retrospectives is that by Hans Landsberg, which investigates work conducted by Landsberg, Sam Schurr, and others. In this article, written mainly for model users, we highlight Landsberg's retrospective as a uniquely valuable contribution to improving forecasting methodologies. We also encourage model users to support such retrospectives more frequently. Finally, we give the current generation of analysts the kind of guidance we believe Landsberg and Sam Schurr would have offered about how to do retrospectives well.

Lunden, M.M., Revzan, K. L., Fisher, M.L., Thatcher, T.L., Littlejohn, D., Hering, S.V., and Brown, N.J. "The Transformation of Outdoor Ammonium Nitrate Aerosols in the Indoor Environment", accepted for publication in *Atmospheric Environment.* LBNL-52795. No abstract available.

Lunden, M.M., Thatcher, T.L., Hering, S.V., and Brown, N.J. "The use of time- and chemically-resolved particulate data to characterize the infiltration of outdoor PM-2.5 into a residence in the San Joaquin Valley." Accepted for publication in *Environmental Science and Technology*. LBNL-52221. No abstract available.

MacLeod, Matthew. Overall multi-media persistence as an indicator of potential for population-level intake of environmental contaminants. Submitted to *Environmental Toxicology and Chemistry* 2003. LBNL-53245.

ABSTRACT
Although it is intuitively apparent that population-level exposure to contaminants dispersed in the environment must related to the persistence of the contaminant, there has been little effort to formally quantify this link. In this paper we investigate the relationship between overall persistence in a multimedia environment and the population-level exposure as expressed by intake fraction (iF), which is the cumulative fraction of chemical emitted to the environment that is taken up by members of the population. We first confirm that for any given chemical contaminant and emission scenario the definition of iF implies that it is directly proportional to the overall multi-media persistence, POV. We show that the proportionality constant has dimensions of time and represents the characteristic time for population intake (CTI) of the chemical from the environment. We then apply the CalTOX fate and exposure model to explore how POV and CTI combine to determine the magnitude of iF. We find that CTI has a narrow range of possible values relative to POV across multiple chemicals and emissions scenarios. We use data from the Canadian Environmental Protection Act Priority Substance List (PSL1) Assessments to show that exposure assessments based on empirical observation are consistent with interpretations from the model. The

characteristic time for intake along different dominant exposure pathways is discussed. Results indicate that POV derived from screening-level assessments of persistence, bioaccumulation potential, and toxicity (PBT) is a useful indicator of the potential for population-level exposure.

MacLeod, M.J.; Bennet, D.H.; Perem, M.; Maddalena, R.L.; McKone, T.E.; Mackay, D.. Dependence of intake fraction on release location in a multi-media framework: A case study of four contaminants in North America. Submitted to *Journal of Industrial Ecology 2003*. LBNL-52369.

ABSTRACT
The extent of human exposure to persistent anthropogenic environmental contaminants is a complex function of the amount of chemical emitted, its physico-chemical properties and reactivity, the nature of the environment, and the characteristics of the pathways for human exposure, such as inhalation, intake of food and water and dermal contact. For some chemicals, the location of emissions relative to areas of high population density or intense food production may also be an important factor. The relative importance of these variables is explored using the regionally segmented BETR North America contaminant fate model and data for food production patterns and population density for North America. The model is applied to four contaminants emitted to air: benzene, carbon tetrachloride, benzo[a]pyrene and 2,3,7,8-tetrachlorodibenzo dioxin. The total continental intake fraction (iF), relating exposure quantity to emission quantity, is employed as a metric for assessing population exposure to environmental contaminants. The results show that the use of continentally averaged parameters for population density and food production provides an accurate estimate of the median of iF calculated for emissions in individual regions, however iF can range from this median by up to 3 orders of magnitude, especially for chemicals transferred to humans through the food pathway. The location of population relative to food production and emissions of chemicals are important variables that should be considered in assessing the public health implications of chemical emissions.

MacLeod, M.J.. On the influence of forests on the overall fate of semivolatile organic contaminants. To be published in *Stochastic Environmental Research and Risk Assessment 2003*. LBNL-52156.

ABSTRACT
Convincing experimental evidence exists that the presence of vegetation, especially forest canopies, enhances scavenging of semi-volatile organic chemicals (SVOCs) from the atmosphere and increases their depositional flux to the terrestrial surface relative to deposition to bare soil. Evidence from several modeling studies indicates that gaseous deposition to vegetation is the most efficient scavenging pathway, and, due to interactions between gas-particle partitioning in the atmosphere and resistance to diffusion through the cuticle of plants, that pathway is available for SVOCs with Log Koa between 7 and 11 and Log Kaw > -6. However, for enhanced scavenging by vegetation to influence the overall regional and global fate of SVOCs, it must represent a process that is competitive with the other fate and transport processes in the ecological system under consideration. The key question in evaluating the importance of the "Forest Filter Effect" on the regional and global fate of SVOCs is: Does scavenging from the atmosphere by vegetation have a significant influence on the inter-media partitioning, long-range transport and/or environmental persistence of SVOCs? Based on evidence presented below from the CoZMo-POP model and supported by results from other models that together represent our current state of knowledge, the Forest Filter Effect does not exert a controlling influence over regional or global contaminant fate and transport.

Maddalena, R.L.; McKone, T.E.; Sohn, M.D.. Standardized Approach for Developing Probabilistic Exposure Factor Distributions. Submitted to *Risk Analysis*. LBNL-52203.

ABSTRACT
The effectiveness of a probabilistic risk assessment (PRA) depends critically on the quality of input information that is available to the risk assessor and specifically on the probabilistic exposure factor distributions that are developed and used in the exposure and risk models. Deriving probabilistic distributions for model inputs can be time consuming and subjective. The absence of a standard approach for developing these distributions can result in PRAs that are inconsistent and difficult to review by regulatory agencies. We present an approach that reduces subjectivity in the distribution development process without limiting the flexibility needed to prepare relevant PRAs. The approach requires two steps. First, we analyze data pooled at a population scale to (i) identify the most robust demographic variables within the population for a given exposure factor, (ii) partition the population data into subsets based on

these variables, and (iii) construct archetypal distributions for each subpopulation. Second, we sample from these archetypal distributions according to site- or scenario-specific conditions to simulate exposure factor values and use these values to construct the scenario-specific input distribution. It is envisaged that the archetypal distributions from step 1 will be generally applicable so risk assessors will not have to repeatedly collect and analyze raw data for each new assessment. We demonstrate the approach for two commonly used exposure factors – body weight (BW) and exposure duration (ED) – using data for the U.S. population. For these factors we provide a first set of subpopulation based archetypal distributions along with methodology for using these distributions to construct relevant scenario-specific probabilistic exposure factor distributions.

Maddalena, R.L., McKone, T.E.. Is there a "forest filter effect" for organic pollutants?. To be published in *Stochastic Environmental Research and Risk Assessment*. LBNL-51882. No abstract available

McKone, T.E.; MacLeod, M.J. Tracking Multiple Pathways of Human Exposure to Persistent Multimedia Pollutants: Regional, Continental, and Global Scale Models. To be published in *Annual Review of Environment and Resources, 2003*. LBNL-52193.

ABSTRACT
Widespread observations of organic compounds in vegetation, soil, animals, and human tissue have motivated research on more accurate characterizations of chemical transport over regional, continental, and global scales. Efforts to assess human and ecosystem exposure to contaminants from multiple environmental media have been evolving over the last several decades. In this review we summarize the development and evolution of the multimedia mass-balance approach to pollutant fate and exposure evaluation and illustrate some of the calculations used in multimedia assessments. We describe the concepts that make possible the Mackay-type mass-balance compartment models. We describe ongoing efforts to use multimedia models to quantify human exposures. We use a series of case studies of varying complexity to illustrate capabilities and limitations of selected multimedia approaches. We look to the future and consider current challenges and opportunities in the field of multimedia contaminant fate and exposure modeling.

McKone, T.E., Sherman, M.H. Residential ventilation standards scooping study. LBNL-53800

ABSTRACT
This document presents the findings of a scoping study commissioned by the Public Interest Energy Research (PIER) program of the California Energy Commission to determine what research is necessary to develop new residential ventilation requirements for California. This study is one of three companion efforts needed to complete the job of determining the ventilation needs of California residences, determining the bases for setting residential ventilation requirements, and determining appropriate ventilation technologies to meet these needs and requirements in an energy efficient manner. Rather than providing research results, this scoping study identifies important research questions along with the level of effort necessary to address these questions and the costs, risks, and benefits of pursuing alternative research questions. In approaching these questions and corresponding levels of effort, feasibility and timing were important considerations. The Commission has specified Summer 2005 as the latest date for completing this research in time to update the 2008 version of California's Energy Code (Title 24).

McWilliams, Jennifer. Review of air flow measurement techniques. LBNL-49747.

ABSTRACT
Airflow measurement techniques are necessary to determine the most basic of indoor air quality questions: "Is there enough fresh air to provide a healthy environment for the occupants of the building?" This paper outlines airflow measurement techniques, but it does not make recommendations for techniques that should be used. The airflows that will be discussed are those within a room or zone, those between rooms or zones, such as through doorways (open or closed) or passive vents, those between the building and outdoors, and those through mechanical air distribution systems. Techniques that are highlighted include particle streak velocimetry, hot wire anemometry, fan pressurization (measuring flow at a given pressure), tracer gas, acoustic methods for leak size determination, the Delta Q test to determine duct leakage flows, and flow hood measurements. Because tracer gas techniques are widely used to measure airflow, this topic is broken down into sections as follows: decay, pulse injection, constant injection, constant concentration, passive

sampling, and single and multiple gas measurements for multiple zones. Selected papers are annotated, and a bibliography is included for each topic with full abstracts.

Mendell MJ, Naco GN, Wilcox TG, Sieber WK. Environmental Risk Factors and Work-Related Lower Respiratory Symptoms in 80 Office Buildings: An Exploratory Analysis of NIOSH Data. *Amer J Indust Med* 2003; 43:630-41. LBNL-51761.

ABSTRACT
Background: We evaluated relationships between lower respiratory symptoms and risk factors for microbiological contamination in office buildings. Methods: The National Institute for Occupational Safety and Health collected data from 80 office buildings during standardized indoor environmental health hazard evaluations. Present analyses included lower respiratory symptom-based outcome definitions and risk factors for potential microbiologic contamination. Multivariate logistic regression models for selected outcomes identified key risk factors. Results: Adjusted odds ratios (95% confidence intervals) for "at least three of four work-related lower respiratory symptoms" were, for debris in ventilation air intake, 2.0 (1.0-3.9), and for poor drainage in air-conditioning drip pans, 2.6 (1.3-5.2). Adjusted associations with risk factors were consistently stronger for outcomes requiring both multiple symptoms and improvement away from work, and somewhat stronger among diagnosed asthmatics. Conclusions: Moisture and debris in ventilation systems, possibly by supporting microbiologic growth, may increase adverse respiratory effects, particularly among asthmatics. Data from more representative buildings are needed to confirm these findings.

Mendell, M.J.; Heath, G.A.. Do indoor environments in schools influence student performance? A review of the scientific literature. To be submitted to *Environmental Health Perspectives* 2003. LBNL-51780.

ABSTRACT
Limited research is available on potential adverse effects of school environments on academic performance, despite strong public concern. We examine the scientific evidence relevant to this relationship by reviewing available research relating schools and other indoor environments to human performance or attendance. As a primary focus, we *critically review* evidence for direct relationships between indoor environmental quality (IEQ) in buildings and performance or attendance. As a secondary focus, we *summarize, without critique,* evidence on potential connections indirectly linking IEQ to performance or attendance: relationships between IEQ and health, between health and performance or attendance, and between attendance and performance. The most persuasive direct evidence showed increases in indoor concentrations of nitrogen dioxide and outdoor concentrations of several specific pollutants to be related to reduced school attendance. The most persuasive indirect evidence showed indoor dampness and microbiologic pollutants to be related to asthma and respiratory infections, which have in turn been related to reduced performance and attendance. Furthermore, a substantial scientific literature links poor IEQ (e.g., low ventilation rate, excess moisture or formaldehyde) with respiratory and other health effects in children and adults. Overall, evidence suggests that poor IEQ in schools can influence the performance and attendance of students, primarily through health effects from indoor pollutants. Also, inadequate IEQ in schools seems sufficiently common to merit strong public concern. Evidence is available to justify (1) immediate actions to protect IEQ in schools and (2) focused research on exposures, prevention, and causation, to better guide policies and actions on IEQ in schools.

Mora, L., Gadgil, A.J., Wurtz, E. Comparing zonal and CFD models of air flows in large indoor spaces to experimental data, *Indoor Air 2003*, Vol. 13:2, pp. 77-85. LBNL-47027.

ABSTRACT
It is inappropriate to use the assumption of instantaneously well-mixed zones to model airflows and pollutant transport in large indoor spaces. We investigate two approaches for describing the details of airflows in large indoor spaces, for accuracy and suitability for integration with multi-zone infiltration models. One approach, called the zonal method, was developed over the last 15 years to provide an improvement over the well-mixed assumption. The second approach is the use of a computational fluid dynamics simulation using a coarse grid model of the large indoor space. We compare velocity predictions from different formulations of zonal methods and coarse-grid *k-e* computational fluid dynamics (CFD) models, to measurements, in a 2D mechanically ventilated isothermal room. Our results suggest that, when airflow details are required, coarse-grid CFD is a better-suited method to predict airflows in large indoor spaces coupled with complex multi-zone buildings, than are the zonal methods. Based on the comparison of

pressure predictions from different models, we offer guidance regarding the coupling of a model of detailed airflow in large spaces to algebraic multi-zone infiltration models.

Price, P.N., Sohn, M.D., Gadgil, A.J., Delp, W.W., Lorenzetti, D.M., Finlayson, E.U., Thatcher, T.L., Sextro, R.G., Derby, E.A., Jarvis, S.A. Protecting Buildings From a Biological or Chemical Attack: actions to take before or during a release. LBNL-51959

INTRODUCTION

This report presents advice on how to operate a building to reduce casualties from a biological or chemical attack, as well as potential changes to the building (e.g. the design of the ventilation system) that could make it more secure. It also documents the assumptions and reasoning behind the advice. The particular circumstances of any attack, such as the ventilation system design, building occupancy, agent type, source strength and location, and so on, may differ from the assumptions made here, in which case actions other than our recommendations may be required; we hope that by understanding the rationale behind the advice, building operators can modify it as required for their circumstances. The advice was prepared by members of the Airflow and Pollutant Transport Group, which is part of the Indoor Environment Department at the Lawrence Berkeley National Laboratory. The group's expertise in this area includes:

• tracer-gas measurements of airflows in buildings (Sextro, Thatcher);
• design and operation of commercial building ventilation systems (Delp);
• modeling and analysis of airflow and tracer gas transport in large indoor spaces (Finlayson, Gadgil, Price);
• modeling of gas releases in multi-zone buildings (Sohn, Lorenzetti, Finlayson, Sextro);
• and occupational health and safety experience related to building design and operation (Sextro, Delp).

This report is concerned only with building design and operation; it is not a how-to manual for emergency response. Many important emergency response topics are not covered here, including crowd control, medical treatment, evidence gathering, decontamination methods, and rescue gear.

Seppanen O, Fisk WJ, and Faulkner D (2003) Cost benefit analysis of the night-time ventilative cooling in office building. *Proceedings of the Healthy Buildings 2003 Conference, December 7-11, 2003*, Singapore. Volume 3, pp. 394- 99. Healthy Buildings 2003, Inc., www.isiaq.org. LBNL-53191.

ABSTRACT

The indoor temperature can be controlled with different levels of accuracy depending on the building and its HVAC system. The purpose of this study was to evaluate the potential productivity benefits of improved temperature control, and to apply the information for a cost-benefit analyses of night-time ventilative cooling, which is a very energy efficient method of reducing indoor daytime temperatures. We analyzed the literature relating work performance with temperature, and found a general decrement in work performance when temperatures exceeded those associated with thermal neutrality. These studies included physiological modelling, performance of various tasks in laboratory experiments and measured productivity at work in real buildings. The studies indicate an average 2% decrement in work performance per degree oC temperature rise, when the temperature is above 25 oC. When we use this relationship to evaluate night-time ventilative cooling, the resulting benefit to cost ratio varies from 32 to 120.

Seppanen O, Fisk WJ (2003) A conceptual model to estimate cost effectiveness of the indoor environment improvements. *Proceedings of the Healthy Buildings 2003 Conference, December 7-11, 2003*, Singapore. Volume 3, pp. 368-374. Healthy Buildings 2003, Inc., www.isiaq.org, LBNL-53193

ABSTRACT

Macroeconomic analyses indicate a high cost to society of a deteriorated indoor climate. The few example calculations performed to date indicate that measures taken to improve IEQ are highly cost-effective when health and productivity benefits are considered. We believe that cost-benefit analyses of building designs and operations should routinely incorporate health and productivity impacts. As an initial step, we developed a conceptual model that shows the links between improvements in IEQ and the financial gains from reductions in medical care and sick leave, improved work performance, lower employee turn over, and reduced maintenance due to fewer complaints.

Shendell, D.G.; Prill, R.; Fisk, W.J.; Apte, M.G.; Blake, D.; Faulkner, D.. Associations between classroom CO2 concentrations and student attendance. To be submitted to *Indoor Air 2003*. LBNL-53586.

ABSTRACT:
Student attendance in American public schools is a critical factor in securing limited operational funding. Student and teacher attendance influence academic performance. Limited data exist on indoor air and environmental quality (IEQ) in schools, and how IEQ affects attendance, health, or performance. This study explored the association of student absence with measures of indoor minus outdoor carbon dioxide concentration (dCO2). Absence and dCO2 data were collected from 409 traditional and 25 portable classrooms from 14 schools located in six school districts in the states of Washington and Idaho. Study classrooms had individual heating, ventilation, and air conditioning (HVAC) systems, except two classrooms without mechanical ventilation. Classroom attributes, student attendance and school-level ethnicity, gender, and socioeconomic status (SES) were included in multivariate modeling. Forty-five percent of classrooms studied had short-term indoor CO2 concentrations above 1000 parts-per-million (ppm). A 1000 ppm increase in dCO2 was associated ($p < 0.05$) with a 0.5% to 0.9% decrease in annual average daily attendance (ADA), corresponding to a relative 10% to 20% increase in student absence. Outside air (ventilation) rates estimated from dCO2 and other collected data were not associated with absence. Annual ADA was 2% higher ($p < 0.0001$) in traditional than in portable classrooms.

Shendell, D.G.. Assessment of organic compound exposures, thermal comfort parameters, and HVAC system-driven air exchange rates in public school portable classrooms in California. LBNL-53804.

ABSTRACT
The prevalence of prefabricated, portable classrooms (portables, relocatables, RCs) has increased due to class size reduction initiatives and limited resources. Classroom mechanical wall-mount heating, ventilation, and air conditioning (HVAC) systems may function improperly or not be maintained; lower ventilation rates may impact indoor air and environmental quality (IEQ). Materials in portables may off-gas volatile organic compounds (VOCs), including formaldehyde, as a function of age, temperature, and humidity.

For a pilot study, public K-12 schools located in or serving target areas within five Los Angeles County communities were identified. In two communities where school districts (SD) consented, 1-3 randomly selected portables, one newer and one older, and one main building control classroom from each participating school were included. Sampling was conducted over a five-day school week in the cooling and heating seasons, or repeated twice in the cooling season. Measurements included passive samplers for VOCs, formaldehyde and acetaldehyde, and air exchange rate (AER) calculation; indoor air temperature and humidity; technician walk-through surveys; an interview questionnaire about HVAC system operation and maintenance (O&M).

For an intervention study evaluating advanced HVAC technologies in comparison to the common conventional technology, and materials for source reduction of VOCs, four RC were manufactured and located in pairs at two schools in two recruited Northern California SD in different climate zones. RCs were built with the two HVAC systems, cabinetry and conduit for monitoring equipment, and standard or advanced interior finish materials. Each RC was its own control in a case-crossover design—HVAC systems alternately operated for 1-2 week intervals in the 2001-02 school year, with IEQ monitoring including aldehyde and indoor air temperature and humidity data.

Measured classroom AER were low, formaldehyde concentrations were below the state indoor air guideline "target level," and concentrations of most target VOCs were low. O&M questionnaire results suggested insufficient training and communication between custodians and SD offices concerning HVAC systems. Future studies should attempt larger sample sizes and cover larger geographical areas but continue to assess multiple IEQ parameters during occupied hours. Teachers, custodians, and SD staff must be educated on the importance of adequate ventilation with filtered outdoor air.

Sherman, M.H.; Walker, I.S.; Wray, C.P.. Instrumented home energy rating and commissioning. LBNL-52216.

ABSTRACT
Currently, houses do not perform optimally or even as many codes and forecasts predict, largely because they are field assembled and there is no consistent process to identify deficiencies or to correct them. Solving this problem requires field performance evaluations using appropriate and agreed upon procedures in the form of a new process called residential commissioning. The purpose of this project is to develop and

document these procedures and to demonstrate the value that applying them could provide in both new and existing California houses. This project has four specific objectives: to develop metrics and diagnostics for assessing house performance, to provide information on the potential benefits of commissioning using a whole-house approach, to develop programmatic guidelines for commissioning, and to conduct outreach efforts to transfer project results to industry stakeholders. The primary outcomes from this project are the development of residential commissioning guidelines and the analytical confirmation that there are significant potential benefits associated with commissioning California houses, particularly existing ones. In addition, we have made substantial advances in understanding the accuracy and usability of diagnostics for commissioning houses. In some cases, we have been able to work with equipment manufacturers to improve these aspects of their diagnostic tools. These outcomes provide a solid foundation on which to build a residential commissioning program in California. We expect that a concerted effort will be necessary to integrate such a program with existing building industry efforts and to demonstrate its use in the field.

Sherman, Max H.; Matson, Nance E.. Reducing Indoor Residential Exposures to Outdoor Pollutants. LBNL-51758.

ABSTRACT:
Basic strategy for providing indoor air quality in residences is to dilute indoor sources with outdoor air. This strategy assumes that the outdoor air does not have pollutants at harmful levels or that the outdoor air is, at least, less polluted than the indoor air. When this is not the case, different strategies need to be employed to ensure adequate air quality in the indoor environment. These strategies include ventilation systems, filtration and other measures. These strategies can be used for several types of outdoor pollution, including smog, particulates and toxic air pollutants. This report reviews the impacts that typical outdoor air pollutants can have on the indoor environment and provides design and operational guidance for mitigating them. Poor quality air cannot be used for diluting indoor contaminants, but more generally it can become an indoor contaminant itself. This paper discusses strategies that use the building as protection against potentially hazardous outdoor pollutants, including widespread pollutants, accidental events, and potential attacks.

Sherman, Max H.; Chan, Wanyu R.. Building Airtightness: Research and Practice. *State of the Art in Ventilation* 8-12, Camden High Street, London NW1 0JH, United Kingdom, James & James. LBNL-53356.

ABSTRACT
This report summarizes the state of the art on building air tightness by reviewing the current and recent literature on both research and practice. The focus of this report is on techniques to measure the tightness of the building envelope and on what has been learned by doing so. This report reviews over 100 of the most important publications relating to the topic. The report covered the fundamentals of air leakage including the hydrodynamics of leaks, which has led to all of the measurement techniques currently in use. The measurement techniques reviewed focus on the fan pressurization technique and its derivates, but the report covers novel techniques as well. Air tightness metrics allow data to be shared and compared and the basic air tightness metrics are reviewed and discussed as well as a brief discussion on norms and normalization. The bulk of the report discusses data which has been taken over the last twenty years and what it can tell us about buildings of different types, locations and properties. [1084]

Sherman, Max H.; Walker, Iain, S.. Advanced Duct Sealant Testing. LBNL-53547.

ABSTRACT:
Duct leakage is a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums, or branches in the duct system. At each of these connections, a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have shown that taped seals tend to fail over extended periods of time. The Lawrence Berkeley National Laboratory (LBNL) has been testing sealant durability for several years. Accelerated test methods were used that continuously expose duct sealants to elevated temperatures (200 to 212°F (93 to 100°C)). We found that typical duct tape (i.e., fabric backed tapes with natural rubber adhesives) fails more rapidly than all other duct sealants. We also tested advanced tape products being developed by major manufacturers. The results of these tests showed that the major weaknesses of the tapes that fail are the use of natural rubber adhesives and the mechanical properties of the backing. The test results also showed that the current UL listings are inadequate for indicating

durability and many tapes showed significant failure when testing using UL 181 B-FX procedures. In addition, the clamps required (but not evaluated) by UL-181B-FX had many failures and their durability also required evaluation. An accelerated test method developed by LBNL is being used as a basis for an ASTM standard under sub-committee E6.41.

Sherman, Max H. ASHRAE and Residential Ventilation. Accepted to ASHRAE Journal 2003. LBNL-53776.

ABSTRACT:
ASHRAE, the American Society of Heating, Refrigerating, and Air-conditioning Engineers, is the world leader in the field of heating, ventilating, air-conditioning and refrigeration (HVAC&R). ASHRAE has recently released a new residential ventilation standard reflecting minimum requirements for homes. They have also released a top ten list of things that homeowners should be aware of to protect their indoor environment. This article provides a summary of what homeowners and HVAC&R professionals should know regarding residential ventilation.

Sippola, Mark R.; Nazaroff, William W.. Particle Deposition from Turbulent Flow: Review of Published Research and Its applicability to Ventilation Ducts in Commercial Buildings. LBNL-51432.

ABSTRACT:
This report reviews published experimental and theoretical investigations of particle deposition from turbulent flows and considers the applicability of this work to the specific case of particle deposition from flows in the ducts of heating, ventilating and air conditioning (HVAC) systems. Particle deposition can detrimentally affect the performance of HVAC systems and it influences the exposure of building occupants to a variety of air pollutants. The first section of this report describes the types of HVAC systems under consideration and discusses the components, materials, and operating parameters commonly found in these systems. The second section reviews published experimental investigations of particle deposition rates from turbulent flows and considers the ramifications of the experimental evidence with respect to HVAC ducts. The third section considers the structure of turbulent airflows in ventilation ducts with a particular emphasis on turbulence investigations that have been used as a basis for particle deposition models. The final section reviews published literature on predicting particle deposition rates from turbulent flows.

Sippola, Mark R.. Particle Deposition in Ventilation Ducts. LBNL-52189.

ABSTRACT
Exposure to airborne particles is detrimental to human health and indoor exposures dominate total exposures for most people. The accidental or intentional release of aerosolized chemical and biological agents within or near a building can lead to exposures of building occupants to hazardous agents and costly building remediation. Particle deposition in heating, ventilation and air-conditioning (HVAC) systems may significantly influence exposures to particles indoors, diminish HVAC performance and lead to secondary pollutant release within buildings. This dissertation advances the understanding of particle behavior in HVAC systems and the fates of indoor particles by means of experiments and modeling.

Sippola, M.R.; Nazaroff, W.W. Modeling particle loss in ventilation ducts. To be published in *Atmospheric Environment.* LBNL-52449.

ABSTRACT
Empirical equations were developed and applied to predict losses of 0.01-100 µm airborne particles making a single pass through 120 different ventilation duct runs typical of those found in mid-sized office buildings. For all duct runs, losses were negligible for submicron particles and nearly complete for particles larger than 50 µm. The 50th percentile cut-point diameters were 15 µm in supply runs and 25 µm in return runs. Losses in supply duct runs were higher than in return duct runs, mostly because internal insulation was present in portions of supply duct runs, but absent from return duct runs. Single-pass equations for particle loss in duct runs were combined with models for predicting ventilation system filtration efficiency and particle deposition to indoor surfaces to evaluate the fates of particles of indoor and outdoor origin in an archetypal mechanically ventilated building. Results suggest that duct losses are a minor influence for determining indoor concentrations for most particle sizes. Losses in ducts were of a comparable magnitude to indoor surface losses for most particle sizes. For outdoor air drawn into an unfiltered ventilation system, most particles smaller than 1 mm are exhausted from the building. Large particles deposit within the

building, mostly in supply ducts or on indoor surfaces. When filters are present, most particles are either filtered or exhausted. The fates of particles generated indoors follow similar trends as outdoor particles drawn into the building.

Sippola, M.R.; Nazaroff, W.W., Experiments Measuring Particle Deposition from Fully Developed Turbulent Flow in Ventilation Ducts. Submitted to *Aerosol Science and Technology 2003*. LBNL-53585.

ABSTRACT
Particle deposition in ventilation ducts influences particle exposures of building occupants and may lead to a variety of indoor air quality concerns. Experiments have been performed in a laboratory to study the effects of particle size and air speed on deposition rates of particles from turbulent air flows in galvanized steel and internally insulated ducts with hydraulic diameters of 15.2 cm. The duct systems were constructed of materials typically found in commercial heating, entilating and air conditioning (HVAC) systems. In the steel duct system, experiments with nominal particle sizes of 1, 3, 5, 9 and 16 µm were conducted at each of three nominal air speeds: 2.2, 5.3 and 9.0 m/s. In the insulated duct system, deposition rates of particles with nominal sizes of 1, 3, 5, 8 and 13 µm were measured at nominal air speeds of 2.2, 5.3 and 8.8 m/s. Fluorescent techniques were used to directly measure the deposition velocities of monodisperse fluorescent particles to duct surfaces (floor, wall and ceiling) at two straight duct sections where the turbulent flow profile was fully developed. In steel ducts, deposition rates were higher to the duct floor than to the wall, which were, in turn, greater than to the ceiling. In insulated ducts, deposition was nearly the same to the duct floor, wall and ceiling for a given particle size and air speed. Deposition to duct walls and ceilings was greatly enhanced in insulated ducts compared to steel ducts. Deposition velocities to each of the three duct surface orientations in both systems were found to increase with increasing particle size or air velocity over the ranges studied. Deposition rates measured in the current experiments were in general agreement with the limited observations of similar systems by previous researchers.[1053]

Sohn, M.D., Sextro, R.G., Gadgil, A.J., Daisey, J.M. Responding to Sudden Pollutant Releases in Office Buildings: 1. Framework and Analysis Tools. *Indoor Air,* 13(3): 267-276 2003. LBNL-47446.

ABSTRACT
We describe a framework for developing response recommendations to unexpected toxic pollutant releases in commercial buildings. It may be applied in conditions where limited building- and event-specific information is available. The framework is based on a screening-level methodology to develop insights, or rules-of-thumb, into the behavior of airflow and pollutant transport. A three-stage framework is presented: (1) develop a building taxonomy to identify generic, orprototypical, building configurations, (2) characterize uncertainty and conduct simulation modeling to predict typical airflow and pollutant transport behavior, and (3) rank uncertainty contributions to determine how information obtained at a site might reduce uncertainties in the model predictions. The approach is applied to study a hypothetical pollutant release on the first floor of a five-story office building. Key features that affect pollutant transport are identified and described by value-ranges in the building stock. Simulation modeling provides predictions and uncertainty estimates of time-dependent pollutant concentrations, following a release, for a range of indoor and outdoor conditions. In this exercise, we predict concentrations on the fifth floor to be an order of magnitude less than on the first, coefficients of variation greater than 2, and information about the HVAC operation and window position most reducing uncertainty in predicted peak concentrations.

Sohn, M.D., TE McKone, and JN Blancato. Reconstructing Population Exposures from Dose Biomarkers: Inhalation of Trichloroethylene (TCE) as a Case Study. *J. of Exposure Analysis and Environmental Epidemiology*, accepted. LBNL-50588.

ABSTRACT
Physiologically based pharmacokinetic (PBPK) modeling is a well-established toxicological tool designed to relate exposure to a target tissue dose. The emergence of federal and state programs for environmental health tracking and the availability of exposure monitoring through biomarkers creates the opportunity to apply PBPK models to estimate exposures to environmental contaminants from urine, blood, and tissue samples. However, reconstructing exposures for large populations is complicated by often having too few biomarker samples, large uncertainties about exposures, and large inter-individual variability. In this paper we use an illustrative case study to identify some of these difficulties and for a process for confronting them by reconstructing population-scale exposures using Bayesian inference. The application consists of interpreting biomarker data from eight adult males with controlled exposures to trichloroethylene (TCE) as

if the biomarkers were random samples from a large population with unknown exposure conditions. The TCE concentrations in blood from the individuals fell into two distinctly different groups even though the individuals were simultaneously in a single exposure chamber. We successfully reconstructed the exposure scenarios for both subgroups - although the reconstruction of one subgroup is different than what is believed to be the true experimental conditions. We were however unable to predict with high certainty the concentration of TCE in air.

Thatcher, Tracy L.; Lunden, Melissa M.; Revzan, Kenneth L.; Sextro, Richard G.; Brown, Nancy J., A concentration rebound method for measuring particle penetration and deposition in the indoor environment, *Aerosol Science and Technology*, V37:847-864, 2003. LBNL-51631.

ABSTRACT
Continuous, size resolved particle measurements were performed in two houses in order to determine size-dependent particle penetration into and deposition in the indoor environment. The experiments consisted of three parts: (1) measurement of the particle loss rate following artificial elevation of indoor particle concentrations, (2) rapid reduction in particle concentration through induced ventilation by pressurization of the houses with HEPA-filtered air, and (3) measurement of the particle concentration rebound after house pressurization stopped. During the particle concentration decay period, when indoor concentrations are very high, losses due to deposition are large compared to gains due to particle infiltration. During the concentration rebound period, the opposite is true. The large variation in indoor concentration allows the effects of penetration and deposition losses to be separated by the transient, two-parameter model we employed to analyze the data. For the two houses studied, we found that as particles increased in diameter from 0.1 to 10 μm, penetration factors ranged from ~1 to 0.3 and deposition loss rates ranged from 0.1 and 5 h^{-1}. The decline in penetration factor with increasing particle size was less pronounced in the house with the larger normalized leakage area.

Thatcher, T.L., D.J. Wilson, E.E. Wood, M.J. Craig, and R.G. Sextro. "Pollutant Dispersion in a Large Indoor Space: Part 1 – Scaled experiments using a water-filled model with occupants and furniture". Submitted to *Indoor Air*. LBNL-50248.

ABSTRACT
Pollutant dispersion experiments were performed in a water-filled 30:1 scale model of a large room. Theoretical calculations were performed to confirm that the effects from losses of molecular diffusion, small scale eddies, turbulent kinetic energy, and turbulent mass diffusivity were minimal, even without matching Reynolds number between model and full scale. In the experiments, uranine dye was injected continuously from a small point source near the floor of the model. Pollutant concentrations were measured in a plane using laser induced fluorescence techniques. The concentration profiles were measured for three interior configurations for the model: unobstructed, table-like obstructions, and table-like and figure-like obstructions. The presence of objects in the model interior had a significant effect of both the concentration profile and fluctuation intensity in the measurement plane.

Wagner, J., D.P. Sullivan, D. Faulkner, W.J. Fisk, L.E. Alevantis, R.L. Dod, L.A. Gundel, J.M. Waldman. Environmental Tobacco Smoke Leakage From Smoking Rooms. Accepted for publication in the Journal of Occupational and Environmental Hygiene. LBNL-51010

ABSTRACT
Twenty-seven laboratory experiments were conducted in a simulated smoking room to quantify rates of environmental tobacco smoke (ETS) leakage to a non-smoking area as a function of the physical and operational characteristics of the smoking room. Data are presented for the various types of leakage flows, the effect of these leaks on smoking room performance and non-smoker exposure, and the relative importance of each leakage mechanism. The results indicate that the first priority for an effective smoking room is to maintain it depressurized with respect to adjoining non-smoking areas. The amount of ETS pumped out by the smoking room door when it is opened and closed can be reduced significantly by substituting a sliding door for the standard swing-type door. An "open doorway" configuration used twice the ventilation flow as those with smoking room doors, but yielded less reduction in non-smoker exposure. Measured results correlated well with results modeled with mass-balance equations (R2 = 0.82-0.99). Most of these results are based on sulfur hexafluoride (SF6) tracer gas leakage. Because five measured ETS tracers showed good correlation with SF6, these conclusions should apply to ETS leakage as well. Field tests of a designated smoking room in an office building qualitatively agreed with model predictions.

Walker, Iain S.; Wray, Craig P.; Guillot, Cryil; Masson, S.. Evaluation of Commercially AvailableTechniques and Development of Simplified Methods for Measuring Grille Airflows in HVAC Systems. LBNL-51551.

ABSTRACT

This report discusses the accuracy of flow hoods for residential applications, based on laboratory tests and field studies. The results indicate that commercially available hoods are often inadequate to measure flows in residential systems, and that there can be a wide range of performance between different flow hoods. The errors are due to poor calibrations, sensitivity of existing hoods to grille flow non-uniformities, and flow changes from added flow resistance. We also evaluated several simple techniques for measuring register airflows that could be adopted by the HVAC industry and homeowners as simple diagnostics that are often as accurate as commercially available devices. Our test results also show that current calibration procedures for flow hoods do not account for field application problems. As a result, organizations such as ASHRAE or ASTM need to develop a new standard for flow hood calibration, along with a new measurement standard to address field use of flow hoods.

Walker, Iain S.; Brenner, Douglas E.; Sherman, Max H.; Dickerhoff, Darryl J.. Evaluation of PEGIT Duct Connection System. LBNL-43382.

ABSTRACT

Most air duct system components are assembled in the field and are mechanically fastened by sheet metal screws (for sheet metal-to-sheet metal) or by drawbands (for flex duct-to-sheet metal). Air sealing is separate from this mechanical fastening and is usually achieved using tape or mastic products after mechanical fastening. Field observations have shown that mechanical fastening rarely meets code or manufacturers requirements and that sealing procedures are similarly inconsistent. To address these problems, Proctor Engineering Group (PEG) is developing a system of joining ducts (called PEGIT) that combines the mechanical fastening and sealing into a single self-contained procedure. The PEGIT system uses a shaped flexible seal between specially designed sheet metal duct fittings to both seal and fasten duct sections together. Figure 1 shows the inner duct fitting complete with rubber seal. This seal provides the air seal for the completed fitting and is shaped to allow the inner and outer fittings to slide together, and then to lock the fittings in place. The illustration in Figure 2 shows the approximate cross section of the rubber seal that shows how the seal has a lip that is angled backwards. This angled lip allows the joint to be pushed together by folding flat but then its long axis makes it stiff in the pulling apart direction. This study was undertaken to assist PEG in some of the design aspects of this system and to test the performance of the PEGIT system.

Walker, I.S.; Sherman, M.H., Heat Recovery in Building Envelopes,. LBNL 53484

ABSTRACT

Infiltration has traditionally been assumed to contribute to the energy load of a building by an amount equal to the product of the infiltration flow rate and the enthalpy difference between inside and outside. Some studies have indicated that application of such a simple formula may produce an unreasonably high contribution because of heat recovery within the building envelope. The major objective of this study was to provide an improved prediction of the energy load due to infiltration by introducing a correction factor that multiplies the expression for the conventional load. This paper discusses simplified analytical modeling and CFD simulations that examine infiltration heat recovery (IHR) in an attempt to quantify the magnitude of this effect for typical building envelopes. For comparison, we will also briefly examine the results of some full-scale field measurements IHR based on infiltration rates and energy use in real buildings. The results of this work showed that for houses with insulated walls the heat recovery is negligible due to the small fraction of the envelope that participates in heat exchange with the infiltrating air. However; there is the potential for IHR to have a significant effect for higher participation dynamic walls/ceilings or uninsulated walls. This result implies that the existing methods for evaluating infiltration related building loads provide adequate results for typical buildings.

Walker, Iain S.; Guillot, Cyril. Experimental Evaluation of Gas Filled Plenum Duct Insulation. LBNL-52084.

ABSTRACT

Forced-air heating and cooling system ducts are often located outside conditioned space in US houses. For these systems to perform efficiently it is important that these ducts be well insulated. Common practice is

to use a glass fiber wrap around the ducts – either field applied or more commonly, integrated into a flexible duct. Most duct insulation has an R-value of 4.2, with R6 and R8 ducts also occasionally used. With glass fiber insulation being about R4 per inch (RSI 0.28/cm), this adds 2 to 4 inches (50 to 100 mm) to the duct diameter. Some building codes are now requiring these higher insulation levels, for example, the EPA requires the use of R6 ducts (for Energy Star ducts: http://www.epa.gov/hhiptool/PDF/Duct_Spec_2002.PDF), and International Energy Conservation Code (BOCA 2003) requires R8 ducts. The difficulty with adding insulation to ducts is the increase in diameter of the ducts that makes them expensive to transport because they take up a large volume and are difficult to install in the confined spaces available for ducts in houses. The objective of this study was to evaluate Gas Filled Plenum (GFP) technology as an alternative duct insulation. GFP ducts have the potential to provide greater insulation levels than existing ducts (for a given thickness of insulation or size of duct) and provide cost savings in transportation. These transportation cost savings are based on the idea of shipping the GFP ducts empty and inflating them on-site. To evaluate this technology for ducts we constructed a prototype duct and determined both its flow and heat transfer resistance in LBNL's duct testing laboratories. The GFP technology works by encapsulating a gas (usually air – but other noble gases such as Argon or Krypton can provide significant increases in thermal resistance with increased cost) in a metalized film jacket. A honeycomb structure is used to keep individual gas pockets small to minimize convection heat transfer. A metallic finish (usually aluminum) minimizes radiation heat transfer between the surfaces.

Walker, Iain S.; Sherman, Max H. Ventilation Technologies Scoping Study. LBNL-53811

ABSTRACT

This document presents the findings of a scoping study commissioned by the Public Interest Energy Research (PIER) program of the California Energy Commission to determine what research is necessary to develop new residential ventilation requirements for California. This study is one of three companion efforts needed to complete the job of determining the needs of California, determining residential ventilation requirements, and determining appropriate ventilation technologies to meet these needs and requirements in an energy efficient manner. Rather than providing research results, this scoping study identifies important research questions along with the level of effort necessary to address these questions and the costs, risks, and benefits of pursuing alternative research questions. In approaching these questions and level of effort, feasibility and timing were important considerations. The Commission has specified Summer 2005 as the latest date for completing this research in time to update the 2008 version of California's Energy Code (Title 24).

Walker, I.S.; McWilliams, J.A.; Konopacki., S.J. Case Study Field Evaluation of a Systems Approach to Retrofitting a Residential HVAC System LBNL-53444.

ABSTRACT

This case study focusing on a residence in northern California was undertaken as a demonstration of the potential of a systems approach to HVAC retrofits. The systems approach means that other retrofits that can affect the HVAC system are also considered. For example, added building envelope insulation reduces building loads so that smaller capacity HVAC system can be used. Secondly, we wanted to examine the practical issues and interactions with contractors and code officials required to accomplish the systems approach because it represents a departure from current practice. We identified problems in the processes of communication and installation of the retrofit that led to compromises in the final energy efficiency of the HVAC system. These issues must be overcome in order for HVAC retrofits to deliver the increased performance that they promise. The experience gained in this case study was used to optimize best practices guidelines for contractors (Walker 2003) that include building diagnostics and checklists as tools to assist in ensuring the energy efficiency of "house as a system" HVAC retrofits. The best practices guidelines proved to be an excellent tool for evaluating the eight existing homes in this study, and we received positive feedback from many potential users who reviewed and used them. In addition, we were able to substantially improve the energy efficiency of the retrofitted case study house by adding envelope insulation, a more efficient furnace and air conditioner, an economizer and by reducing duct leakage.

Walker, I.S.; Mingee, M.D.; Brenner, D.E. Improving Air Handler Efficiency in Residential HVAC Applications. LBNL-53606.

ABSTRACT

In continuing the development of energy efficiency standards, consideration has turned to air handlers used for heating and air conditioning of consumer residences. These air handlers have typical efficiencies of

about 10% to 15% due to poor electric motor performance and aerodynamically poor fans and fan housings. This study was undertaken to examine some of these performance issues, under carefully controlled laboratory conditions, to support potential regulatory changes. In addition, this study examined the performance of a prototype air handler fan assembly that offers the potential for substantial increases in performance. This prototype and a standard production fan were tested in a full-scale duct system and test chamber at LBNL which was specifically designed for testing heating, ventilation, and air conditioning systems. The laboratory tests compared efficiency, total airflow, sensitivity to duct system flow resistance, and the effects of installation in a smaller cabinet. The test results showed that, averaged over a wide range of operating conditions, the prototype air handler had about twice the efficiency of the standard air handler and was less sensitive to duct system flow resistance changes. The performance of both air handlers was significantly reduced by reducing the space between the air handler and the cabinet it was installed in. Therefore any fan rating needs to be performed using the actual cabinet it will be used

Wray, Craig; Walker, Iain; Sherman, Max. Guidelines for Residential Commissioning. LBNL-48767

ABSTRACT

This guide is the culmination of a 30-month project that began in September 1999. The ultimate objective of the project is to increase the number of houses that undergo commissioning, which will improve the quality, comfort, and safety of homes for California citizens. The project goal is to lay the groundwork for a residential commissioning industry in California focused on end-use energy and non-energy issues. As such, we intend this guide to e a beginning and not an end. Our intent is that the guide will lead to the programmatic integration of commissioning with other building industry processes, which in turn will provide more value to a single site visit for people such as home energy auditors and raters, home inspectors, and building performance contractors.

Wray, Craig P.; Matson, Nance E.. Duct Leakage Impacts on VAV System Performance in Large Commercial Buildings. LBNL-53605

ABSTRACT

The purpose of this study is to evaluate the variability of duct leakage impacts on air distribution system performance for typical large commercial buildings in California. Specifically, a hybrid DOE-2/TRNSYS sequential simulation approach was used to model the energy use of a low-pressure terminal-reheat variable-air-volume (VAV) HVAC system with six duct leakage configurations (tight to leaky) in nine prototypical large office buildings (representing three construction eras in three California climates where these types of buildings are common). Combined fan power for the variable-speed-controlled supply and return fans at design conditions was assumed to be 0.8 W/cfm. The VAV system that we simulated had perfectly insulated ducts, and maintained constant static pressure in the ducts upstream of the VAV boxes and a constant supply air temperature at the air-handler. Further evaluations of duct leakage impacts should be carried out in the future after methodologies are developed to deal with duct surface heat transfer effects, to deal with airflows entering VAV boxes from ceiling return plenums (e.g., to model parallel fan-powered VAV boxes), and to deal with static pressure reset and supply air temperature reset strategies.

Wray, Craig P. Duct Thermal Performance Models for Large Commercial Buildings. LBNL-53410.

ABSTRACT

Despite the potential for significant energy savings by reducing duct leakage or other thermal losses from duct systems in large commercial buildings, California Title 24 has no provisions to credit energy-efficient duct systems in these buildings. A substantial reason is the lack of readily available simulation tools to demonstrate the energy-saving benefits associated with efficient duct systems in large commercial buildings.

2002 PUBLICATIONS WITH ABSTRACTS

Abadie, Marc O., Elizabeth U. Finlayson and Ashok J. Gadgil. "Infiltration heat recovery in building walls: Computational fluid dynamics investigations results". LBNL-51324.

ABSTRACT

Conventional calculations of heating (and cooling) loads for buildings assume that conduction heat loss (or gain) through walls is independent of air infiltration heat loss (or gain). During passage through the building envelope, infiltrating air substantially exchanges heat wall insulation leading to partial recovery of

heat conducted through the wall. The Infiltration Heat Recovery (IHR) factor was introduced to quantify the heat recovery and correct the conventional calculations.

In this study, Computational Fluid Dynamics was to calculate infiltration heat recovery under a range of idealized conditions, specifically to understand factors that influence it, and assess its significance in building heat load calculations. This study shows for the first time the important effect of the external boundary layers on conduction and infiltration heat loads.

Results show (under the idealized conditions studied here) that (1) the interior details of the wall encountered in the leakage path (i.e., insulated or empty walls) do not greatly influence the IHR, the overall relative location of the cracks (i.e., inlet and outlet locations on the wall) has the largest influence on the IHR magnitude, (2) external boundary layers on the walls substantially contribute to IHR and (3) the relative error in heat load calculations resulting from the use of the conventional calculational method (i.e., ignoring IHR) is between 3% and 13% for infiltrating flows typically found in residential buildings.

Abushakra, Bass, Iain S. Walker and Max H. Sherman. "A study of pressure losses in residential air distribution systems". *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*; Pacific Grove, California; August 18-23, 2002, Vol. 1, pp.1-14, American Council for an Energy Efficient Economy, Washington, DC. LBNL-49700.

ABSTRACT

An experimental study was conducted to evaluate the pressure drop characteristics of residential duct system components that are either not available or not thoroughly (sometimes incorrectly) described in existing duct design literature. The tests were designed to imitate cases normally found in typical residential and light commercial installations. The study included three different sizes of flexible ducts, under different compression configurations, splitter boxes, supply boots, and a fresh air intake hood. The experimental tests conformed to ASHRAE Standard 120P – *Methods of Testing to Determine Flow Resistance of HVAC Air Ducts and Fittings*. The flexible duct study covered compressibility and bending effects on the total pressure drop, and the results showed that the available published references tend to underestimate the effects of compression in flexible ducts that can increase pressure drops by up to a factor of nine. The supply boots were tested under different configurations including a setup where a flexible duct elbow connection was considered as an integral part of the supply boot. The supply boots results showed that diffusers can increase the pressure drop by up to a factor of two in exit fittings, and the installation configuration can increase the pressure drop by up to a factor of five. The results showed that it is crucial for designers and contractors to be aware of the compressibility effects of the flexible duct, and the installation of supply boots and diffusers.

Abushakra, Bass. Longevity of duct tape in residential air distribution systems: 1-D, 2-D, and 3-D joints. LBNL-51099. No Abstract available.

Apte, M., Hodgson, A., Shendell, D., Dibartolomeo, D., Hotchi, T., Kumar, S., Lee, Seung-Min, Liff, S., Rainer, L., Schmidt, R., Sullivan, D., Diamond, R., Fisk, W.J., (2002) "Energy and indoor environmental quality in relocatable classrooms". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 2, pp.62-69, Indoor Air 2002, Santa Cruz, CA. LBNL-49581.

ABSTRACT

Relocatable classrooms (RCs) are commonly utilized by school districts with changing demographics and enrollment sizes. Four energy-efficient RCs were designed and constructed for this study to demonstrate technologies that simultaneously attempt to improve energy efficiency and indoor environmental quality (IEQ). Two were installed at each of two school districts, and energy use and IEQ parameters were monitored during occupancy. Two (one per school) were finished with materials selected for reduced emissions of toxic and odorous volatile organic compounds (VOCs). Each RC had two HVAC systems, alternated weekly, consisting of a standard heat-pump system and an indirect-direct evaporative cooling (IDEC) system with gas-fired hydronic heating. The hypothesized advantages of the IDEC include continuous outside air ventilation at ≥ 7.5 L s^{-1} per person, ~70% less cooling energy and efficient particle filtration. Measurements include: carbon dioxide, particles, VOCs, temperature, humidity, thermal comfort, noise, meteorology, and energy use. Preliminary IEQ monitoring results are reported.

Apte, Michael, Lara Gundel, Raymond Dod, Gee-Min Chang, and Richard Sextro. "A pilot study of the behavior of gas- and particle-phase ETS tracers in residences". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 2, pp. 500-505, Indoor Air 2002, Santa Cruz, CA. LBNL-49585.

ABSTRACT
Our previous study of environmental tobacco smoke (ETS) in a three-room environmental chamber showed that smoking history significantly influenced inter-room ETS transport , particularly of gas-phase nicotine. We conducted a three-home pilot study where smoking was limited to one room. Single-smoker residences were monitored during five one-week periods while the smoker participated in a smoking cessation program. Nicotine traced ETS particles were detected reliably in the smoking rooms (SRs) and unreliably in the non-smoking rooms (NSRs). On average, the ventilation- and volume-normalized smoking rate, 0.1 Cigarette-$h^{-1}m^{-3}$, added about 17 and 4 □g $m^{-3}$of ETS particles into the SR and NSR, while average nicotine concentration increases were 2 and 0.06 □g m^{-3}, respectively. Thus, nicotine tracers may underestimate ETS particle exposure in a NSR (e.g., a child's bedroom) by a factor of 2 to 8. In other words, ETS exposure predicted from nicotine concentrations could be almost an order of magnitude lower than actual exposure.

Bennett, Deborah H., Thomas E. McKone, John.S. Evans, William W. Nazaroff, Manuele D. Margni, Olivier Jolliet, and Kirk R. Smith. "Defining intake fraction". *Environmental Science & Technology* v.36; pp.207A-211A; May 1, 2002. LBNL-50501.

ABSTRACT
Activities such as comparative risk analysis, life-cycle assessment, emissions trading and sustainable development are creating a growing demand for reliable and consistent information about the potential adverse effects of the thousands of chemicals released to the environment. This demand has fostered measurement and modeling efforts that link emissions to the resulting human exposures and subsequent health effects for a wide range of human products and activities, such manufacture and disposal of consumer goods, cooking, smoking, energy conversion, industrial production, and agriculture. For many pollutants, a preliminary estimate of the human health risk that is posed by an environmental release can be determined from the combination of three factors: (1) the quantity released; (2) the incremental intake per unit release; and (3) the risk of adverse effect per unit intake. This paper addresses the second term, the emissions-to-intake relationship. As discussed in a recent literature review, several researchers have independently developed similar approaches for relating source emissions to human intake for various pollutants and exposure pathways. Consequently, multiple terms, definitions, and units exist for what appears to be a single, yet multifaceted concept. But there are inconsistencies both in terminology and definitions among various researchers quantifying emissions-to-intake relationships. Differences in definitions leads to unnecessary complexity in comparing results from different research groups. Inconsistency in terminology when the same quantity is being calculated leads to further lack of transparency. We formed a working group and prepared this article to communicate our recommendations. for a set of terms and associated definitions that are descriptive, simple, accurate, and consistent both with common usage and usage in all relevant disciplines; are flexible to permit application over a broad range of potential uses; and reflect consensus among a large number of researchers. We propose the term *intake fraction* (*iF*) as the primary label for quantifying the emissions-to-intake relationship.

Because the effort to employ intake fraction is in its early stages and is gaining momentum, now is the time to build consensus on terminology. Doing so will allow us to communicate more effectively both among ourselves and also with practitioners in related fields.

Bennett, D.H., M.D. Margni, T.E. McKone, and O. Jolliet, "Intake Fraction for Multimedia Pollutants: A Tool for Life Cycle Analysis and Comparative Risk Assessment," *Risk Analysis* v.22; no.5; pp. 903-916; October 2002, LBNL-47253

ABSTRACT
We employ the concept of Intake Fraction (*iF*) as an effective way to understand the source-to-dose relationship for pollutant emissions in Life Cycle Analysis (LCA) or comparative risk assessment. Intake fraction is the fraction of chemical mass emitted into the environment that eventually passes into a member of the population through inhalation, ingestion, or dermal exposure. To date, this concept has been primarily applied to pollutants whose primary route of exposure is inhalation. Here we extend the use of *iF* to multimedia pollutants with multiple exposure pathways. We use a level III multimedia model to

calculate *iF* for TCDD and compare the results to one calculated from measured levels of dioxin toxic equivalents in the environment. We calculate *iF* for emissions to air and surface water for 244 chemicals. We correlate the primary exposure route with the magnitudes of the octanol-water partition coefficient, K_{ow}, and of the air-water partitioning coefficient (dimensionless Henry constant), K_{aw}. This results in value ranges of K_{ow} and K_{aw} where the chemical exposure route can be classified with limited input data requirements as primarily inhalation, primarily ingestion, or multi-pathway. For the inhalation and ingestion dominant pollutants, we also define empirical relationships based on chemical properties for quantifying dose fraction. The empirical relationships facilitate rapid evaluation of many chemicals in terms of the potential dose. By defining a theoretical upper limit for *iF* in a multimedia environment we find that *iF* calculations provide insight into the multimedia model algorithms and help identify unusual patterns of exposure and questionable exposure model results.

Bennett DH, Furtaw EJ, McKone TE (2002): A fugacity-based indoor residential pesticide fate model. *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 1, pp. 261-266, Indoor Air 2002, Santa Cruz, CA. LBNL-53458.

ABSTRACT
Dermal and non-dietary pathways are potentially significant exposure pathways to pesticides used in residences. Exposure pathways include dermal contact with residues on surfaces, ingestion from hand- and object-to-mouth activities, and absorption of pesticides into food. A limited amount of data has been collected on pesticide concentrations in various residential compartments following an application. But models are needed to interpret this data and make predictions about other pesticides based on chemical properties. In this paper, we propose a mass-balance compartment model based on fugacity principles. We include air (both gas phase and aerosols), carpet, smooth flooring, and walls as model compartments. Pesticide concentrations on furniture and toys, and in food, are being added to the model as data becomes available. We determine the compartmental fugacity capacity and mass transfer-rate coefficient for wallboard as an example. We also present the framework and equations needed for a dynamic mass-balance model.

Bodnar, A.B., R.L. Maddalena and T.E. McKone. "Addressing locally grown foods in cumulative exposure assessments". Submitted to *Journal of Exposure Analysis and Environmental Epidemiology*, (July, 2002). LBNL-50378.

ABSTRACT
Both laboratory and field studies confirm the importance of vegetation for scavenging semi-volatile organic chemicals (SVOCs) from the atmosphere and a number of exposure studies have found that the dietary pathway is often a significant contributor to cumulative exposure for these chemicals. Exposure calculations based on published concentration data for foods indicate that the potential intake through ingestion is up to 1000 times that of inhalation for several persistent SVOCs. However, little information exists on the source-to-dietary intake linkage for SVOC's. Because of higher SVOC emissions to urban regions, this linkage is particularly important for foods that are grown, distributed and consumed in or near urban regions. The food pathway can also contribute to dietary exposure for populations that are remote from a pollutant source if the pollutants can migrate to agricultural regions and subsequently to the agricultural commodities distributed to that population. We use the characteristic travel distance (CTD) and available data within the CalTOX multimedia model framework to assess the contribution of local food markets to the fraction of cumulative food intake that is attributable to local sources. For a set of three representative multimedia SVOCs- benzo(a)pyrene, fluoranthene, and 2,3,7,8-TCDD, we explore the contribution of airborne SVOC's to cumulative uptake through the local food consumption pathway. We use the population based intake fraction (iF) to determine how SVOC intake varies among food commodities and compares to inhalation. The approach presented here provides a useful framework and starting point for source-to-intake assessments for the air-to-dietary exposure pathway.

Carrié, F. R., Levinson, R., Xu, T. T., Dickerhoff, D. J., Fisk, W. J., McWilliams, J., Modera, M. P., Wang, D. 1999. "Laboratory and field testing of an aerosol-based duct-sealing technology for large commercial buildings". Published in *ASHRAE Transactions*, Jan. 2002. LBNL-44220.

ABSTRACT
Laboratory and field experiments were performed to evaluate the feasibility of sealing leaks in commercial duct systems with an aerosol sealant. The method involves blowing an aerosol through the

duct system to seal the leaks from the inside, the principle being that the aerosol particles deposit in the cracks as they try to escape under pressure. It was shown that the seals created with the current sealant material can withstand pressures far in excess of what is found in commercial-building duct systems. We also performed two field experiments in two large-commercial buildings. The ASHRAE leakage classes of the systems were reduced from 653 down to 103, and from 40 down to 3. Methods and devices specifically devised for this application proved to be very efficient at (a) increasing the sealing rate and (b) attaining state-of-the-art duct leakage classes. Additional research is needed to improve the aerosol injection and delivery processes.

Castorina, R., A. Bradman and T.E. McKone. "Assessing cumulative organophosphate pesticide exposure and risk among pregnant women living in an agricultural community". Submitted to *Environmental Health Perspectives* (August, 2002) LBNL-51334.

ABSTRACT
Approximately 225,000 kilograms of organophosphate (OP) pesticides are used annually in California's Salinas Valley, which is intensively farmed for vegetables and fruit. These activities have raised concerns about pesticide exposures to area residents. As part of a prospective cohort study, we collected three spot urine samples from 462 pregnant women and analyzed them for six dialkyl phosphate metabolites. Based on these urinary metabolite concentrations, we estimated OP pesticide doses with deterministic steady-state models using two methods: the first method assumed the pesticide metabolites were attributable entirely to a single diethyl or dimethyl OP pesticide; the second method adapted U.S. EPA draft guidelines for cumulative risk assessment to estimate dose from a mixture of OP pesticides that share a common mechanism of toxicity. We used pesticide use reporting data for the Salinas Valley to quantify the likely mixture to which the women were exposed. Based on average OP pesticide dose estimates that assumed exposure to a single OP pesticide (Method 1), between 0% and 36.0% of study participants' exposures exceeded the U.S. EPA oral benchmark $dose_{10}$ (BMD_{10}) divided by a 100-fold uncertainty factor, depending on the assumption made about the parent compound. These BMD_{10} values were derived from studies of brain cholinesterase inhibition in rats. 14.7% of the participants' average cumulative OP pesticide dose estimates (Method 2) exceeded the BMD_{10} of the selected index chemical divided by a 100-fold uncertainty factor, regardless of index chemical chosen. An uncertainty analysis of the pesticide mixture parameter suggests that this point estimate could range from 1%-38%. Because our reference value ($BMD_{10}/100$) may not account for the special sensitivity of the developing fetus, this research points to the need for modeling approaches to estimate fetal exposures and assess risk from prenatal OP pesticide exposure.

Cox. S.S., Little, J.C., Hodgson, A.T. (2002) "Predicting the emission rate of volatile organic compounds from vinyl flooring", *Environmental Science & Technology* 36:709-714. LBNL-47094.

ABSTRACT
A model for predicting the rate at which a volatile organic compound (VOC) is emitted from a diffusion-controlled material is validated for three contaminants (n-pentadecane, n-tetradecane, and phenol) found in vinyl flooring (VF). Model parameters are the initial VOC concentration in the material-phase (C_0), the material/air partition coefficient (K), and the material-phase diffusion coefficient (D). The model was verified by comparing predicted gas-phase concentrations to data obtained during small-scale chamber tests, and by comparing predicted material-phase concentrations to those measured at the conclusion of the chamber tests. Chamber tests were conducted with the VF placed top side up and bottom side up. With the exception of phenol, and within the limits of experimental precision, the mass of VOCs recovered in the gas phase balances the mass emitted from the material phase. The model parameters (C_0, K, and D) were measured using procedures that were completely independent of the chamber test. Gas- and material-phase predictions compare well to the bottom-side-up chamber data. The lower emission rates for the top-side-up orientation may be explained by the presence of a low-permeability surface layer. The sink effect of the stainless steel chamber surface was shown to be negligible.

Craig, Paul, Ashok Gadgil and Jonathan Koomey, 2002. "What can history teach us?: A retrospective analysis of long-term energy forecasts for the U.S." *Annual Reviews of Energy and the Environment*, Vol. 27, pp. 83-118) LBNL-50498.

ABSTRACT
This paper explores how long-term energy forecasts are created and why they are useful. It focuses on forecasts of energy use in the United States for the year 2000 but considers only long-term predictions, i.e., those covering two or more decades. The motivation is current interest in global warming forecasts, some of which run beyond a century. The basic observation is that forecasters in the 1950-1980 period underestimated the importance of unmodeled surprises. A key example is the failure to foresee the ability of the United States economy to respond to the oil embargos of the 1970s by increasing efficiency. Not only were most forecasts of that period systematically high, but forecasters systematically underestimated uncertainties. Long-term energy forecasts must make assumptions about both technologies and social systems. At their most successful, they influence how people act by showing the consequences of not acting. They are useful when they provide insights to energy planners, influence the perceptions of the public and the energy policy community, capture current understanding of underlying physical and economic principles, or highlight key emerging social or economic trends.

Daisey, J.M., W.J. Angell, and M.G. Apte. 2002. "Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information," *Indoor Air*, in press. LBNL-48287.

ABSTRACT
We reviewed the literature on indoor air quality (IAQ), ventilation, and building-related health problems in schools and identified commonly reported building-related health symptoms involving schools until 1999. We collected existing data on ventilation rates, carbon dioxide (CO_2) concentrations and symptom-relevant indoor air contaminants, and evaluated information on causal relationships between pollutant exposures and health symptoms. Reported ventilation and CO_2 data strongly indicate that ventilation is inadequate in many classrooms, possibly leading to health symptoms. Adequate ventilation should be a major focus of design or remediation efforts. Total volatile organic compounds, formaldehyde and microbiological contaminants are reported. Low formaldehyde concentrations were unlikely to cause acute irritant symptoms (<0.05 ppm), but possibly increased risks for allergen sensitivities, chronic irritation, and cancer. Reported microbiological contaminants included allergens in deposited dust, fungi and bacteria. Levels of specific allergens were sufficient to cause symptoms in allergic occupants. Measurements of airborne bacteria and airborne and surface fungal spores were reported in schoolrooms. Asthma and "sick building syndrome" symptoms are commonly reported. The few studies investigating causal relationships between health symptoms and exposures to specific pollutants suggest that such symptoms in schools are related to exposures to volatile organic compounds (VOCs), molds and microbial VOCs, and allergens.

De Martinis, B.S.; R.A. Okamoto, N.Y. Kado, L.A. Gundel and L.R.F. Carvalho, Polycyclic aromatic hydrocarbons in a bioassay-directed fractionated extract of PM10 collected in Sao Paulo, Brazil, *Atmos. Environ.* 36, 307-314 (2002), LBNL-48453. No Abstract available.

Diamond, Rick. *What might U.S. homes and workplaces be like in the year 2020--and what are the implications for energy use?* (2002) LBNL-50184.

ABSTRACT
Can lifestyle-based scenarios provide insight into the nature of energy use in our future buildings? Participants in a design charrette brainstormed ideas about the future of US homes and workplaces. The teams started from several descriptions of daily lifestyles, and developed specific building characteristics as the place settings for these narratives. In addition to the characterization of the physical environment, we also speculate as to the forces that would be influential in making these changes. Further reflection was made on the possible unintended consequences of these changes. The rationale for this exercise was to broaden the discussion on future energy use by looking at future scenarios in the context of everyday life.

Diamond, R.C. and M. Moezzi. "Becoming allies: Combining social science and technological perspectives to improve energy research and policy making". *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, California; August 18-23, 2002, Vol. 4, pp. 89-104, American Council for an Energy Efficient Economy, Washington, DC LBNL-50704.

ABSTRACT
Within the energy research community, social sciences tends to be viewed fairly narrowly, often as simply a marketing tool to change the behavior of consumers and decision makers, and to "attack market barriers." As we see it, social sciences, which draws on sociology, psychology, political science, business

administration, and other academic disciplines, is capable of far more. A social science perspective can re-align questions in ways that can lead to the development of technologies and technology policy that are much stronger and potentially more successful than they would be otherwise. In most energy policies governing commercial buildings, the prevailing R&D directives are firmly rooted in a technology framework, one that is generally more quantitative and evaluative than that fostered by the social sciences. To illustrate how social science thinking would approach the goal of achieving high energy performance in the commercial building sector, we focus on the U.S. Department of Energy's Roadmap for commercial buildings (DOE 2000) as a starting point. By "deconstructing" the four strategies provided by the Roadmap, we set the stage for proposing a closer partnership between advocates of technology-based and social science-based approaches.

Erdmann, C.A., Steiner, K.C,, Apte, M.G., (2002) "Indoor carbon dioxide concentrations and SBS symptoms in office buildings revisited: Analyses of the 100 building BASE Study dataset". *Proceedings of Indoor Air 2002* Conference, Monterey, CA, Vol. 3, pp. 443-448. Indoor Air 2002, Santa Cruz, CA. LBNL-49584.

ABSTRACT
In previously published analyses of the 41-building 1994-1996 USEPA Building Assessment Survey and Evaluation (BASE) dataset, higher workday time-averaged indoor minus outdoor CO_2 concentrations (dCO_2) were associated with increased prevalence of certain mucous membrane and lower respiratory sick building syndrome (SBS) symptoms, even at peak dCO_2 concentrations below 1,000 ppm. For this paper, similar analyses were performed using the larger 100-building 1994-1998 BASE dataset. Multivariate logistic regression analyses quantified the associations between dCO_2 and the SBS symptoms, adjusting for age, sex, smoking status, presence of carpet in workspace, thermal exposure, relative humidity, and a marker for entrained automobile exhaust. Adjusted dCO_2 prevalence odds ratios for sore throat and wheeze were 1.17 and 1.20 per 100-ppm increase in dCO_2 ($p < 0.05$), respectively. These new analyses generally support our prior findings. Regional differences in climate, building design, and operation may account for some of the differences observed in analyses of the two datasets.

Faulkner, D., Fisk, W.J., Sullivan, D.P., Lee, S.M., (2002) "Ventilation efficiencies of a desk-edge-mounted task ventilation system". *Proceedings of Indoor Air 2002* Conference, Monterey, CA., Vol. 4, pp.1060-65. Indoor Air 2002, Santa Cruz, CA. LBNL-49939.

ABSTRACT
In chamber experiments, we investigated the effectiveness of a task ventilation system with an air supply nozzle located underneath the front edge of a desk and directing air toward a heated mannequin seated at the desk. The task ventilation system provided outside air, while another ventilation system provided additional space cooling but no outside air. Test variables included the vertical angle of air supply (-15° to 45° from horizontal), and the supply flow rate of (3.5 to 6.5 L s^{-1}). Using the tracer gas step-up and step-down procedures, the measured air change effectiveness (i.e., exhaust air age divided by age of air at the mannequin's face) ranged from 1.4 to 2.7, which is higher than typically reported for commercially available task ventilation or displacement ventilation systems.

Federspiel, C.C., Liu, G., Lahiff, M., Faulkner, D., Dibartolomeo, D.L., Fisk, W.J., Price, P.N., Sullivan, D.P. "Worker performance and ventilation: Analyses of individual data for call-center workers". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 1, pp.796-801. Indoor Air 2002, Santa Cruz, CA. LBNL-50124.

ABSTRACT
We investigated the relationship between ventilation rates and work performance in a call center. We randomized the ventilation controls and measured ventilation rate, differential carbon dioxide (ΔCO_2) concentration, temperature, humidity, occupant density, degree of under-staffing, shift length, time of day, and time required to complete two different work performance tasks (talk and wrap-up). ΔCO_2 concentrations ranged from 13 to 611 ppm. We used multi-variable regression to model the association between the predictors and the responses. We found that agents performed talk tasks fastest when the ventilation rate was highest, but that the relationship between talk performance and ventilation was not monotone. We did not find a statistically significant association between wrap-up performance and ventilation. At high temperatures agents were slower at both the talk and wrap-up tasks. Agents were slower at wrap-up during long shifts and when the call center was under-staffed.

Federspiel, C., H. Li, D. Auslander, D. Lorenzetti, and A. Gadgil. "Modeling transient contaminant transport in HVAC systems and buildings", *Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 4, pp.217-222. Indoor Air 2002, Santa Cruz, CA. LBNL-49603.

ABSTRACT
A mathematical model of the contaminant transport in HVAC systems and buildings is described. The model accounts for transients introduced by control elements such as fans and control dampers. The contaminant transport equations are coupled to momentum equations and mass continuity equations of the air. To avoid modeling variable transport delays directly, ducts are divided into a large number of small sections. Perfect mixing is assumed in each section. Contaminant transport equations are integrated with momentum equations in a way that guarantees mass continuity by using two non-negative velocities for computing the mass transport between elements. Computer simulations illustrate how the model may be used to analyze and design control systems that respond to a sudden release of a toxic contaminant near a building. By coupling transient flow prediction with transient contaminant prediction, the model overcomes a number of problems with existing contaminant transport codes.

Fischer, M., Littlejohn D., M. Lunden, L. Gundel, R. Dod, and N. Brown. "An instrument for automated simultaneous measurements of ammonia and nitric acid in indoor and outdoor air". LBNL-51005. No Abstract available.

Fischer, Marc L., Melissa M. Lunden, Tracy L. Thatcher, David Littlejohn, Thomas W. Kirchstetter, Susanne V. Hering, Richard G. Sextro, and Nancy J. Brown. "Building a predictive model of indoor concentrations of outdoor PM-2.5 for a residential research house in Clovis, California". LBNL-51001.

ABSTRACT
The prevalence of relocatable classrooms (RCs) at schools is rising due to federal and state initiatives to reduce K-3 class size, and limited capital resources. Concerns regarding inadequate ventilation and indoor air and environmental quality (IEQ) in RCs have been raised. Adequate ventilation is an important link between improved IEQ and energy efficiency for schools. Since students and teachers spend the majority of a 7-8 hour school day inside classrooms, indoor contaminant concentrations are assumed to drive personal school-day exposures. We conducted a demonstration project in new relocatable classrooms (RCs) during the 2001-02 school year to address these issues. Four new 24' x 40' (960 ft^2) RCs were constructed and sited in pairs at an elementary school campus in each of two participant school districts (SD) in Northern California. Each RC was equipped with two heating, ventilation, and air conditioning (HVAC) systems, one per module. The two HVAC systems were a standard heat pump with intermittent 25-50% outdoor air ventilation and an energy-efficient advanced system, based on indirect-direct evaporative cooling with an integrated natural gas-fired hydronic heating loop and improved particle filtration, providing continuous 100% outdoor air ventilation at ≥ 15 ft^3 min^{-1} $occupant^{-1}$. Alternate carpets, wall panels, and ceiling panels were installed in two classrooms – one in each pair – based on the results of a laboratory study of VOC emissions from standard and alternate materials. Numerous IEQ and outdoor air quality and meteorological parameters were measured either continuously over the school year or as integrated school day samples during the fall cooling and winter heating seasons. Details of the RC designs, the field monitoring methodology including handling, storage, transport and management of chemical samples and data, and analyses to be conducted are presented.

Fischer, M.L., Lunden, M.M., Thatcher, T.L., Sextro, R.G., Brown, N.J. (2002) " Predicting Indoor PM2.5 Of Outdoor Origin: Testing a transient size-resolved Model Using Intensive Measurements From A Residence". *Proceedings of Indoor Air 2002* Conference, Monterey, CA., Vol. 1, pp.152-157. Indoor Air 2002, Santa Cruz, CA.. LBNL-49615.

ABSTRACT
We report tests of a model for indoor PM2.5 of outdoor origin that incorporates physical mechanisms for time dependent transport, and size dependent penetration and deposition. This work was performed using information obtained from an intensive study of a house near Fresno, CA, USA. During the multi-week study covering two seasons, we measured particles in both indoor and outdoor air, with high temporal, chemical, and size resolution, and other variables that also affect transport and fate. Results suggest that 1) the model captures a significant fraction of the variation in meteorologically forced air infiltration rate, 2) the predicted indoor/outdoor PM2.5 ratio is not consistent with the measured ratio unless a large (unphysical) deposition rate > 2 hr^{-1} is assumed, and 3) the differences between model and measurement in

indoor PM2.5 are likely due to loss of volatile ammonium-nitrate aerosol. We conclude that nitrate particle volitization must be included in the model formulation.

Fischer, M. L., Price, P. N., Thatcher, T. L., Schwalbe, C. A., Craig, M. J., Wood, E. E., Sextro, R. G., and Gadgil, A. J., "Rapid Measurement and Mapping of Tracer Gas Concentrations in a Large Indoor Space." *Atmospheric Environment*, Vol. 35 (2001) pp. 2837-2844 . LBNL-45542.

ABSTRACT
Rapid mapping of gas concentrations in air benefits studies of atmospheric phenomena ranging from pollutant dispersion to surface layer meteorology. Here we demonstrate a technique that combines multiple-open-path tunable-diode-laser (TDL) spectroscopy and computed tomography to map tracer gas concentrations with approximately 0.5 m spatial and 7 second temporal resolution. Releasing CH_4 in a large (7m x 9m x 11m high) ventilated chamber, we measured path-integrated CH_4 concentrations over a planar array of 28 "long" (2-10 m) optical paths, recording a complete sequence of measurements every 7 seconds during the course of hour-long experiments. Maps of CH_4 concentration were reconstructed from the long-path data and compared with simultaneous measurements from 28 "short" (0.5 m) optical paths. On average, the reconstructed maps capture ~ 74% of the variance in the short path measurements. The accuracy of the reconstructed maps is limited, in large part, by the number of optical paths and the time required for the measurement. Straightforward enhancements to the instrumentation will allow rapid mapping of three-dimensional gas concentrations in indoor and outdoor air, with sub-second temporal resolution.

Fisk, W.J., G. Brager, H. Burge, J. Cummings, H. Levin, V. Loftness, M.J. Mendell, A. Persily, S. Taylor, and J.S. Zhang. "Energy-related indoor environmental quality research: A priority agenda". 2002. LBNL-51328.

ABSTRACT
A multidisciplinary team of IEQ and energy researchers has defined a program of priority energy-related IEQ research. This paper describes the methods employed to develop the agenda, and 35 high priority research and development (R&D) project areas related to four broad goals:

1) identifying IEQ problems and opportunities;
2) developing and evaluating energy-efficient technologies for improving IEQ;
3) developing and evaluating energy-efficient practices for improving IEQ; and
4) encouraging or assisting the implementation of technologies or practices for improving IEQ.

The identified R&D priorities reflect a strong need to benchmark IEQ conditions in small commercial buildings, schools, and residences. The R&D priorities also reflect the need to better understand how people are affected by IEQ conditions and by the related building characteristics and operation and maintenance practices. The associated research findings will provide a clearer definition of acceptable IEQ that is required to guide the development of technologies, practices, standards, and guidelines. Quantifying the effects of building characteristics and practices on IEQ conditions, in order to provide the basis for development of energy efficient and effective IEQ control measures, was also considered a priority. The development or advancement in a broad range of IEQ tools, technologies, and practices are also a major component of the priority research agenda.

Consistent with the focus on "energy-related" research priorities, building ventilation and heating, ventilating and air conditioning (HVAC) systems and processes are very prominent in the agenda. Research related to moisture and microbiological problems, particularly within hot and humid climates, is also prominent within the agenda. The agenda tends to emphasize research on residences, *small* commercial buildings, and schools because these types of buildings have been underrepresented in prior research. Most of the research areas apply to both new construction and existing buildings.

Nearly all of the recommended priority R&D project areas include tasks intended to facilitate the communication and implementation of the research results. In addition, the priority agenda includes several projects specifically designed to facilitate or stimulate the use of existing energy-efficient technologies and practices for improving IEQ.

To assure that the research program continues to meet the needs of stakeholders and to facilitate the coordination of research among sponsors, the core team recommends an annual meeting attended by sponsors, a balanced group of stakeholders, and a selection of researchers implementing the agenda.

Fisk, W.J. "How IAQ affects health, productivity". *ASHRAE Journal*, May 2002, Vol. 44(N5):56,58-60. LBNL-51381.

Introduction

This article, a summary of Fisk (2000a, 2000b), estimates the nationwide improvements in health and productivity potentially attainable by providing better indoor environmental quality (IEQ) in U.S. buildings. Estimates include the potential reductions in three categories of health effects, the associated economic benefits, and the potential direct improvements in productivity not mediated through health. Expected costs and benefits of improving IEQ are compared, with a brief discussion of energy implications.

Fisk, W.J. and M.J. Mendell. "Ventilation rates and health". ASHRAE Journal, v.44, no.8 (2002): pp.56-58. LBNL-51382.

Introduction

This article summarizes the review by Seppänen et al. (1999) of current literature on the relationship of ventilation rates and carbon dioxide concentrations in non-residential and non-industrial buildings (primarily offices) with the health of the building's occupants and with the occupants' perceptions of indoor air quality (IAQ). While ventilation rates do not directly affect occupant health or perception outcomes, they affect indoor environmental conditions including air pollutant concentrations that, in turn, may modify the occupants' health or perceptions. The review aims to provide a better scientific basis for setting health-related ventilation standards. Space constraints prohibit a detailed description of both ventilation rate and carbon dioxide concentration studies; therefore, this summary focuses primarily on the ventilation rate studies.

Fisk, W.J., Brager, G., Brook, M., Burge, H., Cole, J., Cummings, J., Levin, H., Loftness, V., Logee, T., Mendell, M.J.,Persily, A., Taylor, S., Zhang, J. (2002) "A priority agenda for energy-related indoor environmental quality research". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 2, pp.984-989. Indoor Air 2002, Santa Cruz, CA. LBNL-50612.

ABSTRACT

A multidisciplinary team of IEQ and energy researchers is working together to define a program of priority energy-related IEQ research. This paper describes the methods employed, ten high priority broad research and development (R&D) goals, and 34 high priority R&D project areas linked to these goals.

Fisk, W.J., Price, P.N., Faulkner, D., Sullivan, D.P., Dibartolomeo, D., Federspiel, C., Liu, L. "Worker productivity and ventilation rate in a call center: analyses of time-series data for a group of workers." LBNL-49356. Report

ABSTRACT

In previous studies, increased ventilation rates and reduced indoor carbon dioxide concentrations have been associated with improvements in health at work and increased performance in work-related tasks. Very few studies have assessed whether ventilation rates influence performance of real work. This paper describes part one of a two-part analysis from a productivity study performed in a call center operated by a health maintenance organization. Outside air ventilation rates were manipulated, indoor air temperatures, humidities, and carbon dioxide concentrations were monitored, and worker performance data for advice nurses, with 30-minute resolution, were analyzed via multivariate linear regression to look for an association of performance with building ventilation rate, or with indoor carbon dioxide concentration (which is related to ventilation rate per worker). Results suggest that the effect of ventilation rate on worker performance in this call center was very small (probably less than 1%) or nil, over most of the range of ventilation rate experienced during the study (roughly 12 L s-1 to 48 L s-1 per person). However, there is some evidence suggesting performance improvements of 2% or more when the ventilation rate per person is very high, as indicated by indoor CO2 concentrations exceeding outdoor concentrations by less than 75 ppm.

Fisk, W.J., Price, P.N., Faulkner, D., Sullivan, D.P., Dibartolomeo, D., Federspiel, C., Liu, L., Lahiff, M. Worker Performance and ventilation: analysis of time-series data for a group of call-center workers,

***Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 1, pp.790-795. Indoor Air 2002, Santa Cruz, CA. LBNL-51724.**

ABSTRACT
We investigated the relationship of ventilation rates with the performance of advice nurses working in a call center. Ventilation rates were manipulated; temperatures, humidities, and CO_2 concentrations were monitored; and worker performance data, with 30-minute resolution, were collected. Multivariate linear regression was used to investigate the association of worker performance with building ventilation rate, or with indoor CO_2 concentration (which is related to ventilation rate per worker). Results suggest that the effect of ventilation rate on worker performance in this call center was very small (probably less than 1%) or nil, over most of the range of ventilation rate (roughly 12 L s^{-1} to 48 L s^{-1} per person). However, there is some evidence of worker performance improvements of 2% or more when the ventilation rate per person was very high, as indicated by the indoor CO_2 concentration exceeding the outdoor concentration by less than 75 ppm.

Fisk WJ, Faulkner D, Palonen J, and Seppanen O (2002) Performance and cost of particle air filtration technologies, *Indoor Air*, 12(4):223-234. LBNL-47833.

ABSTRACT
This paper predicts the reductions in the indoor mass concentrations of particles attainable from use of filters in building supply airstreams and also from use of stand-alone fan-filter units. Filters with a wide efficiency range are considered. Predicted concentration reductions are provided for indoor-generated particles containing dust mite and cat allergen, for environmental tobacco smoke particles, and for outdoor-air fine mode particles. Additionally, this paper uses a simple model and available data to estimate the energy and total costs of the filtration options. Predicted reductions in cat and dust-mite allergen concentrations range from 20% to 80%. To obtain substantial, e.g., 50%, reductions in indoor concentrations of these allergens, the rate of airflow through the filter must be at least a few indoor volumes per hour. Increasing filter efficiencies above approximately ASHRAE Dust Spot 65% does not significantly reduce predicted indoor concentrations of these allergens. For environmental tobacco smoke particles and outdoor fine mode particles, calculations indicate that relatively large, e.g., 80%, decreases in indoor concentrations are attainable with practical filter efficiencies and flow rates. Increasing the filter efficiency above ASHRAE 85% results in only modest predicted incremental decreases in indoor concentration. Energy costs and total costs can be similar for filtration using filters with a wide range of efficiency ratings. Total estimated filtration costs of approximately $0.70 to $1.80 per person per month are insignificant relative to salaries, rent, or health insurance costs.

Goth-Goldstein, R., M.L. Russell, B. Parimoo, and E.H. Weyand. "7H-Benzo[c]fluorene DNA adduct formation in different human cells in culture". LBNL-50479.

ABSTRACT
7*H*-Benzo[*c*]fluorene (B[*c*]F) has been known for a long time as a component of complex mixtures such as coal tar or cigarette smoke. B[c]F has been identified recently as a potent lung tumorigen and a major DNA adduct-forming component of coal tar. We have investigated if human cells have the ability to form B[*c*]F:DNA adducts as detected in lungs of mice treated with B[*c*]F. MCF7 (human breast cancer), HepG2 (hepatoma) and Caco-2 (colon adenocarcinoma) cells were treated with increasing concentrations (0.2 - 10 μg/ml) of B[*c*]F for 20 hours. Adduct formation was evaluated using ^{32}P-postlabeling. A dose response in DNA adduct formation was detected in all three cell lines. In MCF7 and HepG2 cells, two adducts were detected, one of them corresponded to an adduct observed in the lungs of mice treated with B[*c*]F. This adduct is derived from 3-hydroxy B[*c*]F while the second, slower migrating adduct, appears to be unique to human cells. In contrast, Caco-2 cells formed at least four adducts. Two of the three most predominant adducts correspond to the two adducts observed in MCF7 and HepG2 cells while the additional predominate and a minor adduct are derived from 3,4-dihydrodiol B[*c*]F. The adducts derived from 3,4-dihydrodiol B[*c*]F are similar to those observed in mouse lung and skin. The detection of B[*c*]F:DNA adducts clearly demonstrates that human cells have the capacity to metabolically activate B[*c*]F to derivatives that covalently modify DNA. Similarities in the types of B[*c*]F:DNA adducts detected also demonstrates that B[*c*]F activation is similar in both human cells and mouse tissue.

Gundel, L.A.; Sullivan, D.P.; Katsapov, G.Y.; Fisk, W.J. *A Pilot Study Of Energy Efficient Air Cleaning For Ozone,* Formal Report. LBNL-51836

ABSTRACT
This report explores the feasibility of energy efficient low cost ozone removal from indoor air by examining carbon-based filtration options. Several candidate carbon-based materials and configurations were assessed by review of previous work and performance calculations. In addition, a laboratory pilot study was undertaken with the material that showed the most potential promise. This material was a commercially available filter that contained a thin layer of small activated carbon particles in a pleated configuration. For three months ozone (113 ± 13 ppm) in particle-filtered ambient air passed through the filter at a realistic ventilation system face velocity of 0.5 m s^{-1}. Ozone was injected upstream of the filter, and its concentration was monitored continuously upstream and downstream of the filter, as well as in the incoming ambient air. Throughout the three-month period, continuous measurements were made of the ambient temperature and humidity, as well as flow rate and pressure drop through the filter. The ozone removal efficiency was initially 96% and remained at 50% or higher for two and a half months. The estimated ozone removal capacity, before the efficiency dropped below 50%, was 0.3 g ozone per gram carbon. The pressure drop of the air flowing through the ozone filter was 26 Pa. Based on the size, efficiency, measured lifetime, and pressure drop of the ozone filter, it appears that ozone air cleaning may be practical in commercial air handling systems.

Heath, G.A, Mendell, M.J. (2002) "Do Indoor Environments in Schools Influence Student Performance? A Review of the Literature". ***Proceedings of Indoor Air 2002 Conference*****, Monterey, CA, Vol. 1, pp. 802-807. Indoor Air 2002, Santa Cruz, CA. LBNL-49567.**

ABSTRACT
The goal of this paper was to critically review available evidence on relationships between indoor environmental quality (IEQ) in schools and student performance. Because available evidence from schools was limited, the review expanded to include studies on direct relationships between the performance of children and adults and the indoor environments in schools, workplaces, residences, and controlled laboratory settings. The most persuasive available evidence suggests that some aspects of IEQ, including low ventilation rate and less daylight or light, may reduce the performance of occupants, including students in schools. Other evidence identifies additional possible influences, such as pollen and some carpets. Substantial limitations in the quantity and quality of available research findings suggest many questions for future study. Sufficient evidence is available to justify (1) actions to safeguard IEQ in schools and (2) the conduct of focused, well-designed research to help guide future policies and actions regarding IEQ in schools.

Hering, S.V, Lunden, M.M, Kirchstetter, T.W, Thatcher, T.L, Revzan, K.L, Sextro, RG, Brown, N.J, Watson, J. Chow, J. "Indoor, Outdoor And Regional Profiles Of Pm2.5 Sulfate, Nitrate And Carbon". ***Proceedings of Indoor Air 2002 Conference*****, Monterey, CA. Vol. 1, pp. 874-879. Indoor Air 2002, Santa Cruz, CA. LBNL-49980.**

ABSTRACT
Fine particle concentrations were measured simultaneously at three locations: a regional monitoring site in Fresno, California, a backyard of an unoccupied residence in Clovis, California located 6 km northeast of the regional site; and indoors at the same residence. Measurements included 10-min determination of $PM_{2.5}$ nitrate, sulfate and carbon using an automated collection and vaporization system, and black carbon measured by light attenuation through a filter deposit. Specific outdoor $PM_{2.5}$ constituents were compared to assess the appropriateness of using regional data to model indoor concentrations from outdoor sources. The outdoor data show that, in general, the regional results provide a good representation of the concentrations seen at the building exterior. The indoor concentrations showed considerable attenuation as well as a broadening and time-lag for the concentration peaks. The concentration reduction was the largest for $PM_{2.5}$ nitrate, which appears to undergo phase changes in addition to indoor deposition and penetration losses.

Hodgson, A.T, Faulkner, D., Sullivan, D.P., DiBartolomeo, D.L., Russell, M.L., Fisk, W.J. (2002) "Effect of outside air ventilation rate on VOC concentrations and emissions in a call center ***Proceedings of Indoor Air 2002 Conference*****,, Monterey, CA. Vol. 2, pp. 168-173. Indoor Air 2002, Santa Cruz, CA. LBNL-49535.**

ABSTRACT

A study of the relationship between outside air ventilation rate and concentrations of VOCs generated indoors was conducted in a call center. Ventilation rates were manipulated in the building's four air handling units (AHUs). Concentrations of VOCs in the AHU returns were measured on 7 days during a 13-week period. Indoor minus outdoor concentrations and emission factors were calculated. The emission factor data was subjected to principal component analysis to identify groups of co-varying compounds based on source type. One vector represented emissions of solvents from cleaning products. Another vector identified occupant sources. Direct relationships between ventilation rate and concentrations were not observed for most of the abundant VOCs. This result emphasizes the importance of source control measures for limiting VOC concentrations in buildings.

Hodgson, A.T., Apte, M.G., Shendell, D.G., Beal, D., McIlvaine, J.E.R. (2002) "Implementation of VOC Source Reduction Practices in a Manufactured House and in School Classrooms," ***Proceedings of Indoor Air 2002 Conference*****,, Monterey, CA. Vol. 3, pp. 576-581. Indoor Air 2002, Santa Cruz, CA. LBNL-49536.**

ABSTRACT

Detailed studies of a new manufactured house and four new industrialized relocatable school classrooms were conducted to determine the emission sources of formaldehyde and other VOCs and to identify and implement source reduction practices. Procedures were developed to generate VOC emission factors that allowed reasonably accurate predictions of indoor air VOC concentrations. Based on the identified sources of formaldehyde and other aldehydes, practices were developed to reduce the concentrations of these compounds in new house construction. An alternate ceiling panel reduced formaldehyde concentrations in the classrooms. Overall, the classrooms had relatively low VOC concentrations.

Hodgson, A.T., Beal, D. and McIlvaine, J.E.R. (In press) Sources of formaldehyde, other aldehydes and terpenes in a new manufactured house. Indoor Air (accepted for publication). LBNL-47627. Previously reported as submitted.

ABSTRACT

Formaldehyde, less-volatile aldehydes, and terpene hydrocarbons are generally the predominant air contaminants in new manufactured and site-built houses. This study was conducted to identify the major sources of these compounds in a typically constructed, new manufactured house. Specimens of materials used within the house envelope were collected from the production facility. These were individually preconditioned for 19 ± 4 days and tested for emissions of formaldehyde and the other target compounds using small-scale chambers. Several cabinetry materials, passage doors and the plywood subfloor were the predominant sources of formaldehyde and other aldehydes. The plywood subfloor was the predominant terpene source. Whole-house emission rates for combined materials were predicted based on the emission factors and the corresponding material quantities. These predicted rates were compared to whole-house emission rates calculated from measurements made at the house three months after its installation. For 11 of 14 target compounds including formaldehyde, the predicted and calculated rates were within a factor of two. This generally good agreement indicates that the predominant sources were correctly accounted for. Based on these results, practices are proposed for reducing the concentrations of the target compounds in newly constructed houses.

Holman, H.Y., Goth-Goldstein, R., Aaston, D., Mao, Y., and Kengsoontra, J. (2002) Evaluation of gastrointestinal solubilization of petroleum hydrocarbon residues in soil using an ***in vitro*** **physiologically-based model. Env. Science & Tech., 36: 1281-1286. (LBNL-48401). No Abstract available.**

IED Staff. A compilation of papers for the Indoor Air 2002 Conference in memory of Joan M. Daisey. (2002). LBNL-50419. No Abstract available.

Klepeis, N.E. and W.W. Nazaroff. "Characterizing size-specific ETS particle emissions". ***Proceedings of Indoor Air 2002 Conference*****, Monterey, CA. Vol. 2, pp. 162-167. Indoor Air 2002, Santa Cruz, CA. LBNL-50938.**

ABSTRACT

We report a method for estimating the size distribution of particle emissions from indoor sources. The method is applied to concentration data from a series of cigar and cigarette experiments to characterize environmental tobacco smoke particles. The method incorporates a particle dynamics model, which provided good fits to observed concentrations when using, as input, optimal values of mass emission rate

and deposition velocity for each particle size range. The optimal particle emissions were fit to log-normal distributions, yielding mass median diameters of approximately 0.2 m and an average geometric standard deviation of 2.3. The total particle emissions obtained by integrating the empirical size distribution were 0.2 - 0.7 mg/min for cigars and 0.7 - 0.9 mg/min for cigarettes. The measurements of particle size characteristics agree well with prior research, but the integrated mass measurements are consistently lower than those determined from filter-based measurements.

Klepeis, N., M. Apte, L. Gundel, R.G. Sextro, and W.W. Nazaroff. "Size-specific environmental tobacco smoke particle emissions". Accepted for publication in *Aerosol Science and Technology* (September, 2002). LBNL-51049.

ABSTRACT
Because size is a major controlling factor for indoor airborne particle behavior, human particle exposure assessments will benefit from improved knowledge of size-specific particle emissions. We report a method of inferring size-specific mass emission factors for indoor sources that makes use of an indoor aerosol dynamics model, measured particle concentration time series data, and an optimization routine. This approach provides – in addition to estimates of the emissions size distribution and integrated emission factors – estimates of deposition rate, an enhanced understanding of particle dynamics, and information about model performance. We applied the method to size-specific environmental tobacco smoke (ETS) particle concentrations measured every minute with an 8-channel optical particle counter (PMS-LASAIR; 0.1-2+ micrometer diameters) and every 10 or 30 min with a 34-channel differential mobility particle sizer (TSI-DMPS; 0.01-1+ micrometer diameters) after a single cigarette or cigar was machine-smoked inside a low air-exchange rate 20m^3 chamber. The aerosol dynamics model provided good fits to observed concentrations when using optimized values of mass emission rate and deposition rate for each particle size range as input. Small discrepancies observed in the first 1-2 hours after smoking are likely due to the effect of particle evaporation, a process neglected by the model. Size-specific ETS particle emission factors were fit with log-normal distributions, yielding an average mass median diameter of 0.2 micrometers and an average geometric standard deviation of 2.3 with no systematic differences between cigars and cigarettes. The equivalent total particle emission rate, obtained by integrating each size distribution, was 0.2-0.7 mg/min for cigars and 0.7-0.9 mg/min for cigarettes.

Kumar, Satish and William J. Fisk. "IEQ and the impact on building occupants". ASHRAE Journal, v.44, no.4 (2002): pp.50-52. LBNL-51288.

Introduction
Research into indoor environmental quality (IEQ) and its effects on health, comfort, and performance of occupants is becoming an increasing priority as interest in high performance buildings and organizational productivity grows. Facility managers are interested in IEQ's close relationship to energy use in facilities. Employers, by providing excellent indoor environments, hope to enhance employee comfort and productivity, reduce absenteeism and health care costs, and reduce risk of litigation. The increasing interest in this field has put additional pressure on the research community as architects, engineers, facility managers, building investors, health officials, jurists, and the public seek practical guidelines on creating a safe, healthy, and comfortable indoor environment.

Research on the relationships of IEQ to the health, comfort, and productivity of occupants has advanced considerably within the last decade. One of the primary goals of the Indoor Health and Productivity (IHP) Project is to communicate the results of this research, currently reported primarily in research publications, to building professionals. Consequently, the IHP project has worked with a peer review panel to select five key IHP papers and prepare summaries of these papers for publication in ASHRAE Journal.

This article precedes those five summary articles, which will appear in the next five issues of the journal. This article summarizes the methodology employed to select the five papers, briefly summarizes the message of each paper, and discusses the practical implications for architects and engineers.

More information about the objectives of the IHP project, results of research conducted under this project, and project sponsors and partners can be found at www.IHPCentral.org. The web site also has an online bibliography of approximately 900 papers on the topic of indoor health and productivity, drawn primarily from approximately 100 leading international journals and international conferences.

Kumar, Satish and William J. Fisk. "IEQ and the impact on employee sick leave". ASHRAE Journal, v.44, no.7 (2002): pp.97-98. LBNL-51289.

Introduction

When selecting minimum ventilation rates, employers need to strike a balance between the well-recognized energy costs of providing higher minimum ventilation rates and the expected, but less well quantified, health benefits from higher rate of ventilation. This is a summary of the paper by Milton et al. (2000) that found low employee sick leave associated with high ventilation rates in a set of buildings located in Massachusetts. A simple cost-benefit analysis is also presented.

Kumar, S., Fisk, W.J., *The role of Emerging Energy-Efficient Technology in Promoting Workplace Productivity and Health: Final Report*. (2002). LBNL-49706.

Introduction

When selecting minimum ventilation rates, employers need to strike a balance between the well-recognized energy costs of providing higher minimum ventilation rates and the expected, but less well quantified, health benefits from higher rate of ventilation. This is a summary of the paper by Milton et al. (2000) that found low employee sick leave associated with high ventilation rates in a set of buildings located in Massachusetts. A simple cost-benefit analysis is also presented.

Liu, D.L, Nazaroff, W.W. (2002) "Particle Penetration Through Windows". *Proceedings of Indoor Air 2002 Conference*,, Monterey, CA. Vol.1, pp. 862-867. Indoor Air 2002, Santa Cruz, CA. No LBNL Number.

ABSTRACT

This study aims to characterize the fractional penetration of airborne particles through windows, one of the important sites of air leakage through building envelopes. Two aluminum windows were evaluated, one with weatherstripping and one without. For each experiment, a finished window was mounted and sealed in a plywood panel that separated two well-mixed compartments. A small pressure difference was established between the compartments to induce a constant rate of airflow through leakage paths in the window. Particles were injected into one chamber and their concentrations were measured in both chambers. Two methods were employed to evaluate the size-resolved particle penetration: a steady-state method and a dynamic, concentration growth method. The results indicate that airborne particles of 0.2 to 3 m penetrate through both test windows fairly effectively, while significant particle losses are observed for particles smaller and larger than this range.

Lobscheid, C., Gadgil, (2002) "Mixing of a point-source indoor pollution: Numerical predictions and comparison with experiments". *Proceedings of Indoor Air 2002 Conference*,, Monterey, CA. Vol. 4, pp. 223-228. Indoor Air 2002, Santa Cruz, CA. LBNL-49457.

ABSTRACT

In most practical estimates of indoor pollutant exposures, it is common to assume that the pollutant is uniformly and instantaneously mixed in the indoor space. It is also commonly known that this assumption is simplistic, particularly for point sources, and for short-term or localized indoor exposures.

We report computational fluid dynamics (CFD) predictions of mixing time of a point-pulse release of a pollutant in an unventilated mechanically mixed isothermal room. We aimed to determine the adequacy of the standard RANS two-equation *(k-ε)* turbulence model to predict the mixing times under these conditions. The predictions were made for the twelve mixing time experiments performed by Drescher et al. (1995). We paid attention to adequate grid resolution, suppression of numerical diffusion, and careful simulation of the mechanical blowers used in the experiments. We found that the predictions are in good agreement with experimental measurements.

Lorenzetti, D.M. (2002) "Assessing multizone airflow simulation software". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 1, pp. 267-271. Indoor Air 2002, Santa Cruz, CA. LBNL-49578.

ABSTRACT

Several standard multizone modeling programs, in order to improve their computational efficiency, make a number of simplifying assumptions. This paper examines how those assumptions reduce the solution times and memory use of the programs, but at the cost of restricting the models they can express. Applications

where these restrictions may adversely affect the program's usefulness include: (1) natural ventilation, when buoyancy effects dominate mechanically-driven flow; (2) duct system design, when losses in T-junctions affect the system performance; and (3) control system design, when the dynamic transport of pollutants plays a significant role in the simulated system.

Lorenzetti, David M. (2002) "Computational Aspects of Nodal Multizone Airflow Systems", Building and Environment, 37(11): 1083-1090. LBL-46949.

ABSTRACT
The multizone approach to steady-state airflow problems models a building as a network of discrete mass flow paths. A nodal formulation of the problem writes the governing equations in terms of the unknown pressures at the points where the flow paths connect. This paper proves conditions under which the nodal equations yield symmetric positive-definite matrices, guaranteeing a unique solution to the flow network. It also establishes relaxed conditions under which a nodal airflow system yields asymmetric matrices with positive eigenvalues, guaranteeing at least one solution. Properly exploiting the system properties greatly reduces the cost of numerical solution. Thus, multizone airflow programs such as Contam and Comis depend on symmetric positive-definite systems. However, the background literature neglects or simplifies the underlying assumptions, does not assert existence and uniqueness, and even contains factual errors. This paper corrects those errors, states the implicit assumptions made in the programs, and discusses implications for modelers and programmers.

Lorenzetti, David M. (2002) "Predicting Indoor Pollutant Concentrations, and Applications to Air Quality Management". Prepared for Joint WHO-JRC-ECA Workshop on the Role of Human Exposure Assessment in Air Quality Management, Bonn. LBL-51582.

ABSTRACT
Because most people spend more than 90% of their time indoors, predicting exposure to airborne pollutants requires models that incorporate the effect of buildings. Buildings affect the exposure of their occupants in a number of ways, both by design (for example, filters in ventilation systems remove particles) and incidentally (for example, sorption on walls can reduce peak concentrations, but prolong exposure to semivolatile organic compounds). Furthermore, building materials and occupant activities can generate pollutants. This paper surveys modeling approaches for predicting pollutant concentrations in buildings, and summarizes the application of these models.

Lunden, M.M., Thatcher, T.L., Littlejohn, D., Fischer, M.L., Hering, S.V., Sextro, R.G., Brown, N.J. (2002) "The Transformation Of Outdoor Ammonium Nitrate Aerosols In The Indoor Environment". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 5, pp. 74-79. Indoor Air 2002, Santa Cruz, CA. LBNL-50158.

ABSTRACT
Recent studies associate particulate air pollution with adverse health effects; however, the exposure to indoor particles of outdoor origin is not well characterized, particularly for individual chemical species. In response to this, a field study in an unoccupied, single-story residence in Clovis, California has been conducted. Real-time particle monitors were used both outdoors and indoors to quantify PM2.5 nitrate, sulfate, and carbon. The results show that reduced indoor sulfate and carbon levels are primarily due to deposition and penetration losses. However, measured indoor ammonium nitrate levels were often observed to be at significantly lower levels than expected based solely on penetration and deposition losses. The additional reduction appears to be due to the transformation of ammonium nitrate into ammonia and nitric acid indoors, which are subsequently lost by deposition and sorption to indoor surfaces. The size of the effect is dependent upon factors such as temperature, relative humidity, and ventilation rate.

MacLeod, M., D.G. Woodfine, D. Mackay, T.E. McKone, D.H. Bennett, and R.L. Maddalena. "BETR North America: A regionally segmented multimedia contaminant fate model for North America". *Environmental Science & Pollution Research*, v.8; no.3; pp.156-163; 2001. LBNL-50571.

ABSTRACT
We present the Berkeley-Trent North American contaminant fate model (BETR North America), a regionally segmented multimedia contaminant fate model based on the fugacity concept. The model is built

on a framework that links contaminant fate models of individual regions, and is generally applicable to large, spatially heterogeneous areas. The North American environment is modeled as 24 ecological regions, within each region contaminant fate is described using a 7 compartment multimedia fugacity model including a vertically segmented atmosphere, freshwater, freshwater sediment, soil, coastal water and vegetation compartments. Inter-regional transport of contaminants in the atmosphere, freshwater and coastal water is described using a database of hydrological and meteorological data compiled with Geographical Information Systems (GIS) techniques. Steady-state and dynamic solutions to the 168 mass balance equations that make up the linked model for North America are discussed, and an illustrative case study of toxaphene transport from the southern United States to the Great Lakes Basin is presented. Regionally segmented models such as BETR North America can provide a critical link between evaluative models of long-range transport potential and contaminant concentrations observed in remote regions. The continent-scale mass balance calculated by the model provides a sound basis for evaluating long-range transport potential of organic pollutants, and formulation of continent scale management and regulatory strategies for chemicals.

Maddalena, R.l.., T.E. McKone and N.Y. Kado. "Exposure chamber measurements of mass transfer and partitioning at the plant/air interface". *Environmental Science & Technology*, v.36; no.16; pp.3577-3585; August 15, 2002. LBNL-50569.

ABSTRACT
Dynamic measures of air and vegetation concentrations in an exposure chamber and a two-box mass balance model are used to quantify factors that control the rate and extent of chemical partitioning between vegetation and the atmosphere. A continuous stirred flow-through exposure chamber was used to investigate the gas-phase transfer of pollutants between air and plants. A probabilistic two-compartment mass-balance model of plant/air exchange within the exposure chamber was developed and used with measured concentrations from the chamber to simultaneously evaluate partitioning (K_{pa}), overall mass transfer across the plant/air interface (U_{pa}) and loss rates in the atmosphere (R_a) and aboveground vegetation (R_p). The approach is demonstrated using mature *Capsicum annuum* (bell pepper) plants exposed to phenanthrene (PH), anthracene (AN), fluoranthene (FL) and pyrene (PY). Measured values of log K_{pa} ($V_{[air]}/V_{[fresh\ plant]}$) were 5.7, 5.7, 6.0 and 6.2 for PH, AN, FL and PY, respectively. Values of U_{pa} ($m\ d^{-1}$) under the conditions of this study ranged from 42 for PH to 119 for FL. After correcting for wall effects, the estimated reaction half-lives in air were 3, 9 and 25 hours for AN, FL and PY. Reaction half-lives in the plant compartment were 17, 6, 17 and 5 days for PH, AN, FL and PY. The combined use of exposure chamber measurements and models provides a robust tool for simultaneously measuring several different transfer factors that are important for modeling the uptake of pollutants into vegetation.

Matson, N.E., Wray, C.P., Walker, I.S., and Sherman, M.H. (2002) *Potential Benefits of Commissioning California Homes*. LBNL-48258. No Abstract Available.

Marshall, Julian. (2002) *Exposure to Motor Vehicle Emissions: An Intake Fraction Approach, Master's Thesis.* LBNL-51854

ABSTRACT
Motor vehicles are a significant source of population exposure to air pollution. Focusing on California's South Coast Air Basin as a case study, I combine ambient monitoring station data with hourly time-activity patterns to determine the population intake of motor vehicle emissions during 1996 – 1999. Three microenvironments are considered wherein the exposure to motor vehicle emissions is higher than in ambient air: in and near vehicles, inside a building that is near a freeway, and inside a residence with an attached garage. Total motor vehicle emissions are taken from the EMFAC model. The 15 million people in the South Coast inhale 0.0048% of primary, nonreactive compounds emitted into the basin by motor vehicles. Intake of motor vehicle emissions is 46% higher than the average ambient concentration times the average breathing rate, because of microenvironments and because of temporal and spatial correlation among breathing rates, concentrations, and population densities.

Intake fraction (iF) summarizes the emissions-to-intake relationship as the ratio of population intake to total emissions. iF is a population level exposure metric that incorporates spatial, temporal, and interindividual variability in exposures. iFs can facilitate the calculation of population exposures by distilling complex emissions-transport-receptor relationships. I demonstrate this point by predicting the population intake of

various primary gaseous emissions from motor vehicles, based on the intake fraction for benzene and carbon monoxide.

McKone, T.E., Thatcher, T.L., Fisk, W.J., Sextro, R.G., Sohn, M.D., Delp, W.W., Riley, W.J. (2002) "Factors affecting the concentration of outdoor particles indoors: existing data and data needs". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 1, pp. 176-181. Indoor Air 2002, Santa Cruz, CA. LBNL-49570.

ABSTRACT
Accurate characterization of particle concentrations indoors is critical to exposure assessments. It is estimated that indoor particle concentrations depend strongly on outdoor concentrations. For health scientists, knowledge of the factors that control the relationship of indoor particle concentrations to outdoor levels is particularly important. In this paper, we identify and evaluate sources of data for those factors that affect the transport to and concentration of outdoor particles indoors. To achieve this goal, we (i) identify and assemble relevant information on how particle behavior during air leakage, HVAC operation, and particle filtration effects indoor particle concentration; (ii) review and evaluate the assembled information to distinguish data that are directly relevant to specific estimates of particle transport from those that are only indirectly useful; and (iii) provide a synthesis of the currently available information on building air-leakage parameters and their effect on indoor particle matter concentrations.

McKone, T.E. and D.H. Bennett. "Chemical-specific representation of air-soil exchange and soil penetration in regional multimedia models". *Environmental Science & Technology*, (accepted for publication; December, 2002. LBNL-46693.

ABSTRACT
In multimedia mass-balance models, the soil compartment is an important sink as well as a conduit for transfers to vegetation and shallow groundwater. Here a novel approach for constructing soil transport algorithms for multimedia fate models is developed and evaluated. The resulting algorithms account for diffusion in gas and liquid components; advection in gas, liquid, or solid phases; and multiple transformation processes. They also provide an explicit quantification of the characteristic soil penetration depth. We construct a compartment model using three and four soil layers to replicate with high reliability the flux and mass distribution obtained from the exact analytical solution describing the transient dispersion, advection, and transformation of chemicals in soil layers with different properties but a boundary condition at the air-soil surface. The soil compartment algorithms can be dynamically linked to other compartments (air, vegetation, ground water, surface water) in multimedia fate models. We demonstrate and evaluate the performance of the algorithms in a model with applications to benzene, benzo(a)pyrene, MTBE, TCDD, and tritium.

Mendell, M.J., G.M. Naco, T.G. Wilcox, W.K. Sieber. (2002) "Building-related risk factors and work-related lower respiratory symptoms in 80 office building". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 1, pp. 103-108. Indoor Air 2002, Santa Cruz, CA. LBNL-49566.

ABSTRACT
We assessed building-related risk factors for lower respiratory symptoms in office workers. The National Institute for Occupational Safety and Health in 1993 collected data during indoor environmental health investigations of workplaces. We used multivariate logistic regression analyses to assess relationships between lower respiratory symptoms in office workers and risk factors plausibly related to microbiologic contamination. Among 2,435 occupants in 80 office buildings, frequent, work-related multiple lower respiratory symptoms were strongly associated, in multivariate models, with two risk factors for microbiologic contamination: poor pan drainage under cooling coils and debris in outside air intake. Associations tended to be stronger among those with a history of physician-diagnosed asthma. These findings suggest that adverse lower respiratory health effects from indoor work environments, although unusual, may occur in relation to poorly designed or maintained ventilation systems, particularly among previously diagnosed asthmatics. These findings require confirmation in more representative buildings.

Mendell, M.J., Fisk, W.J., Petersen, M.R., Hines, C.J., Dong, M., Faulkner, D., Deddens, J.A., Ruder, A.M., Sullivan, D.P., Boeniger, M.F. (2002) "Indoor Particles and Symptoms Among Office Workers: Results from a Double-Blind Cross-Over Study". *Epidemiology* 13:296-304. LBNL-48217.

ABSTRACT

Background
We studied the effects of removing small airborne particles in an office building without unusual contaminant sources or occupant complaints.
Methods
We conducted a double-blind crossover study of enhanced particle filtration in an office building in the Midwest U.S. in 1993. We replaced standard particle filters, in separate ventilation systems on two floors, with highly efficient filters, on alternate floors weekly over four weeks. Repeated-measures models were used to analyze data from weekly worker questionnaires and multiple environmental measurements.
Results
Bioaerosol concentrations were low. Enhanced filtration reduced concentrations of the smallest airborne particles by 94%. This reduction was not associated with reduced symptoms among the 396 respondents, but three performance-related mental states improved; for example, the confusion scale decreased (-3.7%; 95% confidence limits (CL) = -6.5, -0.9). Most environmental dissatisfaction variables also improved; *eg*, "stuffy" air, -5.3% (95% CL = -10.3, -0.4). Cooler temperatures within the recommended comfort range were associated with remarkably large improvement in most outcomes; for example, per 1ºC decrease, chest tightness decreased -23.4% (95% CL = -38.1, -8.7).
Conclusions
Benefits of enhanced filtration require assessment in buildings with higher particulate contaminant levels, in studies controlling for temperature effects. Benefits from lower indoor temperatures need confirmation.

Mora, L. and A.J. Gadgil. Theoretical study of pollutant mixing in rooms induced by occupancy. *Proceedings, RoomVent 2002,* Copenhagen, Denmark, pp. 257-260. LBNL-49730.

ABSTRACT
Airflow and pollutant transport models are commonly based on the approximation that air is instantaneously well mixed in a zone. In many circumstances this approximation is unsatisfactory. We present a semi-empirical model to predict the time required by a pollutant to disperse in a room, owing to the effects of room occupancy (room mixing induced by thermal plumes, stirring by people walking about and breathing). We base our estimates on previous experimental work correlating the mixing tome for a pollutamt pulse released in a room to the mechanical energy supplied to the room air. Our results suggests that people moving about in a room can induce rapid mixing. For example, the mixing timeresulting from a person walking at 1.4 $m.s^{-1}$ in a 30 m^3 room is predicted to be about 4 minutes . In this case, the assumption that air is well mixed could be reasonable.

Nazaroff, W.W. and B.C. Singer. "Inhalation of hazardous air pollutants from environmental tobacco smoke in US residences". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 2, pp. 477-482. Indoor Air 2002, Santa Cruz, CA. LBNL-50878.

ABSTRACT
In the United States, 48 million adults smoke 5×10^{11} cigarettes per year. Many cigarettes are smoked in private residences causing regular environmental tobacco smoke (ETS) exposure to at least 31 million nonsmokers (11% of the US population), including 16 million juveniles. ETS contains many chemical species whose industrial emissions are regulated by the US federal government as hazardous air pollutants (HAPs). In this paper, average daily residential exposures to 15 HAPs in ETS are estimated for US nonsmokers who live with smokers. The evaluation is based on material-balance modeling, and utilizes published data on smoking habits, demographics, and housing. Newly measured exposure-relevant emission factors are incorporated. Comparison of exposure concentration estimates with health-based guidelines for chronic exposure suggests that aldehydes — specifically acrolein, acetaldehyde, and formaldehyde — should be of particular concern in ETS. Cumulative population intake results are compared for these compounds against other sources of exposure.

Pang, Yanbo, Lara A. Gundel, Timothy Larson, Dennis Finn, L.J. Sally Liu, and Candis S. Claiborn. "Development and evaluation of a novel personal participate organic and mass sampler". Accepted for publication in Environmental Science and Technology. LBNL-50850.

ABSTRACT
Accurate measurement of personal exposure to particulate matter and its constituents requires samplers that are accurate, compact, lightweight, inexpensive and convenient to use. The Personal Particulate Organic and Mass Sampler (PPOMS) has been developed to meet these criteria. The PPOMS uses activated carbon-

impregnated foam as a combined 2.5-□m size-selective inlet and denuder for assessment of fine particle mass and organic carbon. Proof of the PPOMS concept has been established by comparing mass and organic carbon in particles collected with collocated samplers in Seattle, at a central outdoor site and in residences. Daily particulate mass concentrations averaged 10.0±5.2, 12.0±5.3, and 11.2±5.1 μg m^{-3} for the Federal Reference Method, the Harvard Personal Exposure Monitor, and the PPOMS, respectively, for 10 24-h sampling periods. During a series of $PM_{2.5}$ indoor organic carbon (OC) measurements from single quartz filters, the apparent indoor OC averaged 7.7±0.8 μg of C m^{-3}, which was close to the indoor $PM_{2.5}$ mass from collocated Teflon filters (7.3±2.3 μg of C m^{-3}), indicating the presence of a large positive OC artifact. In collocated measurements, the PPOMS eliminated this artifact just as well as the Integrated Gas and Particle Sampler that incorporated a macroreticular poly(styrene- divinylbenzene) (XAD-4) resin-coated denuder, yielding OC concentrations of 2.5 ± 0.4 and 2.4 ± 1.0 μg C m^{-3}, respectively. Thermal analysis for OC indicated that the indoor positive artifact was due to adsorption of gas-phase SVOC. This study shows that the PPOMS design provides a 2.5-□m size-selective inlet that also prevents the adsorption of gas-phase semi-volatile organic compounds onto quartz filters, thus eliminating the filter positive artifact. The PPOMS meets a significant current challenge for indoor and personal sampling of particulate organic carbon. The PPOMS design can also simplify accurate ambient sampling for $PM_{2.5}$.

Price, Phillip N., David M. Lorenzetti, Ashok J. Gadgil, Michael D. Sohn, Woody Delp, and Sondra Jarvis. Information for first responders to a chemical or biological attack. LBNL/PUB-866. No Abstract available.

Price, Phillip N., Woody Delp, Michael D. Sohn, Tracy L. Thatcher, David M. Lorenzetti, Richard G. Sextro, Ashok G. Gadgil, Elisa Derby, and Sondra Jarvis. Advice for first responders to a building during a chemical or biological attack. LBNL/PUB-867. No Abstract available.

Prill, R., Fisk, W.J. "Long Term Performance of Radon mitigation systems". *Proceedings of Indoor Air 2002 Conference*,, Monterey, CA. Vol. 2, pp. 641-646. Indoor Air 2002, Santa Cruz, CA. LBNL-50041.

ABSTRACT
Researchers installed radon mitigation systems in 12 houses in Spokane, Washington and Coeur d'Alene, Idaho during the heating season 1985 –1986 and continued to monitor indoor radon quarterly and annually for ten years. The mitigation systems included active sub-slab ventilation, basement over-pressurization, and crawlspace isolation and ventilation. The occupants reported various operational problems with these early mitigation systems. The long-term radon measurements were essential to track the effectiveness of the mitigation systems over time. All 12 homes were visited during the second year of the study, while a second set 5 homes was visited during the fifth year to determine the cause(s) of increased radon in the homes. During these visits, the mitigation systems were inspected and measurements of system performance were made. Maintenance and modifications were performed to improve system performance in these homes.

Riley, W.J., T.E. McKone, A.C.K. Lai, and W.W. Nazaroff, "Indoor particulate matter of outdoor origin: importance of size-dependent removal mechanisms," *Environmental Science & Technolog*y, v.36; pp.200-207, 2002. LBNL-47437

ABSTRACT
Adverse human health effects have been observed to correlate with levels of outdoor particulate matter (PM), even though most human exposure to PM of outdoor origin occurs indoors. In this study, we apply a model and empirical data to explore the indoor PM levels of outdoor origin for two major building types: offices and residences. Typical ventilation rates for each building type are obtained from the literature. Published data are combined with theoretical analyses to develop representative particle penetration coefficients, deposition loss rates, and ventilation-system filter efficiencies for a broad particle size range (i.e., 0.001-10 um). We apply archetypal outdoor number, surface area, and mass PM size distributions for both urban and rural airsheds. We also use data on mass-weighted size distributions for specific chemical constituents of PM: sulfate and elemental carbon. Predictions of the size-resolved indoor proportion of outdoor particles (IPOP) for various conditions and ambient particle distributions are then computed. The IPOP depends strongly on the ambient particle size distribution, building type and operational parameters, and PM metric. We conclude that an accurate determination of exposure to particles of ambient origin requires explicit consideration of how removal processes in buildings vary with particle size.

Russell, M.L., Goth-Goldstein, R., Apte, M.G., Fisk, W.J. (2002) "Method for measuring the size distribution of airborne rhinovirus". *Proceedings of Indoor Air 2002 Conference*,, Monterey, CA. Vol. 1, pp. 40-45. Indoor Air 2002, Santa Cruz, CA. LBNL-49574.

ABSTRACT
About 50% of viral-induced respiratory illnesses are caused by the human rhinovirus (HRV). Measurements of the concentrations and sizes of bioaerosols are critical for research on building characteristics, aerosol transport, and mitigation measures. We developed a quantitative reverse transcription-coupled polymerase chain reaction (RT-PCR) assay for HRV and verified that this assay detects HRV in nasal lavage samples. A quantitation standard was used to determine a detection limit of 5 fg of HRV RNA with a linear range over 1000-fold. To measure the size distribution of HRV aerosols, volunteers with a head cold spent two hours in a ventilated research chamber. Airborne particles from the chamber were collected using an Andersen Six-Stage Cascade Impactor. Each stage of the impactor was analyzed by quantitative RT-PCR for HRV. For the first two volunteers with confirmed HRV infection, but with mild symptoms, we were unable to detect HRV on any stage of the impactor.

Seppanen, O., Fisk, W.J. (2002) "Relationship of SBS-symptoms and ventilation system type in office buildings. *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 3, pp. 437-442. Indoor Air 2002, Santa Cruz, CA. LBNL-50046.

ABSTRACT
This paper provides a summary of current knowledge about the associations of ventilation system types in office buildings with sick building syndrome symptoms. Most studies completed to date indicate that relative to natural ventilation, air conditioning, with or without humidification, was consistently associated with a statistically significant increase in the prevalence of one or more SBS symptoms, by approximately 30% to 200%. In two of three analyses from a single study (assessments), symptom prevalences were also significantly higher in air-conditioned buildings than in buildings with simple mechanical ventilation and no humidification. The available data also suggest, with less consistency, an increase in risk of symptoms with simple mechanical ventilation relative to natural ventilation. The statistically significant associations of mechanical ventilation and air conditioning with SBS symptoms are much more frequent than expected from chance and also not likely to be a consequence of confounding by several potential personal, job, or building-related confounders. Multiple deficiencies in HVAC system design, construction, operation, or maintenance, including some of which cause pollutant emissions from HVAC systems, may contribute to the increases in symptom prevalences but other possible reasons remain unclear.

Sextro, R.G., Lorenzetti, D.M., Sohn, M.D., Thatcher, T.L. (2002) "Modeling the spread of anthrax in buildings". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA. Vol. 4, pp. 506-511. Indoor Air 2002, Santa Cruz, CA. LBNL-49537.

ABSTRACT
The recent contamination of several U.S. buildings by letters containing anthrax demonstrates the need to understand better the transport and fate of anthrax spores within buildings. We modeled the spread of anthrax for a hypothetical office suite and estimated the distribution of mass and resulting occupant exposures. Based on our modeling assumptions, more than 90% of the anthrax released remains in the building during the first 48 hours, with the largest fraction of the mass accumulating on floor surfaces where it is subject to tracking and resuspension. Although tracking and resuspension account for only a small amount of mass transfer, the model results suggests they can have an important effect on subsequent exposures. Additional research is necessary to understand and quantify these processes.

Shendell, DG, Hodgson, AT, Lee, S-M, Apte, MG, Sullivan, DP, Hotchi, T, Fisk, WJ. "VOCs in New Relocatable Classrooms: Assessment of School-Day Exposures Comparing Interior Finish Materials and HVAC Systems." Poster presented at the joint annual meeting of the International Society of Exposure Analysis (12th) and the International Society of Environmental Epidemiology (14th), Vancouver, B.C., Canada, August 11-15, 2002. ABSTRACT published in *Epidemiology*, 13 (4), S143.

The prevalence of relocatable classrooms (RCs) at schools is rising due to initiatives to reduce K-3 class size, and limited capital resources. Concerns regarding inadequate ventilation and indoor air quality in RCs have been raised. Since students and teachers spend the majority of a 7-8 hour school day inside classrooms, indoor contaminant concentrations are assumed to drive personal school-day exposures. We

conducted a demonstration project in new relocatable classrooms (RCs) during the 2001-02 school year to address these issues. The benefits of upgrades including an energy efficient heating, ventilation, and air conditioning (HVAC) system and alternate interior finish materials were investigated. One specific goal was to demonstrate that improved ventilation coupled with source reduction could lower indoor concentrations of toxic and odorous volatile organic compounds (VOCs), including formaldehyde and acetaldehyde. Four new 24' x 40' (960 ft^2) RCs were constructed and sited in pairs at an elementary school campus in each of two participant school districts (SD) in Northern California. Each RC was equipped with a standard HVAC system with intermittent 25-50% outdoor air ventilation and an energy-efficient advanced system providing continuous 100% ventilation (15 cfm/occupant). Alternate carpets, wall panels, and ceiling panels were installed in two classrooms—one in each pair—based on the results of a laboratory study of VOC emissions from standard and alternate materials. The two HVAC systems were operated on alternate weeks. School day-integrated air samples were collected indoors and outdoors mid-week during eight and nine weeks in the cooling (fall) and heating (winter) seasons, respectively. VOCs were collected on sorbent media and analyzed by thermal desorption GC/MS. Aldehydes were collected on DNPH treated silica gel cartridges and analyzed by HPLC. The effects of material selection on VOC concentrations were evaluated by emissions studies conducted prior to and after the first eight weeks of occupancy and by a comparison of occupied-hour classroom concentrations with the advanced HVAC operational. Slightly lower phenol and 1-methyl-2-pyrrolidinone concentrations in source-modified RCs were attributed to the alternate wall panel. Slightly lower formaldehyde concentrations in these RCs were attributed to the lower-emitting ceiling panels. At one school, teaching materials brought in after the school year began were discovered to be formaldehyde sources. Across SD and RCs in the cooling season, mean concentrations of formaldehyde were 14.1 +/- 6.6 and 30.4 +/- 6.9 $\mu g\ m^{-3}$ during advanced and standard HVAC system operation, respectively. Likewise, acetaldehyde mean concentrations were 6.9 +/- 4.7 and 13.7 +/- 3.7 $\mu g\ m^{-3}$, respectively. Similar reductions were observed for toluene and phenol.

Results suggest improved continuous ventilation provided by the advanced HVAC outweighed source reduction as a VOC control measure in these new RCs.

Shendell, DG, Lee S-M, Apte, MG, DiBartolomeo, DB, Sullivan, DP, Liff, SM, Fisk, WJ, Rainer, LI. "Assessment of Noise Exposures in New Relocatable Classrooms with Standard and Advanced HVAC Systems." Poster presented at the joint annual meeting of the International Society of Exposure Analysis (12th) and the International Society of Environmental Epidemiology (14th), Vancouver, B.C., Canada, August 11-15, 2002. ABSTRACT published in *Epidemiology*, 13 (4), S223.

Anecdotal evidence suggests heating, ventilation, and air conditioning (HVAC) systems in modular classrooms are not operated effectively. Teachers are usually in charge of thermal control. Due to inadequate training in HVAC system operation and indoor environmental quality (IEQ) issues, and the relatively loud noise produced by the HVAC system while meeting cooling or heating demands, teachers may avoid using mechanical ventilation. Adequate ventilation is an important link between improved IEQ and energy efficiency for schools. Indoor air quality and physical environmental stresses including noise can adversely impact the health of young children and teachers. During the school year these occupants spend the majority of the 7-8 hour school day inside their classrooms. Therefore, classroom noise levels can be assumed to drive personal school day exposures. As part of a field project of IEQ and energy efficiency, we investigated noise levels in four new relocatable classrooms (RCs). The RCs were equipped with both standard and advanced HVAC systems, alternately operated in a case-crossover study design. Classroom noise data, measured as A-weighted decibels (dB(A)), were collected continuously for the 2001-02 school year with sound level meters (SLM; Extech #407736, Type II, 1.5 dB(A) accuracy, 0.1 dB(A) resolution). A SLM was suspended downward below the ceiling at the center of each 960 ft^2 RC from a specially designed mobile located ~7.0 ft above the floor. The microphone placement and orientation complied with ANSI and IEC specifications; weekly calibration was performed. Reflectance off ceiling tiles, walls, and student desks were negligible. Descriptive statistics were calculated for each classroom for six distinct time periods: start of school day to recess; recess to lunch; the unoccupied lunch period; lunch to end of school day; overnight; and, weekend. Data were stratified by HVAC system in operation and summarized for four periods: fall cooling season; fall-to-winter transitional period; winter heating season; and spring. This study suggests HVAC systems and occupants were the dominant sources of noise exposure for the RCs indoor environment. In the cooling season, at one school, school-day time-weighted average (Leq) values, in dB(A), were 60.0 and 61.0; at the other school, the values in September were 52.2 and 55.7, and in October were 54.3 and 56.0. Examining specific early morning and lunch periods when HVAC systems were on but RCs unoccupied, the advanced system contributed less noise (4-8 dB(A)) than the standard system (10-15 dB(A)). Mean observed classroom noise levels for several time periods, as

well as school-day and school morning Leq values, exceeded existing school district, state, and international guidelines of 40-50 dB(A).

Shendell, D.G., D. DiBartolomeo, W.J. Fisk, A.T. Hodgson, T. Hotchi, S. Min. Lee, D.P. Sullivan, M.G. Apte, and L.I. Rainer. Final methodology for a field study of indoor environmental quality and energy efficiency in new relocatable classrooms in Northern California. 2002. LBNL-51101

Shendell, D.G., M.G. Apte, J. Kim, and S. Smorodinsky. "Building effective partnerships to conduct school indoor environmental quality assessments and interventions". Submitted, as "Field Action Report," to: American Journal Of Public Health, July 19, 2002. LBNL-50377.

ABSTRACT
Public, private, government, and university stakeholders have focused increasing attention on children's environmental health. Priority areas include healthy school environments; susceptibilities of children to environmental factors and associated illness; and, understanding exposure to biological, chemical, and physical agents. As multidisciplinary teams, we have conducted studies and intervention demonstrations in California public schools. A common theme among them was a "partnership," the collaboration between stakeholders from the aforementioned sectors. Federal funding and local bond measures for planning, maintenance, and modernization of school facilities have recently been authorized. Therefore, beneficial "partnerships" should be established to conduct needed IEQ, environmental health, and productivity research, development and demonstration. This field action report describes benefits for stakeholders and five strategies for future effective collaborations.

Sherman, M.H., Matson, N.E. *Air Tightness of New U.S. Houses: A Preliminary Report*. (2002). LBNL-48671.

ABSTRACT
Most dwellings in the United States are ventilated primarily through leaks in the building shell (i.e., infiltration) rather than by whole-house mechanical ventilation systems. Consequently, quantification of envelope air-tightness is critical to determining how much energy is being lost through infiltration and how much infiltration is contributing toward ventilation requirements.

Envelope air tightness and air leakage can be determined from fan pressurization measurements with a blower door. Tens of thousands of unique fan pressurization measurements have been made of U.S. dwellings over the past decades. LBNL has collected the available data on residential infiltration into its Residential Diagnostics Database, with support from the U.S. Department of Energy. This report documents the envelope air leakage section of the LBNL database, with particular emphasis on new construction.

The work reported here is an update of similar efforts carried out a decade ago, which used available data largely focused on the housing stock, rather than on new construction. The current effort emphasizes shell tightness measurements made on houses soon after they are built. These newer data come from over two dozen datasets, including over 73,000 measurements spread throughout a majority of the U.S. Roughly one-third of the measurements are for houses identified as energy-efficient through participation in a government or utility program. As a result, the characteristics reported here provide a quantitative estimate of the impact that energy-efficiency programs have on envelope tightness in the US, as well as on trends in construction.

Sherman, M.H., Hodgson, A.T. "Fomaldehyde as a Basis for Residential Ventilation Rates" *Journal of Indoor Air* (In Press) (2002). LBNL-49577.

ABSTRACT
Traditionally, houses in the U.S. have been ventilated by passive infiltration in combination with active window opening. However in recent years, the construction quality of residential building envelopes has been improved to reduce infiltration, and the use of windows for ventilation also may have decreased due to a number of factors. Thus, there has been increased interest in engineered ventilation systems for residences. The amount of ventilation provided by an engineered system should be set to protect occupants from unhealthy or objectionable exposures to indoor pollutants, while minimizing energy costs for conditioning incoming air. Determining the correct ventilation rate is a complex task, as there are numerous pollutants of potential concern, each having poorly characterized emission rates, and poorly defined acceptable levels of exposure. One ubiquitous pollutant in residences is formaldehyde. The sources of formaldehyde in new houses are reasonably understood, and there is a large body of literature on

human health effects. This report examines the use of formaldehyde as a means of determining ventilation rates and uses existing data on emission rates of formaldehyde in new houses to derive recommended levels. Based on current, widely accepted concentration guidelines for formaldehyde, the minimum and guideline ventilation rates for most new houses are 0.28 and 0.5 air changes per hour, respectively.

Sherman, M.H., Xu, T.T., Abushakra, B., Dickerhoff, D.J., Wang, D.M., Wray, C.P., and Modera, M.P. (2002) ***Thermal Distribution System Characteristics and Energy Impacts of Duct Leaks in Light Commercial Buildings*****. LBNL-49470.** No Abstract Available.

Siegel, J.A., Nazaroff, W.W. "Modeling Particle Deposition on HVAC Heat Exchangers". ***Proceedings of Indoor Air 2002 Conference*****, Monterey, CA, Vol. 1, pp. 521-526. Indoor Air 2002, Santa Cruz, CA. LBNL-49339.**

ABSTRACT

Fouling of fin-and-tube heat exchangers by particle deposition leads to diminished effectiveness in supplying ventilation and air conditioning. This paper explores mechanisms that cause particle deposition on heat exchanger surfaces. We present a model that accounts for impaction, diffusion, gravitational settling, and turbulence. Simulation results suggest that some submicron particles deposit in the heat exchanger core, but do not cause significant performance impacts. Particles between 1 and 10 µm deposit with probabilities ranging from 1 - 20 % with fin edge impaction representing the dominant mechanism. Particles larger than 10 µm deposit by impaction on refrigerant tubes, gravitational settling on fin corrugations, and mechanisms associated with turbulent airflow. The model results agree reasonably well with experimental data, but the deposition of larger particles at high velocities is underpredicted. Geometric factors, such as discontinuities in the fins, are hypothesized to be responsible for the discrepancy.

Siegel, J.A., McWilliams, J.A., Walker, I.S. (2002) "Comparison between predicted duct effectiveness from proposed ASHRAE standard 152P and measured field data for residential forced air cooling systems". ***ASHRAE Transactions*****, Vol. 109, Pt.1. ASHRAE, Atlanta, GA. LBNL-50008.**

ABSTRACT

The proposed ASHRAE Standard 152P "Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems" (ASHRAE 2002) has recently completed its second public review. As part of the standard development process, this study compares the forced air distribution system ratings provided by the public review draft of Standard 152P to measured field results. 58 field tests were performed on cooling systems in 11 homes in the summers of 1998 and 1999. Seven of these houses had standard attics with insulation on the attic floor and a well-vented attic space. The other four houses had unvented attics where the insulation is placed directly under the roof deck and the attic space is not deliberately vented. Each house was tested under a range of summer weather conditions at each particular site, and in some cases the amount of duct leakage was intentionally varied. The comparison between 152P predicted efficiencies and the measured results includes evaluation of the effects of weather, duct location, thermal conditions, duct leakage, and system capacity. The results showed that the difference between measured delivery effectiveness and that calculated using proposed Standard 152P is about 5 percentage points if weather data, duct leakage and air handler flow are well known. However, the accuracy of the standard is strongly dependent on having good measurements of duct leakage and system airflow. Given that the uncertainty in the measured delivery effectiveness is typically also about 5 percentage points, the Standard 152P results are acceptably close to the measured data.

Siegel, Jeffrey, Iain Walker and Max Sherman. "Dirty air conditioners: Energy implications of coil fouling", ***Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*****, Pacific Grove, California; August 18-23, 2002. American Council for an Energy Efficient Economy, Washington, DC. LBNL-49757.**

ABSTRACT

Residential air conditioning is responsible for a substantial amount of peak electrical demand and energy consumption throughout most of the United States. Coil fouling, the deposition of indoor dusts and other particulate matter on evaporator heat exchangers, increases system pressure drop and, correspondingly, decreases system air flow and air conditioner performance. In this paper, we apply experimental and simulation results describing particle deposition on evaporator coils as well as research about indoor particle and dust concentrations to determine coil fouling rates. The results suggest that typical coils foul

enough to double evaporator pressure drop in 7 - 11 years, much sooner than the expected 15 - 30 year life time for an evaporator coil. The most important parameters in determining coil fouling times are the efficiency of the filter and indoor particle concentrations, although filter bypass and duct and coil design are important as well. The reduced air flows that result from coil fouling cause typical efficiency and capacity degradations of less than 5 %, however they can be much greater for marginal systems or extreme conditions. These energy issues, as well as possible indoor air quality issues resulting from fouling by biological aerosols, suggest that regular coil cleaning and the elimination of filter bypass should be an important part of residential air conditioning commissioning and maintenance practices.

Siegel, J.A. and Wray, C.P. (2002) "An Evaluation of Superheat-Based Refrigerant Charge Diagnostics for Residential Cooling Systems", *ASHRAE Transactions*, Vol. 108, Part 2. LBNL-47476.

ABSTRACT
Although refrigerant charge has an important influence on the performance of residential cooling systems with fixed orifice metering devices, there has been little research to quantify the effects of incorrect charge or design new diagnostics for evaluating charge level. The most common diagnostic for charge level in these systems is the superheat test. In this paper, we examine three superheat technologies/techniques. Two of the diagnostics are appropriate for detecting incorrect charge; one is not. Additionally, measurements at four houses indicate that it is important to measure the condenser air entering temperature with a high degree of accuracy. Measurement of the wet bulb temperature in the return plenum and suction line temperature are equally important, but seemingly easier then measuring the condenser air temperature, as several measurement technologies yielded similar results for these quantities. The importance of refrigerant charge to energy use and capacity of residential cooling systems, the limitations of the superheat test, and the variations in the test method results and interfaces necessitate the development of a standard method or methods to determine refrigerant charge level.

Singer, B.C., A.T. Hodgson and W.W. Nazaroff. "Effect of sorption on exposures to organic gases from environmental tobacco smoke (ETS), *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 2, pp. 138-143. Indoor Air 2002, Santa Cruz, CA. LBNL-49576.

ABSTRACT
The effects of sorption processes on dynamic ETS organic gas concentrations and potential exposures were studied in a carpeted and furnished 50-m^3 room ventilated at 0.6 h^{-1}. Ten cigarettes were machine-smoked on six of every seven days over four weeks. Concentrations of ETS-specific tracers and regulated toxic compounds were quantified during daily smoking, post-smoking and background periods. Potential exposures were calculated by period and day. Large sorption effects were observed for the widely used tracers 3-ethenylpyridine and nicotine, and for several toxic compounds including naphthalene and cresol isomers. Short-term adsorption to indoor surfaces reduced concentrations and potential exposures during smoking, while later reemission increased concentrations and exposures hours after smoking ended. Concentrations during nonsmoking periods rose from day to day over the first few weeks, presumably from increased reemission associated with increased sorbed mass concentrations. For sorbing compounds, more than half of daily potential exposures occurred during nonsmoking periods.

Sippola, M.R., Nazaroff, W.W. (2002) "Modeling Particle Deposition In Ventilation Ducts". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 1, pp. 515-520. Indoor Air 2002, Santa Cruz, CA LBNL-42710.

ABSTRACT
This paper describes predictions from two models of fractional particle loss in four typical HVAC duct runs. One model is a state-of-the-art Eulerian formulation; the second is based on empirical fits to experimental particle deposition data collected in a laboratory. The experiments are briefly described and sample results are presented. The Eulerian model only predicts deposition from fully developed turbulence, while the empirical model can be applied to duct bends and developing turbulence as well. The models predict almost no losses for particles smaller than 1 μm and nearly complete loss of particles larger than 40 μm in all duct runs. The empirical model suggests that particle loss in ventilation ducts is dominated by gravitational settling to the floor of horizontal ducts, and by deposition to zones where turbulent flow is undeveloped, such as in bends and in duct sections immediately after bends.

Sohn, M.D., Reynolds, P., Gadgil, A.J., Sextro, R.G. (2002) "Rapidly Locating Sources And Predicting Contaminant Dispersion In Buildings". (2002) *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 4, pp.211-216. Indoor Air 2002, Santa Cruz, CA. LBNL-49563.

ABSTRACT
Contaminant releases in or near a building can lead to significant human exposures unless prompt response measures are taken. However, selecting the proper response depends in part on knowing the source locations, the amounts released, and the dispersion characteristics of the pollutants. We present an approach that estimates this information in real time. It uses Bayesian statistics to interpret measurements from sensors placed in the building yielding best estimates and uncertainties for the release conditions, including the operating state of the building. Because the method is fast, it continuously updates the estimates as measurements stream in from the sensors. We show preliminary results for characterizing a gas release in a three-floor, multi-room building at the Dugway Proving Grounds, Utah, USA.

Sohn, M.D., P. Reynolds, P., N. Singh, and A.J. Gadgil. Rapidly locating and characterizing pollutant releases in buildings: An application of Bayesian data analysis. *J. of the Air and Waste Management Association*, 52: 1422-1432, 2002. LBNL-47588.

ABSTRACT
Releases of airborne contaminants in or near a building can lead to significant human exposures unless prompt response measures are taken. However, possible responses can include conflicting strategies, such as shutting the ventilation system off versus running it in a purge mode, or having occupants evacuate versus sheltering in place. The proper choice depends in part on knowing the source locations, the amounts released, and the likely future dispersion routes of the pollutants. We present an approach that estimates this information in real time. It applies Bayesian statistics to interpret measurements of airborne pollutant concentrations from multiple sensors placed in the building and computes best estimates and uncertainties of the release conditions. The algorithm is fast, capable of continuously updating the estimates as measurements stream in from sensors. We demonstrate the approach using a hypothetical pollutant release in a five-room building. Unknowns to the interpretation algorithm include location, duration, and strength of the source, and some building and weather conditions. We examine two sensor sampling plans and three levels of data quality. Data interpretation in all examples is rapid; however, locating and characterizing the source with high probability depends on the amount and quality of data, and the sampling plan.

Thatcher, T.L., Lunden, M.M., Sextro, R.G., Hering, S., Brown, N.J. (2002) "The effect of penetration factor, deposition, and environmental factors on the indoor concentration of pm2.5 sulfate, nitrate, and carbon". (2002) *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 1, pp.846-851. Indoor Air 2002, Santa Cruz, CA. LBNL-50160.

ABSTRACT
Indoor exposure to particles of outdoor origin constitutes an important exposure pathway. We conducted an intensive set of indoor particle measurements in an unoccupied house under differing operating conditions. Real-time measurements were conducted both indoors and outdoors, including PM2.5 nitrate, sulfate, and carbon. Because the time-scale of the fluctuations in outdoor particle concentrations and meteorological conditions are often similar to the time constant for building air exchange, a steady state concentration may never be reached. The time-series experimental data were used to determine the effect of changes in air exchange rate and indoor/outdoor temperature and relative humidity differences on indoor particle concentrations. A multivariate regression was performed to investigate the difference between measured indoor concentrations and results from a simple time-dependent physical model. Environmental conditions had a significant effect on indoor concentrations of all three PM2.5 species, but did not explain all of the model variation.

Thatcher, T., M. Lunden, K. Revzan, R. Sextro, and N. Brown. Experimental investigation of the effect of changes in house environment on the indoor concentration of particles of outdoor origin within a residence. LBNL-51002 .
Abstract not available.

Thatcher, T.L., Lai, A.C.K., Moreno-Jackson, R., Sextro, R.G., and Nazaroff, W.W. "Effects of Room Furnishings and Air Speed on Particle Deposition Rates Indoors", *Atmospheric Environment*, Vol. 36(N11), 1811-1819, 2002. LBNL-48414. No Abstract available.

Theaker, I.G. and C.P. Wray. (2002) "Ventilation System Design of Recent Canadian Multi-Unit Residential Buildings", Submited to *ASHRAE Transactions*, Vol. 106, Part 2, 2002. No Abstract available.

Wagner, J., D.P. Sullivan, D. Faulkner, L.A. Gundel, W.J. Fisk, L.E. Alevantis, J.M. Waldman. (2002) "Measurements And Modeling Of Environmental Tobacco Smoke Leakage From A Simulated Smoking Room". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA., Vol. 2, pp. 121-126. Indoor Air 2002, Santa Cruz, CA. LBNL-49785.

ABSTRACT
The purpose of this study is to quantify the effect of various design and operating parameters on smoking room performance. Twenty-eight experiments were conducted in a simulated smoking room with a smoking machine and an automatic door opener. Measurements were made of air flows, pressures, temperatures, two particle-phase ETS tracers, two gas-phase ETS tracers, and sulfur hexafluoride. Quantification of leakage flows, the effect of these leaks on smoking room performance and non-smoker exposure, and the relative importance of each leakage mechanism are presented. The results indicate that the first priority for an effective smoking room is to depressurize it with respect to adjoining non-smoking areas. Another important ETS leakage mechanism is the pumping action of the smoking room door. Substituting a sliding door for a standard swing-type door reduced this source of ETS leakage significantly. Measured results correlated well with model predictions (R^2 = 0.82-0.99).

Walker, I.S. and Wray, C.P. (2002) "Evaluation of Flow Capture Techniques for Measuring HVAC Grille Airflows", Submitted to *ASHRAE Transactions*. LBNL-51550.

ABSTRACT
This paper discusses the accuracy of commercially available flow hoods for residential applications. Results of laboratory and field tests indicate these hoods can be inadequate to measure airflows in residential systems, and there can be large measurement discrepancies between different flow hoods. The errors are due to poor calibrations, sensitivity of the hoods to grille airflow non-uniformities, and flow changes from added flow resistance. It is possible to obtain reasonable results using some flow hoods if the field tests are carefully done, the grilles are appropriate, and grille location does not restrict flow hood placement. We also evaluated several simple flow capture techniques for measuring grille airflows that could be adopted by the HVAC industry and homeowners as simple diagnostics. These simple techniques can be as accurate as commercially available devices. Our test results also show that current calibration procedures for flow hoods do not account for field application problems. As a result, agencies such as ASHRAE or ASTM need to develop a new standard for flow hood calibration, along with a new measurement standard to address field use of flow capture techniques.

Walker, I.S., D.J. Dickerhoff and M.H. Sherman. The Delta Q method of testing the air leakage of ducts. *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, California; August 18-23, 2002, 1:327-338, American Council for an Energy Efficient Economy, Washington, DC LBNL-49749.

ABSTRACT
The DeltaQ test has been developed in order to provide better estimates of forced air system air leakage for use in energy efficiency calculations and for compliance testing of duct systems. The DeltaQ test combines a model of the house and duct system with the results of house pressurization tests with the air handler on and off to determine the duct leakage air flows to outside conditioned space at operating conditions. The key advantage of the DeltaQ test over other methods is that it determines the air leakage flows directly, rather than requiring interpretation of indirect measurements. The results from over 200 field and laboratory tests are presented. The laboratory tests have shown that the DeltaQ repeatability uncertainties are typically 1% or less of system fan flow and that the accuracy of the test is between 1.3% and 2.5% of fan flow (or 13 cfm to 25 cfm (6 to 12 l/s) for this system).

Webb, A.M., Nazaroff, W.W. and B.C. Singer. "Effect of gaseous ammonia on nicotine sorption". *Proceedings of Indoor Air 2002 Conference*, Monterey, CA, Vol. 3, pp. 512-517. Indoor Air 2002, Santa Cruz, CA. LBNL-50879.

ABSTRACT
Nicotine is a major constituent of environmental tobacco smoke. Sorptive interactions of nicotine with indoor surfaces can substantially alter indoor concentrations. The phenomenon is poorly understood, including whether sorption is fully reversible or partially irreversible. We hypothesize that acid-base chemistry on indoor surfaces might contribute to the apparent irreversibility of nicotine sorption under some circumstances. Specifically, we suggest that nicotine may become protonated on surfaces, markedly reducing its vapor pressure. If so, subsequent exposure of the surface to gaseous ammonia, a common base, could raise the surface pH, causing deprotonation and desorption of nicotine from surfaces. A series of experiments was conducted to explore the effect of ammonia on nicotine sorption to and reemission from surfaces. Our results indicate that, under some conditions, exposure to gaseous ammonia can substantially increase the rate of desorption of previously sorbed nicotine from common indoor surface materials.

Wray, Craig P. (2002) "Suite Ventilation Characteristics of Current Canadian Mid-and High-Rise Residential Buildings". 106 (Part 2) 2002. LBNL-43254.

ABSTRACT
This paper characterizes ventilation in residential suites located in ten buildings in major metropolitan areas of Canada. All buildings were between six and thirty-two stories tall and were built between 1990 and 1995.

1. The key findings from field performance tests of these buildings were:
2. Corridor supply airflows usually did not meet design flows.
3. Makeup air paths for suite exhaust were not properly designed.
4. Suite access door leakage was highly variable and usually did not meet smoke control requirements.
5. Airflow from the corridor through the suite access door leakage appeared to be the primary ventilation air supply for suites.
6. Suites were usually well-ventilated, but some were marginally- or under-ventilated.
7. Poor pressure control often allowed transfer air from one suite to another. Inter-suite transfer air fractions ranged from 0 to 45%, with an average of 19%.

In summary, this work showed suite ventilation can be highly influenced by corridor supply flows, by the treatment of corridor access doors, and by transfer airflows. As a result, suite ventilation at any given time in current mid- and high-rise residential buildings is very difficult to predict.

To ensure suite ventilation performs as intended under all operating conditions, the building industry needs to address the identified problems through improved ventilation design, operation, and maintenance practices.

Wray, Craig P., Iain S. Walker and Max H. Sherman. "Accuracy of flow hoods in residential applications". *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, California; August 18-23, 2002, 1:339-350, American Council for an Energy Efficient Economy, Washington, DC LBNL-49697.

ABSTRACT
To assess whether houses can meet performance expectations, the new practice of residential commissioning will likely use flow hoods to measure supply and return grille airflows in HVAC systems. Depending on hood accuracy, these measurements can be used to determine if individual rooms receive adequate airflow for heating and cooling, to determine flow imbalances between different building spaces, to estimate total air handler flow and supply/return imbalances, and to assess duct air leakage. This paper discusses these flow hood applications and the accuracy requirements in each case. Laboratory tests of several residential flow hoods showed that these hoods can be inadequate to measure flows in residential systems. Potential errors are about 20% to 30% of measured flow, due to poor calibrations, sensitivity to grille flow non-uniformities, and flow changes from added flow resistance. Active flow hoods equipped with measurement devices that are insensitive to grille airflow patterns have an order of magnitude less error, and are more reliable and consistent in most cases. Our tests also show that current calibration procedures for flow hoods do not account for field application problems. As a result, a new standard for flow hood calibration needs to be developed, along with a new measurement standard to address field use of flow hoods. Lastly, field evaluation of a selection of flow hoods showed that it is possible to obtain

reasonable results using some flow hoods if the field tests are carefully done, the grilles are appropriate, and grille location does not restrict flow hood placement.

Wray, C.P., Walker, I.S., Siegel, J.A., and Sherman, M.H. (2002) *Practical Diagnostics for Evaluating Residential Commissioning Metrics*. LBNL-45959.

ABSTRACT
In this report, we describe what residential commissioning is, its characteristic elements, and how one might structure its process. Our intent in this discussion is to formulate and clarify these issues, but is largely preliminary because such a practice does not yet exist. Subsequent sections of the report describe metrics one can use in residential commissioning, along with the consolidated set of 24 practical diagnostics that the building industry can use now to evaluate them. Our discussion in the main body of this report is limited to existing diagnostics in areas of particular concern with significant interactions: envelope and HVAC systems. These areas include insulation quality, windows, airtightness, envelope moisture, fan and duct system airflows, duct leakage, cooling equipment charge, and combustion appliance backdrafting with spillage.

Where possible, we also discuss the accuracy and usability of diagnostics, based on recent laboratory work and field studies by LBNL staff and others in more than 100 houses. These studies concentrate on evaluating diagnostics in the following four areas: the DeltaQ duct leakage test, air-handler airflow tests, supply and return grille airflow tests, and refrigerant charge tests. In addition, where possible, we identify the costs to purchase diagnostic equipment and the amount of time required to conduct the diagnostics.

Xu, T.T., Carrie, F.R., Dickerhoff, D.J., Fisk, W.J., McWilliams, J., Wang, D., Modera, M.P. (2002) "Performance of thermal distribution systems in large commercial buildings". *Energy and Buildings* 34:215-226. LBNL-44331.

ABSTRACT
This paper presents major findings of a field study on the performance of five thermal distribution systems in four large commercial buildings. The five systems studied are typical single-duct or dual-duct constant air volume (CAV) systems and variable air volume (VAV) systems, each of which serves an office building or a retail building with floor area over 2,000 m^2. The air leakage from ducts are reported in terms of effective leakage area (ELA) at 25 Pa reference pressure, the ASHRAE-defined duct leakage class, and air leakage ratios. The specific ELAs ranged from 0.7 to 12.9 cm^2 per m^2 of duct surface area, and from 0.1 to 7.7 cm^2 per square meter of floor area served. The leakage classes ranged from 34 to 757 for the five systems and systems sections tested. The air leakage ratios are estimated to be up to one-third of the fan-supplied airflow in the constant-air-volume systems. The specific ELAs and leakage classes indicate that air leakage in large commercial duct systems varies significantly from system to system, and from system section to system section even within the same thermal distribution system. The duct systems measured are much leakier than the ductwork specified as "unsealed ducts" by ASHRAE. Energy losses from supply ducts by conduction (including convection and radiation) are found to be significant, on the scale similar to the losses induced by air leakage in the duct systems. The energy losses induced by leakage and conduction suggest that there are significant energy-savings potentials from duct-sealing and insulation practice in large commercial buildings.

Xu, T., M. Sherman, B. Abushakra, C. Wray, D. Dickerhoff, D. Wang, and M. Modera. Characterizations of thermal distribution systems and energy impacts of duct leaks in light commercial buildings. LBNL-49470. No Abstract available.

Zhao, D,, Little, J.C., Hodgson, A.T. (2002) "Modeling the Reversible Sink Effect in Response to Transient Contaminant Sources". Indoor Air 12: 184-190.LBNL-47095.

ABSTRACT
A physically based diffusion model is used to evaluate the sink effect of diffusion-controlled indoor materials and to predict the transient contaminant concentration in indoor air in response to several time-varying contaminant sources. For simplicity, it is assumed that the predominant indoor material is a homogeneous slab, initially free of contaminant, and that the air within the room is well mixed. The model enables transient volatile organic compound (VOC) concentrations to be predicted based on the material/air partition coefficient (K) and the material-phase diffusion coefficient (D) of the sink. Model predictions are made for four scenarios,

each mimicking a realistic situation in a building. Styrene, phenol, and naphthalene are used as representative VOCs. A styrene butadiene rubber (SBR) backed carpet, vinyl flooring (VF), and a polyurethane foam (PUF) carpet cushion are considered as typical indoor sinks. In scenarios involving a sinusoidal VOC input and a double exponential decaying input, the model predicts that the sink has a modest impact for SBR/styrene, but that the effect increases for VF/phenol and PUF/naphthalene. In contrast, for an episodic chemical spill, SBR is predicted to reduce the peak styrene concentration considerably. A parametric study reveals that for systems involving a high equilibrium factor (K), the kinetic factor (D) will govern the shape of the resulting gas-phase concentration profile. On the other hand, for systems with a relaxed mass transfer resistance, K will dominate the profile.

2001 PUBLICATIONS WITHOUT ABSTRACTS

Apte, M.G., Fisk, W.J., Hodgson, A.T., Russell, M., Shendell. D.G. (2001) "California Demonstration Energy Efficiency-Indoor Environmental Quality Project: Predicted Relocatable Classroom Indoor Air Quality due to Low-Emitting Interior Materials and Enhanced Ventilation." In: *Proceedings of the 11th Annual Meeting of the International Society of Exposure Analysis*, Charleston, SC, November 4-8, 2001 (Abstract).

Apte, M.G., Delp, W.W., Diamond, R.C., Hodgson, A.T., Kumar, S., Shendell, D.G., Sullivan, D.P., Fisk, W.J. (2001) *Report on HVAC Option Selections for a Relocatable Classroom Energy and Indoor Environmental Quality Field Study*. LBNL-49026.

Bennett, D.H., M. Scheringer, T.E. McKone. and K. Hungerbühler, "Predicting Long Range Transport: A Systematic Evaluation of Two Multimedia Transport Models," *Environmental Science and Technology*, 35(6):1181-1189, 2001. LBNL-45690.

Bennett, D.H., T.E. McKone, and W.E. Kastenberg,, "Characteristic time, characteristic travel distance, and population based dose in a multimedia environment: A case study," in D. Paustenbach, (Ed.), *Human & Ecological Risk Assessment: Theory and Practice* (John Wiley and Sons, New York, 2001). LBNL-45815.

Carrie, Francois Remi. (2001) *Laboratory and field testing of an aerosol-based duct-sealing technology for large commercial buildings.* LBNL-44220.

Carrie, F.R., Modera, M.P. (2001) "Experimental investigation of aerosol deposition on slot-and joint-type leaks". *Journal of Aerosol Science*, Vol. **33**:10, pp. 1447-1462. LBNL-48774.

Cox, S.S., Hodgson, A.T., Little, J.C. (2001) "Measuring Concentrations of Volatile Organic Compounds in Vinyl Flooring". *Air & Waste Manage. Assoc.* **51**:174-185 2001. LBNL-47086.

Cox, S.S., Hodgson, A.T., Little, J.C. (2001) *Predicting the Emission Rate of Volatile Organic Compounds from Vinyl Flooring.* LBNL-47094.

Fischer, M.L., P.N. Price, Thatcher, T.L., Schwalbe, C.A., Craig, M.J., Wood, E.E., Sextro, R.G., Gadgil. A.J. (2001) "Rapid measurements and mapping of tracer gas concentrations in a large indoor space". *Atmospheric Environment*, **35**(16):2837-2844. LBNL-45542.

Hodgson, Al, Beal, D. (2001) "Sources of Formaldehyde, Other Aldehydes and Terpenes in a New Manufactured Homes". *Indoor Air.* In Press. LBNL-47627.

Hodgson, A.T., Fisk, W.J., Shendell, D.G, Apte, M.G. (2001) *Predicted concentrations in new relocatable classrooms of volatile organic compounds emitted from standard and alternate interior finish materials*. LBNL-48490.

Klepeis, Neil E., William C. Nelson, Wayne R. Ott, John P. Robinson, Andy M. Tsang, Paul Switzer, Joseph V. Behar, Stephen C. Hern, and William H. Engelmann. "The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants". Journal of Exposure Analysis and Environmental Epidemiology, v.**11**, no.3 (May-Jun. 2001): pp.231-252. LBNL-47713

Lorenzetti, D.M. (2001) "Assessing Multizone Airflow Software". LBNL-47653.

ABSTRACT

Multizone models form the basis of most computer simulations of airflow and pollutant transport in buildings. In order to promote computational effciency, some multizone simulation programs, such as COMIS and CONTAM, restrict the form that their flow models may take. While these tools allow scientists and engineers to explore a wide range of building airflow problems, increasingly their use has led to new questions not answerable by the current generation of programs.

This paper, directed at software developers working on the next generation of building airflow models, identifies structural aspects of COMIS and related programs that prevent them from easily incorporating desirable new airflow models. The paper also suggests criteria for evaluating alternate simulation environments for future modeling efforts.

Liu, D.L., Nazaroff, W.W. (2001) "Modeling pollutant penetration across building envelopes". *Atmospheric Environment,* **35**(26):4451-4462. LBNL-47785.

Lunden, M.M., Thatcher, T.L., Littlejohn, D., Fischer, M.L., Kirchstetter, T.W., Brown, N.J., Hering, S., and Stolzenburg, M. (2001) *Building a predictive model of indoor concentrations of outdoor PM-2.5 in homes*. LBNL-48929.

MacLeod, M., D.G. Woodfine, D. Mackay, T.E. McKone, D.H. Bennett, and R.L. Maddalena. "BETR North America: A regionally segmented multimedia contaminant fate model for North America". *Environmental Science & Pollution Research*, v.8; no.3; pp.156-163; 2001. LBNL-50571.

ABSTRACT

We present the Berkeley-Trent North American contaminant fate model (BETR North America), a regionally segmented multimedia contaminant fate model based on the fugacity concept. The model is built on a framework that links contaminant fate models of individual regions, and is generally applicable to large, spatially heterogeneous areas. The North American environment is modeled as 24 ecological regions, within each region contaminant fate is described using a 7 compartment multimedia fugacity model including a vertically segmented atmosphere, freshwater, freshwater sediment, soil, coastal water and vegetation compartments. Inter-regional transport of contaminants in the atmosphere, freshwater and coastal water is described using a database of hydrological and meteorological data compiled with Geographical Information Systems (GIS) techniques. Steady-state and dynamic solutions to the 168 mass balance equations that make up the linked model for North America are discussed, and an illustrative case study of toxaphene transport from the southern United States to the Great Lakes Basin is presented. Regionally segmented models such as BETR North America can provide a critical link between evaluative models of long-range transport potential and contaminant concentrations observed in remote regions. The continent-scale mass balance calculated by the model provides a sound basis for evaluating long-range transport potential of organic pollutants, and formulation of continent scale management and regulatory strategies for chemicals.

McKone, T.E. and E.G. Hertwich, "The Human Toxicity Potential and a Strategy for Evaluating Model Performance in Life-Cycle Impact Assessment," International Journal of Life-Cycle Assessment, 6(2):106-109, 2001. LBNL-48254.

McKone, T.E., A.B. Bodnar, and E.G. Hertwich, (2001) *Development and evaluation of state-specific landscape data sets for multimedia source-to-dose models*. LBNL-43722.

Matson, N.E., Wray, C.P., Walker, I.S., Sherman, M.H. *Potential Benefits of Commissioning California Homes*. LBNL-48258.

Modera, M.P, Brzozowski, O, Carrie, F.R, Dickerhoff, D.J, Delp, W.W, Fisk, W.J, Levinson, R, Wang, D. (2001) "Sealing Ducts in Large Commercial Buildings with Aerosolized Sealant Particles". *Energy and Buildings,* Vol. **34**:7, pp. 705-714. LBNL-42414.

Piette, M.A., J.H. Eto, I.S. Walker, S. Selkowitz, C.P. Wray, B. Nordman, A. Meier, P. Haves, R. Diamond, J. Harris, M. Moezzi, C. Payne, and J. Koomey. (2001) *Demand-Responsive and Efficient Building Systems as a Resource for Electricity Reliability.* LBNL-47942.

Salsbury, T.I., Diamond, R.C. (2001) "Fault Detection in HVAC Systems Using Model-Based Feedforward Control", *Energy & Buildings*, **33**(4 SI):403-415. LBNL-45867.

Seppanen, O., Fisk, W.J (2001) "Association of ventilation system type with SBS symptoms in office workers." Indoor Air, **12**(2) pp. 98-112.

Seppanen, O., Fisk, W.J. "Association of ventilation system type with SBS symptoms in office workers", *Indoor Air* **12**(2):98-112. 2001. LBNL-47457.

Shendell, D.G., M.G. Apte, D. DiBartolomeo, W. J. Fisk, A.T. Hodgson, S. Kumar, D.P. Sullivan, L.I. Rainer. (2001) "Linking Energy Efficiency and Indoor Environmental Quality to Provide Thermal Comfort and Reduce Children's Exposure to Volatile Organic Compounds: Demonstration Project in New Relocatable Classrooms at Northern California Public Schools." In: *Proceedings of the 11th annual meeting of the International Society for Exposure Analysis*, Charleston, SC, November 4-8, pp. 286-287 (Abstract).

Shendell, D.G., Apte, M.G., Corsi, R., Jenkins, M.P., Kim, J., Smorodinsky, S., Torres, V., J.M. Waldman. (2001). "Studying the Public School Environment and Classroom Indoor Air Quality: Community-based Exposure Assessments Through Public-Private-Government Partnerships, Examples from CA and TX." In: *Proceedings of the 11th annual meeting of the International Society for Exposure Analysis*, Charleston, SC, November 4-8, 2001, pp. 148 (Abstract).

Sherman, M.H., Walker, I.S. (2001) "Heat Recovery in Building Envelopes". In: *Proceedings of Thermal Performance of Exterior Envelopes of Buildings VIII*. ASHRAE, Atlanta, GA In Press. LBNL-47329.

Siegel,J., Wray, C.P., Eng, P. (2001) *An Evaluation of Superheat-Based Refrigerant Charge Diagnostics for Residential Cooling Systems.* LBNL-47476.

Siegel, Jeffrey. (2001) *Fouling of HVAC fin and tube heat exchangers*. LBNL-47668.

ABSTRACT

Fin and tube heat exchangers are used widely in residential, commercial and industrial HVAC applications. Invariably, indoor and outdoor air contaminants foul these heat exchangers. This fouling can cause decreased capacity and efficiency of the HVAC equipment as well as indoor air quality problems related to microbiological growth. This paper describes laboratory studies to investigate the mechanisms that cause fouling. The laboratory experiments involve subjecting a 4.7 fins/cm (12 fins/inch) fin and tube heat exchanger to an air stream that contains monodisperse particles. Air velocities ranging from 1.5 - 5.2 m/s (295 ft/min - 1024 ft/min) and particle sizes from 1 – 8.6 µm are used. The measured fraction of particles that deposit as well as information about the location of the deposited material indicate that particles greater than about 1 µm contribute to fouling. These experimental results are used to validate a model that describes the relative importance of several deposition mechanisms including impaction, Brownian diffusion, turbophoresis and gravitational settling. The analysis is extended to apply to different fin spacings and particle sizes typical of those found in indoor air.

Siegel, J.A., Walker, I.S. (2001) *Deposition of biological aerosols on HVAC heat exchangers*. LBNL-47669.

ABSTRACT

Many biologically active materials are transported as bioaerosols 1-10 µm in diameter. These particles can deposit on cooling and heating coils and lead to serious indoor air quality problems. This paper investigates several of the mechanisms that lead to aerosol deposition on fin and tube heat exchangers. A model has been developed that incorporates the effects of several deposition mechanisms, including impaction, Brownian and turbulent diffusion, turbophoresis, thermophoresis, diffusiophoresis, and gravitational settling. The model is applied to a typical range of air velocities that are found in commercial and residential HVAC systems 1 - 6 m/s (200 - 1200 ft/min), particle diameters from 1 - 8 µm, and fin spacings from 3.2 - 7.9 fins/cm (8 - 16 fins/inch or FPI). The results from the model are compared to results from an experimental apparatus that directly measures deposition on a 4.7 fins/cm (12 FPI) coil. The model agrees reasonably well with this measured data and suggests that cooling coils are an important sink for biological aerosols and consequently a potential source of indoor air quality problems.

Sohn, Michael D., Thomas E. McKone, Mark L. Rigas, Jerry N. Blancato, and Frederick W. Power. Reconstructing exposure scenarios using dose biomarkers: An application of Bayesian uncertainty analysis. LBNL-51256 Abs.

Tenwolde, A., Walker, I.S. (2001). "Interior Moisture Design Loads for Residences ". In: *Proceedings of Thermal Performance of Exterior Envelopes of Buildings VIII*. ASHRAE, Atlanta, GA. In Press.

Thatcher, T.L., Lai, A.C.K., Moreno-Jackson, R., Sextro, R.G., and Nazaroff, W.W. (2001) "Effects of Room Furnishings and Air Speed on Particle Deposition Rates Indoors". *Atmospheric Environment*, **36**(11):1811-1819. LBNL-48414.

Thatcher, T.L., T.E. McKone, W.J. Fisk, M.D. Sohn, W.W. Delp, W.J. Riley, and R.G. Sextro, (2001) *Factors Affecting the Concentration of Outdoor Particles Indoors (COPI): Identification of Data Needs and Existing Data.* LBNL-49321.

Walker, I.S., Siegel, J.A, Degenetais, G. (2001) "Simulation of Residential HVAC System Performance". In: *Proceedings of ESIM2001 Conference*, pp. 43-50. CANMET Energy Technology Centre/Natural Resources Canada, Ottawa, Ontario, Canada. LBNL-47622.

ABSTRACT

In many parts of North America residential HVAC systems are installed outside conditioned space. This leads to significant energy losses and poor occupant comfort due to conduction and air leakage losses from the air distribution ducts. In addition, cooling equipment performance is sensitive to air flow and refrigerant charge that have been found to be far from manufacturers specifications in most systems. The simulation techniques discussed in this paper were developed in an effort to provide guidance on the savings potentials and comfort gains that can be achieved by improving ducts (sealing air leaks) and equipment (correct air-flow and refrigerant charge). The simulations include the complex air flow and thermal interactions between duct

systems, their surroundings and the conditioned space. They also include cooling equipment response to air flow and refrigerant charge effects. Another key aspect of the simulations is that they are dynamic - which accounts for cyclic losses from the HVAC system and the effect of cycle length on energy and comfort performance.

Walker, I.S. (2001) ***Sensitivity of forced air distribution system efficiency to climate, duct location, air leakage and insulation.*** **LBNL 43371**.

ABSTRACT
This study was performed in order to find suitable efficiency and leakage specifications for Energy Star duct systems and provide recommendations on duct insulation specifications. This analysis looks at a typical house, with a selection of duct locations, climates, duct insulation (R-value), and duct leakage. A set of calculations were performed with reduced capacity and airflow to look at the effect of variable capacity systems. This was done to address concerns regarding the increased efficiency of multi-capacity equipment due to good part load performance and how these efficiency gains may be offset by increased duct losses. The duct system efficiencies were calculated using the procedures in proposed ASHRAE Standard 152P "Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems" (ASHRAE 1999). This proposed ASHRAE Standard can be used to calculate duct efficiency for both design and seasonal weather conditions. In this report, the seasonal efficiencies are used for most of the analysis because they are the most appropriate for estimating energy consumption in buildings. The effects at peak conditions are examined for changing duct insulation in order to provide preliminary estimates of the potential responses to time of use pricing.

The study was performed in two parts. The first part focused on duct leakage and the second part on duct insulation. The HVAC systems in the two parts share many attributes, however, they differ in detail and so are treated separately here. All the calculation results are summarized in tables in the Appendix, and specific results are given in the text.

Walker, I.S., Sherman, M.H., Wempen, J., Wang, D., McWilliams, J.A., Dickerhoff, D.J. (2001) ***Development of a New Duct leakage Test: Delta Q.*** **LBNL-47308.**

ABSTRACT
Duct leakage is a key factor in determining energy losses from forced air heating and cooling systems. Several studies (Francisco and Palmiter 1997 and 1999, Andrews et al. 1998, and Siegel et al. 2001) have shown that the duct system efficiency cannot be reliably determined without good estimates of duct leakage. Specifically, for energy calculations, it is the duct leakage air flow to outside at operating conditions that is required. Existing test methods either precisely measure the size of leaks (but not the flow through them at operating conditions), or measure these flows with insufficient accuracy. The DeltaQ duct leakage test method was developed to provide improved estimates of duct leakage during system operation.

In this study we developed the analytical calculation methods and the test procedures used in the DeltaQ test. As part of the development process, we have estimated uncertainties in the test method (both analytically and based on field data) and designed automated test procedures to increase accuracy and reduce the contributions of operator errors in performing field tests. In addition, the test has been evaluated in over 100 houses by several research teams to show that it can be used in a wide range of houses and to aid in finding limits or problems in field applications. The test procedure is currently being considered by ASTM as an update of an existing duct leakage standard.

Walker, I.S., Wray, C.P., Dickerhoff, D.J., Sherman, M.H. (2001) ***Evaluation of flow hood measurements for residential register flows*****. LBNL-47382.**

ABSTRACT
Flow measurement at residential registers using flow hoods is becoming more common. These measurements are used to determine if the HVAC system is providing adequate comfort, appropriate flow over heat exchangers and in estimates of system energy losses. These HVAC system performance metrics are determined by using register measurements to find out if individual rooms are getting the correct airflow, and in estimates of total air handler flow and duct air leakage. The work discussed in this paper shows that commercially available flow hoods are poor at measuring flows in residential systems. There is

also evidence in this and other studies that flow hoods can have significant errors even when used on the non-residential systems they were originally developed for. The measurement uncertainties arise from poor calibrations and the sensitivity of exiting flow hoods to non-uniformity of flows entering the device. The errors are usually large – on the order of 20% of measured flow, which is unacceptably high for most applications. Active flow hoods that have flow measurement devices that are insensitive to the entering air flow pattern were found to be clearly superior to commercially available flow hoods. In addition, it is clear that current calibration procedures for flow hoods may not take into account any field application problems and a new flow hood measurement standard should be developed to address this issue.

Wray, C.P., Sherman, M.H. (2001) "Residential Commissioning to Assess Envelope and HVAC System Performance" (2001) In: *Proceedings of Performance of Exterior Envelopes of Whole Buildings VIII Conference*, Clearwater Beach, FL., December 2001. LBNL-47412.

ABSTRACT
Residential commissioning is a new procedure to ensure that a house can perform optimally or at least meet basic safety, health, comfort, and energy intents. Many procedural elements, such as visual inspection and functional performance diagnostics, already exist in a fragmented environment. Most can be integrated into new industry guidelines for testing and tuning system performance in new and existing houses.

This paper describes a consolidated set of practical diagnostics that can be used now to commission envelope and HVAC system performance. Where possible, we discuss the accuracy and usability of available diagnostics, based on recent laboratory work and field studies. We also describe areas in need of research and development, such as practical field diagnostics for envelope thermal conductance and combustion safety.

Wray, C.P., Walker, I.S., Siegel, J.A., M.H. Sherman. (2001) *Practical Diagnostics for Evaluating Residential Commissioning Metrics*. LBNL-45959.

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Apte, M., Fisk, B., Daisey, J.(2000) "Associations between Indoor CO2 Concentrations and Sick Building Syndrome Symptoms in US Office Buildings: An Analysis of the 1994-1996 BASE Study Data". *Indoor Air,* Vol. 10, pp. 246-257. LBNL-44385.

Bennett, D.H. *Population based dose models for multimedia chemicals with the potential for long range transport*, May 2000. LBNL-45879.

Bennett, D.H., T. E. McKone, and W. E. Kastenberg, "CART screening level analysis of characteristic time – a case study," in *Persistent, Bioaccumulative, Toxic Chemicals II Assessment and New Chemicals*, R.L. Lipnick, B. Janson, D. Mackay, and M. Petreas (Editors), American Chemical Society ACS Symposium Series 773 (American Chemical Society, Washington, DC, 2000). LBNL-43721.

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ABSTRACT

The numerical investigation of airflow and chemical transport characteristics for a general class of buildings involves identifying values for model parameters, such as effective leakage areas and temperatures, for which a fair amount of uncertainty exists. A Monte Carlo simulation, with parameter values drawn from likely distributions using Latin Hypercube sampling, helps to account for these uncertainties by generating a corresponding distribution of simulated results. However, conducting large numbers of model runs can challenge a simulation program, not only by increasing the need for fast algorithms, but also by proposing specific combinations of parameter values that may define difficult numerical problems. The paper describes several numerical approaches to improving the speed and reliability of the COMIS multizone airflow simulation program. Selecting a broad class of algorithms based on the mathematical properties of the airflow systems (symmetry and positive-definiteness), it evaluates new solution methods for possible inclusion in the COMIS code. In addition, it discusses further changes that will likely appear in future releases of the program.

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A Bayesian uncertainty analysis approach is developed as a tool for assessing and reducing uncertainty in ground-water flow and chemical transport predictions. The method is illustrated for a site contaminated with chlorinated hydrocarbons. Uncertainty in source characterization, in chemical transport parameters, and in the assumed hydrogeologic structure was evaluated using engineering judgment and updated using observed field data. The updating approach using observed hydraulic head data was able to differentiate between reasonable and unreasonable hydraulic conductivity fields but could not differentiate between alternative conceptual models for the geological structure of the subsurface at the site. Updating using observed chemical concentration data reduced the uncertainty in most parameters and reduced uncertainty in alternative conceptual models describing the geological structure at the site, source locations, and the chemicals released at these sources. Thirty-year transport projections for no-action and source containment scenarios demonstrate a typical application of the methods.

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ABSTRACT

Residential thermal distribution systems have significant energy and comfort implications due to losses from the distribution system in the form of leakage and conduction and poor distribution from room-to-room within the house. Also, poor mechanical equipment performance, and the interactions between the distribution system and the equipment act to further reduce system capacity and thermal comfort. An example of duct system and equipment interaction is the that airflow over the indoor coils changes the efficiency, capacity and humidity removal of the system resulting in comfort, energy consumption and efficiency changes. To determine if there are any differences in the interactions depending on whether or not the equipment is ENERGYSTAR rated, two houses were tested with standard (SEER10) air conditioners and then retrofitted with ENERGYSTAR (SEER 13) equipment. In addition, the effect of duct leakage was examined by adding leaks to the systems under test. The original plan had been to seal the duct systems, but they were found to be not very leaky. Leakage was added in order to show the effect of reduced leakage. Four additional houses were tested as part of a companion study (Walker et al. (1999)) that did not have equipment changes. Selected measurement results from these houses are presented where appropriate.

This report is in two main parts. The first part discusses the field measurement techniques and results. The second part examines efforts to model distribution system performance using a sophisticated computer simulation program called REGCAP. REGCAP has been developed to specifically include the interactions of duct systems with their surroundings (In this study the duct surroundings are attic spaces). Lastly, a brief summary of related thermal distribution system research is included at the end of the report.

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ABSTRACT

ASHRAE Standard 62.2P is being proposed to address residential ventilation issues. As housing, especially new housing, gets more airtight and better insulated, it has become clear that many homes are under-ventilated. The Standard contains requirements that provide minimum ventilation rates and source control measures necessary for acceptable indoor air quality. This paper uses previously reported analytical techniques to compare the energy costs of various ventilation strategies for a wide variety of climates and housing types. For new construction, we conclude that mechanical ventilation is needed. In new houses with gas heating, the cheapest whole-house system is a central exhaust fan. The marginal energy costs to provide such ventilation are on the order of 50¢ per day. However, other systems can be more appropriate when depressurization, filtration, moisture, and more expensive heating fuels are considered. For most of the existing housing stock, we conclude that infiltration provides adequate ventilation.

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ABSTRACT

The literature review reported here is the first step in a larger 30 month-long project that will lay the groundwork for a residential commissioning industry in California focused on end-use energy and non-energy issues. The intent of the review is to facilitate access to existing literature related to residential commissioning. Emphasis is placed on reviewing documents published over the past 20 years, which represents the period of time over which building commissioning and closely related issues have been actively reported.

This report discusses the status of commercial building commissioning and compares it with residential commissioning. Based on an extensive review of 469 readily available documents, it summarizes existing metrics, diagnostics, and norms for all building types that are relevant for evaluating, tuning, and retrofitting various aspects of new and existing houses. The relevant areas of concern for California houses are: Building Envelope, Cooling Equipment and Heat Pumps, Air Distribution Systems, Indoor Air Quality, Combustion Appliances, Controls, and Other Electrical Appliances.

There is a substantial amount of useful information in the literature about metrics, diagnostics, and norms that are relevant to residential commissioning. However, there are also some significant gaps. This report concludes by highlighting gaps in existing knowledge that require further research and development. Areas in particular need of work include: metrics, diagnostics, and norms for thermal mass and moisture-damage susceptibility; diagnostics for steady-state capacity and efficiency, as well as refrigerant charge level, for cooling equipment and heat pumps; diagnostics and norms for ventilation effectiveness and efficiency; diagnostics to evaluate the potential for backdrafting and combustion gas spillage; and metrics, diagnostics, and norms for controls and other electrical appliances.

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ABSTRACT

We describe a novel modeling technique, based on Duhamel's theorem, to study the effects of time-varying winds on radon transport in soil near buildings. The technique, implemented in the model RapidSTART, reduces computational times for transient, three-dimensional, wind-induced soil-gas and radon transport by three to four orders of magnitude compared with conventional finite-di§erence models. To test model performance, we compared its predictions to analytical solutions of one-dimensional soil-column flow, finite-difference simulations of flow around a full-scale house, and measurements of transient soil–gas and radon entry into an experimental basement structure. These comparisons demonstrate that RapidSTART accurately simulates time-dependent radon transport through soil and its entry into buildings. As demonstrated in a previous study, steady winds can significantly affect radon entry. In this paper, we extend the findings of that study by applying RapidSTART to explore the impacts of fluctuating wind speed and direction on radon entry into a prototypical house. In soils with moderate to high permeability, wind fluctuations have a small to moderate effect on the soil-gas radon concentration field and entry rate into the building. Fluctuating wind direction dominates the impact on radon entry rates, while fluctuating wind speed has little effect. For example, in a soil with a permeability of 10~10m2, diurnal oscillations in wind direction can increase the predicted radon entry rate by up to 30% compared to steady-state predictions. (1999 Elsevier Science Ltd. All rights reserved.

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ABSTRACT
A publicly available aerosol dynamics model, MIAQ4, is coupled to a widely used multizone air flow and transport model, COMIS, to better understand and quantify the behavior of particles in indoor environments. MIAQ4 simulates the evolution of a size and chemically resolved particle distribution, including the effects of direct indoor emission, ventilation, filtration, deposition, and coagulation. COMIS predicts interzonal air-exchange rates based on pressure gradients (due to wind, buoyancy, and HVAC operation) and leaks between the zones and with the outside. The capabilities of the coupled system are demonstrated by predicting the transport of particles from two sources in a residence: environmental tobacco smoke (ETS) and particles generated from cooking. For ETS, MIAQ4 predicts particle size distributions that are similar to the emission source profile because ETS particles, concentrated in the size range 0.1 - 1 μm, are transformed by coagulation and deposition slowly compared with the rates of transport. For cooking, MIAQ4 predicts that the larger-sized particles will settle rapidly, causing a shift in size distribution as emissions are transported to other rooms.

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ABSTRACT
This paper describes the first efforts at developing a set of prototypical buildings defined to capture the key features affecting airflow and pollutant transport in buildings. These buildings will be used to model airflow and pollutant transport for emergency response scenarios when limited site-specific information is available and immediate decisions must be made, and to better understand key features of buildings controlling occupant exposures to indoor pollutant sources. This paper presents an example of this approach for a prototypical intermediate-sized, open style, commercial building. Interzonal transport due to a short-term source release, e.g., accidental chemical spill, in the bottom and the upper floors is predicted and corresponding HVAC system operation effects and potential responses are considered. Three-hour average exposure estimates are used to compare effects of source location and HVAC operation.

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ABSTRACT
Forced air distribution systems in residential buildings are often located outside conditioned space, for example in attics, crawlspaces, garages and basements. Leaks from the ducts to these unconditioned spaces or outside can change flows through the registers and change the ventilation rates of the conditioned spaces. In this study, duct leakage flows were measured in several low-rise apartment buildings. The

leakage flow measurements and other data about the apartments were used to develop a prototype apartment building. The multizone airflow model COMIS was then used on this prototype building to determine internal flows within the building, air flows through the building envelope and the impacts of the duct leakage on the ventilation rates. The effects of sealing the duct leaks were also examined in order to determine changes in infiltration rates resulting from duct retrofits. The simulation results showed that for the prototype tested here, the excess return leakage tended to decrease envelope infiltration flows by about 20% but the total infiltration load including return duct leaks more than doubled during system operation.

Walker, I.S., Sherman, M.H., Siegel, J.A. (1999) *Distribution effectiveness and impacts on equipment sizing for residential thermal distribution systems*. LBNL-43724.

Introduction

Previous studies (including earlier phases of this research project) have shown that losses from residential thermal distribution systems have significant energy and comfort implications. This study looks at the potential for improvement of thermal distribution systems and the possibility of reducing equipment size as a result. These distribution system and equipment interactions were examined through field testing and computer simulation. In addition, this report outlines our efforts to transfer the results of this research to the marketplace so as to reduce energy losses and improve thermal comfort. This study describes the results of efforts made during the Transitional Phase of this Residential Thermal Distribution Systems research. Results of earlier Phases were described in Walker et al. (1997 and 1998).

Wray, C.P. (1999) "Suite Ventilation Characteristics of Current Canadian Mid- and High-Rise Residential Buildings", Submitted to *ASHRAE Transactions*. LBNL-43254.

ABSTRACT

This paper characterizes ventilation in residential suites located in ten buildings in major metropolitan areas of Canada. All buildings were between six and thirty-two stories tall and were built between 1990 and 1995.

The key findings from field performance tests of these buildings were:

1. Corridor supply airflows usually did not meet design flows.
2. Makeup air paths for suite exhaust were not properly designed.
3. Suite access door leakage was highly variable and usually did not meet smoke control requirements.
4. Airflow from the corridor through the suite access door leakage appeared to be the primary ventilation air supply for suites.
5. Suites were usually well-ventilated, but some were marginally- or under-ventilated.
6. Poor pressure control often allowed transfer air from one suite to another. Inter-suite transfer air fractions ranged from 0 to 45%, with an average of 19%.

In summary, this work showed suite ventilation can be highly influenced by corridor supply flows, by the treatment of corridor access doors, and by transfer airflows. As a result, suite ventilation at any given time in current mid- and high-rise residential buildings is very difficult to predict.

To ensure suite ventilation performs as intended under all operating conditions, the building industry needs to address the identified problems through improved ventilation design, operation, and maintenance practices.

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Carrie, F.R., Modera, M.P. (1998) "Particle Deposition in a Two Dimensional Slot from a Transverse Stream", *Aerosol Science And Technology,* Vol. **28**(N3):235-246.

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Walker, I.S., Modera, M.P. (1998) "Field Measurements of the Interactions between Furnaces and Forced Air Distribution Systems", *ASHRAE Trans*., 104(1B): 1805-1816. LBNL-40587.

ABSTRACT

Measurements on three gas and two electric furnaces have been made to examine the field performance of these furnaces and their interactions with their forced-air distribution systems. The distribution systems were retrofitted as part of this study and the impact of retrofitting on furnace performance is discussed. In addition to field measurements, this paper will discuss how forced-air furnace systems are treated in proposed ASHRAE Standard 152P, and applies the resulting equations to the systems tested in the field. The distribution system calculations in Standard 152P are compared to the current methods employed in the "Furnaces" chapter of ASHRAE's *HVAC Systems and Equipment Handbook*, showing how the distribution system efficiencies calculated using Standard 152P can be incorporated into the handbook.

Walker, I., Sherman, M., Modera, M., Siegel, J. (1998) *Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems*. LBNL-41118.

Introduction

This field study concentrated on measurement of duct leakage to outside the conditioned space because this is most useful in energy calculations, e.g., proposed ASHRAE Standard 152P (ASHRAE 1997). For room by room load/comfort requirements, the total duct leakage (including leaks to conditioned space) is more appropriate, particularly for additional comfort considerations. The objective of this field study is to help to identify major sources of uncertainty and to quantify the trade-offs between different test methods. The identification of the areas requiring significant improvement will aid in future development of duct leakage test methods. For example, during the course of this study a new method for correcting house pressure tests to account for the presence of duct leakage in measured envelope leakage was developed.

Each of the measurement techniques investigated has resulted from a different set of priorities and hence compromises. Thus each one of them is measuring a different physical quantity, although they all report the same parameter - duct leakage to outside at operating conditions. Given that real houses do not meet all of the simplifying assumptions that must be made to achieve similarity, the same numbers from each test method are not expected. Potentially these differences can be quite large and one of the benefits of field measurement is that the differences in the measurements helps put a realistic bound on how different some of these leakage diagnostics may be.

To evaluate current duct leakage diagnostic methods, field tests were performed in 17 houses. The field tests were divided into two parts. The first part was performed in occupied S.F. Bay Area houses. The second part was performed in new unoccupied houses (some with unfinished interiors) in Irvine, CA. In the Bay Area, nine houses were tested using four diagnostic techniques.

Walker, I.S., Wilson, D.J. (1998) "Field Validation of Algebraic Equations for Stack and Wind Driven Air Infiltration Calculations", *HVAC&R Research*, 4: 119-139. LBNL-42361.

ABSTRACT

Explicit algebraic equations for calculation of wind and stack driven ventilation were developed by parametrically matching exact solutions to the flow equations for building envelopes. These separate wind and stack effect flow calculation procedures were incorporated in a simple natural ventilation model, AIM-

2, with empirical functions for superposition of wind and stack effect and for estimating wind shelter. The major improvements over previous simplified ventilation calculations are: a power law pressure-flow relationship is used to develop the flow equations form first principles, the furnace or fireplace flue is included as a separate leakage site and the model differentiates between houses with basements (or slab-on-grade) and crawlspaces. Over 3400 hours of measured ventilation rates from the test houses at the Alberta Home Heating Research Facility were used to validate the predictions of ventilation rates and to compare the AIM-2 predictions to those of other ventilation models. The AIM-2 model had bias and scatter errors of less than 15% for wind-dominated ventilation, and less than 7% for buoyancy ("stack-effect") dominated cases.

Walker, I.S., Wilson, D.J., Sherman, M.H. (1998) "A Comparison of the Power Law to Quadratic Formulations for Air Infiltration Calculations", *Energy and Buildings*, 27(3): 293-299. LBNL-41447.

Synopsis

Although the power law has been broadly accepted in measurement and air infiltration standards, and in many air infiltration calculation methods, the assumption that the power law is true over the range of pressures that a building envelope experiences has not been well documented. In this paper, we examine the validity of the power law through theoretical analysis, laboratory measurements of crack flow and detailed field tests of building envelopes. The results of the theoretical considerations, and field and laboratory measurements indicate that the power law is valid for low pressure building envelope leakage.

Walker, I., Siegel, J., Brown, K., Sherman, M. (1998) "Saving Tons at the Register". In: *Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings*, Vol. 1, pp 367-383, American Council for an Energy Efficient Economy, Washington, D.C. LBNL-41957.

ABSTRACT

Duct losses have a significant effect on the efficiency of delivering space cooling to U.S. homes. This effect is especially dramatic during peak demand periods where half of the cooling equipment's output can be wasted. Improving the efficiency of a duct system can save energy, but can also allow for downsizing of cooling equipment without sacrificing comfort conditions. Comfort, and hence occupant acceptability, is determined not only by steady-state temperatures, but by how long it takes to *pull down* the temperature during cooling start-up, such as when the occupants come home on a hot summer afternoon. Thus the delivered tons of cooling at the register during start-up conditions are critical to customer acceptance of equipment downsizing strategies. We have developed a simulation technique which takes into account such things as weather, heat-transfer (including hot attic conditions), airflow, duct tightness, duct location and insulation, and cooling equipment performance to determine the net tons of cooling delivered to occupied space. Capacity at the register has been developed as an improvement over equipment tonnage as a system sizing measure. We use this concept to demonstrate that improved ducts and better system installation is as important as equipment size, with analysis of pull-down capability as a proxy for comfort. The simulations indicate that an improved system installation including tight ducts can eliminate the need for almost a ton of rated equipment capacity in a typical new 2,000 square foot house in Sacramento, California. Our results have also shown that a good duct system can reduce capacity requirements and still provide equivalent cooling at start-up and at peak conditions.

Walker, I.S., (1998) "Technical Background for Default Values used for Forced Air Systems in Proposed ASHRAE Standard 152P", *ASHRAE Trans.*, 104(1B): 1360-1375. LBNL-40588

ABSTRACT

ASHRAE Standard 152P (Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems) includes default values for many of the input parameters required to calculate delivery system efficiencies. These default values have several sources: measured field data in houses, laboratory testing, simple heat transfer analyses, etc. This paper will document and discuss these default values and their sources for forced air systems.

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iamond, R.C., Feustel, H.E., Dickerhoff, D.J. (1996) *Ventilation and Infiltration in Highrise Apartment Buildings*, Lawrence Berkeley National Laboratory, Berkeley. LBNL-38103.

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Hammon, R.W., Modera M.P. (1996) "Improving the Energy Efficiency of Air Distribution Systems in New California Homes." In: *Proceedings of the 1996 ACEEE Summer Study*, pp 2.85-95, American Council for an Energy Efficient Economy, Washington DC. LBL-31636

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Jump, D.A., Walker, I.S. Modera, M.P., (1996), "Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems". In: *Proceedings of the ACEEE 1996 Summer*

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ABSTRACT

Forced air distribution systems can have a significant impact on the energy consumed in residences. It is common practice in U.S. residential buildings to place such duct systems outside the conditioned space. This results in the loss of energy by leakage and conduction to the surroundings. In order to estimate the magnitudes of these losses, 24 houses in the Sacramento, California, area were tested before and after duct retrofitting. The systems in these houses included conventional air conditioning, gas furnaces, electric furnaces and heat pumps. The retrofits consisted of sealing and insulating the duct systems.

The field testing consisted of the following measurements: leakage of the house envelopes and their ductwork, flow through individual registers, duct air temperatures, ambient temperatures, surface areas of ducts, and HVAC equipment energy consumption. These data were used to calculate distribution system delivery efficiency as well as the overall efficiency of the distribution system including all interactions with building load and HVAC equipment. Analysis of the test results indicate an average increase in delivery efficiency from 64% to 76% and a corresponding average decrease in HVAC energy use of 18%. This paper summarizes the pre- and post-retrofit efficiency measurements to evaluate the retrofit effectiveness, and includes cost estimates for the duct retrofits. The impacts of leak sealing and insulating will be examined separately.

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ABSTRACT

Energy losses from forced air distribution systems have a significant impact on the energy efficiency of buildings. Little work has been done to quantify these losses in apartment buildings. In this paper we will discuss field measurements made on four forced air heating systems to evaluate the duct system energy losses to unconditioned basements. The apartments were heated by natural gas furnaces located in the basements. The systems had bare sheet metal ductwork exposed to the basement conditions. The pre-retrofit measurements were made on the systems after sealing large easily visible leaks. The post-retrofit measurements were made after wrapping the ducts in foil backed glass fiber insulation and additional leak sealing. Only the sections of duct exposed to the basement were retrofitted because only these sections were accessible. This study examines the potential energy savings for this type of limited retrofit.

The energy losses were separated into leakage and conduction terms. Leakage measurements were made using register flowhood techniques. Conduction losses were estimated by measuring temperatures in the plenums and at the registers. Analysis of the measurements has shown typical reduction in leakage flow due to duct sealing of about 40%. The reduction in leakage translated into a reduction in energy consumption of about 10%.

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The wind shadow model has been developed to calculate the wind sheltering effects of upwind obstacles for air infiltration calculations. This effect must be determined for infiltration calculations because, in almost all situations, only the unobstructed mean wind speed is known for a building site. This model has adapted the theoretical calculation procedures developed for far wake centreline velocity deficit calculations to near field flows, where shelter has a significant effect. The model uses the concept of a wind shadow projected downstream by upwind buildings to determine the effect of wake velocity reduction on building surfaces. The turbulent nature of the wake is accounted for by "flapping" the wake over a range of wind directions. The effectiveness of this model in accounting for sheltering effects in infiltration calculations has been examined by comparing infiltration model predictions including the wind shadow model to measured data from a row of test houses. The measured data covered a wide range of wind speeds, wind directions and leakage distributions by using over five thousand hours of infiltration measurements from five houses.

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ABSTRACT
Field tests were carried out in two flat ceiling, residential attics at a dedicated test site over a two year period. The scope of this paper is to present measurements of ventilation rates, indoor-attic exchange rates, temperatures and wood moisture contents at various locations in the attics. Attic ventilation rates are correlated with wind speed, wind direction, and attic-outdoor temperature difference. Wind speed is shown to be the dominant driving force for ventilation; however, wind direction is important particularly when the attic is sheltered.

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SYNOPSIS
The ventilation of an attic is critical in estimating heating and cooling loads for buildings because the air temperature in the attic is highly sensitive to ventilation rate. In addition, attic ventilation is an important parameter for determining moisture accumulation in attic spaces that can lead to structural damage and reduced insulation effectiveness. Historically, attic venting has been a common method for controlling attic temperature and moisture, but there have been no calculation techniques available to determine attic ventilation rates. Current practice is to use rules of thumb for estimating attic vent areas.

Simple algebraic relationships are developed here, using functions fitted to an exact numerical solution for air flow through attic envelopes. This algebraic model (AVENT) was developed to be easy to use as diagnostic or design tool. Key factors included in the model are: climate (wind and stack effect), wind shelter, leakage distribution and total attic leakage.

This paper validates the model predictions by comparing to measured data from two attics at the Alberta Home Heating Research Facility (AHHRF). Average errors for the model are about 15% compared to the measured ventilation rates.

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