**Project Name:** Indoor Air Quality Simulator with Interactive Consumer and Lab Interface

**Student Names:** Janet Guntly (Computer Science), Amber Loftis (Chemical Engineering)

**Advisor Names:** Daniel Tauritz, Ph.D. (Computer Science), Glenn Morrison, Ph.D. (Environmental Engineering)

**School Name:** Missouri University of Science and Technology (*http://www.mst.edu*)

**Project Website**: *http://indaqs.mst.edu/*

## Goals and Purpose

Americans spend on average roughly 90% of their time indoors[1] and health risks due to indoor air are ranked among the top five environmental health risks.[2] However, residential air quality is not regulated in most parts of the United States. High indoor pollutant levels are caused by emissions from indoor sources, low air circulation, and chemical reactions generating toxic byproducts. Exposure to indoor air pollutants can result in minor to severe health hazards such as allergies, shortened life span, severe disability, mental retardation, organ dysfunction, nervous system dysfunction, behavioral dysfunction, cancer and death.[3]

One goal of the Indoor Air Quality Simulator (INDAQS) project is to raise consumer awareness about residential indoor air quality. By making informed decisions with the knowledge gained from our interactive consumer interface, users may be able to improve their health. A second goal is to provide a valuable tool for indoor air researchers in the form of an interactive lab interface. This interface should allow researchers to receive results quickly from an easy computational tool for their experiments, thus increasing research productivity.

## Research Process

### *Questions to be Answered*

There are many possible approaches to achieving our stated goals. We decided on a user driven approach where we first formulated the types of questions we want users to be able to pose and then determine the most appropriate model to answer those questions. A typical consumer question might be: how does using a particular household chemical affect my indoor air quality? A typical research question might be: given a partial set of values (possibly measured in a lab setting), what are the values for the unknowns in a common set of indoor air quality equations?

### *Developing Equations and Data*

We identified a system of steady-state rate equations as the most appropriate model to answer the types of questions we previously formulated. These equations are based on existing indoor air quality models that include chemistry, similar to those developed by Nazaroff (1986)[4] and Carslaw (2007)[5]. This model's set of equations quantifiably describes chemicals entering a space through natural ventilation and from an indoor emission source, and being removed from the air via surface reactions, gas phase reactions, and air purifiers. These equations take into account the formation of other chemicals through gas phase reactions as well.

It was also necessary to determine the acceptable ranges and estimated default values for variables in the indoor air equations. We identified these values by performing an extensive literature search. Results from the literature research were compiled to create the ranges and default values for the lab interface in order to alert for possible input mistakes and facilitate swift data entry. Default values were also used in the consumer interface for the variables that the consumer does not enter, making the interface more user-friendly and easier for consumers to use and understand.

***Simulation Engine***

The simulation engine powers both the lab and consumer interfaces. It uses the GNU Scientific Library (GSL) Multidimensional Root Finder[6] to set up the system of equations and attempt to solve for unknown values, if possible. After the unknowns and equations are set up, the solver iterates until it finds a solution. However, there are still several limitations to the simulation engine. One of these is that if there are multiple solutions to the problem, the solver will select the one that is closest to the initial guess (the one it finds first). If this answer contains negative numbers, it is not the desired solution, and the solver must be reset with a higher initial guess and run again. In addition, the number of equations and the number of unknowns must be exactly equal for the solver to function correctly, and the solver seems to have difficulty solving for values that are greater than $1*10^{8}$ or smaller than $1*10^{-8}$.

***Lab and Consumer Interfaces***

Users interact with the simulation engine through web-based lab and consumer interfaces. The lab interface is the more detailed, scientific version intended for indoor air researchers. It prompts the user to input values for all of the different variables in the equations, and asks them to leave any unknowns blank. Several default values are already filled in, in case the user does not wish to enter every one of the many values, and recommended limits are suggested for most variables. In addition, the interface provides the user with a number of options, such as selecting the units their values are in, or entering the components necessary to find a value instead of the value itself. After submitting this information, the simulation engine solves the equations for the unknowns, if possible, and presents the solution to the user. The user can also view all of his or her entries in case any were entered incorrectly.

The lab interface is not practical for ordinary consumers, as they are unlikely to be familiar with the values and terminology used. Instead we created another interface targeting consumers which utilizes a selection of specific scenarios to give consumers some idea of how certain objects affect their indoor air quality. For example, one scenario involves using generic cleaning supplies in a kitchen. In these scenarios, the users are asked for several pieces of information that they are likely to know, such as the season and the square footage of their house. Values from research fill in the rest of the variables. The solver then uses this information to solve for the indoor concentrations of ozone and other chemicals. Then, the solution is compared to various organizations' recommended concentration limits for those chemicals, and output is given to the user in the form of a bar showing which standards the home in the scenario meets. Scenario pages also contain many links to more information about the chemicals and the organizations for the consumer to explore.

## Results and Conclusions

A model for representing residential indoor air quality was identified and the corresponding equations implemented. Usable data for the system was obtained through a literature search. A simulation engine to solve the system of equations for unknowns was created with lab and consumer interfaces to allow different audiences to interact with the model. The lab interface facilitates swift research by solving the system of equations for unknown values. Consumers can use the scenarios we created to gain knowledge about the indoor air in their homes, thus empowering them to make informed decisions affecting their indoor air quality.

Future work on the INDAQS project includes extended validation of the solutions and acceptable ranges of the variables. The equations used in the simulator could be altered to be dynamic temporal-spatial equations in order to more accurately reflect reality. Future lab work on specific emissions or sources of emissions would also expand the possibilities for the interfaces. Finally, more features could be added to the interfaces to provide more knowledge, or increase their attractiveness and user-friendliness, such as adding more scenarios or creating an additional integrated interface, allowing consumers more control over their inputs and permitting researchers to enjoy the benefits of the consumer interface.

## Publications and Presentations

- Project Website: *http://indaqs.mst.edu/*

- Missouri University of Science and Technology - Undergraduate Research Conference, Poster Presentation, 9 April 2008.

- University of Missouri System - Undergraduate Research Day at the Capitol, Jefferson City, Missouri, Poster Presentation, 30 April 2008.

- Simulating Indoor Air Quality: Empowering Consumers & Increasing Research Productivity-Special Seminar, University of North Carolina at Chapel Hill, North Carolina, Presentation, 5 August 2008.

- Simulating Indoor Air Quality: Empowering Consumers & Increasing Research Productivity-Special Seminar, Environmental Protection Agency, Durham, North Carolina, Presentation, 6 August 2008.

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[1] Spengler, John and Samet, Jonathan. Indoor Air Quality Handbook. New York: McGraw-Hill, 2000.

[2] Guide to Air Cleaners in the Home. United States Environmental Protection Agency. Office of Air and Radiation. Oct. 2007.

[3] Godish, Thad. Sick Buildings: Definition, Diagnosis and Mitigation. Boca Raton: Lewis Publishers Inc., 1995.

[4] Nazaroff, William W., and Glen R. Cass. "Mathematical Modelling of Chemically Reactive Pollutants in Indoor Air." Environmental Science & Technology 20 (1986): 924-34.

[5] Carslaw, Nicola. "A new detailed chemical model for indoor air pollution." Atmospheric Environment 41 (2007): 1164-179.

[6] "Multidimensional Root-Finding." GNU Scientific Library - Reference Maual. 29 Apr. 2008 <http://www.gnu.org/software/gsl/manual/html_node/multidimensional-root_002dfinding.html>.