The Nature and Magnitude of the Problem: Building Sources vs. Ventilation

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This is an impressive crowd here today. I am pleased to see you here to talk about indoor air quality with us. I would like to emphasize and I think I speak for all of us in saying that we hope there will be a considerable amount of discussion during this two day session, both after talks if there is time, and also outside and in the public forums. This is a new field, and in any new field there are many misconceptions about problems. Some of the misconceptions will be the fault of the speakers, perhaps, and if that happens we will enjoy the discussion that ensues.

My talk this morning is an introductory talk. It is meant to provide some basis of my perspective on the indoor air quality problem. The research that I am involved with is a research program at the Lawrence Berkeley Laboratory that is funded by the Department of Energy. The Office of Conservation and Renewable Energy of DOE has been a major supporter of research in indoor air quality since the middle 1970's and much of the work that you see in the published literature today has received funding from that particular source.

Indoor air quality as a research issue is a young field. Indoor air quality as an item of concern certainly goes back several centuries. Ventilation standards, after all, are a manifestation of people's concerns about indoor air quality. The issue of air quality in buildings only began to receive research support in the middle 1970's, largely as an offshoot of work in outdoor air pollution. Outdoor pollution experts began to look inside buildings because of several different questions. One was the question- what does a ventilation standard mean if outdoor air is polluted? Why ventilate with outdoor air if the outdoor air you are bringing in is worse than the air inside the building? Another question was the issue of whether the building itself is a safe haven. It is related to the first. Does a building provide an adequate safety barrier against outdoor pollution during an air pollution episode? Those were questions that people asked as soon as they moved inside buildings and began making measurements using some of the stationary monitoring apparatus that EPA had developed by the middle 1970's. They began to realize that pollution sources inside a building were a genuine problem and because of that, indoor air quality research was born. Craig Hollowell at Lawrence Berkeley Laboratory was one of the first people who began to look at this problem. Craig was an outdoor pollution expert and began to look at sources of pollution inside buildings and began to find them.

My talk today will outline these issues, look at my perception about the nature of the problem indoors and then speak a bit about particular research problems. I will not discuss the problems that will be talked about today by other experts in the field. Radon, formaldehyde, particles, and moisture will be covered adequately I am sure by people who are specialists in those areas.

As people began to look at the sources of pollution inside buildings, the issue of whether there were sources present inside buildings was answered affirmatively. A very common way of reporting results was to compare the outdoor measurement that was a reference measurement with the indoor concentrations of pollutants. Typically the indoor/outdoor ratio was a number greater than or considerably greater than 1, indicating that there were sources present in the indoor space. The observations began to capture peoples' attention and the research area called indoor air quality began in a serious way.

Let us examine the public policy implications of the research. One place to find these implications is to look at the standards that exist in the country to govern air quality. We have the National Ambient Air Quality Standards promulgated by EPA and accepted by Congress based on the charter that the EPA received under the Clean Air Act. In that particular set of standards, pollutants in the ambient air are controlled. However, ambient air has a particular definition as the atmosphere that the general public is exposed to exterior to buildings. That interpretation has significant ramifications for our discussions today. OSHA has air quality standards that govern workplace environments, but there are no general public access indoor air quality standards in the United States. There are some guidelines--some very specialized regulations for specialized situations, but, in general, there are no indoor air quality standards.

I say rather glibly that indoor air quality captures the public interest. I think that each of you sitting in the room has to ask herself or himself during this next two-day period whether that is a comment of an environmental scientist who likes to work in this field and is trying to protect his job or whether it is a comment of an over-concerned environmentalist who has a new issue for the month, or whether it is a real issue. One of my tasks and one of the tasks that Harvey [Sachs] has and one of the tasks that Beat [Meyer] has is to try to put that into perspective and to try to present some evidence that, in fact, it is a real issue. If not you can come away from our discussion and say that you can ignore it.

One way of assessing the statement is to talk about comparative risks. That is dangerous because anytime one does a risk analysis, he must look very carefully at the assumptions that are made in preparing a risk estimate for a particular situation. Yet, I would like to say some general things about risks and the way the public responds to risk here in the United States.

In general, people begin to respond to personal risks when the risk reaches the one to ten percent level. By that I simply mean if someone is doing something that has some personal amenity associated with it, like driving a car or smoking a cigarette, and it is pointed out to them that there is some risk of mortality at the one to ten percent level, they begin to make some adjustments in their personal behavior. You may begin to use a seatbelt if you are driving an automobile or you may cut down on your smoking if you are a smoker. The lifetime risk of death in an automobile is about one percent, while the lifetime risk of dying from cigarette smoking is in the order of ten percent. Clearly, there are amenities that some people perceive for each of those actions. I certainly am not going to give up driving an automobile because of a one percent risk, but I will try to minimize the risk. If you move to the occupational level, people will put up with risks of the order of a tenth to one percent risk for things that are related to their personal occupation. They technically have an option of not working in a situation that has some risk to them. Certainly there is also some benefit to their occupation. If one moves to environmental criteria the issue of what risks we tolerate for pollution in the atmosphere or some other thing we have no control over turns out to be the order of a thousandth of a percent to, perhaps, a tenth of a percent. Those are very rough numbers that refer to lifetime risk of mortality, but they give you a kind of reference for the discussion about indoor air quality risk that I want to make.

The National Council on Radiation Protection and Measurements has recently completed a study looking at the lifetime risk of mortality from breathing radon gas within buildings. Typical concentrations in residences in the United States are on the order of one pico-curie per liter (1 pCi/l). Harvey [Sachs] will discuss this in some detail in his talk. Let me go through the numbers quickly. I will be sloppy about definitions in the interest of time. We can pick up on some of these definitions later if necessary. The lifetime risk is on the order of 0.15 percent to develop lung cancer when exposed to a concentration of 1 pCi/l. Radon is a radioactive decay product of radium that is found in soils all over the globe. Radon is found in residences throughout the United States. What does this mean? What kind of concentrations do we see in houses in the United States? We have just finished a study at the lab in which we have collected information about 38 different residential surveys of radon concentrations that have been completed in the United States. This is a sample of roughly 1400 homes; the order of about half of those homes were measured in situations where there was an expectation of high radon concentrations. They were removed from the sample. This is the remainder of the sample, roughly 550 homes.

What is plotted in Figure 1 is the percent of houses in the sample versus radon concentration in pico-curies per liter (pCi/l). This is a log-normal distribution. The solid curve through the distribution indicates a standard log-normal form.

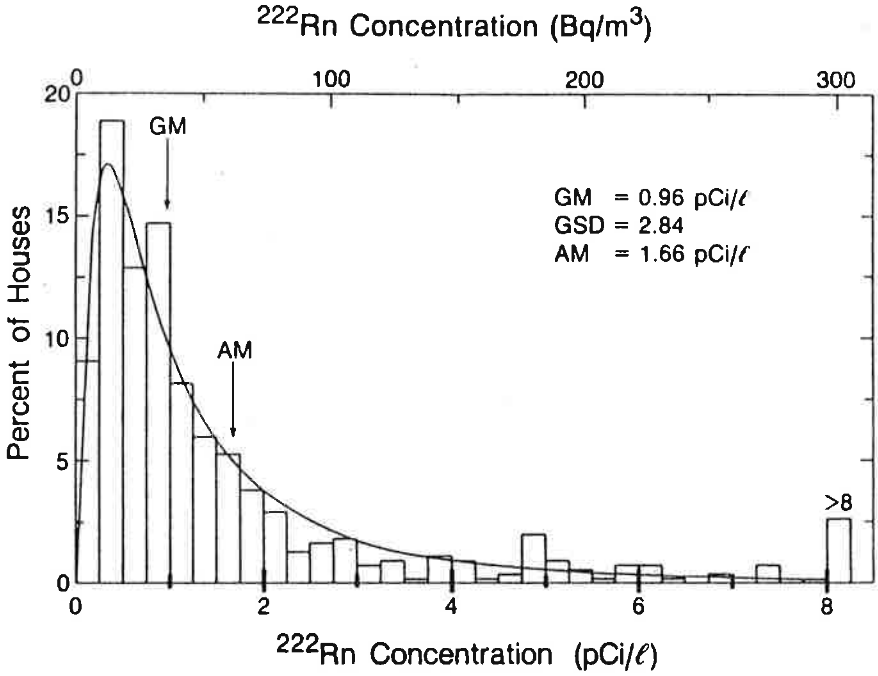
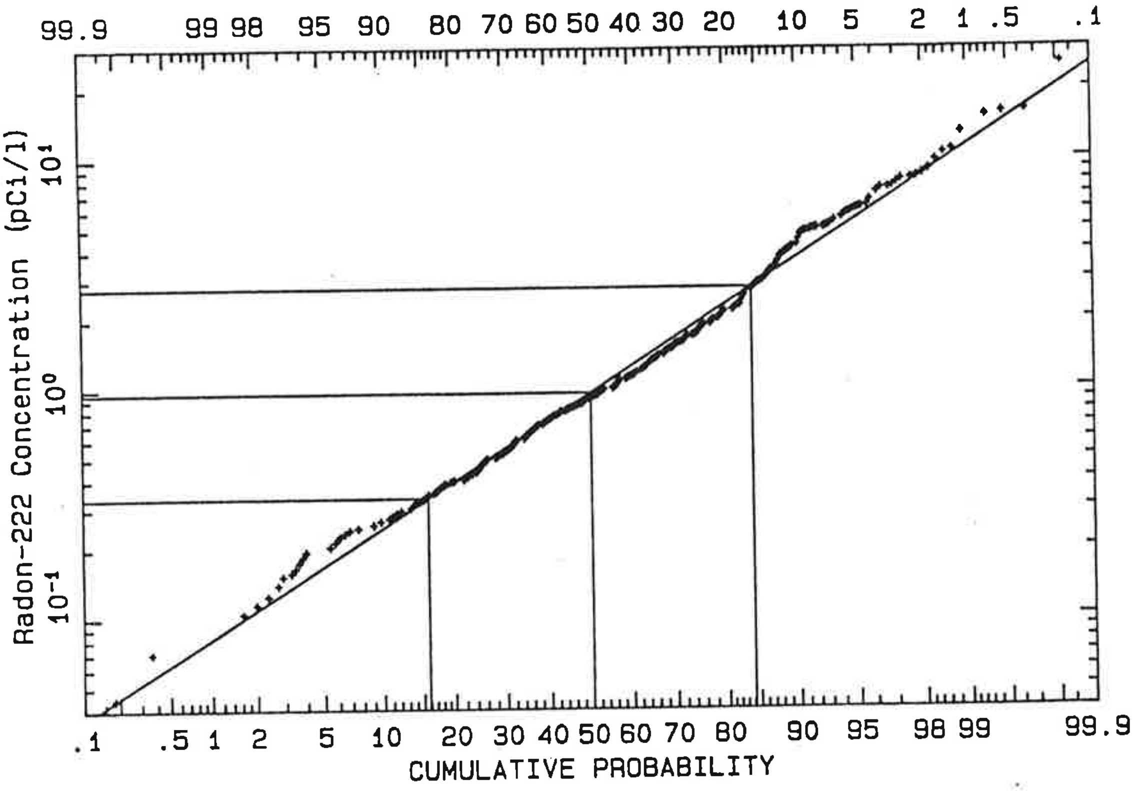


Figure 1

The geometric mean of the distribution, which also turns out to be the median value, half above, half below, is about 1 pCi/l. That is a lifetime risk of 0.15 percent. As we go further out past 8 pCi/l, the number of concern is something quite different. There is another way to explain these data and I want to show you Figure 2. This is a cumulative probability plot and it is a messy plot in a certain sense. Yet in a very real sense it is transparent and conveys a lot of information.

In Figure 2 the vertical axis is the logarithm of the concentration that is seen in these houses. The horizontal axis is a cumulative probability. Using these axes, if the data are plotted cumulatively and lie on a straight line, the data follow a log-normal distribution. That is not the point of the figure here, however. The point of the figure is to pick off the number of homes in this distribution that fall above particular target levels. Fifty percent, the center line on the figure, fall at a concentration of 1 pCi/l.

The National Council of Radiation Protection and Measurements recommends that mitigation of excess concentrations of radon should occur if concentrations exceed 8 pCi/l. If we look along this distribution out to a concentration of 8 pCi/l, we see that roughly two percent of the houses in this distribution fall on or have concentrations above that. Now it is not clear that one can project from a sample of this size which was collected in many different regions of the United States, to the whole housing stock in the United States. But our expectation is that this is not going to be atypical of the final distribution that is seen



Distribution for sets 1-22, except Houston, Pittsburgh, Tennessee

Figure 2

when a real survey is done of air quality in the country. And if we make that extrapolation, we have roughly a million houses in the United States with concentrations of 8 pCi/l or above. Now 8 pCi/l moves the lifetime risk of lung cancer up to about one percent. Thus we project that there are perhaps several million occupants that have that kind of exposure, if they remain in homes with high radon concentrations throughout their lifetimes. One percent risk is a substantial risk. It is something that is not tolerated for typical environmental issues. There is no amenity to breathing radon. Believe me, there is no goodness that comes from breathing radon into your lungs. This number is the most substantial indication of the seriousness of our indoor air quality problem based on health risk. We see that this is not a trivial issue. It is something that we must be concerned about.

Concentrations of other pollutants are also seen at levels that are higher than outdoors. There are clearly examples of indoor sources in many building measurements that are taken. Figure 3 shows the results from an office building in the San Francisco area. Concentration ratios are shown in the last column. Hydrocarbons have an indoor/outdoor concentration ratio of around 10.

SFSS Office Building Air Quality

Contaminant	Concentration	Indoor/Outdoor Ratio
Carbon monoxide	4 ppm	<1
Carbon Dioxide	1000 ppm	≃2
Nitrogen Dioxide	30 ppb	<1
Hydrocarbons	2.5 ppm	≃10
Formaldehyde	41 ppb	≃8
Aliphatic Aldehydes	90 ppb	≃8
Particulates	31 $\mu g/m^3$	≃3
Lead	0.2 $\mu g/m^3$	<1
Sulfur (as $SO_4^{=}$)	2.5 $\mu g/m^3$	<1
Airborne Microbes	179 CFM/m^3	-

Figure 3

Our general conclusion to this is that because concentrations are typically higher indoors than outdoors when we do these comparisons and because people spend as much time indoors as they do, if we look at total exposures and look at personal exposure we can make the argument rather safely that the public health problem associated with indoor air quality is at least as important as the public health problem due to outdoor air quality.

Let me move on now to some other general comments that will help set the stage for other speakers and for later things that I will be saying today. Sources and removal processes are the two factors that cause the balance that leads to the concentration of pollutants that we see in buildings. Sources have many different spatial forms. There are point sources like cigarettes or kerosene heaters. There are surface sources like paneling in a room, or the wallboard or the fabric that covers the wall of a typical room, or someone using a paint stripper that contains methylene chloride in the basement. Those are surface sources and their emission rates typically are dependent on the area of the source. Our understanding of these sources varies widely. We understand the nature of combustion sources rather well at one level. We certainly have a very poor understanding of most of the sources of volatile organic compounds that are seen.

The control of the removal processes will be familiar to those of you who have thought very much about this particular problem. Source removal or source substitution is the primary control mechanism. It is not a mechanism that we tend to deal with in the United States. The Europeans tend to be ahead of us in this particular control technique. Eliminating the source clearly is going to eliminate any problem. Source modification is another control strategy, but in the United States we tend to rely rather heavily on concentration control, namely ventilation, as our way of controlling our air quality. Ventilation certainly is a last resort and it is the reference point, but if we want to be clever about controlling air quality, we should think about other removal processes as well.

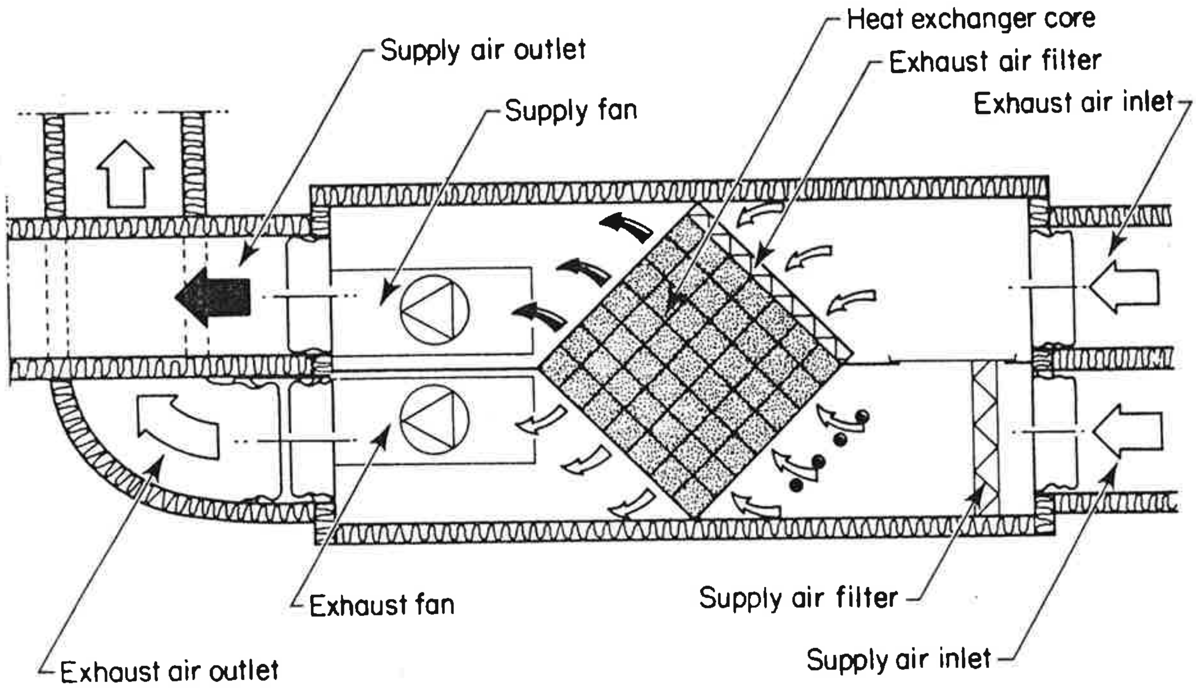


Figure 4

One ventilation system that can be applied with minimal energy costs is an air-to-air heat exchanger as shown in Figure 4. The warm exhaust stream shown in the top right goes through a cross-flow heat exchanger core, loses thermal energy to the incoming cold air (the bottom right), which is then pre-heated and passed into the space. In some situations heat exchangers are very cost effective for residential application. In other situations they tend not to be. One comment I should make about them is that they are only going to be effective (and here we can get into arguments with distributors and manufacturers perhaps) if one puts them into a house that has very low inherent leakage or very low inherent infiltration. They do not change the infiltration of a structure. If I have a house that naturally has an infiltration of one air change an hour (1 ACH) and I add a heat exchanger to the house, my total ventilation rate is going to go up. I will still have that one air change an hour from natural infiltration plus the ventilation caused by the air-to-air heat exchanger. An example of the effectiveness of an air-to-air heat exchanger is given in Figure 5. Measurements were made in nine houses in Rochester, New York, where heat exchangers had been

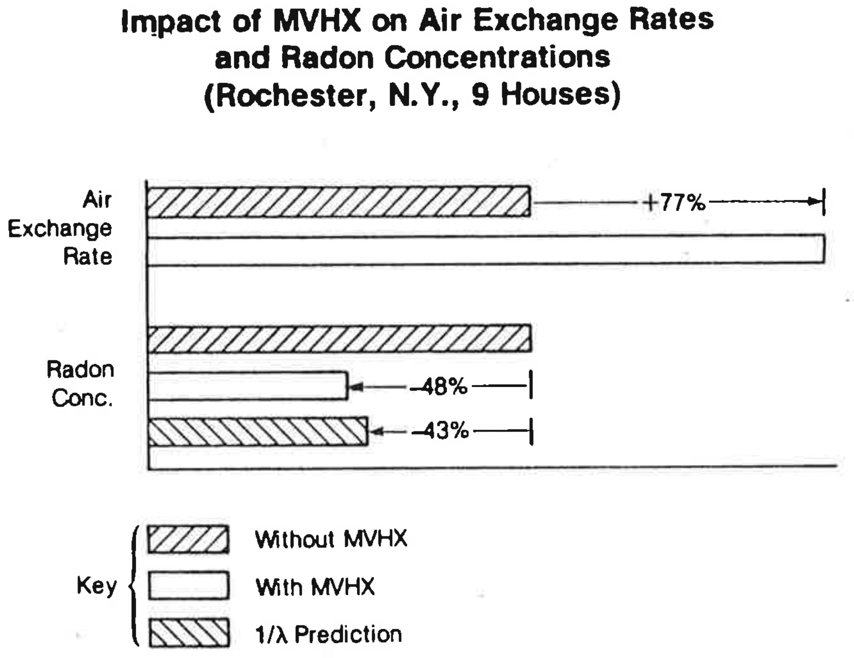
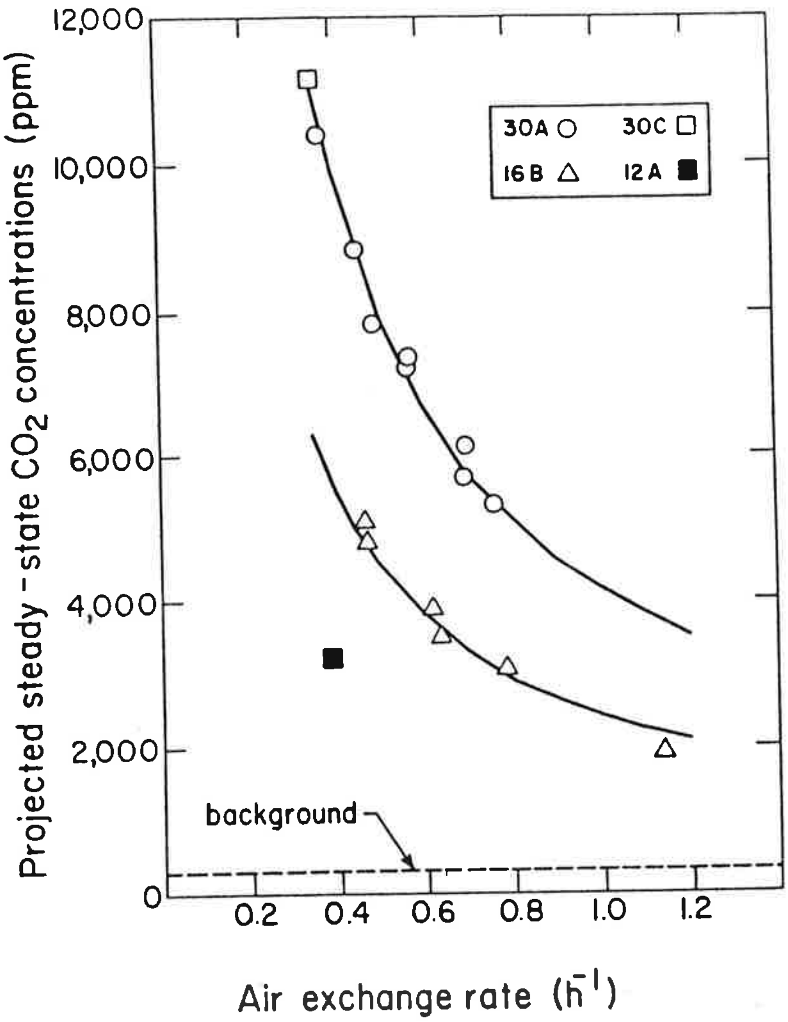


Figure 5

installed. After installation the ventilation rate went up about 80%. The radon concentration dropped roughly 48%. If one would make the prediction that the concentration is the ratio between the source intensity and the ventilation rate, one would predict a 43% reduction. These results agree within statistical uncertainty. The assumption inherent in that kind of calculation is that the source remains constant during that whole process.

The interaction between ventilation and sources is interesting. I would like to show you some field measurement results which illustrate how it works in its best situation and how it probably works more commonly in other situations. These interactions have important implications for standards in particular and for the way we deal with the indoor problem. Typically, in steady state, if we are dealing with a pollutant that has no other removal process, in other words it is not an inherently reactive pollutant, we can make the argument that the concentration we observe is a ratio between an average source strength and a removal rate, which in this case would be a ventilation rate. Figure 6 is an example of a set of measurements where that relationship works very well. These measurements are steady state concentrations of carbon dioxide in a space that is heated with an unvented gas space heater. Here in the Pacific Northwest you probably do not have to deal with unvented combustion heaters very much. Perhaps you have some kerosene space heaters, but gas space heaters are used typically in the lower third of the United States. In sunbelt states there is a need for some adjunct heating during the two month winter and these unvented gas space heaters are often used. The carbon dioxide that comes from the heater is just dumped into the living spaces. The steady state concentrations can be rather high. The figure shows measurements made in a 240 cubic meter house (roughly 1100 square feet of floor area) from two different sizes of unvented gas space heaters. The open circles are a 30,000 BTU heater. The triangles are a 16,000 BTU heater. Measurements were made at different air change rates and are shown on this particular curve running from about 4/10ths of an air change at the first point up

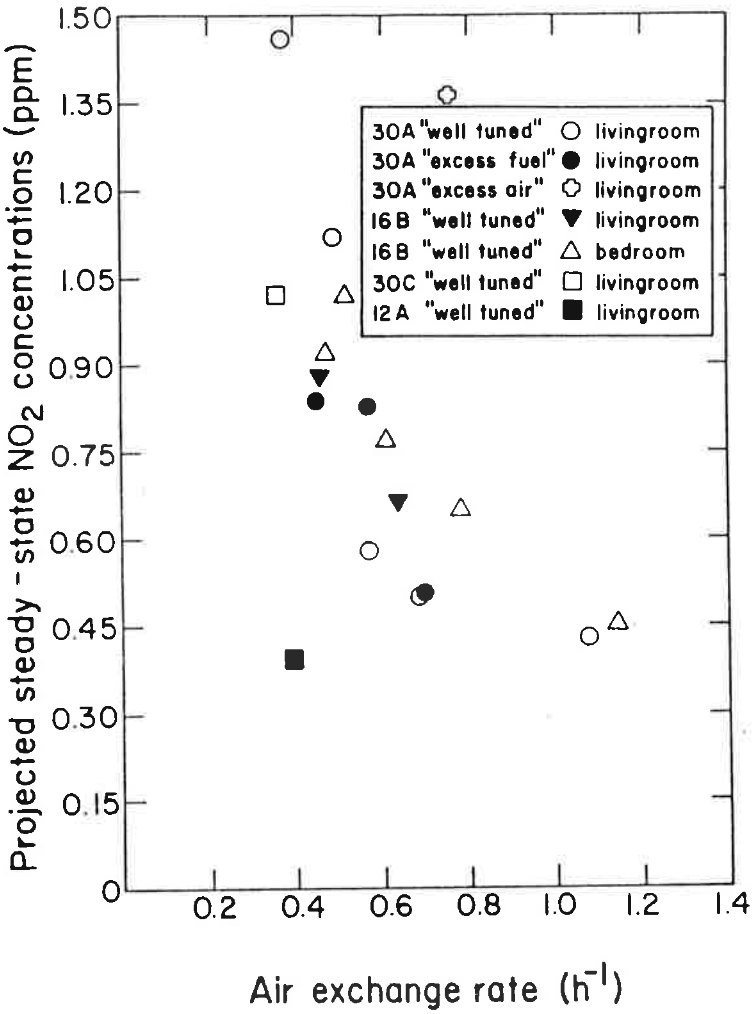


Projected steady-state CO_2 concentrations caused by using unvented gas-fired space heaters versus the house air exchange rate. Tests were conducted in a 240-m^3 unoccupied research house. The solid lines are empirical fits of the data to the reciprocal of the air exchange rate for the 30A/30C and 16B heaters.

Figure 6

to about 1.2 air changes per hour. We see a nice inverse relationship between ventilation rate and steady state concentration. These results come from burns of the order of four to eight hours in the house. This is the way the world should work. Everything is very nice and clean. We have a constant source strength as a result of the chemistry of the combustion of methane to carbon dioxide and water.

If we look at other pollutants we see different kinds of results. In Figure 7 are results of measurements of nitrogen dioxide. The sources are the same sources, but the nitrogen dioxide emission process, in contrast to the carbon dioxide emission process, tends to be quite variable. It depends critically on the temperature of the source and local imperfections in combustion,



Projected steady-state NO_2 concentrations caused by using unvented gas-fired space heaters versus the house air exchange rate. Tests were conducted in a 240-m^3 unoccupied research house.

Figure 7

so that the same kind of 1/ventilation rate concentration dependence in different steady state tests simply does not occur. We see quite variable steady state concentrations. We certainly do not see the relationship between air change rates and concentration that we would expect to see in steady state. If we look at the problem in a different way, we see another set of results. What we were doing in the last two figures was to take the same heater, the same source, and vary the ventilation rate to see whether we can really predict what the concentration is going to be.

Figure 8 shows a different kind of data set. This data set looks at measurements of a particular pollutant, but in different buildings measured as a function of ventilation rate. You can argue that this is a ridiculous figure to show. Clearly the

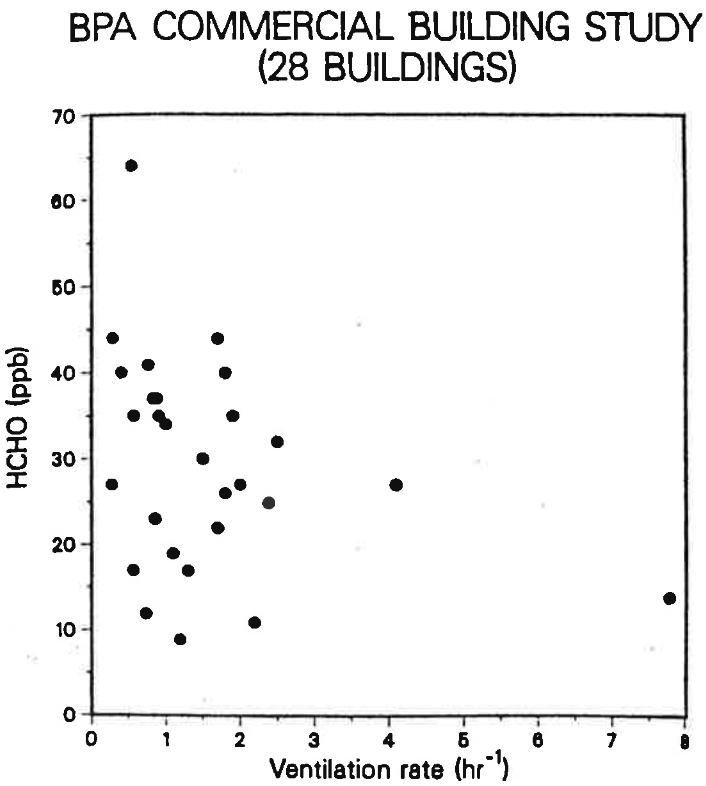


Figure 8

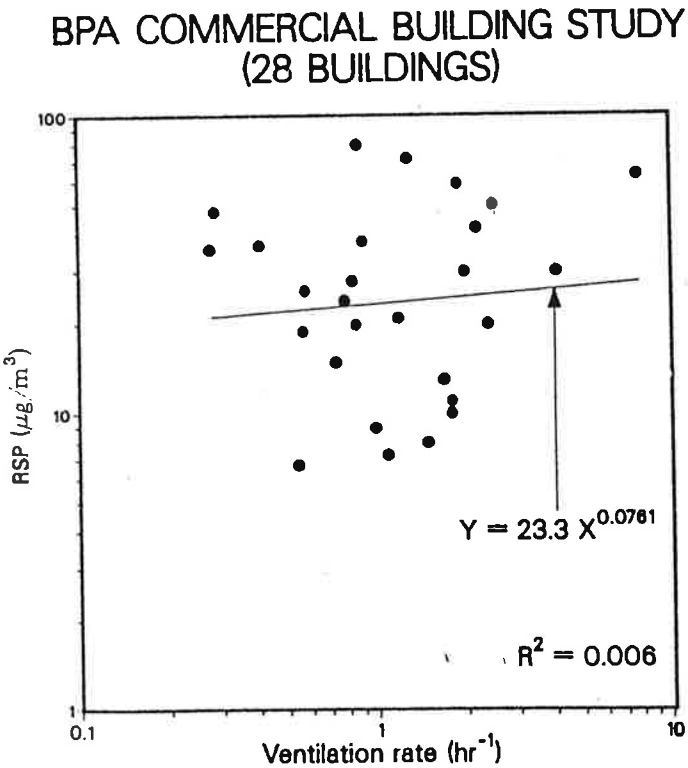


Figure 9

sources are going to be different; we are talking about different buildings. Yet if you think about the assumptions that are made whenever you write a standard that specifies the ventilation rate necessary to have adequate indoor air quality, results such as those shown in the figure are bound to occur. The figure is a set of measurements of formaldehyde concentrations in 28 different commercial buildings in Portland, Eugene, and Spokane. We see a wide variation of concentrations. These averages were taken over a two week period. No measurement is as high as 100 parts per billion (100 ppb) of formaldehyde. Ventilation rates vary from less than 0.5 ACH to a value larger than 7 ACH in one case.

Another set of results, Figure 9, shows concentrations of respirable particles with sizes less than three microns plotted logarithmically as a function of ventilation rate. The respirable particle concentrations in micrograms per cubic meter are shown vertically; ventilation rate is shown horizontally. An inverse relationship between ventilation rate and particle concentration would yield a plot with slope minus one coming down at an negative 45 degree angle. In this case, again, one clearly does not see it. The sources are significantly different as we move from building to building. Another comment to make is that there are concentrations seen here that are above the annual average National Ambient Air Quality Standard for total suspended particles of 75 micrograms per cubic meter.

Measurements of radon concentrations in houses in four different parts of the United States are shown in the next figure (Figure 10). Again, infiltration rate is plotted horizontally on a logarithmic axis; radon concentration is plotted vertically on a logarithmic axis. Again, a complete scatter shot relationship is seen between radon concentration and ventilation rate. Ventilation rate can affect concentrations is a building in a somewhat erratic way, depending on how the source behaves. Still, it is very difficult to look at these results and say there is some ventilation rate that assures indoor air quality. One must also have information about sources.

The house-to-house variation and building-to-building variation is dominated by sources. While ventilation rate is important, pollutant concentration is dominated by sources. This simply

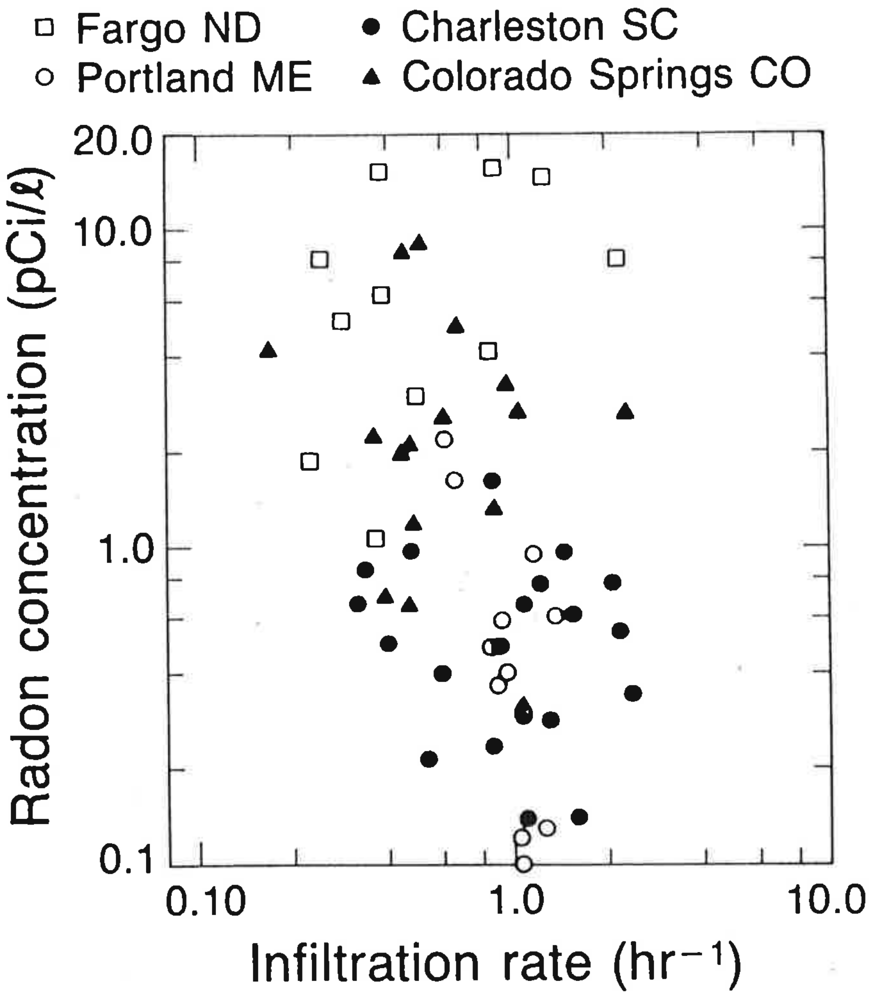


Figure 10

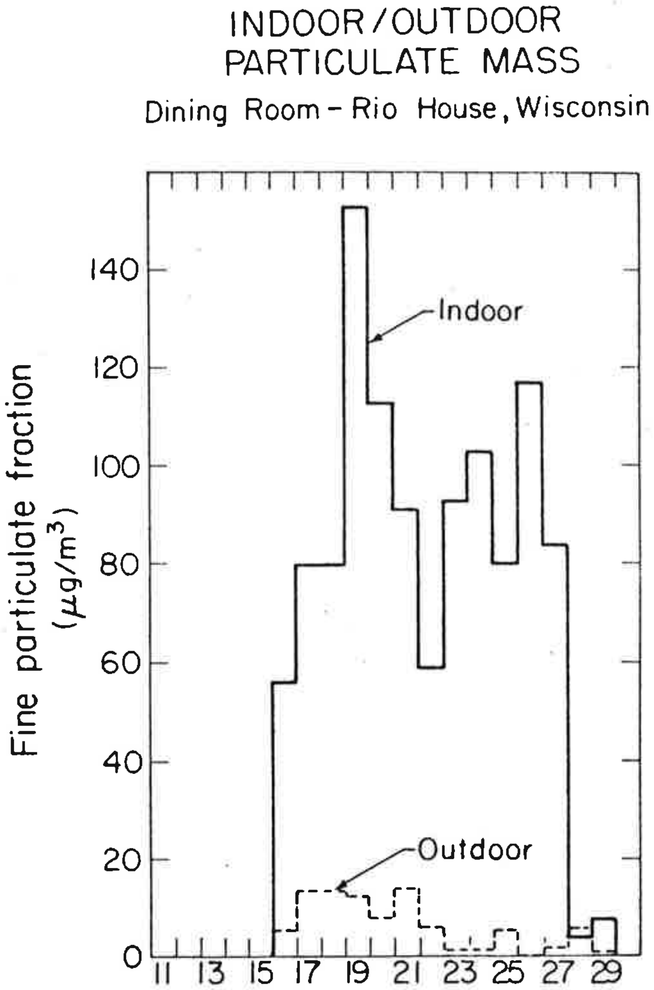
says that minimum ventilation rates to assure air quality have to be set very carefully. One has to make some assumptions about sources to make them rather explicit.

I would like to move now to the issue of current research problems and talk briefly about three different pollutant classes that are not going to be covered later today by the group of experts who are assembled to talk about formaldehyde, radon, particles, and moisture. I would like to talk about tobacco smoke, combustion products from combustion appliances, and finally airborne organic compounds.

In the discussion I will talk about the instrumentation needs, the concentrations that are observed, what sources are, and what the source characteristics are. It will be useful to discuss the health effects as they are currently understood, and finally, to say something about the control of excess concentrations.

Tobacco smoke is a curious indoor pollutant. I think people would agree that tobacco smoke is a very serious health problem to the smoker. That is well researched and people understand those risks very well. The part of the problem I want to talk about is the problem of what I do to you sitting in the audience if I stand in front of you and smoke a cigar or a cigarette. Or the risk you experience if you are sitting in a restaurant and the person at the next table is smoking after they have finished their coffee. What does smoke do to the non-smoker, what kind of things are known, and what is controversial about the issue? There is a fairly good representation of instrumentation to look at products of combustion and particles from cigarette smoke. One need for instrumentation that I would recommend is some kind of an unobtrusive, passive device which would collect the products of combustion from tobacco smoking in a room so that we could measure how much smoking goes on in a space or how many cigarettes are smoked. Concentrations are definitely variable. Figure 11 shows a set of particle measurements. In this case the particles are less than 2-1/2 microns in diameter. This figure shows particle measurements in a home in Wisconsin in which a smoker was present. (For reference the National Ambient Air Quality Standards for total suspended particles is 75 microns per cubic meter.) This is a home in which the smoker is the dominant source. On day 28 in the study, two days before its conclusion, the smoker was shut off. I am not sure how that happened; I was not there at the time. But the concentration of particles dropped to 20 micrograms per cubic meter. Concentrations do depend strongly on the sources in this particular case.

There are two components to tobacco smoke. The source we are talking about here is called sidestream smoke. The mainstream smoke is drawn through the cigarette into the smoker and back out, but the sidestream smoke simply comes from the end of the cigarette. The smoker is a very good filter. You should give people credit for that. Most of the smoke that enters the body stays inside - it does not come back out. So most of the concern about passive smoke comes from the sidestream smoke that comes from the end of the smoldering cigarette, not from the material that is exhaled from the smoker. Health effects are very controversial. Clearly there is an annoyance and an irritation associated with passive smoke. The World Health Organization defines health to be maintenance of well-being, as opposed to avoidance of disease. Under that kind of definition, irritation and annoyance are health problems that have to be dealt with. Perhaps the more important issue, certainly the more controversial issue, is whether there are excess lung cancers among non-smokers from their exposure to sidestream smoke. There have been two major studies, which give conflicting results. A large study in Japan looking at 90,000 persons who were married to smokers and non-smokers, showed a relative risk factor of roughly two when wives of heavy smokers (people who smoked more than 20 cigarettes a day) were compared to wives of non-smokers. A corresponding study in the United States by Garfinkel of 175,000 wives showed no particular difference in cancer rates between non-smoking wives of smoking husbands and non-smoking wives of non-smoking husbands. The reason for using those statistics is simply to show you that there is a significant amount of controversy in this field. In addition, the experimentation, the epidemiological studies, are very difficult to do. One has to control against exposures from other sources of risk if one wants to do the experiment, and that is a very difficult thing to do.



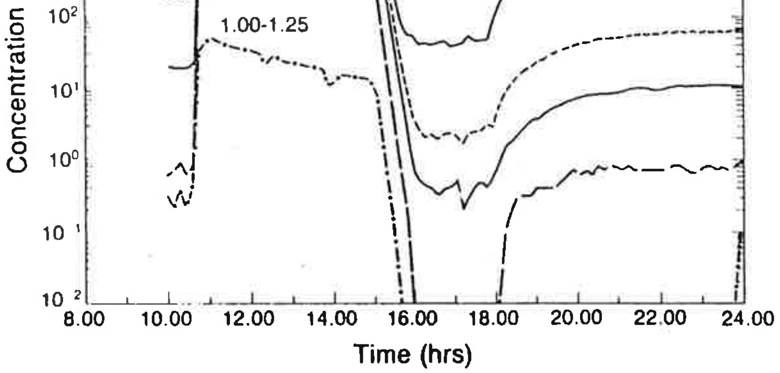
Daily averages of indoor and outdoor fine particle (< 2.5μ) fractions in Wisconsin residence. Smoking permitted from 16 through 27. No smoking on 28 and 29.

Figure 11

There are many kinds of control techniques. One can ban smoking. That is probably an unacceptable thing to do in this country or in any kind of real situation. When Johns Manville began to be faced with their asbestos suits, it quickly became apparent that there was a synergistic effect between asbestos exposure and smoking; so they banned smoking in all their buildings. An incentive program was set up for workers to give up smoking. There were non-smoking areas set up in buildings and finally the smoking was banned from most of their property. That is a very difficult and painful thing to do. Other options are to separate smokers and non-smokers. There is an ordinance in San Francisco that mandates that non-smoker rights to clean air must be observed. This, too, is a difficult thing to enforce, but, nonetheless, there is beginning to be some precedent for particular kinds of actions. I think it would be very nice if we had local task ventilation that we could use so we would have hoods dropped above smokers. My bias is beginning to show and I apologize for that. Still, we know that this technique is an effective control device for gas ranges.

Increasing ventilation is a fourth control alternative, but it tends not to be a very effective control measure. Anytime one has a source that has a buoyancy inherent in it, i.e. a heated pollutant source, mixing of that pollutant through the space is very rapid. Increasing ventilation is an expensive way to control contamination.

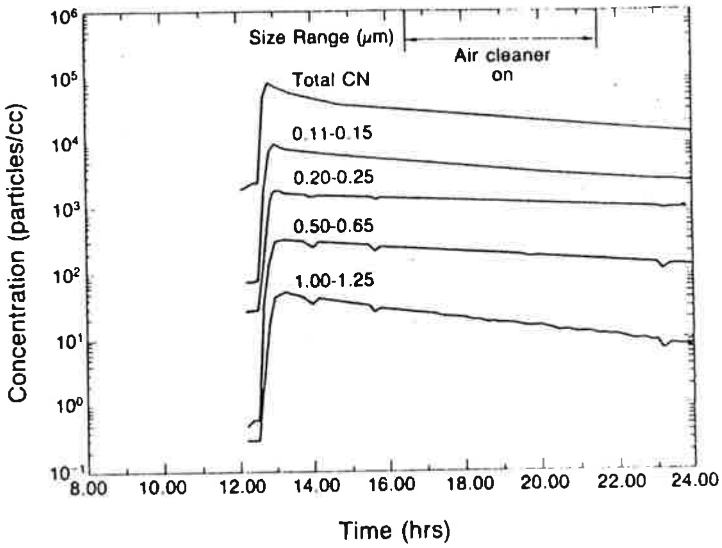
There is another possibility, and that is to use some kind of particle air cleaner. Figure 12 shows measurements of a good set of air cleaners in a research house we operate in the Bay area. A smoking machine was used to artificially increase the number of particles in the space. The air cleaner was turned on and the air cleaner quickly removed roughly 99+ percent of the particles from the space. The device is a HEPA filter, or high efficiency particle air filter. They are large, roughly the size of a stereo speaker and they cost on the order of a couple hundred dollars. There are many other devices around that are more widely sold. They are less expensive. An example of some of these we tested, called panel filters, is shown in Figure 13. They are little table-top devices that have filters in



Semi-log plot of particle concentrations as a function of time for a single-room decay experiment using tobacco smoke and a HEPA-type filter.

Figure 12

them and a small fan. If you are in a room where they are operating you hear a noise and see some dispersion if there is a local pollutant source, like a cigarette, close by. If you look in detail in a laboratory and make measurements of the concentration, however, you see that along the top part of the curve, when the air filter was turned on, virtually nothing happened to the average concentration of particles in the space. You turn it off and you see no response whatever. There may be an amenity associated with them, but it may be just that white noise is pleasant.

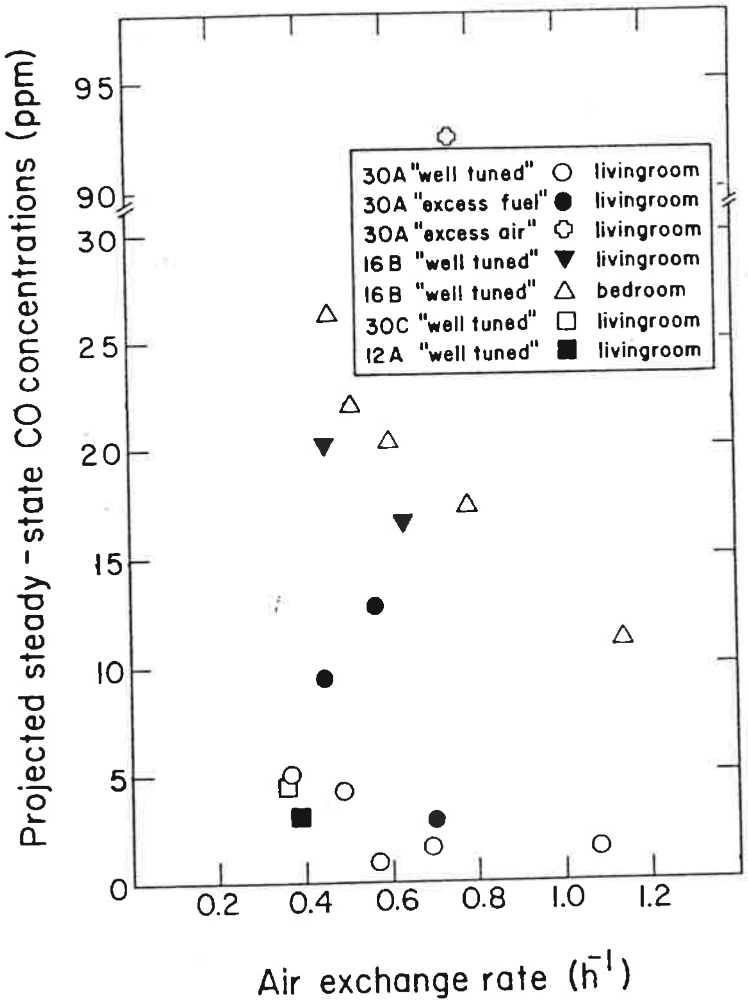


Semi-log plot of particle concentration as a function of time for a single-room decay experiment using tobacco smoke and a small panel-filter air cleaner.

Figure 13

The next thing I would like to talk about are combustion products, i.e. products of combustion from unvented combustion appliances. Again, we will look at instrumentation, concentrations, and sources. We have measured emission rates from these devices in a laboratory setting, and some controlled field tests. If we want to understand population exposures we must have some easy way to measure emission rates from real devices actually in the field. Maintenance is an issue with these devices. Unless there is some inexpensive and quick way to measure emission rates from real devices that are operated in homes, it is difficult to estimate population risks.

Concentrations: Figure 14 shows whole house measurements of carbon monoxide concentrations from an unvented gas space heater operated at steady state. The National Ambient Air Quality Standard (NAAQS) for an eight-hour exposure is nine parts per million (9 ppm). The one-hour exposure limit (NAAQS) is about 35 ppm. Figure 15 presents results of measurements of concentrations of several different pollutants in a small (27 cubic meters) chamber. This is the size of a small room in a house. If one imagines using the strategy to conserve energy that says I will not heat most of my house, rather I will just heat one or two rooms with a kerosene space heater or some other unvented device, the measurements show some risk associated with that. These concentrations should not be projected to whole house concentrations. Carbon dioxide in both cases, goes to roughly 10,000 ppm. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 ppm. The other two



Projected steady-state CO concentrations caused by using unvented gas-fired space heaters versus the house air exchange rate. Tests were conducted in a 240-m^3 unoccupied research house.

Figure 14

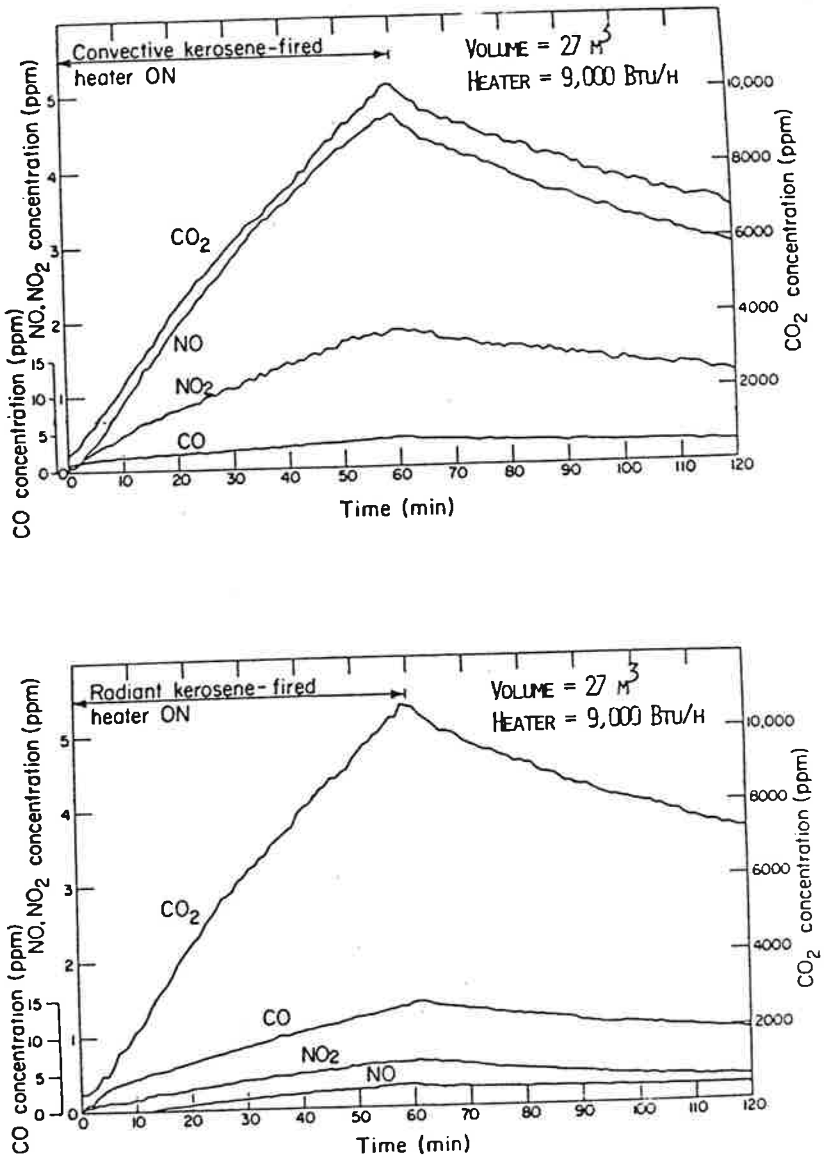


Figure 15

major pollutants in the case of this convective kerosene heater are nitrogen dioxide (NO_2) and carbon monoxide (CO). Nitrogen dioxide reaches a concentration between 1 to 2 ppm after a one-hour burn. The only short-term standard for nitrogen dioxide is California's. It has a limit of 0.25 ppm. Our measurements give concentrations that are a factor of six higher. A radiant kerosene heater has a cooler flame, and therefore does not produce as much nitrogen dioxide, but produces more carbon monoxide because of incomplete combustion. The flame is quenched by the radiant ceramic inserts that are in the flame. In this case the carbon monoxide level gets to about 15 ppm during a burn.

Returning to a curve seen earlier (Figure 6), we see the steady state concentration of carbon dioxide. These are averages for a whole house; levels up to 8,000 ppm at an air change rate of about 6/10ths ACH. Sources tend to be variable in these devices. The source emission rates change with temperature and maintenance. Kerosene heaters have the problem that late in their lifetime they begin to emit soot. We do not understand what process leads to that. Sometimes it is difficult to duplicate but it is a phenomenon that people report from the field. Another major problem involving combustion devices is the issue of malfunctioning appliances. There is some evidence that the number of cracked heat exchangers in gas furnaces is of the order of two to five percent. Nitrogen dioxide concentrations that result from that particular phenomenon can be rather large. Undoubtedly, simple survey techniques that will identify those few percent of problem situations are things that we should be concerned about. Health effects for these sources vary. Typically, the health effect is that which is associated with long-term exposures to low-level concentrations. In most cases we are talking about low concentrations but very long exposures. The studies which will lead to real understanding of those health effects are difficult to do and are only just beginning. We do not have good answers about the health implications of these exposures. In the few cases where concentrations become large, we understand the health effects and they are serious.

One can set up a hierarchy of control techniques for these devices. The first is source removal. Eliminating the source is the best strategy, if at all possible. In some cases it is not possible. There is a warm room project underway in Philadelphia in which kerosene space heaters were used to heat a single room in some low-income apartments. It is not possible to substitute an electric heater for a gas or kerosene heater because the wiring in the building simply cannot supply the added current. Hence, in some situations, source removal is not possible for particular kinds of applications.

Localized ventilation is an effective way to control contamination from these pollutant sources. Range hoods are very effective if they are used. They not only add ventilation to the space, but they effectively reduce the source intensity. By localizing the source, the pollutants do not spread through the house. The final strategy is adding ventilation to the whole house, but, again, that is a poor cousin to localized spot ventilation.

Finally, I would like to go quickly through the last area: airborne organics, not including formaldehyde (although I have one formaldehyde figure). Formaldehyde is the example that is most widely understood of this class of pollutants. If I can speculate now, I would argue that, next to radon, this is probably the area that will cause the most concern in buildings in this country and abroad. The issue we are dealing with is the issue of a large number of pollutants within a space. Figure 16 shows gas chromatographic scan of two air samples. One was taken outside a building and the other taken inside the building at the same time. There must be some indoor sources present if we are to understand or explain this particular scan. Each of the peaks is a different organic compound. There are few seen outside. This building is in the San Francisco Bay area, so it is in a modestly polluted outdoor environment.

The instrumentation needs for this field vary. The concentrations that are seen are very low. In sampling the air one has to concentrate the pollutant and then take it back to analyze it in a laboratory using sophisticated analytical techniques. There are some instruments that are now available to sample air on a real-time basis in buildings. The instrumentation is expensive so the measurements are expensive, but, if it solves a problem, the cost can be justified. The number of pollutants that are emitted from typical products is large. Particle board is commonly associated with formaldehyde and yet, if we look at the other things that are emitted from a typical sample of particle board, we see many different organic compounds present. Many of these are natural products of wood, like the terpenes, for example. Yet, there are many other compounds because particle board is a messy conglomerate of a lot of things. So, many other things are present when particle

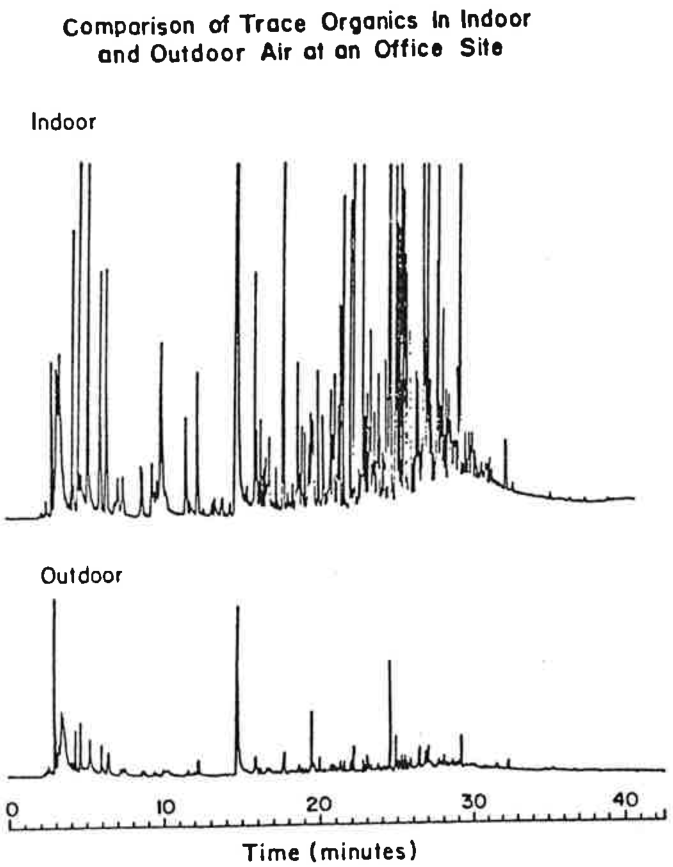


Figure 16

board is used in a typical building.

Many sources emit organic compounds. The list includes building materials, consumer products, furnishings, and cleaning materials. We have a rather poor understanding now of the relationship between source, source use, and organic contaminants that are measured within buildings. The health effects of airborne organics are just beginning to be understood. The number of particular compounds that we are dealing with are very large. The concentrations that are seen in the air are very low. Some of them are carcinogens and mutagens; some of them are simply sensory irritants. Lars Molhave, in Denmark, has looked at compounds from different building materials used in Danish buildings and, in his sample of fifty-two different compounds, roughly 80% were mucous membrane irritants, 25% were suspected carcinogens, and 30% gave off odors that were identifiable. That is just a beginning to our understanding of health effects.

Let me try to summarize this rapid overview simply by saying that this field is relatively new. The number of people who are doing research in the field is still quite small. There are many uncertainties, particularly uncertainties about health effects. We feel we have a good understanding of the health effects from radon; we have modest understanding of some of the effects of other pollutants in the area of organics. Our understanding of the other health effects is quite limited.

Because the research field is concerned with air inside buildings, it has an impact on everyone; for that reason, I strongly urge your continued attention to results that emerge. This is a public health problem of national importance and we do have to pay attention to it.

QUESTION: Do you find any particular relationship between houses with slabs on-grade and the radon problem, compared to houses in general?

ANSWER: We are attempting to unravel that now. We are looking at the impact of different substructure types on radon entry. We have looked in some detail at houses with basements and houses with crawlspaces, but not houses built with slab-on-grade. Certainly in the sample that I mentioned there were houses built with slab-on-grade and some show radon concentrations that are significant. The general issue of radon sources is something that Harvey Sachs will talk about later today. Typically, soils are the dominant source of radon, and pressure-driven flow is the dominant mechanism of radon entry into the building.

QUESTION: Can you tell me in what direction the ASHRAE Ventilation Standard is heading? Are you going to maintain the smoking and non-smoking categories and are you going to keep the similar ventilation rates for residential structures?

ANSWER: In general, the 1981 version of ASHRAE Standard 62 was put together in response to the energy conservation efforts of the late 1970's. I believe there is a general feeling on the committee now that ventilation rates should increase slightly to represent some newer information about occupant comfort within the space. The distinction between smoking and non-smoking will likely be eliminated. The distinction between the two kinds of procedures that are built into Standard 62, a ventilation rate procedure and an indoor air quality procedure, will likely disappear in the new version. Again, that is my personal perspective. Instead there will be a ventilation procedure with some explicit attention paid to sources in the standard. We will see. The ASHRAE Standard, incidentally, is being put together by a committee. It represents kind of a consensus procedure and if any of you are ASHRAE engineers, or will be attending the ASHRAE Chicago meeting in January, we will invite you to come to the committee meeting that is considering the Standard. If you are interested, this is one place to have an impact on the Standard. The meeting is at 8:00 o'clock Sunday morning, January 27th.

I do not anticipate residential rates will change very much. Right now the residential rate in the Standard, if you work it out for a typical house, is 0.4 to 0.5 ACH. There may be a base level of 1/2 ACH, but that is not clear.