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APPLICATION OF AIR CLEANING METHODS FOR THE REMOVAL OF RADON DECAY PRODUCTS

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ABSTRACT

In a series of comprehensive studies, a wide range of air cleaning methods has been evaluated related to their effectiveness in removing radon decay products. Data show that while filtration and electrostatic precipitation were effective in reducing total potential alpha energy concentrations (PAECs), they caused a greater percentage of the radon decay products, subsequently formed, to be unattached. This resulted in a substantial increase in the dose to the bronchial tissues. While enhanced convection removed both the attached and unattached decay products, its overall removal effectiveness was only 50% to 60%. The optimal form of treatment appears to be a combination of enhanced convection and nonuniform space charging. Laboratory studies showed that this combination provides PAEC reductions up to 95%; reductions in the mean dose to the brochial tissues ranged up to 87%. Tests of a portable fan-ion generator in homes yielded PAEC removals from 75% to 90%. Other applications of the fan-ion generator concept include the combination of ion generators with overhead ceiling fans, and with within the wall cavity and between rooms air circulating systems.

INTRODUCTION

One method for minimizing indoor concentrations of radon decay products is to impede the entry of ^{222}Rn into the home. This can be accomplished by removing the source of the radon, diverting the ^{222}Rn before it enters the structure, or placing a barrier between the source and the living space. Although these techniques are readily applicable to new construction, they are not always easy to incorporate into existing housing. For the latter situation, alternative or supplementary approaches are to increase the ventilation rate, or to apply some form of air treatment to remove the radon and/or airborne radon decay products.

EFFECTIVENESS OF AIR CLEANING METHODS

To test the effectiveness of various air cleaning methods for the removal of airborne radon decay products, a series of studies was conducted in a laboratory radon chamber. In later experiments, reported on below, these studies were confirmed, in part, by tests of similar removal systems under realistic conditions in homes. The chamber had a volume of 78 m^3 and a floor area of 22 m^2. To simulate the release of radon from the soil beneath a home, ^{222}Rn was introduced into the chamber through a series of distribution pipes located on the floor. Details of the chamber have been described elsewhere (1). Although the chamber was designed to simulate conditions in a home, no attempt was made to simulate the rapid and erratic transient effects that occur in houses, such as changes in the ventilation or radon intrusion rate with time. To facilitate interpretation of experimental results, all parameters were held constant, although some, such as the aerosol properties, were not easily controlled. Only steady-state data were retained for analysis.

Data obtained in a comparison of the effectiveness of a wide range of air cleaning methods on reductions in the potential alpha energy concentrations are summarized in Figure 1 (2). These studies were similar to those conducted by research workers at the Lawrence Berkeley Laboratory (3), except that the studies reported here were more extensive with regard to the testing of ion generators, and they involved measurements of both the attached and unattached airborne radon decay products as well as estimates of the effects of the various air cleaning methods on the associated dose to the bronchial tissues of the lungs. Each test was conducted at three different room ventilation rates. These rates were controlled by monitoring the rate of air leaving the chamber, and were verified through sulphur hexafluoride tracer measurements. Makeup air infiltrated into the chamber from adjoining laboratories through cracks in the walls, floor and ceiling and from leaks around door jambs and window seals.

Although not shown in Figure 1, the radon concentration was essentially unchanged for all treatment methods. As may be noted from the data presented, the most effective treatment method, based on reductions in potential alpha energy

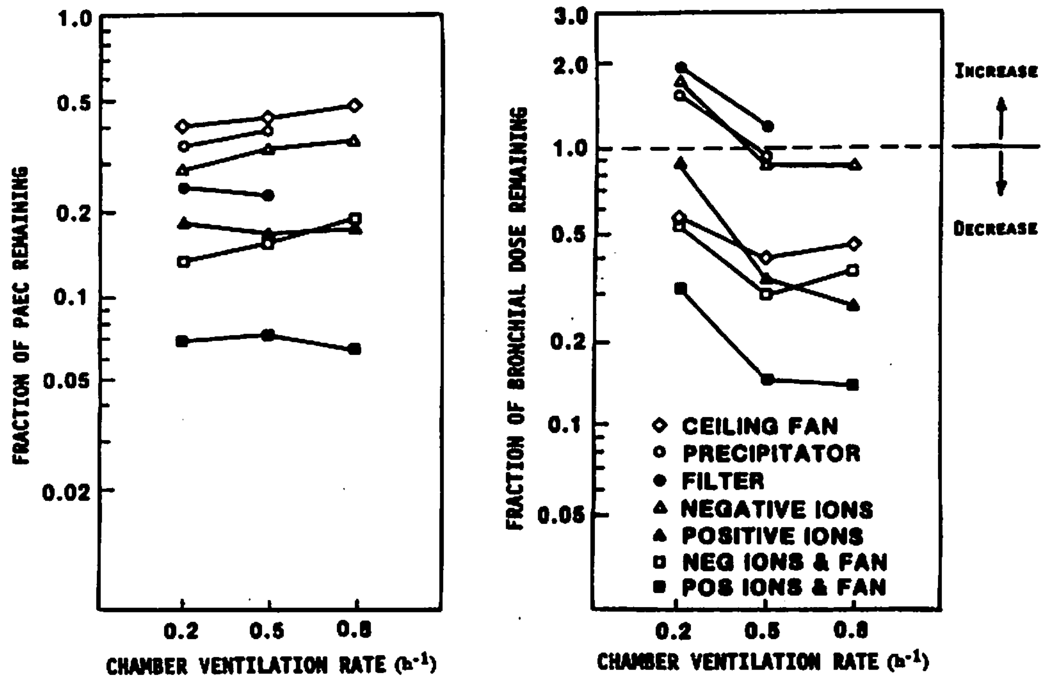

Figure 1. Fractions of PAECs and bronchial doses remaining after application of various air treatment methods.

concentrations (PAECs), was a positive ion generator and ceiling fan combination, the least effective method was a ceiling fan alone, and a positive ion generator was always more effective than a negative ion generator.

In terms of explaining the mechanisms by which these various techniques remove radon decay products, it should be noted that the highly diffusive nature of the smaller airborne particles, and particularly the radon decay products that are in what is called the unattached state, favors removal by deposition onto surfaces by molecular diffusion. The turbulent flow created by a fan facilitates such deposition by reducing the boundary layer thickness at the surface to air interfaces throughout a room and thus reduces the distance that decay products must travel by molecular diffusion before depositing onto room surfaces. The net result is a higher flux of decay products plating onto the walls of a room and a corresponding reduction in their airborne concentrations. Enhanced surface deposition caused by turbulent convection becomes progressively less effective as particle size increases and is relatively unimportant for particle sizes greater than 0.1 micrometer.

In terms of the removals effected by ion generation, mutual repulsion of unipolar air ions in the vicinity of a strong point source of the same polarity creates a spatially nonuniform distribution of airborne charge and an electric field gradient directed radially from the source. Simultaneously, by the process of diffusion charging, decay product atoms, as well as airborne particles to which the decay products are attached, become charged to the polarity of the ion generator. The force exerted by the electric field on these charged particles causes their migration towards the boundaries of the air space, and this results in their deposition onto surfaces and their removal from the air. The greater reductions in PAECs with the positive ion generator are thought to be due to the fact that, following their formation, ^{218}Po and ^{214}Pb atoms initially possess a positive charge. These positively charged atoms migrate more rapidly to surfaces in the presence of a positive nonuniform space charge than in a negative space charge. For a negative space charge to be effective, the decay product atoms must first be made negative by diffusion charging. Air ionization proved effective in reducing the concentrations of both the unattached and attached airborne radon decay products.

Although the reduction in PAEC is informative in terms of the effectiveness of an air cleaning method, the primary consideration is the reduction of the dose to the bronchial tissues of the lungs. Estimates of the bronchial dose that would be produced by the airborne radon decay products after the application of the various methods of air treatment, expressed as a percentage of the dose estimates prior to treatment, are also shown in Figure 1 (2). Calculations of the dose to the bronchial tissues were made using the dosimetry model of Harley and Pasternack (4) as modified by James (5) for application to an indoor environment with a typical aerosol concentration and size distribution.

As may be noted, application of a high-efficiency filter yielded up to a doubling in estimates of the bronchial dose. The reason for this is that high-efficiency filtration removes the dust particles from the air while, at the same time, the radon gas remains. Under these circumstances, the radon decay products, subsequently formed in such an atmosphere (through the continuing decay of the radon gas) have far fewer dust particles to which to attach. More decay products therefore remain in the unattached state. Since, atom for atom, an unattached radon decay product produces 30 to 40 times the dose to the lungs as does the same atom attached to a dust particle (6), the net result is an increase in the dose to the lungs of people breathing the treated air. For purposes of estimating the doses to the bronchial tissues, the unattached fraction of the airborne radon decay products was separately measured, using a diffusion battery (2).

COMBINATIONS OF AIR TREATMENT METHODS

To determine if there would be advantages to combining several air treatment methods into one system, tests were conducted using a combination of a ceiling fan plus a negative ion generator, and a ceiling fan plus a positive ion generator. As may be noted from Figures 1 and 2, the most effective treatment method proved to be a combination of a positive ion generator and a ceiling fan. Such a system provided reductions in PAECs up to 95% and in estimates of the bronchial dose ranging from 68% to 87%. In addition, there was an unexpected benefit of this approach. This was the fact that the combination proved to be synergistic, that is to say, the removal effectiveness of the two methods in combination was better than the sum of the two applied independently (7). This synergism is thought to result from the the ceiling fan blowing the ions towards the floor and walls, thereby reducing ion loss through immediate deposition onto the nearby ceiling. The addition of turbulent convection by the ceiling fan also improves room air mixing. This, in turn, allows the radon decay products and particles to which they attach to become more rapidly charged. As previously noted, the fan also facilitates molecular diffusion to the room walls by reducing the thickness of the air boundary layer.

TESTS OF PORTABLE UNIT

On the basis of the laboratory experiments, a small portable hassock fan-ion generator unit was developed so that the feasibility of the techniques developed could be evaluated in homes under more realistic conditions (8).

LABORATORY EVALUATIONS

Initial evaluations of the portable unit were conducted in the laboratory radon chamber, previously described. For purposes of the studies, the fan-ion generator unit was placed on the floor near the center of the chamber. Measurements of the PAECs of radon decay products were made using a continuous Working Level monitor (portable radiation monitor, Model AB-5, with alpha detection assembly, Model AEP-47) manufactured by the Pylon Electronic Development Company, Ltd., Ottawa, Canada. The resulting data were analyzed using a computer software package (SP-55-01) provided by the same company.

The test sequence was as follows. Measurements were made over a 24-hour period of the background (or baseline) PAECs in the chamber (without treatment), followed by a similar 24-hour series of measurements with the fan-ion generator removal unit in operation. This alternating sequence was performed over a period of seven days. For each sequence of measurements, hourly readings were recorded.

Shown in Figure 2 is a graph of the hourly PAECs for each of the seven days. The test sequence included operation of the fan in the radon removal unit at three different speeds. These correspond to air flow rates of about 0.05, 0.1 and 0.2 m^3/s. On day #2 the fan was operated at the slowest speed; on day #4 it was operated at an intermediate speed; and on day #6 it was operated at the fastest speed. Fluctuations in the PAECs during the first day of the studies were due to problems with the radon generator. Nonetheless, the graph shows that the portable fan-ion generator unit provided a significant and rapid reduction in the PAECs within the chamber. Although approximately six to eight hours were required to reach steady state conditions, a major share of the reduction in PAEC occurred within the first three to four hours after the removal unit was turned on.

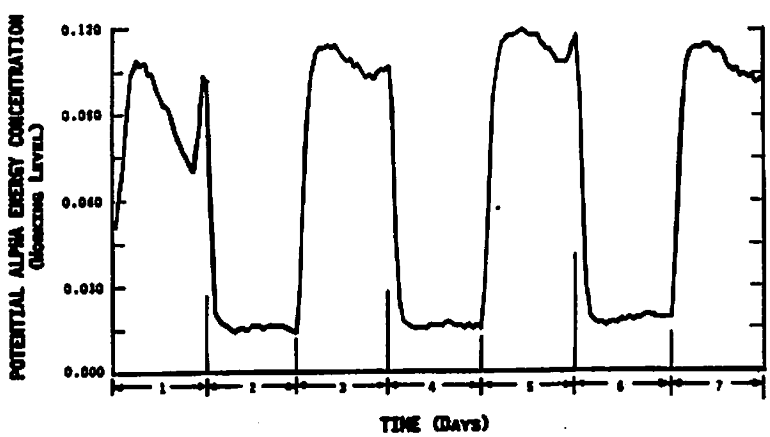

Figure 2. Seven day study of reductions in PAECs provided by hassock fan-ion generator in the laboratory radon chamber. Fan unit was operated on alternate days.

In order to estimate the removal efficiency of the fan-ion generator unit, the average of the last 18 hours within each 24-hour testing period was used. The reason for selecting this time period was to assure that the data being compared represented steady state conditions. On the basis of this approach, calculations show that the effectiveness of the removal unit during these tests, in terms of reductions in the PAEC, ranged from 83% to 86%. As may be noted, the speed of the fan appeared to have no significant effect on the efficiency of the removal unit.

In another series of studies, evaluations were made of the removal effectiveness of the hassock fan-ion generator depending on its position within the radon chamber. Placement of the fan-ion generator unit in the middle of the chamber resulted in an 83% reduction in the PAEC; mounting the unit at the center of the ceiling of the chamber resulted in a 79% reduction in the PAEC; placing the unit on the floor next to the middle of one of the walls of the chamber resulted in a 74% removal; and placing the unit in the corner of the chamber produced a 45% reduction in the PAEC.

FIELD EVALUATIONS

Field studies of the fan-ion generator unit were conducted in a home in Massachusetts having what was considered to be relatively low concentrations of radon, and in a home in Connecticut considered to have relatively high concentrations of radon.

Massachusetts Studies

The studies in the home in Massachusetts were conducted in a finished recreation room located in the basement. The room contained a sofa and chairs, a rug and a fireplace. The room was located in one corner of the basement and had a volume of about 37 m^3 and a floor area of 18 m^2. The room was connected by two doorways to the remainder of the basement. The doors to the recreation room, as well as all windows and doors to the basement, itself, were kept closed during the tests. The remainder of the basement had a volume of about 128 m^3 and a floor area of about 54 m^2.

The sequence of the tests conducted included an initial day (24 hours) of baseline measurements; a second 24-hour sequence with the radon decay product removal unit operating with the fan set at the highest speed; a third 24-hour period with the fan operating at the slowest speed; followed by a final 24-hour period during which baseline measurements were made with the removal unit turned off. The radon removal unit was located on the floor in the center of the room. The PAEC monitor was located about 1 m above the floor, about 1.5 m from the removal unit, and about 1.5 m from the wall.

Shown in Figure 3 is a graph of the hourly PAECs on each of the four days covered in these tests. As may be noted, the PAECs show an increasing pattern during the first and fourth days. This was thought to be due, in part, to changing weather patterns. Shortly after the studies began, a period of rather heavy rain was experienced. Analyses of the data show that the average PAEC of radon decay products for the final 18 hours of the initial 24-hour period (Day 1), during which baseline measurements were being made was 0.0054 Working Levels (WL). The average concentration during the final 18 hours of the next 24-hour period (Day 2) during which the removal unit was being operated with the fan set at the fastest fan speed was 0.0013 WL. Comparing these two readings, the overall efficiency of the removal unit was 76%.

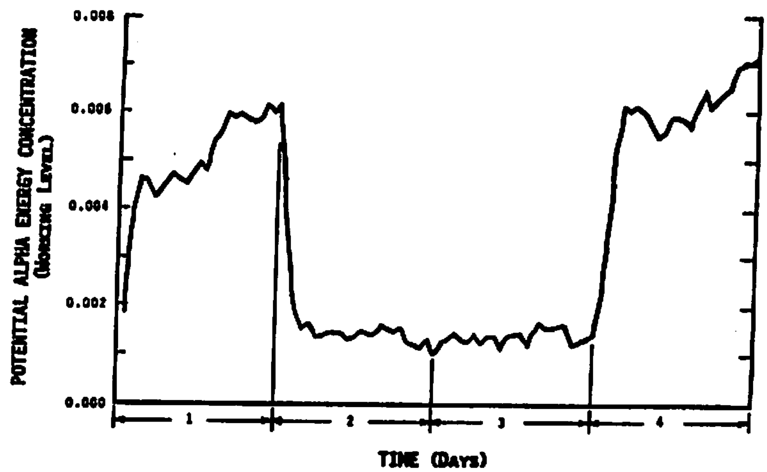

Figure 3. Reductions in PAECs provided by hassock fan-ion generator in basement room in home in Massachusetts. Fan was operated on Days 2 and 3.

During the final 18 hours of Day 3, while the fan-ion generator unit was being operated with the fan set at the slowest speed, the average PAEC of airborne radon decay products was also 0.0013 WL. During the final 18 hours of Day 4, after the removal unit had been turned off, the average baseline PAEC in the room was 0.0062 WL. Comparison of these two numbers shows an overall removal efficiency of 79%. As in the case of the laboratory tests, the speed of the fan appears to have had essentially no effect on the removal efficiency of the fan-ion generator unit.

Connecticut Studies

The home in Connecticut in which studies were conducted was built into the side of a hill with the back, sides, and top being essentially covered with earth. The tests described in this report were conducted in a bedroom located within the house with the fan-ion generator unit being located on the floor in the middle of the room. Except for the door through which entrance was gained, the room had no other openings. The room had a volume of approximately 26 m^3 and a floor area of 11 m^2.

During the studies, which covered a time span of three days, measurements were made simultaneously of the PAECs and the radon concentrations in the room using a second portable radiation monitor (Pylon Model AB-5 with an LAC-300 scintillation assembly). For purposes of these measurements, which were made with and without the fan-ion generator unit in operation, the PAEC and the radon monitors were located about 1 m above the floor, about 1.5 m from the removal unit, and about 1.5 m from the wall. Although it was realized that simultaneous measurements of the radon concentrations and the PAECs would have been useful in the laboratory studies and in the field studies in the home in Massachusetts, the radon monitor was not available at the times these latter studies were being conducted.

Shown in Figure 4 (a) is a graph of the hourly radon concentrations (pCi/L) within the room. Shown in Figure 4 (b) is a graph of the hourly PAECs as observed over the same period of time. As may be noted, the radon concentrations were quite variable over the 3-day period. Again, this was thought to be due, in part, to changing weather patterns. Because data on the radon concentrations were available, however, it was possible to estimate the PAECs that would have been present during the second day had the removal unit not been in operation. This was accomplished by multiplying the average PAEC during Day 1 by the ratio of the average radon concentration on Day 2 to that on Day 1. The estimated value was 0.038 WL. Since the average PAEC measured on Day 2 with the removal unit in operation was 0.005 WL, the removal efficiency was estimated to be 87%. Again, for purposes of this calculation, comparison was made of the PAECs with and without treatment during the last 18 hours of each 24-hour period.

OTHER APPLICATIONS OF THE FAN-ION GENERATOR CONCEPT

In a subsequent series of studies, other applications of the fan-ion generator concept have been developed and tested within the laboratory. One of these (Figure 5) included the development of a "screw-in" type positive ion generator that could be inserted into one of the light socket outlets within an overhead type ceiling fan. Tests of this system, within the radon chamber, provided the highest PAEC reductions that have been observed to date. Removals approaching 95% were routinely attained within the 78 m^3 chamber.

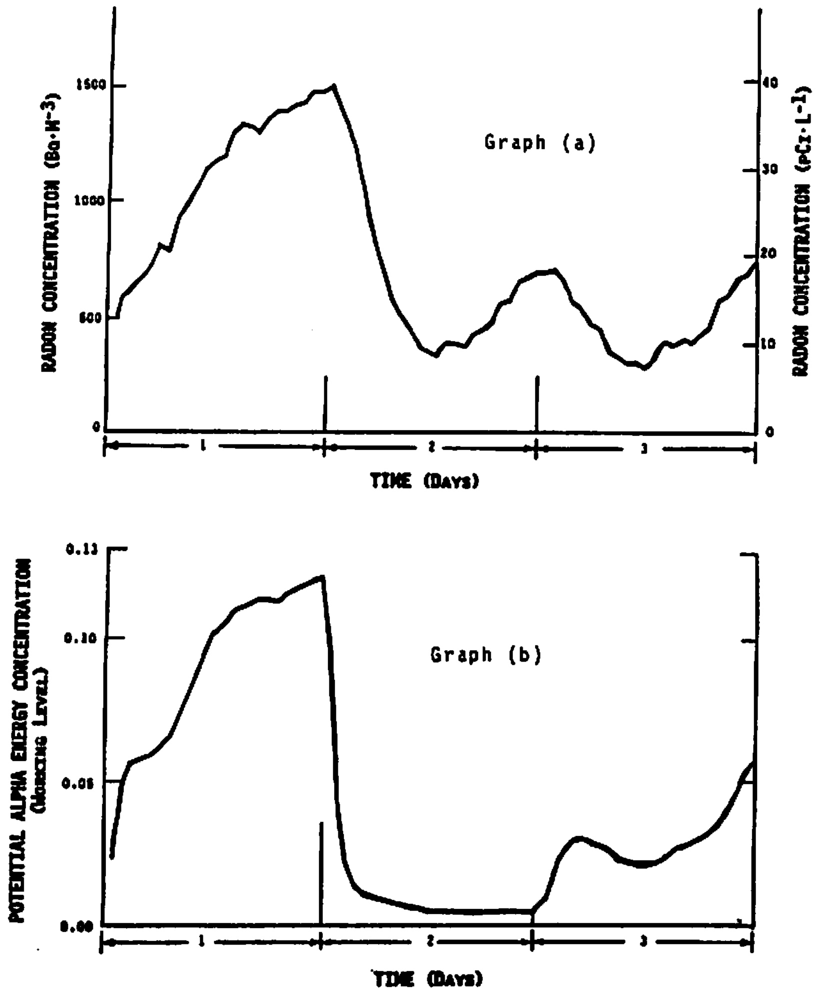

Figure 4. Reductions in PAECs provided by hassock fan-ion generator in home in Connecticut. Graph (a) shows radon concentrations over a three day period; graph (b) shows the hourly PAECs over the same three day period. The removal unit was in operation during the second day.

In another application, a temporary wall was installed in the radon chamber so that it represented two rooms within a home. In an initial series of tests, an inlet grill was installed near the floor and an outlet grill near the ceiling within this wall (Figure 6). A small (approximately 0.05 m^3/s) fan was installed within the wall, using the space between the studs as a flow path, and a positive ion generator was installed in the outlet grill. Operation of this system provided removals in the range of 80% to 85%. One interesting observation in these studies was that the fan must be of a size sufficient to move the air within the room; otherwise the system will not be effective.

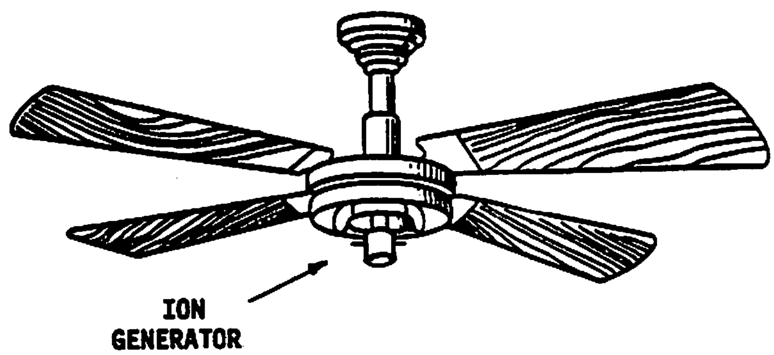

Figure 5. Overhead ceiling fan with "screw-in" ion generator in place.

In another application of the fan-ion generator approach, two independent openings were cut through the wall, each serving as a connection between the two halves of the chamber (Figure 6). Inlet and outlet grills were installed in each with a fan between the grills. Two positive ion generators were installed in the outlet grills of each set of openings, and the air flow in the two systems was directed in oppositive directions so as to maintain an air balance between the two halves of the chamber. Again, tests showed that the PAEC reductions in the two halves of the chamber were in the 80% to 85% range.

DISCUSSION AND CONCLUSIONS

The data reported in this paper show that a fan-ion generator combination is effective in reducing the airborne concentrations of radon decay products (PAECs) in the home. These data have been independently supported by scientists in Canada (9), Denmark (10), and Finland (11). The fan ion-generator combination also provides comparable reductions in estimates of the accompanying doses to the lungs of people breathing the treated air. Such a system, which is simple and relatively inexpensive, can be applied in a variety of ways. These include incorporation of ion generators into a hassock fan, the addition of a "screw-in" type ion generator to an overhead Casablanca type ceiling fan, and use of within and

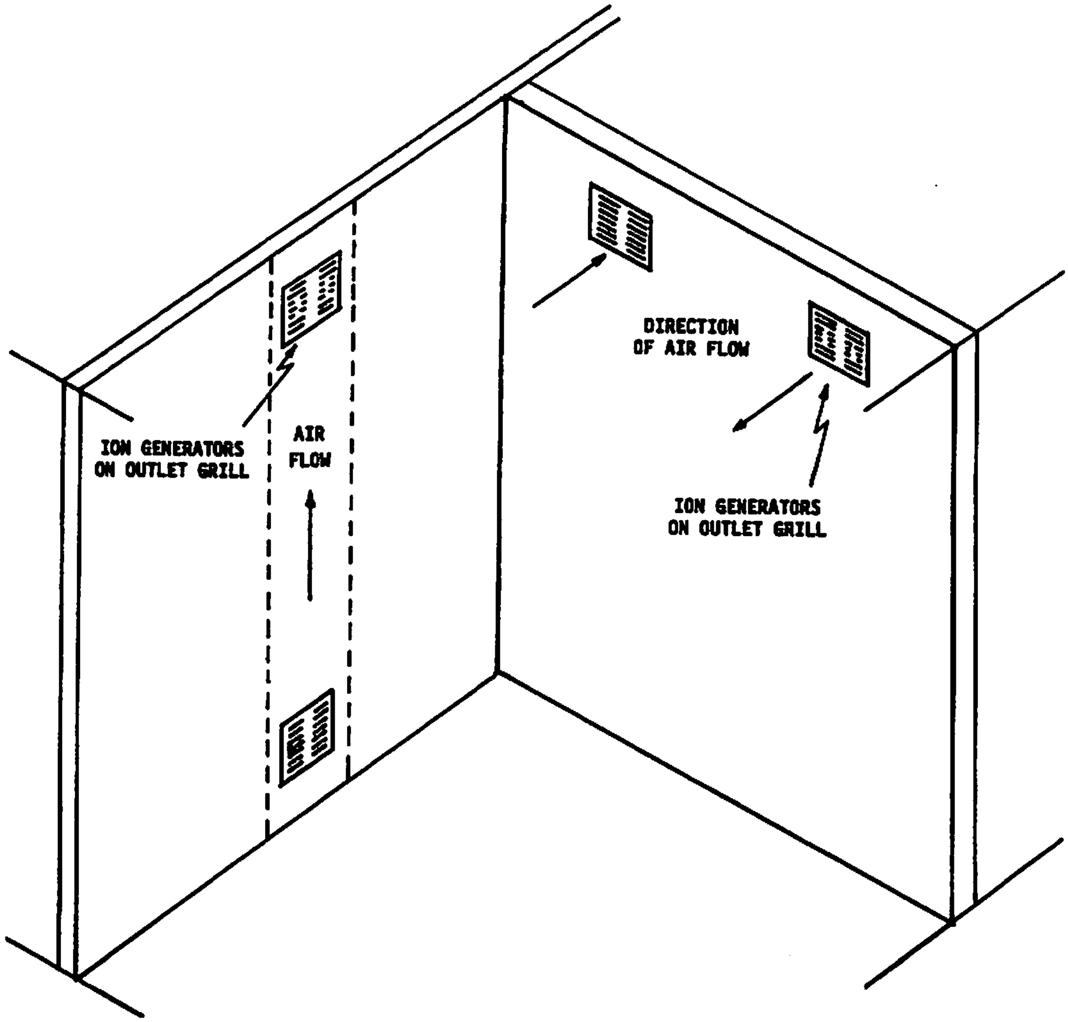

Figure 6. Application of fan-ion generator concept as a within-the-wall unit (left hand illustration) and as between rooms units (right hand illustration).

Note: Both types of units would not normally be installed in a single room.

through wall systems that include a fan with positive ion generators at the outlet grill. Although one might also ask whether installation of positive ion generators in a normal home air heating or cooling system might accomplish the same results, unfortunately this has not proven the case. The metal ductwork, common to all such systems, appears to serve as an electrical ground and negates the benefits of the ions being generated. The hassock fan and the grills used in the systems described in this paper were all constructed of plastic.

Although there are many benefits to the approaches described in this paper, one of the most important is that a fan-ion generator system will remove the airborne radon decay products, regardless of their source and, with routine maintenance, should provide effective removal of the decay products for many years. For homes with modest radon concentrations, where PAEC reductions in the range of 50% would provide adequate removals, installation of a system that provides circulation of the air within the home may be all that is necessary. For homes or buildings with somewhat higher radon concentrations, where removals in the range of 70% - 90% will be adequate, one of the fan-ion generator systems described here may be all that is necessary. For homes with relatively high radon concentrations, some other form of mitigation will undoubtedly be required. Even in these cases, however, some form of air cleaning system may be desirable as an adjunct to the other remedial measures. Even where a supplementary air cleaning system is not necessary from a legal or technical point of view, the presence of such a system can provide added comfort and peace of mind to the homeowner.

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