ORNL-TM-4318

23,226

HOME VENTILATION RATES: A LITERATURE SURVEY

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OAK RIDGE NATIONAL LABORATORY

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SEPTEMBER 1973

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T. H. Handley and C. J. Barton

ABSTRACT

A survey was made of published ventilation rates because this parameter has an important effect on doses to home occupants from airborne radionuclides. The survey was devoted primarily to information on ventilation of single housing units located in the United States including techniques used to measure the ventilation rate. Helium was found to be the most commonly used tracer gas. The available data suggest that the average annual ventilation rate of most occupied houses falls in the range 0.5 to 1.5 air changes per hour. We recommend that this range be adopted for calculations of doses resulting from home exposure to airborne radionuclides. Inclusion of apartments in modern high-rise buildings would raise the recommended upper limit to 2.0 air changes per hour if all ventilation air is from outside the building.

INTRODUCTION

Natural gas from wells stimulated by nuclear devices contains small amounts of ^{3}H (tritium) and ^{85}Kr.[1] Potential doses from tritium introduced hypothetically into the home with the natural gas have been calculated.[1-3] Since the annual doses usually calculated are a function of average air exchange rate, it is necessary to establish an annual average rate for homes under practical living conditions. Air exchange rate is defined as the hourly volumetric rate at which air enters (or leaves) the residence divided by the volume of the residence.[4] In calculating potential yearly doses, we assumed that air in homes exchanged once every hour, but the validity of this assumption has been questioned.[1-3] In a study of doses in homes from radon in natural gas, we consider a range of exchange rates from 0.25 to 2.0 per hour.[5]

This literature survey was performed to determine whether data exists to justify a change in the rate presently used and to collect information on measurement methods.

Air is exchanged in residences either by natural infiltration or by ventilation. Natural infiltration results chiefly from leakage through cracks and interstices around doors and windows that normally is not controlled by residence occupants. Ventilation comprises the controlled displacement of air in the residence by either natural or mechanical means. Some of the variables affecting air exchange rate are inside-outside temperature differential, wind speed and direction, quality of residence construction and its design, topographical setting, and occupant activities.

MEASUREMENT OF EXCHANGE RATE

If the exchange rate is constant, the concentration of a tracer gas will decrease exponentially as indicated by the following equation:[6]

$$C = C_o e^{-It}$$

where

C = concentration at time t,

C_o = concentration at t = 0,

t = time in hours,

I = air exchange rate per hour.

Various tracer gases, such as helium,[4,10,11,18,19,21,27] ethane,[6] sulfur hexafluoride,[8] and inert radioactive gases,[9,14,17] have been used to measure rates. Recently, sulfur hexafluoride has been the preferred tracer gas because of the high sensitivity of detection of this nontoxic gas.[8] In published work, helium is by far the most common tracer used. This choice probably resulted, at least in part, from development of a portable helium meter by the National Bureau of Standards.[7] Helium is cheap, available, and nontoxic; however, the use of helium has been questioned, since it has a higher diffusion rate than air.[10] One test was reported that compared exchange rates obtained with helium and ethane.[21] Ethane has, for all practical purposes, the same density and diffusion rate as air. It was concluded that essentially the same rate was obtained with helium and ethane. The investigator stated that he was satisfied the rates obtained using helium were indicative of the actual air exchange rate and that no appreciable error was introduced by the use of helium. Other investigators have concluded that part of the exchange rate observed with no wind blowing and with no temperature differential, ranging from 0.05 to 0.19 per hour, may be due to the higher diffusion rate of helium as compared to air.[11] Helium does not stratify during determination of air exchange rates.[10]

SUMMARIES OF IMPORTANT INVESTIGATIONS

Elkins and Wensman[6]

Most measurements of air exchange rates of residences reported in the literature were not performed under practical living conditions. Elkins and Wensman measured air exchange rates in two identical modern residences in Canton, Ohio, occupied by families whose activities were not affected by the tests. One house is gas heated, while the other is all electric. All significant variables were monitored, including weather conditions and occupant activities, such as door openings and appliance operation. Ethane tracer gas was used to measure the exchange rates. Tests were conducted during a period of approximately 10 months. The air exchange rate varied by a factor of about 3 from one day to the next. Observed exchange rates varied from 0.24 to 0.83 for the gas-fueled house, while the range was 0.13 to 0.42 for the all-electric house. Based on local weather data and American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) calculation methods,[13] the estimated average rate for the gas-fueled house during a heating season was calculated to be 0.9 air exchange per hour.[12] This value was more or less confirmed by the fact than an exchange rate of 1.0 per hour was required for the ASHRAE[13] calculation of the heat loss for the gas-heated house to be consistent with the measured heat losses over that period. Estimations of the average annual exchange rate for the two houses tested were made by assuming they were located in other cities with different annual average temperatures and wind speeds.[12] The investigator emphasized that these estimates are valid only for the test houses and are no better than the statistical limitations of the data. However, the estimates are internally consistent and reflect the difference in rates due to geographic location. Estimated rates for three of the cities are Chattanooga, 0.50; Spokane, 0.67; and Boston, 1.06 air exchanges per hour.[12]

Coblentz and Achenbach[4]

These investigators made field measurements in ten representative electrically heated houses in Indiana. The houses were described as one- and two-story brick and frame houses, built over basements, crawl spaces, or concrete slabs on the ground. Five of the houses were practically new, while the ages of the others ranged from 20 to 46 years. The houses were unoccupied and outside openings were closed during the tests. Consequently, the measurements do not reflect a practical living situation. Two to four tests were made on each house over a 2-day period. The observed rates, adjusted to the design weather conditions, ranged from 0.54 to 1.45 air changes per hour. These values were in agreement with computed values based on the air change method described in the ASHRAE Guide[13] which ranged from 0.6 to 1.5.

Jordan, Erickson, and Leonard[19]

An especially well-controlled and detailed study of air infiltration rates in two well-built research houses was reported by Jordan, Erickson, and Leonard. Heat was supplied by electricity, and heat contributed by a family and appliances was simulated by electrical heaters. Outer openings were kept closed during the measurements. The investigators concluded that, from a practical standpoint, the air infiltration rate can be taken as 0.33 per hour under almost all weather conditions for houses as well built as these and under conditions of no occupancy. However, during operation of appliances, the investigators reported an increase to values as high or higher than 1.5 air changes per hour. The investigators concluded that, within limitations of the tests, for tightly constructed and electrically heated houses, an air change rate of 0.75 per hour could be "safely" assumed for design purposes.

Bahnfleth, Mosley, and Harris[10]

Infiltration rates in two special research houses were measured and variables affecting infiltration were studied.[20] House 1 was a two-story structure with brick veneer and a basement, heated by a hot-water system; house 2 was a one-story frame building with full basement and a gas-fueled forced warm-air furnace. All outside doors and windows were closed during the tests. House 1 was occupied by 2 to 5 people, while house 2 was unoccupied. Measurements were made during an 8-month period. The observed infiltration for house 1 varied from 0.16 to 0.43 air change per hour, while house 2 ranged from 0.26 to 0.80 air change per hour. During discussions of an oral presentation of results of these studies at an ASHRAE[26] meeting, one of the investigators stated that tests on two additional houses resulted in infiltration rates of 1.5 to 3.0 changes per hour. The higher ventilation rates observed in these houses were attributed in part to poor quality of workmanship.

Tamura and Wilson[11]

Tamura and Wilson measured the "air leakage" during all four seasons of two project-built houses located in Ottawa, Canada. Both are one-story five-room houses of insulated wood-frame construction with full basements. The houses are heated by a forced warm-air system with high-pressure gun-type oil burners. The houses were occupied, but occupant activities were not mentioned. All outside openings were kept closed during tests. During the winter, measured rates varied from 0.25 to 0.41 air change per hour in house 1 and 0.37 to 0.63 air change per hour for house 2. During the summer, measured air change rates varied from 0.07 to 0.16 for house 1 and 0.11 to 0.23 for house 2.

ASHRAE Handbook Calculations[13]

Calculations of air exchange rate, using ASHRAE Handbook methods, have been made for a "characteristic" house located in the Baltimore-Washington area.[22] By definition, the characteristic house has a gas-fired forced warm-air heating system and an air conditioning system. For houses of conventional construction, the air exchange rate was calculated to range from 1.3 to 1.7 per hour; industrial standard construction gave a calculated rate of 1.0 per hour. For houses built by controlled construction methods, the range was 0.33 to 0.67 per hour. Specific details of construction methods referred to were not defined.

Laschober and Healy[27]

Laschober and Healy applied statistical analysis methods to measurements of infiltration rates made during a heating season in two split-level research houses. The average test period duration was 1.5 hr, and all windows and doors were closed during the tests. No ventilation or exhaust fans were used during the tests. The average air change rate in a house heated with a gas-fired hot-water system was 1.19 changes per hour (range, 0.32-2.67). The heating system of the other house is described as a full perimeter air distribution system used in conjunction with a gas-fired or electric furnace. Separate tests were made with each furnace. The average rate for electric heating was 0.61 (range, 0.20-1.60), while the average during heating with gas was 0.84 (range, 0.30-1.79). The difference in average values

(0.23) is very close to the calculated increase in air leakage (0.19) during operation of the gas furnace from air used to burn gas.

Foreign Investigations

Investigators in foreign countries have, in general, used the same techniques as those described in this survey.[9,15-18] Their objectives are similar to ours: to optimize design of heating systems and to measure heat losses. Due to differences in house design and possible differences in occupant activities, results of studies in foreign countries are not considered in this survey.

Multiple Housing Units

This review is limited to the single family residential unit. It is not possible to cover every one of the many residential types, especially since some of them are not represented in the literature on ventilation rates. However, because increasing numbers of people are living in modern high-rise apartment complexes, this type of residence cannot be ignored. Air change in this type of residence is controlled mainly by mechanical means, and we did not find field test results of single units in a complex of units. Many communities rely on the Building Officials Conference of America (BOCA)'s Basic Building Code[25] to establish standards for regulation of high-rise apartment complexes. The BOCA Code requires a minimum fresh air supply for living rooms and bedrooms of 2 air changes per hour; 3 air changes per hour are required for kitchens and 5 air changes per hour are required for bathrooms. A more recent code[28] requires that air temperature control systems be capable of providing 2 air changes per hour and that at least one-fifth of the air supply be taken from the outside. Jennings and Armstrong[29] discussed the importance of recirculated air in ventilation practice, but we have not considered this situation in our study. Our recommended value of two air changes per hour for apartments is based on the assumption that all ventilation air comes from outside the building.

CONCLUSIONS AND DISCUSSION

We suggest a range of 0.5 to 1.5 air changes per hour be used for calculation of dose from exposure to tritium and other radionuclides introduced into the home with natural gas. Available data are insufficient to assign a single value for an average or characteristic occupied house.

This conclusion is based on the following reasoning. An infiltration rate of about 0.3 per hour has been reported for well-built unoccupied research houses.[10,19] This is more or less confirmed by calculated infiltration rates of 0.3 to 0.6 per hour, using ASHRAE methods, for a "characteristic" house, assuming controlled construction techniques.[22] Further confirmation was obtained by private communication with professional investigators in this field who are presently involved in measuring exchange rates. They stated that a rate of 0.3 per hour would be very difficult to maintain under practical living conditions.[23] A statement was also made that an infiltration rate of 0.3 per hour could be assigned to the research house, but that this value would be valid only for low wind speed and a low temperature differential.[24] A practical living situation should result in an exchange rate higher than the infiltration rate observed for unoccupied research houses or infiltration rates calculated from design considerations. This was confirmed by Elkins[12] who reported 0.5 to 1.0 air change per hour (adjusted to local wind speeds) for a modern well-built house that is occupied. Therefore, use of the lower limit of 0.5 air change per hour is suggested.

Assignment of 1.5 air changes per hour for the upper limit is made on the following basis. Infiltration rates for ten representative houses, adjusted to local wind speeds, ranged from 0.54 to 1.45.[4] Ages of five houses in this group ranged from 20 to 46 years. Many houses are older and these cannot be ignored. The higher value of 1.45 air changes per hour probably means that the older houses have a higher rate as compared to modern well-built houses. Based on ASHRAE methods, calculated infiltration rates for a "characteristic" house (assuming conventional construction methods) are reported to range from 1.3 to 1.7 air changes per hour.[22] The rate for a specific house will vary with location due to local wind speeds[12] and may vary as much as a factor of 2. For design purposes, a rate of 0.75 has been recommended for all-electric houses,[19] while gas-fueled houses would have a higher rate.[21] It has been suggested that a yearly average infiltration rate of 1.0 is reasonable from a practical standpoint.[12,23,24] Because activities of house occupants cannot regimented and builders may be careless in implementing designed characteristics of a house, it is the opinion of the reviewers that rates for occupied houses are likely to be higher than rates based on design. Therefore, 1.5 air changes per hour is suggested as a conservative upper limit for the annual average ventilation rate in individual United States homes. It should be recognized that, because pollutants introduced into home atmospheres are removed by ventilation at an exponential rate, the average of doses calculated for the ends of the suggested air change range is not equal to the dose calculated using the mid-range value of 1.0 air change per hour.

Based on the design ventilation rates in the BOCA Building Code, 2.0 air changes per hour is suggested as an average rate for calculations of doses received by occupants of apartments in modern high-rise apartment complexes if all the ventilation air is from outside the building.

REFERENCES

1. C. J. Barton, D. G. Jacobs, M. J. Kelly, "Radiological Considerations in the Use of Natural Gas from Nuclearly Stimulated Wells," *Nuclear Technol.* 11, 335 (1971).
2. C. J. Barton, R. E. Moore, and S. H. Hanna, *Quarterly Progress Report on Radiological Safety of Peaceful Uses of Nuclear Explosions: Hypothetical Exposures to Rulison Gas*, ORNL-TM-3601 (October 1971).
3. D. G. Jacobs, E. G. Struxness, M. J. Kelly, and C. R. Bowman, "Consideration of the Radiological Impact from the Hypothetical Use of Contaminated Natural Gas from Nuclearly Stimulated Reservoirs," *Health Physics* 22, 429 (1972).
4. C. W. Coblentz and P. R. Achenbach, "Field Measurements of Air Infiltration in Ten Electrically Heated Houses," *ASHRAE Journal* 5, 69 (1963).
5. C. J. Barton, R. E. Moore, and P. S. Rohwer, *Contribution of Radon in Natural Gas to the Natural Radioactivity Dose in Homes*, ORNL-TM-4154 (1973).
6. P. H. Elkins and C. E. Wensman, "Natural Ventilation of Modern Tightly Constructed Homes," Conference on Natural Gas Research and Technology, American Gas Association, Inc., and Institute of Gas Technology, Chicago, Illinois, February 28 - March 3, 1971.
7. C. W. Coblentz and P. R. Achenbach, "Design and Performance of a Portable Infiltration Meter," *Trans. ASHRAE* 63, 477 (1957).
8. F. J. Powell, Chief of Thermal Engineering Systems, National Bureau of Standards, Washington, D. C., private communication with T. H. Handley, Oak Ridge National Laboratory, January 3, 1973.

9. A. H. Howland, D. E. Kimber, and R. F. Littlejohn, "Measurements of Air Movements in a House Using a Radioactive Tracer Gas," *Institute of Heating and Ventilating Engineers Journal* 28, 57 (1960).

10. D. R. Bahnfleth, T. D. Mosley, and W. S. Harris, "Measurement of Infiltration in Two Residences, Part 1: Technique and Measured Infiltration," *Heating, Piping, and Air Conditioning* 29(6), 165 (1957).

11. G. T. Tamura and A. G. Wilson, "Air Leakage and Pressure Measurements on Two Occupied Houses," *ASHRAE Journal* 5, 65 (1963).

12. R. H. Elkins, Institute of Gas Technology, private communication with T. H. Handley, Oak Ridge National Laboratory, February 1, 1973.

13. *ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, New York, 1967.

14. Martha Gerrard, "Measurement of Ventilation Rates with Radioactive Tracers," *ASHRAE Journal* 10, 47 (1968).

15. J. B. Dick and D. A. Thomas, "Ventilation Research in Occupied Houses," *The Institute of Heating and Ventilating Engineers Journal* 19, 279-305 (1951).

16. J. B. Dick, "Experimental Studies in Natural Ventilation of House," Department of Scientific and Industrial Research, Building Research Station Note No. 180, Garston, Watford, England.

17. B. G. Collins and D. B. Smith, "The Measurement of Ventilation Rates Using a Radioactive Tracer," *The Institute of Heating and Ventilating Engineers Journal* 23, 270 (1955).

18. J. B. Dick, "Measurement of Ventilation Using Tracer Gas Technique," *Heating, Piping, and Air Conditioning* 22(5), 131 (1950).

19. R. C. Jordan, G. A. Erickson, and R. R. Leonard, "Infiltration Measurements in Two Research Homes," *ASHRAE Journal* 5, 71 (1963).

20. D. R. Bahnfleth, T. D. Mosely, and W. S. Harris, "Measurement of Infiltration in Two Residences, Part II: Comparison of Variables Affecting Infiltration," *Heating, Piping, and Air Conditioning* 29(7), 159 (1957).

21. C. W. Coblentz, discussion of the paper, "Field Measurement of Air Infiltration in Ten Electrically Heated Houses," *ASHRAE Transactions* 69, 358 (1963).

22. Department of Housing and Urban Development, Office of the Assistant Secretary for Research and Technology, *Residential Energy Consumption--Phase 1 Report*, Report No. HUD-HAI-1 (1972).

23. F. J. Powell, Chief of Thermal Engineering Systems, National Bureau of Standards, private communication with T. H. Handley, Oak Ridge National Laboratory, January 1973.

24. C. Hunt, Thermal Engineering Systems, National Bureau of Standards, private communications, with T. H. Handley, Oak Ridge National Laboratory, February 1973.

25. Building Officials Conference of America, Incorporated, *BOCA Basic Building Code*, "Article 5, Light and Ventilation," Fourth Edition, Owl Printing Company, Chicago, Illinois, 1970.

26. W. S. Harris, discussion of the paper, "Field Measurement of Air Infiltration in Ten Electrically Heated Houses," *ASHRAE Transactions* 69, 358 (1963).

27. R. R. Laschober and J. H. Healy, "Statistical Analyses of Air Leakage in Split-Level Residences," *ASHRAE Transactions* 70, 364 (1964).

28. International Conference of Building Officials, *Uniform Building Code*, Vol. 1, 1970 Edition, Pasadena, California.

29. B. H. Jennings and J. A. Armstrong, "Ventilation Theory and Practice," *ASHRAE Journal* 77, Part I (1971).

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