No. 1614

# MEASUREMENT OF INFILTRATION IN TWO RESIDENCES

## Part I: Technique and Measured Infiltration

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DURING the past 40 years many data on infiltration through different types of windows, doors and wall constructions have been obtained in laboratory investigations. A comprehensive bibliography can be found in the ASHAE GUIDE[1]. While laboratory studies have provided invaluable data for design infiltration heat loss estimates, their validity is frequently questioned because of assumptions which must be made to apply laboratory data to a structure having crackage on several exposures. Furthermore, in an actual structure the combined effects of wind and temperature difference cause infiltration, whereas recognized design procedures consider only the effect of wind.

Results of an investigation of infiltration in dwellings were published[2] recently, wherein the infiltration rates were measured by the tracer gas technique[3] using helium as the tracer gas. The apparent success of this method of measuring infiltration prompted procurement by the ASHAE of a helium gas analyzer.

During the winter of 1954–55 an investigation of infiltration in residences using the helium tracer gas technique was begun at the University of Illinois in cooperation with the Society. Infiltration rates were measured in the I=B=R Research Home and in Warm-Air Heating Research Residence No. 2. The results presented here were obtained in the 2 houses during the period from the winter of 1954–55 through the summer of 1956.

The principal objective was to determine the infiltration rates of the 2 houses and to correlate infiltration rates with wind velocity and direction and indoor-

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[1] Exponent numerals refer to References.
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outdoor temperature and pressure differences. An additional objective was to compare measured infiltration rates in the 2 houses with those calculated by the methods presented in THE GUIDE. The techniques used and the measured infiltration data are included in this paper. Part II will consider the effect of the several variables on the infiltration rates in the 2 houses and will include a comparison of the results of the investigations in the 2 houses.

## DESCRIPTION OF RESIDENCES AND INSTRUMENTATION

*I=B=R Research Home*: The Research Home, shown in Figs. 1 and 2 and described[4] in detail in University of Illinois Engineering Experiment Station *Bulle-*

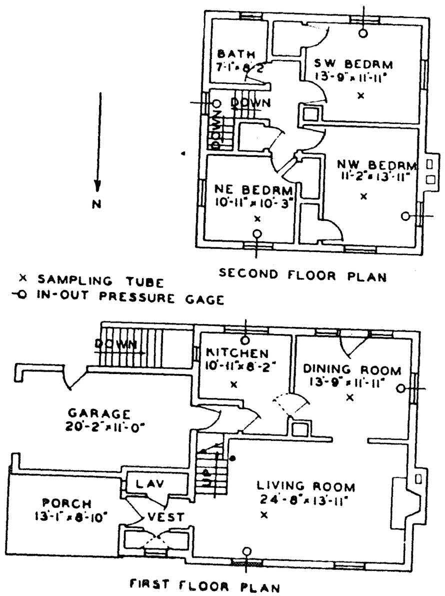


FIG. 1—FLOOR PLANS SHOWING HELIUM SAMPLING TUBE AND INDOOR-OUTDOOR PRESSURE GAGE LOCATIONS IN THE I=B=R RESEARCH HOME

*tin 349*, was a 2-story building with full basement typical of small well-built American homes. The total volume of the 2 stories was 9393 cu ft, and the basement volume was 5084 cu ft. Construction was brick veneer on wood frame, and all outside walls and the second-story ceiling were insulated with mineral wool batts 3⅝ in. thick. A vapor barrier was located between the insulation and the plaster base. The attic was ventilated by louvers in the gable ends. All windows were weatherstripped and of the double-hung type except for the wood casement windows in the kitchen. Storm doors were used on the 2 exterior doors during the winter. The windows and doors were all well fitted. Table 1 gives the crack



widths and lengths throughout the house. The fireplace chimney in the living room was sealed during the study. The Research Home was located on a typical city site, surrounded by trees and houses (see Fig. 2). The largest open area was a small yard to the south. With the exception of one house, located only 12 ft from the west wall, there was no other building closer than 75 ft. The surrounding houses were predominantly 2-story structures.

The Research Home was heated during the winter by a one-pipe hot water heating system. Radiation throughout most of the house was Type R cast-iron baseboard located along the exposed wall in each room. Small tube, 22-in. high radiators were used in the vestibule, lavatory, stair landing, and bath.

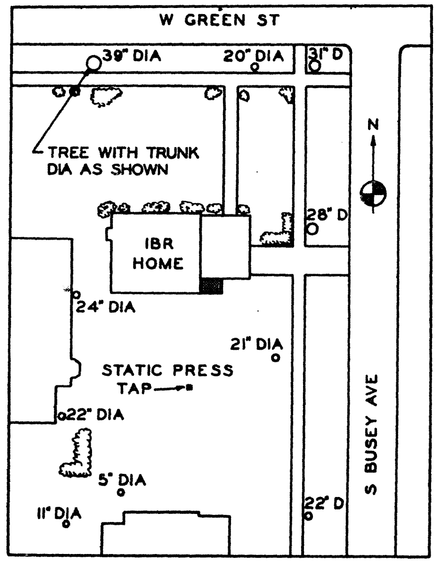


FIG. 2—SITE PLAN FOR THE I=B=R RESEARCH HOME

The chimney to which the gas-fired boiler was connected had a height of 35 ft 2 in. above the basement floor and consisted of a 6½-in. x 11-in. fireclay flue lining enclosed by one course of red brick. The smoke pipe connection was 7 ft 1 in. above basement floor level, and the draft hood was at an elevation of 5 ft 8 in. The chimney extended up through the central part of the house and was completely surrounded by heated space from its base to the level of the second-story ceiling. The plaster walls were separated from the masonry by an air space averaging about 5 in. in width. At the second story and basement ceiling levels this space was packed with mineral wool to decrease the circulation of air between the space around the chimney and the attic or basement. Another chimney of identical measurements and similar construction, but located on an exterior wall, was used for a gas water heater.

There were 2 fan-coil units, one on each story, used for summer cooling. These units were supplied with chilled water from an air-cooled chiller located outside the house. The units were centrally located with a supply register 4 in. from the ceiling of each room. The return grille on the first story was located in the living room next to the stairs. The second floor return was in the hall. These units were used to distribute helium through the house in both summer and winter tests.

Instrumentation for determining infiltration consisted of a helium gas analyzer, a valve manifold panel and sampling tubes. A schematic diagram of the helium analyzer and the manifold panel is shown in Fig. 3. The principle of operation of the analyzer was the same as the one used by J. B. Dick[3]. The sampling tubes, which were ¼-in. OD copper tubing, were located as shown in Fig. 1, with inlets

TABLE 1—EQUIVALENT[a] CRACKAGE OF FIRST AND SECOND STORIES OF THE I=B=R RESEARCH HOME

| Room | Total Length of Crack, ft | | | |
|---|---|---|---|---|
| | S | W | N | E |
| First Floor | | | | |
| Living Room | | | 37.2 | |
| Hall | | | 14.8 | 45.0 |
| Lavatory | | | | 8.9 |
| Kitchen | 27.0 | | | 9.0 |
| Dining Room | 73.6 | 18.6 | | |
| Second Floor | | | | |
| Bedrooms | | | | |
| SW | 17.8 | 17.8 | | |
| NE | | | 17.8 | 15.9 |
| NW | | 15.9 | 17.8 | |
| Hall | | | | 15.9 |
| Bath | 15.9 | | | |
| Total | 134.3 | 52.3 | 87.6 | 94.7 |

[a] Average width of crackage for weatherstripped windows was assumed to be 0.04 in. and for weatherstripped doors, a value of 0.09 in. was assumed. Crack lengths are given in terms of an 0.04 in. crack.

60 in. above the floor in the first and second story rooms. The inlet of the attic tube was 6 in. above the joist, and that in the basement was 15 in. below the floor joists. The sampling tube in the second story hall could be moved to various locations.

Instrumentation for a study of the neutral zone location consisted of 7 differential pressure gages and one recorder, all readable to within ±0.002 in. of water. These gages were connected to outdoor total pressure taps located as shown in Fig. 1. One side of each gage was open to the room. The outdoor total pressure taps consisted of a 3/32-in OD aluminum tube which extended through a window mullion. The end of the tube was flush with the face of a small octagonal aluminum plate mounted against the mullion and parallel to the glass. The indoor-outdoor recorder measured the static pressure difference at the first-story floor level. The outdoor static pressure tap for the recorder was located 32 ft south of the house and 6 in. above the ground. The outdoor static pressure was taken from the center of the inner surface of two 12 in. square plates mounted horizontally ¼ in. apart.



*Warm-Air Heating Research Residence No. 2*: Research Residence No. 2 was a one-story frame structure with full basement. A detailed description has been presented[5] in University of Illinois Engineering Experiment Station *Bulletin 401*. Total volume of the first story was 8084 cu ft, including closets. Basement volume was 8890 cu ft. Walls were insulated with 3⅝-in. mineral wool blanket insulation with vapor barrier attached. The ceiling was fully insulated, and the attic space was vented by louvers in the gable ends and 1-in. slots in the eave overhang on the south and north exposures. All windows were of the horizontal sliding type, with weatherstripping, except the fixed picture window in the living room. The Residence was equipped with storm windows and storm doors during heating studies, but summer studies were made with the storm windows and doors removed. Removal of the storm windows would have no effect on the infiltration rates through the windows since they were fastened directly to the window sash. Since the doors were weatherstripped and well fitted, the change in the infiltration rate through the doors would also be small. Crackage in each exposure expressed in terms of the

TABLE 2—EQUIVALENT[a] CRACKAGE OF FIRST STORY OF RESEARCH RESIDENCE NO. 2

| Room | Total Length of Crack, ft | | | |
|---|---|---|---|---|
| | S | W | N | E |
| Living Room | 100.0 | | | |
| S. Bedroom | 25.0 | 21.5 | | |
| Bath | | 14.5 | | |
| N. Bedroom | | 25.0 | 22.5 | |
| Hall | | | 45.0 | |
| Kitchen-Din. | | | 41.5 | 17.0 |
| Total[b] | 125.0 | 61.0 | 109.0 | 17.0 |

[a] Average width of crackage for weatherstripped windows was assumed to be 0.04 in. For fixed window a value of 0.02 in. and for weatherstripped doors a value of 0.09 in. was assumed.
[b] The sum of the maximum crackages of each room was 251 ft.

crack width of weatherstripped windows is listed in Table 2. The Residence was located on a comparatively open site, remote from buildings and trees. The nearest structures were a one-story weather station about 40 ft to the north, a one-story bungalow about 80 ft northeast and a row of one-story flat-roofed bungalows about 120 ft to the south.

During winter studies the Residence was heated by a gas-fired forced warm-air furnace. The furnace chimney was constructed of prefabricated cement-asbestos sectional units 8 in. in diameter. The total chimney height was 26 ft 11 in. above the basement floor; the 5-in. flue connection was at an elevation of 6 ft 9½ in.; and the opening to the furnace draft hood was at a height of 4 ft 3 in. above basement floor. A separate 4-in. diameter chimney of cement-asbestos material was provided for the gas-fired water heater.

During the early part of the summer a water-cooled condensing unit was used to cool the Residence. This unit was later replaced by a self-contained air-cooled condensing unit. Outdoor air was supplied to the air-cooled condenser through a 14- x 20-in. duct, and the heated air was returned to the outdoors through a duct of the same size. A basement window was replaced by a plywood panel with openings for the condenser air ducts. The cracks between the ducts and the plywood panel and between the window frame and the plywood panel were sealed with caulking compound.

Instrumentation for these studies consisted of a helium gas analyzer, a valve manifold panel and sampling tubes (see Fig. 3). The sampling tubes, which were ¼-in. OD copper tubing, were located as shown on Fig. 4. The sampling tubes extended 60 in. above the floor in the first-story rooms, and that in the basement was 4 in. below the floor joists. The sampling tube in the return-air duct was about 1 ft below the return-air grille.

To obtain indoor-outdoor pressure differentials during the investigation, a static pressure tube[6] was located 6 ft 2 in. above the roof peak and a static pressure tap, made of ⅛-in. iron pipe, was located at the floor level in the living room. Instantaneous values of pressure differential were measured by an inclined draft gage and a continuous record was obtained by a draft recorder. The tube connecting the outdoor static pressure tap to the measuring instruments was exposed to outdoor temperature throughout its length to the point of entry into the basement at the first-story floor level. Hence, the indicated pressure differential was nearly equal to the indoor-outdoor pressure differential at the first-story floor level.

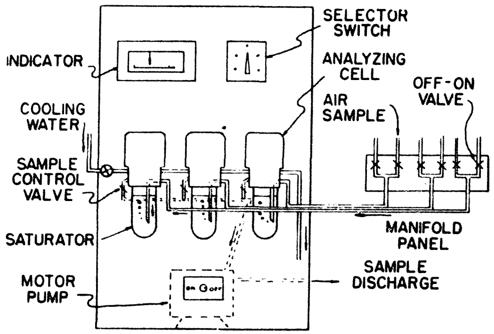


FIG. 3—SCHEMATIC DIAGRAM OF HELIUM ANALYZER AND MANIFOLD PANEL

## TEST PROCEDURE AND SPECIAL TESTS

*Helium Release*: Introduction of helium into the first and second story rooms of the Research Home was accomplished by releasing helium into the return-air plenum of each fan-coil unit through a ⅜-in. OD copper tube with 4 rows of ³⁄₃₂-in. diameter holes spaced on 1½-in. centers. During the release of helium, a pressure of 10 psig was maintained in the release tube. The helium was then distributed directly into the rooms by the unit fans. The second-story rooms received the helium first. In order to give an initial concentration of about 1.3 percent, 125 cu ft of helium was released, which required about 8 min.

In Research Residence No. 2 helium was released into the return-air plenum of the warm-air heating system and drawn through the filter into the furnace casing and forced through the air distribution system into the individual rooms. The volume released was adjusted to give an initial volumetric concentration of helium in the first-story rooms of about 1.3 percent. The time required for admitting this amount of helium (approximately 110 cu ft) was about 5 min.



*Air-Helium Samples*: Air-helium samples were drawn from each station through the sampling tubes, through the manifold panel, and thence to one of the 3 saturators by a pump. Samples were saturated by being bubbled through distilled water in the saturator. Thermal conductivity of the saturated air-helium sample was compared with that of a saturated air sample in the analyzer cell and was then discharged through a ¼-in. OD copper tube into the kitchen of the I=B=R Research Home. The small quantity of helium discharged had a negligible effect on the *apparent* kitchen air change rate. In Research Residence No. 2 the air-helium samples were discharged into the return-air duct downstream from the sampling station.

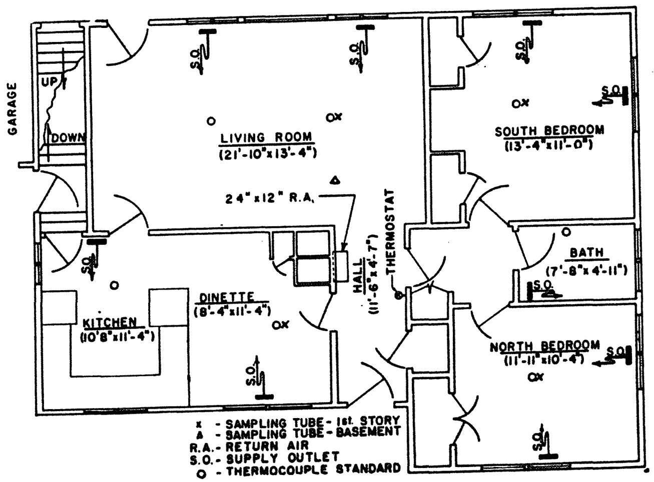


FIG. 4—FLOOR PLAN OF WARM AIR HEATING RESEARCH RESIDENCE NO. 2

*Test Conditions and Data Taken*: (a) *I=B=R Research Home*: All windows and exterior doors were closed during each test except the kitchen door leading to the basement and the outside basement door, which were opened several times during tests. The house was occupied by 2 to 5 persons, and all cabinets, drawers, and closets were opened throughout each test. During several special tests the second story was sealed off from the first.

Concentration of helium at each of the sampling stations was measured at 12 min intervals. Concurrent with the readings of helium concentration, indoor and outdoor temperature and humidity, and indoor-outdoor pressure differences at 8 locations were recorded. Wind speed and direction were obtained from the University Weather Station, located in a residential area similar to that of the Research Home. Wind velocity and direction were measured 15 ft above the roof of a 2-story building. Duration of the tests was from 1 to 1½ hours.

(b) *Warm-Air Heating Research Residence No. 2*: During each study all outside doors and windows were closed. The blower was operated continuously to assure uniform mixing of the air and helium in the rooms, and operation of the gas burner or the refrigeration compressor was controlled by the thermostat on the first story. During most of the studies the living quarters were not occupied. All cabinets, drawers, and closets were closed throughout each test except during 2 special studies made with closets open.

Concentration of helium at each of the sampling stations was measured at 6 min intervals. Wind velocity and direction, indoor and outdoor temperature and humidity, velocity pressure and draft in the smoke pipe, and the indoor-outdoor pressure difference were recorded during each test. Wind velocity and direction were measured at the weather station located 40 ft north of the Residence. The

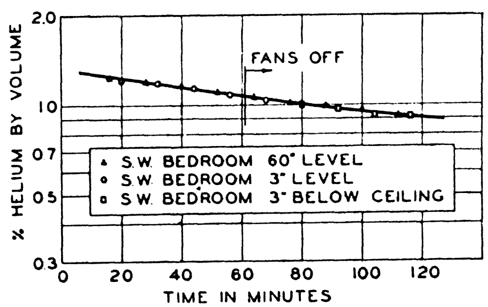


FIG. 5—RATE OF DECAY OF HELIUM FOR THREE ELEVATIONS IN THE SW BEDROOM OF I=B=R RESEARCH HOME

anemometer and direction indicator were located approximately 23 ft above ground level. Duration of the tests varied from 1½ to 2 hr.

*Distribution Tests*: The rate of infiltration determined by the tracer gas technique is valid only when the tracer gas is uniformly distributed in the room. British studies[2] have shown that erroneous *apparent* air change rates could be obtained due to stratification of the tracer gas. Since helium is considerably lighter than air, the validity of taking samples at one point in each room was questioned and several distribution tests were run in each of the houses.

Helium concentration was measured at various levels and in corners of 2 rooms in the I=B=R Research Home. Fig. 5 shows results of a test in the southwest bedroom where the concentration was measured at 3 levels—3 in., 60 in., and 7 ft 6 in. There was practically no difference in concentration at any of these levels, and even after the fans were turned off there was excellent agreement. Since this test was conducted in August, the question of room temperature gradients may arise. However, during summer cooling the gradients were as severe as during winter heating.

Similar results were obtained in Research Residence No. 2. During each study, however, the fan was operated continuously, and no attempt was made to determine the amount of stratification with the fan off.

In the studies in Research Residence No. 2 it was observed that the helium decay curves, when plotted on semi-logarithmic paper, deviated slightly from the predicted straightline relationship. This deviation was attributed to leakage of helium into the closed closets and exterior walls and to absorption by furnishings.



To determine the effect of closets on the decay of helium concentration, several studies were made with the closets opened but with the drawers and cupboards closed. Comparison of the data obtained on similar days with and without the closets closed showed that similar deviations occurred. From this it was concluded that the effect of the closets was not the dominant cause of the observed deviation.

*House Stack Effect Test*: When temperature difference is the only force causing infiltration there is a flow of air into a building near the ground level and out at a higher elevation; this flow reverses when there is a higher temperature outside the building than inside. Flow of air between the first and second stories in the Re-

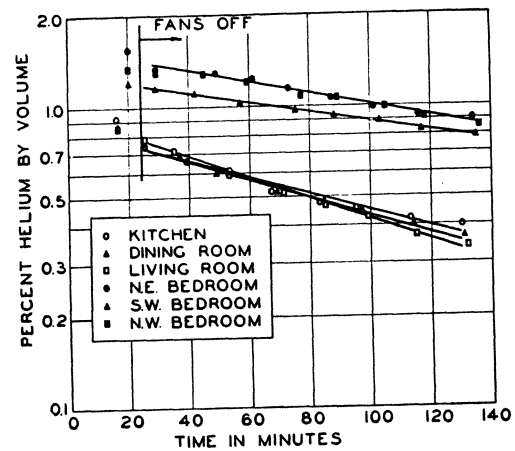


FIG. 6—RATE OF DECAY OF HELIUM WITH FANS NOT OPERATING IN THE I=B=R RESEARCH HOME

search Home was studied by placing a seal between the 2 stories, injecting helium into one story and allowing it sufficient time to mix well, then removing the seal and noting the changes in helium concentration throughout the house.

When helium was released on the second story very little ever reached the first story after removing the seal, but when helium was added initially to the first story a rapid increase was noted on the second story after removing the seal. The results show that most but not all air change between first and second stories was upward during the heating season.

## RESULTS

*I=B=R Research Home*: If it is assumed that the decay of helium concentration per unit time for the whole Research Home is equal to the helium leaving the Home with the exfiltrating air in the same unit time, then

$$-V\,dc = nV c\,dt$$

*where*

$V$ = house volume.
$c$ = instantaneous concentration of helium.

$n$ = number of air changes per unit time.
$t$ = time

the equation when solved gives

$$n = ln\ (c_1/c_2)/(t_2 - t_1)$$

$$\text{or equivalently } c_2 = c_1\, e^{-n(t_2 - t_1)}$$

Thus, on semi-logarithmic paper the decay curves will be straight lines, the slopes of which are directly proportional to the infiltration rate. Typical decay curves for the first and second-story rooms of the Research Home are shown in Fig. 6. Except for the mixing period, 20–30 min, the points fell very close to straight lines.

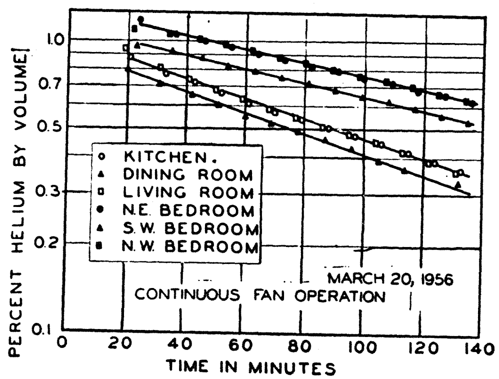


FIG. 7—RATE OF DECAY OF HELIUM WITH CONTINUOUS FAN OPERATION IN THE I=B=R RESEARCH HOME

There was some deviation which may be partly attributed to helium leaking into walls, furniture, and similar places when the concentration was high and then returning to the room air when the concentration had decreased.

The steep living room decay curve was the result of several factors. The vestibule, with a large amount of crackage area, opened directly into the living room. This condition was accentuated when the heating plant was in operation because of the removal of air from the basement through the chimney. Basement air was partly replaced by first story air leaking through cracks around the kitchen door leading to the basement. This caused a greater air change on the first story than when the chimney was cool. The same reasoning can be applied to the dining room in view of the large crackage area there also.

Varying slopes of decay curves in a single story occurred only when the house air was relatively still. Fig. 7 shows that when the fans were operated continuously the slopes of decay curves on any one story were approximately the same. One sampling tube on each story would have given accurate results with the fans in operation. However, provided there is no helium stratification, still air conditions within the house will give a more accurate account of infiltration in individual rooms than when the air is stirred by fans. The slopes of the decay curves for the 2 stories shown in Figs. 6 and 7 should not be interpreted to mean that the infiltra-



tion in the first story is greater than that of the second story. The movement of helium-laden air from the first to the second story would cause the *apparent* air change of the second floor to be less than the actual air change rate.

The infiltration rate for the Research Home was increased very slightly when the fans were operating. This was due to leakage of air from the second story fan unit plenum into the attic. For this reason all test results given here are with fans not operating.

Table 3 gives a summary of the weather conditions during each test. The indoor-outdoor static pressure difference at the first-story floor level and the location of

TABLE 3—SUMMARY OF TEST CONDITIONS—I=B=R RESEARCH HOME

| Test No. | Date | Temperature: Indoor F | Temperature: Outdoor F | In-Out Temp. Diff., F | Avg. Wind Velocity, mph | Max. Wind Gust, mph | Wind Direction | In-Out Press. Diff., in. $H_2O$ | Neutral Zone from First Floor, in. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2–10–56 | 75 | 28 | 47 | 4 | 13 | S | −0.018 | 164 |
| 2 | 2–28–56 | 75 | 24 | 41 | 8.5 | 15 | NW | −0.018 | 155 |
| 3 | 3– 3–56 | 73 | 51 | 22 | 7 | 23 | N | −0.015 | 167 |
| 4 | 3– 8–56 | 73 | 25 | 48 | 13 | 27 | W | −0.021 | 169 |
| 5 | 3–15–56 | 73 | 39 | 34 | 9 | 17 | NE | −0.013[a] | 160[a] |
| 6 | 3–20–56 | 73 | 42 | 31 | 6 | 15 | S | −0.014[a] | 139[a] |
| 7 | 4–10–56 | 73 | 46 | 27 | 9.2 | 20 | E | −0.012[a] | 145[a] |
| 8 | 4–16–56 | 73 | 43 | 30 | 9.7 | 34 | NW | −0.017 | 158 |
| 9 | 4–19–56 | 74 | 61 | 13 | 8.3 | 21 | N | −0.009 | 122 |
| 10 | 5– 3–56 | 74 | 70 | 4 | 5.5 | 15 | S | −0.005 | 115 |
| 11 | 6–27–56 | 76 | 83 | −7 | 9.5 | 22 | W | .. | .. |
| 12 | 7– 5–56 | 76 | 71 | 5 | 6.2 | 12 | NW | .. | .. |
| 13 | 8– 6–56 | 77 | 82 | −5 | 7.5 | 19 | N | .. | .. |
| 14 | 8–14–56 | 75 | 84 | −9 | 6.7 | 17 | N | .. | .. |

[a] Data not shown in Figures.

the neutral zone above the first-story floor level are also given; these values have been omitted for the last 4 tests because of inaccuracy of the pressure measuring instruments. The pressure difference and neutral zone for test No. 10 are questionable for the same reason.

Infiltration rates of the house and individual rooms for all tests are given in Table 4. The rates for the house and rooms were omitted for several tests because they were not representative of actual infiltration rates.

*Warm-Air Heating Research Residence No. 2*: The procedure followed in the analysis of the data obtained in Research Residence No. 2 was the same as that just outlined. The number of air changes at each of the sampling stations on the first story was obtained from the slopes of the helium decay curves plotted on semi-logarithmic paper. A summary of the weather conditions during each test is given in Table 5, and the air change rates calculated from the decay of helium concentration during each test are tabulated in Table 6. The average air change rates listed in Table 6 were computed as the summation of the individual air change rates weighted with respect to room volume. Since the weighted average rate and that measured in the return-air duct differed by only a small amount, the data observed in the return-air duct have been used to represent the air change rate of the entire first story.

TABLE 4—SUMMARY OF MEASURED INFILTRATION RATES—I=B=R RESEARCH HOME

| TEST NO. | No. of Air Changes Calculated from Tests | | | | | | |
|---|---|---|---|---|---|---|---|
| | LIV. RM. | DIN. RM. | KITCH. | NE BED. | NW BED. | SW BED. | HOUSE[d] |
| 1 | 0.43 | 0.33 | 0.29 | 0.27 | 0.26 | 0.24 | 0.32 |
| 2[a] | | | Special Test | | | | 0.38 |
| 3[b] | | | Special Test | | | | 0.35 |
| 4[b] | | | Special Test | | | | 0.43 |
| 5[a] | | | Special Test | | | | ..[e] |
| 6[c] | 0.48 | 0.47 | 0.44 | 0.31 | 0.31 | 0.31 | 0.40[e] |
| 7[c] | 0.08 | 0.07 | 0.09 | 0.34 | 0.32 | 0.32 | 0.26[e] |
| 8 | 0.35 | 0.25 | 0.33 | 0.38 | 0.42 | 0.38 | 0.35 |
| 9 | 0.32 | 0.24 | 0.29 | 0.25 | 0.26 | 0.27 | 0.28 |
| 10 | 0.12 | 0.17 | 0.15 | 0.15 | 0.14 | 0.33 | 0.17 |
| 11 | 0.10 | 0.10 | 0.11 | 0.19 | 0.24 | 0.22 | 0.16 |
| 12 | 0.13 | 0.22 | 0.18 | 0.25 | 0.28 | 0.21 | 0.20 |
| 13 | 0.12 | 0.17 | 0.28 | 0.23 | 0.12 | 0.16 | 0.16 |
| 14 | 0.17 | 0.20 | 0.43 | 0.14 | 0.08 | 0.16 | 0.17 |

[a] *Special Test*—House stack effect test with helium release on first story.
[b] *Special Test*—House stack effect test with helium release on second story.
[c] *Special Test*—Continuous fan operation during test.
[d] The house air change rate was computed from a weighted average of the room rates.
[e] Data not shown in Figures.

TABLE 5—SUMMARY OF TEST CONDITIONS—RESEARCH RESIDENCE NO. 2

| TEST | DATE | TEMPERATURE | | IN-OUT TEMP. DIFF., F | AVG. WIND VELOCITY, MPH | MAX. GUST, MPH | WIND DIRECTION | IN-OUT PRESS., DIFF., IN. $H_2O$ |
|---|---|---|---|---|---|---|---|---|
| | | INDOOR F | OUTDOOR F | | | | | |
| 1 | 12-22-54 | 73.4 | 32.0 | 41.4 | 9 | 15 | SSW | −0.001 |
| 2 | 12-28-54 | 73.5 | 32.0 | 41.5 | 10.5 | 21 | N | 0.003 |
| 3 | 1-11-55 | 73.4 | 31.4 | 42.0 | 5 | 10 | SSE | −0.012 |
| 4 | 1-14-55 | 73.8 | 32.0 | 41.8 | 12 | 29 | S | −0.008 |
| 5 | 1-28-55 | 73.9 | 3.9 | 70.0 | 7 | 11 | WNW | −0.010 |
| 6 | 2-10-55 | 74.6 | 20.6 | 54.0 | 14 | 28 | NNW | 0.028 |
| 7 | 3- 2-55 | 74.7 | 55.2 | 19.5 | 8 | 17 | SSE | 0.006 |
| 8 | 3- 7-55 | 73.3 | 24.7 | 48.6 | 8 | 20 | WSW | 0.006 |
| 9 | 3- 8-55 | 74.4 | 60.0 | 14.4 | 15 | 27 | WSW | 0.027 |
| 10 | 3- 9-55 | 74.9 | 64.8 | 10.1 | 13 | 22 | WSW | 0.024 |
| 11 | 3-14-55 | 73.8 | 64.2 | 9.6 | 10 | 21 | SSE | 0.010 |
| 12 | 3-17-55 | 73.0 | 32.4 | 40.6 | 5 | 8 | SE | −0.008 |
| 13 | 5- 6-55 | 77.8 | 80.8 | − 3.0 | 8 | 17 | S | 0.010 |
| 14 | 5-19-55 | 80.0 | 72.0 | 8.0 | 3 | 5 | W | −0.001 |
| 15 | 6-29-55 | 75.4 | 86.1 | −10.7 | 7 | 15 | SSW | 0.011 |
| 16 | 7- 8-55 | 75.1 | 93.7 | −17.6 | 8 | 20 | SW | 0.016 |
| 17[a] | 7-20-55 | 75.0 | 87.0 | −12.0 | 5 | 13 | E | 0.008 |
| 18[a] | 7-21-55 | 77.7 | 89.9 | −12.2 | 4 | 8 | SE | 0.007 |
| 19[a] | 7-25-55 | 78.2 | 87.5 | − 9.3 | 4 | 13 | S | 0.005 |
| 20[a] | 7-26-55 | 76.2 | 93.5 | −17.3 | 5 | 10 | SW | 0.009 |
| 21[a] | 8- 5-55 | 76.2 | 86.9 | −10.7 | 5 | 9 | SW | 0.007 |
| 22[a] | 8- 5-55 | 76.0 | 88.0 | −12.0 | 5 | 12 | SW | 0.008 |
| 23[a] | 8- 8-55 | 75.0 | 76.2 | − 1.2 | 5 | 11 | SE | 0.005 |

[a] Tests 17 through 23 were made with self-contained air-cooled condensing unit installed in Residence. Leakage of condenser air to recirculation air passage increased infiltration and tests have not been used in analysis.



Tests 1 through 14 in Table 5 were taken during the heating season and with the exception of Test 13 the indoor temperature was greater than that outdoors. Tests 15 through 23 were taken during a summer cooling investigation when the indoor temperature was less than that outdoors.

Of the 9 tests conducted during the summer, only the first 2 have been included in the results. The last 7 tests, which were made with the self-contained air-cooled condensing unit installed, have been omitted because of increased infiltra-

TABLE 6—SUMMARY OF MEASURED INFILTRATION RATES—RESEARCH RESIDENCE NO. 2

| TEST NO. | No. of Air Changes Calculated from Tests | | | | | | NOTES |
|---|---|---|---|---|---|---|---|
| | N BRM | DIN RM | S BRM | LIV RM | RETURN | AVE. | |
| 1 | 0.59 | 0.56 | 0.56 | 0.55 | 0.57 | 0.56 | |
| 2 | 0.57 | 0.54 | 0.54 | 0.56 | 0.54 | 0.55 | |
| 3 | 0.54 | 0.50 | 0.49 | 0.52 | 0.53 | 0.52 | |
| 4 | 0.63 | 0.59 | 0.60 | 0.60 | 0.63 | 0.60 | |
| 5 | 0.93 | 0.76 | 0.77 | 0.78 | 0.80 | 0.80 | |
| 6 | 0.62 | 0.54 | 0.59 | 0.56 | 0.60 | 0.57 | |
| 7 | 0.45 | — | — | 0.32 | 0.33 | — | |
| 8 | 0.50 | — | 0.50 | 0.50 | 0.49 | — | |
| 9 | 0.48 | 0.38 | 0.43 | 0.38 | 0.40 | 0.41 | |
| 10 | 0.41 | 0.38 | 0.40 | 0.36 | 0.38 | 0.37 | |
| 11 | 0.32 | 0.34 | 0.36 | 0.31 | 0.36 | 0.33 | |
| 12 | 0.41 | 0.39 | 0.44 | 0.41 | 0.44 | 0.41 | |
| 13 | 0.27 | — | 0.27 | — | 0.28 | — | |
| 14 | 0.28 | 0.26 | 0.27 | 0.25 | 0.26 | 0.26 | |
| 15 | 0.36 | 0.32 | 0.37 | 0.34 | 0.33 | 0.34 | 1 |
| 16 | 0.38 | 0.36 | 0.38 | 0.37 | 0.36 | 0.37 | 2 |
| 17[a] | 0.59 | 0.54 | 0.52 | 0.54 | 0.51 | 0.54 | 3 |
| 18[a] | 0.63 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 4 |
| 19[a] | 0.37 | 0.36 | 0.37 | 0.36 | 0.37 | 0.36 | 5 |
| 20[a] | 0.45 | 0.43 | 0.43 | 0.42 | 0.42 | 0.43 | 3 |
| 21[a] | 0.63 | 0.56 | 0.56 | 0.56 | 0.56 | 0.57 | 6 |
| 22[a] | 0.33 | 0.34 | 0.37 | 0.34 | 0.37 | 0.35 | 3 |
| 23[a] | 0.34 | 0.37 | 0.35 | 0.37 | 0.36 | 0.36 | 7 |

[a] These studies were not included in comparisons with the winter data.
*Notes*: 1—Water-cooled, unit off; 2—Water-cooled, unit on; 3—Air-cooled, unit on; 4—Air-cooled, unit off, closets open; 5—Air-cooled, duct sealed, closets open; 6—Air-cooled, unit off; 7—Air-cooled, duct sealed

tion resulting from leakage of outdoor air used for condensing into the recirculated room air. The condition of the air-cooled unit during each of the 7 tests is given in the last column of Table 6.

## SUMMARY

1. The Research Home, which was located on a typical city site surrounded by large trees and houses, had a considerably smaller infiltration rate at a given wind velocity measured above tree top level than that of Research Residence No. 2, which was located on a relatively open site, free of trees, and typical of new housing developments.

2. The helium tracer gas technique could be utilized for field measurements of infiltration in a variety of houses, thus providing much needed information on the applica-

tion of laboratory data to actual construction. In houses equipped with warm-air heating systems, a single helium analyzing cell located in the total return-air stream would provide satisfactory indication of the house infiltration rate. In houses equipped with hot water or steam heating systems, a single cell located on each floor would give satisfactory results provided some means were used to keep the room air well mixed.

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## DISCUSSION

Discussions of this paper are combined with Part II. To find them, turn to page 466.

No. 1615

# MEASUREMENT OF INFILTRATION IN TWO RESIDENCES

## Part II: Comparison of Variables Affecting Infiltration

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INFILTRATION measured in the I=B=R Research Home and Warm Air Heating Research Residence No. 2 by the helium tracer gas method and the weather conditions under which the measurements were made were presented[1] in Part I of this paper. The Research Home was a 2-story brick veneer house with full basement, located on a typical city site surrounded by houses and trees. Research Residence No. 2 was a single-story frame structure with full basement, and located on an open site typical of many new housing developments. Differences in location and construction of the 2 houses caused several noticeable differences in the results of the 2 investigations. The objective of this part of the paper is to compare the effects of the variables related to infiltration in the individual houses and to compare the results for the 2 houses.

Since the measured data were obtained over a range of combinations of wind velocity and direction, and indoor-outdoor temperature difference, and since only a limited number of tests were conducted in each house, it was deemed advisable to correct the measured data to specific conditions of wind and temperature difference. The corrections to the original data were determined from the slopes of plots of the original data assuming in all cases that a straight-line relationship existed between the dependent and independent variables. For example, the average increase in infiltration with each mph increase of wind velocity was ob-

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[1] Exponent numerals refer to References.
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