Concrete Blocks' Adverse Effects on Indoor Air and Recommended Solutions

By John S. Ruppersberger[1]

Abstract: Air infiltration through highly permeable concrete blocks can allow entry of various serious indoor air pollutants. An easy approach to avoiding these pollutants is to select a less–air-permeable concrete block. Tests show that air permeability of concrete blocks can vary by a factor greater than 50 (0.63–35 standard L/min/m² at 3 Pa). The surface texture of the blocks correlates well with air permeability; test results of smoother, closed-surface-texture blocks were usually less air-permeable. During construction, air infiltration can be minimized by capping walls and carefully sealing around openings for utilities or other penetrations. Structures with indoor air-quality problems due to soil-gas entry can be mitigated more effectively with less coating material if the blocks have a closed surface texture. All coatings evaluated—cementaceous block filler (which has the lowest applied cost and is more than 99.5% effective), surface bonding cement, water-based epoxy, polysulfide vinyl acrylic, and latex (three coats)—were highly effective (more than 98%) in reducing air permeability when adequately applied. Coating selection should be influenced by expected service life, considering surface condition and cost.

INTRODUCTION

Indoor air of poor quality has been shown to cause considerable ill effects; in particular, an estimated 14,000 deaths annually are due to radon in the United States ("A Citizen's" 1992). Modern building practices using a high resistance to air infiltration in the superstructure often ignore the low resistance to air infiltration of concrete blocks used to build the substructure. These blocks can be a significant entry route for radon gas, needlessly placing the occupants at risk (Hubbard et al. 1988). A study of concrete blocks has therefore been performed. The concern for concrete blocks as an entry route for soil-gas radon is for any building with a high radon concentration inside the hollow core of concrete-block walls that is part of an entry pathway; this is especially associated with basement substructures, but can also include slab-on-grade structures, and even crawl-space structures in certain cases.

Research performed on radon mitigation has typically involved structures with highly elevated radon levels and easily determined openings, such as perimeter floor/wall joints. Pressure-driven radon movement into the building interior is often mitigated by sealing the floor/wall joint and applying active soil depressurization (ASD) to extract the soil gas from beneath the slab and reverse the flow of soil gas away from the indoor air. This method is often effective, and its cost is more appropriate when used to reduce radon in structures with radon values greatly exceeding 4 pCi/L. Most of the radon lung dose exposure to the general population comes from exposure to lower concentrations of radon, below 4 pCi/L. Building less-permeable substructures can help reduce future population dosage, even if ASD or other mitigation techniques are not applied.

BACKGROUND

Soil, gas, often containing 1,000–10,000 pCi/L of radon, is the major source of radon in most buildings. Only a small amount of this gas coming into a structure can produce a health risk. If a building substructure is built with hollow concrete masonry units (CMUs) following common construction practices, rather than poured concrete, it will not offer much resistance to soil-gas entry. These walls are relatively permeable and often have hollow cores open at the top that have been an entry route. Although the amount of radon coming through CMU walls will vary with time from site to site and from house to house, one study found it to contribute approximately 20% of the indoor radon concentration at one house (Hubbard et al. 1988). Another finding of that study was that 50% of air exhausted from one ASD radon mitigation system was from the basement. This inefficiency in the system reduces both the extent of the subslab pressure field and efficiency of radon removal, and increases energy cost to condition outside replacement air to the temperature inside the house. Also, the effectiveness of the mitigation system is jeopardized if CMU walls allow large flows of indoor air into the system.

---

[1]Envir. Engr. (Ret.), Air and Energy Engrg. Res. Lab., U.S. Envir. Protection Agency, MD-54, Research Triangle Park, NC 27711.

Note. Discussion open until September, 1995. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on June 22, 1992. The paper is part of the ***Journal of Environmental Engineering***, Vol. 121, No. 4, April, 1995. ©ASCE, ISSN 0733-9372/95/0004-0348–0356/$2.00 + $.25 per page. Paper No. 4265.

In a Canadian study, external coatings were evaluated for their ability to form an airtight membrane that would remain intact even if cracks occurred in the substrate subsequent to their application ("Laboratory" 1979). Coatings were applied to two adjacent concrete blocks, which were then forced apart to simulate opening a crack. Nine coatings were evaluated; only Tremco 90V and Permapol PRC 305 with an accelerator demonstrated the ability to form an airtight membrane that remained intact over cracks opened to 3 mm.

A Princeton University study found that block-wall air permeability was reduced by 99.5% with two coats of a special rubberized paint, a polysulfide copolymer, while one coat was 91% effective. Two coats of either ordinary latex or oil-base paints reduced wall permeabilities by 95%. Air permeabilities were determined from flow-versus-pressure data (Marynowski 1988).

ASTM has established a standard test method for the rate of air leakage through exterior windows, curtain walls, and doors ("Standard" 1984). This test method covers the determination of resistance of curtain walls to pressure-driven air infiltration. The Environmental Protection Agency test method developed in this study complies with the ASTM test method in every major aspect, differing only in collecting data at the lower pressure differentials of interest typical of indoor air, 1–12 Pa. The instrumentation exceeds accuracy requirements to permit precise measurements at these very low pressures and flows.

MATERIALS AND PROCEDURES

CMUs of the type used in this study are covered by ASTM's standard specification for hollow load-bearing concrete masonry units ("Standard" 1985). This specification covers hollow load-bearing CMUs made from portland cement, mineral aggregates, and water with or without other materials. The three weight classifications are lightweight, medium, and normal based on the weight of concrete: less than 1,682 kg/m^3 (105 lb/cu ft), 1,682–2,002 kg/m^3 (105–125 lb/cu ft), and more than 2,002 kg/m^3 (125 lb/cu ft).

The test stand was designed for a 1.5-m^2 (16-sq-ft) CMU wall as shown in Fig. 1. The wall assembly is made by pouring a concrete footing (122 × 41 × 15 cm [48 × 16 × 6 in.]) on which a block wall of 15 standard blocks and six half blocks is carefully built. Walls of this size were tested rather than single blocks to provide data on mortared CMU walls and to replicate constructed walls more closely than could be done testing single blocks. Mortar construction techniques vary; these walls were built with two strips of mortar on which the base course of blocks are laid. Mortar is applied to all horizontal surfaces of the previous course and to the end of the next block that butts up against the last block on a course in progress. After the wall has set up for more than a week, it is caulked generously on its top and side edges and, while wet, the side and top panels are assembled, then fitted with covers to encapsulate the wall with a plenum on either side. Closed-cell rubber-gasket material was sandwiched between the top, sides, and bottom panels, and between the metal and acrylic plastic covers for the tests on walls built from North Carolina CMUs; for other tests the rubber-gasket material was replaced with weatherstrip caulking "cord" (a soft claylike material commonly sold for weatherproofing) that molds easily to the mating surfaces for an airtight seal yet is also easy to remove to prepare the test stand for reuse in evaluating the next sample of CMUs.

The completed assembly was leak-tested by pressurizing to between 500 and 750 Pa (2 and 3 in. water) using helium gas and searched for leaks using a gas detector. Leak testing was also

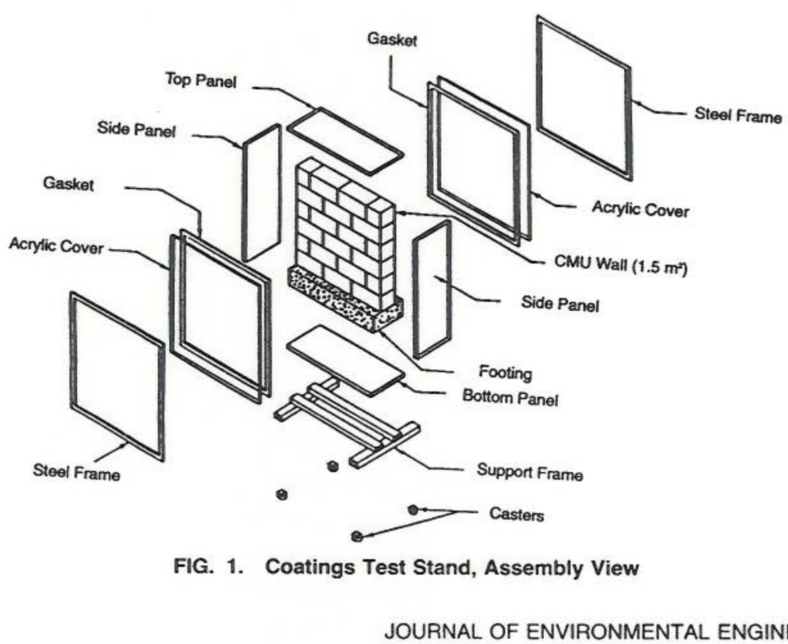


FIG. 1. Coatings Test Stand, Assembly View

conducted on the pressure side of the air-delivery equipment. The control panel was composed primarily of computer-controlled mass-flow controllers, a pressure transducer, a pump, and a bypass valve that provide precise control of flows from less than 0.01 to 50 standard L/min over a pressure range of 1–12 Pa. After baseline data were collected, the acrylic plastic cover over the side of the wall to be painted was removed and the coating was carefully applied. The quantity of coating applied was recorded for each coat. Additional coats were applied a day after the previous coat except when data indicated that the current coat was not dry. It is important to note that the coatings were applied by brush, carefully working material into the block surface and leaving as much material on the wall as possible without runs. Primary consideration was sealing the porous block surface, not the amount of material used. Exceptions were the elastomeric paint, which was applied at its recommended maximum rate, and the surface bonding cement, which was applied using a steel trowel.

The initial wall was constructed as part of prototype development and was used for evaluation of the polysulfide vinyl-acrylic paint. Its baseline flow was as shown in Fig. 2 and Table 1, test B, 35 standard L/min at 3 Pa, or about 2 standard L/min per full block. The remaining five coatings were evaluated from walls built later, from a different batch of blocks. Although from the same local North Carolina manufacturer, meeting the same ASTM specifications for CMUs, the baseline flows were approximately half that of the prototype wall, as shown in Fig. 2, test D, 18 standard L/min at 3 Pa, or about 1 standard L/min per full block. Then an opportunity developed to evaluate blocks received from a Minnesota manufacturer. The baseline flow for that sample of Minnesota blocks is on average approximately an order of magnitude lower than

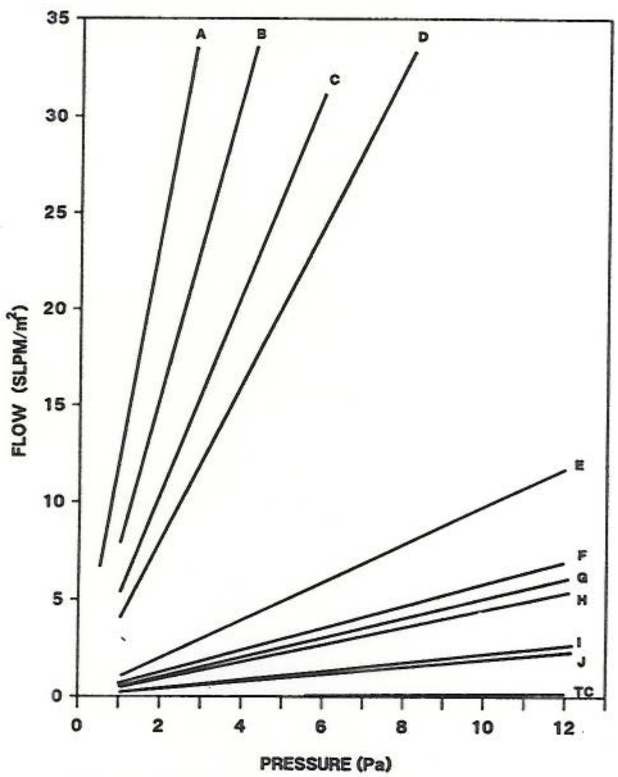


FIG. 2. Airflow through Concrete-Block Walls

TABLE 1. Test Used for Fig. 2

Designation (1)	Legend (2)	Weight (3)
A	Virginia	Light
B	North Carolina, first batch	Light
C	New York	Normal
D	North Carolina, second batch	Light
E	Colorado	Normal
F	Minnesota	Normal
G	Florida, stucco type	Normal
H	Iowa	Normal
I	Florida	Light
J	Florida, paint type	Normal
TC	Typical coated wall	—

the North Carolina blocks, as shown in Fig. 2, test F, 2.7 standard L/min at 3 Pa, or about 0.15 standard L/min per full block. The large variation in air permeability found between the CMUs led to testing additional samples of CMUs from Virginia, Iowa, New York, and Colorado, as well as a subset of three types of CMUs from Florida. The very large variation in air permeability produced concern for selecting the least air permeable block for substructure construction. To facilitate that selection, a field test and simple visual-inspection procedure were developed and evaluated.

Coatings selected for evaluation included a two-part water-based catalyzed epoxy paint, an elastomeric paint, a cementaceous block filler, a fiber-reinforced surface bonding cement, a polysulfide vinyl-acrylic paint, and a latex paint. Selection criteria included an attempt to sample various types of coatings that might be used on CMU basement walls under various conditions. Some coatings are not well suited or even recommended by the producers for negative side (inside) basement walls, but were evaluated because they may already exist on some walls of basements needing mitigation, or because they might be better suited for application to walls under certain conditions than other coatings.

RESULTS

The sensitivity and reproducibility of airflow measurements obtained in this study made comparisons between various samples of CMUs and coatings easy to quantify and to rank in order of performance or "tightness." The data are so precise that you can plot different pressure versus flow lines for the same paint when dry to the touch and several days later when pinholes continued to develop as observed in the polysulfide vinyl-acrylic paint. Data plotted very close to straight lines on arithmetic paper. However, it is important to remember what this work is about: concrete blocks that have much block-to-block and batch to batch variation in air permeability, a parameter not checked as part of manufacturing quality control.

The walls were made large enough to even out the block-to-block variability, and all coating evaluation walls were built with blocks from the same manufacturer. The walls for all but the polysulfide vinyl-acrylic paint applied to the first prototype wall were from the same batch of blocks.

The surface porosity, or roughness, varies widely, and not only has been observed to be an indicator of air permeability but also influences selection of a coating if one should be considered necessary. A rough surface makes a good substrate for stucco, while paints are easier to apply for a continuous coating on a smooth surface. Therefore, the results of coating performance, and even the amount of coating applied to the surface of the blocks, have some variability, because the surfaces of the block test walls varied prior to applying the coating.

Since the primary goal is to provide guidance on reducing indoor air contamination from significant amounts of soil gas coming through concrete-block walls, and all coatings were highly effective if carefully applied in adequate quantity, the emphasis shifted to developing guidance on selecting less–air-permeable blocks for construction. In the event that many walls will not be coated to reduce soil gas entry, it is important to select blocks of low air permeability. Blocks and their selection are discussed, as are coatings.

Coatings

In general, all coatings tested performed well under laboratory conditions when adequate quantities were carefully applied. Paints required two or three coats to achieve 98% CMU air-permeability reduction; cementaceous coatings exceeded 99% effectiveness in one application at lower total cost. The results for coatings are summarized in Table 2 along with estimated costs. Additional brief information about each coating is presented in the following.

Water-Based Epoxy

This is a water-based catalyzed (two-part) epoxy resin paint. Even when applied to a wall with a slightly higher baseline of 19.8 standard L/min, a single coat of this epoxy paint resulted in the lowest airflow for one coat of any paint evaluated, 0.75 standard L/min (96.2% reduction), and was lowest for any two coats of paint evaluated, at 0.01 standard L/min (99.9% reduction). Application was considered easier than average to provide a continuous film.

Elastomeric

Elastomeric paints are sometimes specified in commercial applications where the ability to span cracks and other openings is desired, such as for hairline cracks opening along the mortar joints of CMU walls. The performance of this elastomeric acrylic emulsion paint was second only to the water-based epoxy for one coat (pinholes were observed in the first coat), but matched the excellent performance of the epoxy for the second coat. It was also the most expensive coating evaluated. Application by brush was considered the easiest of all coatings evaluated.

TABLE 2. Effectiveness of Coatings in Reducing Airflow through Concrete Blocks at 3 Pa

Coating (1)	Effectiveness (%) (2)	ESTIMATED COST[a] (dollars) Per Square Meter Material (3)	Labor (4)	Total (5)	Typical Basement[b] Do it yourself (6)	Professional (7)
(a) Greater than 99% Effective						
Epoxy, two coats, water-based	99.9	4.00	3.70	7.10	440	850
Elastomeric, two coats	99.9	5.40	3.20	8.60	590	950
Cementaceous block filler (brushed thick)	99.7	1.50	2.20	3.70	170	410
Surface bonding cement (3 mm troweled)	99.5	2.20	2.40	4.60	240	510
Polysulfide vinyl acrlic, two coats	99.4	3.90	3.20	7.10	430	780
(b) Greater than 98% Effective						
Latex, three coats	98.1	2.40	4.50	6.90	260	760
(c) Greater than 90% Effective						
Epoxy, one coat, water-based	96.2	2.70	2.20	4.90	300	540
Elastomeric, one coat	92.1	4.00	1.90	5.90	440	650
(d) Greater than 75% Effective						
Latex, two coats	84.2	1.80	3.20	5.00	200	550
Polysulfide vinyl acrlic, one coat	78.6	2.50	1.90	4.40	280	480
(e) Less than 75% Effective						
Latex, one coat	42.1	1.20	1.90	3.10	130	340

[a]Costs for brushes, dropcloths, preparation of the basement area and walls, and so on are not included.
[b]"Typical" is assumed to be approximately 110 m² of wall surface, in good condition, ready to be painted.

Cementaceous Block Filler

This is a portland cement plaster that can be troweled, sprayed, or brushed. In keeping with the general trend for application as might be expected by a concerned homeowner, this product was applied with a "masonry brush," after being mixed with water following the instructions on the 1.4-kg (50 lb) bag. Application of a continuous coating of reasonable surface appearance took a little practice, but was not difficult. The single thick coating resulted in an airflow of only 0.06 standard L/min (99.7% reduction); only about half of the flow through the other more expensive and difficult to apply cementaceous coating evaluated, and more than an order of magnitude less than one coat of the most effective paint.

Surface Bonding Cement

This is a mixture of portland cement, fiberglass reinforcement fibers, and proprietary ingredients. Application at the specified minimum 0.32-cm (1/8-in.) thickness will cover about 4.6 m² (50 sq ft) with a 1.4-kg (50-lb) bag. This was the only coating not applied by the author; an expert mason provided by the manufacturer applied the product with a steel trowel to slightly more than 0.32-cm (1/8-in.) thickness. The single application resulted in an airflow of only 0.10 standard L/min. This thicker cementaceous coating allowed more air permeability than the less expensive block filler. A possible factor is the openings associated with the bundles of fiberglass that were long enough to extend from the CMU surface to the coating surface. Still, this coating allowed less than 14% of the flow through one coat of the most effective paint.

Polysulfide Vinyl Acrylic

This paint was evaluated first after the equipment was fully calibrated. Pinholes were observed soon after application (even a thick coat did not prevent them) and their apparent number and size increased with drying time, even after several months. This paint was promoted as a "radon barrier," and made commercially available to radon mitigators. Its cost was about the same as the water-based epoxy, but its performance was much worse; of the coatings evaluated, only the much less expensive latex paint was less effective, as shown by the data in Table 1.

Latex

This semigloss latex paint, commonly available and often sale priced at retail, might be considered the type of paint homeowners often buy, and may have been used to freshen up the basement. The application rate specified on the label is 9.82 m²/L (400 sq ft/gal) or less. Actual coverage on the CMU surface was 2.46 m²/L (100 sq ft/gal) for the first coat; only 1.23 m²/L (50 sq ft/gal) could be painted with three coats at the application rate used for this evaluation.

Application by brush was considered sightly more difficult and time-consuming than the other paints evaluated. One coat was not very effective, allowing about an order of magnitude more air permeability than the water based epoxy or elastomeric paints at one coat. It was the only paint applied with three coats, but that third coat greatly increased the effectiveness, from 84.2% at two coats to 98.1% at three coats; the pinholes, smaller but still numerous after two coats, were effectively filled by the third coat.

Concrete Block

Samples were obtained from North Carolina, Minnesota, Virginia, Iowa, New York, Colorado, and Florida. The results of observations and tests performed on the CMU samples are presented in Tables 3 and 4 and in Fig. 2. The very large difference in air permeability found between these concrete-block walls (more than a factor of 50) in this small sampling of less than 1% of the various CMUs available in the United States produces concern about selecting the least air permeable block for substructure construction.

The selection of low-air-permeability CMUs would be simplified if an existing measured characteristic of CMUs correlated well with air permeability. The impressive difference in air permeability between the Minnesota sample of blocks and the North Carolina sample used first in the coatings evaluations, and the obvious difference in weight of the heavier blocks from Minnesota, supported consideration that air permeability might be inversely proportional to density. This correlation was consistent with blocks received from the first five states; then came the sample from New York, a normal-weight (more dense) block that performed like the lightweight blocks from North Carolina and Virginia. But the New York blocks looked much more like the North Carolina and Virginia blocks; that is, very rough and open porous surface texture. With this "outlier" of a very air-permeable dense block, was a tight, low-permeability, lightweight block also available? After all, visual examination of broken cross sections of dismantled test wall samples had revealed the closed-cell foam appearance of the lightweight aggregate used in the lightweight block samples. Also, the lightweight aggregates used in the sample blocks had a smooth solid looking surface. The lightweight aggregates themselves did not appear very air-permeable, especially when compared with the interconnecting voids visible in broken samples of highly permeable blocks.

The subset of blocks from Florida provided the other outlier to the hypotheses of an inverse correlation of air permeability with density; the lightweight Florida block had very low air permeability. But all the Florida blocks had low air permeability, even the rough-surface texture block intended to take a stucco surface treatment. One thing that all the Florida blocks seemed to have in common was a large amount of finer, sand-sized aggregates. Broken specimens did not reveal the relatively large interconnecting voids observed in highly air permeable blocks. Also, considering the high-sand Florida blocks as a subset, the correlation of rough-surface texture with higher air permeability was consistent with the test data. Therefore, for the samples evaluated in these tests, the inverse correlation of air permeability and density had some major outliers, but the direct correlation of air permeability with rougher, more porous-looking surface texture was consistent with the data.

Informal tests of the direct correlation of air permeability to surface texture were conducted on several occasions by setting representative specimens of individual blocks on display and asking people to assume that they were the blocks available from their local suppliers. Without any additional information or guidance, the observers were then asked to select the type of block they would use to build a basement wall resistant to soil gas (radon), and to rank the other blocks in order of increasing air permeability. These informal tests were conducted with anybody available—technicians, engineers, secretaries, and managers. The results of these informal tests with approximately 20 different people were consistent; everybody picked a low-air-permeability block as their first choice. In ranking the blocks, low-air-permeability blocks were consistently ranked best, followed by a block of intermediate permeability (the Colorado

TABLE 3. CMU Air Permeability and Surface Appearance Observations: CMU Sample by State

Sample (by state) (1)	Air Permeability: At 3 Pa (SLPM/m²) (2)	Air Permeability: Surface appearance (3)
Virginia	>35	Rough/open
North Carolina, batch 1	23.6	Rough/open
New York	15.6	Rough/open
North Carolina, batch 2	12.2	Rough/open
Colorado	3.0	Medium smooth/closed
Minnesota	1.8	Smooth/closed
Iowa	1.4	Smooth/closed

TABLE 4. CMU Air Permeability and Surface Appearance Observations: CMU Sample by Florida Subgroup

Sample (by Florida subgroup) (1)	Air Permeability: At 3 Pa (SLPM/m²) (2)	Air Permeability: Surface appearance (3)
Stucco grade	1.6	Rough/closed
Lightweight	0.7	Smooth/closed
Paint grade	0.6	Smooth/closed

sample) and the highly air-permeable blocks, which nobody chose for their basement. A primary objective of this research program being to develop guidance about soil-gas–resistant substructures built of CMUs, the most consistent guidance based on the samples tested is to compare the surface texture of blocks, then select the one that looks like it would be the most resistant to gas flow.

A field test was developed that uses readily available materials. Tests on single block samples showed adequate precision to differentiate between blocks of low, moderate, and high air permeability. Highly permeable blocks offered such low resistance to airflow that no difference was measured by the "U" tube between pumping the air into the room or through the block sample. A description of the field test follows.

Simple Procedure to Select Concrete Blocks of Low Air Permeability

The following procedure may help determine the permeability differences between the types of blocks available in an area, permitting a more informed choice of concrete blocks.

The materials used were:

- An aquarium pump (Whisper 400 or equivalent)
- Concrete blocks to be tested, plus a spare to support the "U" tube
- 2.7 m (9 ft) of clear aquarium tubing plus 15 cm (6 in.) for each test block to fit the pump
- One tee and one nipple to fit tubing
- One tube of silicone caulk (GE Silicone Clear Household Glue and Seal or equivalent)
- A spatula, 4 cm (1-1/2 in.) wide
- Circular-form 1-cm (3/8-in.) cross section cut from bottom of spent caulk cartridge
- Clear tape
- Sheet of graph paper (10 × 10 grid preferred)
- For each block to be tested, half a cartridge of caulk (Red Devil Lifetime or equivalent)
- For each block to be tested, two 7.6-cm (3-in.) plastic funnels.

The procedure is as follows (see Fig. 3):

1. Label each type of block sample and lay it on its side, 3 cm (1 in.) apart or more.
2. Select two identical 7.6-cm (3-in.) plastic funnels. Carefully trim away any tabs. Center one funnel directly on the surface above one core (void) in the first test block.
3. Hold the funnel down firmly and apply a generous (1-cm [3/8-in.]) bead of cartridge caulk around rim of funnel, touching both funnel and block. Apply two more beads of caulk to the block against first bead. Continuing to hold funnel firmly, use the spatula to spread caulk away from funnel along surface of block to edges, evenly caulking half the block. Repeat using the second funnel on the other half of the block. Repeat the entire process with the remaining test blocks and funnels.
4. While the caulk sets, assemble the aquarium pump and tubing. Cut 0.6 m (2 ft) of tubing; connect one end to the pump and other end to the tee arm. Cut 0.8 m (2-1/2 ft) of tubing and connect one end to tee leg. Shape this tubing into a "U" with the open-ended leg slightly shorter to allow for filling with water in step 9. To prevent kinking, place the circular form inside the bottom of the "U" tubing. Tape the tubing together just above the circular form and near the tee so the arrangement lies flat. Position the tee and "U" tubing on the face of the spare block and use silicone caulk to hold the tee, circular form, and tubing to the block. Leave the center 15 cm (6 in.) 15 cm of tubing free of caulk or tape but flat against block.
5. While "U" tubing caulk sets, cut an 8-cm (3-in.) length of tubing for each funnel plus

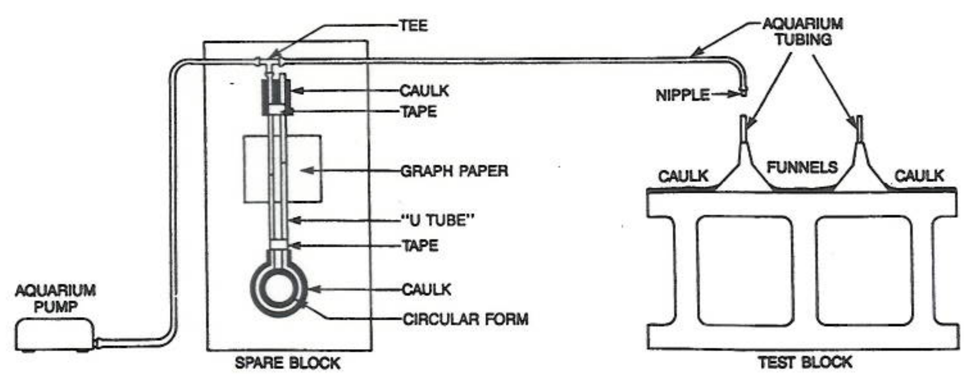


FIG. 3. Concrete-Block Permeability-Test Assembly

one extra. Apply a generous bead of silicone caulk 1 cm (1/2 in.) from one end of a piece of 8-cm (3-in.) tubing and insert into tip of a funnel so about 5 cm (2 in.) of tubing extends from tip. Be sure to use enough caulk to completely seal tubing to tip of funnel, spreading excess caulk over the top edge of the funnel tip and along the tubing to ensure a complete seal. Repeat with remaining tubing and funnels.

6. Connect one end of the remaining length of tubing (about 1.2 m [4 ft] long) to the tee and insert the nipple into the free end.
7. Seal all connections at the tee, the pump, and the nipple with silicone caulk.
8. Allow time for all silicone caulk to cure (at least 4 h, preferably overnight).
9. Tip the block with the attached "U" tubing to a vertical position and fill the "U" tubing half full with water (coloring improves visibility). Mark the center horizontal line (reference line) on a piece of graph paper about 10 cm (4 in.) square and slide it between the center of the "U" tubing and block.
10. Place the reserved 8-cm (3-in.) length of tubing on the nipple.
11. Turn on the pump. Slide the graph paper reference line to the water level in the side of the "U" tubing that is open at the top.
12. Remove the 8-cm (3-in.) tubing from the nipple (do not pinch tubing closed; this may blow water out of "U" tube) and insert nipple into the first block funnel tubing. Wait 30 s. Read the amount of change in water level in the open side of the "U" tubing. Remove the nipple from the funnel and replace 8-cm (3-in.) tubing. Check that the water level returns to the reference line. If not, repeat this step. Record reading. Repeat with the second funnel on the first block.
13. Continue until all blocks are tested and readings are recorded.
14. Review results, and select the block with the highest "U" tubing readings. Higher readings indicate better resistance to air infiltration (low air permeability). Generally, blocks with the smoothest surface texture have the best resistance.
15. If all results are "low," less than 0.25–0.51 cm (0.1–0.2 in.), consider other sources of concrete block or another material, or coat the surface of the constructed block wall with a cementaceous block filler/coating or other durable coating that fills the pores of the block.

CONCLUSIONS

The air permeability of concrete blocks varies widely, by more than a factor of 50 in this small sampling representative of approximately 1% of U.S. production.

Selection of low-air-permeable blocks for soil-gas–resistant substructure construction can reduce pressure-driven inflow through the block-wall surface when compared with the inflow expected through highly permeable block walls. The effects of soil air permeability, application of coatings, openings in the wall, moisture, and other variables will also influence actual inflow through constructed block walls.

When compared with density, a parameter that sometimes correlated inversely to air permeability but with some exceptions, the surface texture, or roughness, appears to be a more consistent indicator of a block's air permeability; a rougher, more open and air-permeable–looking block is often more air permeable than a smoother, closed-surface textured block.

The simple field test procedure developed by this work and described in this paper is able to detect differences between high-, moderate-, and low-permeability blocks.

All six coatings evaluated in this study—cementaceous block filler, fiber-reinforced surface bonding cement, two-part water-based epoxy, elastomeric, polysulfide vinyl acrylic, and latex—were highly effective in reducing air permeability under the conditions of the tests when a sufficient quantity was carefully applied.

Considering both cost and effectiveness, a cementaceous product such as cementaceous block filler offers highly effective flow reductions in a single application at low total cost. Among paints, two coats of the water-based catalyzed epoxy were most effective in these tests, although one coat may be adequate for some situations such as when applied to smooth textured concrete block.

The relationship between flow and pressure data collected from these carefully constructed test walls at this very low pressure range was found to be linear.

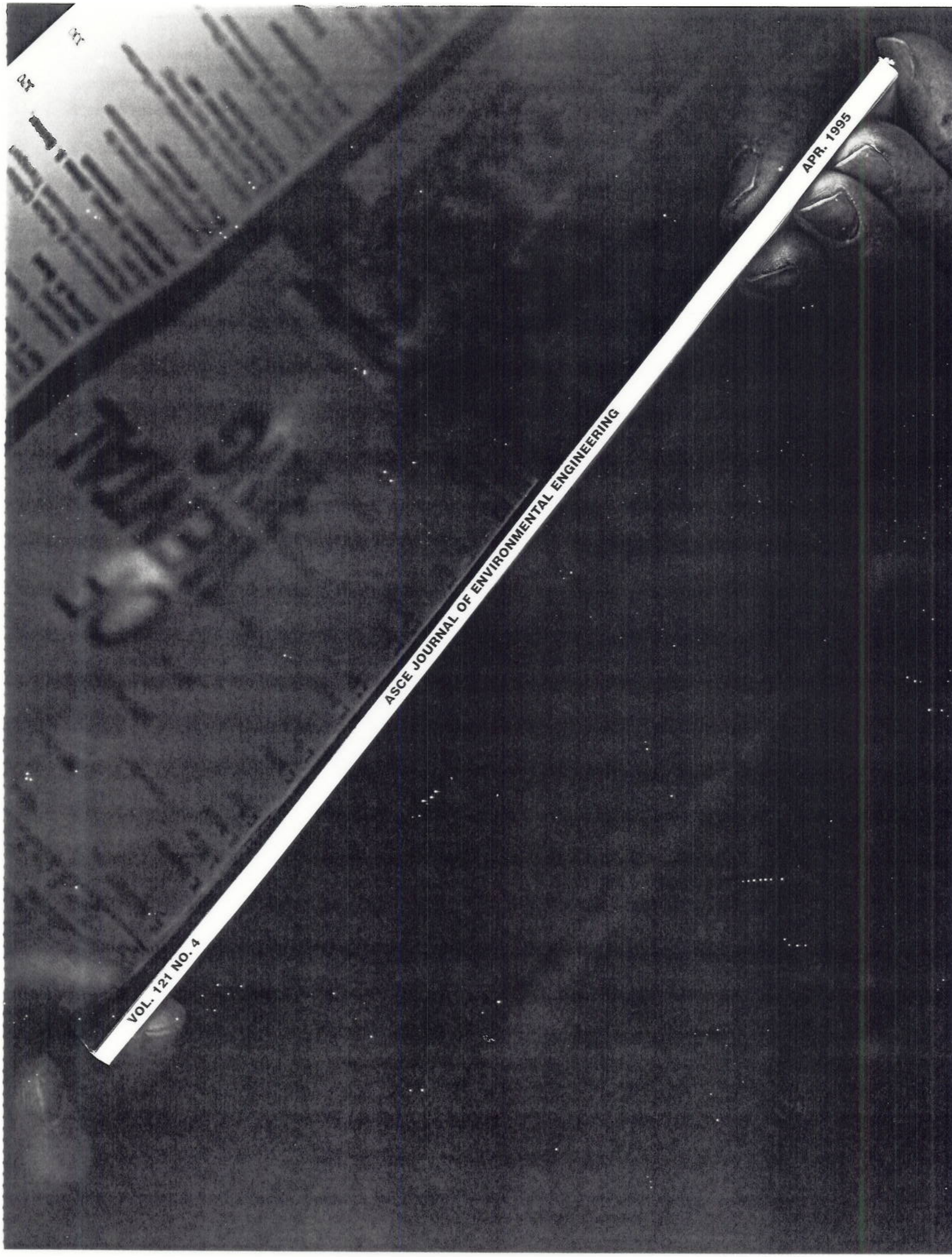
APPENDIX. REFERENCES

"A citizen's guide to radon." (1992). *EPA 402-K92-001*, Envir. Protection Agency, Washington, D.C., May.

Hubbard, L. M., Bohac, D. L., Gadsby, K. J., Harrje, D. T., Lovell, A. M., and Socolow, R. H. (1988). "Research on radon movement in buildings in pursuit of optimal mitigation." *Proc. Am. Council for an Energy Efficient Economy, 1988 Summer Study*, 2, American Council for an Energy Efficient Economy, Asilomar, Calif., 1(13), 42.

"Laboratory tests external coatings." (1979). *Report 9*, DSMA ATCON Ltd., Atomic Energy Control Board Development Program for Radon Reduction, Ontario, Aug.

Marynowski, J. M. (1988). "Measurement and reduction methods of cinder block wall permeabilities." *Working Paper No. 99*, Center for Energy and Environmental Studies, Princeton University, Princeton, N.J.
"Standard test method for rate of air leakage through exterior windows, curtain walls, and doors." (1984). *ASTM E 283-84*, ASTM, Philadelphia, Pa., Sep.
"Standard specification for hollow load-bearing concrete masonry units." (1985). *ASTM C 90-85*, ASTM, Philadelphia, Pa., Jul.


VOL. 121 NO. 4
ASCE JOURNAL OF ENVIRONMENTAL ENGINEERING
APR. 1995