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Performance of wall coatings for concrete and masonry buildings in Alaska

Charles J. Korhonen and John J. Bayer, Jr.

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Coatings traditionally have been applied to the Army's concrete and masonry buildings in Alaska to improve their appearance and to increase their weather resistance. Unfortunately, these materials have not always lasted as long as desired, resulting in high maintenance costs. A visual examination of 151 buildings at three military installations in Alaska revealed that water vapor condensation was a major cause of premature coating failure. This moisture not only caused coatings to deteriorate, but when it froze, it caused spalling of the wall. Laboratory tests proved that coatings with the best field performance had the highest permeance to water vapor. This suggested that more attention be given to defining and selecting breathable coatings.

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PREFACE

This report was prepared by Charles J. Korhonen, Research Civil Engineer, and John J. Bayer, Engineering Technician, Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded under DA Project 4A762784AT42, *Design, Construction and Operations Technology for Cold Regions*; Task BS, *Installation Management and Operation*; Work Unit 022, *Coating and Repair Material for Buildings in Cold Regions.*

Wayne Tobiasson and Stephen Flanders of CRREL technically reviewed this report. The authors thank Susan Taylor of CRREL for her diligent work in examining the coatings with the electron microscope. She opened up another possible technique for evaluating coatings for use in the cold regions.

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CONVERSION FACTORS: U.S.CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4	millimeter
foot	0.3048	meter
$foot^2$	0.09290304	$meter^2$
mil	0.0000254	meter
gr*/hr ft^2	0.697	gr/(hr m^2)
gr/hr ft^2 (in. Hg)	57.214	ng/(s m^2 Pa)
degrees Fahrenheit	t°C = (t°F–32)/1.8	degrees Celsius

*grains

Performance of Wall Coatings for Concrete and Masonry Buildings in Alaska

CHARLES J. KORHONEN AND JOHN J. BAYER, JR

INTRODUCTION

Selecting coatings for buildings in cold regions requires special considerations because harsh conditions can cause coatings to fail more often than necessary. In Alaska, at Forts Greely, Richardson and Wainwright (Fig. 1), concrete and masonry buildings are routinely coated both to increase their weather resistance and to improve their appearance. These coatings include not only the traditional paints,* but some of the newer synthetic resins as well. Unfortunately, they have not always lasted as long as desired; some of them have failed within a short time after application. As a result, a significant portion of the operation and maintenance budget of a building can be spent on repainting walls.

We examined 151 concrete and masonry buildings at the three facilities and tested the same type of coatings used on the buildings in the laboratory to determine why some coatings did or did not perform up to expectations.

Though coatings can fail for a number of reasons, we were most interested in identifying failures related to the cold. In most cases this was difficult to do because many of the failures involved a combination of factors that were not easy to separate out. But by comparing one building to another, looking for similarities, it became apparent to us that moisture, from within buildings, was an underlying cause of paint failure.

This study was conducted in two parts: first, during the spring of 1986 the walls of concrete and masonry buildings at Forts Greely, Wainwright and Richardson were examined for deterioration, and second, during the spring and summer of 1988, the coatings that we observed in the field were studied in the laboratory to quantify their ability to permit water vapor to pass through them.

* The terms coating and paint will be used interchangeably in this report.

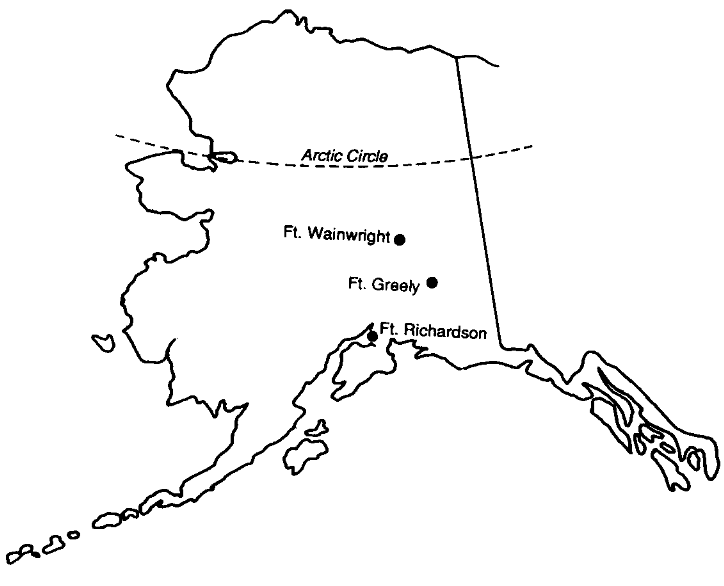


Figure 1. Survey site locations.

FIELD STUDY

The field study consisted of reviewing maintenance records, contract documents and as-built drawings; interviewing maintenance personnel and building occupants; and visually examining, photographing and sampling the walls. Appendix A presents the information gathered for each building. It lists the building use, wall construction, type of coating, age of coating, visual rating of coating, and condition of the wall beneath the coating.

Building humidity

We took no humidity or other moisture measurements during the field study, other than noting the differences in building use, which, when comparing buildings, served to indicate which one might have the higher interior humidity and thus be more likely to have moisture in its walls. The measurements of Flanders et al. (1982), together with our observations, were used to estimate the indoor Relative Humidity (RH) for each building type.

Warehouses are considered to be the driest buildings. About the only contributor to internal humidity is the ground on which the building sits. We estimated their internal humidity at slightly above that of winter air or 5 to 10% RH.

Offices, barracks and residences are more humid. At 0°F outdoor air temperature, Flanders measured their indoor humidity to be about 20, 30 and 35% RH respectively.

Special use buildings, such as mess halls, craft shops and theaters, would have humidities that cycle from low to high depending on building use. At times they might be dry like the warehouses and at other times quite humid. One humidified computer building was maintained at 45% RH year round, which would probably represent the long-term high for most special use buildings. A laundry might be even higher at its maximum.

Wall construction

As-built drawings, spot-checked by visual examinations, provided the source of information on how the various walls were constructed. Figure 2 shows three wall types, each containing an air cavity with either concrete masonry block or poured concrete panel exteriors. Appendix A lists the wall type of each building, along with its exterior coating and whether it had a vapor retarder or not.

Coating types

Concrete and masonry surfaces tend to be alkaline. Cement, lime and their products such as concrete, masonry block and mortar are quite alkaline. Why the concern? Many paint products, particularly the oil-based ones, can be attacked by alkali in a wall. Thus, the choice of paints for concrete and masonry walls is limited to those that can be used in an alkali-rich environment, regardless of what climate the building is in.

Three types of paints were observed on the buildings in this study:

1. Cement.
2. Latex.
3. Textured.

Cement paints were used on 2 buildings, latex paints were used on 58 buildings and textured paints were used on 87 buildings; 5 buildings were uncoated and 1 building was stained. The stain's base material was unknown so it was not listed as a type of coating, though it can be considered one. Also, these numbers add up to more than 151 because portions of two buildings were painted with different coatings and as a result were listed in two categories.

The three coating types are alike in that they each contain a solvent, resin and pigment portion. They differ in the material used for each portion and in the use of other proprietary additives. The solvent dissolves or disperses the resin throughout the paint. The solid pigment, when mixed into the paint, provides color. The resin is the glue that holds the pigment onto the painted surface once the solvent drys.

Table 1 lists the solvent, resin and pigment contents of the coatings in this study. Although RE-NU-IT was not used on the buildings examined, it was included in Table 1 and elsewhere in this report for comparison because it may be used on concrete and masonry buildings in the future. (RE-

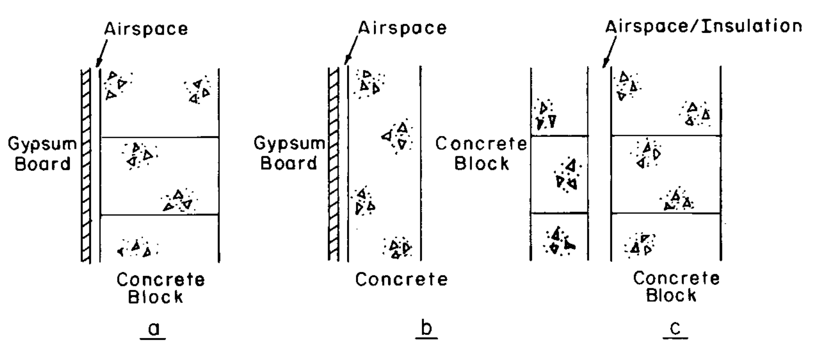


Figure 2. Building wall types (interior on left).

Table 1. Solvent, resin and pigment contents of coatings.

Type	*Federal specification*	*Brand name*	*Solvent*	*Resin*	*Pigment*
Cement	—	—	Water	Portland cement	Titanium dioxide
Latex	TT-P-19	—	Water	Acrylic	Titanium dioxide, silica and other fillers
Latex	TT-P-96	—	Water	Vinyl or acrylic or both	Titanium dioxide, silica and other fillers
Textured	TT-C-555	XL-70	Mineral spirits	Vinyl toluene acrylic	Titanium dioxide, silica and other fillers
Textured	TT-C-555	Sonneborn	Water	Acrylic modified alkyd	—
Textured	TT-C-555	RE-NU-IT	Mineral spirits	Modified alkyd	—
Textured	TT-C-555	Kennitex*	—	—	—
Textured	TT-C-555	Tex-Cote	Mineral spirits	Modified alkyd	Titanium dioxide

* Discontinued

NU-IT has had an impressive record on wooden buildings, adhering where latex paint has blistered and peeled.)

Cement paints are relatively low in cost. By their very nature, they are compatible with highly alkaline surfaces and may be applied directly to new concrete. They are composed chiefly of white portland cement, pigment and water; sand is often used as a filler. When dried, cement paints are hard and brittle and subject to cracking, especially if too thickly applied. Thin coats lack hiding power and durability. When used on the two buildings at Fort Wainwright (Appendix A), the cement paint was mixed on site, worked into the wall surface with a stiff-bristled brush and smoothed off before the cement hardened. To be properly cured, cement-based paints must be kept moist for 48 hours after application. Whether this final step was done or not is unknown, but it is plain to see that application of this paint is labor intensive and requires a fair amount of skill. Largely because of this extra effort needed in application, cement paint has not been used much in Alaska.

Latex paints have been around for the longest time of all the paints at the three Forts. They are economical, easy to apply and are moderately alkali-resistant. They are based on emulsions of various resins, pigments and water. The resin (binder), according to Federal Specification TT-P-19 and TT-P-96 (GSA 1983, 1985), can be vinyl or acrylic or a combination of both. Upon drying, the emulsion becomes hard and stiff, but not brittle like the cement paint. Though TT-P-19 uses coarser ground pigments than TT-P-96, it was not possible to distinguish on which buildings each paint was used, although TT-P-96 is the newer of the two and is supposed to be used in lieu of TT-P-19. The term latex was used in Appendix A to cover either case. (As will be seen later, it would have been useful to distinguish between the two latex paints.)

Textured coatings, according to Federal Specification TT-C-555 (GSA 1973), may come in a wide range of solvent and resin formulations. Two of the textured coatings used on the buildings in this study were oil-based and one was water-based. Although oil-based paints are vulnerable to alkali attack, they can be used on primed concrete. The oil-based coatings (XL-70 and Tex-Cote) were soft and easily dented with a thumb nail, while the water-based coating (Sonneborn) was hard, very much like latex paint. We couldn't find out what the make up of Kennitex was, but it was hard, leading us to believe that it too was water-based. (RE-NU-IT, used on building 1045, a wooden structure at Fort Wainwright, was soft.)

In general, the textured coatings seemed to bond tighter to a wall than latex paint. A knife blade was needed to scrape a small amount of textured paint off a wall, while simply prying with a fingernail often loosened relatively large sections of latex paint. Of all the paints, XL-70 and Tex-Cote seemed to adhere the tightest.

Maintenance costs

Except for touch-up work, repainting is done under contract. The last group of buildings at the three facilities was repainted in 1986 at a cost of $500,000. In addition to this expense, a fair amount of in-house effort and money is expended each year on small repairs, but it was not possible to determine that dollar amount. It was also not possible to compare the 1986 contract costs to the past, as records were not clear on those costs either. However, most of the people we talked to agreed that maintenance painting is gradually becoming a bigger portion of the typical building's maintenance budget.

Part of the reason that costs are escalating is that newer and more expensive paints are being tried in the hope that the paint will last longer. Textured paints are the newest ones being tried. They seem to last longer than latex paint but are more costly. For example, in 1986 priming and painting with XL-70 cost $\$0.24/ft^2$ compared to about $\$0.09/ft^2$ with latex.* (Though high, a recheck of the records reconfirmed the price difference between XL-70 and latex. In-place costs for the other textured paints were not readily available but were considered to be slightly higher than latex.) Thus, to be cost competitive, the XL-70 would have to last about two and a half times longer than latex paint.

Coating life

We used our field observations to estimate the expected life of coatings and compared these results to what maintenance personnel felt were reasonable lives. Our estimates agreed quite well with their experience.

Our estimates were based on a scheme for rating the appearance of one building against another. In this scheme each building was placed into one of four categories: excellent, good, fair or poor. Those buildings whose coatings were not cracked, peeled, crazed, faded or soiled were given "excellent" ratings. Those whose coatings showed signs of wear but did not, in our opinion, need maintenance received a rating of "good." If a building needed minor work it was termed "fair." Those that we felt needed total repainting received "poor." A building that fell between two rating categories was placed in the one it most closely fit or, if that couldn't easily be determined, it was arbitrarily assigned to one of the two ratings. The building-by-building ratings are given in Appendix A.

Once all the buildings were rated, the results were analyzed for aging trends. Such trends, however, were not readily discernable from the individual ratings of Appendix A because the ratings were too widely scattered. It is possible, for example, to find a several-year-old coating with an "excellent" rating and an identical, younger coating with a "poor" rating. These individual differences were smoothed out through averaging to produce a believable aging trend. We grouped each coating by location and age to do this. Table 2 illustrates how the averages were established and Figure 3 presents graphs of the results.

Before commenting on the relative performance of these coatings, let's "validate" Figure 3 by comparing it to painting cycles as seen through the eyes of maintenance personnel at the three bases.

Those responsible for scheduling painting jobs were questioned on repainting frequencies. They did not keep formal records on such things nor did they have the benefit of seeing Figure 3. They relied on experience and could only answer for particular paints, depending on their experience with them. Nevertheless, their answers proved valuable.

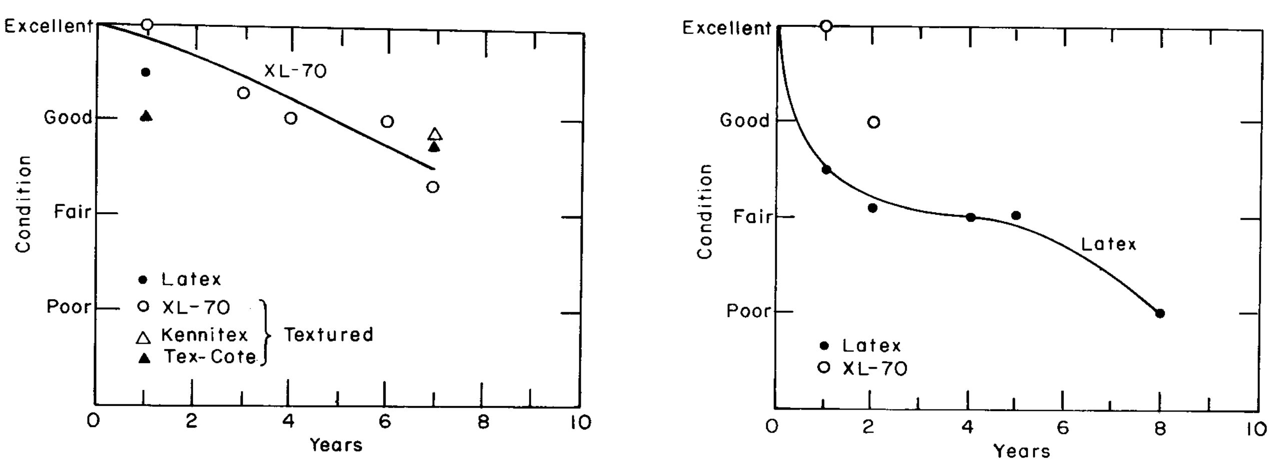
At Fort Greely, maintenance personnel said that latex needs to be repainted every 4 to 5 years on average. There is a gradual decline in paint life with increased paint thickness, but old paint is usually not removed down to bare wall until it is three layers thick. At that point, it is completely removed from the wall because thicker paint films fail too quickly. At Fort Wainwright, latex paint lasts 6 to 8 years. At Fort Richardson, latex is used very little, so personnel there gave us their opinion about textured paints. Though only a few textured-painted buildings have yet to reach a state where they need repainting, the maintenance people felt that these paints should go on to last 10 or more years. (The consensus at Fort Richardson was that latex probably lasted about 8 to 10 years when it was used.)

*Personal communication with D. Fogel, Fort Richardson, 1986.

Table 2. Average paint ratings.

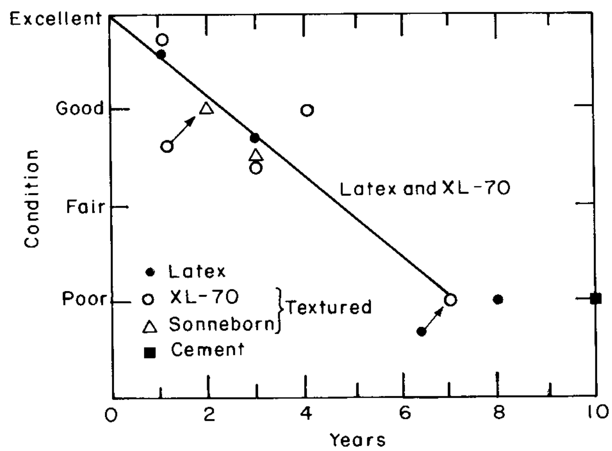
Location	Coating Type	Coating Age	Excellent (4 pts)	Good (3 pts)	Fair (2 pts)	Poor (1 pt)	Average* rating
			Number of buildings at each rating				
Ft. Greely	Latex	1	1	2	2	1	2.5
		2		3	2	2	2.1
		4		1	5	1	2.0 †
		5			2		2.0
		8				1	1.0
	XL-70	1	3				4.0
		2		2			3.0
Ft. Richardson	Latex	1	1	1			3.5
	XL-70	1	3				4.0
		3	1	3			3.3
		4		2			3.0
		6		1			3.0
		7		1	2		2.3
	Kennitex	7	1	7	4	1	2.8
	Tex-Cote	1		1			3.0
		7	1	5	2	1	2.7
Ft. Wainwright	Cement	>10				2	1.0
	Latex	1	4	2			3.6
		3		2	1		2.7
		7				4	1.0
		8				1	1.0
	XL-70	1	5	2			3.7
		2		1			3.0
		3		2	3		2.4
		4		1			3.0
		7				1	1.0
	Sonneborn	2		1			3.0
		3		6	4	1	2.5

* Average rating = Σ (rating × no. of bldgs)/total bldgs.
† Example: [(3×1) + (2×5) + (1×1)]/7 = 2.0



a. Fort Richardson. *b. Fort Greely.*

Figure 3. Averaged condition ratings. Arrows point to dual data point locations.



c. Fort Wainwright.

Figure 3 (cont'd). Averaged condition ratings. Arrows point to dual data point locations.

Figure 3 agrees quite well with these assessments. Since, in our rating system, "fair" represents the point at which work is first needed on a building, we selected it to represent our estimate of coating life. Thus, Figure 3 shows latex paint to last 4 to 5 years at Fort Greely and 4-1/2 years at Fort Wainwright; XL-70 should last 9 years at Fort Richardson (these data were extrapolated). Except for Fort Wainwright, these estimates agree with those of the maintenance personnel. The apparent discrepancy at Fort Wainwright can be explained in that it was our impression that buildings there were not repainted until they reached a rating of "poor." On Figure 3, this relates to a paint life of 7 years, which agrees with the 6- to 8-year cycle reported by the maintenance people.

This "validation" process not only provided a tie to real world experience, but gave us confidence to say something about the coatings not commented on by the maintenance people. For example, though Fort Richardson maintenance personnel expect XL-70 to last longer than latex, we don't expect it to be significantly better. We say this because Figure 3 suggests that XL-70 may be only slightly better than latex at Fort Greely and only equal to latex at Fort Wainwright. Therefore, unless the price difference between latex and XL-70 diminishes, it is not seen as an economical alternative to latex paint.

Kennitex, Tex-Cote and Sonneborn, the other textured paints, are represented by only a few data points on Figure 3 so conclusive evidence about their life expectancy is not available. However, it is worth pointing out that Sonneborn's performance fell below that of latex, Tex-Cote's was about equal to XL-70 and Kennitex's was slightly above that of XL-70. Thus, the oil-based textured coatings were better than the water-based textured coating. But, because none are clearly superior in performance, we considered none of the textured coatings economically better than latex paint.

Cement paint was used on two buildings at Wainwright and is represented by one data point on Figure 3. Its life expectancy, assuming linear deterioration, is about 6 to 7 years. If it were easier to apply, it would be a reasonable alternative to latex paint.

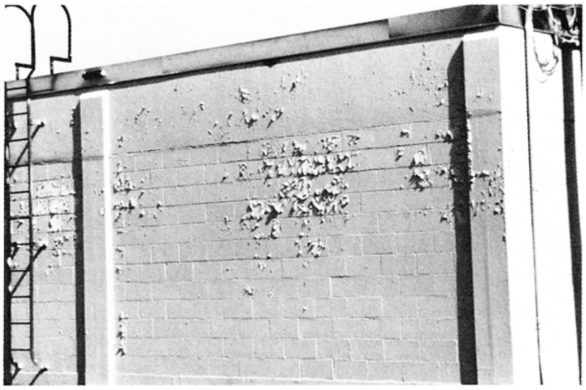
Problems from internal moisture

The following examples illustrate that external coatings were affected by moisture buildup from internal sources and that buildup was worsened by multiple-layered coatings.

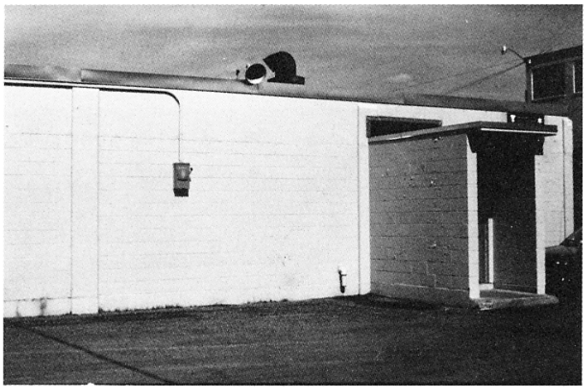
Building 610, Fort Greely, offered the best evidence of moisture from within a building causing exterior paint to debond from a wall. Its walls, starting from the inside, consist of a 1/2-in. gypsum board (painted), a 3/4-in. air space, and 8-in. concrete masonry block (latex coated on the outside). It is divided in half into computer and office space by a concrete block wall. The building is heated to 70°F and maintained at 45% RH on the computer side, while no moisture is intentionally added to the air on the office side. Because some humidity will seep into the drier office space from the computer space, we estimate the office to be at about 30% RH, which is a bit higher than normal office buildings in interior Alaska. (Flanders et al. [1982] measured office humidity typically at 20% RH.)

This humidity difference between the two sides of the building caused the external latex paint to fail at different rates. On the humidified side the paint peeled off the wall every 2 years according to maintenance personnel. On the lower humidity side, the paint lasted for 4 years (Fig. 4). Clearly, indoor humidity is harmful to exterior paint if it can condense behind the paint.

Condensate, although not seen on building 610, was evident behind coatings on other buildings. For example, the dark areas under the left column of windows in Figure 5 (building 4065, Fort Wainwright) were damp. The right windows of that building were exposed to more sunlight and thus had a chance to dry out before this photo was taken (some of the darkness was also caused by dirt). Another building (3591, Fort Wainwright) exhibited damp areas at random locations. On it, water beaded up on the outside face of the wall as the coating was scraped away from damp areas. Removing this coating was relatively easy when water was present but it was not so easy when the wall



a. High humidity side.



b. Low humidity side.

Figure 4. Two-year-old paint on building 610 at Fort Greely with sections of high and low humidity. The paint on the high humidity side of this building failed every 2 years while the paint on the low humidity side lasted 4 years.

behind the coating was dry. There were no obvious ways for exterior water to get behind these coatings. Thus, like building 610, interior humidity had to be the source of the observed moisture. We estimate the humidity of buildings 4065 and 3591 to be between 30 and 40% RH.

Another way to see the effect that indoor moisture has on paint life is to compare the performance of paints on buildings that have vapor retarders to paints on buildings without vapor retarders. Table 3 presents this comparison for latex-coated buildings at Fort Greely (insufficient data prevented a similar analysis at the two other facilities). The data in Table 3 were developed in the same manner as those in Table 2. As can be seen, latex paint degrades 0.71 rating points every year on buildings not containing a vapor retarder and 0.42 points a year on buildings with a vapor retarder. Based on our previously described rating scheme, this translates into paint failure every 3 years for buildings without and 5 years for those with vapor retarders. (We could not determine the quality of installation work for the vapor retarders, but the benefit of having one is demonstrated here.)

Figure 5. Moisture problems on building 4065, Fort Wainwright, which was coated with XL-70 paint. Moisture can be seen as dark areas beneath the left windows.

Table 3. Relative aging rate of latex paint on buildings with type-A walls.

Location	*Vapor retarder*	*Annual loss in rating*
Greely	yes	0.42
	no	0.71*

* Building 610 not included because of its abnormally high indoor RH.

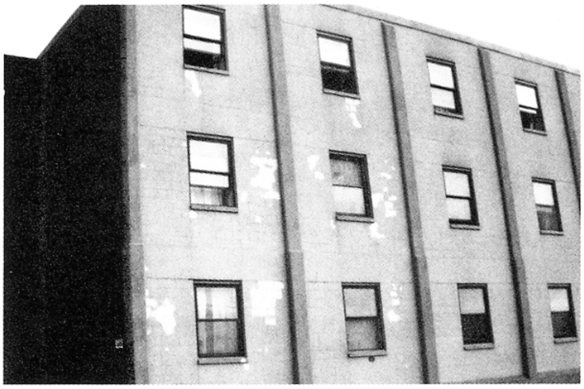
Once water becomes entrapped behind a coating, it can freeze and cause spalling of the wall. Building 3401 at Fort Wainwright provides a good example of that. This building has the longest and most troubled history with textured coatings of all the buildings we studied. In 1979, the existing latex paint was cleaned, primed and coated with XL-70. The multilayered paint began to peel a few years later. Problems eventually became so bad that the loosened paint was removed and another layer of primer and XL-70 was applied. Within a few years the paint failed again.

Many felt that improper application techniques or faulty paint, or both, led to both failures on 3401. A review of contract documents showed that the weather was rainy and cool around the time the coating was applied, so these could have caused the failure. Oil-based paints as a rule are not tolerant of wet walls during application, nor are they

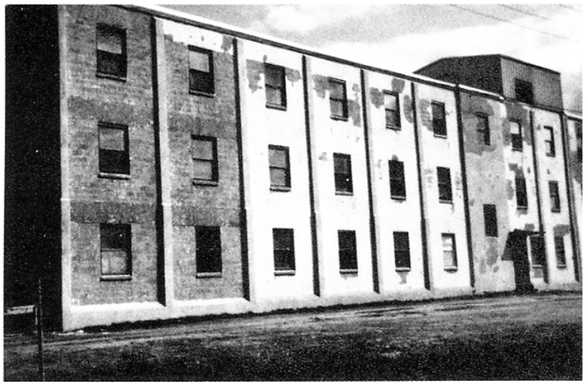
Figure 6. Frost-damaged areas. Large areas of textured coating failed revealing frost-damaged walls, particularly under windows and near bathrooms.

recommended for cold-weather application. On the other hand, our inspection of the building showed us that the paint failed primarily between the original latex paint and the wall. To us, this meant condensation. It was reasonable to suspect that water pushed the latex paint off the wall as it had done to latex paint on other buildings. Only this time, the outer coating of textured paint, being flexible, held together long enough to trap water and cause surface spalling (Fig. 6).

By 1986 it was obvious that the walls of 3401 had to be sandblasted to bare concrete before being painted again (Fig. 7). A return trip to this building in 1988 showed that the single layer of XL-70, applied to primed concrete, was problem-free. The

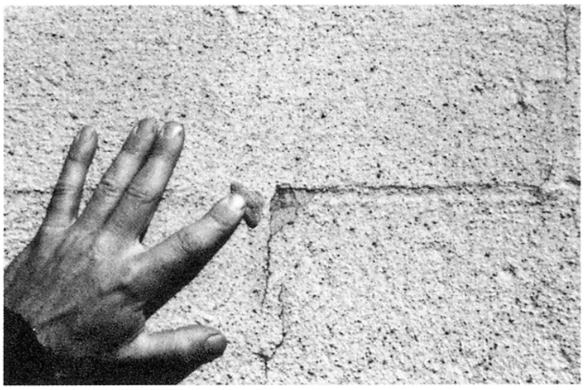


a. Condition of building in 1984.



b. Condition of building in 1986.

Figure 7. Failure of the XL-70 coating on building 3401, Fort Wainwright. Its second recoating is shown beginning to fail in 1984 after being on the building only a few years. In 1986 the building is shown in preparation for a third coating.



a. Building 659, Fort Greely.

b. Building 3721, Fort Wainwright.

Figure 8. Pieces of substrate falling off a building with textured coatings as the paint began to fail. Evidence was most often slight (a) but occasionally a rather large area was affected (b).

thin and relatively breathable* paint had already out-lived the previous thicker and less breathable paint.

On a smaller scale, spalling occurred on several other buildings. In those cases, small bits and pieces of the wall usually came off with the paint (Fig. 8). Interestingly, this only occurred to walls coated with textured paint. Walls coated with latex paint were unmarked (see the frost damage column in the tables of Appendix A). Either textured paint traps more moisture than latex paint because it is less breathable or because it stays intact longer. The laboratory study addresses that issue.

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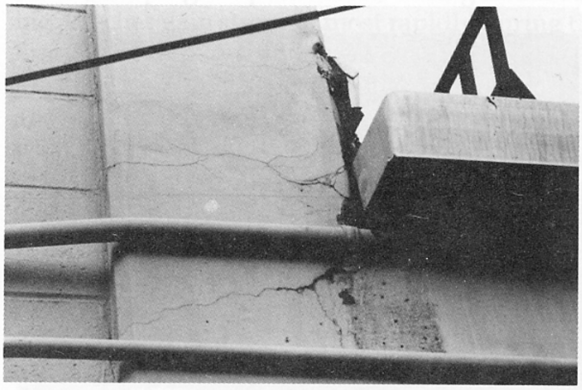
* In this report, breathable refers to how well a paint passes water vapor.

Problems from external moisture

External coatings were not only attacked by moisture from within buildings, but, to a lesser degree, they were also effected by outdoor moisture. Rain and snow had little effect on exterior coatings except when they were concentrated onto small areas of wall. Then, deterioration was striking. Figure 9 shows two examples. In Figure 9a, repeated wettings from water overtopping the roof's edge caused this concrete column to crack by freeze–thaw action. A simple patch will repair this column but, if the water problem is not corrected, freeze–thaw damage will continue. Figure 9b is also related to roof water. In this case the water that made it to internal roof drains was not carried far enough away from the edge of the building to prevent paint erosion.

Ironically, the most dramatic deterioration came from inside-building-air blown onto walls. As



a. Building 628, Fort Greely.

b. Building 764, Fort Richardson. This did not happen if the outlet protruded at least 6-in. past the wall.

Figure 9. Exterior water damage. Water from roofs and roof drain outlets eroded coatings, exposing the subsurface to weathering.

a. Building 662, Fort Greely.

b. Building 35752, Fort Richardson.

Figure 10. Dramatic signs of frost damage from exhaust moisture.

shown in Figure 10, coatings were destroyed and walls were significantly spalled by this warm, moist air. It is possible that thermal cycling, caused by the fan turning on and off, aided in debonding the coatings from the wall, but the spalled concrete could only have been caused by freezing moisture. Much of this damage occurred in as little as 1–2 years after painting.

These types of problems are avoidable. Drains, flashings, gutters, overhangs and downspouts, if kept in repair, would prevent the problems shown in Figure 9. To correct the damage shown in Figure 10, simply redirect the offending moist air away from the buildings.

Problems not related to moisture

The most noticeable change to the coatings caused by something other than moisture was the accumulation of dirt on the walls. Dirt does not mechanically degrade walls or coatings, but its presence usually creates a need for repainting to improve the building's appearance. The rough-surfaced paints seemed to get the dirtiest (Fig. 11). Dirt came from roof runoff water, airborne dust and building occupants.

Although dirt may not directly cause coating failure, repeated paintings, because of dirt, can increase a wall's resistance to vapor flow. And as discussed earlier, heavy films shorten paint life.

The best way to avoid paint buildup and to improve appearance is to wash off the dirt with detergent and water. (We recently learned of a stain for some of the textured coatings that does not increase paint thickness but we are not sure of its effect on breathability.)

Figure 11. Dirty building surface. The rough finish of textured paints makes them more susceptible to soiling than the smoother-surfaced latex paints (building 632, Fort Richardson).

Uncoated buildings

When compared to coated buildings, uncoated buildings required little in the way of maintenance. We examined five uncoated buildings made of textured concrete masonry block (Fig . 12). About the only maintenance required for these blocks might be to remove salt deposits (efflorescence). The salts appear because water that enters a wall dissolves salts in mortar and concrete. Through evaporation, this salt water migrates to the external surface, leaving the salt. Efflorescence is usually harmless.

The most common sources of this water are wind-driven rain, melting snow and construction water. Indoor humidity, identified as a source of wall moisture on the coated buildings, is also a likely source of the efflorescence water in these buildings. Springtime, according to one maintenance person, is the worst time for efflorescence.

Since uncoated buildings are more open to ex-

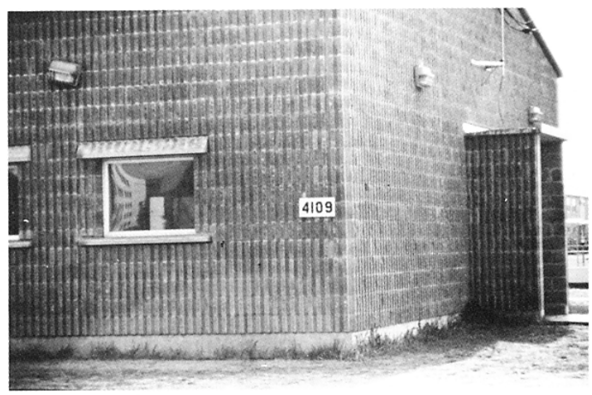


Figure 12. Uncoated buildings performed the best. Except for efflorescence, no other problems were noticed on these types of buildings (building 4109, Fort Wainwright).

Figure 13. Patching problems. Patches failed, often revealing loose substrate below (building 655, Fort Greely).

ternal water than coated buildings, and since the uncoated walls have performed so well, we conclude that coatings are not needed to protect a wall from the outside environment, at least not at the three sites studied in Alaska.

Patches

Patches, really another form of coating, also had difficulty in remaining bonded to a wall. Figure 13 shows a typical patch. It has shrunk inward from its sides, spalled near its edges and loosened at its subbase. Not all these problems are related to the cold. The shrinkage and edge-spalling are indications of poor workmanship, whereas the loose patch may have been caused by frost action.

Patches shrink because of volume changes caused by the evaporation of water from the mix. They can shrink for years, but most of it happens in a relatively short time following placement. Shrinkage is lessened by using as little mixing water as possible and by keeping the patch moist during initial curing. Patches gain strength most rapidly during the first few days following placement. Excessive water loss when a patch is weak will accentuate shrinkage. Whether these patches received proper curing was not determinable, but, after looking at how much they did shrink, it appears to us that they did not.

Patches should never be tapered to a thin edge as spalling will occur, regardless of how well they were cured. Patches should be cut square so that the patch material will have some edge thickness. Normal expansion–contraction forces will crack patches that are too thin. For this patch the perimeter should have been recessed 1/2 in., which it wasn't.

As mentioned, frost action is the likely cause of the entire patch debonding from the wall. We concluded this when several patches were removed, revealing a lightly crumbled subbase—much like that seen behind some of the coatings. As with coatings, patches also need to be breathable.

It would be best to repair concrete with the same material as that of the substrate. In the case of Figure 13, a portland cement mortar of low water content would provide a patch having similar breathability and minimal shrinkage upon final curing.

LABORATORY STUDY

We studied the coatings found on the Alaskan buildings in the laboratory to determine how well moisture could pass through them. They were measured for water vapor transmission with a wet-cup apparatus and were scanned with an electron microscope for holes that might allow water to escape.

Water vapor transmission

Water Vapor Transmission (WVT) provides a measure of the ability of a coating to allow water vapor to pass through it (called breathability here). This is an important property as it affects the potential for moisture buildup behind a coating. Individual coatings were tested for WVT by applying them (Table 4) to a portland cement mortar block and subjecting that block to a steady-state humidity gradient in accordance with ASTM E96 procedures (ASTM 1980). The blocks were sealed, at their perimeters, into galvanized steel pans with wax (Fig. 14), water was added into the space beneath the

Table 4. Application rates of coatings.

*Product**	*Manufacturers' recommended weight (g)*	*Applied weight (g)*	*Paint layer*	*Film thickness (cm)*
RE-NU-IT	27.2	27.1	1	0.031
Sonneborn	38.6	41.9	1	0.050
XL-70	42.3	41.3	1	0.088
	42.3	42.4	2	0.18
TT-P-19	5.6	7.1	1	0.017
	5.6	6.0	2	0.029
TT-P-96	6.01	6.4	1	0.014
	6.01	6.2	2	0.030

* Appropriate primers used beneath all coatings.

Figure 14. "Wet-cup" testing pan. Mortar blocks were sealed into the top of the pan and water was added into the bottom of the pan through a side filling port (arrow) before testing began.

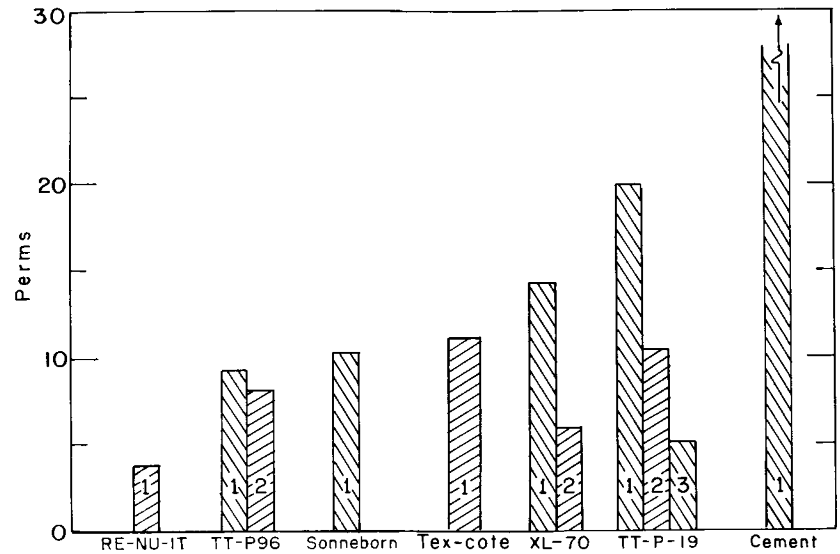


Figure 15. Permeance of coatings. The numbers relate to the layers of paint tested.

specimens through a filling port in the side of the pans and the pans were placed in a room maintained at 80 ± 2°F and 50 ± 2% RH. The pans were weighed daily until a steady rate of weight loss was achieved, as signified by six consecutive weight loss readings being linear. This yielded a measure of the number of grains of water that passed through each square foot of block per hour or WVT.

The WVT of the coatings was separated from that of the block* and was converted into permeance by dividing it by the vapor pressure imposed across the coating during the test. Permeance (gr/hr ft^2 [in. Hg]) is a common method of reporting material breathabilities in technical literature. The permeance of each coating is shown in Figure 15.

Cement paint was by far the most breathable paint tested. It did little to slow water vapor flow through the mortar block. In fact, depending on how the cement paint was formulated, it sometimes acted to increase vapor flow (denoted as no upper limit for cement paint in Fig. 15). We cannot explain why this happened, except to say that the cement paint may have roughened the block's surface, increasing evaporation.

Of the two latex paints tested, TT-P-19 was significantly more breathable than TT-P-96. A single layer of TT-P-19 had a permeance of 20 perms (1 perm = 1 gr/hr ft^2 [in. Hg]) as compared to 10 perms for TT-P-96. A second layer diminished these measurements to approximately 11 and 6 perms respectively. A third layer, the point when Fort Greely removes old paint before repainting, reduces TT-P-19 to 5 perms.

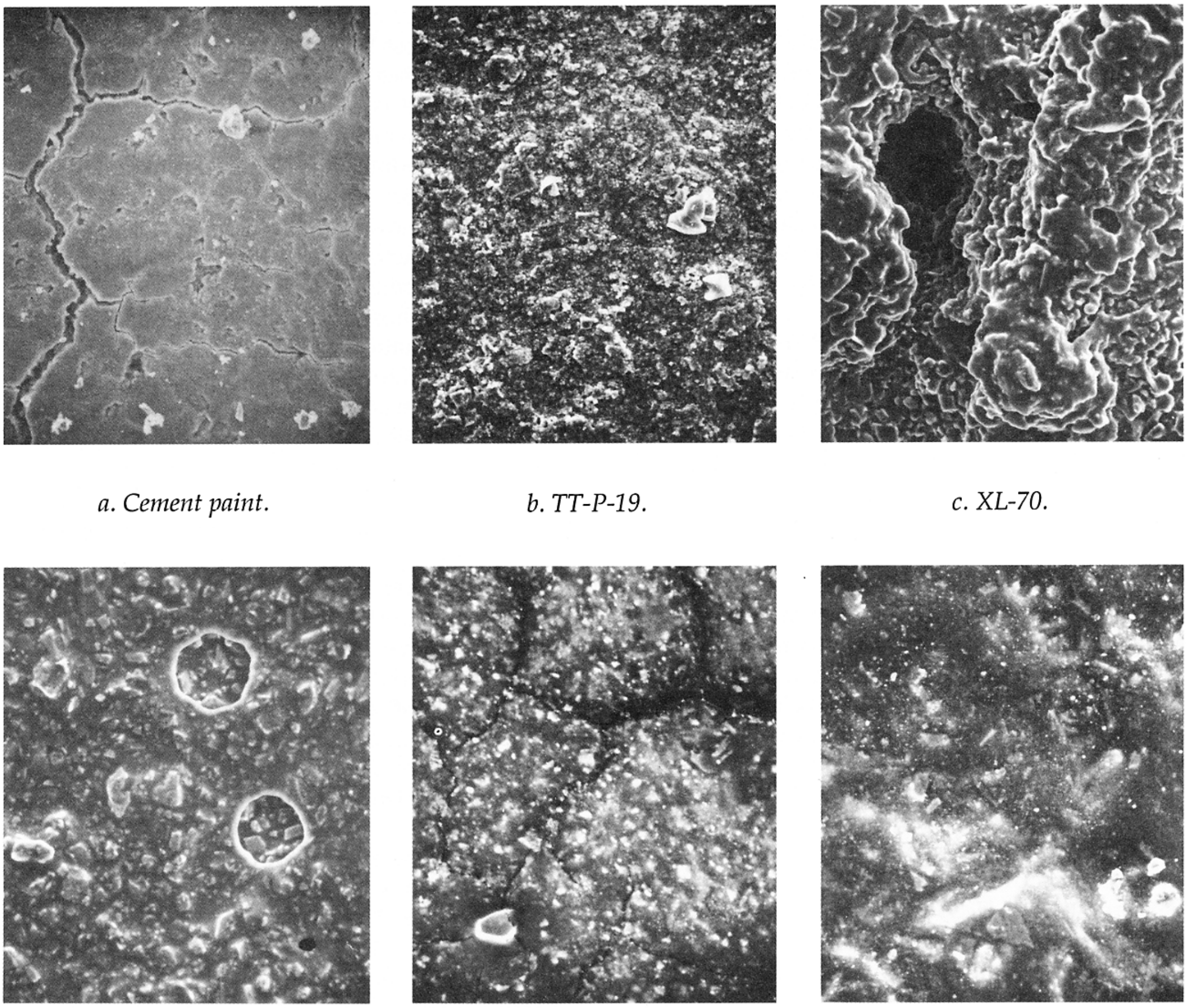
Of the textured paints, XL-70 was the most breathable (14.5 perms), RE-NU-IT was the least breathable (3.7 perms), and Sonneborn (10.6 perms) and Tex-Cote (12.5 perms) were in between. (As mentioned earlier, XL-70 looked the best of all the coatings. We believe that its good performance was caused in part by its breathability, but also by its ability to adhere to a wall and resist the moisture forces behind it.) The RE-NU-IT was not used on the concrete buildings in this report, but because it is the least breathable of all the paints, we feel that it would encounter moisture related problems if it were to be used.

Electron microscope

This test was conducted to determine if, by examining surface features closeup, the relative breathability of a coating could be determined. The surface of each coating was examined with a scanning electron microscope at a ×350 magnification. Samples were prepared by applying the coatings onto pieces of glass.

Figure 16 shows a photomicrograph of each surface. The coatings with the densest looking surfaces are TT-P-96 and RE-NU-IT, which are relatively vapor tight according to the WVT tests. Cement paint is very cracked, and it had the highest permeance. TT-P-19, XL-70 and Sonneborn appear rough and porous. Their WVT results fall between

* Over 200 uncoated blocks (8 × 8 × 1/2-in.) were found to have a WVT range of 3.6 to 16.7 gr/hr ft^2. Only blocks having values between 6.2 and 6.6 were used for testing the coatings. Coatings were subsequently applied to a 7-1/2 × 7-1/2-in. center area with the outer 1/2 in. masked to vapor.



a. Cement paint. *b. TT-P-19.* *c. XL-70.*

d. Sonneborn. *e. TT-P-96.* *f. RE-NU-IT.*

Figure 16. Scanning electron microscope images at ×350 magnification.

those of cement paint and TT-P-96. (Tex-Cote was not included here but we expect its surface would look something like that of XL-70 since it was close to XL-70 in permeance.)

These results indicate that a scanning electron microscope might prove useful as a way to screen coatings according to breathability. More studies are needed to explore this possibility.

DISCUSSION

Coatings can fail for a number of reasons, but, in this study, moisture was a major cause. The source of much of the moisture was from within a building. Thus, the key to extend coatings' lives lies with controlling that moisture. Two ways to achieve that goal are to "tighten" the inside of a wall to restrict the entry of moisture and to "loosen" its exterior to allow the escape of moisture.

Sources of moisture

The location and type of failure provided clues as to the source of moisture that entered a wall. It was easy to determine when the moisture came from outside of the building. In those cases a small area of coating was often completely missing from a wall and nearby was an exhaust fan, a roof edge or a drain pipe that provided the moisture.

Internal moisture came in several forms. Paint problems that occurred under windows put the sills and caulking around the frame under suspicion, for condensation on the window panes can easily run down into the wall below if these joints are not properly sealed. Any damage near the foundation line, such as described in the section on patches, could indicate groundwater drawn up into the wall. The isolated or otherwise randomly spaced problems seen on many of the texture painted walls and even on the uncoated walls can be explained by humidity from within the building. The randomness suggests air leakage more so than it does water entering the wall by diffusion. Diffusion-caused problems would be more indicative of a widespread or uniformly distributed problem as was clearly seen on building 610, Fort Greely.

Although moisture came from several sources, condensation, driven by air leakage and vapor diffusion mechanisms, was the major cause of paint failure.

Moisture buildup

Air leakage is recognized as the more powerful of the two moisture drive mechanisms, but, in Alaska, diffusion can be significant too. According to ASHRAE (1981), water vapor diffuses through walls in amounts proportional to the permeance of the wall to water vapor and to the temperature difference across the wall. This outward diffusing vapor condenses when it reaches its dew point temperature. It is then absorbed by the wall and continues outward as a liquid until it freezes. In sufficient amounts, this water can debond paint and spall walls.

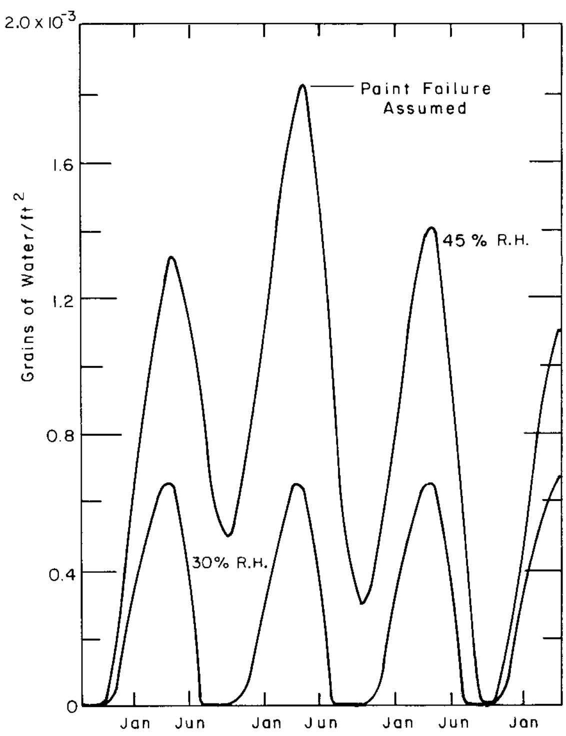


Figure 17. Moisture wetting curves based on diffusion of water vapor for building 610, Fort Greely.

Figure 17 shows the theoretical amount of water, attributable to vapor diffusion, that may build up behind a painted surface. Building 610, Fort Greely, was chosen for this example because it provides dramatic evidence of paint failure based on two very different indoor humidities. Wall cross-section properties are given in Table 5 and indoor-outdoor conditions in Appendix B.

In general, moisture builds up during the winter and dries out during the summer. When the internal building humidity is maintained at 45% RH, calculations suggest that the wall doesn't fully dry the first summer. It continues to wet up to 1820 gr/ft^2 of moisture the second winter. It's during the second year that the paint literally peels off the wall. At that point of distress the wall should become more breathable and moisture buildup should be less intense. To show this effect, we estimated the paint's permeance to increase by 60%. As expected, less moisture accumulates after the second year.

On the low humidity side of the building, where paint lasts 4 years, 657 grains/ft^2 of moisture build up each winter. This is significantly less than the buildup in the 45%-RH wall, but, obviously, it's still enough to cause premature failure.

How much moisture is needed to cause paint failure? To answer this question, we soaked in water a thin layer of concrete block that was about the same thickness as the depth of damage noted on buildings. (Concrete can be frost-damaged when it becomes over 91% saturated with water.) After 24

Table 5. Wall properties of building 610 at Fort Greely.

Layer	*Thermal resistance (ft^2 °F hr/BTU)*	*Moisture resistance* (ft^2hr [in. Hg]/gr)*
Inside air film	0.68	0.00
Primer and paint	0.00	0.31
Gypsum board	0.45	0.03
Air space	1.15	0.00
Concrete block	1.11	0.40
Paint	0.00	1.00
Outside air film	0.17	0.00
Totals	3.56	1.74

* perm = 1/(moisture resistance)

hours of soaking, the thin piece of concrete became saturated with only 300 gr/ft^2 of water. This relatively small amount of water suggests that the walls of building 610 could certainly become wet enough by vapor diffusion alone to experience frost damage. Remarkably, the walls were not damaged. The reason for the lack of frost damage is not clear. Perhaps the wall cavity serves to vent away some moisture that would otherwise accumulate behind the external coatings or the external coating may crack, making the wall more breathable, before critical amounts of moisture build up, or both. Frost damage was evident on other buildings with lower humidities than Building 610, so, from this, we know that the amount of moisture accumulation predicted by Figure 17 is not needed to cause problems.

From the foregoing, it appears that a small amount of moisture is all that is needed to cause paint problems; 300 gr/ft^2 of water will saturate a thin layer of wall to cause problems if it freezes, but if water continually travels outward from within a building, as we know it does, then thin ice layers composed of even much less moisture could also disrupt the wall surface. Without in-situ measurements, it is difficult to say how much water, or from what source. It is reasonable to say, however, that vapor diffusion can be a significant force. When added to the effects of air leakage, coatings that inhibit moisture passage are prone to failure by moisture buildup behind them.

Moisture control

Designers often attempt to block moisture migration into walls by using vapor retarders. Intuitively, we think that a low permeance material would be better than a high permeance one. In practice, however, a wall is usually so full of openings and penetrations that overall continuity of a vapor retarder, rather than its permeance rating, is the issue. Let's explore that for a moment.

If a continuous, unbroken sheet of 4-mil-thick polyethylene were to be installed on the warm side of building 610's walls, the first year's moisture buildup, according to diffusion calculations, would decrease from the 1327 to 12 gr/ft^2 at 45% indoor RH and to essentially nothing at 30% indoor RH. The "poly" should be enough to eliminate moisture problems. However, it wasn't. We saw moisture behind coatings, even on those buildings with vapor retarders. Making adjustments in the vapor diffusion calculations to allow for holes in the vapor retarder doesn't fully account for this moisture either. Thus, without further measurements, one must assume that air leakage accounts for some of the moisture.

Until walls are built more resistant to moisture, the conservative approach to using external wall coatings would be to acknowledge that problem causing moisture will get into a wall. This means that external coatings should be sufficiently breathable so as to not trap this moisture.

Breathable coatings

Current guidance on condensation avoidance is largely based on the principles of vapor diffusion, which say that, in cold climates, exterior paint should be more breathable than the inside surface of the wall. More specifically, Miller (1983) recommends that exterior paint permeance should be five times greater than the inside. Andersen et al. (1984) suggest a ten to one ratio. For buildings with internal polyethylene vapor retarders (0.08 perms), these ratios mean that the exterior paint should be at least 0.4 to 0.8 perms. When no vapor retarder is used other than indoor paint (0.8 perms), exterior paint must be ten times more breathable because of more vapor passing the indoor paint. Federal specification TT-C-555B (GSA 1973) requires exterior paint to be 0.4 perms, regardless of the inside wall surfacing.

Comparing this guidance to our lab results shows that, for buildings with polyethylene vapor retarders, all of the coatings tested exceed the 5:1 and the 10:1 ratios and the Federal paint requirement. Even for buildings with only indoor paint as the vapor retarder, all but RE-NU-IT would be acceptable as external coatings. Yet, we saw these "acceptable" coatings experience problems in the field. For Alaska, it's apparent to us that coatings need to be more breathable than current guidance suggests.

So, how breathable should exterior coatings be? Based on their field performance, we can make some observations about a coating's breathability. For example, we learned from Fort Greely that latex paint should not be thicker than three layers. If it was, early failure was a certainty. According to our laboratory tests, three layers of TT-P-19, the most breathable of the two latex paints, produced a 5-perm coating. This amount of paint would easily satisfy the above permeance guidance for buildings with vapor retarders and would be marginally acceptable for those without vapor retarders. The best performing paint seemed to be XL-70. It adhered the tightest and lasted the longest of all the paints we observed. At one layer thick, which is what all but building 3401 probably had, this paint had a permeance of 14.5 perms. Though this greatly exceeds the guidance for permeance mentioned above, XL-70 was somewhat troubled by moisture buildup. However, until more tests are done, XL-70 is the most breathable paint tested and should be used as a benchmark for selecting coatings in Alaska. Anything with a higher breathability should perform well, while lesser breathability should be suspect.

SUMMARY AND CONCLUSIONS

We examined 151 concrete and masonry buildings in Alaska to determine the causes of premature coating failure. We identified internal building moisture as a major cause of this failure. Water vapor that enters walls via air leaks at cracks, defects and other openings into wall cavities and by diffusing directly through wall materials condenses behind coatings causing them to debond from walls, and, in some cases, leading to surface spalling. Calculations, based on vapor diffusion principles, help to show a correlation between moisture buildup and reduced paint life.

Vapor diffusion, however, accounts for only a portion of the moisture that can enter a wall. Air leakage plays a role, although its exact contribution was not determined in this study. Vapor retarders were effective, but, even with one, problem-causing moisture still entered a wall over the course of an Alaskan winter.

Laboratory tests, when compared to observations made in the field, provide some guidance as to the type of paint needed for exterior coatings. Cement-based paint was the most vapor-permeable coating examined. Its main problem and the reason more use was not made of it is that it is very difficult to apply correctly. Its useful life was estimated to be slightly greater than that of latex paint.

Latex paints have a lot going for them. They are inexpensive, they are easy to apply and they are compatible with alkaline surfaces. Laboratory tests showed them to be relatively breathable. Their drawback is that they appear unable to adhere to a wall for very long once moisture begins to build up behind them.

Textured paints were slightly better than latex in expected life. This better life is explained by textured coatings being able to adhere more tightly to walls than can latex paint and thus being able to resist moisture forces longer. It was also pointed out that most textured coatings examined were only one layer thick, whereas most latex paints were several layers thick. Thus, the textured paints, as examined, were actually more breathable than the in-place latex paint.

Our preliminary conclusions are that, to minimize moisture problems on the buildings studied, exterior coatings should perform like XL-70. They should adhere tightly to a wall and have a permeance of around 14.5 perms.

RECOMMENDATIONS

The findings in this report are not detailed enough to make wholesale changes in current methods of selecting and using coatings for Alaskan buildings, but if the following actions are taken, better coating performance should be expected.

1. Minimize moisture migration into walls by adding a vapor retarder to the warm side of the wall. Air leakage can be minimized by sealing any cracks and openings through which moisture laden air might find access into a wall. This will create a higher interior humidity, which will make the building more comfortable to live in during the normally dry Alaskan winters.
2. For new construction, use coatings of at least 14.5 perms (ASTM E96 [ASTM 1980], wet-cup with paint on cement mortar blocks).
3. For existing construction, avoid more than two layers of paint at Forts Greely and Wainwright. Fort Richardson, due to its milder climate, can probably have several more layers.
4. Redirect the air from fans and water from roofs away from building walls.
5. Based on performance, it would be best not to coat buildings that are currently uncoated.
6. Use TT-P-19 latex paint in lieu of TT-P-96. TT-P-19 also is more cost-effective than XL-70
7. When patching, use materials of the same makeup as the substrate.

NEEDED RESEARCH

The results of this study indicate that moisture from within a building is a cause of coating failure in Alaska. Calculations, based on vapor diffusion principles, help us to understand the general nature of the problem but only in a preliminary way does it help to quantify it. More studies are needed to define moisture movement in walls and the concentrations and distributions of moisture that lead to problems. This could include instrumenting buildings with moisture sensors, improving upon methods for controlling vapor flow and searching for better coatings. The following is a list of needed research:

1. Develop a wall moisture sensor.
2. Measure moisture migration due to diffusion and air leakage.
3. Instrument buildings with humidity sensors.
4. Test other coatings in laboratory and field.

LITERATURE CITED

Andersen, N.E., G. Christensen and F. Nielsen (1984) Moisture insulation of buildings. SBI Directives 139. Horsholm, Denmark: National Construction Research Institute.

ASHRAE (1981) *Handbook of Fundamentals*. New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASTM (1980) E96-80 Water vapor transmission of materials, vol. 4.06. Philadelphia: American Society for Testing and Materials, p. 750.

Flanders, S.N., J.S. Buska and S.A. Barrett (1982) Window performance in extreme cold. USA Cold Regions Research and Engineering Laboratory, CRREL Report 82-38.

General Services Administration (1973) Federal specification TT-C-555B, coating, textured (for interior and exterior masonry surface). U.S. Government Printing Office: 1973-210-818/2140.

General Services Administration (1983) Federal specification TT-P-96, paint, latex base, for exterior surfaces (white and tints). U.S. Government Printing Office: 1984-421-706/839.

General Services Administration (1985) Federal specification TT-P-19, paint, latex (acrylic emulsion, exterior wood and masonry). U.S. Government Printing Office: 1985-461-726/24720.

Miller, B.A. (1983) Moisture and home energy conservation. Prepared for U.S. Department of Energy by the National Center for Appropriate Technology, Butte, Montana.

APPENDIX A: BUILDING SURVEY INFORMATION

The following information was gathered from as-built drawings, observations and discussions with building maintenance personnel. A blank space indicates that piece of information was unavailable. The frost damage column shows if there was damage from water vapor condensing and freezing behind coatings. Frost damage from other sources of moisture is not reflected here. The wall types correspond to Figure 2 in the text. The type of vapor retarder used was not available, although a polyethylene sheet was detected in some walls and is assumed for other buildings when indicated. Addresses for manufacturers of the coatings are as follows:

XL-70 and Tex-Cote	Textured Coatings of America, 2422 East 15th St. Panama City, FL 32405
Sonneborn	Sonneborn Building Products 111 Computer Ave Minneapolis, MN 55435
RE-NU-IT	RE-NU-IT Coatings, Inc. 315 West 39th St. New York, NY 10018

Table A1. Information on buildings from Fort Greely.

Building		*Wall*	*Vapor*	*Coating*	*Coating*	*Coating*	*Frost*
No.	*Use*	*type*	*retarder*	*type*	*age*	*rating*	*damage*
501	office			latex		good	no
503	gym	A	yes	latex	4	good	no
504	fire station			latex	5	fair	no
601	store & warehouse	A	no	latex	5	fair	no
602	gas station			latex	1	excellent	no
603	warehouse			latex	4	fair	no
605	office & warehouse			latex	4	fair	no
608	office & warehouse			latex	4	fair	no
609	office	A	yes	latex	2	good	no
610	office	A	no	latex	2	poor	no
612	office	A	no	latex	2	poor	no
614	office			latex	1	fair	no
615	office			latex	1	fair	no
625	pump house			latex	8	poor	no
628	warehouse	A	yes	latex	2	good	no
650	craft shop & theater			latex	2	good	no
651	bowling lane			latex	1	good	no
652	rec center			latex	1	poor	no
653	NCO club	A	yes	latex	4	fair	no
655	theater & offices			latex	4	fair	no
656	store			latex	2	fair	no
658	warehouse	B	no	latex	2	fair	no
659	barracks & offices	A	yes	textured paint (XL-70)	1	excellent	slight
660	barracks & offices	A	yes	textured paint (XL-70)	1	excellent	no
661	barracks & offices	A	yes	textured paint (XL-70)	1	excellent	no
662	barracks			textured paint (XL-70)	2	good	slight
663	hospital		yes	textured paint (XL-70)	2	good	slight
675	laundry	B	no	latex	4	poor	no
701	mess			latex	1	good	no
802	nursery			none	good	no	

Table A2. Information on buildings from Fort Richardson.

Building		Wall	Vapor	Coating	Coating	Coating	Frost
No.	Use	type	retarder	type	age	rating	damage
1	offices	A	yes	textured paint (XL-70)	7	fair	no
2	theater			latex	1	good	no
3	chapel			latex		good	no
5	commissary	A	yes	textured paint (Tex-Cote)	7	poor	no
6	nursery			latex	1	excellent	no
56	mess hall			latex		fair	no
600	barracks			latex		good	no
602	barracks			latex		good	no
604	clinic			textured paint (Tex-Cote)	1	good	no
606	offices			textured paint (Kennitex)	7	fair	no
618	offices			textured paint (Tex-Cote)	7	excellent	no
620	barracks			textured paint (Tex-Cote)	7	good	no
622	barracks			textured paint (Tex-Cote)	7	good	no
624	barracks			textured paint (Tex-Cote)	7	fair	no
626	barracks			textured paint (Tex-Cote)	7	good	no
628	barracks	A	yes	textured paint (Tex-Cote)	7	good	slight
630	barracks			textured paint (Tex-Cote)	7	good	no
632	barracks			textured paint (Tex-Cote)	7	fair	no
634	dental clinic			textured paint (Kennitex)	7	good	slight
635	offices			textured paint (Kennitex)	7	fair	slight
636	rec center			textured paint (Kennitex)	7	good	no
639	theater			textured paint (XL-70)	7	good	no
640	barracks	A	yes	textured paint (XL-70)	7	fair	no
650	barracks	A	yes	textured paint (Kennitex)	7	poor	no
652	telephone bldg.			latex & XL-70		fair	no
655	mess			latex		good	no
656	offices			latex		excellent	no
658	barracks			textured paint (Kennitex)	7	excellent	no
660	barracks			textured paint (Kennitex)	7	good	no
662	barracks			textured paint (Kennitex)	7	fair	no
664	barracks			textured paint (Kennitex)	7	good	no
666	barracks			textured paint (Kennitex)	7	good	no
668	barracks			textured paint (Kennitex)	7	good	no
670	barracks			textured paint (Kennitex)	7	fair	no

Table A2 (cont'd). Information on buildings from Fort Richardson.

Building No.	Building Use	Wall type	Vapor retarder	Coating type	Coating age	Coating rating	Frost damage
672	offices			textured paint (Kennitex)	7	good	no
700	offices			textured paint (XL-70)	3	excellent	no
704	vehicle storage			textured paint (XL-70)	3	good	no
712	shoppette			concrete block		good	no
724	warehouse			textured paint (XL-70)	3	good	no
726	laundry			textured paint (XL-70)		good	no
730	offices			latex		fair	no
732	Reserve Training Center			latex coated shotcrete	4	poor	no
733	offices			textured paint (XL-70 & stain)	3	good	no
740	Maint. shop			textured paint (XL-70)		fair	no
750	shops			textured paint (XL-70)		fair	no
756	shops			textured paint (XL-70)		good	no
760	shops			textured paint (XL-70)		good	no
764	car wash			concrete block (stained)		fair	no
770	shop			textured paint (XL-70)		fair	no
778	shop			textured paint (XL-70)		good	no
784	shop			textured paint (XL-70)		good	no
796	shop			textured paint (XL-70)		good	no
800	warehouse			textured paint (XL-70)	1	excellent	no
802	warehouse			textured paint (XL-70)	1	excellent	no
804	warehouse			textured paint (XL-70)		fair	no
806	warehouse			latex coated stucco		fair	no
807	warehouse			textured paint (XL-70)		good	no
808	refrig. warehouse			textured paint (XL-70)	1	excellent	no
974	shop			textured paint (XL-70)		good	no
975	shop			textured paint (XL-70)	4	good	
977	offices			textured paint (XL-70)	6	good	no
978	training center			latex		good	no
980	shop			textured paint (XL-70)	4	good	no
1175	pump house			latex		poor	no
35750	transmitter shop			textured paint	4	good	
35752	shop			textured paint	4	good	no

Table A3. Information on buildings from Fort Wainwright.

Building No.	Building Use	Wall type	Vapor retarder	Coating type	Coating age	Coating rating	Frost damage
1001	barracks	C	no	Portland cement with pigment	>10	poor	no
1004	barracks	C	no	Portland cement with pigment	>10	poor	no
1012	warehouse			textured paint (XL-70)	1	excellent	no
1053	warehouse			textured paint (XL-70)	1	excellent	no
2079	offices			latex	0	excellent	no
2080	water storage			latex	1	excellent	no
2104	offices			latex	3	good	no
2107	offices			latex	3	good	no
2108	water storage			latex	3	fair	no
3004	fire station (shower room)			textured paint (XL-70)	3	fair	severe
3011	water storage			latex		poor	no
3015	storage & warehouse		no	textured paint (Sonneborn)	3	poor	slight
3023	warehouse			textured paint (Sonneborn)		fair	slight
3025	laundry & dry cleaners			textured paint (Sonneborn)		fair	
3030	warehouse			latex	1	good	
3401	barracks	C	no	textured paint (XL-70)	7	poor	much
3405	sewage lift station			latex		poor	
3411	barracks	A	yes	latex	7	poor	
3413	barracks	A	yes	latex	7	poor	
3415	barracks	A	yes	latex	7	poor	
3417	barracks		yes	latex	7	poor	
3419	barracks	A	no	textured paint (XL-70)	1	excellent	no
3440	barracks			textured paint (XL-70)	0	excellent	no
3450			no	textured paint (Sonneborn)	3	good	no
3562	PX service station			latex		fair	
3563	sewage lift station			latex	8	poor	
3565	water treatment plant		no	latex	1	good	no
3570	offices		no	textured paint (XL-70)	1	good	no
3591	commissary			textured paint (Sonneborn)	3	fair	some
3597	warehouse		no	latex/textured	8?	fair	no
3701	PX		no	latex (Jarvis)	1	excellent	no
3702	bowling alley		no	latex	1	excellent	no
3706	barracks	B	no	textured paint (Sonneborn)	3	good	no
3707	barracks		no	textured paint (Sonneborn)	3	good	no
3708	barracks	B	no	textured paint (Sonneborn)	3	good	no
3711	offices	B	no	textured paint (XL-70)	3	good	no
3712	barracks	A	no	textured paint (Sonneborn)	2	good	no

Table A3 (cont'd). Information on buildings from Fort Wainwright.

Building No.	Building Use	Wall type	Vapor retarder	Coating type	Coating age	Coating rating	Frost damage
3713	barracks	B		textured paint (XL-70)	3	fair	some
3716	barracks	B		textured paint (Sonneborn)	3	fair	
3718	barracks	B	no	textured paint (Sonneborn)	3	good	no
3719	barracks	B	no	textured paint (Sonneborn)	3	good	no
3720	barracks	B	no	textured paint (Sonneborn)	3	fair	no
3721	barracks	B	no	textured paint (Sonneborn)	3	fair	no
3722	barracks	A	no	textured paint (XL-70)	3	good	no
3723	barracks	B		textured paint (XL-70)	3	fair	slight
4009	office		no	textured paint (XL-70)	1	good	no
4065	hospital			textured paint (XL-70)	4	good	slight
4075	barracks	B	no	textured paint (XL-70)	1	excellent	no
4107	chapel		no	textured paint (XL-70)	1	excellent	no
4108	theater		no	latex		fair	no
4109	grocery		no	none		excellent	no
4320	shoppette			textured paint (XL-70)	2	good	slight
4349	shoppette		no	none		excellent	no
4392	—		no	latex		good	no
—	Reserve center			none		good	

APPENDIX B: BUILDING WALL MOISTURE SPREADSHEETS.

Moisture buildup calculations following ASHRAE (1981) procedures were developed with Lotus 1-2-3. The following two spreadsheets are the results for building 610 at Fort Greely. The interior of the building was divided in half with one half at 45% RH and the other half at 30% RH.

PERIOD	DAYS	* RELATIVE HUMIDITY * INSIDE (%)	OUTSIDE (%)	TEMP. INSIDE (deg. F)	TEMP. OUTSIDE (deg. F)	TEMP. @ X--X (deg. F)	VAPOR PRESSURE INSIDE (in. Hg)	VAPOR PRESSURE OUTSIDE (in. Hg)	VAPOR PRESSURE @ X--X (in. Hg)	MOISTURE FLOW IN grains/ sqft*hr	MOISTURE FLOW OUT grains/ sqft*hr	MOISTURE FLOW TOTAL grains/ sqft*hr	WEEKLY MOISTURE BUILD-UP (gns/wk.)	CUMULATIVE MOISTURE BUILD-UP (grains)
AUGUST														
1-8	8	30.0	74.0	70.0	56.0	56.7	0.19946	0.30154	0.41741	-0.2945	0.1159	-0.4104	-78.80	0.00
9-16	8	30.0	74.0	70.0	56.0	56.7	0.19946	0.30154	0.41741	-0.2945	0.1159	-0.4104	-78.80	0.00
17-23	7	30.0	74.0	70.0	56.0	56.7	0.19946	0.30154	0.41741	-0.2945	0.1159	-0.4104	-68.95	0.00
24-30	7	30.0	74.0	70.0	56.0	56.7	0.19946	0.30154	0.41741	-0.2945	0.1159	-0.4104	-68.95	0.00
SEPTEMBER														
1-8	8	30.0	74.0	70.0	44.6	45.8	0.19946	0.19782	0.27988	-0.1087	0.0821	-0.1907	-36.62	0.00
9-16	8	30.0	74.0	70.0	44.6	45.8	0.19946	0.19782	0.27988	-0.1087	0.0821	-0.1907	-36.62	0.00
17-23	7	30.0	74.0	70.0	44.6	45.8	0.19946	0.19782	0.27988	-0.1087	0.0821	-0.1907	-32.04	0.00
24-30	7	30.0	74.0	70.0	44.6	45.8	0.19946	0.19782	0.27988	-0.1087	0.0821	-0.1907	-32.04	0.00
OCTOBER														
1-8	8	30.0	80.0	70.0	26.0	28.1	0.19946	0.10932	0.15073	0.0658	0.0414	0.0244	4.69	4.69
9-16	8	30.0	80.0	70.0	26.0	28.1	0.19946	0.10932	0.15073	0.0658	0.0414	0.0244	4.69	9.38
17-24	8	30.0	80.0	70.0	26.0	28.1	0.19946	0.10932	0.15073	0.0658	0.0414	0.0244	4.69	14.07
25-31	7	30.0	80.0	70.0	26.0	28.1	0.19946	0.10932	0.15073	0.0658	0.0414	0.0244	4.11	18.18
NOVEMBER														
1-8	8	30.0	76.0	70.0	8.8	11.7	0.19946	0.04499	0.06854	0.1769	0.0235	0.1534	29.45	47.63
9-16	8	30.0	76.0	70.0	8.8	11.7	0.19946	0.04499	0.06854	0.1769	0.0235	0.1534	29.45	77.08
17-23	7	30.0	76.0	70.0	8.8	11.7	0.19946	0.04499	0.06854	0.1769	0.0235	0.1534	25.77	102.84
24-30	7	30.0	76.0	70.0	8.8	11.7	0.19946	0.04499	0.06854	0.1769	0.0235	0.1534	25.77	128.61
DECEMBER														
1-8	8	30.0	72.0	70.0	-0.7	2.7	0.19946	0.02614	0.04329	0.2110	0.0172	0.1939	37.23	165.84
9-16	8	30.0	72.0	70.0	-0.7	2.7	0.19946	0.02614	0.04329	0.2110	0.0172	0.1939	37.23	203.06
17-24	8	30.0	72.0	70.0	-0.7	2.7	0.19946	0.02614	0.04329	0.2110	0.0172	0.1939	37.23	240.29
25-31	7	30.0	72.0	70.0	-0.7	2.7	0.19946	0.02614	0.04329	0.2110	0.0172	0.1939	32.57	272.86
JANUARY														
1-8	8	30.0	69.0	70.0	-5.2	-1.6	0.19946	0.01973	0.03461	0.2228	0.0149	0.2079	39.92	312.77
9-16	8	30.0	69.0	70.0	-5.2	-1.6	0.19946	0.01973	0.03461	0.2228	0.0149	0.2079	39.92	352.69
17-24	8	30.0	69.0	70.0	-5.2	-1.6	0.19946	0.01973	0.03461	0.2228	0.0149	0.2079	39.92	392.61
25-31	7	30.0	69.0	70.0	-5.2	-1.6	0.19946	0.01973	0.03461	0.2228	0.0149	0.2079	34.93	427.53
FEBRUARY														
1-7	7	30.0	67.0	70.0	-1.1	2.3	0.19946	0.02382	0.04245	0.2122	0.0186	0.1935	32.52	460.05
8-14	7	30.0	67.0	70.0	-1.1	2.3	0.19946	0.02382	0.04245	0.2122	0.0186	0.1935	32.52	492.57
15-21	7	30.0	67.0	70.0	-1.1	2.3	0.19946	0.02382	0.04245	0.2122	0.0186	0.1935	32.52	525.08
22-28	7	30.0	67.0	70.0	-1.1	2.3	0.19946	0.02382	0.04245	0.2122	0.0186	0.1935	32.52	557.60
MARCH														
1-8	8	30.0	64.0	70.0	10.9	13.7	0.19946	0.04210	0.07568	0.1673	0.0336	0.1337	25.67	583.27
9-16	8	30.0	64.0	70.0	10.9	13.7	0.19946	0.04210	0.07568	0.1673	0.0336	0.1337	25.67	608.93
17-24	8	30.0	64.0	70.0	10.9	13.7	0.19946	0.04210	0.07568	0.1673	0.0336	0.1337	25.67	634.60
25-31	7	30.0	64.0	70.0	10.9	13.7	0.19946	0.04210	0.07568	0.1673	0.0336	0.1337	22.46	657.06
APRIL														
1-8	8	30.0	60.0	70.0	30.7	32.6	0.19946	0.10199	0.16731	0.0434	0.0653	-0.0219	-4.20	652.86
9-16	8	30.0	60.0	70.0	30.7	32.6	0.19946	0.10199	0.16731	0.0434	0.0653	-0.0219	-4.20	648.65
17-23	7	30.0	60.0	70.0	30.7	32.6	0.19946	0.10199	0.16731	0.0434	0.0653	-0.0219	-3.68	644.98
24-30	7	30.0	60.0	70.0	30.7	32.6	0.19946	0.10199	0.16731	0.0434	0.0653	-0.0219	-3.68	641.30
MAY														
1-8	8	30.0	54.0	70.0	47.1	48.2	0.19946	0.15863	0.30603	-0.1440	0.1474	-0.2914	-55.95	585.35
9-16	8	30.0	54.0	70.0	47.1	48.2	0.19946	0.15863	0.30603	-0.1440	0.1474	-0.2914	-55.95	529.40
17-24	8	30.0	54.0	70.0	47.1	48.2	0.19946	0.15863	0.30603	-0.1440	0.1474	-0.2914	-55.95	473.45
25-31	7	30.0	54.0	70.0	47.1	48.2	0.19946	0.15863	0.30603	-0.1440	0.1474	-0.2914	-48.96	424.49
JUNE														
1-8	8	30.0	68.0	70.0	54.7	55.4	0.19946	0.26437	0.39920	-0.2699	0.1348	-0.4047	-77.71	346.78
9-16	8	30.0	68.0	70.0	54.7	55.4	0.19946	0.26437	0.39920	-0.2699	0.1348	-0.4047	-77.71	269.07
17-23	7	30.0	68.0	70.0	54.7	55.4	0.19946	0.26437	0.39920	-0.2699	0.1348	-0.4047	-68.00	201.07
24-30	7	30.0	68.0	70.0	54.7	55.4	0.19946	0.26437	0.39920	-0.2699	0.1348	-0.4047	-68.00	133.07
JULY														
1-8	8	30.0	70.0	70.0	59.6	60.1	0.19946	0.32444	0.47172	-0.3679	0.1473	-0.5152	-98.92	34.16
9-16	8	30.0	70.0	70.0	59.6	60.1	0.19946	0.32444	0.47172	-0.3679	0.1473	-0.5152	-98.92	0.00
17-24	8	30.0	70.0	70.0	59.6	60.1	0.19946	0.32444	0.47172	-0.3679	0.1473	-0.5152	-98.92	0.00
25-31	7	30.0	70.0	70.0	59.6	60.1	0.19946	0.32444	0.47172	-0.3679	0.1473	-0.5152	-86.55	0.00

PERIOD	DAYS	* RELATIVE * * HUMIDITY * INSIDE (%)	OUTSIDE (%)	TEMP. INSIDE (deg. F)	TEMP. OUTSIDE (deg. F)	TEMP. @ X--X (deg. F)	VAPOR PRESSURE INSIDE (in. Hg)	VAPOR PRESSURE OUTSIDE (in. Hg)	VAPOR PRESSURE @ X--X (in. Hg)	MOISTURE FLOW IN grains/ sqft*hr	MOISTURE FLOW OUT grains/ sqft*hr	MOISTURE FLOW TOTAL grains/ sqft*hr	WEEKLY MOISTURE BUILD-UP (gns/wk.)	CUMULATIVE MOISTURE BUILD-UP (grains)
AUGUST														
1-8	8	45.0	74.0	70.0	56.0	56.7	0.29919	0.30154	0.41741	-0.1598	0.1159	-0.2756	-52.92	0.00
9-16	8	45.0	74.0	70.0	56.0	56.7	0.29919	0.30154	0.41741	-0.1598	0.1159	-0.2756	-52.92	0.00
17-23	7	45.0	74.0	70.0	56.0	56.7	0.29919	0.30154	0.41741	-0.1598	0.1159	-0.2756	-46.31	0.00
24-30	7	45.0	74.0	70.0	56.0	56.7	0.29919	0.30154	0.41741	-0.1598	0.1159	-0.2756	-46.31	0.00
SEPTEMBER														
1-8	8	45.0	74.0	70.0	44.6	45.8	0.29919	0.19782	0.27988	0.0261	0.0821	-0.0560	-10.74	0.00
9-16	8	45.0	74.0	70.0	44.6	45.8	0.29919	0.19782	0.27988	0.0261	0.0821	-0.0560	-10.74	0.00
17-23	7	45.0	74.0	70.0	44.6	45.8	0.29919	0.19782	0.27988	0.0261	0.0821	-0.0560	-9.40	0.00
24-30	7	45.0	74.0	70.0	44.6	45.8	0.29919	0.19782	0.27988	0.0261	0.0821	-0.0560	-9.40	0.00
OCTOBER														
1-8	8	45.0	80.0	70.0	26.0	28.1	0.29919	0.10932	0.15073	0.2006	0.0414	0.1592	30.57	30.57
9-16	8	45.0	80.0	70.0	26.0	28.1	0.29919	0.10932	0.15073	0.2006	0.0414	0.1592	30.57	61.13
17-24	8	45.0	80.0	70.0	26.0	28.1	0.29919	0.10932	0.15073	0.2006	0.0414	0.1592	30.57	91.70
25-31	7	45.0	80.0	70.0	26.0	28.1	0.29919	0.10932	0.15073	0.2006	0.0414	0.1592	26.75	118.45
NOVEMBER														
1-8	8	45.0	76.0	70.0	8.8	11.7	0.29919	0.04499	0.06854	0.3117	0.0235	0.2881	55.32	173.77
9-16	8	45.0	76.0	70.0	8.8	11.7	0.29919	0.04499	0.06854	0.3117	0.0235	0.2881	55.32	229.10
17-23	7	45.0	76.0	70.0	8.8	11.7	0.29919	0.04499	0.06854	0.3117	0.0235	0.2881	48.41	277.51
24-30	7	45.0	76.0	70.0	8.8	11.7	0.29919	0.04499	0.06854	0.3117	0.0235	0.2881	48.41	325.91
DECEMBER														
1-8	8	45.0	72.0	70.0	-0.7	2.7	0.29919	0.02614	0.04329	0.3458	0.0172	0.3287	63.10	389.02
9-16	8	45.0	72.0	70.0	-0.7	2.7	0.29919	0.02614	0.04329	0.3458	0.0172	0.3287	63.10	452.12
17-24	8	45.0	72.0	70.0	-0.7	2.7	0.29919	0.02614	0.04329	0.3458	0.0172	0.3287	63.10	515.22
25-31	7	45.0	72.0	70.0	-0.7	2.7	0.29919	0.02614	0.04329	0.3458	0.0172	0.3287	55.21	570.43
JANUARY														
1-8	8	45.0	69.0	70.0	-5.2	-1.6	0.29919	0.01973	0.03461	0.3575	0.0149	0.3427	65.79	636.22
9-16	8	45.0	69.0	70.0	-5.2	-1.6	0.29919	0.01973	0.03461	0.3575	0.0149	0.3427	65.79	702.01
17-24	8	45.0	69.0	70.0	-5.2	-1.6	0.29919	0.01973	0.03461	0.3575	0.0149	0.3427	65.79	767.81
25-31	7	45.0	69.0	70.0	-5.2	-1.6	0.29919	0.01973	0.03461	0.3575	0.0149	0.3427	57.57	825.38
FEBRUARY														
1-7	7	45.0	67.0	70.0	-1.1	2.3	0.29919	0.02382	0.04245	0.3470	0.0186	0.3283	55.16	880.53
8-14	7	45.0	67.0	70.0	-1.1	2.3	0.29919	0.02382	0.04245	0.3470	0.0186	0.3283	55.16	935.69
15-21	7	45.0	67.0	70.0	-1.1	2.3	0.29919	0.02382	0.04245	0.3470	0.0186	0.3283	55.16	990.85
22-28	7	45.0	67.0	70.0	-1.1	2.3	0.29919	0.02382	0.04245	0.3470	0.0186	0.3283	55.16	1046.01
MARCH														
1-8	8	45.0	64.0	70.0	10.9	13.7	0.29919	0.04210	0.07568	0.3020	0.0336	0.2685	51.54	1097.55
9-16	8	45.0	64.0	70.0	10.9	13.7	0.29919	0.04210	0.07568	0.3020	0.0336	0.2685	51.54	1149.09
17-24	8	45.0	64.0	70.0	10.9	13.7	0.29919	0.04210	0.07568	0.3020	0.0336	0.2685	51.54	1200.64
25-31	7	45.0	64.0	70.0	10.9	13.7	0.29919	0.04210	0.07568	0.3020	0.0336	0.2685	45.10	1245.74
APRIL														
1-8	8	45.0	60.0	70.0	30.7	32.6	0.29919	0.10199	0.16731	0.1782	0.0653	0.1129	21.67	1267.41
9-16	8	45.0	60.0	70.0	30.7	32.6	0.29919	0.10199	0.16731	0.1782	0.0653	0.1129	21.67	1289.08
17-23	7	45.0	60.0	70.0	30.7	32.6	0.29919	0.10199	0.16731	0.1782	0.0653	0.1129	18.96	1308.05
24-30	7	45.0	60.0	70.0	30.7	32.6	0.29919	0.10199	0.16731	0.1782	0.0653	0.1129	18.96	1327.01
MAY														
1-8	8	45.0	54.0	70.0	47.1	48.2	0.29919	0.15863	0.30603	-0.0092	0.1474	-0.1566	-30.07	1296.94
9-16	8	45.0	54.0	70.0	47.1	48.2	0.29919	0.15863	0.30603	-0.0092	0.1474	-0.1566	-30.07	1266.86
17-24	8	45.0	54.0	70.0	47.1	48.2	0.29919	0.15863	0.30603	-0.0092	0.1474	-0.1566	-30.07	1236.79
25-31	7	45.0	54.0	70.0	47.1	48.2	0.29919	0.15863	0.30603	-0.0092	0.1474	-0.1566	-26.32	1210.47
JUNE														
1-8	8	45.0	68.0	70.0	54.7	55.4	0.29919	0.26437	0.39920	-0.1351	0.1348	-0.2700	-51.84	1158.64
9-16	8	45.0	68.0	70.0	54.7	55.4	0.29919	0.26437	0.39920	-0.1351	0.1348	-0.2700	-51.84	1106.80
17-23	7	45.0	68.0	70.0	54.7	55.4	0.29919	0.26437	0.39920	-0.1351	0.1348	-0.2700	-45.36	1061.44
24-30	7	45.0	68.0	70.0	54.7	55.4	0.29919	0.26437	0.39920	-0.1351	0.1348	-0.2700	-45.36	1016.09
JULY														
1-8	8	45.0	70.0	70.0	59.6	60.1	0.29919	0.32444	0.47172	-0.2331	0.1473	-0.3804	-73.04	943.05
9-16	8	45.0	70.0	70.0	59.6	60.1	0.29919	0.32444	0.47172	-0.2331	0.1473	-0.3804	-73.04	870.01
17-24	8	45.0	70.0	70.0	59.6	60.1	0.29919	0.32444	0.47172	-0.2331	0.1473	-0.3804	-73.04	796.97
25-31	7	45.0	70.0	70.0	59.6	60.1	0.29919	0.32444	0.47172	-0.2331	0.1473	-0.3804	-63.91	733.06

APPENDIX C: PERMEANCE COMPARISONS

Information on the permeances of various coatings is published in numerous references but all are not obtained under identical test conditions so all are not directly comparable. To be comparable, or even reproducible by other testing laboratories, permeances should include conditions of testing. The following table illustrates these points.

Table C1. Permeances (gr/hr ft^2 [in. Hg]) of various products.

	Information source		
Product	*CRREL*	*E.I. DuPont & Co*	*ASHRAE*
Tyvek (building paper)	93.8	94	
No. 15 roof felt, asphalt	5.8		5.6
Aluminum foil (0.35 mil)	0.09		0.05(dry-cup)
TT-P-96 (1-in. mortar)	9.3		
TT-P-96 (polyester fabric)	7.0		

All products, except where noted in the table, were tested according to ASTM E96 wet-cup procedures. With identical conditions, results of different testing laboratories are comparable as shown by the Tyvek and no. 15 roof felt results. When conditions vary by only the direction of vapor flow, results vary as shown by wet-cup and dry-cup results for aluminum foil. Varying substrates also affects test results, as the two TT-P-96 tests show.