INSULATION, CONDENSATION AND WOOD DECAY IN POTATO STORAGE BUILDINGS

by
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INTRODUCTION

In the past few years, we have experienced several potato storage structural failures due to rot in wooden structural members where polyurethane had been used in storage walls and ceilings. In addition, serious corrosion has occurred on some steel siding and roofing where polyurethane had been applied directly to the inside surface of the steel sheathing. These problems are not confined to the greater Columbia Basin of Central Washington and Oregon. Similar problems have occurred elsewhere. Serious deterioration of wood structural members in some agricultural buildings insulated with polyurethane was reported in Quebec, Ontario, and other provinces in Canada. In Ontario, as a result of a building survey, several buildings were thoroughly inspected for wood deterioration. The survey report includes the following conclusions:

1. Problems of wood deterioration in vegetable storage buildings, sprayed from the inside with polyurethane, do exist and appear widespread.

2. Little use of treated wood is made in original construction of this type.

3. Vapor barriers sprayed onto the surface of polyurethane are generally not used.

4. More extensive surveying of existing buildings is needed to define the extent of the problem, as well as to determine the importance of initial moisture content, wood species, and polyurethane characteristics.

5. Other buildings (such as refrigerated vegetable storages, steel Quonset-style storages, and livestock buildings) with exposed polyurethane sprayed from the inside should be investigated for moisture migration, and wood and metal deterioration problems.

6. If polyurethane is to be sprayed from the inside in new construction, more treated wood should be used; however, permissible types and methods of treatment must first be better established. A durable porous material, rather than steel, should be utilized as the substrate onto which the polyurethane is sprayed.

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WOOD DECAY

In structural lumber, two major kinds of decay are recognized: "brown rot" and "white rot". Brown rot, also called dry rot, is caused by a fungus which attacks mainly the cellulose in the wood. Most decay occurs when the moisture content of the wood is above the fiber saturation point (24-32%) of the dry weight of the wood. The water vapor in humid air alone, such as in potato storages, will not wet the wood sufficiently to support significant decay. Only when previously dried wood is in contact with water from condensation or other sources, such as a leaking roof, will the wood fibers reach the saturation point. Most decay is relatively slow at temperatures below 50° F, and it essentially ceases below 35° F. Oxygen is also needed to sustain decay growth.

During the potato storage season the conditions exist to support a low level of decay growth. Warmer weather in the spring will accelerate the decay process. Therefore, it is important to dry out the storage structure as rapidly as possible after the removal of the potatoes from the building in order to reduce or stop the growth of the fungus.

Decay Resistance of Wood

Moisture and temperature are the principal factors affecting the rate of decay. The heartwoods of some common species of wood may contain a varying degree of phenolic compounds, gums and resins, and other compounds that usually make it darker and more decay-resistant than sapwood, which is of a light color and is from near the outside of the log. Common species that have some resistance to decay are Douglas fir and western larch (tamarack). Species which are non- or slightly-resistant are pines,hemlock, and spruce.

Wood Preservatives

There seems to be a question of which, if any, wood preservatives can be used safely in structures holding raw agricultural products. The lack of accurate information is widespread. Surface application of treatment is not effective in the long run; however, any surface application which prevents or retards moisture movement into the wood will retard decay.

The Environmental Protection Agency (EPA) proposed restrictions (Federal Register, July 13, 1984) for using wood preservatives including inorganic arsenicals (chromated copper arsenate - CCA), ammonical copper arsenate - ACA, and fluorchrome arsenic phenol - FCAP), pentachlorophenol (and salts), and creosote. On Oct. 28, 1984, the implementation dates for these wood preservative restrictions were postponed indefinitely pending resolution of the appeals. Some of the most important proposed restrictions pertaining to potato storages are:

1. Inorganic arsenicals (CCA, ACA, FCAP) are
   *for commercial use only
   *not to be used where it may contact food or feed

2. Pentachlorophenol (and salts) and creosote may NOT be applied:
   *where there may be direct contact with food and feed
   *in interiors except in support structures in contact with soil. Two coats of sealer must be used.

Pressure-treated wood should not be burned in open fires, stoves or fireplaces. Avoid inhalation of sawdust, and use a dust mask when cutting wood.

A major concern to the potato grower should be to avoid use of treated wood on the inside of a storage where potatoes may come into contact with the wood, or where condensation on treated wood may drip or run into the pile. Another concern should be the potential odors from the chemical (such as from creosote and pentachlorophenol), and the use in air plenums where humidification water could leach chemicals out of the treated wood.

CONDENSATION

Moisture condensation is an important phenomenon in potato storages. When it is not controlled it can lead to very serious structural and environmental problems. There are two major areas where condensation occurs: on the inside surface, and inside the building shell. Surface condensation will occur whenever the room surface temperature reaches the dew point temperature of the room air. Dew point temperature is the saturation temperature at which air can not retain any additional water vapor. When the air is cooled below the dew point temperature, excess water vapor will condense on the surface.

One important relationship to keep in mind is that the higher the relative humidity of the air, the less it can be cooled before condensation occurs. Table 1 illustrates how small the difference is between the storage air temperature and its dew point temperature, especially at the very high humidity levels found in potato storages. Maximum allowable temperature differences for various conditions are shown. Since very high humidity levels are maintained in potato storages, ceiling and wall temperatures must be kept as near as possible to the surrounding air temperature.

Control of surface Condensation

There are several means of preventing or reducing surface condensation. They include: (1) increasing the insulation level to bring the surface temperature closer to the inside air temperature, (2) directing air against the surface, (3) using a building material on the inside that has the capacity of absorbing heat from the potato pile and raising the surface temperatures, and (4) reducing the relative humidity of the inside air, thus lowering the dew point temperature.

Effect of Insulation Level

The effect of the total thermal resistance of the ceiling on the temperature difference between ceiling surface and storage air temperature is shown in Table 2.

For example, with an exposed polyurethane surface one could expect condensation to occur at 91% relative humidity with a thermal resistance value of R-10. Increasing the thermal resistance to R-20 would increase the condensation point to 95% relative humidity, and it would increase to 97% with R-30. Note that increasing the value from R-10 to R-20 is much more effective than increasing it from R-30 to R-40, however, in very cold weather the extra insulation can make a difference between acceptable condensation and very serious condensation.

Table 1. Ceiling dew point temperatures under varying relative humidity levels with an inside air temperature of 45°F.

Inside Relative Humidity	Dew Point Temperature	Allowable Temperature Difference Between Air and Ceiling Surface
%	°F	°F
85	40.7	4.3
90	42.2	2.8
95	43.6	1.4
98	44.5	0.5
100	45.0	0.0

Table 2. Calculated ceiling surface temperature and dew point relative humidity in a potato storage building at an inside temperature of 45°F and an outside temperature of 0°F.

Ceiling R-Value	Ceiling Temperature (°F) and Dew Point Relative Humidity (%) for Material Used					
	Wood or Polyurethane		Galvanized Steel		Aluminum Foil	
	°F	%	°F	%	°F	%
10	42.5	91	40.8	85	39.8	82
20	43.7	95	42.7	92	42.2	90
30	44.1	97	43.4	94.5	43.1	93
40	44.3	97.5	43.9	96	43.6	95

Effect of Air Movement Over the Surface

Air movement over a ceiling or wall surface increases the rate of heat transfer from the inside air to the ceiling surface. The result is a reduced temperature difference between the air and ceiling surface. Table 3 illustrates this effect. For example, by providing a 7.5 mile per hour air velocity over a wood ceiling, the surface temperature would increase from 43.7°F to 44.5°F, with a dew point relative humidity rise from 95% to 98%. For an aluminum foil surface, the dew point relative humidity could be raised from 90% to 98%. Producing such air velocities would require numerous small fans producing air streams sweeping back and forth across the ceiling.

Table 3. Calculated ceiling surface temperature and dew point relative humidity in a potato storage building at an inside temperature of 45°F, an outside temperature of 0°F, and a thermal resistance of R-20.

Ceiling Surface Condition	Ceiling Temperature (°F) and Dew Point Relative Humidity (%) for Materials Used			
	Wood or Polyurethane		Aluminum Foil	
	°F	%	°F	%
Still Air	43.7	95	42.2	90
7.5 mph	44.5	98	44.5	98

Effect of Surface Material

Surface materials can have an even greater effect on condensation than the thermal resistance of the ceiling, especially at relatively low insulation levels. For example, as illustrated in Table 2, at an insulation level of R-10, condensation would occur at 91% relative humidity on a polyurethane surface, but on an aluminum foil surface it would occur at 82% relative humidity. Surface condensation is complex and not well understood. For example, well insulated storage buildings with very smooth and shiny ceiling surfaces often have excessive condensation, but ceilings with a very rough and somewhat absorptive surface texture, such as that obtained with some of the sprayed-on thermal barriers, usually have no visible condensation even with relatively low R-values.

What occurs is that on shiny surfaces the condensed moisture forms large drops due to high surface tension between the water molecules and the molecules of the surface. These large drops run down the smooth surface until they encounter obstacles, such as seams, then they drip onto the potato pile. On rough surfaces, it appears that the condensed moisture spreads evenly in a very thin layer over the entire surface area, thus large droplets never form. Some of the moisture may also be absorbed by the material; however, over a long storage season the material does not appear to become "soaked" with moisture. Some of the moisture may re-evaporate into the atmosphere.

Surface condensation on ceilings may not immediately appear to be detrimental if the water droplets do not fall directly into the potato pile. However, inspection of potato storage buildings with stacking walls has shown that, in some cases, surface condensate has been running down, and accumulating behind the stacking wall, causing severe rot in the sill and in the bottom end of the wooden arches. Several cases of this type have resulted in building failures in 10- to 15-year-old storages in Washington.

Condensation Inside Building Walls

Most insulation materials will transmit a certain amount of water vapor. The rate of vapor flow is a function of the difference in vapor pressures between the inside and outside of a building and the vapor-transmission characteristics of the wall. A vapor-pressure gradient exists similar to a temperature gradient. When there is a difference in temperature on opposite sides of a wall, the warm side usually is the region of higher vapor pressure. In a potato storage building with a high relative humidity, the vapor will diffuse from the inside to the outside during most of the storage season, except in late spring and summer when the outside temperatures are significantly higher than inside temperatures. During cold weather, water vapor may condense and freeze in a wall or ceiling. During a winter, many freeze and thaw cycles do occur. This process will break down the cell structure in foam plastic materials and will reduce its resistance to water vapor flow. Condensed moisture in insulation will reduce its thermal resistance (R), and when the moisture accumulates near wooden structural members it can cause an environment favorable to wood decay.

INSULATION AND VAPOR BARRIERS

Insulation and vapor barriers are important factors affecting not only the environment of the inside conditions of a storage, but also what is happening inside the wall and roof cavities. Foamed plastic insulation has been used in the majority of the storage structures in the Pacific Northwest. The most popular type has been polyurethane sprayed onto the outside stell surface from the inside of the building. There are several reasons for this popularity: (1) It can be sprayed onto uneven surfaces, around protruding structural members, corners, etc., forming a well-sealed barrier. (2) It has a high thermal resistance. (3) It has a relatively high resistance to water vapor penetration. (4) It can be easily transported to the site in liquid form. (5) Retrofit application to existing buildings is relatively easy.

A major disadvantage of polyurethane is its susceptibility to rapid fire spread and to give off heavy, dense, pungent smoke that makes fires difficult to fight. This fire danger can be reduced or prevented by coating the surface with flame-retardent materials, such as liquid polyoid (a trihydrocarbon polymer), cement plaster with a minimum of ½ inch thickness, or other approved fire-retardent materials. Building codes require such a thermal barrier for most of the polyurethane applications. This procedure adds significantly to the cost of polyurethane insulation.

The water vapor transmission characteristic or permeability of a material is designated as "permeance". The unit of permeance is called "perm", which is grains of water vapor transmitted per hour per square foot of surface area per inch of mercury vapor pressure difference (gr/hr- ft^2 -inHg). The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE) recommends a permeance rating of 1.0 perm or less for residences, and 0.1 perm or less for cold storage rooms. A permeance of less than 0.25 perm is advisable for potato storage insulation. Most common building materials are highly permeable and are poor vapor barriers. Table 4 lists the perm ratings for some vapor barriers and some construction materials. Sprayed-on polyurethane has generally been considered an adequate vapor barrier; however, the permeability rating is highly variable. Its effectiveness as a vapor barrier depends upon materials used, how it is applied, and its final density. An average perm value for polyurethane is 1.0 perms per inch of thickness. If four inches are applied, the perm rating would be 1.0 divided by 4, or 0.25 perms.

Table 4. Permeability of materials and vapor barriers.

Materials	Perms*
Building Materials	
Expanded polyurethane, 1" thick	0.4 - 1.6
Polystyrene, 1" thick	1.2
Molded bead polystyrene, 1" thick	2.0 - 5.8
Exterior plywood, 1/4" thick	0.7
Poured concrete wall, 4" thick	0.8
Vapor Barriers	
Aluminum foil, 1 mil	0.0
Polyethylene film, 6 mil	0.06
Kraft & asphalt-laminated building paper	0.3
Two coats of aluminum paint on wood	0.3 - 0.5
Three coats of latex paint of wood	5.5 - 11.0

*Perms = grains of water per hour per square foot per inch of mercury pressure difference (grains/hr-ft^2-inHg).

In the past, a perm rating of 0.5 has been considered acceptable for potato storages. Even with a perm rating of 0.25, a significant amount of moisture can move into and through a wall or ceiling section over a long period of time. Therefore, it is important that the resistance of the exterior wall surface be as low as possible to permit any vapor within the wall to escape to the outside. The practice of spraying polyurethane insulation against the inside steel surface of a potato storage building is therefore not recommended unless a vapor barrier is applied on the inside surface of the insulation. Moisture that would ordinarily escape to the outside becomes trapped near steel siding or roofing and condenses. In severe cases, condensation can saturate the insulation, lowering the insulation level, thus promoting more condensation. Eventually the moisture accumulation will lead to decay in structural members or corrosion of roofing and siding materials. The use of pressure-treated lumber may reduce and delay rot, but it does not completely eliminate the basic problem of moisture accumulation.

Corrosion of galvanized steel sheathing has been observed on many older buildings in the 10-years-and-older category. In the past, some producers of polyurethane did use a chlorinated flame retardent. With this type of insulation, a mild hydrochloric acid was formed when water combined with the chlorine in the fire retardent. This acid eventually can eat through the galvanized coating and corrode the steel. In recent years, less corrosive flame retardents have been used. There is no evidence that corrosion is caused by freon which is used to create the tiny cells in the polyurethane.

PRACTICAL APPLICATION

To bring the surface temperature as close to the inside air temperature as possible in order to reduce surface condensation, one or more of the following measures should be considered:

1. Increase the amount of insulation. A minimum insulation level of R-30 is recommended for the greater Columbia Basin area. Use R-40 in colder areas.

2, Move air along the ceiling surface. This is an effective way to reduce condensation. It is the easiest solution for reducing condensation in buildings with galvanized steel ceilings or in buildings with inadequate insulation. Some storages have a series of fans located near the ceiling to create air movement along the surface. Air returning to the fan house provides very little air movement, the velocity of the return air is very low, and often ceiling obstructions cause the air to take the path of least resistance, which is usually away from the ceiling surface.

3. Use materials for the inside surface that have a rough surface and have the ability to absorb some moisture. This prevents the formation of large water droplets by spreading the condensate over a larger surface area and allows it to evaporate into the air stream.

4. Use building materials in the ceiling with a high capacity for absorbing radiation. Avoid shiny surfaces such as galvanized steel.

5. Heat the ceiling with warm air or radiant lamps. This can be done by mounting electrical heat tape around the eave line inside the building. Warm air will slowly move up along the sloped ceiling, slightly warming the surface.

6. Reduce the relative humidity of the storage air during critical condensation periods. If a good humidification system is used, some condensation will still occur during cold periods. Moisture may form on the ceiling without dripping down into the potato pile. What must be prevented is moisture dripping into the potatoes.

To control condensation and accumulation of moisture inside the walls and roof, the following measures should be considered:

1. Install a vapor barrier on the inside surface or use an insulation material with a rating of less then 0.1 perm. Cover polyurethane with a butyl or hypolon or similar vapor barrier coating. Be sure that there are no cracks, fissures, hole or joints where water vapor can move into the wall.

2. Install a stacking wall to protect polyurethane from damage due to potato pressure or equipment. If no stacking wall is provided, use high-density, high-strength polyurethane in a one-inch thick surface layer.

3. Do not install the insulation directly against the outer wall or roof siding. Provide at least a six-inch air space between the insulation and the wall. Have a continuous vent along the bottom and along the ridge for unobstructed air movement through the vented space. The use of a ventilated attic enhances the movement of moisture to the outside.

4. Cover shiny surfaces with a radiation-absorbing material, such as dull paint, cellulose, or other coatings made for this purpose.

5. Rigid board insulation must have a vapor barrier on the inside surface. All joints must be effectively sealed.

6. The resistance to water vapor flow at the exterior wall should be as low as possible. This will permit the water vapor to escape to the outside. Do not install insulation with a vapor barrier on both sides, as moisture may get trapped inside the insulation, reducing its effectiveness.

To control rot in wooden structural members, the following precautions are recommended:

1. Use pressure-treated lumber which is approved for this type of application.

2. Do not cover wood completely with polyurethane insulation. It will keep the wood saturated, which favors rot.

3. Keep rain out, especially in flat areas and in areas of structural transition, such as storage to plenum and fan house.

4. Vent the building thoroughly, including the plenum area, after the storage season so that all insulation and structural lumber can dry out.

To prevent corrosion of steel to which polyurethane is applied, use the following procedures:

1. Use painted steel rather than galvanized. Be sure that the paint is providing the necessary protection.

2. Use an epoxy-type primer coating on the steel prior to applying polyurethane.

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