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Effects of Thermal Insulations on Electrical Connections and Outlet Boxes

Robert W. Beausoliel
James R. Clifton
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Center for Building Technology
National Engineering Laboratory
U.S. Department of Commerce
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
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EFFECTS OF THERMAL INSULATION ON ELECTRICAL CONNECTIONS AND OUTLET BOXES

By

R. W. Beausoliel, J. R. Clifton, and W. J. Meese

ABSTRACT

When residential walls are retrofitted with "foamed-in-place" urea-formaldehyde or "blown-in" cellulose thermal insulations, the insulation may enter electrical outlet and switch boxes. The effects of these thermal insulations on the safety and durability of electrical components were studied. These studies were carried out at 44, 75, and 96 percent relative humidities with test periods between one and twelve months.

Laboratory test methods were developed and tests performed to determine the electrical and corrosive effects of urea formaldehyde and cellulose thermal insulation contained in electrical outlets and switch boxes. The boxes were tested in humidity controlled closed-glass vessels at ambient temperatures. These tests were of an exploratory nature and did not cover all of the conditions that would exist in a residential wall. The testing methods are described in this report and the results are presented and interpreted.

Results indicate significant corrosion of electrical components and that these thermal insulations can cause shock hazards and increased energy losses. It is concluded that these thermal insulations should be removed from electrical-outlet and switch boxes.

Key Words: Cellulose thermal insulation; corrosion of electrical outlet boxes and devices; electrical devices; humidity, thermal insulation and corrosion of residential wiring; shock hazards; urea-formaldehyde thermal insulation.

PREFACE

This report is one of a group of documentary NBS research and analysis efforts in support of the Department of Energy (DoE) and the National Bureau of Standards (NBS) Building Energy Conservation Criteria Program. This work was supported by DoE/NBS Task Order A008-BCS under Interagency Agreement No. EA 77 A 01 6010.

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DISCLAIMER

Certain commercial equipment, instruments, or materials may be identified in order to adequately specify or describe the subject matter of this report. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

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1. INTRODUCTION

Certain cellulose thermal insulations have been found to be corrosive to metallic building components [1]. The corrosive behavior of the cellulose insulation depends, in part, on the specific flame retardant chemical added to the insulation to reduce its combustibility [2]. The use of cellulose insulation and other thermal insulations in residences may cause accelerated corrosion of electrical boxes and connections. Tests at the National Bureau of Standards (NBS) have demonstrated that when wall cavities are filled with urea-formaldehyde (UF) foam thermal insulation and cellulose thermal insulation, these insulations can sometimes enter and partially fill wall outlet boxes [3]. The insulation has been found in contact with current-carrying elements on both side of duplex receptacles. Inspection of electrical outlet and switch boxes in houses revealed that both cellulose and UF foam thermal insulations entered the boxes and in one case completely filled an outlet box [4].

1.1 PURPOSE AND SCOPE

This investigation was performed to obtain preliminary data for assessing the electrical and corrosive effects of the penetration of UF foam and cellulose thermal insulation into outlet boxes in residential walls.

Laboratory test methods were developed and tests performed to determine the electrical and corrosive effects of urea-formaldehyde foam and cellulose thermal insulation contained in electrical outlet boxes and switch boxes. The boxes were tested in humidity controlled closed-glass vessels at ambient temperature. These tests were of an exploratory nature and did not cover all of the conditions likely to exist in actual residential walls. The testing methods are described in this report and the results are presented and interpreted.

1.2 MOISTURE IN BUILDINGS

Condensation within walls may be a problem in older homes retrofitted with thermal insulation and in new buildings. For example, a condensation problem occurred in a relatively new house located in the temperate climate of Sydney, Australia. Condensation drips produced a large hole in a plastered ceiling and this was followed by electric short-circuit of a fluorescent lighting fixture [5].

In a frame wall, the dew point temperature in cold weather generally occurs in the hollow air space between studs. When the stud space contains a two inch (51 mm) or three inch (76 mm) blanket of thermal insulation, the dew-point temperature may be located within the insulation depending on the weather [6]. Wall outlet boxes are located where condensation often takes place in wall spaces.

Some electrically heated houses have been found to experience significant attic condensation during cold periods. During winter the attics had heavy frost accumulations at gable ends with heavy frost on the roof sheathing.

The frost resulted from air leaking from inside the houses into the attics through holes in electrical boxes and around plumbing stacks. These insulated houses located in northern Manitoba met the insulation standards for electric heating of houses [7]. All weather-stripped windows were triple glazed. The houses had weatherstripping on wooden doors and had storm doors.

Wetness of insulation in walls can occur in many ways:

(a) Use of unvented gas-fired space or room heaters
(b) Furnace humidifiers
(c) Damp basements
(d) Damp crawl spaces
(e) Laundry activities
(f) Hot baths/showers
(g) Kitchen activities
(h) Temperature lowered at night after hot humid day
(i) Sweating cold water and drain piping
(j) Sweating plumbing fixtures
(k) Roof leaks
(l) Wind-driven rain
(m) Water infiltration

The Forest Products Laboratory of the U.S. Department of Agriculture has found that when a relative humidity of 35 percent or more is maintained in houses, condensation may occur during winter months in insulated walls which do not have vapor flow retarding barriers [8]. Moisture condensation could occur in older homes built without vapor barriers that have been retrofitted with insulation. A recent literature search by NBS did not reveal definitive cases of condensation occurring within wall outlet boxes. However, it suggested that the occurrence of condensation within outlet boxes was probable.

2. TEST PROCEDURE AND RESULTS

The basic approach for obtaining known relative humidities was based on ASTM E104, Standard Recommended Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions [9].

A total of 54 vessels were used in the experiment. Of those, 15 vessels were 6"O.D. x 12" tall (0.152 x 0.305 m) and 39 were 6"O.D. x 8" tall (0.152 x 0.203 m). Schematics of humidity vessel setups are shown in figures 1 and 2. Figure 1 shows a typical unenergized setup. Figure 2 shows a powered setup energized by the building supply voltage of 120V AC, 60 Hz. Glass vessels were sandwiched between plywood bases and clear plastic tops* joined with steel screw stock. The tops of each vessel were ground flat to maintain a seal using silicone grease between flat surfaces of the vessel rims and tops. A relative humidity sensor was installed in each vessel. One vessel top had a 1/4" (0.006 m) diameter hose shank installed to permit the measurement of air pressure within the vessel. A small water manometer, referenced to atmospheric pressure, was connected to this shank by way of flexible plastic tubing. The vessel was typical of those containing urea formaldehyde foam insulation. No pressure increase above atmospheric pressure was detected. Temperatures were measured within vessels on plastic flush plates of wall outlet boxes and switch boxes using copper constantan thermocouples and a data acquisition system. The temperatures were 1° - 3°F higher than ambient laboratory air temperature, 70°F (21.1°C). Temperatures will not be considered further in this report.

The following saturated aqueous salt solutions were used in the vessels to maintain desired humidities:

Salt	Relative Humidity
Potassium Sulfate, K_2SO_4	96%
Sodium Chloride, NaCl	75%
Potassium Carbonate Dihydrate, ($K_2CO_3 \cdot 2H_2O$)	44%

The vessels containing salt solutions were placed on a rack fabricated from aluminum angles (figure 3).

The vessels contained outlet boxes with either duplex receptacles or switches. Table 1 gives the test parameters. As indicated, the following distribution of devices were evaluated:

*Poly(methyl methacrylate)

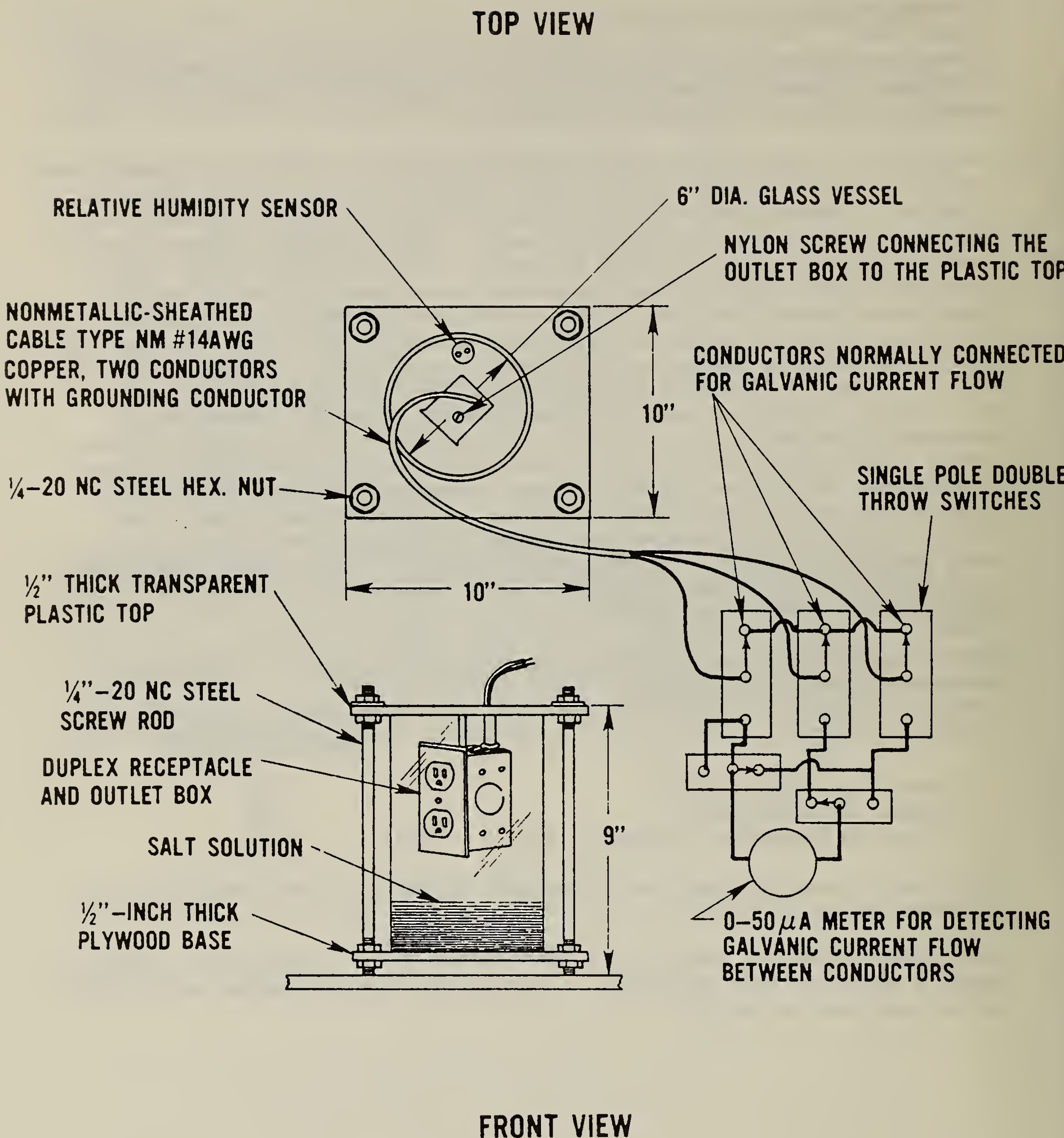

Figure 1. Typical unenergized humidity vessel.

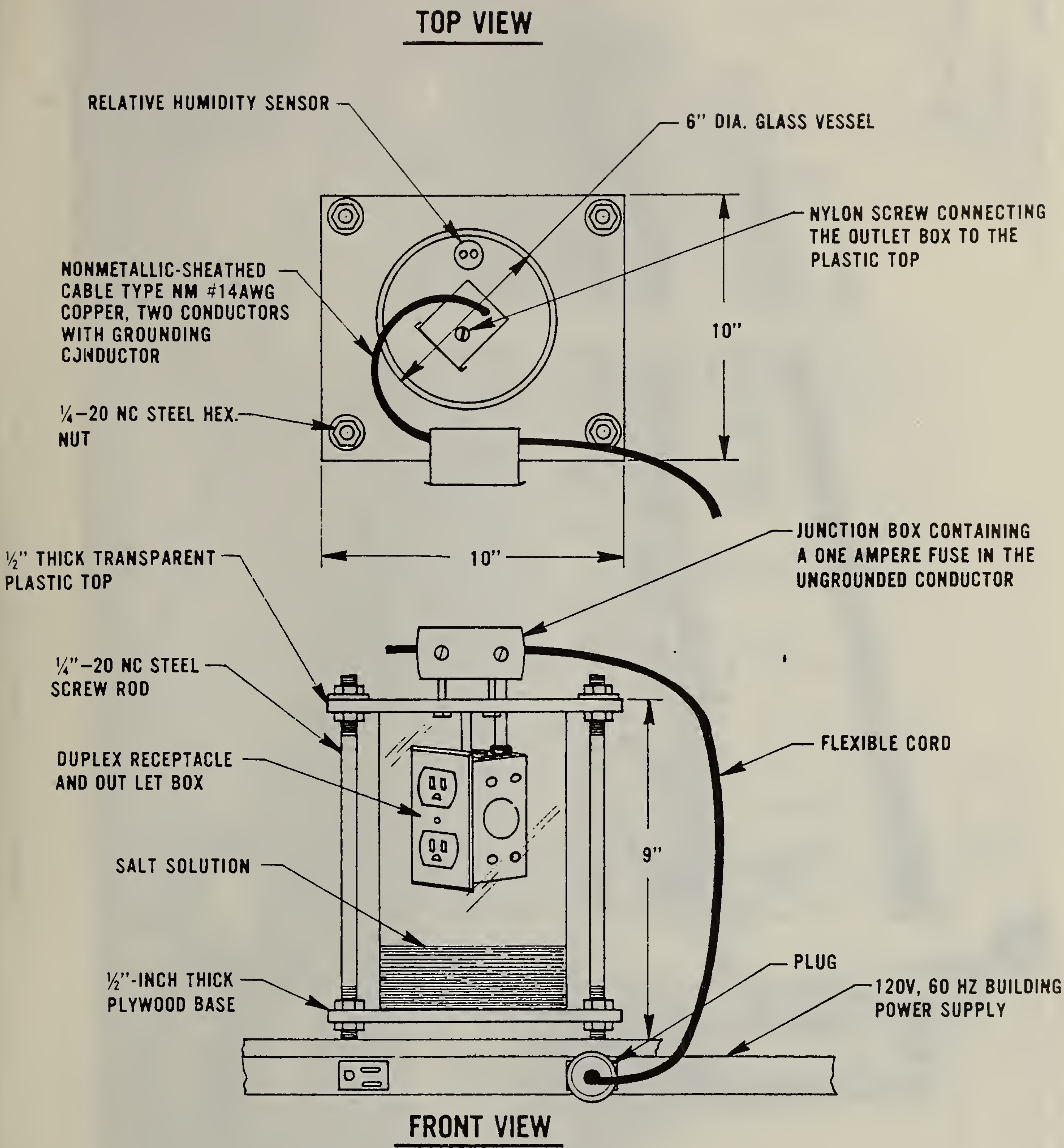

Figure 2. Typical energized humidity vessel.

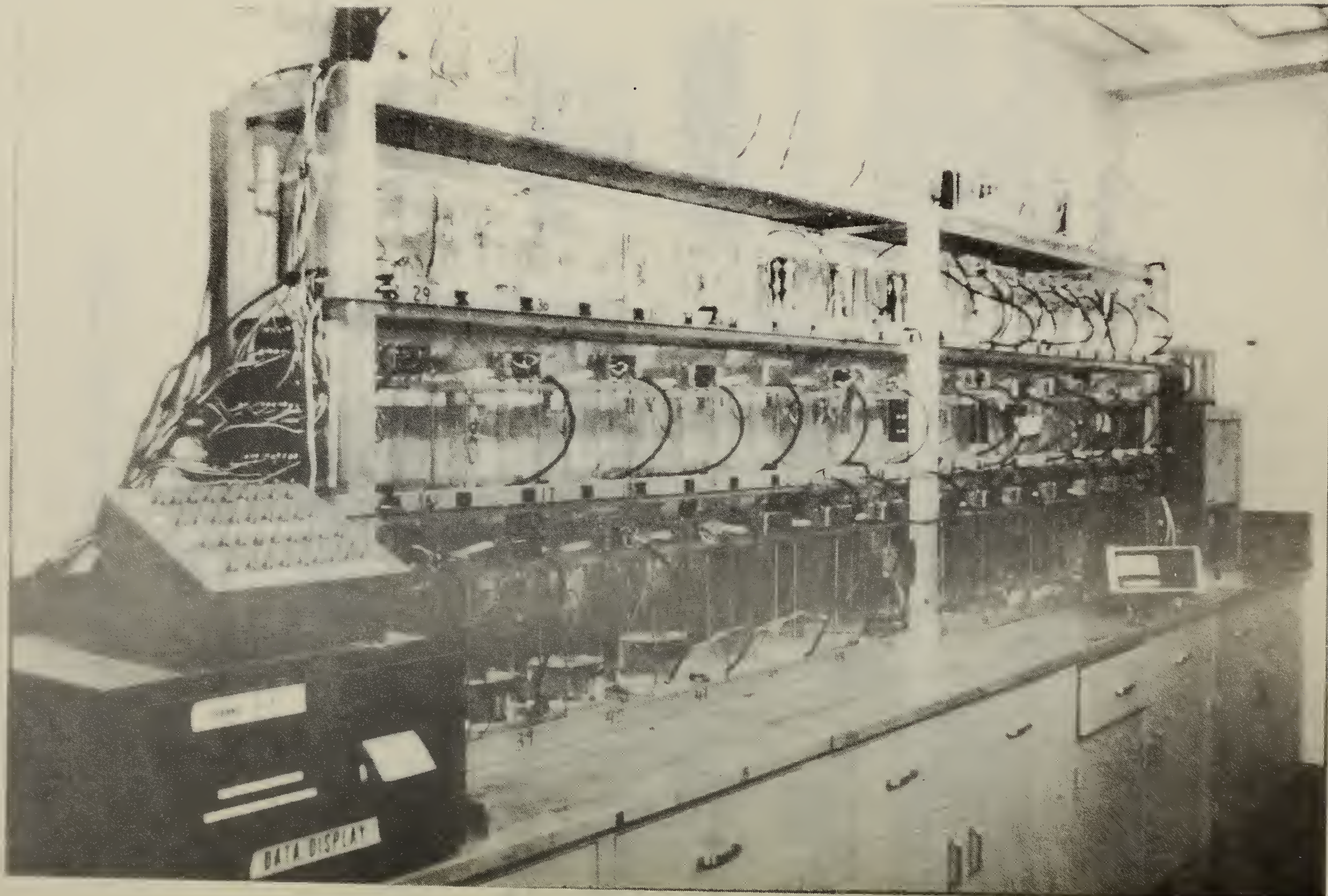

Figure 3. Humidity vessel rack.

Table 1. Humidity Vessel Test Parameters

Specimen No.	Type of Device in Cellulose	Exposure Period Months	% RH	Specimen No.	Type of Device in UF Foam	Exposure Period Months	% RH
1* U	Receptacle	12	96	27* U	Receptacle	6	75
2 U	Receptacle	1.5	96	28 U	Receptacle	1.3	96
3 U	Switch, Open	1.5	96	29 U	Switch, Open	1.3	96
4 U	Switch, Closed	1.5	96	30 U	Switch, Closed	1.3	96
5* P	Receptacle	7	96	31* P	Receptacle	12	75
6 P	Receptacle	1.5	96	32 P	Receptacle	1.3	96
7 P	Switch, Open	1.5	96	33 P	Switch, Open	1.3	96
8 P	Switch, Closed	1.5	96	34 P	Switch, Closed	1.3	96
9 U	Receptacle	3	96	35 U	Receptacle	3	96
10 U	Switch, Open	3	96	36 U	Switch, Open	3	96
11 U	Switch, Closed	3	96	37 U	Switch, Closed	3	96
12 U	Receptacle	4.5	75	38 U	Receptacle	6	75
13 P	Receptacle	3	96	39 P	Receptacle	3	96
14 P	Switch, Open	3	96	40 P	Switch, Open	3	96
15 P	Switch, Closed	3	96	41 P	Switch, Closed	3	96
16 P	Receptacle-Brass Screw	4.5	96	42 P	Receptacle-Brass Screw	6	96
17 P	Receptacle	4.5	75	43 P	Receptacle	12	75
18 P	Switch, Open	4.5	75	44 P	Switch, Open	6	75
19 P	Receptacle	6	44	45 P	Receptacle	6	44
20 P	Receptacle	6	44	46 P	Receptacle	6	44
21 P	Switch, Open	6	44	47 P	Switch, Open	6	44
22 P	Receptacle	4.5	96	48 P	Receptacle	6	96
23 P	Receptacle	12	75	49 P	Receptacle	6	75
24 U	Receptacle	7	96	50 U	Receptacle	6	96
25 P	Receptacle	6	96	51 P	Receptacle	6	96
26 P	Switch, Closed	12	96	52 P	Switch, Closed	12	96
				53* U	Receptacle	6	44
				54* P	Receptacle	12	44

* Control vessels - no thermal insulation.

% RH = nominal percent relative humidity of air in test vessels
P = specimen energized with 120 V, 60 Hz
U = specimen not energized

30 - Duplex receptacles with steel-side wire binding screws
2 - Duplex receptacles with brass-side wire binding screws
12 - Open switches (off)
10 - Closed switches (on)

Of these, the following sets were energized using the 120V AC. 60 Hz building power supply.

21 - Duplex receptacles
8 - Open switches
6 - Closed switches

Half of the total number of outlet boxes were filled by hand with cellulose thermal insulation and half were filled with UF foam thermal insulation. The UF foam insulation was foamed into outlet boxes by a commercial applicator of residential foam based thermal insulation. The insulation occupied the space between the outlet box and the receptacle or switch. The insulation contacted exposed current carrying elements of receptacles and switches. Humidity vessels 1, 5, 27, 31, 53, and 54 contained receptacles without thermal insulation for control purposes.

To estimate the volume of thermal insulation fill in the boxes, the volumes of the air spaces in one switch box and one receptacle box were obtained by filling these boxes with known volumes of water after first sealing holes in the boxes and devices with silicone rubber. Air space volume in the switch box was 171 ml. The receptacle box had an air space volume of 172 ml. The range of the amounts of cellulose insulation added to outlet boxes was 11.6-15.8 g; the average was 13.4 g. The density of loose fill cellulose insulation was determined to be 64 kg/m^3 or about 4 lb/ft^3. The fill density for cellulose should be 3-4 lb/ft^3 for walls [10]. The cellulose was conditioned in the laboratory at 35 percent relative humidity and 70°F (21°C) for longer than a week prior to making mass measurements. From the above information, the volumes of cellulose insulation added to the boxes indicates that the boxes were full of insulation. Visual inspections also indicated the boxes were full and that large voids were not present within the insulation.

The pink-colored cellulose insulation contained on a weight basis 2.0 percent $(NH_4)_2SO_4$ and 1.5 percent $AL_2(SO_4)_5$ and had a pH of 6.9 percent.*

The initial mass of a 4-inch (0.102 m) cube of fresh wet foam was 50.5 g giving a density of about 48 kg/m^3 or 3 lb/ft^3. An insulation contractor introduced UF foam into each outlet box by carefully adjusting the flow of foam. Even with care, it was not possible to get complete or identical fill in all cases. The range of masses of UF foam insulation in the outlet boxes was from 5.0 to 8.9 g. The wet UF foam mass measurements in outlet boxes were made within two hours after filling boxes. Inspection and calculation

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* Chemical analyses performed by the laboratory of the Consumer Product Safety Commission.

suggest that some boxes may not have been completely full. The UF foam insulation filled outlet boxes were dried for 48-hours under room conditions of 35 percent relative humidity and 70°F.

2.1 MOISTURE CONTAINED IN THERMAL INSULATION CONTACTING LIVE ELECTRICAL ELEMENTS

The moisture contents of the cellulose and UF foam thermal insulation specimens placed in wall outlet and switch boxes were determined at the time of test specimen disassembly. The moisture content of the cellulose insulation was also measured before the corrosion tests.

2.1.1 Test Procedure

The wet masses of insulation samples were obtained by weighing samples on a laboratory balance. Dry masses were obtained after drying wet specimens in an air-oven at 124°F (51°C) for 24 hours to constant masses determined by weighing the specimens. The wet mass of an insulation sample minus the mass of the weighing container equaled the combined mass of water and insulation. This combined mass minus the dry mass equaled the mass of water.

2.1.2 Test Results

Results of the determinations of the moisture content of "as received" cellulose thermal insulation exposed to laboratory air indicated that its moisture was 6 percent of the dry mass of cellulose insulation. No results were obtained for UF foam which was foamed into outlet and switch boxes in the wet state.

Cellulose specimens exposed to 96 percent relative humidity gained 119 percent mass of moisture during the first month of exposure and thereafter lost moisture. At the end of the six month exposure, it had an average moisture content of 20 percent of the dry cellulose mass. Because of the smaller number of specimens exposed at 75 percent relative humidity and 44 percent relative humidity, the moisture trend was not seen. However, data indicated 25 percent moisture content when exposed to 75 percent relative humidity for four and one-half months. Six months at 44 percent relative humidity resulted in 0.7 percent moisture gain.

UF foam specimens exposed to 96 percent relative humidity gained mass throughout most of the test period. At the end of one and one third months of exposure, the moisture content was 118 percent of dry mass; at the end of three months, the moisture content was 180 percent; at the end of six months, the moisture content was 168 percent. After six months of exposure at 75 percent relative humidity, the moisture content of UF foam was 110 percent. The moisture content of UF foam was 100 percent dry mass after six months exposure at 44 percent relative humidity.

Figure 4 presents the moisture gain trend for UF foam insulation and the loss trend for cellulose insulation.

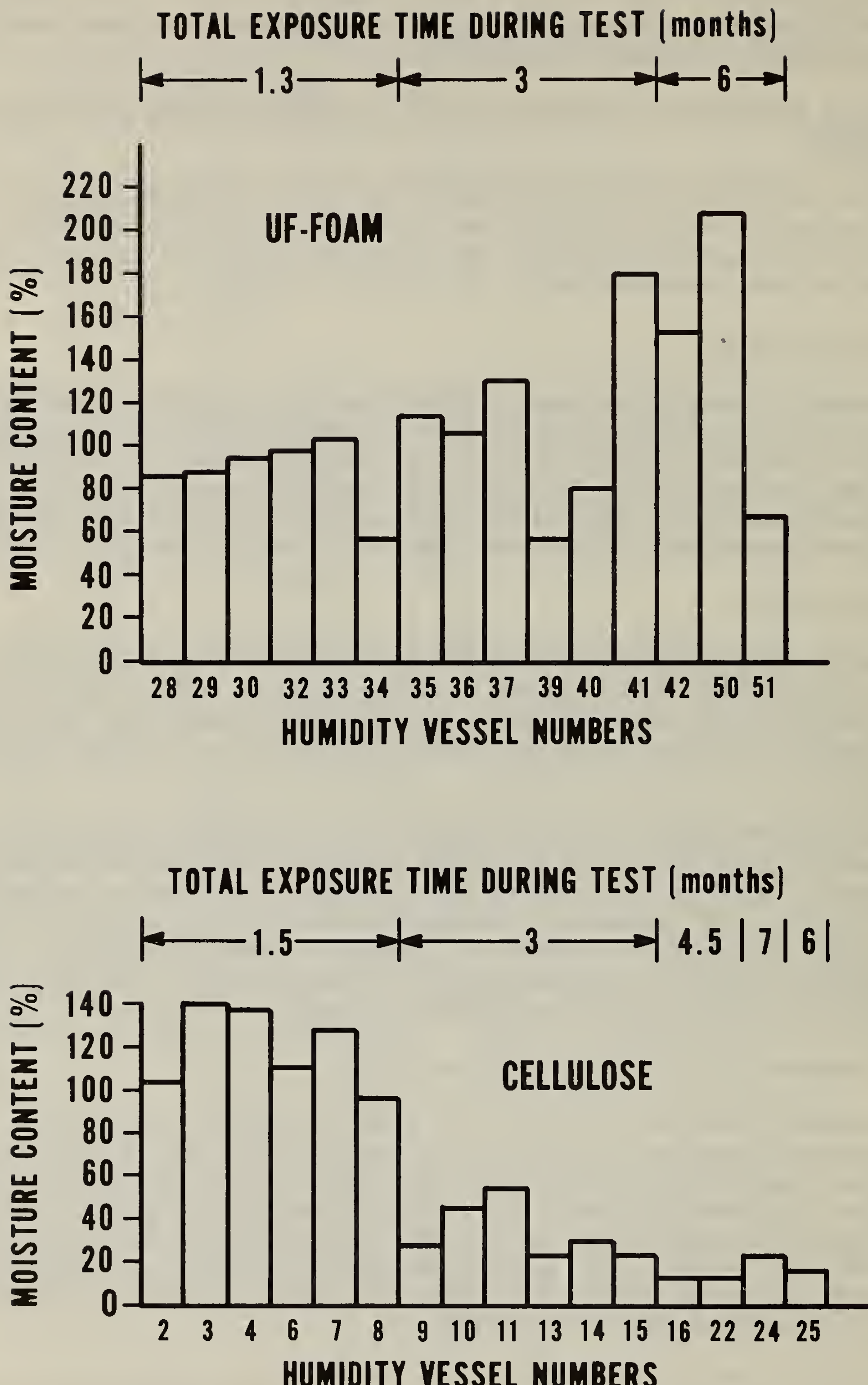

Figure 4. Moisture content of cellulose and UF Foam thermal insulations exposed to 96 percent relative humidity.

The times for moisture gain or loss shown in figure 4 may not be indicative of actual times in residences because of wall geometry and thermal insulation surrounding boxes which were not considered in this study.

2.2 VISUAL INSPECTION OF CORRODED OUTLET BOXES AND DUPLEX RECEPTACLES

In order to eliminate surface films and/or dirt on outlet boxes and devices that could introduce inconsistent corrosion effects, all boxes and devices were cleaned prior to corrosion testing in an attempt to create consistent surface films void of factory workers finger prints, and other matter.

The following procedure was used to clean switches, receptacles, and outlet boxes prior to installation in the humidity vessels.

(a) dipped in trichloroethylene,
(b) washed in soapy water using a biodegradable detergent*,
(c) rinsed in hot water,
(d) rinsed at least twice in distilled water,
(e) dipped in anhydrous ethanol.

Figures 5 and 6 show the corrosion of an outlet box and duplex receptacle when exposed to 96 percent relative humidity and cellulose insulation over a seven month period. The interior of the box shown in figure 5 was covered by a thick brown deposit. Cellulose thermal insulation adhered strongly to this deposit and could not be readily brushed or scraped away from the deposit. Figure 6 shows that about 1/4 of one neutral wire binding screw head of the duplex receptacle was corroded away. A heavy brown deposit appeared on the neutral wire binding screw heads and grounding wire binding screw heads. The ungrounded wire binding screw heads also had brown deposits. Brown deposits were probably iron oxide or rust. The ungrounded wire binding screw heads also had brown deposits. All brass surfaces were tarnished.

In contrast to figure 5 and 6, figure 7 and 8 shows an outlet box that did not contain thermal insulation. This control outlet box was exposed to 96 percent relative humidity for seven months. The interior surfaces of the box were 60 percent covered by a white deposit which is believed to be zinc oxide. One side of the box interior surface had a brown deposit that was one-inch long and one-half an inch wide. The remaining 40 percent of the interior surfaces of the outlet box appeared to be relatively clean and zinc coated. Figure 8 shows that all ferrous metal surfaces (surfaces that attracted a magnet) of the duplex receptacle were covered by a white deposit. All screws were covered by a white deposit. All brass surfaces were bright and shiny. Although this outlet box did corrode, it appears that most of the corrosion occurred on the zinc coating. In effect, the corrosion of the zinc protected the steel base metal of the outlet box. The zinc coating was performing its intended function.

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* Sparkleen

Figure 5. Corroded outlet box #24.

Figure 6. Corroded duplex receptacle #24.

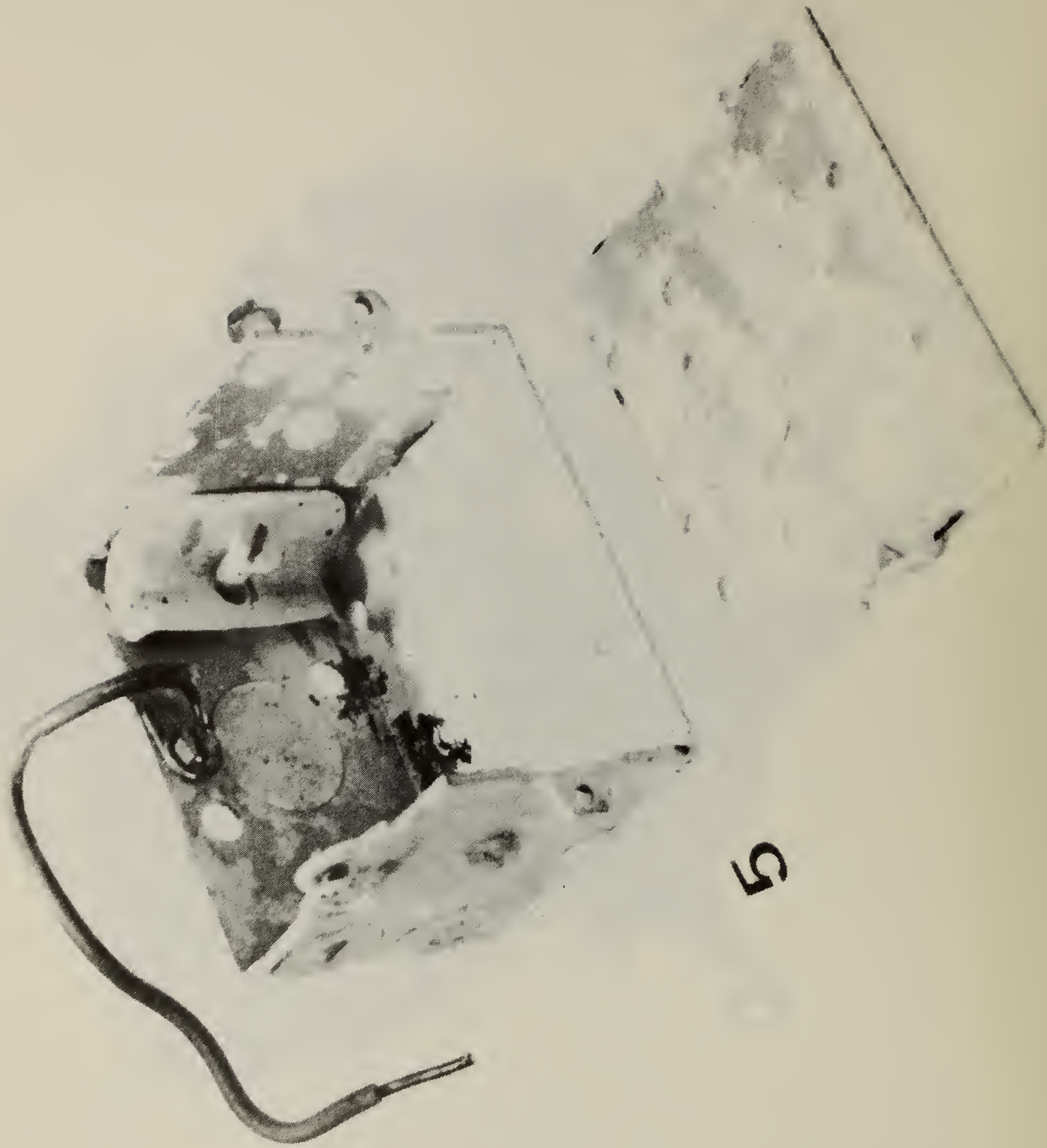


Figure 7. Corroded control outlet box #5.

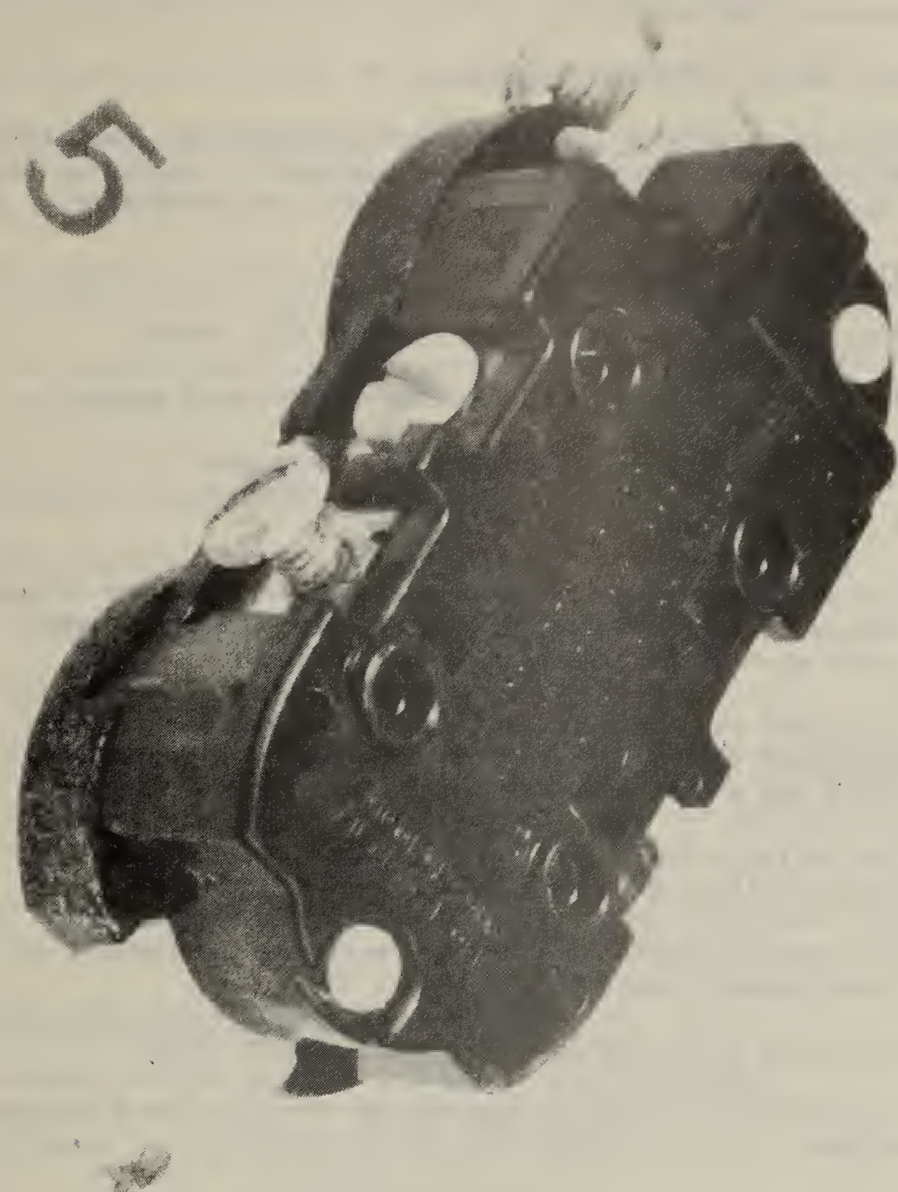


Figure 8. Corroded control duplex receptacle #5

This study included some switches. Corrosion of switch boxes and the metal parts of switches was identical to corrosion reported here for outlet boxes and duplex receptacles.

2.2.1 Inspection of Cellulose Specimens

The following are results of visual inspection by eye of some other wall outlet boxes and duplex receptacles after exposure to cellulose thermal insulation and the indicated relative humidity/time conditions:

<u>Humidity Vessel Specimen # 2</u>

- Duplex receptacle with steel wire binding screws

- Exposed to 96 percent RH for one-and-one-half months

- Unenergized from 120 V building power supply

EXTENT OF CORROSION

- The left side interior surface area of the box was visually estimated to be 80 percent covered with a black deposit mixed with a white deposit (zinc oxide).

- The right side interior surface of the box was visually estimated to be 40 percent covered with a mixture of black and white deposits.

- The bottom interior surface of the box was 60 percent covered with a mixture of black and white deposit.

- The exterior surface of the box was clean except for a black deposit around the holes in the box.

- The black wire binding screws were not corroded.

- A brown deposit (rust) appeared on the white wire binding screws.

- Rust appeared on the grounding wire binding screws.

- A black colored deposit was observed on #14 AWG copper wire loops both in the area under the wire binding screw heads and outside of the heads. This was observed for both "black" and "white" wire screws.

- A black colored deposit was observed over the entire length of the uninsulated grounding wire.

Humidity Vessel Specimen #6

- Duplex receptacle with steel wire binding screws
- Exposed to 96 percent RH for one-and-one-half months
- Energized from the 120V building power supply

EXTENT OF CORROSION

- The left side interior surface area of the box was 50 percent covered with rust and 50 percent zinc oxide.
- The right side of interior surface area of the box was 40 percent covered with rust and 60 percent zinc oxide.
- The interior surface area of the back side of the box was 40 percent covered with rust and zinc oxide.
- The exterior surface area of the box was not corroded.
- Black wire binding screws were tarnished.
- White wire binding screws were corroded.
- A black colored corrosion product was observed on #14AWG copper wire loops both in the area under the wire binding screw heads and outside of the heads. This was observed for both "black" and "white" wire screws.
- A black colored deposit was observed over the entire length of the uninsulated copper grounding wire.

Humidity Vessel Specimen #19

- Duplex receptacle with steel wire binding screws
- Exposed to 44 percent RH for six months
- Energized from the 120 V building power supply

EXTENT OF CORROSION

- The box was not corroded. It looked new.
- The duplex receptacle was not corroded. It looked new.

Humidity Vessel Specimen #23

- Duplex receptacle with steel wire binding screws

- Exposed to 75 percent RH for twelve months

- Energized from the 120 V building power supply

EXTENT OF CORROSION

- The box was not corroded. It looked new.

- The duplex receptacle was not corroded. It looked new.

Humidity Vessel Specimen #25

- Duplex receptacle with a steel wire binding screws

- Exposed to 96 percent RH for six months

- Energized from the 120V building power supply

EXTENT OF CORROSION

- Nearly 100 percent of all interior surfaces of the box were covered by rust.

- The cable clamp (located in the box) screw was frozen with rust. Heavy rust coated the clamp.

- The exterior surfaces of the box were not corroded except for corrosion around the holes in the box

- The black wire binding screw heads were tarnished

- The white wire binding screw heads had heavy rust deposits and a small amount of a white deposit

- The grounding wire binding screw head was rusted.

- Wire loops were tarnished

2.2.2 Inspection of UF Foam Specimens

The following are results of visual inspection by eye of some other wall outlet boxes and duplex receptacles after exposure to UF foam thermal insulation and the indicated relative humidity/time conditions:

Humidity Vessel Specimen #28 -

- Duplex receptacle with steel wire binding screw

- Exposed to 96 percent RH for one-and-one-third months

- Unenergized from the 120V building power supply

EXTENT OF CORROSION

- The interior surfaces of the box were not corroded.
- The exterior surfaces of the box were not corroded.
- The black wire binding head screws were tarnished. Brown rust pits were observed over 50 percent of the surface.
- The copper conductors were not corroded.

Humidity Vessel Specimen #32

- Duplex receptacle with steel wire binding screws
- Exposed to 96 percent RH for one-and-one-third months
- Energized from the 120V building power supply

EXTENT OF CORROSION

- The interior surfaces of the sides, top, and bottom of the box were not corroded.
- The interior surface of the back of the box had a rust spot which was about 0.5 in. (0.013 m) long by 0.25 in. (0.006 m) wide.
- The exterior surfaces of the box were not corroded.
- The cable clamp (located in the box) had 10 percent of its surface rusted.
- Both of the black and the white wire binding screws were tarnished.
- The grounding wire binding screw was not corroded.
- The copper conductors were not corroded.

Humidity Vessel Specimen #43

- Duplex receptacle with steel wire binding screws
- Exposed to 75 percent RH for twelve months
- Energized from the 120V building power supply

EXTENT OF CORROSION

- Interior surfaces of the box were slightly tarnished.
- Exterior surfaces of the box were not corroded. The surfaces looked new.
- Black wire binding screws and loops looked clean and new in appearance.
- White wire binding screw heads were tarnished. Wire loops were bright and clean.

Humidity Vessel Specimen #45

- Duplex receptacle with steel wire binding screws
- Exposed to 44 percent RH for six months
- Energized from the 120V building supply

EXTENT OF CORROSION

- The box was not corroded. It looked new.
- The duplex receptacle was not corroded. It looked new.

Humidity Vessel Specimen #48

- Duplex receptacle with wire binding screws
- Exposed to 96 percent RH for six months
- Energized from the 120V building power supply

EXTENT OF CORROSION

- The interior bottom of the box had heavy rust over 90 percent of the surface.
- The interior surfaces of the sides and top of the box were covered by 60 percent rust.
- The exterior surfaces of the box were not corroded.
- The black wire binding screw heads had rusted.
- Heavy brown rust was observed on the white wire binding screw heads (heavier than the rust on the black wire binding screws).

- The grounding wire binding screw head was rusted
- The copper wire loops under wire binding screws were tarnished.

2.2.3 Inspection of Control Specimens

The following are results of visual inspection by eye of some control wall outlet boxes and duplex receptacles after exposure to the indicated relative humidity/time conditions:

<u>Humidity Vessel Specimen #1</u>

- Control vessel (no thermal insulation in the outlet box)
- Duplex receptacle with wire binding screws made from steel
- Exposed to 96 percent relative humidity for twelve months
- Unenergized from the 120V building power supply

EXTENT OF CORROSION

- the interior surfaces of the outlet box were covered by a white colored deposit. Brown specks estimated to be 1/16 to 1/8 inch in diameter, covered the interior of the box. The specks were separated from each other by about 1/2 inches.
- The surface of the cable clamps in the box was covered by about 95 percent of a brown deposit.
- The exterior surfaces of the outlet box were covered by a white colored deposit. Brown specks, estimated to be 1/16 to 1/8 inch in diameter, occasionally appeared on the exterior of the box. The specks were estimated to occupy 2% of the exterior surface of the box.
- The exterior surface of the left side of the box had a circular patch of rust estimated to be 3/8 inch in diameter.
- Wire binding screw heads were covered by a white deposit.
- Copper wire loops and bare copper grounding wire were tarnished.

<u>Humidity Vessel Specimen #27</u>

- Control vessel (no thermal insulation in the outlet box)
- Duplex receptacle with steel wire binding screws
- Exposed to 75 percent RH for six months

- Unenergized from the 120V building power supply

EXTENT OF CORROSION

- The box was not corroded. It looked new.
- The duplex receptacle was not corroded. It looked new.

Humidity Vessel Specimen #53

- Control vessel (no thermal insulation in the outlet box)
- Duplex receptacle with steel wire binding screws
- Exposed to 44 percent RH for six months
- Unenergized from the 120V building power supply

EXTENT OF CORROSION

- The box was not corroded. It looked new.
- The duplex receptacle was not corroded. It looked new.

2.3 CORROSION CURRENTS

Corrosion is an electrochemical process. For electrochemical corrosion to occur, anode, cathode, conductor and electrolyte must be present. In the present study the anodes and cathodes are located on the electrical boxes and the wires or the box itself. The corrosion currents resulted from electrical potential differences between anodic and cathodic regions. The currents being controlled by the electrical resistance of the electrolyte which is the condensed moisture in the damp thermal insulation. The corrosion current, under ideal conditions, may be used to determine the corrosion rate. The corrosion occurring in the test specimens, however, could not be calculated because of localized corrosion. Localized corrosion currents may not be measured. The measured currents, however, were useful as indicators of amount of corrosion taking place.

2.3.1 Test Procedure

The corrosion currents were measured directly by using a 0-50 μA meter with an internal resistance of 2300 ohms. The meter was installed in the wiring connecting duplex receptacles and switches.

2.3.2 Test Results

The measured corrosion currents were consistent with visual inspection, i.e., 96 percent relative humidity was a corrosive environment and 75 percent and 44 percent relative humidities were much less corrosive environments.

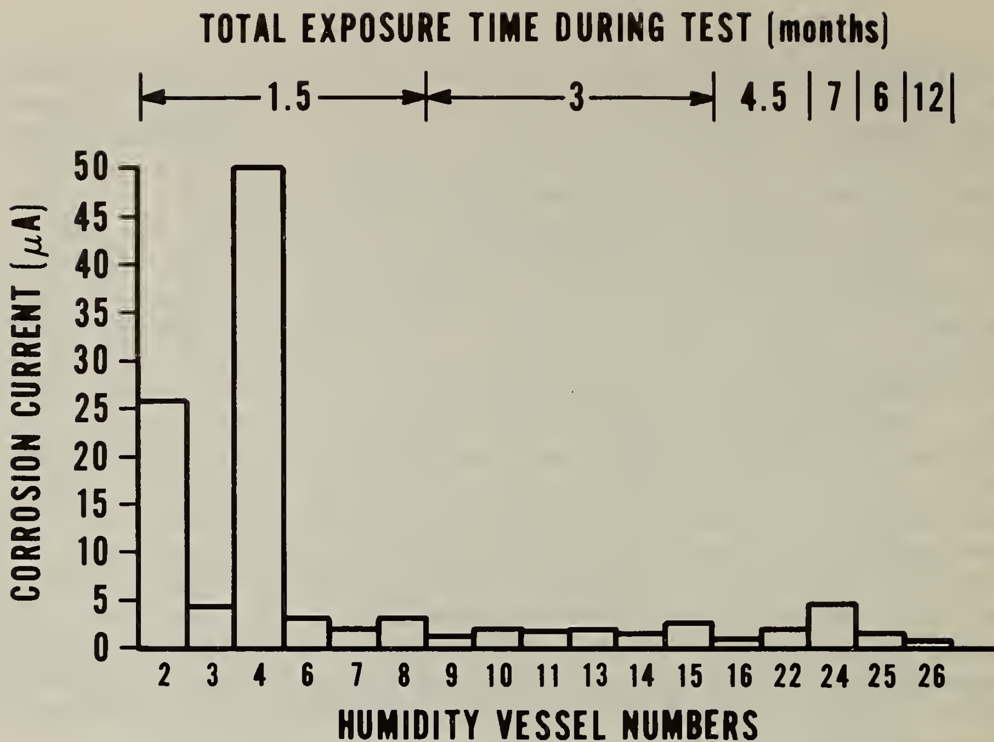
Figure 9 gives two histograms of corrosion currents measured in cellulose thermal insulation filled outlet boxes exposed within the 96 percent relative humidity vessels. Corrosion currents were measured eight days after the start of the tests and at the end of scheduled test periods. Comparison of the eight day and total time exposure histograms shows that corrosion current magnitudes were generally decreasing with time except for the case of number 2 and 4. Figure 10 shows a similar histograms for UF foam filled outlet boxes. Comparison of these histograms shows that corrosion currents are increasing with time. Humidity vessel number 50 is an exception; its not understood why current has greatly decreased. Perhaps, UF foam shrinkage and/or in adequate fill or voids in this case may have resulted in reduced current. Comparison of figures 9 and 10 indicates that corrosion currents in cellulose filled outlet boxes were approximately ten times greater than currents in UF foam filled outlet boxes. Currents within the range 0.3 to 2 μA were measured in cellulose filled outlet boxes exposed to 75 percent relative humidity, and no currents were measured during exposure to 44 percent relative humidity. No current were measured in UF foam filled boxes exposed to 75 and 44 percent relative humidities. No corrosion currents were measured in control vessels. The currents presented in figures 9 and 10 were measured between the ungrounded conductor (black wire) and grounding conductor. Similar currents not present here were measured between the other conductors.

2.4 INSULATION RESISTANCE

Electrical systems use electrical insulating materials to isolate current carrying elements from each other, from ground, and from contact by people. In duplex receptacles and switches, the current-carrying elements such as wire binding screws are electrically isolated from the sides of the metal outlet and switch boxes by the air spaces within the boxes. When the boxes are filled with either cellulose or UF foam thermal insulations, the insulations fill these air spaces between the boxes and current-carrying elements. The thermal insulations serve as electrical insulating materials between current-carrying elements and the boxes. The direct current resistance of an electrical insulating material is referred to as its insulation resistance [11]. The purpose of the tests presented in this section was to compare the insulation resistance of the cellulose and UF foam thermal insulation-filled boxes to the insulation resistance of air-filled boxes.

2.4.1 Test Procedure

A megohm bridge having a measurement range of 0.1×10^6 to 1×10^{12} ohms with a 100 volts dc excitation was used to measure the resistance between the ungrounded conductor (black wire) and grounding conductor of cables connecting the duplex receptacles and the switches. The measurements were taken after one minute of electrification. This is a conventional but arbitrary period [11]. Resistances less than 0.1×10^6 ohms were measured with an ohmmeter.



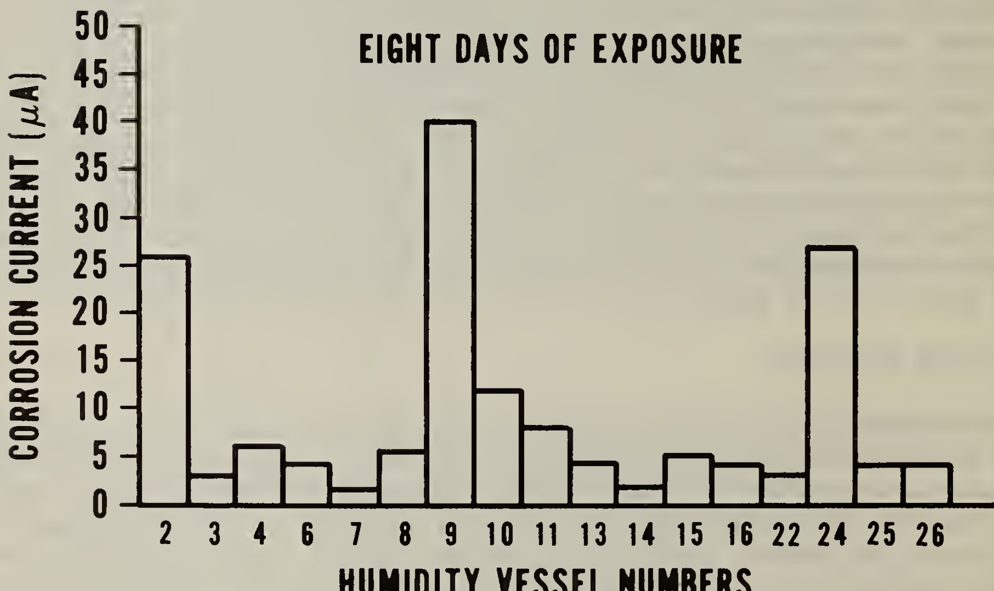
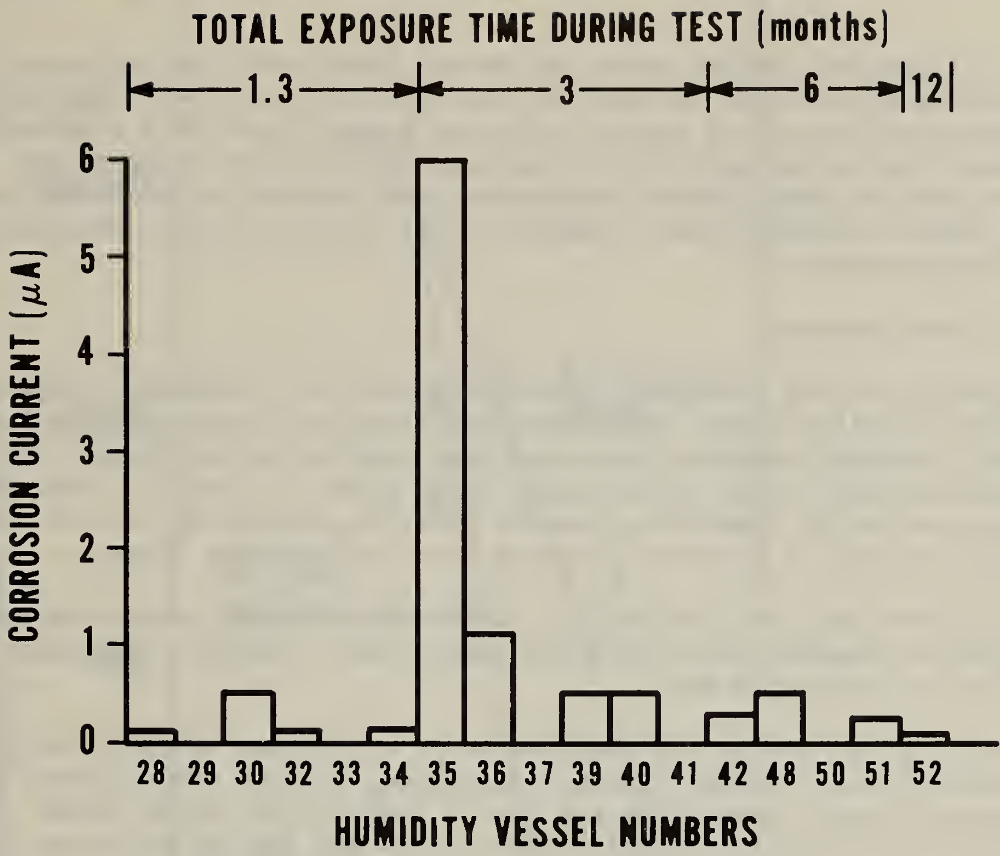


Figure 9. Corrosion currents measured in cellulose thermal insulation filled outlet boxes exposed ot 96 percent relative humidity.



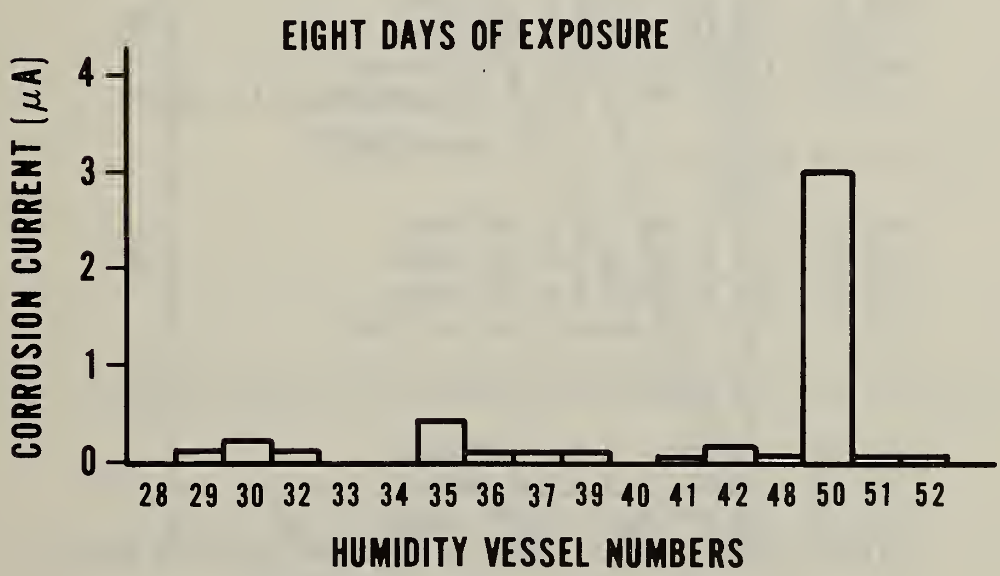


Figure 10. Corrosion currents measured in UF foam thermal insulation filled outlet boxes exposed ot 96 percent relative humidity.

After filling the outlet boxes and switch boxes with the cellulose thermal insulation as detailed in section 2 of this report, these boxes were exposed to laboratory air at 36 percent relative humidity and 69°F temperature for 72 hours before making initial insulation resistance measurements. The boxes filled with UF foam thermal insulation were exposed to laboratory air at the same relative humidity and temperature for 42 hours before making the initial test measurements.

2.4.2 Test Results

Examination of the insulation resistance data for cellulose thermal insulation-filled outlet boxes obtained from test vessels exposed to 96 percent relative humidity indicated that insulation resistances tended to increase slightly with the exposure times given in table 1. The insulation resistances in UF foam-filled outlet boxes exposed to 96 percent relative humidity tended to decrease slightly with the exposure times.

Insufficient data was available to observe insulation resistance as a function of time at other relative humidities; therefore time-dependent data is not presented here.

Figure 11 gives insulation resistances as a function of relative humidity for outlet boxes without thermal insulation, for the outlet boxes filled with cellulose thermal insulation and for UF foam-filled outlet boxes. Figure 11 includes the initial insulation resistances for the outlet boxes exposed to the 36 percent relative humidity of laboratory air. Figure 11 was plotted with averages of insulation resistance measurements taken at the end of the test periods given in table 1. The range of insulation resistance measurements for each relative humidity was as follows:

(a) For cellulose at:

96% RH, $2 \times 10^3 - 2.6 \times 10^5$ ohms
75% RH, $3 \times 10^5 - 1.6 \times 10^6$ ohms
44% RH, $3.5 \times 10^7 - 7.1 \times 10^7$ ohms
36% RH, $105 \times 10^6 - 500 \times 10^6$ ohms (initial data)

(b) For UF foam at:

96% RH, $2.5 \times 10^4 - 6 \times 10^5$ ohms
75% RH, $3.5 \times 10^6 - 5 \times 10^7$ ohms
44% RH, $3.4 \times 10^9 - 5 \times 10^9$ ohms
36% RH, 1×10^{12} ohms (initial data)

(c) For air (no thermal insulation in the outlet boxes)

96% RH, $9 \times 10^5 - 2.5 \times 10^6$ ohms
75% RH, $1 \times 10^9 - 5 \times 10^9$ ohms
44% RH, $5 \times 10^6 - 30 \times 10^9$ ohms
36% RH, $2000 \times 10^6 - 200000 \times 10^6$ ohms (initial data)

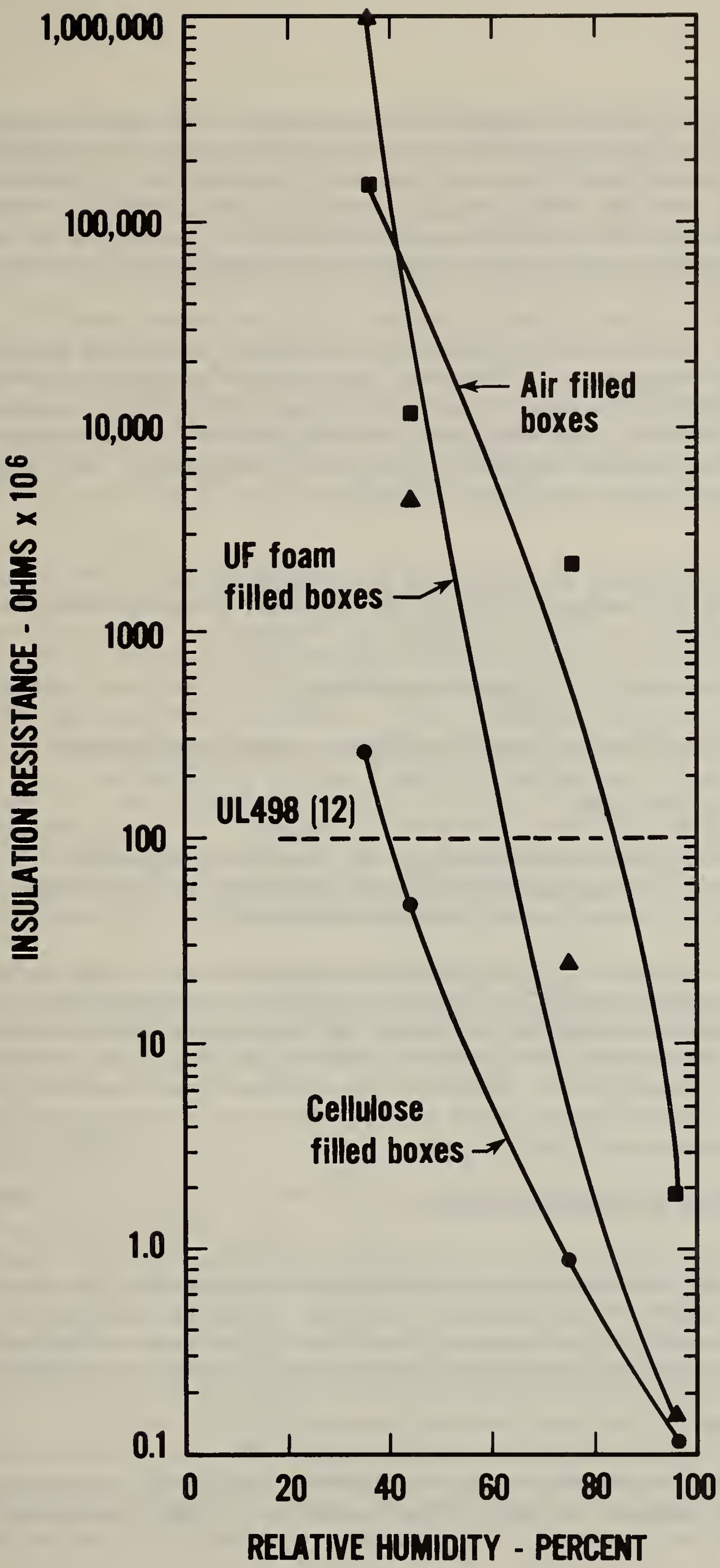


Figure 11. Average insulation resistance of outlet box specimens.

The curves show at 96 percent relative humidity (RH) that the cellulose insulation in outlet boxes reduced the insulation resistance compared to unfilled boxes by more than 93 percent and by 99 percent at 75 percent RH and 44 percent RH. The UF foam reduced the insulation resistance within outlet boxes by 92 percent at 96 percent RH and by 99 percent at 75 percent RH. The UF foam caused a 96 percent reduction of insulation resistance at 44 percent RH.

The dashed line at 100 megohms in figure 11 indicates a minimum acceptable level of insulation resistance. This is judged as an acceptable level based on the UL standard for Attachment Plugs and Receptacles [12]. However, the Standard does not require that receptacles be mounted in outlet boxes for the test and the test is not required at various humidities. The Standard states the following about this test [12]:

> "30.1 When determined as described in paragraphs 30.3 - 30.6, the insulation resistance shall not be lower than 100 megohms between:
>
> A. Live parts of opposite polarity,
>
> B. Live parts and dead metal parts which are exposed to contact by persons or which may be grounded in service, and
>
> C. Live parts an any surface of insulating material which is exposed to contact by persons or which may be in contact with ground in service."

As seen in figure 11, the cellulose insulation-filled box is not in compliance with the 100 megohm criterion for relative humidities higher than 40 percent and the UF foam insulation-filled box does not comply for relative humidities higher than about 62 percent. The air-filled box at 96 percent relative humidity was not in compliance. However, the minimum resistance of the air-filled box was about twenty times greater than the minimum resistances of the thermal insulation-filled boxes.

2.5 DIELECTRIC VOLTAGE WITHSTAND TEST

Residential electric circuits can be subjected to surge voltages resulting from load switching in buildings or from external causes such as lightning. Surge voltages of 1000 or more volts do occur at times on residential wiring [13]. For this reason, it is important that wiring devices be capable of enduring surges without voltage breakdown which may result in fire hazards.

2.5.1 Test Procedure

Dielectric withstand voltages are applied between insulated conductors or terminals or other elements of appropriate polarity, often including the grounding conductor or terminal. The dielectric material of the cable or device is subjected to a voltage considerably in excess of the rated voltage but less than expected breakdown voltage. The standard test tends to indicate capability to withstand rated voltage with superimposed momentary surge or transient voltage level. Nonmetallic-sheathed cables, Type NM are subjected to a voltage of 5000 volts [14]. Armored cables, type AC are subjected to 1500 volts [15]. Receptacles and plugs are usually subject to 1250 volts [12]. All thermal insulation surrounded devices and wiring were subjected to a 60 Hz 1250 volt potential for a period of one minute. This potential was applied initially after filling outlet boxes with thermal insulation and at the end of the test. The potential was applied between ungrounded conductor (black wire) and grounded conductor (white wire), grounding wire and black wire, and grounding wire and white wire. In order to pass this test, circuits and devices had to withstand without breakdown the test potential of 1250 volts AC for a period of one minute.

2.5.2 Test Results

All of the cellulose thermal insulation filled boxes passed the voltage withstand test prior to exposure to constant relative humidities; all cellulose insulation filled boxes exposed to 96 percent humidity failed the test. The cellulose insulation filled boxes exposed to 75 percent relative humidity failed the voltage withstand test. All cellulose insulation filled boxes exposed to 44 percent relative humidity passed the voltage withstand test.

All of the UF foam thermal insulation filled boxes passed the voltage withstand test prior to exposure to constant relative humidities. Seven UF foam filled boxes exposed to 96 percent relative humidity failed the test. All UF foam filled boxes exposed to 75 percent and 44 percent relative humidity passed the voltage withstand test.

All of the control boxes (without thermal insulation) passed the voltage withstand test prior to constant relative humidity exposure. The control boxes exposed to 96 percent relative humidity failed the test. Control boxes exposed to 75 and 44 percent relative humidies passed the voltage withstand test.

2.6 SHOCK HAZARD

The appendix to ANSI C39.5-1974[16] gives the following information concerning shock hazard [16]:

"This American National Standard defines a shock hazard part as one whose voltage to ground exceeds 30 volts r.m.s. or 42.4 volts d.c. or peak, and where the leakage current from the part to ground exceeds 0.5 milliampere when measured by a designated method (3). The criteria of the danger from electric shock are based upon the current which actually flows through the body (5). The value of this current depends upon the body resistance and the voltage across it. The former factor varies over a wide range. It may be considered as consisting of the series combination of the resistances of the skin at the points of contact and the internal resistance of the body."

"The internal resistance of the body is low, and estimates of its value range form 300 to 1,000 ohms (1,2,4). Skin resistance depends upon the condition of the skin and the areas of contact. Under favorable conditions - dry skin and small area of contact - skin resistance may be as high as 500,000 ohms. When the skin is moist its resistance is relatively low. Breaks in the skin at the points of contact reduce its resistance practically to zero. Under this condition the only limitation to current flow is the internal resistance of the body."

"The effects of 60 hertz alternating current on the human body have been described as follows (1):

(1) At about 1 milliampere, the shock is perceptible
(2) At about 10 milliamperes, the shock is of sufficient intensity to prevent voluntary control of the muscles, and may cause freezing to the circuit
(3) At about 100 milliamperes, the shock is fatal if it lasts more than 1 second

With the most highly conductive contact conditions, a voltage of 30 volts can cause the minimum lethal current to flow through the body. Lower values of current can create another danger, that of surprise. A current as little as 1 milliampere (0.001 ampere) may startle a person and cause an accident, such as a fall."

2.6.1 Test Procedure

Shock hazards were determined using a commercially available "Leakage Current Tester" that meets the requirements of ANSI C101.1 [17]. The meter was designed specifically to measure hazardous leakage currents from electrical appliances and other power line operated equipment. The instrument has an insertion impedance resistance of 1500 ohms in parallel with capacitance of 0.15 micro-farads when measuring current. The 1500 ohm resistance simulates the resistance of the human body. The capacitance compensates the meter indication to correspond with the decreasing sensitivities of shock of the body to increasing frequency. The instrument measures both leakage current and voltage with respect to ground. The input resistance of the meter is 500,000 ohms on the voltage measurement range. The test setup is shown in figure 12. A shock hazard might exist in some homes using two-conductor nonmetallic-sheathed cable without grounding conductor and metal outlet boxes, when the outlet boxes contained either UF foam or cellulose thermal insulation. This ungrounded condition was simulated by inserting a two-wire to three-wire adapter in the power supply to the receptacle within the humidity vessel. The grounding wire to the receptacle was reconnected to ground by way of the leakage tester. Voltages with respect to both ground and leakage current were measured in this manner. These exposed voltages and/or leakage currents could exist in an actual residence using a two-wire system if a metal wall plate were used.

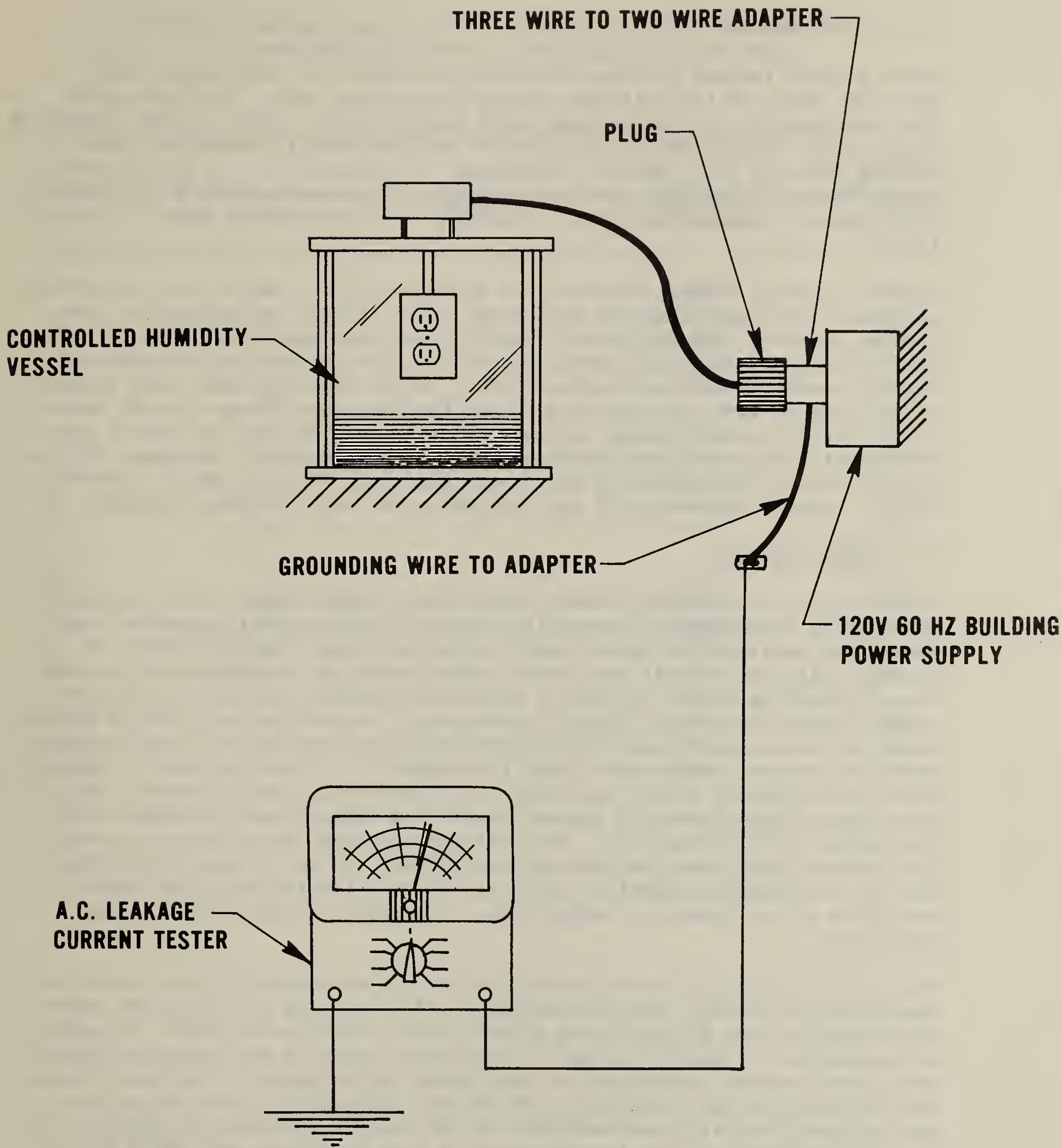


Figure 12. Shock hazard test.

2.6.2 Test Results

Table 2 gives leakage currents and voltages which were taken eight days after the start of the cellulose thermal insulation test. The table shows that specimens 8, 15, and 26 were shock hazards [16]. Table 3 gives leakage currents and voltage taken at the end of various humidity exposure times ranging from 1.5 to 12 months. Specimens 3, 7, 8, 10, 12, 14, and 15 were shock hazards [16]. Five specimens tripped a duplex receptacle type ground fault circuit interrupter (GFCI). The GFCI trip setting was about 2.6 mA [18].

Table 4 presents leakage currents and voltages for UF foam filled outlet box specimens taken approximatley four hours after filling and before the controlled relative humidity tests. Most of these specimens were shock hazards [16]. Twenty of these specimens tripped a duplex receptacle type GFCIs. Table 5 shows currents and voltages after the UF foam specimens were exposed to relative humidity for twelve days and that specimen 39 was a shock hazard [16]. Table 6 gives leakage currents and voltages taken at the end of various humidity exposure times ranging from 1.3 to 12 months. Specimens 29, 30, 32, 35, 36, 37, 39, 42 and 50 were shock hazards. Four specimens tripped GFCIs. Control specimens did not trip GFCIs and were not shock hazards.

2.7 ENERGY LOSSES

Section 2.6 of this report showed that a shock hazard might exist in some homes using two-conductor nonmetalic-sheathed cable without grounding conductor and metal outlet boxes, when the outlet boxes contained either UF foam or cellulose thermal insulation. When homes use grounded metal outlet boxes containing either UF foam or cellulose thermal insulation, increased energy losses can exist. Table 7 shows energy losses for both control outlet boxes and some outlet boxes filled with cellulose insulation. This table is based on leakage current data taken from table 3. It can be seen in table 6 that similar energy losses can occur in UF foam filled outlet boxes. Table 7 shows that energy losses in thermal insulation filled boxes increased with increasing relative humidity. The controls also show an increase in energy lost between the lowest and highest humidities. It can be seen from table 7 for any one relative humidity value that thermal insulation filled boxes have five or ten times the energy losses of boxes not containing thermal insulation.

This results in a net annual energy loss of 922 watt hours in the outlet box exposed to 96 percent relative humidity, 195 watt hours at 75 percent relative humidity, and 82 watt hours at 44 percent relative humidity. It would be impossible to predict the exact total energy loss in all residences which have these thermal insulations in electrical outlet boxes. This would depend on the amount of the cellulose or UF thermal insulation in the outlet box, the relative humidity, and moistness of the thermal insulation. However, it seems reasonable to judge that millions of watt hours per year could be lost.

Table 2. Leakage Currents and Voltages in Cellulose Thermal Insulation Specimens After Eight Days of Test

Vessel No.	R = receptacles S = switch	Voltage volts	Leakage milliamperes	Percent Relative Humidity
5**	R	2	0.005	96
6	R	5	0.75	96
7	S	70	0.32	96
8*	S	95	1.17	96
13	R	6	0.8	96
14	S	75	0.4	96
15*	S	91	0.95	96
16	R	5	0.58	96
17	R	25	0.34	75
18	S	45	0.16	75
19	R	20	0.19	44
20	R	10	0.003	44
21	S	1	0.002	44
22	R	6	0.72	96
23	R	20	0.26	75
25	R	5	0.75	96
26*	S	78	0.85	96
31**	R	2	0.005	75

* Live Part (Shock Hazard) [16]

** Control - no thermal insulation in the outlet box

Table 3. Leakage Current and Voltages in Cellulose Thermal Insulation Specimens at the End of Test

Vessel No.	R = receptacles S = switch	Exposure Time - Months	Voltage volts	Leakage milliamperes	Recent Relative Humidity
1***	R	12	25	0.1	96
2	R	1.5	25*	4.5	96
3**	S	1.5	110*	4	96
4****	S	1.5	-	-	96
5***	R	7	0	0	96
6	R	1.5	2	0.64	96
7**	S	1.5	90	0.58	96
8**	S	1.5	100	1.6	96
9	R	3	16*	4	96
10**	S	3	110*	>10	96
11	S	3	17*	4	96
12**	R	4.5	60	1.1	75
13	R	3	5	0.69	96
14**	S	3	86	0.51	96
15**	S	3	94	0.91	96
16	R	4.5	15	0.52	96
17	R	4.5	30	0.29	75
18	S	4.5	31	0.09	75
19	R	6	4	0.1	44
20	R	6	5	0.1	44
21	S	6	1	0.02	44
22	R	4.5	24	0.73	96
23	R	12	20	0.2	75
24	R	7	10	1.0	96
25	R	6	24	0.76	96
26**	S	12	87	0.87	96

* tripped GFCI
** live part (shock hazard) [16]
*** control - no thermal insulation in the outlet box
**** no data available

Table 4. Initial Leakage Currents and Voltages in UF Foam Specimens

Vessel No.	R = receptacles S = switches	Voltage volts	Leakage milliampeeres
28**	R	70*	8.9
29**	S	74*	7.2
30**	S	46*	5.4
32**	S	75*	10.0
33	S	2.5	0.006
34**	S	45*	3.8
35**	R	60*	7
36**	S	45*	2.7
37**	S	50*	5.6
38**	R	65*	5.7
39**	R	86*	>10
40	S	25	1.3
41**	S	75*	2.8
42**	R	109*	3.2
43**	R	70*	7.7
44**	S	35*	3.0
45**	R	55*	5.8
46**	R	85*	7.2
47**	S	35	1.3
48**	R	60*	7.4
49**	R	90	0.5
50**	R	70*	9.0
51**	R	40*	5.4
52**	S	50*	4.0

* tripped GFCI
** live part (shock hazard) [16]

Table 5. Leakage Currents and Voltages in UF Foam Specimens Taken After Twelve Days of Test

Vessel No.	R = receptacles S = switch	Voltage volts	Leakage milliamperes	Percent Relative Humidity
31**	R	0	0	75
32	R	48	0.45	96
33	S	5	0.0	96
34	S	22	0.34	96
39*	R	56	7	96
40	S	20	0.23	96
41	S	0	0	96
42	R	53	0.18	96
43	R	9	0.4	75
44	S	6	0.1	75
45	R	0	0	44
46	R	50	0.25	44
47	S	17	0.13	44
48	R	38	0.45	96
49	R	32	0.1	75
51	R	28	0.28	96
52	S	0	0	96
53**	R	0	0	44

* live part (shock hazard) [16]

** control - no thermal insulation in the outlet box

Table 6. Leakage Currents and Voltages in UF Foam Vessel Specimens at End (Line Voltage 117 Volts Approximately)

Vessel No.	R = receptacle S = switch	Exposure Time - Months	Voltage volts	Leakage milliamperes	Percent Relative Humidity
27	R	6	10	0.02	75
28	R	1.3	26*	3	96
39**	S	1.3	60	2.5	96
30**	S	1.3	54	3	96
31	R	12			
32**	R	1.3	58	0.62	96
33	S	1.3	5	0.009	96
34	S	1.3	15	0.345	96
35**	R	3	65*	4.1	96
36**	S	3	40	1.6	96
37**	S	3	40*	3.5	96
38	R	6	18	0.04	75
39**	R	3	45	0.75	96
40	R	3	20	0.33	96
41	S	3	0	0.005	96
42**	S	3	90	0.8	96
43	R	6			75
44	R	12	5	0.1	75
45	S	6	2	0.05	44
46	R	6	2	0.05	44
47	R	6	2	0.05	44
48	S	6	25	0.66	96
49	R	6	5	0.01	75
50**	R	6	75*	6.6	96
51	R	6	18	0.5	96
52	S	12			96
53		6	10	0.02	96
54	R	12			44

* tripped GFCI
** live part (shock hazard) [16]

Table 7. Estimated Energy Losses in Outlet Boxes

Vessel No.	Leakage Current-MA	Estimated** Annual Energy Losses-Watt-hours	Relative Humidity-Percent	Exposure Time-Months
1*	0.1	103	96	12
20	0.1	103	44	6
23	0.2	205	75	12
24	1.0	1025	96	7
31*	0.01	10	75	12
53*	0.02	21	44	6

* Controls - no thermal insulation in the outlet box

** For calculation purposes voltage equals 117V and hours in one year equal 8760

3. SUMMARY

When residential walls are retrofitted with "foamed-in-place" urea-formaldehyde or "blown-in" cellulose thermal insulations, the insulations may enter electrical outlet and switch boxes. Condensation and high humidity conditions may be a problem in homes retrofitted with thermal insulation; therefore, the effects of these thermal insulations on electrical outlet boxes, receptacles, and switches were determined at 44 percent, 75 percent, and 96 percent relative humidities and 70°F (21°C) for periods up to twelve months. Two control outlet boxes that did not contain thermal insulations were also tested at each relative humidity. The presence of corrosion on outlet boxes, receptacles, and switches was ascertained by visual inspection and by galvanic corrosion current measurements in electrical branch circuit wiring connecting the outlet boxes, receptacles, and switches. Electrical tests were also made to determine the existance of electric shock hazards and potential electrical energy losses.

3.1 CORROSION OF OUTLET BOXES AND DEVICES

Cellulose thermal insulation in outlet boxes exposed to 96 percent relative humidity gained moisture to 119 percent of the dry mass of the cellulose during the first month of exposure and thereafter lost moisture. The urea-formaldehyde thermal insulation in outlet boxes exposed to 96 percent relative humidity gained moisture throughout most of the test period. Because of the smaller number of specimens exposed to 75 percent and 44 percent relative humidities the moisture trend was not seen. Moisture contents at these lower relative humidities were fractions of the moisture contents at 96 percent relative humidity. The moisture in the types of cellulose and UF foam thermal insulations studied for this report formed the electrolyte necessary for galvanic corrosion.

The measured corrosion currents followed the same trend as the moisture. That is, the corrosion currents measured in the outlet boxes exposed to 96 percent relative humidity decreased with time in the boxes filled with cellulose thermal insulation and increased with time in the boxes filled with UF foam thermal insulation. The corrosion currents in the cellulose insulation filled outlet boxes were about ten times greater than the UF foam insulation filled boxes exposed to 96 percent relative humidity. Relatively small corrosion currents were measured in cellulose thermal insulation filled outlet boxes exposed to 75 percent relative humidity and no currents were measured in cellulose insulation filled outlet boxes exposed to 44 percent relative humidity. No corrosion currents were measured in UF foam thermal insulation filled boxes exposed to 75 and 44 percent relative humidities. No corrosion currents were measured in outlet boxes that did not contain thermal insulation.

Visually ascertained corrosion results were in agreement with measured corrosion current trends; outlet boxes that had the largest corrosion currents had the largest observed amounts of rust. Specimens that did not have large currents or no measured currents usually were not corroded or had slight corrosion. The control outlet boxes exposed to 96 percent relative humidities were an exception. Although no corrosion currents were measured in control boxes, small amount of rust was observed on control outlet boxes including large amounts of white zinc oxide. The observed corrosion of control outlet boxes exposed to 96 percent relative humidity appeared to be much less than the relatively heavy rust deposits within outlet boxes and connections exposed to 96 percent relative humidities and thermal insulation. Controls and thermal insulation filled outlet boxes exposed to the lower relative humidities were not corroded.

3.2 ELECTRIC SHOCK HAZARDS FROM OUTLET BOXES FILLED WITH THERMAL INSULATION

When the cellulose and the UF foam thermal insulations were dry at a relative humidity of 40 percent or less, both the cellulose and UF foam thermal insulations were good electrical insulators. However, when exposed to high relative humidity of 96 percent, both the cellulose and UF thermal insulations used in this study were poor electrical insulators. Even though the electrical resistance between any two conductors of the control boxes dropped to about 2 megohms when exposed to 96 percent relative humidity, the resistance between any two conductors of the controls or air filled box was 20 times higher than the same resistance measurement of the thermal insulation filled boxes exposed to 96 percent relative humidity. See figure 11. Leakage current measurements showed that no control outlet box was a shock hazard. Also, no control outlet box tripped a ground fault circuit interrupter (GFCI). However, the relatively low resistance of the thermal insulation filled outlet boxes exposed to 96 percent relative humidity resulted in potential for shock hazards in ungrounded outlet boxes having metal flush plates; GFCI tripping occurred when some of the thermal insulation filled boxes were grounded. Tables 2, 3, 4, 5, and 6 show the possibility for shock hazards in both the cellulose and the UF foam filled outlet and switch boxes. Table 4 shows that these hazards existed for nearly all UF foam filled boxes after initially filling the outlet boxes with the wet UF foam. It is not known how long this hazard would exist in UF foam filled walls having ungrounded outlet boxes filled with wet UF foam. The length of time would depend on how rapidly the UF foam lost moisture to the surroundings. This would vary with on site conditions of humidity, temperature, ventilation, and moisture content of wall materials.

3.3 <u>ENERGY LOSSES IN OUTLET BOXES FILLED WITH THERMAL INSULATION</u>

In grounded outlet boxes, continuous electric current leakage exists between the ungrounded conductor (black wire) and the grounding conductor and between the ungrounded conductor and grounded conductor (white wire). As shown in table 7 these leakage currents appear in control outlet boxes. The leakage currents are higher at 96 percent relative humidity than at 44 and 75 percent relative humidities. Table 7 shows that the addition of thermal insulation to the outlet boxes increases the leakage currents by five or ten times.

4. CONCLUSIONS

When residential walls are retrofitted with cellulose and UF foam thermal insulations, the insulations may enter electric outlet and switch boxes. Cellulose and UF foam thermal insulations of the types having the characteristics studied for this report should be removed from outlet boxes and switch boxes:

a. to prevent risk of corrosion which might lead to electrical system failure.

b. to prevent possible electric shock.

c. to prevent possible energy losses from increased leakage currents.

5. RECOMMENDATIONS

A field study should be carried out to identify the level of corrosion within outlet boxes and switch boxes as related to geographical locations (seashore versus inland) when the boxes are surrounded by thermal insulation and not surrounded by thermal insulation.

6. REFERENCES

1. Corrosive Attack by Moist Cellulose Insulation; Investigation Report Copper Development Association Inc. (1978).

2. R. W. Anderson and P. Wilks, Survey of Cellulosic Insulation Materials, Report No. ERDA 77-23, Department of Energy, Washington, D.C., 1977.

3. R. W. Beausoliel, W. J. Meese, and L. S. Galowin, Exploratory Study of Temperatures Produced by Self-Heating of Residential Branch Circuit Wiring When Surrounded by Thermal Insulation, NBSIR 78-1477, July 1978.

4. John S. Weidt, Robert J. Saxler, and Walter J. Rossiter, Jr., Field Investigation of the Performance of Residential Retrofit Insulation, NBS TECHNICAL NOTE 1131, September 1980.

5. David Hassall, School of Building, University of New South Wales, Australia, Curing a Condensation Problem, BUILDING INTERNATIONAL (7) (1974) - Applied Science Publishers Ltd., England, printed in Great Britain, 1974.

6. Tyler Stewart Rogers, Director of Technical Pulications, Owens-Corning Fiberglas Corporation, Design of Insulated Buildings for Various Climates, Roberts Printing Company, Toledo, Ohio, 1951.

7. Harold W. Orr, Condensation in Electrically Heated Houses, Division of Building Research, Prairie Regional Station, National Research Council of Canada, Saskatoon, Canada.

8. Moisture Conditions in Walls and Ceilings of a Simulated Older Home During Winter, USDA Forest Service Research Paper FPL 290 1977, U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, Wisconsin.

9. Standard Recommended Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions, ASTM Designation E104-51 (Reapproved 1971), 1974 Annual Book of ASTM Standards, American Society for Testing and Materials.

10. Walter J. Rossiter, Jr., and Robert G. Mathey, Criteria for Retrofit Materials and Products for Weatherization of Residences. NBS Technical Note 982, September 1978.

11. D-C Resistance or Conductance of Insulating Materials - ASTM D 257-66 (Reapproved 1972), Electrical Insulating Materials Test Methods, Part 39, 1974 Annual Book of American Society for Testing Materials Standards.

12. UL Standard 498, Attachment Plugs and Receptacles, April 1, 1974.

13. J. E. V. Raduan, R. W. Beausoliel, and W. J. Meese, An Exploratory Study of Dielectric Breakdown Voltages for Residential Wiring, NBSIR 78-1537, October 1978.

14. UL Standard 719, Nonmetallic-Sheathed Cables (ANSI C33.56-1974).

15. UL Standard 4, Armored Cable, October 2, 1977.

16. Safety Requirements for Electrical, Electronic Measuring and Controlling Instrumentation, ANSI C39.5.

17. American National Standard for Leakage Current for Appliances, ANSI C101.1-1973.

18. R. W. Beausoliel and W. J. Meese. Survey of Ground Fault Circuit-Interrupted Usage for Protection Against Hazardous Shock, NBS Building Science Series 81, March 1976.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

When residential walls are retrofitted with "foamed-in" urea formaldehyde or "blown-in" cellulose thermal insulations, the insulation may enter electrical outlet and switch boxes. The effects of these thermal insulations on the durability of electrical components were studied. These studies were carried out at 44, 75, and 96 percent relative humidities with test periods between one and twelve months.

Laboratory test methods were developed and tests performed to determine the electrical and corrosive effects of urea formaldehyde and cellulose thermal insulation contained in electrical outlet and switch boxes. The boxes were tested in humidity-controlled closed-glass vessels at ambient temperatures. These tests were of an exploratory nature and did not cover all of the conditions that would exist in a residential wall. The testing methods are described in this report and the results are presented and interpreted.

Results indicate that these thermal insulations can cause significant corrosion of electrical components and can cause shock hazards and increased energy losses. It is concluded that these thermal insulations should be removed from electrical outlet and switch boxes.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

cellulose thermal insulation; corrosion of electrical outlet boxes and devices; electrical devices; humidity, thermal insulation and corrosion of electrical wiring; shock hazards; urea-formaldehyde thermal insulation.

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