

PILOT SURVEY OF BRANCH WIRING SYSTEMS  
IN MONTGOMERY COUNTY, MARYLAND

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# PILOT SURVEY OF BRANCH WIRING SYSTEMS

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## ABSTRACT

The type of branch wiring system was identified in a random sample of 200 homes selected from listings of building permits issued in Montgomery County, Maryland [excluding Rockville and Gaithersburg, Md.] in 1969. Approximately 24 percent of the homes had aluminum wiring in all or a portion of the branch circuits and 76 percent had all copper branch circuits. During this phase of the survey, occupants reported prior replacement of a duplex receptacle because of overheating or malfunction in 26 percent of the aluminum wired homes compared to 3 percent of the copper wired homes.

Thermal measurements were made in 124 homes selected to represent four types of wiring systems:

- . 39 Aluminum wired homes with wire binding screw duplex receptacle terminations: one 20 amp and two 15 amp aluminum wire circuits measured
- . 26 Copper wired homes with wire binding screw duplex receptacle terminations: one 20 amp and two 15 amp copper wired circuits measured
- . 31 Copper wired homes with backwiring duplex receptacle terminations: one 20 amp and two 15 amp copper wired circuits measured
- . 28 Homes with both aluminum and copper wired circuits. Measurements were taken on one 20 amp copper wired circuit terminated by wire binding screws or backwiring and two 15 amp aluminum wired circuits terminated by wire binding screws.

Failure rates were based on the percent of homes in which at least one receptacle overheated after testing three circuits for 30 minutes with a load of 75 - 80% of the circuit rating. Seven of the 39 homes (18%) with 15 and 20 amp aluminum circuits had at least one receptacle reaching 100°C (212°F) while this level of overheating was not found in any of the 57 homes with 15 and 20 amp copper circuits. Including the seven homes mentioned, 41 percent of the aluminum wired homes had at least one receptacle overheating to 75°C (167°F) or more, compared with 2 percent (1/57) of the homes wired with copper\*.

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\* Refers to homes in which 3 aluminum or 3 copper wired circuits were measured.

In the sample investigated, there were 10 times as many aluminum wired homes [8/67] with receptacles overheating to a temperature 100°C as there were copper wired homes [1/85].

Receptacles reaching temperatures of 75°C or higher were removed with wiring intact for delivery to a laboratory for monitored testing in a structure simulating home construction. Laboratory cycling is incomplete, but fires have started in three aluminum wired receptacles tested there.

In a projection of 624 aluminum wired homes for which building permits were issued in Montgomery County, Maryland [excluding Rockville and Gaithersburg] in 1969, an estimated 157 homes would have at least one receptacle reaching temperatures of 75°C [167°F] or higher during normal use. In addition, an estimated 85 homes would have duplex receptacles backwired to aluminum circuits - a misapplication by Underwriters' Laboratories standards. If inferences are made to the homes built in Montgomery County between 1966 and 1971, the estimated number of dwellings with unsafe wiring conditions would be multiplied by six.

## PILOT SURVEY OF BRANCH WIRING SYSTEMS

### I. INTRODUCTION

#### Background

Prior to 1965, copper wiring was normally used in branch circuits. Since the mid-sixties, aluminum has been used in significant amounts for branch circuit wiring in single family homes. According to production figures provided by the Aluminum Association, the amount produced in 1971 was three times that produced in 1967. Both the National Bureau of Standards (NBS) and the Aluminum Association made rough estimates of the national total of homes wired with aluminum branch circuits by 1972 as ranging between 1.5 and 2 million homes. Aluminum wire and wiring devices produced prior to revised U.L. specifications issued in June and September of 1972 are referred to as "old technology."

The U.S. Consumer Product Safety Commission has collected hundreds of reports of aluminum wire incidents involving electrical malfunctions in single family dwellings, mobile homes and multifamily dwellings between 1967 and 1976. In these reports, damage ranging from failure of an electrical component to fires with extensive structural damage were documented by fire marshals, electrical inspectors, consumer complaints and Commission investigators.

While these field data support theoretical engineering reports on the behavior of aluminum wire in branch circuits, no valid statistical data on the risks associated with this product were available. As an aid in determining the level of risk associated with "old technology" aluminum wire, the Directorate for Hazard Identification and Analysis collaborated with the Directorate for Engineering and Science to design a statistically valid pilot survey to measure overheating of duplex receptacles in electrical branch circuits of single family dwellings. The study design and plans for implementing the study were reviewed periodically and approved by Dr. Leslie Kish, Research Scientist, Survey Research Center, Institute for Social Research, University of Michigan, Ann Arbor.

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The Study was designed and directed by Rae Newman of the Directorate for Hazard Identification and Analysis (DHI) and William H. King, Jr., of the Directorate for Engineering and Sciences (DFS). Mr. Robert Guenette (DHI) supervised scheduling and conduct of survey with support from the Directorate of Engineering and Science (Robert O'Brien, et al) and from the Directorate of Hazard Identification and Analysis (Louise McGhee, et al).

### Objective

The pilot study sought to determine whether a small sample controlled study was a feasible approach to obtaining data needed by the Commission in appraising the risks associated with "old technology" aluminum wired circuits. The immediate objective of the pilot survey of single family dwellings was to provide a statistical estimate for Montgomery County of:

1. The prevalence of overheated receptacles in single family dwellings wired, during the time period sampled, with aluminum branch circuits and those wired with copper branch circuits.

2. The relative risk of overheated duplex receptacles in aluminum wired circuits compared to similar conditions in copper wired circuits.

Failure rates were computed at the level of 75°C [167°F] or higher or at the level of 100°C [212°F] or higher by type of circuitry.

Montgomery County, Maryland, was chosen for the pilot survey, to minimize the time spent by Commission staff in conducting the survey. Assessment of the preliminary results of the survey was intended before proceeding with plans for obtaining national data by replication of the survey in other areas. The design of the national survey includes an unbiased selection of survey locations.

## II. METHODOLOGY

### Survey Design

A random sample of homes in Montgomery County, Maryland, was chosen for the pilot study. Single family dwellings for which building permits were issued in 1969 provided the frame of 2,710 homes from which a sample of 200 homes was selected. Using a random start and a systematic sampling scheme, four random samples of 50 homes were identified from the permits stratified by the number of permits issued to each subdivision that year.

Homeowners were identified from the addresses in the building permits using a criss-cross index. Letters were sent to homeowners (or occupants) to inform them of the survey and serve as an introduction to the staff member who phoned them at a later date.

Homeowners were contacted by phone to schedule a visit by a licensed electrician to determine the type of wiring and method by which duplex receptacles were terminated. The type of wiring in 15 and 20 amp circuits was examined at the electrical panel box. Two circuits were identified - a 20 amp circuit providing current for a refrigerator and a 15 amp circuit providing current for a television set, preferably color television. A duplex receptacle was examined on each of these circuits to determine how the branch wire was terminated. Data was recorded by a Commission analyst.

Once the type of wiring was identified, homes were selected as eligible for each of the following four categories:

1. Aluminum Wire Binding Screw (Al WBS)

Aluminum wiring in 15 and 20 amp branch circuits terminated to duplex receptacles by wire binding screws. Three aluminum circuits were to be measured in each home.

2. Copper Wire Binding Screw (Cu WBS)

Copper wiring in 15 and 20 amp branch circuits terminated to duplex receptacles by wire binding screws. Three copper circuits were to be measured in each home.

3. Copper Backwiring (Cu BW)

Copper wiring in 15 and 20 amp circuits terminated to duplex receptacles by backwiring [wire pushed into openings in the back of the receptacle]. Three copper circuits were to be measured in each home.

4. Combination Aluminum/Copper [Al/Cu]

Aluminum wire in 15 amp circuits terminated to duplex receptacles by wire binding screws and copper wire in 20 amp circuits terminated to duplex receptacles by wire binding screws or backwiring. One copper circuit and two aluminum circuits were to be measured in each home.

Approximately 30 homes of each type were needed for Phase II of the survey during which thermal measurements were to be made. Random sampling was used when too many homes of a particular type were identified. Where necessary, clustering was used to obtain additional homes of the type required. Homes to the right and left of an eligible home made up the cluster.

In the selected homes, thermal measurements were taken by an electrical engineer from the Directorate for Engineering and Science, CPSC, and an electrician licensed in Montgomery County, Maryland. Procedures were monitored and readings recorded by an analyst from the Directorate for Hazard Identification and Analysis, CPSC. Measurements were taken on three circuits in each house: one 20 amp circuit and two 15 amp circuits. The choice of circuits for thermal testing was as follows:

1. 20 Amp Circuit (Predefined)

The kitchen circuit which supplied current to the refrigerator was designated as the 20 amp circuit to be tested. This may have been a combination circuit which extended from the kitchen to some other room.

2. 15 Amp Circuit (Predefined)

The circuit on which the most frequently used color TV was located was the first choice, with the most frequently used black and white TV as the second choice. If the TV criterion was not applicable, a circuit was selected in the family room or living room, whichever was used most frequently.

3. 15 Amp Circuit (Randomly Selected)

Using a random sampling scheme, one 15 amp receptacle circuit was chosen using a diagram of the electrical service panel box. If the preselected 15 amp circuit was selected as the random circuit, only 2 circuits were measured in that dwelling.

A minimum of 2 duplex receptacles on a circuit must have been readily accessible for the circuit to be suitable for testing. Only easily movable furniture was shifted to reach the receptacles. All of the accessible receptacles on a circuit were tested.

### Thermal Testing

Before activating the circuit under test, the ambient temperature on all accessible receptacles was recorded, and the electrician made a visual examination of the condition and wiring of each receptacle with the cover plate removed. With the circuit activated, a test load of 75 percent of the current rated for that circuit was connected to the last accessible receptacle on the circuit and timed. Thermal readings were taken at the 2 pairs of parallel slots on the face of each receptacle and recorded on a data sheet after 15 and 30 minutes had elapsed. The use of a digital temperature reader prevented observer variability.

Two critical temperatures were used as indices of failure:

- ° 75°C [167°F] is beyond the maximum temperature permitted by industry safety standards as established by Underwriters Laboratories Inc. (UL).

UL 498, Standard for Attachment Plugs and Receptacles, specifies a 30°C [54°F] temperature rise above ambient at the wire terminals when a current of 20 amps passes through the terminals of a standard duplex receptacle.

Assuming an ambient temperature of 20°C [68°F], this standard would allow the temperature to reach 50°C [122°F]. However, since the survey procedure involved the receptacle being tested in the confines of the house wall, whereas standard test procedures utilize open air bench testing, an allowance of 25°C [45°F] was added to reach the 75°C value used.

- ° 100°C [212°F] is a temperature level above which accelerated degradation occurs for the common insulating materials used on wire and receptacles.

If a temperature of 100°C or higher was recorded, the test was discontinued before reaching the temperatures associated with melted insulation and evidence of burning or charring. After confirmation by a monitored retest, the receptacle was removed with wiring intact and saved for future testing.

On completion of thermal testing, all receptacles which registered temperatures of 75°C to 99°C were also removed with wiring intact and saved for further testing. Each receptacle removed was replaced by an appropriate device meeting the Montgomery County standards.

#### Laboratory Testing

Specific instructions for removing, packaging and transporting all receptacles registering a temperature of 75°C or higher at any time during the test were provided in the protocol. These receptacles were delivered to Wright-Malta Laboratory in Ballston Spa, New York, where they were installed in a structure to simulate actual home construction. The receptacles were monitored while operating to determine whether continued use would eventually result in fire. Results of laboratory testing are given in a separate report by Wright-Malta Corporation.

### Equipment

#### 1. Receptacle Continuity Tester (See Figure 1)

The Receptacle Continuity Tester is an instrument designed and built by the National Bureau of Standards. It was inserted in a duplex receptacle to detect large voltage differences across the two binding screws on the same side of a duplex receptacle device. Large voltage differences are indicated by one or both of the built-in lamps illuminating. Such a condition might be caused by the removal of the receptacle break-off tab. This test was done to protect the Voltage-Current Probes (see item 2) from high voltages with which they are not designed to operate.

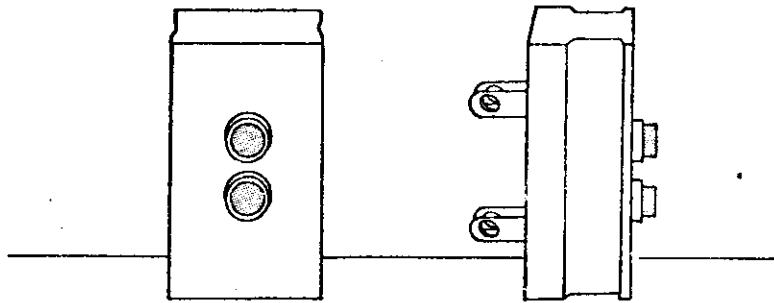


Figure 1. Receptacle Continuity Tester

2. Voltage-Current Probe (See Figure 2)

The Voltage-Current Probe (V-C Probe) is an instrument designed and built by the National Bureau of Standards. It was inserted in a duplex receptacle to sense (1) whether or not the outlet was electrically live, signified by illumination of the lamp labeled voltage and (2) whether or not current was being passed through the terminals of the device signified by illumination of the lamp labeled current. By a trial-and-error procedure, this allowed circuits to be mapped out and enabled determination of which receptacle outlet was the last outlet in that circuit.

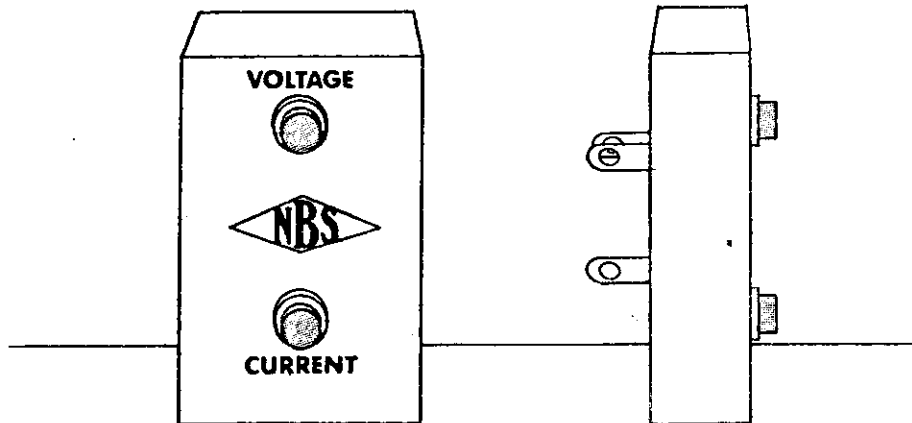


Figure 2. Voltage Current Probe

### 3. Chromel Alumel Thermocouple Temperature Reader (See Figure 3)

The instrument indicating temperature readings and the chromel alumel thermocouples were treated as a system. When the plug with built-in thermocouples was inserted in a duplex receptacle, temperature readings were taken from each of the four parallel blade receptacle openings. Temperature readings were taken on a digital temperature reader manufactured by either Doric Scientific, Omega Engineering, or Leeds and Northrop.

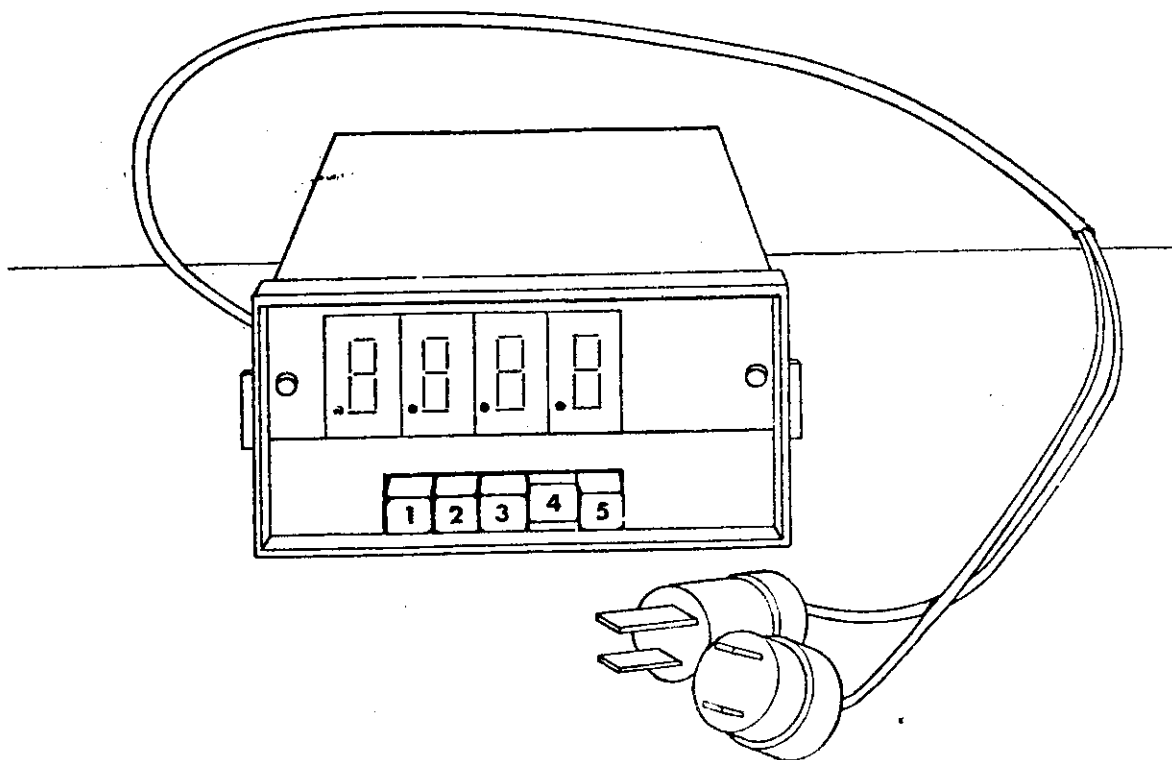


Figure 3. Chromel Alumel Thermocouple Temperature Reader

#### Calibration of Temperature Reader

The temperature indicator and thermocouples were returned to the Commission's Electrical Engineering Laboratory for calibration after every 10 to 15 days of use, or sooner if the instrument had undergone severe shock or harsh treatment or if it showed obviously erroneous readings.

After calibration, a tag or sticker was affixed to the instrument to show the last date of calibration. Records of instrument use and calibration were kept.

4. Current Load Device (See Figure 4)

The Current Load Device is an instrument which was designed and built by the National Bureau of Standards. It was plugged into the last receptacle in the branch circuit which was under test. It was designed to draw 75 - 80 percent of the circuit's rated capacity at 120 watts. It had a built-in switch to determine whether it was a 12 amp or a 15 amp load. When using this device, personnel were protected from shock by a portable Ground Fault Circuit Interrupter manufactured by Square D.

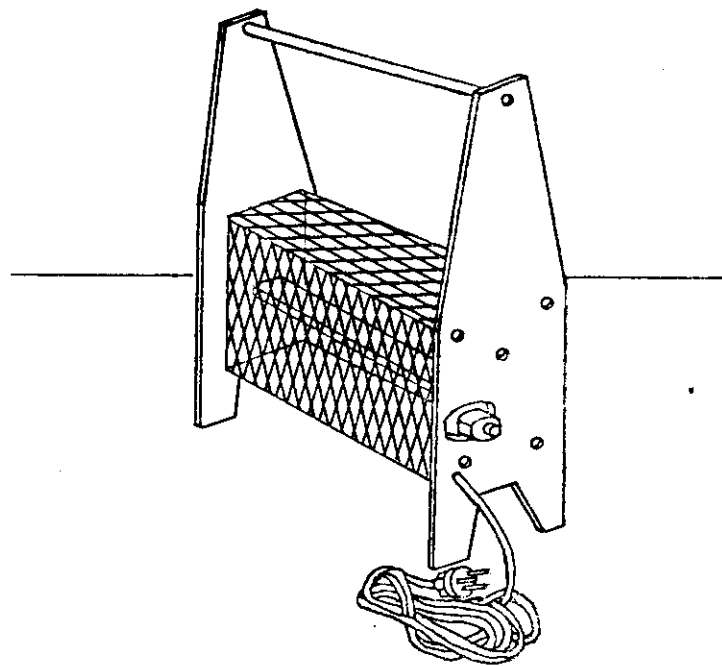


Figure 4. Current Load Device

Phase I - Sampling Response

In 1969, there were 2,710 building permits issued for single family dwellings by the permit issuing place for Montgomery County, Maryland. Two incorporated areas of Montgomery County, Rockville and Gaithersburg, which issued permits as separate jurisdictions, were not included in these records.

A sample of 200 dwellings was randomly selected from the sampling frame of 2,710 building permits. Occupants of these dwellings were contacted first by letter and then by telephone to arrange for Phase I of the survey: identification of the type of wiring system in the homes.

The outcome of attempts to complete Phase I of the survey are shown in Table 1. Five dwellings, were ineligible: 3 permits were for additions to dwellings built prior to 1969 and 2 were for dwellings never built. Of the dwellings eligible for Phase I, 81 percent or 157 dwellings were surveyed. Occupants of 30 dwellings (15 percent) were contacted but refused to permit the survey. Although repeated attempts were made, it was impossible to contact the occupants of eight dwellings (4 percent).

TABLE 1  
SAMPLING - PHASE I

Sampling Results	Random Sample	
	Number	Percent
Total	200	
Ineligible	5	
Total Eligible	195	100%
Completed	157	81%
Refused	30	15%
No Response	8	4%

Phase I - Identifying Wiring Systems

An electrician licensed in Montgomery County, Maryland, examined the type of branch wiring at the panel box in 157 homes. As shown in Table 2, approximately one-quarter of the homes had aluminum branch wiring in one or more circuits and three-quarters of the homes had all copper branch circuits.

To identify the method of terminating the branch wiring to the duplex receptacles, two receptacles were examined; one receptacle on the 20 amp refrigerator circuit and one receptacle on a 15 amp circuit, preferably one used for a color television. These were the two pre-selected circuits being identified for Phase II of the survey.

TABLE 2

ESTIMATED DISTRIBUTION OF MONTGOMERY COUNTY\*\*\*  
SINGLE FAMILY DWELLINGS BY TYPE OF WIRING SYSTEMS

(Permits Issued 1969)

Single Family Dwellings Type Wiring Systems	Sample Homes		Estimates- Montgomery Co.
	Number	Percent	Number
<b>Aluminum</b>	<u>37</u>	<u>23.6%</u>	<u>624</u>
Al WBS	17**	10.8%	286
Al/Cu Combination	13	8.3%	219
Al/Cu Pigtailing	2	1.3%	34
Al BW*	5	3.2%	85
<b>Copper</b>	<u>120</u>	<u>76.4%</u>	<u>2,018</u>
Copper BW	101	64.3%	1,698
Copper WBS	8	5.1%	135
Copper WBS & BW	11	7.0%	185
<b>Total</b>	157		2,642****

\* Misapplication per Underwriters' Laboratories Standards.

\*\* Two homes had some copper circuits in addition to 15 and 20 amp aluminum branch circuits.

\*\*\* Excluding Rockville and Gaithersburg, Maryland.

\*\*\*\* It is assumed that 2.5% of 2,710 permits issued were for dwellings not built, or additions to homes built prior to study period.

Based on this inspection, 17 homes had 15 and 20 amp aluminum branch circuits with wire binding screw terminations. (Two homes had a few copper circuits in addition to the predominantly aluminum circuitry.) Thirteen homes had both aluminum and copper circuits, usually 20 amp copper circuits and 15 amp aluminum circuits. Two homes had copper pigtailed to aluminum wire; copper wire was attached to the aluminum wire by a wire nut and the copper wire was terminated to the receptacle. Thermal measurements of aluminum wiring could not be made at the wire nut termination. Five homes had aluminum branch wiring with the duplex receptacles backwired. Backwiring for aluminum branch circuits has always been considered a misapplication by Underwriters Laboratories standards and therefore was excluded from this study.

Among the 76 percent of homes with all copper branch circuits, backwiring was the termination method most widely used. There were 101 homes with this wiring system, 64 percent of the homes surveyed in the County. Copper branch circuitry with wire binding screw termination was found in eight homes (5 percent). Eleven homes had copper circuits with 15 amp circuits terminated by wire binding screw and 20 amp circuits terminated by backwiring or vice versa.

#### Projected Distribution of Wiring Systems

Projections from the sample provided the estimated distribution of wiring systems within the 2,710 single family dwellings in Montgomery County for which building permits had been issued in 1969. (Table 2, last column)

An estimated 624 homes have aluminum branch circuits for all or part of the branch wiring system. The estimates projected that 286 homes have both 15 and 20 amp aluminum branch circuits with WBS terminations, 219 have both aluminum circuits and copper circuits, and 34 have copper pigtailed to aluminum branch circuits. About 85 homes have aluminum branch circuits terminated to duplex receptacles with backwiring, a widely recognized misapplication. About 1,698 of the 2,018 dwellings wired with copper have duplex receptacles terminated with backwiring. An estimated 135 copper-wired dwellings have wire binding screw terminations. Both methods of termination were used in about 185 copper-wired homes.

### History of Receptacle Repairs

During Phase I of the survey, occupants were asked whether any duplex receptacles had been repaired or replaced during the entire period the respondent had lived in the house. The respondents had an average occupancy of 5.1 years in aluminum wired homes [average age 7.3 years] compared to an average occupancy of 5.6 years for copper wired homes [average age 7.5 years]. Twenty-six percent (9/35) of the aluminum wired homes had one or more receptacles replaced because of malfunction or overheating compared to three percent (4/116) of the copper wired homes. Evidence of burning in replaced receptacles was reported in 14 percent (5/35) of the aluminum wired homes compared to one percent (1/114) of the copper wired homes. All repairs or replacements in copper wired homes were to backwired receptacles.

### Selection of Homes for Thermal Measurements - Phase II

The study design called for thermal measurements to be made in 120 homes, 30 homes of each of four types:

- ° Aluminum branch wiring in 15 and 20 amp circuits with wire binding screw duplex receptacle terminations.
- ° Copper branch wiring in 15 and 20 amp circuits with wire binding screw cuplex receptacle terminations.
- ° Copper branch wiring in 15 and 20 amp circuits with backwiring duplex receptacle terminations.
- ° Aluminum branch wiring in 15 amp circuits with wire binding screw duplex receptacle terminations and copper branch wiring in 20 amp circuits with either wire binding screw duplex receptacle terminations or backwiring.

As shown in Table 2, the only sample type with more than 30 homes originally identified in Phase I was CuBW with 101 dwellings. A random selection of one home in three identified 33 CuBW homes as eligible for Phase II of the survey.

A cluster sample was used to identify additional homes for the other three sample types. One home to the right and one home to the left of the eligible homes were included for the samples of the Al WBS and the Al/Cu Combination homes; two houses right and left were included for the sample of Cu WBS homes.

Cluster Sampling Response

The outcome of efforts to complete Phase I of the survey in the Cluster samples is shown in Table 3. Of the 92 homes selected in the clusters, 10 homes were ineligible: 6 were built prior to 1969, 4 had already been included in the sample as part of overlapping clusters. In the 82 eligible homes, 89% of the Phase I surveys were completed. Refusals in the cluster samples occurred half as often as in the original sample.

TABLE 3  
CLUSTER SAMPLING RESPONSE - PHASE I

Sampling Results	Cluster Sample	
	Number	Percent
Total	92	
Ineligible	10	
Total Eligible	82	100%
Completed	73	89%
Refused	6	7%
No Response	3	4%

Phase II - Sampling Response

The sampling response to Phase II of the survey is outlined in Table 4 for the 230 homes in which the Phase I of the survey had identified the wiring systems, 157 homes from the original random sample and 73 homes from the cluster samples. There were 20 homes ineligible for the survey because the wiring systems did not match any of the four sample types specified. Random sampling to select 30 homes with copper backwiring excluded 69 from the group eligible for thermal measurements.

TABLE 4  
SAMPLING RESPONSE - PHASE II

Sampling Results	Random Sample		Cluster Sample		Total	
	Number	Percent	Number	Percent	Number	Percent
Phase I Completed	157		73		230	
Total Exclusions						
Ineligible	20		9		29	
Sampling Exclusions	69				69	
Total Eligible & Selected	<u>68</u>	100%	<u>64</u>	100%	<u>132</u>	100%
Completed	62	91%	62	97%	124	94%
AL WBS	15		24		39	
Cu WBS	6		20 *		26	
Cu BW	31		0		31	
AL/Cu	10		18 *		28	
Refused	6	9%	2	3%	8	6%

\* One Cu WBS house and one AL/Cu house were built in 1968.

Of the 132 homes eligible and selected for Phase II of the survey, 94% were completed, 91% of the random sample and 97% of the cluster sample. The 124 homes in which thermal measurements were made are indicated by sample type in the "total" column of Table 4: 62 from the original sample and 62 from the clusters.

## Phase II - Characteristics of Homes Surveyed

The 124 homes surveyed in Phase II were valued in the building permits issued in 1969 at a median figure of \$18,000 for Cu BW and Cu WBS homes and \$21,000 for Al WBS and Al/Cu homes (Table 5). The average age of the houses ranged from 7.0 years to 7.7 years and the occupant had lived there an average of 5 to 6.3 years.

The total number of circuits in a house averaged 12.2 for the Al WBS house, and was slightly higher for the other sample types. There were usually more 15 amp circuits than 20 amp circuits.

Thermal measurements were taken on three circuits per house but the number of receptacles measured varied slightly by sample type. There were fewer receptacles measured on copper WBS houses, particularly in the 20 amp circuits. The average number of receptacles was slightly higher in Al/Cu homes on the 20 amp circuits, but the number measured on the two 15 amp circuits was similar for Al/Cu, Cu BW and Al WBS homes.

The ambient temperature before testing of the receptacles in 15 amp circuits ranged from 18°C in copper BW homes to 21.3° in Al/Cu homes. The temperatures were slightly lower on 20 amp circuits.

Voltage and current readings are also given in Table 5 by circuit and sample type. Average voltage (no load) ranged between 121.5 V and 123.3V. The current of the 15 amp test load device for 20 amp circuits averaged 13.1 to 14.0 amps. The 12 amp test load device for the 15 amp circuits averaged between 10.3 to 11.0 amps. In spite of differing voltages observed from house to house, the averages over the sample houses were comparable.

TABLE 5

## CHARACTERISTICS OF 124 SAMPLE HOMES BY SAMPLE TYPE

Characteristic	Sample Type			
	Al WBS	Cu WBS	Cu BW	Al/Cu
Number of Homes	39	26	31	28
Property Value per Building Permits				
Median	\$21,000	\$18,000	\$18,000	\$21,000
Range	\$13,000-\$32,000	\$10,000-\$36,000	\$12,000-\$75,000	\$16,000-\$60,000
Age of House*	7.5 yrs.	7.7 yrs.	7.0 yrs.	7.4 yrs.
Years Occupied*	5.3 yrs.	6.3 yrs.	5.0 yrs.	5.2 yrs.
Total Circuits per House*	<u>12.2</u>	<u>13.5</u>	<u>13.4</u>	<u>14.4</u>
15 Amp.	7.1	6.5	8.3	9.4
20 Amp.	5.1	7.0	5.1	5.0
Number of Receptacles Measured*				
20 Amp. Circuits	3.3	1.8	3.4	4.0
15 Amp. Circuit (TV)	4.0	3.8	3.7	3.8
15 Amp. Circuit (R)	3.7	2.5	4.2	3.9
Ambient Temp.*				
15 Amp. Circuit	21.1°C	20.5°C	18.0°C	21.3°C
20 Amp. Circuit	19.9°C	19.6°C	17.2°C	20.6°C
Voltage & Current*				
<u>20 Amp. Circuit</u>				
Voltage Load	115.0 V	117.9 V	114.7 V	114.6 V
Voltage No Load	122.4 V	123.3 V	121.8 V	122.1 V
Current	14.0 Amp.	13.7 Amp.	13.1 Amp.	13.4 Amp.
<u>15 Amp. (TV) Circuit</u>				
Voltage Load	110.2 V	113.5 V	110.4 V	110.8 V
Voltage No Load	122.7 V	122.6 V	121.5 V	122.0 V
Current	11.0 Amp.	11.0 Amp.	10.3 Amp.	10.9 Amp.
<u>15 Amp (R) Circuit</u>				
Voltage Load	112.0 V	115.1 V	109.0 V	110.4 V
Voltage No Load	122.5 V	123.1 V	121.0 V	122.2 V
Current	10.9 Amp.	11.0 Amp.	10.4 Amp.	10.7 Amp.

\*Average Value

Phase II - Thermal Measurements - Overheating Rate Per Dwelling

As described in the methodology section of the introduction, thermal measurements were taken on three circuits in each dwelling: One 20 amp circuit and two 15 amp circuits. The number and percent of homes with at least one receptacle on any of the three circuits reaching 75°C or higher is shown in Table 6.

TABLE 6

PHASE II. NUMBER AND PERCENT OF HOMES WITH OVERHEATED RECEPTACLES  
BY TYPE OF WIRING

Type of Wiring	Total Homes	Homes with Overheated Receptacles			
		≥ 75°C		≥ 100°C	
		Number	Percent	Number	Percent
Aluminum WBS	39	16	41%	7	18%
Copper WBS	26	0	0%	0	0%
Copper BW	31	1	3%	0	0%
Combination Al WBS/Copper	28	9	*	2	*

\* Comparison by circuit shown in Table 7A and 7B.

Forty-one percent of the homes with all Aluminum WBS circuits had at least one receptacle overheating to 75°C or higher compared to 3% of the homes with all copper branch circuits. Receptacles overheated to this level in 16 of the 39 homes with Aluminum WBS (41%), none of the 26 homes with Copper WBS (0%) and one of the 31 homes with Copper BW (3%).

Eighteen percent [7 homes] of the 39 aluminum wired homes had at least one receptacle overheating to 100°C or higher. Not one (0%) of the 57 homes in which 3 copper wired circuits were measured had a receptacle reaching this temperature.

In the Combination Sample, where one 20 amp copper circuit and two 15 amp aluminum circuits were measured, 9 homes had one or more receptacles reaching 75°C or higher: 6 homes had receptacles overheating on CuBW circuits, 2 homes had receptacles overheating on aluminum wired circuits; only one home had receptacles overheating on both a copper backwired circuit and an aluminum wired circuit.

Receptacles reached 100°C or higher in two homes in the Combination Sample, one receptacle on a copper backwired circuit and one on an aluminum wired circuit.

One copper circuit (20 amp circuit) was measured in each home in the combination sample. Therefore, a comparison was made with the Copper BW sample based on observations of the 20 amp circuit only. As shown in Table 7A, the failure rates in the combination sample were higher than those in the Copper BW sample. They were statistically significant [P=.05] at the 75°C level, but not at the 100°C level.

Table 7A  
COMPARISON OF COMBINATION SAMPLE WITH  
COPPER BACKWIRED SAMPLE

(20 Amp Circuit)

Sample Type	Total Homes	Homes with Overheated Receptacles			
		≥75°C		≥100°C	
		Number	Percent	Number	Percent
Copper BW	31	1	3.2%	0	0%
Combination Al WBS/Copper BW	26*	7	26.9%	1	3.8%
Total CuBW	57	8	14.0%	1	1.8%

\* 2 homes had wire binding screw termination on 20 amp copper circuits.

Results in Cu Backwired circuits in the combination sample suggest that 3% may be a low estimate for overheated receptacles (≥75°C) in CuBW homes. The 95% confidence limits on the combined information from the CuBW and combination sample gives a range of 5% to 23% \*\* for the true rate of overheating (≥75°C) in 57 homes with CuBW compared to the 95% confidence limits in 31 CuBW homes of 0% to 9%. At the 100°C level, the rate shows an increase from 0% to 1.8%.

\*\* Preliminary estimate, without adjustment for cluster sampling.

A similar comparison was made between the combination sample and the Al WBS sample with respect to the 15 amp circuits, as shown in Table 7B. The failure rates on Al WBS circuits were slightly lower in the combination sample, but the differences were not statistically significant ( $P=.05$ ).

Table 7B  
COMPARISON OF COMBINATION SAMPLE WITH  
ALUMINUM WBS SAMPLE

(Two 15 Amp Circuits)

Sample Type	Total Homes	Homes with Overheated Receptacles			
		$\geq 75^{\circ}\text{C}$		$\geq 100^{\circ}\text{C}$	
		Number	Percent	Number	Percent
Aluminum WBS	39	9	23.1%	4	10.3%
Combination Al WBS/Copper	28	3	10.7%	1	3.6%
Total Al WBS	67	12	17.9%	5	7.5%

Phase II - Thermal Measurements - Overheating Rate Per Circuit

All circuits for each type of wiring system were combined, regardless of sample types, for an analysis of failure rates by circuit. The comparison of the failure rates in aluminum and copper circuits is presented graphically in Figure 5. The figures from which these graphs were prepared are included in the Appendix [Tables I and II].

The vertical scale indicates the percent of circuits with overheated receptacles. The two bars in each group represent aluminum and copper circuits. The height of each bar illustrates graphically the percent of circuits with at least one receptacle overheated to  $75^{\circ}\text{C}$  or higher. The height of the darkened area indicates the percent of circuits with at least one receptacle reaching  $100^{\circ}\text{C}$  or higher.

The first two bars show failure rates for all circuits combined, regardless of current rating. At least one receptacle overheated to 75°C or higher in 14.5 percent of 159 aluminum circuits compared to 4.2 percent of 191 copper circuits. At the level of 100°C or higher, the rate was 6.3 percent in aluminum circuits compared to 0.5 percent in copper circuits. The relative risk of at least one receptacle on a circuit reaching 100°C was 13 times as high ( $6.3 \div 0.5$ ) on aluminum circuits as on copper circuits.

The comparison by circuit rating is represented by the next three pairs of bars. At the 75°C level, the failure rate in 39 aluminum 20 amp circuits was 23.1 percent compared to 9.2 percent in 87 copper circuits. In 67 aluminum 15 amp preselected circuits (usually TV) the rate was 13.4 percent compared to 0 percent in 57 copper circuits. In 67 randomly selected 15 amp aluminum circuits, the rate was 9 percent compared to 0 percent in 57 copper circuits.

At the 100°C level, the differences between aluminum circuits and copper circuits were even more pronounced: 10.3 percent to 1.1 percent in the 20 amp circuits, 6.0 percent to 0 percent in the 15 amp TV circuits, and 3.0 percent to 0 percent in the 15 amp random circuit. In the 20 amp circuits, the relative risk of aluminum to copper was 9 to 1. In the 15 amp circuits, relative risk could not be computed since there were zero failures on the copper circuits.

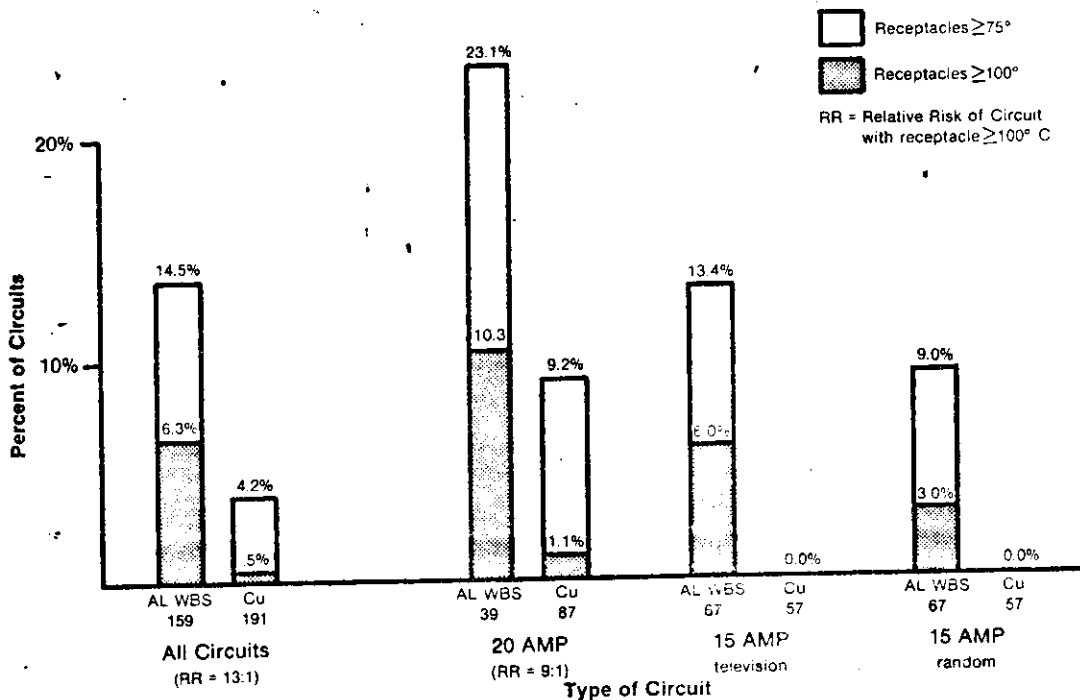


FIGURE 5. PERCENT OF ALUMINUM AND COPPER CIRCUITS WITH AT LEAST ONE OVERHEATED RECEPTACLE

As evident from the bar heights in the 20 amp and 15 amp circuits, the failure rates were highest in the preselected 20 amp circuit (the one selected usually provided current for the refrigerator). The rates for the preselected 15 amp circuit (usually providing current to color or B&W TV) appeared to be higher than those for the randomly selected 15 amp circuit. However, the differences between the 15 amp circuits were too small for statistical significance in the small sample surveyed.

A similar comparison was made in the bar graphs in Figure 6 where the rates for copper circuits were shown separately for wire binding screw and for backwired circuits. No receptacles overheated on copper wire binding screw circuits. Aluminum circuits had higher failure rates than copper backwired circuits--for all circuits combined as well as in circuits rated 20 amps or 15 amps. The failure patterns described in the comparison of aluminum circuits with all copper circuits also applied to comparisons with copper backwired circuits. Even when a comparison is made between aluminum circuits and CU BW circuits only, the relative risk at the 100°C level is 7 to 1 for all circuits and 6 to 1 for 20 amp circuits.

The failure rates per receptacle measured display the same characteristics as evidenced in failure rates by circuit (Appendix Table I). In assessing the figures, it must be remembered that over 1,200 receptacles were measured on the 348 circuits surveyed. While the rates for receptacles are lower in absolute value, they apply to a larger base (number of receptacles per house) than do the rates per circuits. Again, the relative risk of the 100°C level in receptacles on aluminum wired circuits is 15 times that in copper wired circuits. Even when compared with the highest risk of copper circuitry, CuBW, the relative risk is 11 to 1.

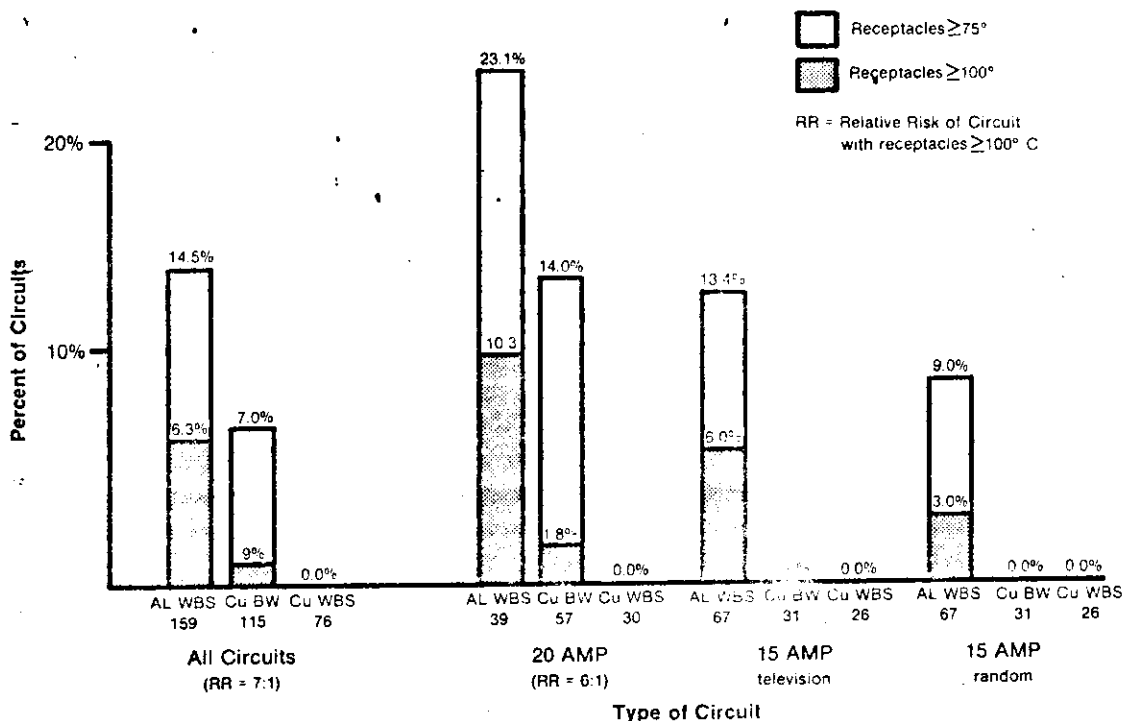


FIGURE 6. PERCENT OF ALWBS, CuBW AND CuWBS CIRCUITS WITH AT LEAST ONE OVERHEATED RECEPTACLE

## Phase II - Thermal Rise - Overheating Rate per Receptacle

Backwiring in copper circuits resulted in higher overheating rates than wire binding screw terminations. The graph of thermal rise by type of wiring and termination indicated that the distribution of thermal rise in backwired receptacles on copper circuits was quite different from the distribution in receptacles with wire binding screw terminations. [Figure 7]

While 97 percent [100% - 3%] of 202 Cu WBS receptacles showed a thermal rise of less than 30°C, only 66 percent [100% - 33.8%] of 430 Cu BW receptacles had low thermal increases. A surprising 32 percent [33.8% - 1.4%] of Cu BW receptacles had a thermal rise between 30°C and 55°C compared to 3 percent of the Cu WBS receptacles. No Cu WBS receptacle and about one percent of the Cu BW receptacles recorded a rise of 55°C or higher (comparable to an absolute temperature of 75°C).

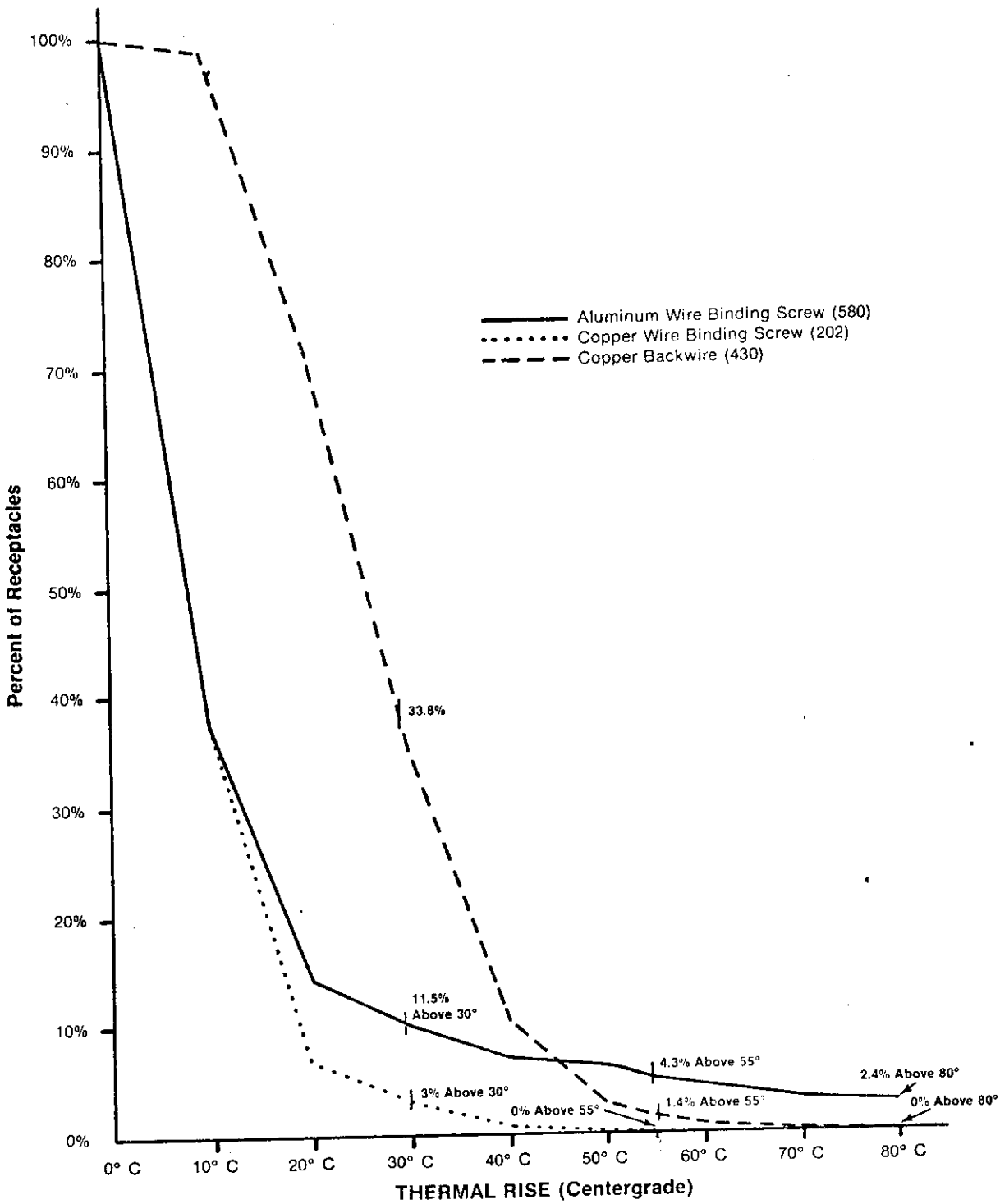
On the other hand, Al WBS receptacles showed a distribution of thermal rise similar to that of Cu WBS receptacles, but with a significant number of receptacles rising 55°C and 80°C - about 4% with thermal rise of 55°C or higher and more than 2% with 80°C or higher.

The high proportion of Cu BW receptacles showing thermal rise between 30° and 55°C may point to the need for additional engineering study with copper backwired receptacles. However, it was Al WBS receptacles which showed the highest proportion of thermal increases above 55°C and above 80°C (comparable to an absolute temperature of 100°C), a level which indicates an unsafe condition.

Backwiring has never been recognized as an acceptable method of termination for aluminum circuits by Underwriters Laboratories' standards and thermal measurements were not taken in homes with Al BW circuits. However, one might speculate that the distribution of thermal rise for Al BW receptacles would be similar in shape to the distribution found in Cu BW circuits, but would show a higher percent of receptacles with thermal rise over 55°C and 80°C, probably even higher than the percent found in Al WBS circuits.

A thermal rise of 80°C added to the average ambient temperature of 20°C was comparable to the absolute value of 100°C used as an index of failure. The 100°C (212°F) index of failure was set low enough so that the test could not create a level of overheating that would melt insulation or have a destructive effect on the residential circuits being measured. Temperatures recorded at  $\geq 100^\circ\text{C}$  were usually still rising, but the test was discontinued before the temperature stabilized.

FIGURE 7. CUMULATIVE PERCENT OF RECEPTACLES WITH TEMPERATURE RISE (AFTER THIRTY MINUTES)



## Phase II - Workmanship

Poor workmanship has frequently been suggested as the primary cause of overheated terminations. Visual examination of receptacles prior to testing revealed wire wrapped in the wrong direction around a screw terminal, or wrapped around less than 2/3 the circumference of the screw [or the converse - the wraparound overlapped] in almost 20 percent of the aluminum wired receptacles compared to less than one percent of the copper wired receptacles with wire binding screws. This could not occur in copper backwired terminals where no screws are wrapped.

Of 111 receptacles with incorrect wiring observed, only 12 overheated to 75°C or higher. The incorrect wiring could have been at any of the four terminations at which temperature was measured on each receptacle - the unsatisfactory wiring coincided with the termination measuring 75°C or higher in 7 receptacles.

The visual examination did not permit torque measurement, but loose screws were observed in one copper wired and 7 aluminum wired receptacles. The thermal measurements of the terminal with the loose screw were 75°C or higher in 2 receptacles, both aluminum wired.

Of the 31 aluminum wired receptacles which reached 75°C or higher, the terminal reaching that temperature had poor wiring in 7 cases and loose screws in 2 cases. In 22 of the receptacles (71%) poor workmanship was not indicated as a factor.

The data collected indicated poor workmanship was observed more frequently on aluminum wire receptacles than on copper wired receptacles, and the rate of overheating in aluminum wired receptacles was higher but not significantly higher when poor workmanship was observed. However, workmanship was not suspect in almost three-fourths of the aluminum wired receptacles which reached 75°C or higher.

### Number of Circuits Tested per House

Based on the information available at this time, it appears that that the failure rate increases as more circuits are measured in a house.

The failure rates per house surveyed were based on the testing of three circuits per house: one 20 amp circuit and two 15 amp circuits. To assess the effect of testing one, two or three circuits per house, an examination of the results in the 39 homes with Al-WBS was made.

TABLE 8

NUMBER OF DWELLINGS WITH OVERHEATED RECEPTACLES IDENTIFIED BY  
NUMBER OF CIRCUITS MEASURED IN 39 DWELLINGS WITH AL-WBS

Number of Circuits Measured Per Dwelling	Dwellings With At Least One Overheated Receptacle			
	≥ 75°C		≥ 100°C	
	No.	Percent	No.	Percent
<b>1 Circuit</b>				
20 Amp	9	23%	4	10%
15 Amp TV	7	18%	3	8%
15 Amp Random (R)	5	13%	2	5%
<b>2 Circuits</b>				
20 Amp + 15 Amp TV	14	36%	6	15%
20 Amp + 15 Amp R	14	36%	6	15%
15 Amp TV + 15 Amp R	9	23%	4	10%
<b>3 Circuits</b>				
20 Amp 15 Amp TV 15 Amp R	16	41%	7	18%

If only one circuit had been tested, the failure rate at 75°C or higher would have ranged from 23 percent for the 20 amp circuit servicing the refrigerator to 13 percent for the 15 amp circuit selected randomly as shown in Table 8.

If only 2 circuits per house had been examined--there were three combination possible--the failure rate would have ranged from 36 percent to 23 percent.

According to the survey design, three circuits were tested resulting in a failure rate of 41 percent at the 75°C level and 18 percent at the 100°C level.

The single family home generally has more than three circuits. Had all circuits in the sample homes been measured, the failure rate in the Al-WBS homes would probably have been higher and the relative risk figures greater than those quoted in this report.

Projection for Montgomery County (Building Permits 1969)

Projecting from the survey results for permits issued in 1969 in Montgomery County (excluding Rockville and Gaithersburg), there were 624 homes completely or partially wired with aluminum branch circuits (Table 2). Based on the failure rates observed in the survey (Table 6 and Table 7B) an estimate of 67 dwellings with at least one receptacle over 100°C (212°F) was made for the group sampled (Table 9). At the 75°C level (167°F) the estimate was 156 homes. Approximately 85 homes are estimated to have duplex receptacles backwired to aluminum wire--an installation procedure that has never been considered acceptable by Underwriters' Laboratories.

TABLE 9

**ESTIMATED NUMBER OF ALUMINUM WIRED DWELLINGS  
WITH AT LEAST ONE OVERHEATED RECEPTACLE**

**Montgomery County, Maryland \*\*  
(Permits Issued 1969)**

Type Wiring and Termination	Estimated Number of Dwellings with Aluminum Branch Circuit		Estimated Number of Dwellings with at least one over- heated receptacle	
	%	Number	>75°C (167°F)	>100°C
A1 WBS	46%	286	117 (41.0%)	51 (17.9%)
Al/Cu	35%	219	39 (17.9%)	16 (7.5%)
Al/Cu Pigtailing	5%	34		
Al BW*	14%	85*		
<b>Total</b>	<b>100%</b>	<b>624</b>	<b>156</b>	<b>67</b>

\* Misapplication per Underwriters' Laboratories Standards.

\*\* Excludes Gaithersburg and Rockville, Maryland.

This would appear to be a conservative estimate, since the failure rates are based on testing only three receptacle circuits per house. The average home usually has at least two 20 amp receptacle circuits and five 15 amp receptacle circuits, plus a number of circuits for fixed appliances such as the dishwasher, disposal, furnace, etc.

Projection for Montgomery County (1966 - 1971)

Between 1966 and 1971 almost 17,000 building permits were issued in Montgomery County, Maryland, for single unit dwellings (Table 11). There are no records of how many of the dwellings were wired with aluminum branch circuits. However, national estimates of the percent of new housing starts with aluminum branch wiring between 1960 and 1972 were made using information provided by the Aluminum Association and by the National Bureau of Standards (NBS). (Table 10) A conversion of yearly production figures on aluminum cable by weight to feet of cable was estimated by the Aluminum Association using a single conversion factor for an assortment of wire sizes (#10 and #12). The average number of feet of branch wire used per home was taken as 1,600 feet, computed from the most conservative estimate made by NBS of 1.5 million homes built by 1972. Based on these gross estimates, and the Census figures on the number of privately owned new single unit housing starts in the United States, the last column of Table 10 indicates the percent of new housing starts with aluminum wiring between 1960 and 1972.

TABLE 10 ESTIMATED PERCENT OF NEW HOUSING STARTS  
WITH ALUMINUM BRANCH WIRING  
(1960-1972)

Year	Gross Footage Aluminum Branch Wire Produced* (000's)	Estimated Number of Aluminum Wired Homes** (1600' per Home)	Privately Owned New Housing Starts***	Estimated Percent of New Housing Starts With Aluminum Wiring
1960-65	85,000	53,000	5,917,000	0.9%
1966	136,000	85,000	780,000	10.9%
1967	175,000	109,000	845,000	12.9%
1968	227,000	142,000	901,000	15.8%
1969	390,000	244,000	811,000	30.1%
1970	430,000	269,000	815,000	33.0%
1971	586,000	366,000	1,153,000	31.7%
1972	357,000	223,000	1,309,000	17.0%
Total	2,386,000	1,491,000		

\*Aluminum Association, Aluminum Wiring Hearings, CPSC, March 27, 1974, Page 206.

\*\*Bunten, Elaine D.; Donaldson, John L.; McDowell, Eugene C.; Hazard Assessment of Aluminum Electrical Wiring in Residential Use. (NBS IR 75-677). National Bureau of Standards. December 1974; p. 37.

\*\*\*Statistical Abstract, Table 1212, U.S. Bureau of the Census, Construction Reports, Series C20.

Less than 1 percent of the homes built before 1966 had aluminum branch circuits. The use of aluminum branch wiring increased from 10.9 percent in 1966 to 33 percent of the new housing starts in 1970 and about the same percent in 1971. By 1972, the amount of aluminum wire produced and the proportion used in new housing starts had decreased substantially by over 40 percent. While the new housing starts increased, the percent of new housing starts with aluminum wire decreased from 32 percent in 1971 to 17 percent in 1972.

Bearing in mind the gross assumptions made, it is noteworthy that the national rates for 1969 were comparable to those for aluminum wired homes found in the survey of Montgomery County. The national average was 30 percent, while the survey in Montgomery County projected 24 percent with the 95 percent confidence limits ranging from 18 percent to 30 percent.

As shown in Table 11, the national rates were used to estimate 3,559 single unit dwellings built with aluminum branch circuits in Montgomery County, Maryland (excluding Rockville and Gaithersburg). Since Maryland banned the use of aluminum wire in branch circuits in May of 1972, this projection was limited to homes built between 1966 and 1971.

TABLE 11 ESTIMATED NUMBER OF ALUMINUM WIRED DWELLINGS  
BUILT IN MONTGOMERY COUNTY, MD.\*  
(1966—1971)

Year	Estimated Percent of New Housing Starts With Aluminum Wire	Building Permits Issued in Montgomery County, Md.*		Estimated Aluminum Wired Dwellings in Montgomery County, Md.
		Total Permits Issued	New Dwellings Built**	
1966	10.9%	2,968	2,894	315
1967	12.9%	2,896	2,824	364
1968	15.8%	2,434	2,373	375
1969	30.1%	2,710	2,642	624***
1970	33.0%	2,529	2,465	813
1971	31.7%	3,456	3,370	1,068
Total		16,993	16,568	3,559

\*Excludes Rockville and Gaithersburg, Maryland.

\*\*Pilot survey: 2.5% of permits were issued for homes not built or additions to homes built in prior years.

\*\*\*Pilot survey identified aluminum wire in 24% of homes in Montgomery County.

While no statistical inferences can be made to years beyond the survey time frame, it is possible to conjecture as to the prevalence of overheated receptacles in homes built in other years. There is no reason to believe that wiring in homes built in 1966, 1967 and 1968 would perform differently than branch wiring which was tested in survey homes built between 1969 and 1971. Estimates of the total number of aluminum wired homes with at least one overheated receptacle were made using the results of the pilot survey.

**TABLE 12 ESTIMATED NUMBER OF ALUMINUM WIRED DWELLINGS WITH AT LEAST ONE OVERHEATED RECEPTACLE**

**Montgomery County, Maryland\*\*  
(Homes Built 1966 - 1971)**

Type Wiring and Termination	Estimated Number of Dwellings with Aluminum Branch Circuit		Estimated Number of Dwellings with at least One over-heated Receptacle	
			$\geq 75^{\circ} \text{C}$	$\geq 100^{\circ} \text{C}$
	%	Number	No. (Rate)	No. (Rate)
A1 WBS	46%	1,635	670 (41.0%)	293 (17.9%)
Al/Cu	35%	1,251	224 (17.9%)	94 (7.5%)
Al/Cu Pigtailing	5%	192		
Al BW*	14%	481*		
<b>Total</b>	<b>100%</b>	<b>3,559</b>	<b>894</b>	<b>387</b>

\* Misapplication per Underwriters' Laboratories Standards

\*\* Excluding Rockville and Gaithersburg

As shown in Table 12, 894 dwellings in Montgomery County are estimated to have at least one receptacle reaching  $75^{\circ}\text{C}$  or higher. Of those, 387 dwellings are estimated to have at least one receptacle reaching  $100^{\circ}\text{C}$  or higher under normal use. In addition, an estimated 481 homes have aluminum branch circuits terminated to a duplex receptacle by backwiring.

These figures support speculations that almost 1,400 homes in Montgomery County have wiring systems which would generally be considered unsafe.

#### IV. DISCUSSION

The pilot survey in Montgomery County, Maryland, was a first step in identifying the magnitude of risk of overheating in duplex receptacles in aluminum wired homes and in copper wired homes in one specified area. The small samples of 26 to 39 homes of each type surveyed provided the following information for the area surveyed:

- ° The rate of overheating was higher for aluminum wiring than for copper wiring whether the rates were compared by dwellings, by circuits, or by receptacles surveyed. While the differences were not always statistically significant, they were confirmed by the consistency observed in 124 dwellings, 350 circuits and 1220 receptacles.
- ° The overheating rates in 20 amp circuits were consistently higher than those in 15 amp circuits.
- ° The relative risk of having one or more overheated receptacles at 100°C or higher in aluminum wired circuits was 13 times that risk in copper wired circuits.
- ° When one 20 amp and two 15 amp aluminum wired circuits were measured in 39 homes, the rate at which overheated receptacles ( $\geq 75^\circ\text{C}$ ) occurred was 41% with 95% confidence limits of 22% to 60%.
- ° The rate of 41% was high enough to be measured in samples of 30 homes, showing the feasibility of a nationwide survey using small samples.

In assessing the data collected in the pilot survey, the limitations of the survey must be recognized. The results are based on small samples, and clustering was necessary to identify 30 sample homes of each type. An analysis of variance of the cluster information available indicated that the homogeneity of the clusters was comparable to that of random sorting of elements. But the variance on the estimates is increased, creating wider confidence intervals.

The combination sample was included so that measurements might be taken on both copper and aluminum circuits in the same home, thereby controlling for workmanship. Interpreting the results in the combination sample presented problems which were not apparent when the pilot survey was designed. Prior to the survey, it was not known that 20 amp circuits have consistently higher rates of failure than 15 amp circuits. This compounded the comparison of measurements on 20 amp copper circuits and 15 amp aluminum circuits in the same dwelling. Also in the combination

sample, the termination technique of the 20 amp circuit was usually different than that of the 15 amp circuit: the 20 amp circuit had backwired copper and the 15 amp circuit had binding screw aluminum terminations. Workmanship is generally not as significant a factor with a simple push-in construction as it is with a wire binding screw construction.

The results in the combination sample do suggest that the 3% overheating rate ( $\geq 75^{\circ}\text{C}$ ) in copper backwired homes (1/31) may be a low estimate. However, there is no reason to believe the copper backwired receptacles in a combination house would behave differently, per se, than those in a copper backwired house. Thermal measurements from additional backwired homes in a national survey should help clarify the perplexing results.

The need for further investigation of copper backwired circuits is supported by the data on thermal rise in receptacles by type of wiring and termination. The graph of thermal rise (difference between ambient temperature and the temperature after 30 minutes of testing) demonstrates notable differences in the performance of backwired and wire binding screw terminations at the middle levels of thermal rise. Almost one-third of the copper backwired receptacles showed a thermal rise between  $30^{\circ}$  and  $55^{\circ}\text{C}$ , a hump in the curve that was non-existent on the distributions of wire binding screw terminated copper or aluminum. But at the upper levels of thermal rise, the rates for Cu BW receptacles decrease and the rates for Al WBS receptacles are the highest.

Thermal measurements were not taken in backwired aluminum circuits because the method of termination was never considered acceptable by Underwriters' Laboratories standards. Projections from the survey in Montgomery County indicated that 14% of aluminum wired homes had duplex receptacles terminated by backwiring, even though Montgomery County followed the National Electrical Code and UL's Standards. Overheating rates in aluminum backwired homes would be expected to be higher than rates found in Al WBS homes because the limited area of contact at push-in backwired terminals would tend to increase the resistance and therefore increase heating at the terminal.

Poor workmanship has frequently been cited as the culprit in the overheating of duplex receptacles wired with aluminum. Yet, three-fourths of the 31 aluminum wired receptacles reaching  $75^{\circ}\text{C}$  or higher had no visual evidence of improper wiring of the terminal reaching that temperature. Nevertheless, poor wiring was observed more frequently on wire binding screw terminations of aluminum wiring (20%) than those of copper wiring (1%). These differences may reflect the inherent difficulty of handling aluminum wire which has a larger diameter than comparable copper wire used for any circuit.

The survey included measures of past experience, present conditions, and laboratory testing \* provided prognosis for future performance.

\* Full report of laboratory testing has been prepared by Wright-Malta Corporation

Aluminum wired receptacles had been replaced at a higher rate than copper receptacles because of malfunction, overheating, and evidence of burning. Aluminum wired receptacles reached higher levels of overheating than copper wired receptacles when compared by dwellings surveyed, circuits tested or receptacles measured. In laboratory testing of receptacles removed after thermal readings of 75°C or higher were recorded, only aluminum wired receptacles reached hazardous temperatures resulting in actual fires. Aluminum wire showed a greater risk of overheating by all three measures: past, present, and future.

Selection of Montgomery County for the pilot survey was a happenstance. Many other areas, such as Southern California and New York have reported more numerous and more serious incidents of electrical malfunctions involving aluminum wire. Montgomery County was chosen primarily for the convenience of the Commission staff in conducting the survey. The homes were randomly selected and every effort was made to obtain unbiased results.

In a projection of 624 aluminum wired homes for which building permits were issued in Montgomery County, Maryland (excluding Rockville and Gaithersburg) in 1969, an estimated 156 homes would have at least one receptacle reaching temperatures of 75°C (167°F) or higher during normal use. In addition, an estimated 85 homes would have duplex receptacles backwired to aluminum circuits - a misapplication by Underwriters Laboratories standards. If inferences are made to the homes built in Montgomery County between 1966 and 1971, the estimated number of dwellings with unsafe wiring conditions would be multiplied by six.

The results in the Montgomery County survey suggest that one-third of the aluminum wired dwellings there have unsafe branch circuits. In interpreting the results of this survey, the relationship of the index measured to the total risk of overheated duplex receptacles in aluminum wired circuits must be considered.

- ° Only three circuits, one 20 amp (refrigerator), one 15 amp (television), and one 15 amp (random), were tested in each house although the average house would have at least two 20 amp and five 15 amp receptacle circuits.
- ° Less than 60 percent of the receptacles on the circuits surveyed were tested because, in addition to not testing the receptacle supplying current to the load device for the test procedure, receptacles blocked by heavy furniture were not tested.

The effect of these constraints is that this survey underestimates the proportion of homes in which aluminum wired duplex receptacles produce overheated conditions.

The results from Montgomery County cannot be projected to other areas, but the pilot survey provides the methodology for extending the survey nationwide. Between 1966 and 1971, approximately 3,500 aluminum

wired homes were built in Montgomery County. Nationwide, a conservative projection estimates there are 1.5 million homes with "old technology" aluminum wire. To assess the overheating rates nationwide, and confirm the results found in Montgomery County, plans are underway to replicate the pilot survey in four areas representing diverse geographic and temperature characteristics. The national survey will take thermal measurements in at least 120 homes of each type of wiring system. This larger data base should provide more precise statistics on the relative risk of overheating in copper and aluminum wired circuits.

**TABLE I**  
**RATE OF OVERHEATED RECEPTACLES BY TOTAL CIRCUITS AND RECEPTACLES MEASURED**  
**AND BY TYPE OF WIRING AND TERMINATION**

**I A. TEMPERATURES  $\geq 75^{\circ}$  C ( $167^{\circ}$  F)**

Parameter Rated  Type of Wiring & Termination	Circuit			Receptacle		
	Total Circuits	Circuits With At Least One Receptacle $\geq 75^{\circ}$ C		Total Receptacles	Receptacles With Temperatures $\geq 75^{\circ}$ C	
	No.	No.	%	No.	No.	%
Al WBS	159	23	14.5%	582	31	5.3%
Cu WBS	76*	0	0%	201	0	0%
Cu BW	115*	8	7.0%	437	9	2.3%
<b>Total</b>	<b>350*</b>	<b>31</b>		<b>1,220</b>	<b>40</b>	

**I B. TEMPERATURES  $\geq 100^{\circ}$  C ( $212^{\circ}$  F)**

Parameter Rated  Type of Wiring & Termination	Circuit			Receptacle		
	Total Circuits	Circuits With At Least One Receptacle $\geq 100^{\circ}$ C		Total Receptacles	Receptacles With Temperatures $\geq 100^{\circ}$ C	
	No.	No.	%	No.	No.	%
Al WBS	159	10	6.3%	582	13	2.2%
Cu WBS	76*	0	0%	201	0	0%
Cu BW	115*	1	0.9%	437	1	0.2%
<b>Total</b>	<b>350*</b>	<b>11</b>		<b>1,220</b>	<b>14</b>	

\*Two circuits have Cu WBS and Cu BW and are counted in both categories.

## APPENDIX

TABLE II  
NUMBER AND PERCENT OF CIRCUITS WITH OVERHEATED RECEPTACLES  
BY CIRCUIT RATING AND BY TYPE OF WIRING AND TERMINATION

II A. TEMPERATURES  $\geq 75^{\circ}\text{C}$  ( $168^{\circ}\text{F}$ )

Circuit Rating  Type Wiring and Termination	Preselected				15 Amp. Random	
	20 Amp.		15 Amp.		Total Circuits	Circuits with Receptacles $\geq 75^{\circ}\text{C}$
	Total Circuits	Circuits with Receptacles $\geq 75^{\circ}\text{C}$	Total Circuits	Circuits with Receptacles $\geq 75^{\circ}\text{C}$		
	No.	No. %	No.	No. %	No.	No. %
Al WBS	39	9 23.1%	67	9 13.4%	67	6 9.0%
Cu WBS	30*	0 0%	26	0 0%	26	0 0%
Cu BW	57*	8 14.0%	31	0	31	0 0%
<b>Total</b>	<b>126*</b>		<b>124</b>		<b>124</b>	

II B. TEMPERATURES  $\geq 100^{\circ}\text{C}$  ( $212^{\circ}\text{F}$ )

Circuit Rating  Type Wiring and Termination	Preselected				15 Amp. Random	
	20 Amp.		15 Amp.		Total Circuits	Circuits with Receptacles $\geq 100^{\circ}\text{C}$
	Total Circuits	Circuits with Receptacles $\geq 100^{\circ}\text{C}$	Total Circuits	Circuits with Receptacles $\geq 100^{\circ}\text{C}$		
	No.	No. %	No.	No. %	No.	No. %
Al WBS	39	4 10.3%	67	4 6.0%	67	2 3.0%
Cu WBS	30*	0 0%	26	0 0%	26	0 0%
Cu BW	57*	1 1.8%	31	0 0%	31	0 0%
<b>Total</b>	<b>126*</b>		<b>124</b>		<b>124</b>	

\* 2 Copper circuits have both WBS and BW receptacles and are counted in both categories.

## APPENDIX

TABLE III  
 NUMBER AND PERCENT OF OVERHEATED RECEPTACLES  
 BY CIRCUIT RATING AND BY TYPE WIRING AND TERMINATION

III A. TEMPERATURES  $\geq 75^{\circ}\text{C}$  ( $167^{\circ}\text{F}$ )

Circuit Rating Type Wiring & Termination	Preselected						15 Amp. Random		
	20 Amp.			15 Amp.			Total		Receptacles
	Total	Receptacles		Total	Receptacles		Receptacles	Receptacles	
	Receptacles	$\geq 75^{\circ}\text{C}$		Receptacles	$\geq 75^{\circ}\text{C}$		$\geq 75^{\circ}\text{C}$	$\geq 75^{\circ}\text{C}$	
No.	No.	%	No.	No.	%	No.	No.	%	
Al WBS	128	13	10.2%	264	13	4.9%	252	6	2.4%
Cu WBS	59	0	0%	100	0	0%	64	0	0%
Cu BW	205	9	4.4%	116	0	0%	129	0	0%
Total	392			480			445		

III B. TEMPERATURES  $\geq 100^{\circ}\text{C}$  ( $212^{\circ}\text{F}$ )

Circuit Rating Type Wiring & Termination	Preselected						15 Amp. Random		
	20 Amp.			15 Amp.			Total		Receptacles
	Total	Receptacles		Total	Receptacles		Receptacles	Receptacles	
	Receptacles	$\geq 100^{\circ}\text{C}$		Receptacles	$\geq 100^{\circ}\text{C}$		$\geq 100^{\circ}\text{C}$	$\geq 100^{\circ}\text{C}$	
No.	No.	%	No.	No.	%	No.	No.	%	
Al WBS	128	5	3.9%	264	6	2.3%	252	2	0.8%
Cu WBS	59	0	0%	100	0	0%	64	0	0%
Cu BW	205	1	0.5%	116	0	0%	129	0	0%
Total	392			480			445		

# PILOT SURVEY OF BRANCH CIRCUITS IN MONTGOMERY COUNTY, MARYLAND

## SUMMARY

The use of aluminum as an alternative to copper in wiring residential branch circuits increased between 1965 and 1970, reportedly, as the price of copper rose during periods of short supply. Conservative projections by the National Bureau of Standards and by the Aluminum Association estimate that 1.5 to 2 million homes with aluminum wired branch circuits were built by 1972.

Reports of electrical malfunctions in aluminum wiring systems of single family dwellings have been collected by the U.S. Consumer Product Safety Commission from fire marshals, electrical inspectors, and concerned consumers during the past few years. These field data support theoretical engineering predictions on the behavior of "old technology" aluminum branch circuitry. "Old technology" refers to aluminum wire and wiring devices produced prior to revised Underwriters Laboratories Inc. (UL) specifications issued in June and September of 1972.

The problem in these systems has been described as heat generation resulting from resistance at the connection of aluminum conductors. In order to determine the level of risk associated with "old technology" aluminum wire, the Directorate for Hazard Identification collaborated with the Directorate for Engineering and Science to design a statistically valid pilot survey to measure overheating of duplex receptacles in electrical branch circuits of single family dwellings. The objective of the pilot survey was to provide statistical estimates for Montgomery County, Maryland, during the time period surveyed, concerning:

- . The prevalence of overheated receptacles in single family dwellings wired with aluminum branch circuits and in those wired with copper branch circuits,

- . The relative risk of overheated duplex receptacles in aluminum wired circuits to similar conditions in copper wired circuits.

Two critical temperatures were used as indices of failure:

- . 75°C (167°F) is beyond the maximum temperature permitted by industry safety standards as established by UL.

- . 100°C (212°F) is a temperature level above which accelerated degradation occurs for the common insulating materials used on wire and receptacles.

A random sample of 200 homes was selected from 2710 building permits issued in 1969. Homeowners were contacted and visits by a licensed electrician and an interviewer were scheduled to determine the type of wiring and method by which duplex receptacles were connected to the wiring. Over 80% of the sample participated in Phase I of the survey.

Approximately 24% of the homes surveyed had aluminum wiring in one or more circuits and 76% had all copper circuits. Backwired aluminum circuits were found in 3 percent of the homes surveyed. Thermal measurements were not made in these homes because backwiring was a misapplication for aluminum wire according to UL standards.

During the first phase of the survey, occupants were questioned about prior repairs to duplex receptacles. Replacements because of overheating or malfunction were reported in 26% of the aluminum wired homes compared to 3% of the copper wired homes. Evidence of burning in the receptacle replaced was recollected by occupants in 14% of the aluminum wired homes compared to less than 1% of the copper wired homes.

The main objective of the survey was to obtain thermal measurements in 4 types of branch circuitry:

1. Aluminum Wire Binding Screw (Al WBS)

Aluminum wiring in 15 and 20 amp branch circuits terminated to duplex receptacles by wire binding screws.

2. Copper Wire Binding Screw (Cu WBS)

Copper wiring in 15 and 20 amp branch circuits terminated to duplex receptacles by wire binding screws.

3. Copper Backwiring (Cu BW)

Copper wiring in 15 and 20 amp circuits terminated to duplex receptacles by backwiring (wire pushed into openings in the back of the receptacle).

4. Combination Aluminum/Copper (Al/Cu)

Aluminum wire in 15 amp circuits terminated to duplex receptacles by wire binding screws and copper wire in 20 amp receptacles terminated to duplex receptacles by wire binding screws or backwiring.

Approximately 120 homes, 30 of each type, were required for Phase II of the survey during which thermal measurements were to be made. Phase I identified 17 homes with Al WBS, 8 homes with CU WBS, 101 homes with Cu BW and 13 homes with Al/Cu. Random sampling was used to identify approximately 30 Cu BW homes. For the other three sample types, clustering was used to obtain additional homes of the type required. Homes to the right and left of an eligible home made up the cluster. Of the homes selected and eligible for thermal measurements, 94% participated in that phase of the survey.

In 124 homes, thermal measurements were taken by an electrical engineer from CPSC and an electrician licensed in Montgomery County, Maryland. Procedures were monitored and readings recorded by a Commission analyst. Measurements were taken on three circuits in each house: one 20 amp circuit and two 15 amp circuits.

Before activating the circuit under test, the ambient temperature on all accessible receptacles was recorded, and the electrician made a visual examination of the condition and wiring of each receptacle with the cover plate removed. With the circuit activated, a test load of 75 percent of the current rated for that circuit was connected to the last accessible receptacle on the circuit and timed. Thermal readings were taken at the 2 pairs of parallel slots on the face of each receptacle and recorded on a data sheet after 15 and 30 minutes had elapsed. The use of a digital temperature reader prevented observer variability.

If a temperature of 100°C or higher was recorded, the test was discontinued before reaching the temperatures associated with melting insulation and evidence of burning or charring. After confirmation by a monitored retest, the receptacle was removed with wiring intact and saved for future testing.

On completion of thermal testing, all receptacles which registered temperatures of 75°C to 99°C were also removed with wiring intact and saved for further testing. Each receptacle removed was replaced by an appropriate device meeting the Montgomery County standards.

Thermal measurements on three circuits per house were computed and sample types were compared. Forty-one percent of the homes with all aluminum WBS circuits had at least one receptacle overheating to 75°C or higher compared to 2% of the homes with all copper branch circuits. Receptacles overheated to this level in 16 of the 39 homes with aluminum WBS (41%), none of the 26 homes with copper WBS (0%), and one of the 31 homes with copper BW (3%).

Eighteen percent (7 homes) of the 39 aluminum wired homes had at least one receptacle overheating to 100°C or higher - not one of the 57 homes in which 3 copper wired circuits were measured had a receptacle reaching this temperature.

In the combination sample, one 20 amp copper circuit and two 15 amp aluminum circuits were measured. Nine homes had at least one receptacle overheating to 75°C; two of the receptacles reached 100°C. This sample was included so that measurements might be taken on both copper and aluminum circuits in the same house. However, the comparison of circuits with different ampere ratings confounded the results. A more detailed discussion is given in the report.

Failure rates for aluminum wiring systems were consistently higher than for copper wiring systems when all circuits for each type of wiring system were combined for an analysis of failure rates. At least one receptacle overheated to 75°C or higher in 14.5 percent of 159 aluminum circuits compared to 4.2 percent of 191 copper circuits. At the level of 100°C or higher, the rate was 6.3 percent in aluminum circuits compared to 0.5 percent in copper circuits. The relative risk of at least one receptacle on a circuit reaching 100°C was 13 times as high ( $6.3 \div 0.5$ ) on aluminum circuits as on copper circuits.

In addition, a comparison by circuit rating indicated failure rates were higher in the 20 amp circuits than in the 15 amp circuits. At the 75°C level, the failure rate in 39 aluminum 20 amp circuits was 23.1 percent compared to 9.2 percent in 87 copper circuits. In 67 aluminum 15 amp preselected circuits (usually the TV circuits), the rate was 13.4 percent compared to 0 percent in 57 copper circuits. In 67 randomly selected 15 amp aluminum circuits, the rate was 9 percent compared to 0 percent in 57 copper circuits.

At the 100°C level, the differences between aluminum circuits and copper circuits were even more pronounced: 10.3 percent to 1.1 percent in the 20 amp circuit, 6.0 percent to 0 percent in the 15 amp TV circuit, and 3.0 percent to 0 percent in the 15 amp random circuit. In the 20 amp circuits, the relative risk of aluminum to copper was 9 to 1. In 15 amp circuits, relative risk could not be computed since there were zero failures on the copper circuits.

In the discussion above, Copper BW circuits and Copper WBS circuits were combined for a comparison with aluminum circuits. When Cu BW and Cu WBS circuits are considered separately, no Cu WBS circuit had a receptacle reaching 75°C. Even when a comparison is made between aluminum circuits and Cu BW circuits only, aluminum circuits had higher failure rates for all circuits combined as well as in circuits rated 20 amps or 15 amps. The relative risk at the 100°C level is 13 to 1 for all circuits and 6 to 1 for 20 amp circuits.

Receptacles reaching temperatures of 75°C or higher were delivered to Wright-Malta Laboratory in Ballston Spa, New York, where they were installed in a structure to simulate actual home construction. The receptacles were monitored while operating to determine whether continued use would eventually result in fire.

While laboratory testing is incomplete at this time, fires have occurred in 3 receptacles removed from survey homes: 2 receptacles which reached 100°C and one which reached 75°C. Detailed results of laboratory testing are given in a separate report.

Projections from the sample provided the estimated distribution of branch wiring systems within the 2,710 single family dwellings in Montgomery County for which building permits had been issued in 1969. An estimated 624 dwellings had aluminum wiring in all or part of the branch circuit systems and 2018 dwellings had all copper circuitry.

Based on the rates observed in the survey, an estimate of 67 dwellings with at least one receptacle over 100°C (212°F) was made for the group sampled (Building Permits 1969). At the 75°C level (168°F) the estimate was 156 homes. This estimate does not include the 85 estimated homes with duplex receptacles backwired to aluminum wire -- an installation procedure that has never been considered acceptable by Underwriters Laboratories.

This is a conservative estimate, since the failure rates are computed after testing only three receptacle circuits per house. The average home usually has at least two 20 amp receptacle circuits and five 15 amp receptacle circuits, plus a number of circuits for fixed appliances such as the dishwasher, disposal, furnace, etc. Based on the information available at this time, it appears evident that the observed failure rate increases as more circuits are measured in a house.

While no statistical inferences can be made to years beyond the survey time frame, it is possible to conjecture as to the prevalence of overheated receptacles in homes built in other years. Using gross assumptions, the estimate of homes in Montgomery County, Maryland (excluding Rockville and Gaithersburg) wired with "old technology" aluminum branch circuits between 1966 and 1971, was computed to be 3,559 homes. Projecting the rates found in the pilot survey to this group of vulnerable homes, suggests that almost 1400 homes in the County have wiring systems which would generally be considered unsafe: approximately 900 homes with temperatures reading 75°C or higher in at least one receptacle and approximately 500 homes which have backwired receptacles in aluminum circuits.