FIXED-POSITION ELECTRIC HEATERS

CONSUMER PRODUCT SAFETY COMMISSION
UNITED STATES OF AMERICA

FINAL REPORT ON FIXED-POSITION ELECTRIC HEATERS
January, 2002

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Fixed-position electric room heaters are non-portable appliances that heat by electricity. In 1998, there were an estimated 1800 fires associated with fixed-position electric heaters that resulted in 10 deaths, 110 injuries, and approximately $19.3 million in property losses. In FY2000, the U. S. Consumer Product Safety Commission (CPSC) initiated a project to address the potential fire hazards associated with these products. The purpose of the project was to:

1) Assess the adequacy of the relevant voluntary standards in addressing fire incidents, and
2) Recommend any warranted improvements.

The applicable voluntary standards are UL 1042 *Electric Baseboard Heating Equipment*, and UL 2021 *Fixed and Location-Dedicated Electric Room Heaters*. In fulfillment of the project objectives, the following activities were completed:

- Field investigations were conducted according to a new Investigative Guideline, resulting in 108 in-scope investigations over two heating seasons.
- Sample recovery efforts resulted in the collection and analysis of 28 field-returned incident heaters from 23 investigations.
- An economic report identified the types, distribution, and populations of heaters.
- Prior investigative studies through the Office of Compliance provided important field incident data and expert analyses.
- The Division of Human Factors evaluated installer and user instructions.
- Laboratory experiments on multiple heaters characterized performance and potential hazards under a variety of conditions.
- A Failure Modes and Effects Analysis compared potential failures with the ability of UL 2021 to detect those failures.
- An independent expert in the field of electrical connections, evaluated the quality and effects of electrical crimp connectors in fixed-position electric heaters.

The results, conclusions, and implications from the staff's assessments and the contractor's evaluation were used as the basis for a set of recommended changes to the voluntary standards, UL 1042 and UL 2021. The proposed changes fall into the following categories:

- Temperature Limiting Controls
- Wiring
- Labels and Instructions
- Evaluation of New Products by Testing Laboratories
- Testing during Production Assembly

The following report and supporting documentation found in the appendices detail the studies undertaken, their results, and the recommended changes to the voluntary standards.

ACKNOWLEDGEMENTS

The project team consisted of members from the directorates across the CPSC, and included:

Mr. Randy Butturini, Engineering Sciences and Project Manager
Ms. Jean Mah, Epidemiology
Mr. Terry Karels, Economics
Mr. Richard Stern and Ms. Valery Ceasar, Compliance
Mr. Terry Van Houten and Ms. Carolyn Meiers, Human Factors
Mr. Dean LaRue, Laboratory Sciences
Ms. Mai Ngo, Engineering Sciences

Mr. William King contributed significantly to the initiation of the project, its timely progress, and to the review of the recommendations. The project team also wishes to thank Mr. Edward Krawiec for his prior work with electric air heaters.

2. INTRODUCTION

Fixed-position electric room heaters are non-portable appliances that convert electricity directly to heat. Typically, the heaters are connected directly to the branch circuit wiring when installed. These products have been in widespread use in the United States for over 50 years. In areas of the country where electricity costs are historically low (primarily the Western States) or where winters are not severe (such as in the South), fixed-position electric heating is often the preferred heating system for small residences.

Some characteristic features of these products are high internal temperatures, high currents, and line voltages. These attributes can contribute to fire incidents. In 1998, there were an estimated 1800 fires that resulted in 10 deaths, 110 injuries, and about $19.3 million in property losses[1]. This data represents a continuation of a declining rate of fires over the previous few years.

The U. S. Consumer Product Safety Commission (CPSC) initiated a project on fixed-position electric heaters in fiscal year 2000, the purpose of which was to:

- Assess the adequacy of the relevant voluntary standards in addressing fire incidents, and
- Recommend any warranted improvements.

The applicable voluntary standards are UL 1042 *Electric Baseboard Heating Equipment*, and UL 2021 *Fixed and Location-Dedicated Electric Room Heaters*.

Previous CPSC work on voluntary standards associated with fixed-position electric heaters occurred in 1983 and focused on requiring that a temperature limiting control (TLC) interrupt all ungrounded conductors when activated. Underwriters Laboratories Inc. (UL) implemented this requirement for open-coil element heaters only. Sheathed heating element heaters were exempted from this requirement.

The CPSC staff evaluation presented here includes several studies. Economic and epidemiological examinations were completed; laboratory and analytical studies were conducted; and a technical study of connectors used in electric heaters was performed by a contracted expert in the field. This report presents the results of the contractor's evaluation and the staff's assessments.

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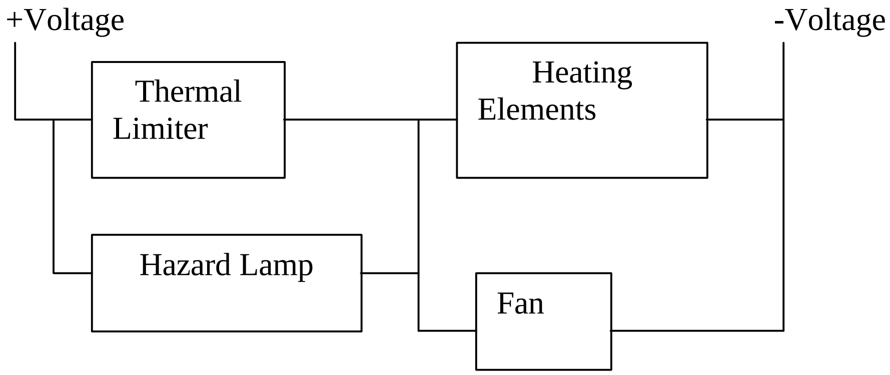
[1] Mah, Jean et al., "1998 Residential Fire Loss Estimates," U.S. Consumer Product Safety Commission, Directorate for Epidemiology, March, 2001.

3. PRODUCT DESCRIPTION

Fixed-position electric heaters create heat by passing electric current through a heating element made of an alloy of nickel and chromium called nichrome. The nichrome heating element may be encased in a metal sheath packed with a magnesium oxide powder or may be exposed in an open-coil geometry. Typically, the heating element is mounted in a frame and is accompanied by a temperature-sensing thermal limiter to detect overheating. An alarm (typically a hazard lamp) is used to alert the consumer of the activation of the limiter. Some heater designs use a fan to force air across the elements as a means of increasing the convective heating rate. Figure 1 shows a block diagram of a typical fixed-position electric heater.

Figure 1: Typical Heater Components

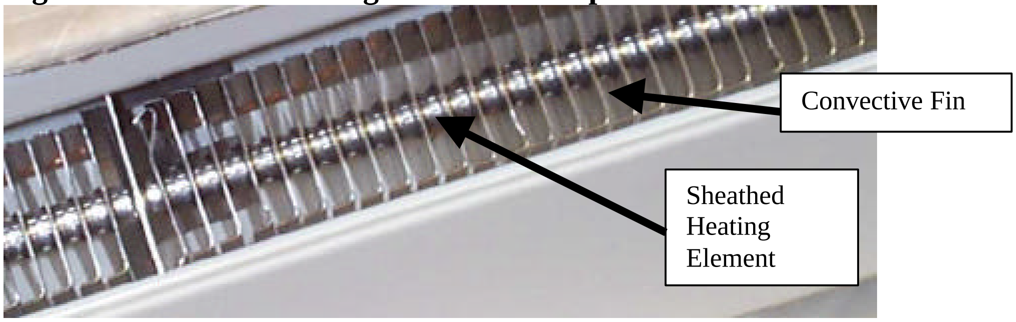


These heaters are generally hard-wired to either 110 or 220 VAC, based on their designs but may be cord-connected heaters that are dedicated to fixed locations.

The three major types of fixed-position electric heaters are natural convection, forced-air convection, and radiant. Natural convection heaters rely upon heating a large surface area to warm nearby air and allow it to rise by convection from the heater into the room. Baseboard heaters are characteristic of natural convection heaters. This design has no fan or hazard lamp and relatively low temperatures on the heating element and convective fins. The heating element is almost always a sheathed design with the heating wire surrounded by a metal tube packed with electrically insulating but thermally conductive magnesium oxide powder. A few baseboard heaters use a fluid instead of the powder, and are called hydronic heaters. Baseboard heaters have openings at the bottom to allow cool air to enter and at the top allowing the warmed air to exit the heater. Figure 2 shows a typical baseboard heater. This particular unit has an optional thermostat at the left end. Figure 3 shows a section of a sheathed heating element design found in baseboard and some wall-insert heaters. The picture shows the convective fins attached to the sheath surface.

Figure 2: Baseboard Heating Unit

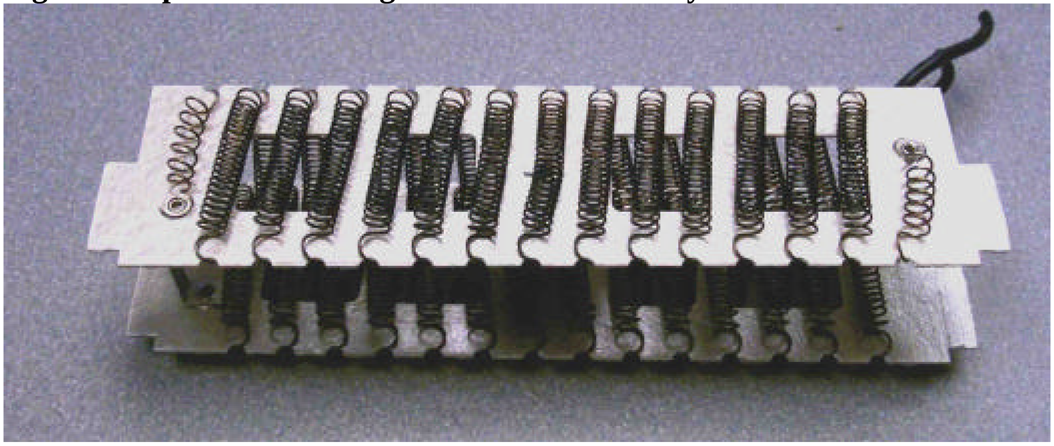
Figure 3: Sheathed Heating Element Example



Forced-air convection heaters use a fan to blow air across a sheathed or open-coil heating element. The heating element is much smaller and hotter than a natural convection heating element of similar wattage due to the moving air's high heat transfer rate. Consequently, forced-air convective heaters are more compact than baseboard heaters. Forced-air heaters typically have louvered slots at the air input and exhaust areas to direct the air into and from the heater. Figure 4 shows some typical forced-air convection heater styles. Figure 5 is a picture of an open-coil heating element that has been removed from a heater. This element is a nichrome alloy wire with a higher resistance than copper conductors. This resistance causes the wire to heat throughout its length. The wire is a live, uninsulated component.

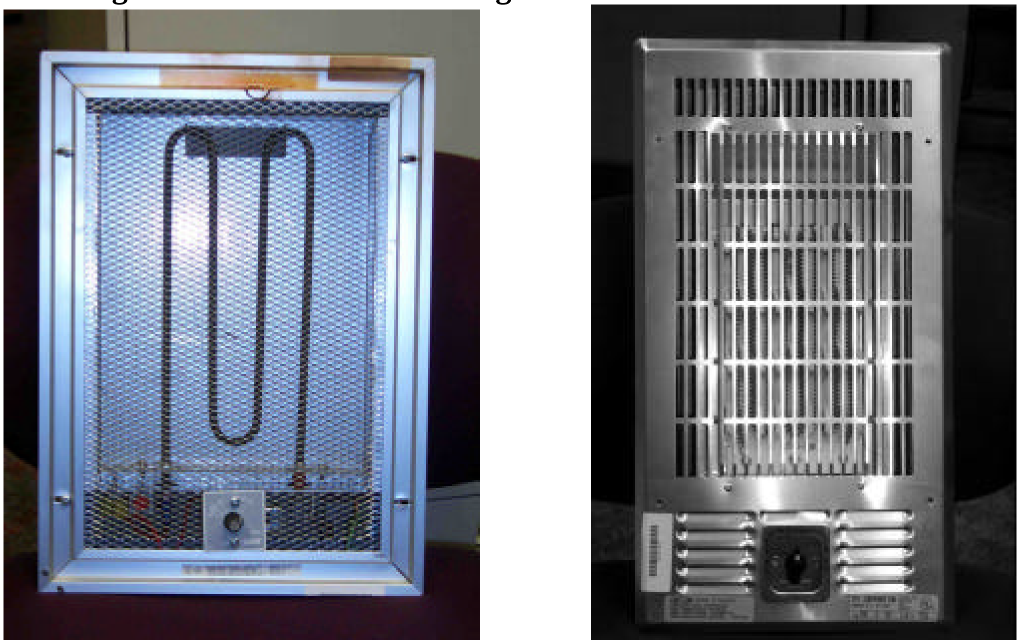
Figure 4: Forced-Air Convection Heaters

Figure 5: Open-Coil Heating Element Subassembly



Radiant heaters emit infrared radiation that impinges directly on an object to warm it instead of creating warm air. The heating element is typically hot enough to visibly glow. This is necessary to create a temperature difference between the heating element and the surroundings high enough to effect a sufficient heat transfer by radiation, rather than convection. Because a line-of-sight geometry is required for heat transfer, radiant heaters have a grid or mesh in front of the heating element rather than a set of louvers, which would reduce the radiation of heat. Further, because the radiation pattern from the heater tends to be dispersive, radiant heaters are typically installed in small rooms, like bathrooms, or in areas where a consumer is likely to be nearby and able to feel the radiation. Figure 6 shows typical radiant heaters.

Figure 6: Radiant Heater Designs



Without a failure of some type or a restriction of the airflow, an air-warming heater can never heat nearby combustibles above the temperature of the exhaust air, which is typically far below the combustion temperature of common household materials. However, radiant heater element surfaces are often well above the combustion temperature of many household materials. The line-of-sight construction requires that the elements present a large surface area to the front of the heater. Therefore, these heaters are capable of continuously adding thermal energy to the surface of an object until equilibrium is reached, perhaps at a temperature above the object's ignition point.

4. VOLUNTARY STANDARDS APPROACH TO HEATER EVALUATION

Two voluntary standards apply to fixed-position electric heaters. For baseboard heaters (and cord-connected heaters whose width is more than 3 times its height), UL 1042 *Electric Baseboard Heating Equipment* is the applicable standard. For other fixed electric heaters (and cord-connected heaters weighing more than 65 pounds), UL 2021 *Fixed and Location-Dedicated Electric Room Heaters* is the proper voluntary standard. UL 1042 was last updated in 1994. UL 2021 underwent revision in 1997.

Both voluntary standards evaluate products similarly. A candidate heater for UL listing undergoes a series of inspections and tests. Typically one, but up to three samples may be submitted for assessment. All evaluations are performed on newly manufactured samples. Unit-to-unit differences that occur due to normal manufacturing variations are not rigorously addressed in the voluntary standards.

Some of the factors examined during an evaluation include checking for adequate spacing between components with different electrical potentials, protecting users against accidentally contacting live electrical parts, providing wiring strain relief, physically supporting the heating elements adequately, and protecting metal parts against corrosion. General requirements for switches, lampholders, and warning label texts are also specified.

A variety of tests are performed on the submitted sample heaters to assess their conformance to the voluntary standard. Measurements of insulation resistance, power input, and leakage current are among the non-performance checks carried out during evaluation. The performance-based tests fall into 2 areas, normal and abnormal operating conditions. Normal operation performance tests involve energizing the unit-under-test for 7 or 8 hours and assuring that the maximum temperature increase of the components and surfaces are below the maximum allowed for each. Abnormal operation testing involves energizing the heater while draped with test fabrics or blocked with a padded wall of fabric and felt. Passing an abnormal operation test requires no emission of flame or molten metal from the heater, and no generation of glowing embers or flames on the test fabrics during the 7 to 8 hour test interval. In UL 2021, if the manufacturer attaches a warning label, the heater is exempted from some of the abnormal operation tests.

5. MARKET INFORMATION (See Appendix A)

A study of the fixed-position electric heater market shows an industry characterized by stability. Little technological innovation, low sales growth, and few new manufacturers typify this market. There are four main manufacturers responsible for about 90 percent of the 2.5 million units sold in the United States annually. Baseboard heaters are reported to account for about 80 percent of sales, with wall-insert, forced-air heaters constituting another 10 percent, and all other types comprising the remainder. One industry group estimated average heater life at 10 years, resulting in a base of about 25 million fixed-position electric heaters in service at any one time.

Manufacturers sell their heater production to wholesalers, who generally sell the heaters to contractors. The contractors install the heaters in new construction or in existing homes requiring supplemental heat. A typical residence using only fixed-position electric heaters may contain 5 to 6 units, spread among the rooms. The heater users are often not the original purchaser of the unit. There are a large number of fixed-position heaters installed in multi-unit apartment buildings, which adds another intermediary between the manufacturer and the ultimate user.

When the average costs of fire-related injury is estimated using the Injury Cost Model, the societal costs of baseboard heater fires is about $16.50, or two-thirds of the average cost of a new unit. Similar calculations on fires associated with wall units resulted in an estimated societal cost of about $65.50. This value is almost one-third higher than the average cost of a heater of this type.

6. HAZARD ANALYSIS (See Appendix B)

Fixed-position electric heater in-depth investigations (IDIs) were assigned from October 1999 through May 2001 using the Investigative Guideline Appendix 120 – *Fixed-Position Electric Heaters* and data record sheet.

Data collection outreach efforts were conducted with the assistance of the Office of Field Operations and various field staff. The Office of Compliance (EXC) assigned forty-eight of the IDIs included in this analysis. Although the assignments were made during the data collection period, a few were based on incidents that occurred prior to 1999. An informational article was placed in the field feedback memo compiled by the Division of Hazard and Injury Data Systems (EPDS) and a conference call was held between the project engineer and field supervisors to introduce the project. An appeal to fire fighters and insurance investigators to provide fixed heater incidents and samples was submitted to the International Association of Arson Investigators (IAAI) monthly publication. The field staff also circulated this request to regional and local fire community publications. Both headquarters and field staff attended regional IAAI meetings to advertise CPSC data collection efforts.

Out of 212 investigations assigned, 108 were completed and eligible for inclusion in the fixed-position electric heater project. The investigations included 45 incidents with fan-forced heaters, 40 incidents with baseboard heaters, 17 with radiant heaters, and 6 of unknown type. Twenty-four of the 45 fan-forced heater incidents did not involve fire scenarios. Three of the baseboard incidents did not involve fire scenarios.

Twenty-three incident heater samples were received from the in-scope IDIs. Of these incident samples, 12 involved wall-insert units from a single manufacturer, and two involved baseboard heaters by the same manufacturer. Any conclusions drawn from the recovered samples should take into consideration that about three-fifths of the heater samples were made by the same manufacturer.

The IDIs reflected the geographical distribution of fixed-position electric heaters being installed in areas that experience mild winters or have inexpensive electric rates. Most western IDIs took place in the Pacific Northwest, while most eastern IDIs took place in the southeastern states. Within the home, the heaters were installed in living areas, bedrooms, bathrooms, and storage areas. Consumers often turned off or operated at the lowest setting heaters installed in storage areas. Over half of the IDIs involved tenants as the user of the heater. Residence owners who did not install the heater represented another 12 percent of users. In half of the IDIs, the consumers were not involved with the installation of the heater. The installer was often identified as a professional electrician, building contractor, or maintenance worker.

Most fires reported in the IDIs were attributed to the ignition of combustibles outside, rather than inside, the heater. Towels, clothing, and bedding (including mattresses) were most often cited as the objects ignited. Fire officials considered the heaters to be “properly operating electrical equipment” with combustibles placed too close by consumers. However, the fires usually damaged the heaters so severely as to make inspection of the unit futile. Thus, the heaters involved in incidents were rarely examined by fire officials for internal failures.

Some IDIs cited dust accumulation in the heater as a contributing factor to fires. In half of the IDIs, it could not be determined whether the heater had ever been cleaned. In IDIs where the cleaning history was known, twice as many heaters had never been cleaned as had been cleaned at least once. Consumers rarely possessed instruction manuals for their heaters, which contain the procedures for cleaning and maintenance. According to evaluations by Human Factors, some manuals indicate that it is the user’s responsibility to clean (typically by vacuuming) any accumulated dust or lint from inside the heater on a regular basis. Without these instructions, the consumer would not know the need for, the procedures to, or the recommended frequency of, cleaning the interior of the heater, or whether the heater is intended to be cleaned.

Understanding the hazards posed by abnormal operation was difficult for users. Consumer action upon noticing that a hazard indicator lamp (a requirement in the voluntary standard UL 2021 since 1992) was lit was not reported in the IDIs. Abnormal operation was described as more overt actions on the part of the heater such as excessive heat output, no heat, rapid cycling of the thermostat, and problems with the heater controls. This implies that the consumers did not know what situations constituted abnormal operation, did not understand the implications of abnormal operation, or did not know what actions to take in the event of abnormal operation.

In 13 percent of the IDIs, consumers mistakenly thought that the fixed heaters were turned off or disconnected from their power source at the time of the incident. In more than half of the IDIs where this was determined, the controlling thermostat did not have a positive "off" position. Four IDIs reported consumers turning the thermostat to its minimum setting and expecting the heater to be disconnected from electric power. Three of these incidents resulted in fires when the ambient temperature in the rooms dropped, the heaters activated and nearby combustibles were ignited.

Baseboard Heaters

The average life of the units in the 40 baseboard heater IDIs was 18 years. With no moving parts, these heaters tend to remain installed and in operation for relatively long periods of time.

Because of the length of wall space they typically covered, as well as their proximity to the floor, consumers often placed beds and furniture up against baseboard heaters. By doing so, consumers acted as though they perceived the heaters as safe heating sources. Yet, 28 of baseboard heater fires were attributed to "combustibles too close" to the heater. The printed warnings on the heater stating that all furniture, materials, and other items should not be placed within 3 feet of the heaters may be impractical, especially in small areas like storerooms or apartments.

The center of a baseboard heater is the location where the highest temperatures are found. The ends of the heater are where the electrical connections to the branch wiring are made. In half of the baseboard IDIs, it was unknown whether ignition or failure occurred near the center or far end of the baseboard heater. Twenty of the baseboard heater IDIs where this information was known indicated that ignition or failure occurred near the far ends of the heater. Of the 12 baseboard heater IDIs that reported internal failures, three involved melted sheathed heating elements. Other IDIs documented problems with electrical connectors, failed temperature limiting controls, and burned off or degraded wire insulation.

Many of the fire incidents occurred when the heaters were energized for an extended period or when the heater was initially energized after a long (sometimes years) period of inactivity. The supposition is that various failure mechanisms were at work that resulted in the incidents documented in the IDIs.

Forced-air Heaters

Forced-air convection heaters involve higher internal and exhaust air temperatures than do baseboard heaters. Their small size, relative to baseboard heaters, means that more electrical power per unit volume is being converted to heat. Heaters documented in the 45 forced-air convective heater IDIs had an average age of 6 years, with half of the units being less than 3 years old.

The use of a fan in a forced-air heater results in a higher rate of dust accumulation. Cleaning, however, was still rare. Sixteen respondents did not know if the heater was ever cleaned. Eighteen of the IDIs where the cleaning frequency was known involved heaters that were never cleaned. One consumer was able to remove the faceplate to the heater but was unable to clean the rear due to the obstructions caused by the internal components.

Similar to baseboard heaters, about two-thirds of respondents who could provide information about the heater controls said that the thermostat did not have a positive “off” position. One non-fire incident occurred when a heater suddenly emitted smoke and displayed a glowing red heating element, while the fan was not operating. Since the heater had been connected to a pre-existing remote thermostat with no positive “off” position at the time of installation, the consumer was forced to disconnect power at the circuit breaker to de-energize the heater.

Heaters listed to the UL 2021 voluntary standard are required to have an alarm (visual lamp or audible buzzer) if the temperature limiting control is an automatic (as opposed to manual) reset type. If the temperature limiting control activates, the alarm is expected to activate in order to notify the user that an abnormal condition exists. Forced-air heaters were the only types of fixed position electric heaters documented in the IDIs that included hazard lamps in their designs. Even though the lamp was illuminated, users usually did not know what the lit lamp meant (an abnormal operating condition), if it was observed at all. No consumers reported seeing an indicator light as being what first alerted them in the incidents. Rather, more drastic effects such as sparks, loud noises, or smoke from the heater most often alerted the users to the hazardous conditions.

The internal failures identified in fan-forced heater fires and potential fires included problems with wire insulation and electrical connections, failed heating elements, failed thermal limiting devices and fan problems. All the models were listed as meeting the current voluntary standard, UL 2021.

Radiant Heaters

The average age of the 17 radiant heaters investigated was 26 years old, the highest among the heater types. Radiant heaters were more often than not reported to have positive “off” positions as part of their temperature controls. Three IDIs involved radiant heater fires where the consumers mistakenly believed the heaters had been disconnected.

Of the 10 heaters that had known cleaning histories, nine had heating elements that had never been cleaned. Thirteen IDIs involved consumers who were tenants. The same number of IDIs involved radiant heaters that were installed as bathroom heaters. Bathroom installation of radiant heaters puts high temperature devices in rooms with small clearances and often very near an abundance of combustible materials such as towels, bathrobes, and paper products.

In addition to fires attributed to combustibles placed too close to the heater, some fires were blamed on internal failures such as electrical overloading and overheating and burnt wiring igniting dust.

Summary

Of the 102 (out of 108) IDIs documenting actual and potential fires in which the heater type was known, baseboard heaters represented 39 percent, forced-air units represented 44 percent, and radiant heaters represented 17 percent. Considering that baseboard heaters are about 8 times more numerous in homes than forced-air units (according to economic data), this data implies a risk difference between these two types of heaters based on our convenience sample of IDIs. Radiant heaters also appear to be involved in fires at a rate higher than their relative population in homes.

7. PRODUCT SAFETY ASSESSMENTS & RECALLS

A review of the Product Safety Assessments (PSAs) performed by the CPSC staff on electric heaters resulted in 47 reports from 1983 to the present. Of these, 9 reports dealt with baseboard heaters, with almost all the remaining reports on wall-insert forced-air convective heaters. The PSAs dealing with baseboard heaters reported most often damaged wiring and connectors. The wall-insert heater problem reports included failed temperature limiting controls, stalled fans leading to overheating conditions, poor electrical connections resulting in overheating, and sudden failures that emitted sparks, molten metal, or flames. The failures noted in the PSA reports are similar to the failure modes reported in the IDIs.

Two PSA reports involved forced-air heaters whose fans stopped rotating. The heating element temperature increased on each heater to the point that the temperature limiting control (TLC) activated and cut electric power to the heating elements. Once cooled, the automatically-resetting TLC re-energized the elements and continued to cycle without consumer interaction or awareness. This created hot spots inside the heater that melted the wiring insulation. Once melted, the wires short-circuited to the grounded heater interior (“heat box”) frame and, in one case, emitted glowing embers into the room. Follow-up testing with other models from the same manufacturer showed similar hot spots and melted insulation. The incident heaters and the tested heaters burned their warning labels before the short-circuit occurred.

Two product recalls were instituted on fixed-position electric heaters in recent years. In 1997, several models were recalled to replace the plastic-body Temperature Limiting Device. The plastic-body device would crack, emit sparks, and fail closed during heater use. A ceramic-body replacement was substituted to resist the heater’s high internal temperatures. In 2000, another recall program was announced. Over 1.9

million heaters were recalled due to defects that could lead to overheating and fire. Among the problems experienced with the recalled heaters were failed sheathed heating elements (the nichrome heating wire short-circuited to the grounded sheath), poor crimp connections, and an excessive accumulation of dust, which was ignited by the heating element and emitted into the room. Emission of flaming or molten particles is forbidden for products listed by Underwriters Laboratories.

8. LABORATORY STUDIES (See Appendix C)

A number of experiments were executed to test the following hypotheses:

- The temperatures achieved anywhere inside or on the surface of a baseboard heater, when subjected to abnormal conditions, are not high enough to lead to ignition of common household fabrics.
- Operation of an electric heater under normal and abnormal conditions listed in UL 2021 and UL 1042 may result in conditions that can damage internal components. UL evaluation of a heater does not consider this.
- Radiant heater operation is evaluated in UL 2021 with a drape of cheesecloth plus duck cloth (the Curtain Drape Test). The properties of terrycloth are sufficiently different from cheesecloth plus duck that a radiant heater that passes the Curtain Drape Test of UL 2021 can ignite terrycloth when the terrycloth is draped over the heater.

A separate exploratory experiment was performed to determine if it was possible to see a change in operation of a forced-air heater after a short-term exposure to airborne dust. The intent of this test was to show that it is possible to evaluate the dust-trapping characteristics of a particular model heater as part of a product evaluation by a testing laboratory.

In selecting and examining the heaters for testing, observations were made with respect to poor grounding arrangements. Several designs in both baseboard and wall-insert heaters had unreliable grounding connections. Some designs relied on mating painted surfaces as a means of grounding. One heater had a wire inserted into a punched sheet metal slot that had been painted as a means of grounding the frame. Often, a single screw thread with no locking mechanism or hardware or other means of resisting vibration-induced loosening was the sole means of establishing a low impedance ground. With these designs, normal manufacturing variations in parts, clearances, and assembly may lead to missing, intermittent or high impedance ground connections on any given heater unit.

Baseboard Heaters

The baseboard heaters under test were draped, partially covered, or had the space between the heating element fins and the exhaust vent stuffed with cotton cloth. During some tests, the temperature limiting control (TLC) was bypassed to simulate a component failure. The heater was mounted to a wall and instrumented with thermocouples at various air inlet and exhaust areas, heating element and fin locations, and wiring routes.

In all of the tests, including those tests with the TLC bypassed, the temperature of the cotton cloth never reached temperatures near its ignition point (about 360 °C). However, some tests resulted in temperatures above the maximum rated temperature of the wiring insulation. The temperature rise was not more than 10 °C over the rated temperature for the wire. This would not manifest itself into a failure during the 7 to 8 hours of a UL test duration but could have long-term effects on the insulation integrity of the internal wiring of a baseboard heater and lead to a shock or fire hazard.

Forced-air Heaters

Similar to baseboard heater results, temperatures above the wiring insulation's maximum rated value were achieved in several circumstances. On one heater, the "thermal momentum," or transient internal temperature rise when power is removed, caused internal temperatures to overshoot the insulation's rating every time the thermostat cycled. This condition occurred during normal operation with no blockages, draping, etc. During the execution of the Stalled Fan Test of UL 2021, the heaters under test cycled on their auto-reset TLCs. During a part of each cycle, temperatures on the internal wiring were measured above the insulation's maximum rated value.

A home's branch circuit wiring must enter the wall can (the metal box attached to the wall) to connect to heater internal wiring. Testing showed that the branch wiring was also subjected to high temperatures. A test heater was installed on an open wooden frame, a condition that allows maximum convective cooling on the wall can. When a barrier was placed nine inches from the exhaust of the forced-air heater, the TLC did not activate. However, the temperatures of some parts of the uninsulated wall can rose to a level over 60 degrees Celsius above 60 °C, a common temperature rating of household branch wiring. In this state, the heater would appear to be operating normally to a consumer. Installing the heater in a wall, especially an insulated wall, would result in wall can temperatures well above those measured using the open wooden frame.

A potential failure mode exists when wiring insulation is operated above its maximum rated value. If the insulation softens, the internal wire may creep through the insulation over an extended period of time and create a potential shock hazard. Further, polyvinyl chloride insulated wiring that is operated above its maximum rated temperature may develop cracks over time[2].

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[2] Donald Fink and H. Wayne Beaty, ed., *Standard Handbook for Electrical Engineers*, Thirteenth Edition, McGraw-Hill, inc., 1993, page 4-153.

Radiant Heaters

Two radiant heater styles were tested, one with a sheathed heating element, and one with an open-coil heating element. Both heaters were tested with terrycloth draping and a combination of cotton duck cloth plus cheesecloth as a simulation of a curtain, as specified in the Curtain Drape Test of UL 2021.

Testing of the sheathed element heater did not result in emission of molten metal, flames, or glowing embers from the heater or either type of draping material. The open-coil heating element heater quickly ignited whatever material was draped over it. When measured with a digital flux meter, the highest measured heat flux at the grill was 0.64 W/cm^2. Prior CPSC testing achieved ignition of cotton batting with a flux of 0.54 (W/cm^2)[3].

Dust Testing

For the exploratory test on dust accumulation, two forced-air heaters were installed in a sealed box. The heating elements were disconnected, leaving the heaters' fans operational. The heater fans were operated for two hours while a combination of ISO test dust[4] and ground cotton lint was stirred into the chamber air. After the exposure period, each heater's heating element was reconnected. The heaters were operated, and temperatures measured. Both heaters showed markedly different operation from their pre-dusted state, including repeated cycling of the TLC, unstable exhaust air temperatures, and charring of the internal dust.

Testing Summary

In summary, the laboratory testing showed that baseboard heaters, even when the TLC was bypassed, did not generate temperatures capable of ignition of combustibles, but did result in temperatures capable of damaging the internal wiring of the heater. Forced-air heater testing showed that abnormal operating conditions, even for a short time, were capable of heating the internal wiring insulation above its maximum rated value. In some cases, the branch wiring insulation was overheated. Testing on radiant heaters did not support the hypothesis that the thermal response of terrycloth is different from curtain material when draped over a heater. The dust testing showed that a short exposure time to a dusty ambient environment could result in easily observable operational changes in a heater, and testing can be used as a means of evaluating whether the heater design might lead to hazardous conditions when in use.

The cycle time of the automatically-resetting TLC was used to calculate how long it would take for a heater operating under abnormal conditions to reach the 100,000 cycle tested life of the TLC. Using measured TLC cycle times and an assumed 152-day heating season, values ranging from 1.6 to 6.2 years were computed. Therefore, operation of the temperature limiting control during long-term use will exceed the tested life of the control long before the expected useful life of the heater is reached.

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[3] *Portable Electric Heaters,* Engineering Project Report, Edward W. Krawiec, September, 1987.

[4] ISO Fine Test Dust 12103-1, A2

9. FAILURE MODES & EFFECTS ANALYSIS (FMEA) (See Appendix D)

An analytical study was performed on a generic forced-air heater design to assess whether identified failure modes would be detected by evaluating a sample according to the requirements in UL 2021, *Fixed and Location-Dedicated Electric Room Heaters*. For each single-point failure named, the effects of that failure were determined. In the event that a particular failure mode would not likely be identified, suggestions were developed to increase the fault coverage of the evaluation. The study uncovered the following:

- Some short-duration continuous and abnormal tests may affect the dielectric resistance of the wiring insulation after the Dielectric Voltage-Withstand Test and Overvoltage Tests have been completed. Short-term abnormal operation may result in an undetected shock hazard.
- Fault coverage is missing for some identified failure modes. The effects of component aging and dust collection are not considered.
- Safety requirements for cord-connected (location-dedicated) heaters include a requirement for use and care instructions, and carton requirements. Glass-paneled heaters are required to withstand an impact on their front surface. These requirements are not extended to other fixed-position heater types.
- Problems that take longer than the test time to manifest a failure may not be detected.

The Failure Modes and Effects Analysis showed that the order and completeness of evaluation under UL 2021 can affect the fault coverage of a heater under test. It is possible for a unit under evaluation by the standard to pass or fail depending on how the tests are performed and in what order. Since short periods of abnormal operation can be expected in a consumer installation, these short periods should not result in hazardous conditions for consumers.

10. HUMAN FACTORS EVALUATION (See Appendix E)

The Division of Human Factors staff conducted a review of UL 2021 with respect to human interface issues. In addition to the review, two Product Safety Assessment Reports were completed, evaluating the human interface with specific heater models.

The review and the PSAs uncovered instances of incomplete, contradictory, confusing, and ineffective instructions and warnings in the labeling and documentation of the products. These instances were found in both the installation and operation instructions. Installation and use instructions were intermingled, even though the installer and user are different persons. In one case, the warning not to remove the grill of the heater was located on a label behind the grill. In another instance, the instructions stated that the grill was to be removed for cleaning and that there were no user-serviceable parts inside the heater. In one instance, consumers were instructed to lubricate the motor elements on older style motors, while newer style motors needed no lubrication. The instructions failed to provide any guidance to the consumer on how to distinguish the older and newer style motors.

Other instructions defined hazard lamp “flashing” as a cycle with a minutes-long period. Consumers were to take different actions if the lamp “flashed” rather than remained constantly lit. In this situation, such a determination would take several minutes of examination to discriminate a “flash” from steady illumination.

11. TECHNICAL EVALUATION OF CRIMP CONNECTIONS (See Appendix F)

Overheating failures of internal crimp wire terminations of fixed-position electric heaters have been noted in many field samples. A contract was awarded to an independent technical expert for the evaluation and analysis of electrical crimp connectors in fixed-position heaters. The technical expert examined 71 power-conducting terminals from 10 new heater samples. The samples were evaluated visually, through microscopic examination and by measuring the connection resistance.

The results of the examinations showed several instances of inadequate mechanical compression and excessive spring-back (the undesired opening up of a crimped down connector due to the elastic properties of the crimp metal) of the crimp connections. Incomplete compression of the wires in the crimp terminals was shown. These factors result in inadequate metal-to-metal contact and subsequent high connection resistance. Excessive spring-back and incomplete compression do not always result in a loose mechanical connection even though the connection resistance is high. Therefore, mechanical tests on sample connections do not adequately evaluate the connection resistance. A more than 2 orders of magnitude difference was measured in the connection resistance of the heaters evaluated. This indicates that present connection evaluation methods allow for high variation in actual connection resistance.

The results indicate that some field failures that are occurring may be attributable to deficiencies that exist in the heater terminations when new. Incorporation of conventional tests during heater manufacturing and more stringent acceptance standards for the various types of crimp terminations were suggested as a means of addressing the deficiencies.

12. INDEPENDENT INVESTIGATORS

As a result of the data collection outreach efforts by CPSC field staff, seven independent investigator technical reports or contacts were received. These reports involved the failure mode determination of fixed-position electric heaters associated with fire incidents. The investigators identified the following failure modes in the products they examined:

- Two cases where a degraded electrical terminal broke and arced to the grounded case.
- Impurities in the sheathed heating element packing created a conductive path between the heater wire and the grounded sheath.
- Two cases of lint build-up and subsequent ignition by an open coil heating element.
- Installation of the heater upside-down (placing safety devices in the wrong locations relative to the heating element and the airflow).
- Sparks emanating from a heater junction box started a fire.
- Overheated heating element scorching nearby combustibles.

One unsolicited report listed several suggestions for safety improvements. In large measure, the suggested improvements by the outside investigator mirrored the project recommendations.

13. RECOMMENDATIONS TO THE VOLUNTARY STANDARDS

Based on the knowledge gained from the previous studies and examinations presented in this paper, CPSC staff presents the following recommendations to improve the applicable voluntary standards. The proposed changes are grouped by area.

A. UL 1042, *Electric Baseboard Heating Equipment*

TEMPERATURE LIMITING CONTROLS AND CONTROL CIRCUITS

1: Add to Section 24, *Automatic Controls and Control Circuits*: All devices shall incorporate a temperature limiting control (TLC) that disconnects power from the heating elements.

Rationale: The abnormal operation test conditions of UL 1042 Section 34 only approximate conditions of actual use and cannot represent all the reasonably expected abnormal operating conditions. Temperature limiting controls should be included in heater designs to protect against conditions that can be expected during consumer use. Testing on heater samples showed very high temperatures with a bypassed temperature limiting control (TLC). Previous recall actions showed that failed TLCs can lead to fires. Thus, the presence of a working TLC is important in reducing fire hazards. The Failure Modes & Effects Analysis also indicated that many possible abnormal operation conditions are not assessed in a 7-hour test. Without a temperature limiting control, a heater has no protection against short-term unforeseen conditions or any other circumstance that results in overheating.

2: Add to Section 24: The operation of a temperature limiting control shall disconnect all ungrounded conductors from the unit when activated. The requirements of Section 24 shall apply to all heating element types, including sheathed heating elements.

Rationale: Abnormal overheating conditions can result in the activation of temperature limiting devices. Some abnormal conditions involve low impedance circumstances that can lead to high currents (but not high enough to activate a circuit breaker) and localized hot spots. Hot spots could result in insulation breakdown or ignition of combustibles. For 220 VAC heaters, disconnecting a single ungrounded conductor may not remove power from the low impedance connection, and may not address the hazard. The Failure Modes & Effects Analysis (Appendix D) predicts failure modes that don't immediately trip circuit breakers and involve excessive current and power that may lead to a fire. Sheathed elements are not now required to have a TLC that disconnects all ungrounded conductors. Yet, evaluation of field heater samples and IDI reports showed sheathed heating elements that failed other than at the ends. Sections of heaters wired for 220 VAC may remain energized under conditions of mid-element short circuits even if the TLC activates. Heaters with sheathed heating elements should have this fault condition covered. The style of the heating element is not a sufficient reason to leave electrical power connected to a heater under detected overtemperature conditions. All power should be removed from the heater when the TLC activates, regardless of heating element type.

3: Add to Section 24: All auxiliary control devices (thermostat or combination thermostat and control switch) shall have a position that disconnects all ungrounded conductors of the supply circuit, regardless of heating element type or markings on the control.

Rationale: Based upon information provided in the IDIs, consumers assume that the lowest position of the switch is synonymous with disconnecting electrical power from the heater. If cleaning or other maintenance is required, and the unit has not been de-energized, the user may be exposed to live parts, especially for heaters connected to 220 VAC. Evaluation of incident data indicates that users believe power has been removed from the heater if the control knob is at its lowest setting, regardless of the markings on the knob. Acting on that belief can expose users to a shock hazard (Section 5). Also, heaters at their lowest setting (not disconnected from all ungrounded conductors) may unexpectedly activate in response to a low ambient temperature. Consumers expecting the heater to remain cold have placed combustibles near the "off" heaters. Subsequent activation resulted in a fire. Consumers should have assurance that heaters whose controls are turned fully down will be and stay de-energized.

WIRING

4: An electric baseboard heater shall be constructed to reduce the risk of electric shock or fire when the appliance is connected to branch circuit power by the use of an integral Arc Fault Circuit Interrupter (AFCI), or connection to another device meeting the requirements of *Standard for Arc Fault Circuit Interrupters*, UL 1699.

Rationale: Epidemiological data and laboratory studies indicate that an electrical fault can occur to render a baseboard heater capable of initiating a fire. Analysis of incident data shows a regular number of baseboard heater fires with the ignition area at the wiring ends of the heater rather than the middle of the heating element, which is the hottest location. Laboratory studies show that baseboard heater temperatures are below the ignition point of combustibles even under extreme conditions when there is no electrical fault. The same studies show that short periods of abnormal operation can seriously degrade the wiring insulation and lead to arcing faults. Integrating series and parallel arc-fault detection can prevent an arcing condition resulting in a fire hazard.

5: Add to Section 13: No normal or abnormal operation test shall result in conditions where the heater wiring reaches temperatures above the maximum rating for the wiring’s insulation.

Rationale: Degradation of the wiring insulation can lead to shock and fire hazards. Laboratory experimentation has demonstrated that abnormal conditions can result in temperatures exceeding the insulation’s maximum temperature rating and subsequent degradation or melting. Two field samples failed due to melted wiring insulation. Over a long time, the wiring may flow through softened insulation and create a shock or fire hazard. Polyvinyl Chloride (PVC) insulation can develop cracks when exposed to elevated temperatures for a period of time. The insulation is necessary to protect the consumer. Operation of the heater normally for a long time, or abnormally for a short time should not degrade the insulation and lessen its insulating properties.

6: Add to Section 26, Grounding: “Any surface intended for a ground connection shall be electrically conductive at the connection area. For example, the area around a hole through which a grounding screw is inserted shall be conductive. The threads of the screw shall not be the only source of grounding contact. All grounding connections shall be made by a positive means, screws, clamps, etc. Tabs or wires in slots, incidental contact, flat surfaces pushed together, or similar means are not acceptable for grounding connections.” Add that all grounding (or earthing) connections shall be compliant with UL 60335-1, *Safety of Household and Similar Electrical Appliances, Part 1: General Requirements*.

Rationale: Continuity to ground is essential to shock protection. Heaters should be designed with features that assure adequate grounding with a high degree of confidence and repeatability from unit to unit. Some heater designs show reliance on installers breaking insulating barriers with no instructions to assure compliance. Other designs showed unreliable grounding connections. The design of the grounding scheme in a heater should be one that provides a very high probability of adequate grounding in every unit manufactured.

TESTING

7: Include a Manufacturing Test to be performed during assembly on a sample basis to evaluate the electrical integrity of the mechanically assembled wiring connections. Such testing shall include:

- Connection Resistance, initial, and maximum increases during accelerated life testing of representative samples
- Manufacturing quality control systems
- Different ratings for power conductors and non-power conductors.

Rationale: Failed wiring connections have been attributed to many fire incidents. To reduce the frequency of poor quality in electrical connections, the variability associated with today's manufacturing processes must be reduced. Technical Studies performed under contract by the CPSC (Section 10 and Appendix H) indicate problems with wiring connectors exist, and can lead to overheating conditions. The Failure Modes & Effects Analysis studies show that manufacturing problems are not addressed by UL 1042 evaluation. Multiple field samples showed corroded and failed crimp connectors. Assurance is needed that units in manufacture are being assembled with good quality connections. Testing during assembly can be used to monitor the quality of the electrical connectors and reduce the variability of the connector manufacturing process to a point where there is a high probability of good internal electrical connections in every assembly.

8: In Section 34 (Abnormal Operation Tests), examine the heater for impending failure modes, such as melted wiring insulation, reduction of the spacing between components, etc., after completion of the tests. For all tests, run the tests for all 7 or 8 hours to see if these secondary effects appear. Interpret Section 13 (Internal Wiring) as applying to normal and abnormal operation.

Rationale: As approximations of events that can occur during years of use, the abnormal tests may not result in a failure during their hours-long operation. However, there may be evidence of incipient internal failures that can occur in field units over a longer term. This evidence may indicate a marginal condition that could lead to a hazard. Testing on samples showed potential failures that take longer than 7 hours to manifest as fire, sparks, etc., i.e. "failure result." Field incidents have occurred where operation over a long time resulted in a failure. Field samples showed that even severe failures can still take days to result in a fire. However, evidence of an impending hazard is apparent inside the heater much sooner. Tested samples should be examined to determine if abnormal operation could result in a potential hazard to consumers.

9: Run the Dielectric Voltage-Withstand Test (Section 58) after the operational tests. Run the Overvoltage Test (Section 35) after the operational tests. Connect a fuse (of a few amperes) through the ground conductor for each test to detect any short-term currents less than the amount required to activate a circuit breaker.

Rationale: Undetected potential failures may affect the electrical insulation properties, create short-circuit or leakage paths to ground, or change the total impedance of the heater. The Failure Modes & Effects Analysis (Section 8) results indicate that testing for one fault condition may expose other faults. The stress of an abnormal test may weaken components other than those tested. Short-term abnormal operation of consumer units should be expected. The heater should be able to withstand such short-term operation without developing a potential consumer hazard. Executing the Dielectric Voltage-Withstand and Overvoltage Tests after other tests is a means of determining whether the testing unduly degraded the electrical integrity of the sample.

10: Apply the requirements of *Impact* (Section 47) to all heater designs.

Rationale: UL 1042 Section 47, *Impact*, applies only to heaters with glass fronts. Thin-walled metal fronts are also susceptible to deforming upon impact. If the front grill of a heater contacts a heating element, a conductive path could be established through the grill. The Failure Modes & Effects Analysis (Section 8) predicts that physical impact on a sheathed heating element can result in a shock or overheating hazard if the conductor wire in the element establishes a path to ground. Sheathed heating element construction is susceptible to failures caused by bending. Heater designs should be capable of withstanding expected impacts without developing a shock or burn hazard.

11: Include in the standard: Any polymeric material within 3 mm. of the live parts of a power connector shall have a minimum Glow-Wire Ignitability Temperature (GWIT) and Glow-Wire Flammability Temperature (GWFT) of 750 degrees C in accordance with IEC 60695-2-1/3 and IEC 60695-2-1/2 respectively, or comply with the Glow-Wire End-Product Test (GWEPT) as described in UL 746C.

Rationale: This recommendation is to minimize the effects of connector failures when they occur. There is an IEC-UL initiative to address the consequences of failed connectors and harmonize standards. This proposal has been approved for other products.

LABELING & INSTRUCTIONS

12: Add to Section 54: Require that all warning labels be formatted in accordance with ANSI Standard Z535.4 for Product Safety Signs and Labels.

Rationale: ANSI Z535.4 was developed for the following reasons: 1) to establish uniform and consistent visual layouts for labels across all categories of products 2) to minimize proliferation of label designs and 3) to achieve application of a national uniform system for recognition of potential personal injury hazards.[5] To promote these objectives, all warning labels should adhere to these guidelines and principles to make safety information more recognizable and noticeable to consumers. Some warning labels incorporated a mixture of text that included clearance specifications, French translations, and other English text. Warning label research indicates that such safety messages are likely to be missed because of competing text. The warnings should be segregated from the rest of the text and should conform to ANSI Z535.4 guidelines to make the label conspicuous and recognizable.

13: Add to Section 54: Require all labels to be heat resistant or located where they will not be subjected to excessive heat during periods of foreseeable abnormal operation. Require all labels to withstand all abnormal tests while remaining readable. Add to Section 54: "The marking shall, unless otherwise indicated, be permanently applied by means such as:

a) etched, molded, die-stamped, or paint-stenciled on the enclosure,
b) stamped or etched on metal, or
c) indelibly stamped lettering on pressure-sensitive labels secured by adhesive.

Pressure-sensitive label secured by adhesive shall comply with UL 969, *Standard for Marking and Labeling Systems*.

Rationale: Foreseeable use of a heater includes temporary periods of abnormal operation. When the abnormal condition is corrected, the heater is still usable and in use. Warnings are still valid and should be readable on the labels, especially for future users of the heater. UL 1278, *Movable and Wall- or Ceiling-Hung Electric Room Heaters* contains the language regarding the permanence of marking. Field incidents and laboratory testing resulted in unreadable warning labels after very short periods of operation at abnormal conditions (Section 6). If a user corrects a temporary abnormal condition the label may no longer exist to warn other users.

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[5] ANSI Z535.4-1998 (1998). Product Safety Signs and Labels. National Electrical Manufacturers Association: Rosslyn, VA.

14: Add to Section 54: Require that instructions on the product that are directed toward the user be accessible and legible and able to be viewed without disassembling the product.

Rationale: Critical warning labels should be placed in proximity to the potential hazard and in plain view to the user. An analysis of an in-wall heater found that labeling on the face of the heat box did not provide adequate warning to users because it was concealed behind the heater grill (Appendix E). Removal of the grill exposes users to a potential hazard from live electrical components.

15: Add to Section 55: Require separate, complete, instructions for the installer and the user.

Rationale: Data indicates that heaters are usually installed by professionals, who are not the end users of the product, and operated by consumers. Each of these groups requires a different set of instructions tailored to the particular performance demands of their tasks. Installers need technical information and consumers need use and care instructions. The instructions relating to each of these different tasks should be located in the product documentation in such a way that the individual groups can readily recognize the sections pertaining to their specific needs.

OTHER SECTIONS

16: In Section 40.1, Stalled Fan Test – add “no risk of electric shock” in addition to no risk of fire.

Rationale: Stalling a fan may result in temperatures high enough to degrade insulation and not immediately result in a fire. A shock hazard may be created instead. Field incident samples and testing for the Office of Compliance showed that a stalled fan condition could melt wiring insulation and create a conductive path between the power conductors and the heater frame.

17: In UL 1042 Section 10.1.1, replace “... accordance with National Electrical Code, ANSI/NFPA 70-1996, would ...” with “... accordance with the current edition of the National Electric Code, ANSI/NFPA 70, would ...” (also in UL 1042, Sections 10.2.1, 10.2.6, 10.2.9, 10.2.13, 19.3, 19.4, 19.7, 19.8)

Rationale: ANSI/NFPA 70 keeps changing. Referring to the latest edition as a typical practice will keep the latest version as the current requirement.

B. UL 2021, *Fixed and Location-Dedicated Electric Room Heaters*

TEMPERATURE LIMITING CONTROLS (TLCs) AND CONTROL CIRCUITS

1: Add to Section 25, *Temperature Limiting Means*: All devices shall incorporate a temperature limiting control that disconnects power from the heating elements.

Rationale: The use of a TLC is allowed to help the heater pass the abnormal operation test conditions of Section 42. These tests only approximate actual use and cannot cover all failure modes or abnormal operating conditions. Temperature-limiting controls should be included in heater designs to protect against conditions that are not and can not be tested. Testing on heater samples showed very high temperatures are achieved with a bypassed TLC. The Failure Modes & Effects Analysis (FMEA) indicated that all possible abnormal operation conditions are not assessed in a 7-hour test. Field samples with failed (shorted) TLCs were involved in fire incidents. The temperature limiting control is the only protection available against unpredictable operating conditions. Every heater should have a means of reacting safely to overheating conditions regardless of how a sample unit performs on a specific test.

2: Add to Section 25: No temperature limiting control intended for operation during abnormal operation shall operate during normal operation. This would parallel the requirement in Section 24.7 in UL 1042.

Rationale: Heaters are in use for many years, on average. If the temperature limiting control were to operate during normal use, it is likely if not a certainty, that the design life of the control would be exceeded. Also, operation of a temperature limiting control during normal use means the loss of thermostatic control by the user. Calculations using observed TLC cycling data showed that the 100,000 cycle life of a TLC would be exceeded in a few years of operation; whereas, the life of a heater is usually 10 years or more. Once the design life is exceeded, the safe operation of a TLC during periods of overheating cannot be assumed. The device needs to be functional when it’s needed.

3: Add to Section 25: A temperature limiting control shall be of the manual reset type. (Eliminate exceptions a, b, and c, from Section 25.1).

Rationale: Operation of a TLC indicates that abnormal temperatures exist in the heater and that there may be a problem. TLCs that automatically reset allow the heater to continue to generate those high temperatures without user intervention or awareness. Under such conditions, components continue to be stressed, and may fail, leading to a fire. Epidemiological data (Section 5) documents incidents where heaters were allowed to continuously operate without user intervention under abnormal conditions until fires resulted. CPSC staff is aware of many fires related to failed TLCs (Section 6). A heater should not be allowed to continue to generate overheating conditions automatically and indefinitely. Once the overheating conditions occur, the heater should de-energize until the consumer addresses the situation.

4: Add to Section 25: The operation of a temperature limiting control shall disconnect all ungrounded conductors from the unit when activated. The requirements of Sections 30.1.6 & 30.1.7 shall apply to all heating element types.

Rationale: Overheating conditions result in the activation of temperature limiting devices. Some abnormal conditions involve low impedance (but not short circuit) circumstances leading to high currents and localized hot spots. Disconnecting a single ungrounded conductor may not remove power from the low impedance connection (especially for heaters connected to 220 VAC), and may not address the hazard of shock or overheating. The Failure Modes & Effects Analysis (Section 8) predicts failures that don’t immediately trip circuit breakers and involve excessive current and power. Evaluation of heater samples and IDI reports showed sheathed heating elements that failed other than at the ends (Section 5). Sheathed elements are not now required to have a TLC that disconnects all ungrounded conductors. Once an overheating condition progresses to the point of activating the TLC, all power should be removed from the heater. By taking this action, the heater (and consumer) can be protected from unforeseen conditions.

5: Eliminate Exception c) in Section 25.1, which allows an automatic reset type temperature limiting control or a M1 style manual reset control as the back-up device in a ceiling-mounted heater or one with a label saying not to mount the heater less than 6 feet from the floor. Heaters mounted high up must have overtemperature protection also.

Rationale: The intent of the exception is to not require M1 style temperature limiting controls in heaters unlikely to be draped because of their location. Overtemperature conditions can still occur in non-draping conditions. The Failure Modes & Effects Analysis predicts overheating caused by conditions other than draping, such as fan problems or high impedance electrical connectors. Laboratory testing with dust accumulation led to overheated units independent of height of installation. Epidemiology data shows incidents involving ceiling-installed heaters that overheated to the point of ignition. In one incident, sparking was observed, but the heater continued to operate until a fire resulted. There are many overheating conditions that do not involve draping the heater. Heaters should have protection against overheating regardless of their installation height.

6: Change Section 26, *Alarms*: All heaters with a thermal cut-off or a reset type temperature limiting control shall have an alarm to alert the user of its activation.

Rationale: Section 26.1 requires alarms only for automatically-resetting TLCs. All heaters should have alarms (audible or visual) in addition to manual-reset TLCs. Previous recommendations call for the use of manual-reset TLCs. The use of a manual-reset device should not allow the removal of alarms from the heater. The alarm is the first indication of a problem to the user. All heaters should be capable of alerting the consumer of an abnormal operating condition resulting in overheating.

7: All auxiliary control devices (thermostat or combination thermostat and control switch) shall have a position that disconnects all ungrounded conductors of the supply circuit, regardless of heating element type or markings on the control.

Rationale: Based upon information provided in the IDIs, consumers assume that the lowest position of the switch is synonymous with disconnecting electrical power from the heater. If cleaning or other maintenance is required, and the unit has not been fully de-energized, the user may be exposed to live parts, especially for heaters connected to 220 VAC. In this case, the single-pole thermostat disconnects only one of the two Hot power conductors from the heater. It remains possible for the user to contact the other Hot conductor. Evaluation of incident data indicates that users believe power has been removed from the heater if the control knob is at its lowest setting, regardless of the markings on the knob. Acting on that belief can expose users to a shock hazard. Also, heaters at their lowest setting (not disconnected from all ungrounded conductors) may unexpectedly activate in response to a low ambient temperature. Consumers expecting the heater to remain cold have placed combustibles near the “off” heaters. Subsequent activation resulted in a fire. Consumers should have assurance that heaters whose controls are turned fully down will stay de-energized.

WIRING

8: Add to Section 15: No normal or abnormal operation test shall result in conditions where the heater wiring reaches temperatures above the maximum rating for the wiring’s insulation.

Rationale: Degradation of the wiring insulation can lead to shock and fire hazards. Laboratory experimentation and field failures have demonstrated that even a short-term abnormal condition can result in arcing and the emission of glowing embers from a heater. Normal operation has been shown to result in temperatures exceeding the insulation’s maximum temperature rating. One heater exceeded the maximum temperatures every time the thermostat cycled (see also Proposal 9). Field samples had overheated wiring that led to arcing. If the insulation is kept below its maximum rated temperature, even under short-term abnormal operation, the consumer continues to be protected against shock and fire hazards.

9: Run the Dielectric Voltage-Withstand Test (Section 47) after the operational tests. Run the Overvoltage Test (Section 42.4) after the operational tests. Connect a fuse of a few amperes capacity through the ground conductor for each test to detect any short-term currents less than the level required to activate a circuit breaker.

Rationale: Abnormal operation may affect the electrical insulation properties, create short-circuit or leakage paths to ground, or change the total impedance of the heater. The Failure Modes & Effects Analysis results indicate that testing for one fault condition may reveal other faults. The stress of an abnormal test may weaken components other than those intended to be tested. Since short-term abnormal operation can be expected in installed heaters, the heater should be designed to withstand those conditions without developing consumer hazards.

10: Add to Section 32: Any surface intended for a ground connection shall be electrically conductive at the connection area. For example, the area around a hole through which a grounding screw is inserted shall be conductive. The threads of the screw shall not be the only source of grounding contact. All grounding connections shall be made by a positive means, for example, screws, clamps, etc. Tabs or wires in slots, incidental contact, flat surfaces pushed together, or similar means are not acceptable for grounding connections. Add that all grounding (or earthing) connections shall be compliant with UL 60335-1, *Safety of Household and Similar Electrical Appliances, Part 1: General Requirements*.

Rationale: Continuity to ground is essential to shock protection. Heaters should be designed with features that assure adequate grounding with a high degree of confidence and repeatability. Some heater designs rely on installers breaking insulating barriers with no instructions to assure compliance. Other designs showed unreliable grounding connections. One field sample had operated with the frame connected to the Hot conductor without activating the circuit breaker. The design of a heater's grounding scheme should be one that assures that every unit manufactured has a low-impedance connection to the branch wiring ground conductor.

LABELING & INSTRUCTIONS

11: Add to Section 60: Require that all warning labels be formatted in accordance with ANSI Standard Z535.4 for Product Safety Signs and Labels

Rationale: ANSI Z535.4 was developed for the following reasons: 1) to establish uniform and consistent visual layouts for labels across all categories of products 2) to minimize proliferation of label designs and 3) to achieve application of a national uniform system for recognition of potential personal injury hazards. To promote these objectives, all warning labels should adhere to these guidelines and principles to make safety information more recognizable and noticeable to consumers. Some warning labels incorporated a mixture of text that included clearance specifications, French translations, and other English text. Warning label research supports the stance that such safety messages are likely to be missed because of competing text. The warnings should be segregated from the rest of the text and should conform to ANSI Z535.4 guidelines to make the label conspicuous and recognizable.

12: Add to Section 60: A label as described in Section 60.29 shall not exempt a heater from any abnormal test (Section 42.7.2. and 42.10.1.1).

Rationale: Presently, if a label is on a heater with the words “Caution - source of possible ignition – high temperature – keep combustible material away from front heater” (sic), the heater model is exempted from a number of abnormal operating tests. However, the number of fires that continue to occur indicate that warning labels are not effective enough to protect users from the consequences of component failures. Three-fifths of the fire investigations included in Appendix B attributed the fires to combustibles stored too close to the heaters. Small rooms with heaters (such as in apartments) may render it impractical or impossible to clear 3 feet in front of a heater (Section 5). A heater should not be dependent upon consumers finding, reading, and strictly following label instructions all the time for safety. All heaters should be required to pass all the abnormal operating tests rather than being exempted from some tests by the presence of a label.

13: Add to Section 60: Require all labels to be heat resistant or located where they will not be subjected to excessive heat during periods of foreseeable abnormal operation. Require all labels to withstand all abnormal tests while remaining readable. Add to Section 60: "The marking shall, unless otherwise indicated, be permanently applied by means such as:

a) etched, molded, die-stamped, or paint-stenciled on the enclosure,
b) stamped or etched on metal, or
c) indelibly stamped lettering on pressure-sensitive labels secured by adhesive.

Pressure-sensitive label secured by adhesive shall comply with UL 969, *Standard for Marking and Labeling Systems*.

Rationale: Foreseeable use of a heater includes temporary periods of abnormal operation. When the abnormal condition is corrected, the heater is still usable and in use. Warnings are still valid and should be readable on the labels, especially for future users of the heater. UL 1278, *Movable and Wall- or Ceiling-Hung Electric Room Heaters* contains the language regarding the permanence of marking. Field incidents and laboratory testing resulted in unreadable warning labels after very short periods of operation at abnormal conditions (Section 6). If a user corrects a temporary abnormal condition the label may no longer exist to warn other users.

14: Add to Section 61: Require that instructions on the product that are directed toward the user be accessible and legible and able to be viewed without disassembling the product or removing the grill.

Rationale: Critical warning labels should be placed in proximity to the potential hazard and in plain view to the user. An analysis of an in-wall heater found that labeling on the face of the heat box did not provide adequate warning to users because it was concealed behind the heater grill (Appendix E). Removal of the grill exposes users to a potential hazard from live electrical components.

15: Expand *Instructions for Use and Care* (Section 61) to cover all heaters within the scope of the voluntary standards, not just cord-connected heaters.

Rationale: Installers and users of fixed-position heaters need instructions too. Section 61.1.1 states that the requirements for use and care instructions are for cord-connected and freestanding heaters only. Failure Modes & Effects Analysis (Section 8) and staff evaluation (Appendix E) show that maintenance is critical to safety. Manufacturers require periodic cleaning of heaters, but are not required to include instructions informing the user of the use and care needed by the product. Lack of maintenance, such as allowing excessive dust accumulation has been attributed to heater fires.

16: Add to Section 61: Require that the use and care guide provide cleaning instructions where applicable or else state that the heater does not need cleaning. Require that instructions provide, when applicable, reasonable cleaning procedures that don't require special tools or skills.

Rationale: Users need explicit instructions to maintain the product in a safe condition and manner. Users are less likely to comply with instructions that are time-consuming or troublesome. The use of special tools or special skills should not be required to clean a heater. Incident samples of in-wall heaters collected from the field show dirt and lint accumulation that may impact the fire hazard potential. CPSC staff discovered that maintenance instructions differ among brands of heaters. Some instruction sets included detailed cleaning instructions, while other sets had no references to cleaning. One set of cleaning instructions for an in-wall heater required the blow-out mode of a vacuum cleaner to dislodge debris from the heating elements. The instructions stated that a second vacuum cleaner would be useful to pick up the debris. It is not reasonable to expect users to clean heaters by blowing dust into a living space.

17: Require that if a heater is to be cleaned as part of a regular maintenance program, the product design should accommodate such cleaning without damaging the heater.

Rationale: Heater parts subjected to cleaning must be capable of withstanding normal cleaning procedures. Maintenance may foreseeably be performed by users, and should not expose them to potentially hazardous conditions, such as live electrical parts. Heaters should be designed so that the user is not likely to damage fragile components when performing the required cleaning. Fragile components should be protected. The cleaning instructions should properly instruct the consumer on how to clean the heater safely and effectively without damaging any components or leaving any electrical connectors loose.

18: Add to Section 61: Require separate, complete instructions for the installer and the user.

Rationale: Data from incidents involving in-wall heaters indicate that in-wall heaters are installed by both professionals, who are not the end users of the product, and consumers. Each of these two groups requires a different set of instructions tailored to the particular performance demands of their tasks. Installers need technical information and consumers need use and care instructions. The instructions relating to each of these different tasks should be located in the product documentation in such a way that the individual groups can readily recognize the sections pertaining to their specific needs. CPSC staff found that an explanation regarding the meaning of a hazard lamp on an in-wall heater was located in instructions geared to installers. The lamp signals an over-temperature condition that is a potential fire hazard. If consumers miss this information because it is embedded within technical installation instructions, the value of the hazard lamp as a signal alert for a potential hazard is nullified.

19: Add to Section 60: Require that installers and users be given specific information on how to respond to an alarm signaling an over-temperature condition. The responses should be plainly detailed in the use and care guide, and should be posted on the product near the alarm.

Rationale: Users must know how to react to an audible or visual alarm signaling overheating conditions. Explicit response instructions should be conspicuously posted on the front of the heater near the alarm, as the use and care manual will not always be available for reference. Staff evaluations of instructions for in-wall heaters found that some did not provide any reference to the function and significance of the alarm. Users were not alerted to what type of immediate corrective action was needed in the event the alarm illuminated. In another instance, users were sent a mixed message on how to react to the alarm signal (Appendix E).

TESTING

20: Include a Manufacturing Test to be performed during assembly on a sample basis to evaluate the electrical integrity of the mechanically assembled wiring connections. Such testing shall include:

- Connection Resistance, initial, and maximum increases during accelerated life testing of representative samples
- Manufacturing quality control systems
- Different ratings for power conductors and non-power conductors.

Rationale: Failed wiring connections have been attributed to many fire incidents. To reduce the frequency of poor quality in electrical connections, the variability associated with today's manufacturing processes must be reduced. Technical Studies performed under contract by the CPSC (Section 10 and Appendix H) indicate problems with wiring connectors exist, and can lead to overheating conditions. The Failure Modes & Effects Analysis studies show that manufacturing problems are not addressed by UL 2021 evaluation. Multiple field samples showed corroded and failed crimp connectors. Assurance is needed that units in manufacture are being assembled with good quality connections. Testing during assembly can be used to monitor the quality of the electrical connectors and reduce the variability of the connector manufacturing process. The assembly of every heater should assure a high probability of good internal electrical connections.

21: Include in the standard: Any polymeric material within 3 mm. of the live parts of a power connector shall have a minimum Glow-Wire Ignitability Temperature (GWIT) and Glow-Wire Flammability Temperature (GWFT) of 750 degrees C in accordance with IEC 60695-2-1/3 and IEC 60695-2-1/2 respectively, or comply with the Glow-Wire End-Product Test (GWEPT) as described in UL 746C.

Rationale: This is to minimize the effects of connector failures when they occur. There is an IEC-UL initiative to address the consequences of failed connectors and harmonize standards. This proposal has been approved for other products.

22: The sensitivity of a heater to dust collection and ignition should be evaluated through exposure testing.

Rationale: Heaters that collect and trap household dust over a period of time exhibit altered operating characteristics. This can lead to accelerated component failure or ignition of the dust and the emission of burning embers into the room. Examination of various designs found that some were intrinsically prone to accumulating and igniting dust. Laboratory experiments have shown that a significant change in performance is observable after a very short exposure time to dusty air (Section 7). Therefore, it is possible to determine through evaluation and testing on new units, the propensity to collect dust and create a potential fire hazard.

23: Add to Section 42: The insulation requirements in Section 39.4 are to be used for all abnormal tests on heaters that are permitted by the manufacturer to be installed in insulated walls.

Rationale: Heaters in insulated installations need to be considered in the abnormal tests. Abnormal conditions with insulated boxes may result in wire insulation degradation or other undesirable conditions inside the heater. Laboratory testing showed that some wall cans get hot enough during abnormal operating conditions to have the potential to affect the branch circuit wiring insulation (Section 7). Short-term abnormal operation may degrade the branch wiring insulation to the point of creating a shock or fire hazard. Heater designs need to prevent overheating of branch wiring during short periods of abnormal operation.

24: In Section 42.10, substitute another suitable, readily available material for the cattle-hair felt.

Rationale: The test cannot be run to specification if the materials are unavailable. Communication with UL has found no source for materials called out by the test. The unavailability of the required materials hinders the relevancy and repeatability of the test. Also, since consumer products are no longer manufactured with cattle-hair felt, the applicability of the test is in question.

25: In Section 42 (Abnormal Operation Tests), examine the heater for impending failure modes, such as melting wiring insulation, reduction of the spacing between components, etc., after completion of the test. For all tests, run the tests for their full duration to see if secondary effects appear. Interpret Section 15 (Internal Wiring) as applying to normal and abnormal operating conditions.

Rationale: Test durations of 7 or 8 hours do not fully approximate the foreseeable lifetime use conditions of a heater. As approximations of events that can occur during years of use, the abnormal tests may not result in a "failure result" during their hours-long operation. However, there may be evidence of incipient failures that can occur in the field if normal or abnormal use were continued. Internal examination of the heater after the limited duration abnormal test may reveal evidence of potential failures. Testing on heaters shows failure modes that will take longer than 7 hours to create a "failure result." For these modes, the heater that may develop a consumer hazard over a long period of time passes its tests. Epidemiological data (Section 5) indicates that heaters are in use for many years. The Failure Modes & Effects Analysis supports the inference that short-term testing on a limited number of samples (one sample) cannot demonstrate all the failure modes. Since the evaluation uses approximations of actual long-term conditions, and is conducted on a limited number of samples, the interior of the tested samples should be examined for problems that could develop over a longer time.

OTHER PROPOSALS:

26: Radiant heaters shall have a maximum flux of 0.5 W/mm^2 or less at a distance of six inches from any point on the heater.

Rationale: Flux values higher than 0.5 W/mm^2 have an increased chance of igniting combustibles. Measurements and laboratory testing have shown that higher radiant heat fluxes quickly lead to ignition of common household materials during draping tests (Section 7). High radiant fluxes have the potential to raise the temperature of a nearby material to its ignition point. Lowering the radiant flux reduces the net power transfer per unit area and lowers the probability of ignition. Heater designs that disperse the radiant energy are capable of transferring the same amount of energy into the room without overheating nearby materials.

27: Include the requirements of *Protection Against Personal Injury* (Section 54.1) to all heater designs. Currently, the requirements are for cord-connected heaters only.

Rationale: If the front grill of a heater contacts a heating element, an electrical or thermally conductive path could be established through the grill. The Failure Modes & Effects Analysis (Section 8) predicts that physical impact on a sheathed heating element can result in a shock or overheating hazard if the conductor wire in the element establishes a path to ground. Sheathed heating element construction is susceptible to failures caused by bending. If an impact disrupts the sheath, or leads to contact with an open-wire heating element, a shock or burn hazard could result.

28: Section 13.6.2 states that the lens of an alarm shall be visible 10 feet in front of the heater and 5 feet up. This is measurable and repeatable, but not very applicable to real life. Heaters are rarely installed 3 feet above the floor. Replace the single-position test with the following: When a heater is installed at its minimum height, the pilot light should be visible at an angle +/- X° from the perpendicular of the heater front and between Y1 and Y2 heights at a distance of 10 feet.

Rationale: Many warning lights are obscured by the grill in front of them. Users must be able to notice the lights and take corrective action. Evaluation by ES and Human Factors (Appendix E) staff found hazard lamps obscured by the grill to the point of invisibility. Epidemiology studies indicate that users never reported a hazard lamp indication as a warning sign of an impending failure. The warning lamp does no good if it is not seen. The hazard warning should be plainly visible from many orientations.

Errata:

Table 31.1 “6/4 mm” should be “6.4 mm.”

32.2 a) “... (see 12.1.25 and 12.1.28), ...” These should be 13.1.25 and 13.1.28.
There is no Table 32.2, use Table 31.2.

33.3.4 “pin” should be “pins.”

Figure 36.1, page 60 A. is “280” supposed to be either 208 or 220?

42.10.1.2 “... moved horizontally one half inch from its initial position ...”
should say “...inch from its initial position **away** from the heater...”

42.10.1.3 “sufficiently” should be “sufficient.”

44 Stalled fan tests: Section 44.1 references exception 3 of 24.2.3. There is no Section 24.2.3. Which section is the correct one?

60.9 Text conflicts with Section 60.7.

60.27 Exception No. 3 calls for requirements in sections 41.10.1 – 41.10.2. There are no such sections in this specification.

Table 7.1 Typographical error, “5.64 inches” should be “5

Section 25.1 Exception, a) refers to the Abnormal Ambient Test, Sections 42.5.2 – 42.13.3.1. Section 42.5.2. through Section 42.12.3 refer to Abnormal Operation Tests, The Abnormal Ambient Test starts with Section 42.13
Change the test name or section numbers for consistency between them.

Section 29.15 “...metal-clad element is a grounded...” should be “... metal-clad element **in** a grounded...”

14. CONCLUSIONS

Fixed-position electric heaters are high energy, high temperature devices that can cause fires when they fail. Millions of these heaters are in service every winter across the nation. Each year, this product group is responsible for thousands of fires and tens of millions of dollars of property damage. The U.S. CPSC staff evaluated fixed-position electric heaters and the applicable voluntary standards to improve the safety of the heater and reduce hazards faced by users.

The voluntary standards created by Underwriters Laboratories, Inc. for fixed-position electric heaters UL 1042 and UL 2021, were last updated in 1994 and 1997, respectively. For the most part, these standards depend upon two factors to determine whether a unit under evaluation meets the standard for safety. First, if the model heater has a label warning consumers to keep combustibles away, the unit is exempted from several performance tests. Second, if the unit does not emit flame, glowing embers, or molten metal during a 7 to 8 hour test period, the heater is considered safe. These criteria are not sufficient to protect consumers.

The usefulness of labels to render a product safe when in use has limited effectiveness. Even if users notice the label and understand its warnings, being able to keep all combustibles, including the carpeting on the floor, three feet from the heater may be impractical or impossible. The installation instructions often state that the heater may be installed less than one foot above a carpeted floor, contradicting the warning label.

Short-duration testing of single units also has limited utility. The performance tests of UL 1042 and UL 2021 are at best approximations of some of the conditions that the products can be expected to be exposed to over their service life. As approximations, a simple pass-fail criterion is not sufficient for products that will be continuously in use every heating season for decades. Examining the tested units to determine whether a failure would have occurred had the test continued has a better chance of uncovering problems.

One exception clause in UL 2021 allows the use of an automatically-resetting temperature limiting control (TLC) in virtually every model heater. When the TLC in a heater activates, that heater is in an unsafe operating condition. The application of automatically-resetting TLCs allows the heater to remain in that unsafe operating condition indefinitely, possibly until a more serious failure occurs. Manually-resetting TLCs in heaters would encourage the user to pay attention to how the heater is functioning and to correct the abnormal conditions (by removing an obstruction that blocks the airflow, for example).

Probably the weakest component in a heater covered by UL 1042 and UL 2021 is the plastic wiring insulation. Most other parts are made of tough metal. Yet the interpretation of the voluntary standards allows designs of heaters that overheat the insulation under normal operating conditions. Abnormal operation makes things worse. Improvements should be made to protect against failure do to insulation degradation.

One of the factors the voluntary standards fail to address in electric heater production is real-life manufacturing variability. The evaluation of a product does not include any assessment of whether mass production is likely to result in units essentially the same as the evaluation unit in its critical features. For example, grounding and crimp connection repeatability are not considered in UL evaluation.

The review of the human interface of fixed-position electric heaters also revealed several shortcomings. Some instructions and warnings were contradictory with other instructions. One heater instruction manual stated that there were no user-serviceable parts inside and later stated that the cover was to be removed for cleaning. One manufacturer suggested operating a vacuum cleaner on reverse to blow any accumulated dust and lint into the room for subsequent cleaning. Consumers are unlikely to follow that cleaning method.

The opportunities for improving the safety of fixed-position electric heaters are also supported by the economics of societal loss. For wall heaters, the losses associated with fires exceed the cost of the heaters. For baseboard heaters, the losses are two-thirds of the heaters' cost. In terms of dollars, society would benefit greatly from an increase in the safety of these devices. For a modest investment in safety, a large net gain can be realized by reducing the fire incidents associated with fixed-position electric heaters.

Over thirty separate recommendations for changes to UL 1042 and UL 2021 resulted from this project. The application of these recommendations should positively impact the number deaths, injuries, and property loss attributed to these products.

Appendix A: Directorate for Economic Analysis

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: June 21, 2002

TO : Randy S. Butturini, ES
Project Mgr, Fixed Space Heaters

THROUGH: Warren J. Prunella, AED, EC

FROM : Terrance R. Karels, EC

SUBJECT : Fixed Position Electric Space Heaters

This memorandum provides some information on the market for fixed position electric space heaters. The information was developed through contacts with industry sources, information from Internet postings, and a 1997 study conducted by the Building Services Research and Information Association (BSRIA) of the United Kingdom.

Fixed position electric space heaters have been in widespread use for over 50 years. The first units were radiant heaters (using a heating coil and reflector), which heat objects through infrared energy. Conductor units, incorporating a fan to force more air through the units, were introduced in the late 1960s. Conductor heaters heat an intermediary, such as liquid or the air itself, and the intermediary carries the heat to the objects.

Types

There is a variety of fixed position electric space heaters available in the marketplace. The two most common are baseboard units (which are low profile heaters installed near the baseboard of the room), and wall units (which are recessed into the wall). Toe (or “kick space”) heaters are commonly installed under the bottom cabinets in the kitchen. Drop-in floor heaters are designed to be recessed into the floor.

Fixed position space heaters are used in multi-family settings, such as apartments and condominiums, as well as in single family structures; they also are used in cabins where only occasional heating is necessary. Since the 1950s, these heaters have been marketed primarily for residential use, but some office and institutional units also use fixed position space heaters.

These heaters are generally installed in new construction, or are added during renovation of existing structures. They are also sometimes installed in areas of the homes that previously had not been used as primary living space (such as lofts or basements). The units are most often professionally installed (by electricians) rather than by consumers themselves. According to industry sources, the average installation is 5 to 6 heaters per structure.

According to industry sources, fixed position electric space heaters represent an attractive alternative to whole-house heating systems because the units themselves are less expensive, and the labor cost associated with installation is substantially less than the cost of installing a ducted whole-house furnace. Florida Power, an electricity provider, reported that space heaters can sometimes result in overall energy savings in the home since heat is only used in areas as needed.

Fixed position electric space heaters are available in a number of power outputs. Baseboard heaters are available from 200 watts to 2,500 watts; the largest selling baseboard heater size is 1,000 watts. Baseboard units are available in lengths of 2 feet to 8 feet. Because of typical household room dimensions, the 4-foot size is described as the most suitable for household applications.

Wall heaters for residential use typically range from 500 watts to 2,500 watts, with the most popular units at 1,500 watts. Some wall units (those most likely destined for institutional applications) are available with as much as 5,000 watts output The heaters may be of 120 volt or 240 volt power; the higher voltage allows for a lower amperage drain for household electrical circuits and allows more products to be on the same circuit.

Prices

The heaters typically are sold to wholesalers who in turn sell them to electrical contractors and installers. However, some fixed position electric space heaters are also sold through home do-it-yourself centers and are available for consumers to install themselves. The average manufacturer price of a baseboard unit is $25; the wall units sell for about $50. Industry sources reported that wholesaler/distributors typically mark up the product by about 30% over their cost; electrical contractor/installers typically add 15% to their purchase costs. The final cost to consumer would also include installation costs, which can easily exceed the cost of the heaters themselves.

Sales and Use

Precise sales data for fixed position electric space heaters are not available through trade sources. While **Appliance (**a trade publication that tracks sales of a wide variety of home heating systems) reports sales of portable electric heaters, it does not gather sales statistics on fixed units. However, industry sources indicate that sales of these units have been stable since the late 1980s, at about 2.5 million units per year. (From 1985 through 1987, sales were estimated at 3 million as a result of a boom in home renovations. Annual sales were at an estimated 2.5 million prior to 1985.) Industry sources project that sales may decline slightly in the future, in response to competition from gas space heaters and gas fireplaces. Baseboard heaters account for about 80% of installed heaters, while wall units account for about 10% of sales. The toe space and drop-in floor heaters essentially account for the remainder of sales.

Appliance reported the industry's estimate of the expected useful life of portable electric heaters at 6 years, but provided no estimate of the expected useful life of installed heaters. BSRIA used 6 years as a surrogate for the expected useful life for installed space heaters in its market study. However, industry sources estimate that fixed position space heaters have an expected average useful life of 10 years; this estimate is based on the expected useful life of the components. Based on the sales information provided and the 10-year manufacturers' life estimate, it appears that there may be some 25 million units available for use. Since the average number per household is 5 to 6, we expect that there are perhaps 5 million residences in the US with these heaters as their home heating sources. Fixed position electric heaters are most commonly sold in regions of the US with lower space heating needs, due to the relatively high cost of electricity. Thus, sales and use of these products is likely to be concentrated in the Southern and Western states.

Manufacturers

The 4 major manufacturers of fixed position electric space heaters reportedly account for about 90% of all the units sold in the US. These companies also produce portable units, based on designs similar to installed units; these portable units are more expensive than fixed heaters because the portable units require finished panels on all sides, pedestals instead of wall mounts, and other features not required for fixed applications. Manufacturers of these products typically purchase the component parts of the heaters, fabricate the steel housing, and assemble the finished product. While some component parts may be imported, there are no known imports of finished fixed position electric space heaters.

There is no trade association representing fixed position electric space heaters. However, member firms (and staff) do belong to technical groups such as the American Society of Heating and Air Conditioning Engineers or trade groups, like the National Electrical Products Distributors Association.

Societal Costs of Fixed Space Heaters

The Directorate for Epidemiology reported that in 1998 there were 1,800 fires, resulting in 10 deaths, 110 injuries, and $19.3 million in property damage associated with fixed space heaters. The 1998 report is the latest available data on fire losses.

The average cost of fire-related injury has been estimated by the Injury Cost Model at about $50,000 (including inhalation and burn injury) per occurrence. Using $5 million as the statistical value per life saved, and the reported value of property losses, fixed space heaters resulted in societal costs of about $75 million in 1998. We previously estimated the number of these products in use at 25 million units. Thus, the societal cost of fixed heater fires was $3 per unit in use in that year. If we assume that the extent of fire damage and the numbers in use would be constant over the product's 10-year average useful life, the societal cost posed by fixed heaters would be about $26 per unit over their useful life (using a 3% discount rate).

Fixed baseboard heaters are reported to account for 80% of the number of units in use, and accounted for 50% of fires. If 50% of the societal costs ($37.5 million) were assigned to the number of baseboard heaters in use (20 million), these products would each accrue an average of about $2 in social costs per year, or about $16.50 over their useful life (discounted at 3%).

Non-baseboard heaters account for 20% of the number of units in use (5 million), yet also account for 50% of reported fires (or $37.5 million in societal costs). Non-baseboard heaters would accrue an average of about $7.50 in societal costs per unit per year, or about $65.50 over its 10 year useful life.

We preliminarily estimate that the societal costs associated with these fixed heater fires could average as much as $16.50 per baseboard heater over its useful life, and $65.50 per non-baseboard heater over its useful life. Thus, if a safety fix could prevent all baseboard heater fires, it could cost as much as $16.50 per unit and still be cost-effective. Similarly, if a safety fix could prevent all non-baseboard-type fixed heater fires, it could cost as much as $65.50 per unit and remain cost-effective.

Appendix B: Directorate for Epidemiology

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: July 5, 2001

TO : Randy Butturini
Project Engineer, Fixed-Position Electric Heaters
Division of Electrical Engineering, Directorate for Engineering Sciences

THROUGH: Susan W. Ahmed, Ph.D.
Associate Exective Director
Directorate for Epidemiology

Russell H. Roegner, Ph.D.
Division Director, Division of Hazard Analysis
Directorate for Epidemiology

FROM : Jean Mah
Division of Hazard Analysis, Directorate for Epidemiology

SUBJECT : Results and Analysis of Data Collection for Fixed-Position Electric Heaters

Fixed-position electric heater in-depth investigations (IDIs) were assigned from October 1999 through May 2001 using the *Appendix 120 – Fixed-Position Electric Heaters* guideline and data record sheet. The data collection period spanned almost two complete heating seasons with the goal of capturing a broad range of incident scenarios. IDIs were assigned from reports found in the Injury or Potential Injury Incident (IPII) file. The IPII file contains information from newsclips; internet and hotline complaints from consumers, attorneys, fire departments, and insurance investigators; Medical Examiner's reports and other sources. Although IPII, and therefore the set of corresponding IDIs, does not constitute a statistical sample, every effort was made to investigate each fixed heater fire or other failure reported to CPSC during the data collection period. As a result, the data collected constitute an anecdotal but inclusive range of problems and concerns that consumers had with these products. Forty-eight of the IDIs included in this analysis were assigned by the Office of Compliance (EXC). Although the assignments were made during the data collection period, a few were based on incidents that occurred prior to 1999.

IPII reports sometimes described heaters as in-wall, wall-mounted, or baseboard, but many times a heater was described only as an electric heater or a space heater. IDIs that turned out not to involve fixed-position electric heaters within the scope of this project account for the *Completed - Product Out-of-Scope* rate of 28 percent. Virtually all of these IDIs actually involved portable electric heaters or gas-fired heating units.

Since the project was concerned with heater fires and heater failures that posed a fire hazard, some IDIs that involved in-scope heaters were coded out-of-scope based on their incident scenarios. The *Completed - Scenario Out-of-Scope* rate of 5 percent represents IDIs where fixed heaters were operated under extreme, unforeseeable conditions, such as with a pen stuck into the fan or with the faceplate removed. IDIs were also placed into this category if a fixed heater failure was unlikely to pose a fire hazard or if the heater's suspected involvement in a fire could not be adequately confirmed.

Sixteen percent of assignments made were terminated, purged or screened prior to completion. Twenty-one IDIs were terminated when consumers or alternate information sources could not be located or refused to participate. Twelve IDIs were purged as duplicate assignments, and one IDI was screened when arson was found to be the cause of fire.

Data collection outreach efforts were conducted with the assistance of the Office of Field Operations and various field staff. An informational article was placed in the field feedback memo compiled by EPDS and a conference call was held between the project engineer and field supervisors to introduce the project. An appeal to fire fighters and insurance investigators to provide fixed heater incidents and samples was submitted to the International Association of Arson Investigators (IAAI) monthly publication. The field staff also circulated this request to regional and local fire community publications. Both headquarters and field staff attended regional IAAI meetings to advertise our data collection efforts. These combined efforts, along with cooperation from EXC, resulted in the collection of incident heater samples from 23 (21%) of the 108 in-scope IDIs. Table 1 below presents the results of the Fixed-Position Electric Heater data collection. Subsequent discussions of the data are limited to only the in-scope IDIs.

Table 1: Data Collection Results, 1999 – 2000 Heating Seasons

Status	**Investigations**
Completed and In-Scope	108
Completed - Scenario Out-of-Scope	10
Completed - Product Out-of-Scope	60
Terminated, Purged or Screened	34
Total Assigned	**212**

In-Scope Investigations

Prior to this data collection, it was hypothesized that fixed heaters were most likely to be used in parts of the U.S. where winters were generally mild and electricity relatively inexpensive. This hypothesis was supported by the distribution of IDIs among the regions. Most western IDIs took place in the Pacific northwest, while most eastern IDIs took place in the southeastern states.

Table 2: Investigations by Region	
Region	**Investigations**
Western	66
Central	10
Eastern	32
Total	**108**

Sixty-one percent of in-scope IDIs took place in the western states, with 46 percent occurring in Oregon and Washington states alone. Thirty percent of IDIs occurred in the eastern states, with only nine percent originating in the central region. (See the *Appendix* for state-to-region mappings.)

Tables 3 and 4 respectively show the distributions of the IDIs based on the room where the fixed heaters were installed and the type of consumer using the heaters.

Table 3: Room Location of Heater	
Room	**Investigations**
Living Area	41
Bedroom	28
Bathroom	23
Storage Area	8
Unknown	8
Total	**108**

Table 4: Consumer Type	
Type	**Investigations**
Tenant Only	56
Owner – Original	28
Owner – Not Original	13
Unknown	11
Total	**108**

Over one-third of the incidents occurred in living areas of the home, which include living and dining rooms, kitchens, hallways and finished basements not primarily used for storage. Fixed heaters were also found in bedrooms and bathrooms, which are smaller, allowing for less space between walls and furniture. Investigations occasionally involved heaters in rooms primarily used for storage. Such heaters typically were turned off or turned to their minimum settings and were inactive for long periods of time between uses. In eight percent of the IDIs, the room location of the heater could not be determined. In a majority of the IDIs, fixed heaters provided the sole source of heat for the room in which they were installed.

Consumer users of fixed heaters were tenants who rented their residences in 52 percent of the IDIs. A similar percentage of investigations took place in multiple-family dwellings, as opposed to single-family detached homes. Interviews with tenant consumers revealed that they rarely possessed the heater instruction manual or performed cleaning and maintenance on the heaters. Twenty-six percent of the IDIs involved consumers who owned their residences at the time the heaters were installed, while twelve percent of the IDIs involved consumers who were not the residence owners at the time the heaters were installed. In ten percent of the IDIs, the type of consumer was not known.

Given the percentage of consumers who were either tenants or not original owners, it is not surprising that in half of the investigations the respondent(s) did not know who installed the heater. Another factor was that officials were the only respondents available in many of the IDIs, and they rarely possessed this information. When this information was known, the installer was more often identified as a professional electrician, building contractor or maintenance worker than as the consumer him or herself.

The age of the heater was also difficult to obtain given the types of consumers and respondents involved in the IDIs. In 31 percent of the IDIs, the heater age was unknown. As Table 5 illustrates, of IDIs where heater age was known, 53 percent involved heaters installed for ten years or less. Twenty-seven percent involved heaters installed for just one year or less.

Table 5: Ages and Cleaning of Heaters

Age Range	**Investigated Heaters**	**Heating Element Cleaned**		
		Yes	**No**	**Unknown**
0 – 1 year	20	1	12	7
2 – 10 years	20	8	7	5
11 – 20 years	17	2	7	8
21 – 40 years	18	2	10	6
Unknown	33	3	3	27
Total	**108**	**16**	**39**	**53**

The cleaning histories of the heaters proved even more difficult to obtain. In virtually half of the IDIs, the respondent(s) could not provide information about whether the heating element had ever been cleaned, either by the consumer or by a professional. In one IDI, the consumer claimed that it was impossible to remove the front grill of the heater, and therefore, to clean the heating element.[1]

For the purposes of this analysis, investigations were divided into fire and non-fire-related IDIs. Fire-related IDIs were further divided according to whether the fire was attributed to combustibles being stored too close to the heater or to an internal failure of the heater. Non-fire-related IDIs occurred when the heaters failed in ways that posed a fire hazard, but the failures did not lead to flames or sparks being emitted from the heater. Table 6 presents the number of IDIs, deaths and injuries associated with each scenario type.

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[1] 000810CCC0948

Table 6: Investigations by Scenario Type			
Scenario Type	**Investigations**	**Deaths**	**Injuries**
Fire	81	5	11
Combustibles Too Close	49	5	11
Internal Failure	29	0	0
Unknown	3	0	0
Non-fire	27	0	0
Total	**108**	**5**	**11**

Fire-related IDIs were identified as those where at least one of the following events was documented in the investigation:

- Flames, either confined to the heater or spread via combustibles
- Involvement of fire department
- Activation of smoke alarm
- Sparks emitted from heater

Internal failures that resulted in fires included the following:

- ruptured or melted heating elements
- damaged thermal limiting devices
- degraded wire insulation
- loose or broken electrical connections
- stalled or overheated fans

In four of the internal failure fires, dust build-up inside the heater was mentioned as a contributing factor to the above conditions.[2] Internal failures identified in the non-fire IDIs were the same as those identified in the fire investigations.

Of the 81 fire IDIs, 15 reported no property damage beyond the heater itself. In 54 fire IDIs, estimated property damages ranged from $50 to $375,000, with a median of $20,000. For the remaining 12 fire IDIs, no property damage estimates were available. In 36 percent of the fire IDIs, an internal failure was observed at the time of the incident or subsequently discovered from an examination of the heater. Sixty percent of fire investigations attributed the fires to combustibles stored too close to the heaters; that is, no internal failures in the heaters were immediately observed during the incident, or subsequently identified. All deaths and injuries identified in the IDIs occurred in fires that involved the latter scenario. The types of combustibles documented in these IDIs are listed in Table 7.

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[2] 000207HCC3143, 001005CCC2020, 000316HWE5012, 000726HWE6027

Table 7: Fires Caused by Combustibles Too Close	
Combustible	**Investigations**
Towel or bathrobe	9
Clothing	8
Mattress (futon or traditional mattress)	8
Multiple Materials	8
Upholstered furniture (sofa, vinyl pillow)	5
Bedding (sheets, blankets)	5
Other Materials	6
Total	**49**

Multiple Materials included combinations of the following: mattress, bedding, clothing, paper, plastic bags, rug, bamboo hamper, wicker basket and sewing fabric. *Other Materials* included a cabinet, carpet, curtains, firewood, paper and toilet paper, respectively.

It should be noted that heaters involved in fire IDIs were rarely examined internally. One reason was that the heaters were so consumed by the fires that attempted examination would have been fruitless. Also, several investigation reports mention that the insurance company chose not to examine the heater because the storage of combustibles too close to it was considered an act of consumer negligence. Fire officials generally shared this opinion, and often cited “properly operating electrical equipment” as the form of heat for the fire, but attributed the cause of ignition to “combustibles too close to heat source”.

Table 8 shows the different ways in which consumers were first alerted to fire and non-fire incidents. The first two columns pertain to the fire IDIs, attributed to combustibles too close and internal failures, respectively, while the third column pertains to non-fire internal failures.

Table 8: How Consumers Were First Alerted to Incidents			
	Fire		**Non-Fire**
How Alerted	**Combustibles**	**Internal**	
Not At Home When Fire Started	18	4	N/A
Saw Flames / Smoke From Fire	9	0	N/A
Heard Smoke Alarm	8	2	N/A
Smelled Smoke / Burning Odor	5	6	8
Saw Flames / Smoke / Sparks At Heater	0	9	0
Heard Noise From Heater	0	6	8
Noticed Abnormal Heater Operation	0	0	8
Noticed Damage to Surroundings	0	1	2
Other	1	0	0
Unknown	8	1	1
Total	**49**	**29**	**27**

Unlike consumers involved in fire IDIs who saw flames or smoke only after combustibles outside the heater had ignited, consumers in internal failure fire investigations often saw these visual warnings inside the heater in time to take corrective measures. Consumers in such internal failure investigations also tended to hear audible warnings from the heater, such as a popping or banging noise, which immediately called their attention to the product. In almost all such investigations, the noise preceded the emission of flames or sparks from the heater. Abnormal heater operations observed by consumers included excessive heat output, no heat output, rapid cycling of the thermostat and problems with heater controls. Types of damage in the home caused by heaters included soot residue around the heater and charred floor coverings below the heater.

In fourteen of the IDIs (all fire-related except for one), consumers mistakenly thought that the fixed heaters were turned off or disconnected from their power source at the time of the incident. Although it was unknown whether the heater had a positive "off" setting in a substantial percentage of the IDIs (38%), in more than half of the known cases, the heaters did not have positive "off" setting. Four such IDIs recorded scenarios where consumers turned heaters with no positive "off" setting to their minimum settings and thought this was equivalent to turning the heaters completely off.[3] Three of these incidents resulted in fires when the ambient temperatures in the rooms dropped, the heaters activated and nearby combustibles were ignited. If consumers detected a problem with a heater, their first impulse was usually to turn the heater off or to its lowest setting. When heaters did not have a positive "off" setting, consumers had to trip the circuit breaker in order to totally disconnect power from the heater.

In four fire IDIs, the heaters had been previously disconnected at their circuit breakers, but the circuit breakers were then inadvertently re-connected, by either

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[3] 000105HWE5008, 000106HWE5011, 000623HCC3289, 000731CCC3363

maintenance people or the consumers themselves.[4] Six IDIs involved scenarios where the fixed heaters had positive “off” positions and were normally turned off because the consumers did not use them. In each IDI, the on/off switch was accidentally turned to “on”, sometimes by the consumers moving furniture or other combustibles up against the heater.[5] One trait shared by heaters in the above IDIs is that they were not activated for extended periods of time. It follows that these heaters were also not cleaned for extended periods of time. Incidents occurred when the heaters were first activated following these periods of inactivity. These scenarios raise questions as to how inactivity and lack of cleaning might have impacted the heaters and their potential for involvement in fires.

Table 9 shows the number of in-scope IDIs completed for each type of fixed-position electric heater. It should be noted that concurrent EXC activities involving some manufacturers of fixed-position electric heaters accounted for 31 of the 108 in-scope IDIs. Specifically, 25 of the fan-forced heater IDIs were assigned by EXC, 22 of which involved the same manufacturer.

Table 9: Investigations by Scenario and Heater Type

Scenario Type	**Baseboard**	**Fan-Forced**	**Radiant**	**Unknown**
Fire	37	21	17	6
Combustibles Too Close	28	3	15	3
Internal Failure	9	17	2	1
Unknown	0	1	0	2
Non-fire	3	24	0	0
Total	**40**	**45**	**17**	**6**

Except in the case of fan-forced heaters, IDIs involved fire scenarios much more often than they involved non-fire scenarios. Except for fan-forced heaters, fire scenarios were more often blamed on combustibles stored too close to the heaters than on internal failures. All IDIs involving radiant and unknown type heaters depicted fire scenarios. The following sections address in more detail the IDI information collected for each type of fixed heater.

Baseboard Heaters

Baseboard heaters generate heat with finned elements that have a large surface area. They circulate the heat into a room by natural convection and, therefore, have no fan or blower. Baseboard heaters documented in the IDIs were between 3 and 12 feet long. Because of the length of wall space they typically spanned, as well as their proximity to the floor, consumers often placed beds and furniture up against them. Fifty-

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[4] 000414HCC0573, 000329HCC0525, 001204HCC0132, 000301HCC0449

[5] 000329HCC0524, 000615HCC3277, 000707HCC3309, 000807HCC3370, 000906HCC0007, 001204HCC0134

eight percent of baseboard IDIs were performed in the western region, with 33 percent performed in the eastern region. Only ten percent were performed in the central region. Baseboard heaters were most commonly found in bedrooms (48%) and living areas (43%). Tenants who rented their residences were the most common type of consumer involved in the baseboard heater IDIs. Table 10 indicates the types of scenarios, as well as any deaths and injuries, associated with the baseboard heater IDIs.

Table 10: Baseboard Heater Investigations by Scenario Type

Scenario Type	**Investigations**	**Deaths**	**Injuries**
Fire	37	2	3
Combustibles Too Close	28	2	3
Internal Failure	9	0	0
Unknown	0	0	0
Non-fire	3	0	0
Total	**40**	**2**	**3**

Ninety-three percent of baseboard IDIs were fire-related. Seventy-six percent of the fires were blamed on the heaters and combustibles being too close to one another, allowing transmitted heat to ignite these nearby items. A single fire was responsible for two fatalities, while two fires resulted in a total of three injuries.

The two fatalities occurred on April 27, 2000, in Nashville, TN. A fire began when a baseboard heater in a couple's bedroom activated during the night and ignited a wicker basket containing sewing fabric. Both the 83 year-old male and 81 year-old female died in the fire while attempting to escape. There were no surviving witnesses to the incident, but the fire reportedly began a little after 3 a.m. while the couple presumably slept. The couple's escape was hampered by a double-keyed deadbolt-lock on the front door that required a key from the inside. The home was equipped with a smoke alarm that activated during the incident. There was no record of the heater being examined after the fire, so it is unknown whether any internal problems existed. The ignition factor listed on the fire incident report was "Heat source too close to combustibles." It is unknown whether the heater complied with the voluntary standard.[6]

Two injuries occurred on December 12, 1995, in Cramerton, NC when a fire began in a living room baseboard heater. The heater was located below a set of low-hanging curtains. A 47 year-old male and a 4 year-old male both suffered 2nd and 3rd degree burns while trying to escape the fire. Property damage was estimated at $35,000. A county fire investigation report cited the probable cause of the fire as the ignition of curtains hanging too close to the heater. This report also states that a "V"-shaped charring pattern was observed on the "east wall next to a baseboard heater". This seems

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[6] 001204HCC0133

to indicate that ignition occurred on one end of the baseboard heater instead of at the center. The age of the heater was unknown, but it did have both UL and NEMA markings on it. The fire department response to the incident was hampered when they were initially given the wrong address of the residence. The home was not equipped with smoke alarms.[7]

A 60 year-old male was injured after he unsuccessfully tried to extinguish a fire in his Roxbury, CT home on February 20, 2000. According to the local fire marshal, a fire began in the living room where a baseboard heater ignited firewood that was stored next to it. The owner of the home sustained 2nd degree burns on his back as he tried to escape the fire. Property damage was estimated at $80,000. The fire marshal believes that heat from the baseboard heater gradually dried out the firewood and heated it to the ignition point. Fire investigators also noted dried out wood paneling on the wall where the heater was installed. The age of the heater and whether it complied with the voluntary standard were unknown. The fire department response to the incident was hampered by fire burning through the telephone wires and cutting off the 911 call for help. The home was equipped with a smoke alarm, but it is unknown whether it activated during the incident.[8]

One IDI involved a baseboard heater installed in a hotel room,[9] while all other baseboard heaters were installed in residences. The average age of baseboard heaters when the age was known was 18 years old. Because these heaters are considered to require low maintenance and have no moving parts, they tend to remain installed for relatively long periods of time. Many baseboard heaters outlived the tenancy of the original homeowners, making age information difficult to obtain.

Table 11: Ages of Baseboard Heaters

AgeRange	**Investigated Heaters**
0 – 1 year	3
2 – 10 years	4
11 – 20 years	9
21 – 40 years	7
Unknown	17
Total	**40**

Sixty percent of baseboard heaters had an unknown cleaning history. Thirty percent of baseboard heaters had never had the heating elements cleaned to the knowledge of the consumers, while ten percent had been cleaned at least once. Since it was not obvious that the cover could or should be removed, many consumers figured that

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[7] 000413HCC0561
[8] 000427HCC0607
[9] 000426HCC0596

there was no way to clean the heating element. One consumer regularly vacuumed the floor closely surrounding the heater and assumed this was adequate.

In almost half (45%) of the baseboard heater IDIs, it was unknown whether the heater controls had a positive "off" position as part of, or in addition to, the temperature controls. Among the 22 IDIs where respondents provided this information, 17 IDIs (77%) indicated that no positive "off" position could be identified as part of the controls.

Although consumers are sometimes warned not to place items within three feet of fixed heaters, due to the length of baseboard heaters, this is often inconvenient if not impractical advice for consumers to follow. This is especially true when baseboard heaters are installed in rooms used for storage purposes or in apartments where space tends to be limited. In one IDI, the consumer's bed was against the heater, and a blanket had fallen onto it. The subsequent fire was traced to the heater igniting the blanket while the consumer was out-of-town. While the baseboard heater involved in the fire was destroyed, an identical heater in the same apartment complex was seen by the CPSC investigator. Once the heater's cover was removed, a warning label could be seen, which read: "CAUTION: HEATER SHOULD NOT BE BLOCKED OR COVERED IN ANY MANNER."[10] In another IDI, a landlord had posted a sign above the baseboard heater's remote thermostat, that read: "PLEASE: DO NOT PUT FURNITURE, BEDDING OR ANY FLAMMABLE MATERIAL ON OR NEAR THE ELECTRIC HEATERS." However, the tenant's bed had been against the heater. The thermostat did not have a positive "off" position, and while the tenant was away on vacation, the temperature in the room activated the thermostat, and a fire ensued.[11] Another fire occurred in an apartment where the tenant had just moved in and lain a mattress against a baseboard heater. The consumer told fire officials that she 'did not use' the heater and had turned it 'off'. In reality, she turned the thermostat to its lowest setting because it did not have a positive "off" setting. The consumer was spending the night elsewhere when temperatures activated the thermostat, and a fire erupted between the heater and mattress.[12]

The following scenarios raise questions as to how prolonged heating cycles might have caused the baseboard heaters to become involved in fires. A consumer in one IDI turned the thermostat to its lowest setting without turning it to the positive "off" position before going on a trip. The consumer also left the window of the room slightly open in order to 'air it out' while she was away. The outdoor temperatures subsequently activated the thermostat and heater, and bedding that contacted the heater eventually ignited.[13] In a similar incident, a baseboard heater fire began in an apartment while the tenants were not at home and their door had been left open. The weather reportedly consisted of high winds and "blizzard conditions", and the open door caused the heater to remain on its heating cycle for an unknown period of time until furniture and clothing around it ignited.[14] A third IDI involved a baseboard heater with no positive "off"

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[10] 001204HCC2126
[11] 000623HCC3286
[12] 000105HWE5008
[13] 001204HCC2126
[14] 000329HCC0526

position that had been turned to its minimum setting. The room had not been entered for two weeks, and a window had been broken during that period, exposing the room to outdoor temperatures of approximately minus seven degrees Celsius (20 degrees Fahrenheit). The heater ran continuously, and clothing around the heater was ignited.[15]

The next set of scenarios pose the opposite question of how infrequent heater use may have contributed to a fire hazard. One baseboard heater fire began in a basement room used for storage. Electricity had been disconnected at the circuit breaker to the heater for about 32 years. The heater did not have a positive "off" position and the circuit breaker to the heater was inadvertently re-connected at some point prior to the fire. A fire eventually started and ignited combustibles close to the heater.[16] Another baseboard heater fire started in a heater that had been turned to its positive "off" position for two and a half years in a spare bedroom used for storage. Less than six hours after the heater was turned on, a fire began, igniting nearby clothing.[17] A fire began in a room where the heater had been turned to its lowest setting for eight and a half months. After turning the thermostat up to start the heating cycle, the consumer left on an errand. About an hour later, she returned home to find the heater and a nearby mattress on fire.[18] Yet another fire occurred on the same day that a consumer turned on the heater "for the first time [that] year" in September. The heater in that IDI ignited a low-hanging blanket that was covering the window.[19] In these IDIs, none of the heater elements had been cleaned during the periods of inactivity.

In half of the baseboard IDIs, it was unknown whether ignition or failure occurred near the center or far end of the baseboard heater. Among the 28 IDIs where this information was reported or could be identified through photographs, 20 (71%) indicated that ignition or failure occurred near the far end of the heater. Of the twelve IDIs that involved internal failures, three involved melted heating elements.[20] Two IDIs mentioned thermal limiting devices that were damaged or failed to operate.[21] Other IDIs documented problems with electrical connectors and burned off or degraded wire insulation.[22]

Fan-Forced Heaters

Fan-forced heaters use a fan or blower to direct air across a metal wire heating element (sheathed or unsheathed) and into the room. The use of the fan instead of natural convection allows for heaters much smaller than baseboard heaters. In addition, the heating elements are usually much hotter than those in baseboard heaters. Compared to radiant heaters, heating elements in forced-air heaters usually operate at a much lower

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[15] 000214HWE5004
[16] 001204HCC0132
[17] 000623HCC3290
[18] 000623HCC3291
[19] 991102HWE5004
[20] 010502CNE6319, 000501HWE6001, 000308HCC3184
[21] 000224HCC3169, 000222HCC3167
[22] 001130HCN0113, 010502CNE6318, 010314HCC0386, 010102HWE5005, 000225HCC3170

temperature because the air movement reduces the element temperature. Fan-forced heater designs have louvered faceplates to direct the forced airflow.

Table 12: Fan-Forced Heater Investigations by Scenario Type			
Scenario Type	**Investigations**	**Deaths**	**Injuries**
Fire	21	1	0
Combustibles Too Close	3	1	0
Internal Failure	17	0	0
Unknown	1	0	0
Non-fire	24	0	0
Total	**45**	**1**	**0**

Fifty-three percent of forced-air IDIs were not fire-related. In those IDIs where fires did occur, 81 percent were caused by identifiable internal failures, as opposed to transmitted heat igniting combustibles. However, the one fatality documented in the forced-air IDIs was attributed to combustibles too close to the heater.

A 20 year-old woman and her sons, aged 3 years and 10 months, respectively, resided in a single-family rental home in Paradise, MT. The only heating appliances for the home were two wall-mounted, fan-forced electric heaters, one of which was installed in the living room. On January 18, 1998, a fire began in the living room, at the point where a sofa arm was approximately two inches from the heater. The woman escaped and her 3 year-old son was rescued; however the 10 month-old son perished in the fire. Rescue efforts were hampered when the mother mistakenly indicated to a rescuer that her son was in his crib, when in fact he was in another part of the house. The home was equipped with a smoke alarm that was functional six months before the incident. The insurance company's private investigator determined the cause of the fire to be the placement of the sofa "too close to the front of the wall heater", which was operating at its highest setting. The heater was five years old and consisted of coiled wire heating elements, which ran horizontally inside the heater, and a fan positioned below the coils. According to the private investigator, ignition occurred on the arm of the sofa and not inside the heater itself. No internal failure could be identified within the heater and the corresponding circuit breaker did not trip. It is unknown whether the heater complied with the voluntary standard.[23]

Of the 45 fan-forced heater IDIs, two involved ceiling-mounted heaters,[24] two involved heaters that were installed in the "kickspace" between the floor and the bottom edge of cabinetry[25] and the remaining IDIs involved wall-mounted installations. Four

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[23] 000302CAA3175

[24] 000607HCC2588, 001101HCC2069

[25] 000204HCC0371, 991222HCC2146

IDIs involved wall heaters installed in a boat,[26] the living quarters of a fire station,[27] a restaurant entrance area,[28] and a bank ATM enclosure,[29] respectively, while all other IDIs involved residential installations.

Information about which room the forced-air heaters were installed in was unavailable in 16 percent of the IDIs. Of the IDIs where room location was known, 58 percent of fan-forced heaters were installed in living areas of the home. Based on information provided in about 30 percent of wall heater IDIs, fan-forced wall heaters were installed in about the same number of interior walls (un-insulated) as exterior (insulated) walls. The average age of the fan-forced heaters investigated was six years old. The median age for these heaters was only three years old; that is, half of the heaters investigated were less than three years old.

Table 13: Ages of Fan-Forced Heaters

Age Range	**Investigated Heaters**
0 – 1 year	16
2 – 10 years	15
11 – 20 years	4
21 – 40 years	3
Unknown	7
Total	**45**

Among the different types of heaters, fan-forced heaters had the largest proportion (44%) of users that were the original owners. Fan-forced heaters also had the largest proportion of installations performed by the consumers themselves. Even so, in about 35 percent of forced-air heater IDIs, it was unknown whether the consumers had ever cleaned the heating element. Among heaters where this information was known, over half (62%) had never been cleaned. This is partly due to several of the heaters being less than one year old. In an IDI involving a kickspace heater fire, the consumer stated that the interior of the heater could not be cleaned, even with the faceplate removed. He noted that the heater was ‘self-enclosed’ and the finned heating element blocked any attempts to clean the rear surfaces of the heater.

Information as to whether a positive “off” position was part of the heater controls was unknown for 36 percent of forced-air heater IDIs. Among IDIs that contained this information, 19 (66%) indicated that no positive “off” position could be identified. One non-fire incident occurred when a heater suddenly emitted smoke and displayed a glowing red heating element, although the fan was not operating. Since the heater had been connected to a pre-existing remote thermostat with no positive “off” position at the

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[26] 000728CCC0881
[27] 000621HCC3285
[28] 001005CCC2020
[29] 000727CCC2708

time of installation, the consumer was forced to disconnect power at the circuit breaker. The incident heater was subsequently collected as a CPSC sample.[30]

A fire in another home began when a sofa was placed against a wall heater that "had not been used in years". The fire marshal believed that the sofa rubbed against the on/off switch, activating the heater, which ignited the sofa after a gradual heat build-up.[31] In another fire-related IDI, the fire department responded and disconnected power from the heater at the circuit breaker. Upon removal of the faceplate and inspection of the heater, they found an on/off switch located inside.[32]

Fan-forced heaters were the only heaters in the IDIs that had indicator lights, such as power lights and/or warning lights. However, none of the consumers reported seeing an indicator light as being what first alerted them in the incidents (see Table 8). According to a consumer who used multiple forced-air wall heaters, "he had observed that the red lights inside these heaters came off and on from the time that they had been first used." The lights alone did not prompt any action from this consumer. At the time of the incident, one of the heaters began to emit smoke and an odor, and he subsequently noticed that the surrounding wall was charred. It is unknown whether any of the indicator lights were on during the incident.[33]

The internal failures identified in fan-forced heater fire and non-fire IDIs included problems with wire insulation and electrical connections (11), failed heating elements (9), failed thermal limiting devices (5) and fan problems (5). The exact types of internal failure in the remaining internal failure IDIs were unknown. Although some heaters exhibiting these failure modes have been addressed by EXC activities, these same models were listed as meeting the current voluntary standard.

Radiant Heaters

Radiant heaters use glowing red metal heating elements (sheathed or unsheathed) and reflectors to direct infrared energy into the room. Radiant heat is primarily absorbed by objects directly in front of the heater and not by the surrounding air, so these heaters are most efficient for heating small spaces, such as bathrooms. The reflective surface behind the heating element works to direct the infrared heat into the room, instead of back into the mounting surface. The temperature of radiant heater elements, typically around 400 degrees Celsius, is the highest of all fixed heater types. Radiant heaters tend to have tightly woven mesh faceplates, rather than louvered ones, to maximize the amount of heat transmitted into the room.

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[30] 000731CCC3363
[31] 001204HCC0134
[32] 001005CCC2020
[33] 000728CCC0881

Table 14: Radiant Heater Investigations by Scenario Type			
Scenario Type	**Investigations**	**Deaths**	**Injuries**
Fire	17	2	6
Combustibles Too Close	15	2	6
Internal Failure	2	0	0
Unknown	0	0	0
Non-fire	0	0	0
Total	**17**	**2**	**6**

Of the various fixed heater types, the fewest number of IDIs were conducted for radiant heaters. All IDIs were fire-related, and 88 percent were blamed on radiated heat igniting nearby combustibles. This is less surprising for radiant heaters than for the other heater types given the relatively high heating element temperatures of radiant heaters. Internal failures that were reported in radiant heaters consisted of electrical overloading and overheating and burnt wiring that ignited dust, respectively. Although radiant heaters accounted for only 16 percent of in-scope IDIs, they were associated with 40 percent of deaths documented in the fixed heater IDIs.

A fire began in an Edison, NJ home on December 18, 1999, when a wall-mounted, radiant heater ignited a towel, hanging from a rack above the heater. The heater was located in a bathroom, where a 77 year-old female was taking a bath. The female suffered 2nd and 3rd degree burns to her face, chest, back and arms, and succumbed to her injuries less than a month after the incident. The fire took place in a multiple-unit, senior housing complex, and six other residents were sent to hospitals with minor injuries. The incident heater was 20 years old and consisted of exposed heating elements protected by a steel grate. A towel rack was positioned above and offset to the right of the heater. This type of heater and this arrangement of the towel rack in relation to the heater were reportedly found throughout other bathrooms in the complex. The unit was equipped with a smoke alarm that activated during the incident. There was no record of the heater being examined after the fire, and the ignition factor was listed in the fire incident report as "combustibles too close to heat". It is unknown whether the heater complied with the voluntary standard.[34]

On February 4, 2000, a Miami Beach, FL fire began when a wall-mounted, radiant heater ignited a towel, hanging from a rack above the heater in a bathroom. A 68 year-old female resident of the home attempted to extinguish the flames when her nightgown or bathrobe ignited, resulting in 2nd and 3rd degree burns to 70 percent of her body. Although the fire in the bathroom apparently self-extinguished, the victim died days later from her injuries. A blood alcohol test taken at the hospital revealed a level of 0.276 in the victim. The heater was reportedly 40 to 50 years old, and it is unknown

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[34] 000329HCC0519

whether it complied with the voluntary standard. A glass towel rack was installed above the heater so that the towel partially or completely covered the front faceplate. Wooden window blinds were installed above the towel rack and were also ignited during the incident. A security system with window sensors activated an audible alarm during the incident. The victim was known by her family to be a heavy drinker, and her intoxicated state likely affected her judgment in reacting to the fire. It was believed that her bathrobe/nightgown was made of highly flammable polyester. The fire investigation report claimed that the interior of the heater showed no damage. According to the police report, the incident heater was used in a simulation with another towel. In the simulation, the heater achieved a maximum temperature of approximately 183 degrees Celsius (361 degrees Fahrenheit), and the towel placed in front of it began to smolder after 15 minutes.[35]

One radiant heater IDI involved a heater installed in a church building, while all other radiant heater IDIs involved residential installations. Thirteen (76%) of the 17 radiant heaters investigated were installed as bathroom heaters. Seventy-six percent of IDIs involved consumers who were tenants. Almost half of the heaters had unknown cleaning histories. Of the ten heaters that had known cleaning histories, nine had heating elements that had never been cleaned by the current consumers. The average age of the radiant heaters investigated was 26 years old, the highest among the heater types.

Table 15: Ages of Radiant Heaters

Age Range	**Investigated Heaters**
0 – 1 year	0
2 – 10 years	1
11 – 20 years	4
21 – 40 years	8
Unknown	4
Total	**17**

Unlike baseboard and forced-fan heaters that were investigated, radiant heaters were more often than not reported to have positive “off” positions as part of their temperature controls. Radiant heaters tended to be controlled by buttons and knobs located on the heaters themselves, as opposed to by remote thermostats. Three IDIs involved radiant heater fires where the consumers believed the heaters had been disconnected. In all three instances, central heating had been installed, and the consumers never used the fixed heaters. In one IDI, a repairperson inadvertently re-connected the heater’s circuit breaker and energized the heater, which was located in a densely packed storage room.[36] In another IDI, the heater was apparently not disconnected, and when a mattress was pushed up against the controls, the heater turned on.[37] In the third IDI, the consumers reported that they had used central heat throughout

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[35] 000413HCC0564

[36] 000414HCC0573

[37] 000906HCC0007

their six-year tenancy, and that they had understood from the landlord that the incident heater was not connected. They had placed a cabinet directly in front of the heater, which inexplicably activated during the incident, and caused a fire.[38]

Given the way radiant heaters are designed to transmit heat and that they are most effective in small rooms, it is not surprising that combustibles were found within short distances of the heaters in the IDIs. Five IDIs documented scenarios where radiant heaters ignited towels or bathrobes that were hung on towel racks above the heater.[39] One IDI reported that "The firm that owned the apartment stated that it believed two years ago [approx. 1997] the state of California banned the use of electric wall heaters in bathrooms of newly constructed houses. It did not know the reason for the ban but believed that the ban was for fire safety."

Unknown Type Heaters

Six investigations involved wall-mounted fixed heaters for which the types of heating elements were unknown due to the minimal amount of available product information.

Table 16: Unknown Type Heater Investigations by Scenario Type

Scenario Type	**Investigations**	**Deaths**	**Injuries**
Fire	6	0	2
Combustibles Too Close	3	0	2
Internal Failure	1	0	0
Unknown	2	0	0
Non-fire	0	0	0
Total	**6**	**0**	**2**

All six IDIs involving unknown type heaters were fire-related. One heater was installed in the men's restroom of a furniture business, but all other heaters were residential installations. Investigation into the restroom heater by the local fire marshal's office found evidence of internal failure, namely arcing in the wiring that connected the heater to the building circuitry.[40]

The scenarios leading to fires could not be identified in two of the IDIs. In one fire, the interior wall was listed by the fire department as the first material ignited, and no combustibles outside the heater were mentioned. However, no information was available as to whether there was any evidence of an internal failure.[41] One unknown type heater

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[38] 000329HCC0525

[39] 000329HCC0519, 000404HCC2408, 000413HCC0564, 991222HCC3080, 000707HCC3308

[40] 010322HCC0411

[41] 010308HCC0366

was involved in a fire where no information was available as to whether it was attributable to combustibles placed too close or to an internal failure.[42]

Three IDIs concerned unknown type heaters installed in bathrooms that ignited towels hung nearby or contacting the heaters.[43] These scenarios were very similar to the radiant heater fires, with one fire resulting in two injuries.

On January 13, 2000 in Bristol, TN, a fire began in a bathroom when a wall-mounted heater ignited towels hanging on a rack nearby. An adult female was treated at a hospital for smoke inhalation and an adult male neighbor who rescued her was treated for smoke inhalation at the scene. The type and age of the heater was unknown, as well as whether it complied with the voluntary standard. The home was equipped with a smoke alarm, which activated during the incident.[44]

Conclusions

In the fixed-position electric heater incidents investigated and analyzed over an approximate one and a half-year span, no single failure scenario was associated with all fires or fire hazards. Based on what respondents were able to observe and reported to CPSC investigators, 45 percent of the scenarios involved fixed heaters that transmitted or radiated enough heat through their faceplates to ignite nearby combustibles. All deaths and injuries documented in the IDIs were associated with this scenario, regardless of the type of heater involved. Considering baseboard heaters alone, 70 percent of the IDIs reportedly followed this scenario. Given that baseboard heaters have the lowest heating element temperature of all the fixed heater types, it is not obvious as to why the combustibles-too-close scenario is so common. However, since deaths and injuries consistently were associated with this scenario, it cannot be overlooked as the most hazardous scenario recorded in the IDIs.

Fifty-two percent of fixed heater scenarios involved component failures within the heaters. About half of these internal failures resulted in fire-related incidents, so it is conceivable that undetected internal failures may have been responsible for some of the combustible-too-close fires. Over 70 percent of internal failures were found in forced-air heaters. The failed components most commonly identified in these IDIs were electrical connections and wire insulation, heating elements, and thermal limiting devices. Since the IDIs indicate that fixed heaters are rarely, if ever, internally cleaned, the influence of excessive dust or dirt should be considered in combination with these failures. Dust may act as a potential combustible inside the heater (as opposed to outside of it) and may turn the fire hazard caused by an internal failure into a fire.

The impact of age and a lack of maintenance over a heater's lifetime arose as issues for baseboard and radiant heaters based on the IDI information. The average ages

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[42] 010116HCC0211

[43] 001204HCC2124, 000329HCC0521, 000710HCC3322

[44] 000329HCC0521

of these heaters involved in the IDIs well exceeded ten years of age. The investigations also contained scenarios where fixed heaters were operated under extreme but foreseeable conditions, such as operating continuously in an active heating cycle and not operating in the active heating cycle for extended periods of time.

As far as consumer interaction with fixed heaters, the IDIs show that consumers generally regard these products as low maintenance heaters. Consumers readily placed combustibles within a short distance from or against the heaters. The installation of towel racks above bathroom wall heaters indicated that building contractors perceived this as an acceptable arrangement. Usually, consumers made no effort to remove the faceplates in order to clean the heating elements. Some consumers also misunderstood the meaning of turning a fixed heater to its minimum setting, as opposed to completely off, although many heaters could not be turned to a positive “off” position.

Appendix

State-to-Region Mappings

Western Region

Alaska
Arizona
California
Colorado
Guam
Hawaii
Idaho
Montana
Nevada
New Mexico
Oregon
Utah
Washington
Wyoming

Central Region

Arkansas
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Michigan
Minnesota
Missouri
Nebraska
North Dakota
Ohio
Oklahoma
South Dakota
Texas
Wisconsin

Eastern Region

Alabama
Connecticut
Delaware
District of Columbia
Florida
Georgia
Maine
Maryland
Massachusetts
Mississippi
New Hampshire
New Jersey
New York
North Carolina
Pennsylvania
Puerto Rico
Rhode Island
South Carolina
Tennessee
Vermont
Virginia
Virgin Islands
West Virginia

Appendix C: Directorate for Engineering Sciences

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

To: File
Through: Hugh McLaurin, Associate Executive Director, Directorate of Engineering Sciences
Linda Edwards, Division Director, Electrical Engineering
From: Randy Butturini
Subject: Results from Laboratory Testing of Fixed-Position Electric Heaters

Date: 7 May, 2002

Introduction:

Fixed-position electric heaters are permanently mounted, heating units intended to warm a room. The designs include radiant, forced-air convective, and natural convection technologies. As part of the two-year project to assess the adequacy of the voluntary standards associated with these heaters, laboratory experiments were conducted to learn how the heaters operated under various normal and abnormal conditions. The applicable voluntary standards are UL 2021 *Fixed and Location-Dedicated Electric Room Heaters*, and UL 1042 *Electric Baseboard Heating Equipment*.

Experiments were conducted in order to evaluate the following hypotheses:

- Operation of an electric heater under normal and abnormal conditions listed in UL 2021 and UL 1042 may result in conditions that can damage internal components.
- The temperatures achieved on a baseboard heater when subjected to abnormal conditions are not high enough to lead to ignition of common household fabrics.
- Radiant heater operation is evaluated in UL 2021 with a drape of cheesecloth and duck cloth. The properties of terrycloth are sufficiently different from cheesecloth plus duck that a radiant heater that passes the Curtain Drape Test of UL 2021 can ignite terrycloth when the terrycloth is draped over the heater.

Procedures:

For the forced-air convective heaters, six heater designs from two different manufacturers were used. The designs of these heaters included propeller and squirrel-cage fan blades, open-coil, hairpin-coil, and finned sheathed heating elements, and 120 and 240 VAC input voltages. For the natural convection heater testing, three heaters from two manufacturers were used. For the radiant heater testing two heater designs from two manufacturers were employed. One radiant heater design had an open-coil heating element; the other design used a sheathed heating element.

Forced-Air Heaters

Each unit under test was installed in an open frame mounting. Electric power (120 or 240 volts AC) was connected as appropriate. Thermocouples were attached to the heater in the following locations.

- All inside surfaces of the wall can
- On the fan motor coil
- On the heating element
- At the intake and exhaust air areas
- At the outer surfaces of the heat box
- Next to the temperature limiting controls and thermal cut-offs
- The exhaust area of the grill
- Other areas that may be heated during operation

Typically, around twenty thermocouples were used per installation. A PC-based data acquisition was interfaced to the thermocouples for automatic data collection and storage. For those thermocouples on non-grounded surfaces (open-coil heating elements), a hand-held meter was used to monitor the temperature.

Each heater tested was operated normally to establish baseline temperatures and assure that the data collection system was functioning. Following the normal test, each heater was tested under the conditions of the Stalled Fan Test in UL 2021. Again a full set of temperature data was recorded from all the installed sensors. Another test executed on heaters was blocking the air intake and exhaust areas of the heater and recording the temperature response. For a few heaters, a 12-inch wide by 14-inch tall barrier was placed at approximately 9 inches from the front of the heater. At this distance, the temperature limiting controls would not activate but the internal temperatures of the heater would be elevated.

Baseboard Heaters

Each baseboard heater tested was installed on a plywood wall attached to a frame. The instrumentation of the thermocouples went as follows:

- Air intake, left side, center, and right side
- Air exhaust, left side, center, and right side
- Heating element sheath, left side, center, and right side
- Heating element fin edge, left side, center, and right side
- Wiring connectors on the left and right sides
- The return wire in the center of the heater
- The temperature limiting control capillary tube in the center of the heater
- The temperature limiting control diaphragm
- The surface of any draping materials
- The surface of the cardboard box used to block the heater

As before, each heater was operated normally in open air. For the baseboard heaters evaluated, the following abnormal operation tests were performed.

- Curtain Drape Test from UL 1042 with the temperature limiting control connected
- Curtain Drape Test from UL 1042 with the temperature limiting control disconnected
- Insulated cardboard box blocking the middle third of the heater with the temperature limiting control connected
- Insulated cardboard box blocking the middle third of the heater with the temperature limiting control disconnected

Radiant Heaters

Similar to the other heater types, each radiant heater tested was installed on an open frame, instrumented with thermocouples, and operated normally to generate baseline data. The location of the thermocouples was as follows.

- On the heating element
- At the temperature limiting device, if present
- On the bottom, center, and top of the heater grill or mesh
- On the outside surfaces of the wall can
- On the outside surfaces of the heat box
- At the input power connections

After a period of normal operation and baseline data collection, each heater tested was subjected to the Curtain Drape Test of UL 2021. In this test the front of the heater is covered with two layers of cheesecloth (towards the heater) and a layer of cotton duck. The Terrycloth Drape Test of UL 2021 was also performed on each heater tested. A single layer of terrycloth is draped over the heater in this test. A heater passes a UL draping test if there is no emission of flame or molten metal, no ignition of the draping material, and no glowing embers on the draping material.

Results:

Temperatures were recorded at several locations on the surface and inside the heater under test. Exhaust air and the surface temperatures of draping and blocking materials were also examined. In a typical test, between 14 and 20 separate temperatures were measured at one-second intervals.

For each test run, the results were examined using a spreadsheet program. The processed data were reviewed by the experimental team, and generalized into the conclusions presented below. Some examples follow.

Forced-Air Convective Heaters

Figure 1 shows the temperatures of two internal locations of the one hairpin-coil heater, the area next to the auto-reset thermal limiter, and the area next to the hazard lamp. The heater's fan was stalled for this test. What this graph shows is that the temperatures around the limiter are above the maximum rated temperatures for the wiring insulation for a portion of each heating cycle.

Figure 2 shows two internal temperatures of a finned, sheathed element heater, the area next to the auto-reset TLC on the left of the heater, and the area besides the thermal cut-off (TCO). In this test, the heater was operated normally (no blockage or stalled fan), then de-energized, as if the room thermostat had cycled the heater off. This data shows that each time the power is removed from the heater, there is an internal temperature rise. The temperature rise in the area of the TCO is sufficient to exceed the maximum temperature rating of the wiring insulation for about 3 minutes. Temperatures in the area of the TLC did not rise above the wiring insulation's rating.

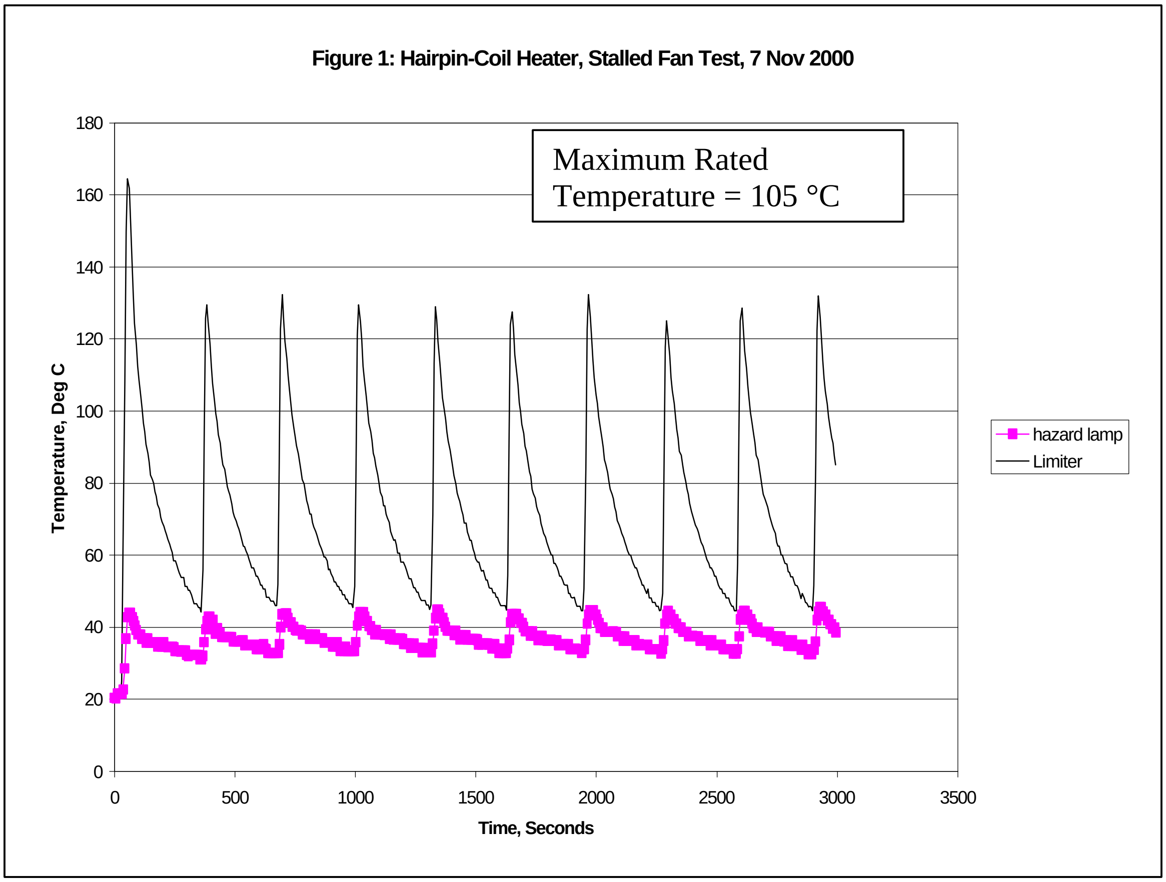


Figure 1: Hairpin-Coil Heater, Stalled Fan Test, 7 Nov 2000

Figure 2: Finned, Sheathed Heating Element.
Normal Operation & Power Off Transients, 21 Nov 2000

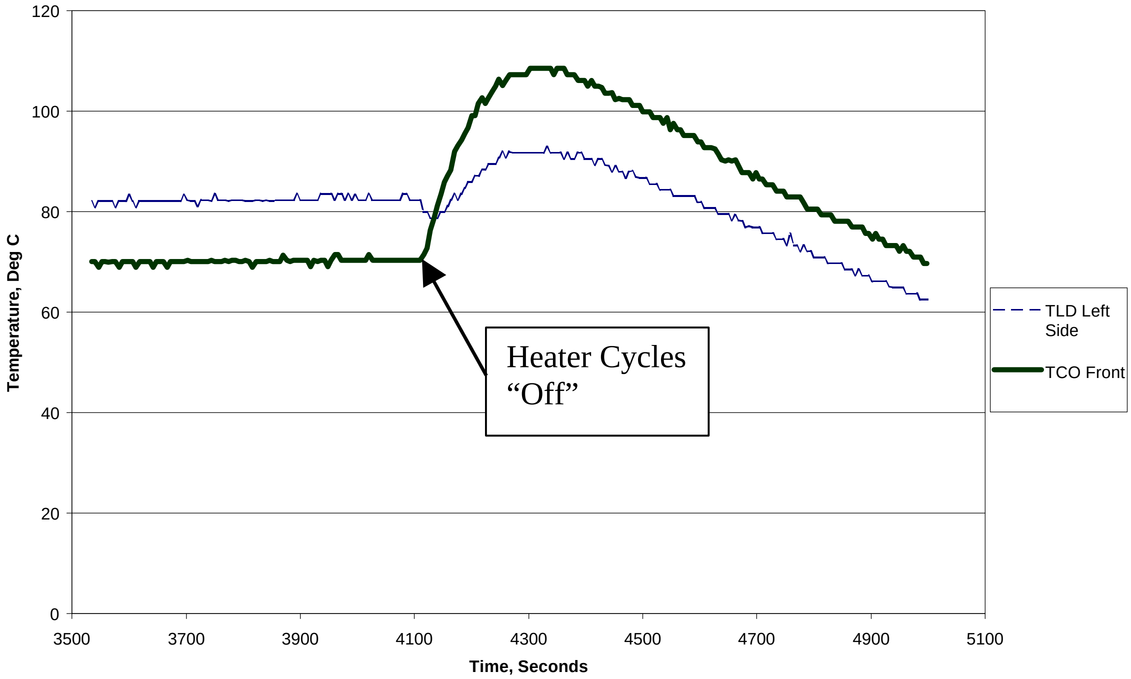


Figure 3 shows that the stalled fan condition can lead to temperatures above the wiring insulation's maximum rating and can result in wall can temperatures in excess of the branch wiring's maximum rated temperature, which can be as low as 60 °C.

Figure 3: Temperature Cycling on Forced-Air Heater, Stalled Fan Test, 10 January 2001

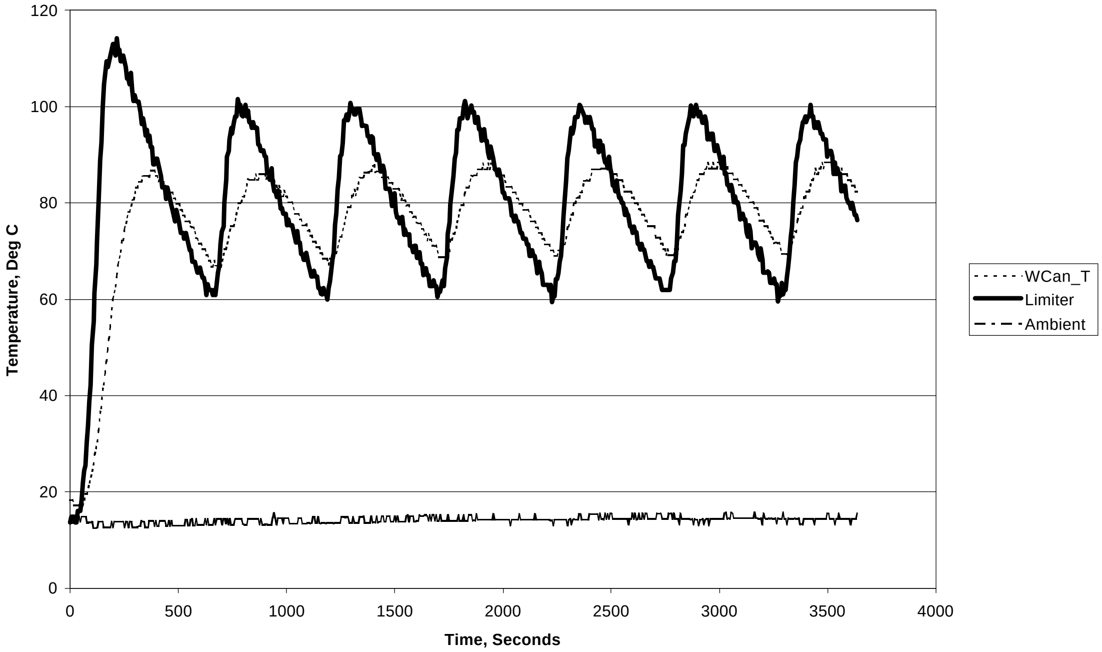
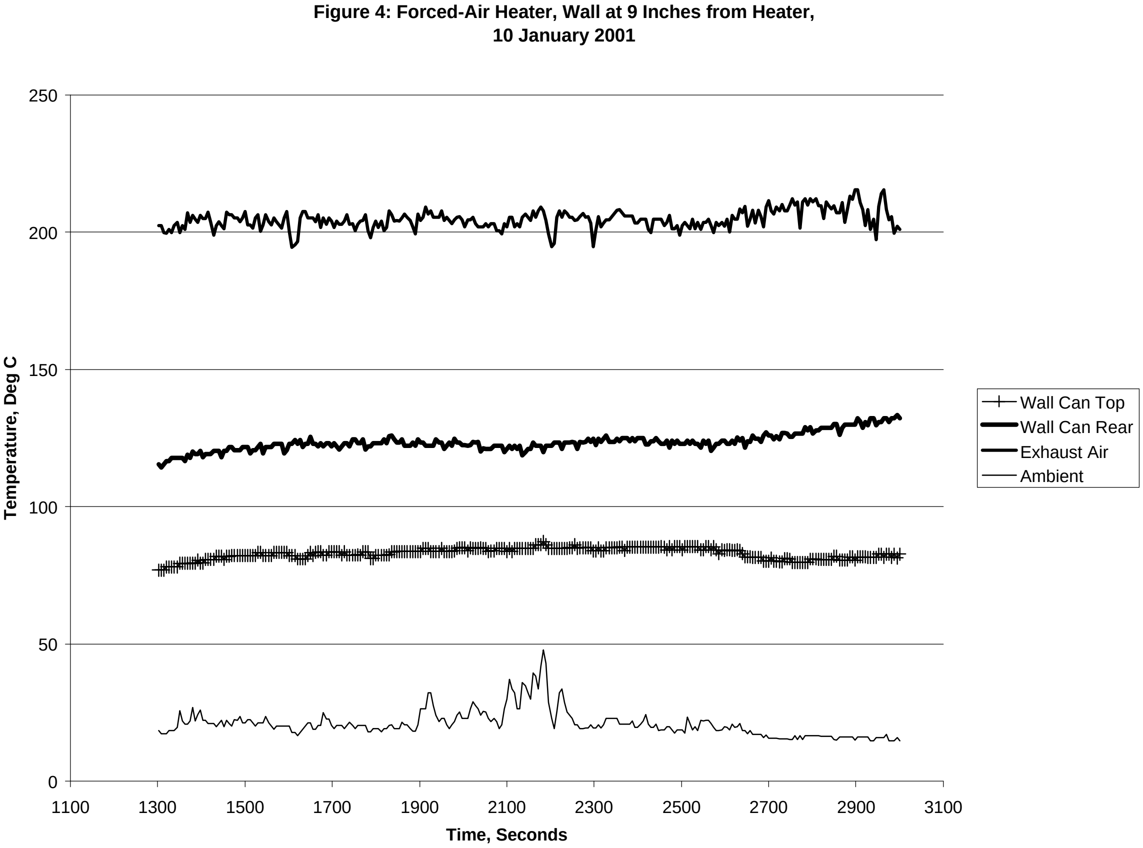


Figure 4 shows that even when the TLC is not activating (which can be considered "normal operation"), wall can temperatures can still exceed the branch circuit wiring' maximum rated value. This test was performed with the wall can operating in the open air. In a wall, the same conditions should lead to still higher temperatures experienced by the wiring insulation.

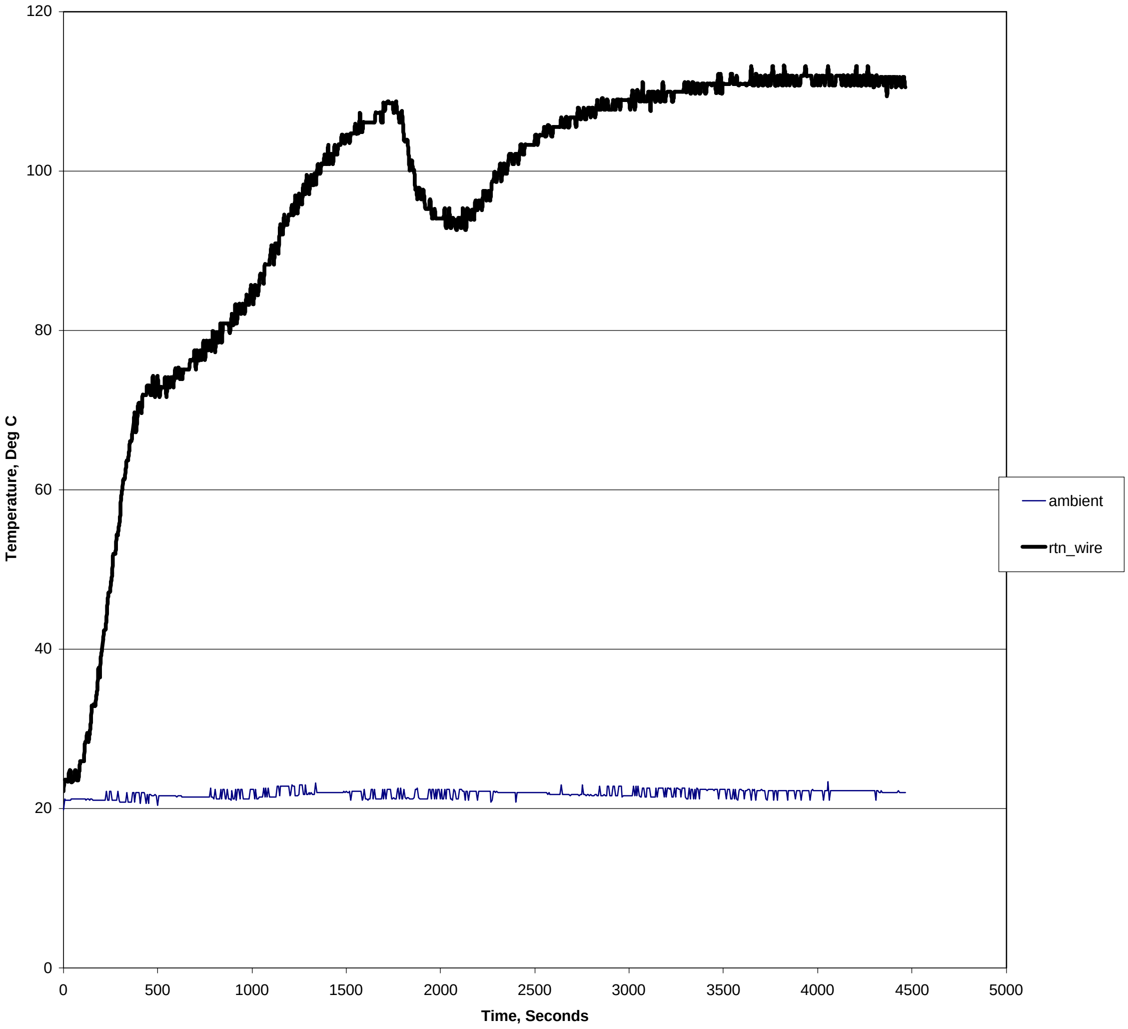


<u>Baseboard Heaters</u>

Baseboard heaters are not immune to temperature effects. Figure 5 shows that the wiring insulation's maximum temperature rating was exceeded without activating the TLC simply by placing a small box 9 inches from the center of the heater. Other, more severe situations, such as a failure of the TLC, resulted in damage to all the plastic parts in the heater, from the wiring insulation, to the wire nut connectors and spacers.

On the other hand, temperatures in a baseboard heater, regardless of the test being run, always stayed below the levels generally needed for ignition of combustible fabrics (about 360 °C for cotton cloth, higher values for other materials). One test consisted of stuffing cotton cloth between the fins of the sheathed heating element and the air defector. The TLC was bypassed for this test. No temperatures were observed that would lead to combustion of cotton cloth.

Figure 5: Baseboard Heater, Cardboard Box with Limiter, No TLC Cycling, 14 Dec 2000



Radiant Heaters

The two radiant heaters tested had different effects on the draping materials. The sheathed element heater design heated and sometimes charred the draping materials, both the curtain and the terrycloth, but did not emit flames, glowing embers, or molten metal. The heater did not ignite the draping material in any test.

The open-coil element heater quickly ignited any material draped over the heater, usually taking 30 seconds or less to generate flames on the draping. Both the curtain and the terrycloth repeatedly ignited. This UL-listed model heater has no Temperature Limiting Control.

The H-201 Digital Heat Flux Meter was used to measure the radiant heat flux at the grill of the open-coil heater. The highest measured value was 0.64 W/cm^2. For the sheathed element heater, the highest flux measured was under 0.5 W/cm^2.

Conclusions:

After analyzing our test results, the following conclusions can be made.

Forced-Air Convective Heaters:

1. Stalled fan conditions usually result in higher temperatures inside a heater than do blocked air input and exhaust conditions.
2. Under stalled fan conditions, a heater can generate temperatures that exceed the maximum rated value for the wiring insulation. Five heaters tested showed this effect.
3. Normally operating heaters (no blockage or stalled fan) may generate temperatures that exceed the maximum rated value of the wiring insulation. Also, heaters operating under partial air blockage conditions insufficient to activate any TLCs, may have internal temperatures that exceed the maximum rated value of the wiring insulation.
4. Temporary abnormal operating conditions can permanently damage warning labels to the point of illegibility.

Natural Convection Heaters:

1. Under normal operation (no activation of any TLCs), some wiring in the heater can reach temperatures exceeding the maximum rated value of the wiring insulation.
2. If a TLC fails to activate, internal temperatures of natural convection heaters can get high enough to damage all the plastic components of the heater, wiring insulation, spacers, bushings, wire nuts, etc. These conditions may create a shock or electrocution hazard, and may generate glowing embers if arcing occurs. Yet, the temperatures generated by the heater are unlikely to lead to ignition of the draping materials.

Radiant Heaters:

1. Passing the Curtain Drape Test in UL 2021 is not a predictor of a heater’s ability to pass the Terrycloth Drape Test of the same voluntary standard.
2. A heater with a high radiant flux can ignite nearby combustibles too quickly for a Temperature Limiting Device to activate. Lowering the flux can reduce the hazard.

To: File
Through: Hugh McLaurin, Associate Executive Director, Directorate of Engineering Sciences
Linda Edwards, Division Director, Electrical Engineering
From: Randy Butturini
Subject: Results from Dust Testing of Fixed-Position Electric Heaters

Date: 29 April, 2002

Introduction:
Operation of forced-air electric heaters involves exposure to household dust and lint over an extended period of time. An experiment was conducted to determine whether it was possible to observe a change in heater performance after a short period of exposure to a dusty environment. If a new heater exhibited altered operation after exposure, it should be possible to determine the relative consumer hazard a particular heater design poses when exposed to dust over a long time period.

Experiments were conducted in order to evaluate the following hypothesis:

- It is possible to evaluate a heater design's sensitivity to dust collection using a new, clean unit, and a short testing period.

Procedure:
Two fan-forced heaters were installed on a wooden frame in their normal vertical orientation. The heating elements of the units were disconnected from electrical power in such a way as to enable the fans to operate when energized. Thermocouples were attached to air inlets, exhausts, heating elements, and the fans of the devices. Sets of "before" temperature measurements were recorded to establish new, normal operating parameters. Sets of digital pictures showing the out-of-the-box cleanliness conditions of the heaters were recorded.

Two heaters were used in the experiment. Heater A has a hairpin-turn open wire heating element. This is considered conducive to collecting dust and lint. Heater B has a sheathed, finned heating element. This design is considered to be less capable of collecting and trapping dust and lint.

A chamber was installed in front of the heaters. This chamber was filled with two types of dust to simulate normal household materials:

ISO Fine Test Dust, #12103-1, A2
Ground, second-cut cotton linters, screened through a 4 micron filter

Two muffin-style fans were also installed in the chamber in order to facilitate stirring of the dust during the testing period.

The dust chamber and heater wall cans were sealed to avoid dust leakage. The two chamber fans and the two heater fans were energized for a period of 2 hours. After the test period, the fans were de-energized, and the chamber was undisturbed for a day to let the remaining airborne dust settle.

After the dust chamber was removed (carefully, so as to disturb the dust and lint on the heaters as little as possible), each heater's heating element was reattached. The heaters were re-energized, and sets of "after" temperature measurements were collected. Each heater had a second set of pictures recorded showing the amount and location of any collected or trapped dust and lint.

Results:

Heater A:

Examining the "before" and "after" temperature responses shows a dramatic change in operation of the heater. While the "before" temperatures show ordinary temperatures that change little, the "after" measurements detail large temperature swings and operation of the Temperature Limiting Control (TLC). The exhaust air temperatures are higher than normal during the first part of the "after" test due to the presence of combustion products of the lint. The dust and lint in this heater scorched, charred, burned, and emitted a few glowing particles into the test room. A strong smell of burning was pervasive while this heater was being tested. The heating element was observed to be glowing red, which is indicative of much higher temperatures than normal operation. Most likely, the airflow across the open-wire element was restricted and overheating of the element resulted.

Figure 1: Heater A Before Dusting,
7 June 2001

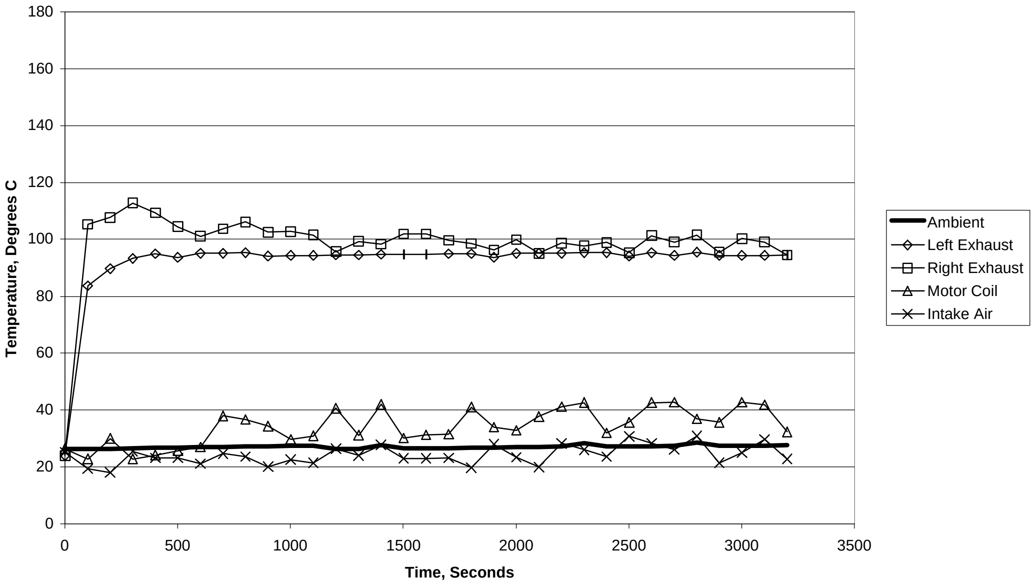
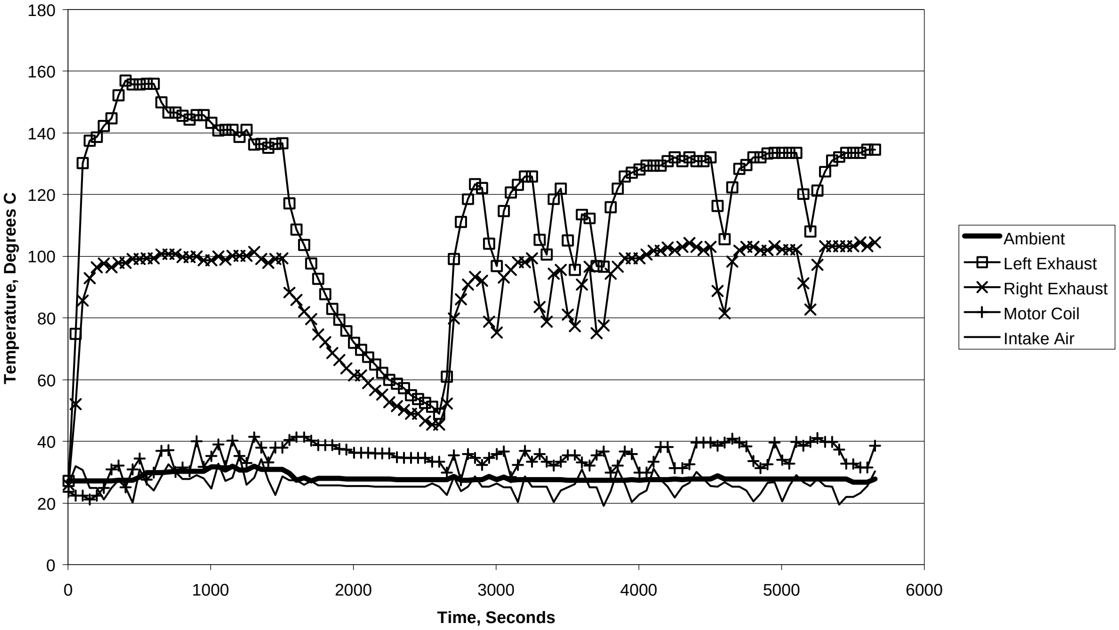


Figure 2: Heater A After Dusting, 13 June 2001



The following pictures show the heating element and fan of this heater sample. Large accumulations of dust are obvious.

Figure 3: Heater A With the Front Cover Removed

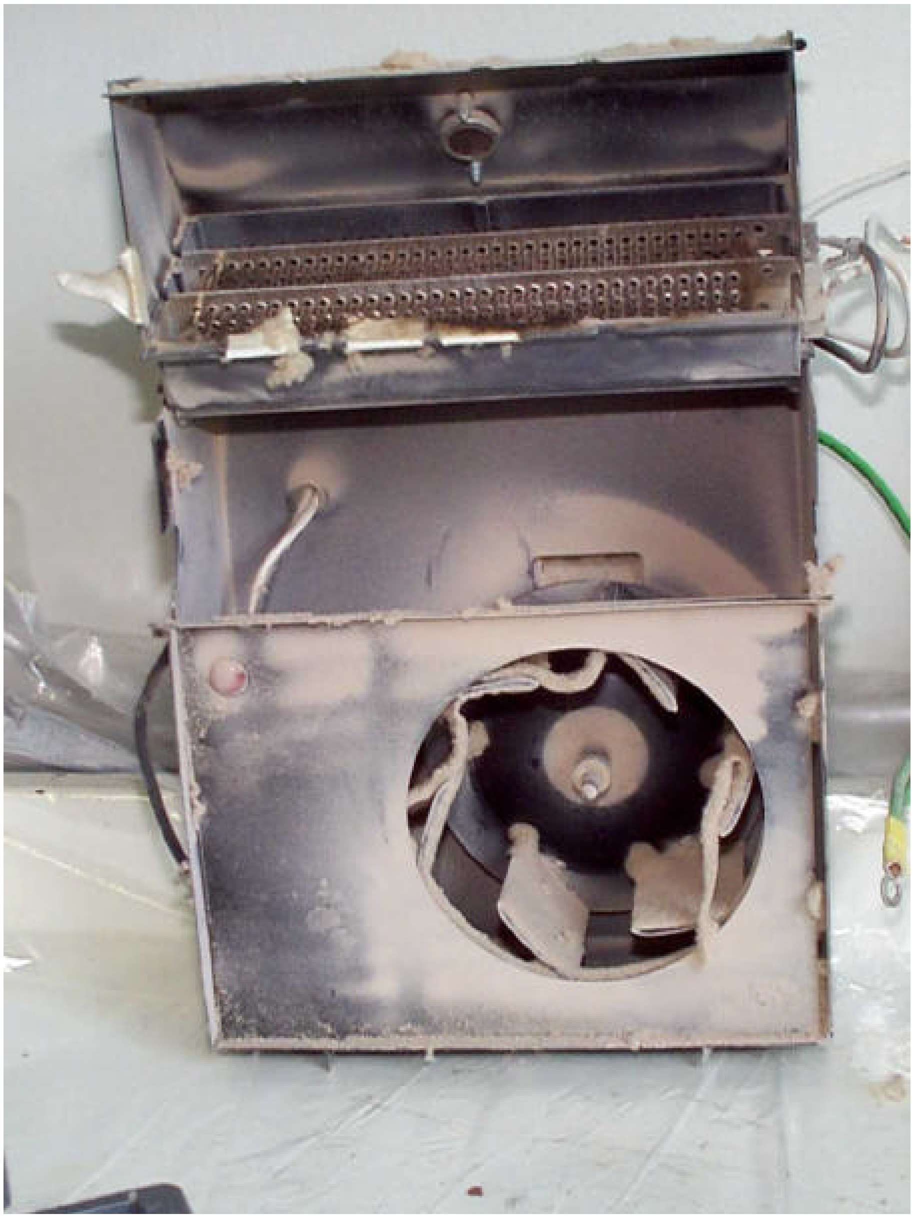


Figure 4: Heater A Heating Element

Heater B:

Heater B also exhibited a marked change after being subjected to dust for a two-hour period. One of the TLC devices in the unit cycled electric power to the device. This behavior is indicative of an interruption of the airflow across the heating elements. Examination of the pictures (Figures 7 & 8) show a great deal of dust trapped within the squirrel-cage rotor of the fan. Some lint/dust can be seen in the heating element area. However, there is little blockage of the airflow path across the element.

Figure 5: Heater B Before Dusting,
7 June 2001

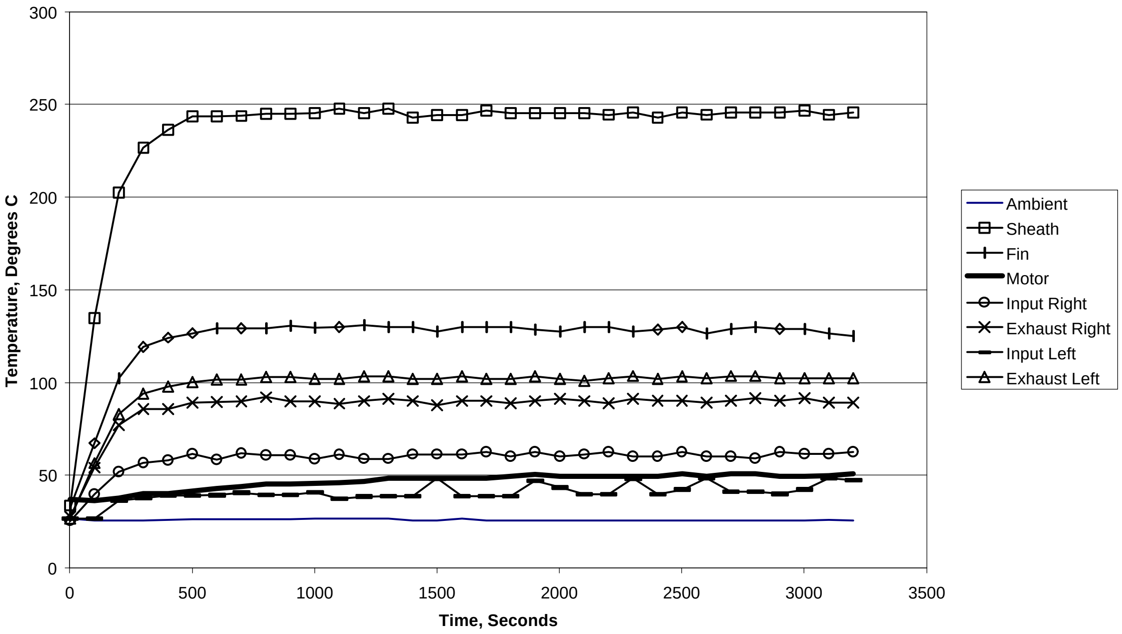


Figure 6, Heater B After Dusting
13 June 2001

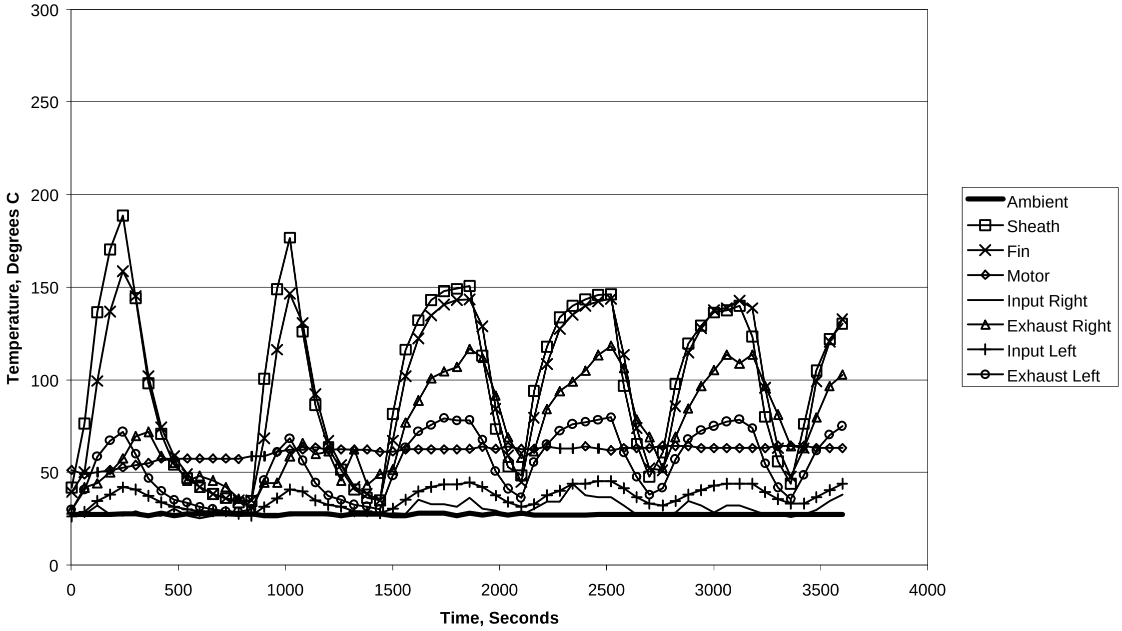


Figure 7: Heater B, Cover Removed

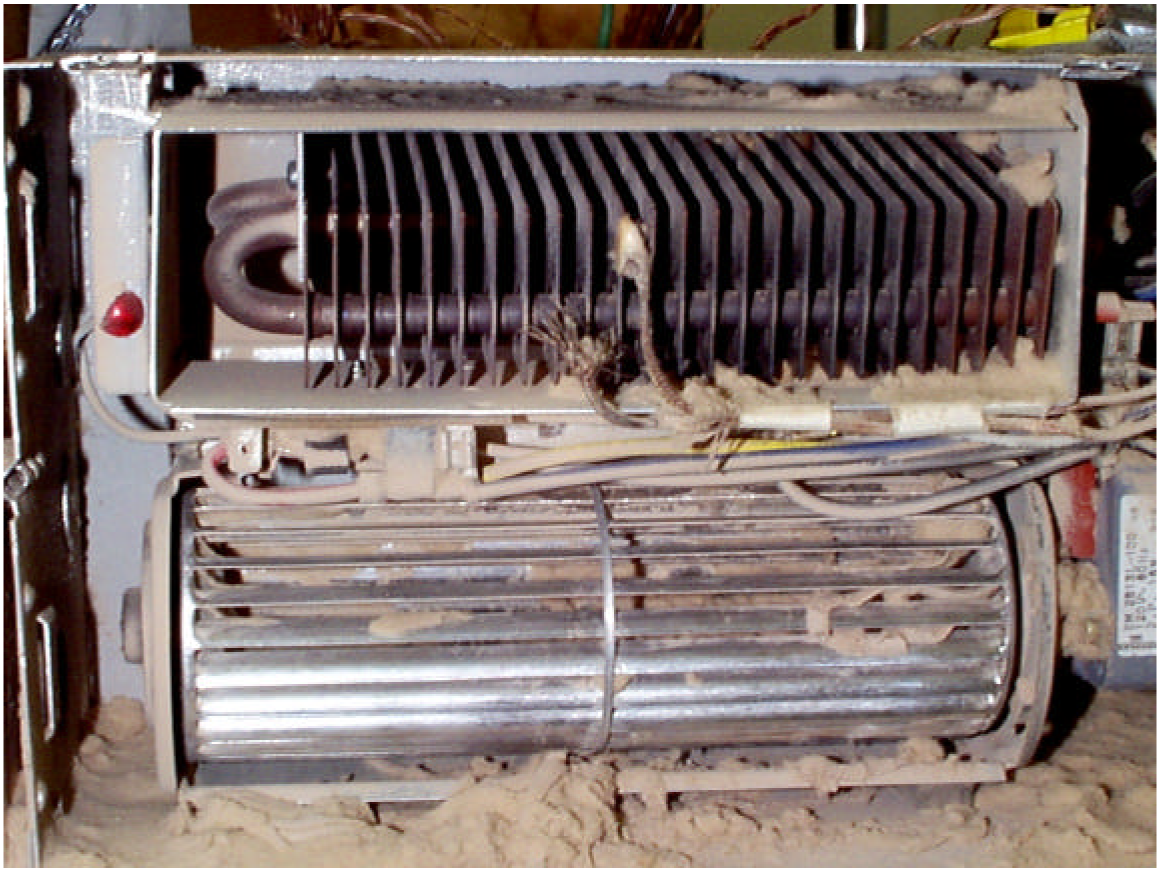
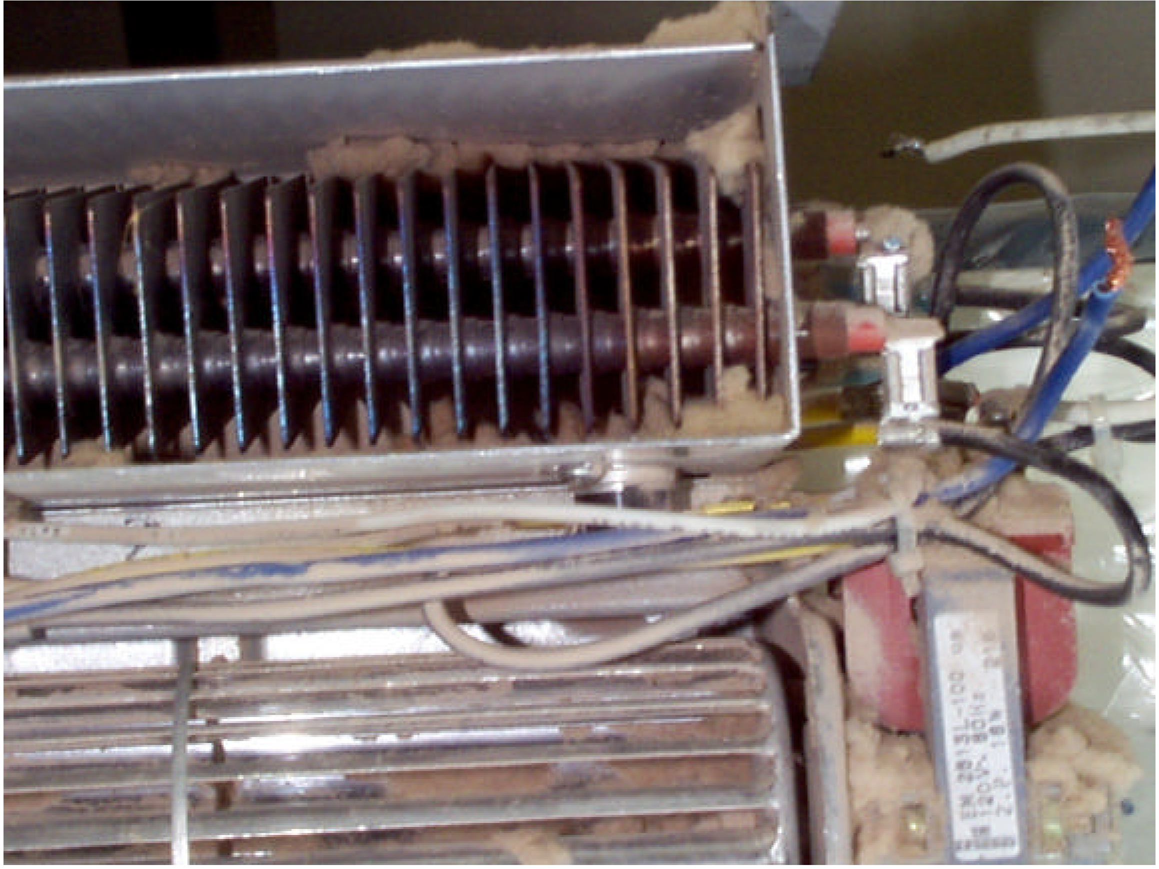


Figure 8: Heater B Heating Element



Conclusions:

With a simple arrangement and easily obtainable standard dust and lint, it is possible to significantly affect the operation of a fixed-position electric heater. Further, the changes to heater operation can be achieved in a short period of time. The equipment needs are simple. The physical evaluation of the heaters after dusting showed characteristics similar to field-obtained heaters that were exposed to environmental dust over a period of years.

In this experiment, the temperatures of various areas were monitored. If flow measurements had been taken, they might have shown a marked change in magnitude and distribution; enough to activate the TLCs in each heater. The heater design considered more prone to blockage by dust and lint ignited some of the trapped material. The heating element on this unit heated to incandescence, a temperature at which nearby combustibles can be ignited.

To:	File
Through:	Hugh McLaurin, Associate Executive Director, Directorate of Engineering Sciences Linda Edwards, Division Director, Electrical Engineering
From:	Randy Butturini
Subject:	**Estimated Temperature Limiting Control Life Under Abnormal Operating Conditions**
Date:	29 April, 2002

In the voluntary standard UL 2021 *Fixed and Location-Dedicated Electric Room Heaters* Section 25, an automatically-resetting temperature limiting control (TLC) used in a heater must withstand an endurance test of 100,000 cycles of making and breaking the heater's rated current. If a heater were to operate continuously on its TLC, how long would it take to reach the 100,000 cycle limit? Would that limit be reached before the expected end of the heater life of around ten years?

To answer these questions, the following equation is used:

Period for 100,000 cycles = (Number of Cycles) x (Cycle Period)

Where the cycle period is the time required for the heater to finish one heating-TLC activation-cooling-TLC deactivation cycle. Using a further approximation that an electric heater will be used energized for 5 months (152 days) during a typical heating season, the number of heating seasons can be estimated as well. Using measured cycle times, the following calculation can be made

TABLE 1: TLC Life Based on 100,000 Cycles

Heater	Cycle Period	Period for 100,000 cycles	Number of Heating Seasons
A	300 seconds	8,333 hours	2.3
B	813 seconds	22,583 hours	6.2
C	200 seconds	5,555 hours	1.5
D	210 seconds	5,833 hours	1.6

As the data shows, even a cycle time of greater than 13 minutes (Heater B) results in reaching the tested life of the TLC in less time than the design life of the heater. Shorter cycle times result in a shorter expected life. For the heaters with around a 5-minute (300-second) cycle time, multiple 100,000-cycle periods would pass before the heater reached its nominal end-of-life age.

These are theoretical calculations based on observed cycling of a heater under test conditions that would result in overheating and subsequent activation of the automatically-resetting temperature limiting control. These calculations assume that the abnormal operating condition is never corrected and that the heater cycles on and off for the full 152-day heating season. Also, the TLC cycle life before failure may be greater or less than the tested value of 100,000.

Even with the above conditions taken into account, continuous operation of a TLC in an electric heater can quickly result in the TLC amassing a large number of cycles of operation. Should the TLC fail in the shorted condition, temperature control under abnormal conditions may be lost, increasing temperatures in the heater until a new thermal equilibrium is reached.

Appendix D: Failure Modes & Effects Analysis

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

To: Dean LaRue, Carolyn Meiers, Terry Karels, Valery Ceasar,
Through: Hugh McLaurin, Associate Executive Director, Directorate of Engineering Sciences
Linda Edwards, Division Director, Electrical Engineering
From: Randy Butturini
Subject: **Generic Heater FMEA Comparison to UL 2021 Testing**
Date: 7 May, 2002

Contained herein is the staff's generic wall heater Failure Modes & Effects Analysis, plus its comparison to the testing and other requirements of UL 2021. Specifically, for each failure mode identified, the effects of that failure and a determination of whether a heater with that failure would pass the voluntary standard requirements is listed. During the analysis and comparison, 4 categories of faults were identified which may be difficult to detect during an Underwriters' Laboratories Inc., heater evaluation. Suggested procedures to increase fault detection coverage are provided. The 4 general categories of fault coverage and suggested improvements are:

1. There are failures which may affect the electrical insulation's dielectric properties, create a short-circuit or leakage path to ground, or change the overall impedance (and thus power consumption) of the heater.
   Suggestions for improvement: Run the Dielectric Voltage-Withstand Test after each operational test.
   Connect a fuse through the ground connector for each operational test.
   Run the Power Input Test after each operational test.

2. Fault coverage is missing for some of the identified failures during an UL 2021 evaluation.
   Suggestions for improvement: Evaluate the heater-supply ground connection integrity.
   Include hot-spot detection or evaluation for creation of such.
   Evaluate the maintenance requirements for completeness and practicality.
   Require in the voluntary standard the same wiring color-coding as required for the supply wiring.

3. Some requirements of UL 2021 are for cord-connected heaters only. These same requirements may also be appropriate for fixed electric room heaters.
   Suggestions for improvement: Extend the requirements of Protection Against Personal Injury (Section 54) to all heater designs, not just those with glass panels.
   Add Instructions for Use and Care (now Section 61 for cord-connected heaters) to cover all heaters within the scope of the voluntary standard.

4. Failures at connectors may take longer than 7 to 8 hours of test time to manifest themselves.
   Suggested Improvements: Include a Manufacturing Test to be performed on the assembly line on a sample basis to evaluate the integrity of the wiring connections (perhaps a pull test on a sample of connectors).

Appendix A is the generic heater failure modes and effects analysis and the potential fault coverage by an evaluation under UL 2021.

Appendix A: Generic Heater Failure Modes & Effects Detection by UL 2021 Evaluation

Fan Assembly Failure Modes and Effects

Failure: Fan blade slips
Effects: A) Less air flows through heater, leading to higher operating temperatures.
B) Fan may be noisy.
C) The fan blade could fall off and hit something.
D) The motor may run warmer.
UL 2021: A) Normal Temperature Test (if TLD operates), Maximum acceptable temperature rise (Table 37.1)
B) UL 2021 has no noise requirements
C) Normal Temperature Test
D) Not detected by UL 2021

Failure: Fan blade pitch changes
Effects: A) Less air flows through heater, leading to higher operating temperatures.
B) The motor may run warmer.
UL 2021: A) Normal Temperature Test (if TLD operates), Maximum acceptable temperature rise (Table 37.1), Abnormal Temperature Tests if flame or glowing embers resuslts.
B) Not detected by UL 2021.

Failure: Mechanical Interference of fan blade rotation
Effects: A) No forced airflow through heater & overheating.
B) Motor is in stalled condition.
UL 2021: A) Normal Temperature Test (if TLD operates), Maximum acceptable temperature rise (Table 37.1)
B) Normal Temperature Test

Failure: Connector failure / Wiring breakage
Effects: A) Fan stops turning, leading to overheating conditions.
B) The motor stays cooler.
C) Possibility of shock hazard being created.
D) Arcing may occur, maybe leading to ignition.
UL 2021: A) Normal Temperature Test
B) Not detected by UL 2021
C) Dielectric Voltage-Withstand Test
D) Normal Temperature Test

Failure: Motor Runs Slow
Effects: A) Motor heats some.
B) Higher operating temperatures result.
C) Wiring or plastic parts may be subjected to temperatures high enough to cause melting or other failures.
UL 2021: A) Not detected
B) Continuous Operating Test (if TLD operates), Maximum acceptable temperature rise (Table 37.1)
C) Short circuit detected by Abnormal Tests, Dielectric Voltage-Withstand Test

Failure: Bearing seizure stops fan rotation
Effects: A) No forced airflow through heater & overheating.
B) Motor is in stalled condition.
UL 2021: A) Normal Temperature Test
B) Normal Temperature Test

Thermal Limit Device Failure Modes and Effects

Failure: Limit device does not/never opens at the setpoint temperature.
Effects: Run away overheating occurs, leading to fire and possibly shock hazards.
UL 2021: Normal Temperature Test

Failure: Autoreset limit device does not reclose when temperature drops.
Effects: Heater stays in the de-energized condition.
UL 2021: Not detected (?). Heater is non-functional.

Failure: Limit device setpoint temperature changes to a higher value.
Effects: Heater operates at a higher temperature before the limit device activates. This may degrade wiring insulation, connectors, or plastic parts, leading to a fire or shock hazard.
UL 2021: Abnormal Operation Tests (if flame/glowing embers), maximum acceptable temperature rise, Table 37.1. No detection of component degradation.

Failure: Limit device senses the wrong temperature (for example, the limit device loosens and moves from its installation position.).
Effects: Heater operates at a higher temperature before the limit device activates. This may degrade wiring insulation, connectors, or plastic parts, leading to a fire or shock hazard.
UL 2021: Abnormal Operation Tests (if flame/glowing embers), maximum acceptable temperature rise, Table 37.1. No detection of component degradation. Dielectric Voltage-Withstand Test

Wall Box Failure Modes and Effects

Failure: Loss of Structural Integrity
Effects: A) Heat box falls in wall box and may overheat.
B) Grill may detach, exposing live and hot parts to the consumer.
C) Fan may stall, leading to overheating
D) Live components may short to the wall box, creating a shock hazard.
UL 2021: A) Enclosure requirements (section 7)
B) Enclosure requirements (section 7)
C) Normal Temperature Test
D) Dielectric Voltage-Withstand Test

Failure: Mechanical interface to wall fails.
Effects: A) Unit falls forward out of wall, creating a shock and fire hazard for nearby combustibles.
B) Unit falls into wall, possibly igniting combustibles where smoke will not be detected by room smoke detectors (grill should make this unlikely).
C) May not be able to reach switches to turn unit off.
D) Unit may operate in non-vertical mode with unexpected results.
UL 2021: A) Enclosure requirements (section 7)
B) Enclosure requirements (section 7)
C) Switches requirements (section 29)
D) Enclosure requirements (section 7)

Failure: Fire gets outside of wall box
Effects: Combustibles may be ignited in the wall out of sight of smoke detectors.
UL 2021: Normal Temperature Test, Enclosure requirements (section 7).

Failure: Grounding connection fails
Effects: A) Latent shock hazard exists, with no indication to consumer.
B) A live part can fault to the wall box (and grill) and keep the heater running until it is touched.
UL 2021: A) Grounding requirements (section 32)
B) Leakage Current Test (if a cord-connected heater)
Dielectric Voltage-Withstand Test (if a permanently wired heater).

Failure: Wall box has no electrical supply access
Effects: Heater cannot be installed or energized.
UL 2021: Supply connections (section 13)

Failure: Installation of the wall box is too deep to attach the grill.
Effects: A) Grill may not be grounded, airflow may be disrupted, heater may draw in previously heated air.
B) Grill may not be grounded.
UL 2021: A) Enclosure requirements (section 7), Normal Temperature Test, Grounding requirements (section 32)

Grill Failure Modes and Effects

Failure: Airflow through the grill may be stopped/lessened.
Effects: A) Heater may overheat. Hot spots may be developed.
B) Internal combustibles (dust) may be ignited and exit the unit.
C) Wall box may get hotter.
UL 2021: A) Normal Temperature Test (if TLD activates),), maximum acceptable temperature rise, Table 37.1, No hot spot detection.
B) Not detected, only new models evaluated.
C) Maximum acceptable temperature rises, table 37.1.

Failure: Grill opening allows contact with hot/live parts.
Effects: Shock and burn hazards may be created.
UL 2021: Enclosure requirements (section 7)

Failure: Unattractive grill may prompt the consumer to replace it with another grill.
Effects: A) Wrong part may disturb the airflow and create hot spots.
B) Wrong part may obscure the hazard lamp.
C) Wrong part may lead to shock or burn hazards.
D) Wrong part may present grounding problems.
UL 2021: A-D) beyond the scope of the voluntary standard

Failure: Grill releases or binds switch, knob, etc.
Effects: A) May not be able to turn heater off.
B) Cannot see the hazard lamp.
C) If a component falls forward, live electrical parts may be exposed, creating a shock hazard.
D) If the thermostat changes position, the wrong operating temperature may be sensed, which could lead to overheating.
UL 2021: A) Switches requirements (section 29)
B) Pilot light requirements (section 13.6)
C) Enclosure requirements (section 7)
D) Switches requirements (section 29)

Failure: Can’t remove the grill.
Effects: A) Heater cannot be cleaned, dust effects will occur (smoke, flaming particles, overheating).
B) Cannot remove the wall box or disconnect branch circuit wiring from the heater.
C) Cannot replace the heat box.
D) Heater may be damaged in an attempt to remove the grill.
E) The grill may be damaged in a removal attempt, exposing live or hot parts.
F) The grill removal attempt may affect the grounding of the grill.
G) The wall may be damaged in a grill removal attempt.
UL 2021:A) Not detected
B) Supply connections (section 13) (?).
C) Not required by UL 2021.
D) Enclosure requirements (section 7).
E) Enclosure requirements (section 7).
F) Grounding requirements (section 32).
G) Not required by UL 2021.

Failure: Grill obscures the hazard lamp.
Effects: An autoreset thermal limit controller may be cycling with no warning available to the consumer. No corrective action will be taken.
UL 2021: Pilot light requirements (section 13.6).

Failure: Grill impact affects the internal components.
Effects: A) A shock hazard may be created by reduced clearances between components.
B) The airflow may be altered, resulting in overheating.
UL 2021:A) Grounding requirements (section 32), Enclosure requirements (section 7), Dielectric Voltage-Withstand Test. No requirement in Seciton 54, Protection Against Personal Injury Test.
B) Normal Temperature Test (if TLD activates).

Failure: The grill is no longer grounded, or a previously nonconductive grill becomes conductive.
Effects: A) A shock hazard possibility may be created.
B) A conductive path between components may be created where the nonconductive grill had previously served as insulation.
UL 2021:A) Grounding requirements (section 32) (?).
B) Dielectric Voltage-Withstand Test.

Reflector Failure Modes and Effects

Failure: Reflectance decreases.
Effects: A) Reflector heats up. Other components may be subjected to overtemperature conditions.
B) Heat output decreases.
UL 2021: A) Normal Temperature Test (if TLD activates).
B) Not detected.

Failure: Reflector becomes ungrounded.
Effects: Some other component connected to the reflector may become ungrounded too.
UL 2021: Dielectric Voltage Withstand Test

Failure: Reflector transmits heat instead of reflecting it.
Effects: Other components may be subjected to overtemperature conditions.
UL 2021: Normal Temperature Test (if TLD activates)

Wiring and Connectors Failure Modes and Effects
Failure: Impedance of a conductor increases.
Effects: A) Potential overheating at the fault site, leading to fire, melted wiring insulation, broken connections, etc.
B) Heater runs cooler.
UL 2021: A) Normal Temperature Test (if TLD activates), otherwise not detected if failure does not occur in 7-8 hours.
B) Not part of UL 2021.

Failure: Ground connection is broken.
Effects: Possible shock hazard if another fault occurs.
UL 2021: Grounding requirements (section 32) (?).

Failure: Electrical insulation fails.
Effects: A) Possible shock hazard.
B) Possible short circuit.
UL 2021: A) B) Dielectric Voltage-Withstand Test

Failure: Supply circuit disconnects.
Effects: A) No power to heater.
B) Live supply wire may contact a grounded surface.
UL 2021: A) Supply connections requirements (section 13)
B) Grounding Requirements (section 32)

Failure: Cannot disconnect heater from supply wiring.
Effects: A) Can’t remove heater from wall without cutting wires.
B) Can’t replace or repair heater parts.
UL 2021: A) Supply Connections (section 13)
B) Not required by UL 2021.

Failure: Mechanical failure of a connector
Effects: Possible shock hazard.
UL 2021: Dielectric Voltage-Withstand Test might detect this.

Failure: Wiring insulation is the wrong color.
Effects: Potential for mis-installation increases.
UL 2021: Not detected if the evaluation unit is installed correctly.

Thermostat Failure Modes and Effects

Failure: Thermostat won’t cycle off.
Effects: A) Heater Thermal Limit Devices are now cycling at limit temperatures. B) Early TLD failure may occur.
UL 2021: A) Not Detected (UL 873 is appropriate standard)
B) Not Detected (UL 873 is appropriate standard)

Failure: Thermostat setpoint is no longer adjustable.
Effects: Temperature setting cannot be adjusted for consumer comfort.

Failure: Thermostat does not disconnect all power conductors at the “off” setting.
Effects: A) Heater may come on when it gets colder.
B) Possible shock hazard if servicing, etc.

Failure: Thermostat control knob becomes conductive.
Effects: Possible shock hazard.

Failure: Thermostat continuously switches on/off (chatters) at the setpoint temperature.
Effects: A) Thermostat may wear out faster than designed.
B) Constant arcing conditions may ignite nearby combustibles.

Heating Element Failure Modes and Effects

Failure: Heating element doesn’t heat.
Effect: Consumer gets cold.
UL 2021: Not a safety problem.

Failure: Heater loses heat capacity.
Effects: Heater cycles at a higher rate and shortens life of components.
UL 2021: Not detected.

Failure: Heating element creates hot spot.
Effects: A) Nearby combustibles may ignite inside or outside of the heater.
B) Connectors may degrade more quickly.
C) Thermal Limit Device may not see hot area.
D) Heater may emit more IR energy.
UL 2021: A) Normal Temperature Test.
B) Not detected
C) Not detected unless flame or glowing embers.
D) Not detected unless element reaches 650 °C.

Failure: Shape of heating element changes.
Effects: A) Possible short circuit ensues.
B) Open coils may touch, leading to lower impedance, higher current and power.
C) May get hot spots.
D) May ignite nearby combustibles.
E) Thermal Limit Device may miss hot spots.
UL 2021: A) Grounding requirements (section 32), Dielectric Voltage-Withstand Test.
B) Normal Temperature Test (if TLD activates), Heating elements requirements (section 16), Power Input Test.
C) Not Detected
D) Abnormal Temperature Test (if flame or glowing embers).
E) Abnormal Temperature Test (if flame or glowing embers).

Failure: Element breaks
Effects: A) No heat.
B) Possible short circuit.
C) If reconnected in a different configuration, may have low impedance heating element.
D) Possible shock hazard if heating element conducts through ground.
UL 2021: A) Not a safety problem.
B) Dielectric Voltage-Withstand Test, Spacings requirements (section 31).
C) Outside the scope of UL 2021 standard.
D) Dielectric Voltage-Withstand Test.

Alarm Failure Modes and Effects

Failure: Alarm does not activate.
Effects: Consumer gets no warning of Thermal Limit Device operation.
UL 2021: Alarms requirements (section 26).

Failure: Consumer can’t see/hear alarm outside of heater.
Effects: Consumer gets no warning of Thermal Limit Device operation.
UL 2021: Pilot Lights requirements (section 13.6).

Failure: Alarm won’t shut off
Effects: A) Consumer has no knowledge of subsequent TLD operation.
B) Annoying alarm may prompt unsafe consumer actions.
UL 2021: A) Alarms requirements (section 26)
B) Not covered by UL 2021.

Instructions Failure Modes and Effects

Failure: Instructions are incorrect, misunderstood, incomplete, etc.
Effects: A) Installation may be incorrect.
B) Consumer may not operate the heater correctly.
C) Consumer may not keep the front of the heater clear of obstructions.
D) Consumer may not maintain/clean the heater.
E) Consumer does not know how to correct failure conditions.
F) Consumer cannot find out repair or replacement information.
UL 2021: A) Marking requirement for wiring diagram (section 60).
B) Instructions for Use and Care (section 61) **only for freestanding cord-and plug-connected heaters (!).**
C) Markings requirements (section 60.29).
D) Instructions for Use and Care (section 61) only for freestanding cord-and plug-connected heaters.
E) Instructions for Use and Care (section 61) only for freestanding cord-and plug-connected heaters.
F) Markings requirements (section 60).

Heat Box Failure Modes and Effects:

Failure: Components move from their correct locations.
Effects: Possible shock and fire hazard.
UL 2021: Dielectric Voltage-Withstand Test, Spacing requirements (section 31).

Failure: Airflow is disrupted.
Effects: Possible overheating of elements.
UL 2021: Normal Temperature Test (if TLD operates).

Failure: Ground connection fails.
Effects: Potential shock hazard.
UL 2021: Grounding requirements (section 32).

Failure: Wall/Heat box are not separable.
Effects: A) Heater might be contaminated during construction phase.
B) Heater replacement is more difficult.
UL 2021: A) Not covered by voluntary standard.
B) Not covered by voluntary standard

Failure: Heat shield effect fails.
Effects: A) Overheating of internal components.
B) Creation of hot spots.
C) Possible overheating of wall box exterior.
UL 2021: A) Normal Temperature Test (if TLD activates).
B) Not detected.
C) Maximum acceptable temperature rises, Table 37.1.

Appendix E: Division of Human Factors

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: October 30, 2001

TO	**:**	Randy Butturini, Project Manager Fixed-Position Electric Heater Project Division of Electrical Engineering
THROUGH	**:**	Dr. Robert Ochsman, Director Division of Human Factors
FROM	**:**	Carolyn Meiers, Engineering Psychologist Division of Human Factors
SUBJECT	**:**	Human Factors Recommendations to UL Standard 2021 for Fixed and Location-Dedicated Electric Heaters

BACKGROUND: The Fixed-Position Electric Heater Project is a two-year initiative begun in FY 00 as part of the Consumer Product Safety Commission's (CPSC) effort to achieve its strategic goal of reduction of deaths due to fire. The goals of the project are to assess the current voluntary standards relevant to fixed-position electric heaters and, where necessary, make recommendations for improvement.

The Human Factors (HF) staff was requested to review current voluntary standards for fixed-position heaters and prior HF Product Safety Assessments (PSAs) on in-wall heaters to provide a technical assessment of human interface issues relating to in-wall heaters. HF staff also took into consideration the findings of the data analysis of incidents involving fixed-position heaters.[1] Areas of concern identified through these sources include warning labels, use and care instructions, and indicator lights. Based on an evaluation of these issues HF staff developed proposals for UL Standard 2021 for Fixed and Location-Dedicated Electric Heaters. These proposals are discussed below.

A. SECTION 60: MARKINGS: WARNING LABELS

PROPOSAL 1: Require that all warning labels be formatted in accordance with ANSI Standard Z535.4 for Product Safety Signs and Labels.

Justification: ANSI Z535.4 was developed for the following reasons: 1) to establish uniform and consistent visual layouts for labels across all categories of products 2) to minimize proliferation of label designs and 3) to achieve application of a national uniform system for recognition of potential

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[1] Mah, J. (2001). Results and Analysis of Data Collection for Fixed-Position Electric Heaters. U. S. Consumer Product Safety Commission: Washington DC.

personal injury hazards.[2] To promote the objectives of ANSI Z535.4, HF staff advocates that all warning labels adhere to these guidelines and principles to make safety information more recognizable and noticeable to consumers.

Supporting Data. A warning label that concerned the disconnection of electrical power on the face of a heat box for an in-wall heater, was incorporated within a mixture of other text that included clearance specifications, French translations, and other English text. Warning label research supports the position that such safety messages are likely to be missed because of competing text. HF staff recommends that this warning be segregated from the rest of the text and that it conform to ANSI Z535.4 guidelines to make the label conspicuous and recognizable. (HF PSA 0774.00: Response to a request to evaluate labeling on face of a heat box for an in-wall heater.) HF staff further recommends that all warning labels regarding the installation and use of in-wall heaters adhere to the ANSI guidelines for the reasons given in the justification statement.

PROPOSAL 2: Require labels to be 1) heat resistant to protect against damage and destruction and to 2) remain legible after exposure to abnormal conditions.

Justification: Labels that are intended to impart critical safety information on a continuing basis should be constructed of materials that provide permanency and legibility.

Supporting Data: CPSC found that heater labels ignited during performance testing and became illegible after very short periods of operations at excessive heat output.

B. SECTION 61: INSTRUCTIONS FOR USE AND CARE

PROPOSAL 1: Require that all products covered under UL Standard 2021 incorporate use and care instructions into the product literature.

Justification: All products within the scope of the UL Standard 2021, including in-wall heaters, need use and care instructions to assure proper and safe operation.

Supporting Data: Subsection 61.1.1 of the standard states that "The requirements in this section are applicable only to freestanding cord- and plug-connected heaters." In-wall heaters are omitted from these requirements.

It is necessary that use and care instructions be required for in-wall heaters. Lack of proper maintenance could impact the safe functioning of the heater. For instance, CPSC testing found that dust accumulation in the

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[2] ANSI Z535.4-1998 (1998). Product Safety Signs and Labels. National Electrical Manufacturers Association: Rosslyn, VA.

body of the heater negatively affected the operation of forced air heaters. The heaters tested "showed markedly different operation from their pre-dusted state, including repeated cycling of the TLC[3], unstable exhaust air temperatures, and charring of the internal dust."[4]

PROPOSAL 2: Require separate, complete, instructions for the installer and the consumer.

Justification: Data from incidents involving in-wall heaters indicate that the majority of in-wall heaters are installed by professionals who are not the end users of the product. Installation instructions needed for installers are not relevant to consumers. Installers and consumer-users require separate sets of instructions tailored to the particular performance demands of their specific needs. Installers need technical information and consumers need use and care instructions. The instructions relating to each of these different tasks should be located in the product documentation in such a way that the individual groups can readily recognize the sections pertaining to their specific needs. An example in which critical safety information was targeted to an inappropriate audience is discussed below.

Supporting Data: HF staff found that an explanation regarding the meaning of an indicator light on an in-wall heater was located in instructions geared to installers. The indicator light signals an over-temperature condition that is a potential fire hazard. If consumers miss this information because it is embedded with technical installation instructions, the value of the indicator light as a signal alert for a potential hazard is nullified.

PROPOSAL 3: Require that the use and care guide provide cleaning and maintenance instructions, where applicable, or state that the heater does not need to be cleaned or maintained.

Justification: Consumers need to be aware of their maintenance responsibilities towards in-wall heaters to assure the heater is operated in a safe manner and condition. The performance of maintenance tasks may impact the safe operation of the heater. Consumers should be informed as to whether their heater needs to be cleaned and maintained and how frequently the procedures should occur. Lack of cleaning and maintenance instructions implies that no upkeep is necessary for the safe operation of the heater.

Supporting Data: HF staff discovered that use and care instructions differ among brands of heaters. Some instructions included detailed cleaning methods while others omitted any reference to cleaning. Because CPSC testing indicate that dirt and lint accumulation may impact the potential for fire,

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[3] Thermal limiting control

[4] Butturini, R. (June 19, 2001). Memo: Results from Dust Testing of Fixed-Position Electric Heaters.

consumers should be informed if their heater needs to be cleaned and how frequently the cleaning should occur. This information should be explicit.

Vague information may impact whether proper maintenance is performed.. HF staff found that one set of in-wall heater instructions detailed the procedure for lubricating motor elements. However, the instructions also stated that new models did not require lubrication but gave no guidance on how to distinguish between the two models.

PROPOSAL 4: Require that if a heater is to be cleaned as part of a regular maintenance program, the cleaning process does not expose consumers to hazardous voltages when the grill of the heater is removed.

Justification: Maintenance procedures performed by consumers should not expose them to potentially hazardous conditions that could result in injury or death.

Supporting Data: An investigation of incidents involving in-wall heaters indicated that there was no positive “off” position for the thermostats. Consumers assumed that the heater was off and no longer operating when it was actually in a minimal temperature position. HF is concerned that the power to the heater may not be truly turned off when consumers clean the product and that they will be exposed to potentially hazardous voltages.

PROPOSAL 5: Require that cleaning procedures are performed with equipment readily available to consumers and that the cleaning procedures are not burdensome.

Justification: Consumers may not comply with instructions they believe are time-consuming or troublesome or for which they do not have the proper equipment. Research consistently shows that the higher the perceived cost of compliance the more likely tasks will be avoided[5].

Supporting Data: HF staff evaluated cleaning instructions for an in-wall heater that required using the blow-out mode of a vacuum cleaner to dislodge debris from the heating elements. This would spray dirt and debris from the heater into the living area. Consumers would have an additional time-consuming task of cleaning this area. The cleaning instructions also stated that a second vacuum cleaner would be useful to pick up the debris.

HF staff believes it is unnecessarily burdensome to expect consumers to clean heaters by blowing dust into a living space that, then, will also need cleaning. While the instructions lead consumers to believe that it would be helpful to have two vacuums when cleaning the heater, some vacuum cleaners can operate in two modes – a blow-out mode and a traditional

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[5] Kotwal, B. and Lerner, N. (1995). Product Labeling Guide. Contract CPSC-C—1132. U.S. Consumer Product Safety Commission: Washington, DC.

vacuuming mode. In addition, because not all vacuum cleaners have a blow-out mode, this task will not be feasible for certain consumers.

C. SECTION 26 ALARMS and INDICATOR LIGHTS

PROPOSAL 1: Require that consumers be given specific information on how to respond to an alarm (visual or auditory) that signals an over-temperature situation. The responses should be plainly detailed in use and care manuals and should be posted on the product near the alarm.

Justification: Consumers must know what actions to take when an alarm signals the development of a potentially hazardous situation. Explicit response instructions should be conspicuously posted on the front of the heater near the alarm because the use and care manual will not always be available for reference.

Supporting Data: A HF evaluation of instructions for in-wall heaters found that in one set of instructions the significance of the indicator light was not documented. It followed, therefore, that consumers were also not informed of corrective measures to be taken in response to the indicator light signal.

Instructions and warning label for another in-wall heater give a mixed message to consumers about precautionary measures to take when the indicator light signals an overheating situation. The instructions state that the heater is equipped with an automatic reset limit control that will automatically turn off the heater if it overheats and will stay on until the limit resets. The inference is that the resetting is automatic, requiring no action on the part of the consumer. However, a warning located separately from the above statement supplies that when the indicator light is lit consumers should check to see if the heater is blocked and to contact an electrician if a cause for overheating cannot be determined.

Indicator-light use must be supported by information detailing the meaning of the light and the appropriate action to be taken in response to its critical signals, otherwise its effect as a safety device is nullified.[6] This information should be complete and consistent in all product documentation. While it is imperative that this information be provided in use and care instructions, investigations of in-wall heater related incidents revealed that consumers did not have available any type of in-wall heater instructions. HF staff recommends that indicator light use be supported by explanatory text located next to the light.

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[6] Annunciation Technologies for the Home. (1993). Carlow International Incorporated for U.S. Consumer Product Safety Commission: Washington DC.

Appendix F: CPSC-S-00-5262, *Evaluation and Analysis of Electrical Crimp Connections in Fixed-Position Electric Heaters*

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EVALUATION AND ANALYSIS OF ELECTRICAL CRIMP CONNECTIONS IN FIXED-POSITION ELECTRIC HEATERS

CPSC-S-00-5262

June 15, 2001

CONTENTS

1. INTRODUCTION AND SUMMARY

Fixed-position electrical heaters are permanently installed for room heating (as opposed to central heating) in homes. Two types are commonly available; baseboard and in-wall. This project examines electrical wire terminations of in-wall heaters. These heaters are sometimes used to supplement central heating, installed in additions or inadequately-heated areas. In other regions, where central heat is seldom required or electrical rates are low, fixed-position heaters are often used as the main heating system. Wire terminations in these heaters are almost universally made by crimping, in which the bare stranded wire is inserted into the portion of a metal terminal that is formed and/or compressed around the wire. Figures 1-1 and 1-2 show a representative fixed-position in-wall heater and crimp terminations in its internal wiring.

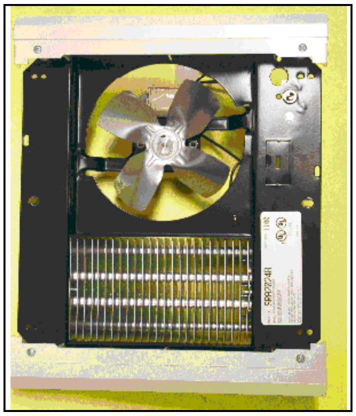


FIGURE 1-1 **HEATER #1**
(front, grill removed)

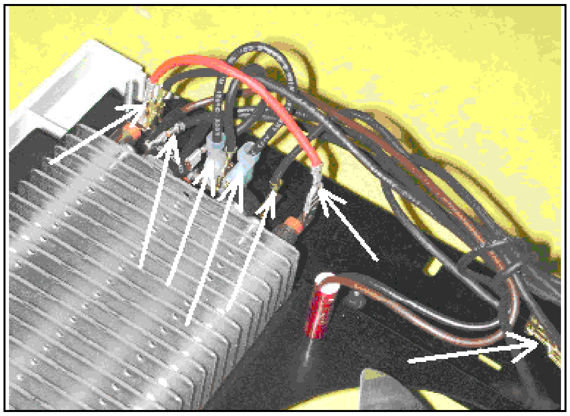


FIGURE 1-2 **INTERNAL WIRING, HEATER #1**
(arrows point to crimp wire terminals)

In the best case, crimping compresses the copper wire strands and the terminal into an essentially solid metal mass, forming a low resistance and long-lived connection. The reliable achievement of this result in mass-produced products requires careful selection of the terminal and, subsequently, careful control of a large number of manufacturing variables. When it is not achieved, the electrical resistance of the wire termination may increase under service conditions to the point where normal current flowing to the heating element causes abnormal heating at the terminal and consequent hazards.

Overheating failures of internal crimp wire terminations of these heaters have been noted in field samples examined by the U.S. Consumer Product Safety Commission (CPSC). In some instances crimped wire termination failures have resulted in hazards of electrical shock and/or fire ignition.

This present study examines crimp wire terminations of new (unused) in-wall heaters manufactured and marketed for residential installation. A total of ten heaters were provided by CPSC, samples of recent production of three different manufacturers. Seventy one of the major current-carrying crimp terminals from these heaters were examined and the connection resistance to the associated stranded copper wires was determined. Several crimp terminals were sectioned and polished for optical and electron microscope examination.

The results reflect a wide quality variation of the crimp terminations. Visual examination revealed some terminals with misaligned crimping dies, and some with copper wire strands not inserted before crimping. The range of the electrical connection resistance measurements was more than two orders of magnitude, indicating poor design and/or quality control of the terminal and/or the manufacturing process in a substantial number of the sample connections. Electrical measurement of individual wire strands in samples of high-resistance crimps show that the wires are not adequately compacted in the terminals. This is confirmed by metallurgical cross sections of sample terminations.

Examination of the sectioned crimped terminals confirms the inadequate mechanical compression. Inadequate compression is one of the known causes of high initial electrical resistance in this type of connection and is also known to be one of the known causes of short life before failure. The cross sections also demonstrate that excessive spring-back of the terminal body occurs subsequent to crimping.

The results of this study strongly indicate that the hazardous field failures that are occurring are attributable to deficiencies that are intrinsic to the heater terminations when new. This may reflect a fundamental design deficiency in certain connector and tooling combinations as well as inadequate manufacturing quality control procedures.

Considering that termination failure in this application has been demonstrated to result in the development of fire and shock hazards, it is important that quality of the terminations be substantially improved. In that context, the voluntary industry standards by which these terminal types are rated for the application have been reviewed. They are found to be seriously inadequate in that they lack effective electrical connection performance criteria and require no life testing. Considering established principles of electrical contact and connection technology, the standards are not stringent enough to assure a satisfactory performance level for the electrical heater application, in which termination failure can result in significant hazard.

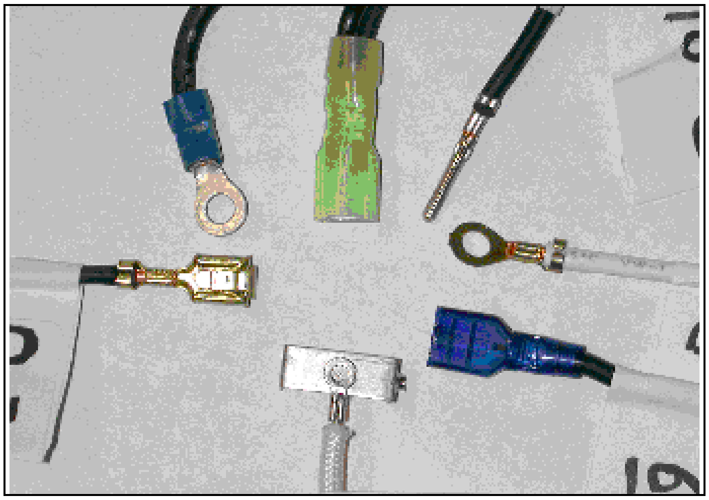
Correction of the deficiencies in the acceptance standards can be accomplished by incorporating conventional electrical contact/connection test methods. Along with more stringent acceptance standards for the various types of crimp terminations must be a higher level of quality assurance for the finished terminal/wire assembly as incorporated in the manufactured heaters.

2. SAMPLES EXAMINED

The crimp connections examined in this study come from the internal wiring of ten new (unused) electric in-wall heaters. Three different manufacturers are represented, and no two heaters are the same model. CPSC provided the heaters for this study. Appendix “A” provides detailed information on the heater samples and identification of the particular point in the wiring from which each sample connection originated. Internal wiring was carefully removed from each heater with appropriate tools, so as to avoid stressing (pulling) the wires in the terminations. Individual connectors with attached wire(s) were then isolated and tagged for identification.

The sample set of wire terminations tested in this project is comprised of all of those carrying significant current to the heater elements. Included are crimp terminations at switching devices (limiter, thermostat, and thermal fuse), heating elements, thermal fuse, and main power feeds. These connections generally carry from several amps current up to full heater current draw, depending on the wiring of the heater and the position of the connector in the circuit. Not tested in this project are wire terminations feeding current only to a heater’s fan motor or indicator light(s). Figure 1-1, showing some of the different types included among the samples tested, demonstrates the variety of form factors involved.

FIGURE 1-1 - SOME OF THE DIFFERENT FORMS OF CRIMP CONNECTORS TESTED

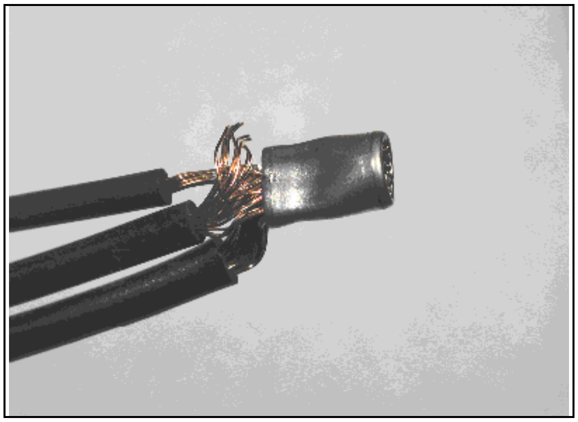


Although the form factors are different, all of these terminals have in common a crimp wire termination. It is the crimp wire termination, made by compressing a portion of the terminal onto or around the wire, that is the focus of this study.

3. VISUAL INSPECTION

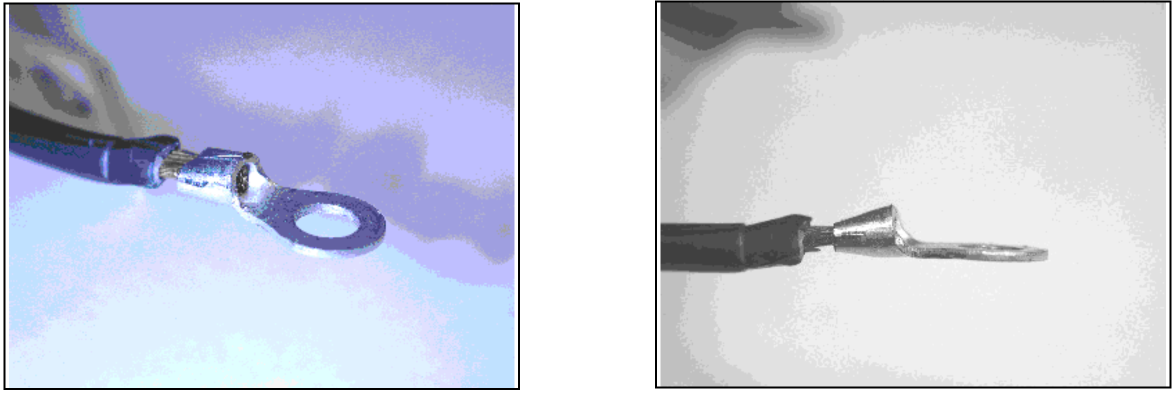
All crimped terminals were inspected visually (after removal of insulation in the case of pre-insulated connctors). Two significant types of defects were noted; wire strands not within the crimp, and misalignment of the crimp die. Figures 3-1 and 3-2 show examples of these defects.

FIGURE 3-1 - WIRE STRANDS NOT WITHIN THE CRIMP (Connector #10-B)



A. Oblique View B. Side View

FIGURE 3-2 - CRIMP DIE NOT PROPERLY ALIGNED (Connector #2-D)



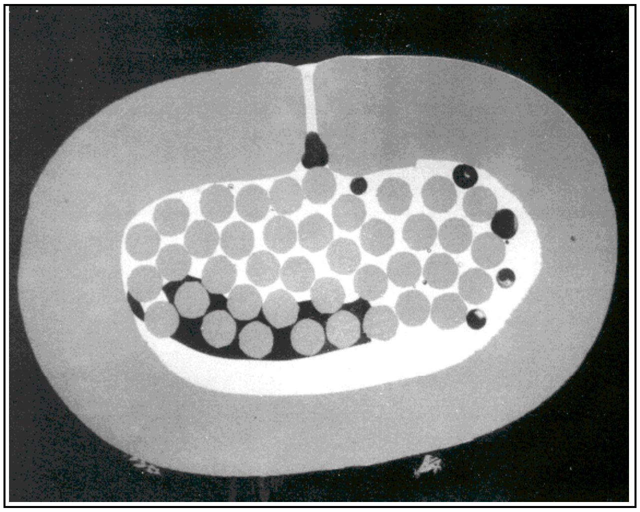
Ten percent (7 out of 71) of the crimp terminals examined had at least one strand of wire out of the crimp. All but one of these samples were pre-insulated type. Among the pre-insulated terminals the defect rate is 17% (6 out of 35). When the current in the wire and/or the number of misplaced strands is low, this defect may be innocuous. When a termination conducts relatively high current and the number of misplaced strands is high, as for instance the terminal illustrated in Figure 3-1 above, hazardous overheating failures may develop in service.

When all of the wire strands are not contained within the crimp, one consequence is the effective reduction of current-carrying cross section of the wire in the vicinity of the termination. Depending on the number of strands out of place, the effect can be substantial, causing destructive overheating in the vicinity of the connector.

A second consequence of misplaced wire strands is that the reduction of wire cross section within the crimp termination may result in inadequate compacting of the strands that are properly placed inside the crimp, causing high resistance and resulting overheating. This is essentially the same as might occur if one used a wire too small for the rated design of the terminal.

With regard to misaligned crimping die, more than 10% of the pre-insulated terminals (4 out of 35) were judged to have significantly misaligned crimps. The example shown in Figure 3-2 (connector #2-D) demonstrated relatively high and erratic connection resistance in the electrical testing (see Table 4-3 and Appendix page A-2). Figure 3-3 below show a cross section of connector #2-D taken close to the smallest (wire end) of the crimped termination after being soldered. (Soldering is done to maintain position of the strands when sectioning and also for the purpose of determining connection resistance - see Section 4.2.) The wire strands are clearly not compacted in this terminal. Essentially, the strands are loose within the crimp.

<u>FIGURE 3-3</u> SECTION OF CRIMP, CONNECTOR #2-D
(Section taken close to smallest portion of crimp, at the wire end, after soldering. The wire strands and connector body show up as grey, solder is white, and voids are black.)



4. ELECTRICAL PERFORMANCE

4.1 CONNECTION RESISTANCE

The fundamental measure of electrical performance of an electric wire termination is its electrical resistance. Resistance to current flow is a basic property of the circuit elements in the electrical current path. A crimped wire termination is a permanent electrical contact, with current passing from the wire strands to the connector body through conductive areas at the mechanical contact surface between the copper wire and the connector body. The connection resistance is the excess above what would be observed for a solid metal structure of the same geometry and materials. In fact, in an ideal crimp connection the connector body and the inserted wire strands are compressed into a virtually solid metal mass that is cold-welded at the contact interface. The measure of success and the predictor of longevity for a crimp wire termination is the connection resistance. The higher the connection resistance, the more likely the termination is to fail in service.

Connection resistance is generally expressed in micro-Ohms ($1\ \mu\Omega = 10^{-6}$ Ohm). For stranded wire terminations it is the cumulative result of three contributing factors; constriction resistance, film resistance, and "equalization" resistance. The first two combined are the components of what is generally called "contact resistance". Only a portion of the apparent contact interface is actual conductive current-carrying area, and this leads to a localized constriction of the current path. Constriction resistance is that due to the reduction of the effective conductive metal cross section area in the microscopic region leading to the conductive spots at the contact interface. The presence of nonmetallic films interposed between the metal components at the contact interface then causes additional resistance in series with the constriction resistance. For the materials of these terminations, oxide and corrosion films that are normally present on the contacting surfaces are resistive relative to the pure metal. The thickness and nature of the surface films is an important variable in the connection system.

The third factor contributing to connection resistance, equalization resistance, results from variations in contact resistance to each of the strands in the terminated wire(s). When the range of strand-to-strand contact resistance in the termination is large, there is a significant difference in the current carried by each strand of the wire. Strands with low contact resistance will carry higher current than strands with high contact resistance. In a sense, the equalization resistance is similar to the constriction resistance but on a macroscopic scale along the length of the wire. It is equivalent to a tapering reduction of the effective metallic cross section of the wire over a relatively long length as it approaches the crimp termination.

Low connection resistance of a crimp termination generally indicates adequate compression of the wire strands in the connector terminal and relatively large actual metallic area at the contact interface. These are the physical requirements for a stable, long-lived crimp connection. If the connection resistance is initially high, there is a corresponding high probability of progressive resistance increase in normal service that can lead to overheating and consequent hazards.

4.2 MEASUREMENT METHOD

Resistance is determined at room temperature at a controlled constant (AC) current of 10A. Potential drop is measured and resistance was then calculated by Ohm's law (R=E/I). Current input to the wires is applied upstream of an equalizer, which is simply a short section of the wire with the strands soldered together. Two measurements are required for each sample to determine the connection resistance. The first measurement is the potential drop of the connector and a section of the terminated wire, and it includes potential drop due to both the connection resistance and bulk resistance (wire and in some instances a section of the connector). Current is applied for approximately two seconds, the time necessary to register an initial relatively stable potential drop reading. A Fluke model #8840A digital multimeter is used to measure potential drop.

The crimped termination is then soldered and, after allowing sufficient time for cooling to room temperature, a second potential drop measurement is made between same measuring points. The potential drop of this second measurement includes that due only to the bulk resistance in the current path between the measuring points. The connection resistance is calculated from the difference between the two potential drop measurements. Figure 4-1 shows a representative wire termination.

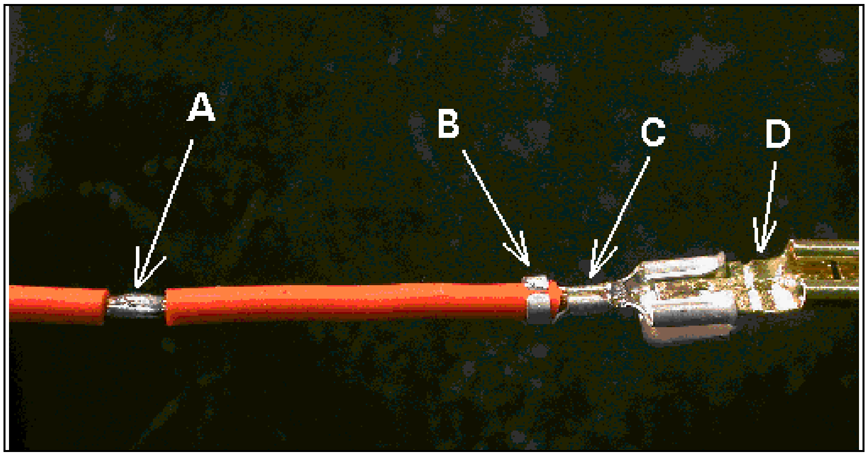


FIGURE 4-1 - REPRESENTATIVE TERMINAL (Sample #2E)

The equalizer is at "A". The wire is connected to the regulated current source at a point to the left of the equalizer. For this type of terminal, potential drop is measured between the equalizer and "B", which is the wire restraint (non current carrying) section of the terminal. After an initial potential drop measurement, the crimp termination "C" is soldered, and the measurement is repeated (after cooling to room temperature). Completing the current-carrying circuit, the terminal is connected to a mating connector tab "D".

The basic method is modified as required to accommodate different wire and connector configurations. For pigtail terminations (splices) the measurements were made between the equalizer on one wire and the equalizer on the other wire(s). The calculated connection resistance is then (appropriately) the wire-to-wire connection resistance of the splice. Provided that each pair of potential drop measurements (before and after soldering) are taken from exactly the same points and at the same (room) temperature, the result yields an accurate value of the connection resistance independent of the configuration variations.

4.3 EXPERIMENTAL RESULTS

For the purpose of comparison, the crimped wire terminals removed from the heaters are grouped according to type of crimp terminal and whether single or multiple wires are terminated together. Within each group may be samples from different manufacturers and of various configurations with respect to the way that they connect to the heater components (quick-connect, eye, and pin connectors, for example). All terminals are plated unless otherwise indicated. The groups are as described below, and tabulated results are provided in Tables 4-1 through 4-7.

Type A - Uninsulated when crimped, single wire. Within this group are both plated and unplated terminals.

Type B - Insulated (“pre-insulated”) when crimped, single wire.

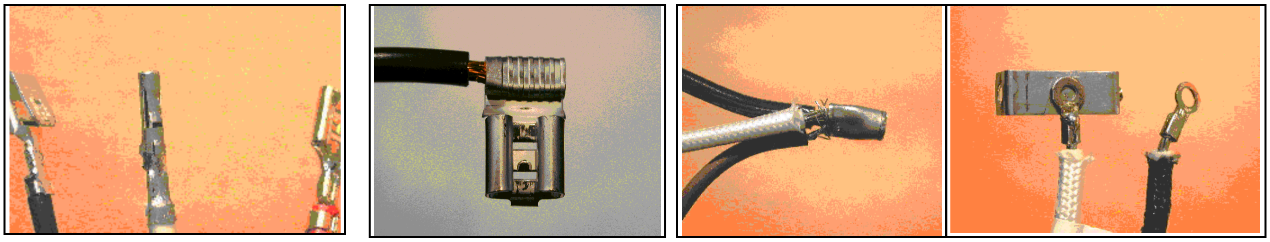
Type C - Insulated (“pre-insulated”) when crimped, multiple wire.

Type D - Insulated (“pre-insulated”) when crimped, “Flag” configuration (quick-connect extending off side of crimp).

Type E - Insulated (or “pre-insulated”) at crimping operation, multiple wire splice “pigtail” connectors (not connected or attached to any circuit component).

Type F - Uninsulated when crimped, plated steel connectors, part of heating element assembly.

Type G - Uninsulated when originally crimped, in-line splicing connector (used in these heaters to splice a thermal fuse into a circuit conductor).



Type "A" **Type "D"** **Type "E"** **Type "F"**
(types D and E shown after removal of insulation)

FIGURE 4-1 REPRESENTATIVE SAMPLES OF CRIMP CONNECTORS

CRIMP #	WIRE SIZE & COLOR	CRIMP DIMENSION (inch)	STRAND TO STRAND RANGE, mV	CONNECTION RESISTANCE (micro-ohms)
1-F	16 B	.064		1176
1-H	16 B	.069	10	1183
1-J	16 B	.074		573
2-C	14 B	.079		266
3-A	14 R	.075	18	900
3-B	14 W	.084		1091
3-C	14 W	.077	2.5	166
3-D	14 W	.074	1.2	595
3-E	14 B	.090		230
3-F	14 (plated) B	.075		165
4-A	14 (plated) B	.078	0.1	53
4-B	14 W	.078	24	2150
4-C	14 B	.078		1709

TABLE 4-1 - CONNECTION RESISTANCE, TYPE "A" UNPLATED TERMINALS
(uninsulated, unplated, single wire)

CRIMP # .	WIRE SIZE & COLOR	CRIMP DIMENSION (inch)	STRAND TO STRAND RANGE, mV	CONNECTION RESISTANCE (micro-ohms)
1-A	14 B	.082		761
1-B	14 W	.075		526
1-C	16 B	.074		61
1-D	16 B	.069		614
1-E	16 B	.066		647
1-G	16 B	.071	17.3	746
1-I	16 B	.062		599
2-A	14 B	.081	8	488
2-B	14 B	.078	12.3	454
2-E	14 R	.076		380
2-H	16 R	.076		364
4-D	14 B	.065		81
4-E	16 W	.066		225
4-H	16 B	.071	15.2	1097
4-I	16 W	.074	0.7	128

TABLE 4-2 - CONNECTION RESISTANCE, TYPE "A" TERMINALS
(uninsulated, plated, single wire)

Tables 4-1 and 4-2 include data on Strand-to-Strand voltage range taken on some of the terminations. This is the difference between the maximum and minimum potential drop observed at exposed strand ends at the end of the wires in the crimp connection. Under a stereoscopic microscope the ends of various strands in the measured connection are contacted using a needle probe tip on the meter lead. The maximum to minimum variation reflects the strand-to-strand current uniformity in the wire near the termination. A low value reflects low contact resistance to all wire strands in the crimp connection.

Also included in Tables 4-1, 4-2, and 4-7 are data on the minimum measured thickness of the compressed crimp. These measurements are made using a sharp-anvil dial caliper, and are accurate to the nearest 0.001". The crimp thickness is sometimes used as a setup and quality control parameter. Dimensional measurements are only taken on samples of uninsulated terminals. Due to wide variations in the crimping of the pre-insulated terminals, meaningful dimensional comparisons are not possible within the specimens examined.

CRIMP #	**WIRE SIZE & COLOR**	**CONNECTION RESISTANCE (micro-ohms)**
GROUP B-1		
2-D	14 B	1479
2-F	14 R	828
2-G	16 R	552
GROUP B-2	(different manufacturer than Group B-1)	
7-B	16 Y	140
7-C	16 BLUE	258
7-D	16 O	157
9-A	14 B	111
9-C	14 B	449
9-G	14 R	828
GROUP B-3		
6-B	14 B	54
6-C	14 B	109
8-B	14 B	171

TABLE 4-3 - CONNECTION RESISTANCE, TYPE "B" TERMINALS
(pre-insulated, plated, single wire)

CRIMP #	WIRE SIZE & COLOR	CONNECTION RESISTANCE (micro-ohms)
5-C	14 B + 20 B	497
5-D	16 W + 20 R	894
6-A	14 B + 20 R	155
6-D	14 B + 20 B	170
8-A	14 B + 20 B	151
9-B	14 B + 20 B	1059
9-F	14 B 14 R + 20 R	720
10-C	16 B + 20 B	635

TABLE 4-4 - CONNECTION RESISTANCE, TYPE "C" TERMINALS (pre-insulated, plated, multi-wire)

CRIMP #	WIRE SIZE & COLOR	CONNECTION RESISTANCE (micro-ohms)
SINGLE WIRE		
7-E	14 B	127
9-D	14 B	593
9-E	14 B	4158
10-A	14 B	149
MULTI-WIRE		
5-B	(2) 14 B	765
7-F	14 B + 20 R	255
7-G	14 B + 20B	62

TABLE 4-5 - CONNECTION RESISTANCE, TYPE "D" TERMINALS ("Flag", pre-insulated, plated)

CRIMP # .	WIRE SIZE & COLOR	CONNECTION RESISTANCE (micro-ohms)	
5-A	14 B + (2)16 B + 20 GY	384	(14 B to 16 B going to terminal 5-F)
		292	(14 B to 16 B going to terminal 5-G)
6-E	14 B + 16 W + 20 BR	331	
6-F	14 B + (2)16 B + 20 BR	257	
7-A	14 B + (4) 16 Y/O/Bl/Gy	925	(14 B to 16 Y)
		470	(14 B to 16 Blue)
		567	(14 B to 16 O)
7-H	(2) 14 B + 16 Gray	139	
8-C	14 B + 16 W + 18 Gy + 20 R	190	
8-D	14 B + (2)16 B	350	(14 B to 16 B with label)
		313	(14 B to 16 B without label)
10-B	14 B + 16 B + 20 B	412	

TABLE 4-6 - CONNECTION RESISTANCE, TYPE "E" TERMINALS
("Pigtail, pre-insulated, plated)

CRIMP # .	WIRE SIZE & COLOR	CRIMP DIMENSION (inch)	CONNECTION RESISTANCE (micro-ohms)
4-F	16 W	0.076	1297
4-G	16 B	0.080	10179
4-J	16 W	0.081	1124
5-E	16 W	0.081	202
5-F	16 B	0.082	427
5-G	16 B	0.082	657

TABLE 4-7 - CONNECTION RESISTANCE, TYPE "F" TERMINALS
(uninsulated, plated steel, part of heating element assembly)

Measuring more than 10,000 μΩ connection resistance, Specimen #4-G had the highest resistance of any in the study. Using thermocouple instrumentation, the temperature rise of this connector in free air at 10 amp current was determined to be 102 degrees C. The potential drop for this connection was somewhat erratic if measured over a period of minutes.

CRIMP #	WIRE SIZE & COLOR	CONNECTION RESISTANCE (micro-ohms)
3-G	14 B	160
3-H	14 B	70

TABLE 4-8 - CONNECTION RESISTANCE, TYPE "G" TERMINALS
(uninsulated, plated, in-line splices for thermal fuse)

Among the 71 connector samples, there are a total of 76 connection resistance measurements. (Some multi-wire connections have more than one path measured.) A summary of the overall connection resistance values is stated as follows:

70 samples (92%) exceed 100 μΩ connection resistance

51 samples (67%) exceed 250 μΩ “ “

12 samples (16%) exceed 1,000 μΩ “ “

2 samples exceed 2,500 μΩ “ “

1 sample exceeds 10,000 μΩ “ “

Overall, the performance is poor. The data for various subgroups suggests that performance for some is better than others. That is to be expected, since there are in fact substantive differences among the connection combinations evaluated. The sample size for each subgroup is too small, however, to support any such conclusions.

5. DISCUSSION

The underlying engineering principles of crimped wire terminations are well understood. It is necessary to establish adequate initial metallic contact at the wire-to-connector interface and subsequently maintain that contact over the long years of service. In service there are a multitude of factors that will cause the connections to deteriorate if the initial metallic contact is not adequate and secure. In many applications the deterioration can be tolerated; sometimes there are no harmful consequences of increasing connection resistance, and sometimes the life of the system (appliance, automobile, toy, etc.) is short relative to the life of the termination. Termination failure in fixed-position residential electric heaters can have severe consequences, and therefore failure-prone terminations should not be used in this application.

Determining whether or not a connection type is likely to fail in service in significant numbers in a particular type of application is generally judged by a test sequence. Relevant to the field failures that have occurred, the focus of the following discussion is on assuring the electrical contact/connection integrity.

First, the initial quality of the connection in terms of establishment of adequate metal-to-metal interface contact is determined. The fundamental measure of that quality is the contact or connection resistance. Relatively low contact resistance reflects maximum possible actual metallic contact at the interface. High resistance reflects substantially less conducting metallic area at the contact interface. To a first approximation, in a primarily metallic contact, the actual metallic area is inversely proportional to the contact resistance squared. A connection with contact resistance ten times the minimum for that design has about 1/100 of the actual conducting metallic area at the interface. Initial resistance (before testing or use) is therefore a significant indicator of connection quality.

Life testing must then be performed to assure that the predicted rate of deterioration (increase of connection resistance with time in service) is within acceptable limits for the application. Life testing consists of exposure of sets of connections to conditions replicating or accelerating the expected service conditions. The relevant service conditions that are expected to be present in fixed-position heater applications involve two different sets of conditions. When actually in use for heating, the connections are subject to cyclic current flow and elevated-temperature environment within the heater assembly. Temperature and current cycling tests are commonly used to replicate or accelerate this type of operating mode for connection life testing. When not in use for heating, the connections are subject to corrosion due to atmospheric moisture and corrosive contaminants and, additionally, ambient temperature fluctuations. Environmental testing is commonly used to replicate or accelerate this exposure for connection life testing.

On completion of life test exposures, connection resistance is again used as the measure of the condition of the contact interface. Typically, a maximum allowable deterioration (maximum resistance) after the life test sequence is set. Provided that the test sample size is large enough and the manufacturing variables are taken into account (worst-case testing), the rigorous testing described is a successful and accepted method for this type of crimped wire termination.

The basic connection acceptance procedure previously discussed is described in the paper "Contact Resistance Failure Criteria", by J.H. Whitley and R.D. Mallucci*, both of whom made outstanding contributions to electrical contact/connector technology over their long careers in research and development with major connector manufacturers. For acceptance of a crimped wire termination they suggest that the contact resistance after life testing should not exceed ten times the contact resistance calculated on the basis of a metallic contact area equal to the cross section area of the wire. Their procedure and the limits that they proposed had been applied successfully within their company. This is the so-called "**10R$_c$**" criterion. In the paper, they comment on this limit as follows:

> *"This criterion, which was at first vigorously opposed by both customer and producer (for opposite reasons), has proved to be both achievable and truly indicative of quality and reliability."*

For the #14 and #16 AWG wires of the heater element power circuits in this present study, their **10R$_c$** limits are 200 and 250 μΩ respectively. This would be the maximum allowable contact resistance after life testing. Among the crimp terminations evaluated in this study, 51 samples (67%) exceed 250 μΩ without application of any life test whatsoever. In other words, they fail the **10R$_c$** criterion as installed in new (unused) heaters.

Whitley and Mallucci point out that the underlying basis for application of a contact resistance criterion is the known fundamental physics of electrical contact (connection) behavior, but the **10R$_c$** limit itself is arbitrary. In other words, it is "in the ballpark" but could be adjusted up or down somewhat. Considering the results for the sample set of this present study, no reasonable upward adjustment of the allowable **R$_c$** limit could move the "ballpark" boundary enough. For instance, if an acceptance limit of **40R$_c$** was used (1000 μΩ, for the #16 wire), 12 samples (16%) would still fail - before any use or life test. The inevitable conclusion is that field failures and associated hazards are expected, and in fact a significant number have occurred.

Beyond the acceptance screening procedure, there must be effective quality control of the terminations as manufactured. Some of the problems apparent in the samples inspected are attributable to specific manufacturing defects or to the cumulative effect(s) of manufacturing variables. Examples of manufacturing defects are the improper insertion of the wires before crimping (wire strands outside of the crimp) and misaligned (or improper) crimping dies. As presently manufactured, the quality assurance procedures for the crimp terminations are inadequate.

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* Electrical Contacts - 1978, Proceedings of the Ninth International Conference on Electric Contact Phenomena and the Twenty Fourth Annual; Holm Conference on Electrical Contacts, Illinois Institute of Technology, Chicago, 1978

The crimp terminal cross sections demonstrate that a major underlying problem is lack of compressive force within the termination after crimping. In many instances the crimp is clearly inadequate, as in the cross sections previously shown in Section 4. Figures 5-1 and 5-2 below show two additional cross sections, for one of the best (lowest resistance) samples and one of the worst samples. The difference in compaction of the wire strands is evident.

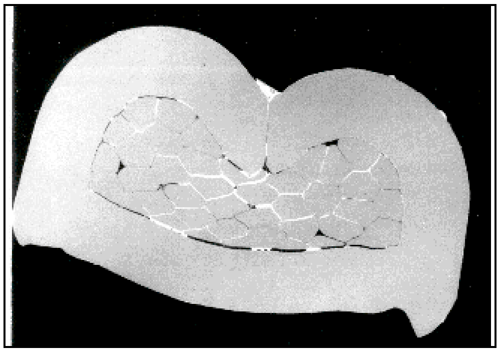


FIGURE 5-1 - CONNECTOR #4-D
Resistance = 81 µΩ

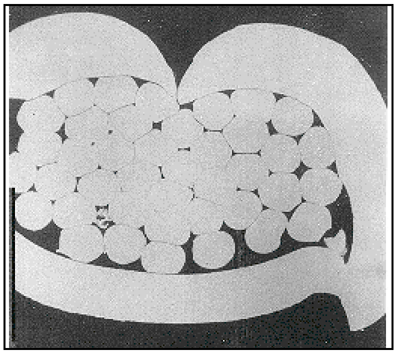


FIGURE 5-2 - CONNECTOR #4-B
Resistance = 2,150 µΩ

Comparing crimps of seemingly identical construction, there is no correlation between the crimp dimension and the initial resistance. For instance, one would conventionally assume that a smaller crimp dimension would correlate with a lower connection resistance. That is not correct, as illustrated by the results on the identical sample pair noted below.

Connector	Crimp Dimension	Connection Resistance
4-H	0.071”	1,097 µΩ
4-I	0.074”	128 µΩ

The lack of correlation is in part due to the large number of variables that influence the performance (resistance) of a crimped termination. In addition to the physical dimension and degree of compaction of the crimp, the performance is strongly influenced by surface films (oxide, corrosion) on both the wire and terminal and by their physical characteristics (hardness, metallurgical heat treatment).

The evaluation conducted in this study addresses only the initial quality of the connections. Life testing would also have to be conducted on the lowest resistance terminations to determine if they are capable of sustained low resistance under the worst-case conditions of actual use. Long-term deterioration of connections of this type is most often induced by corrosion-related processes. Even connections with the lowest initial resistance may be subject to long-term failure. That is why life testing is necessary for qualification of a connector type for the application.

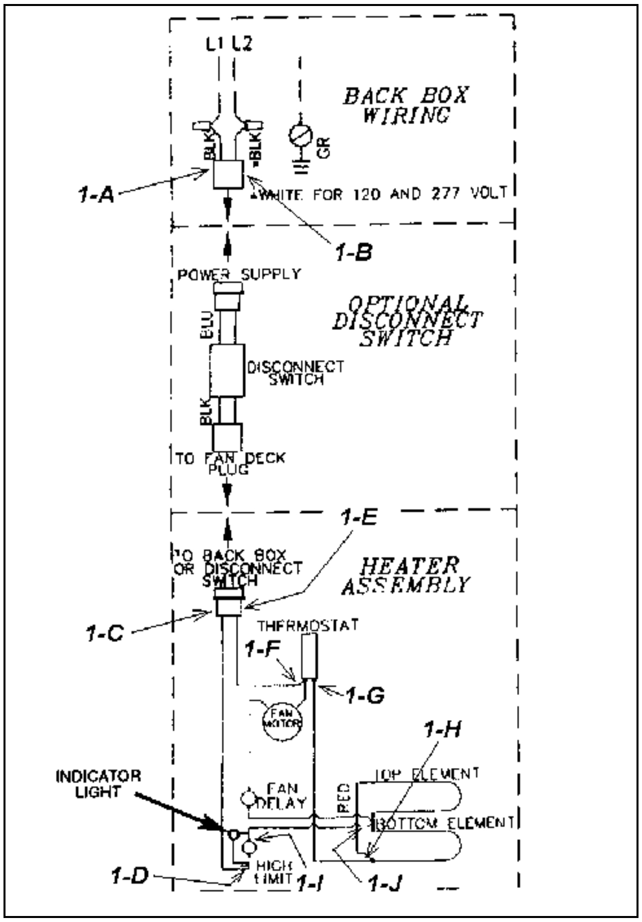
A crimp termination is conceptually visualized as a virtually solid mass of metal, with wire and terminal in intimate contact at the interfaces. Because of an effect generally called “ this is generally incorrect. Springback is the elastic recovery of the distorted metal back towards its original shape. While the crimping dies are closed on the terminal the surfaces are in contact. Springback then occurs when the crimping die is removed. If the outer terminal springs back more than the wire strands, then there is no residual compressive force at the contact interfaces within the termination. Open spaces develop where intimate surface-to-surface contact is expected. This is seen in the section Figure 5-1, above. There is a clear gap along the entire lower contact boundary, and between strands that clearly had been pressed together during the crimping operation. These spaces and gaps allow the ingress of moisture and atmospheric contaminants that can cause corrosion-related failure of crimp terminations in service.

APPENDIX A - HEATER AND SPECIMEN IDENTIFICATION

HEATER #1, 2000/1000W @240V (8.33A)

CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
1-A	A	AMP	14 B	power disconnect, female pin, plated
1-B	A	AMP	14 W	power disconnect, female pin, plated
1-C	A	AMP	16 B	power disconnect, male pin, plated, (Sectioned)
1-D	A	AMP	16 B	plated connector
1-E	A	AMP	16 B	power disconnect, male pin, plated, (Sectioned)
1-F	A	AMP	16 B	
1-G	A	AMP	16 B	Plated connector
1-H	A	AMP	16 B	
1-I	A	AM(P)	16 B	Plated connector
1-J	A	AMP	16 B	

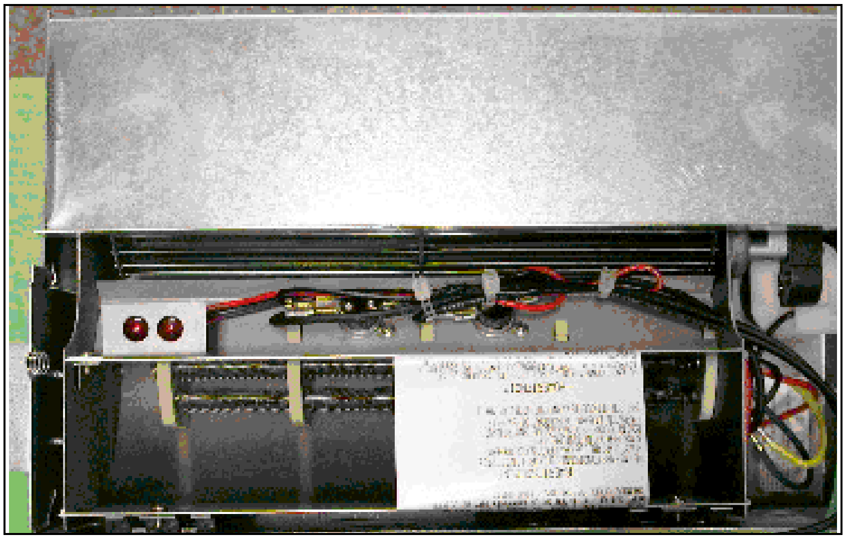
HEATER #1



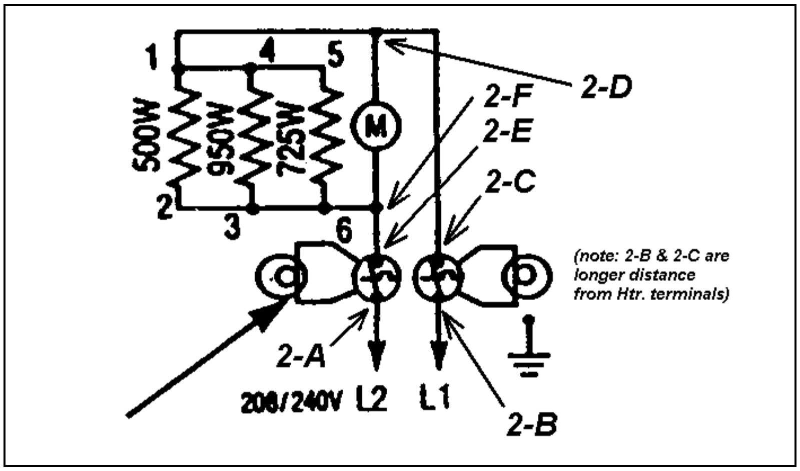
WIRING DIAGRAM*, HEATER #1

* From manufacturer's installation & use instruction sheet, modified.

	HEATER #2,			2200/1500/1100/750W @ 240V (9.17 A)
CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
2-A	A	AMP	14 B	Plated connector
2-B	A	AMP	14 B	Plated Connector, one strand out.
2-C	A	AMP	14 R	
2-D	B	AMP	14 R	Plated connector, dark blue insulation, erratic, Sectioned
2-E	A	AMP	14 R	Plated connector
2-F	B	AMP	14 R	Plated connector, dark blue insulation
2-G	B	AMP	16 R	Plated connector, dark blue insulation
2-H	A	AMP	16 R	



HEATER #2

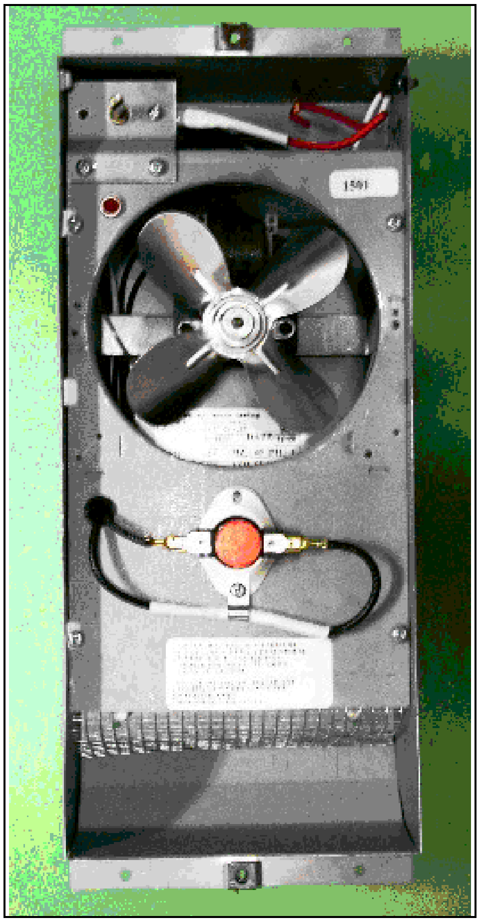


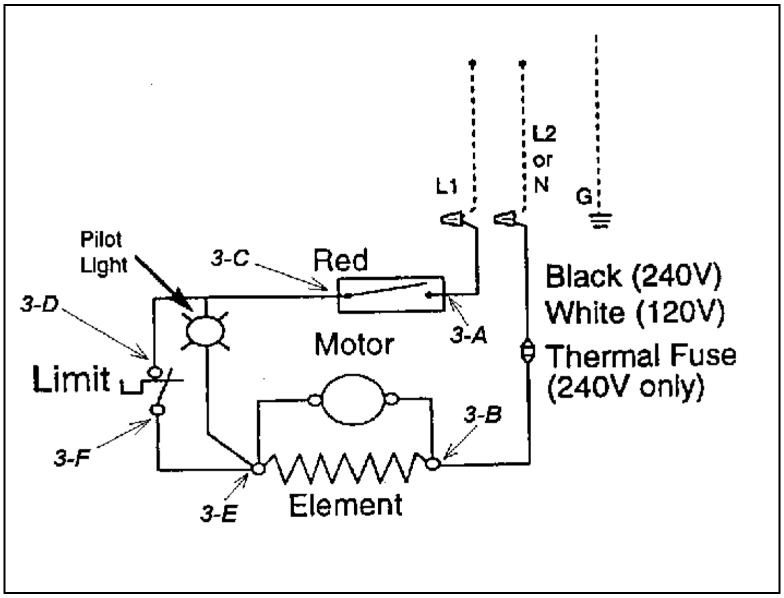
WIRING DIAGRAM*, HEATER #2

* From manufacturer's installation & use instruction sheet, modified.

HEATER #3, 1500W, 120V (12.5A)

CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
3-A	S	I: AMP	14 R	
3-B	A	AMP	14 W	wire size not marked on insulation
3-C	A	I: AMP	14 W	wire size not marked on insulation
3-D	A	I: AMP	14 W	wire size not marked on insulation
3-E	A	I: AMP	14 B	eye type lug, plated wire
3-F	A	I: AMP	14 B	plated wire, coarse stranding
3-G	G	AMP	14 B	Crimp to thermal fuse, plated wires
3-H	G	AMP	14 B	Crimp to thermal fuse, plated wires





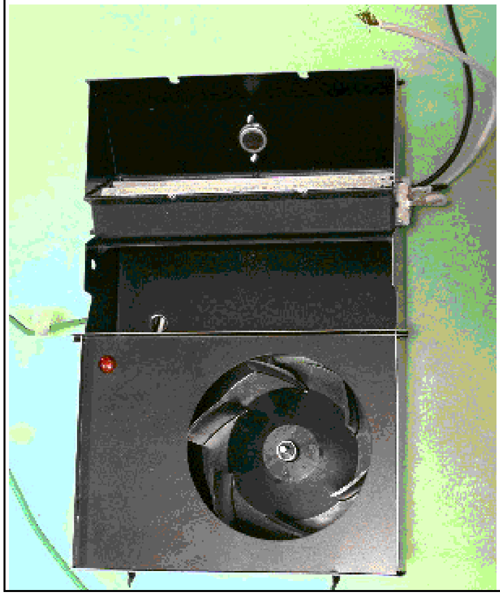
HEATER #3

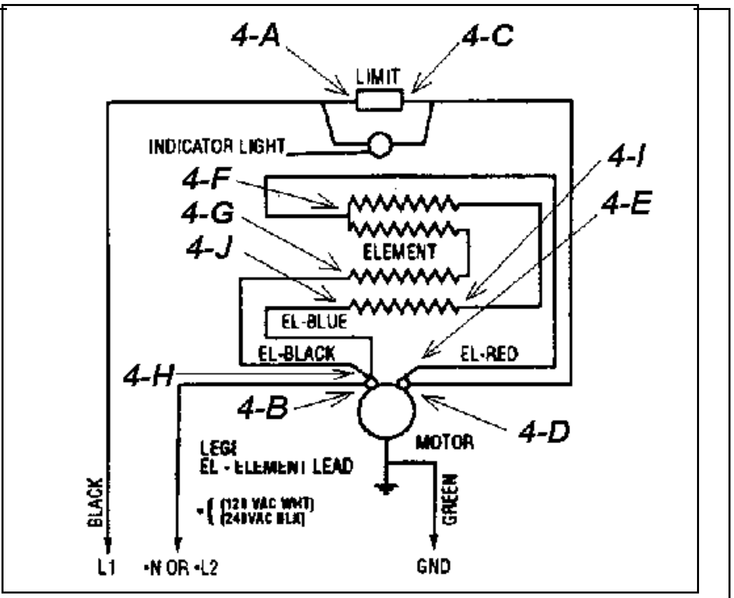
WIRING DIAGRAM*, HEATER #3

* From manufacturer’s installation & use instruction sheet, modified.

HEATER #4, 1500W, 120V (12.5A) (see ckt. diag. Wiring-04)

CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
4-A	A	AMP	14* B	* Plated copper wire
4-B	A	AMP	14 W	Sectioned
4-C	A	AMP	14 B	
4-D	A	AMP	14 B	Plated Connector, Sectioned
4-E	A	!	16 W	Plated Connector
4-F	F		16 W	Plated Connector, Part of Heater Assembly
4-G	F		16 B	Plated steel connector, Part of Heater Assembly, wire strands soldered, temp rise greater than 120C @10A, potential drop erratic, up to 0.5 volt measured.
4-H	A	!	16 B	Plated Connector
4-I	A	!	16 W	Plated connector
4-J	F		16 W	Plated Connector, Part of Heater Assembly, wire strands soldered





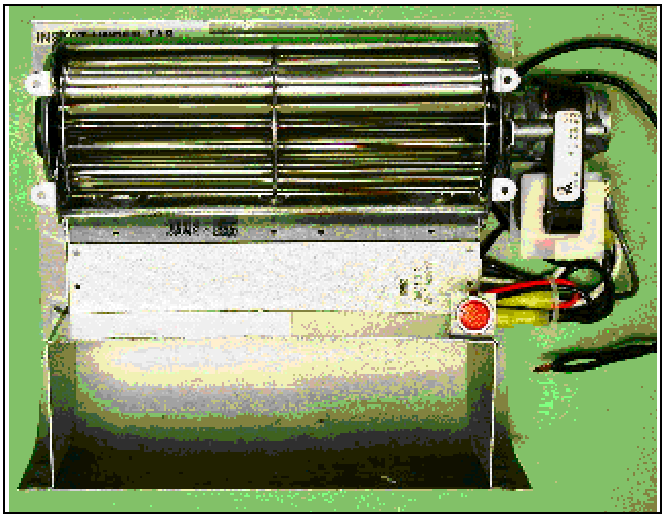
HEATER #4

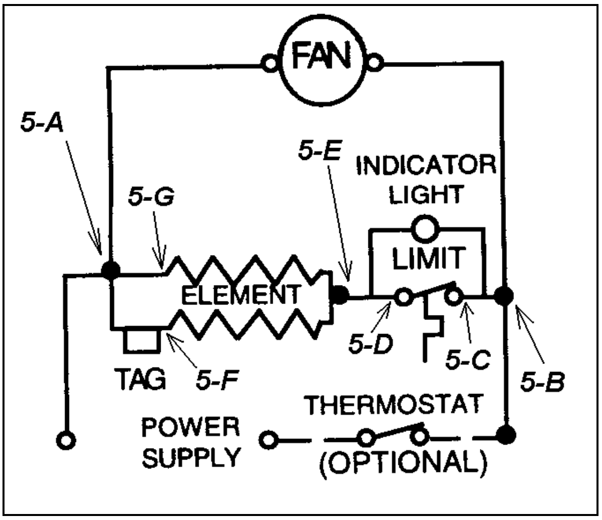
WIRING DIAGRAM*, HEATER #4

* From manufacturer's installation & use instruction sheet, modified.

HEATER #5, 2400W @240V (10A)

CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
5-A	E	MX/ETC 16-10	14B+ (2)16B+ 20GY	Plated connector, strand of gray wire not in crimp
5-B	D	ETC 12-10	(2) 14 B	Plated connector
5-C	C	ETC 12-10	14 B + 20 B	Plated connector
5-D	C	ETC 12-10	16 W + 20 R	Plated connector, W wire plated, 2 strands R wire not in crin
5-E	F		16 W	Plated steel connector, Part of heater assembly, plated wire
5-F	F	?	16 B	Plated steel connector, Part of heater assembly, plated wire
5-G	F	?	16 B	Plated steel connector, Part of heater assembly, plated wire



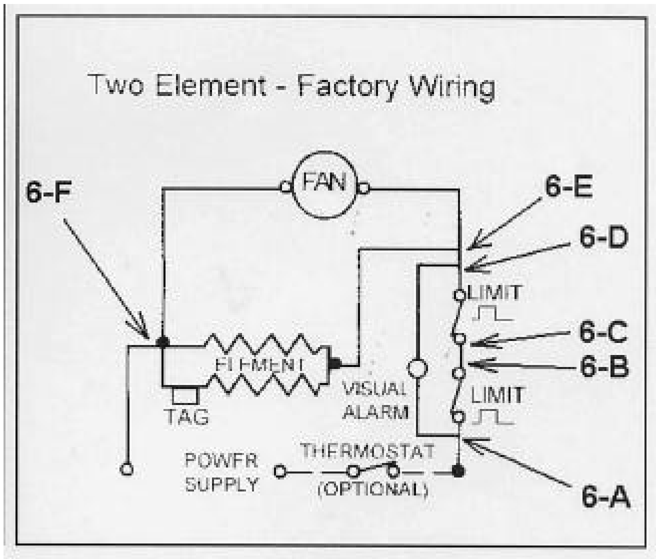


HEATER #5

WIRING DIAGRAM*, HEATER #5

* From manufacturer's installation & use instruction sheet, modified.

	HEATER #6,		maximum 2000W @240V (8.33A)	
CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
6-A	C	ETC 12-10	14 B + 20 R	Plated connector
6-B	B	ETC 16-14	14 B	Plated connector, has extra sleeve, Sectioned
6-C	B	ETC 16-14	14 B	Plated connector, has extra sleeve
6-D	C	ETC 12-10	14 B + 20 B	Plated connector
6-E	E	ETC 16-10	14B+16 W+20BR	Plated connector & #16 W wire, several Br wire strands not in crimp
6-F	E	ETC 16-10	14B+(2)16B+20BR	Plated connector, strands of Br wire not in crimp



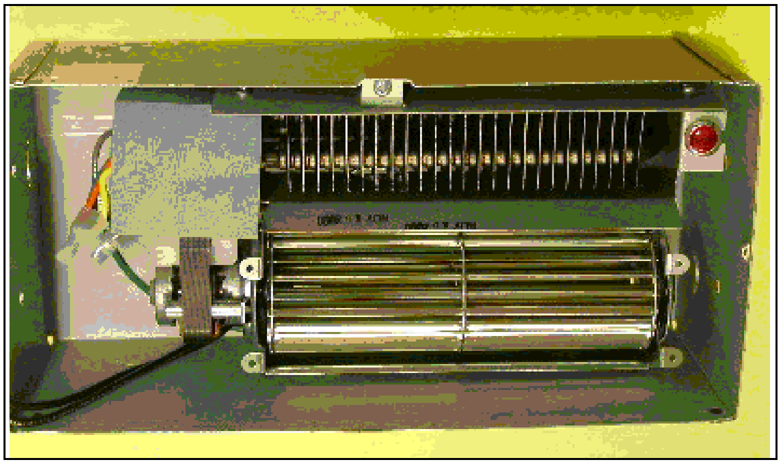
HEATER #6

WIRING DIAGRAM*, HEATER #6

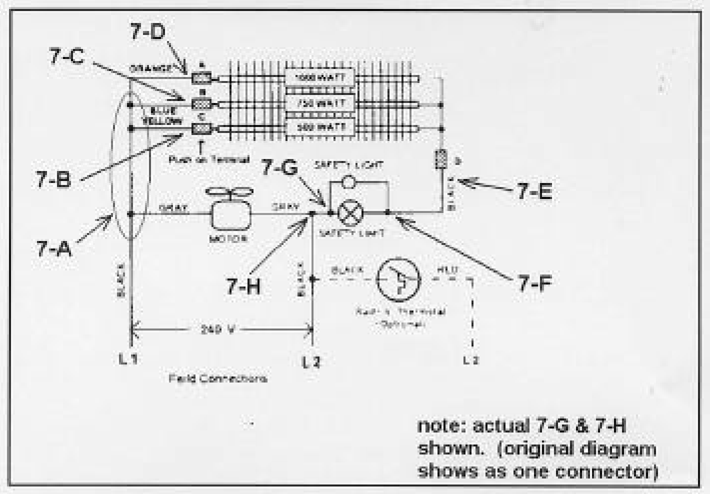
* From manufacturer's installation & use instruction sheet, modified.

HEATER #7, **maximum 2250W @240V (9.4A)**

CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
7-A	E	/ETC 8 NC8	14 B+ (4) 16 Y/O/Bl/G	Plated connector
7-B	B	ETC 16-14	16 Y	Plated connector
7-C	B	ETC 16-14	16 BLUE	Plated connector
7-D	B	ETC 16-14	16 O	Plated connector
7-E	D	ETC 16-14	14 B	Plated connector
7-F	D	ETC 12-10	14 B + 20 R	Plated connector, one strand of #20 R not in crimp
7-G	D	ETC 12-10	14 B + 20 B	Plated connector
7-H	E	ETC 16-10	(2) 14 B + 16 Gray	Plated connector



HEATER #7

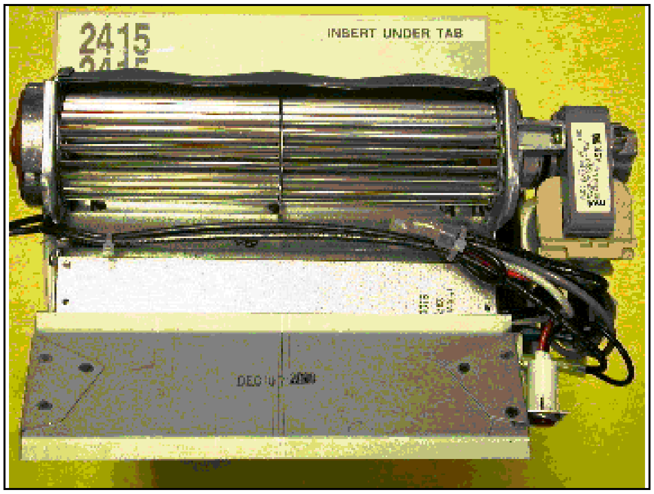


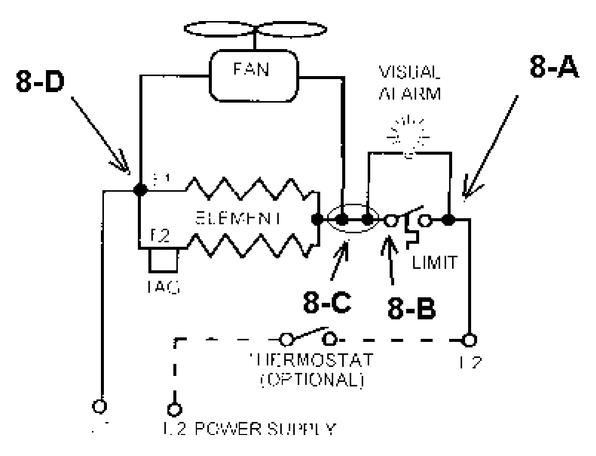
note: actual 7-G & 7-H shown. (original diagram shows as one connector)

WIRING DIAGRAM*, HEATER #7

* From manufacturer’s installation & use instruction sheet, modified.

	HEATER #8,		**maximum 1500W @240V (6.2A)**	
	(as received, limiter bracket distorted & broken from heater element insulating plate)			
CRIMP #	**TYPE**	**MARKING**	**WIRE SIZE & COLOR**	**NOTES**
8-A	C	ETC 12-10	14 B + 20 B	Plated connector, 2 strands of #20 out of crimp
8-B	B	ETC 16-14	14 B	Plated connector
8-C	E	ETC 16-10	4 B+16W+18Gy+20	Plated connector, has extra sleeve
8-D	E	ETC 16-10	14 B + (2) 16 B	Plated Connector, #16 wires plated, loose strand from #14 wire



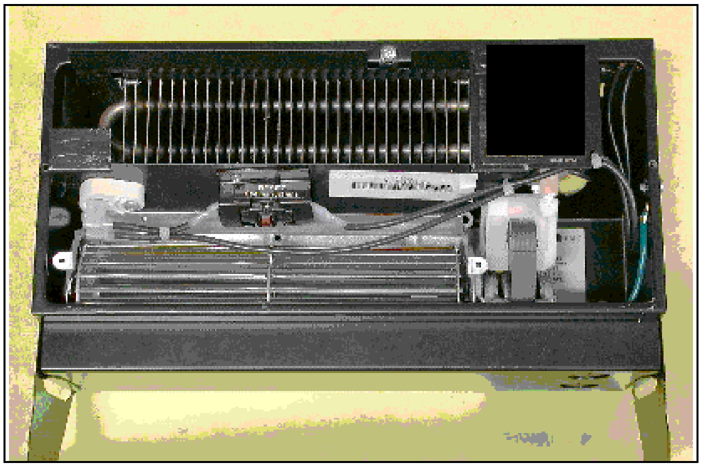


HEATER #8

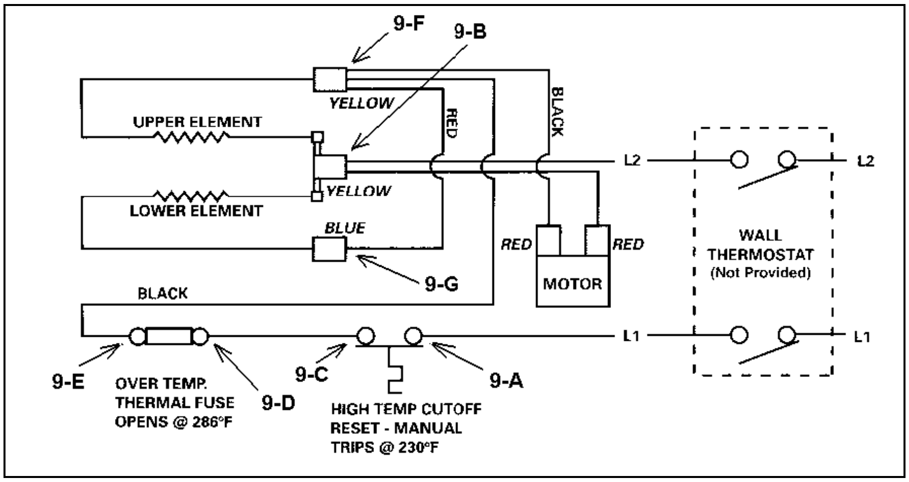
WIRING DIAGRAM*, HEATER #8

* From manufacturer's installation & use instruction sheet, modified.

	HEATER #9		2000W @240V (8.33A)	
CRIMP #	TYPE	MARKING	WIRE SIZE & COLOR	NOTES
9-A	B	ETC 16-14	14 B	Plated connector
9-B	C	ETC 12-10	14 B + 20 B	Plated connector
9-C	B	ETC MX 16-14	14 B	Plated connector
9-D	E	ETC 16-14	14 B	Plated connector
9-E	E	ETC 16-14	14 B	Plated connector
9-F	C	ETC 12-10	14B + 14R + 20B	Plated connector
9-G	B	ETC 16-14	14 R	Plated connector



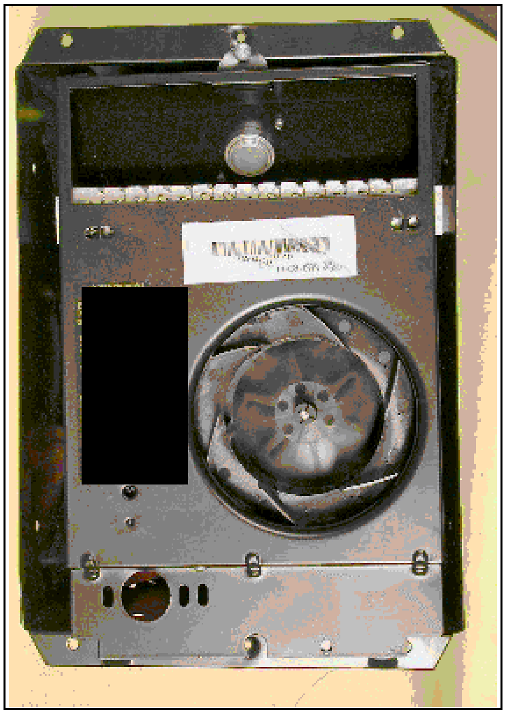
HEATER #9



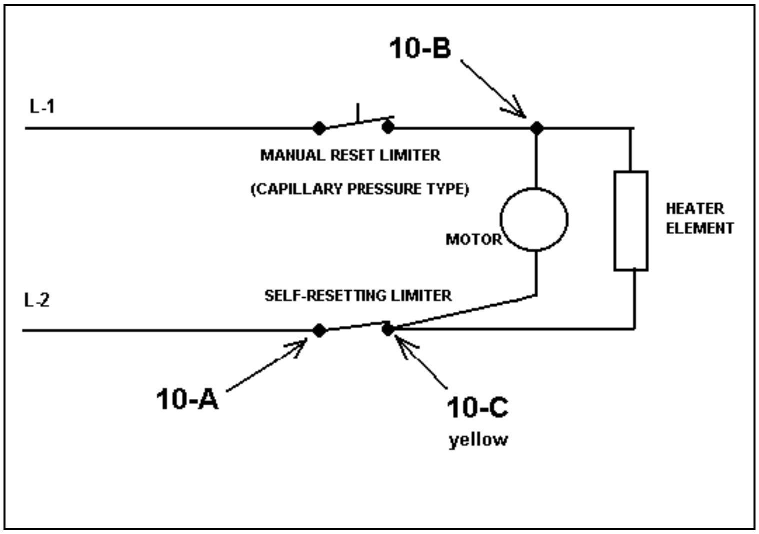
WIRING DIAGRAM*, HEATER #9

* From manufacturer's installation & use instruction sheet, modified.

	HEATER #10		1500W@240V (6.2A)	
CRIMP #	**TYPE**	**MARKING**	**WIRE SIZE & COLOR**	**NOTES**
10-A	D	ETC 16-14	14 B	plated connector
10-B	E	ETC 03MX 16-10	14B+16B+20B	Plated connector, #20 pre-soldered,
10-C	C	ETC 12-10	16 B + 20 B	Plated connector, #20 pre-soldered, loose strands


[redacted]

HEATER #10



WIRING DIAGRAM*, HEATER #10

* From manufacturer's installation & use instruction sheet, modified.