Retrofitting Knob and Tube Wiring
An Investigation into Codes, Assessment, Wiring Practices and Cost

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Introduction

In 1987, an amendment to the National Electric Code (NEC) prohibited the placement of insulation in contact with knob and tube (K&T) wiring. This amendment had a significant impact for low-income weatherization programs around the nation. Retrofitting insulation into sidewalls and attics where K&T or faulty wiring often exists is a major part of that activity and accounts for the greatest energy savings return for weatherization dollars spent. In addition to the code issue of insulating over K&T wiring there are often unsafe alterations, junctions or splices, which must also be addressed prior to insulation activities.

During the summer of 2002, the Pennsylvania Department of Economic and Community Development (PA DCED), the Weatherization Training Center (WTC) at Penn College and STEP Inc., a Weatherization Assistance Program provider, entered into a joint research project. Its purpose was to attempt to identify simple and cost effective wiring retrofits and prescribe safe methods for installing thermal insulation where K&T wiring exists.

During the project, STEP Inc. reviewed 190 jobs that were already receiving weatherization services or were at the audit stage. Twenty three jobs were found to have existing knob and tube wiring. A total of six homes, representing a diverse cross section of housing stock and wiring scenarios, were selected for wiring retrofits. The reports on the work performed are contained in Appendices 3-8.

The goals and expected outcomes of this project were as follows:

- Identify electrical hazards in areas where insulation is planned.
- Establish key elements of an inspection protocol with respect to code and electrical safety.
- Attempt to identify effective and economical methods for addressing K&T wiring or repairing faulty electrical components prior to the installation of thermal insulation.
- Identify competency requirements for those performing electrical work
- Provide conclusions and recommendations.
Overview of Knob and Tube Wiring

Knob and tube wiring was introduced to homes in the 1920’s and continued up to the mid 1950’s. This type of wiring method incorporated single conductors run along the sides of structural members such as floor joists and roof rafters. Knob and Tube wires were fastened to these members with ceramic knobs, keeping the wire spaced away from direct contact with the wood structure. A ceramic tube was installed where the wire passed through a floor joist, keeping the wire from direct contact with the wood. Knob and tube splices were made in the free air space of the structure’s cavities. Commonly referred as “pig-tails,” these splices were fashioned by wrapping one wire around the other wire, soldering the connection and covering with cloth electrical tape. Ceramic tubes were placed close to these splices to relieve the stress on the splice.

Examples of Knob and Tube Wiring

Service Panels

Service or fuse protection in 1920 to 1930 housing stock was usually installed in the attic or on an exterior enclosed porch wall. The fuse panels were 110 volts and consisted of one or two fuses, which protected a single circuit in the house. As modern electrical needs grew in the 1950’s, 240 volt service fuse panels replaced the 110 volt panels. These fuse panels had a limited number of circuits (usually a main lighting and range circuit) and included four fuses to service all the lighting and receptacle loads.

Service panel in attic containing a fused main “disconnect” and three fused circuits
Age of dwellings

Research has shown that fire rates increase as the age of the dwelling increases. In a 1990 survey of 149 electrical fires investigated, the rate of fires in dwellings over 40 years old was 1.5 times that of dwellings 21 to 40 years of age and about 3 times that of dwellings 11 to 20 years old (see Appendix 1). This research project identified that 34% of all the fires investigated originated on branch-circuit wiring. A further breakdown of the number of fires on branch-circuits indicated that fifteen fires were due to mechanical damage or improper installation, eleven from poor or loose splices, six from ground faults, six from miscellaneous overloads, three from improper wiring and three due to knob-and-tube wiring being encapsulated in insulation. Knob and tube wiring only played a small role in the incidents of fire in this study.

Therefore, the safety concerns are not about the knob and tube wiring itself but the alterations and modifications performed on the original wiring. Ceiling light fixtures are an exception, however. Heat generated from years of service and possible overlamping of the light fixture causes the insulation of the fixture as well as the knob and tube wire to degrade and become brittle if disturbed. There is high probability of failure when this condition is present.

Fig.1

Heat damage from the light bulb of the ceiling fixture causing the insulation on the knob and tube wires to break down. This damage is usually only found around the area of the light fixture. Also, the wires within the light fixture and socket itself are often deteriorated.

Alterations

As modern electrical needs grew over time, alterations were performed by homeowners or persons not qualified as residential electricians. Many alterations were not up to standard wiring practices. Considering factors such as the limited number of original receptacles per room, the difficulty of adding new circuits to an existing structure and a limited number of original circuits at the fuse panel, these alterations usually put added stress on the existing wiring system. Knob and tube wiring has the greatest potential for abuse.
When these circuits become overloaded by electric space heaters, window air conditioners, refrigerators and other modern appliances, the properly sized 15-amp fuse usually blows. Some homeowners will replace this 15-amp fuse with a 30-amp fuse to rid themselves of this annoyance.

“Over fusing” significantly raises the temperature of the wires and connections beyond their designed temperature limits. Since the weakest link of the chain is now the wire or faulty connection and not the fuse; a fire hazard may now exist.

All six of the case study houses involved in this project had “do-it-yourself” alterations performed at one time or another. Most of the alterations were of a serious nature and not code compliant. The following cases illustrate a few of the problems found:

**Fig.2**

A newer ungrounded 2 conductor wire was connected to knob and tube wire above the crawl space ceiling. This newer type of wire fed a wall mounted light fixture above the kitchen sink. The light fixture had an on/off switch on the light fixture. This light was easily accessible while standing at the sink. To make matters worse, a 120-volt lamp cord extension was open spliced into the ungrounded wire for an appliance receptacle.

**Fig.3**

There were no wire connectors used to keep the wires from rubbing on the bathroom metal fan/light housing. The fan also had excessive vibration due the dirt buildup on the fan blades. The fixture was not fastened to the structural members and was resting on the plaster lath ceiling.
Fig. 4

There are three different types of wiring connected to this closet light box. Old two-wire cable in the foreground and newer grounded wire with the ground folded back were connected to the original knob and tube wiring. All splices were made outside the box in the attic floor cavity. The ceiling box is being supported by two pieces of wood lath run through the sides of the box.

Fig. 5

A receptacle was needed to feed an air conditioner in the living room. The homeowner made a hole in the basement heating ductwork for easy access to the floor above. Once the wire was brought to that location, another hole was made in the ductwork. A hole was then drilled through the wall stud so that a receptacle could be installed under the window.
Fig. 6

A light duty extension cord was connected to the basement light fixture to add a receptacle for some basement woodworking equipment. The extension cord also had an open splice and was supported by a knot in the cord and a nail.

Fig. 7

This open splice was found in a laundry room addition. The homeowner tucked the wire and open splice into the corner of the original exterior aluminum siding and new drywall. The joint was then sealed with silicone caulking.
Fig. 8

After removing a section of tongue and groove flooring in the attic, a taped splice was found. This splice was fashioned into two pieces of rubber extension cord, which supplied power to a kitchen fan/light.

The types of alterations pictured above were common to all of the houses involved in this project. Most of these “do-it-yourself” alterations were not discovered during the original site evaluation and were discovered only after flooring had been removed or other hidden areas accessed.
Knob and Tube Wiring and the National Electrical Code,


“Concealed knob-and-tube wiring is designed for use in hollow spaces of walls, ceilings, and attics and utilizes the free air in such spaces for heat dissipation. Weatherization of hollow spaces by blown-in, foamed-in, or rolled insulation prevents the dissipation of heat into the free air space. This will result in higher conductor temperature, which could cause insulation breakdown and possible ignition of the insulation.”

While the NEC is clear about disallowing insulation over K&T wiring, the NEC does not discuss the more serious fire hazards resulting from alterations of the original knob and tube wiring. By not insulating these areas, the free air space will offer some protection from overheated splices or connections.

Voltage Drop, Resistance and Heat Generation

Heat is generated in a circuit whenever current flow (amperage) encounters a resistance to the flow. Voltage drop normally occurs when current passes through a wire. A small voltage drop of approximately 1 to 5 % is expected in all electrical circuits. The greater the resistance of a circuit, the greater the voltage drop. Excessive voltage drop can cause excessive heat, creating a concern of the safety of the circuit.

Excessive voltage drop is caused by high resistance in a circuit when:
1. There is a long run of wire of insufficient gauge or size of the wire for the run.
2. The wire size is too small to carry the load.
3. There are point source(s) of high resistance. These include:
   - Poor splices
   - Corroded connections

High resistance point sources, such as loose or corroded connections, should raise the greatest concern before adding thermal insulation (see Appendix 2). Excessive voltage drop also leads to poor efficiency, wasted energy, higher electric bills and damage to electrical equipment.

The National Electrical Code 2002 article 210-19 (a) FPN 4 (“Fine Print Notes”) discusses voltage drop, which states: “where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent, provide reasonable efficiency of operation”
It should be noted that the NEC further defines “Fine Print Notes” as being for informational purposes only. They are not enforceable and are therefore not a mandatory rule. Fine Print notes relate to “reasonable efficiency” of electrical equipment and not fire safety.

Pre and post wiring retrofit voltage drop tests were conducted on a cross section of houses that were included in this project. A “Sure Tester 61-151” that simulates a 20 amp load was used. The tests were performed at ceiling light fixtures and wall receptacles before and after rewiring the old knob and tube. The voltage drop readings indicated only slight reductions and were still well above the 5% suggested values. The voltage drop was checked at the service panel, meter base, weatherhead and the utility equipment.

As an experiment, a wire was disconnected from the circuit at the panel, which fed the area to be rewired. A temporary cord with a receptacle was then installed to accept the voltage drop tester. This cord was connected directly onto a fuse or breaker. The resulting voltage drop reading was then subtracted from the post rewire readings. All of the houses inspected indicated 2 to 3% voltage drop on the service equipment. Subtracting the service voltage drop from the post voltage drop readings of the interior wiring brought most of the total circuit voltage drop values well below 5%. The remainder did not exceed 7%. The pre and post voltage drop field data for the houses can be found in Appendices 3-8.
Electrical Inspection Protocol

This section will discuss electrical inspection protocols followed during the course of this project. They represent standard methods for assessing the safety of knob and tube wiring and provide guidance to the decision making process for K&T wiring retrofits in general.

Access

Improper alterations or modifications that have been made to the original knob-and-tube wiring are often difficult to detect.

Some of the issues are:

- Floored attics
- Inaccessible attic spaces
- Homeowner stored items
- Roof design
- Health and safety issues
- Structural problems

Decision Tree

Different ages and types of houses and the quality of the workmanship of any alterations will likely present challenges in determining the scope of the electrical work needed before thermal insulation may be installed. Key elements to be addressed in an inspection protocol are as follows:

- Identify the attic knob and tube feed circuit at the service panel and determine if any other areas of the house or appliances are on the same attic circuit.
- Determine whether wall or floor receptacles are also being fed from the same knob and tube circuit.
- Identify whether any additional loads on the knob-and-tube are putting stress on the wires. These include seasonal loads such as window air conditioners and portable electric heaters that may not be present during the initial investigation.
- Determine the size and condition of the service panel.
- Determine whether any of the circuits are doubled up in the service box (more than one wire on a fuse or breaker).
- Determine if there any open circuits available at the service panel and whether a new feed will be needed.
- Observe whether chase ways are available within the building enclosure to run new feed wires if needed.
- Determine whether the service panel is properly grounded to current code requirements.
- Determine whether the wires are fused or have the proper breaker sizes for the wire connected to it.
- Identify sub-feed panels that could be utilized for a new feed.
- Determine whether any sub-feed panels are installed to current code requirements.

**Note:** If homeowner alterations are in plain view, anticipate that there will likely be other modifications that are hidden from view.

**Note:** The preliminary assessment of the condition of the electrical system may be done by a trained weatherization auditor/inspector. However, only qualified electrical technicians should assess and make decisions on electrical retrofits.
Conclusions and Recommendations

Wiring Safety and the National Electrical Code

The National Electrical Code 2002 Article 394.12 clearly states that any type of insulation should not be installed over active knob-and-tube wiring. Insulating over K&T wiring would therefore be in violation of the National Code and place WAP subgrantees at risk for liability in cases where the root cause of a fire could be traced to insulation in contact with K&T wiring.

Properly installed and unaltered K&T wiring is not an inherent fire hazard. The research shows that insulating over knob and tube wiring, when that wire is free of problems is rarely a fire hazard. However, insulating over wires can be a critical contributing factor to creating a fire hazard when other problems, such as loose connections or excessive electrical loads, are present. Older housing stock has the greatest potential for alterations due to the increase of modern electrical needs and where those alterations are not up to standard wiring practices. Research indicates that incidences of electrical fires increase with the age of the building and that electrical fires associated with faulty wiring are one of the primary causes.

An inspection protocol for evaluation of knob and tube wiring was developed and utilized throughout the project. Repair scenarios in the accompanying case studies ranged from a simple utilization of the existing knob and tube feed installed into new junction boxes to a radical rewire of the entire top floor with new sub feeds to the service panel. In all cases, NEC code was adhered to. It should be noted that any electrical components installed in conjunction with a wiring retrofit must be done in accordance with the NEC code as they were during this project.

Costs

The cost of replacing a single knob and tube feed line completed by an electrical contractor, by bid, on the case studies ranged from $706 to $2,477. These costs included material, an electrical inspection fee and labor. A labor rate of $28 per person-hour was applied and represents an estimate of the average electrician’s rate for residential applications in PA. Some metropolitan areas may command a higher rate.

Solutions

One of the primary goals of this project was to identify simple, cost effective solutions to bypass K&T wiring in preparation for attic insulation. During the course of the project it was found that unsafe alterations and other problems identified in the sample homes accounted for a majority of hazards.
In short, there is no “silver bullet” where one or two simple types of K&T retrofit measures may apply to a majority of homes. There may be some exceptions to this in areas containing a predominant type of housing stock such as row houses in the City of Philadelphia. The case studies presented in the appendices of this report clearly demonstrate a variety of problems and solutions that did not follow a consistent pattern. The majority of hazards were related to improper alterations, open splices or loose connections and not necessarily to the K&T wiring itself. Also, visual inspection of the electrical wiring system was often complicated due to inaccessible attic spaces, tight clearances, floored attics and items stored by the homeowner.

To insure the safety of the clients, the weatherization program has an obligation to act responsibly in a number of areas of health and safety. This includes following applicable codes related to wiring safety. In summary, the expertise and costs involved in potential K&T wiring retrofits may fall well outside of the scope of what may be defined as preparatory measures in weatherization and may, in some cases, exceed the cost of the energy retrofit itself.

Agencies should not, however, take the position that if knob and tube wiring exists in attic or wall cavities, they may simply walk away from the insulation retrofit. In many cases the wiring may simply be tented over in open attics prior to insulating. Suspicious looking wiring junctions may be identified and dammed prior to insulation. In closed cavities such as shallow roofs, floored attics or walls, insulation should not be blown in blind. Verify whether or not knob and tube wiring or unsafe splices exist. Then avoid those cavities or protect the localized problem area.

**Competency Requirements**

Being able to interpret problems and devise solutions on an electrical system that utilizes existing K&T wiring is often a difficult task and requires a considerable amount of expertise. Detailed assessments and retrofits should only be performed by qualified electricians. Preliminary assessments of the condition of the electrical system may be performed by qualified weatherization auditors or trained technicians. At the very most, the role of a weatherization technician should be limited to the following operations:

- installing open splices into junction boxes
- covering junction boxes
- installing S type fuses
- installing wire connectors
- damming or tenting over suspect wiring prior to installing insulation

It is also reasonable to assume that weatherization technicians may be trained to recognize unsafe wiring and prevent insulation from coming in contact with it. It is recommended that the PA Weatherization Training Center develop a training module to address the issues described above.
Other Conclusions

Voltage drop testing using an Ideal “Sure Tester” was performed in all of the case studies for the purpose of attempting to draw conclusions about the integrity of the wiring. Published research and experience drawn from this project demonstrated that voltage drop testing has serious limitations. This equipment and the testing protocol is designed to identify locations of high resistance (bad connections). It will, however, only display the total voltage drop of the circuit being tested such as a ceiling light fixture, the electrical service panel, the meter base and utility transformer. Also, different models of voltage drop testing equipment have been found to produce different voltage drop readings at the same test site. Therefore, various interpretations about the safety of the wiring may result. More research needs to be conducted on the newer models of voltage drop testing equipment to validate field observations.
References and Resources

Bibliographic References


“What Causes Wiring Fires in Residences,” Linda E. Smith and Dennis McCoskrie, Fire Journal, January/February 1990:


“Handbook, Branch-Circuit Ratings Article 210-19 (a) FPN,” National Electrical Code 2002:

“Five Percent Voltage Drop- A Closer Look,” John M. Birkby, Mike Holt Enterprises, Inc, International Association of Electrical Inspectors, July 1999:

“Asessing the Integrity of Electrical Wiring,” Larry Kinney, Home Energy Magazine, September/October 1995:

Personal Interviews and Correspondence

David Kranz, Kranz Inspection Service, Inc., Williamsport, PA.

David G. Holdren, Commonwealth Electric Inspection Service, Inc. Williamsport, PA.

David Stone, PE. Williamsport, PA.


Fred Eiswerth, Economic & Community Development, Williamsport, PA.
Appendix 1

Contributing Factors Involved in Residential Electrical Fires by Age of Dwelling

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>Number</th>
<th>Percent</th>
<th>&lt;10</th>
<th>11-20</th>
<th>21-30</th>
<th>31-40</th>
<th>Over 40</th>
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<tr>
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<td>2</td>
<td>9</td>
<td>7</td>
<td>29</td>
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<td>Improper Initial Installation</td>
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<td>4</td>
<td>8</td>
<td>3</td>
<td>7</td>
<td>4</td>
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<tr>
<td>Deterioration Due to Aging</td>
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<td>3</td>
<td>5</td>
<td>9</td>
<td>6</td>
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<tr>
<td>Improper Use</td>
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<td>1</td>
<td>2</td>
<td>5</td>
<td>13</td>
<td>1</td>
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<tr>
<td>Inadequate Electrical Capacity</td>
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<td>15</td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>16</td>
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<tr>
<td>Faulty Product</td>
<td>17</td>
<td>11</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>8</td>
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<td>2</td>
<td>4</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>149</strong></td>
<td><strong>100%</strong></td>
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<td>13</td>
<td>25</td>
<td>24</td>
<td><strong>86</strong></td>
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Failure Modes Involved in Residential Electrical Distribution System Fires by Component

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<td><strong>Service equipment</strong></td>
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<tr>
<td>Ground fault (water-deteriorated insulation)</td>
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<td></td>
</tr>
<tr>
<td>Mechanical damage or improper installation</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Gutter touching bare SE conductors</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Loose connection</td>
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<tr>
<td>Equipment overload</td>
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<td></td>
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<tr>
<td>Miscellaneous failures at distribution box</td>
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<tr>
<td><strong>Branch-circuit wiring</strong></td>
<td>50</td>
<td><strong>34</strong></td>
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<tr>
<td>Mechanical damage/improper installation</td>
<td>15</td>
<td></td>
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<tr>
<td>Poor or loose splice</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Ground fault</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Use of improper wiring in circuit</td>
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<td></td>
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<tr>
<td>Knob and tube encapsulated</td>
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<tr>
<td>Miscellaneous overload</td>
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<tr>
<td>Failure of twist-on connector</td>
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<tr>
<td><strong>Receptacle outlets and switches</strong></td>
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<tr>
<td>Loose or poor connection</td>
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<tr>
<td>Mechanical damage</td>
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<td>Overload</td>
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<td>Failure of neutral connector</td>
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<td>Malfunction of switch</td>
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Fire Journal – January/February 1990
## Appendix 1

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<thead>
<tr>
<th>Component</th>
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<tr>
<td>Cords and plugs</td>
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<td>19</td>
</tr>
<tr>
<td>Mechanical damage/poor splice</td>
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<tr>
<td>Overload extension cord</td>
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<td></td>
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<tr>
<td>Overload plug</td>
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<td>Damaged plug</td>
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<td>Miscellaneous – plug</td>
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<td>Miscellaneous – cord</td>
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<tr>
<td><strong>Lighting fixtures and lamps</strong></td>
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<td>Loose or poor connection</td>
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<td>Combustibles too close</td>
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<td>Overlamped</td>
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<td>Switch failure</td>
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<td><strong>Transformer</strong></td>
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<tr>
<td>Improperly installed</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td>149</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: * Less than 1 percent.

Source: Consumer Product Safety Commissions study of 149 investigated fires in the residential electrical distribution system. These fires do not constitute a probability sample.
Appendix 2

Research Highlights on Voltage Drop, Resistance and Heat Generation

Jeffrey R. Gordon and William B. Rose of the University of Illinois, School of Architecture modeled the consequence of point source resistance. The model was prepared to illustrate the condition of an isolated point of high resistance and heat generation in four different scenarios.

The following examples from their report titled “Retrofitting Insulation in Cavities with Knob and Tube Wiring” are presented for illustrative purposes. They point out that insulating over knob and tube wiring, when the wiring is free of problems, is rarely, by itself, a fire problem. However, insulating over wires can be a critical contributing factor to creating a fire hazard when other problems, faults or abuse are present.

Each of the sample scenarios in the study assumed the following:

- a 15-amp circuit that terminates 30 linear feet from the main panel, and therefore contains 60 linear feet of wire (out and back)
- the electrical wire is centered in 3 1/2” of blown cellulose insulation in a 2”x4” wall cavity
- the ambient temperature on either side of the wall is 70°F.

Scenario 3:

Assume that the load test on a circuit showed a voltage drop of 8%. If 4% of the voltage drop is a result of the resistance in the circuit conductors and receptacles, then there is an excess voltage drop of 4% at some point(s) on the circuit. This could be a result of a damaged wire, corroded connection or improper splice. To consider the worst case, assume that all of the excess resistance is located at one point source. In this scenario, the circuit is lightly used, with just a couple of lamps and a clock radio pulling 2 amps of current. The maximum temperature of 96.4°F occurred at the damaged wire.

Analysis: Because the circuit is lightly used, the temperature of the wire at the point of damage is not severe and is unlikely to represent a fire hazard.

Scenario 4:

The situation is the same as in scenario 3, with a point source of resistance resulting from a damaged wire. The homeowner, during a particularly cold spell of weather, plugs a 1200-watt space heater into the circuit. A maximum temperature of 102°F occurred at the point of high resistance in the wire.

Analysis: The maximum temperature of the wire conductor soars past the maximum allowable temperature of 140°F. This extreme temperature occurs at the point of damage in the wire conductor or connection. In this case, a fire is not only possible but also likely.
Appendix 3

Case Study 1:

Original Knob and Tube
Total Attic Rewire
Surface Raceway

This structure is a 100 plus year old single family, balloon-framed home, with a single story kitchen addition with access to a crawl space above the ceiling. The attic was 90% floored, measuring 1240 square feet. The service entrance was a 60-amp fuse panel with two sub-feed panels. The newest sub-feed panel had two extra spaces for additional circuits; however, this panel had no ground conductor. All attic wiring was original knob and tube with no alterations.

The first floor kitchen refrigerator was found to be on the same circuit as the attic knob and tube feeding six second floor ceiling lights and the second floor bathroom receptacle. The wall receptacles were fed from or through the first floor walls and were not connected to the attic wiring. The only alterations were found to be in the kitchen, which consisted of a wall light above the sink, between the windows and an open splice of lamp cord to feed a counter top appliance receptacle (Fig.2 in Report).

Voltage drop readings of the six ceiling light fixtures ranged from 5.4 to 8.4%, and the service equipment voltage drop test indicated 2.3% voltage drop.

Repairs:

1. Installed new ground wire for sub feed panel

2. Installed a new feed wire from the sub-feed panel in the basement to a junction box above the ceiling of the kitchen addition.
Appendix 3

3. Installed surface raceway, new-grounded wire and receptacle up the wall into the area above the kitchen to the new feed junction box to re-feed the refrigerator.

4. Installed surface raceways in the same manner for the light above the sink as well as the counter top receptacle and installed a ground fault receptacle. These circuits were connected to the same new feed junction box above the kitchen ceiling.

![New kitchen countertop GFCI receptacle](image1)

5. Installed a new feed from the basement sub-feed panel to the attic. A receptacle was installed in the first wall junction box in the attic to give the electrical workers power to work as well as the weatherization workers that will follow.

6. Located the area where the knob and tube feed wires entered the attic as well as where the old wiring was run. Removed the section of flooring above the wires and inspected for alterations.

![Central locations in the floor of the attic were selected to install new plastic junction boxes.](image2)
Appendix 3

7. Installed a new-grounded wire between the first junction box, where the receptacle had been installed to the floor junction boxes.

8. Installed a power feed from the closest attic junction box to the ceiling light fixture. Removed the existing light fixture and installed a surface mount light fixture box. Inspected the light fixture for damage and replaced.

9. Removed the existing light switch and installed surface raceway and new wire up the wall into the attic over to the same light fixture.
Conclusion of scenario 1:
This job called for a total rewire of the second floor lighting circuit as well as installation of new switches and light fixtures. The grounding of the sub-feed panel was upgraded so it could be utilized. The receptacles in the kitchen and wall light were rewired. Post voltage drop readings ranged from 4.6 to 6.5%, without subtracting the service voltage drop.

Total material cost: $444
Labor: 70 person hours $1,960 (28 per hour labor rate)
Electrical inspection: $60

Total $2464
Case Study 2:

Excessive Amount of Homeowner Alternations

This structure is a 1930’s vintage, one story, platform framed, single-family home. Total living area is 837 square feet with 100% tongue and groove attic floor. The attic contained very few homeowner-stored items. The electrical service was a new breaker panel located in the basement. The attic wiring method included knob and tube, rubber cord, as well as newer grounded and ungrounded wire. There was an excessive amount of homeowner alterations to the original wiring system throughout the house. (Fig 3, 4, 5 and 8 in Report)

A pole light was connected to the wiring in the attic and the wires were short. Voltage drop readings of the ceiling light fixtures ranged from 2.9 to 5.5% and the service equipment voltage drop indicated a 2.1% voltage drop.

Repairs:

1. Installed a new 20-amp breaker and wire for a new circuit to the attic.

2. Removed multiple sections of flooring in attic and set junction boxes for new circuit.

3. Mounted bathroom fan/light housing to the ceiling joist and installed wire connectors (Fig. 3).

4. Relocated and rewired closet light due to safety and clearance issues (Fig.4).

5. Installed open splices under floor in junction boxes.

6. Removed all knob-and-tube wiring and re-fed circuits from new power feed.

7. Replaced two ceiling light fixtures.
Appendix 4

8. Removed kitchen ceiling paddle fan due to inappropriate mounting hardware and replaced with a light fixture.

9. Rewired two wall switches through an interior wall due to alterations by homeowner.

Conclusion

This case study called for a small section or partial rewire of the knob and tube. The larger issue was the homeowner alterations. A significant amount of time was spent to change out or repair these areas. One area needed to be tented over due to the complexity of the repair. Post voltage drop readings were in the range of 3.1 to 4.6% when not subtracting voltage drop of the service.

| Total material cost: | $167 |
| Labor: 78.5 person hours | $2,198 (28 per hour labor rate) |
| Permit: | $25 |
| Electrical Inspection: | $60 |

**TOTAL:** $2450
Appendix 5

Case Study 3:

Excessive Homeowner Stored Items
Rewiring Done Inside Wall Cavities
No Surface Raceway

The structure is a 1930 vintage, single story, balloon, platform frame, single-family home. The wall construction consist of two by four framing laid flat with a wall cavity width of 1 ½”.

The attic was 100% floored with homeowner-stored items (Fig.9). The total living area is 682 square feet. The service equipment consisted of a 60-amp fuse panel, located in the basement as well as two sub-feed panels and one sub panel no longer in use. The wiring was knob and tube throughout the attic area.

The knob and tube feed wires entered the attic from a receptacle in the hallway. The wires continued to the attic where the knob and tube feeds, hot & neutral, split and went through the floor on opposite sides of the house. The entire house was powered from the attic. No pre or post voltage drop readings were done.

Repairs

1. Installed a new feed line from sub-feed panel to attic to re-feed lighting and receptacles.

2. The power feeds from the attic that fed the basement, a kitchen receptacle, an exterior living room wall receptacle and a hall receptacle were cut.

3. Rewired all of the above (#2) from the basement by using one of the circuits in the sub-feed panel.

4. Installed a paddle fan box as well as the fan in the ceiling of the kitchen to meet code.

5. Removed the switched light fixture from above the sink and removed the fixture switch. This fixture was rewired and a wall switch added for safety.

6. Rewired the porch light as well as the wall switch.
Appendix 5

7. Repaired or replaced the ceiling light fixtures as needed.

Conclusion

This scenario called for two new circuits to lighten the load of the wall receptacles as well as the load of the kitchen. All rewiring was done inside wall cavities with no surface raceway. This presented a challenge due to the narrow wall cavities and was therefore very time consuming. Moving homeowner stored items was also difficult.

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<td>Labor: 80 person hours</td>
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Total: $2,477

Note: An estimate provided by an electrical contractor for the scope of this work was $2,841.
Appendix 6

Case Study 4

No Change Out of Knob and Tube
Install Junction Boxes

This structure is a 1940 vintage Cape Code style, two story single-family dwelling. The structure is platform framed with the attic 70% floored. Attic access is a pull down staircase. Rock wool insulation was present throughout the attic.

Five areas in the open area of the attic contained new romex wire connected to the knob-and-tube without junction boxes. The knob and tube that was installed under the floored attic was run above the rock wool insulation. Voltage drop readings taken at wall receptacles and ceiling light fixtures ranged of 3.7 to 10.5% voltage drop. The voltage drop of the service entrance equipment was 2.5%

Knob and tube wiring above rock wool insulation
Appendix 6

Repair

1. Installed junction boxes at all five locations where knob-and-tube connected to romex type wire.

2. Installed metal plates to protect knob and tube where the wires crossed over top of the floor joists.

Conclusion

No new circuits are needed for this work. The installation of five junction boxes resulted in minimal material and labor cost. Post voltage drop readings were in the range of 3.7 to 9.3% not subtracting the service drop.
Appendix 6

<table>
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Appendix 7

Case Study 5

Contracted Job
Utilize Existing Knob and Tube Feed Wire, Open Attic Area
Utilize Old Romex Wire
Install Junction Boxes

This structure is a two-story, single-family dwelling where renovations to the attic were made to include three extra bedrooms. Two of the bedrooms were in use and the other was under construction. The wiring consisted of a single set of knob and tube coming up through the floor of the attic to an exposed wall of the unfinished bedroom in the attic. The knob and tube wire ran into the cavity above the front bedroom where it was spliced into old cloth romex wire. Open splices were found above this ceiling to provide for third floor switches and receptacles.

Repair

1. The knob and tube wiring was cut where it came up through the attic floor and placed in a 4” square wall box. A GFCI receptacle was installed to protect the remainder of the third floor circuits.

2. From this GFCI receptacle a new 12/2 (with ground romex) wire was run to the area above the front bedroom ceiling that had the open splices in the old cloth covered romex.

3. Existing romex wire was installed in junction boxes and tied into the wall GFCI receptacle.
Appendix 7

Conclusion

Voltage drop readings were taken at ceiling light fixtures and wall receptacles and ranged from 3.2 to 7.9%. Few repairs were needed on this project, and no new light fixtures or devices were installed. No voltage drop readings were done on the service equipment. Post voltage drop readings were in the range of 3.2 to 6.9%.

An electrical contractor was contracted to do the repairs at a cost of $775, which included approximately $50 in material and $60 for an electrical inspection fee. Estimated time to complete the work was 10 person hours.
Appendix 8

Case Study 6

Contracted Job
Repair of New Romex Wire, Junction Boxes
Replace One Section of Knob and Tube

The structure is a two story double family dwelling with 100% floored attic that was not nailed to the floor joists. Two new 12/2 with grounded romex wire feed circuits had been installed at an earlier time that ran from the basement panel to the attic. The entire second floor had been rewired with the exception of the second floor hall light and one receptacle in a second floor bedroom. These were installed with knob and tube wiring. Most of the splices were located in junction boxes that needed to be mounted to floor joists with a junction box cover to be installed.

Voltage drop readings ranged from 5.3 to 10.3%.

Repair

1. Replaced the remaining knob and tube that powered the hall light and bedroom receptacle.

2. Installed three new junction boxes to rewire the old knob and tube.

3. Rewired the second floor attic light fixture.

4. Rewired the attic light fixture and replaced the fixture.
Appendix 8

Conclusion

The rewire was relatively simple. However, after the rewiring of the knob and tube circuit in the attic, the hall light as well as the hall switching no longer operated. The contractor rearranged splices in an attempt to correct the problem. It was determined that the original knob and tube circuit utilized a switched neutral to feed the lighting circuit. Corrective work included switching the lights on the “hot” side.

Post voltage drop readings were in the range of 5.0 to 7.9% voltage drop. No voltage drop readings were performed on the service equipment.

An electrical contractor was contracted to do the work at a cost of $835, which included $60 for an inspection fee and approximately $40 for materials.

Estimated time was two men at four hours each to perform the repairs, and one man at four hours to troubleshoot the lighting problem. Total estimated time to complete the work was 12 person hours.