A Study on Residential Fires due to Electrical Faults in Hong Kong

H.M. Lee[1], W.K. Chow[2] and H.Y. Hung[3]

[1]Graduate Student, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Phone Number: +852 9453 8856, Email: killus2003@yahoo.com.hk
[2]Chair Professor, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Phone Number: +852 2766 5843, Email: beelize@polyu.edu.hk, bewkchow@polyu.edu.hk
[3]PhD Student, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Phone Number: +852 3922 9338, Email: ernest.hung@aecom.com

ABSTRACT

Accidental home fires lead to life and property losses. Electrical fault is one of the causes of residential fires, and its potential hazard is increasing as more electrical appliances are found in each household unit nowadays. Wiring has a higher possibility to be ignited. There were even cases reported that the television set caught fire. Possible reasons for electrical fires in residential buildings will be studied in this paper. Ignition of a television set by itself was taken as an example for experimental investigation. Television set can be a source of fire, insulation and wiring may be weakened and cause fire due to ageing problem. Although the possibility of ignition of a television by itself is low, it is recommended to plug off the socket from the power supply for isolation when the television is not in use.

INTRODUCTION

Statistical data compiled by the government authorities in Hong Kong and Taipei (e.g., Fire Services Department 2008-2010; Taipei City Fire Department 2010) indicated a high rate of residential fires in these two places. The accumulated percentage of fire events in domestic buildings and housing estates was up to 43% from 2008 to 2010 (Fire Services Department 2008-2010) based on the statistics by the Fire Services Department of Hong Kong. Residential fires caused by smoking (Runyan et al. 1992; Ducic and Ghezzo 1980; Chien and Wu 2008) were studied overseas in the past years. In recent years, more electrical appliances are being used in each family unit. The outer-casing of those electrical appliances and other related components such as insulator or even interior parts might be damaged by striking against hard objects, say by children repeatedly, resulting in defect or poor electrical connection. Increase in electrical loading might give potential fire hazard. Electrical fault is the most possible cause of fires (Taipei City Fire Department 2010). Therefore, more attention should be paid to electrical fault in residential buildings. It is necessary to investigate the possible reasons for electrical fires in residential buildings, including new cases such as battery fires (The Sun 2011).

Improper use of the electrical appliance is a major reason causing quite a number of electrical fires. Many users, particulary children and elderly, used to ignore the proper procedure of using electrical appliances as many of them never read the user manual. It had been reported that a new cellular phone was burnt because the user wrongly plugged the power input into other slots! Based on the findings of Smith and McCoskrie (1990), a fire might occur due to inappropriate electrical loading. Also, improper repairs by unqualified persons and removed or damaged insulation might increase the possibility of ignition. Further, electrical cables or wires have a higher possibility to be ignited as reported in the US fire statistics (Hall et al. 1983). Wiring will be discussed on having residential fires due to low-voltage power system faults. Three possible mechanisms that generate transient heat are by poor connection, arcing and overloading.

In this paper, electrical faults that cause residential fires are studied (Lee 2012). From the statistics published, television is a cause of fire in residential flats (Electrical and Mechanical Services Department 2002). A television set was selected for experimental investigation on possible ignition by itself.

POOR CONNECTION

Poor connection was identified (Hall et al. 1983) to be a prominent reason for electrical fires based on statistics from National Fire Protection Association (NFPA). It consists of wirings between the power supply and end-feed use and circuit inside the device. While poor connection exists, improper circuit alternation can induce extreme high temperature and may lead to ignition, depending on the condition of the surroundings. Improper wiring connection by unqualified persons, defective design and lack of maintenance migth lead to poor connection.

Variations among screw-clamp type connection, also push-in, back-wired receptacles are common reasons for poor connection (Smith and McCoskrie 1990). Similarly, deficient contact pressure between portions of male and female receptacles is prone to poor connection, where ignition or arcing will be resulted. Aging, initial design problem and corrosion might be the factors for having high resistance (Gillmana and Le May 2007). Stress between connecting segments may be loosened and lead to poor connection.

In some cases, unintended connection is prone to electric fault. Conductors inside wall or building structure may be pierced by nails or sharp metal components, forming unintended path of circuit and generate high temperature. Moist condition, such as in bathrooms or in springs (Lam 2011), is often a cause of poor connection.

Defective design is another severe cause. For rare condition, the resistance of two wires twisted together will also induce high temperature (Babrauskas 2003). Aluminum cable installation was the major cause of residential fires in the US in 1950s due to different thermal and mechanical properties of aluminum and other materials used in the contacting outlet (Smith and McCoskrie 1990). Fortunately, this

trend stopped in late 1970s.

ARCING

When the electric field between two electrodes is sufficiently high, electrons in air will move faster and there will be elastic collisions. As field strength is increased, electrons will escape from the air molecule and move to the positive electrode. Glow discharge will sustain and heat is then emitted (Tleis 2009). Electric spark or arc will be created and may ignite nearby tinder-type materials. Open circuit or shorting more than one conductors together will produce arcing in air. Arcing can occur across carbonized insulation and in air.

Carbonization can occur by large potential difference among insulation materials of wiring. It can be divided into two classifications: wet tracking and dry tracking. Wet tracking is common due to existence of moisture universally, and it is focused in this paper.

Polyvinyl chloride (PVC), commonly applied for sheltering conductors, is prone to carbonization by comparatively low temperature about 200^{o}C (Babrauskas 2009). Pollutants such as moisture and dissolvable contaminates can step up the breakdown process. The carbonized insulation part becomes a semiconductor and allows current to pass across the insulator, such that an unintended path is formed. Scintillations or carbonization process can start (Babrauskas 2006) under low power level at lower temperature. If it takes place without obstruction, full arcing may be resulted and the high temperature might ignite nearby tinder-type materials.

Arcing in air, considering that a low voltage residential fire is involved, may not independently occur. By opening a circuit or shorting two conductors together, ejection by induced magnetic field will separate them and arcing exists.

However, the chance of ignition is very low. Possible reasons (Babrauskas 2009) are that arcing can only preserve for a very limited period, and arcing may scatter with extracted solid.

OVERLODADING

Overloading is a notable physical mechanism of electrical fire. The main reason for overloading is that the flowing current exceeds the maximum current carrying capacity of the wire or cable (Li 2010; Lau 1997; Wong 2011). Temperature will rise and cause overheating. When overloading occurs, the surrounding materials may melt due to excessive thermal insulation, or even ejection of hot particles if heat emitted from the wire is much higher than the melting point of the material, fire can be resulted. Wrong selection of wire cross-sectional area and improper protective devices sizing would lead to ignition due to these mechanisms. The latter is, modern circuit breaker gives inappropriate allowable period. Circuit breaker would permit an abnormal current, which exceeds the designed range to pass through. It will result in

overloading, and it will be heated up (Lee 2012). In some cases, insulation of wiring may melt and emit hot particles, thus causing fire.

Stray current would cause overloading. One of the factors is current flow through an unintended part of circuit. For insulation failure, it can ignite nearby tinder or produce spark to have fire. Wrong selection of wire coss-sectional area and sheltering material would lead to ignition due to these mechanisms.

In fact, ignition might involve several mechanisms. All contributing causative factors were studied by Smith and McCoskris (1990). To sum up, there are two probable physical explanations for ignition by those factors.

DETERIORATION OF WIRING BY AGEING

According to Gosland (1956), the probability of causing fire by wiring which has been used for more than 15 years is roughly proportional to the age of installation. This indicates that the longer the period the wire is installed, the higher the incidence rate of fire. A possible reason is that conductors used for a long time would allow less electrons to pass through, so the maximum current carrying capacity of the wiring will be decreased year by year, resulting in similar case of improper cable sizing or overheating. The insulation material also has ageing problems such as lowered melting point or even easy to be broken.

However, very few articles documented this phenomenon due to difficulties in collecting wirings used for different lengths of years. The consumption pattern is also very different now from the 1950s, as mentioned by NFPA (2006). As electricity consumption is larger nowadays, wiring might have ageing problems in a shorter period, compared to the conclusion made by Gosland (1956).

Nowadays, the living style has been changed with the advancement of technology. The number of electrical appliances used in residential flats has largely been increased. It is common that each household has at least one television set for entertainment. Nevertheless, television can be a source of causing fire event. From the statistics by the Hong Kong government Electrical and Mechanical Services Department, nearly 30 cases of fire event were suspected to be related to television during 1998 to 2001 (Electrical and Mechanical Services Department 2002, 2007). Japanese statistics (Babrauskas 2001) indicated that one-third of the ignition of television were related to the transformer. Therefore, television will be another target to be studied for investigating the possibility of being ignited. In this paper, the old-style television, using cathode ray tube but not liquefied principle for giving audio, will be focused on.

Generally, transformers applied in televisions are flyback transformers, or called line output transformers. One of its characteristics is that it consists of small-size capacity but output voltage can achieve normal operation of cathode ray tube, which creates audio at monitor, of about 20 kV to 50 kV (Dixon 2001). However, small size

contains thinner insulation of the outer shell. In case of overcoming high voltage with insufficient isolated protection, unintended path may be created by carbonized insulation, thus become a source of fire event. Besides, dust is likely to be accumulated due to electrostatic effect. Under heat-up condition, the dust layer can act as tinder to exacerbate the ignition process. It is mentioned that (Du 2011), to maintain operation of the television memory, current in secondary circuit will not be completely cut but kept in "standby mode", power is still being supplied from the socket outlet. For long-term operation, wiring inside the secondary circuit may overheat, thus it can be an ignition source that causes fire.

Experiments can be conducted to study the temperature and also the current variation of a television under standby mode with long-term observation. The results can be analyzed to find out the possibility of a television being ignited by itself.

AN EXPERIMENTAL STUDY

For the wiring part, the Code of Practice for the Electricity (Wiring) Regulation, published by Electrical and Mechanical Services Department (2009), gives guidelines on how to satisfy the requirements on electrical installation in Hong Kong. This Code of Practice summarizes all recommendations for new electrical installation and relative materials such as the checklist for testing and commissioning process and sample for correct cable sizing in Hong Kong. The situation of electrical installation especially for the wiring part in Hong Kong can be briefly known through reviewing the code. Some reasons for ignition can be roughly estimated. In this paper, by considering residential flats, only wiring and end-feed appliances will be focused on.

For studying the possibility of ignition of a television by itself, a television set (Lee 2012) with a video recorder as shown in Figure 1 will be used for investigation. It is a common type of television in residential flats appeared in 1990s. A layer of dust is accumulated on the outer shell as it has not been used for a long time. Therefore, dusty condition can also be demonstrated.

Figure 1. The television set studied

An experiment was carried out to investigate the current and temperature variation for a television in standby mode. The interior structure should be studied before starting the experiment. The main components of this television are flyback transformer, vertical cathode ray tube (CRT), horizontal CRT and coil.

The surfaces of all components, including the outer shell of the whole television, were connected to thermocouples, and fixed by aluminium sticker and glue. These components were connected to a data logger (serial: midi logger) to record the surface temperature. One thermocouple was fixed for recording the changes of ambient temperature as a control. The data logger took measurement at every 30 minutes interval. Transient temperature rise at vertical CRT, flyback transformer, coil and horizontal CRT are shown in Figure 2.

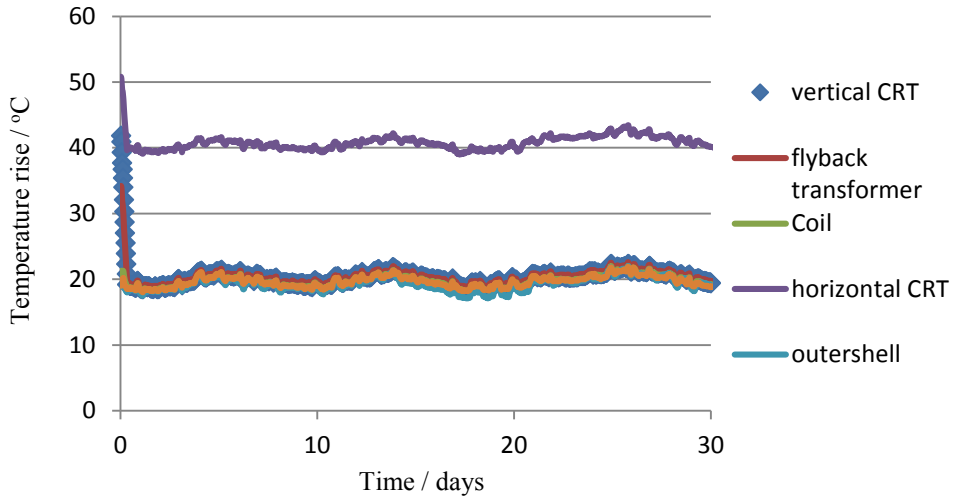

Figure 2. Transient temperature rise measured at different positions

A small resistor was added into part of the circuit for measuring current. Potential differences across the resistor were measured by adding a voltmeter with results sent to another data logger. This data logger recorded the voltage every hour. By known values of resistance and measured voltage, the current passing through the secondary circuit can be calculated by basic laws in electricity.

The experiment was conducted for 30 days without power interruption so that the standby mode was on for a relatively long period for obtaining accurate result. As a safety precaution, the variation of temperature and also the operation of all equipments involved should be checked daily. Temperature and result should be recorded in the log book and all connections between the television and data loggers should be inspected not to be loosened due to unwanted crash or other accident. This is to ensure that the television worked under normal condition, and to avoid real case of ignition.

The results on temperature rise at different parts of the television set and the current are shown in Figures 2 and 3, respectively. Analysis such as poor connection within plug and line can be done from experimental results. Approximate temperature and current can be found from literature review. Thus, the possibility of igniting the television can be estimated by comparison between criteria of average ignition and experimental result.

From temperature rise curves shown in Figure 2, flyback transformer, vertical CRT, coil and outer shell temperatures were all hotter than ambient. Temperatures were kept normally at 0.5^{o}C higher than ambient temperature. The temperature of horizontal CRT was about 20^{o}C higher than ambient temperature. One of the reasons is that the horizontal CRT is independent of the secondary circuit. Therefore, supply current can directly flow without passing through the flyback transformer. However, at 50^{o}C, the horizontal CRT still had a very low possibility to be ignited since the formation of arc or spark are at about 190^{o}C.

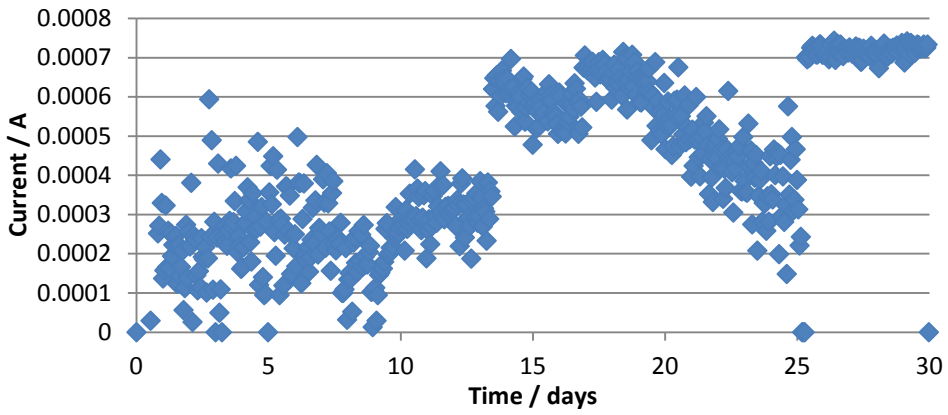

Figure 3. Transient current measured

The results showed an irregular increasing trend from the starting period (day 5 to day 15). However, the current decreased slightly at later stage as in Figure 3, though the value was still higher than the current measured in the first few days. At the end (day 25 to day 30), the current was stably kept at a relatively high level about 0.08 mA.

Compared to normal ignition due to electrical fault, the current from experimental result was still at very low values for ignition. Therefore, by considering temperature and current, the possibility of igniting a television in standby mode is very low.

LOCAL CODES

In Hong Kong, all wiring installation should be based on Code of Practice (CoP) for the Electricity (Wiring) Regulation 2009 Edition (Electrical and Mechanical Services Department 2009). All protective devices, inspection and testing criteria are recorded

so that safety of installation should be ensured to reach an acceptable level in Hong Kong. It will be used to evaluate the possibility of causing fire due to wiring installation. As fires are caused by numerous reasons, the one having the highest possibility (poor connection) will be taken as the main reason to be evaluated.

Code 8 Isolation and Switching of the CoP for the Electricity (Wiring) Regulation (Electrical and Mechanical Services Department 2009) stated that the general circuit breakers should be installed to fulfill minimum requirements in Hong Kong. The connection method is also noticed. Only the first two sections of the 8A part will be focused on as wiring and appliances in residential flats will be concerned.

It pointed out that all appliances or equipment (including lighting) should have their own insulator, which means if wirings inside are connected wrongly, it should be cut by devices of appliance or even devices installed in ring circuit in some serious cases. It means double protection will be given. Another code will be introduced for earthing problems.

Code 13 to Code 15 (Electrical and Mechanical Services Department 2009) guided the wiring characteristics, installation method and also the condition of wiring installed so that the maximum current carrying capacity of the selected wiring will be much more than the current passing through under normal condition. Consequently, there will be higher chances of overheating. Basic protection will also be suggested for the electrical insulation. Types of tinder are listed to avoid placing them near wiring after reading. Therefore, even if spark is given out, fire will not easily occur by reducing tinder.

Code 26 (Electrical and Mechanical Services Department 2009) is on the requirements for specific installations and equipment; 26A(1) guided the number of socket outlets and also the maximum allowable connecting loads in one circuit of a domestic building. It is separated into kitchen, bathroom and other heavy load appliances. Following the guidance and considering interior separation in a flat, as loads are evenly distributed in each circuit during the design stage, overloading condition due to poor design and installation can be reduced. There are worked examples for application of the CoP and checklist in Appendices 12 and 13.

In these examples, especially 12(B), the progress of cable sizing and other equipments can be shown. By calculation, the design current can be found. By matching the cable information, the maximum allowable current of a cable can be found so that the possibility of overloading condition will be very low by using the same method. Checklist is for testing and commission for new low voltage installation. It provides the checklist of each part of circuit, so that for new installation, contractors can carry out installation according to this list for installation with supposed safety criteria.

To sum up, wiring installation guided by the CoP (Electrical and Mechanical Services Department 2009) should have a low possibility of being ignited. It is recommended

that in the design stage, cable sizing procedure should include the consideration of aumoured method, installing condition of cable, etc. Special condition and also insulation material are included so that overheating or overloading situation due to inappropriate sizing can be greatly decreased. However, unclear indication is given for existing cables such as testing and commission period and also preferred time for a cable used, therefore ageing problem of wiring still cannot be completely solved by replacement on time. Physical damage is mainly considered as accident, which is unavoidable. Improper use is an uncontrolled factor which depends on the users and their living style.

Therefore, according to the CoP (Electrical and Mechanical Services Department 2009), overloading condition can be greatly avoided but still the problem due to human factors cannot be solved.

CONCLUSIONS

Electrical fault is a common cause of residential fires, and its potential hazard is increasing as more electrical appliances are being used in each family nowadays. Wiring has a higher possibility to be ignited. Physical damage and improper installation are some of the reasons causing electrical fires. According to the CoP for the Electricity (Wiring) Regulation in Hong Kong (Electrical and Mechanical Services Department 2009), overloading of wiring can be greatly avoided. However, some problems involving human factors still cannot be solved.

Television set can be a source of fire. For long-term usage, insulation and wiring may be weakened and cause fire due to ageing problem and also unintended path created by carbonization. Although television has a low possibility of being ignited by itself, it is recommended to plug off the socket from the power supply for isolation when not in use.

Fires caused by electrical fault were discussed in the literature (e.g. Fire Services Department 2008-2010; Taipei City Fire Department 2010; Runyan et al. 1992; Ducic and Ghezzo 1980; Chien and Wu 2008), but most of the work were focused on industrial fire investigations or fires by high voltage installation. Very few reported on fires by low-voltage installation in residential flats. More articles on this topic can be found in Mainland China, but many were reported 30 years ago. Taking into account the changes in life style, statistics or reasons behind the phenomenon might be different. However, updated statistics are not yet compiled. Battery fire and explosion is a good example (The Sun 2011).

Besides, the cases studied in this paper (Lee 2012) are mainly from Hong Kong. As the living style and electrical consumption habit are different in different countries, the conclusion drawn in this paper may not be applicable to other places.

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