2014

Fire Hazards of Refrigerants in Air Conditioning Control System

Y.W. Ng
The Hong Kong Polytechnic University, Hong Kong S.A.R. (China), yiuwahng@yahoo.com.hk

W.K. Chow
The Hong Kong Polytechnic University, Hong Kong S.A.R. (China), beelize@polyu.edu.hk

Fire Hazards of Refrigerants in Air Conditioning System

Yiu-wah Alexander NG[1], Wan-ki CHOW[2]*

[1] Research Centre for Fire Engineering, Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Email: yiuwahng@yahoo.com.hk

[2] Research Centre for Fire Engineering, Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Phone: +852 2766 5843; Fax: +852 2765 7198, Email: bewkchow@polyu.edu.hk; beelize@polyu.edu.hk

* Corresponding Author

ABSTRACT

Air conditioning control systems are commonly installed in restaurants, commercial buildings, office buildings and institutional buildings in Hong Kong. The systems invariably involve the use of fans for moving the air, filters for cleansing, ducts for air distribution, a control system for regulating the amount of heating or cooling automatically and a refrigerating plant connected to the heat exchange surface. The ducts in turn present the possibility of spreading fire and smoke throughout the building or areas served.

According to the local Code of Practice for Minimum Fire Service Installations and Equipment, when a ventilation or air conditioning control system to a building is provided, it shall stop mechanically induced air movement within a designated fire compartment. In order to fulfil such requirement, the architects and building services engineers will design to install associated equipment of air conditioning control systems to satisfy the relevant fire safety requirements of the local authority, which includes the provision of fire resisting ducting, fire dampers, smoke detectors and fire resisting cables, etc. However, lessons learned from past experience reveal that owners or property management staff of the buildings or covered areas and maintenance contractors will mainly concern the efficiency and energy saving of the systems without paying much attention to the fire hazards arising from the use of refrigerants. It is also noted that fire or explosion incidents involving air conditioning control systems are often attributed to improper maintenance work conducted by maintenance contractors, such as refilling the refrigerating plant with poor quality refrigerants, recharging refrigerants incompatible with the metal parts of the system, refilling refrigerants at high pressure resulting in bursting of piping and joints, valves contaminated by grease, presence of an ignition source in close proximity of the refrigerating plant, etc.

In general, refrigerants present two basic hazards, namely toxicity and flammability. Refrigerants mix readily with air and if flammable, may reach flammable concentrations ready to be ignited by an ignition source. As diffusion may not take place rapidly enough to avoid the hazards in the event of leakage, fire or explosion may occur. With reference to a fire with explosion incident involving air conditioning control system in a restaurant in Hong Kong, this paper will outline and discuss the fire hazards of refrigerants in air conditioning control systems.

1. INTRODUCTION

There are two basic hazards associated with refrigerants, namely toxicity and flammability (Febo, 2003b). Refrigerants mix readily with air and, if flammable, may reach flammable concentrations ready to be ignited by an ignition source. In the event of leakage, fire or explosion may occur as diffusion may not take place rapidly enough. Before the Montreal Protocol, chlorofluorocarbons (CFCs) were commonly used in ventilation and air conditioning control systems. However, as a result of the Montreal Protocol and subsequent meetings to protect the earth's ozone

layer, CFCs and hydrochlorofluorocarbons (HCFCs) as substitute of CFCs have gradually been phased out due to ozone depletion. Although both CFCs and HCFCs are non-flammable, they contribute to ozone depletion. Therefore, they are replaced by alternative refrigerants for meeting the requirements of zero ozone depletion and low global warming potential but with weakness in flammability. Despite efforts have been made by refrigerant manufacturers with an aim to meet all requirements for zero ozone depletion, low global warming potential, low toxicity and non-flammability, the problem of non-flammability still cannot be resolved under the current technology (Japan Refrigeration and Air Conditioning Industry Association, 2012). With reference to a fire with explosion incident involving ventilation and air conditioning control system of a restaurant occurred in Hong Kong, fire hazards of refrigerants in ventilation and air conditioning control systems will be outlined and discussed in this paper with a view to having better understanding of the problem for consideration of the way forward.

2. GENERAL INFORMATION OF A FIRE WITH EXPLOSION INCIDENT IN HONG KONG

Around noon on 9 January 2013, twenty-one persons, including four in serious condition, were injured in an explosion in a 2000 square feet Chinese restaurant on the first floor of a two-storey commercial complex in Hong Kong. Most of the injured suffered burns and scratches caused by fragments of broken glass. The blast triggered a fire and created air currents that caused glass windows facing the street to shatter onto the road and pavement.

When the explosion occurred, the restaurant was packed with lunchtime diners. About 200 people were evacuated from the commercial complex to a place of safety. A restaurant worker said she heard explosions shortly after maintenance workers were conducting a check to the air conditioning system of the restaurant. Witnesses also reported hearing fizzing sounds and seeing white fumes in the dining area before an explosion occurred (South China Morning Post, 2013).

The explosion originated from a 150 square feet plant room housing the ventilation and air conditioning control system of the restaurant. The plant room was located adjacent to the dining area on the same floor of the restaurant.

At the time of the incident, workers of a maintenance contractor were refilling refrigerant into the ventilation and air conditioning control system of the restaurant. When the fire was extinguished, firemen found several compressed gas cylinders inside the plant room. It was believed that some of these cylinders contained refrigerants for refilling the ventilation and air conditioning control system.

3. FIRE HAZARDS OF VENTILATION AND AIR CONDITIONING CONTROL SYSTEM

Ventilation and air conditioning control systems invariably involve the use of fans for moving the air, filters for cleansing, ducts for air distribution, a control system for regulating the amount of heating or cooling automatically and a refrigerating plant connected to the heat exchange surface (Webb, 2003b). All air conditioning and ventilation systems have at least one plant room, normally located on the roof or in the basement. Fans, heaters, filters, and associated equipment that make up a central system air conditioning unit are housed inside the plant room. Relevant components of a ventilation and air conditioning control system from fire hazard viewpoint are ductwork and air filters.

Ductwork serving the ventilation and air conditioning control system is a potential route for the spread of smoke and hot gases. If air conditioning and ventilation ducts pass through a fire-resisting compartment or protected escape routes, the resistance of the compartment or route is obviously compromised – smoke and fire have a ready means of access. It is therefore necessary to maintain the integrity of a compartment. The use of fire and smoke dampers are crucial in limiting the spread of smoke and containing a fire (HM Fire Service Inspectorate Publications Section, 2003).

Air filters are normally situated in the plant room. Their function is to reduce the dust content of incoming air. Any accumulation of dust or dirt on the filters will greatly increase its flammability. Therefore, regular cleaning or replacement of filters is necessary.

4. FIRE SAFETY REQUIREMENTS FOR VENTILATION AND AIR CONDITIONING CONTROL SYSTEMS

In Hong Kong, ventilation and air conditioning control system is classified as fire service installation. The relevant specification is detailed in Section 5.25 of the Code of Practice for Minimum Fire Service Installations and Equipment (FSI Code) administered by Fire Services Department. According to the FSI Code, when ventilation and air conditioning control system to a building is provided, it shall stop mechanically induced air movement within a designated fire compartment. In addition, the plant room housing the ventilation and air conditioning control system is normally provided with suitable fire service installations and equipment, such as fire detection system and fire extinguisher, etc. (Fire Services Department, 2012).

Regarding the provision of passive fire safety requirements for plant room housing ventilation and air conditioning control system, it is under the control Buildings Department. According to the Code of Practice for Fire Safety in Buildings (Fire Safety Code) administered by Buildings Department, plant room is classified as special hazard. Pursuant to the Fire Safety Code, it shall be separated from the remainder of the building by floors, ceiling walls or partition having a minimum fire resistance rating of not less than one hour (Buildings Department, 2011).

5. LEGISLATIVE CONTROL ON REFRIGERANTS

With reference to the fire hazards and fire safety requirements of ventilation and air-conditioning control system mentioned in Sections 3 and 4 above, it is noted that fire safety provisions and measures are in place to guard against the spread of fire when the building or the plant room housing the ventilation and air-conditioning plant is on fire. However, the control of the use of refrigerant in ventilation and air-conditioning control system from the fire hazard viewpoint by the local authority is not stipulated in the relevant Laws of Hong Kong. Should there be leakage of refrigerant at piping or valve of the plant due to fault, poor maintenance or improper handling by craftsmen, refrigerants vaporize and can escape into the atmosphere. The situation may become complicated when hydrocarbon refrigerant having flammable characteristic is used in the ventilation and air-conditioning plant. Under such circumstances, explosion may occur when there is an ignition source in the vicinity.

At present, only the following 7 types of refrigerants (when contained in cylinders) are classified as dangerous goods under the Dangerous Goods Ordinance Chapter 295, Laws of Hong Kong (Government of Hong Kong, 1997b):

(i) Chlorotrifluoromethane (Arcton 13, Freon 13)
(ii) Dichlorodifluoromethane (Arcton 12, Freon 12)
(iii) Dichlorodifluoromethane/Trichlorofluoro- methane Mixtures (Arcton 12/11, Freon 12/11)
(iv) Dichlorofluoromethane (Arcton 21, Freon 21)
(v) Dichlorotetrafluoroethane (Arcton 114, Freon 114)
(vi) Monochlorodifluoromethane (Arcton 22, Freon 22)
(vii) Trichloromonofluoromethane (Arcton 11, Freon 11)

Apart from the above 7 types of refrigerants, other refrigerants contained in cylinder are also under the control of the aforesaid Ordinance. However, it is noted that only storage and conveyance of cylinders containing refrigerants are under the control of the said Ordinance while the refrigerant used in the ventilation and air-conditioning control system is not mentioned.

In addition, it is also noted that Environmental Protection Department only concerns the import of refrigerants from an environmental protection point of view (Environmental Protection Department, 1994) while Labour Department merely focuses on health safety of workers (Occupational Safety and Health Branch of Labour Department, 2000). Although Electrical and Mechanical Services Department is vested with the authority to control town gas, natural gas and liquefied petroleum gas, it appears that the control of the use of refrigerants in ventilation and air conditioning control system is not specifically mentioned in the concerned Ordinance of Hong Kong (Government of Hong Kong, 2004).

Nevertheless, the only action which could be taken by the local authority is limited to the power vested by Food Environmental and Hygiene Department (FEHD) on scheduled premises under Section 94(2) of Chapter 132, Laws

of Hong Kong. Under such provision, it is stipulated that no alteration shall be made to any ventilating and air conditioning control system in any scheduled premises without the permission in writing of FEHD (Government of Hong Kong, 1997a).

6. FIRE HAZARDS OF REFRIGERANTS

The refrigerants commonly used in air conditioning equipment are R-11, R-12 and R-22 (Freon), of which the first two are chlorofluorocarbons (CFCs) and the latter is hydrofluorocarbons (HCFCs). With the phasing out of chlorinated fluorocarbons (CFC)s as a result of the Montreal Protocol to protect the earth's ozone layer, the most common refrigerant used in air conditioning systems is R-22. HCFCs have been promoted as substitutes for CFCs but they also contribute to ozone depletion. Subsequent to a series of meetings after the adoption of Montreal Protocol in 1989, the meeting at Beijing in 1999 concluded that production of HCFCs shall also be banned in developed countries by 2020 and developing countries by 2040 (Febo, 2003a). The main reason for this mandatory amendment is that R-22 also contains high global warming potential. Therefore, R-22 will also be phased out in the near future. As such, the use of hydrocarbon refrigerants having no ozone depleting properties and lower global warming potential as substitute becomes common nowadays. However, hydrocarbon refrigerants are flammable and normally operate under high pressure in ventilation and air-conditioning system. Should there be leakage of such type of refrigerant at piping or valve of the plant due to fault, poor maintenance or improper handling by craftsmen, hydrocarbon refrigerant in the ventilation and air-conditioning system vaporizes and can escape into the atmosphere resulting in explosion when there is an ignition source in the vicinity.

As hydrocarbon refrigerants are flammable, some countries like Singapore (Singapore Civil Defence Force, 2014) have announced to ban its production gradually. New refrigerants are being developed to replace those refrigerants which are no longer in production. Potential replacements include propane and isobutene, and a new category of emerging hydrofluoro-olefin (HFO) refrigerants designated as mildly flammable or A2L under the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) flammability and toxicity classifications (Canadian Property Management, 2013). Although refrigerant manufacturers have tried their efforts to develop alternative refrigerants to meet the requirements of zero ozone depletion and low global warming potential, the problem of non-flammability remains unsolved under the current technology. In fact, their major concerns on the development of new refrigerants are focused on zero ozone depletion, low global warming potential, energy efficiency, production cost and market share, etc. while the concern regarding minimizing the hazards of flammability is low in comparison with the aforesaid issues. Therefore, low-cost propane which is commonly used becomes the essential constituent of alternative refrigerant. As propane is flammable, many alternative refrigerants which are claimed to be safe have not been approved by the authority. In fact, refrigerant manufacturers still have not found new refrigerants that could meet all of the aforesaid requirements. As such, there is still quite a lot of research being carried out to find out the next generation of refrigerants (Canadian Property Management, 2013).

In Hong Kong, R-410A refrigerant is commonly used in the ventilation and air conditioning control systems (Oriental Daily 東方日報, 2013). It is not flammable at ambient temperatures and atmospheric pressure. However, it will become combustible when mixed with air under pressure and exposed to strong ignition sources. Contact with certain reactive metals may result in the formation of explosive or exothermic reactions under specific conditions.

In general, providing good refrigeration characteristics and attempting to minimize the hazards of flammability and toxicity are issues of balance on the development of new refrigerants. Therefore, there are blends of various refrigerants. Some zeotropes which consist of constituent of highly flammable hydrocarbon, such as propane, isobutene and propylene, which move into the A3 classification (Kampmeyer, 2003) but they are marketed as an environmentally safe products for replacing non-flammable refrigerants that have no ozone depleting and lower global warming potential properties. For example, some new alternative refrigerants contain liquefied petroleum gas having 100% alkanes with an explosive range between 2.15% and 9.6% (Canadian Property Management, 2013).

According to the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI), which represents manufacturers, wholesalers and contractors in the Canadian heating, ventilation, air conditioning and refrigeration industries, there are currently no air conditioning systems for homes or businesses within the Canadian market that are designed and compatible for use with hydrocarbon refrigerants. In addition, it is noted that the use of alternative

refrigerants or some zeotropes will also pose a serious fire or explosion risk due to the following (Office of the Fire Marshal, 2013) :-

(i) flammable vapours coming in contact with nearby ignition sources (e.g., pilot lights, spark igniters, etc.) in the event of a leak in the air conditioning system;
(ii) improper use by untrained individuals;
(iii) missing or illegible labels identifying the flammable nature of the refrigerant could result in persons (e.g., fire department members, service technicians, fire investigators, etc.) unaware of the flammable refrigerant and not taking appropriate precautions.

Although HVAC manufacturers are required to phase out the production of R-22 equipment, the use of R-22 refrigerant is still permissible in existing systems prior to being phased out as mandated in Beijing amendment of 1999. As availability of R-22 supplies may become short in the coming years, prices for R-22 will dramatically be increased as a result. As such, many refrigerant manufacturers have stepped up their marketing efforts for alternative refrigerants, claiming that their products are cost-effective "drop-in" replacements for R-22. However, the use of propane or other hydrocarbon refrigerants in any type of air conditioner has not been approved by any authority due to its flammability (Refrigerant Compliance Software, 2013).

Furthermore, propane has also been illegally sold as substitute for R-22. Unapproved refrigerants include R-290, 22a, 22-A, HC-22a and CARE 40. These unapproved products are propane-based and are illegally marketed and sold as a substitute for R-22. Although U.S. Environmental Protection Agency has allowed some flammable hydrocarbon refrigerants to be used in industrial process refrigeration, use of flammables as a retrofit in equipment that was designed for non-flammable materials presents risks to consumers, maintenance workers, service technicians or even firemen who may not be aware and prepared for handling flammable refrigerants. Both overseas and in the U.S.A, it has been reported that individuals have been injured as a result of the use of propane and other unapproved refrigerants in air conditioning systems (United Stated Environmental Protection Agency, 2013).

At present, an array of candidate refrigerants are being used by manufacturers. However, tests reveal that some of the candidate refrigerants appear to have flammability, explosive and toxicity characteristics that have not been adequately addressed (Webb, 2003a).

In addition, it is also noted that there are many fake goods or refrigerants of poor quality in the market (The Sun 太陽報, 2013). Use of such fake goods or poor quality refrigerants might pose serious fire and explosion risk in the event of leakage or improper handling during maintenance.

Owing to the mandatory requirement for protection of the earth's ozone layer of Montreal Protocol and its subsequent enforcement, building owners have to replace old refrigerants having ozone depleting substance in their existing ventilation and air conditioning control systems with alternative refrigerants. However, due to budget constraints, owners or the concerned stakeholders are reluctant to replace the entire system compatible with new refrigerant but merely replacing refrigerants. Therefore, the use of new refrigerant in any cooling system not specifically designed for the type of new refrigerants not only could damage the components or cause malfunction of the system, most importantly, the high pressure of the new refrigerant in the system will cause leakage resulting in explosion when in contact with an ignition source in the vicinity.

7. POSSIBLE CAUSE OF THE FIRE WITH EXPLOSION INCIDENT IN HONG KONG

With regard to the information of the incident reported by newspaper and fire hazards of refrigerants as outlined above, it was believed that cause of the fire and explosion incident might have attributed to the following :-

(i) Although the heat exchange of the ventilation and air-conditioning control system of the restaurant was replaced several years ago for saving energy in that the operator of the restaurant had been honoured with Certificate of Merit in Hong Kong Awards for Environmental Excellence 2011 by Environmental Campaign Committee (Oriental Daily 東方日報, 2013), it was not known whether hydrocarbon refrigerant had been filled into the system at the time of replacement. However, judging from the phenomenon as reported by newspaper, it was very likely that the refrigerant leaking from the ventilation and air conditioning control system or the cylinders containing refrigerant inside the plant room was

flammable. It might be flake or counterfeit product of poor quality. Likely, such product might not have been approved to be used in ventilation and air conditioning control system.

(ii) Craftsmen who carried out the maintenance work of the ventilation and air conditioning control system might not have adequate knowledge of refrigerants. They were also not fully aware of the fire and explosion hazard of refrigerants and the resulting consequence. Due to the lack of knowledge, they might not be able to identify the type of refrigerant in the refrigeration system and its associated hazards. It was highly believed that they did not provide adequate ventilation to avoid accumulation of flammable refrigerants and remove all potential sources of ignition from the plant room and nearby vicinity.

(iii) As the dining area of the restaurant was close to the plant room and full of lunchtime diners at the time of carrying out maintenance work, the maintenance contractor employed by the operator of the restaurant might not have carried out risk assessment and devised appropriate actions to protect the customers of the restaurant prior to commencement of the maintenance work. In addition, there was doubt whether the maintenance contractor had made proper assessment to ascertain if the plant was compatible with alternative refrigerant to meet the requirement of environmental protection.

8. CONCLUSION

Air conditioning control systems are commonly installed in restaurants, commercial buildings, office buildings and institutional buildings in Hong Kong to provide a comfortable environment. However, lessons learned from past experience reveal that owners or property management staff of the buildings and maintenance contractors mainly concern about the efficiency and energy saving of the systems without paying much attention to the fire hazards arising from the use of refrigerants. It is also noted that fire or explosion incidents involving air conditioning control systems are often attributed to improper maintenance work conducted by maintenance contractors, such as refilling refrigerating plant with poor quality of refrigerants, recharging refrigerants incompatible with the metal parts of the system, refilling refrigerants at high pressure resulting in bursting of piping and joints, valves contaminated by grease, presence of source of ignition in close proximity of the refrigerating plant, etc. At present, no new refrigerants could meet all requirements for zero ozone depletion, low global warming potential, low toxicity and non-flammability (Japan Refrigeration and Air Conditioning Industry Association, 2012). In fact, under the current technology, refrigerant with zero ozone depletion, low global warming potential and low toxicity having 100% non-flammability characteristic is not available. Although refrigerant manufacturers claim that their alternative refrigerants are safe and flammability is low, the hazard of fire and explosion still exists when there is a leak of refrigerant from the system or cylinder under pressure in contact with a nearby source of ignition.

9. WAY FORWARD

As the size of problem is unknown in a dense concrete jungle packed with tall buildings in Hong Kong, the industry and the concerned professionals and engineers should take collaborative efforts to make the public aware of the issue and to enhance training for technicians and craftsmen.

Despite the fact that it will take time to conduct further research on the issue for possible consideration of formulating law to control the use refrigerants, maintenance contractor should develop and help building owners implement measures to prevent fire and explosion, which should include the removal or prevention of accumulation of possible flammable refrigerant, the exclusion or effective enclosure of possible sources of ignition and the use of suitable flame-proof equipment (Singapore Civil Defence Force, 2014).

Building owners currently still using hydrocarbon refrigerants should implement measures including disseminating adequate information on the hazards of hydrocarbon refrigerant and displaying warning notices at all entrances of any workroom containing hydrocarbon refrigerants and appropriate locations (Singapore Civil Defence Force, 2014). Should there be no insurmountable constraints, building owners should consider relocating the old plant room from the occupied area of the building to roof or other open areas of the building.

As an interim measure to address possible public concern arising from the use of flammable refrigerants from the fire safety point of view, the authority is recommended to formulate plans to control and tighten inspection on the use of clean refrigerants (Chow, 2013) and system maintenance before the occurrence of more fire and explosion incidents.

REFERENCES

Buildings Department, 2011, Fire Resisting Construction: Protection of Areas of Special Hazard, *Code of Practice for Fire Safety in Buildings*, Buildings Department, Hong Kong: p. 85.

Canadian Property Management, 2013, Flammable refrigerants demand caution, Canada. Available from: http://www.reminetwork.com/articles/flammable-refrigerants-demand-caution/ [Accessed: 1st March, 2014].

Chow W.K. 2013, Lesson Learnt from a Recent Incident in Ma On Shan : Any Explosion Risk for Environmentally Friendly Refrigerants?, *Hot Issue in Fire Engineering*, The Hong Kong Polytechnic University, Hong Kong, China. Available from: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html [Accessed: 1st March, 2014].

Environmental Protection Department, 1994, Air conditioning Refrigeration – A Time for Change, *Practice Note for Professional Persons ProPECC PN 4/94*, Environmental Protection Department, Hong Kong.

Febo H. L., 2003a, Refrigerating Systems, *In* Cote, A.E., *Fire Protection Handbook*, National Fire Protection Association, Quincy, Massachusetts: p. 393.

Febo H. L., 2003b, Refrigerating Systems, *In* Cote, A.E., *Fire Protection Handbook*, National Fire Protection Association, Quincy, Massachusetts: p. 400.

Fire Services Department, 2012, Requirements for Premises: Mechanical Plant Room (Group I), *Code of Practice for Minimum Fire Service Installations and Equipment,* Fire Services Department, Hong Kong: p. 41.

Government of Hong Kong, 1997a, Chapter 132 Public Health and Municipal Services Ordinance, *Laws of Hong Kong*, Hong Kong.

Government of Hong Kong, 1997b, Chapter 295 Dangerous Goods Ordinance, *Laws of Hong Kong*, Hong Kong.

Government of Hong Kong, 2004, Chapter 51 Gas Safety Ordinance, *Laws of Hong Kong*, Hong Kong.

HM Fire Service Inspectorate Publications Section, 2003, Ventilation in Multi-storey Buildings, *Fire Service Manual : Fire Safety : Fire Protection of Buildings*, HM Fire Service Inspectorate Publications Section, London: p. 147-158.

Japan Refrigeration and Air Conditioning Industry Association, 2012, Risk Assessment of Lower Flammable Refrigerants started, *JRAIA News*, vol. 11-03. Available from: http://www.jraia.or.jp/english/about/letter/vol.1103_NL.pdf [Accessed: 4th March, 2014].

Kampmeyer J.E., 2003, Miscellaneous Building Services, *In* Cote, A.E., *Fire Protection Handbook*, National Fire Protection Association, Quincy, Massachusetts: p. 223.

Occupational Safety and Health Branch of Labour Department, 2000, Solvent *The Protection of Workers' Health Series*, Labour Department, Hong Kong.

Office of the Fire Marshal, 2013 Hydrocarbon Refrigerants, *Otario Ministry of Community Safety & Correctional Services,* Canada. Available from: http://www.mcscs.jus.gov.on.ca/english/FireMarshal/FireServiceResources/Communiques/OFM_Com_2013-12.html [Accessed: 5th March, 2014].

Oriental Daily 東方日報, 2013, Explosion in a restaurant injuring 21, Newspaper, *Oriental Daily 東方日報*, Hong Kong. Available from: http://orientaldaily.on.cc/cnt/news/20130110/00176_004.html [Accessed: 1st March, 2014] - In Chinese.

Refrigerant Compliance Software, 2013, EPA Warns Against Use of R-22 Refrigerant Substitutes, *Refrigerant Compliance Software*, U.S.A.. Available from: http://www.refrigerantcompliancesoftware.com/refrigerant-emissions/epa-warns-against-use-of-r-22-refrigerant-substitutes/ [Accessed: 1st March, 2014].

Singapore Civil Defence Force, 2014, Joint Circular on Safe Handling and Use of Hydrocarbon Refrigerants, Singapore. Available from: https://www.wshc.sg/wps/themes/html/upload/cms/file/Hydrocarbon_Refrigerant.pdf [Accessed: 1st March, 2014].

South China Morning Post, 2013, Fireball rips through Ma On Shan restaurant, injuring 21, Newspaper, *South China Morning Post*, Hong Kong. Available from: http://www.scmp.com/news/hong-kong/article/1124086/fireball-rips-through-ma-shan-restaurant-injuring-21 [Accessed: 1st March 2014].

The Sun 太陽報, 2013, Explosion and damaging effect of Refrigerants under heat, Newspaper, *The Sun 太陽報*, Hong Kong. Available from: http://the-sun.on.cc/cnt/news/20130110/00407_003.html [Accessed: 1st March, 2014] - In Chinese.

United Stated Environmental Protection Agency, 2013, EPA Warns Against Use of Refrigerant Substitutes That Pose Fire and Explosion Risk, *News Releases from Headquarters*, U.S.A. Available from:

http://yosemite.epa.gov/opa/admpress.nsf/bd4379a92ceceeac8525735900400c27/61416ea839b0618e85257b9b0065aec0!OpenDocument [Accessed: 1st March, 2014].

Webb W.A., 2003a, Air conditioning and Ventilation Systems, *In* Cote, A.E., *Fire Protection Handbook*, National Fire Protection Association, Quincy, Massachusetts: p. 236.

Webb W.A., 2003b, Refrigerating Systems, *In* Cote, A.E., *Fire Protection Handbook*, National Fire Protection Association, Quincy, Massachusetts: p. 237.

HPB2014NgYW-revised