ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 2/2019

doi: 10.21307/ACEE-2019-020

# FIRE SAFETY IN THE BUILT-ENVIRONMENT: A CASE STUDY IN A RESIDENTIAL FACILITY

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Received: 12.02.2019; Revised: 27.02.2019; Accepted: 31.05.2019

Abstract

**In light of the spread of residential fires worldwide, this paper aims to identify the current fire safety code requirements for providing the minimum level of safety in residential facilities, hence, mitigating the risk of fire occurrence. The paper also presents the findings of a case study to demonstrate the compliance level of a sample residential facility, with code requirements. The case study building is composed of three floors and a basement. It can accommodate 214 persons. It was built in 2013, and it is located in Khobar, Saudi Arabia. The study revealed that the assessed facility had an adequate distribution of fire detection and notification systems. Moreover, the level of the housekeeping practices and concentration of hazardous material was found to be acceptable. However, the means of egress, fire doors and fire suppression systems were not up to code requirements. The study recommended measures to improve the level of safety in the building. These include increasing the number of fire exits; installing sprinkler heads on each floor; distributing fire extinguishers sufficiently; and installing fire rated doors. This study aims at raising awareness about the incidences of fires accidents in residential facilities and their catastrophic implications. It serves to provide a standardized fire safety management checklist, for the use of design professionals and property managers, towards the effective design and maintenance of residential facilities.**

Keywords: **Fires safety; Residential facilities; Checklist, Inspection.**

## 1. INTRODUCTION

Fire safety is one of the most significant concerns in the built-environment domain, due to its vital role for the survival of human beings and protection of properties. Residential facilities provide shelters for people of different ages, gender and even health levels. In fact, most people spend at least one quarter of their lives in their accommodation, practicing several kinds of activities, in different times. These residential facilities should be planned, designed and maintained in a way that would reduce the advent of fire occurrence, or if the worst does happen, reduce loses to a minimum. Therefore, design professionals and facilities managers of residential facilities need to be fully conscious of the fire safety regulations, to reduce risks, hence, achieve an appropriate level of safety. In essence, design professionals and facilities managers need to be aware of the required provisions of passive and active fire safety systems in the building, in order to assess and maintain the compliance of the buildings to the requirements of the fire codes [1]. Also, they need to be aware about the expected human behavior during fire emergencies, so that appropriate housekeeping and evacuation plans could be developed accordingly [2].

Numerous incidences of fire accidents worldwide have taken place over the past few years. These incidences have led to major loses, in terms of life and property. In the United States, for example, the National Fire

Protection Association (NFPA), reported that fire departments have responded to approximately 358,500 residential fires, on an annual basis over a time frame of five years (2011–2015). These fires resulted in approximately 2,510 fatalities, 12,300 injuries, and caused financial losses in properties, estimated at $6.7 billion annually [3]. Further, in Canada, it has been reported that 61,645 residential fires occurred between 2010 and 2014, resulting in 625 fatalities, and 4,759 injuries [4]. Furthermore, in the United Kingdom, the national statistics indicated that there were 168,540 residential fires reported over the period between 2010 and 2015, resulting in 1,110 fatalities and 33,574 injuries [5].

Consequently, it is of paramount significance to understand the characteristics of combustible materials, causes of fire, and high-risk areas to ignition in residential facilities. This study has two objectives. The first is to identify the current fire safety code requirements for providing the minimum level of safety in residential facilities, hence, mitigate the risk of fire occurrence. The second objective is to conduct a case study to demonstrate the compliance level of a sample residential facility with their applicable fire safety code requirements. This study contributes to the existing body of knowledge by raising awareness about the incidences of fires accidents in residential facilities and their catastrophic implications. It serves to provide a standardized fire safety management checklist, for the use of design professionals and property managers, towards the effective design and maintenance of residential facilities.

## 2. METHODOLOGY

The authors have conducted following activities to achieve the objective of this study:

- Reviewing the published literature to identify the characteristics of combustible materials usually found in residential facilities; the causes of fire in residential facilities; the high-risk areas to ignition in residential facilities; and potential risks and losses to the surrounding structures.
- Developing an inspection checklist, based on international fire safety code requirements [6], to assess the provision of fire safety measures in residential occupancies. The inspection checklist included measures pertaining to the means of egress, fire protection systems, electrical installation and distribution systems, fire doors; housekeeping practices; hazardous materials and miscellaneous fire safety requirements.
- Conducting a walkthrough inspection in a selected building, located in Khobar, Saudi Arabia, as a case study to assess the provision of fire safety systems in residential facilities.
- Reporting the findings of the inspection, hence, defining the level of compliance with fire safety code requirements.
- Developing a series of recommendations to improve the fire safety of the audited facility, and emphasizing the role of facilities managers in the maintenance of safety systems in residential facilities.

## 3. LITERATURE REVIEW

A review of the published literature was carried out to identify the characteristics of combustible materials usually found in residential facilities; the causes of fire in residential facilities; the high-risk areas to ignition in residential facilities; and potential risks and losses to the surrounding structures.

### 3.1. Characteristics of Combustible Materials in Residential Facilities

Typically, the initiation of fire is the outcome of the interaction between three ingredients, namely, a heat source, a combustible material, and the availability of enough concentration of Oxygen in the ambient atmosphere. The readily availability of these three ingredients constitute the “fire triangle”, where the absence of one ingredient will hinder the occurrence of ignition [7].

Combustible materials in residential facilities is one of the parameters that should be controlled to reduce the advent of fire development and propagation. Previous studies were conducted to investigate the characteristics of combustible materials in residential facilities. Cooking oils and grease usually found in kitchens are the most critical combustible contents that are readily available in residential facilities. These combustibles can be easily ignite and produce extreme temperature [8, 9, 10]. Fabrics such as clothing, curtains, carpets, mattresses, bedding and upholstered furniture constitute also a significant amount for fire load, that is usually found through other spaces in residential facilities [3, 9]. Combustible wall and ceiling finishes, as well as decorative materials could also contribute to the development of fire in residential facilities [11].

### 3.2. Causes of Fire in Residential Facilities

The causes of fire ignition in residential facilities are numerous. It is essential to realize that the building

spaces that accommodate high concentration of combustibles would facilitate the occurrence of ignition, in the availability of a source of heat. Generally, the most common source of fire ignition in residential buildings is heat. The heat could be present in different ways within residential buildings. Heat could be emitted from electrical equipment and installations, cooking and smoking [12]. The most common cause of residential fires is the cooking fire [3]. Cooking fires have led to major injuries as well as significant financial losses in many cases [9]. In most cooking fires, the ignition occurred due to the readily presence of cooking oil, which is highly ignitable, and could contribute rapidly to fire propagation [13]. Electrical equipment and installations are also a main cause of residential fires [9, 14, 15]. The fire could occur due to malfunctions, failures and lack of maintenance of electrical systems [3]. There are also other causes of fire in residential facilities. These causes are correlated with behavioral aspects such as smoking, playing with heat source, and heating [9].

### 3.3. High-Risk Areas to Ignition in Residential Facilities

Spaces containing sources of ignition as well as concentration of comestibles are considered to be areas of high potential to fire risk in a building. Designers and occupants of residential facilities need to reduce the potential for ignition in these areas. The kitchen is considered to be the riskiest space in term of its potential for the development of fire, due to the readily availability of both ingredients of the fire triangle, namely sources of heat from cooking devices, and combustibles such as oil and grease [10], as well as gas supplies for operating ovens. Therefore, cooking oil needs to be handled carefully, as well as stored properly [13]. Moreover, kitchens in residential facilities need to be adequately ventilated to mitigate the risk of fire, originating from gas supplies, as well as reducing the accumulation of heat. Bedrooms and living rooms are high risk areas to ignition in residential facilities, due to the availability of combustible materials in the form of fabrics such as cloths and furniture [10]. In addition, these spaces might include other electrical equipment that could ignite such as television sets and heaters [8].

### 3.4. Potential Risks and Losses to the Surrounding Structures

The risk of residential fires is not only limited to the unit, or the building in which the fire has occurred. The fire might spread to neighboring structures, and hence, pose a risk to these structures due to the amount of heat being released. For example, the fire that occurred in an apartment building located in Holland Township, Michigan, in the United States has caused damages to the adjacent structures, due to the amount of heat emitted from the flames [16]. Another example is the fire that occurred in the 12-unit apartment building, located in Salt Lake City, Utah, in the United States. The fire was initiated in one of the units, then propagated to the roof in a rapid manner, prior to the arrival of the fire department. The fire has also posed a potential risk to the adjacent structures, and thus, the occupants of these structures were evacuated [17].

## 4. DATA COLLECTION

### 4.1. Building Description

The building selected for the case study is an apartment building, located in Khobar, Saudi Arabia. Figures 1 and 2 illustrate the floor plan and elevation views of the case study building, respectively. The building is classified as "R-2" occupancy, according to the International Fire Code. The classification of "R-2" occupancy is used for categorizing facilities that are used for sleeping and accommodations, where the number of occupants exceeds 5 persons. The occupants are considered to be permanent in the facility, such as boarding houses, hotels (not transient), and apartments [6]. The building is 3 storey building, in addition to a basement used for car parking. It has been continuously occupied since May 2013. The area of each floor is 2,025 $m^2$. Each floor has 16 apartments, varying between 2-3 bedrooms. The building can accommodate 214 persons.

A copy of the as-built drawings of the building was obtained for the purpose of investigating the compliance of the building with the fire safety code requirements. The drawings also served to assess other dimensional measures such as the travel distances, and the locations of fire exits. The set of as-built drawings consisted of a site plan, floor plans, and layouts of the fire safety systems installed in the building.

### 4.2. Inspection Checklist

An inspection checklist, based on the international fire safety code requirements [6], to assess the provision of fire safety measures in residential occupancies was developed. Identification of risks through the utilization of checklists is a recognized methodology for risk assessment. The development of checklists entail the itemization of measures or indicators to be veri-

fied as acceptable or adequate by code requirements [18]. The inspection checklist included 38 measures pertaining to the means of egress, fire protection systems, electrical installation and distribution systems, fire doors; housekeeping practices; hazardous materials and miscellaneous fire safety requirements. Table 1 illustrates the developed inspection checklist for assessing the provision of fire safety measures in the case study building.

## 5. FINDINGS AND DISCUSSIONS

The findings in this section are presented as per the sequence of the safety measures in the developed inspection checklist that was filled-up during the walkthrough inspection of the case study building.

### 5.1. Means of Egress

The means of egress is defined as the continuous, unhindered path of departure from any location in the building to a refuge area, away from sources of hazards [19]. The walkthrough inspection of the means of egress revealed that most of the violations were related to the accessibility of the fire exits, absence of fire-rated doors, swinging in the direction of travel, and exceeded travel distances. The travel distance is the walking distance from a location, where a distress is found, to the nearest fire escape. Access to the assembly area outside the building was obstructed due to security barriers in the site. As the travel distance in R-2 occupancies, should not exceed 15 meters [6], random selection of two points in the building indicated that the travel distances were 27 and 34 meters, respectively, as indicated in Figure 1. Violations to the requirement of travel distance were noted in all three stories. Previous studies have empathized the role of compliance with travel distances with code requirements, due to their impact for occupant's safety in case of emergencies [20, 21].

### 5.2. Fire Protection Systems

The walkthrough inspection was carried out to inspect the provision of fire extinguishers, sprinkler systems, fire alarm systems, and smoke/heat detection systems. The inspection revealed that fire extinguishers were distributed sufficiently in all typical floors according to the code requirements [6], while they were not adequately distributed in the ground floor, as well as the basement. However, extinguishers are replaced every six months by the service provider. The walkthrough inspection indicated that sprinkler systems were only installed in the basement, while code requirements [6] mandate that they should be installed in all floors. Fire alarm systems were sufficiently distributed throughout the building, likewise fire detection systems. Moreover, the inspection concluded that detection systems were adequately provided in kitchens. In several incidences, it has been reported that detection systems have contributed to the survival of occupants in fire accidents [22]. Figure 1 illustrates the locations of the placed fire extinguishers and installed fire alarm and detection systems.

### 5.3. Electrical Installation and Distribution Systems

The walkthrough inspection indicated that all fire safety requirements [6] as per the developed inspection checklist for electrical installation and distribution systems were satisfied. The walkthrough inspection also revealed the availability of a backup electrical supply to power the fire pump, the fire alarm system and the exit signs. This backup electrical supply is a strong necessity since the power supply maybe cut off the building during the fire incident, and hence the operation of the fire protection systems will be hindered due to the lack of power supply [23, 24].

### 5.4. Fire Doors

Fire doors should be clearly identified through "Exit" signs. They should not also be obstructed in any manner, at all times, for the purpose of enabling the occupants to leave the building safely during emergencies [21]. The walkthrough inspection uncovered major violations in the provision of fire doors in the ground floor of the building. The available doors, while called "fire doors", were manufactured out of aluminum frames and glass panels. The doors did not include any fire rated materials in their assembly. Further, it was observed that the each of the two installed two-panel doors have one of the panels fixed, which will lead to a reduced capacity of 50% in terms of door width. These two doors constitute the main doors for gaining entry to the building, as well as escaping from the building in the event of a fire emergency. This reduced capacity of these doors will form a challenge during the evacuation of occupants during the fire emergency. Additionally, these doors were not swinging in the egress direction.

### 5.5. Housekeeping Practices

Housekeeping is an activity that considers the provision of technical fire safety measures, as well as the social aspects pertaining to the occupants' behavior, and its

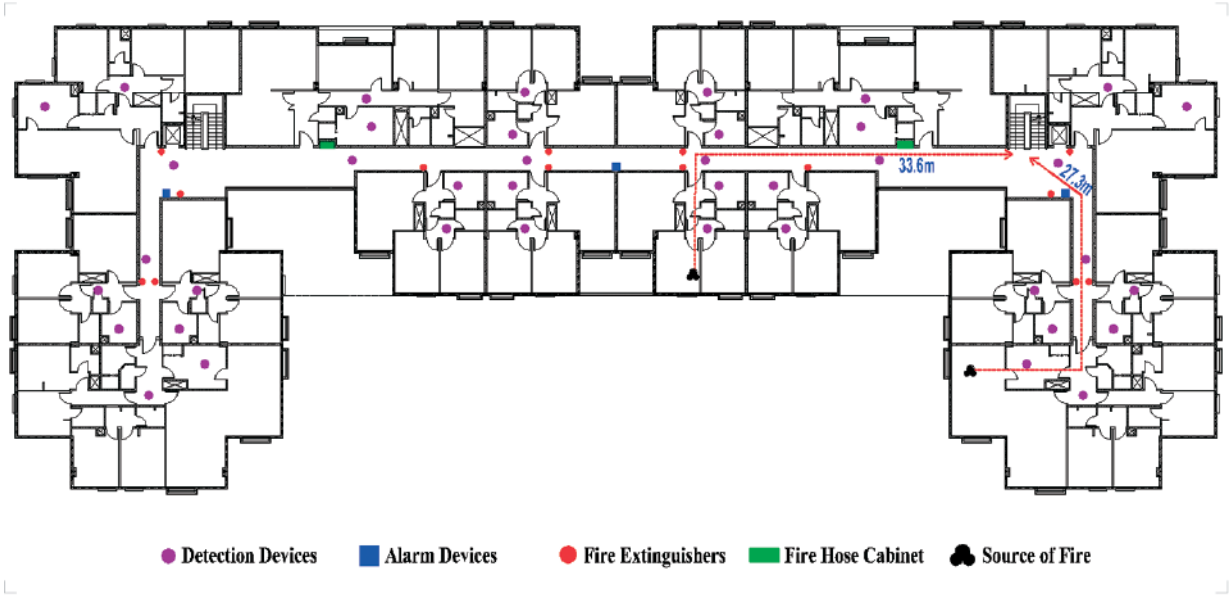


**Figure 1.**
**Floor plan of the case study building**

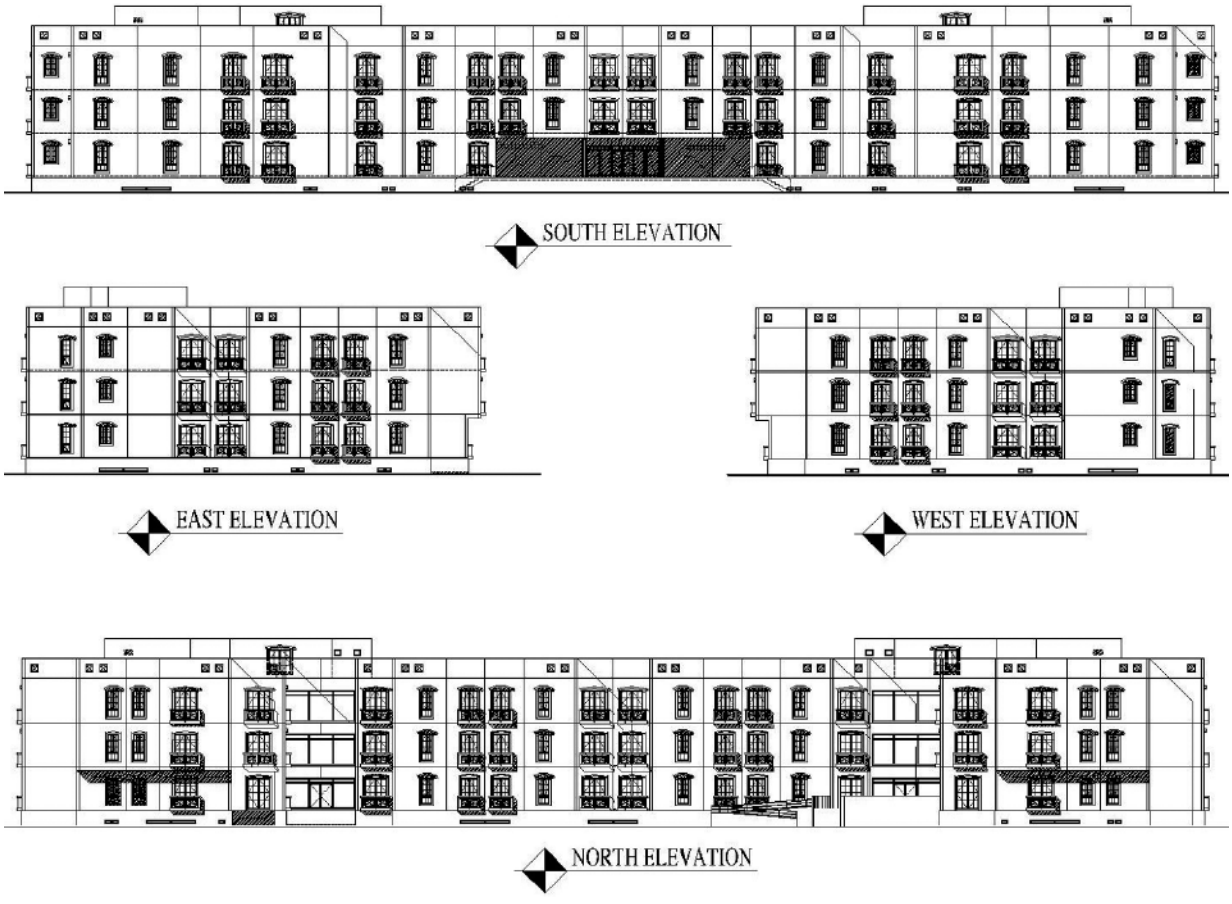


**Figure 2.**
**Elevation views of the case study building**

**Table 1.**
**Code-compliance checklist for fire safety requirements in residential facilities**

| | A. Means of egress | Yes | No |
|---|---|---|---|
| 1. | Exits are not to be less than the required number and capacity as per the code. | | ✓ |
| 2. | Exit doors are swinging in the direction of egress. | | ✓ |
| 3. | The travel distance does not exceed 15 meters. | | ✓ |
| 4. | Exterior doors are leading to discharge outside the building, or a public path. | | ✓ |
| 5. | Corridors are always lighted when the building is occupied. | ✓ | |
| 6. | Exit signs are available, and lighted throughout the building. | ✓ | |
| 7. | There are no barriers that would reduce the width of any exit. | ✓ | |
| 8. | The phrase "PUSH TO EXIT" is available on all fire doors. | | ✓ |
| 9. | Exit lighting could be operated using a standby power supply in case of an absence of municipal power supply. | ✓ | |
| | **B. Fire protection systems** | | |
| 10. | An automatic sprinkler system is installed throughout all floors. | | ✓ |
| 11. | Fire extinguishers are placed every 22 meters, in visible locations. | ✓ | |
| 12. | Fire extinguishers are mounted on walls. | | ✓ |
| 13. | Fire extinguishers are inspected annually. | ✓ | |
| 14. | There is no paint over sprinkler heads, except that of the factory. | ✓ | |
| 15. | Records of fire protection systems' inspections are kept for the past 3 years. | ✓ | |
| 16. | A 1 meter net space is provided around every fire hydrant. | | ✓ |
| 17. | Fire alarms are provided throughout the building. | ✓ | |
| | **C. Electrical installation and distribution systems** | | |
| 18. | Power taps are directly plugged into permeant sockets. | ✓ | |
| 19. | Relocatable cords are not passing through interior walls, finished floors, ceilings, doors or floor finishes, and are not subjected to harm. | ✓ | |
| 20. | Extension cords are not an alternative to permanent wiring. | ✓ | |
| 21. | Extension cords are not damaged. | ✓ | |
| 22. | There are no open junction boxes, as well as open wiring connections. | ✓ | |
| 23. | Electrical motors do not have any accumulations of oil or dirt. | ✓ | |
| 24. | The phrase "ELECTRICAL ROOM" is available on all doors of electrical rooms. | ✓ | |
| | **D. Fire doors** | | |
| 25. | Fire doors are not blocked in any way. | | ✓ |
| 26. | The assemblies of fire doors are not modified in any way. | | ✓ |
| 27. | Fire doors' closers have enough force to close and latch the door. | | ✓ |
| 28. | Fire doors remain in closed positions at all times. | | ✓ |
| | **E. Housekeeping practices** | | |
| 29. | Storage containing combustibles are kept in an organized manner. | ✓ | |
| 30. | The storage space is isolated from heat sources. | ✓ | |
| 31. | There are no combustibles stored in exits, exit enclosures, boiler, mechanical, and electrical rooms. | ✓ | |
| 32. | Dumpsters and containers are adequately provides throughout the building. | ✓ | |
| | **F. Miscellaneous fire safety requirements** | | |
| 33. | The building has a clear, readable address number. | | ✓ |
| 34. | Accessibility to the fire hydrant are not obstructed in any way. | | ✓ |
| 35. | Evacuation plans are clearly posted throughout the building. | ✓ | |
| | **G. Hazardous materials** | | |
| 36. | Flammable liquids are not available in the basement. | ✓ | |
| 37. | There are no more than 10 gallons of flammable and combustible liquids used for operation and maintenance of equipment. | ✓ | |
| 38. | There is no excessive storage of gas containers throughout the building. | ✓ | |

impact on safety [25]. The walkthrough inspection for housekeeping practices in the corridors between the apartment units revealed that the distribution of dumpsters and containers is adequate, according to code requirements [6]. An indoor inspection of a typical apartment unit indicated that the kitchen layout and the installation of the appliances within were in an appropriate level of safety. The apartment units were provided with electrical ovens, rather than gas-source type. Hence, the hazards that can contribute to ignition from gas supplies, are eliminated. A fire blanket was provided in each kitchen, and was mounted on the wall. Moreover, the occupants are well informed about the location of fire extinguishers, since there is one extinguisher available in front of each apartment's door. Occupants are also well informed about the location of the fire hose cabinets, as well as the evacuation plan in each floor, since occupants will pass them through the corridors.

### 5.6. Miscellaneous Fire Safety Requirements

The walkthrough inspection indicated that all the criteria pertaining to the miscellaneous fire safety requirements were satisfactory, except that the building did not have clearly readable address number, being obvious from the street in front of the building, for ease of identification by the fire department in case of a fire emergency.

### 5.7. Hazardous Material

The walkthrough inspection of the case study building indicated that the building is free from high concentration of hazardous materials, as listed in the developed inspection checklist, that could easily ignite and contribute significantly to flame and smoke propagation. However, residential facilities are known to contain high concentration of combustible materials in the kitchen, due to the availability of heat sources, as well as highly flammable martials such as cooking oil and grease. Residential facilities would also contain combustibles in fabrics [10]. These materials would usually emit a toxic fumes during fires, and hence cause serious hazards to occupants [26].

## 6. CONCLUSIONS AND RECOMMENDATIONS

Residential facilities are known to be a high-risk type of buildings to fire occurrence, due to the availability of the kitchen, as an essential functional component within each residential unit. Fire safety in residential facilities should be maintained in an appropriate level to safeguard the life of occupants and protect properties. This paper presented the findings of fire safety inspection of a residential facility, to assess the provision of fire safety systems, for mitigating the risk of fire occurrence. The inspection was conducted upon the development of a risk assessment checklist that included 38 measures to be verified as acceptable or adequate by fire safety code requirements. The walkthrough inspection indicated that there are violations related to the accessibility of the fire exits, absence of fire-rated doors, doors swinging in the opposite direction of travel, and exceeded travel distances to safe locations outside the building. The inspection also revealed an adequate distribution of fire extinguishers in all typical floors, except the ground floor, as well as the basement. Further, the inspection ascertained that all fire safety requirements pertaining to the electrical installation and distribution systems were satisfied. Furthermore, housekeeping measures were deemed satisfactory, according to fire safety code requirements. Nevertheless, the case study building needs to have a clear identification, for ease of identification by the fire fighting personnel, in case of a fire emergency.

The paper concludes with a series of recommendations to improve the fire safety of the audited facility. These recommendations are as follows:

- The number of fire exits should be increased in order to satisfy the required travel distance in the fire safety code.
- Sprinkler systems should be installed throughout all occupied floors, namely the ground, first and seconds floors.
- Fire extinguishers should be adequately distributed in the ground floor. These also need to be mounted on the walls for the ease of handling.
- The available doors should be replaced with fire rated doors, that should swing in the direction of egress.
- The building should have a clear identification, for ease of identification by the fire brigade.
- There should be an adequate number of fire hydrants around the perimeter of the building, for the use of fire fighting personnel to protect the building, as well as nearby structures.

This paper serves as a methodical procedure to audit the provision and up-keep of fire safety systems in existing residential facilities during the operation and maintenance phase, according to the international fire safety code requirements. It provides a practical value to design professional involved in the design of

residential projects, as well as facility managers responsible for day-to-day operations of residential facilities, irrespective of location.

## ACKNOWLEDGEMENT

The authors thank King Fahd University of Petroleum and Minerals for the support and facilities that made this research possible.

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