Evaluation of fire safety maintenance of an educational laboratory facility

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Abstract. This paper aims to evaluate fire safety systems of educational building laboratories by exploring the passive, active systems, and fire safety management. The evaluation was carried out in the University Integrated Engineering Lab in Depok City based on the applicable standards and regulations in Indonesia. Educational laboratories require a high-level safety measure against potential fire hazards due to the nature of the activities and equipment used. A reliable fire protection system and fire safety maintenance program are required to provide a comprehensive safety working environment. Lack of maintenance of fire safety systems is one of the causes of fires in educational laboratories. Triangulation methods consisting of field observation, interview, and document review were applied in this study along with descriptive and comparative analysis. Measurements by means of AutoCAD and Dialux simulation were carried out to support the evaluation process. The results show that the main features of the fire safety systems are installed in these laboratories according to the applicable standards and regulations. However, this study reveals that it is necessary to repair the walls, rearrange the sprinkler’s head spacing, add fire extinguisher, sort waste, and establish a fire emergency response team and safety organization.

1. INTRODUCTION

Fires can occur in all buildings and cause death, injury, property, and environmental damage [1, 2]. Educational manufacturing laboratories that serve as support to a practice-based engineering curriculum that balances analytical and theoretical knowledge of manufacturing that use manual and electronic equipments [3] also possess high potential fire hazards. Therefore, every building must be protected by a fire protection system [4]. Fire safety is an effort to prevent accidents, fires, and explosions that cause harm to humans, property, and the environment [2, 5]. Therefore, to avoid and minimize the impact and potential of fires, every building code, and design strategy requires both passive and active fire protection systems [1]. The building’s fire protection system must function properly all the time, especially when the building is being used by the occupants. Fire safety maintenance by trained personnel is one way to ensure that the system runs appropriately [6]. Fire safety maintenance is an effort to improve the safety of users and property and reduce the potential fire hazards [7] by conducting a periodic inspection, testing, repairing, and replacing fire safety [8]. Maintenance strategy can be improved by evaluating the existing fire safety measures and compare them with the applicable standards and regulations [9, 10, 11]. Some educational laboratories lacking regular maintenance for fire safety systems can be identified through findings of inactive detection systems, removing fire extinguition
systems, avoiding fixation on the systems, unsafe ignition sources, untrained personnel, and lack of education for the building users [7, 8, 10].

This paper takes a case study of the University Integrated Engineering Lab in Depok City that has a mix of teaching and laboratory functions. Activities in the educational laboratory have a high potential for danger, one of which is fire [7, 11]. These include 3D printing activities where heat sources and electronic equipment have a fire hazard potential. Thus, fire hazard potential may result from building design, construction, maintenance of fire protection systems, and the activities and equipment used. Fires can harm the sustainability aspect, namely economic, social, and environmental. The purpose of this paper is to evaluate the fire protection systems in this case study by exploring the passive, active systems and their fire safety management and compare them to the applicable standards and regulations. The results of the evaluation will then be discussed to get the solution to meet the applicable standards and regulations. The discussion can be used as initial input for building managers in carrying out fire safety maintenance to realize sustainable buildings.

2. FIRE SAFETY MAINTENANCE FOR EDUCATIONAL LABORATORIES
The potential fire hazards in educational laboratories can be reduced by complying with standards and regulations and proper fire safety maintenance strategies [12]. SNI issued by the National Standardization Agency (BSN) is a nationally applicable standard in Indonesia. Fire code from National Fire Protection Association (NFPA) is used for standards that do not exist in SNI. In addition, regulations from the Ministry of Public Works related to building fire safety are also referenced in this study.

One way to get a proper fire safety maintenance strategy is to evaluate the fire safety system [10, 13]. Fire safety maintenance includes inspection, testing, adjustment, repair, and replacement of the systems [1, 5, 6, 11]. Fire safety maintenance should be considered on a regular basis to the features that form the fire safety principles [8, 11]. These include means of egress, active and passive fire protection systems, and firefighting access. It becomes a minimum requirement to perform an inspection checklist to the fire extinguisher, damaged fire equipment, and housekeeping program for routine maintenance [14]. Passive fire protection systems control fires or their effects through structural systems or installed building materials that do not require operation in the event of a fire. Meanwhile, active fire protection systems limit the spread of fire and its effects by manual and automatic operation [1]. The maintenance of the passive protection system includes building construction, compartmentalization, protection of openings, and means of escape. In contrast, the active system includes automatic sprinklers, fire extinguishers, fire detection and alarms, hydrants, sound systems, emergency lighting, and emergency signage [14, 15].

3. Materials and Methods
The research framework is structured as shown in Figure 1 to describe the process carried out starting from the background, data collection, and analysis to achieve the research objectives. Data collections include field observation, interviewing building managers and contractors, and checking documents to determine actual fire safety conditions. Finally, the collected data will be analyzed by comparing it to the applicable standards and regulations.
3.1. The case studies

The University Integrated Engineering Lab is a new building that was not fully operational when the study was conducted. This 8-story building is located in Depok City. It has various functions such as showrooms, classrooms, workspaces, and laboratories. The scope of this paper is focused on the Tooling Laboratory and Hangar sections. This facility is located on the 1st floor of the building. These sections were selected as their function has a higher potential for fire hazards compared to the other rooms. The Tooling Laboratory has an area of 509 m², and the Hangar is 481 m², as shown in Figure 2. Both functions are used to make 3D prototypes with metal, polymer, glass, and wood materials for work in the Tooling Laboratory and plastic ore materials in the Hangar. Each material is processed with electronic equipment, as shown in Figure 3 (a & b). At the time when the observation was conducted, not all the equipment had been installed. The fully functional equipment is the one for making prototypes with metal and polymer materials. This building has structures and materials of high fire resistance, such as the Tooling Laboratory construction, which consists of a concrete structure, and the Hangar, with steel structure. The Tooling Laboratory wall consists of a paint-finished concrete wall and light brick walls with grout finish. Hangar walls comprised of an exposed brick wall, light brick walls with grout finish, paint-finished concrete wall, and spandex walls. The floor in Tooling Laboratory is an epoxy floor, while the Hangar floor is a concrete finishing floor. Both spaces have an open-plan layout and adjoining rooms separated by stairs, concrete columns, and walls, as shown in Figure 2.
3.2. Data collection and analysis

Data collection was conducted using triangulation methods consisting of field observation, interview, and document review. The triangulation method is used for internal validation. Observations are performed to identify passive, active fire protection systems, and their maintenance. Interviews are mainly carried out with building managers and the contractor to obtain information related to fire protection systems. In addition, interviews were also conducted with the operators of 3D printing equipment to find out the potential dangers of the equipment. The documents studied are floor plans, equipment specifications, and other supporting data from the building manager and contractor.

The collected data were analyzed descriptively to get a complete picture in the field and compared with applicable local standards and regulations as shown in Table 1. Measurements using AutoCAD and SketchUp software are performed to measure both passive and active fire protection and Dialux simulations to determine the fulfillment of emergency illumination levels.
Table 1. List of standards and regulations that are references in the study.

| Agency                        | Year  | Standard & Regulation                                                                 |
|-------------------------------|-------|---------------------------------------------------------------------------------------|
| Ministry of Public Works and Housing | 2008  | Regulation of the Minister of Public Works No. 26/PRT/M/2008 regarding Technical Requirements for Fire Protection System in Building and the Environment |
|                               | 2009  | Regulation of the Minister of Public Works No. 20/PRT/M/2009 regarding Technical Guidelines for Fire Protection Management in Urban |
| National Standardization Agency | 2000  | SNI 03-1736-2000 Procedure for planning passive protection systems for fire prevention in houses and buildings |
|                               |       | SNI 03-1746-2000 Procedure for planning and installing means of egress for rescue against fire hazards in buildings |
|                               |       | SNI 03-3989-2000 Procedure for planning and installing an automatic sprinkler system for the prevention of fire hazards in buildings |
|                               |       | SNI 03-3985-2000 Procedure for planning, installing, and testing fire detection and alarm systems for the prevention of fire hazards in buildings |
| National Fire Protection Association (NFPA) | 2001  | SNI 03-6574-2001 Procedure for designing emergency lighting, directional signs, and hazard warning systems in buildings |
|                               | 2013  | NFPA 13 Standard for the installation of sprinkler system                                |

4. Results and Discussions

4.1. Result
Both passive and active fire protection system in the University Integrated Engineering Lab, is still in good condition. However, some items need to be adjusted to meet the applicable standards and regulations, as shown in Table 2. At the time of the study, the building was under construction maintenance by contractors. Thus, fire safety management by the owner has not been carried out, and a fire protection organization has not yet been formed. Therefore, a fire safety plan has not yet been prepared. However, housekeeping activities have taken place, including the operator’s routine maintenance work of the 3D printing machine.

4.1.1. Passive fire protection systems
The separation between Tooling Laboratory and Hangar leaves a gap of 27 m², as shown in Figure 4 (a & b) allowing the spread of fire and smoke when a fire occurs. The door in the Tooling Laboratory is a folding metal door and a wooden door that connects to the smoke stop lobby. Meanwhile, the door in the Hangar is a sliding zinc-coated steel (BILS) door. The doors have good fire resistance. The ceilings in both rooms are open without a top. The Tooling Laboratory’s ceiling height is 4 m from the floor, while the Hangar is 12 m. Thus, the distance between the sprinkler’s head and the ceiling, beams, columns, and walls must be considered as it can affect the sprinkler response time.
4.1.2. Active fire protection systems
The sprinkler system in the Tooling Laboratory and Hangar is connected to the primary sprinkler system of the building using water-based automatic sprinklers. The fire extinguishers in the Tooling Laboratory and Hangar consist of dry chemical powder fire extinguishers suitable for the laboratory use of electronic equipment, smoke detector, speaker, hydrant, and support during emergency conditions, namely emergency lighting, and emergency signage, as shown in Figure 5. However, some of the active protection systems installed are not in accordance with the applicable standards and regulations, as shown in Table 2.

4.1.3. Fire safety management
Maintenance activities during the study are housekeeping, which includes cleaning the room floor and glass with non-combustible materials and waste disposal. The waste disposal is carried out without implemented waste segregation. The fire protection organization has not yet been formed so that a fire safety plan has not been prepared, and comprehensive fire safety maintenance activities have not been carried out.
Table 2. Comparison between the fire safety system with applicable standards & regulations.

| Variable                                      | Remark                                                                 |
|-----------------------------------------------|------------------------------------------------------------------------|
| **Passive Fire Protection System**            |                                                                        |
| Compartment (SNI 03-1736-2000)               |                                                                        |
| There is a separation with fireproof walls   | Tooling Laboratory and Hangar are separated by stairs, columns, and a portion of concrete walls |
| Cracks in the wall due to utility pipes must be provided with a fire stopper | Some cracks are not given fire stopper |
| Means of escape (SNI 03-1746-2000)           |                                                                        |
| Exit doors in the form of sliding doors must be easily moved in the event of a fire | The folding door in the Tooling Laboratory is difficult to operate because of the uneven track of the door rail |
| The exit in the form of a sliding door needs to be added with words “in an emergency slide to open” | The door in the Tooling Laboratory and Hangar does not have this inscription yet |
| **Active Fire Protection System**            |                                                                        |
| Automatic Sprinkler (SNI 03-3989-2000 & NFPA 13) |                                                                        |
| The minimum distance of the sprinkler head to the column is 0,6 m and the distance to the beam is 1,2 m | Some sprinkler heads are less than the minimum distance |
| When the building is not equipped with a plafond, then the distance of the sprinkler head and the wall should not exceed 1,5 m | Some sprinkler heads are more than the maximum distance |
| The maximum distance between the sprinkler head and the unobstructed ceiling is 305 mm | Sprinkler head distance and Tooling Laboratory ceiling are more than the maximum standard |
| **Fire extinguisher (Regulation of the Minister of Public Works No. 26/PRT/M/2008)** |                                                                        |
| The maximum distance between Fire Extinguishers is 23 m | Fire Extinguisher in Tooling Laboratory and Hangar more than 23 m |
| Fire detectors and alarm (SNI 03-3985-2000)   |                                                                        |
| The maximum height of the smoke detector calculated from the floor is 9,1 m | The height of the smoke detector in the Hangar is 12 m |
| The smoke detector needs to be installed on the sidewall to guarantee a fast reaction | With a ceiling height of 12 m, Hangar only has a smoke detector on the ceiling |
| Emergency lighting, signs, and warning systems (SNI 03-6574-2001) |                                                                        |
| Floors for walking in safe places, means to go to safe places, and means to public roads, illumination level is at least 10 lux | The average illumination level of emergency lighting in the Hangar is 7.8 lux |
| Exit signs are installed on the door leading to a safe exit | The Hangar door does not have exit signs yet |
| **Fire safety management**                   |                                                                        |
| Housekeeping (Regulation of the Minister of Public Works No. 26/PRT/M/2008) | Waste sorting has not been done |
| Waste segregation must be done especially for combustible waste |                                                                        |
| The organizational structure of fire protection and fire safety plan (Regulation of the Minister of Public Works No. 20/PRT/M/2009) | A fire protection organization has not yet been established so that there is no fire safety plan and maintenance activities such as audits, tests, periodic inspections, replacements, and repairs of fire safety |
| The establishment of a fire protection organization that is responsible for managing fire risk with the task of compiling a fire safety plan and carrying out maintenance of fire safety systems |                                                                        |

4.2. Discussion

The results above show that fire safety in the Tooling Laboratory and Hangar has met the minimum standards for buildings with a high potential for a fire hazard. This is indicated by the design of automatic sprinklers, the availability of fire detectors and alarms, fire extinguishers, emergency lighting, and
emergency signage. This accomplishment has met the applicable standards and regulations in Indonesia. However, some features need to be adjusted to improve the safety in the Tooling Laboratory and Hangar.

Based on the Minister of Public Works Regulation [6], the University Integrated Engineering Laboratory, which has eight floors and has a laboratory function, is included in the fire-resistant construction type A. Thus, the building must design a passive fire protection system by considering the use of materials and building structural components, compartmentalization or separation of buildings based on high levels of fire resistance, and protection against openings. The structure and selection of materials used are of high fire resistance. However, some details do not comply with the SNI [16], such as the separation of the room between the Tooling Laboratory and Hangar which only used stairs, columns, and some concrete walls. The separation of the room that is originally intended to form a compartment must be expanded to the area under the roof, and if there is an opening, it must be provided with a fire stopper. Furthermore, some of the walls in the Tooling Laboratory penetrated by utilities were not equipped with fire stoppers. It is necessary to add a fire stopper in preventing the spread of fire.

According to the SNI [17], the exit in the form of a sliding door must be easily pushed in the event of a fire. Contrarily, the door in the Tooling Laboratory, which is a folding door, is often difficult to open due to the uneven track of the door rail. This needs to be repaired immediately so that the door is easy to open. In addition, it is also necessary to add a sign “in an emergency slide to open” near the door.

Based on the SNI [18] and NFPA [19], Tooling Laboratory and Hangar are classified as moderate to severe fire occupancy due to the activities and equipment used. The classification requires the use of automatic sprinklers for fire safety in the Tooling Laboratory and Hangar. Although the sprinkler system has been implemented, several provisions must be adjusted to conform to the standard. This study reveals that the distance between the sprinkler heads and the concrete ceiling exceeds the safe limit as set out in the standard. In addition, the length of the sprinkler head from the beam and column is less than the minimum distance. In a fire, these findings can affect the sprinkler’s response time due to the heat accumulation. The adjustments of the sprinkler head positions should refer to the standard and carry out by registered consultants and contractors.

Next, the Tooling Laboratory and Hangar fire extinguishers have a distance of more than 23 m. According to the regulation [6], if the length of the fire extinguisher is more than the provision, it can reset the distance or add a fire extinguisher unit. Additionally, according to the standard, the active system that needs to be adjusted is the fire detector and Hangar’s alarm [20]. The smoke detector in Hangar is placed at the height of 12 m according to the ceiling height. This needs to be adjusted to anticipate the response time of the detector and sprinkler. In addition, a wall smoke detector can be added if lowering the detector’s height is not possible. Adjustments also need to be made to the emergency lighting and signages in the Hangar according to the standard [21]. The average illumination level during an emergency in the Hangar is less than 10 lux, namely 7.8 lux. Thus, it is necessary to add an emergency light in the room. It is also essential to add an exit sign at the Hangar door which is currently missing.

Housekeeping activities that have been carried out are still minimal. We need to make improvements to reduce the potential fire hazard. One of the activities that can be done is sorting the waste by separating the combustible waste. In addition, according to the regulations [6, 22], it is necessary to immediately establish a fire protection organization that is responsible for managing the fire safety measures and management. It can be done by compiling a fire safety plan and carrying out other management activities, such as maintenance, periodic inspections, education, fire drills, to documentation each process of management activities. Fire safety plan consists of Fire Protection System Maintenance Plan, Good Housekeeping Plan, and Fire Emergency Plan. These documents will serve as a guide for building managers in managing the fire safety systems.

5. Conclusion
This study shows that the University Integrated Engineering Laboratory has not yet carried out the fire safety maintenance sufficiently considering that the building was under construction maintenance by the contractor at the time of the study. However, the University Integrated Engineering Laboratory has
generally implemented a passive and active fire protection system according to applicable standards and regulations. This study reveals that some measures need adjustment to meet the standard of laboratory functions in the Tooling Laboratory and Hangar. The adjustment should refer to the applicable standards and regulations in Indonesia. The adjustments that should be made are in the fire safety maintenance corridor, which includes repairs, additions, rearrangements, and the formation of a fire protection organization. The results of this study can be the initial input for establishing the fire protection organization.

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