Weighting The Fire Protection Systems Technical Requirements to Determine Flats Reliability Against Fire Hazards

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ABSTRACT

Flats are multi-story buildings built to serve a region that is divided into functionally structured sections, both in horizontal and vertical directions consisting of each unit that can be owned and used separately. Flats are often identified as poorly maintained buildings, especially in infrastructure and facilities that support the security, convenience, and safety of occupants and buildings. Fire in flats can be caused by various things including human, natural, and accidental factors. Fire prevention can be performed properly when flats managers and occupants can understand the risks that can trigger fires as well as those that can hinder the rescue process. This study tries to find out the weight of fire protection systems' technical requirements to determine flats' reliability against fire hazards based on the Minister of Public Works Regulation, National Fire Protection Association, and American Society For Testing and Materials. Through the filtering phase analyzed with Relative Importance Index followed by the weighting phase analyzed with Pairwise Comparison, the result obtained an order of requirements from the highest to lowest weight are Means of Escape (24,1%), Active Protection Systems (18,9%), Passive Protection Systems (14,5%), Utilities (13,5%), Site Planning (10,1%), Occupancies (9,8%) and Housekeeping (9,1%).

Keywords : buildings reliability, fire hazards, fire protection systems, flats, infrastructure management & facilities, relative importance index

INTRODUCTION

The flat is a building that provides residential functions with various safety and convenience facilities for occupants who can be students, low-income communities, civil servants, societies, and others. The regional arrangement, fulfillment of a decent dwelling place needs, and limited land in urban areas are the reasons why the government is intensively built flats in recent years. During the 2015-2019 period, the Ministry of Public Work and Housing (MPWH) has built more than 800 towers with a total of more than 49.000 units spread throughout the country (Directorate General of Housing Provision).

The diversity and complexity of flats construction, both in terms of allotment and occupancies, demand higher safety and security aspects of the building and its environment. One most important safety aspects of flats building are safety against fire hazards. In addition to reasons of safety aspects, securing buildings against fire hazards has become the responsibility of building managers and all users in protecting various things in the building.

Fire is a problem that cannot be separated from humans. Fire is an oxidation event with all three elements (fuel, oxygen, and heat) which results in loss of property and even death (Sari, 2007). Losses caused by fire are not only in the form of building damage but also a loss that concerns morals and human life. Causes of fire according to Triyono are due to human negligence such as lack of understanding of fire prevention, inadvertent use of tools that can cause fire, natural events that occur during disasters, ignition itself which often occurs in chemical warehouses, and because of deliberate intent for sabotage purposes, eliminate traces of crime or seek personal gain.

As an asset, flats must be managed properly and refer to applicable principles and regulations. Assets and facilities must be managed to deal with all forms of risks that can occur, including the risk of fire (Soemitro & Suprayitno 2018; Suprayitno & Soemitro 2018). A previous study related to the evaluation of fire disaster evacuation path in the UNIB multipurpose building circulation, stated the existing systems are sufficient to meet the standards required by applicable regulations, however, it is necessary to add several aspects that increase the evacuation effectiveness such as portable fire extinguisher, emergency lighting and additional door that directly leads to the outside of the room (Seftyarizki, Ramawangsa & Saputri 2019). Besides, Minister of Public Works Regulation No.26/PRT/M/2008 explains according to the development of increasingly complex building implementation in terms of intensity, technology, and infrastructure needs and facilities, every building developer must pay attention to several technical requirements in the fire protection system of buildings and environment such as site planning, means of escape, passive and active fire protection systems, utilities and housekeeping. Moreover, some occupancy factors may affect the safety of buildings and occupants as described in the *American Society For Testing and Materials* E 931 – 94 (ASTM E-931). Therefore, this study will be discussed further related to the weighting of the fire protection systems' technical requirements to determine flats' reliability against fire hazards, particularly for low to medium-level flats.

These technical requirements are further referred to as factors. Factors identification is considered important in early-stage due to understanding buildings' performance and reliability against fire hazards may be influenced by several factors where the factors have a value. These factors can be supporting or resisting factors that can be strong or weak or can be easy or difficult to be manipulated factors (Suprayitno, Soemitro, Maulana & Hesna 2020).

Factors filtering along with the factors' importance weighting to determine flats' reliability against fire hazards are arranged based on the respondents' opinions who are experts in the field of building management and fire disaster management. Filtering and weighting factors results are expected to be a tool to evaluate the completeness of the fire protection system in a building.

RESEARCH METHOD

This research uses the following thinking path: determining background, goal, research method, data collection, analysis, and end with conclusions. The method used in this study consisted of identifying factors based on related literature under the research objectives, followed by determining factors that are considered important through processing the results of the factor filtering questionnaire with the Relative Importance Index (RII) and weighting factors through processing the results of the factor weighting questionnaire using the Pairwise Comparison method.

DATA COLLECTION

Basic Principles of Analysis

Factors identification and weighting results must be used in designing the assessment model of the flats' reliability against fire hazards which then becomes the basis for evaluating all important aspects of the level of flats' reliability against fire hazards including technical requirements such as site planning concepts, passive and active protection system conditions, means of escape reliability, utility readiness and non-technical factors such as occupant behavior and the disciplining when applying the flats housekeeping. All of these stages are executed to produce an observed building reliability index value.

Filtered factors are obtained from several kinds of literature such as scientific papers, journals also domestic and foreign regulations following with research objectives. Furthermore, respondents filled out questionnaires to determine the importance level of each factor.

Weighted factors are considered to have a significant effect on the flat's reliability against fire hazards because each respondent is considered to have given an opinion on each factor and has been allowed to provide feedback or input if the factor has a very important or unimportant tendency or other things are not listed in the questionnaire.

Retrieved factors in this research are those approved by the respondents who are experts in their respective fields. Furthermore, these factors are weighted by Pairwise Comparison with the 1-9 scale of importance assessment. Through the factors weighting questionnaire distribution to all respondents, then we get a recapitulation of all factors weight that indicates a sub-factor weighs importance on all the factors it supports. The factor's weight recapitulation then becomes the basis for designing the assessment model of flats reliability against fire hazards which can be used to assess, facilitate the implementation of the inspections, and find deficiencies as well risks that exist in a building against fire hazards.

Factor Identification

This study uses research variables formed by obtained factors from several kinds of literature and regulations such as Minister of Public Works Regulation No.26/PRT/M/2008 concerning Technical Requirements for Fire Protection Systems in Buildings and the Environment, American Society For Testing and Materials (ASTM E 931 – 94) and *National Fire Protection Association* (NFPA). Seven factors are consisting of 49 sub-factors, and these factors are considered important to flats' reliability against fire hazards. Each subfactor represents a suggested component according to the standard literature reviewed to ensure the flats' reliability against fire hazards. Furthermore, all sub-factors will be filtered using a research questionnaire related to sub-factor filtering by the respondents, then the questionnaire results are processed using the RII method.

Research Instruments

Data in this study were collected using a questionnaire. This study uses non-probability sampling which is not a randomly selected sampling technique. The type of non-probability sampling chosen is purposive sampling, which is the chosen sampling unit based on certain considerations to obtain a sampling unit that has the desired characteristics. This technique is used especially if there are only a few people who have expertise in the field being studied. Determining the number of sampling used using the saturation sampling method. According to Sugiyono (2011), saturation sampling is a sampling technique when all members of the population are used as samples. The amount of sampling in this study was taken using a saturation sampling technique because the number is relatively small as many as 15 respondents.

Respondent selection consideration from the Directorate General of Human Settlements is based on its institution tasks that focus on standards and regulations arrangement related to building construction, the convenience of building accessibility as well as reliability, and building protection systems. Respondent selection consideration from the Directorate General of Housing Provision is based on its institution tasks that focus on standards and regulations arrangement related to technical guidelines for the flats construction, management, and implementation requirements. Respondent selection consideration from the Fire and Disaster Management Agency is based on their versed in dealing with fire disasters, socializing with various groups of people that need fire service assistance, fire protection systems testing and investigation in various types of buildings, as well as understanding the factors that influence the occurrence of fire disaster and obstacles in its response. Respondent selection consideration from the practitioner's field is intended to obtain different perspectives from practitioners who are experienced in the field. Practitioners can deliver an overview regarding regulations input, opinions, or criticism as well as review phenomena that occur or may occur from several different scientific aspects but are related to each other.

RESEARCH ANALYSIS

Factor Filtering

This study uses the Relative Important Index (RII) method for eliminating factors that are considered less important and ensuring the used factors are important according to respondents' opinions who are experts in their respective fields. The RII method was chosen because the collected questionnaire results can be analyzed statistically so it is quite practical in data collection and more comprehensive in determining factors. RII starts with estimated factors identification that takes effect then continues with the factor filtering questionnaire distribution to eliminate factors that are considered not important based on respondents' perceptions. The questionnaire was prepared using a Likert scale which states the level of agreement on the used variables. RII is the terminology first used by Mayer et al. The formula for RII has been applied based on the reference from Hardjomuljadi (2014). RII calculations can use Formula 1 as follows.

$$RII = \sum W / (A \times N) \tag{1}$$

Description :
W = the weight given to the factors (range from 1 to 6)
A = highest weight (5 in this study)
N = total number of respondents

RII range is obtained by dividing evenly into five categories according to the used Likert scale. After the calculation, the value can be classified as shown in Table 1. below.

Table 1. Rank of Relative Important Index (RII)

Range of RII value	Ranking
0,880 – 1,000	Very important
0,710 – 0,870	Important
0,540 – 0,700	Moderate
0,370 – 0,530	Less important
0,200 – 0,360	Not important

After obtaining the RII value, the cut-off point is then determined according to the table above. Qualified factors or are considered important are those that meet the RII value ≥ 0.750 which ranked important/approved in the previous Table.

Data Analysis

After all, factors have passed the filtering stage through the factor filtering questionnaire distribution filled by the respondents, then obtained the RII value of each factor has been calculated based on the formula described in the sub-chapter above. RII value recapitulation of accepted factors is shown in Table 5. Moreover, several sub-factors have sub-standard values, so it is considered less important to flats' reliability against fire hazards and decided not to be involved in the weighting phase.

The means of escape factor has three sub-factors that do not meet the requirements, which are as follows.

1. Emergency doors are considered less important because it is only required in high-rise buildings above 5 levels or if the flat has a vertical means of transportation other than stairs.
2. Exit passageway is considered less important because not required to have protected rooms on flats that connects the emergency stairs door to open space. Most flats have direct access from the emergency stairs discharge to the assembly point through an open space or lobby on the ground floor.
3. Emergency lighting is considered less important and similar to "means of egress illumination" which already arrange means of egress illumination completeness including emergency lightning, its source, and standard performance, so it does not need to be assessed as new sub-factors.

The passive protection system factor which concerned with building design both structurally and architecturally has a sub-factor that does not meet the requirements are as follows.

1. A smoke Barrier is considered to be less important because it is required in high-rise buildings with a lift as vertical means of transportation. The smoke barrier is rarely used in flats, especially low-level flats.

The active protection system factor that works synergically with passive protection systems to protect buildings and occupants against fire hazards has two sub-factors that do not meet the requirements, which are as follows.

1. Water supply is considered to be less important because it has been fulfilled by the "Water Source" subfactor which includes water source needs during an emergency for a fire fighting process.
2. Mechanical ventilation and smoke control systems are considered less important because it is more commonly used in high-rise buildings that have emergency staircases that are separate from the building or have their own space.

The utility factors or building facilities that support comfort, health, and communication aspects, have three sub-factors that do not meet the requirements, which are as follows.

1. Lightning protection system maintenance and inspection are considered less important and as part of the "Lightning protection system" which requires the system to be maintained and tested as it should.
2. Disposal Funnel is considered less important because it is rarely used in flats and normally used in buildings with underground parking or a fairly large kitchen.
3. Static electricity control is considered less important and similar to "Electrical hazard control".

The housekeeping factor or efforts to maintain, manage, and operate a building or dwelling along with its equipment and occupants, has two sub-factors that do not meet the requirements, which are as follows.

1. The Historical record is considered less important and as part of "Fire protection system inspection, testing, and maintenance" so that it does not need to be separated as a new subfactor.
2. Confined / restrained are considered less important and can not be measured with certainty.

The occupancies factor or occupant behavior and ability in overcoming fire hazards have three sub-factors that do not meet the requirements, which are as follows.

1. Ease of evacuation is considered less important since unable to be measured with certainty but is quite predictable by the other factors present which are compulsory components of flats fire protection.

2. Purposeful and accidental ignition is considered less important and difficult to measure with certainty because it needs to be deepened towards the social environment of the assessed flats.

Weighting Factor

Each considered important factor is weighted using the Pairwise Comparison method which stems from the Analytic Hierarchy Process (AHP). A pairwise comparison matrix usually refers to each comparing process between the paired variables to assess which variable has a higher weight. The scale used can be seen in Table 2. as follows.

Table 2. Pairwise Comparison Scale

Index	Definition
1	Equally important
2	Equally or slightly more important
3	Slightly more important
4	Between slightly more and much more important
5	Much more important
6	Between much more and far more important
7	Far more important
8	Between far more and extremely more important
9	Extremely more important

A pairwise comparison of the selected index shows the tendency of the importance of one factor compared to other factors. The use of AHP Calculator (Multiple Input) K.D. Goepel 07.06.2015 version will be done to facilitate weighting questionnaire results calculation that has been given by the experts.

Data Analysis

After all, factors have passed the weighting stage through the factor weighting questionnaire distribution that was filled by the respondents. The questionnaire results were then processed by AHP Calculator (Multiple Input) K.D. Goepel 07.06.2015 version so each factor weight is obtained as shown in Table 3. below.

Table 3. Factor Weight

Factor	Weight
Means of Escape	24.10%
Active Protection System	18.90%
Passive Protection System	14.50%
Utilities	13.50%
Site Planning	10.10%
Occupancies	9.80%
Housekeeping	9.10%
Total	100%

Each factor consists of several sub-factors which are the constituent components that influence the value of the overall factor. Each subfactor has a different weight obtained based on the weighting questionnaire results previously described. There is always the most and least important sub-variable in each variable that is indicated by the opposite weight value of both sub-factors which became the highest one and another is the lowest. Each subfactor's weight towards its factors can be seen in Table 4 below.

Table 4. Subfactor Weight

Subfactor	Weight
Means of Escape	
Means of Egress Reliability	24.1%
Means of Egress Sign	21.3%
Exit Discharge	20.5%
Stairwell Protection	18.5%
Means of Egress Illumination	15.6%
Active Protection Systems	
Detector and Fire Alarm	21.3%
Portable Fire Extinguisher	21.0%
Automatic Sprinkler Systems	19.0%
Fire Pump	18.2%
Standpipe and Hose	10.9%
Response Time	9.7%
Passive Protection Systems	
Building Construction	52.0%
Firestop	48.0%
Utilities	
Fire Control Center	28.2%
Emergency Electricity	25.7%
Electrical Hazard Control	23.3%
Lightning Protection System	22.8%
Site Planning	
Water Sources	23.9%
Fire Truck Access	19.1%
Personnel Access	17.4%
Fire Hydrant	16.7%
Internal Road	12.5%
Buildings Distance	10.5%
Occupancies	
Trained Occupants	41.0%
Insulation/Restriction	21.5%
Impairment	21.4%
Sleep Activity	16.1%
Housekeeping	
Fire Protection Systems Inspection	21.4%
Internal Fire Control	15.5%
Floors Maintenance	12.5%
Smoking Control	11.9%
Friction Control	11.0%
Yard Control	10.0%
Prohibited Items	9.7%
Waste Disposal	8.0%

In Table 4, it can be seen the order of each sub-factor weight that can be considered to assess the flats' reliability against fire hazards is as follows:

1. Means of Escape have the highest weight because, in low and middle-level buildings, rescue and evacuation are the main targets that must be achieved as soon as possible. A fire extinguisher is considered can be done along when evacuation takes time. This is because low and medium-level buildings evacuation can still be done effectively and efficiently because the level of a building and occupancy complexity are still classified as normal or not necessary to take peculiar action as should be applied to high-rise buildings. This is proven by the means of egress reliability and sign taking two highest ranks which means the condition of the means of escape is very important for the safety of occupants of a building against fire hazards.
2. Active Protection System takes second place in factor weighting, this is due to deliver an effective and efficient evacuation, occupants must be supported by several aspects of active protection such as portable fire extinguishers which are particularly needed to overcome the fire during the evacuation process as well as detector and alarm system is very helpful for occupants to immediately cognize and save themselves as soon as possible before the danger of fire further complicates the evacuation process.
3. Passive Protection System has the third-highest weight due to being able to execute effective evacuations, building conditions must be supportive to not endanger the occupants during evacuation. Firestop and building construction are considered important for occupant safety. The longer a building can resist fire, the greater the evacuation success rate of all occupants in a building.
4. Utilities become the next factor that is considered important to the flats' reliability against fire hazards. Utilities have several important aspects to support the evacuation process, including the fire control center that functions to monitor the building condition, track the fire hazard source, and notify the entire building to immediately conduct an evacuation. Besides, emergency electricity is also considered quite important as means of escape emergency lighting when a blackout occurs due to damaged main electrical systems by fire.
5. Site planning is the fifth highest-ranking factor in determining flats' reliability against fire hazards. Site planning is a factor that guarantees environmental conditions and access during the evacuation. Water sources such as groundwater tanks, roof tanks, and others are considered the most needed in site planning, this is because various aspects of active protection systems require reliable water sources to function properly. Decent fire truck access is also important for the evacuation process, therefore adequate access conditions due to its construction, dimension, and unobstructed conditions are considered to bring a major impact on site planning factors.
6. Occupancies are considered less important in the safety of buildings and occupants. However, there are several obtrusive aspects in the occupancy factor such as training schedule or trained occupants in dealing with fire disasters, and the occupants' condition with both physically and mentally limited is considered to be difficult to evacuate so it needs certain demand related to the situation.
7. Housekeeping ranks last as an important factor. Some notable aspects of housekeeping factors with the highest weight are scheduled to fire protection system inspection, testing, and maintenance as well as building managers' readiness to control fires and the frequency of building management training that is held regularly.

CONCLUSION

Based on questionnaire results that were submitted by the respondents as well as data analysis using the methods and tools described earlier, the following conclusions can be obtained:

1. The factors arranged by their significance in determining flats' reliability against fire hazards are as follows: Means of Escape (24,1%), Active Protection Systems (18,9%), Passive Protection Systems (14,5%), Utilities (13,5%), Site Planning (10,1%), Occupancies (9,8%) and Housekeeping (9,1%).
2. Each factor consists of some subfactors which are the constituent components that influence the value of the overall factor. Means of escape consist of 5 subfactors, active protection systems consist of 6 subfactors, passive protection systems consist of 2 subfactors, utilities consist of 4 subfactors, site planning consists of 6 subfactors, occupancies consists of 4 subfactors and housekeeping consists of 8 subfactors.

RECOMMENDATION

1. For further research, it is recommended to apply the weighted factors to certain flats as a research object, so that the flats' reliability against fire hazards can be known based on technical requirements fulfillment for fire protection systems under referenced regulation. Besides, it can be seen whether the implementation results are suitable for existing conditions.
2. Factors weighting for high-rise flats can show different results because of their demand for more complex and complete technical requirements such as emergency doors, mechanical ventilation, refugee area, smoke barrier, and fire lift. Therefore, other factors filtering and weighting are needed to determine high-rise flats' reliability against fire hazards.

REFERENCES

ASTM E931/94. *American Standard Test Material Fire Test: E 931 – 9, Standard Practice for Classification of Occupancies for Their Relative Fire Hazard.*

Direktorat Rumah Susun (2020), *Laporan Kinerja Direktorat Rumah Susun T.A 2019,* Direktorat Jenderal Penyediaan Perumahan, Jakarta.

Hardjomuljadi, S. (2014), "Factor Analysis on Causal of Construction Claims and Disputes in Indonesia (concerning the construction of hydroelectric power project in Indonesia)". *International Journal of Applied Engineering Research, Volume 9.*

Irdayani dan Hardjomuljadi, S. (2016), "Kendala Proyek Konstruksi Yang Dikerjakan Secara Swakelola Di Kabupaten Pinrang". *Jurnal Konstruksia, Vol. 8, No. 1, Desember 2016.*

NFPA 13/07. *National Fire Protection Association, Standard for the Installation of Sprinkler Systems, 2007 Edition.*

PerMen PU 26/08. *Peraturan Menteri Pekerjaan Umum Nomor 26/PRT/M/2008 tentang Persyaratan Teknis Sistem Proteksi Kebakaran Pada Bangunan Gedung dan Lingkungan.*

Sari, K.J. (2007). Evaluasi Sistem Pencegahan Dan Penanggulangan Kebakaran Pada Gedung Fakultas Ilmu Keperawatan Universitas Indonesia Kampus Depok, Tahun 2007. *Skripsi.* Program Sarjana Kesehatan Masyarakat Peminatan Keselamatan dan Kesehatan Kerja. Fakultas Kesehatan Masyarakat. Universitas Indonesia. Depok.

Seftyarizki, D., Ramawangsa, P.A., & Saputri D.O. (2019). "Evaluasi Jalur Evakuasi Bencana Kebakaran Pada Sirkulasi Gedung Serbaguna UNIB". *Jurnal Manajemen Aset Infrastruktur & Fasilitas, Vol. 3, Edisi Khusus 1, Maret 2019.*

Sugiyono. (2011), *Metode Penelitian Kuantitatif, Kualitatif dan R&D,* Penerbit Afabeta, Bandung.

Suprayitno, H. & Soemitro R.A.A. (2018), "Preliminary Reflexion on Basic Principle of Infrastructure Asset Management". *Jurnal Manajemen Aset Infrastruktur & Fasilitas, Vol. 2, No. 1, Maret 2018.*

Suprayitno, H., Soemitro R.A.A., Maulana, A.M., & Hesna, Y. (2020), "Preliminary Reflection on Performance Indicator and Performance Factor for Infrastructure Asset Management". *Journal of Infrastructure & Facility Asset Management, Vol. 2, No. 1, March 2020.*

Triyono, A. (2001). "Teknik Penanggulangan Bahaya Kebakaran Di Perusahaan".*Majalah Hiperkes Dan Keselamatan Kerja, vol. XXXIV, No. 3, hal 34. Depnaker. Jakarta.*

UU 28/2002. *Undang – undang Nomor 28 Tahun 2002 tentang Bangunan Gedung.*