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Reliability Analysis of Early Fire Detection Systems to Ensure Occupant Safety and Comfort: Case Study of Grand Jati Junction Apartment Building, Medan

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ABSTRACT
The Grand Jati Junction Medan Apartment Building is one of the high-rise buildings with a mixed-use concept that has a high spatial complexity. This architectural complexity directly affects the performance and reliability of active protection systems, especially the early fire detection system. This study aims to analyze the reliability of early detection components (smoke detectors, heat detectors, and manual call points) and correlate them with architectural variables such as corridor spatial configuration, ceiling height, ventilation system, and interior layout of residential units. Using a quantitative descriptive method with a spatial overlay approach and field inspection based on SNI 03-3985-2020 and NFPA 72 standards, the study results show that the reliability of the early detection system in the Grand Jati Junction Medan Apartment Building falls into the "Good" category. However, several potential critical points of detection delay were found in units with modifications of solid partition interiors and transition areas between commercial-residential zones caused by micro air circulation patterns. This study recommends adjustments to detector layouts based on architectural zoning to ensure both safety and occupant comfort.

Keywords: *Detection Delay, Fire Detection Reliability, Grand Jati Junction Medan, High-Rise Building Architecture, Spatial Planning.*

ABSTRAK
Gedung Apartemen Grand Jati Junction Medan merupakan salah satu bangunan bertingkat tinggi dengan konsep mixed-use yang memiliki kompleksitas tata ruang yang tinggi. Kompleksitas arsitektural tersebut secara langsung memengaruhi kinerja dan keandalan sistem proteksi aktif, khususnya sistem deteksi dini kebakaran. Penelitian ini bertujuan untuk menganalisis keandalan komponen deteksi dini (detektor asap, detektor panas, dan manual call point) serta mengorelasikannya dengan variabel arsitektural, seperti konfigurasi ruang koridor, tinggi plafon, sistem ventilasi, dan tata letak interior unit hunian. Penelitian ini menggunakan metode deskriptif kuantitatif dengan pendekatan overlay spasial dan inspeksi lapangan berdasarkan standar SNI 03-3985-2020 dan NFPA 72. Hasil penelitian menunjukkan bahwa tingkat keandalan sistem deteksi dini pada Gedung Apartemen Grand Jati Junction Medan berada dalam kategori "Baik". Meskipun demikian, ditemukan beberapa titik kritis yang berpotensi menyebabkan keterlambatan deteksi, terutama pada unit yang mengalami modifikasi interior berupa partisi masif serta pada area transisi antara zona komersial dan hunian yang dipengaruhi oleh pola sirkulasi udara mikro. Penelitian ini merekomendasikan penyesuaian tata letak detektor berdasarkan zonasi arsitektural guna meningkatkan efektivitas sistem deteksi kebakaran sekaligus tetap menjamin keselamatan dan kenyamanan penghuni.

Kata kunci*: Arsitektur Bangunan Bertingkat Tinggi, Grand Jati Junction Medan, Keandalan Deteksi Kebakaran, Keterlambatan Deteksi, Tata Ruang.*

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Introduction

The development of high-rise buildings in Indonesia, particularly in Medan, has increased significantly over the past decade, driven by urban growth and the need for vertical land use. One manifestation of this development is the Grand Jati Junction Apartment in Medan, which integrates vertical residential and commercial functions within a mixed-use building. This multifunctional building concept provides efficient use of space and increases economic activity, but also increases the complexity of building safety management, particularly against fire risks. High occupancy density, diverse activities, and complex spatial configurations make high-rise buildings more vulnerable to fire emergencies than low-rise buildings (Ahrens, 2019). In the context of high-rise buildings, an early fire detection system is the first line of defense. The reliability of an early fire detection system is determined not only by the technical specifications of devices such as smoke detectors, heat detectors, and manual call points, but also by the architectural characteristics of the building where the system is installed. Factors such as corridor configuration, ceiling height, room shape, the presence of drop ceilings, modifications to interior partitions, and the ventilation and air conditioning (HVAC) system can affect the movement patterns of smoke and heat towards the detection sensors. These conditions can cause detection delays, namely delays in the detector recognizing early signs of fire due to obstruction of smoke or heat distribution within the room (Babrauskas & Peacock, 1992).

The relationship between room characteristics and fire detection system performance has been the focus of numerous studies. Chow (2001) explained that room configuration and ventilation systems influence smoke propagation patterns and the effectiveness of fire safety systems in high-rise buildings. Klote et al. (2012) also emphasized that room geometry and air movement are important factors influencing the response of smoke detection and control systems. More recent research by Jang and Hwang (2023) showed that corridor characteristics and room configuration can influence the activation time of smoke and heat detectors in fire scenarios. These findings indicate that architectural aspects are closely related to the performance of early fire detection systems. However, most previous research has focused on technical testing of detection devices, smoke propagation simulations, or general evaluation of fire safety systems. Studies specifically linking architectural variables, such as corridor configuration, ceiling height, interior layout of residential units, and ventilation systems, to the reliability of early fire detection systems in mixed-use apartment buildings are still relatively limited. Furthermore, studies evaluating the actual condition of existing buildings and considering changes in spatial layout due to interior modifications by occupants are also scarce, particularly in the context of high-rise apartment buildings in Indonesia.

Based on these conditions, there is a research gap in the form of limited research that integrates the evaluation of the reliability of fire detection systems with the analysis of architectural characteristics of buildings in real operational conditions. This study offers novelty in the form of an analysis of the relationship between the reliability of early fire detection systems and architectural variables, including the spatial configuration of corridors, ceiling heights, ventilation systems, and interior layout of residential units in mixed-use apartment buildings. Unlike previous studies that emphasized technical and simulative approaches, this study uses an evaluative approach on existing buildings through spatial analysis and field inspections based on SNI 03-3985-2020 and NFPA 72 standards.

This study aims to analyze the reliability level of the early fire detection system consisting of smoke detectors, heat detectors, and manual call points at the Grand Jati Junction Apartment in Medan and examine its relationship with the architectural aspects of the building. The results of the study are expected to provide recommendations for arranging a more effective fire detection system according to the characteristics of the building space, as well as provide input for designers, building managers, and stakeholders in improving the quality of fire safety in high-rise buildings in Indonesia.

Research Method

This study uses a quantitative descriptive approach supported by qualitative analysis to evaluate the reliability of the fire early detection system at the Grand Jati Junction Apartment in Medan and examine its relationship with the architectural characteristics of the building. Data were collected through field observations, direct measurements, documentation, and document studies. Observations were conducted to identify the type, number, condition, and location of smoke detectors, heat detectors, and manual call points. Measurements were made on architectural variables, including corridor configuration, ceiling height, ventilation system, and layout and partitions in residential units. Document studies included the collection of building floor plans and technical data on fire protection systems. The research sample was determined using purposive sampling, namely areas representing the characteristics of the building's main spaces, including corridors, transition areas, and Mahogany 3 BR residential units with varying room and ventilation configurations.

The analysis was conducted through four stages, namely: (1) inventory and mapping of fire detection device locations; (2) spatial analysis of the architectural characteristics of the building; (3) comparative analysis by comparing existing conditions with the provisions of SNI 03-3985-2020 and NFPA 72; and (4) spatial overlay analysis to identify the relationship between spatial configuration and the reliability of the early fire detection system.

The dependent variable in this study is the reliability of the early fire detection system, while the independent variables include corridor configuration, ceiling height, ventilation system, and interior layout of residential units. The analysis results are used to identify areas with potential detection delays and to develop recommendations for improving the effectiveness of fire detection systems in high-rise apartment buildings.

Result and Discussion

Identification of Existing Components

The early fire detection system at the Grand Jati Junction Apartment Building in Medan uses an Addressable Fire Alarm System. Its main components include:

1. Input Device yaitu Smoke Detector, Heat Detector dan Manual Call Point (Break Glass).

(a) (b) (c)

Figure 1. (a) Smoke Detector Honeywell System Sensor No. 882, (b) Heat Detector Rate of Rise Esser AHR 871, (c) Manual Call Point (Break Glass)

Photo of existing equipment at the Grand Jati Junction building in Medan ,2026

2. The Control Device is the Master Control Fire Alarm (MCFA), which is connected to the Annunciator Panel in the control room on the semi-basement floor.

(a) (b)

Figure 2. (a) Main Control Fire Alarm Notifier by Honeywell, (b) Sub-Control Fire Alarm Notifier by Honeywell

Photo of existing equipment at the Grand Jati Junction building in Medan ,2026

3. Output Devices are: Alarm Bell, Strobe Light, and interconnection to Pressurized Fan (emergency stair smoke suppression fan) and Home Lift (lift goes straight down to the ground floor).

(a) (b)

Figure 3. (a) Pressurized Fan Machine, (b) Ducting Pressurized Fan

Photo of existing equipment at the Grand Jati Junction building in Medan, 2026

Qualitative Analysis of Reliability

The following is a qualitative analysis of the reliability levels for each existing component:

1. Detector (Smoke and Heat Detector):
   a. General Reliability Level:
   Fire detection systems that use smoke detectors and heat detectors generally have a reliability level in the medium to high category, with an operational effectiveness range of 75% to 95%, depending on environmental conditions, device quality, and the implementation of regular maintenance.
   b. Reliability Factor:
      - Heat Detector:
        Heat detectors have a relatively high level of mechanical and electronic reliability and tend to have a low false alarm rate. However, these devices have limitations in detecting fires in their early stages, particularly in combustion conditions that produce smoke without a significant increase in temperature.
      - Smoke Detector:
        Smoke detectors have high sensitivity to combustion particles, allowing them to detect fires in their early stages more quickly. However, their reliability can be reduced by the accumulation of dust, dirt, and insects entering the sensor chamber, potentially increasing the frequency of false alarms and reducing detection accuracy.
   c. Existing Weak Points:
   Fire detector performance in existing systems can potentially decline due to sensor aging, particularly in optical and ionization sensors. Furthermore, inappropriate installation locations, such as placing smoke detectors near kitchen areas, steam sources, or high-humidity environments, can affect detection accuracy and increase the likelihood of false alarms.

2. MCFA (Main Control Fire Alarm):
   a. General Reliability Level:
   The Main Control Fire Alarm (MCFA) system boasts a very high level of reliability, with estimates ranging from 90% to 98% under normal operating conditions. This high level of reliability makes the MCFA a key component in a fire protection system, detecting, processing, and coordinating responses to fire indications.
   b. Reliability Factor:
   The reliability of MCFAs is supported by the implementation of strict design standards, both in modern systems and in conventional systems still in operation. Generally, these systems are designed with a fail-safe principle, so that failures in certain components can be detected and their impact on overall system function minimized. Furthermore, MCFAs are equipped with supervisory circuits capable of continuously monitoring system conditions, including detecting disturbances such as open circuits or ground faults.
   c. Existing Weak Points:
   Despite its high level of reliability, several factors can potentially degrade the performance of MCFAs in existing systems. One major factor is the condition of the backup battery. Field findings indicate that battery capacity degradation, age-related damage, and corrosion of the battery terminals can cause system failure during a power outage. Furthermore, environmental factors such as high humidity and dust accumulation in poorly maintained control rooms can accelerate the corrosion process on electronic circuit boards, potentially reducing the reliability and operational lifespan of MCFAs.
3. Alarm Bell (Sound Indicator):
   a. General Reliability Level:
   Alarm bells have a relatively high level of reliability, with operational reliability estimates ranging from 85% to 95% under adequate installation and maintenance conditions.
   b. Factors Affecting Reliability:
   The reliability of alarm bells is supported by their simple mechanical and electrical construction. These devices generally operate on the principle of an electric motor or solenoid that drives a striking mechanism against the bell plate, resulting in a relatively small number of critical components that could potentially fail. This design simplicity contributes to the device's high operational reliability.
   c. Potential Weaknesses in the Existing System:
   Despite having a high level of reliability, several conditions in the existing system can affect the performance of the alarm bell, including:
   - Mechanical Failure due to Component Jamming:
     In devices that don't receive regular testing and maintenance, the bell's axle or striking mechanism can become jammed due to corrosion, dust accumulation, or other debris buildup. This can hinder the striking mechanism's movement and reduce the effectiveness of the alarm function.

- Decrease in Sound Intensity Due to Voltage Drop:
  Aged and degraded cable installations can cause voltage drops in power distribution lines. This voltage drop can potentially reduce the sound intensity of the alarm bell and even cause the device to fail, especially at installation points far from the Main Fire Alarm Control Panel (MFACP).

Correlation of System Reliability with Architectural Conditions

Spatial and Architectural Studies

One unit of Grand Jati Junction Apartment has 2 floors, and the sample for the study is the Mahogany 3BR Type:

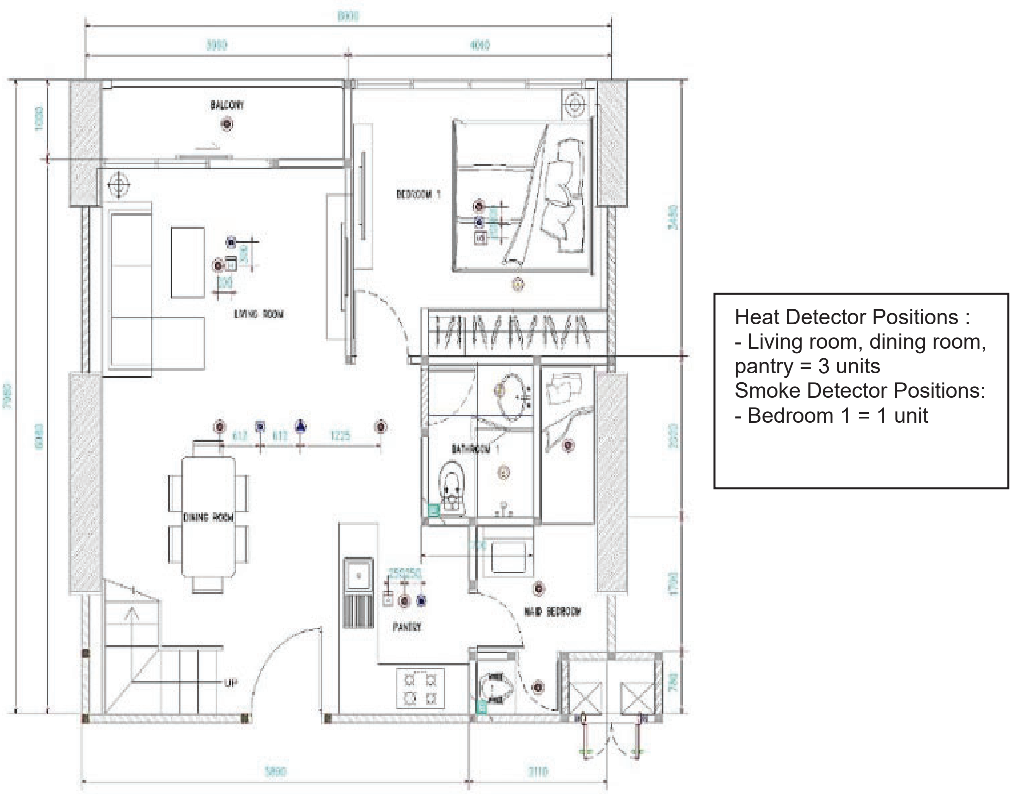

Figure 4. First Floor Plan

MEP drawing at Grand Jati Junction Medan, 2021

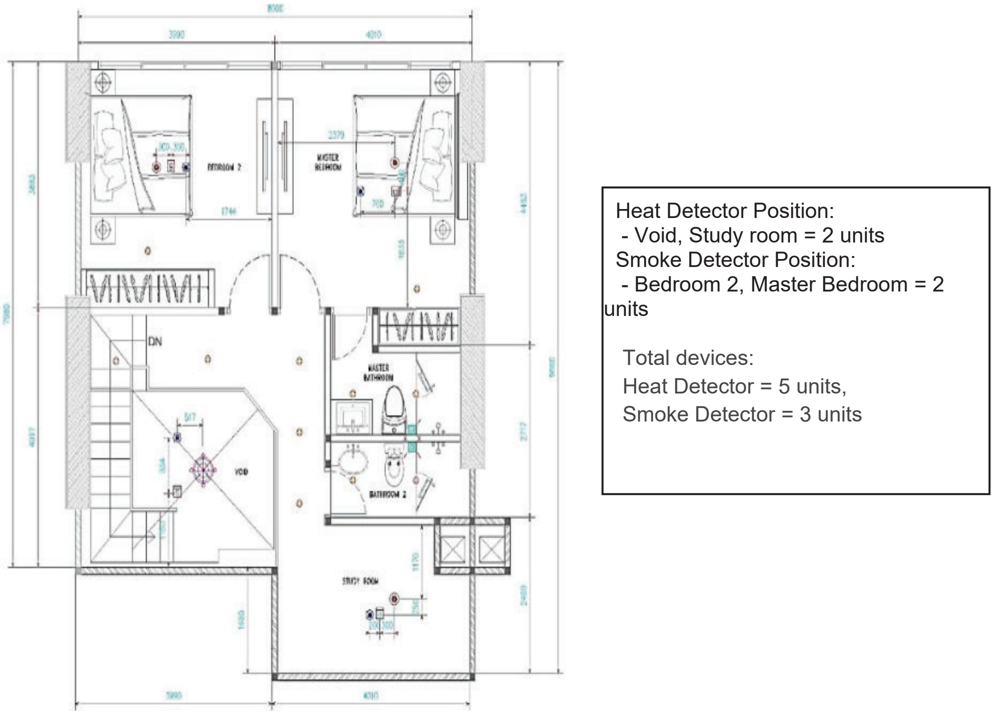

Figure 5. Second Floor Plan

MEP drawing at Grand Jati Junction Medan, 2021

Unit Interior Design Intervention and Detector Reliability

In several sample units at Grand Jati Junction that were modified or renovated with the addition of a massive partition (for example, separating the work area from the bedroom in the Mahogany 3BR), the building's built-in smoke detectors were often left on one side of the room. Architecturally, this partition creates a dead air space. If a fire starts on the side of the room without a detector, the partition will trap the smoke, drastically reducing the reliability of the early detection system. In the sample unit above, the detectors were placed in every area of the room, so the detection coverage met the requirements.

Ceiling Height and Beam Structure:

The apartment units at Grand Jati Junction have relatively high ceilings, at 2.7 meters and 2.5 meters, to create a spacious and comfortable visual impression. Based on fire dynamics theory, the higher the ceiling, the greater the volume of smoke plume that must form before it reaches the ceiling sensor, resulting in a dilution effect.

Corridor Configuration and Smoke Distribution

The corridors of the Grand Jati Junction Apartment are designed with a natural air circulation system with casement windows at each end of the corridor. Architecturally, the distance between smoke detectors in the corridor has met the requirements (not exceeding the maximum range of 9 meters), namely 6.5 meters. However, the architectural study found potential obstacles in the transition area or the "L"-shaped corridor bend. If smoke accumulates in the corner of the corridor, horizontal air movement due to ventilation can cause the smoke to swirl in the corner of the room (air pocket) before reaching the sensor, which has the potential to cause a detection delay of several critical seconds Figure 6.

Heat Detector Position:
- Corridor = 14 units

Smoke Detector Position:
- Panel Room, Janitor = 3

Figure 6. Corridor Area

MEP drawing at Grand Jati Junction Medan, 2021

Conclusion

The fire early detection system at the Grand Jati Junction Apartment in Medan generally has a good level of technical reliability and is supported by a modern addressable system. However, this reliability aspect does not stand alone; its performance is closely tied to the building's spatial geometry and architecture.

Interior modifications by users (new room partitions), corridor geometry, and the effects of ceiling height are key architectural factors that can potentially reduce detector sensitivity. Alignment between the mechanical-electrical fire layout and the architectural layout is crucial to preventing early detection failures. To maintain and improve system reliability at Grand Jati Junction Medan, the following architectural policy points are recommended:

1. Interior Fit-Out Regulations: Building management must issue strict guidelines for residents renovating their units. If a massive partition is constructed, residents must add a new detector branch point within the isolated space.
2. High Ceiling Effect Compensation: In areas with high ceilings or prominent structural beams, detector placement should refer to the beam pocket zoning, not simply based on flat geometric distances (grid).

- Detectors should not be installed too close to corner walls. The minimum distance from the edge of the wall is 10 cm, and the maximum distance is 15-30 cm from the corner where the wall meets the ceiling to avoid dead air spaces (dead air spaces where smoke has difficulty circulating).
- Architectural and HVAC Alignment: Placement of smoke detectors in corridors must be at least 1.5 meters from the building's AC supply register to prevent the blowing of clean air from expelling smoke from the detector sensor.

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