Increased Functionality & Cost Effectiveness of Smart Building Technologies Incorporating Addressable Fire Alarm Notification

A Graduate Student Independent Study Project

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Executive Summary

Buildings have continued to become smarter over time, incorporating a variety of sensors to collect data and control different processes. By monitoring ambient and changing conditions, occupancy levels, and energy demands, building owners can save money and provide a more comfortable and safer environment for occupants. Today, fire alarm systems are also interfaced to control certain emergency operations within the building such as elevator recall or HVAC shutdown. Addressable notification appliances present an opportunity to further increase the functionality and usefulness of fire alarm systems. A system employing addressable notification appliances can be utilized to broadcast personalized messages to select areas of the building with nearly unlimited flexibility. Other notable features of the addressable notification equipment include: regulated 29 VDC power, the ability to T-tap circuitry, self-testing capabilities and lower current draws for each appliance. Each of these features can result in significant cost savings when compared to a conventional notification system.

For this project, the team was tasked with investigating the increased functionality and cost effectiveness of addressable notification systems manufactured by Johnson Controls International (JCI) for two different building uses. JCI provided a fire alarm system layout for a high-rise hotel building and requested that wiring diagrams be prepared for two systems: one utilizing conventional notification appliances and the other using addressable notification appliances. The purpose of this exercise was to develop shop level drawings that could be used for cost estimating purposes and to demonstrate the advantages of the addressable notification system. After completing the system layouts, the two sets of drawings were submitted to a third-party electrical contractor for pricing. Based on these cost estimates, it was determined that a fire alarm system utilizing addressable notification for the hotel building would be $45,700 (9.15%) less expensive than a system with conventional notification appliances of the same layout. The two major takeaways were that the cost of equipment and wiring for each system are virtually the same and the major cost savings are a result of the significantly reduced number of labor hours (900 hours less) required to install the system with addressable notification appliances.

The project team was also tasked with providing a high-level fire alarm notification design for a high school building and elaborating on the functional differences between conventional and addressable notification systems in an educational building. The team then produced a code compliant notification design for the school building and determined the differences in control equipment required for each system. Through this exercise the team was able to discuss the limitations of a conventional notification system caused by physical circuitry and highlight the benefits of an addressable notification system in a building with ever changing emergency situations to plan for. The capabilities of the addressable and conventional systems were then compared by considering a series of conditions that may occur during a weather-related emergency.

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List of Acronyms

A – Amperes

AHJ – Authority Having Jurisdiction

cd – Candela

EVACS – Emergency Voice and Communication System

HVAC – Heating, Ventilation, and Air Conditioning

IBC – International Building Code

IDC – Initiating Device Circuit

IDNAC – Intelligent Device Notification Appliance Circuit

IEBC – International Existing Building Code

IFC – International Fire Code

IoT – Internet of Things

JCI – Johnson Controls International

MNS – Mass Notification System

NAC – Notification Appliance Circuit

NFPA – National Fire Protection Association

SLC – Signaling Line Circuit

V - Volts

VAC – Volts Alternating Current

VDC – Volts Direct Current

WAMNS – Wide Area Mass Notification System

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1.0 Introduction

Buildings across the world are becoming smarter and safer due to continuing advancements in technology. Modern buildings are equipped with sensors and associated controls used to automate systems aimed at improving occupant comfort and safety and energy efficiency within the building. Along with smart sensors and technology in buildings, fire alarm system technology has also become smarter and capable of controlling other systems within the building through supervised system interfaces. In addition to this, fire alarm notification systems have evolved over time and have the capability to provide occupants with clearer and more concise messaging during a variety of emergency situations.

Fire alarm systems utilizing an Emergency Voice and Communication System (EVACS) were a major step forwards in the fire safety industry. For several cycles of code revisions, these systems have been required in all new high-rise buildings by both NFPA 101, *Life Safety Code*, and the International Building Code (IBC). There are two main advantages of an EVACS system over a system using traditional horn strobes. First, the system uses speakers that broadcast spoken audio to occupants. This has been proven to facilitate more effective evacuations than tone signaling alone (Hoskins & Mueller, 2019). In addition, first responders are able to use a microphone at the fire alarm control panel to broadcast live voice messages to selected zones in the building.

Although speaker audio has advantages over tone signaling, the conventional notification appliances that have been used in these systems for years have a number of limitations. All conventional appliances on a circuit must be wired in series. This places restrictions on the designer when considering circuit routing options and is likely to result in less-than-optimal circuit routing. In addition, conventional zones operate on an ‘all-or-nothing’ basis; when an alarm signal is received, the circuit receives power and actuates all alarm appliances across the zone. As such, the information in pre-recorded messages and live paging cannot be personalized beyond the physical circuit configuration. Addressable notification appliances present an opportunity to further increase the functionality of a fire alarm system, much like the introduction of EVACs had done a number of years ago.

Each addressable notification appliance has an address (e.g. SP-1-1) and a location description (e.g. Second Floor Electrical Closet) associated with it. The fire alarm control panel supervises each individual appliance to ensure the integrity of the circuit. Since the appliances are supervised at a device level, parallel pathways known as T-taps are permitted in the circuits. T-taps allow for more efficient circuit routing which can translate to cost savings in both material and labor. The appliances can also be controlled individually or programmed into groups to send messages to selected areas of the building without any respect for physical circuit routing. This study was completed with the intent of demonstrating the increased functionality and cost savings that addressable notification appliances can offer. One section of the study analyzes the cost savings associated with installing addressable notification appliances in a high-rise hotel building. The other section of this study considers increased functionality that addressable technology can provide to a combined fire alarm/mass notification system in a high school.

2.0 - Background

2.1 - Relevant Code Requirements

For this project, the team has been tasked with analyzing fire alarm systems in a hotel building which is classified as Residential (Group R-1) occupancy by the International Building Code. Per IBC §907.2.8.1, a manual fire alarm system that activates the occupant notification in accordance with Section 907.5 shall be installed in all Group R-1 occupancies. This hotel building is classified as a high rise, (defined by the IBC as any building where the highest occupiable level is greater than 75 feet above the level of fire department access), and as such must comply with additional requirements of Section 403 (High-Rise Buildings) in addition to the occupancy specific requirements. All high-rise buildings are required to be provided with an Emergency Voice and Communication System (EVACS). This section of the report is not intended to serve as an exhaustive code review, but rather will highlight relevant code provisions and discuss how they relate to the project scope.

2.1.1 - Detection in Sleeping Rooms

Sleeping rooms are required to be provided with smoke detection, which is commonly achieved through the use of smoke alarms or smoke detectors. Although commonly misconstrued by the public, there are important differences in these two pieces of equipment. Smoke alarms are not connected to the building fire alarm system and function autonomously. In some cases, the smoke alarms may be interconnected with a supervisory circuit. A smoke alarm contains a built-in speaker to alert occupants that smoke has been detected in the area. Smoke detectors, on the other hand, are typically connected to either a signaling line circuit (SLC - addressable) or an initiating device circuit (IDC - conventional), and do not contain a means to notify occupants. The notification alarm appliances in the building that are typically installed on a conventional NAC to alert occupants of a fire when a smoke detector sends an alarm signal to the fire alarm control panel.

Single/multiple station smoke alarms are required to be installed in all sleeping areas, and along the path of the means of egress from the sleeping area to the exit access corridor. Since the hotel rooms are arranged as one large space, a single smoke alarm in each room is often able to satisfy both of these requirements. Smoke alarms are required to receive their primary power from the building power source and are typically required to be provided with battery backup (IBC 2018, §907.2.10.6).

Smoke detectors are permitted to be used in lieu of smoke alarms, but there are two important requirements that must be met: First, the activation of the smoke detector within the unit shall initiate an alarm notification in the sleeping unit, and only in the sleeping unit. In addition, activation of a smoke detector in a sleeping unit shall not activate notification appliances outside of the unit, as long as a supervisory signal is generated and properly monitored by the fire alarm control unit (IBC 2018, §907.2.10.7).

If the fire alarm system designer wishes to use smoke detectors throughout the building and forego smoke alarms entirely as noted above, compliance with the provisions of §907.2.10 is typically achieved by installing smoke detectors on sounder bases. Sounder bases are used in conjunction with smoke detectors to generate a local alarm tone without needing to use any of the notification appliances in the building. Installing a sounder base within every sleeping unit can quickly drive-up material and installation costs. While other initiating devices on the SLC have a fairly low current draw and are powered by the SLC itself, the audible tone of the sounder base demands considerable power and requires a separate 24VDC feed to be run on an auxiliary power circuit from fire alarm control equipment. Installing this additional circuit will add to the overall cost of the system in terms of labor and potentially require additional fire alarm control equipment to be installed. However, if the building is equipped with an addressable notification system, in one case sounder bases and in the other case smoke alarms can be omitted due to the ability to program the addressable notification appliance in hotel rooms and suites to sound when smoke is detected by a system smoke detector.

2.1.2 - Notification

The IBC contains requirements for zoning of the EVACS. In accordance with IBC §907.5.2.2, the building shall be zoned as follows:

- Each floor
- Elevator Groups
- Interior Exit Stairways
- Areas of Refuge

With conventional notification appliances, this zoning is accomplished by connecting all speakers in a desired zone to a single speaker circuit. When an initiating device sends an alarm signal to the panel, NACs throughout the building are activated based on the programmed system sequence of operations. Because the zones are defined by the physical routing of the circuit to each appliance, the designer's options are limited if additional zoning flexibility and functionality is desired as a result of building rehabilitation projects or system upgrades. The only way to further divide the building into zones would be to add more speaker circuits, which will translate into a greater demand for control equipment, wiring and labor to install and consequently, higher costs. These limitations do not apply to addressable notification appliances as they can be programmed to operate as desired without respect to physical speaker circuitry.

2.1.3 - Inspection, Testing, and Maintenance

IBC §907.8 states that all inspection, testing, and maintenance for fire alarm and fire detection systems shall be in accordance with Section 907.8 of the International Fire Code. IFC §907.8 requires all testing to be performed in accordance with the schedules of NFPA 72, *National Fire Alarm and Signaling Code*. Chapter 14 of NFPA 72 provides requirements for both initial acceptance testing and periodic testing for each type of fire alarm system component. For annual periodic testing, two criteria must be met:

- Verify the operation of each audible notification appliance.
- Verify that each visible notification appliance flashes.

In order to verify these two items on a system with conventional fire alarm notification appliances, the individuals conducting testing must walk the entire building with the notification appliances active. This task is not only time consuming but is also disruptive to the building occupants. Scheduling tests during an unoccupied building period alleviates the complaints from occupants but paying a premium hourly rate to the contractors for night testing can put an increased cost burden on the owner. The self-test features of the addressable notification can alleviate many of these difficulties.

2.2 - Class Designations Based on Circuit Integrity

Maintaining circuit integrity of the fire alarm system is critical. The failure of an HVAC system in a building may only cause some temporary discomfort to the occupants, but a fire alarm system malfunction can have dire consequences. Due to the critical nature of these systems, NFPA 72 requires all fire alarm circuits to be monitored for integrity; this assures that the system is ready to perform the proper functions in the event of a fire. NFPA 72 defines seven distinct pathway class designations. Each class designation has different performance characteristics that specify how the circuit is to be supervised and how it should function under abnormal conditions. Of the seven class designations, Class A and Class B pathways are the most widely used in traditional fire alarm systems throughout the United States. Figure 1 shows the difference in wiring between a Class A and Class B circuit.

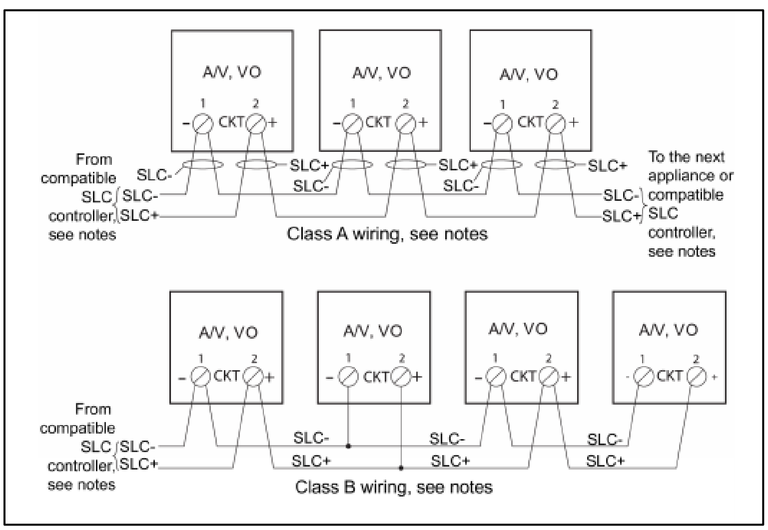

Figure 1: Class A vs. Class B Wiring (Simplex, 2020)

The primary difference between these two classifications is that Class A circuits are required to include a redundant pathway, while a Class B circuit is permitted to be a single pathway. If an open occurs in a Class B circuit, all appliances downstream of the open will no longer be operable. Class A circuits address this issue by configuring the circuit as a loop with a redundant path; both ends of the circuit are connected to a fire alarm control panel or power supply. If an open is to occur on a Class A circuit, the circuit remains operable through the redundant path. For this reason, some jurisdictions may require Class A circuitry if increased reliability is desired.

2.3 - Conventional vs. Addressable Circuits

There are three main types of circuits used in fire alarm systems: initiating device circuits (IDC), signaling line circuits (SLC), and notification appliance circuits (NAC). IDCs are inherently conventional and SLCs are inherently addressable.

In a conventional fire alarm system, each circuit serves as a zone. The fire alarm control panel monitors the integrity of each circuit, but not the individual devices on the circuit. When a signal is received, the panel identifies the zone from which the signal originated (i.e., Second Floor - Right Hand Side). With conventional notification, each piece of equipment must be wired in series to facilitate proper circuit supervision. The series terminates at an end of line resistor, through which the panel is constantly sending a small amount of current for supervision.

In an addressable fire alarm circuit, the panel is routinely communicating with each individual piece of equipment on the circuit. While conventional initiating devices only transfer power, addressable devices are equipped with the ability to send/receive data to/from the fire alarm control panel. Each device is assigned an address during the fire alarm control panel programming, and this address is used to register the specific device that produced an alarm status (i.e., Second Floor - Closet 203). Specific fire safety functions such as elevator recall, or AHU shutdown can be actuated through the use of addressable control modules. Because the panel is supervising each device, it is not necessary to provide a continuous path between the panel and an end of line resistor. With this restriction lifted, many designers and installers choose to take advantage of a practice known as T-Tapping. Figure 2 shows an example of T-tapping.

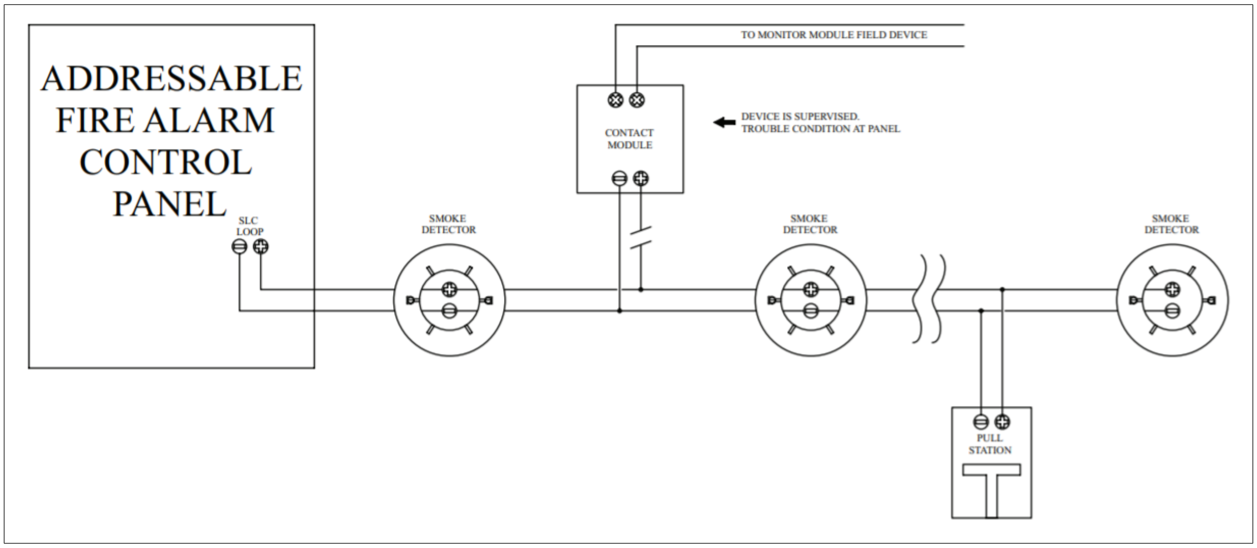

Figure 2: T-Tapping on a Class B Signaling Line Circuit (Potter, 2017)

Appropriately named, a T-tap occurs where a parallel path is spliced to branch off of a circuit, resulting in a "T" shape in the circuit. This method of wiring can be beneficial because it uses less wire and can be more convenient for installing contractors where traditional device to device wiring can be difficult and present issues to system installers. However, it must be noted that T-tapping is prohibited in Class A circuits as it compromises the redundant path. Additionally, some jurisdictions prohibit T-tapping due to the decreased reliability of the single pathway and the increased difficulty in performing maintenance on the system. The increased difficulty in performing maintenance on a circuit with multiple T-taps is due to the amount of time and effort required to disconnect each branch of the circuit to find a fault or short. It is incredibly important for electricians to be provided with accurate as-built drawings of a fire alarm system to understand where any t-taps may be. System designers also need to be aware of this when designing circuits so they can lay out any branches in a systematic manner.

2.4 - Evacuation Strategies

The size of modern buildings and the number of occupants present within these structures makes a total simultaneous evacuation in the event of a fire impractical and unnecessary. Instead, partial or phased evacuations are used to facilitate safe and efficient evacuation of the occupants who are in proximity of the fire area. The NFPA Fire Protection Handbook (20th Edition) highlights the key difference between these two evacuation strategies, stating "A phased evacuation is a total evacuation, but not all at once." A partial evacuation, by contrast, will not necessarily reach a point of total evacuation. After the floors closest to the fire are cleared, the idea is that the passive and active fire protection features of the building will protect occupants on other floors from the dangers of fire and smoke. Per IBC Section 907.5.2.2, the EVACS in high rise buildings is required to operate on at least the floor of alarm origin, the floor above, and the floor below. The EVACS is required to sound an alert tone and then deliver directions in accordance with the fire safety and evacuation plans required by Section 404 of the International Fire Code. These plans must detail the general structure of the evacuation plan (i.e. total, partial, or phased), identify all escape routes and describe the pre-programmed voice messages.

When installing a system using conventional notification appliances, the only way to satisfy the zoning requirements of the IBC is by running a separate circuit to each zone. The panel can be programmed to sound any combination of zones based on the inputs that are received, but the zones operate on an all-or-nothing basis. If increased zoning flexibility is desired (i.e. two zones per floor), then additional circuits must be installed.

Addressable notification technology presents nearly unlimited zoning flexibility. Each addressable notification appliance is capable of being assigned to a number of distinct groups[1] through programming at the panel. Any speaker throughout the building can be assigned into a given group, without any respect to the actual routing of the circuits. Consider, for example, a high-rise building with four interior exit stairways. If conventional notification appliances are used, each stairway would need to be provided with a separate notification appliance circuit. When addressable notification is utilized, each stair speaker can be physically connected to any NAC throughout the building. The speakers would then be assigned to a programmable group that could be configured to automatically sound upon certain inputs, or manually selected for paging during an evacuation. Several evacuation strategies that highlight the advantages of addressable notification technology are proposed in the results sections of this report.

2.6 - Literature Review

Smart buildings utilize a variety of sensors throughout the building to monitor and control certain conditions and processes. This relies on a concept called the 'Internet of Things' (IoT). The IoT is a massive network of devices connected through the internet. Any physical device with an on/off switch and internet connection capabilities can become part of the IoT, such as a smart lightbulb or thermostat controlled by a cell phone application (Clark, 2016). These lightbulbs and other smart technologies targeted towards homeowners are becoming more widely used, but the real value of smart building technologies lies in commercial building management. Smart building technologies can allow building owners to increase their energy efficiency, as well as the safety and comfort of the occupants. Potential conditions to be monitored include temperature, lighting, carbon dioxide levels, sound, and airflow (Tadokoro, 2014). The data from the sensors can then be used for a wide range of applications such as controlling HVAC equipment to adjust temperature or airflow rates, turning lights on or off based on the occupancy of the space, or creating highly detailed reports on energy usage trends.

[1] The Simplex TrueAlert ES addressable notification appliance is capable of being assigned to up to three groups.

Gartner, a technology analytics company, published a study to predict trends in the smart building technologies market. The building automation segment was predicted to have the highest growth rate in 2020 of all market segments, greater than both healthcare and automotive by over 10%. This growth was measured in terms of the number of individual devices connected to the IoT. As these devices become more mainstream, building managers are getting more creative with how they utilize their IoT. Some less common applications include wayfinding, inventory and asset tracking, and vibration sensing. Where IoT devices are used to control lighting in certain areas of the building, the possibility arises that lights could be turned off when an emergency occurs. These devices can be interfaced with the fire alarm system in the building to override any lighting controls that may interfere with a safe evacuation upon a fire alarm signal (Penny, 2018).

As smart building technologies continue to grow in popularity, it logically makes sense that the ‘intelligence’ of a building’s fire alarm system should increase. While addressable initiating devices are now commonplace in new fire alarm installations, addressable notification appliances are a relatively new technology. As such, the amount of information available on the subject is rather limited. To date, the project team is only aware of one other study that has been completed regarding the potential benefits of addressable notification appliances. A 2018 report by Puchovsky in collaboration with Johnson Controls analyzed the differences in installation and material costs between addressable and conventional fire alarm notification appliances. The results of the study indicate that a 4.57% cost savings can be achieved by installing addressable notification appliances in place of conventional appliances (Puchovsky, 2018). Although the addressable equipment has a greater upfront material cost, this is offset by savings in labor, electrical materials, and wiring. The scope of this 2018 study was similar to this project, but Johnson Controls believes that a greater cost savings can be demonstrated by fully capitalizing on the advantages of addressable notification during the design process. Puchovsky’s study did not specifically consider the cost savings that may be associated with inspection, testing, and maintenance activities, nor did it quantify the potential value that these appliances can offer in terms of increased functionality in the built environment.

3.0 - Hotel Study

The project team was tasked with reviewing a fire alarm design for a high-rise hotel building and develop wiring diagrams that could be used to develop cost estimates from a third-party fire alarm contractor. This study was completed with two main objectives:

1. Quantify the potential cost savings that addressable notification technology may be able to offer.
2. Understand how to best utilize addressable notification technology to provide improved functionality of fire alarm systems.

3.1 - Design Approach

JCI provided an AutoCAD drawing package of a 12-story hotel building as the basis for the design. A full fire alarm system layout was included in the drawing package, detailing the proposed locations of all initiating devices and notification appliances in the building. To begin, the drawings were reviewed for compliance with the most recent editions of the International Building Code & NFPA 72 *National Fire Alarm and Signaling Code*. The drawing review included, but was not limited to:

- Confirm that visible notification is provided as required by code, and that coverage complies with the provisions of NFPA 72 Chapter 18.
- Confirm that the spacing and location of speakers is consistent with industry best practices for intelligibility.
- Verify that manual pull stations are provided at every exit, with additional pull stations provided to meet travel distance requirements.
- Verify that smoke detection is provided in all elevator lobbies and elevator machine/control rooms and that smoke alarms (or sounder base smoke detectors) are provided in each sleeping room.

Several notification appliances were relocated based on the findings of the review and minor drafting errors were corrected throughout the drawings. All fire alarm equipment depicted in this study is manufactured by JCI. As such, JCI provided technical data sheets for all of the equipment that was used. Before proceeding with the design, it was necessary to examine these data sheets in order to quantify technical specifications that would impact the system layout such as power supply capacity, amplifier power, and notification appliance current draws. The same power supply is used for both the conventional and addressable notification appliances. The appropriate module is then installed on the power supply to provide either three conventional NACs or three IDNACs. Tables 1 & 2 summarize the relevant design parameters from the technical data sheets.

Table 1: Conventional and Addressable Notification Appliance Module Specifications

Equipment	**Outputs**	**Maximum Load on ES-PS/ES-XPS**	**Starting Voltage**
Conventional NAC Module	Three 3A NACs	3A / NAC 9A / Module	24 VDC
IDNAC Addressable Notification SLC Module	Three 3A SLCs	3A / SLC 9A / Module	29 VDC Regulated

Table 2: Notification Appliance Current Draws

Equipment	**15cd**	**30cd**	**75cd**	**110cd**	**135cd**	**185cd**	**Operating Voltages**
Addressable Speaker-Strobe	0.047A	0.057A	0.100A	0.132A	0.160A	0.208A	23-30VDC
Conventional Speaker-Strobe	0.040A	0.063A	0.124A	0.168A	-	-	16-33VDC
Addressable Speaker	0.09A						N/A

Class B wiring diagrams were produced for two different fire alarm system designs: one utilizing conventional notification appliances and the other utilizing addressable notification appliances. The wiring diagrams were drawn in AutoCAD. The final drawings show the proposed routing, with tags to identify the specific wires within each pathway. It was determined that three wire tags would be required to properly identify all wires in the addressable system layout: Speaker Audio Circuit, IDNAC, and SLC. The conventional system required four wire tags: Speaker Audio, NAC Visual, SLC, and 24 VDC power for the smoke detector sounder bases.

The first step to complete the wiring diagrams was to determine the approximate power requirement for the visual notification appliances on each floor. For the addressable system layout, audible-only notification appliances were also included in the current draw total, since the addressable speakers require a small amount of power in order to be properly supervised. The power demand for the floor corresponds to the number of circuits that will be needed, since each NAC/IDNAC on the power supply is limited to 3A. Best practices were followed when designing the circuits in this building and a 15% spare capacity safety factor was maintained on each individual circuit. As a result, the maximum capacity of a single circuit in this design was kept below 2.55A. Calculations showed that a single NAC/IDNAC circuit for each typical residential floor of the hotel (Floors 3-11) would be able to provide the required power. Additional circuits were needed on Levels 1, 2, and 12 to account for the increased number of visual notification appliances serving the common areas on these levels.

After approximating the current draw requirements, preliminary locations for control equipment were selected throughout the building. Fire alarm wiring between floors in high rise buildings is required to be protected with either specialized fire-rated circuit integrity cables or 2-hour fire resistance rated construction in accordance with the requirements for pathway survivability in NFPA 72 §24.3.14.4.1. With this in mind, a central telecommunications closet was identified to serve as the enclosure for the main fire alarm riser throughout the building. The fire alarm control panel was placed in the fire command center on Floor 1. Power supplies and 50W amplifiers were located throughout the building, primarily in telecommunication closets.

Once the initial circuit layout was drawn, it was validated through voltage drop calculations. The calculations ensure that the last appliance on the line will receive the minimum voltage for which it is listed. Voltage is lost due to the resistance of the conductors in the wiring and also as the circuit passes through each appliance. The wire resistance is an inherent material property that will vary depending on wire gauge, and the amount of loss is proportional to the amount of current flowing in the circuit. For the conventional system, voltage drop calculations were completed using the point-to-point method in which the voltage drop between each individual appliance is calculated. This is more accurate than the lump sum method, in which the designer sums all current draws and wire lengths and assumes that all appliances are located at the most remote point on the circuit. A spreadsheet was utilized to accurately map out the path of the circuit and complete the calculations. The fundamental equation used in the spreadsheet are as follows:

$$V_{Drop} = 2 * L * R * (I_{Point\ Calculated} + I_{Remaining\ Appliances})$$

Where:

$L = Length\ of\ Wire\ (ft)$

$R = Resistance\ of\ Wire\ (\Omega/ft)$

$I_{Point\ Calculated} = Current\ Draw\ of\ Point\ Calculated\ (A)$

$I_{Remaining\ Appliances} = Sum\ of\ Current\ Draws\ all\ appliances\ downstream$

This equation is carried out at each point on the circuit to determine the feed voltage at each appliance. Voltage drop calculations for the addressable system are more complicated due to the presence of T-Taps throughout the system. Traditional voltage drop calculation methods cannot account for T-Taps. JCI provided a proprietary spreadsheet that was used for voltage drop calculations of the addressable notification system. When a system is designed with T-taps, voltage drop calculations are generally only concerned with the longest continuous run of circuitry since all appliances are not connected in series. The voltage drop in a T-tapped circuit is analogous to hydraulic calculations for pressure in a sprinkler system. In both instances, the designer is ensuring the minimum operating pressure or voltage is maintained at the most remote point of the system. The proprietary spreadsheet provided by JCI proved to be a very useful tool as it provided the team with visual tools for mapping the circuit and showing each branch of the circuit. The visual circuit mapping is something that can be a very powerful tool for contractors to show the connection point for each appliance, and what numbers were used in the calculations. Figure 3 shows an example of the visual map generated by the voltage drop calculator.

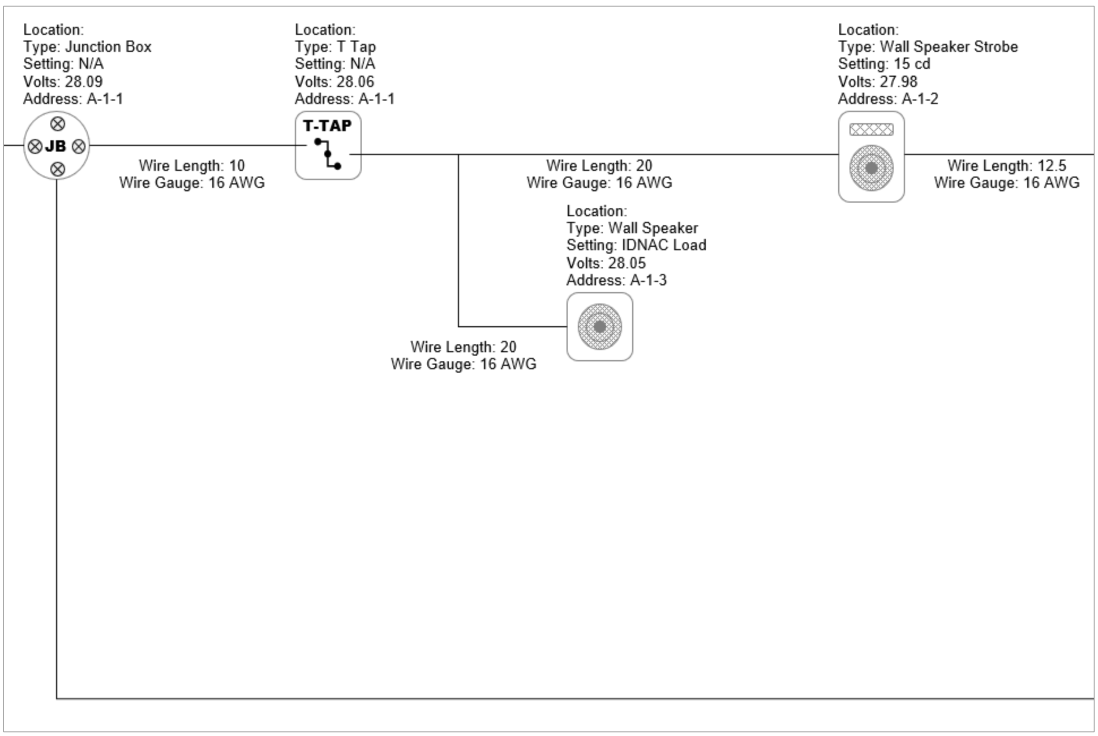

Figure 3: Example Circuit Drawing from Johnson Controls' Voltage Drop Calculator

One team member drafted the conventional system wiring diagrams while the other team member focused on the addressable system. A conceptual riser diagram was also drawn for each system. Once the designs were completed, the drawings were exchanged for peer review within the project team. The final design package was sent to JCI and a third-party electrical contractor. JCI provided a bill of materials and the electrical contractor provided a cost estimate for each system that considered both labor and material costs.

3.2 - Results

On April 7, 2021 the project team received the cost estimate for both fire alarm systems from the third-party electrical contractor. The third-party contractor provided cost estimates for one system using conventional notification appliances and the other with addressable notification appliances.

Both systems used were designed with addressable initiating devices. The scope of work captured in each of the cost estimate includes the following:

- Provide design documents for local AHJ and field installation.
- Provide and install Autocall brand fire alarm system technology.
- Provide and install fire alarm cable in a Class B manner based on the requirements of NFPA 72.
- Provide system programming.
- Provide all necessary acceptance testing for a complete system per local AHJ permitting requirements.
- Provide labor estimates for project coordination, site meetings and supervision of field activities.
- Provide all weatherproof devices and main control equipment back boxes.

The cost estimate was inclusive of all that would be expected of a contractor in a new fire alarm system installation. The cost estimates also included a list of excluded items that were not considered. These exclusions include:

- Lifts and/or access to work areas 12' above the finished floor.
- 120 VAC circuitry and terminations
- Kitchen Hood interface circuitry and terminations.
- HVAC interface circuitry and terminations for shutdown operations to fire alarm supplied control relays.
- Conduit and conduit related back boxes to be provided and installed by others.
- Painting, patching, coring of concrete and sprinkler interface devices.
- Elevator interface circuitry to be provided and terminated by others.

Each of the excluded items are items that require coordination beyond the information that was provided to the project team. Although it is not believed that these exclusions will have a significant impact on the cost estimates, it is important to note all exceptions that were taken to understand what was not accounted for in the scope of work.

The total cost of the fire alarm system utilizing conventional notification appliances was estimated to be $499,500. The material cost for this estimate includes a total cost of $101,057.10 for the equipment and $27,882 for wiring. The cost of labor for this project was estimated to be $370,560.90.

The total cost of the fire alarm system utilizing addressable notification appliances was estimated to be $453,800. The cost of materials in this estimate includes a total cost of $107,161.37 for the equipment, and $21,032 for wiring. The cost of labor for this project was estimated to be $325,606.32. The cost to install a fire alarm system utilizing addressable notification was estimated to be $45,700 less expensive than a traditional conventional notification system; a 9.15% savings.

Table 3 summarizes the labor hours considered in this estimate for both fire alarm systems. Table 4 summarizes the overall cost differences between the two systems.

Table 3: Comparison of Labor Time Estimates

Task	Conventional System Labor Hours	Addressable System Labor Hours
Project Management	120	120
Design & Permit Prep	80	80
Purchasing	10	10
Shop & Deliverables	10	10
Device Installation	2516	2096
Wiring Installation	1393	1051
Pre-Testing Labor	180	120
Final-Testing Labor	220	180
Programming Labor	120	80

Table 4: Comparison of Costs for Equipment, Wiring, and Labor

Category	Conventional	Addressable	Delta
Equipment	$101,057	$107,161	$6,104 (+6.0%)
Wiring	$27,882	$21,032	$6,805 (-24.6%)
Labor	$370,561	$325,607	$44,954 (-12.1%)
Overall	$499,500	$453,800	$45,700 (-9.2%)

3.3 - Discussion

3.3.1 - Equipment and Wiring

The overall cost associated with materials needed in each system is nearly equivalent. When the cost of the equipment and wiring for each system is added together, the total cost difference between the two systems is $745.73. The cost of equipment in the addressable notification system is $6,104.27 more expensive than that of the conventional notification equipment. For this system, it was estimated that the addressable notification equipment would be 5.7% more expensive than the conventional notification equipment as illustrated in the figure below. Figure 4 shows the difference in equipment costs for each system.

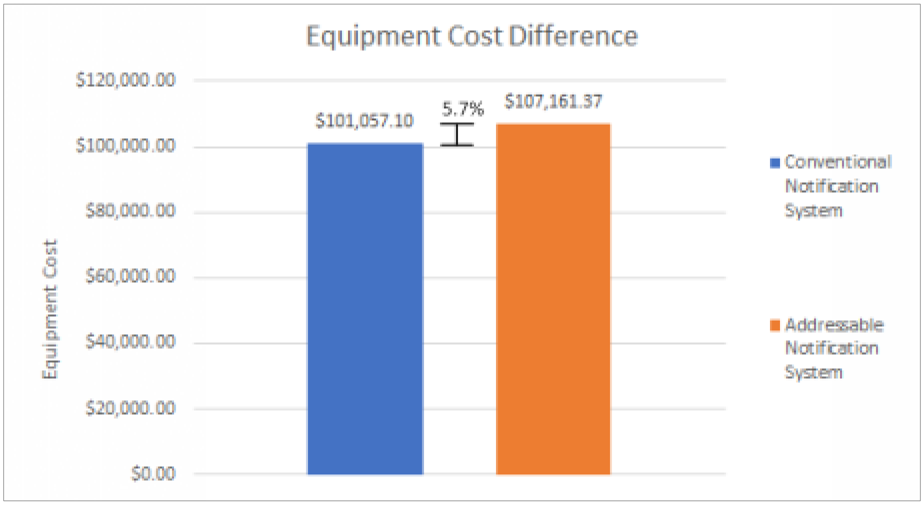

Figure 4: Comparison of Fire Alarm Equipment Costs

The material cost of wiring in the addressable notification system is $6,805 less expensive than what is required in the conventional notification system. For these proposed systems, there was an estimated material cost savings of 32.5%. Figure 5 shows the difference in wiring costs for each system.

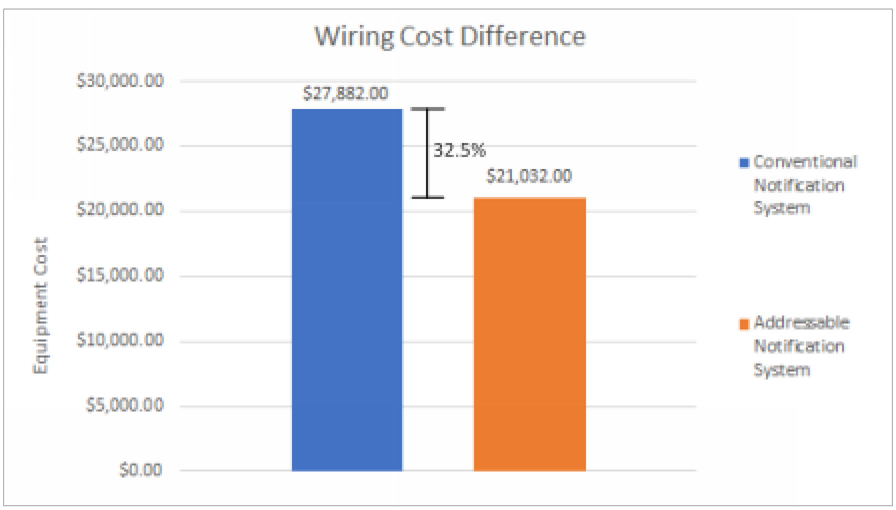

Figure 5: Comparison of Fire Alarm System Wiring Costs

The difference in material cost for these two systems nearly offset each other, meaning that the major cost savings in these systems is due to the time required to install the system. The difference in material pricing is quite subjective depending on the size and layout of a building, which will affect the quantity of notification appliances required for a code compliant system and the amount of wire used in the system. One might expect that in a larger area or taller building than the hotel building that these systems were designed for, the differences in the cost of wiring may be more drastic and offset the higher material price of the addressable notification equipment.

The total cost of materials to complete this project only account for 25.8% of the total cost of the conventional notification system, and 28.2% of the total cost of the addressable notification system. The overall cost of equipment when compared to the cost of labor to install these systems is a significant difference. From a cost savings standpoint, this difference emphasizes that fire alarm system designers should strive to optimize circuitry designs to be as efficient as possible in terms of labor for system installation. The iterative design process used by the team on this project helped eliminate extra wire and time required to install it by optimizing circuit routing in the building for both types of notification systems.

As mentioned above, the differences in material costs for each type of system virtually offset each other for this particular building. Each design was provided with identical quantities and locations of both initiating devices and notification appliances. The difference in fire alarm equipment prices comes from the addressable notification appliances and control equipment as they are more expensive than their conventional counterparts due to the technology within the appliance. The difference in the material cost of wiring is a result of the ability to T-tap the addressable notification circuits, whereas the conventional notification appliance circuits must be wired in series throughout. The ability to T-tap the circuits allows the designer of the system to be much more efficient with routing and the individual circuits to be longer in length. This can be attributed to the voltage drop advantages in a T-tapped system and the higher starting voltage of the addressable notification equipment. The 29VDC power supply allows for 6V of voltage drop, which is more than a traditional conventional system utilizing a 24 VDC power supply.

The price of conduit was not considered in this estimate. Depending on the jurisdiction and type of circuits installed in accordance with NFPA 72, fire alarm circuits may be required to be installed in metal conduit or a metallic raceway, which can quickly escalate the price of the system through both material and labor costs.

It should be noted that if a system like this were installed in a jurisdiction where T-taps and/or Class B circuitry are prohibited, the magnitude of the cost savings associated with the addressable system would decrease. In an instance that one of these conditions is prohibited by local code amendments, the only meaningful difference in the notification appliance circuitry between the two systems are the different current draws of the appliances and the extra voltage drop allowed by the addressable equipment. The ability to T-tap the notification appliance circuits in the addressable systems presents a major opportunity for cost savings in a larger building due to the lower quantity of wire and time to install. Where T-taps are not allowed, the main selling point of the addressable system would be the increased functionality, flexibility and long-term cost savings offered by the addressable equipment.

3.3.2 – Labor Hours

The difference in cumulative labor time required for each system results in a labor cost difference of approximately 12.1% ($44,954), several percentage points higher than the overall cost difference of the two systems. This indicates that the labor discrepancies are responsible for a larger portion of the overall cost difference than the material cost variance.

The cost estimate provided to the team was produced using labor rates from the Texas area. According to the U.S. Bureau of Labor Statistics, the average wage in Texas for a fire alarm system installer is S23.77/hour. For the purpose of discussion, this can be compared to the two extremes across the country. Fire alarm system installers in Massachusetts are paid an average of $33.97/hour, 43% higher than those in Texas who are paid an average of $23.77/hour. A similar worker in Florida receives an average hourly wage ($21.75/hr) that is 8.5% lower than those in Texas (U.S. Bureau of Labor Statistics, 2020). This variance shows that the geographical location could have a significant impact on the overall cost of the system, especially when the project is estimated to take thousands of labor hours to complete. The price of materials is expected to stay fairly consistent across the country. The hourly labor rate of a fire alarm system installer is proportional to the expected cost savings. Consider Massachusetts, where fire alarm system installers are paid 43% more than individuals in Texas.

Define the baseline labor rate in Texas:

x = $23.77/hour

Total Labor Hours for Conventional System: 4,649 hours

Total Labor Hours for Addressable System: 3,747 hours

Represent the baseline labor cost for each system as follows:

Conventional System Labor Cost = $4{,}649x = \$110{,}507$

Addressable System Labor Cost = $3{,}747x = \$89{,}066$

Represent the adjusted labor cost for each system as follows:

Conventional System Labor Cost = $1.43x * 4{,}649\ hours = 6{,}648x = \$158{,}023$

Addressable System Labor Cost = $1.43x * 3{,}747\ hours = 5{,}538x = \$127{,}360$

Baseline Labor Cost Differential: $21,441

Adjusted Labor Cost Differential: $30,663

Delta: $\frac{\$30{,}663 - \$21{,}441}{\$21{,}441} * 100 = 43\%$

The calculations show that a 43% increase in the labor rate will result in a 43% increase in the magnitude of the cost difference. The geographical labor rate variation analysis does not consider any profit margins or overhead that the contractor would incorporate into their estimates. When looking at the labor hours calculated for this project in particular, the major differences come from the installation labor, pre- and final-testing and programming labor. Figure 6 shows the breakdown of labor hours considered in this cost estimate.

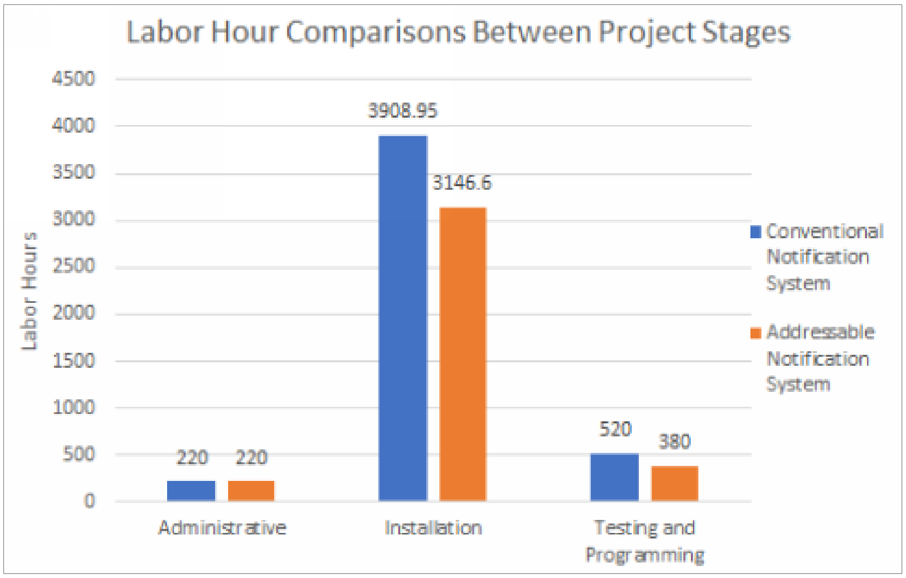

Figure 6: Labor Hour Comparisons Between Project Stages

The major difference in installation labor hours between the two systems is a clear indicator for potential cost savings. The flexibility and ability to T-tap the notification appliance circuits in the addressable notification system allows the system to be installed with less wiring, which results in less time spent pulling the wire from appliance to appliance and the time it takes to connect the appliance to the circuit. For this project, it was estimated that the time to install the wiring for the addressable notification system would take 342.1 hours less than that of the conventional system, which is nearly one third of the estimated hours (32.5%). Figure 7 shows the difference in time required to install the wiring for each system.

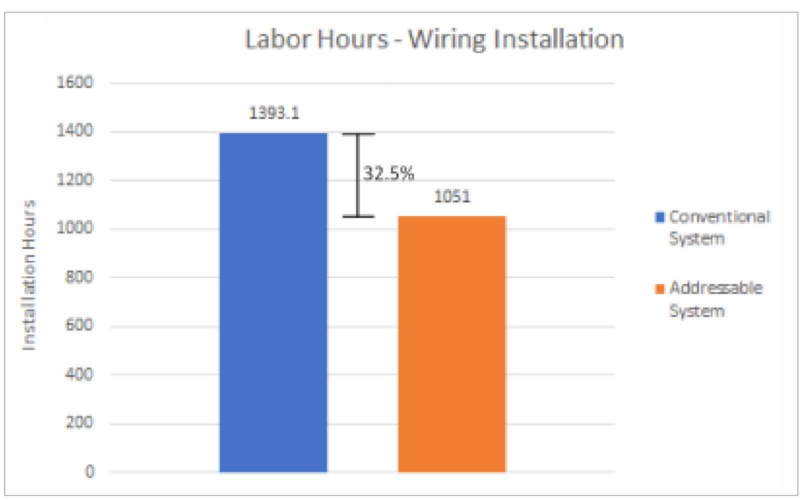

Figure 7: Wiring Installation Labor Hour Comparison

Similarly, the estimated installation time for the addressable notification appliances was 420.25 hours less than the conventional notification appliances. This amounts to a 20% difference in labor time required to install the addressable notification appliance, as shown in Figure 8.

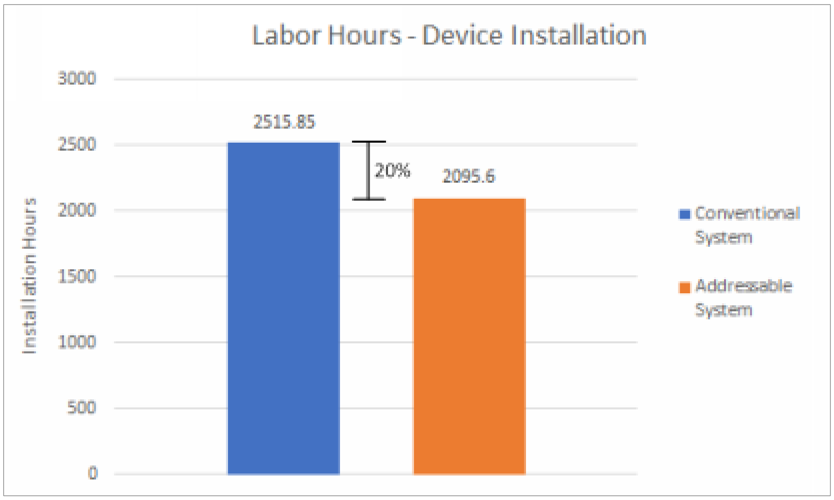

Figure 8: Device Installation Labor Hour Comparison

The shorter time to install the addressable appliances may be a result of the fewer connections needed to be made (only one leg of the circuit on T-tapped branches) and the easier to install backplates used on the addressable notification appliances. Ultimately, this difference amounts to 762.35 total labor hours saved on the material installation portion of the project for the addressable notification system.

The difference in the pre- and final-testing portions of this project can be attributed to the self-test features of the TrueAlert ES appliances. A test of all notification appliances in the building can be conducted by one individual standing at the fire alarm main control panel. The addressable notification appliances generate a testing report each time they are activated that will confirm proper functionality of the device. The estimated difference between testing the fully addressable system and the system with conventional notification appliances is 40 hours.

The cost estimates provided to the project team also indicated that the programming of the fully addressable system would take 40 hours less than that of the system with the conventional notification appliances. The third-party contractor who provided the estimate noted that the Autocall brand system software is provided with programming features that allow for easier and quicker grouping of notification zones than the conventional system. This feature is especially useful for when the fire alarm system is used as a mass notification system and more complex zoning and grouping of notification is required to meet the needs of the building. While the programming savings offered by the addressable notification system are important to note, 40 hours is a relatively small difference when compared to the other labor categories.

3.3.3 - Evacuation Strategies

At first glance, addressable notification technology presents the opportunity to redefine the standard evacuation strategy for residential high-rise buildings. However, upon further consideration, the project team concluded that there are limited viable evacuation strategies on the residential floors of a high-rise hotel building. Traditional evacuation strategies in high-rise buildings (floor of fire event, and floors above and below) meet the needs of most hotel building layouts and multiple messages may become confusing to occupants. One potential advantage of having programmable groups as a part of the addressable notification system would be to broadcast different messages over the speakers in the main corridors and hotel rooms. Ultimately, the value of the increased capabilities of the addressable notification system for evacuation strategy flexibility are limited in a building like the hotel analyzed by the project team.

Simplex has proposed a potential evacuation strategy for a residential high-rise building utilizing addressable notification that occurs in three phases. In the example evacuation strategy, a smoke detector senses burning toast and only the occupants of the apartment where the smoke was detected are delivered the following message “Smoke has been detected in your apartment - please evacuate”. If the smoke were to travel into the corridor and be sensed by a smoke detector in the hallway, the entire floor of the fire event would be broadcasted the following message, “Smoke has been detected on your floor - please evacuate”. Simultaneously, occupants on the floors above and below the fire incident will be alerted with the following message to prepare them for evacuation if necessary, “Smoke has been detected on a nearby floor. Please await further instructions”. If a corridor smoke detector or waterflow switch on the floor activated, the system would immediately enter the alarm state and alert the fire floor, floor below, and floor above. This is just one example of the potential evacuation plans that can be developed and utilized with addressable notification appliances and the ability to program different audio groups for evacuation messages.

3.4 - Conclusions

After analyzing the cost estimates provided to the project team for the two notification systems, it was determined that fire alarm systems utilizing addressable notification appliances can provide a significant cost savings for system installation and long-term maintenance of the system. The system utilizing addressable notification was estimated to cost $45,700 (9.15% of the total cost) less than a system with an identical layout utilizing conventional notification appliances. The vast majority of the cost savings associated with the installation of the fire alarm system can be attributed to the cost of labor and the time saved on installing wiring and devices, as well as convenient programming and testing features of the system. Cost savings associated with labor may be even greater depending on the labor rates of the given area. For this particular building, the cost savings associated with the decreased wire lengths in the addressable system were virtually nullified by the higher unit price of the addressable notification appliances which made the total material cost of each system very similar.

The project team was able to conclude that the cost savings associated with the addressable notification system may be increased in larger buildings where the ability to T-tap circuits and cut down on total wire length is further emphasized. It is also important to note that the savings associated with reduced wire lengths and T-tap capabilities may be negated by local code amendments, but the addressable notification equipment still provides the benefit of lower current draws and longer circuit lengths as a result of the increased voltage drop. When looking at the long-term maintenance of the fire alarm system, the addressable notification has many advantages including less control equipment maintenance, easier and more convenient testing of notification appliances, and the ability to pinpoint circuitry problems with addressable points in the system. Section 4.0 will further explore the increased functionality that addressable notification appliances can provide.

4.0 - High School Study

This section of the report considers a retrofit fire alarm installation in an existing high school building. The following assumptions were made before commencing this study:

- The project team has been contracted by the State Department of Education to upgrade the fire alarm system in a local high school. It is early in the design process, and the stakeholders have requested several different schematic level designs for comparison.
- The school is located in a jurisdiction that has adopted the 2018 Edition of the International Building Code without significant local amendments.
- In addition to the fire alarm upgrades, the school will be concurrently undergoing rehabilitation work consistent with the definition of Level 3 Alterations in the International Existing Building Code (IEBC). IEBC Section 904.2 states that when Level 3 alterations are performed in a building, the fire alarm and detection shall be provided in accordance with Section 907 of the International Building Code as required for new construction.

The high school being considered in this portion of the study is two stories in height and measures approximately 275,000 ft^2 in gross area. The floor plan of the school is shown in Figures 9 and 10.

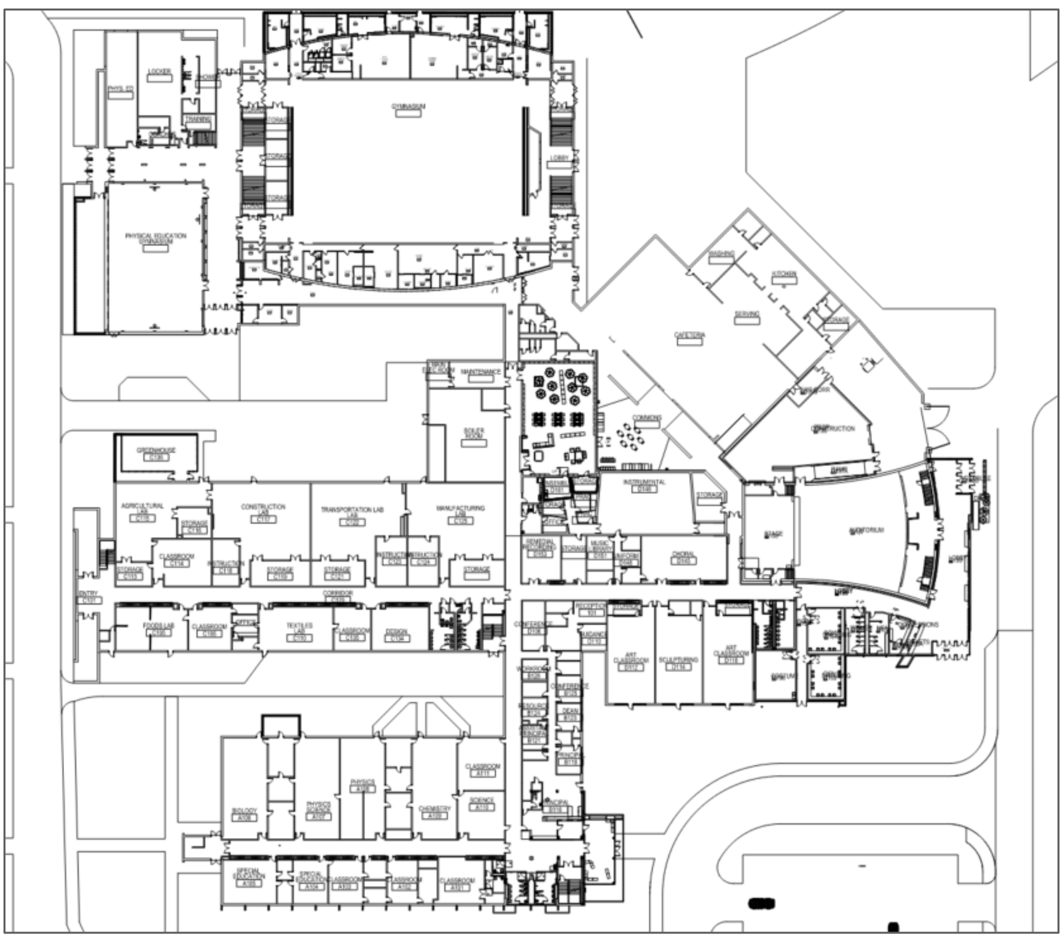

Figure 9: High School – First Floor Plan

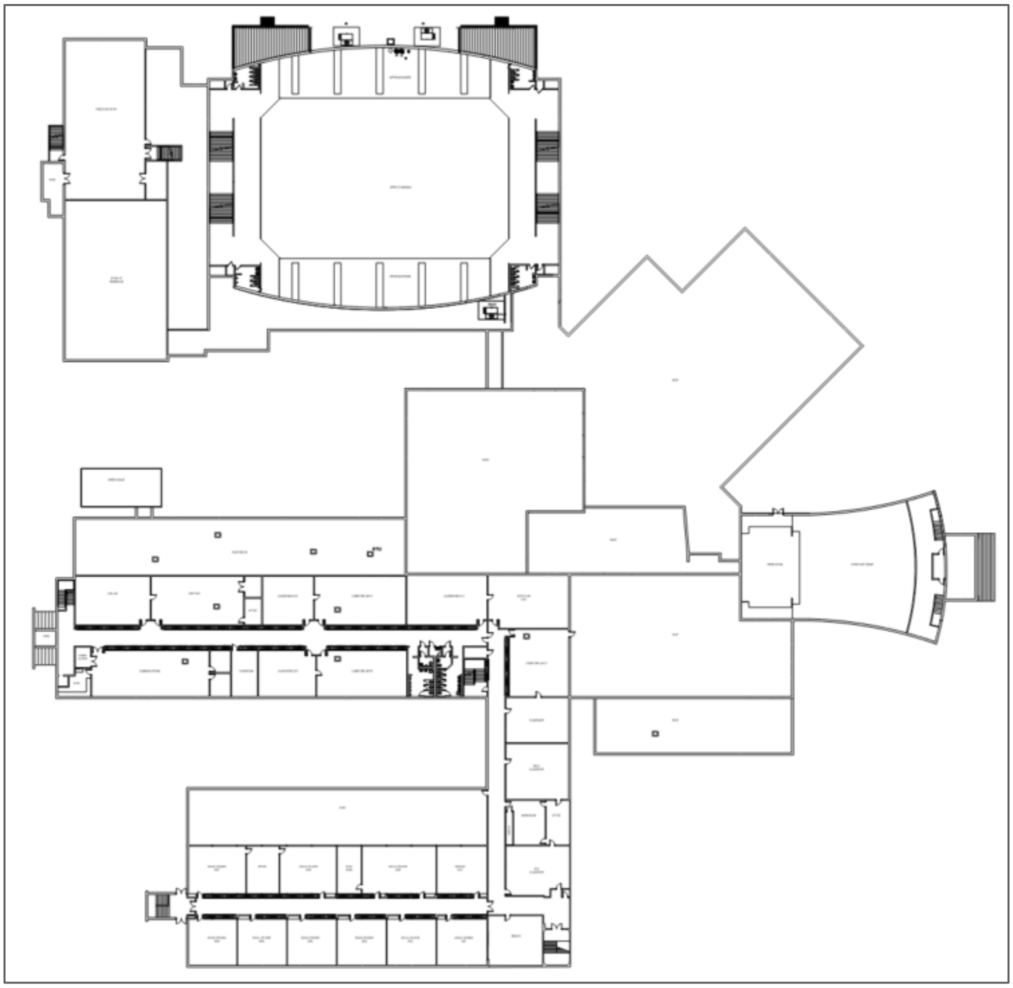

Figure 10: High School – Second Floor Plan

4.1 - Minimum Code Requirements

The high school is classified as a Group E occupancy in accordance with IBC Section 305. All Group E occupancies shall be provided with a manual fire alarm system that activates the occupant notification signal utilizing an emergency voice/alarm communication system (EVACS). The EVACS shall operate upon the actuation of any automatic fire detector, sprinkler waterflow device, or manual fire alarm box and shall automatically sound an alert tone followed by voice instructions giving approved information. Speakers throughout the building shall be provided by paging zones, provided (at a minimum) as follows:

- Elevator groups
- Interior Exit Stairways
- Each floor
- Areas of refuge

4.2 - Design Options

All of the aforementioned code requirements can be satisfied by installing conventional notification appliances throughout the building. Section 4.2.1 presents a design basis for a fire alarm system utilizing conventional notification appliances. Recognizing the limitations associated with conventional notification, Section 4.2.2 presents a design basis for a fire alarm system utilizing addressable notification technology throughout. The two designs compare a high-level zoning/circuit routing configuration for each system. The project team believes that this approach effectively captures a number of the differences between the two technologies and will allow the stakeholders to understand the increased functionality that addressable notification can offer.

The State Department of Education has also recognized the need to be able to effectively communicate with building occupants in emergency situations and has requested that the project team determine what additional system components would be required for the system to function as a combined in-building mass notification/EVACS system. Section 4.2.3 contains this information and also explores how to best leverage the capabilities of addressable notification to provide safe and efficient communication to building occupants during all types of emergencies.

4.2.1 - Conventional System Schematic Design and Narrative

When first starting to consider the zoning and circuit routing of conventional NACs, there are three main things to keep in mind:

1. All appliances must be wired in series. *This will control the circuit routing.*
2. Allowable voltage drop is limited to 4.4 VDC, based on 85% of a standard 24VDC power supply as required by NFPA 72. *This will control the maximum allowable circuit length. Voltage drop is directly proportional to the circuit load.*
3. Circuits cannot span multiple floors, to satisfy the paging zone requirements of the IBC.

With these considerations in mind, the team laid out a schematic level design for a conventional notification system. The proposed location for this fire alarm control panel is in the main office area of the building. This will serve as a convenient and accessible location for the fire department and trained personnel to access. Notification throughout the building is to be provided by conventional speaker-strobe appliances. The project team located notification appliances throughout the building in accordance with the requirements of the IBC and Chapter 18 of NFPA 72. Using the information from the material data sheets, the team populated a PDF of the floor plan with the current draw values for each physical space. The current draws were summed and divided by 2.55A (3A NAC loaded to 85% capacity) to determine the lowest number of circuits. For example, consider a building in which the sum of the current draws from all notification appliances is 14.4A:

$$14.4A / 2.55A \text{ per NAC} = 5.56 \rightarrow 6 \text{ NACs}$$

If the total current draw of the appliances in the building were the only variable to consider, a minimum of six NACs would be required in this building. This number will quickly become irrelevant since the maximum allowable circuit length is controlled by voltage drop, but it provides a starting point and ensures that the designer is not wasting time trying to split the building into fewer zones than are physically required. In the high school, the total notification appliance current draw was estimated to be 27.9A using conventional notification appliances. This corresponds to a minimum of 11 NACs.

$$27.87\text{A} / 2.55\text{A per NAC} = 10.9 \rightarrow 11 \text{ NACs}$$

With this information in mind, the team developed basic wiring diagrams and subdivided the building into zones. The initial layout consisted of one NAC supplied from the FACP and eight additional ES-PS power supplies remotely located throughout the building providing power to an additional 26 circuits. The layout was validated using the lump sum method for calculating voltage drop. This method is conservative in that it assumes that all appliances are located at the most remote point on the circuit, yielding a result of the worst-case voltage drop. Voltage drop calculations for the initial layout showed that the circuit runs were excessively long throughout the building. Additional remote power supplies were added and the zones were further subdivided in an iterative process until the voltage drop for each circuit was within an acceptable range. By locating power supplies throughout the building, circuits lengths are shortened and voltage drop can be kept within acceptable limits. Figure 11 shows the proposed zoning of the conventional fire alarm system on the first floor of the high school and Figure 12 shows the proposed zoning on the second floor.

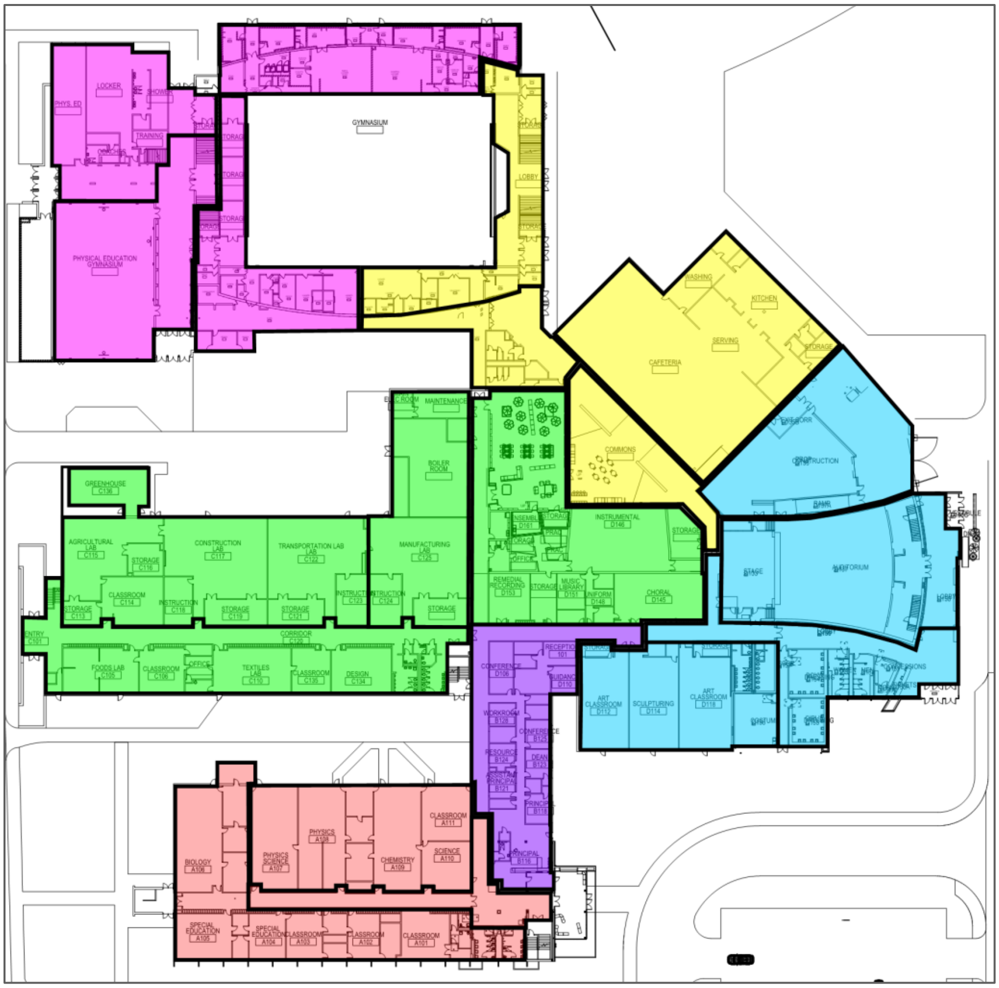

Figure 11: Conventional System Zoning – First Floor

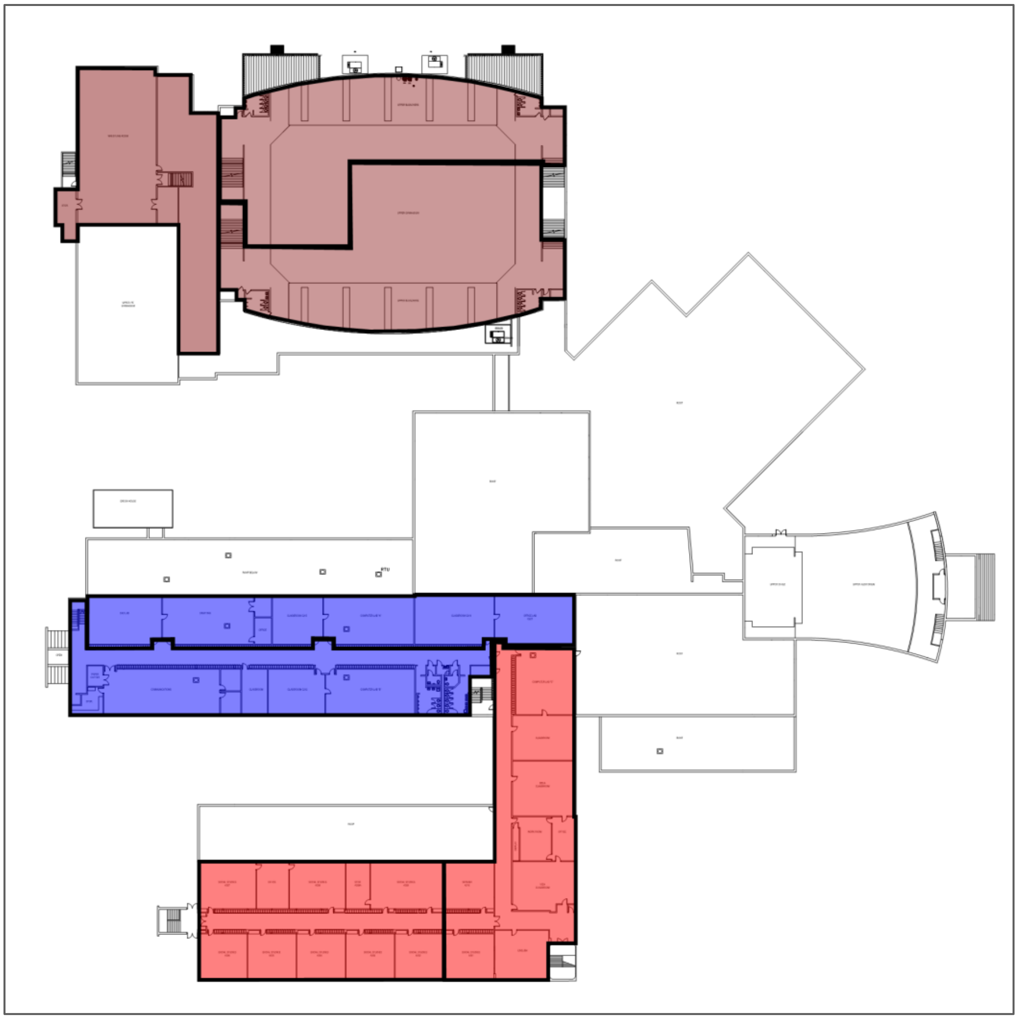

Figure 12: Conventional System Zoning – Second Floor

The conventional system contains 27 Class B NACs throughout the building, spread across the master ES-PS power supply at the fire alarm control panel and 8 remotely located ES-PS power supplies. As previously mentioned, this proposed system would be code compliant, but the team believes that there are a number of limitations associated with the conventional system design. To fully realize the functionality that today's technology can offer to better protect building occupants from a wide range of hazards, a similar exercise was completed for an addressable system in Section 4.2.2.

4.2.2 - Addressable System Schematic Design and Narrative

As stated above, a similar exercise was conducted to determine the necessary control equipment required to provide a code compliant addressable notification system in the same high school building.

The same notification layout was used to determine how many notification appliance circuits would be required to supply every notification appliance in the building with the required power.

One added benefit of the addressable system is the use of a repeater that can be added in series with a notification appliance circuit to refresh the power capacity available on the circuit while not refreshing the voltage drop on that circuit. The repeater is an additional piece of control equipment that should be placed in a safe and concealed location, much like a standard remote power supply. It should be noted that while the conventional speakers do not have a current draw associated with them, the addressable speakers have a small current draw to facilitate device-level supervision.

It was determined that the notification appliances in the schematic level design would require a total of 23.745A. Dividing this number by 2.55A (maximum of 85% capacity on each circuit) results in a total of 10 notification appliance circuits (IDNACs for addressable equipment), required to power all of the notification appliance circuits. From here the building was subdivided into zones and basic wiring diagrams were developed for Class B IDNACs utilizing T-taps as permitted when using the addressable notification technology. The voltage drop on the IDNACs were confirmed through a simple lump calculation using the alarm current of the circuit, the length of the circuit at its most remote point and the resistance for 14 AWG wire. The layout consists of 3 NACs supplied by the master ES-PS power supply in the fire alarm control panel, and 7 NACs powered by three remote ES-PS power supplies. Figure 13 shows the proposed zoning of the addressable notification system on the first floor of the high school and Figure 14 shows the proposed zoning on the second floor.

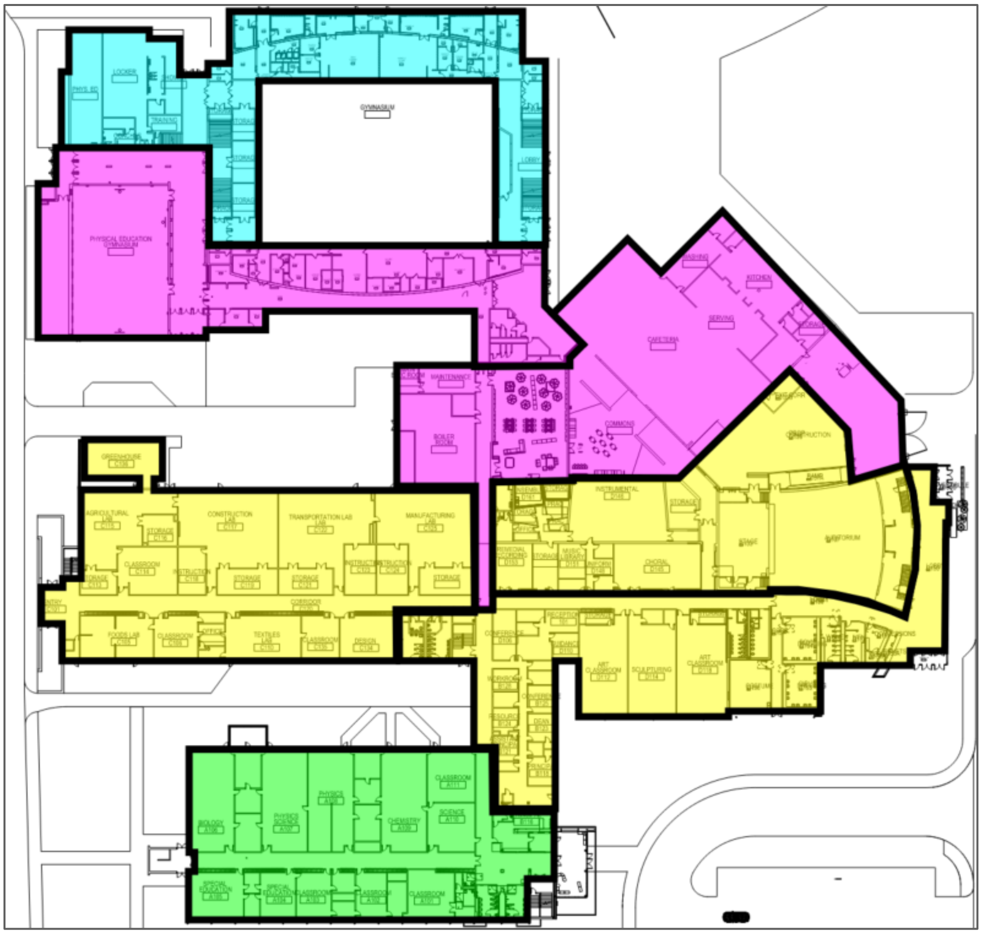

Figure 13: Addressable Notification Zoning – First Floor

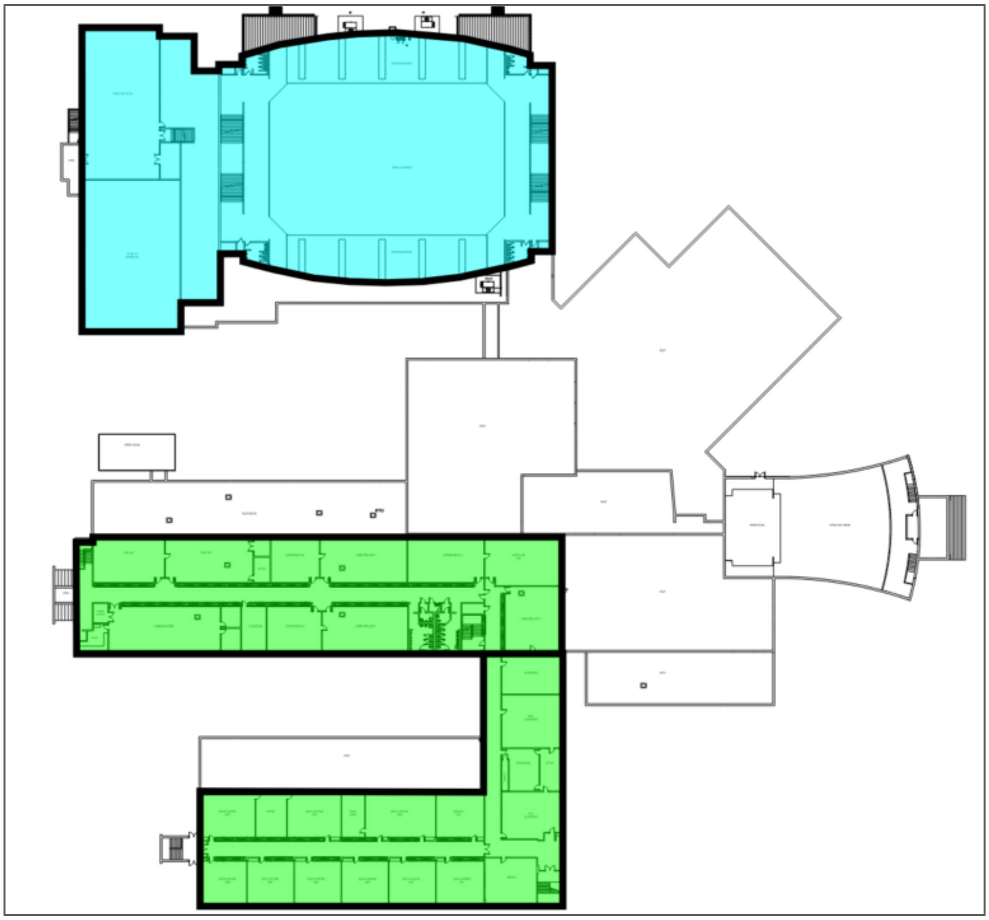

Figure 14: Addressable Notification Zoning – Second Floor

It is apparent that there is a significant difference between the fire alarm control equipment required for each type of notification system. While the conventional notification system required a total of 27 Class B NACs, the addressable system can be assembled with 10 Class B IDNACs. The addressable notification system only requires the use of three power supplies and one repeater, while the conventional system requires nine power supplies.

In addition to the lower demand for control equipment discussed above, the addressable system is also able to provide multiple targeted messages to certain areas of the building through the use of programmable groups. Conventional notification appliance circuits operate on an “all-or-nothing” basis, in that all appliances on a given circuit will sound/flash simultaneously when the circuit is activated. Since the addressable notification appliances are supervised on an individual device level, the fire alarm control panel is able to be programmed to actuate individual devices on a circuit, or even a group of selected appliances spread across multiple physical circuits. Each appliance is capable of being assigned to a maximum of three groups. In the case of combination audible/visual appliances, the speaker and the strobe are considered separate appliances for the purpose of grouping. Figures 15 and 16 show an example of how the programmable groups could be configured in the high school.

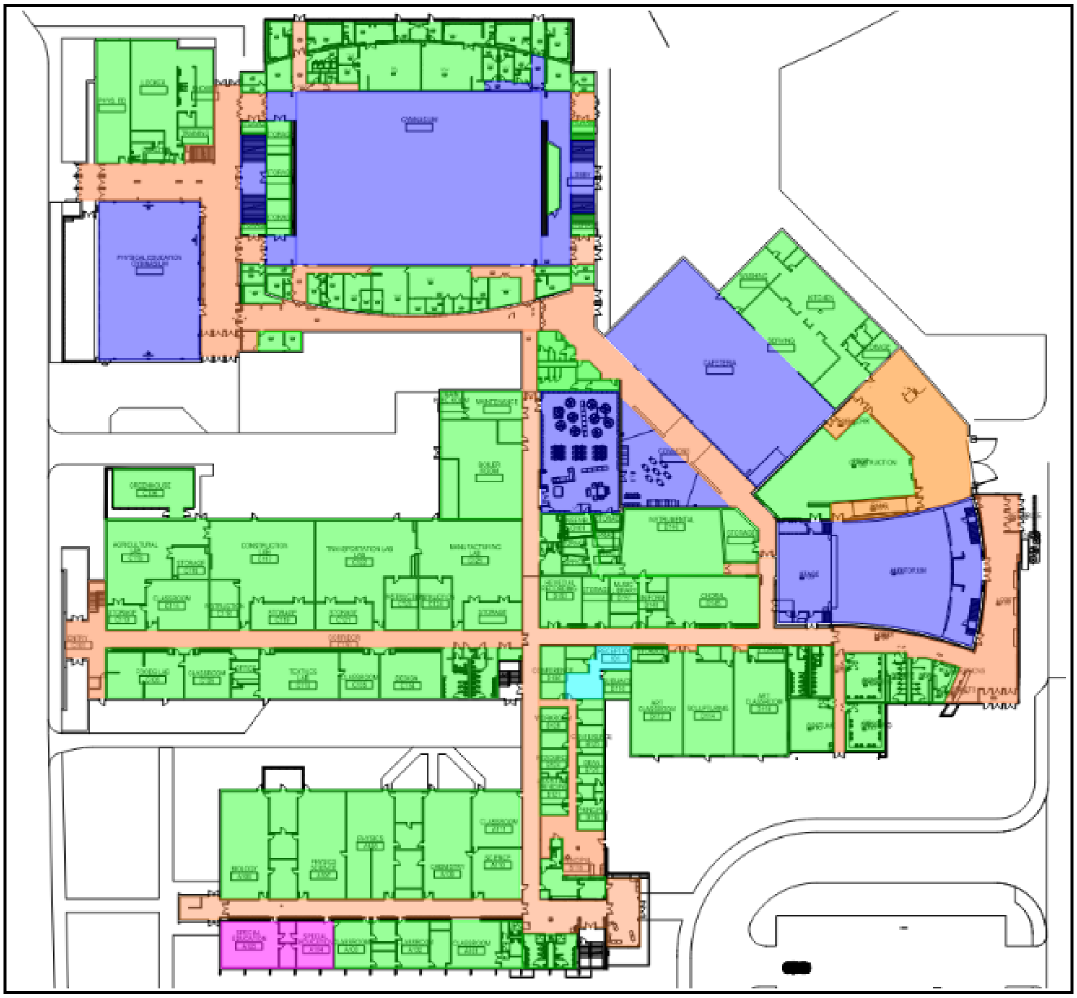

Figure 15: Proposed Programmable Group Configuration – First Floor

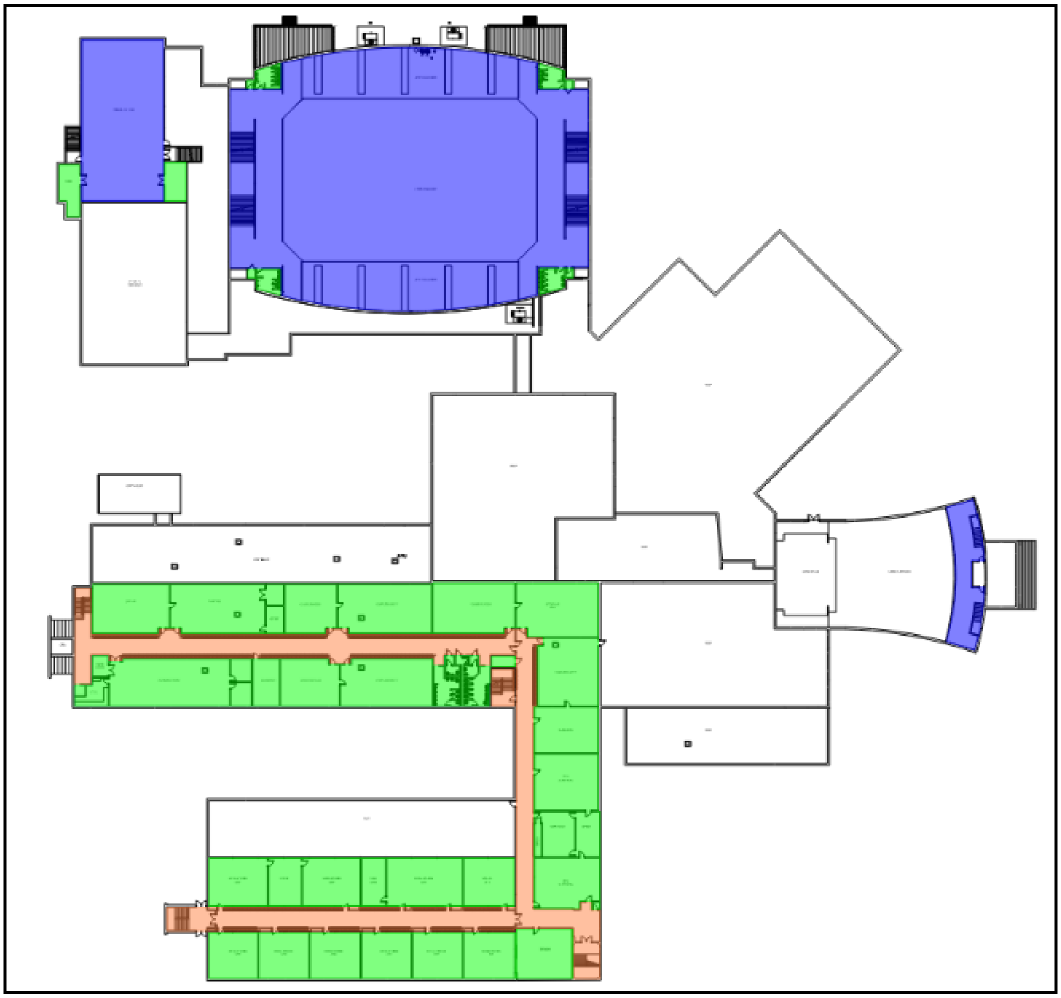

Figure 16: Proposed Programmable Group Configuration – Second Floor

Here, the building was divided into groups based on the expected use of each space. The blue group is comprised of all assembly spaces in the building (i.e. gymnasiums, auditoriums, cafeteria). Assembly occupancies are expected to have a highly concentrated occupant load. Because these areas are typically used for after school functions such as sporting events, plays and musicals, and other community events, it is expected that there may be a larger proportion of occupants who are unfamiliar with the building. For these reasons, the team believes it would be advantageous to be able to broadcast messages to all assembly areas in the building at once.

In Figure 3 above, the orange group includes all corridors in the building and the green group consists of all other occupiable areas. The team acknowledges the same messages would probably be broadcast to both the green/orange groups during a fire emergency since the building should be using a total evacuation procedure. The advantages of corridor/room grouping are discussed in more detail with regards to mass notification applications in Section 4.2.3. The small pink zone in the bottom left-hand corner of Figure 3 encompasses the two special education rooms in the school. Certain messages may be omitted from this space, or perhaps audible only/visual only notification could be used under certain circumstances. This will minimize disruption to the occupants in these rooms who may be sensitive to loud noises or flashing lights. As previously mentioned, each appliance can be assigned to a maximum of three groups. Figures 15 and 16 only shows one level of grouping. A greater degree of functionality can be achieved by defining additional groups, without affecting the configuration shown in Figures 15 and 16. For example, the main gymnasium is part of the assembly occupancy group. The nine speaker strobe appliances within the gym could be assigned to their own group (through programming), or both gymnasiums could be grouped together. The team believes that programmable group divisions within a building needs to be carried out on a case-by-case basis. There is no one size fits all approach to evacuation strategies and the potential risks for each building. The ideal grouping configuration is dependent on the unique features of the building as well as the desired features and functionality that the stakeholders would like the system to provide. There are virtually unlimited combinations that could be implemented based on the facility's needs.

4.2.3 - Mass Notification and PA System Considerations

The benefits that addressable notification technology can provide are not limited to fire alarm applications. The team believes that a system utilizing addressable notification appliances and designed with mass notification capabilities would be able to deliver increased value and functionality to the end user without a significant increase in cost or equipment demand. NFPA 72 defines an in-building mass notification system as, “A system used to provide information and instructions to people in a building using intelligible voice communications and including visible signals, text, graphics, tactile, or other communication methods”. Combination of mass notification with fire alarm systems is permitted by NFPA 72 if the combined systems comply with the requirements of Section 23.8.4. This section primarily addresses the interfacing of non-fire alarm equipment with the fire alarm system.

The additional equipment that is required to allow a system to function as a combined fire alarm/mass notification system will vary based on the manufacturer and model of the fire alarm control unit. Certain control units have been designed with this purpose and mind and are listed in accordance with the requirements of both UL 864, *Standard for Control Units and Accessories for Fire Alarm systems,* and UL 2572, *Mass Notification Systems*. Fire alarm control units meeting this criteria will not require any non-fire alarm equipment to be interfaced with the system. Constant supervision modules are required to be installed to ensure that the circuit is supervised while the system is being used for non-fire alarm purposes. When a NAC is energized to deliver an audio message, the circuit is no longer supervised for integrity. A constant supervision module installed on the audio amplifiers facilitates supervision of the NACs while the system is being used to deliver audio that is not related to a fire alarm condition. This is accomplished by derating the output power of the amplifier to 70%.

With all of this in mind, the only relevant requirement from NFPA 72 §23.8.4 relates to message priority. Fire alarm signals are required to be distinctive and clearly recognizable. Signals shall be indicated as follows in descending order of priority:

1. Signals associated with life safety.
2. Signals associated with property protection.
3. Trouble signals associated with life/and or property protection.
4. All other signals

In accordance with NFPA 72 Section 24.5.13, the local building mass notification system shall have the ability to override the fire alarm system with live voice or manual activation of a higher priority message. Each building utilizing a mass notification system is required to develop and maintain an emergency response plan that defines voice message priority scheme based on a risk assessment of the facility. Messages that are defined as having a higher priority than fire alarm signals are permitted to override the fire alarm system. A common example of this that is particularly applicable to a school setting would be an active shooter incident. The intruder may attempt to trigger the fire alarm system to draw occupants out of a safe location. An authorized individual at the fire alarm control unit would be able to instantly override the evacuation signal and deliver a live/pre-recorded message that assures occupants will receive safe, informed, and timely messages.

The constant supervision modules used to facilitate non-alarm audio messages can be installed on systems using either addressable or conventional notification appliances. The differences between the two systems in regards to fire alarm signaling have been discussed in detail in the previous sections, and the primary difference in functionality remains the same here: the addressable system can actuate any combination of notification appliances throughout the building without respect to physical circuit routing. A fire alarm signal in a school such as this one would always trigger a total evacuation of the building. A mass notification message, on the other hand, may instruct occupants to evacuate, shelter in place, or relocate themselves within the building. The complexity of these messages presents an opportunity to fully utilize the addressable notification programmable groups to deliver information to occupants effectively.

Consider a weather-related emergency, such as a tornado or a hurricane. A document published by the Michigan Committee for Severe Weather Awareness states that the ultimate goal during a tornado event at a school is “to quickly inform teachers and students of the threat of a tornado and to move them as quickly as possible to a pre-designated shelter”. Rooms with windows and open spaces with large roof spans are the most susceptible to tornado damage. This means that interior corridors may be an acceptable pre-designated shelter, or students may be directed to several different safe rooms throughout the building.

A mass notification system with conventional notification appliances would be able to accomplish the goals defined above by means of a pre-recorded message or live voice paging. The system could broadcast a voice message that instructs occupants to relocate to their pre-designated shelter. However, since the division of paging zones is restricted to the physical speaker circuits, the system has limited capabilities. To exemplify this, we have compared the theoretical performance and capabilities of an addressable mass notification system to that of a conventional system in a number of situations. Assume that the school has developed an emergency action plan and has designated 6 shelter areas throughout the first floor. Each classroom has been assigned a shelter area to report to in case of a weather-related emergency.

<u>Situation 1:</u> **Paging zones that correspond to the emergency action plan need to be programmed into the fire alarm/mass notification system.**

> **Conventional:** Paging zones must be defined by coordinating with the school's emergency action plan *during* the design process to ensure that the physical circuit layout corresponds to the desired zones. By dividing the building in this manner, the messages that are delivered to the occupants can be tailored to direct certain zones to a specific shelter area.
>
> **Addressable:** After the system is installed, groups are programmed in the system to correspond directly to the shelter area assignments developed in the emergency action plan. Any group can be defined, without respect to physical circuit routing.

<u>Situation 2:</u> **Notification within shelter areas is disruptive and stressful to occupants.**

> **Conventional:** The message continues to constantly sound throughout the building for the specified duration. Once occupants reach shelter areas, they are subjected to high intensity flashing strobes for the duration of the event. Deactivating the notification within the shelter area would mean deactivating the entire zone, which would not be acceptable.
>
> **Addressable:** The speaker and strobe of an addressable appliance can be controlled independently from each other. The system can be programmed to omit strobes and only sound audible notification within the shelter areas to provide a more comfortable environment. It is safe to assume that anyone who is in the shelter has already been alerted to the emergency. As another option, an alternate pre-recorded audio message could be played within the shelters after a predetermined period. Outside of shelter areas, the signaling remains unchanged to direct any remaining occupants to the shelters.

<u>Situation 3:</u> **An authorized individual at the control panel would like to use live voice paging to provide individualized updates to each shelter area.**

> **Conventional:** The zones containing shelter areas are selected for live paging. The pre-recorded message is that directing occupants to the shelter area is interrupted not just within the shelter, but throughout the entire zone(s). If the speakers in two shelter areas happen to

sit on the same NAC, it would not be possible to broadcast an individualized message to each area.

Addressable: Each shelter area is programmed to belong to two different groups. One group is the individual shelter area, and the other is a group of all six shelter areas. An authorized individual at the panel can use live paging to provide updates to each area individually or select the group of 6 to conveniently page all shelters. In either case, the signaling outside of the shelter area(s) in corridors and classrooms remains the same and will continue to direct occupants to the shelter.

Situation 4: The school undergoes minor renovations and has designated new shelter areas. The assignment of occupants to shelter areas has also changed.

Conventional: The paging zones that were originally programmed into the panel are now functionally useless, as the division of shelter area assignments no longer corresponds to the physical circuits within the building. As such, the pre-recorded messages would need to be edited to be more generic (i.e., no longer directing occupants to a specific shelter area), or the paging zones would need to be re-wired to correspond to the new shelter assignments. At this point, a successful relocation would rely on all occupants remembering their shelter area assignment, which may be difficult during a stressful emergency situation.

Addressable: The programmed groups can be modified at any time to remain consistent with the emergency action plan. All changes take place through the system software at the panel.

4.3 - Discussion and Comparison of Design Options

4.3.1 - Equipment

The high-level schematic fire alarm design put together by the project team for the high school building required vastly different numbers of control equipment between the two types of notification systems. The conventional notification system required a total of nine (9) ES-PS power supplies to be located throughout the building, while the addressable notification system can be powered by only four (4) of the same power supplies. This will have a number of implications on the cost of installation as well as the cost of maintenance over time for the respective systems. In Section 3.0 of this report, the cost analysis that was carried out for the hotel evaluated a fire alarm system design using conventional notification appliances that required twice as many power supplies as the addressable system. The results of this cost analysis showed that the material costs for both systems would be functionally equivalent despite the addressable appliances being inherently more expensive. In the high school the conventional system requires three times as many power supplies when compared to the addressable system. This suggests that the layout of the building can have a significant impact on the demand for control equipment, and that cost savings associated with the addressable system may be even greater than what the hotel study yielded. The potential savings will quickly be compounded when considering the cost of testing and replacing batteries within the power supplies throughout the building.

Another advantage of the addressable system relates to the location of the power supplies. In the conventional system, power supplies will need to be located remotely throughout the building in order to keep circuit lengths down and comply with voltage drop requirements. The 29VDC regulated power supplies in the addressable notification system allow for much longer circuit runs, which may allow the system designer the flexibility to centralize control equipment in the building. This will facilitate easier troubleshooting and testing in the future if all equipment is in one spot as opposed to spread out in numerous locations throughout the building.

4.3.2 - Functionality

In addition to the notable differences in control equipment demand, the conventional and addressable system will also vary drastically in the capabilities and functionality that they are able to deliver to the end user. One advantage that could be easy to overlook given all of the other advantages of the technology, is simply that the appliances are addressable. If an appliance malfunctions or is damaged, the panel will immediately annunciate the exact address and location of the appliance. The individual at the panel would then be able to travel directly to this location and determine how to address the issue. If there was a circuitry issue (e.g., open, ground, short) occurred on a conventional notification system, the panel would annunciate a trouble signal for the entire circuit. It would then be the responsibility of the fire alarm technician to deduce where the problem originated, which will likely be time consuming and require a large number of devices to be disconnected from the circuit to pinpoint the issue.

The self-test feature of the addressable notification system provides a convenient way for a single individual at the fire alarm control unit to instantly test all appliances in the building. The test only takes a few minutes to complete, and then a detailed test report is automatically generated to review the status of each appliance. NFPA 72 Table 14.4.3.2 provides testing requirements for fire alarm system components. This table requires that the candela rating of each visual appliance must be verified to match the approved shop drawings. This could be an incredibly time-consuming exercise with the conventional notification system, but the addressable notification system can instantly display and change the candela rating of any appliance from the fire alarm control unit through programming. Initial acceptance testing of the addressable notification system will still require a physical walkthrough with appliances sounding to verify appliance location, sound pressure level, and intelligibility. Once the acceptance testing has been completed, annual periodic testing will no longer require the appliances to sound or flash. This allows for testing to be completed at any time of day, without disruption to the building occupants. Building owners may also be inclined to carry out testing more frequently than is mandated by the code, which can only serve to increase the safety and reliability of the system.

Another major advantage of the addressable notification system centers around the programmable groups. The groups within the system can be programmed to meet the exact needs of the facility. The conventional system, on the other hand, is limited by the physical circuits in respect to zoning. Mass notification applications present an excellent opportunity to fully utilize the refined grouping capabilities of the addressable notification system. Experts in the human behavior field have concurred that occupants need sufficient information in order to make safe and timely decisions during an emergency. As the information becomes more detailed and personalized, people are able to become aware of their situation and properly weigh their options. The Simplex 4100ES fire alarm control unit can be configured for up to 8 channels of digital audio, meaning that as many as 8 different messages could be broadcast to different zones in the building simultaneously. Utilizing these channels to broadcast personalized messages to different zones will increase the amount of information that occupants receive and increase the likelihood of a safe and efficient response.

The tornado scenario discussed in Section 4.2.3 is just one possibility in a vast list of potential emergencies. The unfortunate reality is that active shooter incidents have become increasingly common in schools over time. From 1992 to 2002, the United States averaged 122 days between school shootings. From 2015 to 2018 this dropped drastically: one shooting every 77 days. With this in mind, it only makes sense that schools should be provided with technology that will increase communication capabilities during such an event. A tornado or other weather-related event will typically have a fairly static response procedure: when the weather alert is received, students move to their assigned location and shelter in place. Adding the human element to an active shooter incident introduces a number of other variables. If first responders are trained in the operation of the Simplex 4100ES panel, they will be able to instantly broadcast a live message to any speaker or group of speakers. This, combined with video monitoring in the corridors can result in an extremely powerful tool to communicate with occupants.

The risk analysis of the school would determine which scenarios should be considered, as well as the priority ranking for messaging. The exact configuration of programmable groups within the building, as well as the content of the pre-recorded messages, will depend on the features and functionality that the stakeholders want. As long as the basic requirements for paging zones in the IBC are satisfied, the possibilities are endless. This is perhaps the biggest advantage of the addressable notification appliances: flexibility. Section 3.0 demonstrated that there are significant cost savings associated with the installation of an addressable notification system in place of a conventional one. It is clear that the cost savings are only a small piece of the larger picture; Addressable notification appliances also present a tremendous value in the sense of increased functionality.

5.0 – Conclusions and Future Work

Addressable notifications systems will provide significant cost savings due to easier installation, decreased wiring lengths, and less required control equipment when compared to conventional notification appliances. In the high-rise hotel that was analyzed in the first part of this paper, the addressable system cost $45,700 less than the conventional system. This corresponds to a cost savings of 9.2%. The majority of the cost differential is attributed to the reduced labor time required to install the addressable system. The cost savings associated with an addressable notification system are dependent on the size and layout of the building. In addition to the savings during design and installation, addressable systems are expected to offer long term cost savings through the self-test features and ease of maintenance. Although the costs were not quantified in the high school portion of this paper, the addressable system is expected to deliver similar cost savings due to the reduced demand for control equipment. It was determined that the conventional system would require 27 NACs across 9 power supplies. The addressable system only requires 10 NACs and 4 power supplies, primarily due to the ability to T-Tap, reduced appliance current draw, and 29VDC power supply.

In addition to the lower cost, addressable notification appliances can provide increased functionality to the end user. One key feature of this technology is the addressability, which is expected to increase the efficiency of performing maintenance on the system. Because each appliance can be controlled individually, targeted messages can be broadcast to specific areas of the building. This is accomplished through programmable groups that can be altered at the fire alarm control unit at any time. These groups can include any individual speaker in the building, with no respect to physical circuit routing. Where combined audible and visual appliances are installed, the speaker and strobe are individually controllable. Addressable notification appliances are also equipped with self-testing features. An individual at the panel can instantly test all appliances in the building at the push of a button and generate a detailed status report. This will limit disruption to occupants in the building and also decrease the required labor for testing. Mass notification system applications present an opportunity to leverage the full capabilities of addressable notification, since the message content and desired system functionality are expected to vary depending on the nature of the emergency.

As previously mentioned, many of the cost savings associated with addressable notification systems are negated if the system is installed with Class A circuits instead of Class B. Due to the requirement for a redundant pathway, Class A circuits cannot be T-tapped. All appliances must be wired in series to maintain the integrity of the loop. Future work should examine the impact on cost savings when Class B circuits are not permitted. The high school study considered the integration of an in-building mass notification system with the fire alarm system. Future research could examine the use of addressable notification appliances in a wide area mass notification system (WAMNS) that encompasses multiple buildings and outdoor areas.

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