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Evaluation of Intrusion Sensors and Video Assessment in Areas of Restricted Passage

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Evaluation of Intrusion Sensors and Video Assessment in Areas of Restricted Passage

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ABSTRACT

This report discusses an evaluation of intrusion sensors and video assessment in areas of restricted passage. The discussion focuses on applications of sensors and video assessment in suspended ceilings and air ducts. It also includes current and proposed requirements for intrusion detection and assessment. Detection and nuisance alarm characteristics of selected sensors as well as assessment capabilities of low-cost board cameras were included in the evaluation.

Acknowledgments

The authors of this report wish to acknowledge Martin Sandoval, Jose Vigil, and Tim Malone, all of Department 5849, for their input and assistance in the installation, testing, and data collection for the sensors and assessment equipment evaluated as part of this project.

References

Some of the data used in this report was obtained from previously documented reports. Information from these reports that was directly relevant to areas of restricted passage was included as part of this report to encompass known testing in areas of restricted passages. Some information from each of the following reports was referenced or included as part of this report.

Type: Internal Lab Report
Title: ***Restricted Passage Areas***
Date: October 1995
Author(s): Charles Ringler, Chris Hoover, Tim Malone

Type: Internal Lab Report
Title: ***Performance Testing Procedures Restricted Passage Areas***
Date: June 1995
Author(s): Charles Ringler, Chris Hoover

Type: Sand Report -- SAND96-0514
Title: ***Evaluations of Fiber Optic Sensors for Interior Applications***
Date: October 1995
Author(s): Tim Malone, Martin Sandoval

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1. Introduction

The purpose of the Restricted Passage Task was to develop, demonstrate, and evaluate sensor and assessment technologies for use in areas of restricted passage throughout the DOE Complex. A part of this task included defining sensor and assessment system requirements and test procedures for specified areas of restricted passage.

This report will focus primarily on test results of sensors and assessment equipment evaluated for use in areas of restricted passages. Relevant portions of previously written lab reports on requirements and test procedures will be included in this report for the purpose of clarity and completeness. The titles of these lab reports are: *Restricted Passage Areas (October 1994)* and *Performance Testing Procedures Restricted Passage Areas (June 1995).*

1.1 Areas of Restricted Passage

An *area of restrictive passage* shall be defined as any service area, such as suspended ceilings, raised floors, air ducts, tunnels used for conduit or wire runs, or any other opening greater than 96 square inches that could provide a path between a protected and nonprotected area. Restricted passage areas are normally accessed only by authorized maintenance personnel and are normally not under constant surveillance.

1.1.1 Tunnels

Areas of restricted passage defined as tunnels are usually controlled areas such as wire runs between buildings or maintenance and equipment rooms that are usually reserved for access by authorized personnel. Access to these areas is usually controlled by locks on doors or hatches and may or may not have sensors on these access openings. Defining sensor and assessment systems for these areas would be similar to protecting a room against intrusion by adding proven sensor technologies. The extent of protection added to a tunnel should equal or exceed the level of protection of the protected area that it borders. Adding intrusion detection and assessment to tunnels is similar to protecting a room indoors (re-evaluating technologies to protect this type of area was not conducted as part of this task). Figure 1 shows an example of what may be considered a tunnel defined as an area of restricted passage.

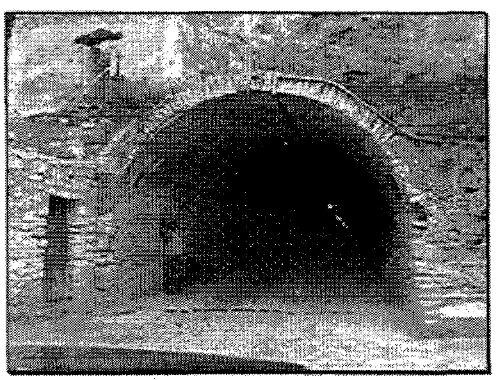


Figure 1. Example of a Tunnel as an Area of Restricted Passage

1.1.2 Air Ducts

Heating and air conditioning ducts that run between a protected and nonprotected area and that are of sufficient size to permit a person or object going from one area to another was considered an area of restricted passage. For these type of areas, intrusion sensors with assessment would be necessary to maintain the security level of the protected area. A primary focus for this report was evaluating intrusion sensors and assessment capabilities in air duct applications. Figure 2 shows an example of an air duct defined as an area of restricted passage.

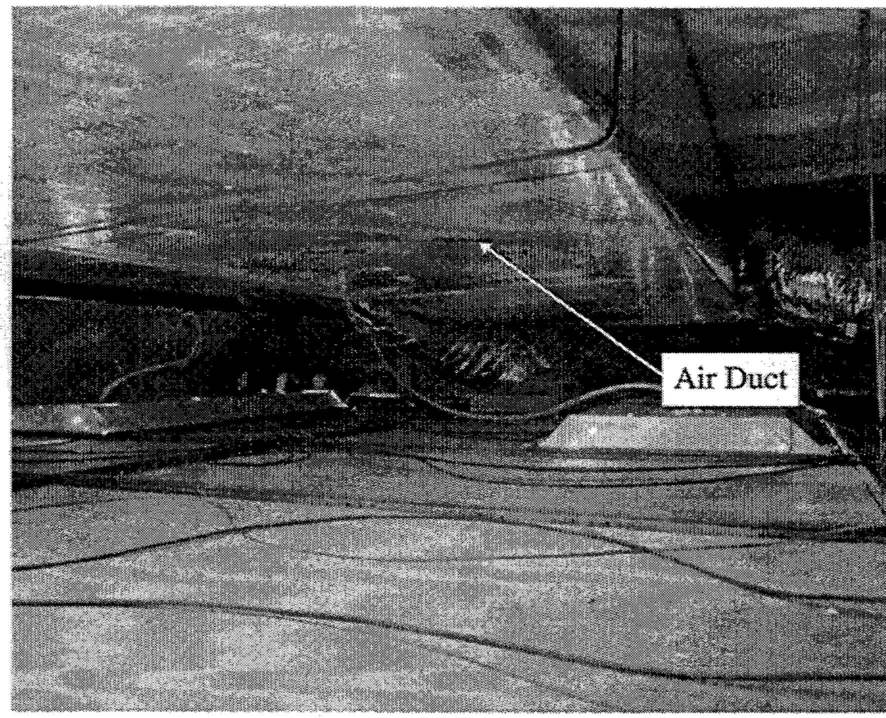
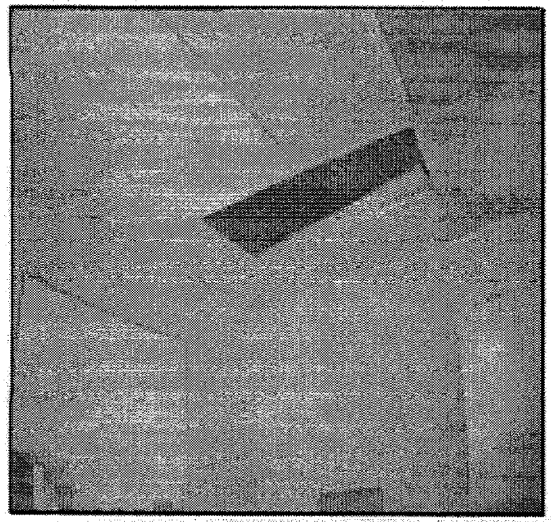


Figure 2. Example of an Air Duct as an Area of Restricted Passage

1.1.3 Suspended or False Ceiling

A protected area with a false or suspended ceiling is an area of restricted passage where an adversary could possibly hide himself, or an object, while the protected area is in access and then later enter undetected into the area. For this type of area intrusion sensors and assessment were considered a requirement. This report will present the results of testing several types of intrusion sensors and means of assessment in protected areas with suspended ceilings. Figure 3 shows an example of an area with a false suspended ceiling.



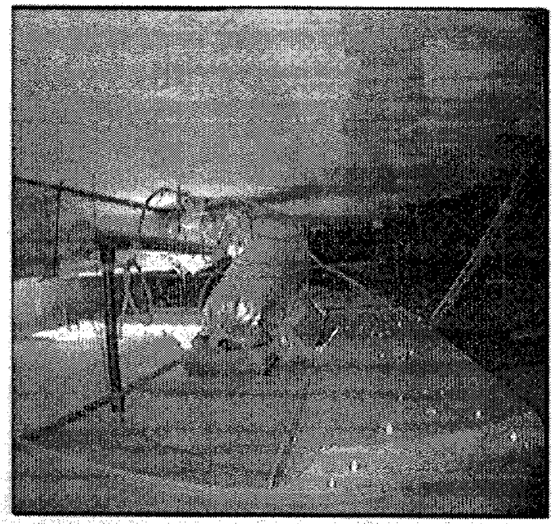


Figure 3. Example of a Suspended Ceiling as an Area of Restricted Passage

1.1.4 Raised or False Floors

A protected area with a raised or false floor may be a restricted passage location, such as trailers set up as mobile offices containing sensitive information or computer rooms constructed with an area below the floor for convenient cable runs. Either of these applications may have intrusion systems inside the room but not have sensors protecting the area between the raised floor and the room. Though the number of areas of this type is probably limited across the DOE Complex, they must also be protected if there is an undetected path for an adversary to hide or place objects that could breach the security measures associated with that area. Placing sensors and assessment systems in these areas would be similar to protecting restricted passage areas such as suspended ceilings or air ducts, depending on size. As a result, a sensor and assessment system evaluation was not conducted in areas with raised floors. Figure 4 shows an example of an a movable office complex with a raised floor.

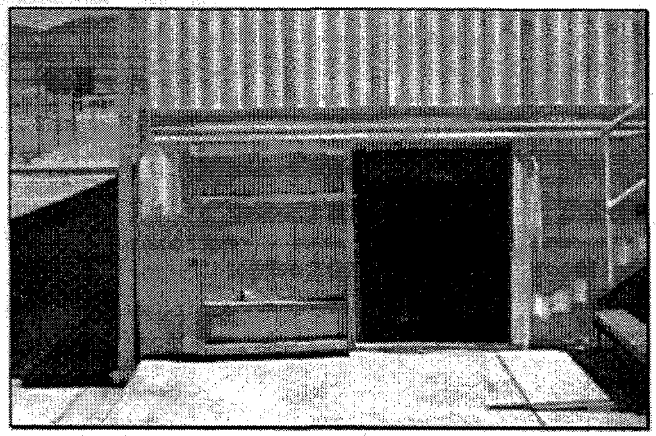


Figure 4. Example of a Raised Floor as an Area of Restricted Passage

2. Background

As DOE facilities began to tighten security and look for ways to use technology to reduce threats and lifecycle costs across the DOE Complex, the need arose for more secure and cost-efficient ways to address security concerns associated with areas of restricted passage. The goal of the restricted passage task was to advance the state-of-the-art in sensor and assessment technologies for use in areas of restricted passage. The technologies should reduce lifecycle costs and threats to the DOE Complex. Objectives of the task were to develop, evaluate, and demonstrate technologies for protection of tunnels, service areas, suspended ceilings, raised floors, and air ducts.

2.1 User Needs

Sites that are being remodeled or would like to upgrade their security against potential insider threats using technology in a cost-efficient manner have requested information on applicable sensor and assessment technologies for use in areas of restricted passage.

2.2 Reduced Threat and Lifecycle Costs

The existing requirements that pertain to restrictive passage areas are directed primarily towards the outsider (i.e., bars or wire mesh on openings leading to nonsecured areas) and do not incorporate real time intrusion detection. Currently, a roving security patrol visually inspects these openings for possible intrusions. To increase the level of security against the outsider and the insider, additional security measures should be implemented.

As a general example, an insider could be authorized in an area where there are false ceilings and/or ducts. This insider could either hide in one of these areas, hide equipment or unauthorized material, or use a restricted passage area to gain access to an area in which he is not authorized. A roving patrol may or may not notice a ceiling or duct penetration which would create a need for an intrusion detection and assessment system in these restricted passage areas.

Any point in a protected facility (either high- or low-level security) with restricted passage areas that provide an intrusion path for an adversary or place to hide an object (e.g., ease dropping device, bomb) without immediate detection would provide a potential security or sabotage threat to that facility.

Installation of an intrusion detection and assessment system in restrictive passage areas would reduce the threat of an insider gaining undetected access to the area. Such a system would also reduce the threat of an outsider gaining undetected access should the initial point of protection (physical barrier) be breached. In addition, it would enable the security force to know immediately where an intrusion attempt has been and provide video assessment for each alarm.

Furthermore, an intrusion detection and assessment system in restrictive passage areas could reduce lifecycle costs to the DOE Complex by potentially reducing the time required for a patrol to check each restricted passage area for penetration (i.e., ceiling tiles, service area doors, duct and tunnel openings). The system would provide early detection, alarm location, and video assessment that would decrease the probability of an adversary successfully accomplishing acts of theft or sabotage.

3. Test Requirements -- Detection and Assessment

DOE orders were reviewed to determine what existing requirements pertained to areas of restricted passage. Additional requirements were suggested to cover and clarify those concerns pertaining to intrusion detection and assessment in areas of restricted passages. The results of the review of existing and suggested new requirements were documented in the lab report titled *Restricted Passage Areas (October 1994).*

4. Evaluation Testing

Evaluation test plans were developed based on the established requirements for areas of restricted passages. These test plans used for evaluation testing were based on test procedures documented in a lab report titled *Performance Testing Procedures - Restricted Passage Areas (June 1995).* For clarity and completeness, portions of the written performance test procedures that pertained to testing conducted in this evaluation will be summarized and included in this section of the report.

4.1 Test Areas and Data Collection

The evaluation test results presented in this report are based on intrusion sensors and assessment systems evaluated in two different applications or areas of restricted passage.

4.1.1 Suspended Ceiling Application

Testing on sensor and assessment systems for use in a suspended ceiling application was conducted in a room within a movable office complex that had both raised floors and a suspended ceiling. The room was located next to a door exiting the building that was a high activity location. The room also had two windows that allowed day and night changes to be a factor in the room's lighting conditions. Data was collected by the Sandia-developed Nuisance Alarm Data System (NADS).

A total of six sensor types were evaluated in a suspended ceiling application. Assessment in the suspended ceiling application was performed by video from four separate cameras. Intrusion sensor manufacturers and types evaluated are listed in Table 1. Assessment equipment used during the evaluation is discussed in Section 7.

Sensor Type	Model #	Manufacturer
Fiber Optic	M105	Fiber SenSys, Incorporated
Wireless PIR	C-206 Sharpshooter	Inovonics Corporation
Laser Curtain	L-180 A.I.R. Shield	Millennium Sensor Corporation
Wireless Movement	WATCH	Inovonics Corporation
Video Motion Detector	VMD-1000	Digispec Corporation

Table 1. Sensors Evaluated in Suspended Ceilings

Figure 5 shows a basic connection diagram of sensors, video assessment, and data collection equipment used in the suspended ceiling application.

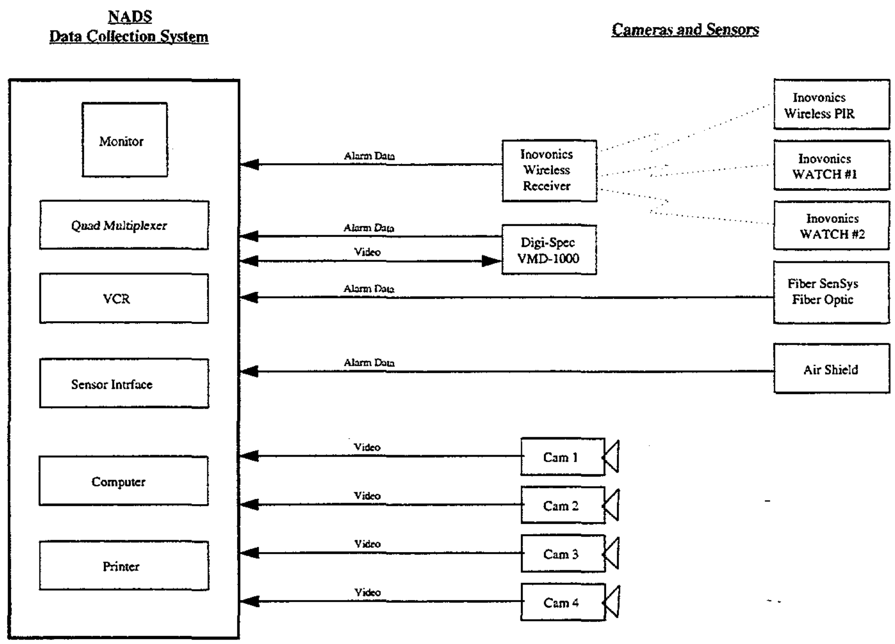


Figure 5. Suspended Ceiling Test Setup

4.1.2 Air Duct Application

In order to facilitate testing, an air duct application was simulated in a laboratory environment. Three different sizes and layouts of air ducts were purchased and assembled in a controlled laboratory environment. The sizes selected were a 12-inch square duct built in an "L" configuration, an 18-inch square duct built in a "T" configuration, and a 24-inch square duct built in a straight line configuration. All ductwork was built and assembled according to industry SMANKA standards that pertain to constructing the ductwork using the proper gauge of sheet metal for the size and dimensions of the ductwork.

The test area in which the ductwork was assembled and the sensors and assessment systems evaluated were located in a test bunker at Sandia's Video Test Laboratory. The test area allowed testing under controlled lighting and environmental conditions. Figure 6 shows an overall view of the assembled ductwork in the bunker test area.

Figure 6. Assembled Air Duct in Test Area

Several types of sensors and cameras were tested as part of the evaluation for the air duct application. Table 2 is a list of the sensors tested, including model numbers and manufacturers. Section 7 discusses the assessment equipment used in the evaluation.

Sensor	Model #	Manufacturer
Barrier Bar Pressure Switch	BB-1XL	Sentrol, Inc.
Barrier Bar Mercury Tilt	BB-2	Sentrol, Inc.
Fiber Optic	M105	Fiber SenSys
Photoelectric, Diffuse Sensing	FZDM35R7301	Baumer Electric
Photoelectric, Diffuse w/suppression	FHDK50R7001	Baumer Electric
Passive Infra Red (PIR)	Sharpshooter	Sentrol, Inc.
Passive Infra Red (PIR)	Apollo S	Racal-Guardall
Stress Sensor	Pulsor	Sure Action Inc.
Strain Gauge	M21L -- Microcell	Kistler-Morse
Ultrasonic Proximity, dual transducer	RU100-CP40-AP6X2	Turck Inc.
Ultrasonic Proximity, single transducer	UNOK30P1102	Baumer Electric
Video Motion Detection	DVMD-32	Gyyr

Table 2. Sensors Evaluated in Air Ducts

Figure 7 shows the basic connection diagram for sensors, video assessment and data collection equipment used in air duct applications. As with the suspended ceiling application, a NADS data collection system was set up to monitor intrusion and nuisance alarm data. An Adpro ten channel frame storage unit was used to assist in data collection from the ten cameras used for assessment purposes.

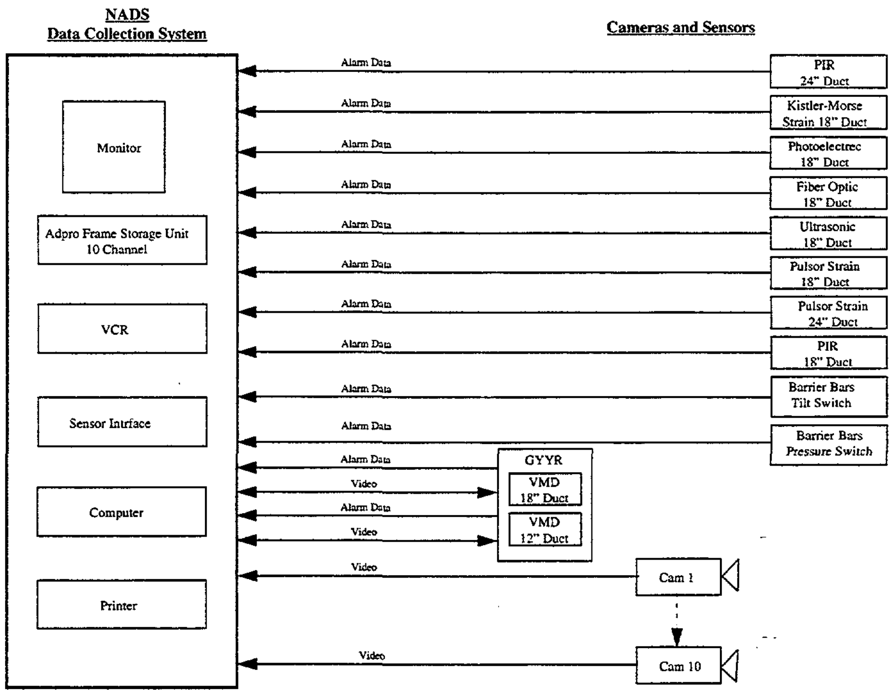


Figure 7. Air Duct Test Setup

4.2 Intrusion Sensor Test Plans

Intrusion sensor testing included detection tests as well as evaluating the sensor's ability to reject real and simulated nuisance alarms. Detection testing verified an intrusion sensor's ability to detect an intruder or object entering an area of restricted passage equipped with intrusion detection sensors. Detection testing checked for dead spots in a sensor's detection zone to confirm the sensor's correct sensitivity and alignment.

Nuisance alarm testing consisted of monitoring a sensor for any alarms not caused by an actual intrusion attempt. Nuisance alarm testing included monitoring each sensor in a controlled environment as well as in active areas where actual or simulated nuisance alarm sources were a regular occurrence.

4.2.1 Detection Tests

Detection testing for the evaluation tests was based on the performance testing procedures developed for areas of restricted passage. Portions of the test procedures relevant to this evaluation test will be presented in this report. The test procedures for detection testing were developed based on the proposed new requirements for areas of restricted passage listed in section 3.2.

Detection testing was performed for evaluating two levels of threat. The first level was against a human intruder entering the protected area of restricted passage. A higher threat level was to detect a 6-inch square test object being placed or passed through a protected area. Figure 8 shows a picture of the 6-inch square test object used for the evaluation tests.

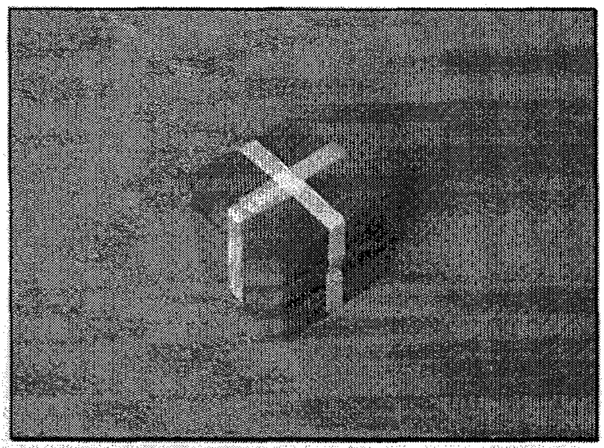


Figure 8. Test Object Used for Evaluation Testing

4.2.1.1 Suspended Ceiling Test Procedure

The first step for detection testing in suspended ceiling applications involved defining the area or number of ceiling tiles included in a sensor's detection zone. The defined area was tested against intrusion, first with a 6-inch square test object and then, if unsuccessful, by an intrusion attempt by a person.

Each ceiling tile in an evaluated sensor's detection zone was tested at four locations to ensure proper sensitivity settings. Figure 9 illustrates the locations of the test points on each tile.

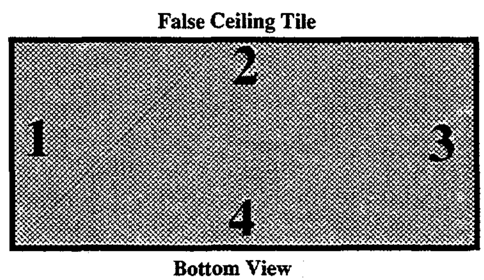


Figure 9. Suspended Ceiling Tile Test Points

Note: All ceiling tile clips were removed for the duration of evaluation testing of sensors in suspended ceiling applications.

At each of the four illustrated test points in Figure 9, the tile was lifted at approximately 1 inch per second, just enough to place the 6-inch square object into the area between the false and true ceiling and then return the tile to its original position. If the test object could be inserted into the ceiling at any of the test points, the detection test was reported as a missed detection for the object test and then a similar test was performed to determine if the sensor detected a person attempting to enter into the space above the suspended ceiling. A person using a step ladder would carefully remove the ceiling tile being tested and place his head and shoulders above the suspended ceiling. If the sensor could not detect a person's head and shoulders in its detection zone, the detection test for a person was reported as a missed detection.

4.2.1.2 Air Duct Test Procedure

The air duct detection test procedure was similar to the suspended ceiling test procedure in that detection tests were performed to detect either a person and/or a 6-inch square test object passing through a sensor's defined detection zone. The first step was to define the detection zone of the sensor being tested.

Once a sensor's detection zone was defined, detection tests for an intruder were conducted by a person crawling through the sensor's detection zone at approximately 1 inch per second.

This process was also repeated with the 6-inch square test object being pushed, pulled or thrown through a sensor's detection zone to determine the sensor's detection characteristics. The test object was passed through each sensor's detection zone, at different locations, until all possible detection paths through the air duct were covered. The test object was pushed or pulled through a sensor's detection zone at approximately 1 inch per second. Where possible, the test object was also thrown through the sensor's detection zone to determine if the sensor was susceptible to fast moving objects. Figure 10 illustrates the test locations in an air duct for a test object.

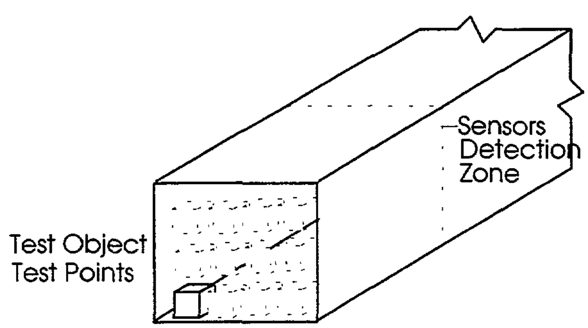


Figure 10. Air Duct Sensor Test Locations

4.2.2 Nuisance Alarm Tests

Once a sensor's detection characteristics were determined to be the best possible, each sensor was monitored for nuisance alarms. Nuisance alarm data was collected in environments where there was little external activity as well as when personnel or potential nuisance alarm sources were present in the area.

Examples of nuisance alarms that the sensors in the suspended ceiling application were subjected to included the normal closing and opening of nearby doors, doors slamming, people banging on bordering walls, turning on and off lights in the room, and changing light conditions due to the blinds on the windows being opened and closed.

Examples of nuisance alarms that the sensors in the air duct applications were subjected to included lights being turned on and off in the bunker, the bunker door being opened and closed causing light changes, people walking near the openings of the air duct, vibrations from banging on the side of the air duct, temperature changes in the bunker, air flow down the air duct, and vibrations caused by starting and stopping of fans connected to the air ducts.

4.3 Video Assessment Test Plans

Video assessment test plans evaluated the effectiveness of low cost cameras for alarm assessment in areas of restricted passage.

The issues covered as part of assessment testing included the ability of the camera or combination of cameras to effectively cover a sensor's detection zone and determine the cause of an alarm. Factors such as onboard lighting, or the ability to see in low light levels, were considered an important feature considering the locations for which the cameras would be required to provide assessment. The use of separate LED panels for lighting was evaluated along with cameras that provided their own onboard LEDs for light.

5. Evaluation Testing in Suspended Ceilings

Several separate sensors and assessment configurations were evaluated for use in suspended ceiling applications. The results for each of the sensors and the camera and lighting systems evaluated will be presented in sections pertaining to each individual piece of equipment.

An overall graphical illustration of the location of the sensors and cameras evaluated for suspended ceiling applications are shown in Figure 11. Sensor detection zones will be shown in the section devoted to each individual sensor. Ceiling tile, light, and vent locations in the test area are also shown in Figure 11. The overall room dimensions were 24 feet x 12 feet; the lights were 2 feet x 4 feet; the vents were 2-feet square. The tiles in the room were 2-feet square and 2 feet x 4 feet.

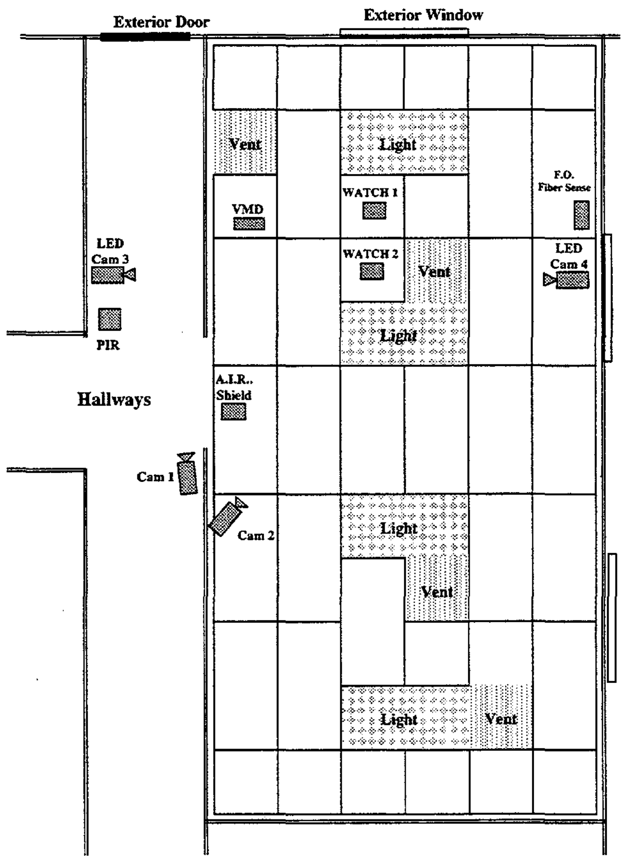
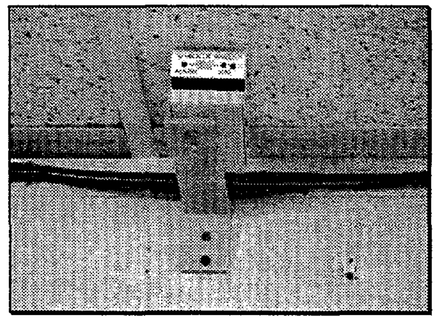


Figure 11. Sensor and Camera Locations in Suspended Ceiling Tests

The sensor locations, shown in Figure 11, are approximate locations of the main sensor processor, not the sensor's detection zone. Cam 1 was installed below the ceiling tiles to view the activity at the exterior door; Cam 2 was installed below the ceiling tiles to view the activity near the ceiling in the test room; Cam 3 and Cam 4 were cameras with onboard LEDs and were installed above the suspended ceiling to view any unauthorized activity.

5.1 A.I.R. Shield

Millennium Sensor Corporation's Model L-180 A.I.R Shield uses proprietary active infra-red technology to define a precise invisible intrusion boundary defined by reflective tape. This sensor projects a laser beam to a strip of reflective tape using a rotating mirror. The tape reflects the light signal back to the mirror and is received by the sensor unit. It forms a sensored plane, about 1/4 inch thick, defined by the reflective tape. Features, specifications, and cost of the A.I.R. Shield sensor, as listed by the manufacturer, are as follows:



Features

- The A.I.R. Shield provides continuous planar barrier coverage of a protected area.
- Detection is independent of object warmth or speed.
- Detection range is up to 30 feet.
- Barrier plane boundaries are asymmetrically adjustable, up to 180 degrees on either side of the sensor.
- Sensor may be mounted in any position or orientation.
- Beams are reflected from adhesive-backed reflective tape, 1 to 2 inches wide.
- Reflective surfaces such as mirrors introduced into the barrier plane are detected and alarmed.
- One step calibration by a single button initiates microprocessor alignment and calibration, which is remembered during power off condition.
- Output is in alarm condition during calibration to prevent unauthorized re-calibration.

Specifications

- Laser Output CLASS 1 (Eye Safe)
- Wavelength: 780 nm
- Alarm Update Rate: < 100 milliseconds
- Optical Power: <3 mW
- D.C. Power: +12 VDC @ 200 milliamps
- Size: approx. 1.7" x 2.2" x 4.7"
- Shield angle: (adjustable) 0 to 180 degrees
- Standard Form C SPDT Output

Cost

A starter kit # L-180SK that includes a L-180 sensor, an alignment tool, and 15 feet of reflective tape cost $380. An additional 150-foot roll of reflective tape is approximately $30, and individual L-180 sensors are $350.

Application

The A.I.R. Shield L-180 sensor was installed to form a detection barrier that would detect an object or person trying to access the area above a suspended ceiling. The sensor was installed below the suspended ceiling as close as possible to the ceiling tiles without the sprinkler heads from the fire alarm sprinklers blocking the beam. The barrier plane was established by installing 2-inch thick reflective tape on two walls of the protected room. The maximum area a single sensor can cover is defined by the length and configuration of the reflective tape. The maximum length in any configuration of reflective tape is 30 feet. Figure 12 shows the detection zone used for evaluation testing of the A.I.R. Shield sensor. The total length of reflective tape used in evaluation testing was 20 feet.

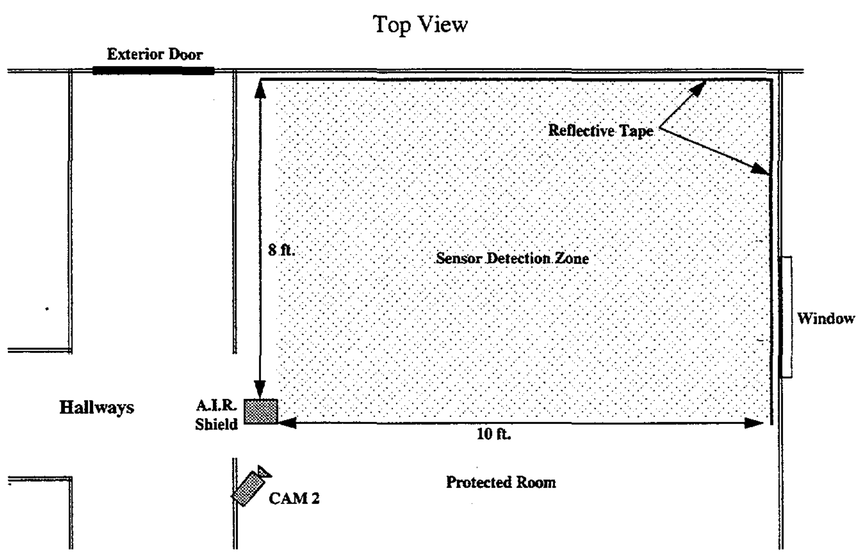


Figure 12. A.I.R. Shield Detection Zone

5.1.1 Detection Tests

Detection tests for the A.I.R. Shield sensor were conducted at a minimum of four locations on each ceiling tile located in the sensor's detection zone. Table 3 shows the results of the detection testing conducted on the A.I.R. Shield sensor. The tests were run multiple times to check that the sensitivity level of the sensor did not vary over time.

# of Tests	# of Detections	# of Missed Detections	Comments
127	127	0	Very high detection rate

Table 3. A.I.R. Shield Detection Test Results

As the test results show, the A.I.R. Shield has a very good detection capability. The majority of tests were done by breaking the beam at different locations with a small (1-inch diameter) test pole. This shows that the A.I.R. Shield sensor exceeds the detection criteria for a minimum object size of 6 square inches.

5.1.2 Nuisance Alarm Tests

Nuisance alarm testing for the A.I.R. Shield consisted of monitoring over a period of time for any nuisance or false alarms. Table 4 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
1,114	6	Door Slamming	Near mounting location of sensor
	34	Insect (Moth)	Very hard to see on assessment
	229	Unknown	Suspected alarms from insects

Table 4. Air Shield Nuisance Alarm Test Results

As the test results show, the A.I.R. Shield sensor experienced nuisance alarms due to doors opening and closing near the mounted sensor. This shows how important a stable mounting surface is to this type of sensor. The sensor was tested in a room located in a movable trailer that did not have sturdy walls for mounting.

The other recorded source of nuisance alarms was due to a moth flying through the sensor's beam. This was real hard to see on the assessment tapes due to the small size of the insect. It is suspected that the high number of nuisance alarms recorded as unknown was for the most part caused by flying insects that could not be seen on the assessment tape. This conclusion is based on the fact that most nights that had large numbers of nuisance alarms, also had several alarms recorded as moths. Most of these unknown alarms were grouped together over the same period of time (within a few hours of each other). For instance, a 6-hour reporting period recorded 83 unknown alarms, and the next several days reported only 6 unknown alarms.

The manufacturer stated that objects that pass through the Air Shield's detection zone in less than 100 milliseconds are ignored to limit nuisance alarms caused by flying insects. Evaluation testing revealed that this time limit should be increased to limit the number of alarms caused by insects and vibrations from doors or wall movement.

5.1.3 Installation and Maintenance Issues

Installation of the A.I.R. Shield sensor required mounting to a solid wall, as close as possible to the ceiling and wall. Alignment of the sensor was accomplished with a beam finder included with the sensor starter kit purchased for the evaluation. The beam finder allowed the user to detect where the laser beam was and allowed proper positioning of the reflective tape.

Installation of the sensor and reflective tape for the test area required approximately 2 hours, once the installation instructions were understood and the detection zone defined.

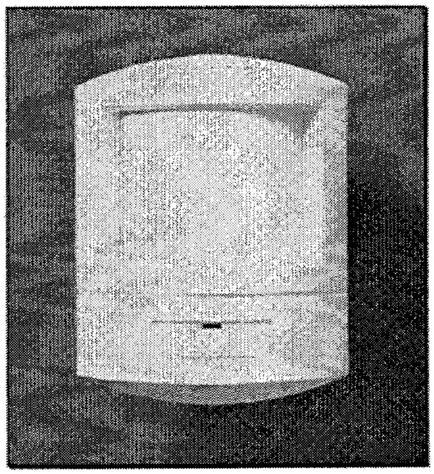
Maintenance issues associated with the A.I.R. Shield would be, for the most part, dependent on the environment. In order to maintain low nuisance alarm rates, insects in the area must be kept to a minimum. A good bond between the reflective tape and the wall must be maintained in order for the sensor to stay calibrated. Also, if the wall in which the sensor is mounted is not of solid construction and moves easily a higher number of nuisance alarms could be generated.

5.1.4 Vulnerabilities

Reflective tape was placed around a small object and inserted into the detection zone of the A.I.R. Shield. It was detected at all tested locations except right next to the reflective tape on the far wall. The system could possibly be defeated by this method if an entire object was covered with reflective tape, the object size was small, and the object was inserted at the farthest edge of the sensor's detection zone near the reflective tape. An alarm was generated when an object of any size was covered with reflective tape and inserted into any other location other than at the edge of the detection zone.

If access to the edges of the sensor's detection zone can be obtained, a flat, thin object covered with reflective tape (side of cardboard box) can be slowly introduced at an angle into the detection zone and actually change the area the detection zone covers. This defeat method required some experimentation but is a defeat possibility.

5.2 Wireless PIR



Inovonics C-206 wireless passive infrared detector is a low-current PIR that is highly sensitive to moving infrared sources and features increased immunity to RFI, vibration, static, lighting, temperature changes, and other false alarm sources. The detector utilizes a dual pyroelectric sensor with jumper-selectable one or two zone detection. It also features a sequence processor that combines bi-directional pulse counting and event verification. An opaque, frosted-white, visible-light filtering fresnel lens focuses the infrared energy on the pyroelectric sensor while reducing false alarms from stray light sources. The unit features five interchangeable lenses: standard, long range, extra wide angle, pet alley, and curtain. The unit is powered by a 3.5 volt lithium battery and incorporates a wireless transmitter compatible with Inovonics' line of wireless sensors.

Cost
The C-206 is a wireless PIR sensor with a dealer cost of $110. Inovonics has multiple types of receivers with different features and costs. The receiver used for monitoring the C-206 PIR was the C-703 16 channel receiver with LED panel that costs $390.

Application
The C-206 wireless PIR was installed above the suspended ceiling utilizing the curtain lens configuration. The PIR curtain was set up to detect a person entering its detection zone. The C-206 PIR sensor was mounted on its side to get the curtain beam to protect as many ceiling tiles as possible. It was difficult to have a single sensor cover a large area

due to the amount of objects present above the suspended ceiling. These objects or obstructions blocked sections of the PIR curtain beam, which created dead zones (areas of no detection).

Figure 13 shows the detection zone and location of the C-206 as it was installed for test and evaluation. The detection zone was determined by running detection tests. As can be seen, several PIR sensors may be necessary to completely cover all locations above a suspended ceiling. For evaluation purposes, only one sensor was installed for determining detection and nuisance alarm characteristics. The detection zone shown was the area that was used for detection tests although the actual curtain sensor may have partially covered other ceiling tiles not shown in the detection zone pattern. This was done due to the probability that detection coverage for the ceiling tiles not covered by this PIR's detection zone would be better covered by an additional PIR sensor.

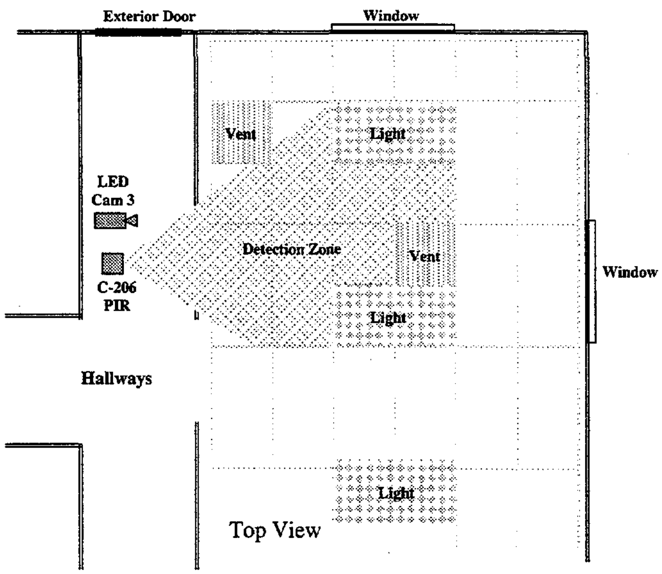


Figure 13. C-206 PIR Detection Zone

5.2.1 Detection Tests

Detection testing for the C-206 wireless PIR was conducted by a person on a step ladder lifting each ceiling tile in the sensor's detection zone and placing his head and shoulders above the suspended ceiling. If the sensor alarmed, it was recorded as a detection; if it did not alarm, it was recorded as a missed detection. Detection tests were conducted several times in the same locations to determine if the sensor's sensitivity levels changed throughout the test period. Detection testing with the test object was not performed because the PIR could not detect the test object (the object too closely matched the background temperature). Table 5 shows the C-206 PIRs detection test results.

# of Tests	# of Detections	# of Missed Detections	Comments
28	28	0	No object detection testing

Table 5. C-206 PIR Detection Test Results

As the detection test results show, the PIR mounted above the ceiling detected all attempts of a person entering the area through the ceiling tiles. Some locations were more sensitive than others, but all areas in the detection zone did alarm when a person's head and shoulders were above the suspended ceiling. Some areas other than the ones included in the sensor's detection zone (illustrated in Figure 13) would detect intrusions, but these were not included as part of the sensor's defined detection zone due to unreliable detection at those locations.

5.2.2 Nuisance Alarm Tests

Nuisance alarm testing for the C-206 PIR consisted of monitoring over a period of time for any nuisance or false alarms. Table 6 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
1,114	1	Power Glitch	Expected to cause an alarm

Table 6. C-206 PIR Nuisance Alarm Test Results

As the nuisance alarm test results show, the wireless PIR sensor evaluated did not have nuisance alarms other than a single alarm due to a power glitch in the receiver's AC line.

5.2.3 Installation and Maintenance Issues

Using a wireless PIR minimized the installation time for the sensor because hardwire cabling was not necessary. Multiple PIR sensors would be required to protect most restricted passage areas above suspended ceilings due to blind spots created by vents and other obstructions that block or interfere with a PIR's detection pattern. For this reason, the setup time could be time consuming in order to properly position each PIR to achieve full area coverage.

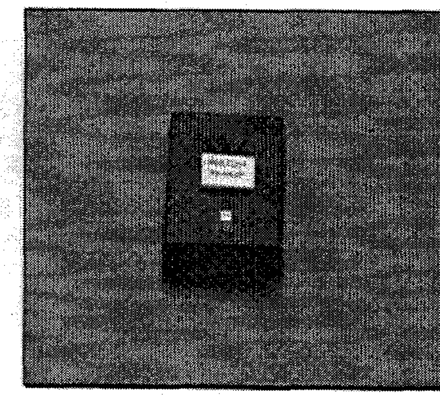
Over time, dust may accumulate on the lens of a PIR sensor when installed above a suspended ceiling. This could cause the sensor's detection pattern to change or cause a loss in sensitivity. This would be determined by periodic performance testing on each sensor. The actual amount of maintenance due to dust accumulating on the lens of a PIR would be dependent on the area of installation.

An installation issue with installing any equipment, including PIR sensors, above a suspended ceiling would be in meeting safety and fire code regulations that may apply to the area. An example is that the equipment may have to be plenum rated or housed in special enclosures to meet safety codes. These issues were not addressed as part of this evaluation.

5.2.4 Vulnerabilities

Vulnerabilities associated with using a wireless PIR as an intrusion detection sensor has to do with the wireless communication link as well as characteristics of PIR sensors. A wireless link is vulnerable to signal jamming, although the wireless PIR evaluated did incorporate state-of-health checks to minimize successful undetected jamming attempts. All PIR sensors are vulnerable to intruders who can closely match the background temperature.

5.3 WATCH



The WATCH sensor is a low power wireless sensor that transmits alarm information to a receiver whenever it is moved. The sensor was originally developed by Sandia National Labs and now is manufactured by Inovonics Corporation. The WATCH sensor uses the same frequency as the C-206 PIR described in the previous section so the same receiver was used to monitor both sensors. The WATCH sensor is a portable battery powered device containing a transmitter, an array of jitter switches to detect movement, and optional software for authentication of the transmitted signal, if required. The battery will last for about a year under normal operating conditions. The sensor reports state-of-health, low battery, and alarm messages back to the receiver and operates in the 900 MHz frequency range.

<u>Cost</u>
A WATCH transmitter will cost approximately $150 when purchased in quantities from Inovonics Corporation. As with the wireless PIR, the WATCH sensor can be used with a variety of receivers manufactured by Inovonics. The receiver used for the evaluation was the C-703, 16-channel receiver with LED panel that costs $390.

<u>Application</u>
Two WATCH sensors were evaluated under the suspended ceiling application. In order to maximize the coverage provided by a single WATCH sensor, each of the two sensors used was attached to a rigid piece of lightweight rigid material. This section of rigid material was placed above the suspended ceiling, across a section of tiles in order to detect someone attempting to move the tiles to gain access to the area above the suspended ceiling.

Figure 14 shows the coverage provided by the two WATCH sensors used for evaluation testing. It is possible that even more area could be covered by attaching more lightweight, rigid material together to form a grid covering more tiles. Whenever a ceiling tile was moved, it would cause the rigid piece of material to move which caused the attached WATCH sensor to alarm.

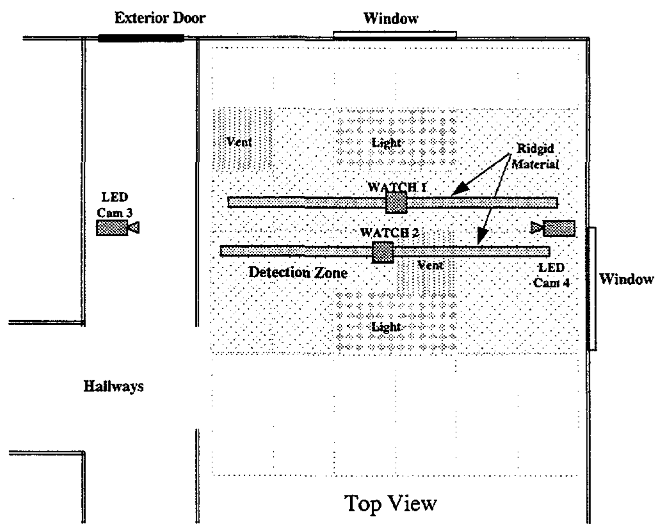


Figure 14. WATCH Sensor's Detection Zone

5.3.1 Detection Tests

Detection testing on WATCH sensors in suspended ceiling applications consisted of attempting to insert the 6-inch square test object into the area above the suspended ceiling covered by the WATCH sensor's detection zone. Each ceiling tile in the detection zone was tested according to the test procedures for suspended ceilings. Multiple detection tests were run to determine the detection characteristics of the WATCH sensors. Each of the WATCH sensors (WATCH 1 and WATCH 2) had their sensitivity set at the most sensitive level allowed. Table 7 shows the results of detection testing for each of the WATCH sensors evaluated.

# of Tests	# of Detections	# of Missed Detections	Sensor
28	28	0	WATCH 1
28	25	3	WATCH 2

Table 7. WATCH Sensor Detection Test Results

As the detection test results show, WATCH 1 sensor did not miss any intrusion attempts. WATCH 2 sensor missed three detections with all three being in the same location near the end of the sensor's detection zone. The tiles located at the end of the rigid material, of which the WATCH sensors were attached, were the least sensitive tiles. Careful movement of the tiles would allow the test object to be inserted above the suspended ceiling without detection. This could possibly be minimized by decreasing the size of the detection zone covered by a single WATCH sensor.

5.3.2 Nuisance Alarm Tests

Nuisance alarm testing for the WATCH sensors consisted of monitoring over a period of time for any nuisance or false alarms. Table 8 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Sensor
1,114	127	Door	WATCH 1
	77	Unknown	WATCH 1
	8	Door	WATCH 2
	5	Unknown	WATCH 2

Table 8. WATCH Nuisance Alarm Test Results

As the nuisance alarm test results reveal, WATCH sensors are susceptible to vibrations from slamming doors or anything that causes the ceiling tiles and, therefore, the WATCH sensor to vibrate. Sensitivity levels could be lowered on the sensors to lower their susceptibility to vibrations, although this would mean smaller detection zones due to decreased sensitivity levels. The results also show a substantial difference in the number of nuisance alarms from WATCH 1 to WATCH 2. The sensitivity of a WATCH sensor is somewhat dependent on the angle the WATCH sensor is mounted. WATCH 1 required additional adjustments to compensate for the numerous nuisance alarms.

5.3.3 Installation and Maintenance Issues

The WATCH sensors used for evaluation testing required little installation time. Two different types of lightweight rigid material were used for the test with little differences seen in their performance. It is important to keep the weight of the material as light as possible so that the weight added to the suspended ceiling tiles is kept to a minimum. It is important that any material added to the area above the suspended ceiling meets all safety and fire requirements related to the area above the suspended ceiling.

An installation issue for WATCH sensors is that all ceiling tiles in a room must be protected which may require attaching several pieces of rigid material together to cover all ceiling tiles. It may require several WATCH sensors to cover a room depending on the size and layout of the room. The WATCH sensors should not be installed in areas that are susceptible to vibration, or the number of nuisance alarms will increase dramatically.

As with any battery powered device, a certain amount of maintenance is required in order to change out batteries and reprogram the sensors.

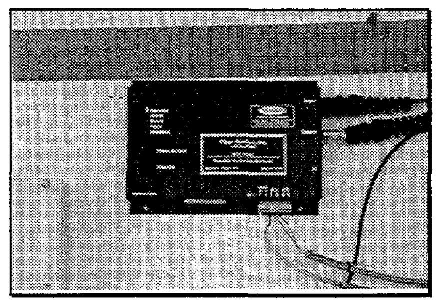
5.3.4 Vulnerabilities

Vulnerabilities associated with the WATCH sensor include attacking the wireless communication link. This vulnerability could be limited by adding the authentication option and closely monitoring the state-health-messages generated by the sensor.

Another vulnerability directly associated with the concept in which the sensor was installed has to do with a person being able to remove a ceiling tile section without moving the rigid material laying across the top of it. This could be done by cutting a hole in the tile or maneuvering the tile in a way to remove it without lifting but by lowering it into the protected room. If this can be done without sufficient vibrations, the WATCH sensor would never alarm and a path into the area would be created that would allow access by an object as well as a person. While this approach may require patience and careful maneuvering, it is a possible way to defeat the WATCH sensor.

If the protected area is placed in access, a knowledgeable person could create a path into the area by moving the WATCH sensors rigid material covering the ceiling tile into a different location. When the system was put back in secure state, the WATCH sensor would not report that it is no longer monitoring the same area. This could be visually verified through the assessment cameras or through other means but should be considered before placing the protected area in access for any extended period of time.

5.4 M105 Fiber Optic Sensor



The Fiber SenSys, Inc., M105 fiber optic sensor is intended for exterior applications such as on fences or buried in gravel. The sensor is also intended for interior applications such as in walls or above suspended ceilings. The M105 consists of a signal processor (shown in picture at right) and a length of fiber optic cable. The system is sensitive to vibration movement and bending and can be ordered in varying cable lengths up to the maximum length of 2000 meters. The unit requires the use of a hand-held calibrator to set up or change parameters and to gain system information useful for trouble shooting. The calibrator consists of an alphanumeric keyboard with a liquid crystal display.

For a more detailed explanation of the setup, specifications, and operational features used during testing, refer to the Sandia lab report titled *SAND96-0514, Evaluations of Fiber Optic Sensors for Interior Applications by Martin W. Sandoval and Timothy P. Malone.* The detection and nuisance alarm test data contained in this report on fiber optic sensors in suspended ceiling application was obtained from the report listed above.

Cost

The M105 fiber optic alarm processing unit cost is $2,035. A MC100 hand-held programmer is required to remotely program the processor and costs $1350 (a PC with manufacturer's software can also program the processor). Cable cost for the fiber optic sensor system varies with length. The cost for two lengths of SC-100 meter connectorized sensing cable is $492; the cost for SC-200 meter cable is $754.

Application

A suspended ceiling in a movable office complex was used to conduct testing for applications in restricted passage areas. The fiber optic sensor cable was installed on the top side of the suspended ceiling and arranged so that two strands of the cable lay across each of the individual ceiling tiles. The alarm processing unit was mounted on the wall 6 inches beneath the false ceiling for easy access.

Figure 15 shows the suspended ceiling layout, fiber optic cable placement, and the tiles used for detection tests. The numbers indicate the tiles tested for detection. These tiles were arbitrarily chosen and represent a sample of all tiles. The tests were conducted in such a manner that the experience of the perpetrator varied from inexperienced with no technical background to a technically capable intruder with detailed knowledge about the fiber optic sensor and how it was installed.

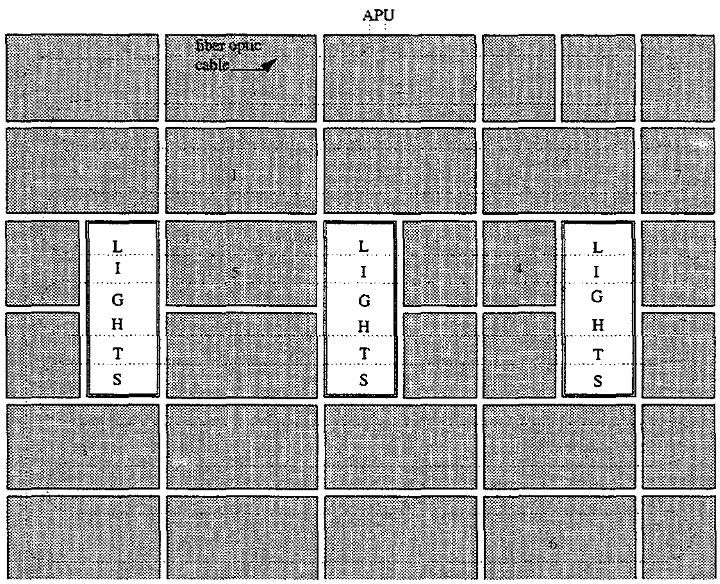


Figure 15. M105 Fiber Optic Sensor Detection Zone

5.4.1 Detection Tests

Detection tests on the fiber optic sensor varied slightly from the test plans detailed in this report. The primary difference was the speed in which the test object was inserted into the detection zone. For the M105 fiber optic sensor, detection tests consisted of slowly lifting each corner and side of individual tiles 6 inches, at a rate of approximately 2 inches per minute instead of the rate of 1 inch per second used for other sensors evaluated. Table 9 shows the test results for detection testing on the M105 fiber optic sensor tested in a suspended ceiling application. Refer to Figure 15 for the location of the tile number tested.

Tile No.	# of Tests	# of Detections	# of Missed Detections	Comments
1	75	73	2	--
2	75	62	13	--
3	75	72	3	--
4	75	74	1	--
5	75	72	3	--
6	75	75	0	--
7	75	30	45	Tile near wall

Table 9. M105 Fiber Optic Detection Test Results

Out of 31 ceiling tiles, 7 were tested for detection of movement. These were randomly located throughout the room. The system detected movement on five of the tiles with a high probability of detection. Two tiles, both located next to a wall, ended up with less sensitivity. For these two tiles, the sides of the tiles adjoining the wall had the least sensitivity. The cable laying loose on the tiles combined with where the cable was positioned on the tile resulted with minimal sensor cable disturbance and, therefore, less sensitivity.

For all the tiles, detection sensitivity deteriorated slightly as more tests were conducted. After repetitious testing, tiles could be moved slightly farther before causing the fiber optic sensor to alarm. This was due to the shifting of the fiber optic cable away from the side of the tile that was being repeatedly lifted.

5.4.2 Nuisance Alarm Tests

Nuisance alarm data collection for the ceiling application concluded with 2324 hours logged. Most of the data collected occurred during evening and night time hours as well as 24-hour monitoring during weekends. Table 10 shows the number of nuisance and unknown alarms recorded during the alarm data collection period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
2,324	30	Door Slamming	Door near mobile office test area
	79	Unknown	See below description for causes

Table 10. M105 Fiber Optic Nuisance Alarm Test Results

The only known nuisance alarms were caused by slamming doors near the room where the testing was being conducted. An exterior door, closed by an automatic door closer, caused vibrations within the movable office complex when the door hit the closed position resulting in nuisance alarms. Interior doors near the test room also caused some nuisance alarms when they were closed.

Unknown alarms are described as alarms that cannot be identified by video tape assessments. Possible sources for the unknown alarms include personnel activity not within view of data collection video camera, high winds, thunder and aircraft, all of which cause vibrations in the structure. During the testing period, nuisance and unknown alarm rates generally increased as time progressed. Reasons for the increase are not known. Possibilities include increased personnel activity, changes to the environment or changes to the sensor itself.

5.4.3 Installation and Maintenance Issues

Installation of fiber optic cable above a suspended ceiling could become labor intensive, depending on the way the fiber optic cable was installed. This evaluation test consisted of simply laying the cable across the ceiling tiles evenly in order to cover all tiles in the protected area with a minimum of two strands of cable. While this installation concept required the minimum installation time, it also had problems associated with the cable moving every time a ceiling tile was lifted for testing, which meant increased test times. The sensitivity for each ceiling tile after testing could not be easily verified due to the cable once again sliding out of place when the ceiling tile was moved.

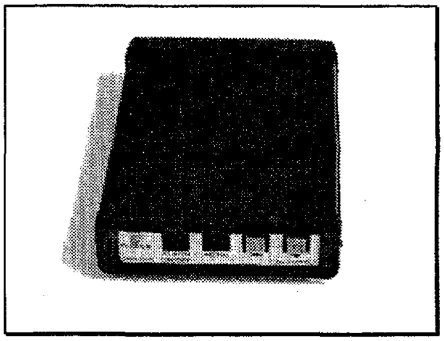
For this reason, a more labor-intensive method of installation is suggested that would keep the cables positioned correctly over the ceiling tiles. This could be done in several ways. For example, the cable could be tied to the clips on the ceiling tiles or the cables could be suspended from the ceiling to hang just over each tile allowing the tile to be moved and the cable to return to its original position.

A major factor in the nuisance and unknown alarms appears to be construction of the movable office complex. Doors closing and external events caused vibrations within the structure. These could not be filtered out with the sensor frequency filtering parameters without degrading detection of tile movement. Installation in a more permanent type structure should improve nuisance alarm performance.

5.4.4 Vulnerabilities

The primary vulnerability associated with using a M105 fiber optic sensor system in a suspended ceiling application is that the system is dependent on movement of a ceiling tile upwards into its detection zone. If a perpetrator could cut a hole or remove a ceiling tile without disturbing the cable, an object could then be placed into the area above the suspended ceiling without detection. It is granted that the perpetrator must know where to cut a hole and how much movement could be tolerated before an alarm would be reported, although a knowledgeable insider may have this type of information. A tile destroyed by an adversary during removal would eventually be detected by a visual inspection of the room by roving security patrols.

5.5 VMD-1000 Video Motion Detector (VMD)



The Digispec VMD 1000 is a single channel video motion detector manufactured for use in interior applications. This particular VMD was selected as part of the evaluation test because it was available for evaluation (was previously purchased for a different project) in suspended ceiling applications. The VMD-1000 has a video input, a video output, and alarm output. The unit is low powered, DC operated (12 Vdc @ 295 ma), and complies with PAL and NTSC video standards for color or black and white. There are setups for adjusting the alarm output time, turning an alarm buzzer on or off, turning movement sparkles on or off, adjusting the sensitivity level, and defining the area of interest by turning on or off 72 individual detection zones.

Cost

The purchase price for the VMD-1000 was $525. This price did not include a camera.

Application

The VMD-1000 was evaluated for use as an intrusion detection sensor in the area above a suspended ceiling to detect intrusion by a person or 6-inch square test object. The VMD-1000 was tested on a single LED camera mounted in, and viewing the area above, a suspended ceiling. The video output from a Sanyo VDC-9212 LED board camera was fed into the video input of the VMD-1000 to monitor for intrusions. Figure 16 shows the location of the camera and the detection zone of the VMD-1000. Figure 17 shows the field of view of the camera and the sensored zones as displayed by the VMD-1000.

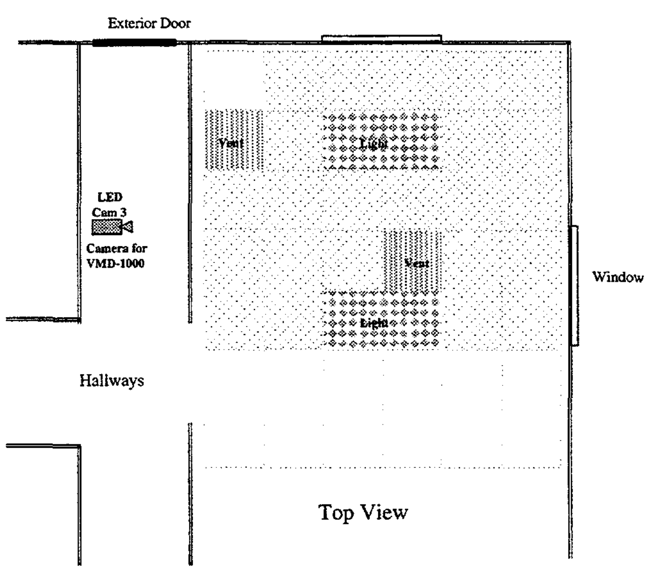


Figure 16. VMD-1000 Sensor Detection Zone

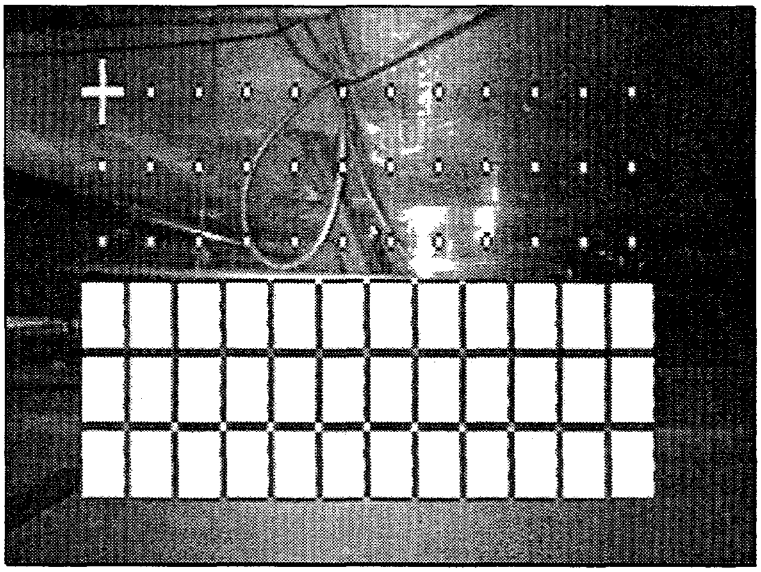


Figure 17. VMD-1000 Camera View

5.5.1 Detection Tests

Detection testing for the VMD-1000 consisted of attempting to insert a 6-inch square test object into the area above the suspended ceiling that was in the VMD-1000's detection zone illustrated in Figure 16. Table 11 shows the results of detection testing for the VMD-1000. All detection testing was conducted with the florescent lights in the room on.

# of Tests	# of Detections	# of Missed Detections	Comments
28	24	4	Results with room lights on

Table 11. VMD-1000 Detection Test Results

The ability of the VMD-1000 to detect an object being placed in its defined detection zone was directly related to the amount of light change introduced into the area whenever a ceiling tile was moved. In some areas, detection was much higher than others. Sensitivity levels were adjusted to find a balance between the system's ability to detect and its ability to reject nuisance alarms. The detection zone of the VMD sensor, illustrated in Figure 16, was defined through multiple testing of ceiling tiles at different locations. Some detections were recorded during setup at locations not included in the sensor's detection zone, but the detection rate at these locations was low. The four missed detections occurred when the ceiling tiles located the farthest distances from the camera were moved very slowly, allowing the test object to be inserted into the area above the suspended ceiling.

5.5.2 Nuisance Alarm Tests

Nuisance alarm testing for the VMD-1000 consisted of monitoring the sensor for any nuisance or false alarms. Table 12 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
1,114	54	Room Lights	Lights toggled on or off
	19	Door Slamming	Caused camera to vibrate
	123	Unknown	Minor light changes probable cause

Table 12. VMD-1000 Nuisance Alarm Test Results

Nuisance alarms from the VMD-1000 were primarily due to changing light conditions in the test area. The VDM-1000 would alarm 100% of the time whenever the lights in the room were toggled on or off because the system saw this as a significant change in the scene.

Light changes due to reflections or from some minor light change in the room would also have an effect on the amount of light entering the area above the suspended ceiling. At times, this relatively small change in light conditions would cause nuisance alarms.

The camera connected to the VMD sensor was mounted near an exterior door in the movable office complex. When the door was closed hard, it would cause the camera to vibrate. The evaluated VMD perceived this movement as a change in the scene and alarmed. This type of nuisance alarm would not be normal in a fixed-site application where the camera was mounted on a sturdy wall.

The unknown alarms usually occurred at night. Although no visible light changes could be seen on the assessment tape, the suspected reason for the unknown alarms was that small changes in the light conditions in the detection area occurred. The room where testing was conducted had three windows that allowed light from car headlights, sunlight, and light poles to have an effect on the amount of light in the test area. Although verification of these alarm sources was not apparent on the assessment tape, it is highly probable that some source of exterior light caused the VMD-1000 to have many alarms classified in this evaluation as unknown.

Data collection for nuisance alarm data was conducted with the lights in the room off as well as when the lights in the room were left on. There seemed to be little difference in the number of nuisance alarms recorded during either of these conditions.

5.5.3 Installation and Maintenance Issues

Installation of the VMD-1000 was relatively simple and required little knowledge due to the limited number of parameters required to set up the system. All that was required for hardware installation was to tap the video signal used to assess the area above the suspended ceiling. One advantage of VMDs is that the installation uses an existing camera's video signal to monitor for intrusion. There is no maintenance required for the VMD other than if the camera view changes, the sensitivity and detection zones may need to be readjusted.

5.5.4 Vulnerabilities

Vulnerabilities associated with the VMD-1000 is similar to the vulnerabilities associated with any VMD. A very slow moving object will be ignored by the VMD as background noise, and if movement in the VMD's detection zone closely resembles the background, reliable detection may not occur.

5.6 Summary of Results for Suspended Ceilings

Table 13 is a summary of the results of the evaluation testing for each sensors' detection and nuisance alarm characteristics. The ***Detection %*** column was calculated based on the number of tests ran versus the number of tests missed. The ***Nuisance Alarms in 1,114 Hours*** column was the total number of nuisance alarms recorded from all sources during 1,114 hours of data collection. The ***Type Intrusion*** column shows whether the detection test results were based on detecting a 6-inch square test object or a human intruder. It was assumed that any sensor that could detect a 6-inch square test object could also detect a human intruder.

Sensor	Detection %	Nuisance Alarms in 1,114 Hours	Type Intrusion
Laser Curtain (A.I.R. Shield, Millennium Corp.)	100%	269	6" Square Test Object
Wireless PIR (Sharpshooter, Sentrol)	100%	1	Human Intruder
Wireless Movement (WATCH 1, Inovonics)	100%	204	6" Square Test Object
(WATCH 2, Inovonics)	89%	13	
Fiber Optic (Fiber SenSys)	87%	62	6" Square Test Object
Video Motion Detector (Digispec, VMD 1000)	86%	142	6" Square Test Object

Table 13. Summary of Evaluation Test Results for Suspended Ceilings

Five intrusion detection sensors had their detection and nuisance alarm characteristics evaluated for use in suspended ceiling applications. Four out of the five sensors evaluated had the capability to detect a 6-inch square test object being placed in the area above the suspended ceiling. The exception was the PIR sensor that would detect a person but not an object being placed above the suspend ceiling. The following sections give a brief summary of the characteristics of each sensor evaluated for use as an intrusion detection sensor in suspended ceiling applications.

5.6.1 A.I.R. Shield Laser Curtain

Millennium Corporation's A.I.R. Shield sensor detected 100% of the intrusion attempts conducted during the evaluation. The sensor's detection zone was located a few inches below the suspended ceiling, which made installation and assessment easier because the area above the suspended ceiling did not require access. However, this also made the sensor susceptible to nuisance alarms. As Table 13 shows, the A.I.R. Shield sensor had a high rate of nuisance alarms from insects and from the instability of the surface on which it was mounted.

The A.I.R. Shield sensor would have better nuisance alarm characteristics in an environment that allowed mounting on a stable wall (not a movable office complex). Insects (moths), which was the other major source of nuisance alarms, may not be a factor in a more controlled environment.

Care should be taken when using the A.I.R. shield sensor due to its susceptibility to being defeated by a knowledgeable intruder. If an intruder has undetected access to the area directly underneath the sensor, the sensor's detection zone can be varied by inserting an object covered with reflective tape into the sensor's detection zone. Knowledge of the sensor's operational characteristics is required to successfully accomplish this defeat method.

5.6.2 Wireless Passive Infrared (PIR)

Sentrol's wireless PIR sensor would not detect the 6-inch square test object, but it had a 100% detection rate for an intruder entering its detection zone. A crucial factor in using PIR sensors in areas above a suspended ceiling is that multiple sensors must be installed to cover blind spots from obstructions. A PIR sensor's detection pattern is based on line-of-site so anything that blocks the sensor's detection curtain causes blind areas.

Nuisance alarms were not a factor for the PIR sensor evaluated in the suspended ceiling application. Although results may vary in different environments, in general, PIR sensors should not have high nuisance alarm rates when used above suspended ceilings.

A PIR sensor detects changes in temperature between objects and their backgrounds to determine if an alarm should be generated. When a person or object matches or closely matches the background temperature, the PIR sensor becomes vulnerable and may not provide sufficient detection.

5.6.3 Wireless Movement (WATCH)

Inovonics Corporation's WATCH sensor had two sensors evaluated as intrusion sensors in suspended ceiling applications. The movement sensitivity of each sensor varied due to the angle of its installed jitter switches. Of the two sensors evaluated, one detected 100% of intrusions, and the other detected 89% of intrusions. As table 13 shows, the more sensitive sensor had a higher detection rate as well as a higher nuisance alarm rate.

WATCH sensors will have high nuisance alarm rates when used in areas susceptible to vibrations. The area of evaluation was a room in a movable office complex, and slamming doors and wind caused the building to move enough to cause nuisance alarms. These sensors may work better in a more stable environment that is free from any vibrations.

Since the WATCH sensors are wireless, installation time is minimized. On the other hand, the sensor is susceptible to jams, as with any wireless sensor. Wireless sensors also require periodic maintenance to change batteries.

5.6.4 Fiber Optic Sensor

The Fiber SenSys fiber optic sensor detected 87% of intrusions during the evaluation period. The evaluation testing was conducted with the fiber laying directly on top of each ceiling tile. After each test, the fiber had to be repositioned on top of each tile, which became time consuming. The majority of missed detections occurred on the tiles near the wall. With a different installation method, the detection rate could improve. A more permanent means of installation should be considered when using the fiber optic sensor in suspended ceiling applications.

Nuisance alarms from the fiber optic sensor were caused primarily from vibrations caused by slamming doors and high winds. A more stable environment could reduce the number of nuisance alarms. A different means of installation in which the fiber was suspended above the ceiling tiles instead of laying directly on them may also improve the nuisance alarm results.

5.6.5 Video Motion Detectors

Digispec's VMD-1000 video motion detector detected 86% of intrusions during the evaluation period. Missed detections were usually at the cameras far field of view and occurred when the ceiling tile was moved at the minimum detection speed.

Nuisance alarms for the VMD-1000 occurred any time there was a light change seen by the camera. Interior VMDs would have high nuisance alarm rates in areas where the lights were not controlled and in any area susceptible to external light sources (rooms with exterior windows).

Detection and nuisance alarm results for an interior VMD in a suspended ceiling application would improve if detection testing was only for an intruder and not a test object. Sensitivity levels could then be increased, which would decrease the nuisance alarm rate while maintaining a high detection rate.

6. Evaluation Testing in Air Ducts

Several different sensors and assessment configurations were evaluated for air duct applications. The results of detection testing and nuisance alarm data for each of the sensor and assessment configurations are categorized in sections pertaining to each individual sensor and/or assessment system evaluated.

Three separate sizes and shapes of air ducts were assembled in order to conduct evaluation testing. A graphical illustration showing a top view of each of the three sizes of air ducts used for evaluation testing is shown in Figure 18, Figure 19, and Figure 20. Sensor and camera locations are shown in their approximate installed locations, with more detail presented in later sections.

Figure 18 shows the 12-inch square air duct used for testing. The duct was constructed out of 20 gauge sheet metal to SMANCA standards and assembled in an "L" configuration. The length of the 12-inch air duct was approximately 20 feet x 10 feet with all sections bolted together. A sealing putty was used to form seals between the assembled sections of the air duct.

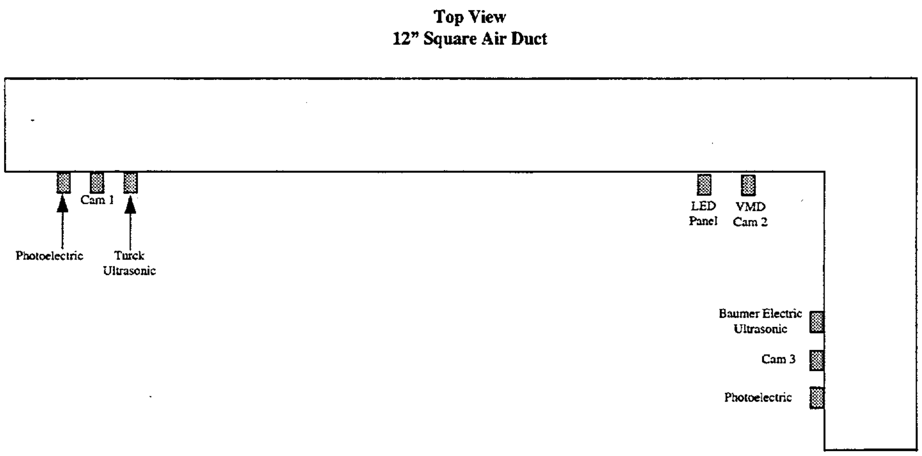


Figure 18. Sensor and Camera Locations in 12″ Air Duct

Figure 19 shows the 18-inch square air duct with the approximate locations of the sensors and cameras used for testing. The duct was constructed out of 20 gauge sheet metal to SMANCA standards and assembled in a "T" configuration. The length of the 18-inch square air duct was approximately 20 feet, with a 10 foot "T" section. All sections were bolted together. A sealing putty was used to form seals between the assembled sections of the air duct.

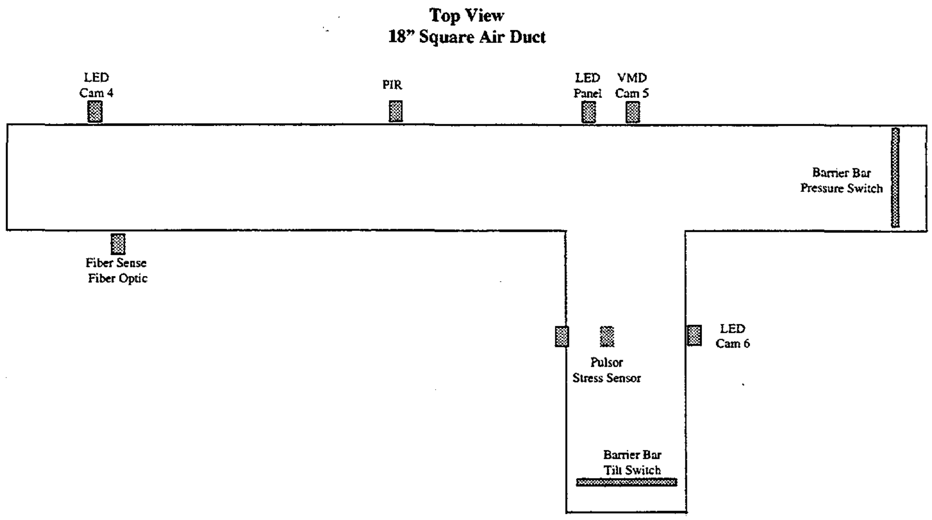


Figure 19. Sensor and Camera Locations in 18″ Air Duct

Figure 20 shows the layout of the 24-inch square air duct with the approximate locations of the sensors and cameras used for testing. The duct was constructed out of 20 gauge sheet metal to SMANCA standards and assembled as a straight section of air duct approximately 20 inches long. All sections were bolted together, and a sealing putty was used to form seals between the assembled sections of the air duct.

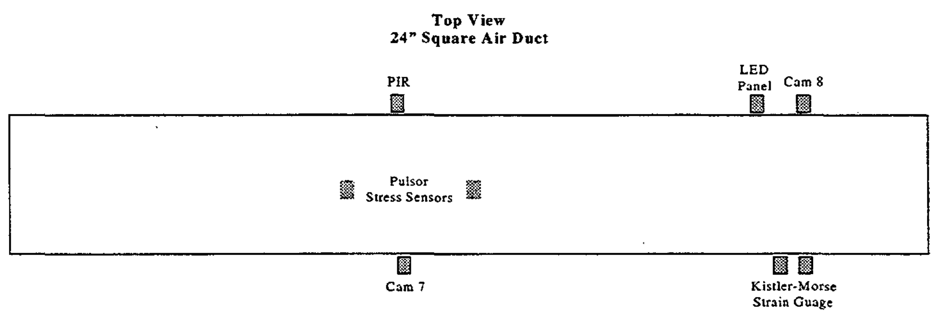


Figure 20. Sensor and Camera Locations in 24″ Air Duct

6.1 M105 Fiber Optic Sensor

The Fiber SenSys M105 fiber optic sensor is the same sensor described in section 5.4 of this report. The same sensor processor that was tested in the suspended ceiling application was also tested in an air duct application. Actual implementation of an M105 fiber optic sensor in an air duct application would not be the most cost efficient means of utilizing fiber optic technology to protect air ducts. The M105 system was tested in this application primarily to demonstrate a conceptual approach as to how fiber optic technology could be used in air duct applications as an intrusion sensor.

<u>Cost</u>
See section 5.4.

<u>Application</u>
The approach evaluated for using a fiber optic sensor in an air duct application was to install the fiber optic cable in a grid configuration inside the air duct. The grid should be installed so that an object or person could not pass through without generating an alarm. The fiber optic sensor was evaluated in the 18-inch air duct. Figure 21 shows the grid configuration used for evaluation testing. Several small mounting holes had to be drilled in the air duct in order to mount the hooks that held the fiber optic cable. An option to using hooks to hang the fiber optic cable would be to string the cable through the drilled holes in the duct material. The tension of the cable was adjusted to disallow the 6-inch square test object from being passed through the grid (constructed of fiber optic cable) without breaking or damaging the cable.

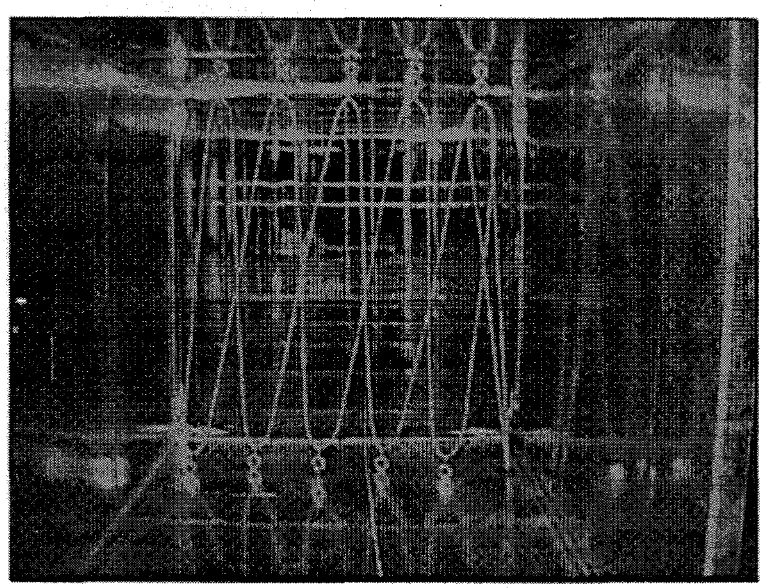


Figure 21. M105 Fiber Optic Sensor in Air Duct

The M105 fiber optic sensor had its sensitivity levels adjusted to ignore any movement except extreme tension or bending. A lower cost fiber optic system that monitored only continuity or gross changes in the fiber optic cable may be sufficient for this type of application. The M105 was used because of its availability, but it may be an overkill for what we were trying to accomplish by using fiber optics to detect a person or object passing through an air duct.

6.1.1 Detection Tests

Detection testing for the M105 fiber optic sensor consisted of attempting to pass a 6-inch square test object through the sensor's detection zone. The sensor's detection zone was simply the physical location of the fiber optic cable. Table 14 shows the results of detection testing for the M105 fiber optic sensor in an air duct application.

# of Tests	# of Detections	# of Missed Detections	Comments
28	28	0	6" Test Object Results

Table 14. M105 Fiber Optic Detection Test Results

As the test results show, with the proper installation, a fiber optic sensor detected all attempts of intrusion during testing. The M105 fiber optic sensor signaled an alarm condition well before the fiber optic cable was broken, damaged, or disconnected from the installation hooks. All attempts to pass the test object though the sensor's detection zone was detected.

6.1.2 Nuisance Alarm Tests

Nuisance alarm testing for the M105 fiber optic sensor consisted of monitoring alarms over a period of time for any nuisance or false alarms. Nuisance alarm sources included the starting and stopping of a fan installed on the air duct to simulate air flow and vibrations similar to a normal operational air duct. Table 15 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	1	Unknown	Cable must have proper tension

Table 15. M105 Fiber Optic Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, the M105 fiber optic sensor had only one nuisance alarms due to an unknown cause. During the installation and setup, several adjustments were required because there were several hundred nuisance alarms recorded during air flow testing. The air from a fan caused the fiber to move back and forth causing numerous alarms. The tension on the fiber cable was tightened and the alarms no longer occurred. Proper installation and tension on the cable were important factors in achieving the recorded nuisance alarm results.

6.1.3 Installation and Maintenance Issues

Installation of fiber optic cable in an air duct to form a physical barrier required drilling several small holes in the air duct to install the fiber optic cable. In the test configuration it was also necessary to gain access to the inside of the air duct to install the hooks and cable. This type of setup would probably work best if installed at or near normal access openings.

The optional installation method of stringing the fiber optic cable through drilled holes in the air duct would not require access to the inside of the duct. This type installation would require holes big enough for the connectors of the fiber optic, unless the connectors were installed after the cable was installed in the air duct. The installer would then have to use a fish tape or similar device to assist in threading the cable through the holes.

Issues in any air duct installation include the presence of insulation wrapped around most air ducts and the effect on a room's air flow of installing sensors on air ducts. The sensor's ability to meet all safety codes, such as being plenum rated, also requires consideration prior to installation.

6.1.4 Vulnerabilities

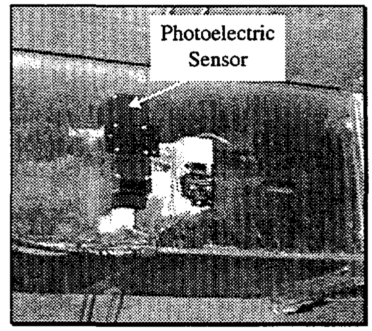
There are few vulnerabilities associated with the concept of installing fiber optic cable in an air duct to detect either an object or a person. How and where the sensor was installed in the air duct would be the primary issues of vulnerability. If a perpetrator could defeat the system by simply bypassing the sensored area and then entering the air duct, the sensor would not provide any protection. Therefore, care should be taken when choosing the location to install any sensor in air ducts.

Trying to defeat the fiber sensor itself would require special tools and a sophisticated adversary. Depending on the type of fiber optic continuity sensor selected, this type of defeat attempt would be very difficult when working inside the air duct. One of the primary advantages to using fiber optic sensors is in the level of effort required to defeat the sensor by attacking the fiber optic cable.

6.2 Baumer Electric Photoelectric Sensors

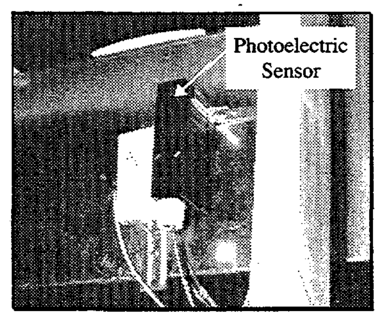
Two Baumer Electric industrial grade photoelectric sensors were evaluated as intrusion sensors for air duct applications. The model numbers tested were FZDM35R7301 and FHDK50R7001. Both models evaluated were diffuse-type photoelectric sensors. Photoelectric diffuse sensors have the emitter and receiver in the same housing.

The basic operating principle behind diffuse photoelectric sensors is that the emitter sends out a beam of pulsed infrared light that is reflected directly by the target. When the beam of light hits the target, it is diffused in all directions and some light is reflected back. The receiver sees only a small portion of the original light, switching the sensor when the target is detected within the effective scan range. The operating range is dependent largely on the reflective properties of the target's surface. Both models of sensors had adjustable sensing distances. An advantage over other types of photoelectric sensors is that sensing is done from only one side of an installation.



There were differences in the models of diffuse photoelectric sensors selected for evaluation. Primary features of the FZDM35R7301 diffuse photoelectric sensor are:

- 100" sensing range
- Adjustable sensing distance
- 35 mm rectangle beam
- Flashing LED alignment indicator



The FHDK50R7001 photoelectric sensor uses diffuse sensing with background suppression by triangulation. It not only senses the light intensity, like the diffuse sensor, but it senses the distance of the object to the sensor. This is accomplished by the sensor having one emitter and two receivers. Primary features of the FHDK50R7001 diffuse photoelectric sensor are:

- Diffuse sensing with background suppression by triangulation
- 19" to 78" sensing range
- Adjustable sensing distance
- 50 mm rectangle beam

The two separate diffuse-type sensors were selected to determine if there was an advantage of one type over the other in detection and nuisance alarm characteristics.

<u>Cost</u>
The cost of Baumer Electric's Model # FZDM35R7301 diffuse photoelectric sensor is $351. The cost of Model # FHDK50R7001 diffuse photoelectric sensor with background suppression is $553.

<u>Application</u>
Both models of photoelectric sensors were installed on a 12-inch square air duct for test and evaluation. The 12-inch duct was selected for testing because it was the only size air duct in the test configuration that required only one photoelectric sensor to protect the entire duct against passage of the 6-inch square test object. One of the photoelectric sensors was placed near each end of the air duct as shown in Figure 18. This was done to facilitate detection testing of each of the photoelectric sensors.

The goal of using the photoelectric sensor was to protect the air duct with a single beam of light against passage of a person or 6-inch test object. The photoelectric sensors were installed on the side of the 12-inch air duct near the center and the sensing range adjusted to alarm when the test object disrupted the light beam. A rectangular hole was cut in the side of the air duct to allow the photoelectric beams to project into the inside of the duct. Figure 22 shows a graphic illustration of the photoelectric sensor detection zone inside a

12-inch square air duct. The 6-inch square test object is also shown inside the 12-inch square air duct.

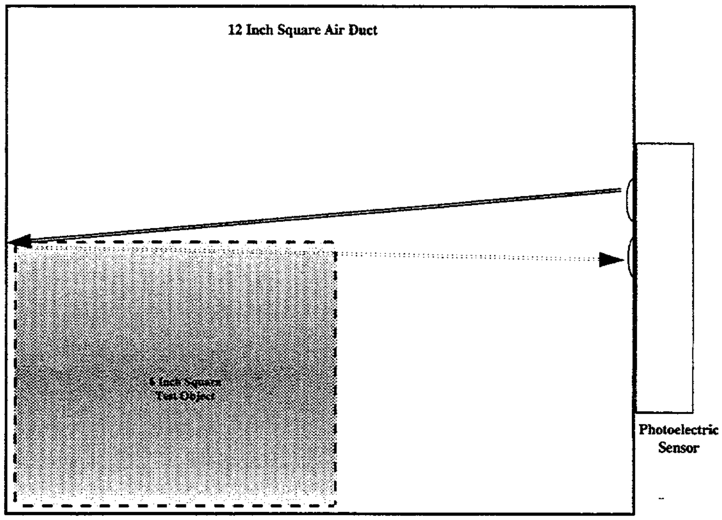


Figure 22. Photoelectric Sensor Detection Zone

6.2.1 Detection Tests

Detection testing for the photoelectric sensors evaluated consisted of attempting to pass a 6-inch square test object through the sensors' detection zone. This test was conducted multiple times covering the total volume of the 12-inch square air duct for each sensors detection zone. Table 16 shows the results of detection testing for the Baumer Electric photoelectric sensors evaluated.

# of Tests	# of Detections	# of Missed Detections	Sensor Model #
28	28	0	FZDM35R7301
28	28	0	FHDK50R7001

Table 16. Photoelectric Sensor Detection Test Results

As the detection test results show, the photoelectric sensors evaluated detected all intrusion attempts. The 6-inch square test object could not physically pass through the 12-inch square air duct without temporarily breaking the photoelectric beam.

6.2.2 Nuisance Alarm Tests

Nuisance alarm testing for the Baumer photoelectric sensors consisted of monitoring alarms over a period of time for any nuisance or false alarms. Part of the nuisance alarm tests included subjecting the sensors to outside light sources including room lights and sunlight through near by doors. Table 17 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	Sensor Model #	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	FHDK50R7001	0	-NA-	No nuisance alarms
	FZDM35R7301	2	Light Changes	Sunlight reflections
	FZDM35R7301	665	Unknown	662 alarms in 6 hours

Table 17. Photoelectric Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, the photoelectric sensor that had a background suppression feature (# FHDK50R7001) had no recorded nuisance alarms. The other photoelectric sensor had 662 of 665 "Unknown" nuisance alarms occur at night over a 6-hour period. It was unclear why the sensor had this number of alarms, but over the entire evaluation period it proved to be a singular incident. The two nuisance alarms due to "Light Changes" occurred when the door to the test bunker was opened allowing sunlight to shine directly at the area where the photoelectric sensor was located. It was determined that extreme light changes could cause this model (# FZDM35R7301) of photoelectric sensor to occasionally alarm.

6.2.3 Installation and Maintenance Issues

Installation of the photoelectric sensors used for the evaluation required cutting a rectangular hole in the side of the air duct. This allowed the light beams from the photoelectric sensor to protect the area inside the air duct. The size of hole required would be dependent on the size and type of photoelectric sensor installed.

Installation of photoelectric sensors in air duct applications does not require access to the inside of the air duct. This is a positive feature since some air ducts requiring protection may be extremely difficult to access. Photoelectric sensors can protect any size of air duct as long as there is a light beam spaced a minimum of 6 inches from the outer walls of the duct and from each other. Several photoelectric sensors may be required to protect a large air duct. For example, a single photoelectric sensor could protect a 12-inch square air duct where it would require two photoelectric sensors to protect a 18-inch square air duct. This is assuming that the detection requirements are to detect a 6-inch square test object.

The only maintenance required on photoelectric sensors is in very dusty or polluted environments the lens of the detector should be periodically cleaned because this may effect the sensor's sensitivity.

6.2.4 Vulnerabilities

Vulnerabilities associated with the application in which photoelectric sensors were used in the air duct application primarily have to do with properly protecting the sensor housing where the sensing range adjustments are made. All photoelectric sensors do not have range adjustments, although the models used for evaluation testing did contain these adjustments.

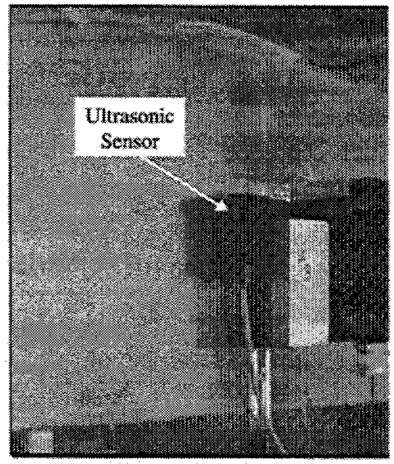
In order to prevent a perpetrator from readjusting the sensitivity of the photoelectric sensor, the sensor should be housed in an electrical box with a tamper switch. This would prevent tampering with the sensor. It would also serve to protect the sensor from dust.

A sophisticated adversary may be able to defeat a photoelectric sensor by inserting an object made of material similar to the sheet metal that an air duct is constructed of near the outer edge of the detection zone. This may change the detection zone enough to possibly pass a test object through undetected. While this type of defeat is possible, it is unlikely because 1) the adversary would not have the positive feedback of alarm data, and 2) the working area inside an air duct is limited.

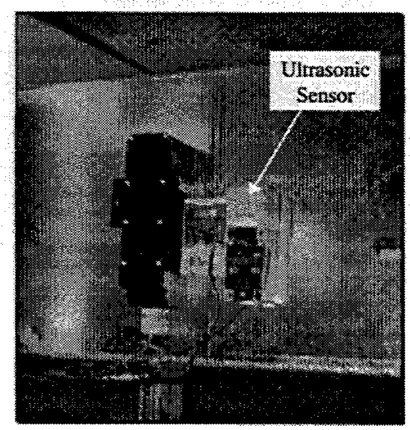
6.3 Ultrasonic Sensors

Ultrasonic sensors were evaluated as intrusion detection sensors in air duct applications. An ultrasonic sensor transmits and receives sound signals. The time elapsed between emitting and receiving is proportional to the distance of the object from the sensor. The sensor's output status is dependent on adjustments to the sensor's operating window (detection zone). The distinctive directional characteristics and compact size of ultrasonic sensors make them ideal for confined spaces. An advantage of ultrasonic sensors over photoelectric sensors is that they can detect transparent objects and also sense objects of any color or shape that fall in the sensor's detection zone. A disadvantage of ultrasonic sensors is that each sensor has a blind region directly in front of the sensor in which objects cannot be detected due to multiple reflections of the signal. This blind region ranges from 1 inch up to several inches, depending on the sonic cone angle.

The two types of ultrasonic sensors evaluated were from different manufacturers. Baumer Electric's Model # UNDK30P1102 ultrasonic proximity sensor contained a single transducer that served both as the emitter and receiver. Turck's Model # RU100-CP40-AP6X2 ultrasonic proximity sensor contained dual transducers, one serving as the emitter and one as a receiver.



Baumer Electric's model # UNDK30P1102 ultrasonic proximity sensor contains a single sonic transducer that both transmits and receives sound signals. The transducer emits a short burst of pulses that are reflected by an object back to the same transducer. After emission of the sound waves, the ultrasonic sensor will switch over to receive mode. The time elapsed between emitting and receiving is proportional to the distance of the object from the sensor. The received echo is electronically processed by the output when the target is within an adjustable range. This sensor has an adjustable sensing distance of 4 to 28 inches, a sonic cone angle of 10 degrees, and a blind region of 4 inches.



Turck's Model # RU100-CP40-AP6X2 ultrasonic proximity sensor contains two sonic transducers where one is the emitter and the other is the receiver. The sensor emits a sonic pulse that reflects back from any object entering the sonic cone. The time taken for this echo to return to the sensor is directly proportional to the distance of the object because sound has a constant velocity. The sensor's output status is dependent on the comparison of this time with the setting of the operating window. The operating window is adjustable in depth and distance by means of two potentiometers. Adjustments to the operating window affect the near and far detection points of the operating window that defines the sensor's detection zone. The sensor's operating window is adjustable from .2 meters to 1 meter. The sensor has a sonic cone angle of 60 degrees and a blind area of 2 inches.

Cost

Baumer Electric's Model # UNDK30P1102 ultrasonic proximity sensor's cost was $297. An additional relay was added to the sensor's output to provide the required signal to the data collection system.

Turck's Model # RU100-CP40-AP6X2 ultrasonic proximity sensor's cost was $368. The LSAP-2 mounting bracket for the sensor was an additional $10.

Application

Each of the ultrasonic sensors evaluated were installed in the 12-inch air duct. Each sensor was mounted to the side of the air duct and a hole was drilled to allow the sonic cone beam to enter the inside of the air duct. The Baumer Electric ultrasonic sensor was located near one end of the air duct, and the Turck ultrasonic sensor was located near the other end. The physical locations of each of the ultrasonic sensors are shown in Figure 18.

The primary differences, other than cost, in the two ultrasonic sensors evaluated was in the size of their detection zones and blind areas. Both sensors had cone shaped detection zones, but the Turck had a much smaller blind area and larger detection area due to the use of two transducers instead of one. The use of two transducers in the Turck ultrasonic sensor, as well as its larger size, required a larger hole in the air duct than required for the Baumer Electric sensor.

For evaluation testing, the sensors were mounted directly on the air duct with no offset. A permanent installation would require the sensor to be offset the distance of the blind zone away from the outer edge of the air duct. This would prevent shielding of the sensor when something is inserted into its blind area. Figures 23 and 24 show the detection zones for each of the evaluated ultrasonic sensors.

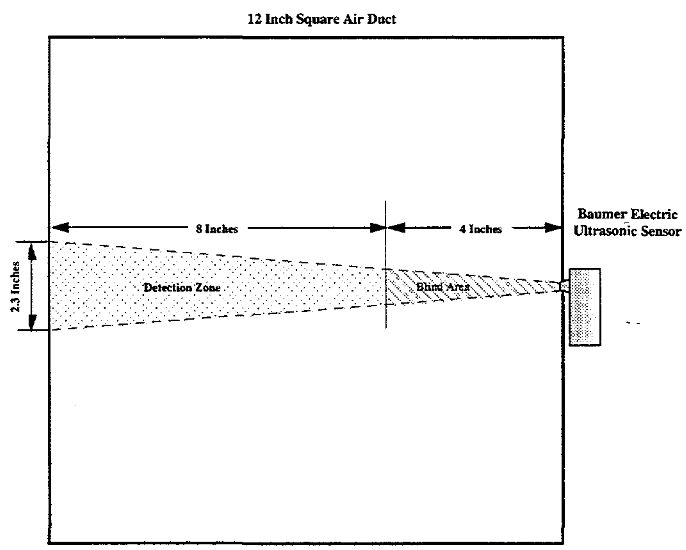


Figure 23. Baumer Electric Ultrasonic Sensor Detection Zone

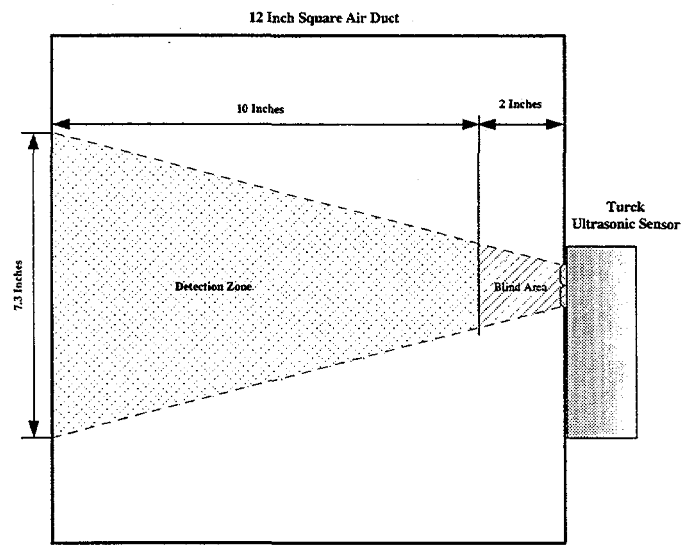


Figure 24. Turck Ultrasonic Sensor Detection Zone

6.3.1 Detection Tests

Detection testing for the ultrasonic sensors evaluated consisted of attempting to pass a 6-inch square test object through each sensors detection zone. This test was conducted multiple times covering the total volume of the 12-inch square air duct for each sensor's detection zone. Table 18 shows the results of detection testing for the Baumer Electric and Turck ultrasonic sensors.

# of Tests	# of Detections	# of Missed Detections	Sensor
28	28	0	Baumer Electric Ultrasonic Sensor
28	28	0	Turck Ultrasonic Sensor

Table 18. Ultrasonic Sensor Detection Test Results

As the detection test results show, both types of ultrasonic sensors detected all intrusion attempts with the 6-inch square test object.

6.3.2 Nuisance Alarm Tests

Nuisance alarm testing for each of the ultrasonic sensors evaluated consisted of monitoring alarms over a period of time for any nuisance or false alarms. Table 19 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	3	Unknown	Baumer Electric Ultrasonic Sensor
	0	-NA-	Turck Ultrasonic Sensor

Table 19. Ultrasonic Sensor Nuisance Alarm Test Results

As the results of nuisance alarm data collection show, ultrasonic sensors will have a low nuisance alarm rate in air duct applications. Baumer Electric's ultrasonic sensor had three alarms during the evaluation period of which the cause was unknown.

6.3.3 Installation and Maintenance Issues

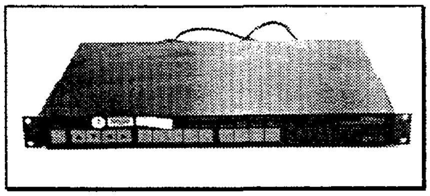
Installation of the ultrasonic sensors used in the evaluation did not require access to the inside of the air duct. A hole had to be drilled in the air duct to allow the sonic beam cone to monitor the inside of the air duct. The size of the required hole in the air duct is dependent on the type of ultrasonic sensor used.

The ultrasonic sensors used for evaluation purposes were not offset from the outer edge of the air duct and placed in an electrical box. This would be recommended if ultrasonic sensors are used to protect air ducts due to the bind area near the face of each ultrasonic sensor. The amount each sensor would need to be offset would be equal to the sensor's blind area. An additional electrical box to protect the sensor from tampering should be of sufficient size to allow the sensor to be offset from the duct. A tamper switch should be installed inside the cover of the electrical box to protect unauthorized entry.

6.3.4 Vulnerabilities

Vulnerabilities associated with the air duct application in which the evaluated ultrasonic sensors were used had to do primarily with properly protecting the sensor housing where the sensing range adjustments are made and protecting the blind area of each sensor. If the blind area is accessible, a perpetrator can simply insert a flat object in the sensor's blind area and disable the sensor without alarming it. For this reason, the sensor must be offset from the outer edge of the air duct a distance equal to or greater than the sensor's blind area distance. The sensor then must be enclosed in a protective housing (electrical box with tamper) to prevent tampering with the sensor's sensitivity.

6.4 GYYR Video Motion Detector (VMD)



The Gyyr DVMD 32 is a self contained video motion detection system in a rack mount chassis. The system was selected for use as a VMD sensor in the air duct evaluation due to its availability from a previous project which evaluated exterior VMDs. Previous tests showed the Gyyr VMD to have many of the false alarm characteristics associated with indoor VMDs. The Gyyr VMD was selected primarily to get a base line on how interior VMDs would perform in air duct applications.

The Gyyr VMD was advertised as an exterior VMD although previous evaluations by Sandia proved it to have high false alarm rates in exterior environments. The DVMD32 accepts up to 8 camera inputs, has a built-in quad, and 32 separately adjustable detection zones that can be used to define detection zones for the eight camera inputs. Specific parameters and setup details of the Gyyr VMD are not included in this report. The purpose of this test was to evaluate the characteristics of interior VMDs when used in air duct applications, not a specific VMD model.

Cost

The Gyyr DVMD32 video motion detector was an eight camera VMD and cost $3,330. The expected cost to use a VMD for air duct applications would be around $300 to $500 per channel or sensor. Most of the currently available interior VMDs would be expected to have similar test results in air duct applications.

Application

Two cameras that were connected to two separate channels of the Gyyr VMD were used for evaluation testing of a VMD in air duct applications. Each camera viewed the inside of an air duct through a 5/8-inch hole drilled in the side of the air duct. Each of the cameras connected to the Gyyr VMD had an external light source supplied by a small LED panel installed near each camera. The physical location of the cameras used for VMD sensor evaluation tests were shown previously in Figure 18 for CAM 2 and in Figure 19 for CAM 5.

The detection zone for each of the VMD sensors was set up with four detection cells and adjusted to detect the 6-inch square test object. Figure 25 shows the detection zone and camera's field of view for Gyyr VMD CAM 2 and Figure 26 shows the detection zone and camera's field of view for Gyyr VMD CAM 5.

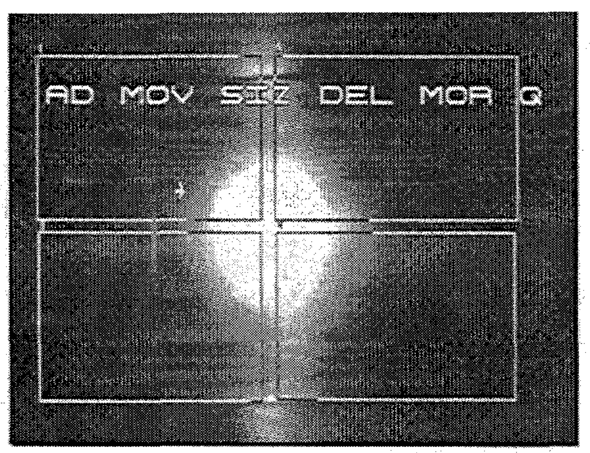


Figure 25.
Gyyr VMD CAM2 Detection Zone

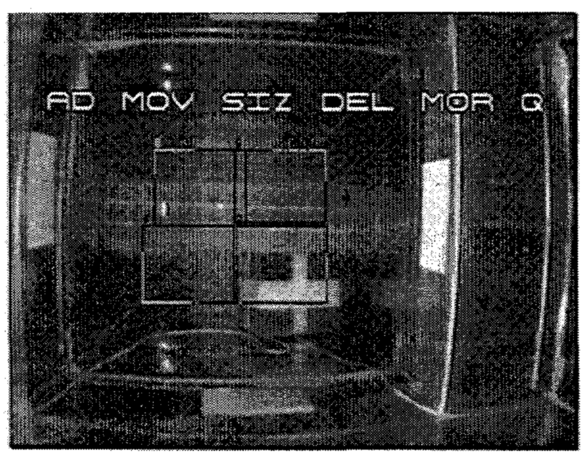


Figure 26
Gyyr VMD CAM5 Detection Zone

Each of the cameras selected for evaluation of a VMD sensor was selected for a specific reason. CAM2, on the 12-inch air duct, was located far enough away from vent openings that the outside light changes in the room from people moving near the vents or lights turned on and off was minimal. CAM5, on the 18-inch air duct, was viewing a portion of the inside of the air duct with a vent opening. Consequently, anyone walking near the vent or any significant light changes in the room were realized inside the air duct being monitored. The purpose of choosing these two locations was to evaluate potential nuisance alarm effects based on the location of a camera used as a VMD sensor.

6.4.1 Detection Tests

Detection testing for the Gyyr DVMD32 VMD consisted of attempting to pass a 6-inch square test object through the sensor's detection zone. The detection parameters for both channels of the Gyyr VMD were set up to get as near to 100% detection as possible. Multiple tests were run on both CAM2 in the 12-inch air duct and CAM5 in the 18-inch air duct. Table 20 shows the results of detection testing for the Gyyr VMD.

# of Tests	# of Detections	# of Missed Detections	Comments
23	23	0	Gyyr VMD CAM2
23	23	0	Gyyr VMD CAM5

Table 20. Gyyr VMD Detection Test Results

As previously stated and confirmed by the detection test results, the evaluated VMD had a high probability of detection in air duct applications. Detection testing for objects that closely matched the background and detection testing at very slow speeds (less than 1 inch per second) was not included in the scope of this evaluation.

6.4.2 Nuisance Alarm Tests

Nuisance alarm testing for the Gyyr DVMD32 VMD consisted of monitoring alarms over a period of time for any nuisance or false alarms. Several tests were done to change lighting conditions near and around the air ducts, such as people walking past or near the area and opening and closing doors. Table 21 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Sensor
926	1	Light Change	Gyyr VMD CAM 2
	26	Light Change	Gyyr VMD CAM 5

Table 21. Gyyr VMD Nuisance Alarm Test Results

As the nuisance alarm test results reveal, the evaluated VMD was susceptible to light changes of any kind. CAM 5 was viewing a vent in the end of the 18-inch air duct and alarmed almost every time a person passed within a few feet of the vent. The person passing the vent changed the light entering the vent enough to set off the VMD. CAM 2 was located farther away from vents and, therefore, had no nuisance alarms do to light changes caused by activity near the end of the vent. Air ducts are typically constructed of sheet metal that is highly reflective. Care must be used in choosing a camera location to use a VMD for monitoring the inside of an air duct. Basically, the more controlled an area the better a low-cost VMD sensor will work. The sensitivity levels for CAM 5 could have been lowered more to reduce the nuisance alarm rate which may or may not have effected the detection levels for the 6-inch square test object.

6.4.3 Installation and Maintenance Issues

One of the primary benefits of using video motion detectors is that installation is very easy, assuming the camera being used is already in place. For an air duct application, the most important step (after choosing a VMD) is selecting the location for the camera. The camera's field of view should cover the entire area to be protected and should be mounted in a location that is free from external light sources, which could cause nuisance alarms. The addition of an additional controlled light source (LED panel) near the camera allows the camera enough light for assessment and minimizes the effect of exterior light sources.

The VMD sensor should require no maintenance. Any maintenance required to a VMD system is usually associated with camera maintenance, which directly affects the operability of the associated VMD sensor.

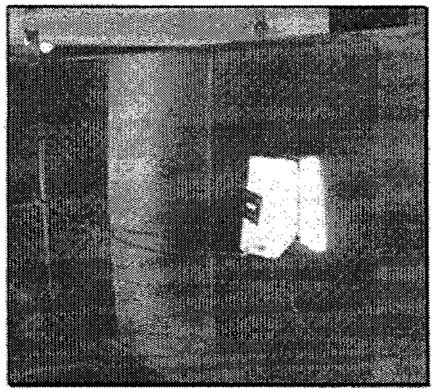
6.4.4 Vulnerabilities

Vulnerabilities associated with VMDs in general will also apply, to a somewhat lesser extent, to VMDs being used in air duct applications. A primary vulnerability for a VMD is that if an object or person can blend into the background and move slow enough, a VMD may not provide reliable detection.

In the case of air ducts, this process would be much more difficult than in a large open area. In the confined space of an air duct, an object or person will cause a significant portion of the scene to change when passing through the VMD's detection zone. Even though an object may blend into the background, an air duct with artificial light (LED panel) will cause objects to have shadows. These shadows are light changes that cannot be avoided and would cause a VMD sensor to alarm.

6.5 Passive Infrared (PIR) Sensor

Passive Infrared (PIR) sensors were evaluated as intrusion detection sensors for air duct applications. A PIR sensor detects the presence of an object when its detection zone is interrupted by an object having a different temperature than the temperature of the background. The sensor does not transmit a signal for interruption or reflection. Instead, the sensor responds to the energy emitted by a human intruder, which is approximately equivalent to the heat radiated by a 50 W light bulb. PIR sensors adapt to slow changes in background temperatures that occur over a period of minutes or more and respond to short-term changes.



Two PIR sensors were evaluated in the air duct application. The 18-inch square air duct had a *Sentrol -- Sharpshooter* PIR, and the 24-inch square air duct had a *Racal Guardall*

-- *Apollo S* PIR installed as intrusion sensors. The basic operating principle behind each model PIR evaluated was the same, so details of each are not included in this report. The intent of this report is to determine the detection and nuisance alarm characteristics of PIR sensors when used for intrusion detection in air duct applications.

Cost

PIR sensors can range in cost anywhere from $50 to $100 per sensor, depending on several available options. The PIR sensors used for evaluation testing had an approximate cost of $75 at the time of purchase and were selected only because of their availability as excess equipment from other projects.

Application

The Sentrol PIR sensor was installed on the 24-inch square air duct and the Racal Guardall PIR was installed on the 18-inch square air duct. The sensor was mounted to the outside of each air duct with a hole cut in each air duct to allow the sensor to monitor the inside of each air duct. Each sensor had their coverage patterns adjusted so that movement by a person at the openings of each air duct would be ignored. Figure 27 shows the approximate detection zones for the PIR sensors installed on each of the air ducts. The detection zone was established by a person crawling through the air duct until the PIR sensor alarmed.

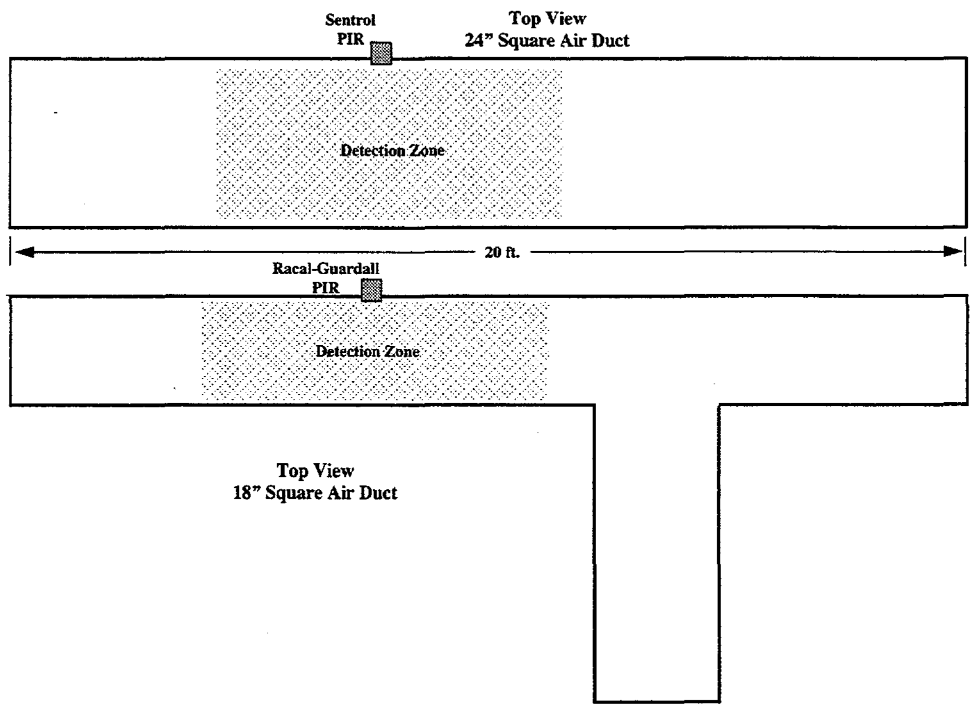


Figure 27. PIR Sensor Detection Zones

6.5.1 Detection Tests

PIR sensors were designed to detect human intruders and was not expected to detect small objects. Therefore, the test object was not used for detection testing. Detection testing for the PIR sensors consisted of an intruder crawling through the detection zone at a rate no slower than 1 inch per second. Table 22 shows the results of detection testing for crawling intruders by the PIR sensors used in both the 18 inch and 24 inch air duct applications.

# of Tests	# of Detections	# of Missed Detections	Comments
15	15	0	PIR in 18" square air duct
15	15	0	PIR in 24" square air duct

Table 22. Passive Infra Red Sensor Detection Test Results

As the detection test results show, PIR sensors had a high detection rate for crawling intruders in air ducts. The detection tests were for a crawling intruder who was not dressed in any special clothing, and the temperature in the air ducts was at normal room temperature when testing was conducted. The results of detection tests could vary when the temperature in the duct neared that of an intruder, or when an intruder dressed so that a PIR sensor would have difficulty detecting the heat from his body. Testing of these defeat methods was not conducted as part of this evaluation.

6.5.2 Nuisance Alarm Tests

Nuisance alarm testing for PIR sensors consisted of monitoring alarms over a period of time for any nuisance or false alarms. An evaporative cooler fan was installed at the end of each air duct to simulate temperature changes and moving air that was typical of actual air duct applications. Table 23 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	0	-NA-	PIR in 18" square air duct
	14	Unknown	PIR in 24" square air duct

Table 23. Passive Infrared Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, the PIR sensor installed in the 18-inch square air duct had no nuisance alarms, and the PIR sensor in the 24-inch square air duct had 14 nuisance alarms from unknown causes. The 14 unknown alarms all occurred at night over a 4-hour period of time.

Although an attempt to simulate air flow and temperature change in an air duct was made, actual testing in an operational air duct should be done to determine if the nuisance alarms would increase. The distance that air has to travel before it reaches the detection zone of a PIR sensor affects whether the PIR sensor has time to adapt to the change of environment without false alarming. Although cool air was used during evaluation testing, no alarms from this source were recorded, which may or may not be similar to the conditions encountered in a real air duct application.

6.5.3 Installation and Maintenance Issues

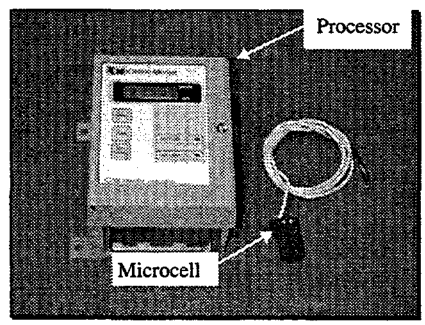
Installation of PIR sensors in air duct applications consisted of cutting out a square hole in the side of the air duct so that the sensor could monitor the inside of the air duct. Access to the inside of the air ducts was not a requirement for installation but would be required in sensor adjustment and to verify detection characteristics.

6.5.4 Vulnerabilities

A standard vulnerability for PIR sensors is that if an intruder can wear enough clothes so that he appears to be the same temperature as the background, the PIR sensor will not alarm. In addition, with cool and hot air moving down the air duct, it could be that there would be times that a PIR sensor would be more susceptible to defeat.

6.6 Strain Gauge Sensor -- Microcell

The Kistler-Morse Model #M21L Microcell sensor is a bolt-on strain gage that measures the deflections in a vessel's support structure caused by the weight of the material stored inside. As the weight changes, the Microcell sensor transmits a proportional electrical signal to a separate Weight Indicator Processor. The Processor then conditions the signal to provide weight information.



The Model #1000/1020 Weight Indicator processor continuously processes information from the Microcell sensors and converts the information so that changes in weight can be monitored. Depending on the model selected, the weight indicator processor allows the operator to define either one or two set point values. A relay will switch when the weight of the monitored vessel no longer falls within the range defined by the set points. One version of processor allows both a high and low set point relay and the other allows a single set point relay that trips when the reading exceeds the defined value. Each Weight Indicator Processor can monitor from 1 to 40 Microcell sensors wired in parallel.

<u>Cost</u>
A Microcell Model #M21L includes all mounting hardware and costs $310 each. A Model 1000 weight indicator in a NEMA-4 enclosure with two set point relays will cost $1,295 each.

<u>Application</u>
The Microcell strain gauge sensor was installed in two different configurations on the 24-inch square air duct. One configuration had the Microcell bolted directly to the side of the air duct. The other configuration had the Microcell sensor bolted first to a 1/8-inch thick by 1-inch wide by 18-inch long piece of steel bar. The steel bar was then mounted to the side of the air duct with several sheet metal screws. The configuration that used a steel bar as extra support was recommended by the manufacturer. The engineers were

concerned with the Microcell sensor being too sensitive to be directly mounted to an air duct. This was also the primary reason both Microcell sensor configurations had the sensor mounted to the side instead of to the bottom of the air duct.

For monitoring purposes a separate processor was used to monitor each Microcell sensor. Several tests were performed to determine the proper sensitivity levels required for the Microcell sensor to work properly. The detection zone of a single Microcell sensor mounted to the side of the 24-inch square air duct covered approximately 4 to 5 feet on either side of the sensor. Figure 28 is a picture of the installed M21L Microcell strain gauge sensors used for evaluation testing.

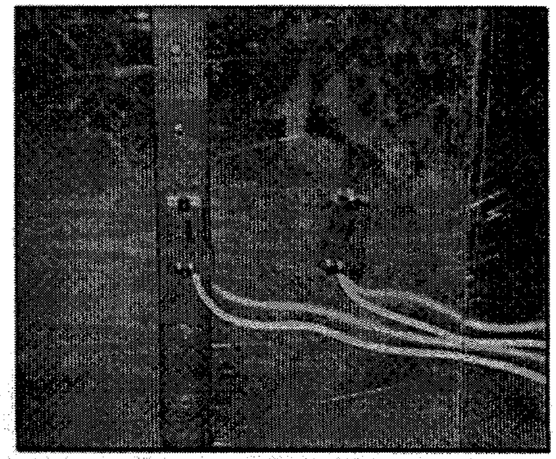


Figure 2. M21L Strain Gauge Sensor

6.6.1 Detection Tests

The M21L Microcell strain gauge sensor was designed to detect weight changes of large volumes of material stored in containers. Weight changes of a few pounds would usually be considered insignificant. The test object used for evaluation testing weighed less than 1 pound and, therefore, was not used for detection testing of the Microcell sensor. The sensitivity parameters on the weight indicator processor were set up to detect changes caused by an intruder and to ignore small weight changes due to expanding metal or vibrations. Detection testing for the Microcell strain gauge sensors consisted of an intruder crawling through the detection zone at a rate no slower than 1 inch per second. Table 24 shows the results of the detection tests for both installations of the Microcell sensors on the 24-inch square air duct.

# of Tests	# of Detections	# of Missed Detections	Comments
18	18	0	Microcell (direct mounting)
18	18	0	Microcell (re-enforced mounting)

Table 24. Microcell Strain Gauge Sensor Detection Test Results

As the detection test results show, the Microcell strain gauge sensors had a high probability of detection for a crawling intruder. Attempts at bridging the sensor were not attempted although crawling as close as possible to one side of the air duct and varying the speed of intrusion was part of the testing. The results shown in Table 24 were obtained after several adjustments to the sensitivity of the Microcell sensors.

6.6.2 Nuisance Alarm Tests

Nuisance alarm testing for the Microcell strain gauge sensors consisted of monitoring alarms over a period of time for any nuisance or false alarms. Table 25 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	0	-NA-	Microcell (direct mounting)
	0	-NA-	Microcell (re-enforced mounting)

Table 25. Microcell Strain Gauge Sensor Nuisance Alarm Test Results

No nuisance or false alarms were recorded during evaluation testing. The settings on the weight indicator processor revealed small changes in Microcell sensor readings over time, but the weight changes were not significant enough to cause a false alarm. Extreme vibrations or temperature changes could possibly cause a nuisance alarm due to the sheet metal in the air duct expanding. However, this is unlikely because the sensor parameters are set up to trip on the weight change from a human intruder and to ignore small changes.

6.6.3 Installation and Maintenance Issues

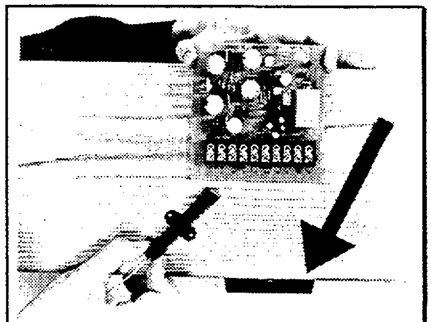
Air duct installation of the Microcell strain gauge sensors required drilling two mounting holes per sensor. No access to the inside of the air duct was required for installation. Setting the parameters on the weight indicator processor would require a person or an object of sufficient weight to simulate a person inside the air duct.

Testing revealed that the sensitivity or weight indication of the strain gauge sensor, when mounted to an air duct, may possibly drift over time. For this reason, performance testing on the sensor may be periodically required. The weight changes observed during the evaluation period was not significant enough to require maintenance. Additional testing would be required to determine if the small variance in sensor readings would eventually require readjustments to the sensor.

6.6.4 Vulnerabilities

The primary vulnerability when using a Microcell sensor in air duct applications is the sensor's susceptibility to an intruder who attempts to bridge across the sensor's detection zone. Bridging could possibly occur in air ducts if an adversary carried a rigid piece of material of sufficient length to bridge across the sensor's detection zone. If bridging is a threat, it could be minimized by installing more sensors to increase the size of the detection zone so that it could not be easily defeated by bridging. An intruder would need to know where each Microcell sensor is mounted and its sensitivity level in order to successfully defeat the sensor by bridging. This would be difficult if the sensors are on the outside of the duct and the intruder is on the inside. A factor to consider when installing additional sensors is that assessment would be required in a larger area and possibly more than one camera would be required.

6.7 Pulsor -- Stress Detection Sensor


A Model 4014 Stress Processor and a Model 4012 Stress Sensor, (one shown mounted, another hand held).

The Pulsor Stress Detection System from Sure Action, Inc., uses a series of solid state sensors that detect intrusions when epoxied to any structural member that momentarily flexes, even slightly, under the load produced by an intruder. These sensors are based on piezo-resistive technology. The sensors are connected to a single processor to analyze the resistive changes produced by the sensor's mechanical flexing. There are various models of processors that monitor from one to four zones with up to four sensors per zone. Each zone has a relay output and the processor is powered by 12 Vdc. The system was designed as a motion detection system that responds to movements characteristic of a walking person. It was designed to ignore slow signals or changes as well as fast vibrations.

Some of the advertised advantages of a Pulsor Stress Detection System are listed below:

- Pulsor detectors are made from solid state silicon chips and will detect momentary structural flexures on the order of a few thousandths of an inch.
- Pulsors look at structural stress as a function of the intruder's weight. Consequently, by adjusting their sensitivity at the processor, they can detect differences between a person and a small animal.
- Pulsors detect momentary changes in structural flexure and are not affected by long-term changes.
- Pulsors were designed to be epoxied underneath a structural member that flexes, thus making its presence and location unknown to most adversaries.

<u>Cost</u>

A minimum Pulsor Stress Detection System consists of a single processor and a sensor. Each Pulsor Sensor costs approximately $28; a single zone processor costs $90.

<u>Application</u>

A Pulsor Stress Detection System was installed in two locations to evaluate its detection characteristics in air duct applications. The first system had two sensors spaced approximately 5 feet apart, epoxied to the bottom side of a 24-inch square air duct. The sensors were connected to the signal processor, and the sensitivity was adjusted to detect a person crawling through the air duct. If either of the sensors detected a sufficient stress change, an alarm would be generated by the signal processor. The idea behind this configuration was to establish a larger detection zone using two stress sensors.

A second Pulsor Stress Detection System was installed on the 18-inch square air duct. Two stress detection sensors were epoxied to the air duct, one on the bottom side and one on the side. The primary detection sensor for a person crawling inside the air duct was the sensor epoxied to the bottom side of the air duct. The sensor mounted on the side of the air duct would also detect a crawling person inside the air duct by lowering the sensitivity at the signal processor. The primary purpose for having the sensor mounted to the side of the air duct was to allow easier access during testing and demonstrations. Both sensors were wired to the signal processor, and an alarm from either would cause the processor to signal an alarm to the data collection system. This configuration had a smaller detection zone than when two sensors were mounted and spaced apart as in the 24-inch square air duct application. Figure 29 shows the approximate detection zones for the Pulsor sensors installed on the 24-inch square and the 18-inch square air ducts.

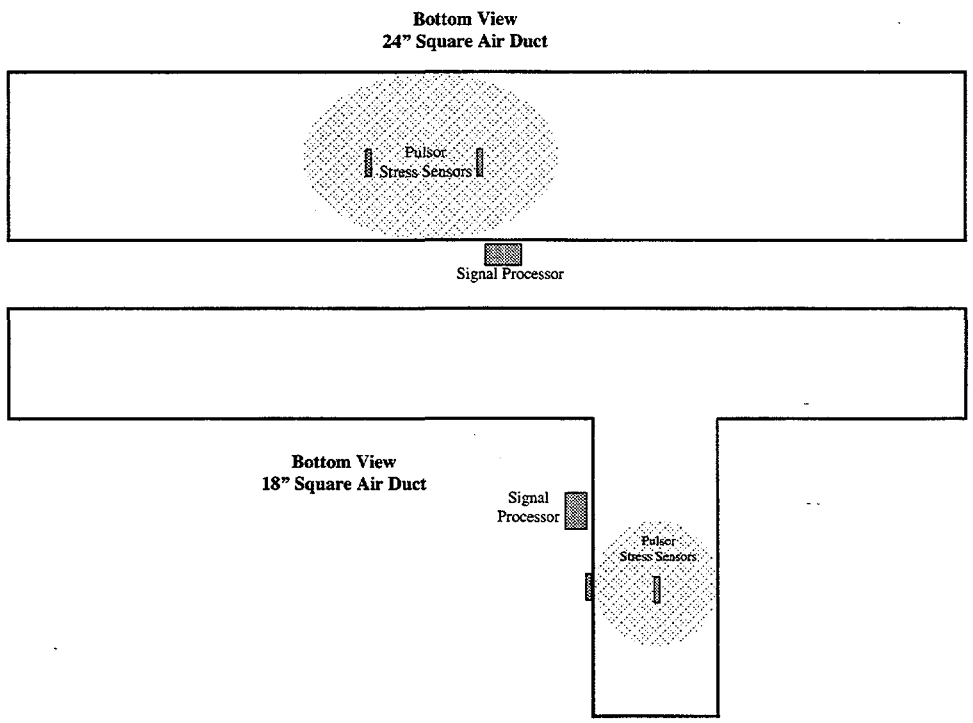


Figure 28. Detection Zone for Pulsor Stress Detection Sensors

6.7.1 Detection Tests

The Pulsor Stress Detection System was designed to ignore any weight changes of approximately 60 pounds or less. Object testing was not conducted on this intrusion sensor because it could not and was not expected to detect small objects—only people. Detection testing for the Pulsor Stress Detection System consisted of an intruder crawling through the detection zone at a rate no slower than 1 inch per second. Table 26 shows the results of detection testing for crawling intruders by the Pulsor system on both the 18 inch and 24 inch air duct applications.

# of Tests	# of Detections	# of Missed Detections	Comments
23	23	0	24" Square Air Duct
16	16	0	18" Square Air Duct

Table 26. Pulsor Strain Gauge Sensor Detection Test Results

As the detection test results show, the Pulsor Stress Detection System has a high probability of detection for an intruder crawling inside the air duct. Tests were not performed where the intruder used bridging attempts to defeat the sensors.

6.7.2 Nuisance Alarm Tests

Nuisance alarm testing for the Pulsor Stress Detection System consisted of monitoring alarms over a period of time for any nuisance or false alarms. The sensors were subjected to simulated real live conditions such as air flow and vibrations. Table 27 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Sensor Location
926	0	-NA-	18" Square Air Duct
	0	-NA-	24" Square Air Duct

Table 27. Pulsor Stress Detection Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, there were no recorded nuisance alarms on the Pulsor Stress Detection Sensors during the evaluation period. This type of sensor technology will have a low nuisance alarm rate in air duct applications because the structure has to actually flex, and fairly quickly, to signal an alarm.

6.7.3 Installation and Maintenance Issues

Installation of the Pulsor Stress Detection System to an air duct is a relatively simple process. No holes or drilling are required because the sensor is simply epoxied directly to the air duct, using the epoxy recommended and supplied by the manufacturer. The sensor is then wired back to the signal processor and the sensitivity is adjusted. The only possible installation issues would be in meeting the local fire safety codes for equipment installed in areas were plenum-rated equipment is required. In this case, the sensors and signal processor would have to be installed in enclosures that meet all safety codes.

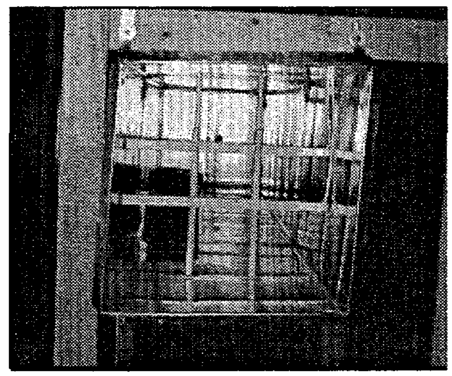
There is no known maintenance required to the Pulsor Stress Detection System although long-term tests have not be conducted.

6.7.4 Vulnerabilities

The Pulsor Stress Detection System has potential vulnerabilities when used in air duct applications. The system could be susceptible to a very slow moving intruder or an intruder who attempts to bridge across the sensor's detection zone. Bridging could possibly occur in air ducts if an adversary carried a rigid piece of material of sufficient length to bridge across the sensor detection zone. If bridging is a possibility, it could be minimized by installing more sensors to increase the size of the system's detection zone to one that could not be easily defeated by bridging. The low cost of additional Pulsor sensors (up to four can be used on the basic processor) would make this solution to bridging an easy and cost-efficient process. The intruder would also need to know where each sensor is mounted, which may be difficult if the sensors are on the outside of the duct and the intruder is on the inside. A factor to consider when installing additional sensors is that assessment would be required in a larger area and possibly more than one camera would be required.

A slow moving intruder could eventually defeat the sensors, assuming he knew where they were installed in the air duct. The signal processor treats slow changes detected by the sensors as normal and adjusts accordingly. The sensitivity adjustment has some control over how long this takes. The sensor did reliably detect a person crawling at 1 inch per second. Tests were not conducted at any slower speeds. However, it is assumed that an intruder with enough time could probably get through the sensor's detection zone.

6.8 Barrier Bar Mercury Tilt Sensor



Sentrol's Barrier Bar Mercury Tilt Sensor, Model BB-2XL, was designed to protect window vents and other hard to protect openings. The sensor assembly consists of a square spring-loaded tube with a mercury switch that fits openings from 12 inches to 40+ inches. The barrier bars are constructed of plastic tubes with optional aluminum reinforcement for added security and stability. The sensor assembly is position sensitive and the bar must be installed in the horizontal position. The mercury switch inside the bar responds to tilting and twisting approximately 15 degrees. The loop response time of the monitoring system determines how sensitive the switch is based on how fast a switch opening can be detected. Vertical bars can be installed on the horizontal bar to cover more area. Figure 30 shows a layout of the construction of the BB-2XL Barrier Bar Mercury Tilt Sensor.

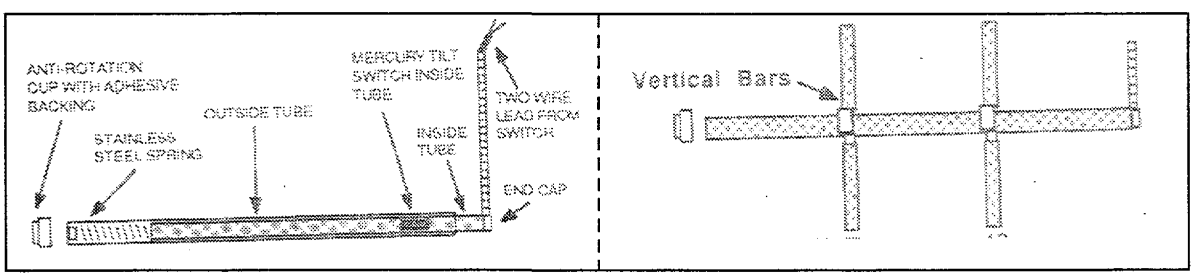


Figure 29. BB-2XL Barrier Bar Mercury Tilt Sensor Assembly

<u>Cost</u>
The cost of Sentrol's Barrier Bar Mercury Tilt Sensor, Model # BB2XL, was $23.25 each. Two barrier bar sensors were required to protect an 18-inch square air duct bringing the total cost to $46.50.

<u>Application</u>
Two barrier bar mercury tilt sensors were installed in one end of the 18-inch air duct. Two sensors were used in order to not allow an opening greater than 6 inches for the test object to pass through undetected. Access to the inside of the air duct was required to install the barrier bar sensors so the sensors were placed about 1 foot into one end of the

18-inch air duct. Careful positioning of the bars was required in order to get the mercury sensors to set up and operate properly. The two sensors used to establish a detection zone were wired in a series where an alarm from either would cause an open circuit to the alarm monitoring system. End-of-line resistors could be added inside the horizontal bar to protect against line tampering. Any time a test was run, the mercury tilt sensor(s) would stay in alarm until the horizontal bars were repositioned correctly.

6.8.1 Detection Tests

Detection testing for Sentrol's Barrier Bar Mercury Tilt Sensor consisted of attempting to pass a 6-inch square test object through the protected area. For this, two barrier bar tilt sensors were installed inside one end of the 18-inch square air duct (see picture in section 6.8). Table 28 shows the results of the detection tests.

# of Tests	# of Detections	# of Missed Detections	Comments
23	23	0	--

Table 28. Barrier Bar Tilt Sensor Detection Test Results

Each of the openings in the barrier bar tilt sensor's detection zone was less than 6 inches square, which required the movement of one of the bars in order to create an opening large enough to allow the 6-inch square test object to be pushed through. As the detection test results show, any time the barrier bar was moved, an alarm was generated.

6.8.2 Nuisance Alarm Tests

Nuisance alarm testing for Sentrol's Barrier Bar Mercury Tilt Sensor consisted of monitoring alarms over a period of time for any nuisance or false alarms. Table 29 shows the result of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	0	NA	No recorded nuisance alarms

Table 29. Barrier Bar Tilt Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, there were no recorded nuisance alarms during the evaluation period.

6.8.3 Installation and Maintenance Issues

Installation of the barrier bar tilt sensor in an air duct application required access to the inside of the air duct for installation, setup, and testing. To facilitate accessibility and installation, barrier bar tilt sensors were installed near a vent in the end of an air duct. To use this type of sensor to protect air ducts, it is necessary that the installer has direct access to the inside of the air duct where the sensor is to be installed. This would limit the use of barrier bar sensors to areas that a person could safely enter.

Installation of barrier bars required cutting the plastic portion of the tubes to the correct size for the area being monitored. A single hole drilled into the air duct was required to allow the wiring to each mercury tilt switch to exit. Positioning of each of the two barrier bars required a meter to allow correct positioning of the bars. Overall, installation efforts of barrier bar technology would be directly related to the accessibility to the area that the sensors are being installed.

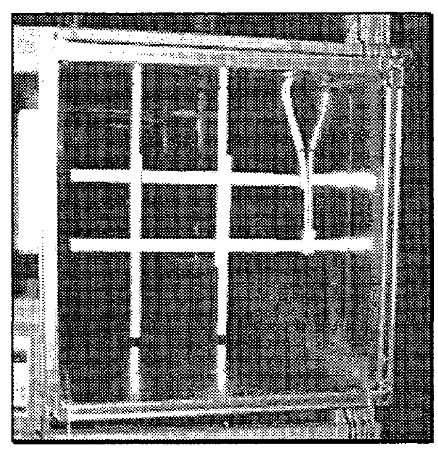
Any time testing on a barrier bar tilt sensor was required, the horizontal or vertical bars had to move slightly to cause an alarm. The sensor would then require realignment in order for the sensor to return to the secure state. This could prove to be a time-consuming task if access to the inside of the air duct is difficult.

6.8.4 Vulnerabilities

The use of the barrier bar tilt sensor technology is a low-cost means of protecting openings against intrusions, although this type of sensor does have vulnerabilities. A major vulnerability is that with a little patience, the bars could be slowly moved in the horizontal plane without tilting the sensor. The sensor does have double sided adhesive tape on the end and tension from springs inside the bars to make this task more difficult, but not impossible. This is especially true if a perpetrator was just trying to move the bars a little way to allow insertion of an object. It would be much more difficult to completely remove the bars in order for a person to move through the air duct.

The addition of another tilt mercury switch, wired in a series inside each horizontal bar, would make defeating the sensor more difficult. However, it would also make setup and testing more difficult because the sensors must all be reset to their exact position to return to a secure state after an alarm.

6.9 Barrier Bar Pressure Sensor



Sentrol's Barrier Bar Pressure Sensor, Model BB-2XL, was designed to protect window vents and other hard-to-protect openings. The barrier bar pressure sensor is similar to the barrier bar mercury tilt sensor except for the type of sensing switch used. While the mercury tilt sensor uses a mercury switch and is position sensitive relative to the angle of the bar, the barrier bar pressure sensor is not position sensitive but is monitoring a gold contact snap action switch. The snap action switch requires pressure from the spring loaded tube assembly to remain in the secure state. When the barrier bar is removed, the switch is deactivated which causes an alarm. An optional second switch can be installed on each end of the barrier bar for increased security. A tamper cover is installed around the switch to deter tampering. Figure 31 shows a layout of the construction of the BB-1XL Barrier Bar Pressure Sensor.

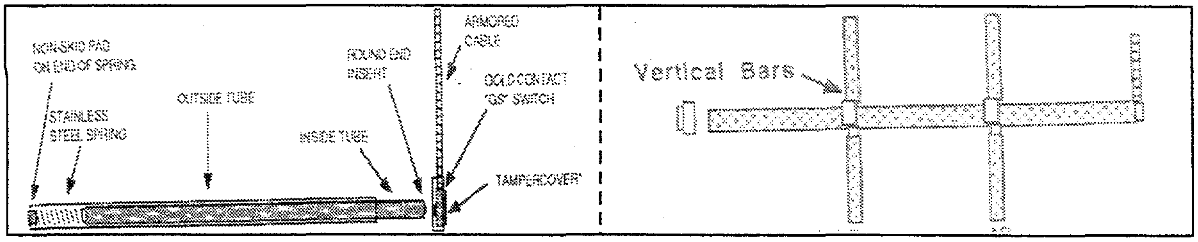


Figure 30. BB-1XL Barrier Bar Pressure Sensor Assembly

Cost

The cost of Sentrol's Barrier Bar Pressure Sensor, Model # BB1XL, was $25.95 each. Two barrier bar sensors were required to protect an 18-inch square air duct, bringing the total cost to $51.90. An additional snap action switch, #GS-1, is recommended for each barrier bar pressure switch assembly installation.

Application

Two barrier bar pressure sensor assemblies were installed in one end of the 18-inch air duct. Two barrier bar sensors were used in order to prevent an opening greater than 6-inches square that would allow the test object to pass through undetected. Access to the inside of the air duct was required to install the barrier bar sensors; the sensors were placed about one foot into one end of the 18-inch air duct. An optional set of two 12-inch vertical bars were added to the standard barrier bar to create a larger barrier. Positioning of each of the two barrier bar assemblies was required in order to prevent the 6-inch square test object from being pushed through unimpeded. The two sensors used to establish a detection zone were wired in a series where an alarm from either would cause an open circuit to the alarm monitoring system.

6.9.1 Detection Tests

Detection testing for Sentrol's Barrier Bar Pressure Sensor consisted of attempting to pass a 6-inch square test object through the protected area created by two barrier bar pressure sensors installed inside one end of the 18-inch air duct (see picture in section 6.9). Table 30 shows the results of detection tests.

# of Tests	# of Detections	# of Missed Detections	Comments
23	23	0	Results with single switch

Table 30. Barrier Bar Pressure Sensor Detection Test Results

The results of the detection tests were based on several attempts at defeat. The assumption was made that a snap action switch would be installed at each end of the barrier bar. Otherwise, the sensor could be easily defeated by keeping pressure on the end of the bar with the switch and moving the other end of the bar so that the test object could pass through. This required little skill or knowledge so detection data is based on the results of a snap action switch being installed at both ends of the barrier bar.

With switches installed on each end of the barrier bar, the sensor assembly had a high detection rate. Destructive defeat measures, such as cutting the bars, was not part of the detection tests and could dramatically change the detection results if successful.

6.9.2 Nuisance Alarm Tests

Nuisance alarm testing for Sentrol's Barrier Bar Pressure Sensor consisted of monitoring alarms over a period of time for any nuisance or false alarms. Table 31 shows the results of data collection for nuisance alarms during the evaluation test period.

Hours of Operation	# of Nuisance Alarms	Cause of Nuisance Alarm	Comments
926	0	-NA-	No recorded nuisance alarms

Table 31. Barrier Bar Pressure Sensor Nuisance Alarm Test Results

As the nuisance alarm test results show, the barrier bar pressure sensor had no recorded nuisance or false alarms during the evaluation period.

6.9.3 Installation and Maintenance Issues

Installation of the barrier bar pressure sensor in an air duct application required access to the inside of the air duct for installation, setup, and testing. To facilitate accessibility and installation, barrier bar tilt sensors were installed near a vent opening in the end of the 18-inch square air duct. To use this type of sensor to protect air ducts, it is necessary that the installer has direct access to the inside of the air duct where the sensor is to be installed. This would limit the use of barrier bar sensors to areas that a person could safely enter.

Installation of barrier bars required cutting the plastic portion of the tubes to the correct size for the area being monitored. A hole drilled into the air duct was required to allow the wiring from each switch to exit the duct. Each snap action switch could be installed with adhesive tape or with optional screws. Screws are recommended in air duct applications for both increased security and stability. Positioning of each of the two barrier bars required a meter to allow correct positioning of the bars. Overall, installation efforts of barrier bar technology would be directly related to the accessibility to the area the sensors are being installed in.

Any time testing on a barrier bar pressure sensor was done it required the horizontal bars to be moved slightly away from the snap action switch mounted to the duct at each end of the barrier bar. The sensor would return to the secure state whenever the bar was replaced. Realignment of the bar to the switch assembly required little effort.

6.9.4 Vulnerabilities

As mentioned earlier, the use of the barrier bar pressure switch with a single snap action switch is defeated with minimal effort. This would not be a recommended installation for air duct applications. The recommended approach of installing a snap action switch at each end of the spring loaded barrier bar would be a much more difficult, although not impossible, system to defeat.

In order to defeat a two switch assembly, a perpetrator would have to cut out a section of the barrier bar while maintaining pressure on each switch. This would require additional hardware to accomplish.

The current snap action switch assembly did not allow the addition of resistors inside the switch housing although armored cable was used to protect the cable coming out of the switch. Without line supervision at the switch, the vulnerability exists of a perpetrator bypassing the closed switch with a jumper and disabling the switch. The only current deterrent against this with the present configuration is the use of armored cable exiting the switch housing.

6.10 Summary of Results for Air Ducts

Several sensor types were evaluated for use as intrusion sensors in air duct applications. In addition to the sensors described in this report, microwave sensors were also considered as a conceptual approach to protecting air ducts against intrusions. This evaluation revealed that Microwave sensors could not be set up to monitor the inside of an air duct due the effect caused by the amount of sheet metal around the sensor. Multiple reflections would not allow the microwave sensor to stabilize. Therefore, microwave sensors were not permanently installed on an air duct for continued evaluations.

Table 32 is a summary of the results of the evaluation testing for each evaluated sensor's detection and nuisance alarm characteristics. The ***Detection %*** column was calculated based on the number of tests ran versus the number of tests missed. The ***Nuisance Alarms in 926 Hours*** column was the total number of nuisance alarms recorded from all sources during 926 hours of data collection. The ***Type Intrusion*** column shows whether the detection tests results were based on detecting a 6-inch square test object or a human intruder. It was assumed that any sensor that could detect a 6-inch square test object could also detect a human intruder.

Sensor		Detection %	Nuisance Alarms in 926 Hours	Type Intrusion
Fiber Optic (Fiber SenSys)		100%	1	6" Square Test Object
Photoelectric (Diffuse)		100%	667 *	6" Square Test Object
Photoelectric (Diffuse with background suppression)		100%	0	6" Square Test Object
Ultrasonic (Baumer Electric Single transducer)		100%	3	6" Square Test Object
Ultrasonic (Turck Dual transducer)		100%	0	6" Square Test Object
VMD (Gyyr)	CAM 2	100%	1	6" Square Test Object
	CAM 5	100%	26	
PIR (Sharpshooter, 24" duct)		100%	14	Human Intruder
PIR (Apollo S, 18" duct)		100%	0	Human Intruder
Strain Gauge (Microcell, direct mounting)		100%	0	Human Intruder
Strain Gauge (Microcell, re-enforced mounting)		100%	0	Human Intruder
Stress Detector (Pulsor, 24" duct)		100%	0	Human Intruder
Stress Detector (Pulsor, 18" duct)		100%	0	Human Intruder
Barrier Bar Pressure Switch (Sentrol)		100%	0	6" Square Test Object
Barrier Bar Mercury Tilt Switch (Sentrol)		100%	0	6" Square Test Object

Table 32. Summary of Evaluation Test Results for Air Ducts

** - 662 of these alarms occurred during the same night due to a unknown cause.*

The following sections will summarize the characteristics for each type sensor evaluated for use in an air duct application.

6.10.1 Fiber Optic Sensor

The Fiber SenSys Fiber Optic Sensor was one of the most expensive, least vulnerable systems evaluated. The Fiber SenSys Fiber Optic Sensor detected 100% of intrusions and had a low nuisance alarm rate. Access to the inside of the air duct is not required for installation although several holes drilled in the air duct is required. Nuisance alarms would increase on this sensor in areas of extreme vibration or in locations with very high air flow.

6.10.2 Photoelectric Sensor

Two types of diffuse photoelectric sensors were included in the air duct sensor evaluations. Both types detected 100% of intrusions during evaluation testing. The photoelectric sensor that had background suppression was a more expensive sensor but had no recorded nuisance alarms during the evaluation period. Several nuisance alarms were recorded on the photoelectric sensor that did not have background suppression, although most of the recorded alarms occurred during a single night.

Photoelectric sensors will have a high detection rate because the area being protected is no larger than 12-inch square inches per sensor. If the area is any larger, more than one sensor would be required to detect the 6-inch square test object.

6.10.3 Ultrasonic Sensor

Two types of ultrasonic sensors were included in the air duct sensor evaluations. Both types detected 100% of intrusions with the test object. The dual transducer ultrasonic sensor (Turck) had no recorded nuisance alarms during the test period. The single transducer ultrasonic sensor (Baumer) had three nuisance alarms during the evaluation period. The results of the evaluation indicate that ultrasonic sensors have a low nuisance alarm rate when used in an air duct application.

The primary vulnerability with ultrasonic sensors is the blind area right next to the sensor head. Therefore, the sensor must be off-set the distance of the blind zone during installation or else the sensor can easily be defeated.

The single transducer had a narrower detection beam than the dual transducer, which would restrict the size of an air duct that could be protected without the addition of an additional sensor.

6.10.4 Video Motion Detector (VMD)

The Gyyr video motion detector was evaluated on two cameras mounted in separate locations. Evaluation testing on VMD sensors in air ducts revealed that VMDs can have a high detection rate with a low number of nuisance alarms as long as the camera was not mounted near any external light source. A VMD sensor installed near external light sources will have a high nuisance alarm rate. The test results shown in Table 32 emphasize the fact that nuisance alarms increase when a VMD monitors a camera directed at a vent. The vent opening allowed external light changes to be visible to the camera.

6.10.5 Passive Infrared (PIR)

Passive infrared or PIR sensors were evaluated in the 18-inch square and the 24-inch square air ducts. Although the PIR sensors could not detect the 6-inch square test object, both had 100% detection rates for a human intruder. Nuisance alarms recorded during the evaluation period were low. One PIR had no alarms and the other had 14, all which occurred at night and within a 4-hour span of time. Installation of a PIR sensor does not require access to the inside of the air duct, although performance testing would, unless a simulated test device was used.

Although evaluation tests included simulated air duct conditions (including normal and cooled air flow testing), actual tests in operational air ducts may reveal different nuisance alarm results. This is primarily due to the fact that PIR sensors detect heat changes between an object and its background. The evaluation testing did not involve the temperature change extremes that can occur in an operational air duct.

6.10.6 Strain Gauge Sensor

Kistler-Morse's Microcell strain gauge sensor detected 100% of intrusions and no nuisance alarms recorded during the evaluation period. Different sensor mounting was evaluated with no differences in the overall detection and nuisance alarm results. Installation of the sensor required no access to the inside of the air duct although the sensor must have holes drilled in the duct for mounting.

The Microcell strain gauge sensor could be vulnerable to bridging attempts by a knowledgeable adversary. This vulnerability could be reduced by adding more Microcell sensors (connected to the same processor) which would extend the detection zone of the system making bridging more difficult.

The Microcell strain gauge sensor was designed to detect small weight changes in large containers such as grain bins. The results of the evaluation showed this technology to have high detection and low nuisance alarm rates although this particular sensor may be more sensor than is required to achieve the required results. There are less costly sensors of this type on the market that may produce similar results.

6.10.7 Stress Detector

The Pulsor Stress Detector from Sure Action, Inc., detected 100% of intrusions with no recorded nuisance alarms during the evaluation period. The Pulsor sensor is similar to the Microcell strain gauge sensor in that they both detect small weight changes when mounted to support structures. The Pulsor sensor is a low-cost sensor that requires no access to the inside of, and no holes in, an air duct for installation.

Multiple sensors can be installed and connected to the same processor to increase the size of the detection zone to minimize attempts of defeat by bridging. The Pulsor system is susceptible to slow changes in that the processor automatically adjusts to keep nuisance alarms low. This is different from the Microcell system processor that used preset high and low values which would alarm on very slow changes that exceeded its preset parameters. A benefit to the Pulsor is that its exact location cannot be determined from inside the air duct because mounting holes are not required.

6.10.8 Barrier Bar Pressure Sensor

Sentrol Corporation's Barrier Bar Pressure Sensor detected 100% of intrusions with no recorded nuisance alarms during the evaluation period. Detection data was gathered based on a pressure switch being installed at both ends of the barrier bar. This is an optional feature that must be included. Otherwise, the sensor is easily defeated. This type of sensor requires access to the inside of the air duct for installation.

The Barrier Bar Pressure Sensor is vulnerable to an adversary who has the proper equipment to cut out a section of the bar while maintaining pressure on both pressure switches. This defeat method would not be easy while working inside the confined space of an air duct but would be possible with the proper equipment.

6.10.9 Barrier Bar Tilt Sensor

Sentrol Corporation's Barrier Bar Tilt Sensor detected 100% of intrusions with no recorded nuisance alarms during the evaluation period. Initial installation of the Barrier Bar Tilt switch required careful positioning in order to set up the sensor properly. The size of the detection zone can be increased for larger air ducts by installing additional barrier bars. Installation should be such that there is not an opening large enough for the 6-inch test object to be passed through without having to physically move a barrier bar.

An adversary could possibly move the barrier bar very slowly and carefully without alarming the sensor as long as the bar was maintained in the same horizontal and vertical positions. While this defeat method is possible, considering the fact that an adversary would be working inside an air duct, defeat by this method would be not be an easy task.

A more secure concept of using barrier bar technology is to combine a pressure switch and tilt switch on the same bar. An adversary would then need to defeat both sensors to gain undetected access through the air duct.

7. Video Assessment in Areas of Restricted Passages

There is little value to having an intrusion detection system if a means of quickly assessing the cause of alarms from the intrusion detection system is not available. In order to achieve a timely means of assessment, there are two basic approaches available: 1) a guard can be stationed at or near each intrusion sensor or 2) cameras can be installed for video assessment. This portion of the evaluation focused on the issues associated with using video assessment in areas of restricted passage.

7.1 Equipment Selection, Cost, and Location

Areas of restricted passages are usually associated with interior applications where high resolution cameras are not necessary. Lower cost, smaller sized board cameras were the primary source of video selected for alarm assessment. The only exceptions were the extra cameras used to monitor the doors, which was CAM 1 in the suspended ceiling application and CAM 9 and CAM 10 in the air duct application. These were interior cameras previously used on other projects and were re-used to provide additional assessment cameras. These cameras were used to determine when activity was occurring near the test area that may cause the sensors under evaluation to alarm. Information on these cameras was not included because a permanent installation would not require them.

Table 33 shows camera and LED panel manufacturer, model #, cost, and the application they would be used in for alarm assessment. The Label column is for identifying the camera or LED panel based on the illustrated locations in Figure 32 for the suspended ceiling application and Figure 33 for the air duct application.

Manufacturer	Model #	Cost	Application	Label
CCTV Corp.	GBC CCD-100-2	$193	Suspended Ceiling	CAM 2
Sanyo	VDC-9212	$367	Suspended Ceiling	CAM 3
Sanyo	VDC-9212	$367	Suspended Ceiling	CAM 4
Visual Methods	IR6X6	$235	12", 18", 24", Air Ducts	LED Panel
CCTV Corp.	GBC MOD-275	$135	12" Air Duct	CAM 1
CCTV Corp.	GBC CCD-200-2	$230	12" Air Duct	CAM 2
Marshall Elec.	V-1204	$189	12" Air Duct	CAM 3
Marshall Elec.	V-1204	$189	18" Air Duct	CAM 4
Marshall Elec.	V-1209	$249	18" Air Duct	CAM 5
Marshall Elec.	V-1204	$189	18" Air Duct	CAM 6
Marshall Elec.	V-1209	$249	24" Air Duct	CAM 7
Marshall Elec.	V-1206WL	$219	24" Air Duct	CAM 8

Table 33. Assessment Equipment Information List

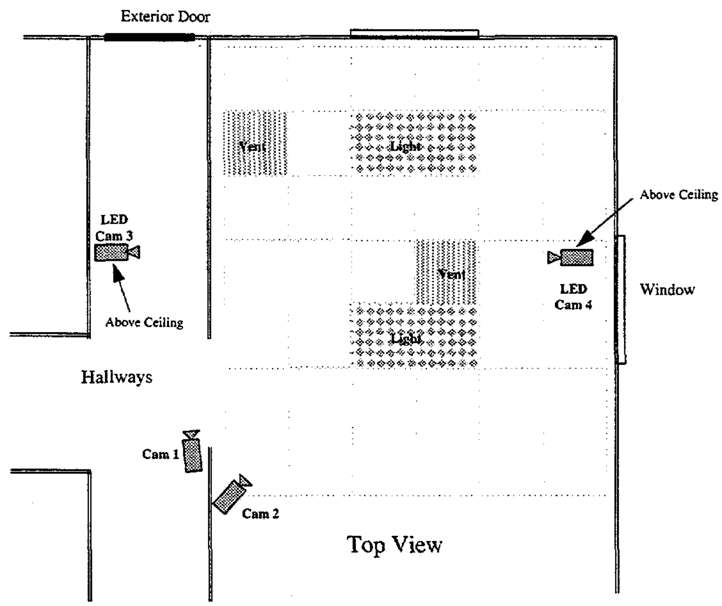


Figure 31. Suspended Ceiling Camera Locations

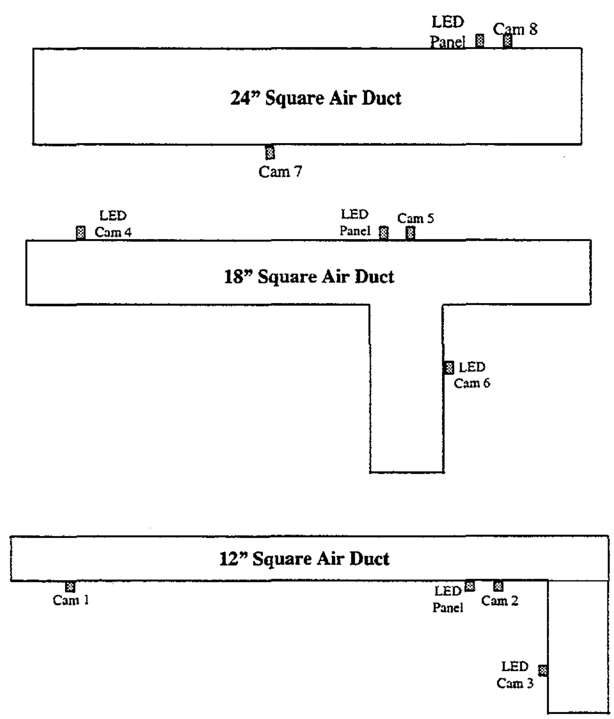


Figure 32. Air Duct Camera and LED Panel Locations

7.2 Camera Field of View and Equipment Mounting

Basic requirements should be followed in the selection and installation of assessment equipment for use in areas of restricted passage. The basic requirements include a camera and lens combination that covers the same area as a sensor's detection zone, the assessment area must have enough light for assessment to occur, and camera quality should have sufficient resolution to allow object classification for assessment. All the cameras evaluated were interior board type CCD cameras. Additional light for areas was provided by LED panels or cameras with onboard LEDs.

7.2.1 Assessment for Suspended Ceilings

There were four cameras used during the alarm assessment evaluation for the suspended ceiling testing. CAM 1 was an existing interior camera used to strictly monitor the exterior door of the test area for alarms caused by the personnel entering and leaving the building. CAM 2 was mounted underneath the ceiling tiles and was the primary assessment camera for the A.I.R. shield sensor and for any intrusions attempted from the room into the area above the suspended ceiling. CAM 3 and CAM 4 were two LED cameras mounted above the suspended ceiling tiles to monitor alarms and intrusion attempts that could not be viewed from CAM 2. The following paragraphs contain specific features for each of the cameras, as well as each camera's field of view.

<u>CAM 2</u>

CAM 2 is a GBC 1/3 inch, 12 Vdc, CCD camera. The camera features include built-in electronic shutter, 320 lines of resolution, 2 lux, built-in 2.5 mm lens (optional lens available), and is sized smaller than a pack of cigarettes. Figure 34 shows a picture of the camera mounted to the wall, as well as the camera's field of view.

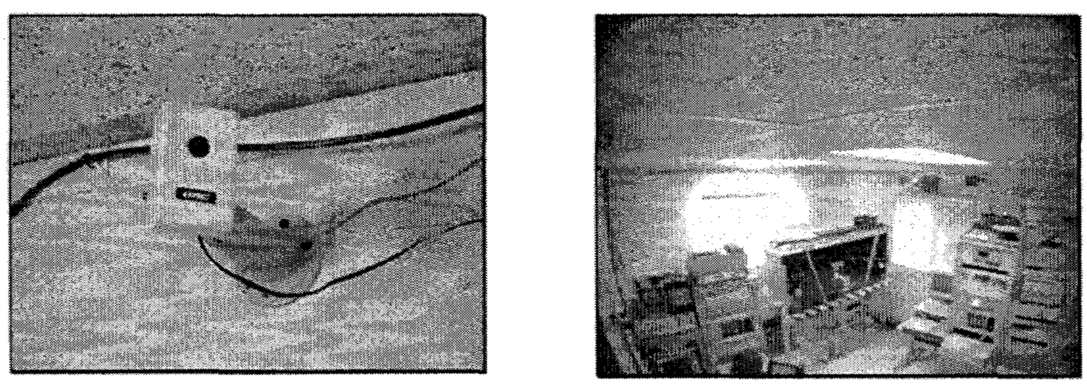


Figure 33. GBC Miniature Surveillance Camera (CAM 2)

CAM 2 was installed primarily to access alarms from the Air Shield sensor. This camera's field of view, shown in Figure 34, allowed assessment of alarms caused by personnel attempting to gain access to the area above the suspended ceiling. Alarms caused by small insects were not easily determined with this camera. Higher resolution cameras or multiple cameras covering smaller areas would allow assessment of alarms caused by small objects such as insects, although the tradeoff is an increased cost for more assessment equipment.

Lighting for CAM 2 was provided by the florescent lights in the room. Figure 34 shows the camera pointed at two exterior windows. This should be avoided if possible because the sunlight entering from the windows during the day could cause washed out areas in the video scene. A proper installation would have the camera facing away from the windows while still covering the protected area.

CAM 3

CAM 3 is a Sanyo 6 inch, 12 Vdc, CCD camera with 18 onboard infrared LEDs. The camera has an electronic iris and 400 lines of resolution. The camera was packaged to be disguised as a smoke detector. For the suspended ceiling application, the outer cover (made of smoked glass) was removed to allow more light from the LEDs on the camera to be utilized. Figure 35 shows a picture of the camera with the *cover on* and the field of view when mounted above the suspended ceiling.

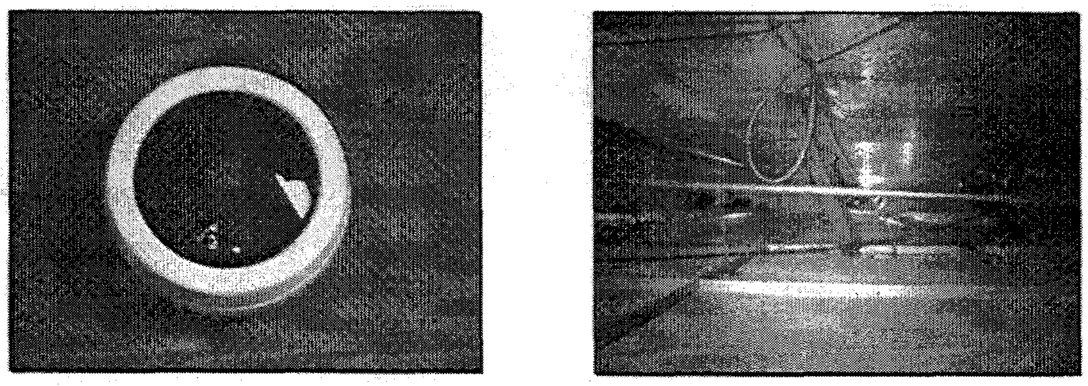
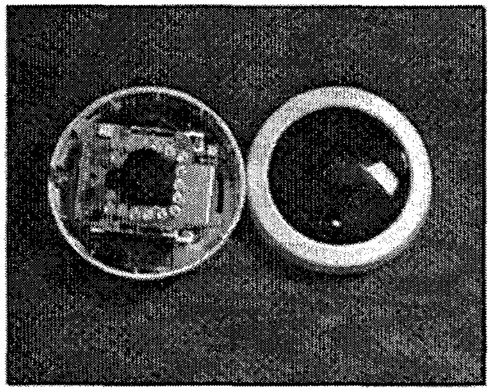


Figure 34. Sanyo LED Camera (CAM 3)

CAM 3 was installed to assess alarms from sources that could not be determined from CAM 1. An example would be if an adversary entered the protected area through the roof or any area other than from inside the protected room. CAM 3 has its own light source composed of several onboard LEDs. The additional light source seen in Figure 35 is from the back side of the florescent lights in the room. The light generated by another identical LED camera (CAM 4) installed above the suspended ceiling on the opposite side of the room can also be seen.

CAM 4

CAM 4 is identical to CAM 3 but was located at a different location in the suspended ceiling (see Figure 32). Most configurations above suspended ceilings will require more than one camera for assessment due to the limited views available in above ceiling applications. Figure 36 shows a picture of the camera with the *cover off* and the field of view when mounted above the suspended ceiling. Care should be used when installing the cameras with onboard LEDs so that reflections from the LEDs do not create blooming in the cameras' view. CAM 3 and CAM 4 had to be manually focused once installed above the suspended ceiling.



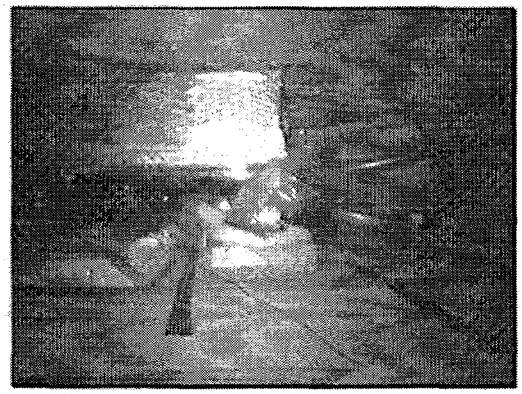


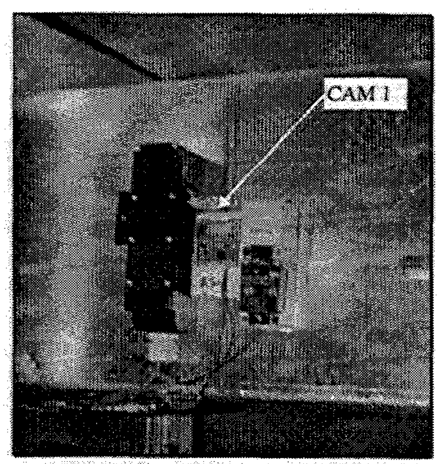
Figure 35. Sanyo LED Camera (CAM 4)

7.2.2 Assessment in Air Ducts

There was a total of ten cameras used for assessment purposes in air duct applications. Eight of the cameras, CAM 1 thru CAM 8, assessed the inside of the air ducts. Two cameras, CAM 9 and CAM 10, assessed activity occurring on the outside of the air ducts. It was necessary to have cameras viewing the inside and the outside of the air ducts in order to determine most causes of nuisance alarms. A brief description and picture of each camera mounted to an air duct, with its associated field of view, will be presented in the following paragraphs. A graphical illustration showing approximate locations for each of the cameras listed was previously shown in Figure 33.

<u>CAM 1</u>

CAM 1 is a miniature board camera from CCTV Corporation, Part # GBC-MOD-275. The camera is a CCD 1/3-inch format camera with 380 lines of resolution, a .3 lux light rating, and a 3.6mm lens. The camera size is 1.93 inches high x 1.93 inches wide and does not have a case or housing. The camera is powered from an external 12 Vdc supply (not included) and has external connections for video out and power. Figure 37 shows the camera mounted to a block of wood that is attached to a 12 inch square air duct.



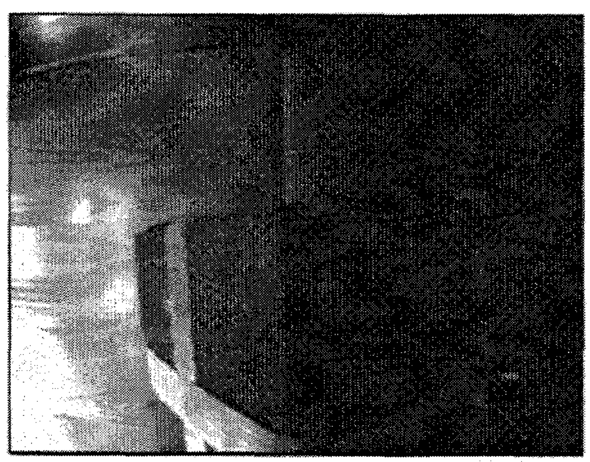


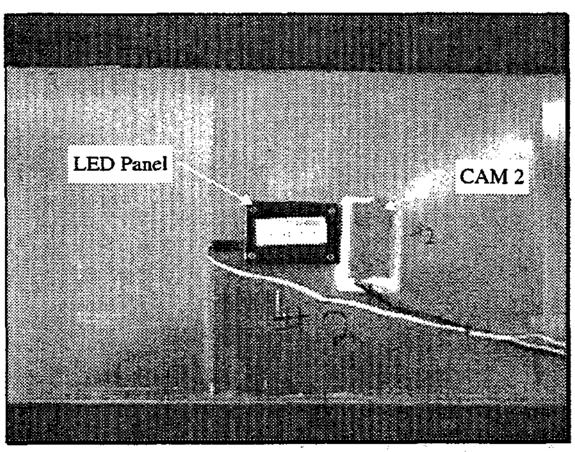
Figure 36. CCTV Corporation's GBC MOD-275 Camera (CAM 1)

The primary purpose of CAM 1 was to provide alarm assessment inside the 12-inch square air duct for alarms from the photoelectric and ultrasonic sensors. A small hole was drilled in the air duct allowing the lens of the camera to view the inside of the air duct. Figure 37 shows the 6-inch square test target as it passed through the field of view of CAM 1. The camera was mounted approximately 2 feet from a vent, which provided sufficient light for assessment purposes. The photoelectric sensor's beam of light illuminated the test target when it passed through the sensor's detection zone which provided an additional source of light for the camera.

CAM 2 with LED Panel

CAM 2 is a microminiature, low-light, surveillance camera with audio from CCTV Corporation, Part # GBC-CCD-200-2. The camera has a 1/3-inch format with a built-in electronic shutter and is smaller than a pack of cigarettes. The camera has 420 lines of resolution, .03 lux, and a built-in 2.5mm ultra wide angle lens (other lens sizes available). The camera is powered from a 12 Vdc power source (supplied) and is packaged in a plastic housing. The audio portion of this camera was not tested as part of this evaluation.

The IR6X6 LED Panel from Visual Methods, Inc., is an indoor illuminator that emits infrared light invisible to the human eye. According to the manufacturer's specifications, in total darkness, a single IR6X6 panel provides sufficient light to positively identify an individual from a distance of more than 30 feet. The solid state illuminator operates without fans and is powered by a 12 Vdc source (supplied). The unit can be battery powered and draws 500ma at 12 Vdc. The size of the illuminator is 3 inches x 2 inches x 1 inch. Figure 38 shows a picture of CAM 2 and an LED Panel mounted to a 12-inch square air duct. Figure 38 also shows a picture of the field of view from CAM 2, with the test target in the scene.



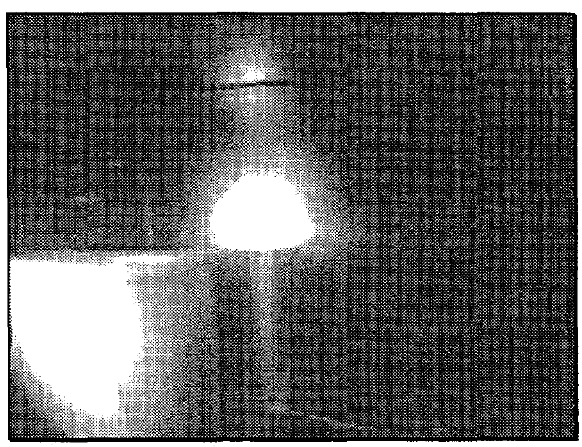


Figure 37. CCTV Corporation's GBC CCD-200-2 Camera (CAM 2) and LED Panel

The primary purpose of CAM 2 and the LED Panel was to provide a camera and light source to connect to a VMD sensor. This camera location was selected to be as far as possible away from external light sources from vent openings. This was because the VMD sensor would have fewer nuisance alarms when it was not influenced by light changes from external sources. A hole was drilled in the air duct to allow access for the camera lens and the LED panel.

As can be seen in Figure 38, the test target is illuminated by the LED Panel. Also a bright circle of light is reflected off the back side of the air duct from the LED Panel. This could probably be avoided by angling the camera away from the LED Panel or increasing the mounting distance between the camera and LED Panel.

<u>CAM 3</u>

CAM 3 is a miniature board camera with a built-in infrared light source and is manufactured by Marshall Electronics, Part # V-1204. The camera's features include 380 TV lines of resolution, .5 lux sensitivity, 6 hi-output infrared LEDs that illuminate out to 10 feet in total darkness, auto-electric iris control, built-in 3.3mm ultra wide angle lens, and runs on 12 Vdc at 120 ma. The camera size is 1.95 inches wide x 3.9 inches high x .98 inches deep when not packaged in the optional cases. The camera is available pre-packaged in cases or as a bare PC board. Figure 39 shows CAM 3 mounted to a piece of wood and then mounted to a 12-inch square air duct. Figure 39 also shows the test target in CAM 3's field of view. Different mountings of the same camera (#V-1204) are shown in Figures 40 and 42.

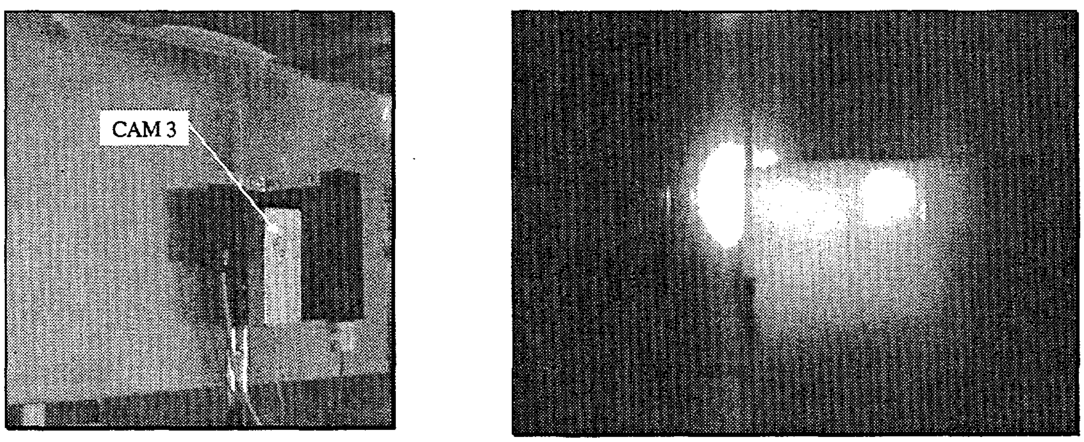


Figure 38. Marshall Electronic's V-1204 LED Camera (CAM 3)

The primary purpose for CAM 3 was to provide assessment for the photoelectric and ultrasonic sensors mounted on both sides as shown in Figure 39. The camera's wide angle lens and added light provided a field of view that covered the detection zones created by the photoelectric and ultrasonic sensors. Figure 39 shows the effect of the camera's on-board LEDs when reflected off the inside of the air duct. This blooming effect can be minimized by angling the camera so that the infrared light generated by the LEDs is directed down the air duct instead of directly across it. An example of this same camera mounted at an angle is shown in Figure 40. A large hole must be drilled in the side of the air duct to allow angling a camera to look down the length of an air duct. A smaller hole can be used when the camera is looking directly across the width of the air duct.

CAM 4

CAM 4 is a Marshall Electronic's camera, Part # V-1204, identical to the one described as CAM 3. The primary purpose of CAM 4 is to provide alarm assessment information for the fiber optic sensor installed inside the 18-inch square air duct. CAM 4 was mounted at an angle to minimize the reflections from the camera's on-board LEDs and to cover more area inside the 18-inch square air duct. If the camera was not mounted at an angle, the 6-inch square test object could pass through the 18-inch square air duct without appearing in CAM 4's field of view. A larger hole had to be cut in the air duct to allow CAM 4 to be mounted at the required angle. Figure 40 shows CAM 4 mounted to the 18-inch square air duct and CAM 4's field of view. Notice that the camera is mounted at the maximum angle possible without cutting a hole large enough to insert the camera inside the air duct. Some applications may require the camera to be mounted in a way so that the camera lens is actually inside the air duct.

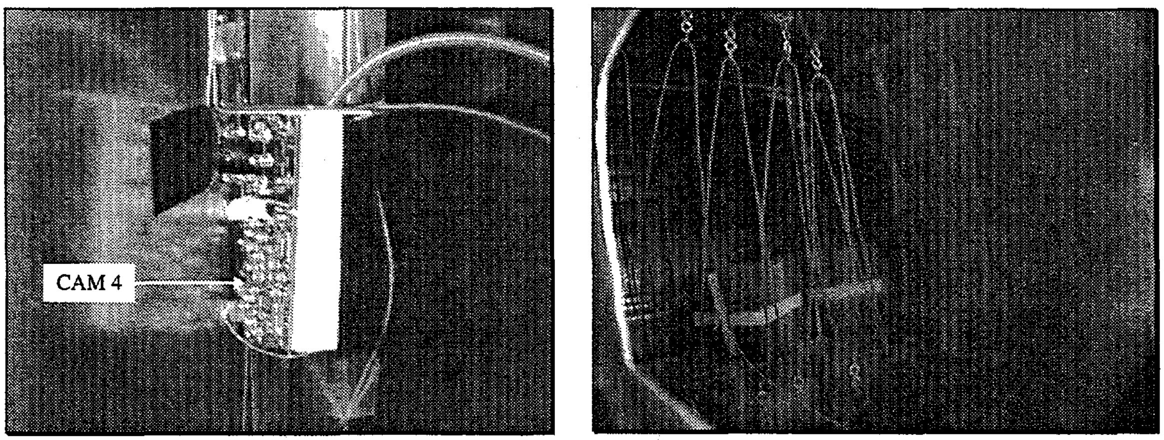


Figure 39. Marshall Electronic's V-1204 LED Camera (CAM 4)

A total of three Marshall Electronic's V-1204 cameras were used to evaluate assessment in air duct applications. The cameras evaluated were not in cases (as can be seen in Figure 40). Permanent installations would require the cameras to be housed in cases available from the manufacturer.

CAM 5 with LED Panel

CAM 5 is a Marshall Electronics, Part # V-1209, microminiature CCD camera that features 380 horizontal lines of resolution with a 3.6 mm lens. The camera is housed in a plastic housing and requires 9 Vdc to operate. The camera's size is approximately 1 inch x 1 inch .75inches. This model camera was purchased prior to the evaluation testing and is currently a discontinued camera. Similar cameras are available on the commercial market.

CAM 5 was used with a Visual Methods, Inc., IR6X6 LED panel to provide light inside the air duct. This LED panel was the only type used in this evaluation and was described previously with CAM 2. Figure 41 shows CAM 5 and the LED panel mounted at the "T" section of the 18-inch square air duct. This mounting location allowed the camera to view any objects passing in any direction through this section of the air duct. The LED panel in combination with external light provided the assessment view pictured in Figure 41.

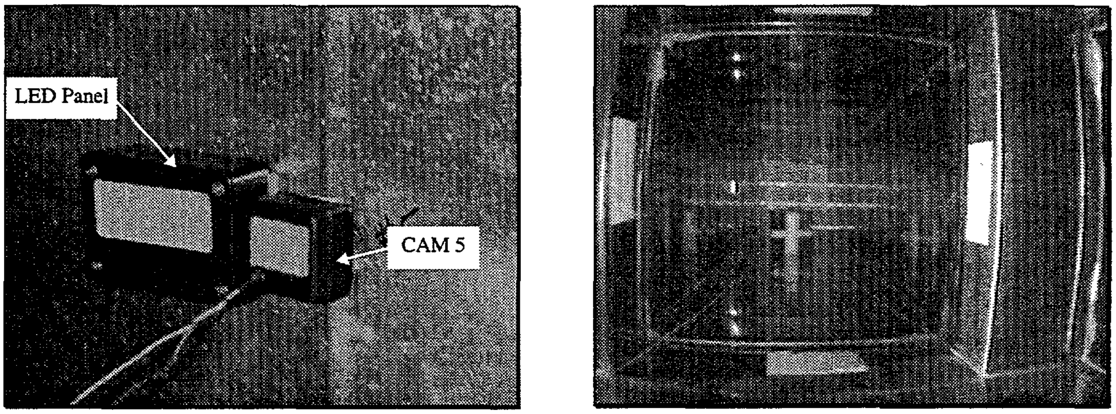


Figure 40. Marshall Electronic's V-1209 Camera (CAM 5) with LED Panel

CAM 5 served two functions in the evaluation testing. First, it provided assessment for the barrier bar tilt switch mounted at the end of the air duct and served as a backup camera to assess alarms from the Pulsor stress sensor. Secondly, the CAM 5 used the camera's output as a VMD sensor. The camera view was influenced by external light sources because it was aimed at a vent. For this reason, it was selected as a video source to evaluate a VMD sensor in air duct applications. Holes had to be drilled in the air duct for both the camera and the LED panel.

CAM 6

CAM 6 is a Marshall Electronic's, Part # V-1204, LED board camera identical to CAM 3 and CAM 4, which was described previously. The primary purpose of CAM 6 was to monitor alarms generated by the Pulsor stress sensor installed on the 18-inch square air duct. Figure 42 shows the mounting of CAM 6 and its associated field of view. As previously mentioned, when a camera with LEDs is directed at a close reflective object such as the back side of the air duct shown in Figure 42, the camera will have a blooming effect. The field of view shown in Figure 42 shows the test target inside the air duct.

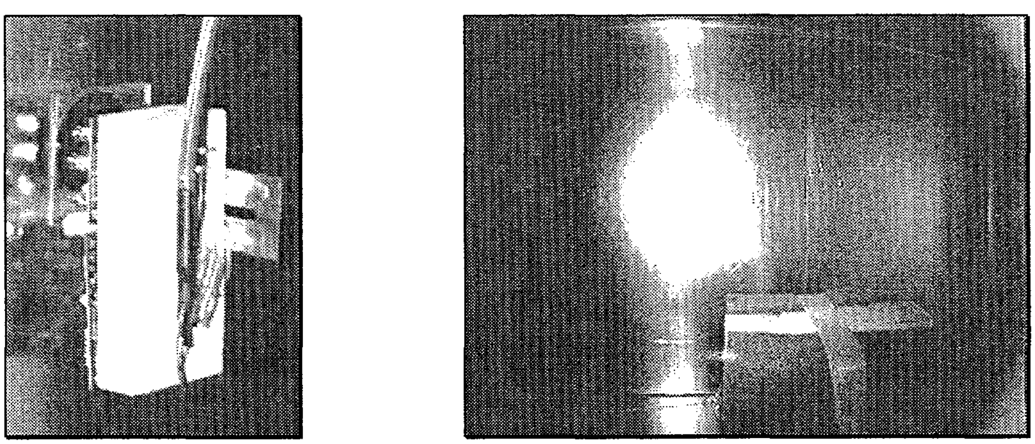


Figure 41. Marshall Electronic's V-1204 LED Camera (CAM 6)

CAM 7

CAM 7 is a Marshall Electronic's V-1209 microminiature camera identical to the previously described CAM 5. Figure 43 shows CAM 7 mounted to the 24-inch square air duct. The camera was mounted on a corner of the air duct to cover as much of the width of air duct without angling the camera. The primary purpose of CAM 7 was to provide assessment for the PIR and Pulsor stress sensors installed on the 24-inch square air duct. Although this camera's field of view did not cover the entire width of the air duct, it did provide a sufficient view for assessment of an adversary in the air duct. External lights from vent openings in the air duct provided light for this camera.

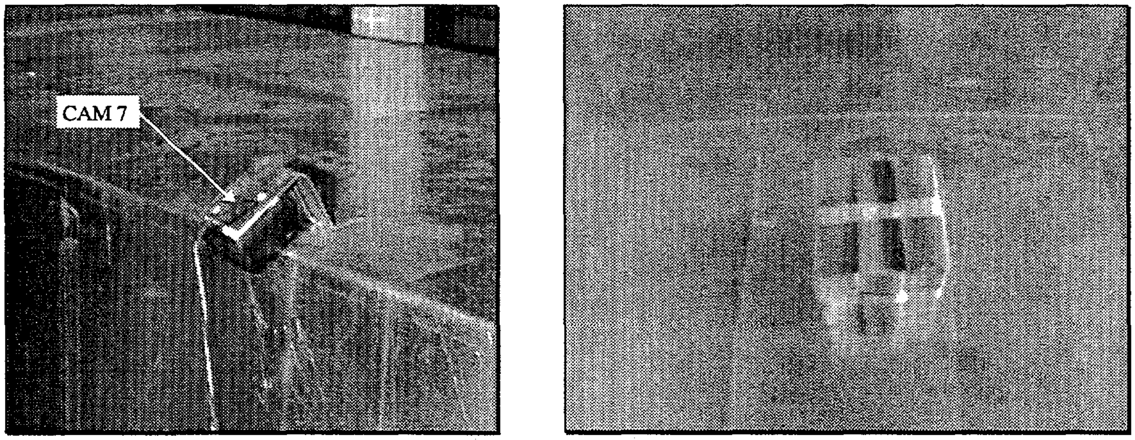


Figure 42. Marshall Electronic's V-1209 Camera (CAM 7)

CAM 8 with LED Panel

CAM 8 is a Marshall Electronic's microminiature 1/3-inch CCD camera, Part # V1206-WL. The camera features 380 TV lines of resolution, .05 FC sensitivity, built-in ultra wide angle 3.6 mm lens (optional C-mount adapter), and electronic auto iris with a range of .5 to 80 lux. The camera is available as a bare PC board, or in small enclosures as shown in Figure 44. The camera is powered by 12 Vdc at 140 ma. and the PC board size is 1.8 inches wide x .81 inches high x 2.7 inches long. A previously described LED panel was also used with CAM 8. Figure 44 shows CAM 8 and the LED panel mounted to a 24-inch air duct.

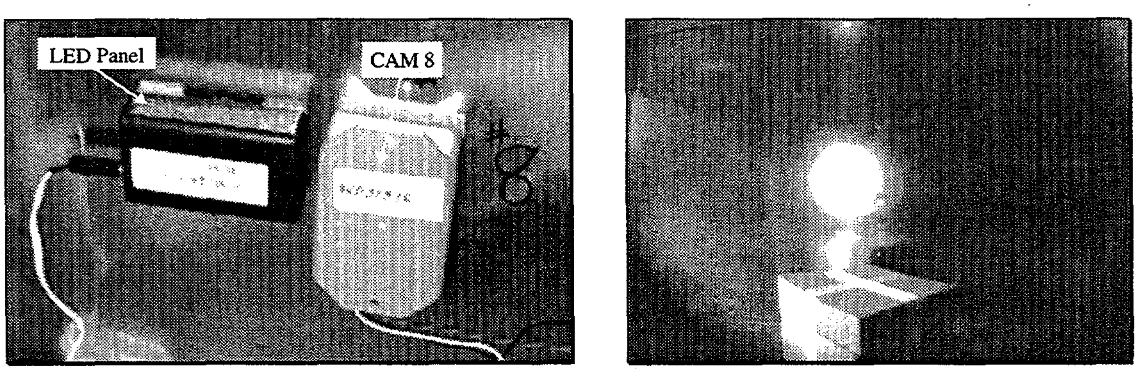


Figure 43. Marshall Electronic's V1206-WL Camera (CAM 8) with LED Panel

The primary purpose of CAM 8 was to assess alarms from the Kistler-Morse strain gauge sensors mounted to the side of the 24-inch square air duct. CAM 8 provided an interior view of the area directly inside the air duct proportional to where the sensors were mounted. Figure 44 shows the field of view presented by CAM 8. Due to the range of area covered by the strain gauge sensor, mounting the camera at an angle would be necessary to cover the sensors entire detection zone.

7.3 Assessment Issues in Areas of Restricted Passage

Several issues should be considered when designing assessment systems for use in areas of restricted passages. Section 7.3.1 will discuss design issues specific to suspended ceiling applications and Section 7.3.2 will discuss design issues specific to air duct applications. Issues that will be addressed include camera selection, camera location, camera coverage, and adequate lighting for assessment.

An issue pertaining to installing any equipment, including cameras, in areas of restricted passage is to ensure that no safety or fire codes are violated. An example is that some areas may require all installed equipment to be plenum rated. Special enclosures may be required to meet all fire and safety codes. This evaluation did not include researching the fire or safety hazards associated with installing equipment in suspended ceilings or on air ducts.

7.3.1 Assessment Issues in Suspended Ceilings

Assessment in suspended ceiling applications will not require the high-resolution, high-cost cameras associated with assessment in perimeter applications. The lower-resolution, smaller-size, lower-cost board cameras now available on the commercial market will provide adequate assessment in most suspended ceiling applications. The limited area that a single camera can cover, due to obstructions associated with suspended ceiling areas, will not require the high resolution associated with assessment cameras that have wide field of views. The trade off is that multiple cameras will be required to monitor smaller defined areas.

When designing an assessment system for suspended ceiling applications, a single camera may not provide adequate assessment. The area above a suspended ceiling has obstructions that limit the area a single camera can cover. At a minimum, an assessment system must cover an area equal to an installed sensor's detection zone. Another reason multiple cameras would be required in most suspended ceiling applications is the direction of attack used by an adversary. If an adversary enters the suspended ceiling area through the walls above a suspended ceiling or through the true ceiling, a camera viewing the area above the suspended ceiling would be required for assessment purposes. If an adversary is in the protected room that has a suspended ceiling and attempts to place an object into the restricted area above the suspended ceiling, a camera viewing the underneath side of the suspended ceiling would be necessary for assessment. The camera above the suspended ceiling may show a ceiling tile moving, but it cannot determine what caused the ceiling tile to move.

As in any assessment system design, adequate lighting is required for a camera to provide alarm assessment. Although the area above a suspended ceiling gets some light from external sources (back side of florescent lights), it was not sufficient for alarm assessment. Therefore, additional lighting was supplied. This evaluation looked at low-power, infrared light sources to provide this additional light. Some of the board cameras evaluated were purchased with on-board infrared LEDs that provided illumination of objects up to approximately 10 feet. A combination of cameras with on-board LEDs provided sufficient light for assessment in the area used for the evaluation. Although infrared lights were evaluated, any light source could be used to light the area above a suspended ceiling as long as basic camera and lighting layout design criteria was followed. This includes not aiming cameras directly at a light source or any reflected light source and maintaining light to dark ratios that do not create blind areas in the camera's field of view.

7.3.2 Assessment Issues in Air Ducts

Board cameras were selected for use as cameras for video assessment in the air duct evaluation. Small camera size and short viewing distances in air duct applications made board cameras a good choice. Added benefits of selecting board cameras for video assessment in air duct applications were in lower-cost, power-efficient equipment.

Camera location and mounting in an air duct application is dependent on the size of detection zone being covered by the camera. A board camera with a wide angle lens mounted directly to the side of an air duct may not provide adequate coverage of the area inside the air duct. It was determined that angling the camera to look down the length of an air duct provided the best coverage of most sensor's detection zones. Side mounting was only adequate in the smaller (12-inch square) air ducts where a sensor's detection zone was narrow (e.g., ultrasonic, photoelectric, or VMD sensors).

Mounting a board camera at an angle to allow more coverage inside an air duct in many instances would require the lens portion of the camera to protrude inside the air duct. The larger the camera the larger the mounting hole to angle the camera becomes. Slightly more expensive cameras with small remote lenses would possibly be a better choice when it is necessary to angle a camera's view.

The sensors evaluated for intrusion detection in air duct applications were mounted on the outside of the air duct. The sensor's detection zone was on the inside of the air duct. In order to protect against tampering with the sensor's controls, the sensor should be housed in an enclosure with a tamper switch. Video must then be provided for the area outside the air duct to assess alarms from the tamper switch. This should be a consideration when designing the assessment system and determining sensor and camera locations.

Providing lighting for video assessment inside air ducts was required in all instances except when sensors were located next to a vent, which provided sufficient light for assessment. This would require that the light source near the vent be always left on, otherwise additional lighting would be required. Most areas inside air ducts will require an additional source of light for video assessment. The evaluation of light sources for video assessment inside air ducts included using cameras with on-board infrared LEDs as well as installing separate infrared LED panels. The evaluation revealed that either of these concepts to provide additional light would work as long as proper camera angles and placement of infrared light sources were followed. The separate LED panel provided more light than the LEDs installed on the cameras. The trade off is that the cost for an LED panel is near the same cost of a board camera that already has on-board LEDs.

As the pictures showing the camera's field of view in Section 7 show, the sheet metal, of which air ducts are constructed, is a highly reflective material. When a camera and its associated light source are not angled to look down an air duct, a bright circle of reflected light from the side of the air duct is present in the camera's field of view. This does not provide a good video scene for assessment. Because of the highly reflective nature of sheet metal used in construction of air ducts, all reflected light sources may not be able to be avoided but should be minimized. Pointing a camera directly at a vent in an air duct that could be subjected to external light sources can cause assessment to be difficult. These factors should be considered when adding an additional light source for viewing the inside of an air duct.

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