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SECURITY AS A DESIGN PARAMETER FOR HEATING, VENTILATION AND AIR-CONDITIONING SYSTEMS

A Thesis in

Architectural Engineering

by

John R. Volcheck

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

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ABSTRACT

Heating, ventilating, and air-conditioning (HVAC) systems are designed to meet a number of performance criteria including ventilation, energy consumption standards, and indoor air-quality. Recent biological weapons attacks on buildings and the prospect of chemical attacks due to terrorism have placed a new emphasis on security as a building design parameter. A number of government and private-sector organizations (e.g., the U.S. Army Corps of Engineers, ASHRAE, NIOSH, and IFMA) have published guidlines for improving the resistance of buildings to airborne biological and chemical releases. These documents have not, to date, been critically compared in the literature. An extensive literature review reveals that existing guidance does not fully define a process that leads to affordable improvements in HVAC security.

This thesis documents and evaluates the process of designing an HVAC system for commercial buildings with security as a priority. Each step in the procedure, from threat assessment to attack scenario modeling are analyzed and recommendations made for optimization in regards to HVAC system selection. The objective of this thesis is to provide enhancements to the HVAC design process and apply it to a case study utilizing a real building.

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1. Introduction

1.1 Background

Engineers and architects are tasked with designing a building environment that meets ever-increasing standards of thermal comfort, indoor air quality, energy efficiency, functionality, and safety. When referring to "security" in mechanical systems, it is a reference to an HVAC system that assists in the protection of the building occupants from a biological or chemical agent. Prior to the September 11th 2001 attacks on the World Trade center and Pentagon, commercial buildings utilizing secure mechanical systems were limited to specific industries. Government (i.e. research and high security), healthcare (hospitals and pharmaceuticals), and military applications are examples of industries that routinely design environments with contaminant control as a priority. Effective control of contaminants is possible in these industries because the source, concentration, and type of agents are known. Hospitals have operating and isolation rooms that use filtration and zoning to prevent internal cross contamination of known airborne pathogens. Terrorism has added a new element to engineering mechanical systems because of the vast types of agents that could be used. Building owners and engineers must now ask the questions of "Which agent poses the greatest threat to this building and how can we provide added security?"

Following the World Trade Center/Pentagon attacks, the threat of terrorism and subsequent anthrax dispersion in postal facilities exposed vulnerabilities in the current mechanical design process. The primary weak point is that mechanical security is typically never addressed in the design phase of commercial buildings. Commercial facilities such as airports, large office complexes, and manufacturing buildings now require some level of mechanical security in conjunction with architectural features. Security measures can be as simple as relocation of outside air intakes or involve more rigorous air-cleaning technologies such as ultraviolet germicidal irradiation (UVGI). Future designs will require engineers to perform a threat assessment in addition to the standard load calculations and HVAC system selection. Building owners are looking towards engineers to develop guidance and solutions that are reasonable and can be economically implemented.

1.2 Project Objective

The objective of this project is to enhance the existing HVAC design methodology in commercial buildings and optimize security. The evaluation will encompass threat assessment, potential agent types, air cleaning technologies, HVAC system types/selection, and available modeling programs. The capstone of the project will apply the process to a case study commercial building and provide recommendations for optimization.

1.3 Project Scope

The scope of this study encompasses an existing commercial five story facility in which to model an HVAC design approach. The task was to bring together the large amounts of information in different fields (mechanical, microbiology, military/government), and develop a useful enhancement to the existing design process used by HVAC consulting engineers.

1.4 Project Approach

The first step in the project was to conduct an extensive literature review of existing guidance for each subject area of the process. Sources such as ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers), the GSA (General Services Administration), and the United States Military were the starting points for the information search.

Analysis of the available agents found in the literature review was the next step. The goal was to create concise tables of biological and chemical agents that are most likely to be used in an attack. In the biological realm, there are hundreds of microorganisms, but relatively few have characteristics adaptable to weapons. Similarly, for chemicals the focus was on the agents with weapons potential. The mode of transmission for agents was limited to airborne, because this poses the greatest threat to an HVAC system.

The next phase of the project evaluates the different HVAC systems such as re-circulating and 100% outside air, and compares the potential protective capability of each system. Available air cleaning technologies are reviewed for compatibility with HVAC system types and effectiveness in eliminating agents.

Existing software for simulating building attack scenarios are addressed along with the overall capabilities and complexities. The apex of the research will combine all of the individual steps into a case study of an actual high threat commercial building.

1.5 Security Disclaimer

The research, materials, and conclusions in this thesis contain no information on how to construct or disperse a biological or chemical weapon. The commercial building utilized in the final simulation will not be identified by name or location, and will be slightly architecturally altered as an additional precaution. The building attack simulations will be detailed enough to serve as a benefit to HVAC consulting engineers, without providing vulnerabilities to those who may do harm. Any information within the simulation that could be used for harmful intentions will be deleted. In addition, the views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

2. Literature Review

2.1 Introduction

Considerations for the design of heating, ventilation and air-conditioning (HVAC) systems typically include comfort, ventilation, space requirements, first cost, operating and maintenance cost. In addition, system design is affected by code requirements for fire and smoke, earthquake and refrigerant safety. Inspection of any representative cross-section of buildings reveals that, except in special circumstances, the resistance of HVAC systems to airborne hazards is either a low priority or not addressed at all. One clear example of this fact is the widespread use of unprotected ground-level outside air intakes. Another is the general modest level of air cleaning capability of typical systems. A third is the frequent use of system zoning that ensures rapid dissemination of contaminants from their point of origin throughout a building via re-circulating air distribution systems. Only a small number of government, industrial, medical, and laboratory facilities routinely incorporate features intended to contain and or destroy airborne contaminants with methods such as once-through air supply or high efficiency filtration.

The September 11 attacks on the World Trade Center and Pentagon, subsequent anthrax mailings, and the knowledge that terrorist organizations around the world may possess chemical, biological or radiological weapons (CBRWs) have altered owner and designer perceptions. The awareness that any building could be the target of a terroristic CBRW attack has fostered much discussion of how the security of existing and future buildings can be improved. This dialogue has resulted in the publication of several new guidance documents intended to assist owners and designers to reduce the vulnerability of buildings to CBRW attacks and other "extraordinary events." The objective of this literature review is to analyze and compare the scope and nature of the recommendations found in these documents, to note how new guidance supplements or supercedes prior design practices and to identify any significant deficiencies that should be addressed by future standards and guidelines.

2.2 Guidance Documents

Prior to September 11, guidance pertaining to building and HVAC security was derived primarily from sources catering to government applications. The concept of "safe" design is not new, but it was never considered a priority for commercial buildings. The scope of HVAC security recommendations in these documents is generic and typically refers the designer to applicable ASHRAE standards based on the application. Table 2-1 lists the primary guidance literature available before the attacks and new documents published subsequent to them.

Table 2-1: Guidance Before/After Attacks

Pre 9/11/01 Guidance
National Research Council Commission on Engineering and Technical Systems (CETS) *Protection of Federal Office Buildings against Terrorism* (1988)
General Services Administration (GSA) *Public Buildings Service: Balancing Security and Openness* (1999) *Facilities Standards: Mechanical Engineering* (2000c) *Facilities Standards: Security Design* (2000d)
Post 9/11/01 Guidance
American Institute of Architects (AIA) *Building Security Through Design* (2001)
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) *Report of Presidential Ad Hoc Committee for Building Health and Safety under Extraordinary Incidents* (2003)
International Facility Management Association (IFMA) *Addressing the Threat of Terrorism: Guidelines for Prevention and Response* (2002)
National Air Filtration Association (NAFA) *Position Statement on Bio-Terrorism* (2001)
National Institute for Occupational Safety and Health (NIOSH) *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks* (2002) *Guidance for Filtration & Air-Cleaning Systems to Protect Building Environments From Airborne Chemical, Biological, or Radiological Attacks* (2003)
U.S. Army Corps of Engineers (USACE) *Protecting Buildings and their Occupants from Airborne Hazards* (2001)
Kowalski *Immune Building Systems Technology* (2002)

The General Services Administration (GSA 1999, 2000a, 2000b) documents focus on discipline specific requirements for meeting sustainability, energy performance and quality targets in construction. The security issues addressed focus on site development. Similarly, the CETS guidance provides threat checklists, but the focal point is site security.

Documents issued subsequent to 9/11/01 more directly address security concerns. All sources recommend incorporating a threat assessment and providing locks for mechanical rooms into the design considerations. The AIA document provides a brief overview of security, but specific direction on HVAC design is limited. The IFMA guidelines are written primarily to assist facility owners/operators in developing a terrorism response plan. The HVAC portion recommends using better filtration techniques and rapid agent detection systems. The ASHRAE (2003) guidance is the most comprehensive. Multiple facets of security design are addressed, including risk assessment to determine the acceptable degree of vulnerability of a building.

The NAFA literature provides a brief overview of possible contaminants in relation to particle size. The U.S. Army Corps of Engineers literature suggests a variety of HVAC security measures aimed at protecting building occupants from airborne hazards. Items such as OA intakes, zone separation, single-switch controls for sheltering and purging, and filtration options are discussed. It further recommends combining the individual elements of security into an overall protective-action plan. NIOSH provides recommendations placed in four general categories; (1) things not to do, (2) physical security, (3) ventilation and filtration, and (4) maintenance, administration, and training. The recently published handbook "Immune Building Systems" by Kowalski (2002), while not a consensus document, provides detailed discussion on many aspects of hardening mechanical systems against biological weapons.

2.3 Threat Analysis

The first topic addressed by the majority of publications is performance of an accurate threat analysis. The American Institute of Architects (AIA) defines a threat as "any action with the potential to cause harm in the form of death, injury, destruction, disclosure, interruption of operations, or denial of services" (AIA 2001). The threat analysis will help define the appropriate level of security measures to consider.

Guidance for performing a threat assessment ranges from a concise list of questions, to comprehensive analysis of each engineering/architectural discipline with check lists and coordination with emergency responders. Ultimately, the building owner must decide which assessment is adequate to the individual building. Table 2-2 is a list of questions developed by the Commission on Engineering and Technical Systems (CETS 1988) that can be used as a stand alone assessment or as a starting point for a more detailed analysis. The primary use for this guide is the protection of federal office buildings, but the checklists also have value for commercial buildings.

Table 2-2: Example Considerations for Threat Assessment (CETS 1988)

1. Building construction	11. Critical personnel
2. Building perimeters	12. Leased or owned space
3. Building entrances	13. Window height
4. Identify critical missions	14. Tenants adjacent to facility
5. Vehicle movement	15. Control of underground passageways
6. Lighting systems	
7. Exterior door construction	16. Key control system
8. Blast zones established	17. Security manager
9. Roof/Utility openings	18. Total building height
10. Motion detectors	19. Height of adjacent bldgs.

ASHRAE (2003) and AIA (2001) both describe and endorse development of a risk management plan, which is a step-by-step approach ranking the threats and then implementing counter measures based upon threat ranking and economics. The major difference between the two is the starting points of the analysis. The AIA process begins with asset analysis and concludes with determining what level of risk is perceived. The

ASHRAE process starts by assuming the risk is present and progresses to evaluation of the methods available for risk mitigation. ASHRAE also recommends re-evaluation and modifications after implementation of the security measures if needed. This issue is not addressed in the AIA document. It is crucial for facility managers to recognize that security requirements in commercial buildings will change with the occupants and mission. The additional step of re-evaluating security periodically and not just during initial construction will help optimize building security on a recurring basis.

2.4 HVAC System Design

Threat analysis considers the overall facility, but the heart of any preventive strategy lies with the integration of safe mechanical design into architectural context. Balance between openness and security (GSA 1999) can be achieved if the engineer and architect coordinate their designs to reduce the risk of CBRW agents being introduced into a building.

Locations for outside air (OA) intakes and mechanical rooms are a fundamental security issue. Outdoor air intakes are vulnerable points of entry for contaminants. Engineers usually locate the OA louvers as close to the HVAC unit/mechanical room as possible to reduce the amount of ductwork required. This may not be possible when security is an elevated priority. Most of the surveyed documents recommend elevating OA intakes to the highest point possible. Elevated OA intakes have two security advantages over ground-level intakes. One is that a ground level release outside the building will be diluted before reaching an elevated intake. The other is the reduced likelihood that a

CBRW source could be placed directly into an elevated intake (U.S. Army 2001). GSA guidance (GSA 2000c) favors locating elevated intakes on a wall, while (ASHRAE 2003) recommends a roof location. Extra security can be provided by covering the intake with wire mesh screen and incorporating an angle which prohibits an object from being thrown from ground level into the opening (Kowalski 2002). When elevation of ground level intakes is not possible, several security measures can be incorporated to minimize potential threats. Enclose the ground level intake area to make it non-accessible to the public, non-visible, and utilize intrusion alarm sensors (NIOSH 2002). Table 2-3 compares the actual recommendations given for locating OA intakes with general guidelines and/or specific height requirements if given.

Table 2-3: Guidance for Outdoor Air Intakes

Specific Recommendation with Reference
1. 12 ft minimum and sloped metal mesh inlet (NIOSH 2002)
2. 10-15 ft minimum (Kowalski 2002)
3. Elevate to highest practical level (ASHRAE 2003) (U.S. Army 2001) (GSA 2000d) (AIA 2001)

NIOSH (2002) suggests the use of ducted returns instead of plenum returns because they make the introduction of CBRW agents more difficult. NIOSH also recommends design of systems to minimize mixing between air handling zones. Similarly, USACE (2001) recommends separate HVAC zones to minimize the potential spread of an airborne hazard within the building. ASHRAE (2003) advises routing ductwork to avoid unauthorized access and preclude the insertion of a biological or chemical agent into the air distribution system.

A further measure proposed by NIOSH is the use of low leakage-fast acting (less than 30 seconds) dampers, which facilitate isolation of contaminated areas in the case of an event that requires HVAC system shut down.

2.5 HVAC Control Systems

Control systems potentially have a significant role to play in response to CBRW attacks if they are designed to do so. Several security guidance documents address control system design.

ASHRAE (2003) recommends dividing control schemes into two modes: normal operation and extraordinary periods of operation. When a system is in its extraordinary mode of operation, two responses are possible based on whether or not the building HVAC system has protective features. When protective features are not available, shutting down the system is the only alternative to normal operation. However, this may increase exposure to the agent if it is being released internally, so conditions under which a shut down would occur should be carefully reviewed. When protective measures are available during an internal release, HVAC controls should isolate the zone and start ant special air-cleaning components. Controls should also operate intake and exhaust dampers to regulate building pressures. During an external release of a known agent, with protective measures in place for that agent, the system should continue to run. When there is doubt regarding either the agent or the efficacy of countermeasures, the system should be shut down.

The US Army Corps of Engineers (USACE 2001) recommends using the ventilation system and smoke-purge fans in a manner responsive to the release location. Sheltering in place should be used in response to an external release for which there is forewarning. All fans that produce air exchange should be shut off before the cloud of hazardous material envelopes the building. Sheltering in place has one disadvantage; the protection it provides diminishes with the duration of the hazard. If the release is internal, the ventilation fans can be used to purge the building. However, USACE recommends that if the hazardous material has been identified before release or immediately upon release, purging should not be employed because it may spread the agent.

General Services Administration (GSA 2000d) states that the mechanical system should continue the operation of key life safety components following any incident. The only issue addressed is smoke control systems. GSA recommends having stand alone control panels (located away from high risk areas) for smoke removal equipment in the event control wiring is severed from the main control system. The purpose is to allow the stand alone controls to be wired into the emergency power grid for system operation during a power outage.

NIOSH (2002) recommends evaluating HVAC control options based on six criteria. These criteria are system shut down, zone pressurization, air purge (100% OA if internal release), specialized exhaust for some areas, pressurized egress routes, and procedures and training incorporated into the building's emergency response plan. Detailed response recommendations are not given.

Kowalski (2002) describes a control logic concept that can be implemented regardless of the presence of any air-cleaning technologies. Control systems are classified into three categories, detect-to-alarm, detect-to-isolate, and detect-to-treat. Detect-to-alarm systems are used for evacuation and emergency response. Detect-to-isolate systems are primarily for shutting down the ventilation system or isolating the building envelope. Detect-to-treat systems will determine whether an attack has already occurred and will result in occupants being sent for medical treatment. Figure 2-1 is a graphical representation of this control logic.

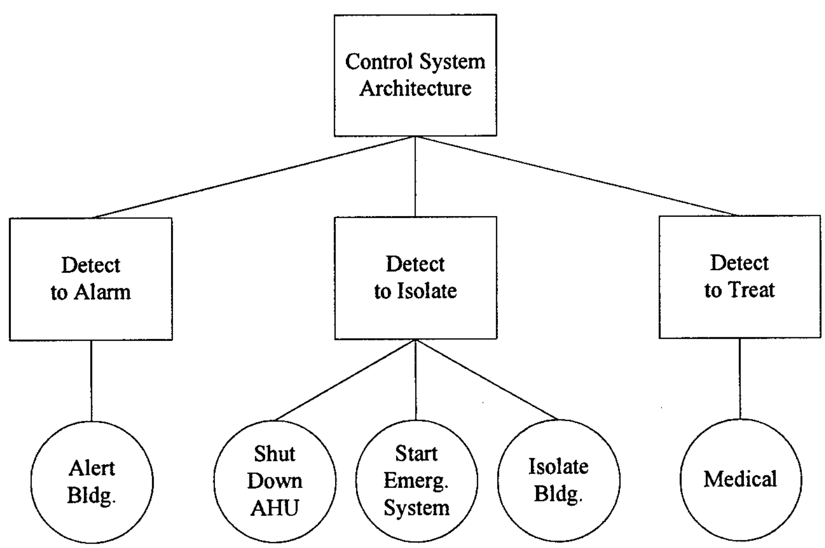

Figure 2-1: Breakdown of Control System Architecture

2.6 HVAC Air Cleaning Technologies

In addition to containment and purging, contaminants that have entered a building may be removed or destroyed by a variety of gas phase and particulate air cleaners. These include media filters, electrostatic precipitators, activated carbon filters, ultraviolet germicidal irradiation devices, and others. HVAC security guidance published to date confines itself mainly to filtration as a means of cleaning contaminated air during an attack.

ASHRAE (2003) recommends selecting/retrofitting filters with the highest minimum efficiency reporting value (MERV) rating that is physically feasible and economically justified. The MERV rating of a filter is defined and established by testing procedures described in ASHRAE Standard 52.2 (ASHRAE 1999). When filtration efficiency increases, so can the related pressure drop, requiring larger fans and motors and increasing the energy cost associated with operating the system. Consideration must also be given to gas and vapor removal technologies for possible chemical agents. Selection of higher efficiency filtration should be incorporated in the initial building risk assessment for cost and priority.

The National Air Filtration Association (NAFA) recommends maintaining positive building pressure to the outside environment and passing air through a filter that has as high a MERV value as possible within the HVAC system's design capability. The filters must be on the suction side of the air handler to prevent leakage into the building environment. Gas phase filtration should be considered where there is a risk of chemical agent attack. NAFA guides designers to use ASHRAE standard 52.2 as the guideline for selecting filters.

Kowalski (2002) recommends filtration in accordance with MERV ratings, but also incorporates new technologies such as UVGI and carbon absorption. The available technologies are presented based on application, advantages, and disadvantages. Table 2-4 shows common air-cleaning technologies and their associated applications.

Table 2-4: Air Cleaning Technologies

Technology	Application	Advantages	Disadvantages
Dilution Ventilation	Purging of interior contaminants	Effective against all chem/bio agents	Requires high air exchange rates to be effective: can be costly
Filtration	Removal of airborne particulates	Effective against large airborne particles	Effectiveness depends on efficiency; high efficiency can be costly
UVGI	Disinfection of airborne pathogens	Effective against viruses and many bacteria	High power required for spores; can be costly
Carbon Absorption	Removal of gases and vapors	Effective against airborne chem agents	Has little effect on microbes

The guidance from Kowalski (2002) also breaks down which technologies are applicable for various agents in greater detail. Figure 2-2 shows this breakdown.

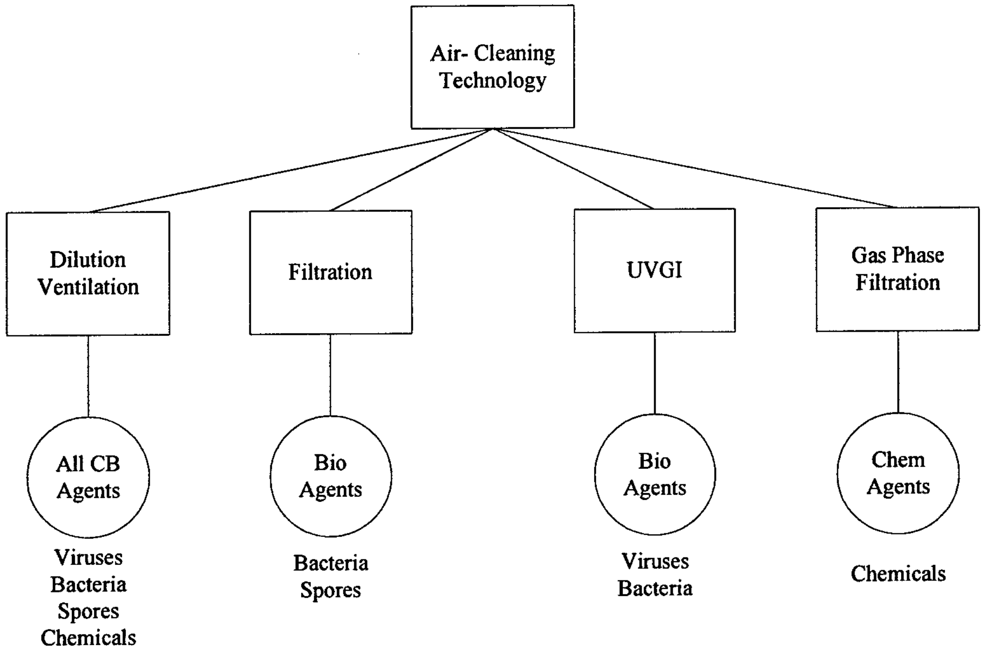

Figure 2-2: Breakdown of Technologies for Air Cleaning and disinfection

2.7 Deficiencies in Existing Guidance

It is evident from the nature of the guidance summarized in the preceding discussion that few recommendations have been provided. The most detailed advice relates to the reduction in number and better protection of points of entry for CBRW agents. Choices of system type, control sequence, and contaminant control methods are not addressed in detail. This lack of detail is, to some extent, intentional. First, it is the combined responsibility of the building owner and engineer to evaluate each case and apply good judgment. Second, historical data on intentional CBRW incidents is limited (ASHRAE, 2003), and makes it difficult to predict future events.

Based on the documents reviewed, the following are missing elements that should be added to future guidance based on the discretion of the system designer and the specific building conditions.

- *A structured mechanical design process that leads to HVAC system selection or operation that is affordable and provides a sufficient level of security.* The designer is asked by most documents to "consider" large amounts of security options without a clear path of resolution. The literature would benefit from examples or at least generic descriptions of a process that leads logically to a more secure building.

- *Merits of alternative HVAC system types in relation to operation and performance during an attack scenario.* Research and literature pertaining to system operation in attack scenarios is minimal at best. An example is the relative merits of 100% outside air systems that supply airflow equal to the ASHRAE Standard 62 ventilation requirement without recirculation and systems that provide larger air change rates to spaces but re-circulate mixed air to all of the spaces served by a system. The trade-offs between greater compartmentalization and reduced dilution need to be explored. Zoning options (core/perimeter, floor by floor, etc.) are a related aspect of design for which there is little guidance.

- *Use of contaminant modeling computer software in design.* The addition of a new parameter to the design process logically necessitates that specific analyses related to it be performed. Multizone modeling software, (for example, NIST 2002) that can be used to predict the distribution of contaminants within a building modeled as a collection of well-mixed zones through intentional and unintentional air leakage paths and by HVAC systems and can also model the removal of contaminants by filters and other cleaning devices. Computational fluid dynamics modeling provides an even greater level of detail when necessary or desired.

- *Biological and chemical detection capabilities in relation to HVAC system operation.* Literature such as IFMA (2002), recommend monitoring the air (rapid detection system) to classify and quantify hazardous substances. In contrast, ASHRAE (2003) states that reliable detection systems are not currently available for commercial HVAC equipment.

3. Biological and Chemical Agents

3.1 Introduction

Understanding the basic types, characteristics, and effects of biological and chemical agents is a first step in the analysis for safe building design. To design an effective HVAC system that detects, filters, controls, or eliminates contaminants, it is crucial to define the agents. There are hundreds of microorganisms capable of affecting human health, but only a few dozen are capable of being adapted to a biological weapon (AFJM 32-4003). Similarly, there are a great multitude of chemicals, but the emphasis will be placed on agents that cause great harm to humans with only short exposure times. The biological and chemical agents represented in this chapter will focus on the primary threats that a design engineer should consider, but it is not meant to be an exhaustive list.

3.2 Biological Agents

A biological agent is a microorganism (or toxin derived from it) which causes disease in humans, plants, or animals. We can classify these agents by their type (AFJMAN 32-4003, Kowalski 2002):

- Pathogens: Disease causing micro-organisms such as bacteria, mycoplasma (protozoa), rickettsia, fungi, or viruses. They are either naturally occurring or altered by random mutation or recombinant DNA techniques.

- Toxins: Poisons that are naturally produced through the metabolic activities of living organisms. Toxins are non living substances and their effects cannot be spread from person to person.
- Bioregulators/Modulators (BRM's): Biochemical compounds, such as peptides that occur naturally in organisms. They will act as neurotransmitters and modify our neural responses. These compounds can be produced by chemical synthesis.

Biological agents are not detectable by any of the five physical senses (sight, smell, taste, touch, and hearing) when disseminated as an aerosol. There is also a delay effect that is typical with biological agents. Time is required for the specified agent to reproduce in the host. This incubation period will vary from days to weeks depending on the specific agent.

3.2.1 Structural Characteristics of Microorganisms

In addition to classification by type, biological microorganisms can also be organized by order of decreasing size as follows: fungi, protozoa, bacteria, rickettsiae, and viruses. Microorganisms are very small and therefore their unit of measurement is the micron. One micron is equivalent to 1/1000 of a millimeter or 1/25,400 of an inch. The size of these organisms is especially important to the HVAC engineer because any effective filtration technique will be a function of particle size. Typically, the higher the MERV (minimum efficiency reporting value) of the filter, the higher percentage of contaminant removal. This issue will be addressed in greater detail in chapter four.

3.3 Chemical Agents

Chemical agents are primarily classified by their physical state and physiological action. The physical states include solids, liquids, or gasses. We can classify the physiological actions into the following groups:

- Choking agents: These agents primarily cause pulmonary edema, also known as "dry land drowning". The chemicals irritate and inflame tissues from the nose to the lungs and cause a choking sensation. Phosgene (CG) is one of the choking agents that was widely used during WW1 and caused the majority of chemically induced casualties.
- Nerve agents: When inhaled, ingested, or absorbed into the body it will interfere with our ability to relax the muscles after a movement. Paralysis with the possibility of death is the end result of exposure to nerve agents. In general terms, "G" series agents present a larger vapor hazard than "V" series agents. However, in terms of persistency and toxicity "V" series agents are the deadliest nerve agents known to man.
- Blister agents: These agents will cause inflammation, blisters, and general destruction of body tissues. The vapors will primarily attack moist tissue. Vulnerable areas include the eyes, mucous membranes, and the respiratory tract. Mustard (H) is the most well known blister agent.
- Blood agents: These agents are primarily absorbed into the body by normal breathing. The agent blocks the use of oxygen in the cells of the body and prevents the transfer of oxygen from the blood to body tissues.

- Vomiting agents: These agents will cause nausea, vomiting, pain in the nose and throat, and tears. These agents are typically non-lethal.
- Tear agents: A large flow of tears and irritation to the skin are the results of exposure to these agents. Nausea and vomiting can also be a side effect of exposure to large amounts of tear agents, although this agent is typically considered non-lethal. The most common application of tear agents is in military training and police crowd control utilizing
  O-chlorobenzylidene (CS), also known as "tear gas".

3.4 Dose and Epidemiology Terminology

When evaluating the CBW agents, the following standard terminology is utilized to describe doses of CBW agents (Kowalski 2002):

- ID_{50}: Mean infectious dose (BW agents). The dose or number of microorganisms that will cause infections in 50 percent of an exposed population. This applies only to pathogens. Units are always in terms of number of microorganisms , or, more correctly, the number of colony forming units (cfu).
- ID_{50}: Mean incapacitating dose (CW agents). The dose of a chemical agent that will incapacitate 50 percent of an exposed population. This applies to toxins or chemical weapons.
- LD_{50}: Mean lethal dose. The dose or number of microorganisms that will cause fatalities in 50 percent of an exposed population. Applies to microorganisms, toxins, or chemical weapons. For microorganisms, the units are number of

microbes (or cfu). For toxins and chemicals, the units are mg/kg. It represents an absorbed, inhaled, injected, or ingested dose per bodyweight.

- LC_{50}: Mean lethal concentration. The concentration of chemical agents in the air that will cause 50 percent fatalities in the exposed population. Does not apply to microorganisms and is not used for toxins. The units are mg/m^3.
- $L(Ct)_{50}$: Mean lethal dose. The dose or product of concentration (C) times exposure time (t) that will cause fatalities in 50 percent of an exposed population. Units are $mg \bullet min/m^3$. Identical to LD_{50} expressed in $mg \bullet min/m^3$.
- CD_{50}: Mean casualty dose. The dose that will cause casualties in 50 percent of an exposed population. Applies primarily to incapacitating chemical agents such as tear gas (CS).

Standard databases of agents will typically include a prediction of total fatalities based upon the LD_{50} value mentioned above. The mathematical relation between these two entities can be defined by equation 3.1 (Kowalski 2002):

$$y = 0.5^{0.1\left(\frac{x - LD_{50}}{LD_{50}}\right)} \tag{3.1}$$

Where:

x = Dose of agent

y = Total fatalities

LD_{50}= Mean lethal dose (as defined above)

Equation (3.1) is important to the HVAC engineer because it is the basis for comparing air-cleaning systems in a building attack simulation.

3.5 Potential Biological and Chemical Agents

The following tables list agents that have the potential to be used against a building in an attack scenario. In table 3-1, the biological agents described are focused on sources that have the greatest airborne potential. There are other means of transmission available such as food, water, and vector (mosquito's), but airborne agents pose the most immediate threat to an HVAC system.

Table 3-1: Potential Airborne Biological Agents

Biological Agents					
Microorganism (w/common name if applicable)	Type	Incubation Period	LD_{50}	ID_{50}	Size (microns)
Bacillus anthracis (Anthrax)	Bacteria	2-3 days	28000	10000	1-1.25
Brucella (Brucellosis)	Bacteria	5-60 days	~	1300	0.566
Corynebacterium diphtheriae (Diptheria)	Bacteria	2-5 days	~	~	0.7
Coxiella burnetti (Q fever)	Bacteria	14-21 days	~	10	0.283
Legionella pneumophila (Legionaire's Disease)	Bacteria	2-10 days	140000	<129	0.52
Mycobacterium tuberculosis (TB)	Bacteria	4-12 weeks	~	1-10.0	0.637
Yersinia pestis (Plague)	Bacteria	2-6 days	~	100	0.707
Ebola-GE (Hemorrhagic fever)	Virus	2-21 days	~	10	0.09
Influenza (Flu)	Virus	2-3 days	~	20	0.098
Junin	Virus	2-14 days	1-100000	~	0.12
Marburg	Virus	7 days	~	~	0.039
Variola (smallpox)	Virus	12-14 days		10-100	0.224
Aflatoxin	Toxin	NA	0.3	~	2.24
Botulinum (Botulism)	Toxin	NA	1E-06	~	2.24
Ricin	Toxin	NA	0.003	~	2.24
Substance P	Bioreg.	NA	1.4E-05	~	2.24

Table 3-2 is a list of chemical agents ordered by their potency based on the exposure dose. The code column represents the military designations for these agents. In the commercial chemical industry the military designation is sometimes replaced with a CAS number or HAZMAT ID.

Table 3-2: Potential Chemical Agents

Chemical Agents					
Chemical Agent	Code	Type	$L(Ct)_{50}$	LD_{50}	State
VX	VX	nerve agent	10	6	Liquid
Cyclohexyl Sarin	GF	nerve agent	35	5	Liquid
Soman	GD	nerve agent	70	0.01	Liquid
Sarin	GB	nerve agent	100	0.108	Liquid
Tabun	GA	nerve agent	135	0.01	Liquid
Sulfur mustard	HD	Vesicant/blister	1000	20	Liquid
Nitrogen mustard	HN-3	Vesicant/blister	1000	~	Liquid
Lewisite	L	Vesicant/blister	1200	38	Liquid
Phosgene oxime	CX	Vesicant/blister	1500	25	Powder
Nitrogen mustard	HN-2	Vesicant/blister	3000	2	Liquid
Phosgene	CG	Choking agent	3200	660	Gas
Cyanide chloride	CK	Blood agent	3800	20	Gas
Hydrogen cyanide	AC	Blood agent	5070	50	Liquid
Chlorine	CL	Choking agent	52740	~	Gas

4. Contamination Transport Analysis

4.1 Introduction

Personal experience in HVAC consulting engineering combined with an extensive literature review revealed the current mechanical design process typically neglects any type of multi-zone airflow modeling. Combining the characteristics of potential biological and chemical agents into the modeling scenario is the next logical step in HVAC security analysis. Considering that airborne agents pose the most immediate threat to HVAC systems, multi-zone airflow modeling provides the tools necessary to analyze agents in parallel with HVAC system operating parameters. Contamination transport analysis is the most notable enhancement that would improve the existing design process. Basic multi-zone modeling enables the HVAC designer to evaluate the building mechanical systems from a security perspective and provide the owner with realistic options for implementation based on qualitative results.

4.2 Available Analysis Programs

Design engineers have several options available when choosing software to assess building airflows and contaminant concentration dispersal. The most sophisticated programs utilize computational fluid dynamics (CFD), which utilize various turbulence models to predict distributions of variables (velocity, temperature, concentration) within a defined space. In general, CFD programs are expensive, require time consuming input, and are not inherently suitable for analyzing large buildings with multiple zones. In addition, CFD requires sophisticated users and can easily give plausible but misleading or incorrect results when not applied correctly.

A second software option available to engineers and complementary to CFD is the multi-zone modeling software CONTAMW 2.0 (NIST 2002). The CONTAMW program simulates the release and distribution of a selected contaminant in a facility. CONTAMW 2.0 was selected for the thesis model based on cost (free), ability to model multiple zones in a large multi-story building, and easy manipulation of contaminant source locations within the model. The CONTAMW software is readily available through the internet to consulting engineers and could be incorporated into the HVAC design package with minimal impact to project costs and timeline.

A primary difference between the two analysis programs concerns the ability to model concentration distribution in a space. It is not possible to reliably resolve agent concentration distribution in a space with the CONTAMW software, but you cannot practically model a complete building of any significant size and complexity using CFD. CFD is "sophisticated" on one level, but limited on another.

4.3 Building "X" Floorplan

The building used for simulation is an existing five-story research facility with approximately 6400 square feet per floor. The floor-to-floor height for each level is 12 feet. The layout concentrates labs in the core and office space on the exterior perimeter. In future reference, the building being modeled will be referred to as "Building X".

Tables 4-1 and 4-2 show the CONTAMW nomenclature and figures 4-1 through 4-6 detail the layout of each floor.

Table 4-1: CONTAMW General Icon Nomenclature

Icon Category	Component Icons
Walls	
Zones	
Duct Segments	
Duct Junctions	
Duct Terminals	
Simple AHS	
Airflow Paths	

Table 4-2: CONTAMW AHU Icon Nomenclature

Icon	Description
	Air-handling system
	Room air supply (inlet) of an air-handling system
	Room air return (outlet) of an air-handling system

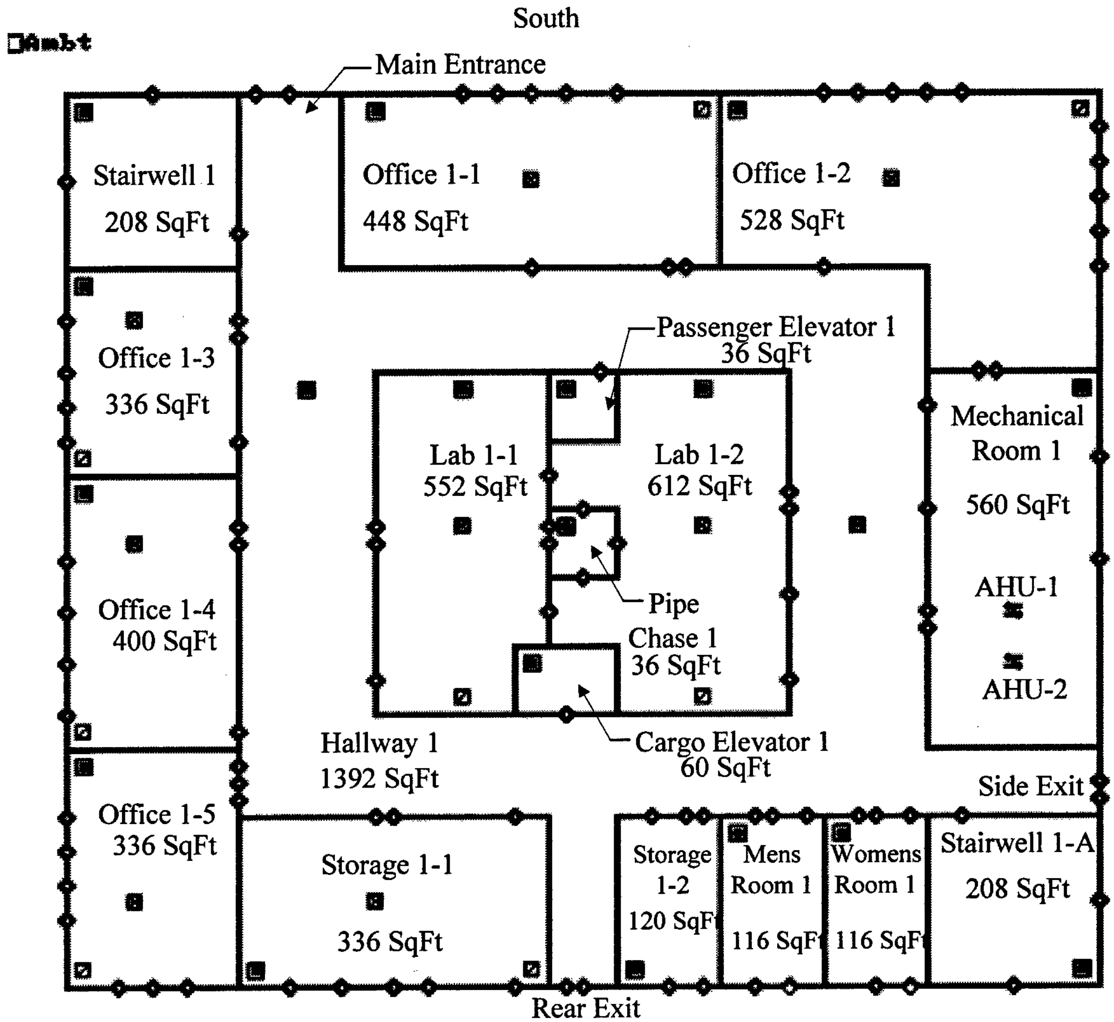

Figure 4-1: Building "X" First Floor

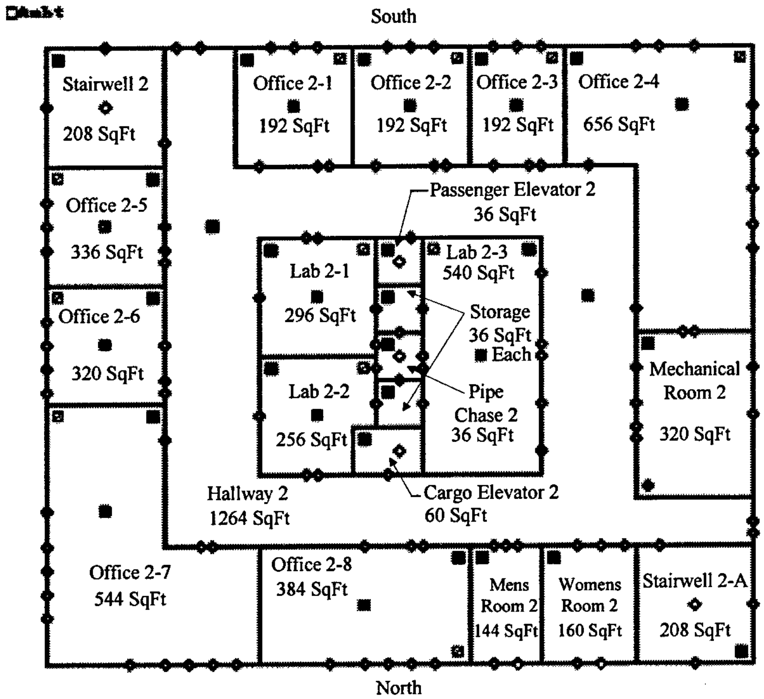

Figure 4-2: Building "X" Second Floor

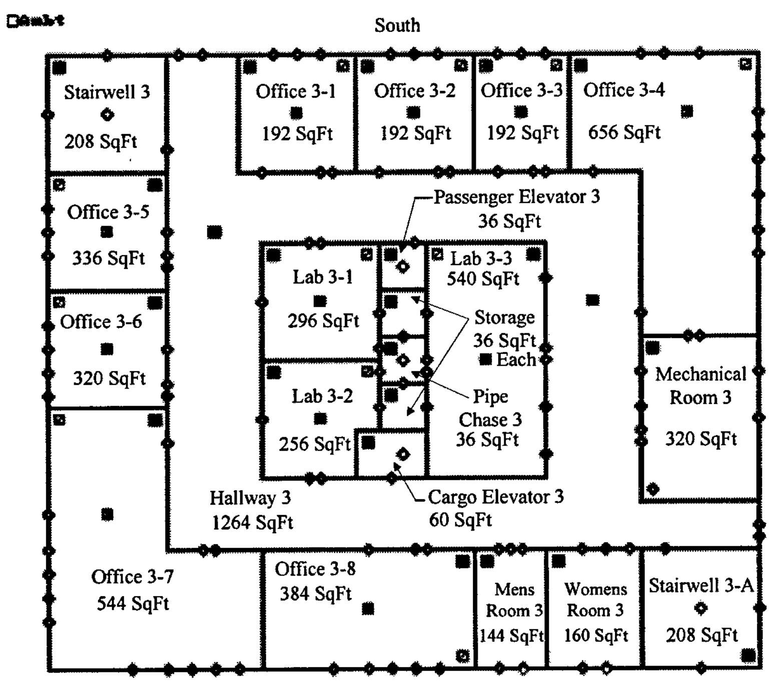

Figure 4-3: Building "X" Third Floor

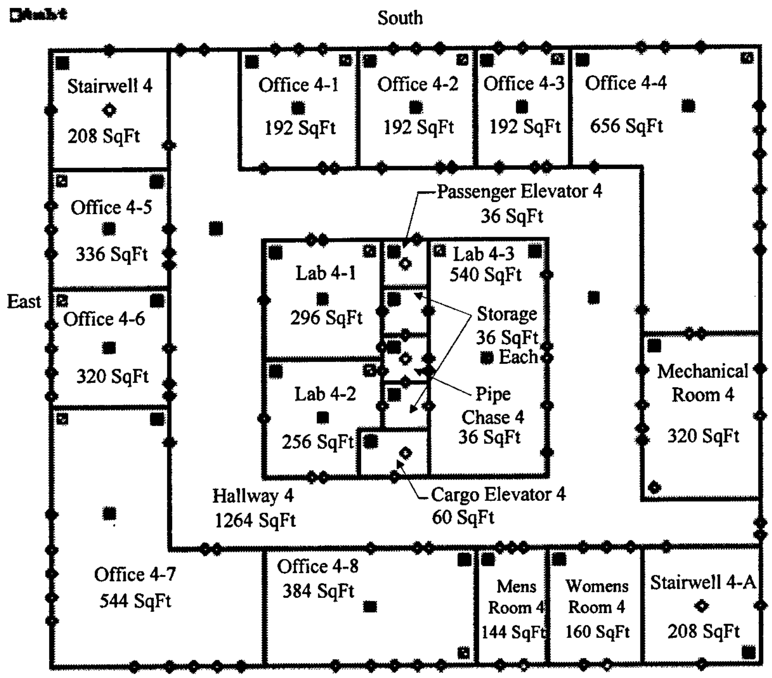

Figure 4-4: Building "X" Fourth Floor

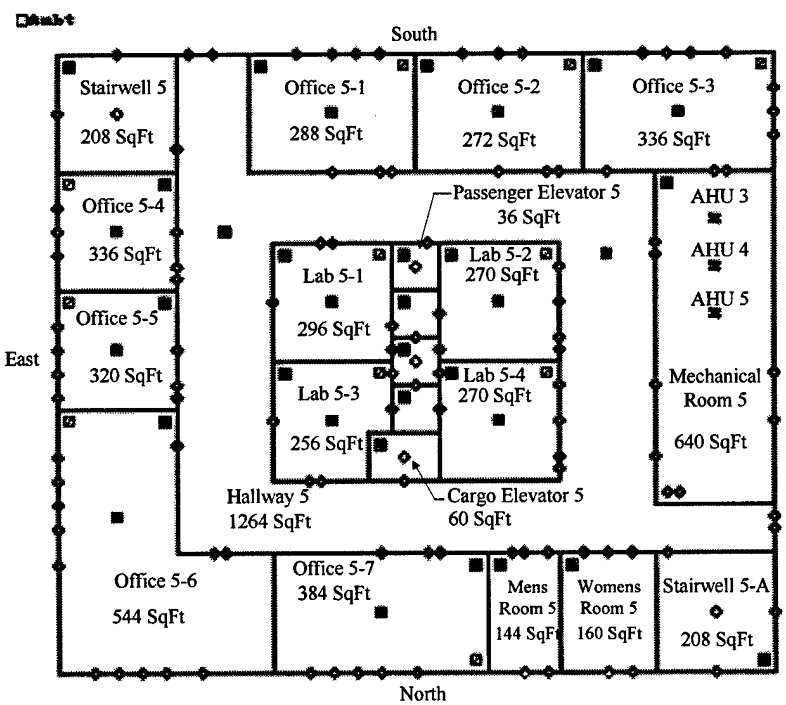

Figure 4-5: Building "X" Fifth Floor

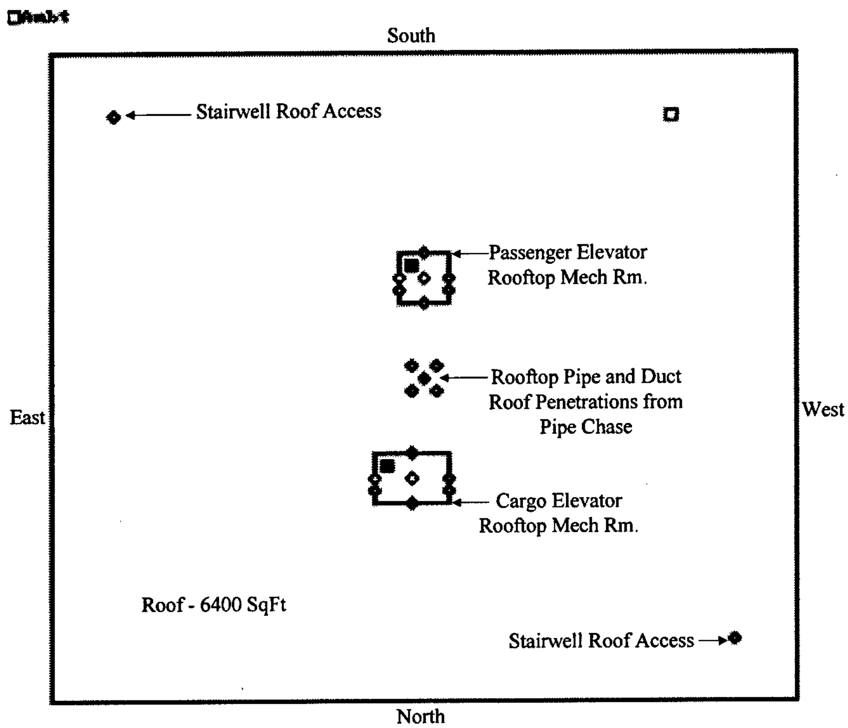

Figure 4-6: Building "X" Roof

4.4 CONTAMW Assumptions and Airflow Mathematical Model

The CONTAMW 2.0 software uses mathematical relationships to model the airflow and contaminant dispersion and therefore incorporates several assumptions to simplify the model. The simplifications made possible by these assumptions are the primary reason CONTAMW is capable of simulating large multi-zone facilities using contemporary computing resources. The following are the main assumptions made for the Building X model. These are underlying assumptions to CONTAMW, not just Building X.

- *Well mixed zones*: Each zone is treated as a single node, wherein the air has uniform (well-mixed) conditions throughout. These conditions include temperature, pressure, and contaminant concentrations.

- *Trace Contaminants*: Trace contaminants are those that are found in low enough levels that they will not affect the density of air in a zone. The building X contaminant utilized is a trace contaminant.
- *Thermal effects*: CONTAMW takes thermal buoyancy between spaces into account. However, it is not a thermal analysis program.

CONTAMW performs airflow calculations using the mass flow power law formula. The model used for building X incorporates the estimated leakage area (ELA) data from ASHRAE (1993). Equation 4-1 is the power law formula with associated variables defined.

$$Q=C(\Delta P)^n \tag{4-1}$$

Where:

Q: Mass flow rate

C: Flow Coefficient

ΔP: Pressure difference across the flow path

n: Flow exponent

Once the flow elements (e.g. windows and doors) in CONTAMW are defined, the power law formula determines the mass flow rate based upon the input parameters. Table 4-3 represents the values input for building X.

Table 4-3: Simulation Power Law Values

Element	Flow Exponent	Flow Coefficient
Windows	0.65	1.0
Exterior Wall	0.65	1.0
Duct Penetrations	0.65	0.6
Interior Open Door	0.60	1.0
Stairwell Doors	0.65	1.0
Elevator Doors	0.65	1.0
Roof Access Hatch	0.65	1.0
Water Heater Vent	0.65	1.0
Main Entry Doors	0.65	1.0

The associated ELA values used in the simulation are represented in Table 4-4.

Table 4-4: ELA Values for Simulation

Common Name	CONTAMW Element Name	Description	ELA Value
Roof Access	DRATFDWE RAV	Door, Roof Access, weather stripped	22 cm^2/item
Main entry door	DRDBNW RMX	Door, Double, not weather stripped	22 cm^2/m^2
Elevator doors	DREL CMX	Doors, Passenger Elevators	0.35 cm^2/item
Utility Penetr.	PECA RMX	Piping, Plumbing, Wiring penetrations	2.0 cm^2/item
Water Heater	WHGS RAV	Gas water heater	20 cm^2/item
Duct Penetr.	CPEN RAV	HVAC wall/ceiling penetrations	5.0 cm^2/item
Outside Wall	WLEXOF CAV	Exterior wall, Office Bldg.. Mean	4.1 cm^2/m^2
Window	WN006C CMX	Commercial Operable window	3.46 cm^2/m
Stairwell Door	DRSR14 CMN	Stair shaft doors	75 cm^2/door

4.5 Building Pressurization Test

The first step after the building has been rendered and the individual zones established, is to perform a pressurization test, the simulated equivalent of a "blower door test". This test determines the air-tightness of the rendered building and allows the engineer to find any incorrect leakage that may adversely affect simulation results. The test is performed by setting one of the 1st floor zones to a constant pressure of 50 Pa, running the simulation, and then observing the airflows out of that zone. The pressure drop on every path to the ambient zone should be close to (-50 Pa) or (-0.2 in H_2O). Appendix A contains the results of the blower door test performed on building X.

4.6 Zone Definition and Outside Air Schedule

The second step in creating the model was to specify the individual zones on each level and schedule the outside air requirements in accordance with ASHRAE (1999). The outside air requirements will be incorporated into the design of the AHU airflows. Tables 4-5 through 4-9 represent the rooms/zones created in the simulation, the attributes of the zone, and affiliated outside airflow based on occupancy. The roof zone is not scheduled in these tables because airflows are not directed to this location. The roof has to be treated as a zone in CONTAMW for the purpose of applying an ambient temperature to the roof location. It is important to create this roof zone to precipitate stack effects during the simulation.

Table 4-5: First Floor Zones and Outside Air Schedule

First Floor					
Room/Zone	**Area ft^2**	**Volume ft^3**	**People**	**OA/Person (CFM)**	**Total OA (CFM)**
Office 1-1	448	5377	6	20	120
Office 1-2	528	6337	6	20	120
Office 1-3	336	4032	3	20	60
Office 1-4	400	4800	5	20	100
Office 1-5	336	4032	4	20	80
Storage 1-1	336	4032	6	20	120
Storage 1-2	120	1440	2	20	40
Lab 1-1	552	6625	4	20	80
Lab 1-A	612	7345	4	20	80
Stairwell 1	208	2496	0	0	0
Stairwell 2	208	2496	0	0	0
Mens Room 1	116	1392	0	0	0
Womens Rm 1	116	1392	0	0	0
Hallway 1	1392	16706	0	0	0
Cargo Elev 1	60	720	0	0	0
Pass. Elev 1	36	432	0	0	0
Pipe Chase 1	36	432	0	0	0
Mech Room 1	560	6721	0	0	0
Totals:	6400	76807	40	N/A	800

Table 4-6: Second Floor Zones and Outside Air Schedule

Second Floor					
Room/Zone	**Area ft^2**	**Volume ft^3**	**People**	**OA/Person (CFM)**	**Total OA (CFM)**
Office 2-1	192	2304	2	20	40
Office 2-2	192	2304	2	20	40
Office 2-3	192	2304	2	20	40
Office 2-4	656	7872	6	20	120
Office 2-5	336	4032	3	20	60
Office 2-6	320	3840	3	20	60
Office 2-7	544	6528	7	20	140
Office 2-8	384	4608	7	20	140
Mens Room 2	144	1728	0	0	0
Womens Rm 2	160	1920	0	0	0
Stairwell 2	208	2496	0	0	0
Stairwell 2-A	208	2496	0	0	0
Lab 2-1	296	3552	2	20	40
Lab 2-2	256	3072	2	20	40
Lab 2-3	540	6480	4	20	80
Hallway 2	1264	15168	0	0	0
Cargo Elev 2	60	720	0	0	0
Pass. Elev 2	36	432	0	0	0
Pipe Chase 2	36	432	0	0	0
Mech Room 2	320	3840	0	0	0
Lab Storage	56	672	0	0	0
Totals:	6400	76800	40	N/A	800

Table 4-7: Third Floor Zones and Outside Air Schedule

Third Floor					
Room/Zone	**Area ft^2**	**Volume ft^3**	**People**	**OA/Person (CFM)**	**Total OA (CFM)**
Office 3-1	192	2304	2	20	40
Office 3-2	192	2304	2	20	40
Office 3-3	192	2304	2	20	40
Office 3-4	656	7872	6	20	120
Office 3-5	336	4032	3	20	60
Office 3-6	320	3840	3	20	60
Office 3-7	544	6528	7	20	140
Office 3-8	384	4608	7	20	140
Mens Room 3	144	1728	0	0	0
Womens Rm 3	160	1920	0	0	0
Stairwell 3	208	2496	0	0	0
Stairwell 3-A	208	2496	0	0	0
Lab 3-1	296	3552	2	20	40
Lab 3-2	256	3072	2	20	40
Lab 3-3	540	6480	4	20	80
Hallway 3	1264	15168	0	0	0
Cargo Elev 3	60	720	0	0	0
Pass. Elev 3	36	432	0	0	0
Pipe Chase 3	36	432	0	0	0
Mech Room 3	320	3840	0	0	0
Lab Storage	56	672	0	0	0
Totals:	6400	76800	40	N/A	800

Table 4-8: Fourth Floor Zones and Outside Air Schedule

Fourth Floor					
Room/Zone	**Area ft^2**	**Volume ft^3**	**People**	**OA/Person (CFM)**	**Total OA (CFM)**
Office 4-1	192	2304	2	20	40
Office 4-2	192	2304	2	20	40
Office 4-3	192	2304	2	20	40
Office 4-4	656	7872	6	20	120
Office 4-5	336	4032	3	20	60
Office 4-6	320	3840	3	20	60
Office 4-7	544	6528	7	20	140
Office 4-8	384	4608	7	20	140
Mens Room 4	144	1728	0	0	0
Womens Rm 4	160	1920	0	0	0
Stairwell 4	208	2496	0	0	0
Stairwell 4-A	208	2496	0	0	0
Lab 4-1	296	3552	2	20	40
Lab 4-2	256	3072	2	20	40
Lab 4-3	540	6480	4	20	80
Hallway 4	1264	15168	0	0	0
Cargo Elev 4	60	720	0	0	0
Pass. Elev 4	36	432	0	0	0
Pipe Chase 4	36	432	0	0	0
Mech Room 4	320	3840	0	0	0
Lab Storage	56	672	0	0	0
Totals:	6400	76800	40	N/A	800

Table 4-9: Fifth Floor Zones and Outside Air Schedule

Fifth Floor					
Room/Zone	**Area ft^2**	**Volume ft^3**	**People**	**OA/Person (CFM)**	**Total OA (CFM)**
Office 5-1	288	3456	4	20	80
Office 5-2	272	3264	4	20	80
Office 5-3	336	4032	4	20	80
Office 5-4	336	4032	3	20	60
Office 5-5	320	3840	3	20	60
Office 5-6	544	6528	7	20	140
Office 5-7	384	4608	7	20	140
Lab 5-1	296	3552	2	20	40
Lab 5-2	270	3240	2	20	40
Lab 5-3	256	3072	2	20	40
Lab 5-4	270	3240	2	20	40
Hallway 5	1264	15168	0	0	0
Mens Room 5	144	1728	0	0	0
Womens Rm 5	160	1920	0	0	0
Stairwell 5	208	2496	0	0	0
Stairwell 5-A	208	2496	0	0	0
Mech Room 5	640	7680	0	0	0
Cargo Elev 5	60	720	0	0	0
Pass. Elev 5	36	432	0	0	0
Lab Storage	72	864	0	0	0
Pipe Chase 5	36	432	0	0	0
Totals:	6400	76800	40	N/A	800

4.7 Threat Scenarios

The goal in choosing threat scenarios is to construct a set of scenarios that make it possible to identify the set of parameters that will result in the most stringent likely event. The combination of threat scenarios with design criteria (e.g. dose, concentration) leads to the identification of system requirements. This data is easily obtained using the CONTAMW software and enables building owners to make informed decisions regarding HVAC system selection in conjunction with the threat assessment and cost parameters.

Eight simulations were performed that analyze how two different HVAC system types performed when a contaminant is released in a specific zone or exterior area. The first system evaluated was a re-circulating air system with a central AHU located in the mechanical room and associated supply and return points in each zone. Two variations were used for the re-circulating system, a single AHU servicing the entire building, and multiple units (one for each floor).

The second HVAC system operated in the simulation was a once-thru or 100% outside air unit (similar in airflow to a Dedicated Outdoor Air System, Mumma (2002)). Similar to the re-circulating system, two variations were used for the model (single AHU and multiple AHU's). The simulations were all run with interior building temperatures set at 72 Deg F and the exterior temperature set to 5 Deg F. Table 4-10 represents the simulations run for the thesis with the associated airflows. Table 4-11 gives the definitions for the simulation nomenclature.

Three separate locations were used for contaminant release locations. These zones were hallway 1, storage 1-1, and a simulated exterior release into the outside air intakes of the AHU. The goal of the interior releases was to compare system performance with a release in the core of the building versus one of the perimeter spaces.

Table 4-10: Thesis Simulations

Simulation	AHU Designation	AHU Service	Supply Air	Ret./Exh. Air	OA min.
1. Int-FF-OnceThru	AHU-1	First Floor	1800 CFM	1295 CFM	800 CFM
	AHU-2	Second Floor	1800 CFM	1285 CFM	800 CFM
	AHU-3	Third Floor	1800 CFM	1285 CFM	800 CFM
	AHU-4	Fourth Floor	1800 CFM	1285 CFM	800 CFM
	AHU-5	Fifth Floor	1800 CFM	1285 CFM	800 CFM
2. Int-FF-Recirc	AHU-1	First Floor	5800 CFM	5000 CFM	800 CFM
	AHU-2	Second Floor	5800 CFM	5000 CFM	800 CFM
	AHU-3	Third Floor	5800 CFM	5000 CFM	800 CFM
	AHU-4	Fourth Floor	5800 CFM	5000 CFM	800 CFM
	AHU-5	Fifth Floor	5800 CFM	5000 CFM	800 CFM
3. Int-SF-OnceThru	AHU-1	Entire Bldg.	9000 CFM	6430 CFM	4000 CFM
4. Int-SF-Recirc	AHU-1	Entire Bldg.	29000 CFM	25000 CFM	4000 CFM
5. IntO-SF-OnceThru	AHU-1	Entire Bldg.	9000 CFM	6430 CFM	4000 CFM
6. IntO-SF-Recirc	AHU-1	Entire Bldg.	29000 CFM	25000 CFM	4000 CFM
7. Ext-SF-OnceThru	AHU-1	Entire Bldg.	9000 CFM	6430 CFM	4000 CFM
8. Ext-SF-Recirc	AHU-1	Entire Bldg.	29000 CFM	25000 CFM	4000 CFM

Table 4-11: Simulation Nomenclature

Nomenclature	Description
Int	Interior release of contaminant. Simulations with this designation utilize a first floor hallway release of specified agent.
IntO	Interior release of contaminant. Simulations with this designation utilize a first floor agent release in one of the perimeter office or storage areas.
Ext	Exterior release of specified agent into outdoor air intakes of AHU. Only used for single AHU scenarios.
FF	Floor by Floor AHU system. A single AHU is specifically designated for each floor in the building.
SF	Single Floor AHU. One AHU is located on the first floor mechanical room and serves the entire building.
OnceThru	Designation for the once thru or 100% outside air HVAC system.
Recirc	Designation for the re-circulating AHU system.

4.8 Contaminant for Simulation

A generic contaminant is used for the simulation, referred to as "Agent-1" within the model. Table 4-12 gives the molecular weight and initial release concentration of Agent-1 at release. The concentration of 20,000 PPM was picked arbitrarily and not meant to parallel any known agents. The molecular weight is a required input parameter for CONTAMW and was based on the weight of water.

Table 4-12: Agent-1 Characteristics

Agent-1	
Initial concentration at release	20,000 PPM
Molecular Weight	18 Kg/Kmol

4.9 Exposure Calculation

To evaluate the various exposure concentrations between scenarios for a specific zone, numerical integration will be utilized in the form of Simpson's rule to determine the area under the concentration (PPM) versus time curve. Simpson's Rule is defined by equation 4-2.

$$(h/3)[f(x_o)+4(x_1)+2f(x_2)+\ldots\ldots+4f(x_{n-1})+f(x_n)] \quad (4\text{-}2)$$

Where:

h= width of each sub-interval

$x_o,x_1,x_2\ldots$etc= points at the beginning and end of each subinterval

The constant multiples on the function values follow the pattern 1,4,2,4,....4,2,4,1.

5. Results and Recommendations

5.1 Introduction

The goal of interpreting the CONTAMW output results was to identify the differences between HVAC system types in relation to contaminant dispersal within the building. In each case, the following items will be evaluated for comparison purposes:

- Time required to reach near zero concentration levels within the agent release zone
- Zone (Other than release zone) with highest concentration of contaminant

There are many variables and scenarios that can be modeled using the CONTAMW software, but these were chosen because they provide the design engineer with core information required for HVAC system selection with security as a priority.

5.2 Analysis of Int-FF-OnceThru versus Int-FF-Recirc Simulations

The first simulation run compared the two HVAC system types with a dedicated AHU for each floor of the building. An initial concentration of 20,000 (PPM) was instantaneously released in hallway 1 and the simulations were run for a 24 hour time period.

5.2.1 Int-FF Hallway Analysis (Agent Release Zone)

The once thru system had a smaller dose value and achieved a reduction to zero concentration in 11h:20m:00s less than the re-circulating system. Table 5-1 shows the comparison between the two simulations.

Table 5-1: Int-FF Time to Near Zero Concentration Level and Exposure Correlation

Simulation	Zone	Time to Zero Concentration(h:m:s)	Exposure	Exposure Difference	Percentage
Int-FF-OnceThru	Hallway 1	2h:35m:00s	621285	-34736	-5.29%
Int-FF-Recirc	Hallway 1	13h:55m:00s	656021		

The graphical representation of the Int-FF hallway zones is represented in figures 5-1 and 5-2.

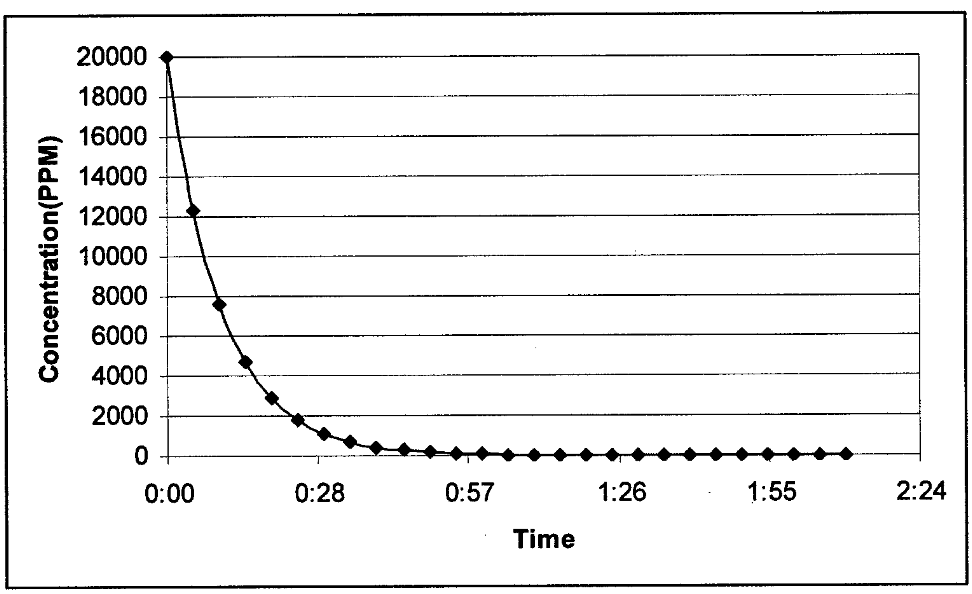

Figure 5-1: Int-FF-OnceThru, Hallway 1 (Release Zone) Graph

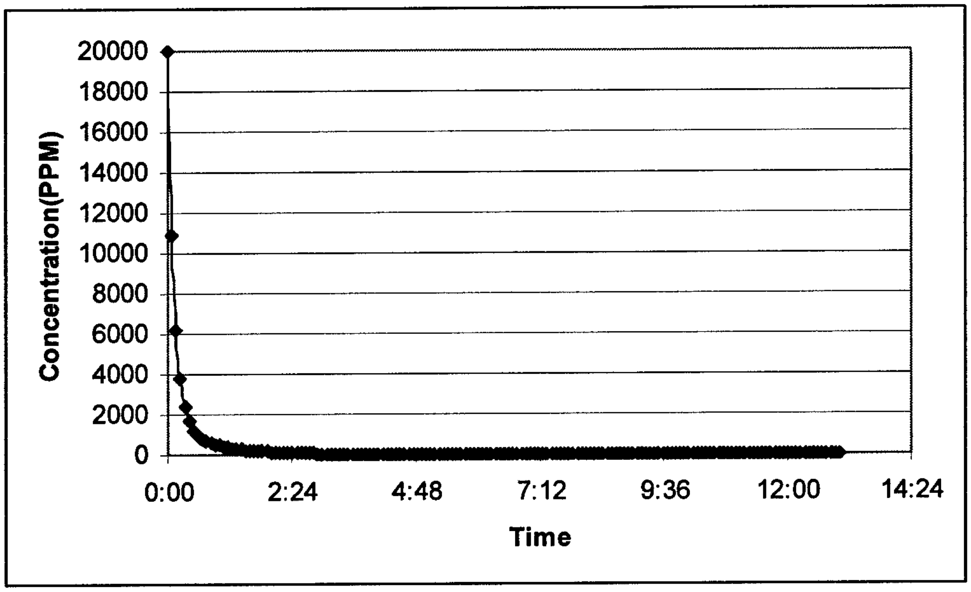

Figure 5-2: Int-FF-Recirc Hallway 1 (Release Zone) Graph

5.2.2 Zone (Other than release zone)with highest concentration of contaminant

The zone (other than release zone) with the highest concentration of agent-1 was office 1-5 for both the recirculation and once thru systems. The recirculation system peaked at a concentration of 2200 PPM and the once thru system peaked at 2270 PPM. The dosages for office 1-5 are 388,560 for the r e-circulating system and 295,577 for the once thru system. Figures 5-3 and 5-4 show exposure(concentration) versus time for these specific zones.

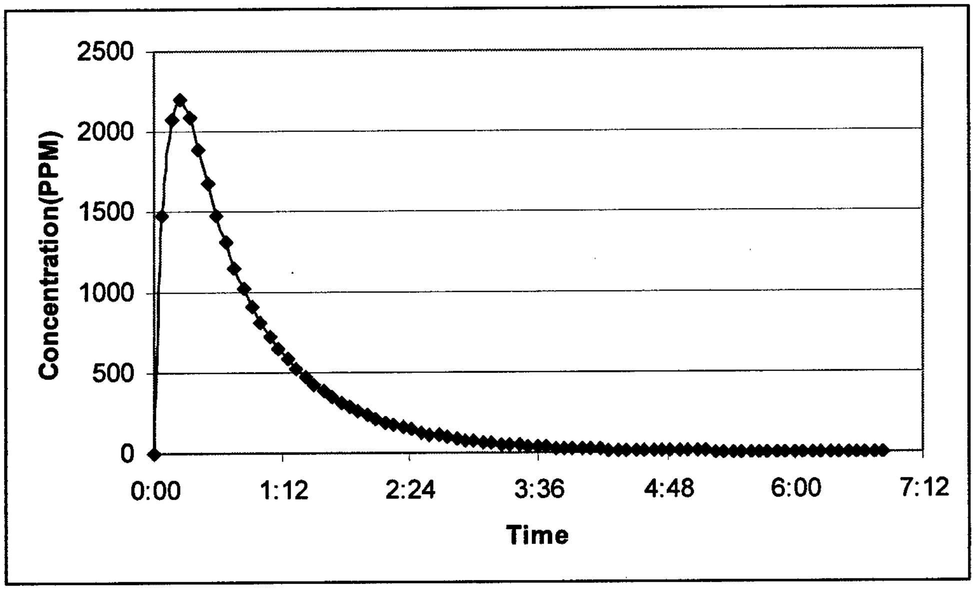

Figure 5-3: Exposure versus Time for Int-FF-Recirc, Office 1-5

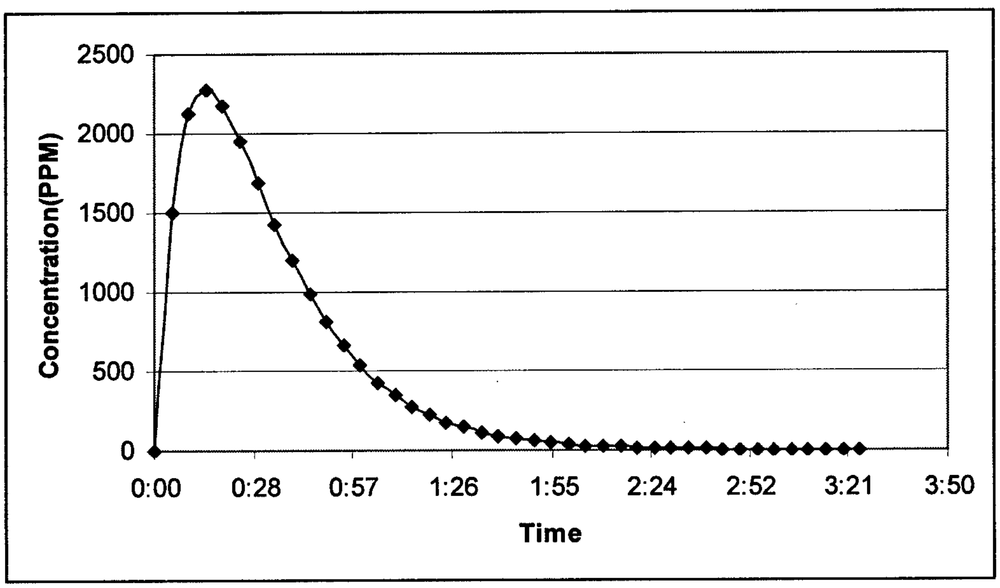

Figure 5-4: Exposure versus Time for Int-FF-OnceThru, Office 1-5

5.3 Analysis of Int-SF-OnceThru versus Int-SF-Recirc Simulations

The second simulation scenario also utilizes the instantaneous hallway release, but in this case there is a single AHU located on the first floor that services the entire building. The SF-OnceThru system reduced to zero concentration 10:45:00 less than the re-circulating system. Table 5-2 shows the comparison between the hallway releases for the Int-SF simulation.

Table 5-2: Int-SF Time to Near Zero Concentration Level and Exposure Correlation

Simulation	Zone	Time to Zero Concentration	Exposure	Exposure Difference	Percentage
Int-SF-OnceThru	Hallway 1	2:30:00	604761	+82935	+13.7%
Int-SF-Recirc	Hallway 1	13:15:00	521826		

The graphical representation of the Int-SF hallway zones is represented in figures 5-5 and 5-6.

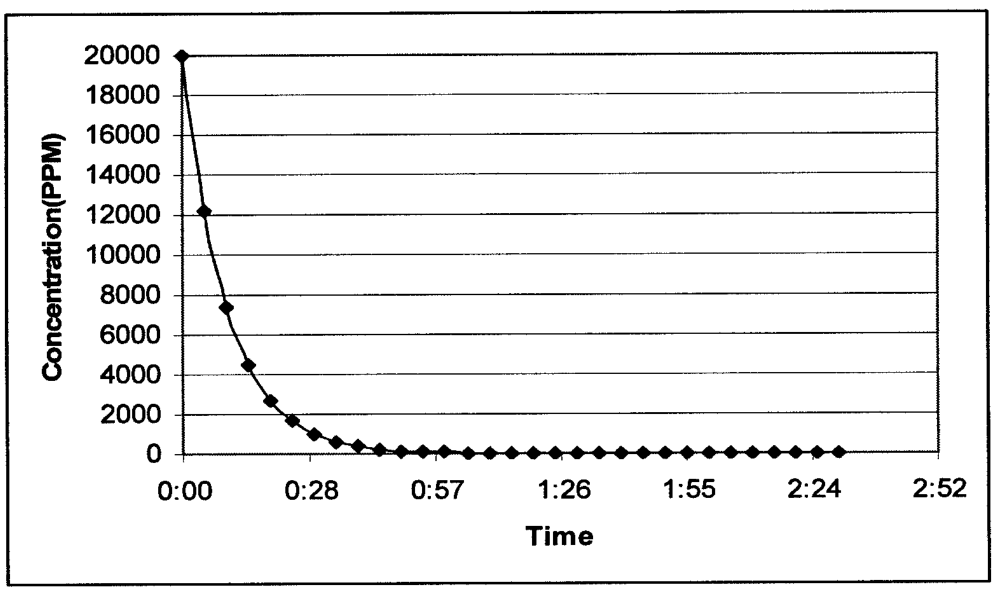

Figure 5-5: Int-SF-OnceThru, Hallway 1 (Release Zone) Graph

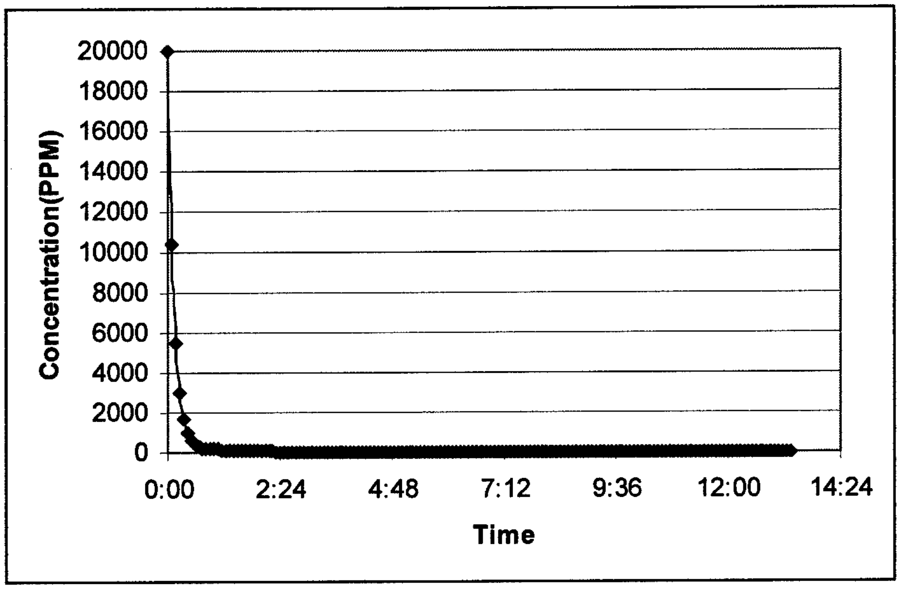

Figure 5-6: Int-SF-Recirc, Hallway 1 (Release Zone) Graph

5.3.1 Zone (Other than release zone)with highest concentration of contaminant

The zone (other than release zone) with the highest concentration in the SF simulations paralleled the first Int-FF simulations and showed Office 1-5 had the highest concentration of agent-1. Table 5-3 details the values corresponding to this simulation.

Table 5-3: Int-SF Time to Near Zero Concentration Level and Exposure Correlation

Simulation	Peak Location	Peak Value	Time to Near Zero Concentration	Exposure
Int-SF-OnceThru	Office 1-5	2300 PPM	5:20:00	290,674
Int-SF-Recirc	Office 1-5	1240 PPM	13:40:00	163,174

The most notable difference between the Int-SF re-circulating and once-thru simulations can be found in the analysis of contamination dispersion. In the once-thru simulation, agent-1 was essentially contained to the first floor. The only trace of agent-1 on upper levels was found in the elevator shafts and this is attributable to the stack driven effects. The re-circulating system essentially transported the contaminant to all levels of the building. Figure 5-7 shows the different concentrations delivered to the level above the release and the top floor in the building.

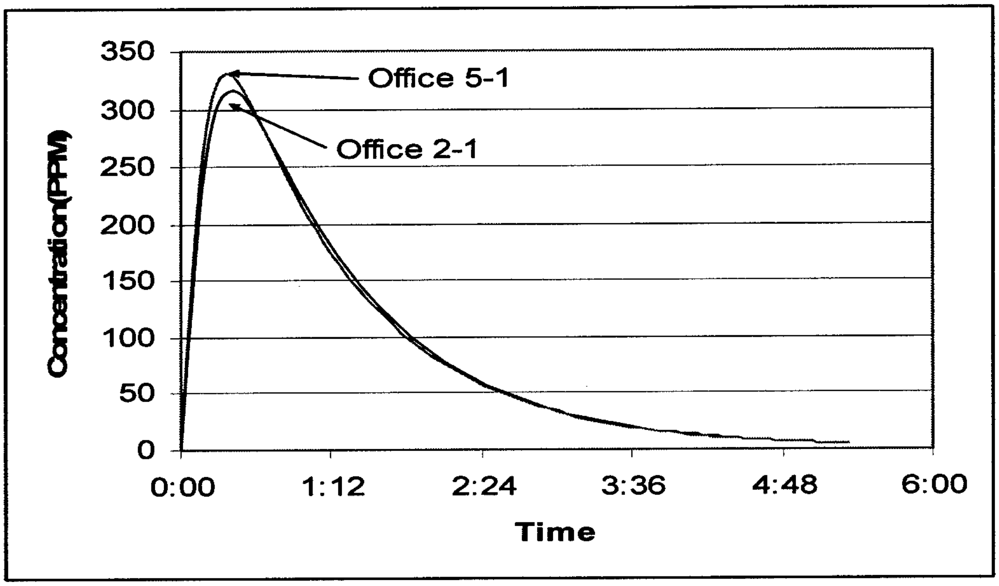

Figure 5-7: Int-SF-Recirc, Office 2-1 and 5-1 Exposure versus Time

5.4 Analysis of IntO-SF-OnceThru versus IntO-SF-Recirc Simulations

The Int0-SF simulations changed the location of the agent-1 release from the first floor hallway to the first floor storage 1-1 zone. This space also utilized an instantaneous release of 20,000 PPM of agent-1. The IntO-SF simulation using the once-thru system essentially isolated the agent within the storage 1-1 release zone. The IntO-SF simulation utilizing the re-circulating system distributed the contaminant throughout the building on all levels. Table 5-4 shows the time to zero concentration and dose for the models.

Table 5-4: IntO-SF Time to Near Zero Concentration Level and Exposure Correlation

Simulation	Release Zone	Time to Zero Concentration	Exposure	Exposure Difference	Percentage
IntO-SF-OnceThru	Storage 1-1	8h:10m:00s	1917959	+1060251	+223%
IntO-SF-Recirc	Storage 1-1	12h:15m:00s	857708		

5.4.1 Zone (Other than release zone)with highest concentration of contaminant

Due to the isolation capabilities of the once-thru system, only the IntO-SF re-circulation system was evaluated for this specific criteria. Office 3-5 had the highest concentration of agent-1 with a peak of 148 PPM. The associated dose value was 36,901 and the time required to reach zero concentration was 12:00:00. Figure 5-8 represents this data.

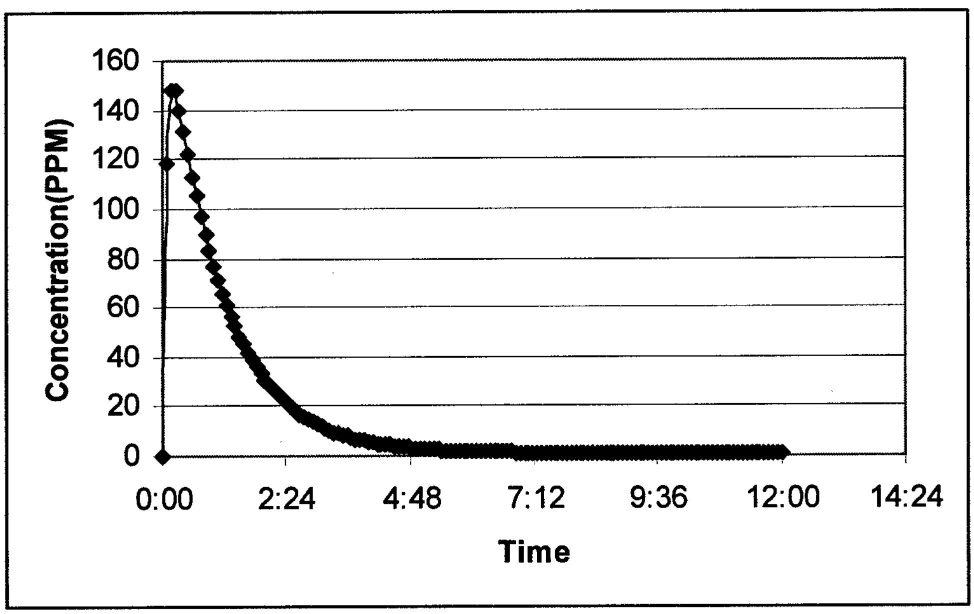

Figure 5-8: IntO-SF-Recirc, Office 3-5, Exposure versus Time

5.5 Analysis of Ext-SF-OnceThru versus Ext-SF-Recirc Simulations

This scenario simulates the release of 20,000 PPM of agent-1 into the outside air intakes, essentially placing the contaminant into the supply air-stream of the AHU. There is a single AHU located in the first floor mechanical room servicing the entire building for this model.

5.5.1 Zone with the Highest Concentration of Contaminant for Ext-SF

In both the re-circulating and once-thru systems, the peak concentration was found in office 3-5. Table 5-5 contains the comparison values obtained for office 3-5.

Table 5-5: Ext-SF Time to Near Zero Concentration Level and Exposure Correlation

Simulation	Release Zone	Highest Concentration Zone	Time to Zero Concentration	Exposure	Exposure Difference
Ext-SF-Recirc	Exterior	Office 3-5	15h:10m:00s	310962	+248602
Ext-SF-OnceThru	Exterior	Office 3-5	2h:30m:00s	62360	

Figures 5-9 and 5-10 show the graphical interpretation of the concentration versus time for office 3-5.

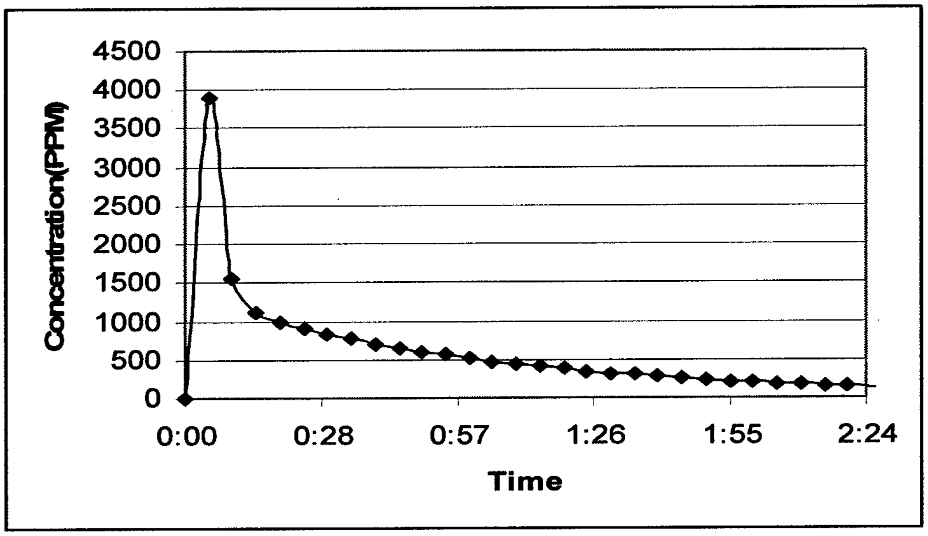

Figure 5-9: Ext-SF-Recirc, Office 3-5, Exposure versus Time

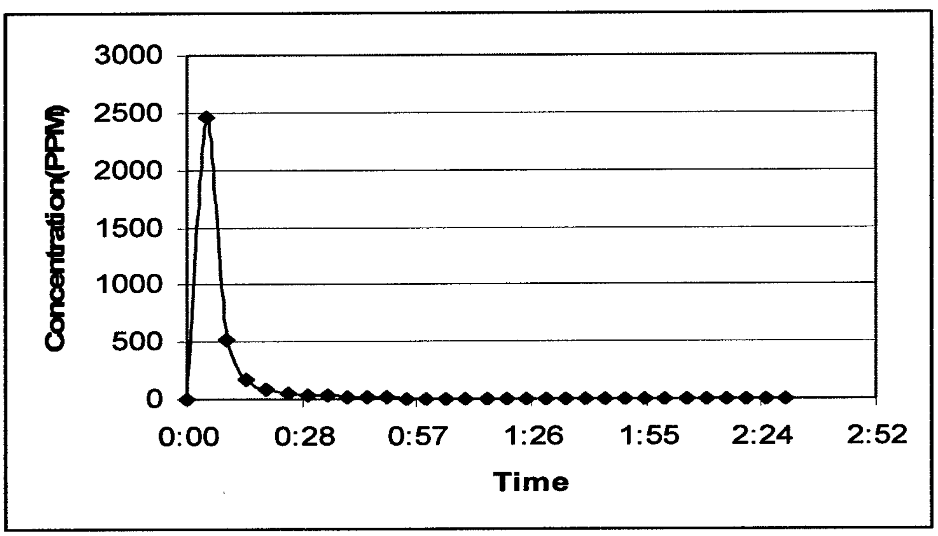

Figure 5-10: Ext-SF-OnceThru, Office 3-5, Exposure versus Time

5.6 Recommendations

The most significant enhancement that can be added to the current HVAC design process with regards to security, is to utilize the capabilities of multi-zone modeling. Prior experience as a consulting engineer and current affiliations with design firms confirm that multi-zone modeling is not typically applied to the current process. The CONTAMW software provides the analytical tools to establish HVAC system performance in the presence of a known contaminant. The CONTAMW program is less complicated than CFD software and can easily be implemented into any project.

The literature review revealed the general nature of existing guidance in relation to making decisions about HVAC system types and operation. Establishing a multi-zone model allows the practicing engineer to provide building owners with system options based upon modeled data versus general recommendations. The simulation data gives buildings owners a stronger understanding of how airflows and contaminants are moving throughout the building. In addition, HVAC system selection can be realistically prioritized based on parameters such as threat assessment and economics.

Based on the building "X" simulation run in this research, the following recommendations could be made to the building owner.

- *Weak points within the Building*: The modeling showed that office space 1-5 and 3-5 consistently had the highest concentrations of agent-1. When doing a threat assessment, it would be wise to locate non-essential functions in these zones, or if HVAC system type cannot be altered possibly provide a higher level of filtration.

- *Alternative HVAC Merits*: The simulation revealed the benefits of a once-thru system in terms of reducing the time to zero concentration. In each simulation, the time to zero value was significantly less than the re-circulating system. The once thru system performed exceptionally well when the release was located in a perimeter office, essentially limiting the contaminant to the release zone. The dosage of contaminant was higher due to lower airflows, but the system also removed the agent faster. If the 100% outside air system were utilized, due to the reduced airflows, a parallel system would have to be added (e.g. radiant or fan coils) to handle the heating and cooling loads.
- *Floor by Floor versus Single AHU*: The simulation validated that a floor by floor system helped restrict contaminant flow to different levels of the building. If special filtration or cost is a factor, then floor by floor zoning could be used to reduce the associated risk. Understanding where the most vulnerable locations or zones are in the building is valuable knowledge when determining protection measures.

Another option for analytical comparison of the building simulations is to put all release scenarios on an equal quantity basis. The exposure(concentration) versus time graphs enable the designer to isolate the critical zones and then normalize the results by taking into account zone volumes and an associated concentration scale factor. The concentration (x) volume of release zone (indoor release) or concentration (x) flow rate (x) release duration (OA release) would be the same for all cases. Appendix B uses simulations 3 and 4 (Int-SF-OnceThru versus Int-SF-Recirc) to show the graphs and values associated with this type of analysis. In addition, it is important for the final analysis to account for local concentrations and exposures and at some measure of overall building performance.

Ultimately, the building owner will have to choose which measures to implement, but these simulations provide a solid basis upon which to rank the options. As time progresses, the technology surrounding secure HVAC systems will become more inexpensive and widely available. This will enable more commercial facilities to utilize some level of secure HVAC technology (e.g. air sampling, solid state detection) without incurring large operating or first costs. When HVAC is addressed from the beginning of the design phase, enhancements (even inexpensive ones such as locks on mechanical rooms) can be more readily achieved. It is imperative for the mechanical disciplines to "Lead the Way" on this issue, because a building's HVAC system can provide vital protection when designed properly.

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Appendix A: Blower Door Test Data

project: JRV BlowerDoorTest

description:

simulation date:	1-Jan
simulation time:	0:00:00
ambient temperature:	20.0 –C
barometric pressure:	101325.0 Pa
wind speed:	0.0 m/s
wind direction:	0.0 deg

level: First elevation: 0.0 ft

zone P T		path	from			dP	Flow1		Flow2
Stairwell1	0.200	72.0 STW2	Stair		well2/2nd				-1229.54
		WLEXOF_CAV	Ambt			-0.201			-11.53
		WLEXOF_CAV	Ambt			-0.201			-11.53
		DRINOP_RAV	Hallway1/Fi		rst	0.0	01	1252.59	
Office1-1	0.201	72.0 WNOO6C	_CMX	Ambt		-0.2	02	-9.74	
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WLEXOF_CAV	Ambt			-0.202			-11.55
		WNOO6C_CMX	Ambt			-0.202			-9.74
		return	AHU-1		n/a				0
		supply	AHU-1		n/a				0
		DRINOP_RAV	Hallway1/Fi		rst	0.0	00	50.51	
		HvacSupply	Hallway1/Fi		rst	0.0	00	0.00	
		HvacReturn	Hallway1/Fi		rst	0.0	00	0.00	
Office1-2	0.201	72.0 WNOO6C	_CMX	Ambt		-0.2	02	-9.74	
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WLEXOF_CAV	Ambt			-0.202			-11.54
		return	AHU-1		n/a				0
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WNOO6C_CMX	Ambt			-0.202			-9.74
		supply	AHU-1		n/a				0
		WNOO6C_CMX	Ambt			-0.202			-9.74
		WNOO6C_CMX	Ambt			-0.202			-9.74
		DRINOP_RAV	Hallway1/Fi		rst	0.0	00	101.02	

		WLEXOF_CAV	Ambt		-0.202			-11.54
		HvacReturn	Hallway1/Fi	rst	0.0	00	0.00	
		HvacSupply	Hallway1/Fi	rst	0.0	00	0.00	
Office1-3	0.201	72.0 WLEXOF	_CAV Ambt		-0.2	02	-11.55	
		supply	AHU-1	n/a				0
		HvacSupply	Hallway1/Fi	rst	0.0	00	0.00	
		HvacReturn	Hallway1/Fi	rst	0.0	00	0.00	
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		DRINOP_RAV	Hallway1/Fi	rst	0.0	00	40.77	
		return	AHU-1	n/a				0
Hallway1	0.201	72.0 WLEXOF_	CAV Ambt		-0.2	2	-11.55	
		DRDBNW_RMX	Ambt		-0.202			-224.46
		DRINOP_RAV	Stairwell1/	First	-0	.001	-1252.59	
		DRINOP_RAV	Office1-1/F	irst	-0.	000	-50.51	
		HvacSupply	Office1-1/F	irst	-0.	000	0.00	
		HvacReturn	Office1-1/F	irst	-0.	000	0.00	
		DRINOP_RAV	Office1-2/F	irst	-0.	000	-101.02	
		HvacSupply	Office1-3/F	irst	-0.	000	0.00	
		HvacReturn	Office1-2/F	irst	-0.	000	-0.00	
		HvacReturn	Office1-3/F	irst	-0.	000	0.00	
		HvacSupply	Office1-2/F	irst	-0.	000	-0.00	
		DREL_CMX	Elevator1/F	irst	-0.	208	-1.01	
		DRINOP_RAV	MechRm1/Fir	st	-0.00	0	-68.22	
		DRINOP_RAV	Office1-3/F	irst	-0.	000	-40.77	
		HvacReturn	Lab1-2/Firs	t	-0.000			0
		HvacSupply	Lab1-2/Firs	t	-0.000			0
		PECA_RAV	MechRm1/Fir	st	-0.00	0	-0.00	
		HvacSupply	Office1-4/F	irst	-0.	000	0.00	
		HvacSupply	Lab1-1/Firs	t	-0.000			0
		supply	AHU-1	n/a				0
		HvacReturn	Office1-4/F	irst	-0.	000	0.00	
		HvacReturn	Lab1-1/Firs	t	-0.000			0
		PECA_RAV	Lab1-2/Firs	t	-0.000			0
		HvacSupply	MechRm1/Fir	st	-0.00	0	-0.00	
		HvacReturn	MechRm1/Fir	st	-0.00	0	-0.00	
		DRINOP_RAV	Lab1-1/Firs	t	-0.000			-1.43
		DRINOP_RAV	Lab1-2/Firs	t	-0.000			-2.24
		DREL_CMX	CargoElev1/	First	-0	.208	-1.01	
		DRINOP_RAV	Office1-4/F	irst	-0.	000	-40.77	
		DRINOP_RAV	Office1-5/F	irst	-0.	000	-71.80	
		HvacSupply	Office1-5/F	irst	-0.	000	-0.00	
		DRDBNW_RMX	Ambt		-0.202			-224.46
		HvacReturn	Office1-5/F	irst	-0.	000	-0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.55
		HvacSupply	Storage1-1/	First	-0	.000	0.00	

	HvacReturn	Storage1-1/	First -0	.000	0.00	
	DRINOP_RAV	Storage1-1/	First -0	.000	-50.51	
	DRINOP_RAV	Storage1-2/	First -0	.000	-21.29	
	HvacReturn	Storage1-2/	First -0	.000	0.00	
	HvacSupply	Storage1-2/	First -0	.000	0.00	
	PECA_RAV	MensRoom1/F	irst -0.	000	0.00	
	DRINOP_RAV	MensRoom1/F	irst -0.	000	-11.54	
	HvacSupply	MensRoom1/F	irst -0.	000	0.00	
	PECA_RAV	WomensRoom1	/First -	0.000	0.00	
	DRINOP_RAV	WomensRoom1	/First -	0.000	-11.54	
	HvacSupply	WomensRoom1	/First -	0.000	0.00	
	DRINOP_RAV	Stairwell1-	A/First			-1252.591
	WLEXOF_CAV	Ambt	-0.202			-11.55
	DRDBNW_RMX	Ambt	-0.202			-224.46
Lab1-1 0.201 72	.0 PECA_RAV	Lab1-2/Fi	rst -0.0	00	0.00	
	HvacSupply	Hallway1/Fi	rst 0.0	00	0.00	
	supply	AHU-1	n/a			0
	PECA_RAV	PipeChase1/	First -0	.010	-0.80	
	HvacReturn	Hallway1/Fi	rst 0.0	00	0.00	
	HvacExhaust	PipeChase1/	First -0	.010	-0.63	
	PECA_RAV	Lab1-2/Firs	t -0.000			0
	DRINOP_RAV	Hallway1/Fi	rst 0.0	00	1.43	
	return	AHU-1	n/a			0
Elevator1 -0.007	72.0 ShaftE	lev2 Elevat	or2/2nd			-1.01
	DREL_CMX	Hallway1/Fi	rst 0.2	08	1.01	
Lab1-2 0.201 72	.0 PECA_RAV	Lab1-1/Fi	rst 0.0	00	0.00	
	HvacReturn	Hallway1/Fi	rst 0.0	00	0.00	
	PECA_RAV	PipeChase1/	First -0	.010	-0.80	
	HvacSupply	Hallway1/Fi	rst 0.0	00	0.00	
	supply	AHU-1	n/a			0
	HvacExhaust	PipeChase1/	First -0	.010	-0.63	
	PECA_RAV	PipeChase1/	First -0	.010	-0.80	
	PECA_RAV	Hallway1/Fi	rst 0.0	00	0.00	
	PECA_RAV	Lab1-1/Firs	t 0.000			0
	DRINOP_RAV	Hallway1/Fi	rst 0.0	00	2.24	
	return	AHU-1	n/a			0
MechRm1 0.201 7	2.0 CPEN_RAV	MechRm2/	2nd -0.	001	-0.36	
	DRINOP_RAV	Hallway1/Fi	rst 0.0	00	68.22	
	WHGS_RAV	Ambt	-0.202			-56.32
	PECA_RAV	Hallway1/Fi	rst 0.0	00	0.00	
	WLEXOF_CAV	Ambt	-0.202			-11.55
	HvacSupply	Hallway1/Fi	rst 0.0	00	0.00	
	HvacReturn	Hallway1/Fi	rst 0.0	00	0.00	
Office1-4 0.201	72.0 HvacSu	pply Hallwa	y1/First	0.000	0.00	

		supply	AHU-1	n/a				0
		HvacReturn	Hallway1/Fi	rst	0.0	00	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.55
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		return	AHU-1	n/a				0
		DRINOP_RAV	Hallway1/Fi	rst	0.0	00	40.77	
PipeChase1	0.191	72.0 Chase	2 PipeC	hase2/2nd				-3.67
		PECA_RAV	Lab1-2/Firs	t	0.010			0.8
		PECA_RAV	Lab1-1/Firs	t	0.010			0.8
		HvacExhaust	Lab1-1/Firs	t	0.010			0.63
		HvacExhaust	Lab1-2/Firs	t	0.010			0.63
		PECA_RAV	Lab1-2/Firs	t	0.010			0.8
CargoElev1	-0.007	72.0 Shaft	CargEle2 Carg	oElev2/2nd				-1.01
		DREL_CMX	Hallway1/Fi	rst	0.2	08	1.01	
Office1-5	0.201	72.0 DRINOP	_RAV Hallwa	y1/First		0.000	71.80	
		HvacSupply	Hallway1/Fi	rst	0.0	00	0.00	
		HvacReturn	Hallway1/Fi	rst	0.0	00	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.55
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		supply	AHU-1	n/a				0
		WNOO6C_CMX	Ambt		-0.202			-9.74
		return	AHU-1	n/a				0
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WNOO6C_CMX	Ambt		-0.202			-9.74
		WLEXOF_CAV	Ambt		-0.202			-11.55
MensRoom1	0.201	72.0 PECA_R	AV Hallwa	y1/First		0.000	0.00	
		DRINOP_RAV	Hallway1/Fi	rst	0.0	00	11.54	
		HvacSupply	Hallway1/Fi	rst	0.0	00	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.55
		EF-1	Ambt		-0.202			0
WomensRoom1								
0.201		72.0 PECA	_RAV Hall	way1/First		0.000	0.00	
		DRINOP_RAV	Hallway1/Fi	rst	0.0	00	11.54	
		HvacSupply	Hallway1/Fi	rst	0.0	00	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.55
		EF-2	Ambt		-0.202			0
Storage1-1	0.201	72.0 HvacS	upply Hallw	ay1/First		0.000	0.00	
		HvacReturn	Hallway1/Fi	rst	0.0	00	0.00	
		DRINOP_RAV	Hallway1/Fi	rst	0.0	00	50.51	
		supply	AHU-1	n/a				0

	return	AHU-1	n/a		0
	WNOO6C_CMX	Ambt	-0.202		-9.74
	WNOO6C_CMX	Ambt	-0.202		-9.74
	WNOO6C_CMX	Ambt	-0.202		-9.74
	WLEXOF_CAV	Ambt	-0.202		-11.55
	WNOO6C_CMX	Ambt	-0.202		-9.74
Storage1-2 0.201	72.0 DRINO	P_RAV Hallw	ay1/First	0.000 21.29	
	HvacReturn	Hallway1/Fi	rst 0.0	00 0.00	
	HvacSupply	Hallway1/Fi	rst 0.0	00 0.00	
	WNOO6C_CMX	Ambt	-0.202		-9.74
	WLEXOF_CAV	Ambt	-0.202		-11.55
				2nd -0.000 -	
Stairwell1-A 0.20	0 72.0 STW	2A Sta	irwell2-A/	1229.54	
	DRINOP_RAV	Hallway1/Fi	rst 0.0	01 1252.59	
	WLEXOF_CAV	Ambt	-0.201		-11.53
	WLEXOF_CAV	Ambt	-0.201		-11.53

level: 2nd elevat ion: 12.0 ft

zone P T	path	from	dP	Flow1	Flow2
Stairwell2 0.028	72.0 STW3	Stair	well3/3rd		-931.49
	WLEXOF_CAV	Ambt	-0.202		-11.57
	WLEXOF_CAV	Ambt	-0.202		-11.57
	STW2	Stairwell1/	First 0	.000 1229.54	
	DRINOP_RAV	Hallway2/2n	d -0.00	0 -274.92	
Office2-1 0.028	72.0 WNOO6C	_CMX Ambt	-0.2	02 -9.76	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WLEXOF_CAV	Ambt	-0.202		-11.57
	return	AHU-2	n/a		0
	supply	AHU-2	n/a		0
	DRINOP_RAV	Hallway2/2n	d 0.00	0 31.09	
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
Office2-2 0.028	72.0 WNOO6C	_CMX Ambt	-0.2	02 -9.76	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WLEXOF_CAV	Ambt	-0.202		-11.57
	return	AHU-2	n/a		0
	supply	AHU-2	n/a		0
	DRINOP_RAV	Hallway2/2n	d 0.00	0 31.09	
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
Office2-3 0.028	72.0 WNOO6C	_CMX Ambt	-0.2	02 -9.76	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WLEXOF_CAV	Ambt	-0.202		-11.57

		return	AHU-2	n/a				0
		supply	AHU-2	n/a				0
		DRINOP_RAV	Hallway2/2n	d	0.00	0	31.09	
		HvacSupply	Hallway2/2n	d	0.00	0	0.00	
		HvacReturn	Hallway2/2n	d	0.00	0	0.00	
Office2-4	0.028	72.0 WNOO6C	_CMX Ambt		-0.2	02	-9.76	
		WNOO6C_CMX	Ambt		-0.202			-9.76
		WLEXOF_CAV	Ambt		-0.202			-11.57
		return	AHU-2	n/a				0
		supply	AHU-2	n/a				0
		WNOO6C_CMX	Ambt		-0.202			-9.76
		WNOO6C_CMX	Ambt		-0.202			-9.76
		WNOO6C_CMX	Ambt		-0.202			-9.76
		DRINOP_RAV	Hallway2/2n	d	0.00	0	45.73	
		WNOO6C_CMX	Ambt		-0.202			-9.76
		HvacSupply	Hallway2/2n	d	0.00	0	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.57
		HvacReturn	Hallway2/2n	d	0.00	0	0.00	
		WNOO6C_CMX	Ambt		-0.202			-9.76
		DRINOP_RAV	Hallway2/2n	d	0.00	0	45.73	
Office2-5	0.028	72.0 return	AHU	-2	n	/a	0.00	
		WLEXOF_CAV	Ambt		-0.202			-11.57
		WNOO6C_CMX	Ambt		-0.202			-9.76
		supply	AHU-2	n/a				0
		DRINOP_RAV	Hallway2/2n	d	0.00	0	31.09	
		WNOO6C_CMX	Ambt		-0.202			-9.76
		HvacSupply	Hallway2/2n	d	0.00	0	0.00	
		HvacReturn	Hallway2/2n	d	0.00	0	0.00	
Hallway2	0.028	72.0 WLEXOF_	CAV Ambt		-0.2	2	-11.57	
		WNOO6C_CMX	Ambt		-0.202			-9.76
		DRINOP_RAV	Stairwell2/	2nd	0.	000	274.92	
		DRINOP_RAV	Office2-1/2	nd	-0.0	00	-31.09	
		HvacSupply	Office2-1/2	nd	-0.0	00	0.00	
		HvacReturn	Office2-1/2	nd	-0.0	00	0.00	
		DRINOP_RAV	Office2-2/2	nd	-0.0	00	-31.09	
		HvacSupply	Office2-2/2	nd	-0.0	00	0.00	
		HvacReturn	Office2-2/2	nd	-0.0	00	0.00	
		DRINOP_RAV	Office2-3/2	nd	-0.0	00	-31.09	
		HvacSupply	Office2-3/2	nd	-0.0	00	0.00	
		HvacReturn	Office2-3/2	nd	-0.0	00	0.00	
		DRINOP_RAV	Office2-4/2	nd	-0.0	00	-45.73	
		DRINOP_RAV	Office2-5/2	nd	-0.0	00	-31.09	
		HvacSupply	Office2-4/2	nd	-0.0	00	0.00	
		HvacSupply	Lab2-1/2nd		0			0
		HvacReturn	Lab2-1/2nd		0			0
		DREL_CMX	Elevator2/2	nd	-0.2	07	-1.00	

			HvacReturn	Office2-4/2	nd	-0.0	00	0.00	
			HvacSupply	Office2-5/2	nd	-0.0	00	0.00	
			HvacReturn	Office2-5/2	nd	-0.0	00	0.00	
			DRINOP_RAV	Lab2-3/2nd		0			0
			DRINOP_RAV	Lab2-1/2nd		0			-0.6
			supply	AHU-2	n/a				0
			DRINOP_RAV	Office2-4/2	nd	-0.0	00	-45.73	
			DRINOP_RAV	Office2-6/2	nd	-0.0	00	-40.85	
			HvacSupply	Lab2-3/2nd		0			0
			HvacReturn	Lab2-3/2nd		0			0
			DRINOP_RAV	MechRm2/2nd		0			-67.62
			HvacSupply	Office2-6/2	nd	-0.0	00	0.00	
			HvacReturn	Office2-6/2	nd	-0.0	00	0.00	
			PECA_RAV	Lab2-3/2nd		0			0
			PECA_RAV	MechRm2/2nd		0			0
			DRINOP_RAV	Lab2-2/2nd		0			-0.6
			HvacSupply	MechRm2/2nd		0			0
			DRINOP_RAV	Office2-7/2	nd	-0.0	00	-103.02	
			HvacReturn	MechRm2/2nd		0			0
			DRINOP_RAV	Lab2-3/2nd		0			-2.9
			HvacSupply	Lab2-2/2nd		0			0
			HvacReturn	Lab2-2/2nd		0			0
			DREL_CMX	CargoElev2/	2nd	-0.	207	-1.00	
			WNOO6C_CMX	Ambt		-0.202			-9.76
			WLEXOF_CAV	Ambt		-0.202			-11.57
			HvacSupply	Office2-7/2	nd	-0.0	00	-0.01	
			HvacReturn	Office2-7/2	nd	-0.0	00	-0.01	
			DRINOP_RAV	Office2-8/2	nd	-0.0	00	-50.61	
			HvacSupply	Office2-8/2	nd	-0.0	00	0.00	
			HvacReturn	Office2-8/2	nd	-0.0	00	0.00	
			HvacSupply	MensRoom2/2	nd	-0.0	00	0.00	
			PECA_RAV	MensRoom2/2	nd	-0.0	00	0.00	
			DRINOP_RAV	MensRoom2/2	nd	-0.0	00	-11.57	
			HvacSupply	WomensRoom2	/2nd	-0	.000	0.00	
			DRINOP_RAV	WomensRoom2	/2nd	-0	.000	-11.57	
			PECA_RAV	WomensRoom2	/2nd	-0	.000	0.00	
			DRINOP_RAV	Stairwell2-	A/2nd		0.000	274.92	
Lab2-1	0.028	72	.0 HvacSuppl	y Hallway2/	2nd	0.	000	0.00	
			HvacReturn	Hallway2/2n	d	0.00	0	0.00	
			return	AHU-2	n/a				0
			DRINOP_RAV	Hallway2/2n	d	0.00	0	0.60	
			supply	AHU-2	n/a				0
			PECA_RAV	Lab2-3Stora	ge/2nd		-0.000	0.00	
			HvacExhaust	PipeChase2/	2nd	-0.	009	-0.60	
Elevator2	-0.179		72.0 ShaftE	lev3 Elevat	or3/3rd				-2.01
			DREL_CMX	Hallway2/2n	d	0.20	7	1.00	
			ShaftElev2	Elevator1/F	irst	0.	000	1.01	

Lab2-3 0.028 72	.0 return	AHU-2	n/a		0
	DRINOP_RAV	Hallway2/2n	d 0.00	0 0.00	
	DRINOP_RAV	Lab2-3Stora	ge/2nd		-0.77
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacExhaust	PipeChase2/	2nd -0.	009 -0.60	
	supply	AHU-2	n/a		0
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
	PECA_RAV	PipeChase2/	2nd -0.	009 -0.77	
	DRINOP_RAV	Lab2-3Stora	ge2/2nd		-0.77
	PECA_RAV	Hallway2/2n	d 0.00	0 0.00	
	DRINOP_RAV	Hallway2/2n	d 0.00	0 2.90	
Office2-6 0.028	72.0 return	AHU	-2 n	/a 0.00	
	WLEXOF_CAV	Ambt	-0.202		-11.57
	WNOO6C_CMX	Ambt	-0.202		-9.76
	supply	AHU-2	n/a		0
	DRINOP_RAV	Hallway2/2n	d 0.00	0 40.85	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
Lab2-3Storage 0.0	28 72.0 PE	CA_RAV La	b2-1/2nd	0.000 0.00	
	DRINOP_RAV	Lab2-3/2nd	0		0.77
	PECA_RAV	PipeChase2/	2nd -0.	009 -0.77	
PipeChase2 0.019	72.0 Chase	3 PipeC	hase3/3rd		-7.77
	PECA_RAV	Lab2-3Stora	ge/2nd	0.009 0.77	
	HvacExhaust	Lab2-1/2nd	0.009		0.6
	Chase2	PipeChase1/	First 0	.000 3.67	
	HvacExhaust	Lab2-3/2nd	0.009		0.6
	HvacExhaust	Lab2-2/2nd	0.009		0.6
	PECA_RAV	Lab2-3/2nd	0.009		0.77
	PECA_RAV	Lab2-3Stora	ge2/2nd	0.009 0.77	
MechRm2 0.028 7	2.0 DRINOP_R	AV Hallway2	/2nd 0	.000 67.62	
	WHGS_RAV	Ambt	-0.202		-56.42
	PECA_RAV	Hallway2/2n	d 0.00	0 0.00	
	WLEXOF_CAV	Ambt	-0.202		-11.57
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
	CPEN_RAV	MechRm1/Fir	st 0.00	1 0.36	
Lab2-2 0.028 72	.0 return	AHU-2	n/a		0
	HvacExhaust	PipeChase2/	2nd -0.	009 -0.60	
	PECA_RAV	Lab2-3Stora	ge2/2nd	-0.000 0.00	
	DRINOP_RAV	Hallway2/2n	d 0.00	0 0.60	
	supply	AHU-2	n/a		0

	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
				2nd -0.009	-
Lab2-3Storage2 0.	028 72.0 P	ECA_RAV P	ipeChase2/	0.77	
	PECA_RAV	Lab2-2/2nd	0		0
	DRINOP_RAV	Lab2-3/2nd	0		0.77
Office2-7 0.028	72.0 return	AHU	-2 n	/a 0.00	
	DRINOP_RAV	Hallway2/2n	d 0.00	0 103.02	
	WLEXOF_CAV	Ambt	-0.202		-11.57
	supply	AHU-2	n/a		0
	WNOO6C_CMX	Ambt	-0.202		-9.76
	HvacSupply	Hallway2/2n	d 0.00	0 0.01	
	HvacReturn	Hallway2/2n	d 0.00	0 0.01	
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WLEXOF_CAV	Ambt	-0.202		-11.57
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	Wall-S	Ambt	-0.202		-11.57
CargoElev2 -0.179	72.0 Shaft	CargEle3 Carg	oElev3/3rd		-2.01
	ShaftCargEl	e2 CargoElev1	/First	0.000 1.01	
	DREL_CMX	Hallway2/2n	d 0.20	7 1.00	
Office2-8 0.028	72.0 DRINOP	_RAV Hallwa	y2/2nd	0.000 50.61	
	HvacSupply	Hallway2/2n	d 0.00	0 0.00	
	HvacReturn	Hallway2/2n	d 0.00	0 0.00	
	supply	AHU-2	n/a		0
	return	AHU-2	n/a		0
	WLEXOF_CAV	Ambt	-0.202		-11.57
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
	WNOO6C_CMX	Ambt	-0.202		-9.76
MensRoom2 0.028	72.0 HvacSu	pply Hallwa	y2/2nd	0.000 0.00	
	PECA_RAV	Hallway2/2n	d 0.00	0 0.00	
	DRINOP_RAV	Hallway2/2n	d 0.00	0 11.57	
	WLEXOF_CAV	Ambt	-0.202		-11.57
	EF-3	Ambt	-0.202		0
WomensRoom2 0.028	72.0 Hvac	Supply Hall	way2/2nd	0.000 0.00	
	DRINOP_RAV	Hallway2/2n	d 0.00	0 11.57	
	PECA_RAV	Hallway2/2n	d 0.00	0 0.00	

		WLEXOF_CAV	Ambt	-0.202		-11.57
		EF-4	Ambt	-0.202		0
					3rd -0.000	-
Stairwell2-A	0.02	8 72.0 STW	3A Sta	irwell3-A/	931.49	
		DRINOP_RAV	Hallway2/2n	d -0.00	0 -274.92	
		STW2A	Stairwell1-	A/First	0.000 1229.54	
		WLEXOF_CAV	Ambt	-0.202		-11.57
		WLEXOF_CAV	Ambt	-0.202		-11.57
level: 3rd	elevat	ion: 24.0 ft				
zone	P T	path	from	dP	Flow1	Flow2
Stairwell3	-0.144	72.0 STW4	Stair	well4/4th		-643.69
		WLEXOF_CAV	Ambt	-0.203		-11.61
		WLEXOF_CAV	Ambt	-0.203		-11.61
		STW3	Stairwell2/	2nd 0.	000 931.49	
		DRINOP_RAV	Hallway3/3r	d -0.00	0 -264.57	
Office3-1	-0.144	72.0 WNOO6C	_CMX Ambt	-0.2	03 -9.80	
		WNOO6C_CMX	Ambt	-0.203		-9.8
		WLEXOF_CAV	Ambt	-0.203		-11.61
		return	AHU-3	n/a		0
		supply	AHU-3	n/a		0
		DRINOP_RAV	Hallway3/3r	d 0.00	0 31.21	
		HvacReturn	Hallway3/3r	d 0.00	0 0.00	
		HvacSupply	Hallway3/3r	d 0.00	0 0.00	
Office3-2	-0.144	72.0 WNOO6C	_CMX Ambt	-0.2	03 -9.80	
		WNOO6C_CMX	Ambt	-0.203		-9.8
		WLEXOF_CAV	Ambt	-0.203		-11.61
		return	AHU-3	n/a		0
		supply	AHU-3	n/a		0
		DRINOP_RAV	Hallway3/3r	d 0.00	0 31.21	
		HvacSupply	Hallway3/3r	d 0.00	0 0.00	
		HvacReturn	Hallway3/3r	d 0.00	0 0.00	
Office3-3	-0.144	72.0 WNOO6C	_CMX Ambt	-0.2	03 -9.80	
		WNOO6C_CMX	Ambt	-0.203		-9.8
		WLEXOF_CAV	Ambt	-0.203		-11.61
		return	AHU-3	n/a		0
		supply	AHU-3	n/a		0
		DRINOP_RAV	Hallway3/3r	d 0.00	0 31.21	
		HvacSupply	Hallway3/3r	d 0.00	0 0.00	
		HvacReturn	Hallway3/3r	d 0.00	0 0.00	
Office3-4	-0.144	72.0 WNOO6C	_CMX Ambt	-0.2	03 -9.80	
		WNOO6C_CMX	Ambt	-0.203		-9.8
		WLEXOF_CAV	Ambt	-0.203		-11.61

		return	AHU-3	n/a				0
		Wall-S	Ambt		-0.203			-11.61
		supply	AHU-3	n/a				0
		WNOO6C_CMX	Ambt		-0.203			-9.8
		WNOO6C_CMX	Ambt		-0.203			-9.8
		DRINOP_RAV	Hallway3/3r	d	0.00	0	46.82	
		WNOO6C_CMX	Ambt		-0.203			-9.8
		WNOO6C_CMX	Ambt		-0.203			-9.8
		HvacSupply	Hallway3/3r	d	0.00	0	0.00	
		WLEXOF_CAV	Ambt		-0.203			-11.61
		HvacReturn	Hallway3/3r	d	0.00	0	0.00	
		DRINOP_RAV	Hallway3/3r	d	0.00	0	46.82	
Office3-5	-0.322	72.0 return	AHU	-3	n	/a	0.00	
		WLEXOF_CAV	Ambt		-0.026			-3.03
		WNOO6C_CMX	Ambt		-0.026			-2.56
		supply	AHU-3	n/a				0
		DRINOP_RAV	Hallway3/3r	d	0.17	8	0.00	
		WNOO6C_CMX	Ambt		-0.026			-2.56
		HvacSupply	Hallway3/3r	d	0.17	8	4.07	
		HvacReturn	Hallway3/3r	d	0.17	8	4.07	
Hallway3	-0.144	72.0 WLEXOF_	CAV Ambt		-0.2	3	-11.61	
		WNOO6C_CMX	Ambt		-0.203			-9.8
		DRINOP_RAV	Stairwell3/	3rd	0.	000	264.57	
		DRINOP_RAV	Office3-1/3	rd	-0.0	00	-31.21	
		HvacReturn	Office3-1/3	rd	-0.0	00	0.00	
		HvacSupply	Office3-1/3	rd	-0.0	00	0.00	
		DRINOP_RAV	Office3-2/3	rd	-0.0	00	-31.21	
		HvacSupply	Office3-2/3	rd	-0.0	00	0.00	
		HvacReturn	Office3-2/3	rd	-0.0	00	0.00	
		DRINOP_RAV	Office3-3/3	rd	-0.0	00	-31.21	
		HvacSupply	Office3-3/3	rd	-0.0	00	0.00	
		HvacReturn	Office3-3/3	rd	-0.0	00	0.00	
		DRINOP_RAV	Office3-4/3	rd	-0.0	00	-46.82	
		DRINOP_RAV	Office3-5/3	rd	-0.1	78	0.00	
		HvacSupply	Office3-4/3	rd	-0.0	00	0.00	
		HvacSupply	Lab3-1/3rd		0			0
		HvacReturn	Lab3-1/3rd		0			0
		DREL_CMX	Elevator3/3	rd	-0.2	07	-1.00	
		HvacReturn	Office3-4/3	rd	-0.0	00	0.00	
		HvacSupply	Office3-5/3	rd	-0.1	78	-4.07	
		HvacReturn	Office3-5/3	rd	-0.1	78	-4.07	
		PECA_RAV	Lab3-2/3rd		0			0
		supply	AHU-3	n/a				0
		DRINOP_RAV	Lab3-1/3rd		0			-0.6
		DRINOP_RAV	Lab3-2/3rd		0			-1.36
		DRINOP_RAV	Office3-4/3	rd	-0.0	00	-46.82	
		HvacSupply	Lab3-2/3rd		0			0

	HvacReturn	Lab3-2/3rd			0			0
	DRINOP_RAV	Office3-6/3	rd	-0.0		00	-41.01	
	HvacSupply	Office3-6/3	rd	-0.0		00	0.00	
	PECA_RAV	Lab3-4/3rd			0			0
	DRINOP_RAV	MechRm3/3rd			0			-68.3
	HvacReturn	Office3-6/3	rd	-0.0		00	0.00	
	HvacSupply	Lab3-4/3rd			0			0
	PECA_RAV	MechRm3/3rd			0			0
	DRINOP_RAV	Lab3-3/3rd			0			-0.6
	HvacReturn	Lab3-4/3rd			0			0
	HvacSupply	MechRm3/3rd			0			0
	DRINOP_RAV	Office3-7/3	rd	-0.0		00	-101.61	
	HvacReturn	MechRm3/3rd			0			0
	DRINOP_RAV	Lab3-4/3rd			0			-1.36
	HvacSupply	Lab3-3/3rd			0			0
	HvacReturn	Lab3-3/3rd			0			0
	DREL_CMX	CargoElev3/	3rd	-0.		207	-1.00	
	HvacSupply	Office3-7/3	rd	-0.0		00	-0.00	
	HvacReturn	Office3-7/3	rd	-0.0		00	-0.00	
	WLEXOF_CAV	Ambt			-0.203			-11.61
	WNOO6C_CMX	Ambt			-0.203			-9.8
	DRINOP_RAV	Office3-8/3	rd	-0.0		00	-50.81	
	HvacReturn	Office3-8/3	rd	-0.0		00	0.00	
	HvacSupply	Office3-8/3	rd	-0.0		00	0.00	
	PECA_RAV	MensRoom3/3	rd	-0.0		00	0.00	
	DRINOP_RAV	MensRoom3/3	rd	-0.0		00	-11.61	
	HvacSupply	MensRoom3/3	rd	-0.0		00	0.00	
	PECA_RAV	WomensRoom2	/3rd	-0		.000	0.00	
	DRINOP_RAV	WomensRoom2	/3rd	-0		.000	-11.61	
	HvacSupply	WomensRoom2	/3rd	-0		.000	0.00	
	DRINOP_RAV	Stairwell3-	A/3rd			0.000	264.57	
Lab3-1 -0.144 72	.0 HvacSuppl	y Hallway3/	3rd	0.		000	0.00	
	HvacReturn	Hallway3/3r	d	0.00		0	0.00	
	return	AHU-3	n/a					0
	DRINOP_RAV	Hallway3/3r	d	0.00		0	0.60	
	supply	AHU-3	n/a					0
	PECA_RAV	Lab3-2Stora	ge/3rd			-0.000	0.00	
	HvacExhaust	PipeChase3/	3rd	-0.		009	-0.60	
Elevator3 -0.351	72.0 ShaftE	lev4 Elevat	or4/4th					-3.01
	DREL_CMX	Hallway3/3r	d	0.20		7	1.00	
	ShaftElev3	Elevator2/2	nd	0.0		00	2.01	
Lab3-2 -0.144 72	.0 return	AHU-3	n/a					0
	PECA_RAV	Hallway3/3r	d	0.00		0	0.00	
	supply	AHU-3	n/a					0
	DRINOP_RAV	Hallway3/3r	d	0.00		0	1.36	
	DRINOP_RAV	Lab3-2Stora	ge/3rd					-0.76

	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
	HvacExhaust	PipeChase3/	3rd	-0.	009	-0.60	
Office3-6 -0.144	72.0 return	AHU	-3	n	/a	0.00	
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	supply	AHU-3	n/a				0
	DRINOP_RAV	Hallway3/3r	d	0.00	0	41.01	
	WLEXOF_CAV	Ambt		-0.203			-11.61
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	WNOO6C_CMX	Ambt		-0.203			-9.8
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
Lab3-2Storage -0.1	44 72.0 PE	CA_RAV La	b3-1/3rd		0.000	0.00	
	DRINOP_RAV	Lab3-2/3rd		0			0.76
	PECA_RAV	PipeChase3/	3rd	-0.	009	-0.76	
PipeChase3 -0.153	72.0 Chase	4 PipeC	hase4/4th				-11.68
	PECA_RAV	Lab3-2Stora	ge/3rd		0.009	0.76	
	HvacExhaust	Lab3-1/3rd		0.009			0.6
	HvacExhaust	Lab3-2/3rd		0.009			0.6
	Chase3	PipeChase2/	2nd	0.	000	7.77	
	HvacExhaust	Lab3-3/3rd		0.009			0.6
	HvacExhaust	Lab3-4/3rd		0.009			0.6
	PECA_RAV	Lab3-4Stora	ge/3rd		0.009	0.76	
MechRm3 -0.144 7	2.0 CPEN_RAV	MechRm4/	4th	-0.	000	-0.06	
	WHGS_RAV	Ambt		-0.203			-56.65
	DRINOP_RAV	Hallway3/3r	d	0.00	0	68.30	
	PECA_RAV	Hallway3/3r	d	0.00	0	0.00	
	WLEXOF_CAV	Ambt		-0.203			-11.61
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
Lab3-3 -0.144 72	.0 return	AHU-3	n/a				0
	HvacExhaust	PipeChase3/	3rd	-0.	009	-0.60	
	PECA_RAV	Lab3-4Stora	ge/3rd		-0.000	0.00	
	DRINOP_RAV	Hallway3/3r	d	0.00	0	0.60	
	supply	AHU-3	n/a				0
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
Lab3-4 -0.144 72	.0 HvacExhau	st PipeChase	3/3rd	-	0.009	-0.60	
	return	AHU-3	n/a				0
	PECA_RAV	Hallway3/3r	d	0.00	0	0.00	
	DRINOP_RAV	Lab3-4Stora	ge/3rd				-0.76
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	supply	AHU-3	n/a				0

	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
	DRINOP_RAV	Hallway3/3r	d	0.00	0	1.36	
Lab3-4Storage -0.1	44 72.0 PE	CA_RAV Pi	peChase3/3		rd	-0.009	-0.76
	PECA_RAV	Lab3-3/3rd		0			0
	DRINOP_RAV	Lab3-4/3rd		0			0.76
Office3-7 -0.144	72.0 return	AHU	-3	n	/a	0.00	
	DRINOP_RAV	Hallway3/3r	d	0.00	0	101.61	
	WLEXOF_CAV	Ambt		-0.203			-11.61
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
	WNOO6C_CMX	Ambt		-0.203			-9.8
	supply	AHU-3	n/a				0
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WLEXOF_CAV	Ambt		-0.203			-11.61
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
CargoElev3 -0.351	72.0 Shaft	CargEle4 Carg	oElev4/4th				-3.01
	ShaftCargEl	e3 CargoElev2	/2nd	0	.000	2.01	
	DREL_CMX	Hallway3/3r	d	0.20	7	1.00	
Office3-8 -0.144	72.0 DRINOP	_RAV Hallwa	y3/3rd		0.000	50.81	
	HvacReturn	Hallway3/3r	d	0.00	0	0.00	
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	supply	AHU-3	n/a				0
	return	AHU-3	n/a				0
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WNOO6C_CMX	Ambt		-0.203			-9.8
	WLEXOF_CAV	Ambt		-0.203			-11.61
MensRoom3 -0.144	72.0 PECA_R	AV Hallwa	y3/3rd		0.000	0.00	
	DRINOP_RAV	Hallway3/3r	d	0.00	0	11.61	
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	EF-5	Ambt		-0.203			0
	WLEXOF_CAV	Ambt		-0.203			-11.61
WomensRoom2 -							
0.144	72.0 PECA	_RAV Hall	way3/3rd		0.000	0.00	
	DRINOP_RAV	Hallway3/3r	d	0.00	0	11.61	
	HvacSupply	Hallway3/3r	d	0.00	0	0.00	
	EF-6	Ambt		-0.203			0

	WLEXOF_CAV	Ambt	-0.203		-11.61
Stairwell3-A -0.14	4 72.0 STW	4A Sta	irwell4-A/	4th -0.000 - 643.69	
	DRINOP_RAV	Hallway3/3r	d -0.00	0 -264.57	
	STW3A	Stairwell2-	A/2nd	0.000 931.49	
	WLEXOF_CAV	Ambt	-0.203		-11.61
	WLEXOF_CAV	Ambt	-0.203		-11.61

level: 4th elevat ion: 36.0 ft

zone P T	path	from	dP	Flow1	Flow2
Stairwell4 -0.316	72.0 STW5	Stair	well5/5th		-343.21
	WLEXOF_CAV	Ambt	-0.205		-11.66
	WLEXOF_CAV	Ambt	-0.205		-11.66
	STW4	Stairwell3/	3rd 0.	000 643.69	
	DRINOP_RAV	Hallway4/4t	h -0.00	0 -277.16	
Office4-1 -0.316	72.0 WLEXOF	_CAV Ambt	-0.2	05 -11.66	
	WNOO6C_CMX	Ambt	-0.205		-9.84
	WNOO6C_CMX	Ambt	-0.205		-9.84
	return	AHU-4	n/a		0
	supply	AHU-4	n/a		0
	DRINOP_RAV	Hallway4/4t	h 0.00	0 31.34	
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
Office4-2 -0.316	72.0 WLEXOF	_CAV Ambt	-0.2	05 -11.66	
	WNOO6C_CMX	Ambt	-0.205		-9.84
	WNOO6C_CMX	Ambt	-0.205		-9.84
	return	AHU-4	n/a		0
	supply	AHU-4	n/a		0
	DRINOP_RAV	Hallway4/4t	h 0.00	0 31.34	
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
Office4-3 -0.316	72.0 WNOO6C	_CMX Ambt	-0.2	05 -9.84	
	WLEXOF_CAV	Ambt	-0.205		-11.66
	return	AHU-4	n/a		0
	supply	AHU-4	n/a		0
	DRINOP_RAV	Hallway4/4t	h 0.00	0 21.50	
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
Office4-4 -0.316	72.0 WNOO6C	_CMX Ambt	-0.2	05 -9.84	
	WNOO6C_CMX	Ambt	-0.205		-9.84
	WNOO6C_CMX	Ambt	-0.205		-9.84
	WLEXOF_CAV	Ambt	-0.205		-11.66
	return	AHU-4	n/a		0

		WNOO6C_CMX	Ambt		-0.205			-9.84
		supply	AHU-4	n/a				0
		Wall-S	Ambt		-0.205			-11.66
		WNOO6C_CMX	Ambt		-0.205			-9.84
		DRINOP_RAV	Hallway4/4t	h	0.00	0	51.92	
		WNOO6C_CMX	Ambt		-0.205			-9.84
		WNOO6C_CMX	Ambt		-0.205			-9.84
		WLEXOF_CAV	Ambt		-0.205			-11.66
		HvacSupply	Hallway4/4t	h	0.00	0	0.00	
		HvacReturn	Hallway4/4t	h	0.00	0	0.00	
		DRINOP_RAV	Hallway4/4t	h	0.00	0	51.92	
Office4-5	-0.316	72.0 return	AHU	-4	n	/a	0.00	
		WNOO6C_CMX	Ambt		-0.205			-9.84
		WNOO6C_CMX	Ambt		-0.205			-9.84
		supply	AHU-4	n/a				0
		DRINOP_RAV	Hallway4/4t	h	0.00	0	31.34	
		WLEXOF_CAV	Ambt		-0.205			-11.66
		HvacReturn	Hallway4/4t	h	0.00	0	0.00	
		HvacSupply	Hallway4/4t	h	0.00	0	0.00	
Hallway4	-0.316	72.0 WLEXOF_	CAV Ambt		-0.2	5	-11.66	
		WNOO6C_CMX	Ambt		-0.205			-9.84
		DRINOP_RAV	Stairwell4/	4th	0.	000	277.16	
		DRINOP_RAV	Office4-1/4	th	-0.0	00	-31.34	
		HvacSupply	Office4-1/4	th	-0.0	00	0.00	
		HvacReturn	Office4-1/4	th	-0.0	00	0.00	
		DRINOP_RAV	Office4-2/4	th	-0.0	00	-31.34	
		HvacSupply	Office4-2/4	th	-0.0	00	0.00	
		HvacReturn	Office4-2/4	th	-0.0	00	0.00	
		DRINOP_RAV	Office4-3/4	th	-0.0	00	-21.50	
		HvacSupply	Office4-3/4	th	-0.0	00	0.00	
		HvacReturn	Office4-3/4	th	-0.0	00	0.00	
		DRINOP_RAV	Office4-4/4	th	-0.0	00	-51.92	
		DRINOP_RAV	Office4-5/4	th	-0.0	00	-31.34	
		HvacSupply	Lab4-1/4th		0			0
		HvacReturn	Lab4-1/4th		0			0
		DREL_CMX	Elevator4/4	th	-0.2	07	-1.00	
		HvacSupply	Office4-4/4	th	-0.0	00	0.00	
		HvacReturn	Office4-4/4	th	-0.0	00	0.00	
		HvacReturn	Office4-5/4	th	-0.0	00	0.00	
		PECA_RAV	Lab4-2/4th		0			0
		HvacSupply	Office4-5/4	th	-0.0	00	0.00	
		supply	AHU-4	n/a				0
		DRINOP_RAV	Lab4-1/4th		0			-0.6
		DRINOP_RAV	Lab4-2/4th		0			-1.35
		DRINOP_RAV	Office4-4/4	th	-0.0	00	-51.92	
		HvacSupply	Lab4-2/4th		0			0
		DRINOP_RAV	Office4-6/4	th	-0.0	00	-41.17	

	HvacReturn	Lab4-2/4th		0			0
	DRINOP_RAV	MechRm4/4th		0			-68.49
	HvacReturn	Office4-6/4	th	-0.0	00	0.00	
	PECA_RAV	Lab4-4/4th		0			0
	HvacSupply	Office4-6/4	th	-0.0	00	0.00	
	PECA_RAV	MechRm4/4th		0			0
	DRINOP_RAV	Lab4-3/4th		0			-0.6
	DRINOP_RAV	Lab4-4/4th		0			-1.35
	HvacSupply	MechRm4/4th		0			0
	HvacReturn	MechRm4/4th		0			0
	DRINOP_RAV	Office4-7/4	th	-0.0	00	-102.02	
	HvacSupply	Lab4-4/4th		0			0
	HvacReturn	Lab4-4/4th		0			0
	HvacSupply	Lab4-3/4th		0			0
	HvacReturn	Lab4-3/4th		0			0
	DREL_CMX	CargoElev4/	4th	-0.	207	-1.00	
	WLEXOF_CAV	Ambt		-0.205			-11.66
	WNOO6C_CMX	Ambt		-0.205			-9.84
	HvacSupply	Office4-7/4	th	-0.0	00	-0.00	
	HvacReturn	Office4-7/4	th	-0.0	00	-0.00	
	DRINOP_RAV	Office4-8/4	th	-0.0	00	-51.01	
	HvacSupply	Office4-8/4	th	-0.0	00	0.00	
	HvacReturn	Office4-8/4	th	-0.0	00	0.00	
	PECA_RAV	MensRoom4/4	th	-0.0	00	0.00	
	DRINOP_RAV	MensRoom4/4	th	-0.0	00	-11.66	
	HvacSupply	MensRoom4/4	th	-0.0	00	0.00	
	PECA_RAV	WomensRoom4	/4th	-0	.000	0.00	
	DRINOP_RAV	WomensRoom4	/4th	-0	.000	-11.66	
	HvacSupply	WomensRoom4	/4th	-0	.000	0.00	
	DRINOP_RAV	Stairwell4-	A/4th		0.000	277.16	
Lab4-1 -0.316 72	.0 HvacSuppl	y Hallway4/	4th	0.	000	0.00	
	HvacReturn	Hallway4/4t	h	0.00	0	0.00	
	return	AHU-4	n/a				0
	DRINOP_RAV	Hallway4/4t	h	0.00	0	0.60	
	supply	AHU-4	n/a				0
	PECA_RAV	Lab4-2Stora	ge/4th		-0.000	0.00	
	HvacExhaust	PipeChase4/	4th	-0.	009	-0.60	
Elevator4 -0.524	72.0 ShaftE	lev5 Elevat	or5/5th				-4.02
	DREL_CMX	Hallway4/4t	h	0.20	7	1.00	
	ShaftElev4	Elevator3/3	rd	0.0	00	3.01	
Lab4-2 -0.316 72	.0 return	AHU-4	n/a				0
	PECA_RAV	Hallway4/4t	h	0.00	0	0.00	
	supply	AHU-4	n/a				0
	DRINOP_RAV	Hallway4/4t	h	0.00	0	1.35	
	DRINOP_RAV	Lab4-2Stora	ge/4th				-0.76
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	

	HvacExhaust	PipeChase4/	4th -0.	009 -0.60	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
Office4-6 -0.316	72.0 return	AHU	-4 n	/a 0.00	
	WNOO6C_CMX	Ambt	-0.205		-9.84
	WNOO6C_CMX	Ambt	-0.205		-9.84
	supply	AHU-4	n/a		0
	DRINOP_RAV	Hallway4/4t	h 0.00	0 41.17	
	WLEXOF_CAV	Ambt	-0.205		-11.66
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
	WNOO6C_CMX	Ambt	-0.205		-9.84
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
Lab4-2Storage -0.3	16 72.0 DR	INOP_RAV La	b4-2/4th	0.000 0.76	
	PECA_RAV	Lab4-1/4th	0		0
	PECA_RAV	PipeChase4/	4th -0.	009 -0.76	
PipeChase4 -0.326	72.0 Chase	5 PipeC	hase5/5th		-15.58
	PECA_RAV	Lab4-2Stora	ge/4th	0.009 0.76	
	HvacExhaust	Lab4-1/4th	0.009		0.6
	HvacExhaust	Lab4-2/4th	0.009		0.6
	Chase4	PipeChase3/	3rd 0.	000 11.68	
	HvacExhaust	Lab4-3/4th	0.009		0.6
	HvacExhaust	Lab4-4/4th	0.009		0.6
	PECA_RAV	Lab4-4Stora	ge/4th	0.009 0.76	
MechRm4 -0.316 7	2.0 CPEN_RAV	MechRm5/	5th -0.	000 -0.01	
	CPEN_RAV	MechRm5/5th	0		-0.01
	DRINOP_RAV	Hallway4/4t	h 0.00	0 68.49	
	WHGS_RAV	Ambt	-0.205		-56.87
	PECA_RAV	Hallway4/4t	h 0.00	0 0.00	
	WLEXOF_CAV	Ambt	-0.205		-11.66
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
	CPEN_RAV	MechRm3/3rd	0		0.06
Lab4-3 -0.316 72	.0 return	AHU-4	n/a		0
	HvacExhaust	PipeChase4/	4th -0.	009 -0.60	
	supply	AHU-4	n/a		0
	PECA_RAV	Lab4-4Stora	ge/4th	-0.000 0.00	
	DRINOP_RAV	Hallway4/4t	h 0.00	0 0.60	
	HvacSupply	Hallway4/4t	h 0.00	0 0.00	
	HvacReturn	Hallway4/4t	h 0.00	0 0.00	
Lab4-4 -0.316 72	.0 HvacExhau	st PipeChase	4/4th -	0.009 -0.60	
	return	AHU-4	n/a		0
	PECA_RAV	Hallway4/4t	h 0.00	0 0.00	
	DRINOP_RAV	Lab4-4Stora	ge/4th		-0.76
	supply	AHU-4	n/a		0

	DRINOP_RAV	Hallway4/4t	h	0.00	0	1.35	
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	
	HvacReturn	Hallway4/4t	h	0.00	0	0.00	
Lab4-4Storage -0.3	16 72.0 PE	CA_RAV Pi	peChase4/4		th	-0.009	-0.76
	PECA_RAV	Lab4-3/4th		0			0
	DRINOP_RAV	Lab4-4/4th		0			0.76
Office4-7 -0.316	72.0 return	AHU	-4	n	/a	0.00	
	DRINOP_RAV	Hallway4/4t	h	0.00	0	102.02	
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	supply	AHU-4	n/a				0
	WNOO6C_CMX	Ambt		-0.205			-9.84
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	
	HvacReturn	Hallway4/4t	h	0.00	0	0.00	
	WLEXOF_CAV	Ambt		-0.205			-11.66
	WLEXOF_CAV	Ambt		-0.205			-11.66
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
CargoElev4 -0.524	72.0 Shaft	CargEle5 Carg	oElev5/5th				-4.02
	ShaftCargEl	e4 CargoElev3	/3rd	0	.000	3.01	
	DREL_CMX	Hallway4/4t	h	0.20	7	1.00	
Office4-8 -0.316	72.0 DRINOP	_RAV Hallwa	y4/4th		0.000	51.01	
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	
	HvacReturn	Hallway4/4t	h	0.00	0	0.00	
	supply	AHU-4	n/a				0
	return	AHU-4	n/a				0
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WNOO6C_CMX	Ambt		-0.205			-9.84
	WLEXOF_CAV	Ambt		-0.205			-11.66
MensRoom4 -0.316	72.0 PECA_R	AV Hallwa	y4/4th		0.000	0.00	
	DRINOP_RAV	Hallway4/4t	h	0.00	0	11.66	
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	
	EF-7	Ambt		-0.205			0
	WLEXOF_CAV	Ambt		-0.205			-11.66
WomensRoom4 - 0.316	72.0 PECA	_RAV Hall	way4/4th		0.000	0.00	
	DRINOP_RAV	Hallway4/4t	h	0.00	0	11.66	
	HvacSupply	Hallway4/4t	h	0.00	0	0.00	

	EF-8	Ambt	-0.205		0
	WLEXOF_CAV	Ambt	-0.205		-11.66
Stairwell4-A -0.31	6 72.0 STW	5A Sta	irwell5-A/	5th -0.000 - 343.21	
	DRINOP_RAV	Hallway4/4t	h -0.00	0 -277.16	
	STW4A	Stairwell3-	A/3rd	0.000 643.69	
	WLEXOF_CAV	Ambt	-0.205		-11.66
	WLEXOF_CAV	Ambt	-0.205		-11.66

level: 5th elevat ion: 48.0 ft

zone P T	path	from	dP	Flow1 Flow2	
Stairwell5 -0.489	72.0 DRATF	DWE_RAV Amb	t -0.	207 -63.09	
	WLEXOF_CAV	Ambt	-0.206		-11.71
	WLEXOF_CAV	Ambt	-0.206		-11.71
	STW5	Stairwell4/	4th 0.	000 343.21	
	DRINOP_RAV	Hallway5/5t	h -0.00	0 -256.71	
Office5-1 -0.489	72.0 WLEXOF	_CAV Ambt	-0.2	06 -11.71	
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WNOO6C_CMX	Ambt	-0.206		-9.88
	return	AHU-5	n/a		0
	supply	AHU-5	n/a		0
	DRINOP_RAV	Hallway5/5t	h 0.00	0 41.34	
	HvacSupply	Hallway5/5t	h 0.00	0 0.00	
	HvacReturn	Hallway5/5t	h 0.00	0 0.00	
Office5-2 -0.489	72.0 WLEXOF	_CAV Ambt	-0.2	06 -11.71	
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WNOO6C_CMX	Ambt	-0.206		-9.88
	return	AHU-5	n/a		0
	supply	AHU-5	n/a		0
	DRINOP_RAV	Hallway5/5t	h 0.00	0 31.47	
	HvacSupply	Hallway5/5t	h 0.00	0 0.00	
	HvacReturn	Hallway5/5t	h 0.00	0 0.00	
Office5-3 -0.489	72.0 WLEXOF	_CAV Ambt	-0.2	06 -11.71	
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WNOO6C_CMX	Ambt	-0.206		-9.88
	return	AHU-5	n/a		0
	WNOO6C_CMX	Ambt	-0.206		-9.88
	supply	AHU-5	n/a		0
	WNOO6C_CMX	Ambt	-0.206		-9.88
	WLEXOF_CAV	Ambt	-0.206		-11.71
	DRINOP_RAV	Hallway5/5t	h 0.00	0 72.81	

			HvacSupply	Hallway5/5t	h	0.00	0	0.00	
			HvacReturn	Hallway5/5t	h	0.00	0	0.00	
Office5-4	-0.489		72.0 return	AHU	-5	n	/a	0.00	
			WNOO6C_CMX	Ambt		-0.206			-9.88
			WNOO6C_CMX	Ambt		-0.206			-9.88
			supply	AHU-5	n/a				0
			DRINOP_RAV	Hallway5/5t	h	0.00	0	31.47	
			WLEXOF_CAV	Ambt		-0.206			-11.71
			HvacSupply	Hallway5/5t	h	0.00	0	0.00	
			HvacReturn	Hallway5/5t	h	0.00	0	0.00	
MechRm5	-0.489	7	2.0 HvacSupp	ly Hallway5	/5th	0	.000	0.00	
			HvacReturn	Hallway5/5t	h	0.00	0	0.00	
			WHGS_RAV	Ambt		-0.206			-57.11
			PECA_RAV	Hallway5/5t	h	0.00	0	0.00	
			WLEXOF_CAV	Ambt		-0.206			-11.71
			DRINOP_RAV	Hallway5/5t	h	0.00	0	68.78	
			CPEN_RAV	MechRm4/4th		0			0.01
			CPEN_RAV	MechRm4/4th		0			0.01
Hallway5	-0.489		72.0 WLEXOF_	CAV Ambt		-0.2	6	-11.71	
			WNOO6C_CMX	Ambt		-0.206			-9.88
			DRINOP_RAV	Stairwell5/	5th	0.	000	256.71	
			DRINOP_RAV	Office5-1/5	th	-0.0	00	-41.34	
			HvacSupply	Office5-1/5	th	-0.0	00	0.00	
			HvacReturn	Office5-1/5	th	-0.0	00	0.00	
			DRINOP_RAV	Office5-2/5	th	-0.0	00	-31.47	
			HvacSupply	Office5-2/5	th	-0.0	00	0.00	
			HvacReturn	Office5-2/5	th	-0.0	00	0.00	
			DRINOP_RAV	Office5-3/5	th	-0.0	00	-72.81	
			HvacSupply	Office5-3/5	th	-0.0	00	-0.00	
			HvacReturn	Office5-3/5	th	-0.0	00	-0.00	
			DRINOP_RAV	Office5-4/5	th	-0.0	00	-31.47	
			HvacSupply	Lab5-1/5th		0			0
			HvacReturn	Lab5-1/5th		0			0
			DREL_CMX	Elevator5/5	th	-0.2	07	-1.00	
			HvacSupply	MechRm5/5th		0			0
			supply	AHU-5	n/a				0
			HvacReturn	MechRm5/5th		0			0
			HvacSupply	Office5-4/5	th	-0.0	00	0.00	
			PECA_RAV	Lab5-2/5th		0			0
			HvacReturn	Office5-4/5	th	-0.0	00	0.00	
			DRINOP_RAV	Lab5-1/5th		0			-0.6
			DRINOP_RAV	Lab5-2/5th		0			-1.35
			HvacSupply	Lab5-2/5th		0			0
			DRINOP_RAV	Office5-5/5	th	-0.0	00	-41.34	
			HvacReturn	Lab5-2/5th		0			0
			HvacSupply	Office5-5/5	th	-0.0	00	0.00	

			PECA_RAV	Lab5-4/5th		0			0
			PECA_RAV	MechRm5/5th		0			0
			HvacReturn	Office5-5/5	th	-0.0	00	0.00	
			DRINOP_RAV	Lab5-3/5th		0			-0.6
			DRINOP_RAV	Lab5-4/5th		0			-1.35
			DRINOP_RAV	Office5-6/5	th	-0.0	00	-102.44	
			HvacSupply	Lab5-4/5th		0			0
			DRINOP_RAV	MechRm5/5th		0			-68.78
			HvacReturn	Lab5-4/5th		0			0
			HvacSupply	Lab5-3/5th		0			0
			HvacReturn	Lab5-3/5th		0			0
			DREL_CMX	CargoElev5/	5th	-0.	207	-1.00	
			WLEXOF_CAV	Ambt		-0.206			-11.71
			WNOO6C_CMX	Ambt		-0.206			-9.88
			HvacSupply	Office5-6/5	th	-0.0	00	-0.01	
			HvacReturn	Office5-6/5	th	-0.0	00	-0.01	
			DRINOP_RAV	Office5-7/5	th	-0.0	00	-51.22	
			HvacSupply	Office5-7/5	th	-0.0	00	0.00	
			HvacReturn	Office5-7/5	th	-0.0	00	0.00	
			PECA_RAV	MensRoom5/5	th	-0.0	00	0.00	
			DRINOP_RAV	MensRoom5/5	th	-0.0	00	-11.71	
			HvacSupply	MensRoom5/5	th	-0.0	00	0.00	
			PECA_RAV	WomensRoom5	/5th	-0	.000	0.00	
			DRINOP_RAV	WomensRoom5	/5th	-0	.000	-11.71	
			HvacSupply	WomensRoom5	/5th	-0	.000	0.00	
			DRINOP_RAV	Stairwell5-	A/5th		0.000	256.71	
Lab5-1	-0.489	72	.0 HvacSuppl	y Hallway5/	5th	0.	000	0.00	
			HvacReturn	Hallway5/5t	h	0.00	0	0.00	
			return	AHU-5	n/a				0
			DRINOP_RAV	Hallway5/5t	h	0.00	0	0.60	
			supply	AHU-5	n/a				0
			PECA_RAV	Lab5-2Stora	ge/5th		-0.000	0.00	
			HvacExhaust	PipeChase5/	5th	-0.	009	-0.60	
Elevator5	-0.696		72.0 ElevCa	bleOp PassEl	evMechRm/R		oof	-0.000	-5.02
			DREL_CMX	Hallway5/5t	h	0.20	7	1.00	
			ShaftElev5	Elevator4/4	th	0.0	00	4.02	
Lab5-2	-0.489	72	.0 return	AHU-5	n/a				0
			PECA_RAV	Hallway5/5t	h	0.00	0	0.00	
			supply	AHU-5	n/a				0
			DRINOP_RAV	Hallway5/5t	h	0.00	0	1.35	
			DRINOP_RAV	Lab5-2Stora	ge/5th				-0.76
			HvacSupply	Hallway5/5t	h	0.00	0	0.00	
			HvacExhaust	PipeChase5/	5th	-0.	009	-0.60	
			HvacReturn	Hallway5/5t	h	0.00	0	0.00	
Office5-5	-0.489		72.0 return	AHU	-5	n	/a	0.00	

	WNOO6C_CMX	Ambt		-0.206			-9.88
	WNOO6C_CMX	Ambt		-0.206			-9.88
	supply	AHU-5	n/a				0
	DRINOP_RAV	Hallway5/5t	h	0.00	0	41.34	
	WLEXOF_CAV	Ambt		-0.206			-11.71
	HvacSupply	Hallway5/5t	h	0.00	0	0.00	
	WNOO6C_CMX	Ambt		-0.206			-9.88
	HvacReturn	Hallway5/5t	h	0.00	0	0.00	
Lab5-2Storage -0.4	89 72.0 DR	INOP_RAV La	b5-2/5th		0.000	0.76	
	PECA_RAV	Lab5-1/5th		0			0
	PECA_RAV	PipeChase5/	5th	-0.	009	-0.76	
PipeChase5 -0.498	72.0 PECA_	RAV Amb	t	-0.	198	-5.57	
	PEDW_R	Ambt		-0.198			-2.78
	PEDW_R	Ambt		-0.198			-2.78
	PECA_RAV	Ambt		-0.198			-5.57
	PEDW_R	Ambt		-0.198			-2.78
	PECA_RAV	Lab5-2Stora	ge/5th		0.009	0.76	
	HvacExhaust	Lab5-1/5th		0.009			0.6
	HvacExhaust	Lab5-2/5th		0.009			0.6
	Chase5	PipeChase4/	4th	0.	000	15.58	
	HvacExhaust	Lab5-3/5th		0.009			0.6
	HvacExhaust	Lab5-4/5th		0.009			0.6
	PECA_RAV	Lab5-4Stora	ge/5th		0.009	0.76	
Lab5-3 -0.489 72	.0 return	AHU-5	n/a				0
	HvacExhaust	PipeChase5/	5th	-0.	009	-0.60	
	PECA_RAV	Lab5-4Stora	ge/5th		-0.000	0.00	
	DRINOP_RAV	Hallway5/5t	h	0.00	0	0.60	
	supply	AHU-5	n/a				0
	HvacSupply	Hallway5/5t	h	0.00	0	0.00	
	HvacReturn	Hallway5/5t	h	0.00	0	0.00	
Lab5-4 -0.489 72	.0 HvacExhau	st PipeChase	5/5th	-	0.009	-0.60	
	return	AHU-5	n/a				0
	PECA_RAV	Hallway5/5t	h	0.00	0	0.00	
	DRINOP_RAV	Lab5-4Stora	ge/5th				-0.76
	supply	AHU-5	n/a				0
	DRINOP_RAV	Hallway5/5t	h	0.00	0	1.35	
	HvacSupply	Hallway5/5t	h	0.00	0	0.00	
	HvacReturn	Hallway5/5t	h	0.00	0	0.00	
Lab5-4Storage -0.4	89 72.0 PE	CA_RAV Pi	peChase5/5		th	-0.009	-0.76
	PECA_RAV	Lab5-3/5th		0			0
	DRINOP_RAV	Lab5-4/5th		0			0.76
Office5-6 -0.489	72.0 return	AHU	-5	n	/a	0.00	
	DRINOP_RAV	Hallway5/5t	h	0.00	0	102.44	

	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	supply	AHU-5	n/a			0
	WNOO6C_CMX	Ambt		-0.206		-9.88
	HvacSupply	Hallway5/5t	h 0.00		0 0.01	
	HvacReturn	Hallway5/5t	h 0.00		0 0.01	
	WLEXOF_CAV	Ambt		-0.206		-11.71
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WLEXOF_CAV	Ambt		-0.206		-11.71
					/Roof -0.000	-
CargoElev5 -0.696	72.0 ElevC	ableOp2 Cargo	ElevMechRm		5.02	
	ShaftCargEl	e5 CargoElev4	/4th 0		.000 4.02	
	DREL_CMX	Hallway5/5t	h 0.20		7 1.00	
Office5-7 -0.489	72.0 DRINOP	_RAV Hallwa	y5/5th		0.000 51.22	
	HvacSupply	Hallway5/5t	h 0.00		0 0.00	
	HvacReturn	Hallway5/5t	h 0.00		0 0.00	
	supply	AHU-5	n/a			0
	return	AHU-5	n/a			0
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WNOO6C_CMX	Ambt		-0.206		-9.88
	WLEXOF_CAV	Ambt		-0.206		-11.71
MensRoom5 -0.489	72.0 PECA_R	AV Hallwa	y5/5th		0.000 0.00	
	DRINOP_RAV	Hallway5/5t	h 0.00		0 11.71	
	HvacSupply	Hallway5/5t	h 0.00		0 0.00	
	EF-9	Ambt		-0.206		0
	WLEXOF_CAV	Ambt		-0.206		-11.71
WomensRoom5 - 0.489	72.0 PECA	_RAV Hall	way5/5th		0.000 0.00	
	DRINOP_RAV	Hallway5/5t	h 0.00		0 11.71	
	HvacSupply	Hallway5/5t	h 0.00		0 0.00	
	EF-10	Ambt		-0.206		0
	WLEXOF_CAV	Ambt		-0.206		-11.71
Stairwell5-A -0.48	9 72.0 DRA	TFDWE_RAV A	mbt -		0.207 -63.09	
	DRINOP_RAV	Hallway5/5t	h -0.00		0 -256.71	
	STW5A	Stairwell4-	A/4th		0.000 343.21	
	WLEXOF_CAV	Ambt		-0.206		-11.71
	WLEXOF_CAV	Ambt		-0.206		-11.71

level: Roof eleva tion: 60.0 ft

zone P T	path	from	dP			Flow1	Flow2	
PassElevMechRm -								
0.	868 72.0 W	LEXOF_CAV	Ambt					-0.01
	Louver1	Ambt			0			-4.94
	ElevCableOp	Elevator5/5	th	0.0		00	5.02	
	DRDBNW_RMX	Ambt			0			-0.06
	WLEXOF_CAV	Ambt			0			-0.01
	WLEXOF_CAV	Ambt			0			-0.01
	WLEXOF_CAV	Ambt			0			-0.01
CargoElevMechRm								
-0	.868 72.0	WLEXOF_CAV	Ambt					-0.01
	Louver2	Ambt			0			-4.94
	ElevCableOp	2 CargoElev5/	5th	0.		000	5.02	
	DRDBNW_RMX	Ambt			0			-0.06
	WLEXOF_CAV	Ambt			0			-0.01
	WLEXOF_CAV	Ambt			0			-0.01
	WLEXOF_CAV	Ambt			0			-0.01

systems:

name a	ir flows:
reci	rc outside
AHU-1 0.	00 0.00
AHU-2 0.	00 0.00
AHU-3 0.	00 0.00
AHU-4 0.	00 0.00
AHU-5 0.	00 0.00

Note:
flows in scf m
pressures in in. H2O
temperatures in ~F
* indicates limit e xceeded

Appendix B: Equal Quantity Basis Analysis (Int-SF)

The Int-SF-OnceThru simulation yielded the highest numerically integrated exposure of Agent-1 in the hallway 1 release zone, therefore this zone will set the 100% (or 1.00) value by which other zones will be compared. Figure B-1 shows the dose versus time for hallway 1 of the Int-SF-OnceThru simulation. Peak dosage was reached at 1hr:00min with a dosage value of 503,208. Another zone can now be compared to this data utilizing the appropriate scale factor to make the room volumes equal.

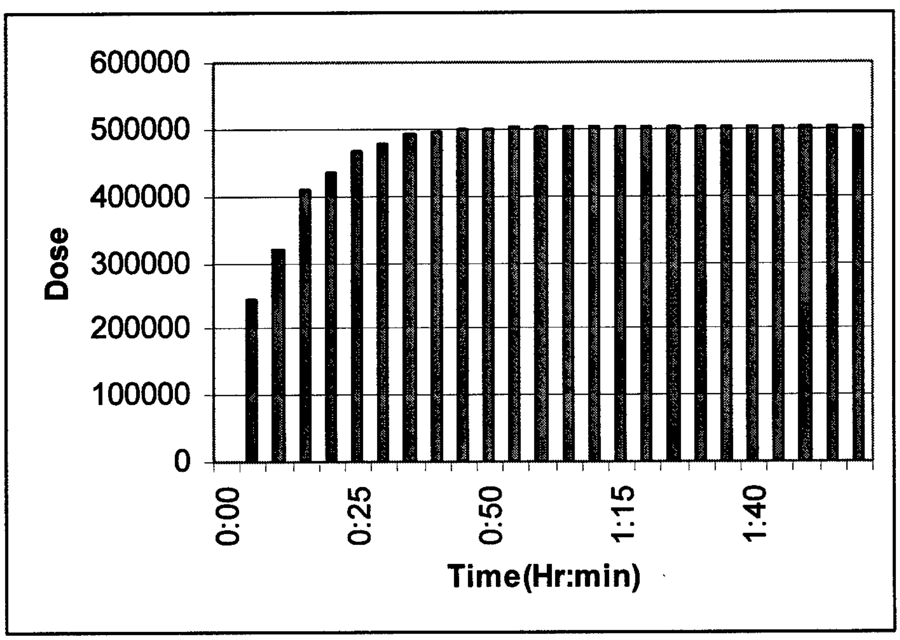

Figure B-1: Int-SF-OnceThru Dose versus time for Hallway 1

Office 1-5 can now be compared to the hallway 1 zone using a scale factor of 4.14 (Hallway1 =16,706 ft^3 versus Office 1-5 = 4032 ft^3). Figure B-2 represents Office 1-5 in this Dose versus time format. The dose in Office 1-5 was 57% of the maximum dose found in hallway 1 at time equals 1:00 hour.

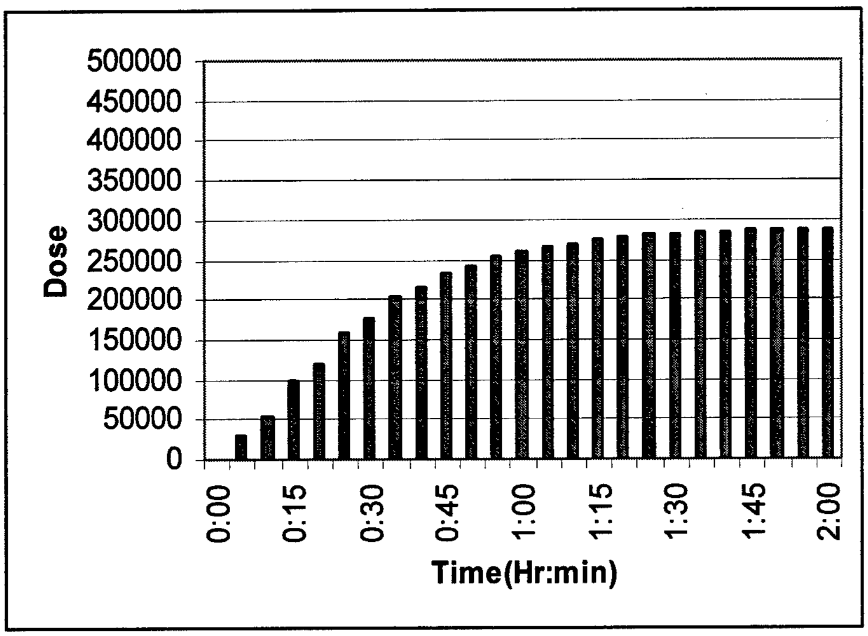

Figure B-2: Int-SF-OnceThru Dose versus time for Office 1-5.