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Energy Auditing and Technological Renovation of the Printer's Building for

Davis Publications, Worcester, MA

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Abstract

The Printer's Building in Worcester, MA is an architectural landmark. Built in 1923, it was designed to be an advanced structure for its time. Eighty-five years later, the building is no longer the state-of-the-art building it once was. The project goal was to reduce the energy inefficiency within the building. This project consisted of two parts. The first was to audit the building and locate its inefficiencies. Following the audit, recommendations were made for technologies that will reduce the energy usage of the Printer's Building by making it more efficient in all areas. The audit was accomplished by examining all the systems within the building, and the current efficiency at which they are performing. The recommendations for implemented technology were determined by a cost versus benefit comparison, while keeping in mind the limited budget that is available for making changes. Attention was also paid towards utilizing advanced sustainable technologies within the structure. The end objective of the project was presenting ways in which the Printer's Building can reduce its overall energy consumption, in an effort to transform into a sustainable structure.

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Authorship

This entire project was created and executed by all group members. The contents of the paper were contributed to equally, with all members writing sections and editing the entire report. All members contributed equally to the entire report, as well as attending group meetings and conducting on-site research.

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Executive Summary

The Printer's Building in Worcester, Massachusetts, is an old yet historically rich building. Constructed in 1923, it was created to house multiple floors of printing presses, utilizing then-advanced technology to create a structure that could support a vast amount of concentrated weight. However, the building's architecture, which was both technologically advanced and innovative for the time, is now outdated in an era of new technologies and growing global concerns about energy consumption and misuse.

This project was created to assist in the reduction of energy use of the building and its inhabitants, in hopes of creating a more environmentally friendly, sustainable structure. Due to its long history, there were many outdated and wasteful objects still incorporated within the building. The goal of this project was to perform an energy audit on the Printer's Building, locating areas of inefficiency in all aspects of the structure, and make a series of recommendations that would improve the efficiency of the building, both in its structure and in the active systems.

Methodology Overview

Our Methodology consisted of concise, targeted steps to define what aspects of the building audit needed to be completed and a time frame for their completion. Our first step was to target areas of improvement. We made a preliminary list, based on industry recommendations and standards of the most problematic systems and structural areas. This list was created to guide the audit, and identify unnecessary areas of the building audit that would have wasted time and resources. We then compared different auditing techniques to determine a specific assessment method and plan. Currently, there is a lack of a standard method in the industry for an easily understood auditing practice. Many auditing companies utilized varied walk-through techniques and recommended areas, so the project made it a priority to synthesize as many different methods as possible, and determine which one would bring about the most clarity during the actual process. We determined that a "Level" system was the most easily understood, and yet still the most sophisticated. In this method, there are three levels, with each one representing

different steps in the process. This project required a level-two audit, which focused on general systems (like HVAC and electrical), structural health, and envelope efficiencies.

When evaluating these methods, it was clear that both procedures and equipment needed to be established for the physical walk-through audit. Required tools, like a Thermal Imager or Photometer, needed to be located and reserved for use during the audit applications. Proper procedure also had to be developed and followed, so no extraneous or incorrect data was recorded. The audit focused on both general systems (like boilers and air conditioning) within the building, and the quality or health of structural components, such as windows, roofing, and other areas. After noting and investigating these inefficient areas, technological improvements were researched and compared for each individual unit. A cost/benefit analysis was performed between a list of suggested replacements and the current technologies to determine whether it would be cost-effective to replace the existing units with new, updated ones. A timeline was then created to instruct the owners on what systems were the most important to replace first, and what items could be delayed until funding was available.

Key Findings

The project initially focused on a level-two audit. The systems that were analyzed included the windows, heating, ventilation, air conditioning units, all lighting and their subsequent systems, and any other item that looked ancient or inefficient (i.e. broken, mechanically worn-down).

The most important focus, pre-site evaluation, was the condition of the windows. Some of these structures were from the original 1920's building, and therefore in decrepit shape. Single-layered, with peeling glaze and broken panes, these portals were venting heat to the outside quite rapidly, as it was discovered when reviewed by the Thermal Imager. To maintain the integrity of the building, and drastically increase the energy efficiency, the windows needed to be replaced. It was discovered that the owner had already secured an efficient, double-paned window to be installed gradually throughout the building when the appropriate funds became available. However, due to the enormity of the building and the price of each window, only half of a floor could be completed each year. Therefore, other alternatives were needed to assist in

retaining heat, without an exorbitant cost. Two of the alternatives that were the most effective were window films and cell-type window blinds. Film, the best technological choice, is a thin plastic covering applied to the windows by a professional. It allows visible light through, while retaining at least 50% more heat and reflecting 80-99% of ultraviolet rays from outside. Cell-type blinds, while not the most technologically innovative, were a solid second alternative. These blinds consist of fabric sewn into a honeycomb-like structure, which uses stagnant air to insulate the interior spaces. Although the best, most pioneering choice was the film, the cost of applying film to the entire Printer's Building was too prohibitive, and was not efficient enough to justify the cost versus purchasing and installing vast sets of cell-type shades. The blinds will reduce the heat loss by 10-15%, while still being inexpensive enough to cover the entire building.

A central boiler, located in the basement, supplies the heat to the building. This boiler heats the entire building through a centralized steam system, consisting of a single zone and extending through all seven floors. Many alternatives were considered for the installation of new boilers to improve the efficiency of the system, but all choices were far too costly to justify the increase. The group decided to focus more on retaining the created heat, instead of finding ways to efficiently heat the old building.

There are numerous air conditioning units within the building, of all different sizes, ages, and manufacturers. Although some systems are relatively current, there are others that are disastrous. The building houses, at minimum, four water-cooled A/C units, all installed prior to the 1980's. These systems waste enormous resources and were a primary focus for replacement. However, newer efficient units did not justify the replacement costs at this time. If money was available, new air-cooled units would be beneficial, but not a priority.

The ventilation systems seemed to be in decent condition; there were no flaws that could justify the replacement of the entire network. The only recommendations consisted of replacing any filters present in the air conditioning units and the ductwork with high-efficiency filters.

The electrics within the building were also areas of concern. The project had originally considered replacing all incandescent bulbs with fluorescents, a huge energy-saving possibility.

However, we discovered during the inspection that most of the lighting fixtures within the building were already fluorescent, so no quick changes could be performed. Instead, the group focused on other areas of inefficiency, such as replacing magnetic ballasts within the lights with brand new electrical ones, or upgrading the fluorescent tubes currently installed with newer ones that require less electricity to provide the same amount of light. Other changes were considered to improve the electrical use in the building. Upgrades such as motion sensors were recommended, as they allow the lighting to remain on only in used areas, and would unfailingly turn off at night when no activity was detected. These and other changes can save electricity, and therefore reduce the overall bill and inefficiencies of the current system.

Recommendations

We then used all gathered data to make an informed set of recommendations on how the energy use within the building could be significantly reduced.

1. Apply cell-type window shades to all exposed windows;
2. Replace all incandescent bulbs in building with compact fluorescents;
3. Replace all magnetic ballasts in trafficked areas of building with electric ballasts;
4. Detach all unused warehouse lights from electrical plugs;
5. Replace all light switches with motion sensors in all trafficked areas of building;
6. Replace any remaining incandescent exit signs with new Light Emitting Diode exit signs;
7. Replace all regular filters within air conditioning units with high-efficiency filters;
8. If possible, install new air conditioning units on the 2nd, 4th, 5th floors with air-cooled machines, replacing older, large units.

The changes suggested can be implemented fairly quickly, with little comparative impact on the annual budget on the building. When put into operation, however, they will save a

significant amount of money on the overall operation of the structure. These steps are crucial to the evolution of the Printer's Building into a sustainable technology showcase.

Chapter 1: Introduction

The Printer's Building was built in Worcester in 1923 to house an early-twentieth-century printing company. In the eighty-five years since the building's construction, its role has changed. Now the 94,000-square-foot structure is home to a variety of industries, including Davis Publications, WICN Radio, and the WPI Worcester Community Project Center. The building's architecture, which was both technologically advanced and innovative for the time, is now outdated in an era of new technologies and growing global concerns about energy consumption and misuse.

Due to the increased cost of and pollution due to easily obtainable energy, green and sustainable building design has been a popular new idea in building and planning over the past 10 years. Office buildings currently account for 39% of the United States' primary energy usage, cause 39% of the carbon dioxide emissions, and consume 70% of the electricity produced (USGBC, 2008). The utilization of green, or environmentally friendly, technology within the office building is aimed at reducing the overall consumption and footprint of a building. Sustainable building technology aims at reducing the amount of resources that the building needs to acquire externally to function. For most applications green and sustainable technologies overlap and can almost be considered synonymous. The benefits of green and sustainable architecture are numerous, including environmental, economic and health benefits. Reducing both solid and gaseous waste, along with consuming fewer natural resources, lessens the environmental impact of these structures. Economically, a green building reduces operating costs with its increased efficiency. Finally, the health of people using the building will be enhanced as the air, thermal, and acoustic environments will be improved.

Wyatt Wade, the representative of the Printer's Building, is ready to update the structure to continue its history of being a building of innovation. The structure is in need of modernization to reduce the cost of operation and improve the efficiency in the building's usage of natural resources. In order to reach the ultimate goal of turning the building into a demonstration site of green and sustainable design, many systems and variables will need to be examined, including the heating, ventilation, lighting, insulation, windows, and electrical systems. Also the building could potentially house a source of renewable energy, such as a wind turbine or solar panels.

In the reconstruction and remodeling of the Printer's Building, Davis Publication, Inc. had many specific objectives. Their first objective was to determine the current state of the building, both technologically and in terms of energy consumption. This was accomplished by analyzing the current building systems, also known as performing an energy audit. In this audit, all systems were reviewed for both efficiency and overall condition. Two of the major systems targeted were the electrical and HVAC systems. These items utilize the most energy within the building, and had the potential to waste the most resources through inefficiency. The project also calculated how much heat was being lost through the windows and through the lack of insulation in the walls and ceiling. All the other various utilities and objects were also examined for their impact towards turning the Printer's Building into a structure supporting sustainable technology.

The second major objective of the project was to determine the quality of the audited systems, and to conclude different ways of improving them. Such recommendations included installing a new boiler, changing the windows, or adding solar panels. Focusing on the most inefficient systems, this project recognized the greatest gain in energy efficiency by renovating

such equipment, saving both time and money that could be put into the eventual restoration of the building.

Once the areas of improvement and different methods of change were ascertained, a “roll-out” plan was created. This plan, which is the project’s final objective, consists of a timeline of modifications to be implemented on the building; it makes recommendations for immediate improvements that can be performed to instantly save the building money. In creating the timeline, special attention was placed on finances, cost-to-benefit ratio, and changes that would bring the structure further towards achieving one of the green standards, such as Energy Star-rated or LEED certified.

Although the idea of green and sustainable building has been present in American society for years, it is still a relatively new concept. The push for sustainability is increasing rapidly, fueled by high costs of energy, the depletion of natural resources and the increasing evidence of human’s ecological footprint on the Earth. Both economically and politically, “Going Green” is the new catchphrase across the United States. In many areas of society, there is an ever-growing demand for every sector of the economy to convert to a sustainable design.

Albeit this rush seems to be widespread and well documented, the availability of both green products and technical information are not that abundant. However, with the recent developments in the green technology field, there are a growing number of case studies that pertain to the project, such as the Friends Committee on National Legislation’s newly-renovated, LEED-certified green building, finished in 2007. This was first public building to be renovated with green technology on Capitol Hill. Many other examples can be found in varied places, from

college campuses to industrial sites. Nationwide, over 60 buildings have received some LEED certification with 840 waiting to be certified. This shows that the interest in sustainable design is a common idea, and one that is important to the future of the Earth.

Chapter 2: Background

2.1 Global Change

Earth is in a constant state of change. Every action undertaken by its inhabitants affects the environment, no matter how small. With all of the modern human technologies that are deemed a necessity here in the United States, comes a great effect on the natural world. The United States, while consisting of only 4% of the entire world's population, is responsible for 25% of the total CO₂ emitted into the atmosphere (A World of Imbalance, 2008). CO₂ is a molecule that exhibits a "greenhouse effect" when introduced into the atmosphere; it effectively prevents heat from radiating away from the Earth's surface, creating a warming trend within the atmosphere. Other known greenhouse gasses are CH₄, N₂O, and chlorofluorocarbons (CFC's), all of which cause the greenhouse effect, and contribute towards the intensified issue of global climate change. Global warming is an issue that scientists have only begun to see, as recent data exhibits the fact that the Earth's temperature has risen nearly by 2 degrees F over the previous one hundred years. Annually, it is increasing by 0.32 degrees F (Environmental Protection Agency, 2008). Concerned by this rapid inflation in base temperature, many international agencies, such as the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization, and other panels of the UN, are organized to govern on a global scale and monitor these ever-changing conditions. There are also organizations from separate nations, such as the United States Environmental Protection Agency (EPA), which oversees the issue and aims to reduce the U.S. greenhouse gas emissions by 18% by 2012 (Environmental Protection Agency, 2008).

Many factors in the United States contribute toward the emission of these gasses; two of the major producers are motor vehicles and buildings. Buildings, as a combined entity, contribute 39% of all CO₂ and 36% of all greenhouse gas emitted within the United States (United States Green Building Council, 2008). These high levels of discharged gasses cause rising temperatures within the atmosphere and also influence other aspects of climate change. It is found in the IPCC's 2007 climate change report that there has been a reduction of snow coverage due to the warming of the atmosphere; there has been a reported 5% drop in snow coverage across the Northern Hemisphere and a general decrease in the Southern Hemisphere as well. The IPCC's report also links global warming to a near 2-mm-a-year rise in sea levels. This organization is closely monitoring the association of the intensity and pattern of weather across the world with the current rise in temperatures, to determine if there is a pattern (Change, 2007).

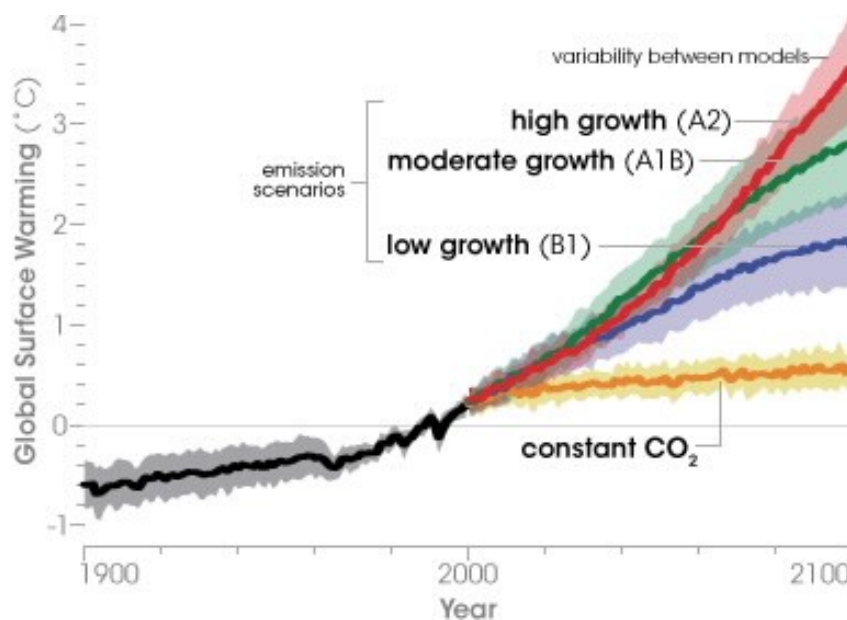


Figure 1. Temperature Projections up To the Year 2100, Based on Various Scenarios and Global Climate Models (Environmental Protection Agency, 2008)

The IPCC report projects the temperature in the following years to increase up to 4 degrees C by the year 2100. This can be seen in Figure 1. Figure 2 shows there is evidence that there has already been an increase in sea level, and that rise is projected to grow during this century to over 300mm.

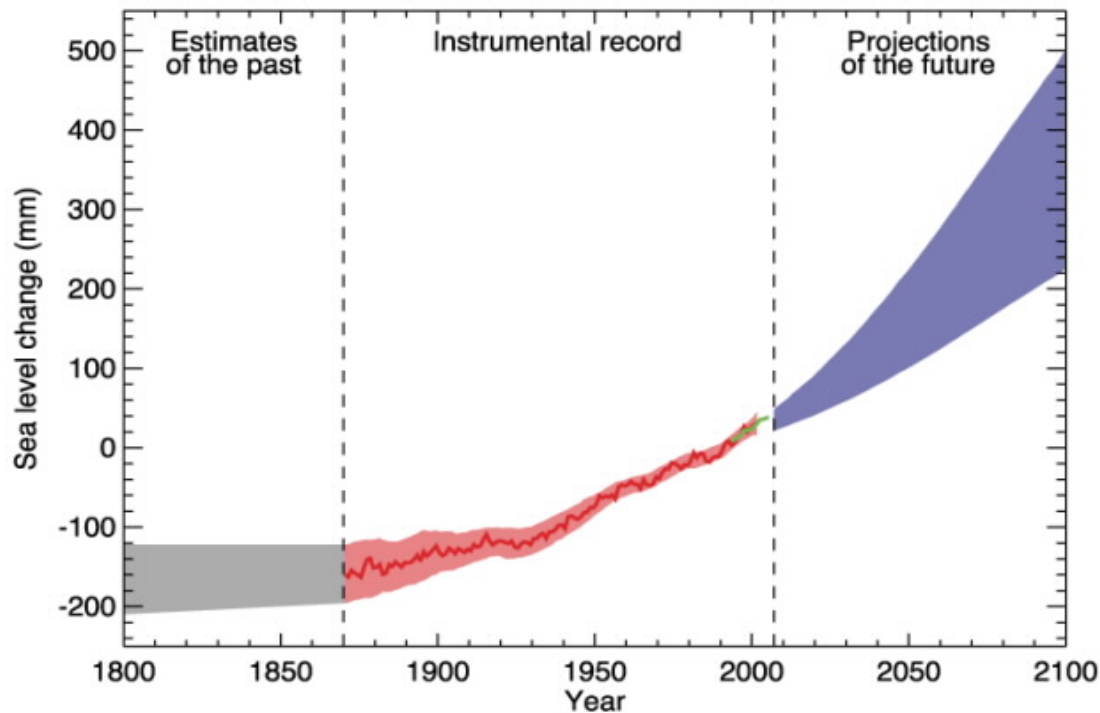


Figure 2. Past and Projected Sea Levels (Environmental Protection Agency, 2008)

If this global warming trend continues, it could cause many different changes that would be very detrimental to the environment, affecting the habitat and potential population sizes of many organisms and vegetation across the world. Some changes that could occur across the globe are a continuing rise in ocean levels, further melting of the polar ice caps, and a depletion of the ozone layer. All of these are serious changes that need to be addressed immediately; if not, drastic and permanent changes could happen to Earth.

2.1.1 Laws & Incentives for Change in the U.S.

With the growing concerns over global warming, the federal (and many state) legislatures have introduced legislation that provides both grants and tax incentives to buildings that utilize certain types of sustainable technology or building methods. These have been created in order to encourage both homeowners and businesses to utilize green technology in their everyday operations. The LEED (Leader in Energy and Environmental Design) Rating System is one such guideline. This program, founded by the United States Green Building Council, evaluates buildings in various categories on aspects of green technology employed within the structure. It recognizes standout structures in this field by awarding different LEED certification medals, acknowledging that structure's contribution to a sustainable environment. It also provides significant tax incentives. Although this is the biggest green certification program within the United States, other programs exist, such as the BREEAM certification in the European Union. All these existing certification programs attempt to reduce energy needs, both within the private and the public sectors. However, current building renovation is a difficult process to evaluate. Since the structure is being changed, an energy audit needs to be performed to assess the biggest energy losses, and how such wastes can be eliminated.

2.2 Building Audits

Constructing and maintaining buildings requires a sizeable amount of energy. They consume 39% of the US's primary energy and 70% of all electricity produced (USGBC, 2008). Building construction is a large industry on its own. It contributes up to 14% of the United States' total GDP (USGBC, 2008). With the price of electricity and energy rising, it is becoming even more critical to know how energy is consumed in a building (Options, 2006). That is why

energy audits are undertaken. They can be performed at many different stages of construction and upkeep. Energy audits can be carried out while a building is in the design stage to determine how much energy will be used (USGBC, 2008). Once the building process begins, they can also be performed to determine projected waste and consumption. This is especially important when trying to qualify for LEED certification (USGBC, 2008).

In an analysis that attempts to reduce energy usage, it may be quite difficult to pinpoint exactly where faults lie within the structure. Becoming more environmentally friendly by reducing energy needs is a very broad concept, and there are many different ways in which approaches can be evaluated. Given all the choices, it is often challenging to distinguish between the methods that offer a thorough examination leading towards a reduction in energy usage, and those that are not as effective in pinpointing weak areas. Throughout the past 20 years, attempts by businesses to “Go Green” usually resulted in failure due to improper advice and information, therefore making both people and companies skeptical of any energy evaluation. Luckily, there have been many advances made in technology in the past 10 years, as well as growing education and certification within the environmental auditing field. This has created proven methods that can provide a homeowner or company with a thorough and trustworthy way of obtaining a methodical evaluation of a building’s weaknesses.

2.2.1 Why Audit?

There are many reasons for energy audits, including

- Increasing profit;
- Lowering the utility bills;

- Increasing the comfort of interior space;
- Planning a remodel or upgrade;
- Reducing the carbon footprint and environmental impact of the building;
- Helping to reduce American reliance on foreign energy;
- Discovering any rebates and incentives that qualify for the building.

An energy audit is the only professional way to determine where a house or a building is losing energy and how much is being lost. It can enlighten a homeowner or building manager about how many resources are being needlessly wasted or how efficient the building and the interior systems are. There are many different types of system audits that can be performed on a building. Choosing the right type of audit is determined by the size and shape of the building, and by the depth or cost of the audit (Kutz, 2006). However, to become LEED-certified, there are numerous factors that need to be considered. These include regional public transportation, water usage and hot-spot size (USGBC, 2008).

2.2.1.1 Advantages and Disadvantages

There are advantages and disadvantages to having a structure audited. However, the advantages far outweigh the negatives. The benefit of having a building audited is empirically the opportunity to save money. Any structure may be inefficient in various ways. For example, energy could be lost through rapid heat dispersion due to poor insulation through the attic and windows, continuously operating lights or machinery, outdated air conditioning/heating equipment, or many other problem areas. A professional auditor can use both specialized equipment and experience to pinpoint the specific weak systems and the most wasteful ones.

When the inefficient areas are identified, then measures can be taken to prevent further energy loss, ranging from insulating heat-loss areas to replacing the entire HVAC units that are outdated or corrupt. The identification of problem areas and their improvements will result in saving resources and reducing the utility bill with clear financial benefits.

On the other hand, there are some disadvantages to energy audits. The biggest problem is the price of the audit itself. Commercial sites almost always need a professional auditor, due to the complexity of the systems and the variety of processes that usually occur in a large building. However, that can lead to financial problems, mainly because commercial auditors are expensive. First of all, they require (depending on State legislation) certain technical degrees or qualifications and many hours of experience (Everblue, 2008) to become certified energy auditors, which can take many months or years. Also, the equipment used by these auditors can contribute to a prohibitively large audit price. Devices like infrared thermal imagers, used to show where heat is being lost, can range from \$5,000 to above \$100,000 (C. Boggiano, personal communication, September 23, 2008), a sizable investment for many auditors. Both the necessary training and the equipment required to perform a thorough and accurate audit can make the final audit price very high. This cost may prevent many companies from obtaining an audit. The high cost can offset any possible benefit that may be gained through the systems analysis.

A “free” audit, usually available from an energy provider’s website, can be another possible disadvantage, because although these audits are a quick and cheap way to evaluate a structure, they are prone to errors and false readings (Home Energy Yardstick, 2008). Since these websites are intended for a general energy overview, they cannot tailor the audit to the

clients' specific needs, and this can possibly create major errors in identifying locations of inefficiency within a building. If such a situation happens, it can cause a company or a homeowner to spend thousands of dollars on unnecessary equipment or insulation.

Energy audits are a new and, currently, rarely utilized idea within the commercial and residential industry. Although there are many possible disadvantages to having an audit, they are vastly outweighed by the positives that could come from having the building or residence reviewed for energy usage. When preformed correctly, an audit on a building can both reduce operating costs and make the building friendlier to the environment.

2.2.2 Audit Processes

There are many ways that a professional auditor can determine energy inefficiencies in buildings. When auditing a commercial building, a professional looks at five specific areas; the building's envelope, the insulation present, the ductwork within the facility, the HVAC (Heating/Ventilation/Air Conditioning) systems, and the electrical draw. These areas are usually the most inefficient, or they bleed the most energy, thus the easiest and quickest way to determine a building's energy loss is to evaluate them. Auditors also focus on the heating and cooling systems since they account for 50% of a building's energy usage, and if they are leaky or inefficient, they could account for a large quantity of wasted energy (C. Boggiano, personal communication, September 23, 2008).

2.2.2.1 Building Envelope

A building's envelope is essentially the physical structure, the "shell" of the building, and how well it is sealed against the surrounding environment. It is also how efficiently the building

controls and renews the interior air and environment. For a home or small building, the air inside must be renewed every three hours (100% of the volume of the air must be refreshed) in order to maintain a healthy environment. Since interior air quality is two to five times worse than exterior, this air exchange is essential for human occupation (Everblue, 2008). Ventilation can occur through either natural or mechanical sources. An auditor can use specialized equipment to calculate airflow through the building, determining if there is a leak in the system. Such inefficiencies can be found by a walk-through audit, focusing on improper insulation, leaky ductwork, incorrectly installed windows, or another problem.

2.2.2.2 Insulation Efficiency

An infrared thermal imager analyzes the efficiency of the insulation within a building. Since his device can view infrared waves, which is the wavelength of heat, it can see where heat is being vented to the outside, both across the entire building and in specific areas of the envelope (Everblue 2008). Usually, darker colors mean that those areas are colder, and lighter colors or white means that the area is very warm.

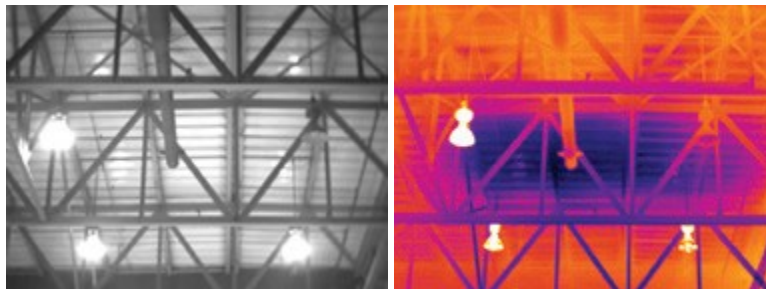


Figure 3. Infrared Imaging Pinpoints Energy Loss (Infrared Thermography, 2008)

The insulation also plays a big role in the building's envelope. If good insulation is present but air is still venting even through a little area, it is not effective. Since heat takes the path of least resistance, a small pocket within any insulation can ruin the usefulness of that padding (see

Figure 3). Therefore, a thorough examination of a building's insulation is beneficial for both its envelope and the heat preservation of that structure.

2.2.2.3 HVAC Analysis

Another main system that is evaluated in an energy audit is the HVAC. This can be accomplished in two ways, through a deterministic or a statistical approach (Kutz, 2006). A deterministic audit depends on energy principals and the building's data (Kutz, 2006). In this method, an overall thermal transfer value is determined and then compared to established data taken from other buildings. Past weather data is also included in this analysis to help produce a yearlong energy audit (Yeziroa, Dongb, & Elite, 2008). Different types of computer-based deterministic approaches are Energy_10, Green Building Studio web tool, bequest and EnergyPlus (Net, 2008). A statistical approach is one that is almost entirely based on data (Kutz, 2006). Basically it is an analysis of records of past consumption (Kutz, 2006). As with a deterministic analysis, this data is then compared to information from other buildings of similar use and size. Unlike a deterministic approach, the data from other buildings is used as a benchmark to determine how the audited building's energy use compares to the reference structure's energy use (Kutz, 2006).

2.2.2.4 Ductwork

Within an HVAC unit, the ductwork throughout the building plays a huge part in the overall system's energy usage. A building is classified into two separate spaces: conditioned and unconditioned. Conditioned space is defined as an insulated, heated and lit area. Since ductwork passes through both spaces during its cycle, both areas affect the ductwork's energy loss. If the ductwork is improperly sealed or insulated in the unconditioned space, a sizable amount of heat

or cooling can be lost when it passes through the unconditioned area. The average duct system leaks 30% of conditioned air into the unconditioned space, resulting in higher bills and shortening the life of the equipment (Everblue, 2008).

2.2.2.5 Lighting

Lighting is usually the second biggest energy draw for a building, second only to the HVAC system. There are several ways to complete an electrical audit of the lighting. When performing a walk-through, a photometer is usually used to analyze the amount of illumination within a given space to determine if the area is improperly lit. In addition to a photometer, a total system analysis can be used, which is when a mathematical breakdown of the general electrical distribution is preformed (Kutz, 2006). These values are then used to compute how much electricity is going to each individual system (Zhang & Wei, 2006).

An audit cannot solely focus on the lighting, however, no matter how simple that analysis may be. Many national organizations consider other energy reductions much more highly than reduced electrical draw. For example, the LEED certification checklist rates a reduction in freshwater use much more highly than reduced power needs.

2.3 Technology Implementation

Green technology is a relatively new idea in building design. These techniques help lower the consumption of energy and other natural resources, as well as reduce emissions. An additional benefit of sustainable equipment is decreasing the operating costs of the building. These technologies range from simple fixes like changing light bulbs to more involved processes such as installing solar panels or a wind turbine.

2.3.1 Quick Changes or Modifications

Quick changes are the small modifications that can be executed for relatively little money and labor, but will net an energy consumption payoff fairly quickly. Many of these technologies' accessibility and low cost of installation make these fixes very appealing; some installations are as simple as replacing light bulbs. The main objective is to gain energy efficiency for the building with a rapid payoff and a small upfront cost. These fixes can net financial benefits within a short period of time, since the building is using less energy and resources to complete necessary tasks such as providing lighting, heating, air circulation, and so forth.

2.3.1.1 Lighting Fixes

New fluorescent light bulbs are much more efficient than those of the 1970's, the decade when the energy crisis first catalyzed the use of fluorescents. Replacing the old bulbs with new efficient ones can save multiple watts per bulb. For example, a typical four-foot bulb requires 40 watts of power, where a new florescent can generate the same lumen output while only requiring 34 or 32 watts (Wulfinghoff, 1999). In addition, the newer phosphors present in these higher-efficiency lights are not as prone to lumen output decrease as the old bulbs. The old fluorescent light bulbs lose 10 to 40 percent of their light output with age, while the newer lights will not face nearly as big a loss (Wulfinghoff, 1999).

Another simple lighting strategy is to remove bulbs and ballasts in areas that are over lit, or where the amount of lighting is more than needed. Removing the unneeded bulbs will help decrease energy costs. However, to truly take full advantage of the potential savings, the

accompanying ballasts need to be removed since they still draw power even when the bulb is not present in the fixture (Wulfinghoff, 1999).

Replacement ballasts are available that are intended to only power one bulb and can be installed in areas where the number of active light bulbs is being decreased. In addition, the ballasts can be replaced along with the bulbs to increase the fixture's efficiency. The new magnetic ballasts are more efficient than the older ones, but to really have a large increase in efficiency a new hybrid or full electric ballast should be used. The downside of these two latter options is that they cost more than typical magnetic ballast. However, through the increased efficiency they will pay for themselves within a couple of years.

Another improvement to lighting that is simple and inexpensive is replacing old lighting with modern fluorescent or HID lighting. There are options as simple as replacing the bulbs with screw-in fluorescent bulbs. For example, a 20-watt fluorescent replacement bulb can produce the same illumination as a 75-watt incandescent bulb (Wulfinghoff, 1999). For a greater cost, entire fixtures can be replaced with either fluorescent or HID fixtures. It may take more time for the savings to cover the upfront cost, but the long-term payoff is greater.

2.3.2 Longer-Term Renovations

There are multiple options for longer-term items of implementation. They require a greater financial commitment and more time for installation, but have the potential to yield much larger gains both financially and environmentally. These technologies pertain to the windows, insulation, ventilation system, heating system, and air conditioning, among other things.

2.3.2.1 Window Technologies for Lighting

There are many ways that windows can be utilized to increase the efficiency of a building. Good windows can improve the lighting, and the heat gain, while reducing thermal loss in the structure. Theoretically even on an overcast day the amount of sunlight that a building receives is enough to fulfill all of its lighting requirements (Wulfinghoff, 1999). The reality is that with the shape of most buildings, there are areas that cannot be lit well enough, or at all, by daylight alone. For areas that do have window access there is also the problem of dealing with direct sunlight, which is normally too intense to be used for lighting purposes.

One option for distributing direct lighting is to use a glaze on the windows. The glaze spreads the light so that it becomes more of an indirect light as opposed to the direct lighting that would come through clear glass. This measure would be effective for windows that are exposed to direct sunlight such as the south side of the building. Since windows that do not face the sun receive indirect light, the measure is not necessary in these locations. The big problem with glazing is that it is a costly option to retrofit to an existing building, and the payoff period is long and variable depending on how much electric lighting is eliminated by the technology (Wulfinghoff, 1999).

Another method is to install light shelves on the inside of windows that are exposed to direct sunlight. These shelves, which are located in the upper half of the window, reflect the sunlight that comes in the window and spread it across the ceiling and walls, turning it into the useful indirect sunlight. These shelves are cheaper and easier to install than the glaze. The downside is that they only utilize a partial amount of sunlight due to the angle of the sun. Also,

the shelves need to be kept clean to allow them to reflect the most light, which is commonly ignored for periods of time. Then, once darker dust covers the white color of the shelf, the effectiveness will drop significantly (Wulfinghoff, 1999).

Two items that would work well for improving the lighting, in conjunction with a method like the reflecting shelf, are using light-colored window shades or drapes and wall paint. The shades will allow some light to come through as useful incandescent light, so the amount lost through the shelving setup will be less than if a heavy or dark shade was used. For extremely cold weather, having a heavier shade may be beneficial for covering a window and providing additional insulation when it is no longer exposed to sunlight. The light-colored walls and ceiling will reflect most of the light that enters the room. The reflection of light compared to the absorption that would be present with darker colors allows the room to be as bright as possible with the lighting, both natural and artificial, in the room.

2.3.2.2 Window Technologies for Insulation

Windows fundamentally are not very efficient for maintaining comfortable building temperature. In the winter the windows allow a great heat loss and in the warmer months the sunlight that comes in through windows provides unwanted heat to the building. New technologies help to manage this heat transfer through windows. Most of these require replacing the entire window and are expensive, but the long-term financial benefits can make such upfront costs worthwhile.

A double-pane window, with an inert gas between the panes, increases the insulation value by decreasing the heat lost by conduction (Wills, 2001). Such method works well for cold

climates where a well-insulated window minimizes heat loss. Another consideration in deciding on window types is the material of the window frame. Wood or vinyl frames transfer less heat than aluminum frames, but lack some of the structural strength. If the strength of aluminum is needed, having an air gap in the frame can help reduce the heat loss and bring the value closer to that of a vinyl frame.

2.3.2.3 Heating System

Heating systems in old buildings offer multiple options for improving efficiency. These options range from localizing thermostats to updating the monitoring systems on the boiler itself. Localizing thermostats for smaller regions allows the heat to only go to the areas of the building that need it without wasting energy by heating unneeded areas. If certain areas are overheated in order to obtain necessary temperature levels in other zones of a building, the hot areas could cause a larger energy waste as their occupants open the windows to balance the temperature.

Barring any possibility of zone heating, installing equipment that closely monitors the efficiency of the boiler's multiple systems can help to keep a more consistent output. Typical heater services check how the boiler is working every year, but having this instrumentation would help identify areas that need to be maintained on a more consistent basis. This would improve both the economical and environmental efficiency of the boiler (Wulfinghoff, 1999).

2.3.2.4 Green Roofing

Green roofs, or more technically known as “vegetative roofs”, are roofs covered with vegetated spaces or gardens installed. There are two main types of green roofs; intensive and

extensive roofs (Living Roofs, 2008). Intensive vegetative roofs have plants on them that possess deep-growing roots, like trees and bushes; this system requires the host building to have a complex irrigation system and extra support for the weight on the roof. Extensive green roofs are a more common and much less expensive system, as its vegetation has a very thin, non-intrusive root structure that generally requires no maintenance or irrigation. Extensive systems generally cost much less than intensive ones and require no additional support to the building, since the systems are actually lighter than common non-green roofs. They can be installed as mature grown sedum mats onto an existing roof, or can be grown from a thin layer of recycled crushed brick or aggregate and planted with sedum or wildflowers (Living Roofs, 2008). In some cases, they can even be left to populate naturally. Benefits of green roofs include extended roof life due to less exposure of the roofs' waterproof membrane to the climate and solar radiation, and an increase in the insulation of the roof, saving in heating and cooling costs to the building.

Green vegetation helps the building better manage its thermal insulation, consequentially helping it keep the temperature of a building more consistent. Even if it does not greatly impact the average temperature of a building, it can greatly reduce the extreme high temperatures to which a building may be exposed (Niachou, 2001).

2.3.2.5 Electrical Usage

Along with the simple fixes that apply to lighting, there are more involved processes that can decrease the energy consumption from the artificial lighting system of a building. Some of these technologies include daylight-linked photoelectric switching, time switching, and motion sensor switching and localizing manual switching (Li, 2000). The most complex of these

switching methods is the daylight-linked photoelectric switch. This switch analyzes the amount of light in the room from daylight and other sources. Then it turns on the lighting that it controls as needed to bring the lighting up to the luminescence requirements for the room (Li, 2000). The trick with this setup is locating the sensors in the correct spots so that the switch receives a true indication of the amount of light in the entire room.

Time switches work well for large areas of a building that are mostly unoccupied at certain times of day, since it could shut down the lighting and save the respective energy costs when the building area is empty. This switching can cause problems, for example, when the building lighting has to be used for variable amounts of time. Also, daylight savings time and the changes in the duration of time that the building is exposed to daylight can be a factor in the switch's effectiveness.

Localizing manual light switches helps to cut down on illuminating areas of a building that do not require the lighting. Shrinking the zones covered by each switch can make it more difficult to turn on large areas of light at once, but the benefit of not turning on excess lighting in unnecessary areas is a good exchange.

2.3.2.6 Electrical Generation

A building can cut its energy dependency by generating its own energy. The two most widely compatible methods are by collecting energy from either wind or solar means. Hydropower also would be a renewable energy source that could potentially power a building, but unless the building has access to a moving waterway, hydropower is not feasible.

Solar energy is one of the most well-known forms of renewable energy. There are two main ways that the sun's energy can be converted to energy, through thermal and electric energy generation (Energy Information Administration, 2008). In both cases, the heat of the sun is directly used to heat another media, such as water or areas within the building. Solar energy is also used to create electricity through photovoltaic cells or at a solar power plant (Energy Information Administration, 2008). A photovoltaic cell is made out of silicon and when the sun's heat hits it, it causes the molecules in the silicon to move change charge, creating an electron deficit, and therefore electricity (Energy Information Administration, 2008). Most solar power plants do not use photovoltaic reactions, but simply reflect the sun's heat at a central point where thermal heat generation takes place. This heat will then create steam and create electricity in the same way a normal, coal-using plant creates electricity.

Solar energy is completely limitless, but right now it has some negatives. The biggest drawback is that it can be extremely inefficient, since photovoltaic cells only capture about 20-40% of the sun's energy (Department of Energy, 2008). Solar cells are also inordinately expensive, and it takes a long time to recoup the initial costs. Another reason why they can be impractical is that solar energy is only beneficial in areas that receive a lot of sun, such as California (Department of Energy, 2008). Even in these areas, large tracts of land are required because the sun is not always shining in certain areas (Energy Information Administration, 2008). In the Northeast, anything but thermal solar heating is greatly inhibited due to the long, snow-filled winters.

Wind turbines come in many shapes and sizes, but there are two main types; ones with vertical axis and ones with horizontal axis. The traditional horizontal axis wind turbines, HAWT,

look like a large-scale fan, transferring the wind's kinetic energy into electricity. There are many models built by manufacturers across the world including companies such as General Electric in the United States (Wind Turbines, 2008). Horizontal turbines rotate around a horizontal axis, as a stereotypical windmill does. The generator is located at the axis of the windmill and where the turbine attaches to the tower that supports it. On the other hand, vertical axis wind turbines, VAWT, spin around the vertical axis, and the generator is located at the bottom of the turbine.

When comparing vertical and horizontal axis turbines of similar size in turbulence and mixed direction wind, a vertical axis turbine creates 20-40% more energy than a horizontal axis turbine (About Small Wind, 2007). Vertical axis wind turbines are also more applicable to buildings because of their ability to operate with very minimal amounts of vibration and noise. Finally, since the generator is located at the bottom of the turbine instead of being elevated in the air, VAWT's provide easier access for maintenance. However, although the horizontal turbines take more space than comparable vertical turbines, they perform with greater efficiency. For example, vertical axis wind turbines are not able to withstand the wind speeds at high altitudes in the way horizontal turbines can. They must be positioned lower to the ground because of this, and thus are exposed to more turbulent, less effective wind.

Wind turbines on buildings are becoming increasingly popular and lower in price. However, they are all dependent on the strength and the quantity of the wind provided to them in order to produce electricity. It is essential to have a strong wind flow around the building location to maximize the turbine's output and minimize the time of its payback.

2.3.2.7 Water Recycling and Harvesting

A big trend in sustainable building design has been waste water recycling, as in using “gray” water or recycled water for additional purposes such as industrial use, irrigation or toilet flushing. Wastewater recycling was traditionally done off-site, but more recent sustainable designs have on-site wastewater recycling that can reuse up to 100% of the buildings' water. An example of this is the Sweetwater Creek state Park Visitor Center in Lithia Springs, Georgia.

The state park building uses all waterless toilets and urinals that are connected to composting bins underground, which enable the soil to be enriched. This building has employed another popular technique to be more sustainable with water. By using a rainwater harvesting system to supply the building with treated water, Sweetwater Creek State Park is projected to save up to 77% on its drinkable water supply (Gerding, 2008). Reedy Fork Elementary School in Greensboro, North Carolina has also employed rainwater harvesting to save 750,000 gallons of non-potable water a year. Its harvesting system starts with a catch on the school’s roof, which sends the water to an underground cistern. The water is then pumped out of the cistern through a more efficient filter, chlorinated, and then transferred into the school’s toilets and non-potable applications (Nicklas M., 2008). This allows it to follow normal waste procedures without impacting the city’s water supply.

2.4 Case Study: Cambridge City Hall Annex

The Cambridge City Hall Annex was built in 1871 on 344 Broadway St. in Cambridge, Massachusetts. This building was renovated and restored from October of 2002 to February 2004 into a showcase or demonstration site for sustainable building technologies in Massachusetts. The 33,000-square-foot building was transformed from an inefficient blunder to a state-of-the-art LEED-NC Gold standard building. The Cambridge City Hall Annex has received many awards

and distinctions for its renovation including the Sustainable Buildings Industry Council First Place Exemplary Sustainable Building Award 2006, and the Massachusetts Historical Commission Preservation Award 2005 (Turner, 2008).

The nearly \$12 million dollars of renovations brought countless renewable technologies and ideas to the Cambridge building. Solar power is one of the many technologies employed on the building, with 28-kilowatt photovoltaic roof-mounted panels. The Cambridge City Hall Annex utilizes day lighting with coverage of 90% of the building integrated into their intelligent lighting system, which reduced energy consumption greatly (Cambridge City Hall Annex, 2008).

The heating and cooling system is one of the building's most interesting aspects. Ground source heat pumps to heat the building with a variable air volume distribution system to regulate the office space (Turner, 2008). Because these systems meet the entire building's heat requirements most of the time, no additional resources are used.

The building used a wide variety of technologies to achieve a LEED gold certification. Along with the use of recycled construction materials, they employed a 50% more-efficient irrigation system, alternative transportation methods, a white roof to absorb less heat, low-e double-glazed pane operable windows, CO₂ sensors, and segregation of indoor pollutants such as copiers and printers. This building was projected to decrease its energy use by 56%, and although it fell short of this goal, it still reduced overall emissions by 40%. Not only did the efficiency of the building increase, but also many employees responded that they felt their work effectiveness had improved due to the upgraded work environment (Turner, 2008).

2.5 Summary

The information gathered in this chapter provided a background for the various issues that are being addressed in this project. The auditing information indicated a spectrum of options available and allowed the group to select the method that we thought worked best given the present constraints of the project. Our research on technologies provided a background on green and sustainable technologies that could be suggested for application within the Printer's Building. This information served as a foundation for the methodology that the group used to complete the project.

Chapter 3: Methodology

This Interactive Qualifying Project focuses on both the assessment of the Printer's Building energy usage, and making informed recommendations for the implementation of new, energy-saving technology that could be utilized to help to turn the building into a sustainable structure. Although it is common knowledge that energy-saving technology dictates a "green" lifestyle, not many people understand how to both assess an existing structure for inefficiencies, and employ that data to create a cost-effective renovation plan that utilizes a broad range of green technology, which can be readily executed.

3.1 Areas of Improvement

Although it might seem necessary to audit and renovate the building immediately, we have determined some crucial steps that need to be taken. Before any actual audit begins, one of the most important tasks was to perform a quick, walk-through appraisal. This was conducted to determine certain focus areas for the actual audit (Kutz, 2006). Once those significant locations are established, we quantified the amount of energy used in each of these regions, and then established values of estimated energy after possible renovations. After speaking with the sponsor, Wyatt Wade, and other occupants of the Printer's Building, we had determined a few preliminary areas of particular concern.

One of the main areas we examined was the heating and cooling system: the boiler and air conditioner efficiencies. This system is usually one of the biggest problems in any old building, and after meeting with Mr. Wade, it came to the forefront of our attention. He informed us that the boiler was installed in the 1970's and that many of the air conditioner units within the building are not much newer. With this knowledge, we believe that the effectiveness could be

greatly increased if these units were replaced, thus lowering the energy demand for this system. Therefore, specific attention was paid to both correctly analyze the efficiencies of those systems, as well as pinpoint multiple areas for new technological renovations. We also learned that although the building is 94,000 square feet, there is only one heating zone and temperature controller for the entire building. We investigated ways to change this, because heating unused areas causes drastic inefficiency.

Another system that was brought to specific concern was the lighting. Presently, most of the Printer's Building is only occupied during the workday (although there are plans to add apartments in the future). However, certain lights, like the ones in the stairwells, are continuously operating. Mr. Wade noted these lights as being far too bright for their purposes; therefore we investigated these situations when determining how to reduce energy usage.

A third important area for concern was the general insulation of the building. Currently, the Printer's Building has no insulation in the roof or between the multiple floors, thus creating an area of large heat transfer and energy loss. The exterior of the building is also known to have many defects. Specifically, the windows and masonry are in poor condition. Mr. Wade has already determined that new windows will be installed. This report helps him to establish the order and areas of installation. We also audited the energy loss through the walls of the structure. Since these are solid brick or concrete, recommendations for efficiencies were difficult due to the lack of materials/insulation available for such structures, and we had to determine other creative methods of heat containment.

3.2 Comparing Auditing Techniques to Determine Specific Assessment Plan

A common approach to auditing a building is imputing the data from the building into a computer program such as Energy_10, Green Building Studio web tool, eQuest and EnergyPlus (Yeziroa, Dongb, & Leite, 2008). All of these programs are used frequently in the field of energy auditing, and are great for computing many different variables and areas of inefficiencies. Using data gathered through a preliminary analysis, we determined which program is most useful for our audit. However, the Green Building Studio web tool is expensive; consequentially we chose not to utilize it during the audit. Energy Plus has been shown to be one of the more accurate tools available, and accordingly we initially focused on development with that program (Yeziroa, Dongb, & Leite, 2008). Along with a computer model, we did quantitative comparisons, using established equations developed to solve for multiple variables, including whole-building inefficiency.

3.3 Establishing Procedures and Equipment for Physical Audit

A physical audit, also known as a walk-through audit, is one performed by a professional in the field. Although computer analysis can pinpoint general areas and give specific energy sectors to examine, only a physical audit will accurately determine weak areas (the regions high in inefficiency), and notice any further signs of energy loss that a computer program has missed. Although these programs are extraordinary in providing an overall estimate, they lack the necessary capabilities to adapt to each building type, therefore limiting their effectiveness on a personal level.

We have compiled a basic method for a physical audit, which we followed to pinpoint inefficient locations within the building. The initial plan was to:

1. Obtain two years' bills for all energy use (including electrical and natural gas);
2. Graph the energy use in a spreadsheet, for a visual reference on past energy control;
3. Obtain the building's mechanical, electrical, and architectural drawings;
4. Draw up floor plans of current conditioned space (heated or cooled areas within the building);
5. Calculate the gross square footage of the building and of each floor's occupied area.
6. Develop a building profile, including age, occupancy, description, history, and existing conditions of electrical, mechanical, and architectural systems;
7. Note major energy users or systems and their locations within the building.

During the physical audit, we focused on five major areas: the building's envelope, including ceilings and floors, the lighting systems, the HVAC unit and accompanying ductwork, the water heating units, and the power systems. Two of the major engineering tools that we utilized were photometers and thermal imagers. These items are utilized by auditors to give them a quantitative method to record and analyze "unseen" energy loss, both through lighting fixtures and structure heat loss.

The specific assessment method that we followed is based on a system of "levels", all of which assess the stages and rigor of the audit for future reference. Level-one audits consist of a general walk-through audit, focusing on the general, easily reviewable areas of the building. This method puts more focus on finding simple problems, such as incorrect light bulbs or any other glaring waste of resources. This audit can take between a day and a month to perform, depending on the type and size of the building. A level-two audit is more in-depth. This walk-through examines large, complex systems, and how they function or relate to the surrounding environment. For example, for a ductwork system, a level-one audit may focus on filter changes and obvious holes, while a level-two audit would focus on the airflow and exchange within the

system, and re-routing excessive lengths, which lose energy. A level-three audit examines one system (or many systems, depending on the time constraints or scope of the project), to evaluate the entire efficiency of the unit. In reference to the ductwork example, a level -three audit would focus on the entire system's ducts, any equipment (air conditioners or heaters) attached, and how everything interacts within the building. It would analyze everything in exhaustive detail, from mechanical health to spatial interactions. This is also the longest audit to perform, taking upwards of two months for a single system.

To audit the electrical systems, specifically lighting, we compiled data of occupation of the building and when the lights were active, to determine which sections were using a majority of their resources on lighting. To establish the actual lighting in different areas, we used a photometer. This tool is relatively cheap, compared to a thermal imager, and shows the actual illumination in specific areas. This data was evaluated against suggested values for office illumination to see if areas had unnecessary lighting.

One of the ways we helped Mr. Wade to update windows was through a thermographic inspection. Before our project, the method in which the windows were prioritized for replacement was by identifying the ones that were in the worst physical quality. However, through a thermographic analysis, we concluded which windows were actually the most inefficient. Although a window might seem to be in poor quality, it can actually be losing less heat than a "newer" window, depending on the quality and type of the new window. If a new window is single-paned, or does not possess a glaze, it could be venting more heat than a dual-paned older window. The windows losing the most heat--usually the old single-paned type--

were prioritized for replacement; without this analysis, replacing structurally sound windows that are cosmetically out of date could result in wasted money.

3.4 Identifying Best Practice for Technological Improvement

After the energy and efficiency audit was conducted we located the areas that were in need of improvement. A quick walk-through inspection was used to determine areas that looked in need of enhancement, and to target areas that needed to be audited in depth and analyzed more exhaustively than others. We evaluated the level-two audit of the building. The results of the audit showed spots that are very inefficient in thermal energy, letting large amounts of heat in or out of the building. The audit also located fixtures or spots that are inefficient in other ways, such as machinery inefficiency. Such data from the Printers Building was structured from most to least efficient overall. Along with these targeted areas of maximum wastefulness, other areas where inexpensive fixes can be implemented will be a priority.

3.5 Determining Cost/Benefit for Possible Technologies

The technologies available as replacements for current equipment in an existing building are varied in cost, availability, ease of use, simplicity of installation and effectiveness. After evaluating the areas that needed the most improvement, a decision was made about what technology needed to be implemented in these sections. Using data from the audit, the amount of the energy needlessly lost for areas of the building can be determined. This data can be used to create a model of energy consumption within different regions of the building over a specified duration of time. The model would serve as a control to compare against the data that could be generated when the new energy-saving technology is implemented. We researched the cost of

installation and appropriate energy use information for each upgrade that could be implemented within the building. The energy data gathered was next compared with the information collected earlier. The differences in the energy data was evaluated at a current estimated energy cost to determine the financial savings for that particular renovation over a designated time period. This method showed the cost/benefits of the particular fix over different periods of time, and was used to determine which technologies will have the largest financial impact. The upfront costs were considered and prioritized, as there is a severely limited budget to work with for upgrading the building.

While conducting this analysis, we also took into consideration the types of businesses that inhabit the Printer's Building. They each have their own habits and requirements of resources. We assessed each company in those areas and adapted our technology recommendations to their operating methods to make certain that our equipment choices do not affect their work environment or profitability in a negative fashion. Many of these companies are not highly profitable, so we had to make recommendations that would not affect their bottom line. Only then, would they be willing to follow such guidelines. Similarly, we chose technology that took into account the habits of all companies, and prioritized the effectiveness of that equipment's operation within the building.

A comprehensive list was made for Davis Publications as to which technologies to implement in the building that would be the most effective with the biggest return. These systems were tailored to focus more on immediate energy-saving changes that would have a direct effect on the structure's resource usage. We continued to research and investigate appropriate technologies and examine other case studies throughout the project to expand our

knowledge to include many pieces and applications of equipment, so that we could make an informed and extensive recommendation at the conclusion.

3.6 Possibilities for Financial Benefits

Finding financial support for the transformation of the current Printer's Building to a more efficient structure was imperative, due to the high cost of most technological improvements. We researched through both federal government grants and opportunities available from the local Massachusetts government. We examined the prospects for tax incentives or paybacks made available to those buildings that reduce energy usage or create electricity on-site.

While searching for opportunities available to the Printer's Building, it was important to first determine its classification. There are grants for businesses and commerce, as well as grants for residential housing and multi-use buildings. The determining factor was which grants were applicable to a structure like the Printer's Building.

We were always careful in our analysis, examining each grant for an expiration date, or ineligibility requirements. Grants change from year to year, so we did not recommend anything that would not be immediately applicable.

3.7 Creating a Timeline of Implementations

The green technologies that need to be employed to turn the Printer's Building into a sustainable building cost more than what is available for Davis Publications to invest in one year. The initial recommendations for implementation in the building focused on the least efficient systems. Many of these, like the windows, were too expensive to completely change out in a one

year with Davis Publications' current budget. When we discovered a system (like the windows) that was too costly to entirely replace in one fiscal year, only partial changes were suggested in that period. To complement this area of large expense, some minor cost changes were recommended. Examples of this ranged from changing light bulbs and taking down unnecessary fixtures, to closing unused ductwork and regulating air intake. These inexpensive fixes have the potential to rapidly pay for themselves, saving additional money for Davis Publications that could be utilized in the following years for more expensive upgrades.

Despite the high initial costs, renovating the most inefficient systems first will net the largest decrease in energy misuse in the building, and therefore will have the biggest drop for operating costs. Once the initial price of this technology is returned through the energy savings, the money saved could go towards increasing the budget for the renovation of the Printer's Building. Making these changes as early as possible will save the resources of Davis Publications, and a bigger budget in the ensuing years that will facilitate additional changes.

Consequently, our recommendations mainly focused in immediate, relatively easy –to-accomplish methods or employable technologies that the Printers Building can follow to reduce energy needs. A longer-term plan could use both our recommendations and the money saved to plan out additional renovations or equipment replacements.

The timeline for the inclusion of new technology to the building was dependent on the outcome of the audit, and also on what areas of the building would see the most cost-effective gains. Changes in either of these variables will change the course of implementation to optimize the use of the company's resources.

Chapter 4: Findings

This chapter shows the results from the data-gathering methods presented in the Methodology chapter. This information supports the group's initial thoughts on the state of the building and how to improve it. The following subsections show what the group gathered for relevant data and how that data is useful to this project.

4.1 History of Utility Usage

One of the first steps in performing an energy audit is to look at the history of the building's energy use. This information is important because it shows us trends and spikes in energy use. We are only concerned with the past two years because we want to examine the current energy uses, and are not interested in any data gathered from companies that have already vacated the building.

The first system that we fully analyzed was the electrical, which was measured in kilowatt-hours. Figure 4 shows what we expected, a large increase in electrical use during the summer months of July and August. During these two months the building averaged an energy use of 93,000 kWh. This is about 1/5 of the average annual energy use of the building, 476,080 kWh. The sudden increase in electrical use during this time is due to the air conditioning units. We conclude this because during the winter, electrical use drops significantly, despite the use of electrical heaters.

Even though there is an increase in electrical use during the summer and decrease during the winter, the total use does not fluctuate a very large amount (max =48000kWh, min=31,000kWh). This high constant electrical draw is due to equipment, which is not influenced by the weather, such as lighting, machinery, and computers.

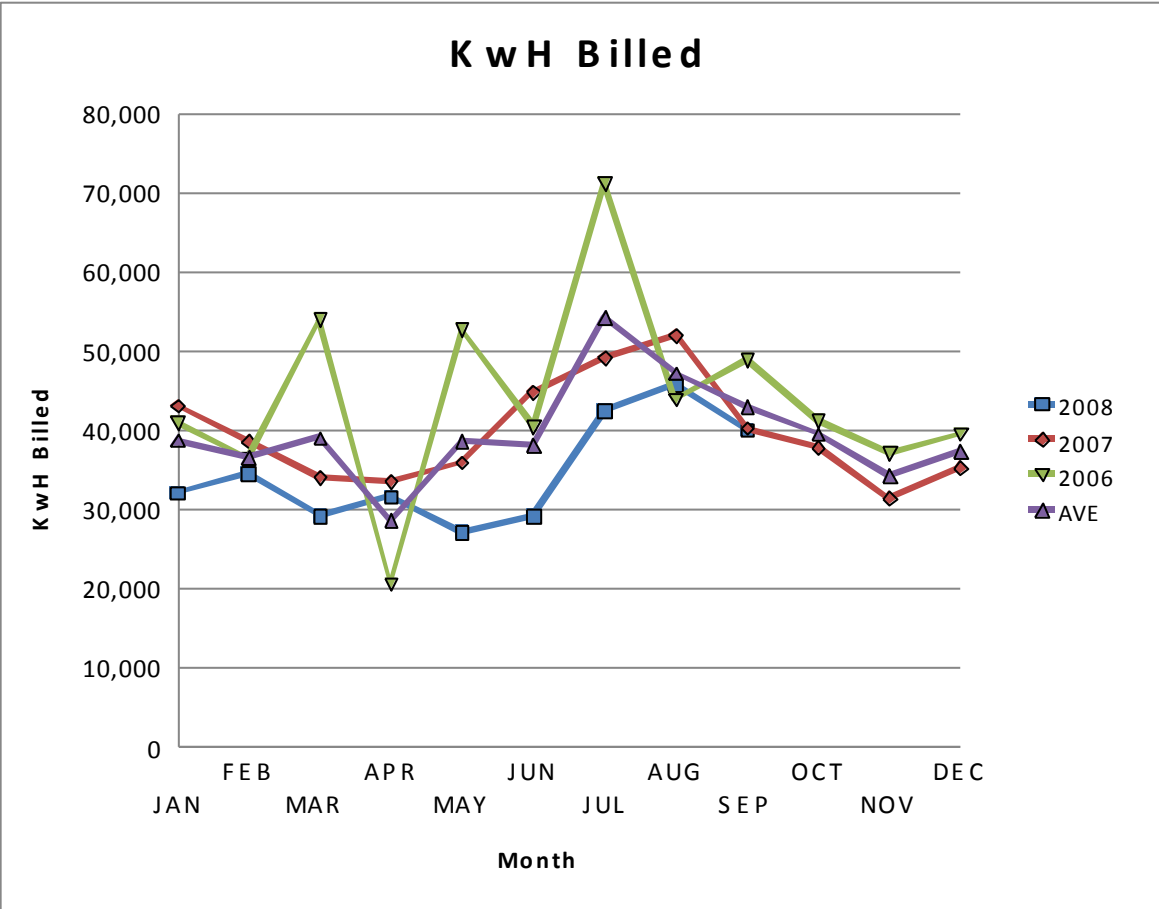


Figure 4. Graph of Kilowatt-Hours Used by the Printer's Building, By Month

When we first analyzed the graph, we saw the great spikes in 2006's data (green line), which is probably because the electrical company did not actually measure the meters. Instead, they just estimated the usage within the building. Therefore, this data was used in creating the average (purple line); but we did not spend time analyzing the peaks and valleys of that year.

The other system we analyzed was the gas or main heating system, which is measured by therms billed. As expected, there is a large spike in gas use during the colder months, November to April, as can be seen on Figure 5. These six months account for almost 97% of the total gas

use. Due to increased gas requirements, improvements should be focused on reducing the amount of energy used to heat the building, not the amount used to heat water for other uses, such as hot water for sinks.

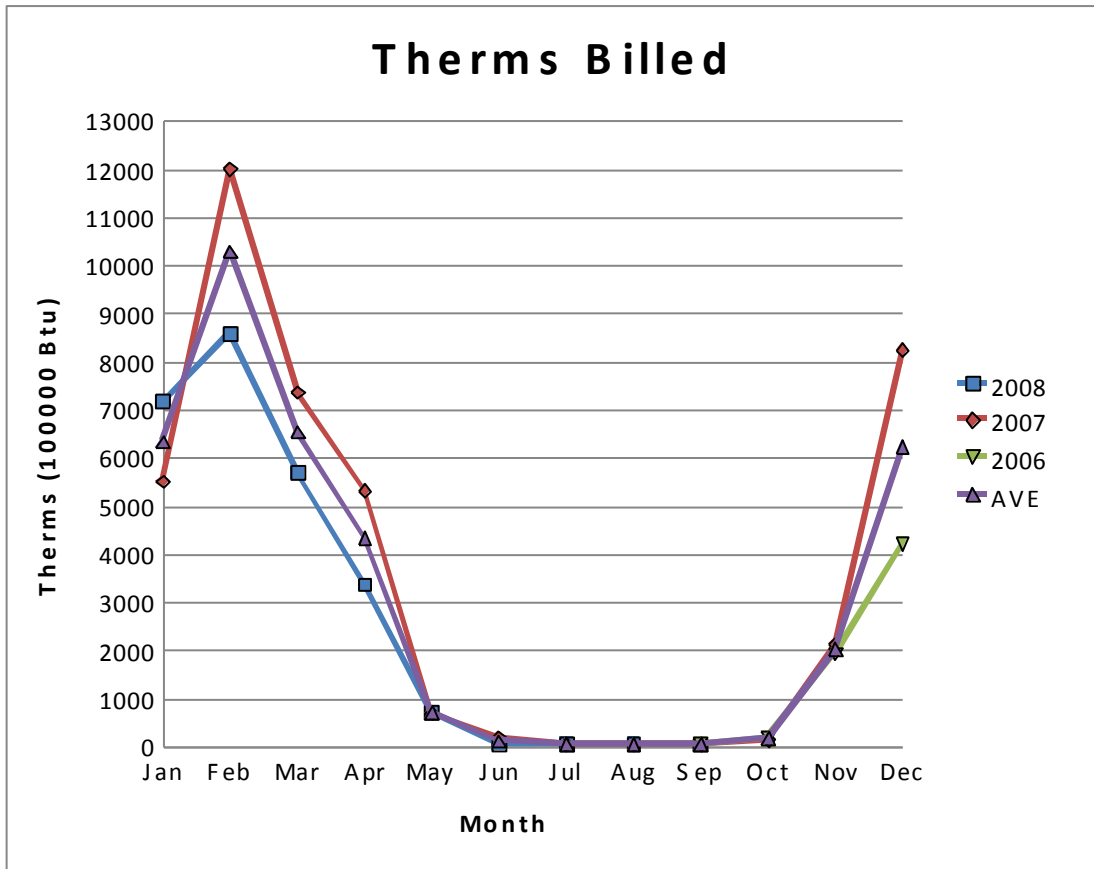


Figure 5. Graph of Energy Usage of Printer's Building, By Month

In addition to electricity and gas, we were also hoping to examine the water use and sewage output. However, we were unable to obtain this information from the building manager in a timely manner to analyze it properly.

4.2 Walk-Through Audit

The level-two audit provided preliminary data on many aspects of the building including the quantity and type of lighting, the number of computers, the presence of air conditioning and its location, placement of ventilation units, and quantity of heating sources per floor. This information allowed the group to identify areas where obvious energy-saving changes could be made.

4.2.1 Lighting

Most of the lighting in the building is fluorescent, which is much more efficient than incandescent lighting. The fixtures in many areas appear dated, indicating that they utilize magnetic ballasts, which do not possess the efficiency of modern electric ballasts.

The hallway on the third floor uses overhead track lighting, which Mr. Wade noted was required to light up the art hung throughout that hallway. A potential switch to HID lighting could save electricity while still providing the desired lighting.

In addition, the group concluded that the radio studio was overlit, and could save energy by removing some of their light fixtures. This area is especially important since the radio station is one of the only areas in the building that is in constant use, so any inefficient or unnecessary lighting could prove highly expensive.

There were many fixtures in various warehouses, and in most cases there were enough lights or window space to provide more than adequate illumination to the location at any time of day or night. At the time the audit was conducted most of these lights were not active, and since most of the building is essentially empty at night it is safe to assume that most of these lights are not being utilized in the building's current setup.

4.2.2 HVAC System

While analyzing the HVAC systems throughout the Printer's Building, we noticed that most of the units located in the building appeared to be antiquated systems, which we assumed caused huge energy draws. The age of the air conditioners in the building brings to question their potential efficiency. To properly review the status and efficiency of the units, every model number was acquired for all air conditioning or circulation units. This data was then used in conjunction with literature acquired from Terence Vanecek, a representative at Carrier Corporation, to determine their lifecycle and efficiency ratings.

Every unit built in the United States is tested for its efficiency and rated with an energy efficiency ratio, or EER. EER's range from 1 to 36, with 36 being the theoretically most efficient, and 1 being completely wasteful. When we analyzed the units within the building, we discovered that all fall between the range of 8 and 9, which is not terribly efficient at all. Therefore, outfitting the building with new HVAC systems would greatly increase energy efficiency. Vanecek recommended an overhaul of the chillers and air-handling units to equipment with an EER of no less than 13. These new units would be approximately 30% more efficient due to the increased EER's $(1 - (\text{current EER}) / (\text{new EER})) \times 100 = 1 - 9/13 = .3 \times 100 = 30\%$. Although this improvement would be tremendous for the building, the upfront cost of replacing the units would be too extreme and not practicable at this time.

Due to the excessive cost of new HVAC units, we pursued different avenues to find ways to make the current systems more efficient. Actions like simple maintenance, having the belts on the motors tightened on the current units, could save a great deal of energy. Maintaining a schedule for changing the filters on the units could also improve the efficiency, since dirty

particle-filled filters lead to a reduction in airflow, causing the motor to work harder and use more energy to move air through the system. The type of filter used in the system can affect the efficiency as well; there is higher-efficiency media and construction used in some filters that allow the motor to use less energy to move the same amount of air through the system. We created a life cycle cost analysis based on ten years of use of the same type of filter assuming it is changed twice a year for one of the larger units in the building; this unit was located on the 4th floor and uses 8 filters for the system. The life cycle cost analysis showed us that using the existing filters for the ten year period would cost \$11,207, and is demonstrated in Figure 6.

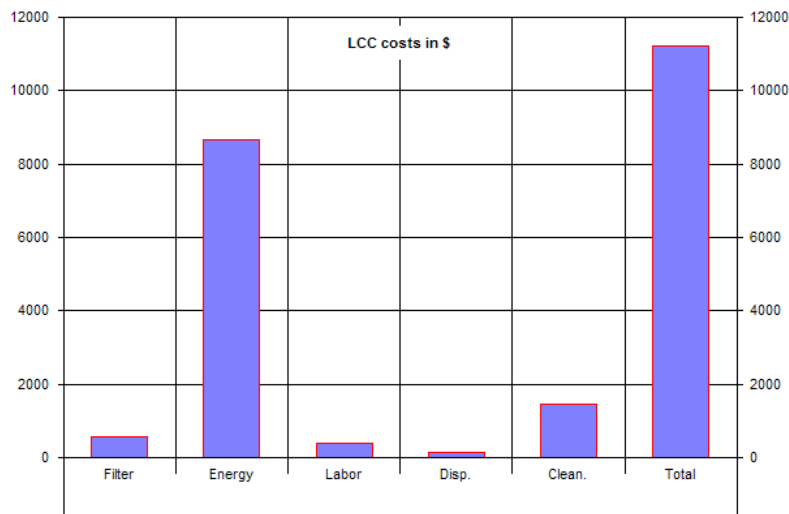


Figure 6. 10-year Cost Analysis of Existing Filters in Carrier 38JB016520

Performing the same analysis using energy efficient filters, it was determined that the total life cycle cost would be \$8,134, saving the building \$3,073. This is demonstrated in Figure 7.

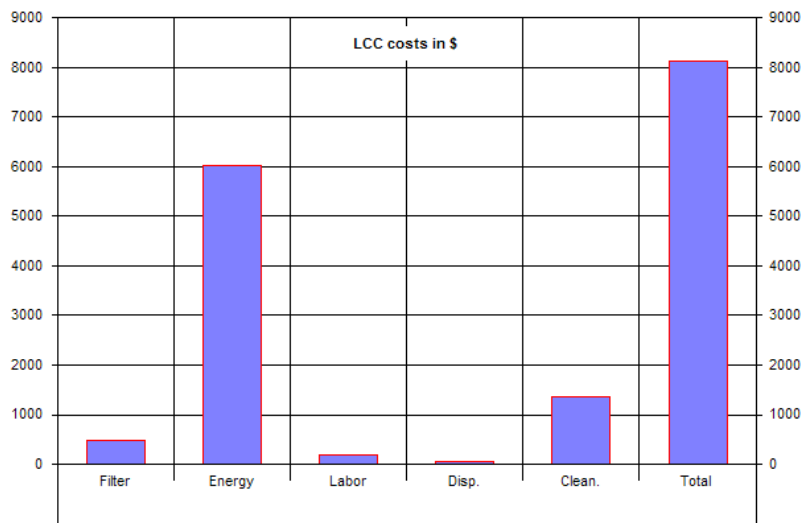


Figure 7. 10-year Cost Analysis of Energy-Efficient Filters in Carrier 38JB016520

The savings netted from changing to energy-efficient filters is approximately \$300 each year for just one of the many units in the building. Making these changes for all of the HVAC equipment within the building could add up to remarkable savings.

The heating system in the building is a natural gas boiler that was installed in the 1970's. This boiler, located in the basement, provides heat from a centralized steam system piped throughout the building. Since this setup possesses only one heating zone, the steam is not evenly distributed throughout the building. None of the heating pipes within the building are insulated, so consequentially as the steam rises through these pipes, heat is released unevenly, with the lower floors receiving the majority of the heat.

In addition to the central heating system, many floors had electrical units to assist in warming the space. The second through fifth floors each had one or two mobile electric heaters, while the seventh floor holds both electric baseboard heating and electric overhead heaters. The

suspended heaters are in an alarmingly bad location; heat rises, and accordingly these units need blower fans to blow the warm air down, increasing the inefficiency of the system.

4.2.3 Other Energy Draws

Some of the floors had other large electrical draws, such as a hot water heater or dishwasher (sixth and first floors, respectively). All the floors except the basement and sixth floors house computers, which are subject to daytime use. These computers may possibly be left on at night causing an unnecessary electrical draw. The first and seventh floors also house large servers that consume fairly large amounts of energy. The first, second and third floors all have large copiers that can create a large electrical draw when operating.

The fifth floor houses the building's only active printing presses. There are 11 machines located in the warehouse on that floor, but only four were observed to be in use when the audit was conducted. Not many recommendations can be made in relation to the printing machines, since they are essential to Miles Press and expensive to replace. However, their energy usage is important to note when considering the overall energy management within the building.

The first floor encompasses the radio station, which, not including lighting and computer power, has a large energy draw. The station boasts five satellite feeds along with other studio equipment used to produce and broadcast their shows. These items are essential to the station and cannot be eliminated, but recommendations can be made for using more energy-efficient equipment.

In the basement there are three vending machines. Two of these are drink machines and the other one is a snack distributor. They all are constantly running and drawing electricity. During the walk-through one of the drink machines was completely empty but still plugged in.

Unplugging this machine when it is not holding any beverages will help decrease energy usage in the building, and the snack distributor could be placed on a timer or motion sensor, to be deactivated when the building is not in use.

4.2.4 CAD Floor Plans

As part of the audit it was extremely important to map the locations of some of the essential systems in the building, like the HVAC units and ductwork. The only floor plan that could be obtained was those from 1923, and even then, they only displayed the exterior walls of the building. Since no interior floor plans could be found, and since such things could not be determined if they even existed, the group created CAD drawings that served as blueprints of the building. These drawings contain layers, each one containing different information such as HVAC systems, conditioned/unconditioned space, and include a breakdown of the floor space by usage. They also map the location of storm windows within the building, or where the windows have been boarded up (see Figure 8).

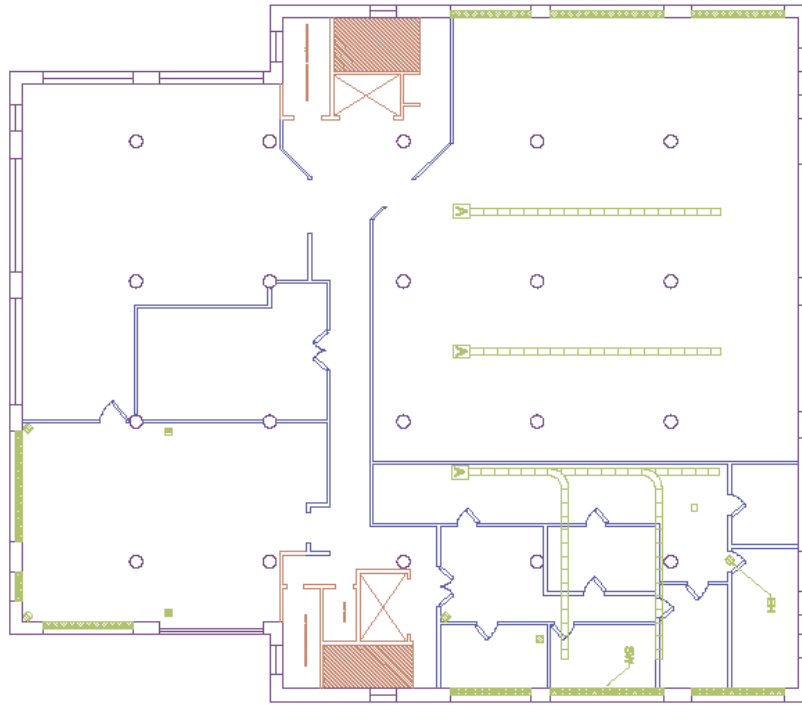


Figure 8. Seventh Floor Plan with HVAC

These floor plans provide an easy way to calculate the exact percentage of warehouse space versus the percentage of conditioned space. Each floor is drawn separately and has all the offices and rooms represented so that it is easy to calculate the square footage of the conditioned or unconditioned space of the Printer's Building. We input those figures into computer models which analyze a building based on usage types, to determine if the space is efficient or not.

In reference to the floor plans, both the areas with storm windows and the locations of boarded up windows are marked. This will aid Mr. Wade when he chooses which windows to upgrade. Storm windows change the rate of heat loss, as seen by the thermal imager readings, and if the areas where the storm windows are installed can be easily identified; the installation location of the new windows might be changed to achieve the most heat efficiency in the desired areas.

4.3 Computer Model

Many different computer programs were assessed during the evaluation of the Printer's Building. These included eValuator, Energy Star, and Energy Plus. Along with these programs, online data was used to compare the Printer's Building to the national and international standard.

Energy Plus and eValuator were far less helpful than initially expected. Energy Plus seemed like it could be a very valuable tool; however, this proved not to be the case. After looking further into the program, we discovered that it required many long and complex files of building data to compute an energy audit. These files requested data which was unavailable to us, like the wall's thermal coefficients, and had to be input into a program in an extremely complex way. Also, Energy Plus only gave a theoretical energy audit, which put forward data that we could obtain in a much easier method. We decided not to focus much on eValuator for similar reasons. This tool helps to determine more accurate cost-to-benefit ratios by taking into account variables such as inflation and maintenance costs. However, we could not obtain maintenance costs for current equipment; consequentially we decided to just use a much simpler ratio, calculated by upfront cost versus annual savings.

The only online tool we spent copious amounts of time using was Energy Star. This program utilizes basic building data to determine energy use and emissions. A building's use is then selected, and the program will show how much energy has to be reduced, percentage-wise, in order to meet that selected goal.

Once the building's data was inputted, we determined that we wanted the Printer's Building to be at a level of 75 (top 25% of buildings in the US); this number is the minimum to receive Government Energy Star certification. In order to reach this goal, the building would have to reduce energy consumption from 56.6 kBtu/sqft/year to 39.4 kBtu/sqft/year. This in turn would save annually approximately \$256,000 and reduce building's CO₂ emission from 377.4 metric tons/year to 262.5 metric tons/year. Figure 7 illustrates what would be required to reach the top 10%.

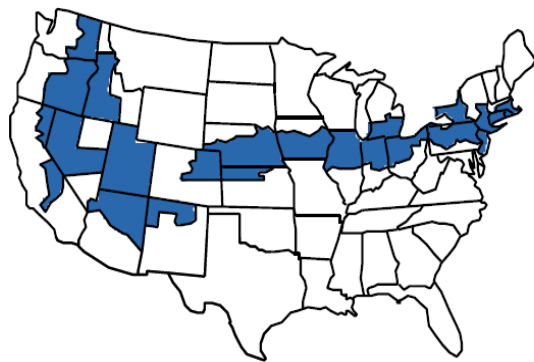
Table 1. Energy Star Data Table (Energy Star 2008)

Target Energy Performance Results (estimated)			
Energy	Design	Target	Top 10%
Energy Performance Rating (1-100)	46	75	90
Energy Reduction (%)	N/A	28	46
Source Energy Use Intensity (kBtu/Sq. Ft./yr)	98.9	68.8	51.1
Site Energy Use Intensity (kBtu/Sq. Ft./yr)	56.6	39.4	29.3
Total Annual Source Energy (kBtu)	9,297,356.5	6,467,338.1	4,806,977.8
Total Annual Site Energy (kBtu)	5,322,485.0	3,702,376.0	2,751,864.7
Total Annual Energy Cost (\$)	\$ 115,866	\$ 80,598	\$ 59,906
Pollution Emissions			
CO₂-eq Emissions (metric tons/year)	377.4	262.5	195.1
CO₂-eq Emissions Reduction (%)	-4%	28%	46%

www.energystar.gov

Along with using a computer-based analysis, we compared the building's data to published figures and a similar building in Worcester. This proved to be helpful because it gave us another benchmark to attain. However, this data proved to be somewhat misleading, as was later realized.

The first comparison we analyzed was the average energy use for office and unrefrigerated warehouse, which takes into account local weather patterns. We found that the average energy use for a building with 47.2% warehouse and 52.8% office was about 80 kBtu/sq.ft/year, far more than what the Printer's Building uses. However, we believe that the warehouse areas within the Printer's Building use far less energy than the average warehouse because they are not heated and rarely utilize active lighting. It is noteworthy that this data is only the average energy use for buildings of this size and type; this is important to recognize because the number of energy efficient or Energy Star-certified buildings in the U.S. (approximately 4,100 as of 2007) is far less than the number of non-efficient buildings. Above average does not denote efficiency – it only means that the building is using slight less energy and utilizing slightly smaller amounts of natural resources than its counterparts, which could still mean that it is terribly inefficient as compared to energy-star rated buildings



U.S. Climate Zone 2		
Building Type	Annual Energy Use (kBtu/sq.ft.)	Annual Energy Cost (\$/sq.ft.)
Education	88	\$1.08
Food service	169	\$2.19
Health care (inpatient)	269	\$2.63
Health care (outpatient)	84	\$1.25
Lodging	92	\$1.54
Office	95	\$1.49
Public assembly	77	\$1.26
Religious worship	61	\$0.68
Restaurant	250	\$3.99
Retail	87	\$1.21
Warehouse (non-refrig.)	64	\$0.80
Warehouse (refrigerated)	65	\$1.45

http://www.seco.cpa.state.tx.us/TEP_Production/c/EPAEnergyStarSmallBusinessGuide.pdf

Figure 9. Climate Zone Containing Worcester, MA (Texas Energy Partnership, 2008)

Along with comparing the data to published figures, we examined the Osgood-Bradley Building in Worcester, MA. This building was built in the early 1900's out of reinforced concrete, similar to the construction of the Printer's Building. Also, it uses a single zone, gas-to-heating system with centralized distribution, which again is exactly like the Printer's Building. The only major difference between the two is the use of the building. The Osgood-Bradley Building is 37.5% manufacturing, 10% office, 7.5% retail, while the rest of the space is unused warehouse and storage. At 14,400 sq ft, it is also slightly larger than the Printer's Building.

We found out that the two buildings consumed a very size-proportional amount of natural gas over a specified time period. During the same two years, the Printer's Building consumed 36,982 therms and the Osgood-Bradley building consumed 48,878 therms. However, the Printer's Building required far more electricity. It used 476,080kWh, compared to the

94,700kWh of the Osgood-Bradley Building. This is due mostly to Davis Publication, Miles Press, and WCIN, who have the largest electrical draws in the Building.

4.4 Use of Thermal Imager

To fully investigate how efficiently the building is insulated, a thermal imager was utilized to review the structure. These images display hot and cold areas in the walls, windows and roof of the building. The findings here demonstrate how the old single-pane windows in the building allow large amounts of heat loss, and how the loss is decreased in areas where storm windows are present. The most efficient casement was the new window on the second floor. The imager readings also show that the use of simple lightweight window blinds can greatly reduce the amount of heat lost.

The roof's heat readings were lower than what the group initially anticipated them to be, but were still significant. One area on the roof that lost large amounts of heat was at the top of the elevator shafts.

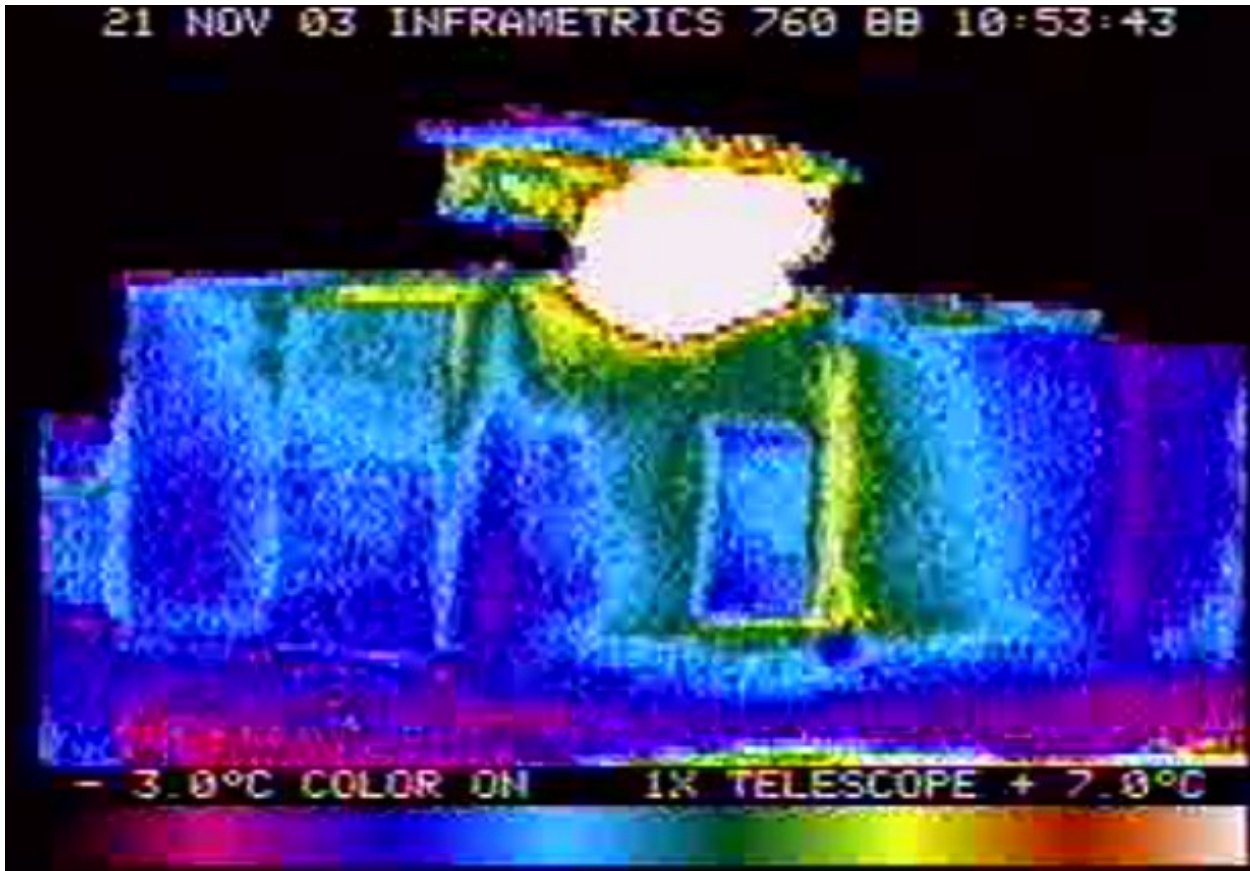


Figure 10a. Thermal Image of the Service Elevator Shaft



Figures 10b & 10c. Photos of Service Elevator Shaft

Photographs in Figures 10a, 10b and 10c were taken upon the roof of the building, looking at the service elevator shaft. There is no clear picture of 10a, so 10b and 10c are compilations of the elevator shaft from two different angles. The large brighter colored area near the door in Figure 10a shows that a significant amount of heat is escaping, which is also true at the top of the elevator shaft. The sun, heating the glass, could cause the white coloring that appears in Figure 10a. It is a mostly shaded area, however, so we believe it is mainly due to escaping heat.

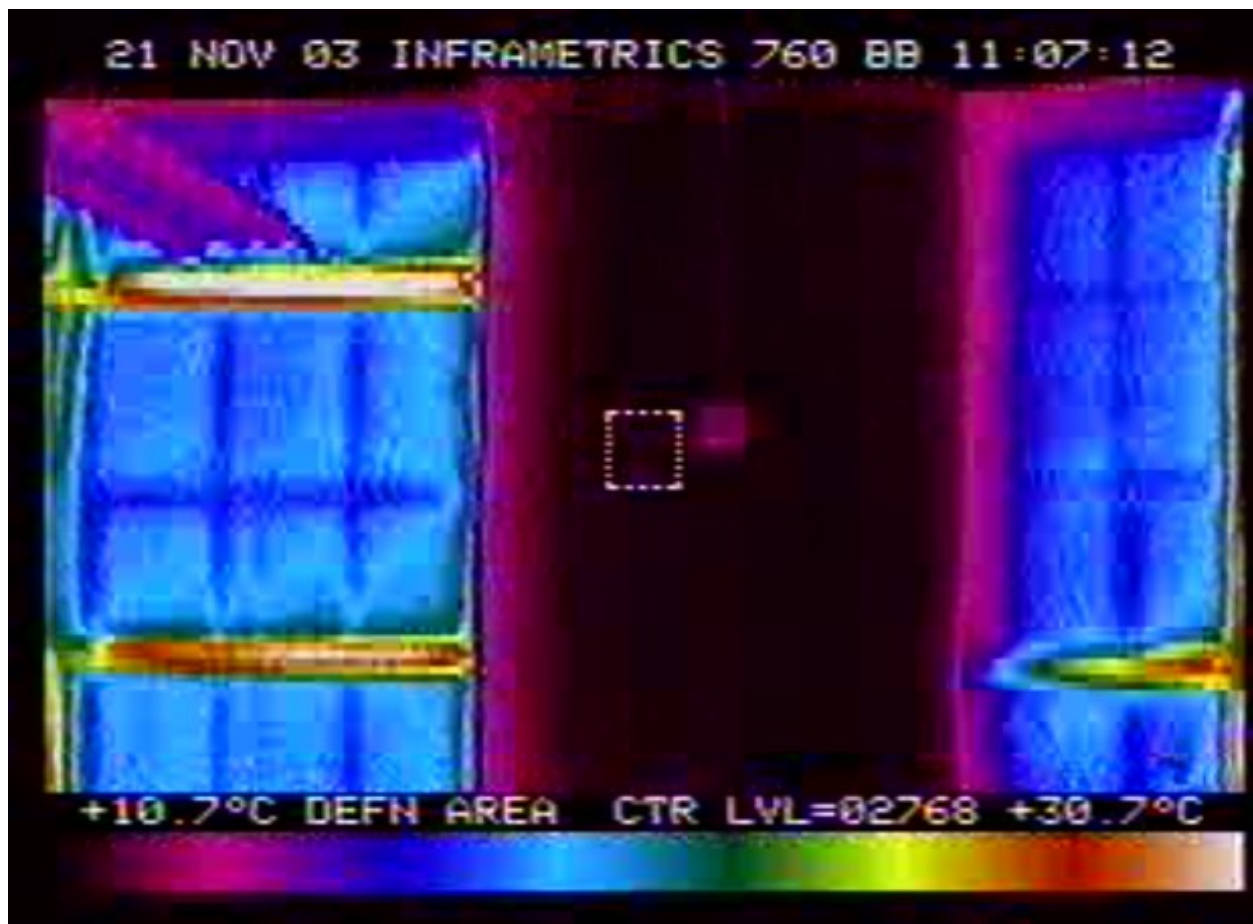


Figure 11a. Seventh Floor Warehouse Thermal Image

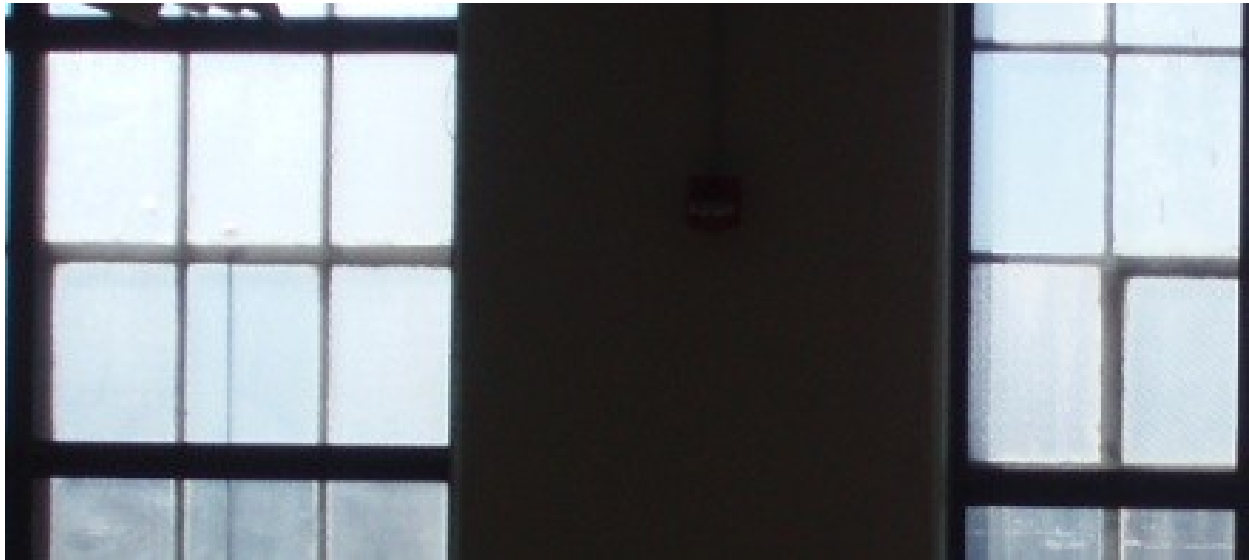


Figure 11b. Photograph of Seventh Floor Warehouse

Photographs in Figures 11a and 11b were taken in the 7th floor warehouse, on the south side. These windows featured storm window overlays. The interior temperature was 15 °C. The metal is usually colder than the windows; however, in this case, the metal frames were hotter due to the sun's radiance upon them. This picture also demonstrates how effective the storm windows are, since the thermal energy of the sun is not being easily transmitted (reference Figure 13). Despite the sun, the concrete remained cold, since it was transmitting the outside temperature inwards (and therefore radiating heat outside very fast).

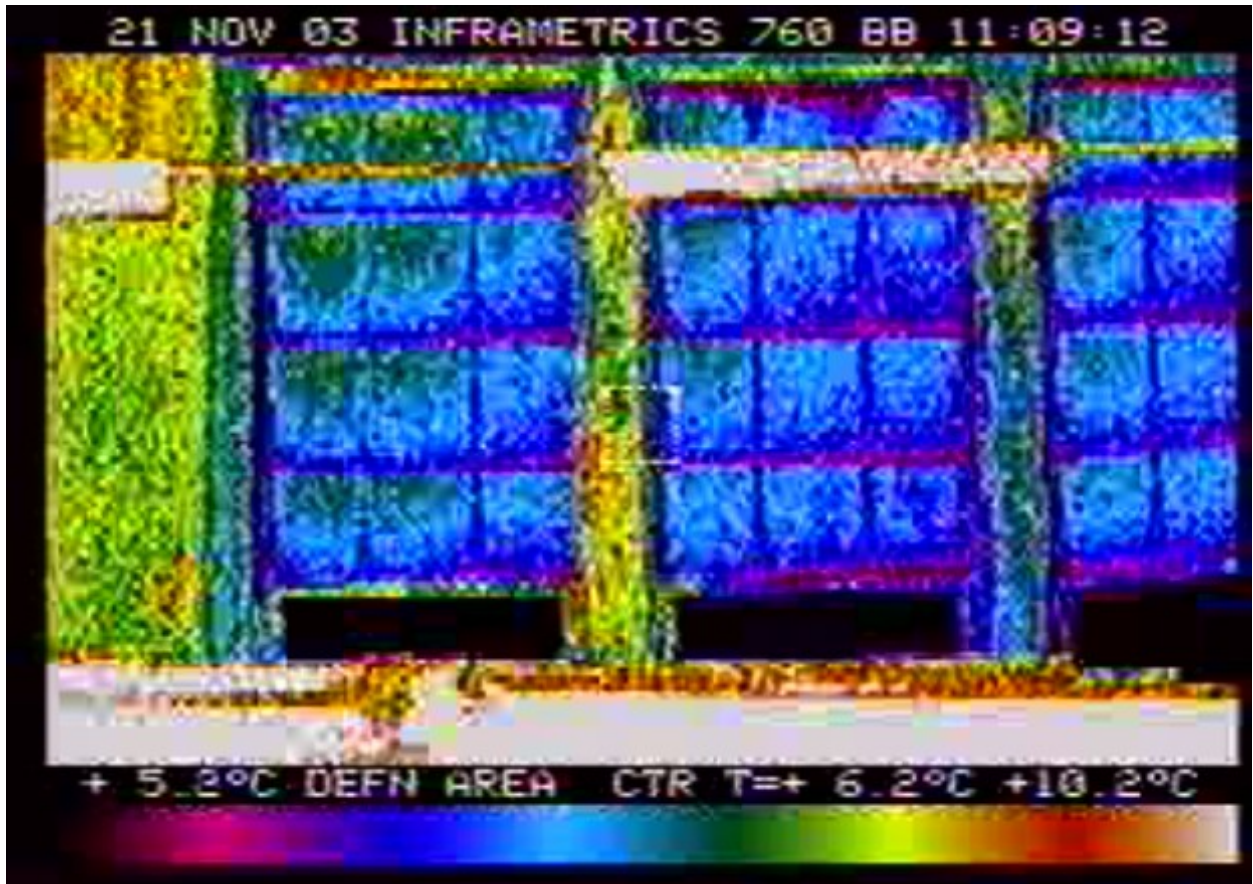


Figure 12a. Glazed Window on Seventh Floor Thermal Image



Figure 12b. Photograph of Glazed Window on Seventh Floor

We also inspected the glazed windows on the 7th floor, as seen in Figure 12, in the same room as the Figure 11. However, these windows were in the shade, which is why they are shown to be much colder, both in the metal frames and the panes themselves. This side would be a top priority for window shades or other treatments. The concrete was about the same temperature as the prior pictures, as expected.

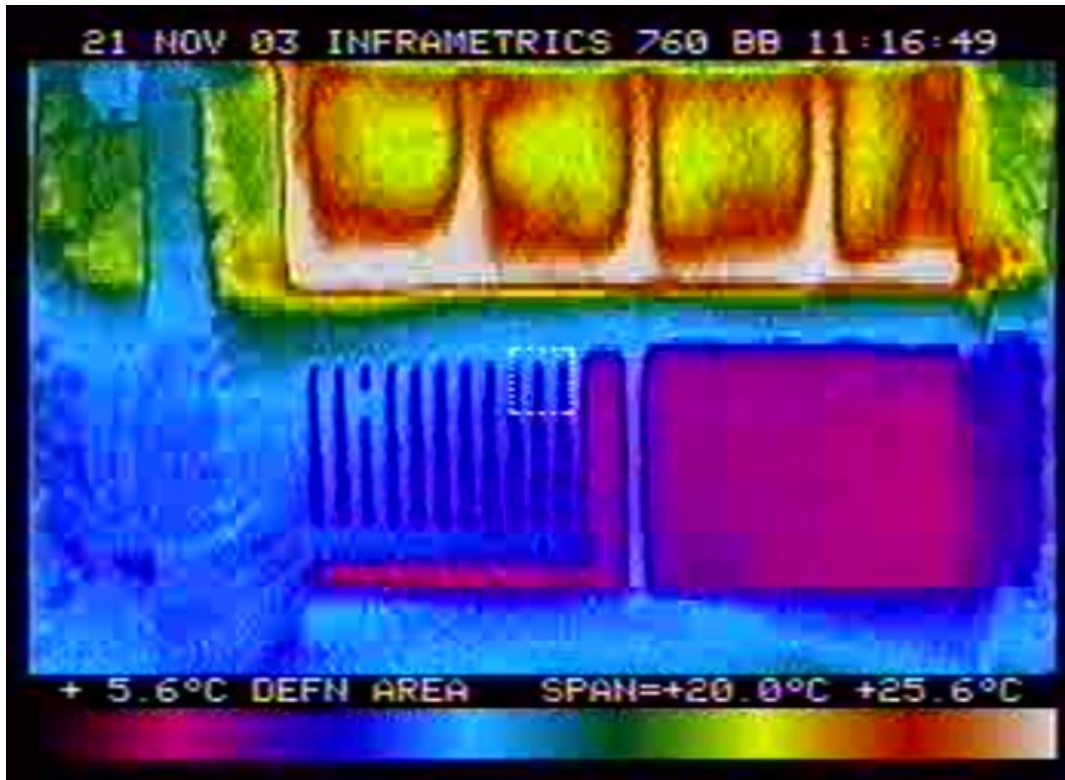


Figure 13a. Thermal Image of Seventh Floor Window without Storm Window



Figure 13b. Photograph, Seventh Floor Window without Storm Window

Like the two preceding figures, Figure 13 was from the 7th floor warehouse, except it was taken on the opposite side of the elevator shaft, within the smaller room. The characteristics of this window are similar to Figure 11 because the sun was also heating these windows. However, they do not have storm windows, which is why they were much warmer. Along with keeping cold air from entering, storm windows can also limit the flow of solar heating.



Figure 14a. Thermal Image of Regular Window, Storm Window, and Blinds



Figure 14b. Photograph of Regular Window, Storm Window, and Blinds

Figure 14 was one of the most influential pictures we took. It was taken in Mr. Wade's office, and demonstrates the heat-retaining ability between shades (dark part of photo), storm windows, and regular single-paned windows. The temperature of the room was 21.4 °C, which was almost the exact temperature of the combination shades and storm windows (far right of Figure 14b). This shows that both blinds and storm windows are incredibly effective at retaining heat, as compared to regular windows.



Figure 15a. Thermal Image of Ductwork in Davis Publications

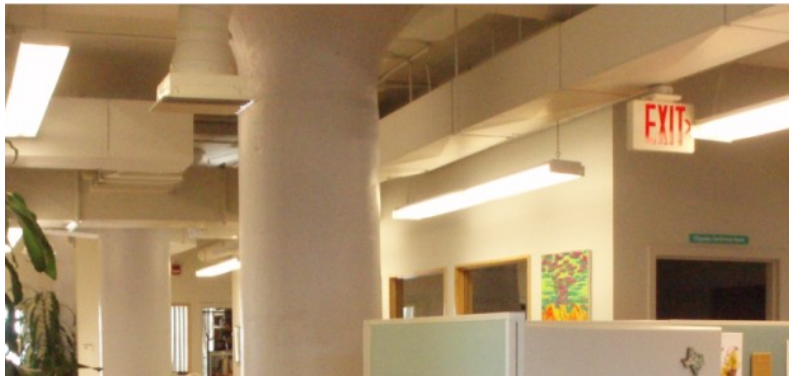


Figure 15b. Photograph of Ductwork in Davis Publications

We took the image in Figure 15 to determine if there was a significant amount of leakage within the HVAC ductwork. These pictures demonstrate that there is very little leakage (since the pipes are so cold although they are moving warm air). This is beneficial because leaking ductwork will greatly reduce the efficiency of HVAC units, and since there is little leakage, we do not have to recommend insulating the ductwork.



Figure 16a. Thermal Image of Second Floor New Window and Adjacent Old Window



Figure 16b. Photograph of Second Floor New Window and Adjacent Old Window

Figure 16 shows a replacement window, newly installed on the second floor. It is located on the right side of Figures 16a and 16b. The building owner chose this window earlier in the year, to use as a replacement throughout the whole building. Figure 16a demonstrates that the new window retains a significantly larger amount of heat than the old window, and is therefore very efficient. It was warmed throughout the day due to solar glare, and the photo was taken in sunlight, but as the sun receded, it did not lose nearly as much heat to the outside environment as the old window.

4.5 Use of Photometer

Late in the term the group was able to obtain a photometer, an instrument used to take light readings and measurements. We recorded different readings from various rooms, hallways and stairwells. The meter was very sensitive to the direction that it was facing, and a tilt of ten degrees could drastically change the reading. The light readings were considerably higher in areas that were in direct sunlight in comparison with areas that were on the shaded side of the building. One good example of this was in the stairwells. The south stairwell, which was in the sun, gave a reading of 275-foot candles, while the north stairwell, at the same height and amount of active lighting, read 20-foot candles.

The meter also gave a wide range of readings when measuring the light in a hallway depending on where it was in relation to the nearest light. On the seventh floor hallway the readings varied from 14-foot candles to 42-foot candles, although the meter was only moved 3 meters down the hall.

The initial goal of using the photometer was to obtain an overall reading for a room and compare that reading to the standards, thus showing us if the room has adequate lighting. Table

2 shows a list of foot-candle readings for different types of rooms. Due to the finicky nature of the device and the readings obtained, the only area where we could acquire usable data was in the north stairwell. This staircase was consistently between 20 and 25 foot-candles. This is notable because the stairwells were areas that Mr. Wade thought were overlit, however, they fall right inside the range required for such an area, as seen in Table 2.

Table 2. Common Lighting Requirements (Jones, 1998)

Common Lighting Requirements*			
Type	Foot-candles	Type	Foot-candles
Assembly/Inspection		Warehouse	
Simple	20-50	Inactive	5-10
Moderate	50-100	Active	
Complex	100-200	Large items	10-20
Very Complex	200-500	Small items	20-50
Exacting	500-1000	Boiler Room	20-50
Machine Shops			
Rough Bench	20-50		
Fine bench or			
Machine work	200-500		
Control Room	20-100	Corridors, Lobbies	10-20
Mechanical Room	20-50	Office	40-100

*See IESNA guidelines for much more detail.

4.6 Available Technologies

In the Background section, multiple green technologies were researched. Many of those researched are not feasible for the building due to either financial or physical restraints. There are some, however, that are within the building's means, and can be recommended. They will be recommended in order for the building to gain the most improvement for the cost of changes.

4.6.1 Window Treatments

Throughout the analysis of the Printer's Building, we were constantly evaluating all locations and items in an attempt to discover areas that were the most inefficient. Not surprisingly, we noticed that the windows within the building were one of the most wasteful aspects of the structure. The existing windows were determined to be a problem even before the audit began, and when they were analyzed with the thermal imager, the data confirmed our initial hypothesis. Since there are a vast number of windows in the building, they must contribute to the universal heat loss, as well as the large use of natural resources. Most of the windows cannot be immediately replaced due to financial reasons, so there must be a method devised to reduce the inefficiency of the windows while they are waiting to be replaced. Two of the most effective methods for window insulation are the addition of a solar-reducing window film, and the installation of window coverings.

We researched many methods to reduce the heat loss through the windows, but none were as unobtrusive as window tinting. A window film (or tint) consists of a thin, flexible plastic covering that is professionally installed directly onto the glass panes of the window. This method allows the window to transmit visible light, and still trap heat inside while reflecting ultraviolet radiation. Due to the insulating properties of the film, utility costs can be reduced by as much as 15%, and the solar heat gain through the glass can be reduced up to 76 percent (Conrad, 2008). These coverings do not distort, leaving an impression of an unobstructed window. Film is especially attractive due to its affordability. Since it is essentially a thin plastic (not unlike thick saran wrap), it is incredibly cheap to produce, ranging from \$3-\$12 a square foot. Even one of the best films on the market does not cost more than \$14/sq ft. Although this is seemingly an expensive upfront cost, these films are scratch resistant, highly indestructible,

and are usually guaranteed for life. Also, compared to conventional indoor solar protection and controlling devices such as shutters, shades or draperies, window films not only maintain the unobstructed window but are an effective and economical method of conserving glass energy loss and increase indoor comfort (Conrad, 2008). This makes the overall value of the window film very worthwhile.

However, window films have one major flaw that eliminates their applicability within the Printer's Building: they cannot be removed and re-installed. Most films are bonded to the glass using special adhesives, preventing them from shifting or being taken off and used elsewhere (Advanced Solar, 2007). Also, the film is cut to each individual pane, so film from an old warehouse window would not fit on the newer, more economical windows being installed every year. Therefore, any investment towards coating the existing 1920's windows with film would eventually be lost when the windows are replaced. Although films are a remarkable way to insulate a building while still maintaining natural daylight, we had to unearth another method to insulate the windows in which the investment could be justified.

The second option that was touched upon was the installation of a window covering; blinds, draperies, or shutters. Our biggest concern with these methods of window treatment is that most of the products available on the market drastically reduce, or even completely mask, all daylight when they are employed. This defeats the purpose of utilizing these shades, conserving energy, since more lighting would be required to compensate for the lack of natural light, thus adding more to the final utility costs of the building. Although heavy draperies or solid shutters could reduce the heat loss an appreciable (but unmeasured) quantity, the amount of lighting needed after installation of such items makes a heavy, light-blocking curtain economically

infeasible. Also, many of the simple draperies on the market are untested or unrated, so finding a good insulating covering with a significant R-value is a difficult proposition.

There is one type of shade, however, that can both insulate the interior and allow natural lighting to enter the building. This type of covering is called a “cell” shade, and it is a simple and cheaper alternative for window insulation. The concept of this blind is that a window-wide “cell” is created when the shade is extended, trapping and controlling airflow between the conditioned interior and the unheated exterior (Blinds, 2008). These cells are similar in concept to a skiing jacket or a bed comforter, where they use a pocket of neutral air that possesses high resistance to energy transference, to insulate from the surrounding environment. These cells can be arrayed both vertically and horizontally, allowing it to cover the entire window, and increase the isolative properties (re. Figure 17) (Blinds, 2008).



Figure 17. Cell/Honeycomb Shades (Rocky Mountain Shades, 2007)

Although these shades are not terribly inexpensive, they can be cheaper than even window film, since they are made of basic materials and have an established, streamlined production method. For example, a basic cellular, light-filtering shade can cost around \$215 for a 7'x7' blind (Blinds, 2008). However, an advanced film can cost as much as \$588 for the same area coverage (Conrad, 2008). Another positive is that, while not transparent, they still allow a higher percentage of natural lighting to enter the facility, so that a lesser quantity of electric lights can be used to maintain proper visible conditions. These shades are indeed not as efficient or applicable as a film, but they are more useful within the Printer's Building due to their portability and removability. These coverings can be installed on any older window within the structure, be removed during new window installation, and then be re-installed on the new openings without affecting their operability. They can be utilized when the window is replaced without having to re-cut or re-measure, and that makes them incredibly more cost effective than a window film.

For example, the back wall of the Printer's Building is 100.5 feet, and windows cover approximately 90 feet of those windows. Each window is on average 8 feet high. Therefore, there is 720 square feet of window space to cover. Assuming a film cost of \$12 per square foot for advanced film, the total cost is \$8640 not including extra, unseen materials or labor, which is mandatory according to the manufacturer's website (Conrad 2008). When the new windows are installed, the film would need to be re-applied to help maintain energy efficiency, bringing the total cost of the film to \$17280.

On the other hand, assuming the same dimensions as above, the price will be re-calculated using cellular blinds. A major discount retailer quotes \$327 for an 8' high x 9' wide

shade. That means that to cover a 90' wall of windows, it would take approximately \$3270, not including extra, unseen materials or labor (which could be in-house, greatly reducing cost).

When the new windows are installed, no new fixtures or sizing needs to occur, since the new windows fit into the same area as the old. Therefore, total price remains at \$3270, or \$14010 *less* than window films over the lifetime of both window treatments. With the monthly average electrical bill at \$5700, and an average heating bill of approximately \$4000, the film would reduce both electrical *and* gas usage by 50% (about 35-40% more efficient than the shades) to be more economically feasible than the cellular blinds. By utilizing cellular shading, the Printer's Building can incorporate a cost-effective way to conserve their overall usage of natural resources, and reduce their monthly utility bill.

Windows treatments are not the only way to save money and reduce dependency; there are other methods available that can cut energy costs while still helping the Printer's Building become environmentally friendly.

4.6.2 Lighting Changes

Among the feasible implementations for the Printers Building changes in the lighting may be one of the easiest and most effective. Many of the light bulbs and most of the fluorescent ballasts that we found in the building during our initial walk-through audit are out of date and can gain a great deal of efficiency with newer technology.

Compact Fluorescent Lights (or CFL's) have been around since the 1990's. Originally, these light bulbs were very expensive and not very comparable to regular incandescent light bulbs. Recently though, these bulbs have lowered in price considerably--they are still more

initially expensive than incandescent bulbs, but cheaper in the long run since they use less electricity to function, and have a considerably longer lifespan. A double blind study published by *Popular Mechanics* in the May 2007 issue of their magazine compared several different CFL's to a traditional incandescent bulb. The study also measured the brightness and color temperature of the bulbs using a Konica Minolta photometer operated by a lighting expert from Parsons, The New School for Design located in Manhattan. *Popular Mechanics* found that the incandescent bulbs were measured to be brighter than the CFL's; however, the participants of the double blind study did not notice a vivid difference between the incandescent and the CFL's being tested. This perceived brightness, along with color of light displaced and efficiency of the CFL's gave every CFL tested a higher rating than the incandescent. Among the highest-rated bulbs, the Philips brand Marathon bulb is the least expensive, making it the most cost beneficial product tested, and a great choice for the Printer's Building (Masamitsu, 2007). All of the *Popular Mechanics* results are posted in the Appendix.

Bulbs like the Philips Marathon bulbs are Energy Star qualified, which can bring huge savings to the Printer's Building. Energy Star has a calculator that computes both annual cost and a life cycle cost estimate to demonstrate the payback and savings of Energy Star qualified bulbs using purchase price, maintenance cost, and energy cost. Based on our initial walk-through audit, we spotted 98 incandescent bulbs in the building. For the purpose of the calculation we made a few assumptions. First, we assumed that all the incandescent bulbs are 75-watt bulbs costing 50 cents each. We also assumed that the CFL's were 19-watt bulbs costing 3.50 each, and lastly we assumed that the bulbs run for the entirety of an 8-hour workday. This enabled us to calculate that the 98 incandescent bulbs cost \$4,221 dollars annually in operating cost as opposed

to \$805 dollars for the CFL's. In the lifetime of 98 CFL bulbs, 98 traditional bulbs cost \$13,312dollars where the same number of compact fluorescent cost \$2,872 dollars for their life cycle. Replacing all of the incandescent bulbs with CFL's would yield a life cycle savings of \$10,440 dollars and pay for the difference in higher price CFL's in a little less than two months (U.S. EPA; U.S. DOE, 2008). The table from the energy star calculator is posted as Table 3.

Table 3. Annual Life Cycle Cost of CFL's vs. Incandescent (U.S. EPA; U.S. DOE, 2008).

Annual and Life Cycle Costs and Savings for 98 CFLs			
	98 ENERGY STAR Qualified Units	98 Conventional Units	Savings with ENERGY STAR
Annual Operating Costs*			
Energy cost	\$805	\$3,219	\$2,414
Maintenance cost	\$0	\$1,002	\$1,002
Total	\$805	\$4,221	\$3,416
Life Cycle Costs*			
Operating cost (energy and maintenance)	\$2,529	\$13,263	\$10,734
Energy costs (lifetime)	\$2,529	\$10,116	\$7,587
Maintenance costs (lifetime)	\$0	\$3,147	\$3,147
Purchase price for 98 unit(s)	\$343.00	\$49.00	#####
Total	\$2,872	\$13,312	\$10,440
		Simple payback of initial additional cost (years) [†]	0.1

* Annual costs exclude the initial purchase price. All costs, except initial cost, are discounted over the products' lifetime using a real discount rate of 4%. See "Assumptions" to change factors including the discount rate.

With hundreds of overhead fluorescent lights with magnetic ballasts throughout the building there is a large opportunity to save money. Newer electronic ballasts for fluorescent lights like GE's high-efficiency UltraMax™ Ballast, shown in Figure 17, are up to 90% more efficient than the antique magnetic ballasts found in the Printer's Building, and 40% more efficient than standard electronic ballast systems (General Electric, 2008). We can see the opportunity for savings by replacing the ballasts for lights that are used frequently in the office or conditioned spaces within the building.



Figure 18. GE UltraMax Ballast (General Electric, 2008)

At this time though it does not seem practical to alter the lights in the unconditioned warehouse spaces, based on our findings from the initial walk-through and additional time spent auditing the building. We found that many of the lights in those areas remain off continuously. In these areas, many of the fixtures should be completely disconnected since the ballasts still draw small amounts of electricity even while the fixture is off. The walk-through audit showed that there are a large number of light fixtures in these areas, most of which are permanently off and not needed. Some should be left connected to provide any required extra light, but most can be removed. Another good way to help decrease unnecessary lighting is by installing motion sensors.

4.6.3 Motion Sensors

Motion sensors are an important, but highly underused, resource within commercial buildings. Sensors allow the worker or employer to control the duration and frequency of the interior lights. They also facilitate shutting off all lights when the office is vacated, which saves an innumerable amount of energy.

Motion sensors are not complicated devices. They can utilize light, microwaves, or sound, actively injected into the surroundings, to detect motion or change of state, signaling that there is someone present. However, the most commonly used sensor is an infrared sensor, which uses body heat as a trigger for activation. These sensors are known as passive sensors, since they do not flood the surrounding environment with signals, but instead rely on energy generated from other sources for initiation (Motion, 2008). These types of sensors are the most inexpensive to install, and operate quite reliably.

We recommend that infrared passive sensors be installed in all highly trafficked areas, but not within the warehouses. The warehouses usually receive a good amount of light from the sun, so the fixtures are rarely utilized. Motion sensors would only trigger the lights at unnecessary times, therefore wasting energy on a space that did not need the lighting already. However, the office spaces are a different situation. Most exhibit continuously active lighting, whether there are workers in the building or not. Installed motion sensors would monitor general and personal office space, deactivating the light (and any other electrical devices attached to it) when the space is not in use. The amount of energy that is saved cannot be exactly calculated, since the times in which the lighting will be off are unknown. Nevertheless, they can reduce lighting dependency by as much as 30%, reducing energy accordingly. Obviously, one should utilize judgment onto the placement and time limit of the sensors, as to not impinge upon necessary

lighting (stairwells, studio lighting, etc). Many simple units are relatively inexpensive, never more than \$20 (GoodMart, 2008), and work effectively. They can be installed in any location where a light switch already exists, so replacement is easy and labor costs are very low. This installation should be a priority, since it will exhibit immediate dividends on the electric bill.

4.6.4 Exit Signs

Another way to cut down on the amount of energy is to update the exit signs, as mentioned in the Background. There are 18 signs currently in use in the building. Incandescent backlit signs use approximately a 40-watt bulb to light the sign. This is extremely inefficient. To correct this problem two possible replacements were researched in depth; Light Emitting Diode (LED) fixtures and Light Emitting Capacitor (LEC). Both of these offers a substantial drop in energy usage, using two watts and one-quarter watts, respectively. Also, both these units do not require any maintenance, such as light bulb changes. There is a significant difference in the cost of these two replacement units. A LED sign with thermoplastic housing costs around \$19 per unit, while the LEC unit costs approximately \$65 per unit. Table 4 shows the cost/benefit of changing the building's signs to either LEC or LED. The table is based on incandescent backlit signs, even though most of the signs found in the building are already backlit by LED's. Because of the high upfront cost of LEC, even with its extremely low energy usage, it takes nearly 20 years at the current electricity cost for the LEC to have an overall cost less than a LED sign. Since the life span of these fixtures is listed as being around 20 years it makes no financial sense to use LEC instead of LED. Potentially in a few years when the LED units currently being used in the building need to be replaced, the LEC upfront cost may have dropped enough to make it a

viable option for replacement. Please note that the chart uses incandescent backlit signs as the base unit of comparison even though many of the observed signs were already LED.

Table 4. Energy Usage Comparison of Exit Signs for Printer's Building.

	Incandescent	LED	LEC
Number of Exit signs	1	1	1
Wattage	40	2	0.25
Hour Usage	24	24	24
Day Usage	365	365	365
kWh Used per year	350.4	17.52	2.19
Cost per year at 15 cents per kWh	52.56	2.63	0.33
Cost for change per unit	0	21	65
Cost for total change	0	21	65
Net 1 year Cost	52.56	23.63	65.33
Net 3 year Cost	157.68	28.88	65.99
Net 5 year Cost	262.8	34.14	66.64
Net 10 year Cost	525.6	47.28	68.29
Net 20 year Cost	1051.2	73.56	71.57

4.7 Exterior Financial Incentives

To upgrade the Printer's Building to a green or sustainable building from its current state will take a decent amount of money, more than Davis Publications has budgeted. There are many grants and other government benefits that could help to ease this upfront financial burden, but most are commissioned at the beginning of the new calendar year. Also, many change year-to-year, making recommendations difficult at this time. The grants we investigated were mostly

disbursed by the time we got to them, in the 11th and 12th months of the year. As the building implements some of the recommended changes it will further itself down the path towards being eligible for one of these grants. After the beginning of the new year, or possibly after some of these changes have taken place, the grants should be revisited by a later group to thoroughly investigate where the Printer's Building is eligible.

4.8 BREEAM versus LEED

The long-term goal of this project was to develop a plan to turn the Printer's Building into a demonstration site for sustainable construction. This would be accomplished by comparing the Printer's Building to national and international standards, and then implementing changes to meet or surpass these benchmarks. The main sets of standards for sustainable sites are developed by LEED, BREEAM, and HK- BREEAM. However, HK-BREEAM will not be considered because of both its similarity to the other two standards and its inactivity outside of China. These programs offer standards for remodeling large office buildings and have the same general criteria.

For our project we focused mainly on energy use, such as gas and electric utilizations. This was because it offered the greatest potential for an economic saving, thus allowing more finances for other upgrades. Both LEED and BREEAM put much of their emphasis on energy use, with 25% and 20% of their respective credits going towards energy reduction (W.L. Lee, 2008). However, the way in which these points are distributed varies, as shown in Figure 19. In LEED certification, credits are distributed in a linear way, and if a building reduces energy use by 60%, it will receive all credits (W.L. Lee, 2008). This 60% reduction will generally make the

building be in the top 95% for energy star (LEED, 2008). This is far above the goal we have set for the Printer’s building, which is to be atop 75% (Energy Star rated).

To receive all the possible credits for BREEAM certification, the building must become a zero emissions building (BREEAM, 2008). This is something that should be a long-term goal of the building. To turn into a true demonstration site, the building must exceed the national standards and be one of the leaders on a global scale.

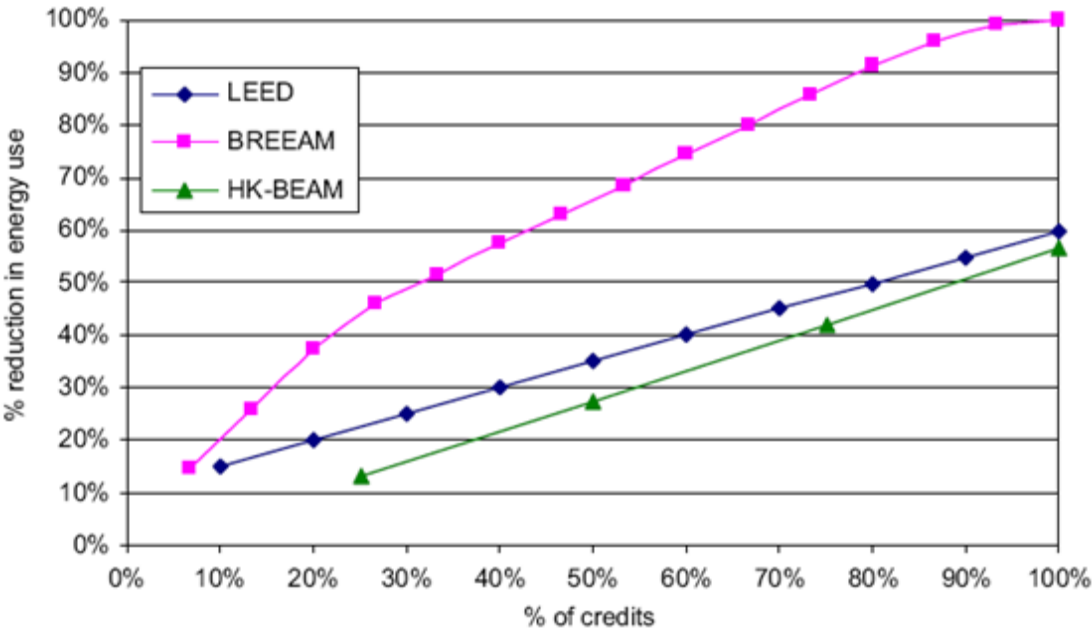


Figure 19. Amount of Reduction in Energy Usage Required for Certification (BREEAM, 2008)

The zero emissions criteria demonstrates that in the UK, and in the many other countries that follow BREEAM standards, people believe that buildings should strive to reach a level of zero emissions. However, the actual energy use for buildings in the UK and US illustrates something different. In the US, buildings tend to use less energy than the UK, as shown in Figure 19 (W.L. Lee 2008). This shows that the top tier buildings in the UK are extremely energy efficient, but the cumulative sector is not.

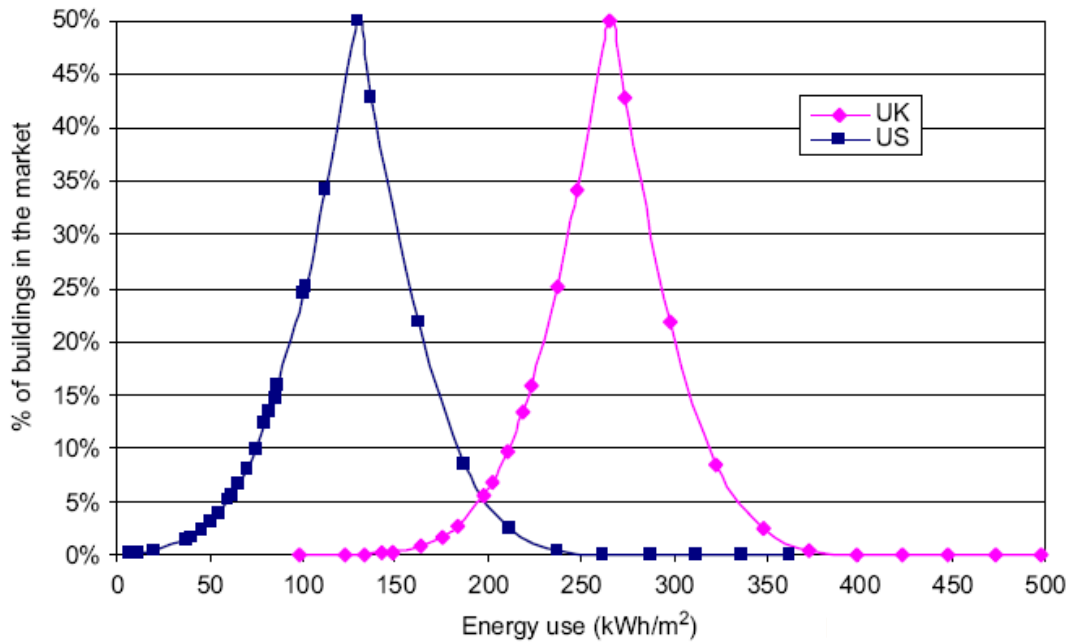


Figure 20. Energy Usage of Buildings; United States vs. the United Kingdom (BREEAM, 2008)

Along with energy use, both LEED and BREEAM allot points for transportation to the site, water usage, sewage output, indoor lighting, interior air quality, site design, and product use. The main way in which the two rating systems differ in this aspect is that LEED awards points based on percentage reduction and BREEAM on specific goals or benchmarks. This will help the Printer's Building's future attempts to become LEED-certified due to the antiquated building, which will be easy to improve, percentage-wise.

Chapter 5: Conclusion & Recommendations

The goal of this project was to create steps that the Printer's Building could utilize to become a demonstration site for a green and sustainable architecture. There were three objectives that consisted within this goal. The first was to perform an energy audit on the building to assess its current level of efficiency. The second objective was to research energy conservation measures that could be applied to the weak areas of the building. Lastly, from this research, the group created a series of recommendations detailing changes that the Printer's Building can utilize to become more energy efficient. These objectives proved to be more complex than initially anticipated, with unforeseen complications arising, but we were able to achieve the desired results and leave a solid foundation for the following groups.

The walk-through audit of the building provided a copious amount of data that was used for following steps, but that in itself was not enough to research any changes. We needed to obtain some more detailed information, such as the history of utility usage for the building and the building's floor plans. It took an extenuating amount of time for the group to acquire data, and some of it did not exist. The floor plans of the building, required during the audit to calculate square footage and calculate unconditioned space, had to be generated by the group, which consumed a highly unanticipated amount of time, but the our effort provided Mr. Wade with a detailed and current floor plan of his building. The group also had to wait for the technological instrumentation to become available. We did not receive the photometer until the sixth week of the project, limiting how much data could be taken with it, and the data gathered from using the thermal imager took at least two weeks after the device was used to be processed.

The delay was not detrimental to our project, however, since we still had time to receive the data and thoroughly analyze it.

The time restraints listed above, along with the knowledge that there was a follow-up IQP working on the next step of the same project, caused us to shift our goal slightly from the initial one presented in the proposal. We still performed the proposed audit, but slightly changed the technological recommendations section. We decided to focus more on immediate options for decreasing the operating costs of the building and leaving longer-term possibilities for future research. This is only one of the foci of turning a building into a green structure, but it is the one where the building nets the greatest financial benefit. The additional funds made available by these changes can help fund other green renovations in the future.

We recommend that the next IQP group focus more on long-term goals. They can take the performed audit and determine methods that can be implemented within a 3- and 5-year plan to make the building more sustainable. Many of the building's systems can be greatly improved, especially the insulation and heating. Using the LEED or BREEAM certification parameters to compare each part of the building to previously set standards will be the best method for completion.

The group thoroughly enjoyed working on this project. We generated a great amount of useful data for our sponsor and created many recommendations he can utilize to begin updating his building. This report also serves as a basis for the next group to use for starting their research, ultimately furthering the ultimate project goal. The work we have completed over the past fourteen weeks goes beyond reducing the operating costs of the Printer's Building, and if

these steps are taken, it will successfully lead to influencing other buildings in the Worcester area to embrace the green technology movement.

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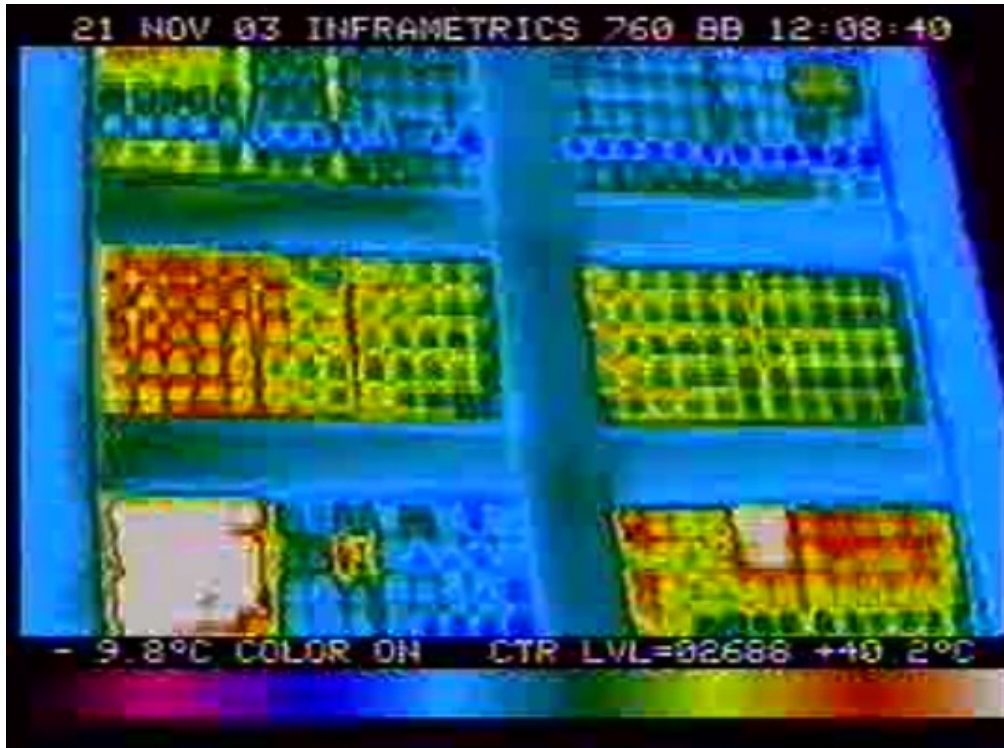
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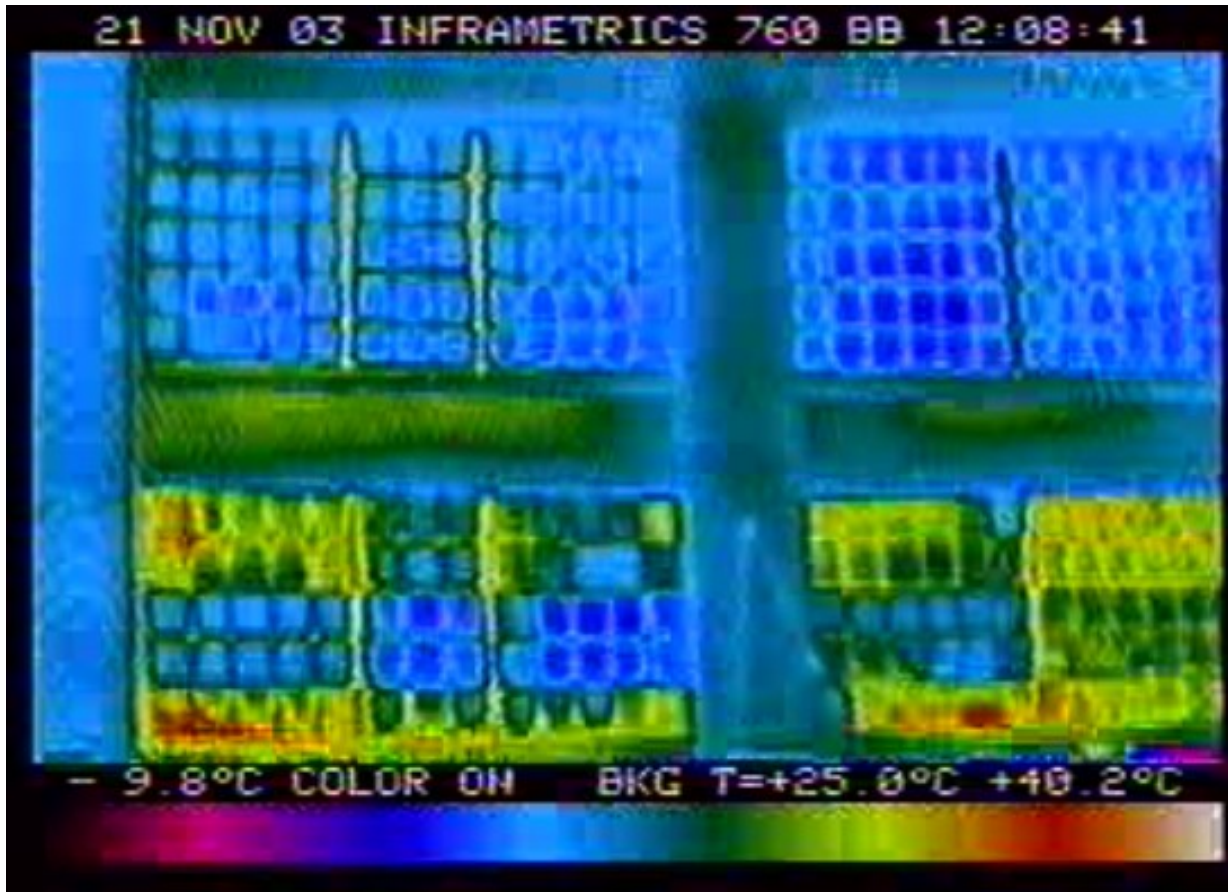
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Appendix A: Additional Outside Thermal Images

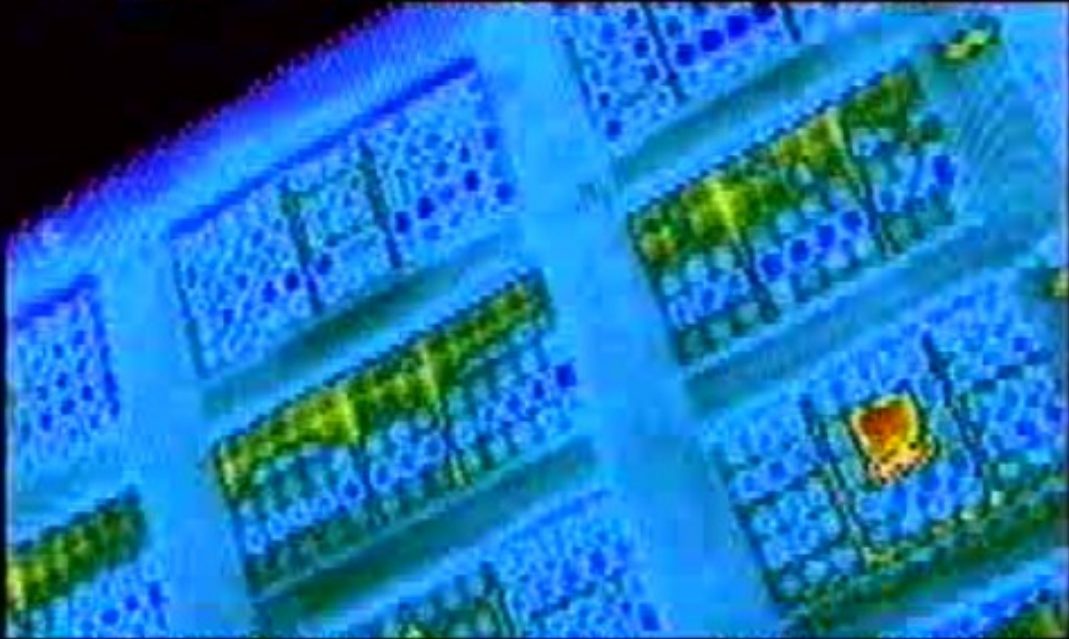
All images contained in this appendix were taken from the south-west outside of the Printer's Building.





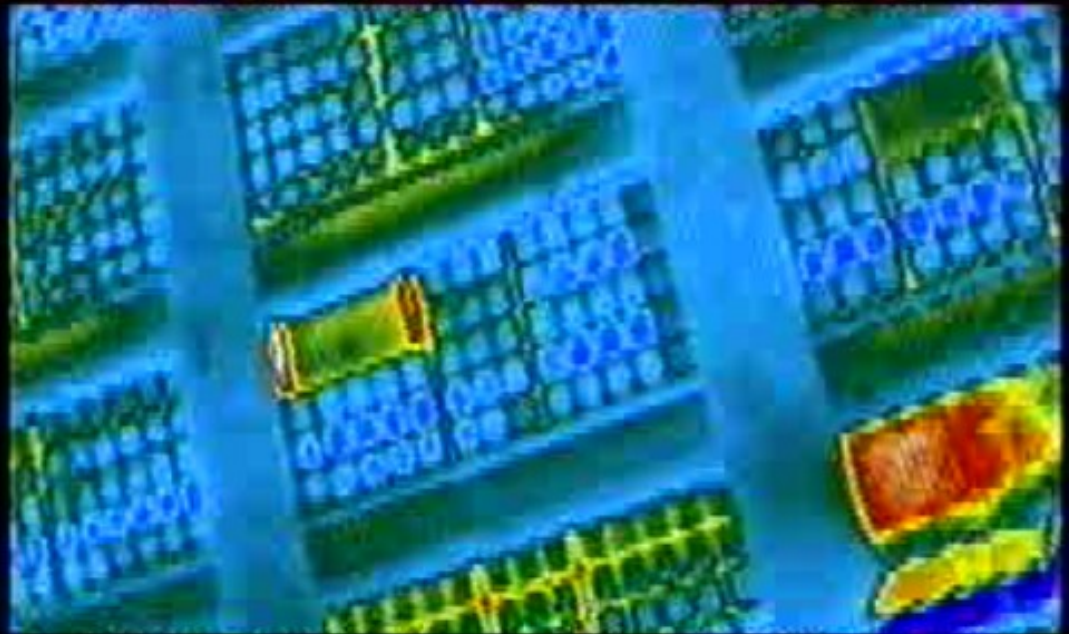


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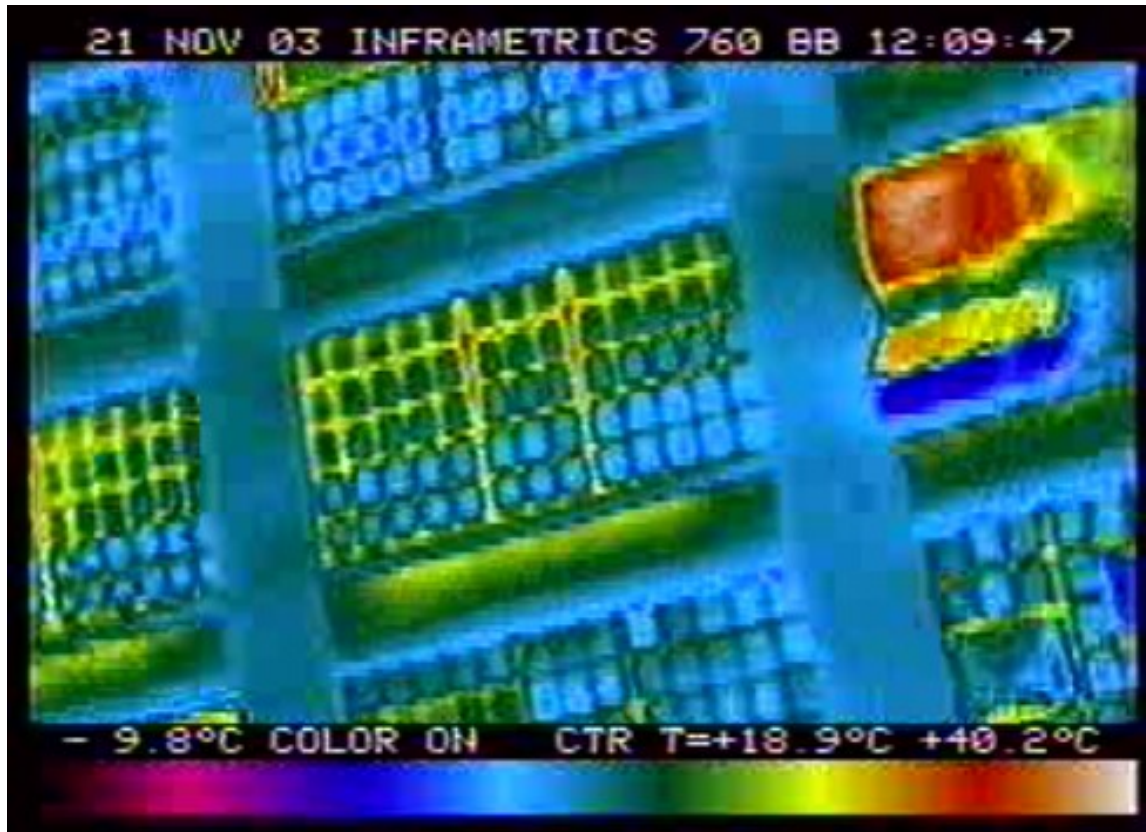


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- 9.8°C COLOR ON SCNR= +15.4°C +40.2°C



Appendix B: Filter Calculations

LCC-report

Printer Bldg Carrier 38JB016520 Energy Efficient Filters

Data for LCC calculation

Total number of filters	8
Total Airflow	10003 CFM
Life of installation, yr	10 years
Outdoor environment	Moderate: 66-80 AQI
Indoor environment	Moderate dust generation
Running time	6000 h/year
Interest	3 %
Labor	3 % increase, %/yr
Energy cost	0.15 \$/KWh
increase, %/yr	3 %
Disposal of filter cost	1 \$
increase, %/yr	3 %
Efficiency of fan	60 %
Duct Cleaning cost	0.2 \$/ft ² duct area
Cleaning interval	10 years
MLE	21.0 %

FILTERS 30/30@ M8 1"

Media	Cotton/Polyester
Size	24 " 24 " 2 (in.)
Effective media	17.3 ft ²
Filter price	6.66 \$
Labor cost	3 \$/Filter
Airflow	1429 CFM (70 % Return air)
Pressure drop	0.18 in.wg
Final pressure drop	0.65 in.wg
Average pressure drop	0.34 in.wg
Filter life	6000 hours
Number of filter changes	10

LCC costs in \$ based on 10 years lifetime of installation

FILTERS 30/30@ M8 1"

Total filter cost	469
Installation cost	21
Labor	189
Energy	6020
Disposal	63
Duct Cleaning cost	1372
TOTAL-LCC	8134 \$

LCC for installation

30/30@ M8 1"	8134 \$
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LCC for installation	8134 \$
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ECI Value	41.0 \$/%
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LCC-report

Printer Bldg Carrier 38JB016520 Existing Filters

Data for LCC calculation

Total number of filters	8
Total Airflow	10003 CFM
Life of installation, yr	10 years
Outdoor environment	Moderate: 66-80 AQI
Indoor environment	Moderate dust generation
Running time	6000 h/year
Interest	3 %
Labor	3 % increase, %/yr
Energy cost	0.15 \$/KWh
increase, %/yr	3 %
Disposal of filter cost	1 \$
increase, %/yr	3 %
Efficiency of fan	60 %
Duct Cleaning cost	0.2 \$/ft ² duct area
Cleaning interval	8 years
MLE	11.0 %

FILTERS Prec-Pre-Pleat 40 LC M8 1" (Ma 5a)

Media	Synthetic/Charged
Size	20 * 25 * 1 (in.)
Effective media	9.0 ft ²
Filter price	3.8 \$
Labor cost	3 \$/Filter
Airflow	1429 CFM (70 % Return air)
Pressure drop	0.18 in.wg
Final pressure drop	1.35 in.wg
Average pressure drop	0.49 in.wg
Filter life	3000 hours
Number of filter changes	20

LCC costs in \$ based on 10 years lifetime of installation

FILTERS	Prec-Pre-Pleat 40 LC M8 1"
Total filter cost	532
Installation cost	21
Labor	399
Energy	8666
Disposal	133
Duct Cleaning cost	1456
TOTAL-LCC	11207 \$

LCC for installation

Prec-Pre-Pleat 40 LC M8	11207 \$
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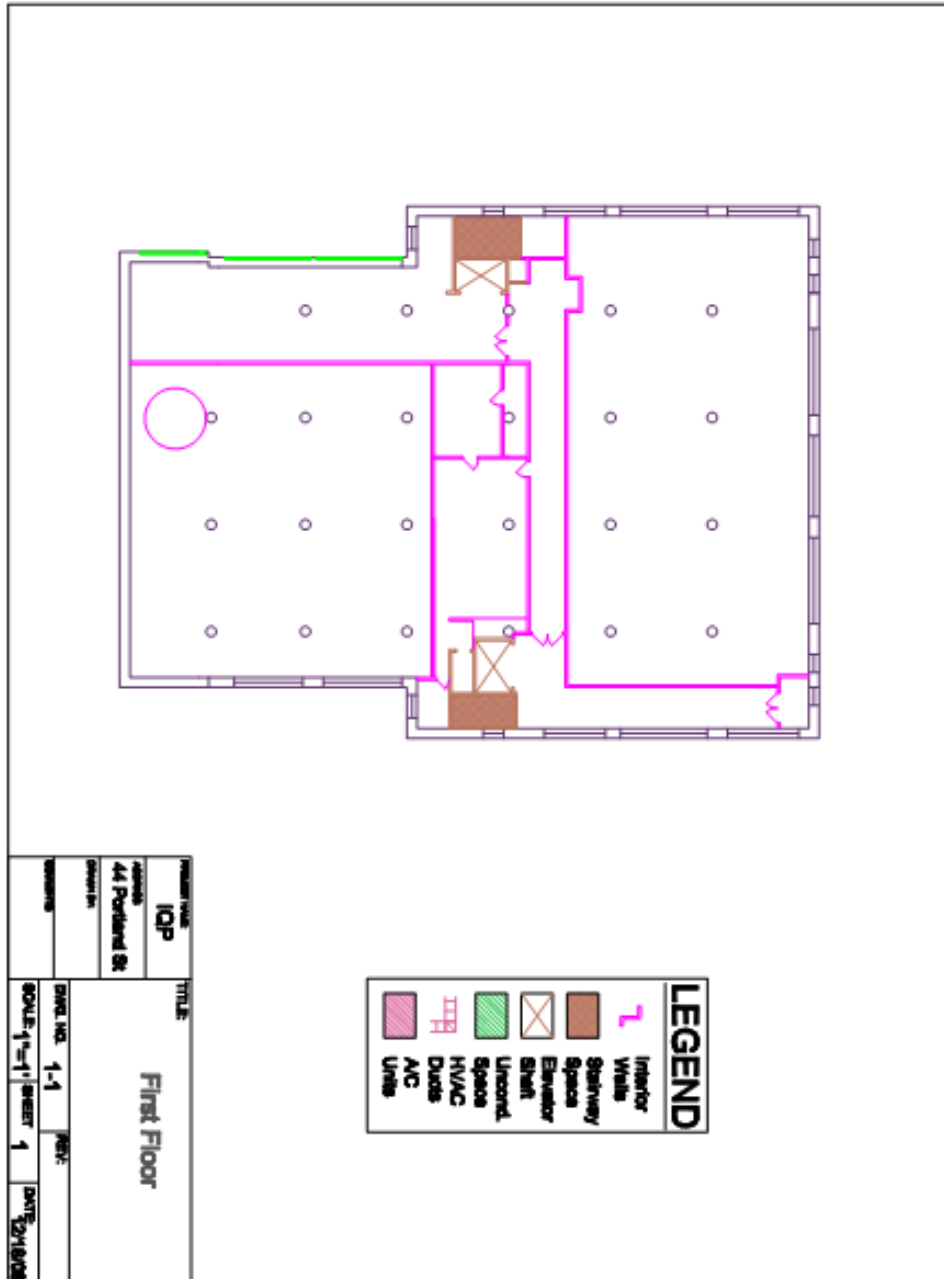
LCC for installation 11207 \$

ECI Value 112.5 \$/%

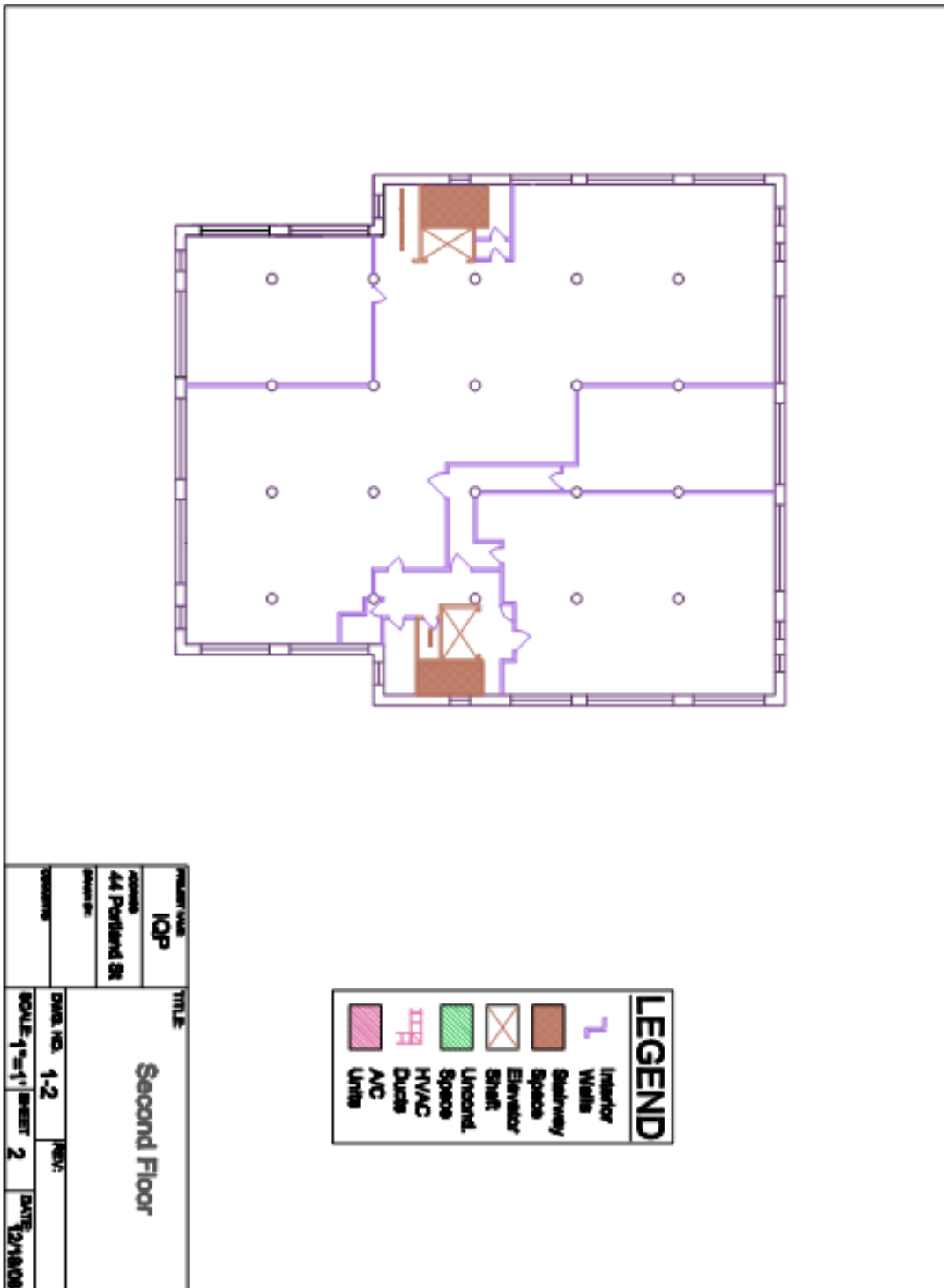


Appendix C: CAD Floor Plans of Printer's Building

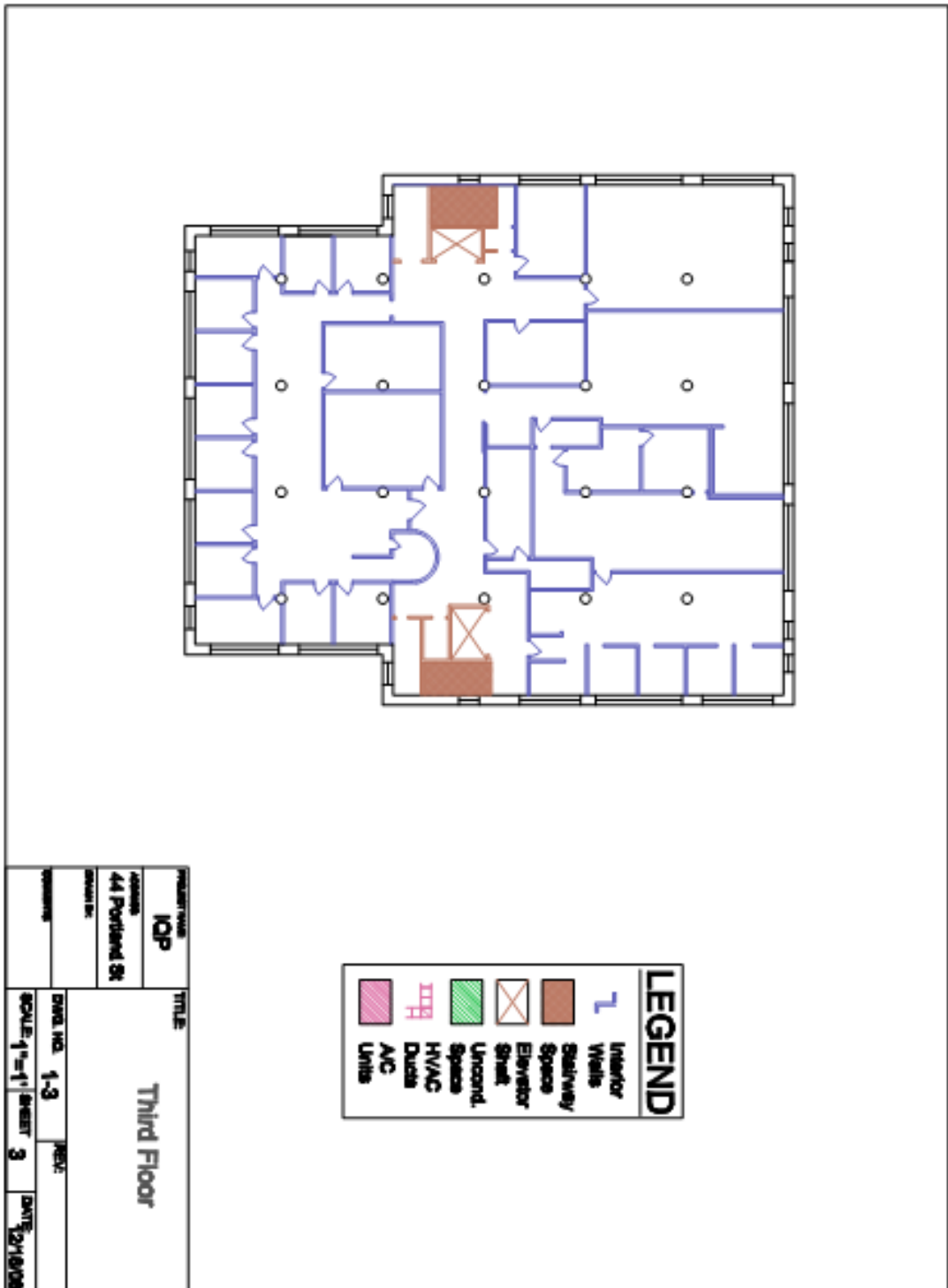
Regular Floors



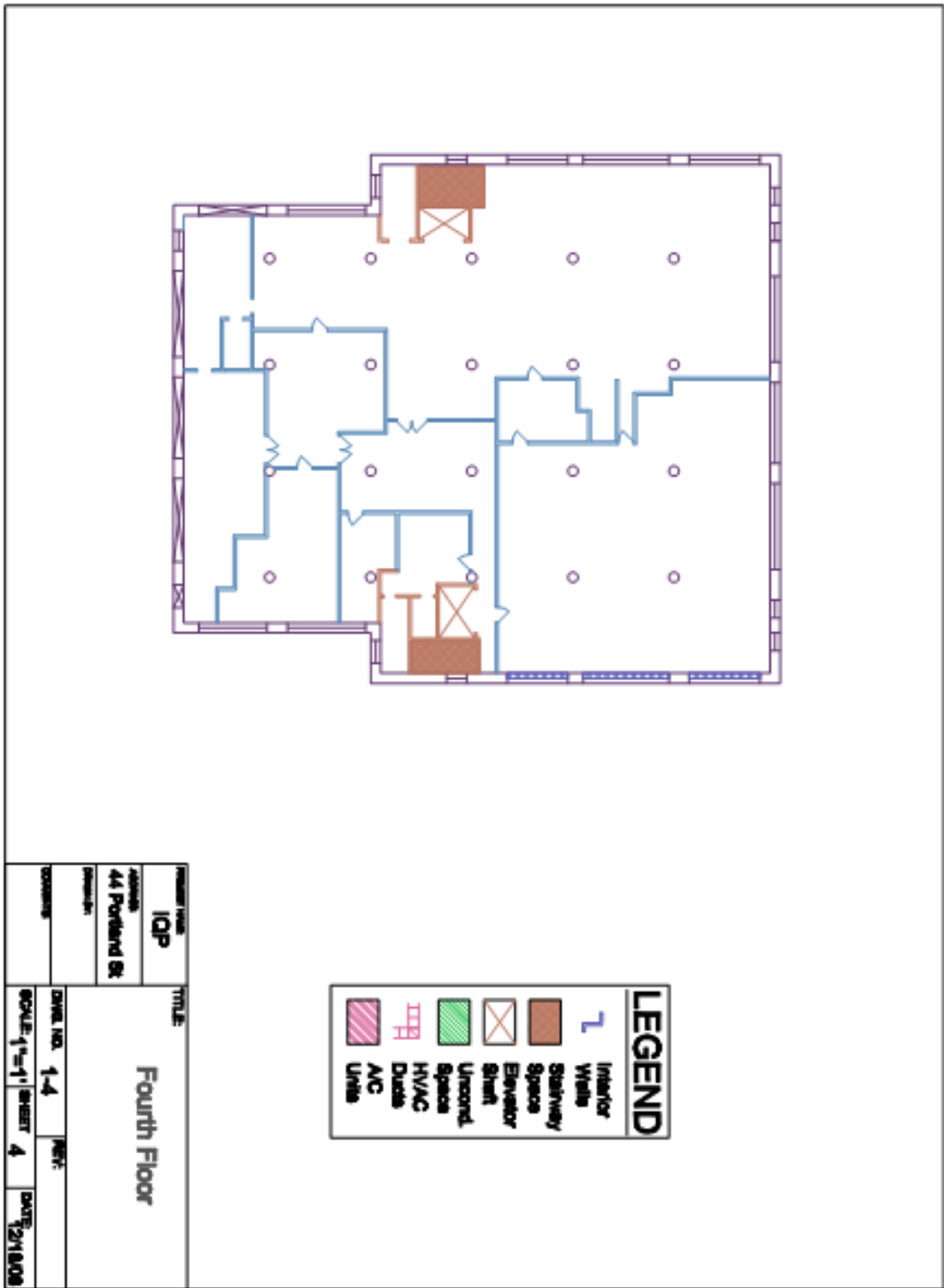
First Floor



Second Floor



Third Floor

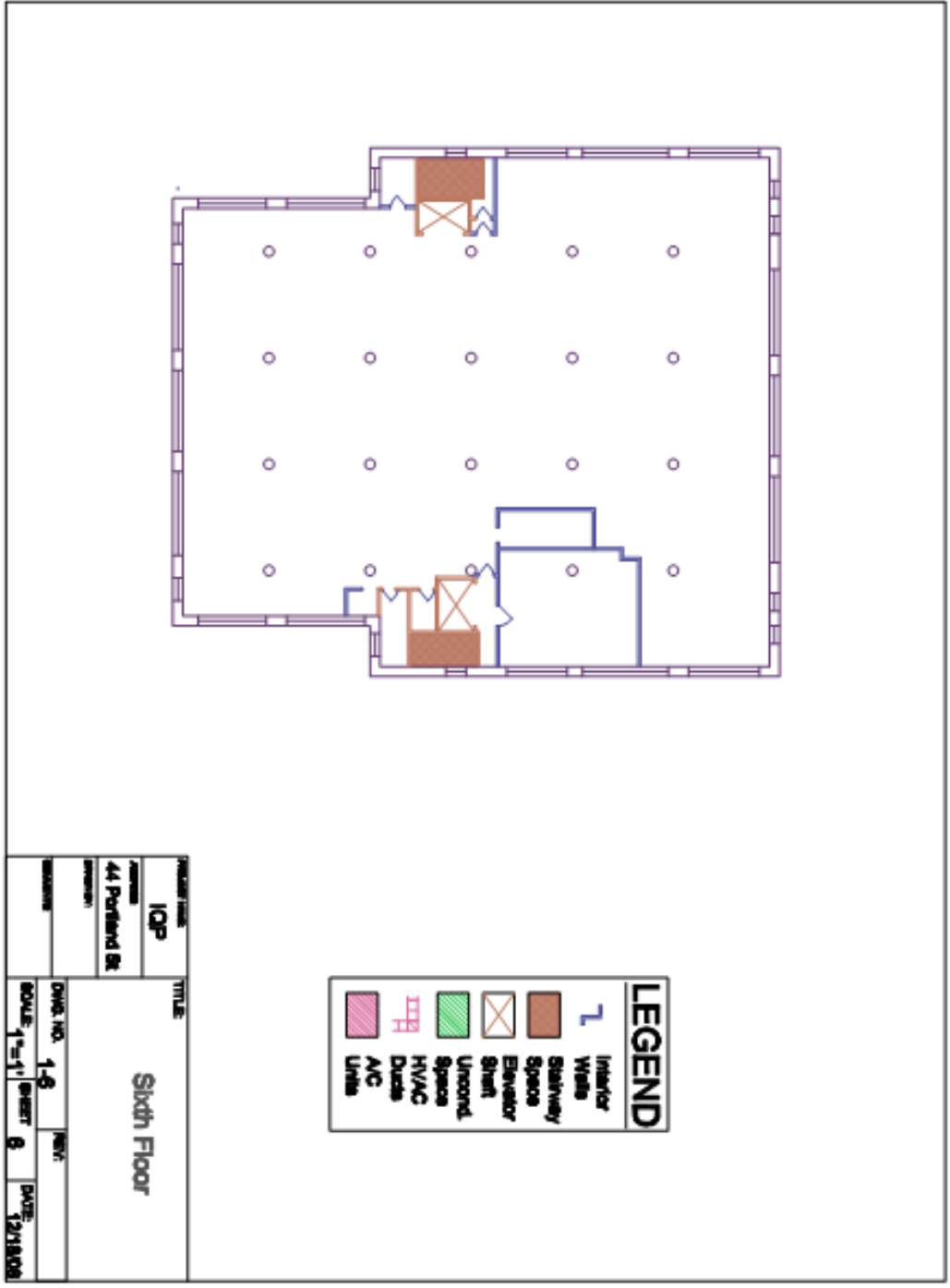


PROJECT TITLE	44 Portland St.		
PROJECT NO.	1-4		
DATE	12/18/08	REV.	4
Fourth Floor			
PROJECT NO.	1-4	REV.	4
DATE	12/18/08	REV.	4

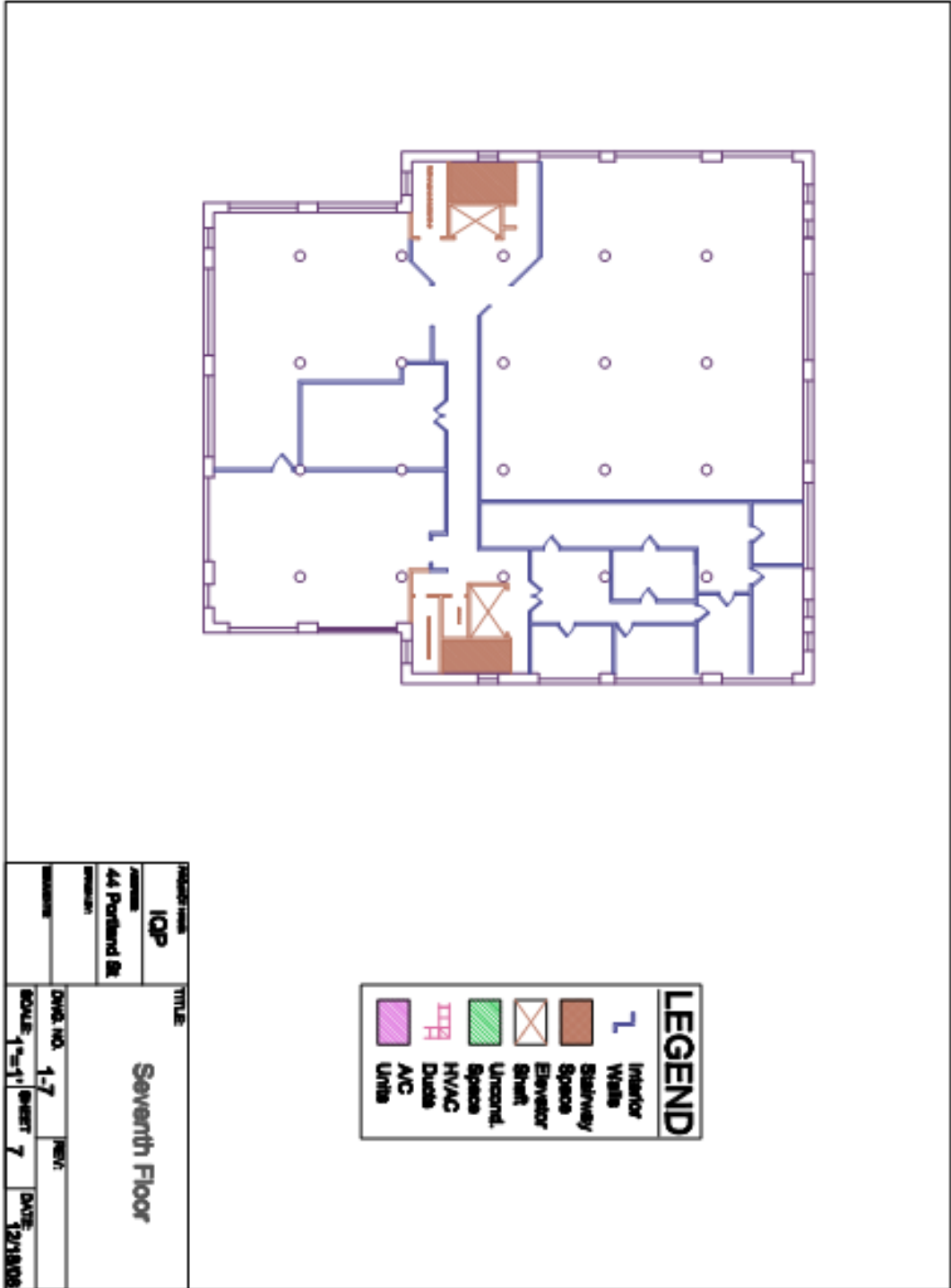
Fourth Floor



Fifth Floor



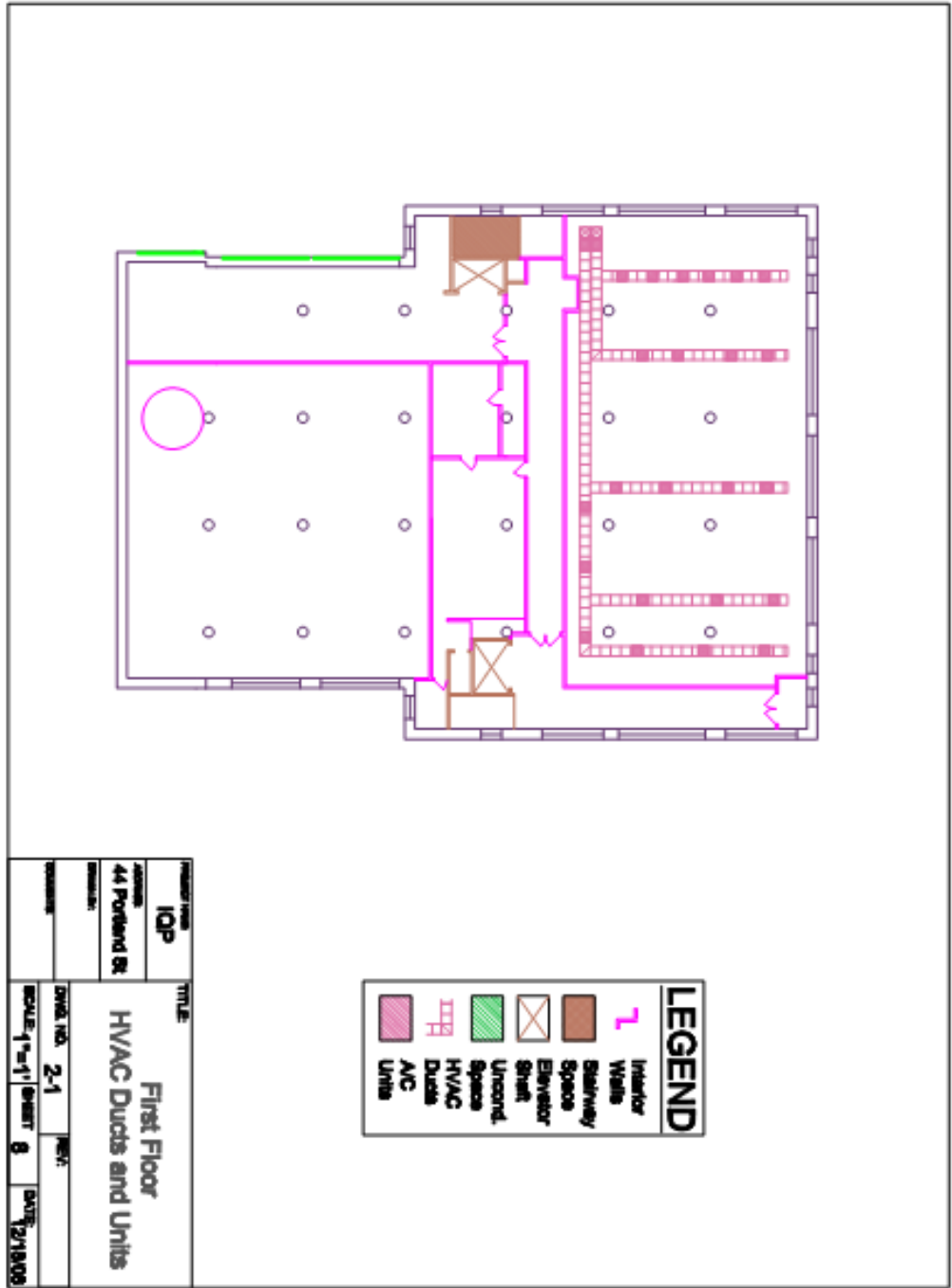
Sixth Floor



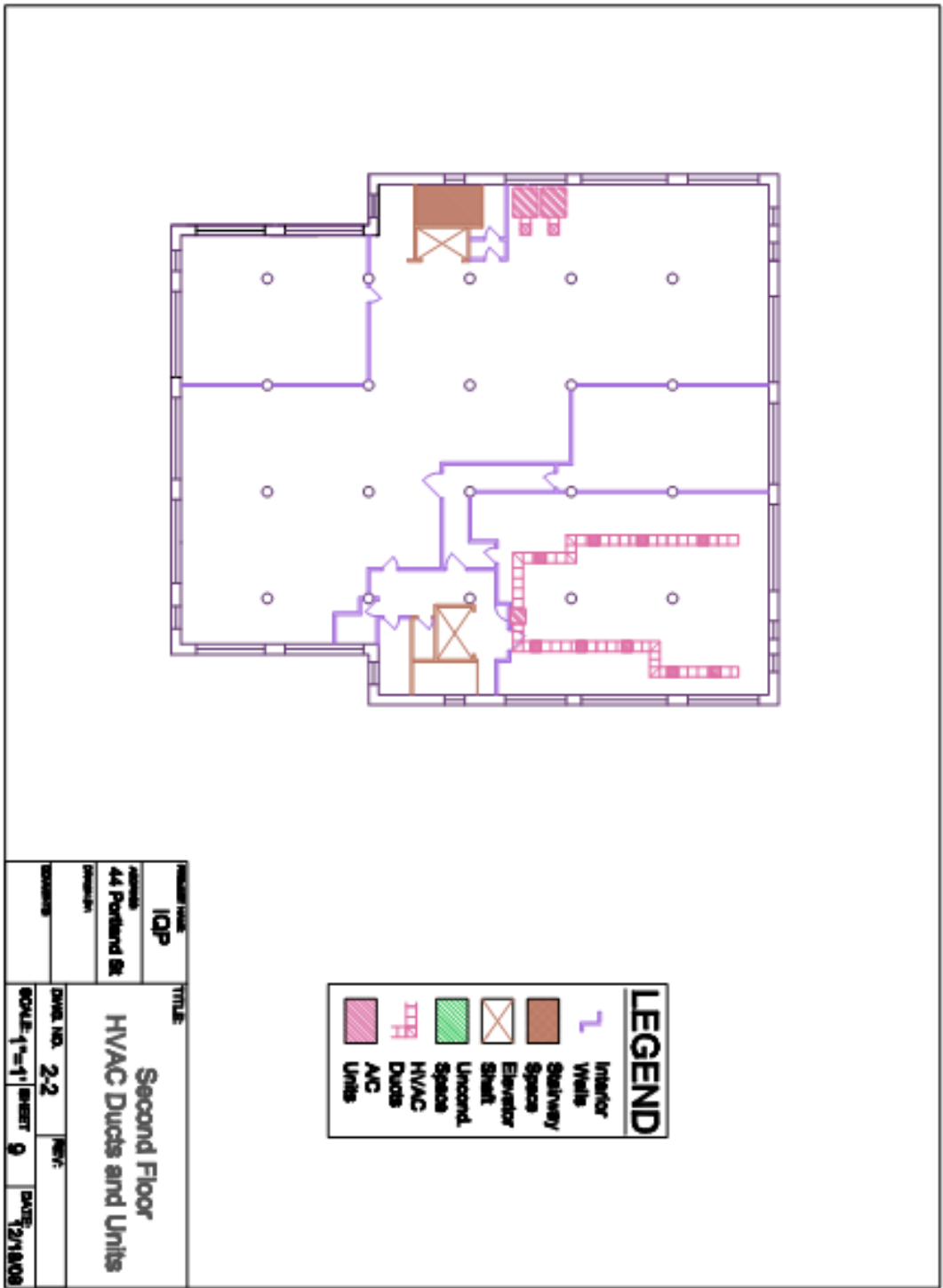
PROJECT NAME	ICP		
ADDRESS	44 Portland St		
PROJECT NO.			
DATE	1-7	REV:	
SCALE	1"=1'	SHEET	7
DATE	12/18/08		
TITLE	Seventh Floor		

Seventh Floor

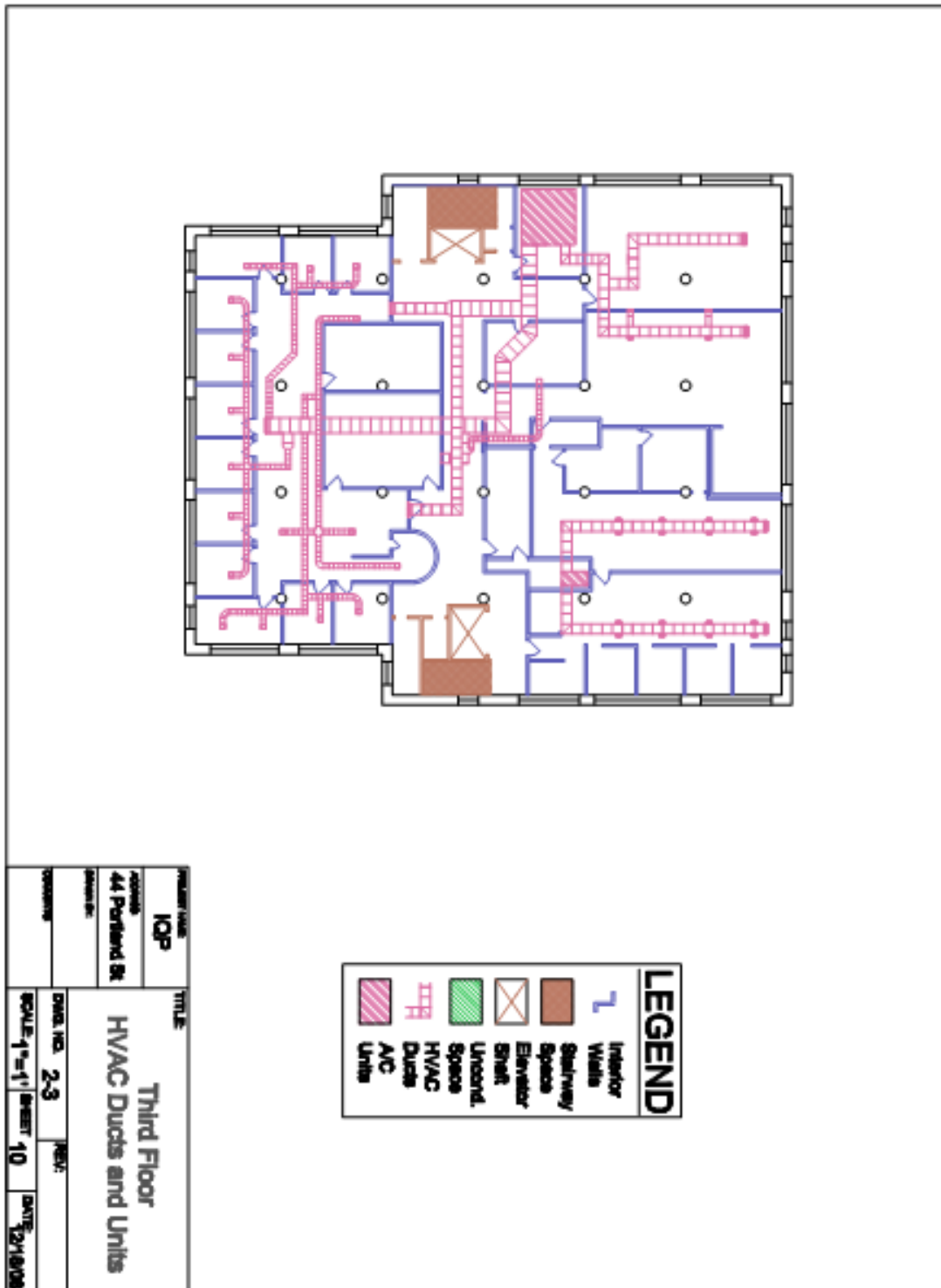
HVAC and Ductwork



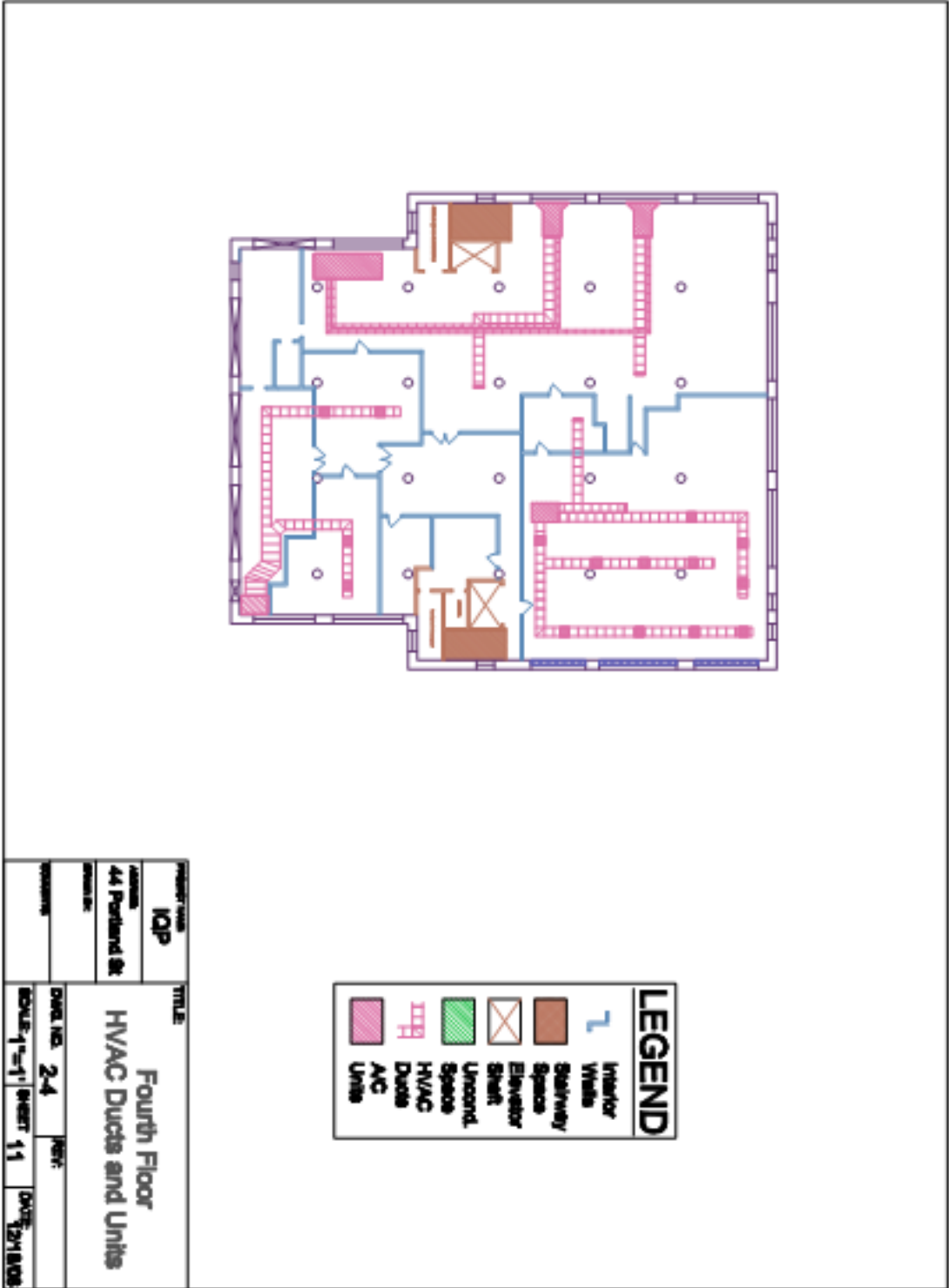
First Floor



Second Floor



Third Floor
102

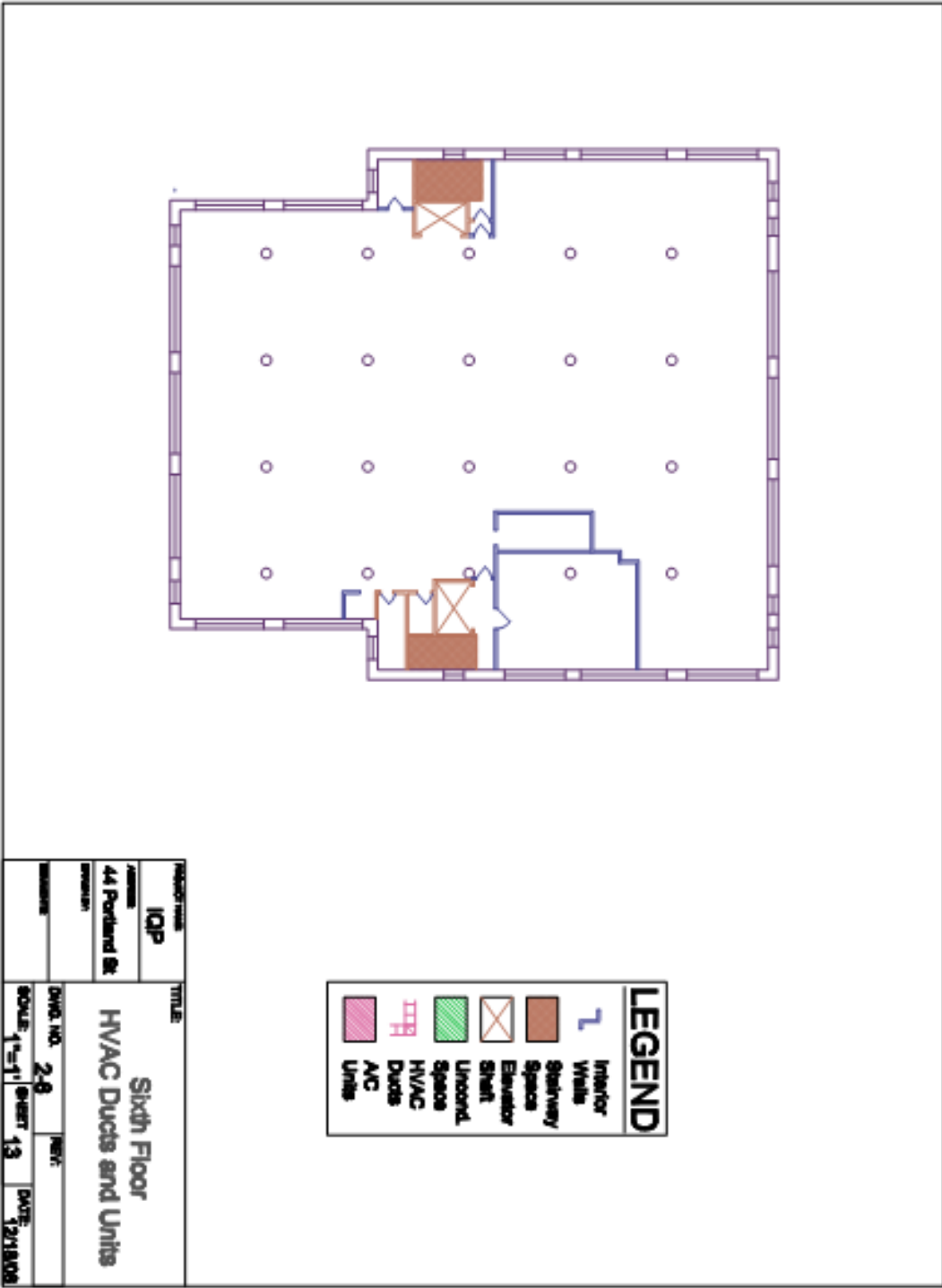


PROJECT NAME ICP	TITLE Fourth Floor HVAC Ducts and Units
ADDRESS 44 Portland St	
DATE NO. 2-4	REV. 11
SCALE 1/8"=1'-0"	SHEET 11
	DATE 12/18/08

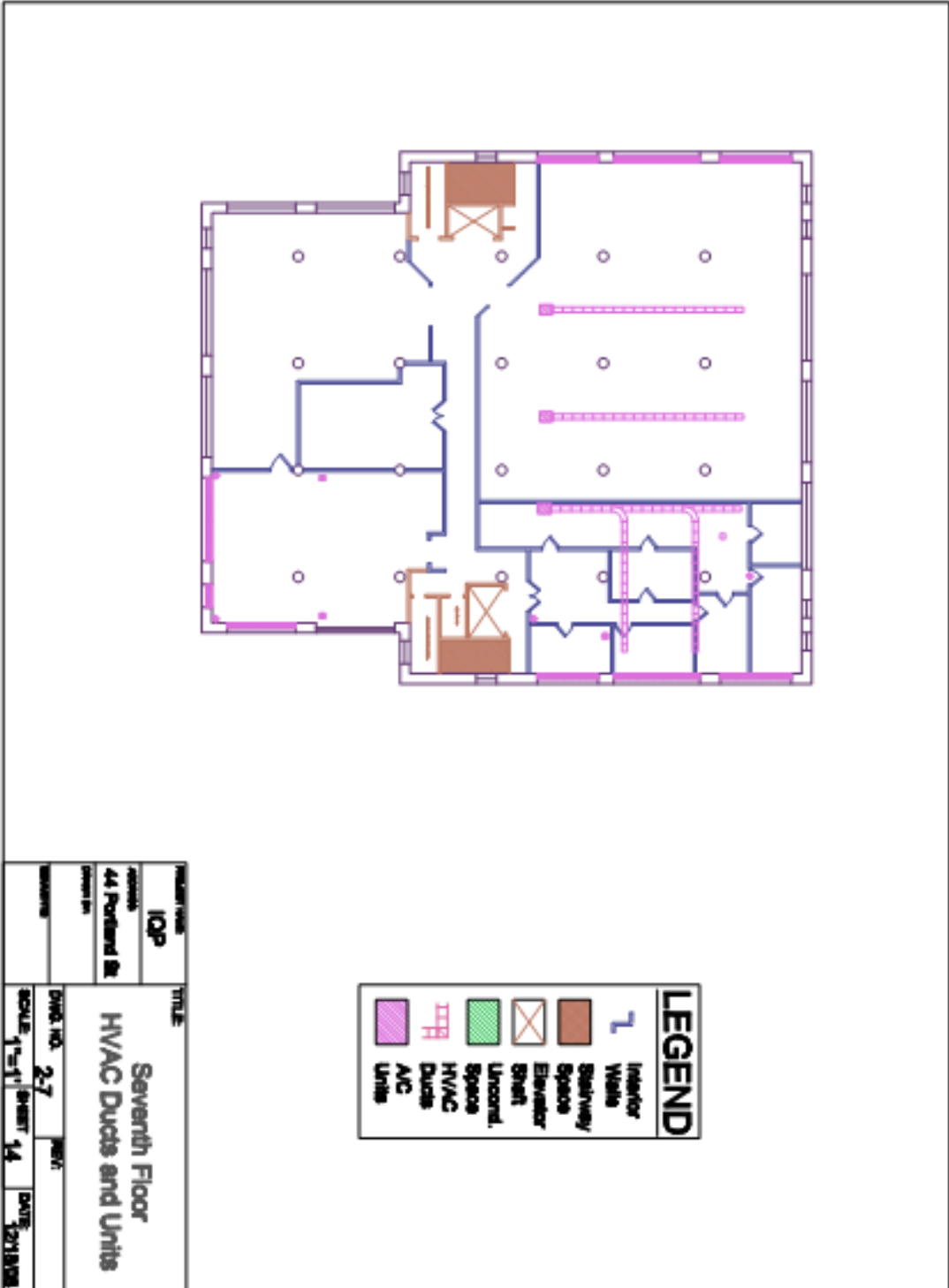
Fourth Floor



Fifth Floor

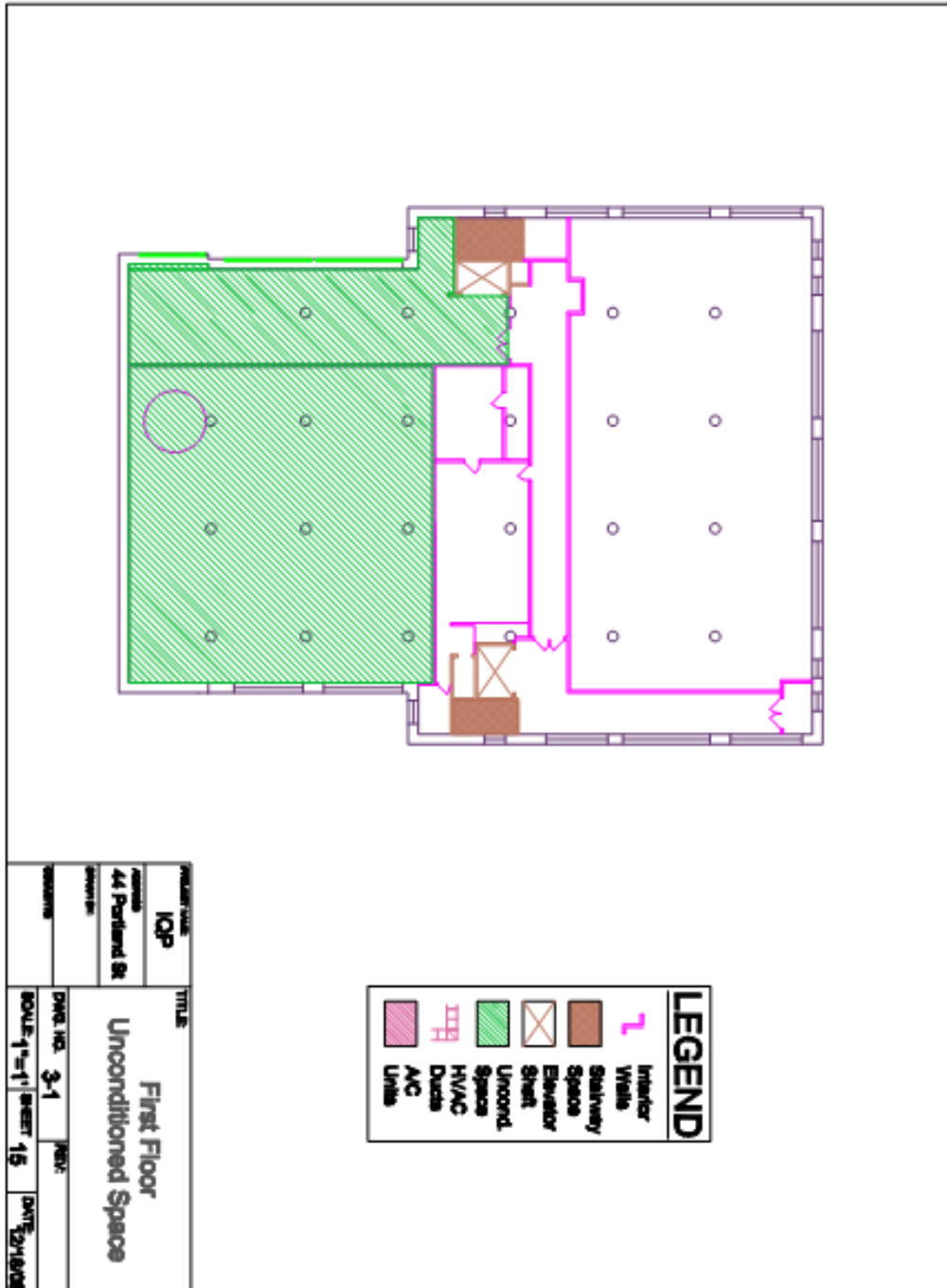


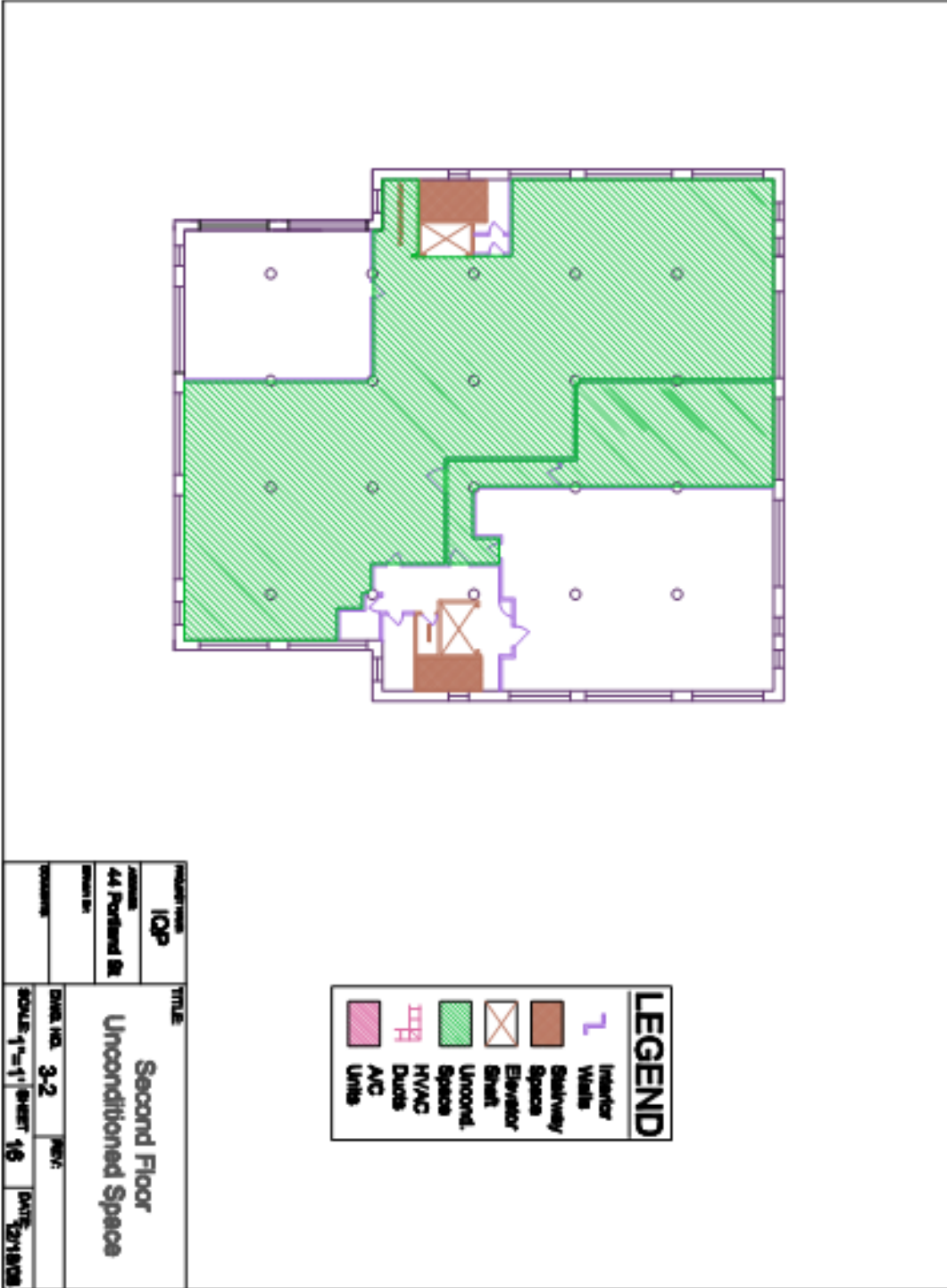
Sixth Floor



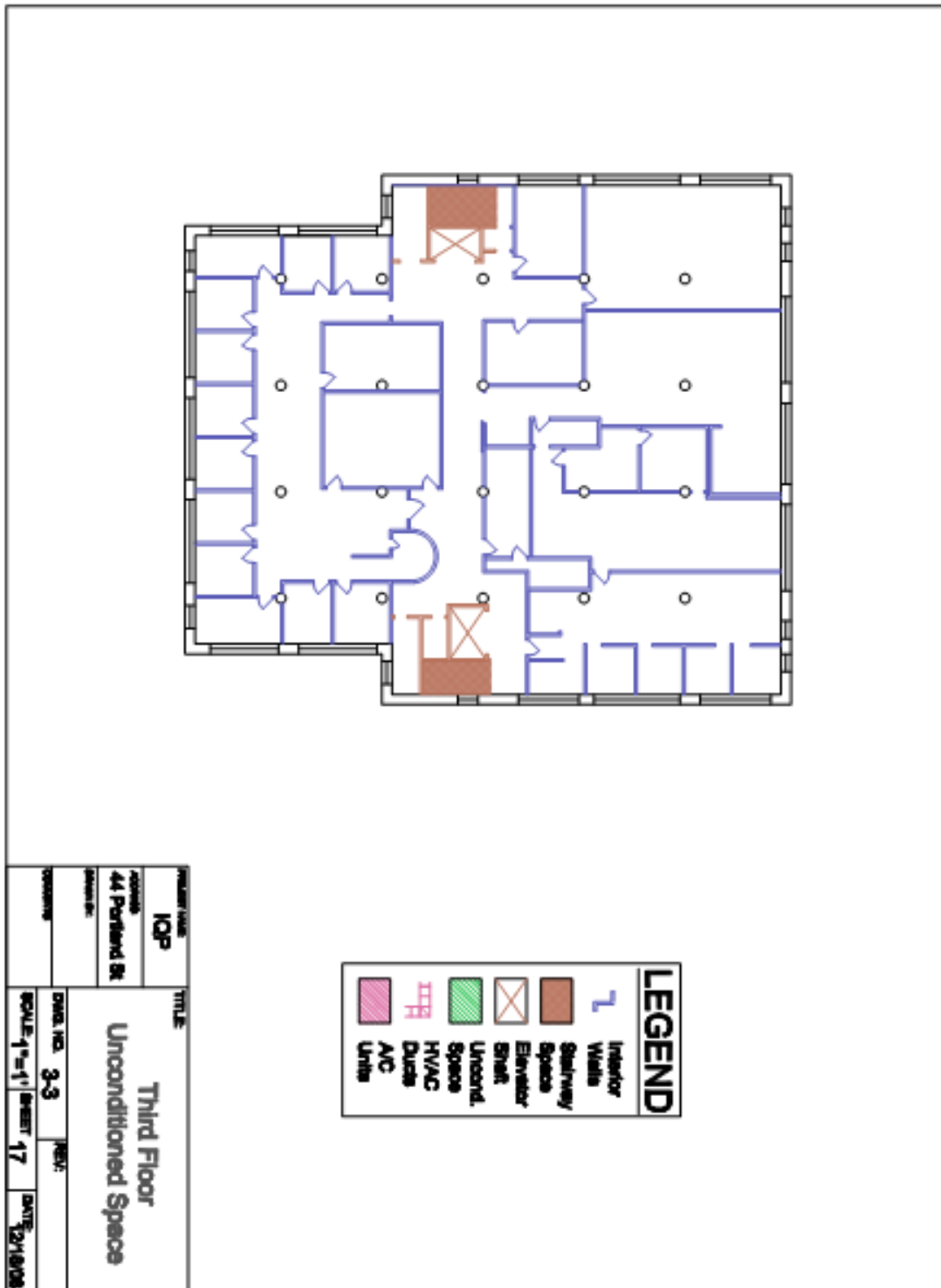
Seventh Floor

Unconditioned Spaces

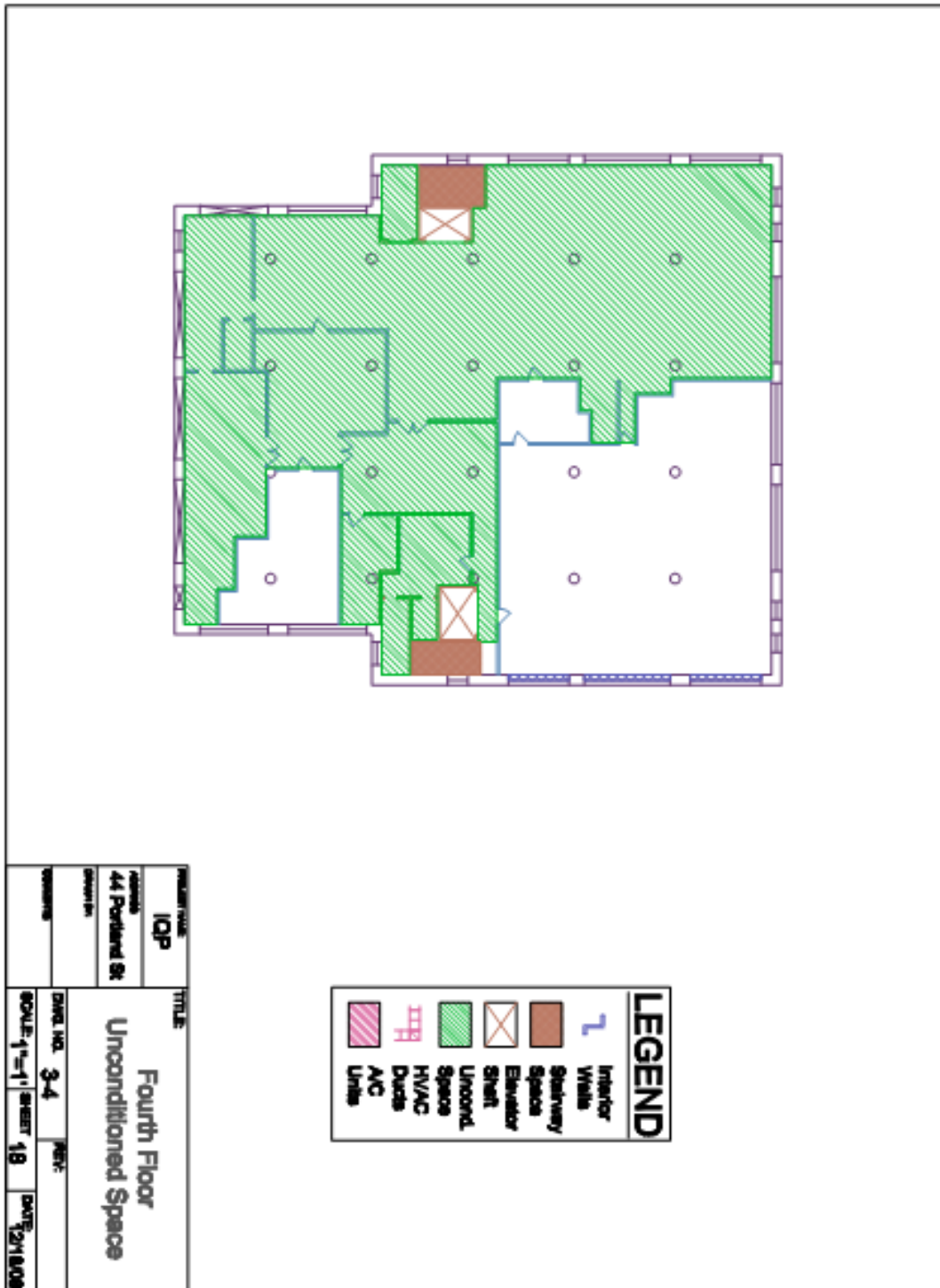




Second Floor



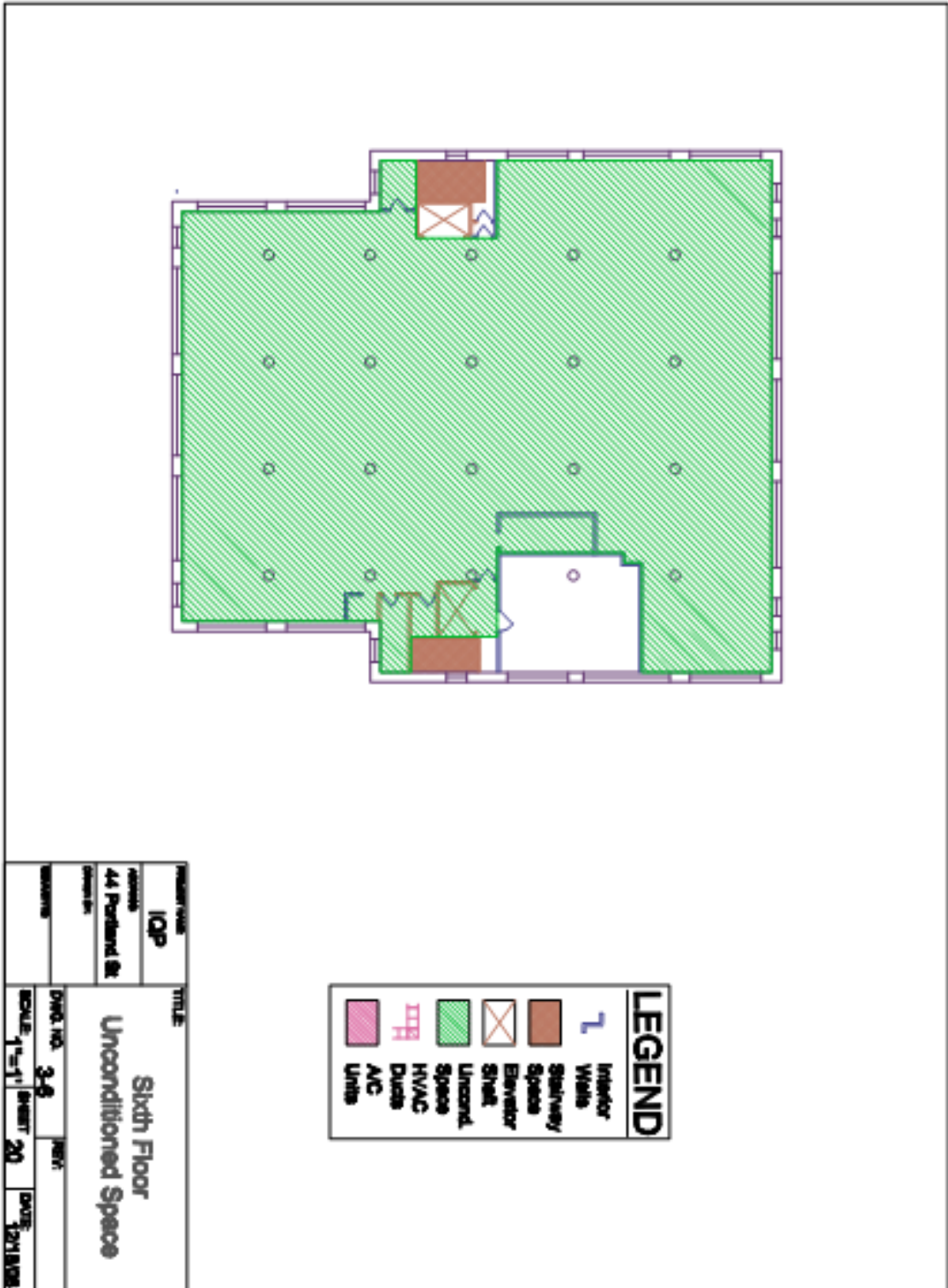
Third Floor
 109



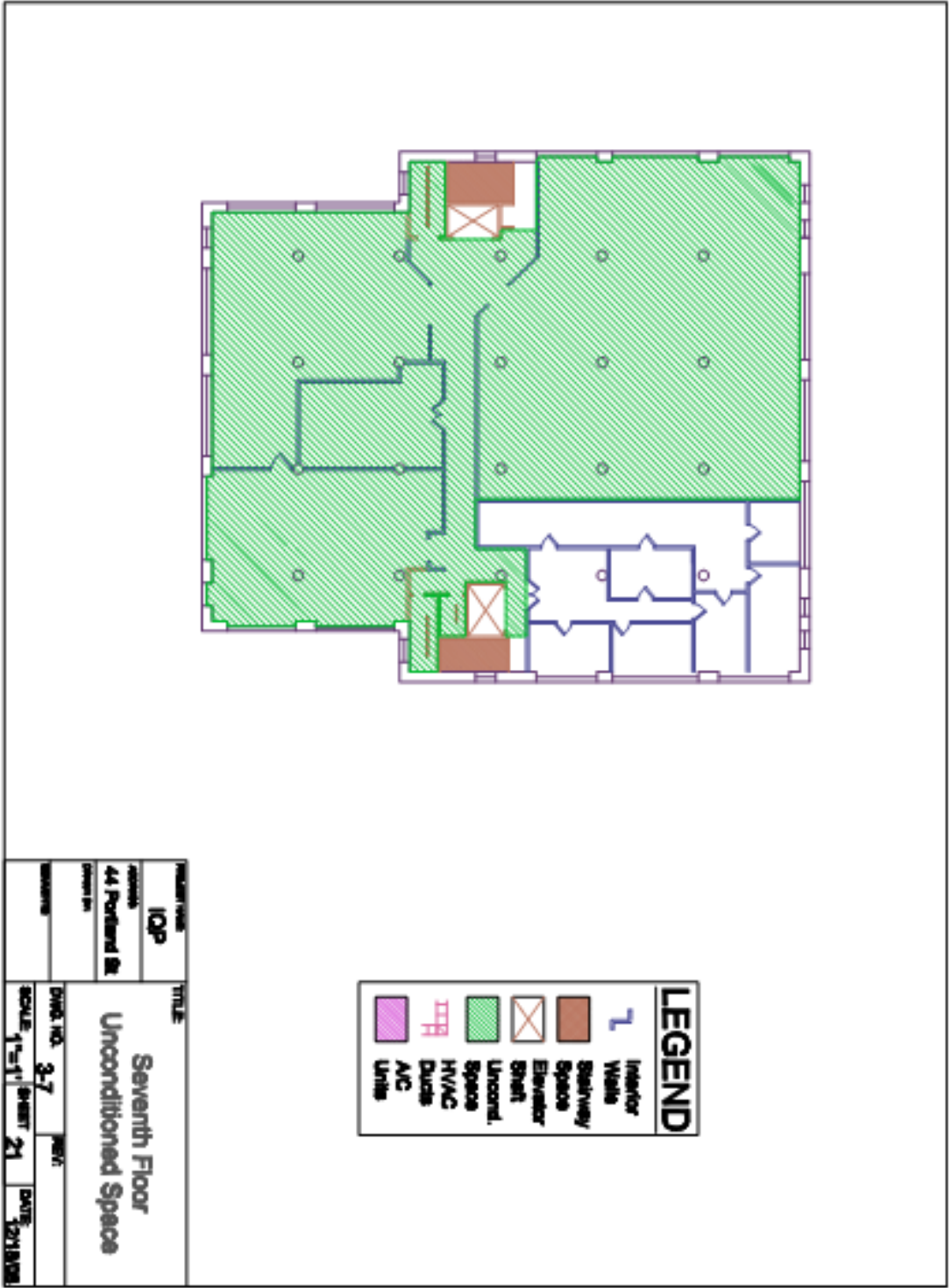
Fourth Floor



Fifth Floor



Sixth Floor



Seventh Floor
113